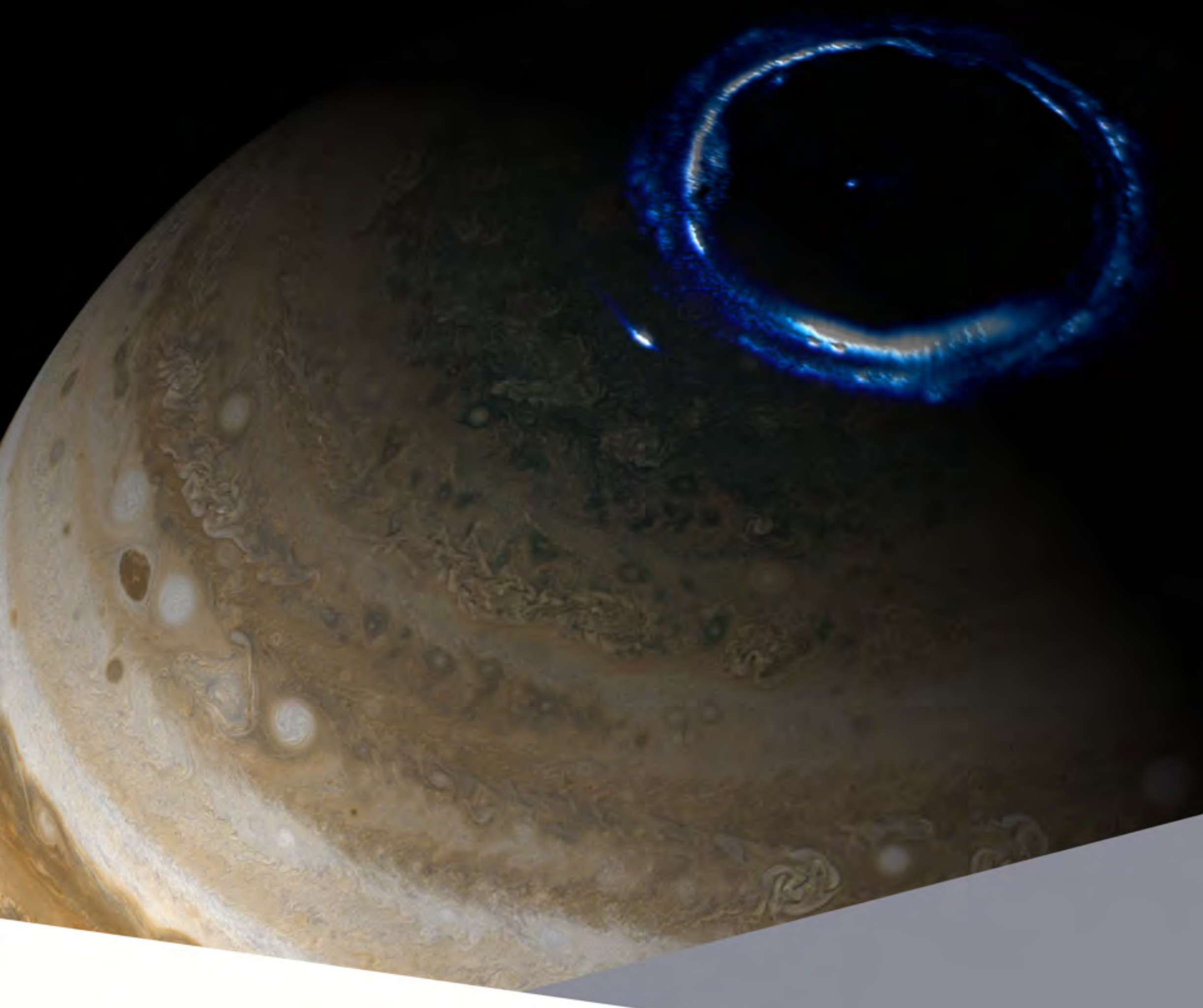
Magnetospheres of the Outer Planets Meeting 2022

Liège July 11 - 15 2022



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This is the 07-07-2022 version of the MOP22 program.

This template originates from LaTeXTemplates.com and is based on the original version at:
https://github.com/maximelucas/AMCOS_booklet

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About

Magnetospheres of Outer Planets Meetings

This meeting aims at advancing our understanding of the magnetospheres of the four giant planets and their interactions with the solar wind, planetary atmospheres and magnetic fields, as well as with their moons.

MOP meetings gather experts from all around the world for a week in order to present and discuss their most recent studies and to enhance collaborative research. The conferences are usually organized every other summer. A list of past meeting can be found on the LASP MOP website.

For this in-person version of the MOP meeting, we welcome contributions about any subject related to the Magnetospheres of the Outer Planets (Jupiter, Saturn, Uranus and Neptune). The list of topics includes, but is not restricted to, in situ and remote sensing observations, theory or simulations of the entire magnetosphere or its components, magnetosphere-ionosphere-thermosphere coupling, comparative planetology, moon-magnetosphere interactions, auroras and future missions. Contributions dedicated to science outreach and teaching are also welcome, provided that they are directly or indirectly related to the Magnetospheres of the Outer Planets.

Local Organizing committee

Denis Grodent (ULiège)
Marie-Nöelle Chevalier (ULiège)
Jean-Claude Gérard (ULiège)
Viviane Pierrard (BIRA/IASB, UCL)
Guillaume Sicorello (ULiège)
Gilles Wautelet (ULiège)
Bertrand Bonfond (ULiège)
Jean-Michel Dusoulier (ULiège)
Kamolporn Haewsantati (ULiège)
Estelle Portassau (ULiège)
Lauriane Soret (ULiège)

Science Organizing committee

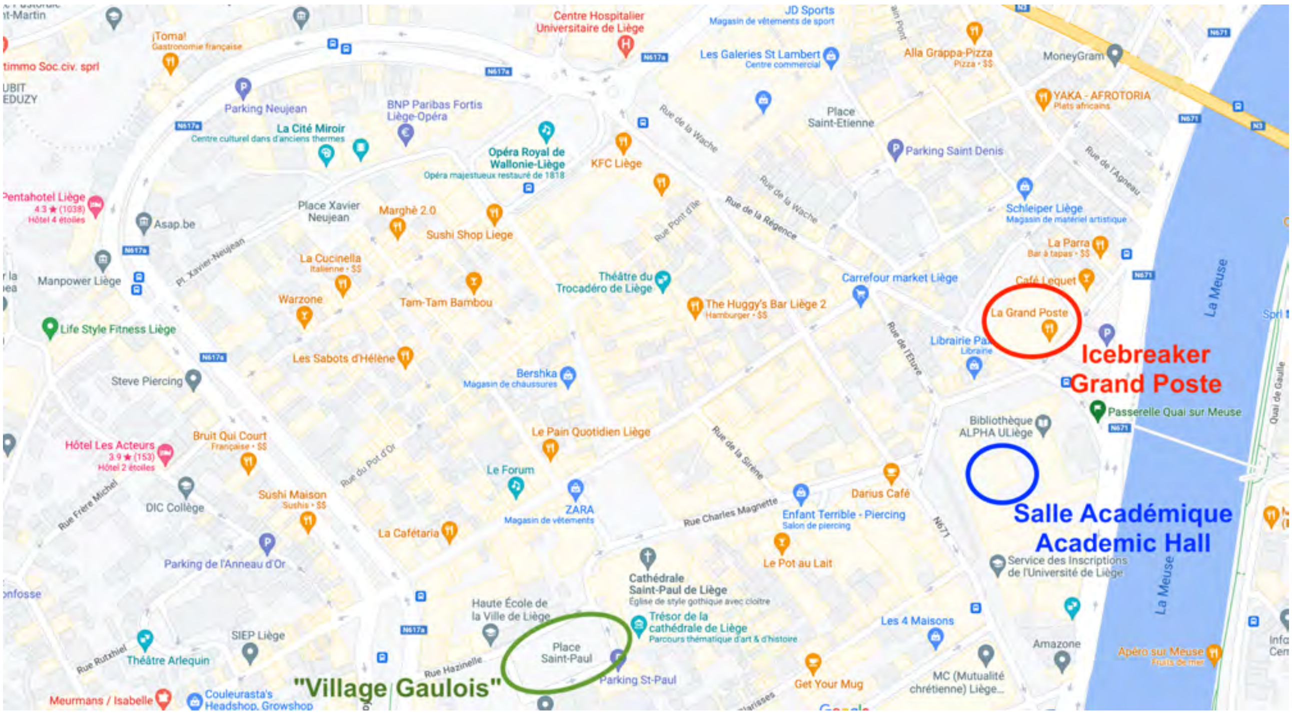
Bertrand Bonfond (ULiège, Belgium)
Caitriona Jackman (DIAS, Ireland)
Philippe Louarn (IRAP, France)
Alessandro Mura (INAF, Italy)
Gabrielle Provan (University of Leicester, UK)
Ali Sulaiman (University of Iowa, USA)
Denis Grodent (ULiège, Belgium)
Tomoki Kimura (Tokyo University of Science, Japan)
Adam Masters (Imperial College, UK)
Philippa Molyneux (SwRI, USA)
Abigail Rymer (Johns Hopkins University, USA)
Marissa Vogt (Boston University, USA)

Practical Information

Venue

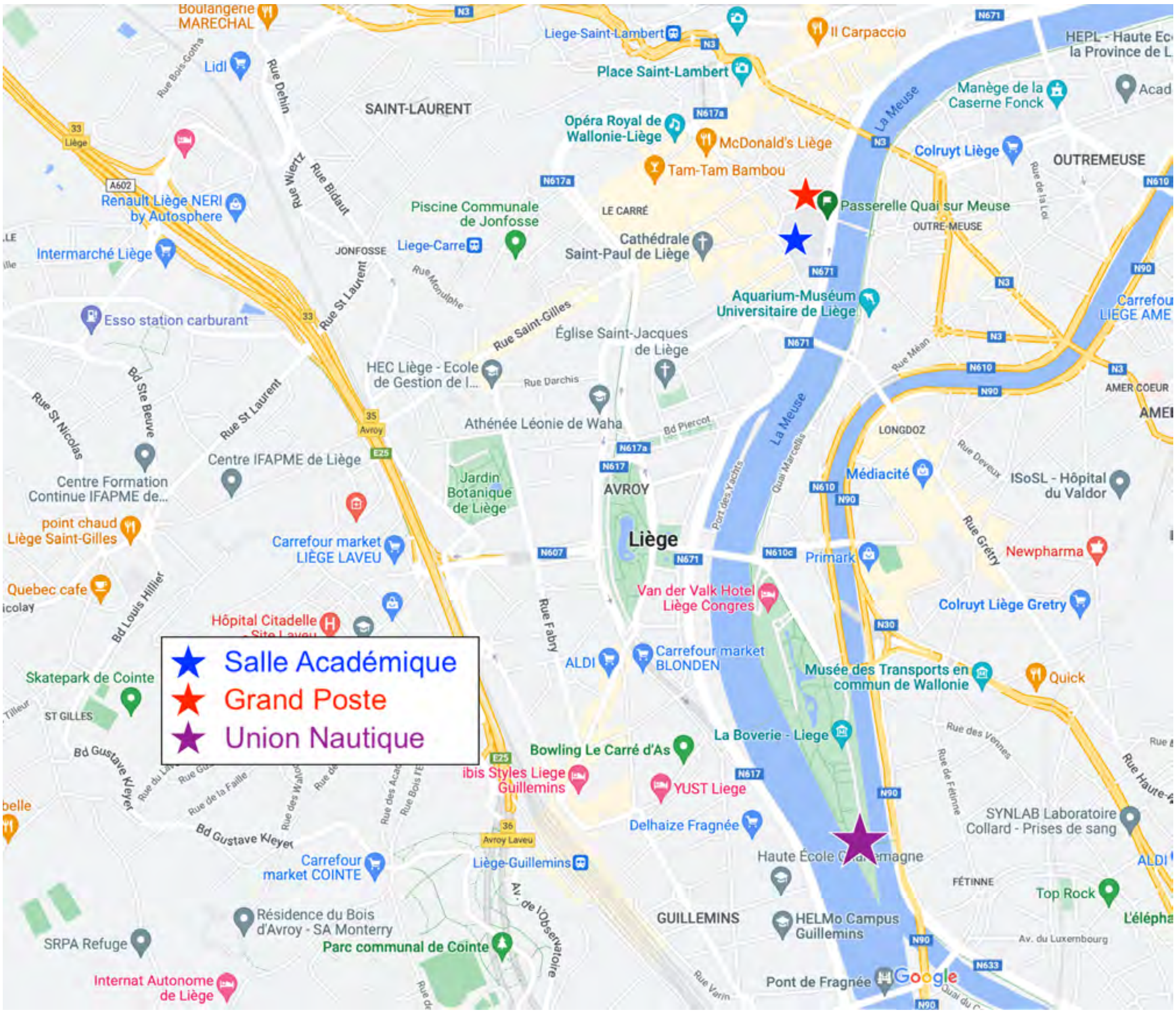
The MOP2022 meeting will take place at the Academic Hall Place du 20-Août 7 4000 Liège (Belgium). The Academic Hall is located at the end of the main entrance hall. The posters will be presented in the Professors’ Hall, on the first floor of the building.

Ice Breaker



An Ice Breaker will take place on Sunday 10th between 17:00 and 19:00 at the newly renovated Grand Poste, in the Cour des Carrioles, which will be privatized for us. The Grand Poste is located Quai sur Meuse 19, 4000 Liège – Belgique, right next to the University main building.

Conference Dinner



For the participants who registered for this event, a conference dinner will be organized on Wednesday 13th at 18:30 at the Union Nautique Club House, located at the end of the Parc de la Boverie (25-minute walk from the conference hall).

Talks and posters

The contributed talks will be 15 minutes long (12 minutes + questions), the invited talks will be 20 minutes long (17 minutes + questions) and the tutorial talks will be 25 minutes long (20 minutes + questions). The preferred aspect ratio for the slides is 16:9.

For the posters, the orientation will be vertical and the width of the supporting panels is $\sim$1m. The preferred format is thus vertical A0. The presenters will have the opportunity to showcase their poster with a short 1-slide oral presentation during the lightening sessions just before the poster sessions.

For more information and updates, please visit our website.

Schedule

CT: Contributed Talk, TT: Tutorial talks, IT: Invited Talk.

Sunday, 10 July

17:00 - 19:00	**Ice breaker**

Monday, 11 July

8:30–9:00	**Registration**		
9:00 - 9:15	**Opening words from Prof. Pierre Wolper, Rector of the University of Liège**		
	Chairperson: Adam Masters		
09:15 - 09:40	TT	**Fran Bagenal** University of Colorado Boulder	What has Juno Revealed about Jupiter's Magnetosphere?
09:40 - 10:00	IT	**Michel Blanc** IRAP, France	Magnetosphere-Ionosphere-Thermosphere Coupling at Jupiter: Current Understanding and Critical Questions
10:00 - 10:15	CT	**Peter Delamere** University of Alaska Fairbanks	Structure and dynamics of Jupiter's dawnside magnetosphere
10:15 - 10:30	CT	**Aneesah Kamran** University of Leicester	Azimuthal field signatures associated with magnetosphere-ionosphere coupling in the Jovian magnetosphere: Comparison between Juno observations and theoretical modeling
10:30 - 11:00	**Coffee break**		
	Chairperson: Dale Weigt		
11:00 - 11:15	CT	**Aaron West** University of Minnesota, USA	3D Time-Domain Multifluid Investigations of Jovian Kinetic FLR Responses
11:15 - 11:35	IT	**Binzheng Zhang** Hong Kong University	Modelling of polar regions: a comparison between the Earth, Jupiter, and Saturn
11:35 - 11:50	CT	**Dimitrios Millas** University College London (UCL)	Particle motion and pitch angle scattering due to magnetic field curvature in the Jovian magnetosphere
11:50 - 12:05	CT	**William Kurth** University of Iowa	Ionospheric Electron Densities Inferred from Juno Plasma Wave Observations

12:05 - 12:20	CT	**Corentin Louis** Dublin Institute for Advanced Studies	Effect of magnetospheric disturbances on Jovian radio emissions: an in situ case study from Juno data
12:20 - 13:50	**Lunch break**		
	Chairperson: Philippe Louarn		
13:50 - 14:05	CT	**Philippe Zarka** Observatoire de Paris - CNRS - PSL	Jupiter's Auroral Radio Emissions Observed by Cassini: Rotational Versus Solar Wind Control, and Components Identification
14:05 - 14:20	CT	**Emilie Mauduit** LESIA - Observatoire de Paris	Ubiquitous Jupiter fast drifting radio bursts reveal Alfvenic electron acceleration
14:20 - 14:35	CT	**Adam Boudouma** LESIA	Numerical modelization of Jovian plasma emissions.
14:35 - 14:50	CT	**Peter Damiano** Geophysical Institute, University of Alaska Fairbanks	Electron signatures associated with mid-latitude Alfven wave perturbations inferred from Juno magnetometer observations
14:50 - 15:05	CT	**Barry Mauk** Johns Hopkins APL	Structure of Zone I of Jupiter's Main Aurora
15:05 - 15:20	CT	**Bob Lysak** University of Minnesota	Magnetosphere-Ionosphere Coupling in Jupiter's Polar Caps: Implications for Megavolt Potentials
15:20 - 15:50	**Coffee break**		
	Chairperson: Corentin Louis		
15:50 - 16:05	CT	**Heidi Becker** Jet Propulsion Laboratory, California Institute of Technology	Juno's highest energy particle observations at Jupiter
16:05 - 16:20	CT	**Emma Woodfield** British Antarctic Survey	The effect of Z-mode waves on the electron radiation belt at Jupiter.
16:20 - 16:35	CT	**Scott Bolton** Southwest Research Institute	Juno Observations of Jupiter's Synchrotron Emission and Radiation Belts
16:35 - 16:50	CT	**Elias Roussos** Max Planck Institute for Solar System Research, Germany	A source of very energetic oxygen in Jupiter's innermost radiation belts
16:50 - 17:10	IT	**Quentin Nenon** IRAP-CNRS	Open science questions in the radiation belts of Jupiter
	Surprise!		

Tuesday, 12 July

	Chairperson: Laurent Lamy		
09:00 - 09:25	TT	**Bob Lysak** University of Minnesota	Auroral Acceleration Processes at the Giant Planets
09:25 - 09:40	CT	**Dale Weigt** University of Southampton	Identifying jovian X-ray auroral families: tying the morphology of X-ray emission to associated magnetospheric dynamics
09:40 - 09:55	CT	**Seán McEntee** Dublin Institute for Advanced Studies (DIAS)	Long-term exploration of Chandra X-ray observations of Jupiter: equatorial and auroral emissions
09:55 - 10:10	CT	**Affelia Wibisono** MSSL/UCL	Two decades of Jupiter's X-ray emissions as measured by XMM-Newton's RGS and EPIC instruments
10:10 - 10:25	CT	**Matt Rutala** Boston University	Shedding New Light on the Enigmatic Motions of Jupiter's Auroral Main Emission
10:25 - 10:55	**Coffee break + Group photo**		
	Chairperson: Licia Ray		
10:55 - 11:10	CT	**Jonathan Nichols** University of Leicester	Hubble Space Telescope observations of Jupiter's FUV auroras during the Juno Extended Mission
11:10 - 11:25	CT	**James O'Donoghue** JAXA Institute of Space and Astronautical Science	Global upper-atmospheric heating at Jupiter by the recirculation of auroral energy
11:25 - 11:45	IT	**William Dunn** UCL	Towards Unifying Jupiter's X-rays with Radio, UV, Magnetic Field and Plasma Observations
11:45 - 12:00	CT	**Randy Gladstone** Southwest Research Institute	Juno-UVS Views of the Average Jovian Aurora and its Variability
12:00 - 12:20	IT	**Kamolporn Haewsantati** LPAP, STAR Institute, Université de Liège, Liège, Belgium	Jupiter's polar auroral bright spot observations by in situ measurements and remote sensing
12:20 - 13:50	**Lunch break**		
	Chairperson: Gabrielle Provan		
13:50 - 14:05	CT	**Ruoyan Wang** University of Leicester	Simultaneous Measurements of Ion Winds and Neutral Flows in Jupiter's Northern Aurora
14:05 - 14:20	CT	**Tom Stallard** University of Leicester	Jupiter's flywheel atmosphere and why azimuthal ion flows dominate over corotation breakdown in the ionosphere: An explanation of simultaneous measurements of ion winds and neutral flows in Jupiter's northern aurora

14:20 - 14:35	CT	**Annika Salveter** Institute of Geophysics and Meteorology, University of Cologne, Cologne, Germany	Jovian auroral electron precipitation budget - A Statistical Analysis of Diffuse, Mono-energetic, and Broadband Auroral electron distributions
14:35 - 14:50	**Future MOP presentations**		
14:50 - 16:10	**Poster lightning presentations 1**		
16:10 - 18:00	**Poster session 1**		

Wednesday, 13 July

	Chairperson: Lucas Liuzzo		
09:00 - 09:15	CT	**Josh Wiggs** Lancaster University	Examining Interchange at the Outer Planets using JERICHO: a Kinetic-Ion, Fluid-Electron Hybrid Plasma Model
09:15 - 09:40	TT	**Joachim Saur** University of Cologne	Turbulence in the Magnetospheres of the Giant Planets
09:40 - 09:55	CT	**Omakshi Agiwal** Boston University	The Contribution of Global Periodic Perturbations Towards Circulation and Mass Loss in Saturn's Magnetosphere
09:55 - 10:10	CT	**Wayne Gould** Lancaster University	Detecting the Solar Wind in Saturn Kilometric Radiation with Mutual Information
10:10 - 10:25	CT	**Joe Kinrade** Lancaster University	Synthesising remote sensing observations of Saturn's global plasma dynamics: testing the relationship between Saturn's ENA and narrowband SKR emissions.
10:25 - 10:55	**Coffee break**		
	Chairperson: Chris Arridge		
10:55 - 11:10	CT	**Anthony Sciola** Johns Hopkins University Applied Physics Laboratory	Particle entry, escape, and energization at Saturn through global convection and wind-magnetosphere interaction
11:10 - 11:25	CT	**Simon Wing** Johns Hopkins University	Periodic narrowband radio wave emissions and inward plasma transport at Saturnian magnetosphere
11:25 - 11:40	CT	**Siyuan Wu** Southern University of Science and Technology	Cassini Observation of the 1st harmonic of Saturn Kilometric Radiation: A Case study
11:40 - 11:55	CT	**George Xystouris** Lancaster University	Cassini Langmuir Probe observations during solar eclipses by Saturn and the Main Rings: photoelectrons and rings optical depth
11:55 - 12:10	CT	**Jamie Jasinski** NASA Jet Propulsion Laboratory, California Institute of Technology.	Reconnection at Neptune's pole-on magnetosphere during the Voyager 2 flyby
12:10 - 13:40	**Lunch break**		
13:40 - 13:55	CT	**Laurent Lamy** LESIA, Observatoire de Paris / LAM, Aix-Marseille Université	The twisted magnetosphere of Uranus between solstice and equinox

13:55 - 14:10	CT	**Noé Clément** Laboratoire d'Astrophysique de Bordeaux (France)	An Assessment of the Role of Ionospheric Conductances in Magnetosphere-Ionosphere-Thermosphere Coupling at Giant Planets, Based on Space Data and Modelling Tools
14:10 - 14:25	CT	**Shengyi Ye** Southern University of Science and Technology	Waves from the magnetospheres of giant planets revealing their interaction with solar wind
14:25 - 14:40	**Future MOP vote**		
14:40 - 14:55	**Community codes**		
14:55 - 15:25	**Coffee break**		
16:30 - 18:00	**Visit of Liège (Optional)**		
18:30 - 00:00	**Social dinner (Optional)**		

Thursday, 14 July

	Chairperson: Lorenz Roth		
09:00 - 09:15	CT	**Howard Smith** JHU APL	Defining Io's neutral oxygen torus and magnetospheric source with Hisaki observations and 3-D modeling
09:15 - 09:40	TT	**Jamey Szalay** Princeton University	The satellite footprints in Jupiter's aurora and the processes giving rise to them
09:40 - 09:55	CT	**Stephan Schlegel** Institute of Geophysics and Meteorology, University of Cologne, Germany	Alternating emission features in Io's footprint tail: Magnetohydrodynamical simulations of possible causes
09:55 - 10:15	IT	**Alessandro Moirano** INAF - IAPS	Temporal variability of the Io-induced aurorae on Jupiter: a proxy for plasma variations in the magnetosphere
10:15 - 10:45	**Coffee break**		
	Chairperson: Alessandro Mura		
10:45 - 11:00	CT	**Baptiste Cecconi** Observatoire de Paris	Jovian auroral radio source occultation modelling and application to the JUICE science mission planning
11:00 - 11:15	CT	**Marshall Styczinski** Jet Propulsion Laboratory, California Institute of Technology, USA	Magnetic sounding of icy moons with constraints from multiple investigations
11:15 - 11:30	CT	**Amanda Hendrix** Planetary Science Institute	Io's Neutral Atmosphere as Observed by Cassini UVIS
11:30 - 11:45	CT	**Kurt Retherford** Southwest Research Institute	New Horizons Alice Observations of Io's Extended UV Atmospheric Emissions and Implications for Mass Loading from the Neutral Cloud
11:45 - 12:05	IT	**Ryoichi Koga** Nagoya University	Hisaki observation of the oxygen neutral cloud around Io's orbit before and during the enhancement event of Io plasma torus
12:05 - 13:35	**Lunch break**		
	Chairperson: Ali Sulaiman		
13:35 - 13:50	CT	**Oleg Shebanits** Swedish Institute of Space Physics	Induced currents in Titan's dusty ionosphere
13:50 - 14:05	CT	**Konstantin Kim** Swedish Institute of Space Physics	Density spikes in the ionosphere of Titan as seen by Cassini-Huygens
14:05 - 14:25	IT	**Corey Cochrane** Jet Propulsion Laboratory, California Institute of Technology	Electromagnetic induction inside Uranus' and Neptune's large moons

14:25 - 14:40	CT	**Haje Korth** Johns Hopkins Applied Physics Laboratory	Europa Clipper Mission Update
14:40 - 14:55	CT	**Pontus Brandt** The Johns Hopkins University Applied Physics Laboratory	PEP-Hi: Energetic Particle Investigation and ENA Imaging of the Jovian System and Its Icy Moons
14:55 - 16:10	**Poster lightning presentations 2**		
16:10 - 18:00	**Poster session 2**		

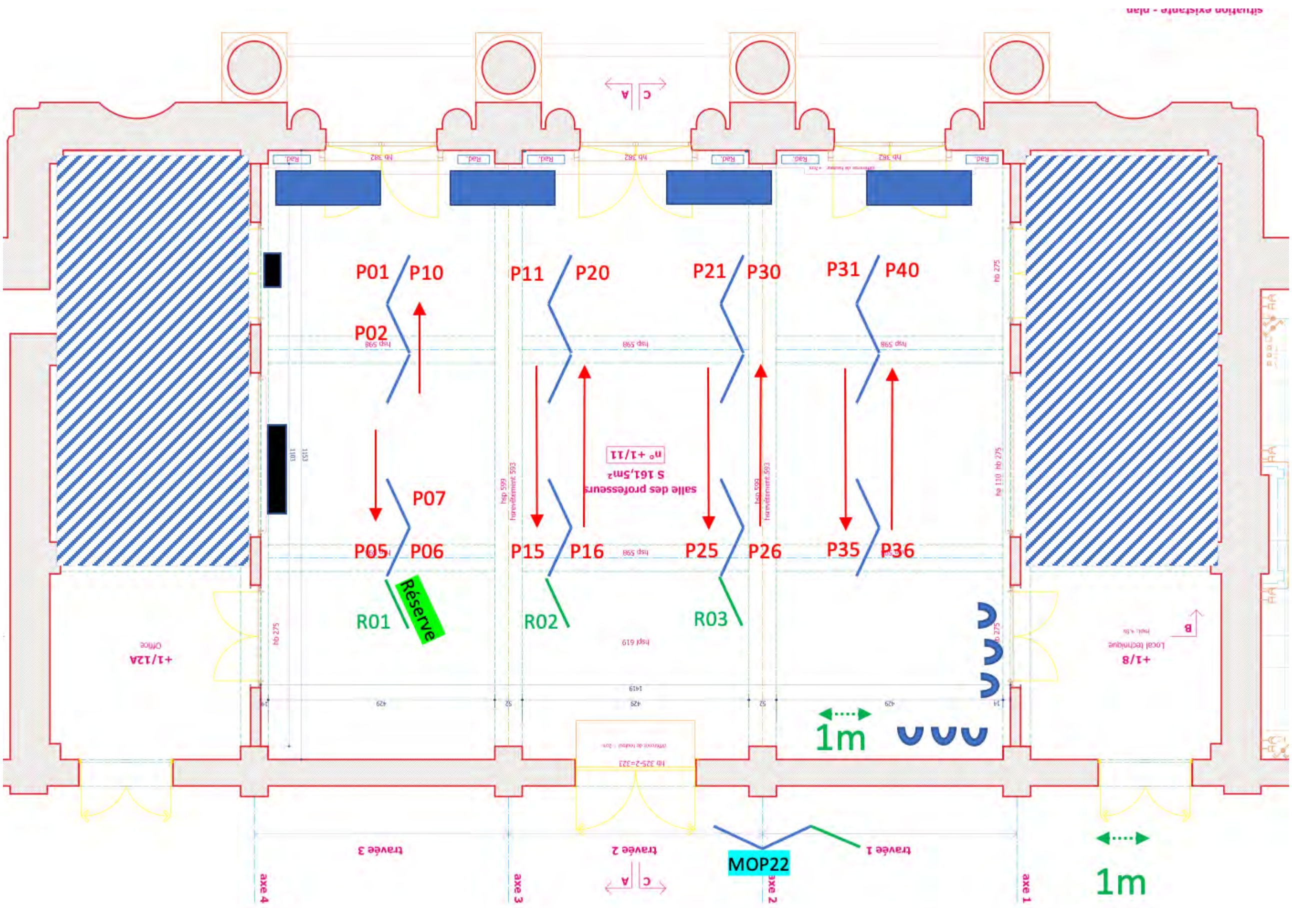
Friday, 15 July

	Chairperson: Philippa Molyneux		
09:00 - 09:15	CT	**Peter Addison** Georgia Institute of Technology	Effect of the Magnetospheric Plasma Interaction and Solar Illumination on Ion Sputtering of Europa's Surface Ice
09:15 - 09:35	IT	**Camilla Harris** NASA Postdoctoral Program at JPL	Simulations of Europa's Interaction with Jupiter's Magnetosphere
09:35 - 09:50	CT	**Lorenz Roth** KTH Royal Institute of Technology, Stockholm	Europa's UV emissions from 2014-2020: Molecular atmosphere, hydrogen corona and constraints on plumes
09:50 - 10:05	CT	**Jamey Szalay** Princeton University	H2+ pickup ions from Europa-genic H2 neutrals orbiting Jupiter
10:05 - 10:20	CT	**Drew Coffin** University of Alaska Fairbanks	Examining the Europa plasma environment via a multi-dimensional physical chemistry model
10:20 - 10:50	**Coffee break**		
	Chairperson: Vincent Dols		
10:50 - 11:05	CT	**Frederic Allegrini** Southwest Research Institute	Plasma observations during the June 7, 2021 Ganymede flyby from the Jovian Auroral Distributions Experiment (JADE) on Juno
11:05 - 11:20	CT	**Stefan Duling** University of Cologne, Institute of Geophysics and Meteorology	Ganymede MHD Model: Magnetospheric Context for Juno's PJ34 Flyby
11:20 - 11:40	IT	**Thomas Greathouse** Southwest Research Institute	UVS Observations of Ganymede's Aurora During Juno Orbits 34 and 35
11:40 - 11:55	CT	**Shahab Fatemi** Umeå University, Sweden	Ion dynamics at the magnetopause of Ganymede
11:55 - 12:10	CT	**Nawapat Kaweeyanun** Imperial College London	Can Ganymede's magnetopause interactions help us probe the moon's subsurface ocean?
12:10 - 13:40	**Lunch break**		
	Chairperson: Aljona Blocker		
13:40 - 13:55	CT	**George Clark** Johns Hopkins Applied Physics Lab	Energetic Charged Particle Observations during Juno's Close Flyby of Ganymede
13:55 - 14:10	CT	**Rob Ebert** Southwest Research Institute/University of Texas at San Antonio	Evidence for Magnetic Reconnection at Ganymede's Upstream Magnetopause during the PJ34 Juno Flyby
14:10 - 14:25	CT	**Philip Valek** Southwest Research Institute	In situ ion composition observations of Ganymede's outflowing ionosphere
14:25 - 14:35	**Short break**		

14:35 - 14:50	CT	**Joachim Saur** University of Cologne	Alternating north-south brightness ratio of Ganymede’s auroral ovals: Hubble Space Telescope observations during the Juno PJ34 flyby
14:50 - 15:05	CT	**Peter Kollmann** JHU/APL	Ganymede’s radiation cavity and radiation belt
15:05 - 15:20	CT	**Lucas Liuzzo** Space Sciences Laboratory, University of California, Berkeley	Energetic particle fluxes onto Callisto’s atmosphere
15:20 - 15:35	**Concluding remarks**		

Poster sessions

The poster sessions on Tuesday and Thursday will take place in the "Salle des Professeurs" on the first floor.



Poster session 1 - Tuesday July 12

Sariah Al Saati [1] IRAP, CNRS-UPS-CNES [2] École polytechnique	**[P15] -** Magnetosphere-Ionosphere-Thermosphere Coupling study at Jupiter Based on Juno First 30 Orbits and Modelling Tools
Fran Bagenal University of Colorado Boulder	**[P5] -** Emptying of Jupiter's Plasma Disk in March 2018
Aljona Blöcker Ludwig Maximilian University of Munich (LMU)	**[P8] -** Plasmoids and Dipolarizations in the Jovian Magnetotail: Statistical Survey of Ion Acceleration with Juno Observations
Bertrand Bonfond Université de Liège	**[P23] -** An overview of the radiation bursts observed by Juno-UVS above the polar regions

Baptiste Cecconi Observatoire de Paris	**[P24] -** A consolidated catalogue of Jovian decametric radio observations observed in Nançay from January 1978 to December 1990
Frank Crary University of Colorado, LASP	**[P1] -** Transport and Ion Anisotropy in the Io plasma torus
Marie Devinat Institut de Recherche en Astrophysique et Planétologie (IRAP)	**[P16] -** A new, general model for radial transport of plasma, angular momentum and energy in the magnetospheres of Jupiter and Saturn
William Dunn UCL	**[P27] -** The First Detection of X-rays from Uranus and the Next Observing Campaign
Rob Ebert Southwest Research Institute/University of Texas at San Antonio	**[P9] -** Plasma Observations Across Jupiter's Southern Polar Magnetopause
Georg Fischer Space Research Institute, Austrian Academy of Sciences	**[P25] -** Fine and coarse spectral structures of Jovian radio emissions revealed by Juno and Cassini
Kento Furukawa Tohoku university	**[P4] -** Localized hot electron inflow on the dusk side during transient brightening in Io plasma torus observed by Hisaki/EXCEED
Jean-Claude Gérard LPAP - STAR Institute, ULiège	**[P32] -** H_3^+ auroral densities, cooling rate and conductance from Juno FUV and infrared observations
David Gómez University of Texas San Antonio/Southwest Research Institute	**[P33] -** Mapping Jupiter's Lyman-α Airglow with Juno UVS
Denis Grodent Université de Liège	**[P28] -** Jupiter's colorful hair
Antoine Groulard University of Liège, Belgium	**[P29] -** Dawn-Dusk asymmetry in Jupiter's main auroral emissions
Hannah Joyce Lancaster University	**[P17] -** The Effects of Local Time Asymmetries in Auroral Currents on Ionospheric Outflow at Jupiter
Adam Masters Imperial College London	**[P20] -** Magnetic reconnection near the planet as a possible driver of Jupiter's mysterious polar auroras
Henrik Melin University of Leicester	**[P33] -** Ionospheric heating above Jupiter's Great Red Spot: NASA IRTF iSHELL observations
Blake Mino University of Alaska Fairbanks, Geophysical Institute	**[P10] -** Applying Information Theory to GAMERA Simulations of Jupiter and Saturn-like Magnetospheres
Hiroaki Misawa Tohoku University	**[P26] -** Reconsideration for causalities of occurrence features of Io-related Jupiter's radio emission
Luke Moore Boston University	**[P34] -** Chasing Shadows in Jupiter's Ionosphere: constraints on electron density and chemical lifetime
Diego Moral Pombo Lancaster University	**[P27] -** Three case studies tracking injection signatures in the UV aurora at the Jovian Southern hemisphere

Jeffrey Morgenthaler Planetary Science Institute	**[P3] -** Using Io Input/Output observatory (IoIO) observations to determine if mass flow in Jupiter's magnetosphere driven by internal or external processes
Jeffrey Morgenthaler Planetary Science Institute	**[P2] -** Using the Io plasma torus as a probe of Io's atmosphere (yes, you read that right)
Quentin Nenon IRAP-CNRS	**[P6] -** Pitch angle distribution of MeV electrons in the magnetosphere of Jupiter
Chung-Sang Ng University of Alaska Fairbanks	**[P11] -** The Diffusion-Advection Turbulent Heating Model for Giant Planet Magnetospheres: New Results Based on Juno Data
Tatphicha Promfu Chiang Mai University	**[P31] -** Case study of Ganymede's footprint location shifts in respond with the volcanic eruptions at Io and the solar wind compression
Gabrielle Provan University of Leicester	**[P19] -** Magnetosphere-ionosphere coupling at Jupiter during Juno's Prime mission
Licia Ray Lancaster University	**[P14] -** Quasi-Static Acceleration Regions as the source of Bi-Directional Electron Beams at Jupiter
Licia Ray Lancaster University	**[P13] -** Revealing the local time structure of Alfvén radii and travel times in the Jovian Magnetosphere
Abigail Rymer JHUAPL/NASA HQ	Withdrawn - A Novel Source of Radiation Belt Particles at Jupiter
Andrew Schok University of Alaska Fairbanks	**[P12] -** Magnetic field fluctuations in Jupiter's magnetosphere: GAMERA model and Juno data comparison
Ali Sulaiman University of Iowa	**[P21] -** Jupiter's low-altitude auroral zones: Fields, particles, plasma waves, and density depletions
Jamey Szalay Princeton University	**[P22] -** Closed Fluxtubes and Proton Conics in Jupiter's Polar Cap
Emma Thomas University of Leicester	**[P35] -** How windy are Uranus' aurorae?: Measuring ionospheric ion flows and extending the cartography of the infrared aurorae at Uranus
Marissa Vogt Boston University	**[P18] -** Developing shared computing code for the MOP community
Suwicha Wannawichian Chiang Mai University	**[P30] -** Prospect of connection between Jupiter's main emission power and the satellites' footprint brightness
Chongjing Yuan Institute of Geology and Geophysics, Chinese Academy of Sciences	**[P7] -** Energetic electron spectra at L<20 in the Jovian magnetosphere: Observations from Galileo and Juno

Poster session 2 - Thursday July 14

Peter Addison Georgia Institute of Technology	**[P25] -** Influence of Europa's Time-Varying Electromagnetic Environment on Magnetospheric Ion Precipitation and Surface Weathering
Omakshi Agiwal Boston University	**[P5] -** First Steps Towards a New Saturn Ionosphere Model Including Ring-Planet Coupling and Electrodynamics
Sofia Burne IAFE, UBA - CONICET	**[P17] -** MULTIPLE IMPACTS OF ICMES ON THE SATURN-TITAN SYSTEM: T96 OBSERVATIONS REVISITED
Shane Carberry Mogan New York University	**[P21] -** Evidence for H2 and Constraints on H2O in Callisto's Atmosphere
Baptiste Cecconi Observatoire de Paris	**[P11] -** Effect of an interplanetary coronal mass ejection on Saturn's radio emission
Sebastian Cervantes Institut für Geophysik und Meteorologie, Universität zu Köln	**[P29] -** Constraints on Europa's subsolar atmosphere based on a joint analysis of HST spectral images and Galileo magnetic field data
George Clark Johns Hopkins Applied Physics Lab	**[P1] -** Comprehensive Observations of Magnetospheric Particle Acceleration, Sources, and Sinks (COMPASS): A Dedicated Jovian Radiation Belt Mission to Unlock the Secrets of the Solar System's Greatest Particle Accelerator
Alexandre De Becker Hong Kong University	**[P37] -** Analysis of the sodium jets detected on Io with TRAPPIST
Vincent Dols LASP/Colorado University	**[P36] -** Io's Electron Beams
Anne-Cathrine Dott Institute of Geophysics and Meteorology, University of Cologne	**[P38] -** Latitudinal Variation of Io's Sublimation Atmosphere Explained by a Model Considering Thermal Inertia
Charles Haynes Georgia Institute of Technology	**[P24] -** Emission of Energetic Neutral Atoms at Callisto and Europa
Vincent Hue Southwest Research Institute	**[P39] -** The satellite auroral footprints at Jupiter: A Juno perspective
Hans Huybrighs Khalifa University	**[P26] -** The effect of perturbed fields, charge exchange and plumes on energetic proton depletions during the Galileo flybys of Europa
Caitriona Jackman Dublin Institute for Advanced Studies	**[P12] -** A statistical view of the response of Saturn's radio emissions to solar wind driving
Thomas Kim Los Alamos National Laboratory	**[P14] -** First Glimpse at Thermal Ion Properties of Individual Water Group Ions in Saturn's Magnetosphere
Laurent Lamy LESIA, Observatoire de Paris / LAM, Aix-Marseille Université	**[P34] -** Determining the beaming of Io decametric emissions : a remote diagnostic to probe the Io-Jupiter interaction

Lucas Liuzzo Space Sciences Laboratory, University of California, Berkeley	**[P4] -** Formation of a tilted plasma wake at Neptune's moon, Triton
Xuanye Ma Embry-Riddle Aeronautical University	**[P16] -** Flux tube entropy and Flux tube content of the Saturn's Magnetospheres
Pippa Molyneux Southwest Research Institute	**[P19] -** UV reflectance spectra of Jupiter's icy moons: Spectral effects of surface processing by Jovian magnetospheric plasma
Alessandro Mura INAF	**[P40] -** Infrared images of Jupiter Aurora: 5 years of H_+^3 observations at Jupiter
Go Murakami Japan Aerospace Exploration Agency	**[P2] -** Life-environmentology, Astronomy, and PlanetarY Ultraviolet Telescope Assembly (LAPYUTA) mission: instrument overview and technical developments
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Elias Roussos Max Planck Institute for Solar System Research	**[P22] -** Transient heavy ion radiation belts at the orbits of Europa, Ganymede and Callisto

Shinnosuke Satoh Tohoku University	**[P28] -** A Test Particle Simulation of Jovian Magnetospheric Electrons Precipitating into Europa's Oxygen Atmosphere
Stephan Schlegel Institute of Geophysics and Meteorology, University of Cologne, Germany	**[P31] -** Density Model of the Io Plasma Torus Constrained by the Io Footprint Positions
David Strack University of Cologne, Germany	**[P23] -** Callisto's moon-magnetosphere interaction: MHD parameter studies for Galileo's C03 and C09 flyby
Ali Sulaiman University of Iowa	**[P35] -** Small-scale signatures of Io's flux tube: Evidence of filamentation?
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Emma Woodfield British Antarctic Survey	**[P9] -** Wave-Particle Interactions at Saturn: The Impact of Multiple Wave Types on the Dynamics of Saturn's Electron Radiation Belt.
Siyuan Wu Southern University of Science and Technology	**[P13] -** Rotational Modulation of the 20 kHz Saturn Narrowband Emissions
Rikuto Yasuda Tohoku University	**[P18] -** Numerical radar simulation for the explorations of the ionosphere at Jupiter's icy moons
Zeqi Zhang Imperial College London	**[P6] -** Secondary electron emission from the Cassini spacecraft in Saturn's ionosphere: An alternative to charged dust?

What has Juno Revealed about Jupiter's Magnetosphere?

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KL (keynote lecture)

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Juno has been orbiting Jupiter for six years, making over 40 orbits of the giant planet. The polar orbit provided unique views of Jupiter's aurora as well as in situ measurements of the particles and fields in the polar regions. Away from Jupiter, Juno made magnetospheric measurements out to $\sim$100 RJ from dawn to midnight to evening in local time, traversing the equatorial plasma sheet many times. At the same time, Earth-based instruments have measured auroral UV and radio emissions as well as the upper atmosphere. This tutorial review talk summarizes what we have learned about Jupiter's vast magnetosphere from the Juno mission so far and anticipates what the extended mission might reveal.

Magnetosphere-Ionosphere-Thermosphere Coupling at Jupiter: Current Understanding and Critical Questions

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The dynamics of the Jovian magnetosphere is controlled by a complex interplay between the planet's conducting upper atmosphere, its moons and the solar wind: anchoring of planetary magnetic field lines into the conducting layers of the thermosphere drags them into corotation with the planet; interactions with the solar wind superimpose on corotation a Dungey-type system of convection cells, likely significant at very high latitudes; finally, centrifugal forces acting on outward flow of Iogenic plasma induce partial sub-corotation and are believed to drive a second circulation cell, i.e. the Vasyliunas cycle, connecting the middle magnetosphere to the magnetotail and magnetospheric boundaries. Exchanges of particles, momentum and energy between the planet, its moons and its magnetosphere resulting from the competition between these three elementary transport cycles are mediated by Magnetosphere-Ionosphere-Thermosphere (MIT) coupling processes which display both similarities and differences with their Earth and Saturn counterparts:

- d.c. electric current systems and waves connecting the Jovian thermosphere-ionosphere to the equatorial magnetosphere (the plasmasheet) transfer angular momentum between the two regions;
- a puzzling diversity of particle transport and acceleration processes, revealed by Juno observations, takes place along auroral and polar magnetic field lines;
- connection of these particle acceleration processes to the complex morphology of Jovian auroral emissions remains poorly understood;
- This interplay of current systems, waves and particle acceleration processes controls the degree of dynamical coupling or decoupling between the Jovian plasma sheet and the two conjugate ionospheres;
- Finally, momentum deposition into the thermosphere produced by high-latitude ionospheric currents combines with Joule heating and particle precipitation to drive large-scale meridional and zonal wind systems which redistribute high-latitude energy deposition to other latitudes.

In this review, we will highlight what has been learnt about these four MIT coupling processes from the unique combination of space-borne observations, Earth-based observations and models that has been prevailing during the Juno era . We will particularly emphasize:

- detailed characterizations of the key parameters of MIT coupling at ionospheric altitudes (ionospheric conductances, current systems and energy deposition rates) made possible by multi-instrument analysis of Juno data and models;

- comprehensive global-scale monitoring of plasma and energy transport in the Jupiter system made possible by JAXA's Hisaki mission;
- direct observations of horizontal ionospheric plasma motions in the Jovian IR auroral emission regions performed by Earth-based telescopes;
- contributions of advanced dynamic models of magnetosphere, ionosphere and thermosphere to our understanding of how this coupled system works.

We will identify some of the most critical open questions and will suggest ways to address them by maximizing synergies between observations and modelling, from Juno's Extended Mission to future observations by JUICE and other new space probes.

Structure and dynamics of Jupiter's dawnside magnetosphere

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Jupiter's dawnside outer magnetosphere can be characterized as a competition between internally-driven sunward flow and solar wind-driven tailward flow, leading to a highly variable and poorly understood region of the magnetosphere. Following the Voyager I flyby, an extended region along the dawn flank was characterized as a boundary layer or magetospheric wind that was distinctly different from the equatorially confined magnetodisc [Gurnett et al., 1980, Krimigis et al., 1979]. An analysis of energetic particle data from multiple spacecraft led Delamere and Bagenal [2010] to refer an extended cushion region along the dawn flank, presumed to be on closed magnetic field lines. Now, Juno's polar orbit is ideally suited to diagnose this perplexing region of the magnetosphere. Following Huscher et al., [2021] and Phipps and Bagenal [2021], we have organized the Juno data according to distance from the centrifugal equator plane to understand meridional structure as well as temporal variability of the magetodisc. The Juno data will be compared with GAMERA (Grid Agnostic MHD for Extended Research Applications) global simulations to understand the meridional structure, with particular focus on the role of a possible closed flux region in the dawn tail [Zhang et al., 2021]. Based on simulation results, we consider three general processes that contribute to temporal variability in this region: 1) global-scale surface waves on the magnetopause boundary (e.g., Kelvin-Helmholtz waves), 2) plasma injections from magnetotail processes (e.g., tail reconnection), and 3) internal magnetodisc density structures advecting azimuthally and radially. Finally, some of these processes may be amplified by variations in the solar wind, which we will qualitatively address by simulating global magnetospheric response to simple variations in solar wind dynamic pressure.

Azimuthal field signatures associated with magnetosphere-ionosphere coupling in the Jovian magnetosphere: Comparison between Juno observations and theoretical modeling

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We have analyzed magnetic field data obtained during high-altitude traversals of Jovian middle magnetosphere field lines during the first ten northern hemisphere inbound data-taking passes by the Juno spacecraft, for the presence of azimuthal perturbations associated with magnetosphere-ionosphere coupling currents. Full traversals from outer to inner field lines occurred on all ten passes at radial distances $\sim$7-16 RJ (T1 traversals), followed in four cases by reversed traversals (T2) at $\sim$4-7 RJ. Signatures of intense upward field-aligned currents were observed in all cases, closely co-located with the statistical main auroral oval when mapped along field lines to the ionosphere. Two T1 sheets carry currents $\sim$10 MA per radian of azimuth in ionospheric colatitudinal layers $\sim$1.2°, closely comparable with the $\sim$8.5 MA rad-1 theoretical model value of Cowley et al. 2008 (doi.org/10.5194/angeo-26-4051-2008). The remainder typically carry half the current $\sim$5.1 MA rad-1 in layers half the width $\sim$0.56°, thus with comparable current densities $\sim$425 nA m-2. The T2 currents are smaller $\sim$3.4 MA rad-1 with current densities $\sim$120 nA m-2, a difference that may relate to locations on opposite sides of the main oval as reflected in near-contemporaneous UV observations, though ionospheric field strengths are not greatly different. Comparison with northern hemisphere near-periapsis currents derived by Kotsiaros et al. 2019 (doi.org/10.1038/s41550-019-0819-7) on the same passes inside $\sim$2 RJ yields a cross-correlation coefficient $\sim$0.7 with the T1 currents, though their mean values $\sim$3.8 MA rad-1 are more comparable with T2 currents than with mean T1 currents $\sim$6.2 MA rad-1. The differences may have spatial, temporal, or methodological origins. At present, we are investigating the relation between UV auroral brightness and the field-aligned current signatures by studying concurrent Juno UVS observations and magnetic field measurements.

3D Time-Domain Multifluid Investigations of Jovian Kinetic FLR Responses

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Field line resonances (FLRs) form as eigenmodes of Alfven waves between conductive ionospheric boundaries along magnetic field lines. When kinetic Alfven waves develop along an FLR, electron inertial effects can limit the width of the structure and lead to dispersive wave trains that in turn can accelerate particles. To address this nonlinear process, we present a 3d time-domain multifluid plasma simulation of FLRs using the JRM33 magnetic field model (Connerney et al. 2021) and a plasma mass density model in a dipolar coordinate system modified to support Jupiter's magnetic deviations. This is compared to a frequency domain solution for Jovian FLRs using a wave shooting method. Radial (M-shell) maps of the FLR frequencies and local wave power evaluate the system sensitivity to initial driving conditions. This model approach provides the framework for deeper investigations of kinetic plasma ULF wave dynamics at Jupiter.

Modelling of polar regions: a comparison between the Earth, Jupiter, and Saturn

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The polar region of a planetary magnetosphere is critical for understanding the mass, momentum and energy coupling through solar wind-magnetosphere interactions, especially for auroral emissions. The generation of an open magnetosphere is driven by the classic Dungey cycle, which applies to the terrestrial magnetosphere but not necessarily to the giant magnetospheres rotating much faster than the Earth. We use three-dimensional global simulations to study the configuration of polar magnetospheres by considering both solar wind merging and planetary rotation. We reveal that the speed of planetary rotation, inducing strong convectional electric fields, is the key factor in determining the structure of polar magnetospheres and energy dissipations. By increasing the influence of planetary spin over solar wind merging, we show that the Earth-type open magnetosphere may transit to the Jupiter-type closed magnetosphere with significant dawn-dusk and hemispheric asymmetries, and the polar aurora would eventually evolve to the Jupiter-type, with intense emissions near the magnetic poles. Such transition may also explain the highly dynamic auroral morphologies observed at Saturn, which resemble both the terrestrial and Jovian systems. This study provides a theoretical framework describing fundamentals of magnetospheric physics, which is applicable to the Saturn, Jupiter and exo-planets systems.

Particle motion and pitch angle scattering due to magnetic field curvature in the Jovian magnetosphere

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The complex morphology of the magnetospheres of the giant planets Jupiter and Saturn, and in particular the elongated magnetodisc structure in the middle magnetosphere, have implications for the bouncing and drifting motions of charged particles. The magnetodisc is believed to contribute to the effective 'scattering' of the pitch angle after each equatorial crossing of charged particles (electrons, protons, heavier ions) with sufficient energy which, in turn, modifies their trajectory and may eventually lead the particle to enter the loss cone.

Using a numerical particle tracing code, compatible with our UCL magnetodisc code, we examine the behaviour of different charged particles in the Jovian magnetodisc, assuming different values for their initial energy and equatorial pitch angle. We focus on the non-adiabatic motion of adequately energetic particles, whose gyroradius eventually becomes comparable to the radius of curvature of the local magnetic field lines.

Our results can potentially be of interest for the planning and interpretation of magnetic field and particle data from missions such as JUICE and, in a broader context, are connected to auroral studies related to the giant planet systems.

Ionospheric Electron Densities Inferred from Juno Plasma Wave Observations

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Juno's highly eccentric polar orbit takes it to perijove distances of $\sim$1.06 R_J on each orbit. For the first perijove, this occurred just north of the planetary equator, but has precessed north by about a degree per orbit over the prime mission. Typical altitudes at perijove are about 4000 km above the 1-bar level, but the minimum altitudes vary through the mission. The Waves instrument on Juno observes a number of plasma wave modes in and near the ionosphere that provide information on the local electron number density, including electron plasma oscillations that occur at the electron plasma frequency f_{pe} and whistler-mode hiss which has an upper frequency limit of f_{pe} in Jupiter's strongly magnetized inner magnetosphere. The electron plasma frequency provides the electron number density by $N_e = (f_{pe}/8980)^2$ where frequency is in Hz and N_e is in cm^{-3}. At times, other characteristic frequencies of the plasma, such as the lower hybrid resonance frequency f_{LH} and the L=0 cutoff $f_{L=0}$ can be observed. Along with the electron cyclotron frequency f_{ce} given directly by the magnetic field strength measured by the Juno Magnetometer instrument, such characteristic frequencies provide multiple means of determining the electron number density. Where two or more of these characteristic frequencies can be found, simultaneously, and they give the same value for N_e, we gain confidence in the inference. Where possible, we compare the Waves electron densities with ion densities and compositions measured by JADE, with assumptions about the charge state of the ions and charge neutrality. Determinations of scale heights revealed a large range for these from 230 km to 1700 km. However, a simple model for these based on an assumed temperature of 1000 K and a variation in the dominant ion in the composition appears to fail. The short scale heights would seem to indicate H_3^+ as the dominant species, but JADE compositions do not confirm this. Alternately, spatial variations may be responsible for the variations, perhaps related to the magnetic field dip angle.

Effect of magnetospheric disturbances on Jovian radio emissions: an in situ case study from Juno data

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During its 53-day polar orbit around Jupiter, Juno often crosses the boundaries of the Jovian magnetosphere, namely the magnetopause and bow shock, as well as the plasma disc (located at the centrifugal equator). The positions of the magnetopause and bow shock allow us to determine the dynamic pressure of the solar wind (using both the updated model of Joy et al. 2002 by Ranquist et al., 2020 and/or in situ data) which allows us to infer magnetospheric compression or relaxation, while the observations of plasma disc perturbations allows us to infer magnetospheric reconfigurations.

The aim of this study is to examine Jovian radio emissions during magnetospheric perturbations. We then use our analysis to determine the relationship between the solar wind and Jovian radio emissions (observed and emitted from different regions of the magnetosphere, from different mechanisms, and at different wavelengths from kilometers to decameters).

In this presentation, we show case studies for each typical case (bow shock, magnetopause and plasma disk crossings) and show that the activation of new radio sources is related to magnetospheric disturbances. By performing a statistical study of these crossings, we hope to be able to show the relationship between the activation of new radio sources (emission intensity and extension, source positions) and the solar wind (dynamic pressure, magnetic intensity, ...), with the aim of being able to use observations of planetary radio emission as a proxy for the solar wind.

Jupiter's Auroral Radio Emissions Observed by Cassini: Rotational Versus Solar Wind Control, and Components Identification

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Reanalyzing Cassini radio observations performed during Jupiter's flyby of 2000-2001, we study the internal (rotational) versus external (solar wind) control of Jupiter's radio emissions, from kilometer to decameter wavelengths, and the relations between the different auroral radio components. For that purpose, we build a database of the occurrence of Jovian auroral radio components bKOM, HOM, and DAM observed by Cassini, and then frequency-longitude stacked plots of the polarized intensity of these radio components. Comparing the results obtained inbound and outbound, as a function of the Observer's or Sun's longitude, we find that HOM & DAM are dominantly rotation-modulated (i.e., emitted from searchlight-like sources fixed in Jovian longitude), whereas bKOM is modulated more strongly by the solar wind than by the rotation (i.e., emitted from sources more active within a given Local Time sector). We propose a simple analytical description of these internal and external modulations and evaluate its main parameters (the amplitude of each control) for HOM + DAM and bKOM. Comparing Cassini and Nançay Decameter Array data, we find that HOM is primarily connected to the decameter emissions originating from the dusk sector of the Jovian magnetosphere. HOM and DAM components form a complex but stable pattern in the frequency-longitude plane. HOM also seems to be related to the lesser arcs identified by Voyager. bKOM consists of a main part above 40 kHz in antiphase with HOM occurrence, and detached patches below 80 kHz in phase with HOM. The frequency-longitude patterns formed by DAM, HOM and bKOM remain to be modeled. This work has been published in : Zarka, P., Magalhães, F. P., Marques, M. S., Louis, C. K., Echer, E., Lamy, L., Cecconi, B., and Prangé, R., Journal of Geophysical Research: Space Physics, 126, e2021JA029780, 2021. https://doi. org/10.1029/2021JA029780

Ubiquitous Jupiter fast drifting radio bursts reveal Alfvénic electron acceleration

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Jovian radio emissions are a prominent signature of electron acceleration in Jupiter's magnetosphere. These electrons can be accelerated by two mechanisms : parallel electric fields and associated potential drops (Louarn et al. 1990), and Alfvèn waves (Ergun et al. 2006, Bagenal et al. 2017). At Jupiter, Alfvèn waves are the most important mode involved in the far-field interaction between Jupiter and Io (Saur et al. 2004). By analogy with Earth, Ergun et al. (2006) suggested that part of the Jovian auroras could also be due to Alfvén accelerated electrons. The signature of such an acceleration has been directly observed only for the Io-Jupiter interaction, in the form of fast drifting decametric radio bursts in the time-frequency plane - the so-called S-bursts (Hess et al., 2007a). Ground-based radio observations obtained with the Juno-N receiver at the Nancay Decameter Array, with high time-frequency resolution, are analyzed in this work. We developed a method, based on Fourier and Radon transforms, allowing us to automatically detect fast drifting structures in massive dynamic spectra data. We processed and analyzed one month of observations (april 2021), totalling several terabytes of data. We detected a number of such drifting structures : part of them is related to Io-Jupiter emissions as expected, with drifts values consistent with previous studies (Hess et al. 2007b) ; but we also detected structures related to the Ganymede-Jupiter interaction and to the main aurora. The measured drift rates allow us to estimate electron energies and periods of the Alfvèn waves. These results bring the evidence of Alfvènic electron acceleration in the Ganymede-Jupiter circuit and above the Jovian auroras, suggesting the ubiquity of Alfvèn wave acceleration. It opens the possibility to remotely study them using sensitive, high time-frequency resolution radio observations.

Numerical modelization of Jovian plasma emissions

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Jupiter's magnetosphere generates two kinds of radio emissions below 40 MHz: the maser-cyclotron emissions and the plasma emissions. The first ones are produced at high magnetic latitudes (auroral regions) by out-of-equilibrium electronic distributions, with typical energies of 1-10 keV, through a mechanism that directly converts the perpendicular energy of electrons into electromagnetic waves.

The second ones, much less studied, result from the conversion of electrostatic waves at ω_L, ω_{pe}, ω_{UH} or their harmonics, into electromagnetic waves through mode conversion mechanisms. Their production involves the plasma distribution in the jovian intern magnetosphere (mainly driven by the volcanic activity of the Io satellite), and its gradients. It is these plasma emissions that we choose to study here.

First, I will present the phenomenology of these emissions and their latitude-frequency distributions, determined from the first 3 years of Juno observations along its polar orbit [1]. Then I will describe the main theoretical frameworks for the generation of Jovian plasma emissions [2, 3] on which I based my modelizations, as well as the models used to compute the electron density n_e [4] and the magnetic field B [5]. The modelelization of the latitude-frequency distributions of the plasma emissions is then predicted as a function of several parameters (emission frequency, angle (B,∇n_e), $||\nabla n_e|$, direction of the emitted wave vector) for which we have systematically explored the effects. We simplify the treatment of the propagation of the radio waves between the source and the observer (straight line propagation, shadowing of the emission at ω_{pe}). Finally, the comparison between the simulated diagrams and the Juno observations is done by cross-correlation and by boolean comparisons of the latitude-frequency occurrence areas.

I will present and interpret the main results obtained so far. For instance, we were able to deduce from this study that theoretical frameworks describing plasma emissions at ω_{pe} (such as [2]) predict emissions at frequencies significantly lower than those observed, while plasma emissions at $2\omega_{UH}$ [3] lead to diagrams quite similar to those observed.

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Electron signatures associated with mid-latitude Alfven wave perturbations inferred from Juno magnetometer observations

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Simulations of the Gyrofluid-Kinetic-Electron model (Damiano et al., 2019) have illustrated broadband electron signatures qualitatively consistent with Juno JADE and JEDI observations due to high latitude inertial Alfvén waves (e.g. Damiano et al., 2019; Coffin et al., 2022). In the work to date, we have assumed analytically derived perturbations with which to initialize the simulations. Correspondingly, analysis of Juno magnetometer observations illustrate an abundance of perpendicular magnetic field perturbations evident at mid-latitudes and a range of L shells indicative of the presence of Alfvén waves (e.g. Lorch et al., 2022). In order to make a more quantitative assessment of the high-latitude impact of these perturbations, we analyze Juno MAG data to derive a few examples of perpendicular magnetic field perturbations $\delta B_\perp(t) = \delta B(t) - \delta B_{||}(t)$, where $\delta B(t) = B(t) - B_o(t)$ and $B_o(t)$ is the background magnetic field determined from a running average. The resulting profiles of $\delta B_\perp$ are used to initialize the GKE simulations at the corresponding L shell and latitude and, where feasible, the background density is set consistent with the density moment inferred from observations (e.g. Huscher et al., 2021). The simulation domain parallel to the background magnetic field encompasses from the top of the torus to 1.5 R_J in geocentric altitude and the resulting local and high-latitude electron response in the simulations are analyzed and presented.

Structure of Zone I of Jupiter's Main Aurora

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Based on Juno-measured energetic particles with electron energies >30 keV and ion energies >50 keV, three regions with substantial UV auroral emissions were defined for Jupiter's main aurora (Mauk et al., 2020): the low-latitude diffuse aurora, a mid-latitude Zone I of downward electron acceleration, and a higher latitude Zone II of bi-directional electron acceleration. These definitions are refined by Sulaiman et al. (2022, submitted). Zone I and Zone II are associated with upward and downward electric currents, respectively. In the original study, each of the two Zones were represented as being bi-modal (although that term was not used). In Zone I we sometimes observe downward electron inverted-V electrostatic acceleration and sometimes broadband acceleration with greater energy fluxes. Using Juno JADE plasma data, Szalay et al. (2020) recently revealed that in Zone I, upward ion electrostatic acceleration below the spacecraft can co-exist with downward broadband electron acceleration above the spacecraft. Here we ask the question: does downward electrostatic electron acceleration always accompany even the broadband-generated Zone I auroral emissions? We note that many Zone I ion auroral structures cannot be fully characterized with the Juno plasma sensor because of a dependence on spacecraft rotation for angular coverage. Here we bring to bear a different ion data product with several deficiencies compared to JADE data, but with angular sampling occurring at the same cadence as that used for the electrons. That product is the Juno JEDI time-of-flight x pulse-height (TOFxPH) data with proton energies measured down to 10 keV. We find the following: 1) We verify that upward electrostatic ion acceleration below the spacecraft can coexist with downward broadband electron acceleration above the spacecraft. 2) Sometimes in Zone I broadband regions there are no measureable upward ion fluxes above 10 keV. 3) During transitions between electrostatic and broadband acceleration, upward ion electrostatic acceleration can disappear to being no larger than 10 keV as compared to downward electron characteristic energies of several hundred keV. 4) During those same transitions, the upward ion acceleration can be replaced with upward conic ion distributions without evidence of electrostatic acceleration. There appears to be a continuum between the two states in Zone I.

Mauk, B. H., et al., (2020), JGR, doi:10.1029/2019JA027699 Sulaiman, A. H. et al. (2022), JGR, submitted. Szalay, J. R. et al., (2021), GRL, doi:10.1029/2020GL091627

Magnetosphere-Ionosphere Coupling in Jupiter's Polar Caps: Implications for Megavolt Potentials

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Observations from the Juno satellite indicate the presence of large potential drops of over 1 Megavolt accelerating ions downward over the polar cap regions (Clark et al., 2017; Mauk et al., 2020). Since the field-aligned currents in this region are very weak, it is difficult to understand how such potentials can be generated and maintained. We have developed a simple model of magnetosphere-ionosphere coupling that provides a framework for understanding these potentials. The co-rotation of Jupiter's magnetosphere with the planet provides an electromotive force (emf) that can act as the generator of field-aligned currents. This model indicates that currents up to 0.1 μA/m2 could be generated by the corotation and that a perpendicular potential of over 10 MV can be generated in a patch of corotation that extends 10°in latitude. However, depending on the value of the ionospheric Pedersen conductance, this emf can be shorted out by the development of a polarization electric field. To determine the degree of this polarization, we assume that the magnetospheric response to this perturbation is characterized by an effective impedance of the flux tube, which depends on the flow velocity in the outer magnetosphere if the flux tube is closed or the solar wind speed if it is open. A parallel potential drop can be maintained when the drift velocity of the electrons exceeds their thermal speed, leading to the development of plasma turbulence or double layers. This condition could require that the plasma densities are very low, the order of 10-2 cm-3. Observations from the Waves instrument indicate that this may indeed be the case at times over the polar cap, while recent observations from JADE also indicate depletions over the polar cap (Pollock et al., 2020). Further analysis including models of the current-voltage relationship and conditions for the formation of double layers for this downward current region will be discussed.

Clark, G., et al. (2017), Energetic particle signatures of magnetic field-aligned potentials over Jupiter's polar regions, Geophys. Res. Lett., 44, 8703-8711, doi:10.1002/2017GL074366

Mauk, B. H., et al. (2020). Energetic particles and acceleration regions over Jupiter's polar cap and main aurora: A broad overview. Journal of Geophysical Research: Space Physics, 125, e2019JA027699. https://doi.org/10.1029/2019JA027699

Pollock, C. J., et al. (2020). A persistent depletion of plasma ions within Jupiter's auroral polar caps. Geophysical Research Letters, 47, e2020GL090764. https://doi.org/10.1029/2020GL090764

Juno's highest energy particle observations at Jupiter

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Juno has discovered magnetically trapped >125 MeV protons and GeV Z>1 ions between $\sim$18°-46° magnetic latitude at the inner edge of Jupiter's electron belt (radial distances of 1.12-1.41 Jovian radii) (Becker et al., 2021). These particles are detected as penetrating radiation signatures in the images of Juno's Stellar Reference Unit (SRU) star camera. Detections have occurred while Juno is magnetically connected to Jupiter's halo and gossamer rings, but not its main ring; a behavior reminiscent of the equatorial observations of high energy carbon and sulfur by the Galileo Probe. The energy and morphology of the ionization signatures allows us to constrain the GeV ions to species of $2 \leq Z \leq 8$, with possible additional contributions from species as heavy as sulfur. We will discuss this evolving SRU investigation as well as recent relativistic electron observations in the region local to Ganymede's orbit.

Becker, H. N., et al. (2021). High latitude zones of GeV heavy ions at the inner edge of Jupiter's relativistic electron belt. Journal of Geophysical Research: Planets, 126, e2020JE006772. `https://doi.org/10.1029/2020JE006772`

The effect of Z-mode waves on the electron radiation belt at Jupiter.

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It has been shown that acceleration of electrons by Z-mode waves is an important mechanism in the radiation belts of Saturn, particularly in the region inside the orbit of the moon Enceladus. This region has a very low plasma density in the presence of a relatively strong magnetic field resulting in a low ratio of the plasma frequency to the electron gyrofrequency. These plasma conditions are highly conducive to the presence of Z-mode waves and to strong wave particle interactions of those waves with the electrons. A similar region is thought to exist at Jupiter, inside the orbit of Io where the plasma density is expected to be very low and the magnetic field is very strong. This region has very little data at low latitudes, but the Juno spacecraft has been collecting Z-mode wave data at the higher latitudes as surveyed in recent published work. We use the available data and comparisons with similar density scenarios at Saturn to investigate the effect of the Z-mode waves on the electrons at Jupiter using quasi-linear modelling techniques. In this presentation we discuss the results of these investigations on the electron populations in the most intense region of Jupiter's radiation belts.

Juno Observations of Jupiter's Synchrotron Emission and Radiation Belts

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Juno is in a close polar orbit that passes through Jupiter's inner radiation belts providing in-situ measurements of high energy particles and dust as well remote measurements of the synchrotron emission from its unique perspective. The Juno Microwave Radiometer (MWR) measures the radio emission in 6 channels, at wavelengths ranging from approximately 1.4 to 50 cm, with 100 ms sampling throughout each spin of the spacecraft. There is a long history of Earth based observations of Jupiter's synchrotron emission using single dish radio telescopes and interferometric arrays such as the VLA. Earth based observations are constrained in viewing geometry as well as frequency due to confusion by Jupiter's atmospheric thermal emission which becomes a significant noise source at wavelengths below about 5 cm. The Juno data set provides a remarkable view of the Jovian synchrotron emission over a wide range of viewing angles, from inside the radiation belts, and provides a means of separating atmospheric thermal emission from synchrotron emission. While the MWR synchrotron data set is unprecedented, the size and variety of the data set also make analysis complex. Results from MWR will be presented along with companion data from Juno's radiation monitoring program. The Initial results comparing data against models will be presented.

A source of very energetic oxygen in Jupiter's innermost radiation belts

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Jupiter hosts the most hazardous radiation belts of our solar system that, besides electrons and protons, trap an undetermined mix of heavy ions. The details of this mix are critical to resolve because they can reveal the role of Jupiter's moons relative to other less explored energetic ion sources. Here, we show that with increasing energy and in the vicinity of Jupiter's moon Amalthea, the belts' ion composition transitions from sulfur- to oxygen-dominated due to a local source of, multiply charged, $\geq$50 MeV/nucleon oxygen. Contrary to Earth's and Saturn's radiation belts, where their most energetic ions are supplied through atmospheric and ring interactions with externally accelerated cosmic rays, Jupiter's magnetosphere powers this oxygen source internally. The underlying source mechanism, involving either Jovian ring spallation by magnetospheric sulfur or stochastic oxygen heating by low-frequency plasma waves, puts Jupiter's ion radiation belt in the same league with that of astrophysical particle accelerators.

Open science questions in the radiation belts of Jupiter

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Our understanding of radiation belts in the solar system has been revolutionized by the Van Allen Probes at Earth, Cassini at Saturn, and Galileo and Juno orbiters at Jupiter. In addition, Clipper and JUICE will offer a new view of the Jovian radiation belts in the next decade. In this presentation, we build upon this legacy to show that the radiation belts of Jupiter will nevertheless keep more of their secrets hidden. We rely on the comparison with other planets and on the heritage of past missions to Jupiter to formulate seven critical scientific questions that need to be addressed to achieve physical understanding beyond phenomenological characterization. We highlight why these seven secrets are worth unveiling not only for magnetospheric physics and space physics, but also for the fields of astrophysics and planetary science. In particular, the radiation belts of Jupiter represent the closest analogue within our solar system to some distant astrophysical accelerators, they enable the study of fundamental high-energy plasma physics, such as adiabatic charged particle acceleration and wave-particle interactions, and they impact the surfaces and subsurfaces of icy moons. Finally, we present the measurements required to close these outstanding questions.

Abstracts - Tuesday oral presentations

Auroral Acceleration Processes at the Giant Planets

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The auroral emissions at Jupiter and Saturn appear to share many of the basic processes that have also been studied at Earth. However, the aurora at each planet varies in how these processes are driven. A variety of plasma processes are associated with auroral acceleration: [1] direct acceleration by parallel electric fields, either distributed along the field line or localized in a strong double layer; [2] parallel acceleration by wave processes, particularly due to the presence of kinetic Alfvén waves or whistler mode waves that can interact with electrons at the Landau resonance; [3] ion acceleration at cyclotron resonances, that can give rise to ion conic distributions; and [4] acceleration by stochastic fields, such as multiple charge clumps/holes or weak double layers. The formation of all of these forms of parallel electric fields is associated with strong field-aligned currents, and so auroral acceleration generally depends on the generation of these currents. At Earth, the solar wind-magnetosphere interaction drives the magnetospheric convection that is associated with the region-1 current system, while transient effects such as magnetospheric substorms drive field-aligned currents that form the so-called substorm current wedge. At Jupiter, the solar wind source is minor, and the primary driver of the main current system is the breakdown of co-rotation. Juno observations have indicated that the currents consist of into a more equatorial Zone I upward current region and a poleward Zone II, that is largely downward current but frequently shows bidirectional distributions. Zone I contains both monoenergetic acceleration as well as broadband acceleration, likely due to wave processes or stochastic fields. This zone is reminiscent of the upward region 1 currents in the pre-midnight sector on Earth. However, the waves that produce the broadband acceleration are not always seen in this region, leading to the suggestion that they are damped out before reaching Juno altitudes. The Zone II region is primarily downward currents, but also contains strong broadband acceleration producing auroral emissions, unlike at Earth where the downward current regions are usually dark. In addition, at Jupiter, auroral emissions are also associated with the Galilean moons, particularly Io. These emissions are dominated by acceleration due to Alfvén waves excited by the motion of the moon through Jupiter's magnetosphere. Although Saturn's auroral zone have not been as well observed, there were a few passes over the auroral zones during the last year of Cassini operations when the satellite came closer to the planet. These observations indicate that Saturn represents a middle ground between Earth and Jupiter, with the aurora being largely driven by co-rotation while the upward and downward current regions are structured more like those at Earth. Therefore, while there are some similarities between the basic mechanisms of auroral acceleration at the three planets, the conditions under which the auroral field-aligned currents are driven are unique to each planet.

Identifying jovian X-ray auroral families: tying the morphology of X-ray emission to associated magnetospheric dynamics

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Many recent studies have found that using the single hot spot nomenclature may not be representative of the brightest jovian X-ray auroral emissions, implying there may be more than one auroral driver. We explore this idea further by separating the concentrated X-ray emissions found from Chandra within the northern auroral region into physics-informed 'X-ray auroral families', with particular focus on Juno-era observations (24 May 2016 - 8 September 2019) . We define five X-ray families based on their location with respect to the UV main oval: X-ray noon, dusk, polar region, dawn, and the low latitude extension (LLE) region.

To avoid observation bias, we analyse emissions over a $\sim$3-hour interval within a central meridian longitude (CML) range of 80° - 250°. We compare the distribution of auroral photons within each family to magnetospheric dynamics found from simultaneous UV Hubble Space Telescope (HST), Juno (Waves and MAG) data and inferred solar wind conditions from a 1D MHD propagation model to infer the state of the magnetosphere during each Chandra window. We find two distinct categories of X-ray morphology from our family definitions: fully polar aurora and low latitude emissions (e.g. when LLE photon distribution $>$ 10% of all auroral emissions). From our visibility modelling of each X-ray family, all five families rotate into view between our CML range.

Therefore, we suggest the non-uniform distribution of X-ray auroral photons across all observations is likely associated with the switching on/off of magnetospheric drivers opposed to visibility effects (e.g. planetary tilt). Our preliminary results suggest that fully polar aurora emissions are likely to occur during or just after a compression event, from comparison between the UV dynamics and X-ray behaviour, agreeing with in situ Juno data. We therefore suggest that using a combination of UV-X-ray auroral dynamics may provide us with a possible proxy to monitor solar wind/magnetospheric conditions when an upstream monitor is absent.

Long-term exploration of Chandra X-ray observations of Jupiter: equatorial and auroral emissions

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We present the outputs of a new pipeline to analyse observations of Jupiter taken by the Chandra X-ray Observatory (CXO) over $\sim$ 2 decades. New processing techniques have been developed that optimise the oblateness of Jupiter by incorporating data from the JPL Horizons program to better constrain the limb of the planet. We also showcase a new Pulse Invariant (PI) filtering method which accounts for Chandra instrument degradation over the span of the observations. This method also limits background contamination by filtering over PI channels where the source dominates the background. We then present two applications of this pipeline;

1. A statistical study of the X-ray emissions emanating from Jupiter's disk region using 19 years of CXO observations. Previous work has suggested that these emissions are consistent with solar X-rays elastically scattered from the planet's upper atmosphere. We compare the CXO results with data from the Geostationary Operational Environmental Satellites (GOES) X-ray Sensor (XRS), which provides solar X-ray fluxes for the wavelength band 1-8 Å(long channel), to quantify the correlation between solar activity and jovian disk counts. Initial results show a poor statistical correlation between the data-sets, even when restricting for Earth-Sun-Jupiter (ESJ) angle, which may be a result of the increasing degradation of the instrument. The high spatial resolution on board the CXO enabled the disk morphology to be studied and compared with surface magnetic field data from the JRM09 (Juno Reference Model through Perijove 9) internal field model. We identify a preference of jovian disk emission at $\sim$ 3-5 Gauss surface magnetic field strength, suggesting that the production mechanism of the jovian disk X-ray emissions is more complex than previously thought.

2. Preliminary analysis from a recent CXO campaign that took place from July-October 2021 consisting of 8 Chandra observations of Jupiter with a total exposure time of 504 ks (140 hours). These observations coincided with Juno orbiting into the dusk magnetosphere of Jupiter, thought to be the most likely source region for driving of jovian auroral X-rays. One leading theory for the driver of these emissions is Ultra Low Frequency (ULF) waves propagating along jovian magnetic field lines due to processes on the dusk flank of the magnetosphere. This campaign presents the first ever opportunity for contemporaneous in situ and X-ray observations at this location. We present the first images and timing analysis from these observations.

Two decades of Jupiter’s X-ray emissions as measured by XMM-Newton’s RGS and EPIC instruments

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XMM-Newton has helped to revolutionise our understanding of Jupiter’s X-ray emissions over the last 2 decades. For example, data from the X-ray observatory revealed that electron bremsstrahlung is responsible for the high energy (hard) X-rays from the planet’s aurora and that these emissions tend to be brighter at the south than the north, contrary to the low energy (soft) X-ray emissions (Branduardi-Raymont et al., 2007). More recently, these hard X-ray emissions have been found to brighten with the appearances of dawn storms and injection events in the UV aurora and that there may have been more than one source of electrons precipitating at the time (Wibisono et al., 2021). Spectral analysis of Jupiter’s aurorae with XMM-Newton confirmed that an important source for the soft X-ray emissions were precipitating high charge state oxygen ions (Branduardi-Raymont et al., 2004). Finally, XMM-Newton has sometimes observed the soft X-ray aurora to pulse with periods of tens of minutes - some of those times, the poles pulse independently of each other (Dunn et al., 2017) while at other times they do so in unison (Wibisono et al., 2020). Comparing remote observations by XMM-Newton and in-situ measurements by Juno shows the importance of wave-particle interactions in the production of these pulsations (Yao & Dunn et al., 2021; Dunn & Yao et al., submitted).

All those discoveries were made using data from XMM-Newton’s European Photon Imaging Camera (EPIC) instrument. Jupiter data from the second X-ray instrument on board XMM-Newton, the Reflection Grating Spectrometer (RGS), have largely been untouched with only those from November 2003 having been analysed. RGS allows for high resolution spectral analysis of the soft X-rays. Results from those early observations showed that the oxygen emission lines at 0.7 keV that dominate Jupiter auroral spectra have a broad component. The widths of those lines suggest that the oxygen ions were precipitating with speeds of the order of 5000 km/s and energies of 2.5 MeV (Branduardi-Raymont et al., 2007).

We present our initial results from the analysis of 17 observations spanning a period of almost 20 years by EPIC and RGS: we examine the sequence of RGS spectra gathered over the years and present fits of these high resolution data. We also demonstrate how Jupiter’s equatorial X-ray emissions (mainly due to Thomson elastic scattering of solar X-rays) correlate with the solar activity over two of its cycles.

Shedding New Light on the Enigmatic Motions of Jupiter's Auroral Main Emission

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Within Jupiter's omnipresent auroral main emission, several small-scale transient phenomena exist with brightnesses and apparent motions that significantly differ from the main emission at large. The dawn storms, one of the most striking of these phenomena, are much brighter than the typical main emission and appear to lag behind corotation by >30%. The origins of these small-scale auroral features within Jupiter's coupled magnetosphere-ionosphere system is uncertain, and the drivers of their subcorotational motion are largely open questions. The Jovian aurorae are frequently used as an observable TV screen through which the state of the dynamic magnetosphere is displayed, and understanding the origins and drivers of specific parts of the main emission aurora is essential to interpreting this message. Here, we present measurements of these short-term variations in the main emission using over 140 hours of archival Hubble Space Telescope (HST) observations and characterize how the main emission varies in time, as a function of location. To handle the nearly 400 orbits of HST exposures, we have developed routines to automatically create keograms of the main emission and identify and track auroral features therein. Using this technique, we have constructed one of the first statistical surveys of the Jovian main emission to focus on the short-term evolution of the aurorae. We focus first on the dawn sector, to address the enigmatic motions of Jupiter's auroral dawn storms. Here, we find that auroral features in Jupiter's remotely-observable dawn sector (6-9 LT) lag behind corotation more frequently than would be expected if only dawn storms- which are historically rare, occurring in just $\sim$10% of previous observations- lagged behind corotation. Further, we find no apparent correlation between brightness and corotation rate, indicating that some dim auroral features behave similarly to the bright dawn storms. Multiple physical factors may influence this observed motion, but we focus on the effects of the solar EUV modulation of Jupiter's ionospheric conductance, which changes suddenly near the dawn terminator. To further explore these effects on the local time evolution of the main emission, we extend this survey across the main emission and compare auroral brightness and evolution directly to in-situ measurements of the equatorial plasma velocity and theory. The resulting correlations show where the apparent motion of auroral features is related to the motions of the equatorial plasma and the estimated background conductance of the ionosphere. Taking this together, we present a coherent picture of the local time evolution of auroral features in Jupiter's main emission and the physical processes responsible for them.

Hubble Space Telescope observations of Jupiter's FUV auroras during the Juno Extended Mission

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We present Hubble Space Telescope observations of Jupiter's far-ultraviolet auroras obtained as part of a programme of observations covering 3 years of Juno's Extended Mission, GO-16675. The observations obtained to date were scheduled near to PJs 37 (October 2021), 38 (November 2021) and 42 (May 2022). The aim of the observations presented is to compare the auroral emissions with in situ Juno measurements in the equatorial middle magnetosphere region inside $\sim$30 RJ. Of particular interest are comparison of equatorward diffuse emission with electron populations near Europa, and of the main emission intensity and latitude with plasma and magnetic field data in the middle magnetosphere. The latter will shed light on the relation between the main auroral emission and magnetosphere-ionosphere coupling currents, and radial force balance in the magnetosphere. In this presentation we discuss the preliminary results from the observations obtained to date.

Global upper-atmospheric heating at Jupiter by the recirculation of auroral energy

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Jupiter's upper atmosphere is significantly hotter than expected based on the amount of solar heating it receives. This temperature discrepancy is known as the 'energy crisis' due to it's nearly 50-year duration and the fact it also occurs at Saturn, Uranus and Neptune. At Jupiter, magnetosphere-ionosphere coupling gives rise to intense auroral emissions and enormous energy deposition in the magnetic polar regions, so it was presumed long ago that redistribution of this energy could heat the rest of the planet. However, most global circulation models have difficulty redistributing auroral energy globally due to the strong Coriolis forces and ion drag on this rapidly rotating planet. Consequently, other possible heat sources have continued to be studied, such as heating by gravity and acoustic waves emanating from the lower atmosphere. Each global heating mechanism would imprint a unique signature on global temperature gradients, thus revealing the dominant heat source, but these gradients have not been determined due a lack of planet-wide, high-resolution data. The last global map of Jovian upper-atmospheric temperatures was produced using ground-based data taken in 1993, in which the region between 45°latitude (north & south) and the poles was represented by just 2 pixels. As a result, those maps did not (or could not) show a clear temperature gradient, and furthermore, they even showed regions of hot atmosphere near the equator, supporting the idea of an equatorial heat source, e.g. gravity and/or acoustic wave heating. Therefore observationally and from a modeling perspective, a consensus has not been reached to date. Here we report new infrared spectroscopy of Jupiter's major upper-atmospheric ion H_3^+, with a spatial resolution of 2o longitude and latitude extending from pole to equator, capable of tracing the global temperature gradients. We find that temperatures decrease steadily from the auroral polar regions to the equator. Further, during a period of enhanced activity possibly driven by a solar wind compression, a high-temperature planetary-scale structure was observed which may be propagating from the aurora. These observations indicate that Jupiter's upper atmosphere is predominantly heated via the redistribution of auroral energy, and therefore that the influences of Coriolis forces and ion drag are observably overcome.

Towards Unifying Jupiter's X-rays with Radio, UV, Magnetic Field and Plasma Observations

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In 1979, while the Voyager spacecraft were undertaking their paradigm-shifting multi-instrument explorations of the Jovian system, the Einstein X-ray observatory was also taking the first X-ray images of the planet (Metzger et al. 1983). Two decades later, the launch of the highly complementary Chandra and XMM-Newton X-ray observatories ushered in the modern era of X-ray astronomy. These cutting-edge astrophysics platforms uncovered a treasure trove of high energy astrophysical emissions from Jupiter. In particular, at the poles, they revealed a variety of vibrant aurorae: impulsive auroral flares which occur with a regular periodic beat every few 10s of minutes (Gladstone et al. 2002); flickering dim ion aurora (Dunn et al. 2020); electron bremsstrahlung aurora from along the main emission (Branduardi-Raymont et al. 2004; 2008) and hints of a transient electron aurora coincident with auroral injection events (Wibisono et al. 2021).

In this talk, we explore connections between these X-ray auroral emissions and in-situ waves, plasma and magnetic field measurements by Juno (e.g. Yao & Dunn et al. 2021) and UV observations by the Hubble Space Telescope. We show that the impulsive bursts of auroral X-rays share the same periodicity with kHz radio emissions and UV flares from the auroral zone and electromagnetic ion cyclotron waves, and anti-phase variations in the plasma and magnetic field, which may be indicative of slow mode or mirror mode waves. We will speculate on how these shared multi-waveband periodicities may be causally linked.

We will also show overlaid X-ray and UV aurora videos, that explore further auroral connections between the UV and X-ray aurora, highlighting shared morphology and timing signatures between the

two wavebands. Particularly, this reveals connections between emissions in the active region, on the boundary of the swirl region and in the dark polar region.

Finally, we close the talk by touching on other potentially transformative X-ray capabilities for the outer planets including: direct imaging of the radiation belts by Suzaku (e.g. Numazawa et al. 2021), direct imaging of planetary magnetosheaths, and the elemental fingerprint fluorescence glow from the surfaces of the Galilean satellites, produced through moon-plasma interactions (e.g. Nulsen et al. 2020).

Juno-UVS Views of the Average Jovian Aurora and its Variability

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Using high-spatial resolution UVS data from over forty different Juno perijoves, we have made average (and variance) maps for the northern and southern auroras of Jupiter, for a range of sub-solar longitudes. While the auroral brightness and color ratio maps for individual perijoves can be strikingly different, the average maps allow features that are nearly always present, but are relatively faint, to stand out. In contrast, variance maps highlight structures which are much brighter but happen more rarely. Here we examine how the typical Jovian aurora varies with time and local time, and extract the relative brightness between the northern and southern auroras.

Jupiter's polar auroral bright spot observations by in situ measurements and remote sensing

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This work presents the in situ observations and remote sensing during the Juno flyby over Jupiter's auroral bright spot in the polar region. The data were collected from Juno-UVS, JEDI, Waves, and MAG instruments when Juno flew close to the bright spot position during perijove (PJ) 3, PJ15, and PJ33. The results show an enhancement of the high energy particle fluxes (30-1200 keV) observed by JEDI either during the crossing of a bright spot detected by Juno-UVS (PJ3) or, at least, very near (PJ15 and PJ33). These particles are dominated by upward electrons, implying that the acceleration process took place below the spacecraft. In addition, the Waves instrument observes the intensification of whistler-mode waves at the same period of particle enhancement during PJ3 and PJ33, and before the observed enhanced particle flux for PJ15. These relationships suggest that a form of wave-particle interaction is taking place, which would contribute to the particle acceleration in both directions along the field lines and cause the UV auroral bright spot emission. Furthermore, the magnetic deviations observed by the MAG instrument suggest the presence of downward magnetic field-aligned currents. Although the fixed position of bright spot in System III suggests that the processes giving rise to them are close to the planet, it remains possible that their root cause still lies further away in the magnetosphere (either at high or low latitude). Further understanding the polar bright spot phenomenon requires investigating the flux tubes topology connected to this region using MHD simulations, and additional Juno field and particle observations beneath the acceleration region.

Simultaneous Measurements of Ion Winds and Neutral Flows in Jupiter's Northern Aurora

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We present profiles of ionospheric and neutral wind velocities in the northern auroral region of Jupiter using data obtained on June 2nd, 2017, with the Near Infrared Echelle Spectrograph (NIRSPEC) instrument on the Keck II telescope. Doppler shifts of H2 and H_3^+ lines near 2.1 microns were measured to derive the velocities above the peak emission altitude. Ion flow velocities are consistent with previous observations (Johnson et al. 2017; Stallard et al. 2001), while the neutral flows agree with the model prediction (Millward et al. 2005). The neutral flows are found mostly corotating with the ionic components in the non-auroral regions, but significantly sub-rotating inside the auroral oval. In subtracting one from another we reveal two strong blue-shifted currents along the main auroral oval, potentially due to a twin cell current in the region. It appears that the current asymmetry matches with the intensity asymmetry, suggesting that the currents are blue shifting on both sides of the planet within the potential current-carrying layer. This is in complete contrast with predictions from the breakdown in corotation models of auroral generation. Notably, auroral ion winds are not matched by weaker neutral winds, an important approximation in current models (known as the k factor). Our observation highlights the importance of understanding the complex flows in the atmosphere and their effects on magnetospheric currents and suggests that azimuthal currents have a significant role in the generation of aurora at Jupiter.

Jupiter's flywheel atmosphere and why azimuthal ion flows dominate over corotation breakdown in the ionosphere: An explanation of simultaneous measurements of ion winds and neutral flows in Jupiter's northern aurora

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Recent observations of Jupiter's ionosphere and neutral atmosphere have revealed startling relative ion flows within Jupiter's northern auroral region, suggesting the main aurora is flanked by two blue-shifted flows, one at dawn and the other at dusk. This appears to contradict current predictions for ionospheric flows, failing to show ions driven by the expected breakdown in co-rotation. In this presentation, we will attempt to explain this extraordinary result.

Over the past forty years, we have focused on the breakdown in corotation as the main driver of auroral enhancement, but there is a growing range of auroral and magnetospheric observations that appear to contradict this model - highlighted within Bonfond et al.'s (2020) Six Pieces of Evidence Against the Corotation Enforcement Theory to Explain the Main Aurora at Jupiter .

Ionospheric wind measurements have previously revealed significant regions of sub-corotation across the polar region, with localised regions of some super-corotation at dawn (Johnson et al., 2019). These measurements only provide half the picture of atmospheric flows, since any ion motion is only meaningful when contrasted against the flow of the surrounding neutral atmosphere.

Recent measurements using Keck provide these neutral flows, dramatically re-aligning our understanding of how the ionosphere is moving. The neutral atmosphere is flowing in a vortex focused on the auroral region itself. This agrees with predictions from early models of neutral flow (e.g. Achilleos et al., 2001; Millward et al., 2005), that showed the neutrals moving into a tight vortex at speeds at least 70% of the driving ions within a few hours.

However, recent observations have shown that this vortex buries deeply into atmosphere, with 300m/s flows at 100 microbar (Cavalie et al. 2021) and enhanced heating at 1 millibar (Stirling et al., 2020), much deeper than the modelled 0.8-0.04 microbar Pedersen layer. This turns the neutral atmosphere into a giant flywheel, accelerated by the long-term breakdown in corotating magnetospheric plasma. Instead of forcing the magnetosphere to corotate, driving magnetospheric currents, the thermosphere happily sub-corotates at speeds approaching the driving speeds of the magnetosphere.

As such, the ions and neutrals sub-corotate in balance when averaged over all local times. However, in direct contrast with this, at dawn and dusk the ions flow with the surrounding magnetosphere, with significant super-corotation at dawn and sub-corotation at dusk. The flywheel neutral atmosphere is not significantly affected by these winds, as the super- and sub-corotation is balanced over a full magnetospheric rotation.

As a result, against the medium of the flywheel neutral atmosphere, the ionosphere sees sunward shears on both flanks, the jovian 'Dungey-Vasyliunas' equivalent of Region 1 and 2 currents. The observed aurora is likely the combination of breakdown in corotation currents combined with significant auroral currents from this Dugney-Vasyliunas cycle. The location of the main aurora aligns with the location of the downward currents of this cycle, providing a potential source of the predominantly downward and blended bi-directional currents observed by Juno.

This potentially fundamentally re-casts our understanding of Jupiter's aurora; we await the ensuing discussions at MOP with enthusiasm!

Jovian auroral electron precipitation budget - A Statistical Analysis of Diffuse, Mono-energetic, and Broadband Auroral electron distributions

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Recent observations by the Juno spacecraft have shown that electrons contributing to Jupiter's main auroral emission appear to be frequently characterized by broadband electron distributions, but also less often mono-energetic electron distributions are observed as well. In this work, we quantitatively derive the occurrence rates of the various electron distributions contributing to Jupiter's aurora. Therefore we perform a statistical analysis of electrons measured by the JEDI-instrument within 30-1200 keV from the first 20 orbits. We determine the electron distributions, either pancake, field-aligned, mono-energetic, or broadband, through energy and pitch angles to associate various acceleration mechanisms. For instance, mono-energetic distributions are caused by potential drops and broadband distributions by stochastic acceleration. The statistics of our study show that field-aligned accelerated electrons at magnetic latitudes greater than 76° are observed $74.2\% \pm 8.7\%$ of the observed time averaged over the dipole L-shells, while the occurrence rate of diffuse aurora is $15.8\% \pm 8.7\%$. Whereas pancake distributions, indicating diffuse aurora, are prominent at smaller magnetic latitudes (<76°) with $88.3\% \pm 8.3$%. Within the field-aligned electron distributions we see a dominating fraction of broadband distributions $93.0\% \pm 3.3\%$ of the time and a small fraction of isolated mono-energetic distribution structures over $7.0\% \pm 3.3\%$ of the time. Furthermore, these intensity statistics coincide with the findings from our energy statistics regarding the electron distributions. Occurrence rates thus also characterize the overall energetics of the different distribution types. This study indicates that stochastic acceleration is dominating the auroral processes in contrast to Earth where the discrete aurora is dominating. Furthermore, we found little evidence for mono-energetic distributions, most of the time being suppressed by overlaying strong broadband distributions.

Examining Interchange at the Outer Planets using JERICHO: a Kinetic-Ion, Fluid-Electron Hybrid Plasma Model

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Plasma is injected into the magnetospheres of both gas giants in the outer planets from sources located on satellites orbiting them, Io at Jupiter and Enceladus at Saturn. Material ejected from these moons forms tori surrounding their planetary bodies at distances corresponding to the source's orbit, however these regions are not continually expanding and therefore must have loss mechanisms associated with them. The processes responsible for loss in the two systems are ejection as energetic neutrals and by bulk transport into sink regions in the outer magnetosphere, though the proportion of material removed by these varies. The physical process generally considered to be responsible for bulk transport is the centrifugal-interchange instability, analogous to the Rayleigh-Taylor instability, but with centrifugal force replacing gravity. This mechanism allows magnetic flux tubes containing hot, tenuous plasma to exchange places with tubes containing cool, dense plasma, moving material from the inner to outer magnetosphere whilst returning magnetic flux to the inner magnetosphere. In order to examine the transport we have developed a full hybrid kinetic-ion, fluid-electron plasma model in 2.5-dimensions, JERICHO. The technique of hybrid modelling allows for probing of plasma motions from the scale of planetary-radii down to the ion-inertial length scale, considering constituent ion species kinetically as charged particles and forming the electrons into a single magnetised fluid continuum. This allows for insights into particle motions on spatial scales below the size of the magnetic flux tubes. Results from this model will allow for the examination of bulk transport on spatial scales not currently accessible with state-of-the-art models, improving understanding of mechanisms responsible for moving particles between flux tubes and from the inner to the outer magnetosphere. We have applied JERICHO to both the Jovian and Saturnian systems and this presentation will examine the distribution of ions, current densities and electromagnetic field perturbations, analysing how they evolve both spatially and temporally. This will allow for insights into the radial motions of plasma directed radially outwards, as well as the corresponding response in the associated fields.

Turbulence in the Magnetospheres of the Giant Planets

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The magnetospheres of the outer planets exhibit turbulent phenomena in plasma environments which are qualitatively different compared to the solar wind or the interstellar medium. The key differences are the finite sizes of the magnetospheres limited by their physical boundaries, the presence of a strong planetary background magnetic field, and spatially very inhomogeneous plasma properties within the magnetospheres. Typical turbulent fluctuations possess amplitudes much smaller than the background magnetic field and are characterized by Alfvén times, which can be smaller than the non-linear interaction time scales driving the turbulent cascade. The magnetospheres of the outer planets are thus interesting laboratories of plasma turbulence. In Jupiter's and Saturn's magnetospheres, turbulence is well-established thanks to the in-situ measurements by several spacecraft, in particular the Galileo, Juno and Cassini orbiters. In contrast, the fluctuations in Uranus' and Neptune's magnetospheres are poorly understood due to the lack of sufficient data. Turbulence in the outer planets' magnetospheres have important large-scale effects on the systems as a whole. The dissipation of the turbulent fluctuations through wave-particle interaction is a significant heat source, which can explain the large plasma temperatures observed in the middle and outer parts of the magnetospheres. Similarly, turbulent wave fluctuations can strongly contribute to the acceleration of particles responsible for the various types of the auroral phenomena on the planets.

The Contribution of Global Periodic Perturbations Towards Circulation and Mass Loss in Saturn's Magnetosphere

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Magnetic reconnection is a process during which magnetic energy is released as kinetic energy. It is considered a crucial driver of energy transport and mass loss within Saturn's magnetosphere. On long-term timescales, is thought to be predominantly driven by the rapid rotation of equatorially mass-loaded flux tubes (i.e. the Vasyliunas cycle), but there is some non-negligible driving from the solar wind as well (i.e. the Dungey cycle). In this study, we investigate an atmospheric driven phenomenon that modulates Saturn's magnetosphere every $\sim$ 10.6 hours, known as planetary period oscillations (PPO), as an additional driver of magnetic reconnection at Saturn. Using an empirical model of PPO dynamics and Cassini magnetic field and plasma measurements, we find that PPO-driven magnetic reconnection is likely to occur in Saturn's magnetosphere, however, the occurrence of the phenomenon depends on temporally variable characteristics of the PPO systems and spatial asymmetries within Saturn's equatorial magnetosphere. Thus, it is not expected to be an on-going process. On year-long timescales, we find that PPOs are expected to be on par with the Dungey Cycle in driving circulation within Saturn's magnetosphere. However, on $\sim$1-2 week-long timescales, under specific conditions where PPO-driven reconnection is expected to be active, this phenomenon can become more significant than the Vasyliunas cycle, and thus dominate circulation within Saturn's magnetosphere. On long-term timescales, this process is estimated to remove upwards of $\sim$20% of the mass loaded into the magnetosphere by Enceladus.

Detecting the Solar Wind in Saturn Kilometric Radiation with Mutual Information

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Due to a lack of upstream monitors, the effects of the solar wind on magnetospheres other than Earth's are not well understood. At Saturn, previous investigations of this relationship have been restricted to time limited case studies. However, it is known that the solar wind plays an important role in magnetospheric dynamics. As such, a general method is needed to investigate the relationship between the solar wind and planetary magnetospheres. In 2017 Cassini came to the end of its mission life, leaving behind a 13 year legacy which includes continuous magnetospheric data. We present a large-scale statistical study of Saturn Kilometric Radiation as a proxy for the solar wind, building a method of comparison being generally applicable to other celestial objects and data sets. Due to the lack of direct solar wind monitoring at Saturn, we use a solar wind propagation model (Tao et al. 2005) to explore several solar wind parameters and their relationship with Saturn Kilometric Radiation.

Mutual information measures the strength of a relationship between two variables, and by extension, how much can be inferred from one about the other. We use mutual information to characterise the strength of the relationship between various Solar Wind parameters e.g. velocity, density, tangential magnetic field strength, and Saturn Kilometric Radiation. Here, we present the complete analysis of the compared data sets over the full time period of the Cassini Mission, estimating the mutual information and its uncertainty between Saturn Kilometric Radiation and propagated Solar Wind variables. We also characterise the strength of the relationship by Saturn Season and by day vs night. We find that the strongest relationships exist between the tangential magnetic field and SKR.

Additionally, we demonstrate the general applicability of the method, which has been tested on well-characterised Earth-based data sets as a means of validation. The work is also extended to characterise the response time of the magnetosphere to Solar Wind forcing at Earth and explore uncertainties in the propagated solar wind arrival time at Saturn.

Synthesising remote sensing observations of Saturn’s global plasma dynamics: testing the relationship between Saturn’s ENA and narrowband SKR emissions.

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Saturn’s kilometric radio (SKR) and energetic neutral atom (ENA) emissions are important remote diagnostics of the planet’s magnetospheric dynamics, intensifying during periods of global-scale plasma injection, and displaying characteristic planetary periodicity. Here we focus on the narrowband emissions between 5-40 kHz, thought to originate near density gradients at the edges of the plasma torus, and test the hypothesis that narrowband SKR production might be enhanced by inward-moving plasma following global injection events. Global scale ENA signatures have been associated with both 5 and 20 kHz nSKR emissions, particularly at dusk-evening local times where plasma injections are expected to have moved inwards through the magnetosphere, triggering interchange instabilities.

We use a new set of calibrated equatorial ENA projections to test the relationship between Saturn’s ENA and narrowband SKR emissions. We analyse 40 case studies of ENA morphology that show global injection signatures, 15 of which also have possible auroral conjugacy in Cassini UVIS images. We show that in cases of favourable viewing coverage, the narrowband SKR emission intensity peak coincides with the rotation of ENA enhancement through the dusk local time sector, building on the results of Wing et al., 2020. We test for radial distance dependence by constraining ENA keograms over a set of distances covering the edges of the plasma torus, and quantify the relative timing of nSKR enhancements through correlation of the ENA intensity with flux density in the 5 and 20-40 kHz emission bands.These results contribute towards our developing picture of how global plasma injection events can influence Saturn’s inner magnetosphere, linking together two valuable sources of remotely-sensed global emissions, the ENAs and SKR.

Particle entry, escape, and energization at Saturn through global convection and wind-magnetosphere interaction

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We perform a high resolution 3D magnetohydrodynamic simulation of Saturn with the GAMERA model using a steady solar wind. The model exhibits continuous Kelvin-Helmholtz waves along the magnetopause, Vasyliunas-type convection, and frequent injection flows from the tail into the dawn sector as a result of the convection cycle. We then seed test H+ particles in the solar wind and magnetotail to investigate these physical processes, their interaction with one another, and their role in particle entry, escape, and energization.

In particular, the dawn-side injection flows create a clear dawn-dusk asymmetry in the plasma temperature, and in this sector the sunward injection flows compete with the anti-sunward-propagating KH waves along the magnetosheath, creating a complex region of particle energization and exchange. The simulations are compared with Cassini observations.

Periodic narrowband radio wave emissions and inward plasma transport at Saturnian magnetosphere

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The abrupt brightening of an Energetic Neutral Atom (ENA) blob or cloud has been interpreted as plasma injection in the Satirnian magnetosphere (termed ENA injection herein). Morphologically, there appears to be two types of abrupt ENA cloud brightening: [1] the brightening of a large cloud usually seen at distances > 10-12 Rs (Rs = 60,268 km) in the midnight or postmidnight region; [2] the brightening of a smaller cloud usually seen at distances < 10-12 Rs around 21-03 magnetic local time (MLT). Among many radio waves observed at Saturn, type 2 ENA injections correlate best with the 5 kHz narrowband waves. Using Cassini INCA and RPWS data, we examine the periodicities of the type 2 ENA injections and the 5 kHz narrowband emissions as well as their cross-correlations, which have been previously used to measure the lag times or phase differences. Because correlational analysis can only establish linear relationships, we also use mutual information to establish linear and nonlinear relationships. On average, the peak of the 5 kHz narrowband emission lags those of the type 2 ENA injection by about a few minutes to 2 hr. The injection of hot plasma to the inner magnetosphere can lead to temperature anisotropy, which can generate electrostatic upper hybrid waves, which upon encountering the high density gradient at the outer edge of the Enceladus density torus, can mode convert to the Z mode and then to O mode. The 5 kHz narrowband waves commonly propagate in the O mode.

Cassini Observation of the 1st harmonic of Saturn Kilometric Radiation: A Case study

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Clear first harmonic emissions of Saturn Kilometric Radiation (SKR) are discovered during the Cassini grand finale orbits. Both O mode and X mode fundamental emissions are observed, that are accompanied by X mode harmonics. Analysis of the 34 cases found shows that the frequency ratio between the fundamental and harmonic emissions is 2.01$\pm$0.08 and the harmonic emissions show weaker intensities relative to the fundamental emissions. The intensity relation between the two types of harmonics, i.e. O-X (fundamental-harmonic) and X-X, is different, which implies that the generation mechanisms are different for the two different type of harmonics. We discuss this generation in the context of previous studies of harmonic planetary auroral radio emissions. The direction finding analysis of a clear case, with Cassini close to the source, shows that the fundamental and harmonic emissions are generated in the same source region. The generation of the two types of harmonics can be attributed to different plasma densities and energy distributions in the source regions.

Cassini Langmuir Probe observations during solar eclipses by Saturn and the Main Rings: photoelectrons and rings optical depth

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The Langmuir Probe (LP) onboard Cassini was one of the three experiments that could measure the cold inner magnetospheric plasma, along with the Radio and Plasma Waves Science (RPWS) and the Cassini Plasma Spectrometer (CAPS). While the century-old LP theory looks quite straight-forward, in reality things are much more complicated.

The operation of the LP is quite simple: by applying positive bias voltages, the probe attracts the electrons and repels the ions of the surrounding plasma. From the resulting current-voltage curve characteristics of the ambient electrons can be estimated, i.e. density and temperature. When negative bias voltages are applied to the probe the characteristics of the ambient ions can be estimated, i.e. density, temperature, and mass.

Though the LP operation and interpretation are quite simple and straightforward, there are assumptions made and therefore the theoretical models may not always reflect the actual plasma conditions in Saturn's magnetosphere. For this study we are focused on the effect of the photoelectrons, i.e. electrons generated by the incident sunlight on Cassini's surfaces, that are difficult to calibrate for on the ground and then observe and characterise in the LP data.

We present algorithms for identifying when Cassini is in the shadow of Saturn and its rings, and when the LP is in the shadow of Saturn, its rings or Cassini itself. The LP data inside and outside the eclipses are compared using the algorithms developed. In this presentation we will first discuss the impact of the photoelectron generation from the spacecraft surfaces to the LP current-voltage curves, and understand the variations of the measured plasma density connected with the photoelectrons. Then, using that knowledge, we attempt to define the optical depth of the rings in the wavelengths the LP operates in.

Reconnection at Neptune's pole-on magnetosphere during the Voyager 2 flyby

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The pole-on configuration occurs when the polar magnetosphere of a planet is directed into the solar wind velocity vector. Such magnetospheric configurations are unique to the Ice Giant planets. This means that magnetic reconnection, a process which couples a magnetosphere to the solar wind, will be different at the Ice Giants when they are pole-on compared to other planets. The only available in situ measurements of a pole-on magnetosphere are from the Neptune flyby by Voyager 2 which we analyze in this paper. We show that dayside magnetopause conditions were conducive to magnetic reconnection. A plasma depletion layer in the magnetosheath adjacent to the magnetopause was observed. Plasma measurements inside the magnetospheric cusp show evidence of multiple reconnection taking place at the magnetopause, before the spacecraft crossed the open-closed field-line boundary. A possible travelling compression region from a nearby passing flux rope was also observed providing further supporting evidence that multiple x-line reconnection occurred during the flyby. During a perfectly pole-on configuration, reconnection will not depend on the orientation of the interplanetary magnetic field as is the case at other planetary magnetospheres. The occurrence of reconnection will not vary because the area of the dayside magnetopause where anti-parallel shears occur will be approximately equal for all interplanetary magnetic field orientations. Therefore, we suggest that rotating into and out of the pole-on configuration will likely drive the on-off / switch-like dynamics observed in simulations. The pole-on configuration is most likely an important rotational phase for driving Ice Giant magnetospheric dynamics.

The twisted magnetosphere of Uranus between solstice and equinox

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The magnetosphere of Uranus is certainly the most atypical of the solar system. The highly tilted and offset magnetic field with respect to the spin axis, itself almost in the ecliptic plane, produces a highly asymmetric magnetosphere, whose configuration with respect to the solar wind flow strongly varies over very different timescales ranging from a planetary rotation ($\sim$17 h) to seasons (a Uranian revolution lasts 84 years). While Cassini and Juno have enabled the in-depth study of the auroral processes at work at Saturn and Jupiter, our current knowledge of the Uranian auroral emissions and of the underlying mechanisms responsible for particle energization, still mostly relies on Voyager 2 in situ and remote observations acquired during the flyby of the planet at solstice in 1986. Since then, the Hubble Space Telescope re-detected and imaged the Uranian UV aurorae from Earth past the equinox of 2007, bringing new insights on an unknown solar wind/magnetosphere configuration with auroral signatures largely different from those detected by Voyager 2. Here, we present HST follow-up observations acquired between equinox and solstice, in yet another different geometry of the magnetosphere, oblique and twisted.

An Assessment of the Role of Ionospheric Conductances in Magnetosphere-Ionosphere-Thermosphere Coupling at Giant Planets, Based on Space Data and Modelling Tools

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The dynamics of giant planets magnetosphere is controlled by a complex interplay between these planets fast rotation, their solar-wind interaction, and possible moon plasma and momentum sources. At the ionospheric level, two key parameters controlling the degree of coupling of magnetospheric motions to planetary rotation are the Pedersen and Hall ionospheric conductances, which regulate the intensity of currents coupling magnetosphere and ionosphere and the rate of transfer of angular momentum and power between them. In this talk we will present a parametric study of the dependence of Pedersen and Hall conductances on the structure and composition of these planets upper atmospheres and on the characteristics of auroral and polar particle precipitation, using generic thermospheric and ionospheric models and ground-truth validation by Juno, Cassini and Voyager data. We will discuss the implications on the degree of importance that the thermosphere-ionosphere has in the enforcement of corotation of the magnetospheric plasma.

Waves from the magnetospheres of giant planets revealing their interaction with solar wind

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Rapid changes in solar wind conditions perturb the planetary magnetospheres, changing their sizes and properties of the plasma within, providing energy for the generation of radio emissions and plasma waves, revealing the dynamic processes in the planetary magnetospheres, e.g. magnetic reconnections and hot plasma injections. The emissions often display periodicities caused by fast planetary rotation and magnetic compression waves induced by solar wind impact, providing valuable information about the coupling process between magnetosphere and ionosphere. Solar wind compressions increase the plasma density in the magnetosheath, which keeps low-frequency radio emissions from escaping the planetary magnetosphere emissions (e.g. continuum radiation at Jupiter and narrowband emissions at Saturn). We will discuss recent observations made by Juno and Cassini and their implications for planetary magnetospheric dynamics.

Induced currents in Titan's dusty ionosphere

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Titan hosts a conductive ionosphere and has therefore a magnetosphere induced by the interaction with Saturn's magnetic field and magnetospheric plasma. The shielding currents and associated electric fields induced by this interactions have been derived earlier, prior to the detection of dusty plasma and only for select flybys, relying on model-derived ionospheric conductivities. In this study we revisit these currents using the full Cassini in-situ dataset and full plasma content of Titan's ionosphere (electrons, positive ions, and negative ions/dust). In particular, we investigate the feasibility of a hypothesized secondary Pedersen current layer below the photoionization peak.

Density spikes in the ionosphere of Titan as seen by Cassini-Huygens

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The Cassini-Huygens spacecraft made in-situ measurements of Titan's plasma environment during 127 close encounters from 2004 until the end of the mission in 2017. The collected data still reveal unknown processes and structures and is therefore interesting for further investigations. During our analysis of Radio and Plasma Waves System/Langmuir probe (RPWS/LP) data we have observed, primarily on the outbound leg, a localised increase of the electron density up to 1.6 times to the background level. This feature, appearing as an electron density spike in the data, is found during 28 of 127 of flybys. The data from RPWS/LP, the Cassini Plasma Spectrometer (CAPS), the Ion and Neutral Mass Spectrometer (INMS) and magnetometer (MAG) is used to calculate electron densities, electron temperatures, ion and neutral composition and magnetic field characteristics. The average position of these structures in coronation and elliptical frame is also investigated. We identify that the electron density spikes are primarily observed on the dayside of Titan and that they vary in size with solar EUV flux. We also observe magnetic field signatures that could suggest the presence of current sheets within majority of cases. The estimated spatial scale of the density spikes along the trajectory of the spacecraft is approximately 500 km, and the larger ones are located at lower altitudes compared to the smaller ones. We outline and discuss possible reasons for the formation of these density spikes, including current sheets, outflowing plasma or the formation of an ionospheric layer created by increased ionisation.

Electromagnetic induction inside Uranus' and Neptune's large moons

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The best evidence for the existence of subsurface oceans within moons of our solar system arises from interpretation of magnetic field measurements collected by the magnetometer on the Galileo spacecraft in the vicinity of Europa and Callisto. The putative salty oceans within these moons are able to conduct electrical currents driven by Jupiter's strong time-varying magnetic field, producing a unique secondary magnetic field signature that can be measured externally by a spacecraft. Some of the large moons of Uranus and Neptune also may contain subsurface oceans, based on their geological features. Unfortunately, Voyager 2 did not pass close enough to any of these moons for its onboard magnetometer to measure the field signatures associated with a conductive ocean. In this presentation, we demonstrate how the strong and highly dynamic magnetic environments of these planets facilitate magnetic induction studies of their moon's interiors. More specifically, we show how magnetic induction can be used to detect and potentially characterize subsurface oceans within these icy bodies for single- or multi-flyby mission concepts, even when faced with the confounding factors of a conductive ionosphere, local plasma current perturbations, spacecraft timing and position uncertainties, data outages, model uncertainties, and various sources of instrument noise. Thus, this work provides insights into required magnetometer performance and guidance into trajectory design for possible future mission concepts to the ice giant systems.

Europa Clipper Mission Update

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With a launch readiness date of late 2024, NASA's Europa Clipper will set out on a journey to explore the habitability of Jupiter's moon Europa. At the beginning of the next decade, the spacecraft will orbit Jupiter, flying by Europa more than 40 times over a four-year period to observe this moon's ice shell and ocean, study its composition, investigate its geology, and search for and characterize any current activity. The mission's science objectives will be accomplished using a highly capable suite of remote-sensing and in-situ instruments. The remote sensing payload consists of the Europa Ultraviolet Spectrograph (Europa-UVS), the Europa Imaging System (EIS), the Mapping Imaging Spectrometer for Europa (MISE), the Europa Thermal Imaging System (E-THEMIS), and the Radar for Europa Assessment and Sounding: Ocean to Near-surface (REASON). The in-situ instruments comprise the Europa Clipper Magnetometer (ECM), the Plasma Instrument for Magnetic Sounding (PIMS), the SUrface Dust Analyzer (SUDA), and the MAss Spectrometer for Planetary Exploration (MASPEX). Gravity and radio science will be achieved using the spacecraft's telecommunication system, and valuable scientific data will be acquired by the spacecraft's radiation monitoring system. Major milestones from the past year include selection of a launch vehicle and launch readiness date by NASA, evaluation of candidate tours by the science team, and preparations for the cruise and operational phases of the mission. The project, flight system, and payload have completed their Critical Design Reviews, and the mission has recently completed its System Integration Review. Spacecraft subsystems and payload are actively being developed, and assembly, test, and launch operations have begun in March 2022. In the meantime, the science team is preparing a set of manuscripts describing the mission science and the instruments that enable these investigations for publication in the journal Space Science Reviews.

PEP-Hi: Energetic Particle Investigation and ENA Imaging of the Jovian System and Its Icy Moons

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Juno has been orbiting Jupiter for six years, making over 40 orbits of the giant planet. The polar orbit provided unique views of Jupiter's aurora as well as in situ measurements of the particles and fields in the polar regions. Away from Jupiter, Juno made magnetospheric measurements out to $\sim$100 RJ from dawn to midnight to evening in local time, traversing the equatorial plasma sheet many times. At the same time, Earth-based instruments have measured auroral UV and radio emissions as well as the upper atmosphere. This tutorial review talk summarizes what we have learned about Jupiter's vast magnetosphere from the Juno mission so far and anticipates what the extended mission might reveal.

Jovian auroral radio source occultation modelling and application to the JUICE science mission planning

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Occultations of the Jovian low frequency radio emissions by the Galilean moons have been observed by the PWS (Plasma Wave Science) instrument of the Galileo spacecraft. We show that the ExPRES (Exoplanetary and Planetary Radio Emission Simulator) code accurately models the temporal occurrence of the occultations in the whole spectral range observed by Galileo/PWS. This validates of the ExPRES code. In addition to supporting the analysis of the science observations, the method can be applied for preparing the JUICE moon flyby science operation planning.

Magnetic sounding of icy moons with constraints from multiple investigations

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Magnetic measurements have provided some of the strongest evidence available for a present-day, liquid water ocean inside Europa. Future missions are expected to use such measurements to constrain interior properties of Europa, Ganymede, and other icy moons. Variations in the magnetic field applied by the parent planet give rise to secondary, induced magnetic fields within electrically conducting materials—including saline ocean waters. Induced magnetic fields are measurable outside the body, making them accessible to orbital and flyby missions as well as landed missions. Magnetic fields are not screened by the ice shell, so the induced field can be used to directly constrain the conductivity structure of extant oceans. All of the giant planets have strong magnetic fields and at least one icy moon, giving these techniques broad applicability. However, numerous factors complicate the interpretation of magnetic measurements, posing difficulty to their use in placing constraints on interior structure. Among these complicating factors are a lack of laboratory measurements relevant to the subsurface oceans of icy moons, degeneracies between ocean properties when certain simplifying assumptions are made, and additional magnetic field contributions from space plasmas. We are working to mitigate these effects and improve on past magnetic sounding investigations by a variety of methods. We address the lack of laboratory measurements by directly measuring the electrical conductivity of solutes that may be expected in subsurface oceans at relevant temperatures, pressures, and concentrations. We model depth-dependent conductivity of ocean waters with the PlanetProfile framework, applying self-consistent geophysics constrained by bulk properties such as mass and axial moment of inertia. Adding realistic depth dependence to ocean conductivity reduces the parameter space of possible induced field models, providing better constraints on characteristics of the interior when compared against spacecraft measurements. We further constrain the induced field model by incorporating the effects of asymmetric tidal bulges in evaluating the induced field expected for a candidate ocean model. We use detailed statistics to evaluate the magnetic excitations applied to the icy moons over a variety of forcing periods with greater precision than any previous model, and to minimize the effects of plasma magnetic fields in magnetic sounding analyses to the extent possible. Together, the variety of techniques we are developing improve every step of forward modeling the induced magnetic fields of icy moons and will enhance the information obtainable from spacecraft measurements. These improvements are of critical importance to magnetic investigations of upcoming missions, especially Europa Clipper and JUICE, and also in understanding available measurements from past missions.

Io’s Neutral Atmosphere as Observed by Cassini UVIS

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Observations by the Cassini Ultraviolet Imaging Spectrograph (UVIS) (late 2000- early 2001) provide a unique perspective on the Io’s atmosphere and neutral clouds compared to Earth-based UV observations, along with wider spectral coverage for more diagnostic clues to processes and abundances; furthermore the timing of the Cassini observations bridgesgaps between Hubble Space Telescope UV observations in 1997-2000 and 2010-2012, New Horizons in 2007, and Hisaki UV observations in 2014-2015, to help understand temporal changes in the system.

During the Cassini flyby of the Jupiter system, UVIS made measurements of Io, its atmosphere and torus, obtaining EUV-FUV spectroscopy of this system. We describe observations made on December 30, 2000 and January 6, 2001 to demonstrate the variable nature of the environment. The Cassini UVIS uses two-dimensional CODACON detectors to provide simultaneous spectral and spatial images. Two spectrographs provide spectral images in the EUV (563-1182Å) and FUV (1115-1912Å) ranges. The detector format is 1024 spectral by 64 spatial pixels. The spectral pixels are 0.25 mrad and the spatial pixels are 1 mrad projected on the sky. The low-resolution slits used for these Io observations are 1.5 X 64 mrad and 2.0 X 64 mrad for FUV and EUV, respectively. The low-resolution slits have a spectral width of 4.8Å in both channels. We utilize torus measurements to constrain electron temperature and describe implications for SO2, sulfur and oxygen in the Io atmosphere and their spatial extent in the Io vicinity.

New Horizons Alice Observations of Io's Extended UV Atmospheric Emissions and Implications for Mass Loading from the Neutral Cloud

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New Horizons observed Io's UV auroral and airglow emissions with its Alice instrument in 2007 during the spacecraft's Jupiter encounter. Retherford et al., Science, 2007 reported an initial analysis of auroral brightness variations upon eclipse ingress and egress, providing evidence for changes in the relative contribution of sublimation and volcanic sources in shadow and at night. We discuss here an additional set of twenty five Io observations obtained with Alice while the satellite was in sunlight at various solar phase angles and locations within the Io plasma torus. These data allow a statistically meaningful trending analysis to be performed to better understand diurnal atmospheric variability. Neutral atomic oxygen and neutral and ionized atomic sulfur emission brightnesses are determined after subtraction of background Io plasma torus emission features also present in the Alice data, with seven especially good case studies to compare with model simulations. We discuss the role of SO2 transport from Io to the neutral cloud with respect to simulations of the Io plasma torus source rate.

Hisaki observation of the oxygen neutral cloud around Io's orbit before and during the enhancement event of Io plasma torus

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Io is the most volcanically active body in the solar system which is the important target to understand the processes from the generation of gasses from geologically active bodies to the escape of the gasses into space. Observation of spatial distribution of Io's oxygen neutral cloud is important to understand the escape process of neutrals from Io, as well as the source and loss processes of IPT. However, such spatial distributions were poorly observed so far. The extreme ultraviolet spectrograph called EXCEED installed on the JAXA's Hisaki satellite observed the Io plasma torus continuously in 2014-2015. By using Hisaki data, we derived the spatial distribution of atomic oxygen emissions at 130.4 nm, and found a dense region of neutral oxygen near Io (called banana cloud), as well as a longitudinally uniform diffuse region along the Io's orbit. The radial distribution showed the neutral oxygen cloud spreads out to 7.6 Jupiter radii (RJ), where the brightness drops below $\sim$1 R. There is a dawn-dusk asymmetry of the oxygen emission from 5 to 6 RJ, and the emission on the dusk side emission was larger than that the dawn side. By applying our 3-D Monte Carlo model, we are able to reconstruct these distributions from the observations as well as the particle source parameters. Surprisingly, the model explains the observation result well in case that oxygen source preferentially ejected from the side of Io facing Jupiter, rather than ejected isotopically. We also found the enhancement of OI brightness started around day of year 20 in 2015, and continued for 3 months (hereafter, referred to as the high density period). The radial distribution of oxygen cloud showed the outward expansion up to 8-8.6 RJ during the period from January to March of 2015, and recovered by April. Assuming the north-south thickness of oxygen cloud is 1.2 RJ, the estimated number density of oxygen cloud in the Io's orbit is $\sim$90 cm-3 during the high density period. This is three times larger than that during the normal density period ($\sim$30 cm-3). It is clear that the total amount of the neutral increased during the high density period, and the distribution width along the orbit may be enlarged. In this presentation, we introduced the observation results of Io's neutral cloud mentioned above, and science feasibilities of Io and Europa neutral clouds and volcanic plumes in the future UV space telescope project.

Defining Io's neutral oxygen torus and magnetospheric source with Hisaki observations and 3-D modeling

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The Jovian system is very intriguing with extremely different particle sources ranging from the volcanic Io to the frozen world of Europa with both existing within Jupiter's relatively high radiation magnetospheric environment. While Voyager, Galileo and Cassini provided historic observations of this unique environment, they also raised numerous questions. As the dominant source of particles to Jupiter's magnetosphere, Io is of particular importance. However, this source is not well understood with total rate estimates varying from 700-2400 kg/sec and even the specific source mechanisms (ex. volcanic vs. sublimation) are under debate. Thus, characterizing the Io source is required to understand Jupiter's magnetosphere as well as enabling understanding of the minor (but extremely important) source, Since its launch in 2013, the JAXA Hisaki (SPRINT-A) mission offers the potential to answer some of these questions and help make future missions more successful.

The JAXA Hisaki mission has provided unprecedented observations of the Jovian system with its extreme ultraviolet (EUV) spectroscope (EXCEED) instrument. In particular, it's UV neutral oxygen line of sight observations provide the best glimpse so far of Jovian neutral particle populations. This is exciting in that for the first time, the neutral tori can be directly observed on time scales that constrain satellite sources. The current Hisaki oxygen UV line of sight (LOS) observations are already revealing an intriguing amount of spatial and temporal. This data can also shed unprecedented insight into neutral torus distributions, which could subsequently provide essential information about the sources and mechanisms from Io. However, 3-D modeling is required to interpret the complex and dynamic observational geometries. Here we present research that combines Hisaki neutral oxygen LOS observations with computational modeling to identify and characterize Io's source of particles to Jupiter's magnetosphere and the resulting neutral tori populations.

Alternating emission features in Io's footprint tail: Magnetohydrodynamical simulations of possible causes

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Io's movement relative to the plasma in Jupiter's magnetosphere creates Alfvén waves propagating along the magnetic field lines which are partially reflected along their path. These waves are the root cause for auroral emission, which is subdivided into the Io Footprint (IFP), its tail and leading spot. New observations of the Juno spacecraft by Mura et al. (2018) have shown puzzling substructure of the footprint and its tail. In these observations, the symmetry between the poleward and equatorward part of the footprint tail is broken and the tail spots are alternatingly displaced. We show that the location of these bright spots in the tail are consistent with Alfvén waves reflected at the boundary of the Io torus and Jupiter's ionosphere. Then, we investigate three different mechanisms to explain this phenomenon: [1] The Hall effect in Io's ionosphere, [2] travel time differences of Alfvén waves between Io's Jupiter facing and its opposing side and [3] asymmetries in Io's atmosphere. For that, we use magnetohydrodynamic simulations within an idealized geometry of the system. We use the Poynting flux near the Jovian ionosphere as a proxy for the morphology of the generated footprint and its tail. We find that the Hall effect is the most important mechanism under consideration to break the symmetry causing the Alternating Alfvén spot street . The travel time differences contributes to enhance this effect. We find no evidence that the inhomogeneities in Io's atmosphere contribute significantly to the location or shape of the tail spots.

The satellite footprints in Jupiter's aurora and the processes giving rise to them

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Auroral emissions provide a unique window into the complex dynamic phenomena that occur throughout planetary space environments. While many auroral features magnetically map to broad areas in planetary magnetospheres, the aurora generated by the interaction of a rotating planet with its moon(s) are confined to a small region and allow for a more precise determination of the auroral source regions and physical processes sustaining their aurora. The study of moon-magnetosphere interactions at the outer planets has been reinvigorated with recent in-situ data. Specifically, Juno measurements at Jupiter have given critical insight into the nature of these interactions, providing simultaneous in-situ particles and fields measurements along with high-resolution imaging of Jovian auroral phenomena for the first time. We are now uniquely posed to provide a comprehensive view of the magnetic coupling between celestial bodies supported by both remote and in-situ observations given Juno's unprecedented dataset. This tutorial will review the processes associated with satellite auroral footprints, discuss these processes in the context of recent in-situ observations at Jupiter, and highlight recent significant advances in our understanding of these complex phenomena.

Temporal variability of the Io-induced aurorae on Jupiter: a proxy for plasma variations in the magnetosphere

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The orbital motion of the three innermost galilean moons - Io, Europa and Ganymede - within Jupiter's magnetosphere is known to be associated with auroral signatures, which can be detected in the UV, visible and IR wavelengths near the polar regions of the planet. Indeed, the moons interact with the magnetic field and plasma surrounding Jupiter, setting up a system of currents that ultimately transmit the perturbation to Jupiter's ionosphere. Such currents are carried by Alfven waves, whose direction of propagation and speed are determined by the magnetic field geometry and plasma distribution in the magnetosphere.

The auroral signatures due to the moon-magnetosphere interaction exhibit several features, most notably a very bright main spot - usually referred as footprint or Main Alfven Wing spot (MAW) - a possible precursor - the trans-hemispheric electron beam (TEB) - and a fading tail.

The JIRAM instrument onboard Juno is equipped with an IR imager designed to inspect auroral emission in the 3.2-3.7 micron band with unprecedented spatial resolution, which it has been doing for more than 40 spacecraft orbits up to now. Restricting the present discussion solely to the aurorae due to Io, it was observed by JIRAM that the relative position between the MAW and the TEB varies not only with Io's longitude - as already observed by HST - but also with time. Indeed, images taken by JIRAM during perijove 11 and 32 when Io was at the same longitude (within 1.5 degrees) showed that the relative distance between the two features was remarkably different. Bearing in mind that the plasma distribution, together with the magnetic field configuration, determines the position of the footprint, it is proposed here that such discrepancy is a reflection of potential variability of the dense plasma environment where Io orbits.

Effect of the Magnetospheric Plasma Interaction and Solar Illumination on Ion Sputtering of Europa's Surface Ice

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For the entire ion energy range observed at Europa, we calculate spatially-resolved maps of the surface sputtering rates of H_2O, O_2, and H_2 from impacts by magnetospheric ions. We use the perturbed electromagnetic fields from a hybrid model of Europa's plasma interaction, along with a particle-tracing tool, to calculate the trajectories of magnetospheric ions impinging onto the surface and their resultant sputtering yields. We examine how the distribution of the sputtering rates depends on the electromagnetic field perturbations, the angle between the solar radiation and the corotating plasma flow, and the thickness of the oxygen-bearing layer within Europa's surface. Our major findings are: (a) Magnetic field-line draping partially diverts the impinging ions around Europa, reducing the sputtering rates on the upstream hemisphere, but allowing for substantial sputtering from the downstream hemisphere. In contrast, zero sputtering occurs in much of the downstream hemisphere with uniform electromagnetic fields. (b) If the oxygen-bearing surface layer is thin compared to the penetration depth of magnetospheric ions, thermal ions dominate the O_2 sputtering rates, and the region of strongest sputtering is persistently located near the upstream apex. However, if the oxygen-bearing layer is thick compared to the penetration depth, energetic ions sputter the most O_2, and the location of maximum sputtering follows the sub-solar point as Europa orbits Jupiter. (c) The global production rate of O_2 from Europa's surface varies by a factor of three depending upon the moon's orbital position, with the maximum particle release occurring when Europa's sun-lit and upstream hemispheres coincide.

Simulations of Europa's Interaction with Jupiter's Magnetosphere

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The circulation and natural periodicities within Jupiter's magnetosphere drive interaction of magnetospheric plasma and magnetic fields with Europa's surface, atmosphere, and ionosphere. Computational models have been developed to simulate this interaction and explain observations of the Voyager and Galileo missions, and prepare for the up-coming JUICE and Europa Clipper missions. These models may incorporate numerous features and effects: Jupiter's magnetospheric plasma and magnetic fields; Europa's O_2 atmosphere; Europa's tenuous ionosphere; the icy surface of the moon; water plumes; the time-varying magnetic field induced in Europa's sub-surface ocean; and the effects of the plasma interaction on pick-up ions and electromagnetic fields. Simulation techniques run the gamut from analytic representations of the electromagnetic properties of the interaction, fluid models that emphasize the plasma bulk properties, 3-dimensional models that simultaneously solve the electromagnetic and plasma properties with magnetohydrodynamic or hybrid approaches, and test-particle simulations of energetic particles. Inherent to the design of each simulation are trades such as limited accuracy for increased computational efficiency, or between comprehensive treatment of many features versus focus on particular effects. By comparing the results of simulations with different strengths, and by incorporating the results of prior simulations in the specifications of new ones, more complete models for Europa's plasma interaction can be constructed.

Since the late 90s such simulations have been used to understand how Europa's different features couple together as a system. In this presentation, I will review the different space plasma simulation techniques that have been applied to model Europa's interaction with Jupiter's magnetosphere. I will highlight several key examples from the literature, conventions in the model representations of different features, and trends in the interpretation of model results. I will conclude by summarizing the state of models for Europa's plasma interaction today, and identify likely avenues that simulations may explore in the future based on the current trends. With JUICE scheduled to launch in 2023, and Europa Clipper in late 2024, I will also point out how observations from these missions will improve future models.

Europa's UV emissions from 2014-2020: Molecular atmosphere, hydrogen corona and constraints on plumes

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We have analyzed a set of Hubble Space Telescope images of Europa's ultraviolet emissions taken on 24 days between 2014 and 2020. The images show oxygen emissions that originate from electron impact excitation of the global O_2 atmosphere and a contribution from a stable H_2O atmosphere on the trailing hemisphere. The oxygen emission brightness and morphology undergo systematic variations correlated to the periodically changing plasma environment as previously found for a subset of this dataset. The derived sub-solar H_2O atmosphere component suggests a considerable atmospheric asymmetry when the trailing hemisphere is illuminated. The hydrogen Lyman-alpha signal in the data confirms the presence of an extended H corona around Europa, with similar densities at all orbital longitudes. After correction for the H corona contribution and reflected sunlight, we systematically search for localized emissions related to H_2O plumes in the Lyman-alpha images. We set upper limits on the H_2O column densities at the limb of Europa in all images.

H_2^+ pickup ions from Europa-genic H_2 neutrals orbiting Jupiter

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Water-group gas continuously escapes from Jupiter's icy moons to form co-orbiting populations of particles, or neutral toroidal clouds. We report the first observations of H_2^+ pickup ions in Jupiter's magnetosphere from 13-18 Jovian radii, confirming the presence of a neutral H_2 toroidal cloud. Pickup ion densities are consistent with an advecting Europa-genic cloud source. As the observed H_2^+ ions are originally produced from H_2 lost from Europa, the abundance of detected ions allows us to determine how much neutral H_2 is lost from Europa. Hence, these observations presented here for the first time directly measure ions from a neutral H_2 toroidal cloud at Jupiter, prove the cloud provides an additional plasma source in Jupiter's magnetosphere, and provide the most direct constraints on Europa's loss of neutral H_2 via observations of the neutral toroidal cloud's primary loss process - pickup ions.

Examining the Europa plasma environment via a multi-dimensional physical chemistry model

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Europa is a key topic of interest for future missions due to its subsurface ocean being a suitable location for extraterrestrial life. To better understand this ocean, upcoming missions such as NASA's Europa Clipper intend to differentiate the magnetic induction signature from this subsurface ocean from magnetic field perturbations caused by the interaction between the moon and the surrounding plasma in the Jovian magnetosphere. To do this requires an understanding of the sharply varying plasma environment at Europa (Bagenal et al, 2015), due to the moon's location in the outer portion of the Io plasma torus. Key processes informing this surrounding plasma include the convolution of physical chemistry in the inner torus (near Io) and global transport processes. In addition, we analyze the presence of superthermal electrons that are modulated by the System III/IV periodicities and critical in producing subcorotational dynamics in the torus (Coffin et al, 2020). These superthermal electrons may be partially sourced by radial transport through the region of Europa's orbit (Hikida, 2020).

Using a multi-dimensional physical chemistry model (described in Coffin et al, 2020), we investigate expected plasma conditions at Europa. Physical chemistry models are essential for understanding the mass and energy flow through the torus and take into account the interplay between charge exchange, ionization rates, and azimuthal and radial transport. In addition, the authors analyze the response of the torus to eruptions at either Io (sulfur and oxygen ions) or Europa (additional oxygen ions), and the resulting effects on chemical and transport balances. In particular, the ratios of ionized oxygen species at Europa are poorly constrained (Steffl, 2004).

Plasma observations during the June 7, 2021 Ganymede flyby from the Jovian Auroral Distributions Experiment (JADE) on Juno

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We report on plasma observations from Juno/JADE during the Ganymede flyby on June 7th, 2021. Juno approached Ganymede from southern latitudes, passed through the wake region, then through its magnetosphere to closest approach (1046 km from the surface) on the night side, and then back into Jupiter's plasma disk. We describe general plasma properties in the regions explored along the trajectory. We infer that Juno traversed a region of open field lines where one end intercepts Ganymede and the other Jupiter. The observations do not support Juno crossing into the closed field line region. The ion composition near Ganymede is very different than that of the nearby plasma environment. H_2^+ and H_3^+ ions were detected near Ganymede and in the wake region. Low energy ($\sim$0.1 to 1 keV) electrons are enhanced just outside the magnetopause, in the wake (inbound trajectory) and in the magnetopause boundary layer (outbound trajectory).

Ganymede MHD Model: Magnetospheric Context for Juno's PJ34 Flyby

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On June 7th, 2021 the spacecraft Juno visited Ganymede and provided the first in situ observations since Galileo's last flyby in 2000. The measurements obtained along a one-dimensional trajectory can be brought into global context with the help of three-dimensional magnetospheric models. Here we apply the model of Duling et. al. 2014 to conditions during the recent Juno flyby. In addition to the global distribution of plasma variables we provide mapping of Juno's position along magnetic field lines, Juno's distance from closed field lines and detailed information about the magnetic field's topology such as the boundary between open and closed field lines on Ganymede's surface. To estimate the sensitivity of the model results, we carry out a parameter study with different upstream plasma conditions and other model parameters. Utilizing auroral observations by Juno our model indicates that Juno did not enter the closed field line region unless the plasma pressure was exceptional low.

UVS Observations of Ganymede's Aurora During Juno Orbits 34 and 35

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Juno UVS, an ultraviolet spectrograph sensitive to wavelengths 68-210 nm, performed unique observations of Ganymede's aurora on the approach to Juno's 34th and 35th perijoves (PJ). The combination of Juno's 2 rpm spin rate, UVS' 7.2° long dog-bone shaped slit, and the UVS scan mirror allows for the recording of 7.2°wide scans across Ganymede's disk every 30 s. Through the wide slits we are able to capture integration times of 17 ms per spin for each resolution element in the observed swath. For the PJ34 Ganymede encounter on June 7, 2021 at 16:56:08 UTC, Juno UVS captured data during 16:52-16:56-17:04 UTC at altitudes varying from 1124-1044-6750 km. Over this time period Ganymede's angular diameter varied from 89°-91°-33° on the sky, while the nadir solar phase angle varied from 148°-98°-32°. Juno UVS achieves a spatial resolution of 0.2° giving a best-case nadir spatial resolution of 4 km (0.08° Ganymede latitude). The PJ34 UVS data provide a sparse, but high-resolution look at Ganymede's aurora, and can be used to locate the last closed field lines to an accuracy of about one degree of latitude. For the PJ35 Ganymede encounter on July 20, 2021 at 16:48:30 UTC, Juno UVS captured data during 16:32-16:48-17:27 UTC. The increased observational period relative to the PJ34 encounter is due to the larger range, 52,610-49,999-67,060 km, making the angular extent of Ganymede only 5.5°-5.7-4.3° on the sky (at a nadir solar phase angle 99°-81°-44°) and the best-case nadir spatial resolution 175 km (comparable to HST imagery). UVS not only spatially resolved Ganymede, but also spectrally separates the prominent 130.4 and 135.6 nm O auroral emissions, and their diagnostic brightness ratio.

Global Simulations of Ganymede's Magnetosphere during Juno's Close Flyby

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On its PJ34 orbit, the Juno spacecraft flew by Ganymede with a closest approach altitude of about 1000 km. During this flyby, Juno passed through the near-Ganymede magnetotail, a region that was not explored previously, thereby providing a unique opportunity to study the structure and dynamics of the moon's magnetotail. To place the Juno observations into proper global context, we have simulated Ganymede's magnetosphere using a series of global models with increasing complexity and sophistication, including ideal MHD, Hall MHD and MHD with Embedded Particle-In-Cell (MHD-EPIC) models. The simulations are driven by upstream conditions consistent with Juno in situ measurements, and incorporate an ionosphere model that takes into account effects of solar illumination and surface sputtering. Comparisons of our simulation results with Juno data will be presented to facilitate interpretation of the particles and fields as well as auroral observations, and implications for the global configuration and temporal variability of Ganymede's magnetosphere during the Juno flyby will be discussed.

Can Ganymede's magnetopause interactions help us probe the moon's subsurface ocean?

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The permanent magnetic field of Jupiter's moon Ganymede is thought to arise from an Earth-like dynamo in the moon's outer core, alongside a secondary time varying magnetic field induced by convection in the moon's subsurface ocean. Magnetic fields of Jupiter and Ganymede meet along a current boundary known as the upstream magnetopause, whose location depends on delicate pressure balance and presence of plasma-magnetic interactions including magnetic reconnection. As Ganymede traverses the Jovian plasma sheet, magnetopause conditions vary at half-Jovian synodic period ($\sim$5.4 hr), leading to equal-period oscillations of Chapman-Ferraro (C-F) currents and subsequently Ganymede's magnetospheric field. In this work, we show that the C-F magnetic signal will diffuse into Ganymede's subsurface ocean and cause magnetic induction. Then, we constrain the maximum amplitude of the C-F magnetic oscillation, obtaining maximum ocean inductive response of $\sim$1-10 nT. Improved magnetopause motion tracking is required to further specify this range. Nevertheless, the response magnitudes lie comfortably within resolution of the magnetometer aboard the JUpiter ICy moon Explorer (JUICE). Hence, magnetopause interactions may become a viable tool for future induction-based study of Ganymede's subsurface ocean.

Ion dynamics at the magnetopause of Ganymede

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We study the dynamics of the thermal O^+ and H^+ ions at Ganymede's magnetopause when Ganymede is inside and outside of the Jovian plasma sheet using a three-dimensional hybrid model of plasma (kinetic ions and charge neutralizing electron fluid). We investigate the contribution of different electric field terms, including the convective, Hall, ambipolar, and Ohmic and find that the Hall term is the dominant term at the magnetopause and in the magnetotail. We also present the global structure of the electric fields and power density ($\mathbf{E} \cdot \mathbf{J}$) in the magnetosphere of Ganymede and show that the power density at the magnetopause is mainly positive and on average is +0.95 nW/m^3 and +0.75 nW/m^3 when Ganymede is inside and outside the Jovian plasma sheet, respectively, but locally it reaches over +20 nW/m^3. Our kinetic simulations show that ion velocity distributions at the vicinity of the upstream magnetopause of Ganymede are highly non-Maxwellian where the dominant component of the velocity distribution is parallel to the background magnetic field (i.e., $T_{||} > T_{\perp}$). At the magnetopause, however, ions are substantially heated and the dominant component of the velocity distribution is perpendicular to the background magnetic field (i.e., $T_{||} < T_{\perp}$). We also investigate the energization of the ions interacting with the magnetopause and we find that the energy of those particles on average increases by a factor of 8 and 30 for the O^+ and H^+ ions, respectively. The energy of these ions is mostly within 1–100 keV for both species after interaction with the magnetopause, but a few percentage reach to 0.1-1 MeV. Our kinetic simulations show that a small fraction ($<$25%) of the co-rotating Jovian plasma reach the magnetopause, but among those more than 50% cross the high power density regions at the magnetopause and gain energy. We show a few example of ion trajectories that interact with the magnetopause and explain their dynamics. Finally, we compare our simulation results with Galileo observations of Ganymede's magnetopause crossings (i.e., G8 and G28 flybys). There is an excellent agreement between our simulations and observations, particularly our simulations fully capture the size of the magnetosphere and reproduce the sharp magnetic transients at the magnetopause crossings.

Energetic Charged Particle Observations during Juno's Close Flyby of Ganymede

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Ganymede-Jupiter's largest moon-is the only known moon in the Solar System to generate its own internal magnetic field (Kivelson et al., 1996, Gurnett et al., 1996) and therefore its space environment is of high scientific interest. In part, what makes Ganymede so interesting is that its magnetic field forms a mini-magnetosphere, with field lines connected to both hemispheres, i.e., closed , embedded within Jupiter's magnetosphere where the Alfvénic Mach number (MA) is < 1 and therefore classified as a sub-Alfvénic interaction.

With just six flybys, the Galileo mission fundamentally changed our understanding of Ganymede and its space environment (e.g., Kivelson et al., 1996; Gurnett et al., 1996; Williams et al., 1997; Frank et al., 1997) while also providing comprehensive particle and field measurements that serve as fiducial points for magnetohydrodynamic (MHD) simulations (e.g., Paty and Winglee, 2004; Jia et al., 2008; Duling et al., 2014) and interpreting remote ultraviolet observations (e.g., McGrath et al., 2013). Even so, there are many fundamental outstanding questions regarding Ganymede and its interaction with Jupiter's magnetosphere (e.g., see reviews by Kivelson et al., 2004 and Saur et al., 2021). A better understanding of the space environment around Ganymede is also important as it is a diagnostic medium to detect and characterize Ganymede's subsurface ocean (Kivelson et al. 2002, Saur et al. 2015). That brings us to the purpose of this letter: to document new observations from the close Ganymede encounter with the Jupiter polar orbiting mission, Juno.

On 7 June 2021, NASA's Juno mission obtained unique measurements of Ganymede's magnetosphere during a close flyby that brought the spacecraft within ∼1,000 km of its surface. Here Jupiter Energetic particle Detector Instrument (JEDI) observations are presented and analyzed. The electron pitch angle distributions reveal distinct regions of Ganymede's magnetosphere that can be characterized as inbound and outbound magnetospheric boundaries, a magnetotail/wake region, and Ganymede's open field line region. Evidence for energy dependent electron pitch angle structuring is also documented both outside and within Ganymede's magnetosphere. Electron precipitation is observed and mapped to Ganymede's surface along Juno's magnetic footprint.

Evidence for Magnetic Reconnection at Ganymede's Upstream Magnetopause during the PJ34 Juno Flyby

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Juno made a close flyby of Ganymede and flew through its magnetosphere on June 7, 2021. This flyby included a crossing of Ganymede's upstream magnetopause on the outbound segment of the spacecraft transit. We present plasma and magnetic field observations near that magnetopause crossing from Juno's Jovian Auroral Distributions Experiment (JADE; McComas et al. 2017) and magnetometer (MAG; Connerney et al. 2017), respectively. JADE observed enhanced electron fluxes, including accelerated, streaming electrons with uni- and bi-directional pitch angle distributions, as Juno crossed the magnetopause current layer (MCL) as identified by the magnetic field observations. The acceleration of cold ions, both protons and heavy ions originating from Ganymede, was also observed on approach to the magnetopause along with a possible mixing of ions from Ganymede and Jupiter's plasma sheet within the MCL. These observations are used to examine the physics of plasma interactions at this boundary, including evidence that magnetic reconnection, considered a key driver of magnetospheric dynamics at Ganymede, was occurring along the magnetopause at that time.

In situ ion composition observations of Ganymede's outflowing ionosphere

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The Juno spacecraft flew by Ganymede on 7 June 2021. During this flyby, the spacecraft passed through the Ganymede magnetosphere, approaching to an altitude of 1000 km. While inside the magnetosphere, the Jovian Auroral Distributions Experiment-Ion (JADE-I) sensor observed outflowing ionospheric ions. The outflowing ions include O2+, water group ions (WG+), H2+, H+, and H_3^+. Numerically calculated densities agree with the electron density determined by the Waves instrument. The light ions (H+, H2+, and H_3^+) have a different character than the heavy ions (WG+ and O2+). The light ions appear to be in hydrostatic equilibrium, and the altitude profile is generally symmetric across the day-night boundary. H_3^+ ions are an exception, with the ratio of H_3^+/H2+ being a factor 4 lower on the dayside than the night side. The heavy ions have higher densities on the dayside than the night side. Velocity distributions show the ionospheric ions are outflowing, with no bi-directional flow except possibly near the magnetopause. The outflowing flux of light ions peak near closest approach, but the heavy ions peak on the dayside, similar to the density. Here we will present the JADE-I observations of the outflowing ions from the Ganymede ionosphere.

Alternating north-south brightness ratio of Ganymede's auroral ovals: Hubble Space Telescope observations during the Juno PJ34 flyby

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We report results of Hubble Space Telescope (HST) observations from Ganymede's orbitally trailing side which were taken around the flyby of the Juno spacecraft on June 7, 2021. We find that Ganymede's northern and southern auroral ovals alternate in brightness such that the oval facing Jupiter's magnetospheric plasma sheet is brighter than the other one. This suggests that the generator that powers Ganymede's aurora is the momentum of the Jovian plasma sheet north and south of Ganymede's magnetosphere. Magnetic coupling of Ganymede to the plasma sheet above and below the moon causes asymmetric magnetic stresses and associated electromagnetic energy fluxes carrying the power driving the auroral emission. No clear statistically significant time-variability of the auroral emission on short time scales of 100s could be resolved. We show that Ganymede's auroral emission at OI 1356 Å requires electron energy fluxes of several tens of mW m^{-2}.

Ganymede's radiation cavity and radiation belt

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Ganymede's magnetosphere is unique in the solar system because it is centered on a strongly magnetized moon that is embedded within the strong magnetic field of a planet. Here we study this configuration based on combined measurements from the recent Juno flyby that provided high quality data and the past Galileo flybys, some which reached deeper into Ganymede's field than Juno.

We treat Ganymede like a planetary magnetosphere and organize the energetic particle measurements in the respective magnetic coordinates to avoid ambiguities between changes in distance, latitude, and equatorial pitch angle coverage. We find that Ganymede is surrounded by a large radiation cavity where the radiation intensities are smaller compared to surrounding magnetosphere of Jupiter. Particles are lost onto Ganymede during their bounce motion. The smooth shape of the pitch angle distribution suggests that the particle losses are enhanced by scattering, possibly due to wave-particle interaction.

Deep within the cavity, at an altitude range below 1000km, Ganymede is forming a standalone radiation belt that reaches up to hundreds of keV for oxygen and sulfur ions, and to at least MeV energies for protons and electrons. This finding may seem somewhat surprising given that Ganymede's field is similarly weak as Mercury's where no radiation belts have been found. However, we calculate several trapping criteria and find that trapping up to these energies is indeed feasible at Ganymede.

In principle, Ganymede's radiation belts may form simply from accumulating the radiation produced in Jupiter's magnetosphere. However, we find that the physics of Ganymede's belt may instead be very similar to its planetary counterparts. Ganymede's phase space density is rising toward Ganymede, suggesting that the radiation may be accelerated locally or be a transient phenomenon. Further analysis on the time dependence of the radiation belt may be possible through the upcoming JUICE mission that will flyby and orbit Ganymede.

Energetic particle fluxes onto Callisto's atmosphere

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Jupiter's moon Callisto is exposed to a highly dynamic magnetospheric environment. During a full synodic period, properties of the local magnetospheric field and thermal plasma environment change by an order of magnitude, and Callisto's resulting interaction with the ambient plasma displays a strong variability.

In this study, we combine results from the AIKEF hybrid and GENTOo test-particle models to constrain the variability of energetic particle dynamics and quantify their flux onto the top of Callisto's atmosphere during a synodic period. For three positions of Callisto with respect to the center of the Jovian current sheet (at maximum distance above, maximum distance below, and embedded within), we model the interaction between Callisto's atmosphere/ionosphere, its induced field, and ambient magnetospheric plasma environment, and we trace energetic ions (hydrogen, oxygen, and sulfur) and electrons through the perturbed electromagnetic fields. Our findings highlight the important role that Callisto's interaction with the low energy magnetospheric plasma and signatures associated with the moon's induced field have on shaping the dynamics and flux patterns of the high-energy particles, which may play a role in the asymmetric ionization of, and energy deposition into, Callisto's neutral atmosphere.

Magnetosphere-Ionosphere-Thermosphere Coupling study at Jupiter Based on Juno First 30 Orbits and Modelling Tools

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The dynamics of the Jovian magnetosphere is controlled by the complex interplay of the planet's fast rotation, its solar-wind interaction and its main plasma source at the Io torus, mediated by coupling processes involving its thermosphere, ionosphere and magnetosphere, referred to as MIT coupling processes . At the ionospheric level, these processes can be characterized by a set of key parameters which include ionospheric conductances, currents and electric fields, transport of charged particles along field lines which carry electric currents connecting the ionosphere and magnetosphere, and among them fluxes of electrons precipitating into the upper atmosphere which trigger auroral emissions. Determination of these key parameters in turn makes it possible to estimate the net deposition/extraction of momentum and energy into/out of the Jovian upper atmosphere. A method based on a combined use of Juno multi-instrument data (MAG, JADE, JEDI, UVS, JIRAM and WAVES) and three modelling tools was first developed by Wang et al. (2021) and applied to an analysis of the first nine Juno orbits to retrieve these key parameters along the Juno magnetic footprint. In this communication we will extend this method to the first thirty Juno science orbits and to both north and south main auroral ovals crossings. Our results make it possible to characterize how the local systems of field-aligned electric currents, height-integrated ionospheric conductances, electric currents and fields, and Joule and particle heating rates vary across the main ovals between their poleward and equatorward edges. They suggest that southern current systems display a trend consistent with the generation of a region of sub-corotating ionospheric plasma poleward of the main aurora, while this dominant trend is not found around the northern main auroral oval. These results are discussed in the light of the previous space and ground-based observations and currently available models of plasma convection and current systems, and their implications for the dynamics of the thermosphere, ionosphere and magnetosphere of Jupiter are assessed.

Emptying of Jupiter’s Plasma Disk in March 2018

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Huscher et al. (2021) presented a survey of the Juno-JADE plasma data over orbits 5-26 between March 2017 and April 2020, focusing on the inbound plasma sheet crossings. There was one particular orbit, PJ12, where the plasma sheet was notably absent with very low densities. Juno traversed from 50 RJ in to 10 RJ between Day Of Year 87 to 91 in 2018. The orbits before and after showed typical plasma sheet densities. The Juno-JEDI data showed low energetic particle fluxes at these times and the Juno-FGM magnetic field data were consistent with a significantly reduced magnetodisc current (Connerney et al. 2020). We present the range of Juno data for this period, compare with extrapolation of solar wind conditions to 5 AU, and estimate the time scales for emptying and re-filling of the plasma disk.

Plasmoids and Dipolarizations in the Jovian Magnetotail: Statistical Survey of Ion Acceleration with Juno Observations

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Jupiter’s magnetosphere provides a unique natural laboratory to study processes of energy transport and transformation. Strong electric fields in spatially confined structures such as plasmoids and dipolarizations can be responsible for ion acceleration to high energies. We focus on the effectiveness of ion energization and acceleration in plasmoids and dipolarizations. Therefore, we present a statistical study of plasmoid and dipolarization structures in the predawn magnetotail, which were identified in the magnetometer data of the Juno spacecraft from 2016 to 2018. For our study we additionally use the energetic particle observations from the Jupiter Energetic Particle Detector Instrument (JEDI) which discriminates between different ion species. We are particularly interested in the acceleration of oxygen, sulfur, helium and hydrogen ions in plasmoids and how these processes are affected by the event properties, such as the radial distance and the local time of the observed plasmoids inside the magnetotail. We find significant heavy ion acceleration in plasmoids close to the current sheet center which is in line with the previous statistical results on acceleration in plasmoids based on Galileo observations conducted by Kronberg et al. (2019). The observed effectiveness of the acceleration is dependent on the position of Juno during the plasmoid event. Furthermore, we investigate if non-adiabatic acceleration of ions is present in plasmoids and dipolarizations and if the acceleration process is related to electromagnetic fluctuations.

An overview of the radiation bursts observed by Juno-UVS above the polar regions

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One of the surprising results from the Juno mission is the quasi-ubiquitous finding of anti-planetward charged particles escaping along the magnetic field lines from the polar-most regions. Some of these electrons are so energetic (on the order of 10MeV) that they can penetrate through Juno's ultraviolet imaging spectrograph (Juno-UVS)'s shielding and hit the detector. Contrary to the continuous radiation bombardment that is typically observed when Juno crosses the radiation belt's horns and which causes a quasi-continuous background on the UV images, the radiation-caused noise observed above the poles registers on the images as parallel stripes looking like bar-codes. In this study, we further explore these so-called bar-code events that have been observed during the 40 first Juno orbits and we essentially confirm earlier results based on a more limited number of observations. Among other results, we will show plots of their occurrence superposed to maps of the aurora, demonstrating that they are quasi-systematically connected to the polar region. We will also show that they mostly appear when UVS is pointed down to Jupiter, a signature of a field-aligned, up-going population. While there are upward MeV electron beams over a broader range of latitudes, the subset of the most intense beams is in the polar region. These beams are seen in the north and south but in the northern hemisphere they are more prevalent when the polar region is not illuminated.

A consolidated catalogue of Jovian decametric radio observations observed in Nançay from January 1978 to December 1990

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A series of five Jovian decametric radio emission catalogues covering 13 years of observations (1978 to 1990) and published between 1981 and 1993 has been compiled after a digitisation process. The new catalogue has been validated and is provided in a standardised and interoperable format.

Transport and Ion Anisotropy in the Io plasma torus

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Ion cyclotron waves have often been observed in regions of plasma production. The initial ring-beam distribution of pickup ions is highly anisotropic. This temperature anisotropy is unstable and generates electromagnetic ion cyclotron waves. The waves can be easily identified, since they are narrow-band, left-circularly polarized, transverse and at a frequency slightly less than the gyrofrequency of the pickup ions. Such waves were commonly observed by the Cassini spacecraft, near the equator and between 3.5 and 6 Saturn radii from the planet. The Galileo spacecraft observed these waves in the vicinity of Io and Europa. However, to date, no such waves have been observed by the Juno spacecraft, despite being in regions where plasma production and ion anisotropy would be expected.

This presentation describes a model of ion temperature anisotropy which explains these non-detections. Unlike the case of Saturn's magnetosphere, the densities in the Io plasma torus are sufficient for Coulomb collisions to reduce anisotropy on timescales comparable to the ionization and transport rates. Further, ion production at Jupiter involves more electron impact ionization (which drives both anisotropy and plasma transport) relative to charge exchange (which drives anisotropy but not transport) than is the case in Saturn's magnetosphere. Finally, collisions reduce anisotropy very rapidly once plasma has been transported out of the immediate region. These results, combined with the observations and lack of observations of ion cyclotron waves, may indicate that plasma sources in Jupiter are relatively local and concentrated near the vicinity of moons, as opposed to occurring in a broad, distributed neutral cloud.

A new, general model for radial transport of plasma, angular momentum and energy in the magnetospheres of Jupiter and Saturn

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The magnetospheres of giant planets are governed by the interplay of these planets' fast rotation, the solar wind and inner plasma sources. In the Saturn and Jupiter magnetospheres, plasma is mainly produced by the ionization of neutral gas tori at the radial location of active moons: Io at Jupiter and Enceladus at Saturn. The mechanisms by which these moon-associated plasma sources are redistributed throughout these magnetospheres involve both plasma motions and magnetic flux tube exchanges. These motions are coupled to the rotation of the planets through electric current systems originating in the equatorial plasma disk and closing into their upper atmosphere and ionosphere.

Models of the net effects of these different mechanisms on the radial transport of plasma are needed to adequately reproduce the observed populations of electrons and ions in the magnetospheres of giant planets and to establish the net budgets of exchange of plasma, angular momentum and energy between moons, magnetospheres and their host planets. Up to now, two different types of transport models have been developed. The first type (Cowley and Bunce, 2001; Cowley et al., 2005 and following studies) assumes an infinitely thin plasma disk with null temperature and pressure and derives the transport of angular momentum in the magnetosphere with due account of magnetosphere-ionosphere-thermosphere (MIT) coupling. In the second type of model (Bagenal and Delamere, 2011; Ng et al., 2018), radial diffusion of full flux tubes with finite temperature is calculated throughout the disk, taking into account hydrodynamical properties of the plasma and turbulent heating in the absence of MIT coupling.

A self-consistent modelling of radial transport in the magnetosphere of giant planets requires the unification of the two approaches into a full description of the interactions between the plasma disk content, the magnetosphere and the ionosphere-thermosphere of the planet. In this communication, we introduce an approach combining these two types of models to design a more general model. This new type of model will describe radial transport of plasma, angular momentum and energy in the Jupiter and Saturn magnetospheres taking into account both diffusive/advective plasma transport and exchange of angular momentum with the planet's upper atmosphere. It will be tested against magnetosphere observations by the Juno mission at Jupiter and the Cassini mission at Saturn.

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The First Detection of X-rays from Uranus and the Next Observing Campaign

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Within the solar system, X-ray emissions have been detected from every planet except the Ice Giants: Uranus and Neptune. Here, we present three Chandra X-ray Observations of Uranus (each 24-30 ks duration): an Advanced CCD Imaging Spectrometer (ACIS) observation during solar maximum on 7 August 2002 and two High Resolution Camera (HRC) observations during solar minimum on 11 and 12 November 2017. The ACIS observation from 2002 shows a low signal but statistically significant detection of X-rays from Uranus. The measured Uranus X-ray fluxes of 10-15-10-16 erg/cm2/s from this detection are consistent with upper limits and modelling predictions in previous work (Ness & Schmidt. 2000; Cravens et al. 2006). The photon energy distribution from this observation is consistent with an X-ray emission from charge exchange or scattering of solar photons, as observed for Jupiter and Saturn. The two HRC observations from 2017 constitute non-detections. For 11 Nov 2017, the X-ray emission coincident with Uranus' location is dimmer than 98% of the Field of View. For 12 November 2017 the Uranus region was 4 times brighter, and brighter than 94% of the Field of View (1.6 standard deviations > Field of View mean). At this time the Uranus coincident X-ray signature also exhibits timing variation distinct from the field of view.

While the 3 original Chandra observations of Uranus were short-duration, exploratory observations designed to test for a detection, our team (PI: Wibisono) recently won an extended campaign, which will constitute 120 hours of XMM-Newton observations of Uranus. These will provide higher sensitivity spectral and temporal resolution of the X-ray emissions from Uranus. We close the poster by outlining these exciting new observations.

Plasma Observations Across Jupiter's Southern Polar Magnetopause

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Juno's orbit during its extended mission provides an opportunity for in-situ exploration of the outer regions of Jupiter's southern polar magnetosphere. Exploring these regions to investigate the interaction and accessibility to the interplanetary medium is a key magnetospheric science objective of the extended mission. The spacecraft made its first crossing of Jupiter's polar magnetopause at high southern latitude on December 25, 2021 at a radial distance of 97 RJ and has made several additional crossings since. We report on plasma observations near these magnetopause crossings along with spatial information for where they occurred. The observations show clear, extended entries into the polar magnetosheath along with boundary regions containing a mixture of Jovian and solar wind plasma. These observations will provide important constraints for the 3-D structure of Jupiter's polar magnetosphere and new understanding for how the solar wind interacts with Jupiter's magnetosphere at high latitude.

Fine and coarse spectral structures of Jovian radio emissions revealed by Juno and Cassini

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Cassini flew past Jupiter in 2000/2001, and Juno is orbiting the gas giant since mid-2016. Both spacecraft were or are equipped with radio and plasma wave instruments being able to measure radio emissions with high time and frequency resolution. In this presentation, we focus on the spectral properties of Jovian kilometric radiation (KOM), which can take the form of a narrow-banded (nKOM) or a broad-banded (bKOM) emission. The generation mechanism of the two emissions is probably different. It is certain that bKOM is caused by the cyclotron maser instability, whereas nKOM might be caused by a mode conversion of upper hybrid waves at the boundary layer of the Io plasma torus. This might also lead to different spectral structures: While nKOM is very smooth and practically shows no fine structures, one can find zebra patterns and striations in bKOM, the latter being mostly downward drifting linear features with bandwidths of a few 100 Hz. On the other hand, the kilometric radiations at Saturn or Earth not only show striations, but they are also full of linear features with bandwidths of the order of 1 kHz and durations of some tens of seconds. Such fine structures are almost absent in bKOM, and the linear features of positive and negative slope seen in bKOM spectra should rather be called coarse structures: Their typical bandwidth is around 10 kHz, and they last for some tens of minutes. We also investigate the occurrence of these coarse bKOM structures.

Additionally we show the fine structures of other radio waves at Jupiter like trapped continuum emission, Jovian anomalous continuum, narrowband emissions, and several emissions below the electron cyclotron frequency like lightning whistlers, chorus, hiss and possible Z-mode emissions.

Localized hot electron inflow on the dusk side during transient brightening in Io plasma torus observed by Hisaki/EXCEED

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The Hisaki satellite has observed 10% transient increases in the intensity of the Io plasma torus (IPT) emission in the inner magnetosphere (r$<$8Rj) over a time scale of several to ten hours after a transient brightening of Jupiter's UV auroral emission. Since the plasma convection in the Jupiter magnetosphere is dominated by the planetary rotation, it has been considered that the fast transport of energy in the radial direction is not significant. However, this transient phenomenon suggests that the effects of transient energy release in the middle or outer magnetospheres, which cause auroral brightening, extend to the IPT on a time scale of a few tens of hours. Considering that the relaxation time of hot electrons with energy of several hundred eV in the IPT due to Coulomb collisions is comparable to the time scale of the brightening, previous studies interpreted the cause of brightening as the influx of hot electrons into the IPT from outer part of the magnetosphere. In this study, we investigated the start local time (LT) of the IPT brightening from the extreme ultraviolet (EUV) spectra observed by the HISAKI satellite and clarified the inflow position of hot electrons in the IPT. The field-of-view of the EUV spectrograph onboard the HISAKI satellite is 360 arcsec and enables to observe the radial spatial structure of the IPT emission in both dawn and dusk sides. We obtained the intensity of sulfur ion emission by integrating the EUV spectrum from 65 nm to 77 nm in wavelength, and then determined the start LT of the IPT brightening by dividing the spatial distribution of the IPT into 10 parts in each dawn and dusk region (20 regions in total). The integration time was set to 10 minutes. In order to detect the IPT brightening with an amplitude of 10%, the trend of the intrinsic periodic variations in the torus (System III period: 9.93 h, System IV period: 10.14 h, and Io's orbital period: 42.46 h) were fitted by the least-squares method and eliminated from the data. The transient brightening event in the IPT was defined as an event in which 16 among of the 20 regions showed an increase in emission of at least 2σ from mean in a 10-hour period. 19 brightening events were identified in 2014-2016. Among them, the start LT positions were identified for 16 events. 13 events started in the dusk side, and 9 of them were localized at LT14-16. Assuming that the cause of the brightening is the inflow of hot electrons, this result indicates that inflow of hot electrons in the IPT tend to localize at LT14-16. In the rotation-dominant magnetosphere, the transport of plasma in the radial direction is thought to be caused by interchange instability driven by centrifugal forces. Since the centrifugal force which acts on plasmas is independent of LT, it is expected that inflow of hot electron would occur in all LT region. The result presented here shows different picture of Jovian magnetosphere from that previously thought.

H_3^+ auroral densities, cooling rate and conductance from Juno FUV and infrared observations

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Auroral precipitation significantly enhances the H_3^+ ion density in the Jovian ionosphere as a result of the creation of H_2^+ ions followed by charge transfer on ambient H_2 molecules. This density enhancement has several important consequences:

- it generates additional cooling through infrared radiation to space (the H_3^+ thermostat effect) - it increases the ionospheric conductance which is an important component of the current loops connecting the Jovian magnetosphere and ionosphere - it makes it possible to image the auroral structures at high latitude - it provides an excellent remote sensing tool to probe the thermospheric temperature

During a few perijove passes, simultaneous infrared (JIRAM) and ultraviolet (UVS) quasi-global maps of the Jovian aurora are available. The globally integrated H_3^+ cooling power is in the range 2-4 terawatts in both hemispheres, close to the particle heating power. We use the FUV H_2 brightness and color ratio to derive the characteristics of the electron precipitation and model the H_3^+ radiance for each UVS map pixel. Comparison of H_3^+ modeled radiance maps with the JIRAM observations generally shows good agreement, with some localized differences. The spatially integrated H_3^+ cooling powers from the model are in close agreement with the global JIRAM values. In this presentation, we compare the H_3^+ column density derived from the UVS images and model with values in the literature based on H_3^+ ground based spectral measurements. We also illustrate the H_3^+ density altitude distribution at different locations and investigate its dependence on the methane profile we use. These results will be useful for validation of 3-D models of the global Jovian energy balance in the upper atmosphere.

H_3^+ auroral densities, cooling rate and conductance from Juno FUV and infrared observations

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The UltraViolet Spectrograph (UVS) instrument on board Juno measures the H2 Lyman and Werner bands whose brightness is a proxy of the precipitated auroral electron flux. The 3.3-3.6 μm spectral window of the JIRAM L-band imager maps the H_3^+ thermal radiance with unprecedented spatial resolution. During a few perijove passes, datasets provide simultaneous infrared and ultraviolet quantitative quasi-global maps of the Jovian aurora. The globally integrated H_3^+ cooling power is in the range 2-4 terawatts in both hemispheres, close to the particle heating power. We also use the FUV H2 brightness and color ratio to derive the characteristics of the electron precipitation and model the H_3^+ radiance for each UVS map pixel. Comparison of H_3^+ modeled radiance maps with the JIRAM observations shows general good agreement with some local differences. The spatially integrated H_3^+ cooling powers from the model are in close agreement with the global JIRAM values. In this presentation, we compare the H_3^+ column density derived from the UVS images and model with values in the literature based on H_3^+ ground based spectral measurements. We also illustrate the H_3^+ density altitude distribution at different locations and investigate its dependence on the methane profile we use. These results will be useful for validation of 3-D models of the global Jovian energy balance in the upper atmosphere.

Mapping Jupiter's Lyman-α Airglow with Juno UVS

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Jupiter's low latitude upper atmosphere is a region with notable airglow emissions. We can view these emissions using Juno's UltraViolet Spectrograph (UVS). A major component of Jupiter's far-utraviolet airglow is from Lyman alpha (Lyα) emissions largely caused by scattering of solar Lyα light off H atoms in Jupiter's thermosphere. Juno's low altitude (3500 km above the 1-bar level) perijoves allow UVS to detect hydrogen Lyα emissions in all directions, and to create maps that inform us about the vertical structure of Jupiter's upper atmosphere. We present preliminary results to characterize these emissions and how they vary with respect to spacecraft latitude, longitude, zenith angle, and local time information. We will use the results from many perijove passes to model the atmosphere and determine properties about the population of hydrogen that we find in Jupiter's low latitudes.

Jupiter's colorful hair

D. Grodent [1]***, B. Bonfond*** [1]***, J.-C. Gérard*** [1]***, K. Haewsantati*** [1,2]***, G. Sicorello*** [1]***, G.R. Gladstone*** [3]***, T. Greathouse*** [3]***, V. Hue*** [3]***, J. Kammer*** [3]***, R. Giles*** [3]***, A. Moirano*** [4]***, A. Mura*** [4]

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Auroral emissions on Jupiter form intricate structures. They may be conveniently separated by transient and more permanent features. Transient features often appear in the poleward-most sector of the auroral polar region and are usually found to depend on the direction of the Sun. Interestingly, the brightness and morphology of these polar emissions, at least in the north, appear to depend both on local time, but also on the sub-solar longitude. On the other hand, the permanent or longer-lifetime auroral emissions are frequently associated with the main and outer emissions and are found to move close to corotation with Jupiter. However, this distinction between transient auroral features that are poleward and fixed in local time, and permanent features that are equatorward and corotating is somewhat artificial and may not include other types of auroral emissions. The dawn storm and the polar bright spot are two examples of such auroral emissions not following this simple categorization.

The global morphology of Jupiter's aurora was largely constrained by observations with HST, which only sees Jupiter's dayside hemisphere. Thanks to the polar orbit of Juno, we now have access to views of the aurora at all local times and in particular to the night side hemisphere. We have combined HST-STIS, Juno-UVS and Juno-JIRAM observations of Jupiter's UV and IR aurora to bring forward a new type of auroral structure - Jupiter's hair - forming long-term multiple arcs whose orientation and location are influenced by local time. They extend from the poleward boundary of the main emission to the polar region, in the afternoon sector. This structure presumably encompasses previously found auroral features like the poleward auroral filament, transpolar arcs, and the auroral bridge structure.

Dawn-Dusk asymmetry in Jupiter's main auroral emissions

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Previous studies of Hubble Space Telescope's (HST) observations of the UV main auroral emissions at Jupiter indicate that the dusk side of the aurora is brighter than the dawn side, contrary to some theoretical expectations. However, images from the HST suffer from an incomplete view of the pole and from a selection bias related to the inclination of the magnetic dipole. Now that Juno is orbiting Jupiter, more data and better views of the auroral regions are being collected. Using UVS, the UV spectrograph on board Juno, we can create comprehensive maps of the auroral regions for both the northern and southern hemisphere, without any orientation bias. Based on Juno's 39 first perijoves and using the model of Jupiter's magnetosphere from Vogt et al. (2011), we could isolate the auroral features associated with the dawn and dusk sectors. Then, we derive the power emitted by the dawn and dusk parts of the aurorae and compare our results to the previous HST observations.

The Effects of Local Time Asymmetries in Auroral Currents on Ionospheric Outflow at Jupiter

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Ionospheric outflow is a process driven by pressure gradients between the magnetosphere and ionosphere. This gradient generates an ambipolar electric field between the electrons and heavier ions, which are then accelerated into the magnetosphere. Though identified as a process that occurs at Jupiter, there have not been many studies on the phenomena, as the source of plasma it provides to the magnetosphere is considered less important than that from Io. Quantifying the ionospheric outflow rate, however, is essential to understanding the dynamics of the Jovian system. Preliminary studies have shown that ionospheric outflow rates vary with latitude due to auroral currents. However, the effects of dawn-dusk asymmetries in Jupiter's main auroral emission have not yet been considered. We will investigate how local time variations in auroral current densities and emission width affect ionospheric outflow rates using the recently developed IonoSpheric Outflow in Rapidly Rotating Systems (ISORRS) model. We will discuss how variations in the outflow may feed into magnetosphere-ionosphere coupling dynamics.

Magnetic reconnection near the planet as a possible driver of Jupiter's mysterious polar auroras

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Auroral emissions have been extensively observed at the Earth, Jupiter, and Saturn. These planets all have appreciable atmospheres and strong magnetic fields, and their auroras predominantly originate from a region encircling each magnetic pole. However, Jupiter's auroras poleward of these main emissions are brighter and more dynamic, and the drivers responsible for much of these mysterious polar auroras have eluded identification to date. We propose that part of the solution may stem from Jupiter's stronger magnetic field. We model large-scale Alfvénic perturbations propagating through the polar magnetosphere towards Jupiter, showing that the resulting <0.1° deflections of the magnetic field closest to the planet could trigger magnetic reconnection as near as 0.2 Jupiter radii above the cloud tops. At Earth and Saturn this physics should be negligible, but reconnection electric field strengths above Jupiter's poles can approach 1 V m-1, typical of the solar corona. We suggest this near-planet reconnection could generate beams of high-energy electrons capable of explaining some of Jupiter's polar auroras. Beyond this core idea, we go on to assess the potential source of triggering perturbations from the magnetosphere and explore the role of the ionosphere as a potential reason for hemispheric and local time asymmetries in the swirl emissions. Finally, we outline hypotheses that can be tested by observations made by the ongoing Juno mission.

Ionospheric heating above Jupiter's Great Red Spot: NASA IRTF iSHELL observations

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[1] University of Leicester [2] JAXA [3] Boston University

Ground-based observations of the H_3^+ ionosphere above the Great Red Spot (GRS) have been shown by O'Donoghue et al. (Nature, 2016) to be several hundreds of degrees Kelvin hotter than the surrounding upper atmosphere. This indicated the presence of a heating source, not related to the redistribution of auroral energy. Instead, it was suggested that gravity/acoustic waves generated within the fierce storm propagate upwards in altitude into the upper atmosphere where they break and release their energy. Here, we revisit this hypothesis with observations taken with the NASA IRTF iSHELL instrument in 2019 and 2021. The GRS region was scanned on each occasion to produce a map of the region, revealing temperature and ion density fields. We show that whilst wave heating was present on one occasion, it was largely absent on another. This suggests that the mechanism is variable withe time. We also explore the location of the heating relative to the GRS, identifying where in the troposphere these waves are generated.

Applying Information Theory to GAMERA Simulations of Jupiter and Saturn-like Magnetospheres

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The inner mechanisms driving electron density fluctuations in the magnetospheres of outer planets such as Saturn and Jupiter are not fully understood. In order to further understand these fluctuations, we employ information theory. Information theory is a useful tool for understanding the flow of information in a system by examining how the changes in one parameter affect another. This allows us to determine causal relationships between variables, even nonlinear relationships. We utilize information theory to investigate the links between parameter changes in various regions of the magnetosphere as a function of lag time, such as how magnetic field changes in the midnight tail sector affect the electron density in the dawn sector. This process is extended to several other combinations of parameters such as vorticity and particle velocity in other regions of the magnetosphere as well. These methods are applied to magnetospheric simulations of Saturn and Jupiter produced by the GAMERA (Grid Agnostic MHD for Extended Research Applications) code, a reinvention of the high-heritage LFM code. Applying information theory will allow us to better understand the electron density fluctuations and structures present in these simulations.

Reconsideration for causalities of occurrence features of Io-related Jupiter's radio emission

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The following questions; 'What kind of magneto-ionic wave Jupiter's auroral radio emission is?' and 'How the radio emission is generated?' have been long years of subjects. I have investigated the subjects based on numerical calculations using several kinds of magnetic field and plasma density models, however, the questions have not been resolved yet: a hypothesis of a special energy transporter which does not meet with the observation results was needed. Recently Jupiter's new magnetic field model 'JRM09' was proposed based on the JUNO Jupiter explorer conducting in-situ magnetic field measurements near Jupiter (Connerney+, GRL, 2018). We have tried to make a 3D raytracing analysis for Io-DAM using the JRM09 model. The preliminary analyses show that R-X mode waves are preferable as Io-DAM and the JRM09 model gives more natural explanations for the origin of Io-DAM, though there still remain some questions on restriction of 'Io-DAM' and on origin of Io-C; i.e., some additional energy input process(es) so as to meet the ray emitting conditions with the observed Io-DAM sources.

Chasing Shadows in Jupiter's Ionosphere: constraints on electron density and chemical lifetime

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[1] Boston University [2] University of Leicester [3] JAXA

We present observations and modeling of the response of Jupiter's non-auroral ionosphere to the passage of Ganymede's shadow near local noon. Such eclipses occur regularly at Jupiter and offer a unique opportunity to measure the chemical lifetime of the dominant molecular ion at the giant planets, H_3^+. The chemical loss of H_3^+ is mainly through dissociative recombination with electrons. Therefore, the rate of H_3^+ decay after eclipse onset is an excellent proxy for a fundamental ionospheric component that is difficult to measure remotely, and has never been measured during the daytime: electron density. Similarly, the post-eclipse rise of H_3^+ is directly correlated with net ion production, and any increase in the modeled, solar EUV-driven H_3^+ rise could therefore be due to ionization from particle precipitation sources (e.g., pitch-angle scattering of radiation belt particles). Our initial results are not definitive, but so far show that, if present at these latitudes, particle precipitation is extremely minimal.

Three case studies tracking injection signatures in the UV aurora at the Jovian Southern hemisphere

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Radial transport in Jupiter's magnetosphere can be traced using UV auroral images. We extend previous analysis of Jupiter's secondary auroral oval (observed as transient arcs located between the main emission and the Io footprint) to understand the processes controlling its appearance. We present three case studies, each with images of the northern and southern aurorae spaced over several days, to show the development of the secondary oval following dawn storms and/or injection signatures. These observations reveal how plasma transport and associated auroral precipitation vary over timescales of hours to days.

By focusing on the injection signatures' behaviour spanning several consecutive HST visits, we will further investigate both their magnetospheric drivers and the cause for the distinct Southern morphology. By tracing the temporal evolution of the auroral emission through different morphological families (as defined by Grodent et al., 2018) we will obtain a more complete depiction of the injection signatures on the Jovian Southern hemisphere.

Finally, by estimating a mean location for the Southern main oval from the existing HST data, the latitudinal shifting of features such as the injection signatures and the secondary oval can be studied. This displacement is directly associated with the reconfiguration of the magnetic field lines.

Using Io Input/Output observatory (IoIO) observations to determine if mass flow in Jupiter's magnetosphere driven by internal or external processes

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Jupiter's magnetosphere is heavily mass-laden thanks ultimately to Io's volcanism. This mass flux causes several major features: its overall large size, extended magnetodisk and strong current sheet. Importantly, modulation of this mass flux is not directly coupled to modulation of the flux of material from Io: this material is buffered for a period of 20 – 80 days in the Io plasma torus (IPT). Once having left the IPT, plasma spirals out of the magnetosphere within a matter of days (e.g. Baganal & Delamere 2011). In this way, physical mechanisms in the IPT ultimately control mass flux in the magnetosphere.

The rate of transport through the IPT has been observed to increase non-linearly as the flux of material from Io increases (Brown & Bouchez 1997) at the same time as a population of superthermal electrons grows (Steffl et al. 2008, Yoshioka et al. 2018). Observational and theoretical considerations suggest these electrons are excited by Alfven waves in the IPT that are triggered by mass flow in the IPT (Frank et al. 2000, Hess et al. 2011). However, particle injection events, which have their source from reconfiguration of the middle and outer magnetosphere also provide hot electrons into Jupiter's inner magnetosphere (e.g. Louarn et al. 2014). Do the electrons that are related to mass flow in the IPT derive their source from inside the IPT or the middle and outer magnetosphere? Theoretical and observational work differs on the answer to this question (Copper et al. 2016 and Coffin et al. 2020, Yoshikawa et al. 2016, Yoshioka et al. 2018, Hikida et al. 2020).

We are addressing this question from a perspective different than previous workers. Rather than concentrating on UV emissions stimulated by superthermal electrons, we use visible S+ 673 nm emissions stimulated by the thermal electrons to observe the total mass to the IPT. We use contemporaneously recorded images of the inner 150 Rj of the Jovian sodium nebula, which capture the key physical processes of the creation of pickup ions and loss due to neutralization (Wilson et al. 2002). As a result, we can solve the following mass balance equation for the last term, the material flux out of the torus, which is not directly observable due to low contrast relative to the background plasma.

$$\frac{dM_{IPT}}{dt} = \frac{dM_{in\_ionization}}{dt} - \frac{dM_{out\_neutralization}}{dt} - \frac{dM_{out\_plasma}}{dt}$$

We use modulation in the dawn-dust electric field, measured using the positions of the IPT ansas, as a proxy for events in the middle and outer magnetosphere. We will present an analysis of 5 years of data collected by PSI's Io Input/Output robotic observatory (IoIO), focusing on modulation of the IPT ansa positions and $\frac{dM_{IPT}}{dt}$, and a preliminary estimate of the next two terms in the above equation.

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Using the Io plasma torus as a probe of Io's atmosphere (yes, you read that right)

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Various spectroscopic emission lines in Io's atmosphere are excited by plasma torus electrons. Thus, Io's integrated atmospheric emission has been used as a proxy for the upstream torus electron density (e.g., Scherb & Smyth 1993, Oliversen et al. 2001). Detailed spectro-imaging studies have shown Io's atmospheric emission is distributed non-uniformly. Bright spots are seen on Io's sub- and anti-Jovian hemispheres, roughly at the tangent points of Jupiter's magnetic field on Io. There is also more uniformly distributed diffuse emission (Roesler et al. 1999, Geissler et al. 2004, Roth et al. 2014).

We use 3000 spectroscopic observations of Io in [OI] 630 nm, collected over an 18-year period (an extension of the Oliversen et al. dataset), to constrain the free parameters of the Smyth & Marconi semi-empirical plasma torus model. The model provides values for the electron density that are fixed in the natural "plasmacentric" coordinate system of the plasma, which accounts for effects such as Jupiter's offset, tilted dipole field and the ratio of the corotational to convection electric field, $\vec{\epsilon}$ (Smyth & Combi 1988). The version of the model we use is based on the electron density profile measured by Voyager 1 and uses parameters very close to those found for the ground-based case by Smyth, Peterson & Marconi (2011; their Figure 17a), specifically:

- $|\vec{\epsilon}|$ = 0.025
- The electron density is scaled by 0.76 inside of 5.72 Rj in plasmacentric coordinates
- The scale factor that converts model electron density to [OI] 630 nm emission is 2.0 $\pm 0.8 \times 10^{15}$ R cm^3

Interestingly, when Io is east of Jupiter, the model scale factors are systematically 25% higher than on the west. This effect is does not have its origins in the spectroscopic extractions or model, suggesting it is an intrinsic property of Io's atmospheric interaction with the torus.

One possible explanation of this effect is found in the modulation of the relative brightnesses of Io's diffuse and spot emissions. In the UV, the diffuse component is 25% brighter on the east (Roth et al. 2014, Figure 10). The UV morphology work was normalized to Io's total brightness to avoid the complication of modulation by electron density – the larger effect. By using our results, which account for modulations in the electron density through the Smyth & Marconi torus model and calculations that account for different excitation rates between the UV and visible emission lines, a more comprehensive picture of Io's atmospheric interaction with the torus can be derived.

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Pitch angle distribution of MeV electrons in the magnetosphere of Jupiter

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The magnetosphere of Jupiter harbors the most extreme fluxes of MeV electrons in the solar system and therefore provides a testbed of choice to understand the origin, transport, acceleration, and loss of energetic electrons in planetary magnetospheres. Along this objective, the Pitch Angle Distribution (PAD) of the charged particles may reveal signatures of the dominant physical processes. Here, we analyze for the first time the PAD of MeV electrons observed by the Galileo-Energetic Particle Detector (EPD) in orbit around Jupiter from 1995 to 2003. Our first finding is that the MeV electron PADs observed by the EPD telescopes, with relatively large angular apertures, appear relatively isotropic with a flux anisotropy lower than a factor of 3. The fine anisotropy observed by Galileo-EPD reveals persistent pancake distributions for MeV electrons at L=9. At L=15, L=19, and L=26-60, pancake, isotropic, and scattered beam field-aligned distributions have been observed. The scattered beam distributions transiently have intensities comparable to or greater than the isotropic and pancake distributions. This last finding suggests that auroral acceleration mechanisms may be an important if not dominant source of trapped MeV electrons in the middle magnetosphere of Jupiter.

The Diffusion-Advection Turbulent Heating Model for Giant Planet Magnetospheres: New Results Based on Juno Data

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The ion temperature of the magnetospheres of Jupiter and Saturn was observed to increase substantially from about 10 to 30 planet radii. This suggests that there should be some heating sources to counter the cooling effect due to adiabatic expansion. There have been several models trying to explain such observation using different heating mechanisms, including a heating model for Jupiter based on magnetohydrodynamic (MHD) turbulence [Saur, Astrophys. J. Lett., 602, L137 (2004)] with flux-tube diffusion. More recently, an MHD turbulent heating model based on advection was shown to also explain the temperature increase at Jupiter [Ng et al., J. Geophys. Res., 123, 6611 (2018)] and Saturn [Neupane et al., J. Geophys. Res., 126, e2020JA027986 (2021)]. We have developed this turbulent heating model further [Ng et al., Geophys. Res. Lett., 49, e2021GL096662 (2022)] by combining effects from both diffusion and advection. The combined model resolves the physical consistency requirement that diffusion should dominate over advection when the radial flow velocity is small and vice versa when it is large. Comparisons with observations show that previous agreements using the advection only model are still valid for larger radial distance. Moreover, the additional heating by including diffusion for smaller radial distance results in a faster increase of the temperature than predicted by the advection only model. New results from this model based on the latest Juno data will be presented.

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Case study of Ganymede's footprint location shifts in respond with the volcanic eruptions at Io and the solar wind compression

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We present here a study of the latitudinal variations of the location of Ganymede's footprint (GFP) observed by the Hubble Space Telescope (HST) in 2007 and 2016. We assess the variation of GFP locations based on both internal and external factors, which are 1) fluctuations of the mass outflow rate (M) of the magnetospheric plasma originating from Io's volcanic activity and 2) solar wind variations, respectively. The plasma density inside Jupiter's magnetosphere increases due to the volcanic material on Io resulting in the stretching of magnetic field lines, which affects the equatorward shift of GFP. Meanwhile, the solar wind compression affects the decreased size of the magnetosphere, resulting in the poleward shift of GFP. Deviations of GFP location are assessed by comparison with the Ganymede mapped path by JRM33 (Connerney et al.,2022) and with the average path by Bonfond et al., 2017. We focus in particular on four epochs for which there are observations of the GFP with similar System III longitude: 1) DOY 054 and DOY 068 (February - March 2007), 2) DOY 132, DOY 154, and DOY 161 (May - June 2007), 3) DOY 178 and DOY 199 (June - July 2016), and 4) DOY 148 and DOY 155 (May - June 2016). We compare the observation with the magnetodisc model (Nichols et al., 2015) by considering the variation of the hot plasma parameter (Kh) and M to the field line mapping in Jupiter's ionosphere for the magnetosphere size of 80 RJ and 50 RJ (during the compression). We found that the observational results are consistent with the positions mapped by the magnetodisc model. In addition, the modelled result shows that the compression of the magnetosphere could relate to the increase of Kh in Jupiter's magnetosphere. The results show that the shifts of GFP in case 1 and case 3 could be affected by the external factor. We also found the slightly equatorward shift in case 4 which could be dominated by the internal factor. Additionally, we presented the special event in case 2 where GFP is located in a similar location, which could be affected by the internal and the external factors at the same time.

Magnetosphere-ionosphere coupling at Jupiter during Juno's Prime mission

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We study magnetosphere-ionosphere coupling at Jupiter during the Juno prime mission, considering magnetic field observations from Juno's Perijoves 1-32. We compare the azimuthal magnetic field and the associated determination of the Jupiter's ionospheric meridional Pedersen current, with predictions from a model of magnetosphere-ionosphere coupling developed at the University of Leicester. We find that the Leicester model closely predicts the magnitude of the residual azimuthal field component of the field across the middle and outer magnetosphere regions, and across the tail. However, we highlight two areas of discrepancies between the model and the data. On field lines mapping to the outer magnetosphere region, the model predicts an increase in the magnitude of the Bphi component of the magnetic field with ionospheric colatitude, whilst we observe a decrease. This could suggests that the community needs an updated ionospheric angular velocity flow model for the Juno era. Furthermore, we do not observe the predicted upward-directed current at the boundary between the outer magnetosphere and field lines mapping to the tail. Currently the model includes a constant ionospheric conductivity. We suggest that the model might be improved by considering a variable ionospheric conductivity. Finally, we produce maps of meridional ionospheric currents and discuss the variation of ionospheric currents with local time.

Quasi-Static Acceleration Regions as the source of Bi-Directional Electron Beams at Jupiter

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Particle precipitation at Jupiter is responsible for the most powerful aurora in our solar system. If charged particles are accelerated along the planets magnetic field at high-latitude, they can precipitate into the atmosphere, interacting with the atmospheric constituents, and resulting in auroral emission. The generated aurora depends on the type of precipitating particle, its energy, and the atom it interacts with in the atmosphere.

At Earth, there has been significant research into double layers (also known as quasi-static acceleration regions, or field-aligned potentials) as a mechanism for charged particle acceleration in the high-latitude auroral regions. Double layers are characterised by an ordering of plasma into adjacent layers of equal and opposite charge, which results in sharp gradient in the electric field - the acceleration region. Although short lived phenomena, these acceleration regions can be inferred in spacecraft data through the presence of inverted-V structures, field aligned acceleration, and kilovolt to megavolt potentials. Although well studied at Earth, few double layer signatures have been detected at Jupiter by the Juno spacecraft.

Using a 1-D spatial, 2-D Vlasov model, we examine high-latitude field lines connected to Jupiter's auroral regions, in order to examine the impact of double layers. Taking advantage of model parallelisation, the use of a high-performance computing system, and by examining a reduced section of the field line, we can calculate density and potential profiles along the field line, and how they evolve over time. We enforce the formation of a double layer, and thus, an acceleration region, close to the planet, by holding the ionospheric end of our model at a fixed potential. In the present investigation, we focus on the upward current region.

Our results indicate that the repeated collapse and reformation of the double layer, is responsible for intense mono-energetic electron beams, which are sourced from Jupiter itself. The double layers are short lived phenomena, but due to their idealised treatment, they quickly reform. These resultant beams travel in both directions from the maximum spatial extent of the acceleration region - towards the outer magnetosphere and towards the ionosphere, where the electrons can precipitate. Such a result has significant implications: firstly, it offers an explanation to the repeated detection of upward travelling electron beams observed by the Juno spacecraft. Moreover, it explains the absence of double layers observed by Juno - they are short lived phenomena, lasting less than a second in an idealised scenario, and extend a maximum distance of 2.5 RJ along the high-latitude magnetic field. Lastly, our model indicates that electrons which originate from Jupiter contribute a significant amount to the overall electron precipitation population.

Revealing the local time structure of Alfvén radii and travel times in the Jovian Magnetosphere

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Plasma in the Jovian magnetosphere requires angular momentum transfer to be brought towards corotation with Jupiter's ionosphere. This is facilitated by Alfvén waves. However, past the Alfvén radius, the radial velocity of the plasma is greater than the Alfvén velocity, such that the plasma becomes decoupled from the ionosphere. Jupiter's middle magnetosphere is often assumed to be axially symmetric, however, studies have shown significant local time asymmetries to be present in the magnetic field data (e.g. Vogt et al. [2011], Lorch et al. [2021]). Previous estimates of the Alfvén radius location did not account for such local time asymmetries. Here we show that the location of Jupiter's Alfvén radius varies strongly with local time. We find a minimum Alfvén radius of 30 RJ at midnight and, most interestingly, that no Alfvén radius within 60 RJ between 08 LT and 20 LT. This implies that plasma can become decoupled at in the midnight-dawn sector while still orbiting Jupiter, and then enter a region where re-coupling is possible. Additionally, Alfvén travel times for distances greater than 40 RJ allow plasma to move between different regions of radial current density before having momentum transferred. The implication is that the angular momentum supplied would no longer be appropriate to the local conditions of the rotated plasma, leading to less efficient magnetosphere-ionosphere coupling.

A Novel Source of Radiation Belt Particles at Jupiter

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The discovery of polar energetic neutral atoms (ENAs) at Jupiter leads us to revisit a previous speculation that they might be a source of radiation belt particles. The scenario would be that some fraction of the ENAs produced in the auroral zone become re-ionized in time to become trapped on closed radiation belt field lines, thus providing a source of keV-MeV particles without the need for additional energization processes. In this presentation we will introduce the suggested process and discuss whether it might provide a significant additional source of radiation belt particles.

Magnetic field fluctuations in Jupiter's magnetosphere: GAMERA model and Juno data comparison

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The ability to quantify and understand magnetic field fluctuations in Jupiter's magnetosphere is an important basis for further understanding transport processes and magnetodisc structure. The Juno spacecraft has a polar orbit around Jupiter, moving farther longitudinally from dawn to dusk as each orbit progresses, this trajectory allows us a look at the magnetic field properties in the dawn, midnight, and dawn/midnight sectors. Recent Grid Agnostic MHD for Extended Research Applications (GAMERA) global simulations of Jupiter's magnetosphere [Zhang et al., 2021] suggest that the dawnside magnetosphere is characterized by closed magnetic field lines that either corotate with the planet in the form of the magnetodisc, or map to large distances along the dawn-tail flank region and, therefore, do not appear to corotate. To test the validity of the modeled magnetic field topology, we quantified magnetic field fluctuations as functions of distance from the centrifugal equator plane [Phipps and Bagenal, 2021], local time (i.e., by Juno orbit) and radial distance. In various spatial regions we examined periodicities due to magnetic field fluctuations on two time-scales. The time-scale from 1-60 minutes may be associated with eigenoscillations of the magnetodisc resonant cavity. The time-scale from 1-10 hours could be related to internally (e.g., magnetodisc structure and Vasiliunas tail reconnection) vs. externally driven periodicities (e.g, Kelvin-Helmholtz waves). Observations made will then be compared to analysis done on the GAMERA global simulation of Jupiter's magnetosphere.

Jupiter's low-altitude auroral zones: Fields, particles, plasma waves, and density depletions

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The Juno spacecraft's polar orbits have enabled direct sampling of Jupiter's low-altitude auroral field lines. How various auroral signatures can be reconciled across all datasets and fit into the bigger picture of Jupiter's auroral generation mechanisms remains to be established. Jupiter's main aurora has been classified into distinct zones , based on repeatable signatures found in energetic electron and proton spectra. We combine fields, particles, and plasma wave datasets to analyze Zone-I and Zone-II, which are suggested to carry the upward and downward field-aligned currents, respectively. We find Zone-I to have well-defined boundaries across all datasets. H+ and/or H_3^+ cyclotron waves are commonly observed in Zone-I in the presence of energetic upward H+ beams and downward energetic electron beams. Zone-II, on the other hand, does not have a clear poleward boundary with the polar cap, and its signatures are more sporadic. Large-amplitude solitary waves, which are reminiscent of those ubiquitous in Earth's downward current region, are a key feature of Zone-II. Alfvénic fluctuations are most prominent in the diffuse aurora and are repeatedly found to diminish in Zone-I and Zone-II, likely due to dissipation, at higher altitudes, to energize auroral electrons. Finally, we identify sharp and well-defined electron density depletions, by up to two orders of magnitude, in Zone-I, and discuss their important implications for the development of parallel potentials, Alfvénic dissipation, and radio wave generation.

Closed Fluxtubes and Proton Conics in Jupiter's Polar Cap

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We present a discrete observation of diverse plasma populations and evidence of closed magnetic topology at Jupiter's polar cap. Two distinct populations of protons are observed over Jupiter's southern polar cap: a 1 keV core population and 1-300 keV dispersive conic population at 6-7 RJ planetocentric distance. We find the 1 keV core protons are likely the seed population for the higher-energy dispersive conics. Contemporaneous observations of whistler-mode emissions indicate the presence of outward field-aligned electrons, suggestive of parallel electric fields. We find transient wave-particle heating in a pressure-cooker process is likely responsible for the proton acceleration. The plasma characteristics and composition during this period show that Jupiter's polar-most field lines can be topologically closed, with conjugate magnetic footpoints connected to both hemispheres. Finally, these observations demonstrate energetic protons can be accelerated into Jupiter's magnetotail via wave-particle coupling.

How windy are Uranus' aurorae?: Measuring ionospheric ion flows and extending the cartography of the infrared aurorae at Uranus

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Measurements of H_3^+ at Uranus for 30 years have but recently shed light into the morphology of Uranus's infrared aurora. Observations in late-2006 by Thomas, et al., in review showed enhanced emissions in the northern hemisphere similar in latitudinal range to the northern aurora (Herbert and Sandel, 1994). Surrounding temperatures confirmed these enhancements were not thermally driven, and with elevated column densities it was surmised these emissions were the first near-infrared auroral observations of the northern infrared aurora. Similarly, a strong dawn enhancement in infrared emissions was observed in mid-2016 by Melin, et al., 2019. These emissions were localised to latitudes associated with southern aurora but were unable to confirm if the event was auroral as no physical parameters (temperature, ion density or ion flows) were investigated. Together these campaigns were unable to fully chart the whole aurorae and so the mystery of the complete auroral morphology at Uranus has remained largely unanswered.

Our recent research has taken these investigations and further extended our cartography of the upper atmosphere of Uranus, by surveying observations over the last two decades. To confirm if enhancements are auroral, additional surveys of H_3^+ temperature, column density and in some campaigns, the first observed ionospheric ion flows at Uranus have been produced. The study of ion flows at Jupiter (Stallard, et al., 2016 and Johnson, et al., 2017) and Saturn (Stallard, et al., 2019 and Chowdhury, et al., 2022) allowed a greater understanding of the ionosphere-magnetosphere connectivity at these planets, and so using ion flow results as a definitive indicator of auroral activity we can begin to understand the ionosphere-magnetosphere interactions at Uranus. We present further analysis of observations presented by Melin, et al., 2019 (including an extra 2 days of analysis not previously published) with particular focus on these ion flows. Initial findings present significantly varied ion flows at auroral latitudes showing a glimpse of the ion transport systems at the planet's aurora. We also observe an enhanced H_3^+ intensity on the dusk limb of Uranus, as was first seen in Melin, et al., 2019, suggesting the lifetime of H_3^+ is far longer than expected.

These initial ion flow findings at Uranus present a unique avenue of investigation of auroral detection at Uranus and with the use of high spectral resolution instruments, we hope this tool will strengthen upcoming JWST observations by surveying and drawing out the first complete auroral structures across Uranus.

Developing shared computing code for the MOP community

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We report on recent efforts to provide the MOP community with shared computer code to perform common calculations that can aid in planning scientific observations and data analysis. Last year we developed code that calculates the magnetic field in Jupiter's magnetosphere using the CAN current sheet model updated for the Juno era (Connerney et al., 2020) and the JRM09 internal field (Connerney et al., 2018). Links to our IDL, MATLAB, and Python code can be found at https://lasp.colorado.edu/home/mop/missions/juno/community-code/. We are now finalizing code to calculate the new JRM33 internal field model (Connerney et al., 2022) and other pre-Juno internal field models. Here will we give a status update on our work and discuss lessons learned so far. We welcome input from the community on what resources they would find helpful and we encourage others to contribute to a shared code repository.

Prospect of connection between Jupiter's main emission power and the satellites' footprint brightness

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Jupiter's auroral main emission and satellites' footprints, for example, the main Alfvèn wing spot (MAW) of Io, have a strong connection with the Alfvèn waves generated in the magnetosphere. However, the locations in the magnetosphere relating to the origins of the auroral particles responsible for those auroral features are much different. While the main emission is mapped to the location approximately at 20-30 RJ, close to the open-close field line boundary, the satellites' footprints (the main spot) are tightly connected to the Alfvènic perturbation taking place in their vicinities. The FUV images taken by two instruments, the Solar Blind Channel (SBC) of the Advanced Camera for Surveys (ACS) and STIS Multi-Anode Microchannel Array detector, onboard the Hubble Space Telescope (HST) during two campaigns, in 2007 and 2016, are chosen to present the cases where the satellite footprints locate at similar locations in the ionosphere. In addition, the main emission power is determined based on the boundary of the average main emission given by Nichols et al. (2017). The main emission powers observed at similar Jupiter's CMLs are especially focussed to ensure a similar configuration of the auroral feature, with respect to the magnetic field structure. While the connections with the auroral power with the solar wind dynamic pressure, velocity, and the interplanetary magnetic field were extensively studied by Clarke et al. (2009) and Nichols et al. (2009, 2017a, 2017b), the possibility of correspondence between main emission power and the satellite's footprint brightness at different times will be investigated.

Energetic electron spectra at L<20 in the Jovian magnetosphere: Observations from Galileo and Juno

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It has been shown that down to L 20 and around the magnetic equatorial plane in the Jovian magnetosphere, adiabatic heating associated with radial transport is the major acceleration process for energetic and relativistic electrons. However, the situation at L<20 is less constrained, as wave-particle interactions and the corresponding non-adiabatic acceleration and losses become effective. If radial transport continues to dominate, especially that synergistically driven by injections and a convective electric field, its dependence on local time (LT) and electron energy would leave imprints on the energy spectra distribution. We exploit the flux measurements of 10s to 100s of keV electrons at L<20 made by the Galileo orbiter throughout the mission, and by the Juno orbiter from 2016 to 2020. For each individual orbit of Galileo, we search for its intersection with Juno's trajectory in (LT, magnetic latitude, L-shell) grids. We then normalize the spectra in the intersection grids to compare between the two orbiters the spectral features of cutoff energy and power law exponents. We also compare the spectral indices during the inbound segment of each Galileo orbit with those during the outbound one, and apparent differences are observed. It is necessary to distinguish between the contribution on such differences from steady-state LT configuration and from time variations. The spectra distribution of individual orbits are accordingly evaluated against the average distributions over year-long and mission-long periods.

Abstracts - Poster session 2

Influence of Europa's Time-Varying Electromagnetic Environment on Magnetospheric Ion Precipitation and Surface Weathering

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We combine the electromagnetic fields from a hybrid model with a particle-tracing code to calculate the time-varying spatial distribution of magnetospheric ion flux onto the surface of Jupiter's moon Europa. The electromagnetic fields at Europa are perturbed by the sub-alfvénic interaction of the moon's ionosphere and induced dipole with the magnetospheric plasma. These perturbations substantially modify magnetospheric ion trajectories at all energies. We calculate spatially resolved surface flux maps of thermal and energetic ions for various distances between Europa and the center of Jupiter's magnetospheric plasma sheet. The upstream ion distributions are constrained through in-situ particle data from the Galileo and Juno spacecraft. These maps are then combined to obtain the average distribution of magnetospheric ion surface flux over a full synodic rotation. Our results show that the draping and pileup of the magnetic field reduce ion flux onto Europa's trailing hemisphere by several orders of magnitude, while a significant number of the incident ions are deflected onto the leading hemisphere. Taking into account the deflection of energetic ions in the draped electromagnetic fields shifts the region of minimum energetic ion surface flux from Europa's wakeside equator to its ramside equator. This generates an inverted bullseye pattern of energetic ion flux centered at the trailing apex. Despite drastic changes to the morphology of the ion surface flux when the alfvénic plasma interaction is included, we still find a strong correlation between variations of sulfuric acid concentration observed across Europa's surface by Galileo and our modeled sulfur influx pattern.

First Steps Towards a New Saturn Ionosphere Model Including Ring-Planet Coupling and Electrodynamics

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The Cassini Grand Finale revealed that there is still much that we do not understand about Saturn's upper atmosphere. In-situ observations reveal highly complex coupling between the planetary atmosphere and rings and inter-hemispheric electrodynamic coupling at latitudes that are magnetically connected to the intra D-ring region in the magnetosphere. Current Saturn models are ill-suited to treating electrodynamics and ring-planet interactions at Saturn. Thus, we adapt SAMI, a well-known terrestrial ionosphere model that is flux-tube based and already includes electrodynamics, to Saturn, with the aim of using it in conjunction with existing Saturn models such as the STIM-GCM (Saturn Thermosphere Ionosphere Model) to decipher the long-standing unexplained morphologies in Saturn's ionosphere and investigate the ring-atmosphere coupling and electrodynamics revealed by the Cassini end-of-mission data. We will present initial results having adapted SAMI to Saturn, showing the full extent of the atmospheric chemistry and model capabilities at present. We will discuss future directions of development towards the construction of the new model capable of resolving the complex ring-atmosphere coupling and electrodynamics, and the possibility of adapting this model to other planets.

MULTIPLE IMPACTS OF ICMES ON THE SATURN-TITAN SYSTEM: T96 OBSERVATIONS REVISITED

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Titan is Saturn's largest moon and in quiet-time conditions, it orbits around its parent planet just within the margins of its magnetosphere. Saturn's magnetopause position is controlled by the solar wind pressure but also by the planet's internal magnetospheric processes involving ionospheric currents and plasma from its moons and rings.

With more than 120 close flybys between 2004 and 2017, the Cassini spacecraft characterized Titan's plasma environment. Out of these, the so-called T96 flyby on December 1, 2013, stands out as the only one where Cassini found Titan in the supermagnetosonic and super-Alfvénic solar wind. Consistently, the formation of a collisionless bow shock and a Mars-like induced magnetosphere was observed around the moon (Bertucci et al., 2015). This one-of-a-kind encounter occurred because of compression of Saturn's magnetosphere resulting from the arrival of at least one fast ICME, whose associated SEP were previously reported (Roussos et al., 2018).

In this work, we try to provide a more complete description of the plasma environment around T96 by [1] Identifying and following the ICMEs that were responsible for Saturn magnetospheric compression from 1 to 10 AU, [2] following the evolution of the location of Saturn's magnetospheric boundaries as they respond to the impact of the ICMEs, and [3] analyzing the effects of Saturn's magnetospheric dynamics on Titan's induced magnetosphere by looking at the properties of the piled-up magnetic field including fossil fields.

To achieve this, we used magnetic field and particle data from Cassini's MAG, MIMI, LEMMS, and RPWS to study the plasma around the Saturn-Titan system, as well as STEREO to trace back the space weather events. We identified the impact of two interplanetary shocks and associated ICMEs near Saturn-Titan, one prior to Cassini's closest approach to the moon and responsible for the initial magnetospheric compression, and the other one shortly after. Combined, these events caused an unprecedented compression of the Kronian magnetopause that left Titan outside this boundary for (at least) 5 days, reaching a stand-off distance of 13-15 Rs and magnetosheath values of up to 12 nT against a solar wind pressure of 0.1-0.3 nPa. In addition, we found that the accumulated magnetic pressure in Titan's induced magnetosphere was compatible with the solar wind dynamic pressure during the periods of highest plasma compression.

Evidence for H2 and Constraints on H2O in Callisto's Atmosphere

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We explore the parameter space for the composition and densities of Callisto's atmosphere with contributions to its H corona from sublimated H_2O and radiolytically produced H_2 using the Direct Simulaton Monte Carlo (DSMC) method. The spatial morphology of the observed H corona produced by photon and magnetospheric electron induced dissociation at eastern elongation is described by tracking the motion of and simulating collisions between the hot H atoms and thermal molecules in Callisto's atmosphere.

Sublimated H_2O produced from the surface ice, whether assumed to be intimately mixed with or distinctly segregated from the dark, non-ice or ice-poor regolith, cannot explain the structure of the H corona. The observation instead suggests the presence of a roughly global source, which we suggest is H_2. Such an atmospheric component is also capable of reproducing the enhanced electron densities observed $\sim$500–2300 km from Callisto's surface by Galileo's plasma-wave instrument. Thus, we provide the first evidence of H_2 in Callisto's atmosphere.

Comparison with the morphology of the observed H corona allows us to estimate an upper limit for the *ab initio* surface source rate of H_2: $\sim 2\times10^{28}$ s^{-1}. This value is the required source rate to reproduce the H_2 neutral atmosphere with a surface density of $\sim10^8$ cm^{-3}, which in turn can reproduce the structure and abundance of the observed H via photodissociation. However, we show that this source rate and surface density can be reduced when including additional sources of H, such as electron impact-induced dissociation. Future work will look to include interactions with an ionosphere that can produce even more H, namely $H_2^+ + e \rightarrow$ H + H, thereby possibly further reducing the amount of H_2 required. The H_2 escape rates as well as estimated atmospheric lifetimes are used to obtain initial estimates for a neutral H2 torus co-rotating with Callisto. We also place a rough upper limit on the peaks in H_2O density ($\lesssim 10^8$ cm^{-3}) and sublimation flux ($\lesssim 10^{12}$ cm^{-2} s^{-1}), which are 1–2 orders of magnitude less than that assumed in previous models of Callisto's atmosphere. Based on these results, the role of H_2 versus H_2O as a source of the H corona needs re-examining at Europa and Ganymede.

Effect of an interplanetary coronal mass ejection on Saturn's radio emission

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The Saturn Kilometric Radiation (SKR) was observed for the first time during the flyby of Saturn by the Voyager spacecraft in 1980. These radio emissions, in the range of a few kHz to 1 MHz, are emitted by electrons travelling around auroral magnetic field lines. Their study is useful to understand the variability of a magnetosphere and its coupling with the solar wind. Previous studies have shown a strong correlation between the solar wind dynamic pressure and the SKR intensity. However, up to now, the effect of an Interplanetary Coronal Mass Ejection (ICME) has never been examined in detail, due to the lack of SKR observations at the time when an ICME can be tracked and its different parts be clearly identified. In this study, we take advantage of a large ICME that reached Saturn mid-November 2014 [Witasse, 2017]. At that time, the Cassini spacecraft was fortunately travelling within the solar wind for a few days, and provided a very accurate timing of the ICME structure. A survey of the Cassini data for the same period indicated a significant increase in the SKR emissions, showing a good correlation after the passage of the ICME shock with a delay of about 13 hours and after the magnetic cloud passage with a delay of 25-42 hours.

Constraints on Europa's subsolar atmosphere based on a joint analysis of HST spectral images and Galileo magnetic field data

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In this study, we constrain Europa's tenuous atmosphere on the subsolar hemisphere by combining two sets of observations: oxygen emissions at 1304 A and 1356 A from Hubble Space Telescope (HST) spectral images, and Galileo magnetic field measurements from its closest encounter, the E12 flyby. We describe Europa's atmosphere with a three-species model: global $\mathrm{O_2}$ and O, and localized $\mathrm{H_2O}$ present as a near-equatorial plume and as a stable distribution concentrated around the subsolar point on the moon's trailing hemisphere. First, we find that several column densities of these neutral gases fit the observed ratio of OI 1356 A to OI 1304 A emissions from Roth (2021) within its uncertainties. We then apply a three-dimensional magnetohydrodynamic (MHD) code to characterize the interaction of the moon and its atmosphere with the Jovian magnetosphere. Our combined modelling based on the oxygen emission ratio profile from Roth (2021) and on magnetic field data allows us to derive constraints on the density and location of $\mathrm{O_2}$ and $\mathrm{H_2O}$ in Europa's atmosphere. Finally, we assess the robustness of our results by performing a parameter study for the location of the $\mathrm{H_2O}$ atmosphere and the electron impact ionization rate. We demonstrate that 50% of the $\mathrm{O_2}$ and $\mathrm{H_2}O$ abundances from Roth (2021) are required to jointly explain both the HST and Galileo measurements. The column densities of $1.24 \times 10^{18}\mathrm{m}^{-2}$ and $1.47 \times 10^{19}\mathrm{m}^{-2}$ for $\mathrm{O_2}$ and $\mathrm{H_2O}$, respectively, derived by our analysis however still lie within the uncertainties of Roth (2021). Our results provide additional evidence for the existence of a stable $\mathrm{H_2O}$ atmosphere at Europa.

Comprehensive Observations of Magnetospheric Particle Acceleration, Sources, and Sinks (COMPASS): A Dedicated Jovian Radiation Belt Mission to Unlock the Secrets of the Solar System's Greatest Particle Accelerator

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Radiation belts are found at Earth, Jupiter, Saturn, Uranus, and Neptune, which combined represent all of the sufficiently sized and magnetized planets in the Solar System. This fact is quite remarkable, since it implies that particle trapping and acceleration in magnetospheric systems is potentially a universal process in planetary magnetospheres and likely beyond to other astrophysical systems. Of these known radiation belt systems around the Sun, Jupiter reigns supreme. The Jovian magnetosphere traps - and presumably accelerates - relativistic ions up to multiple giga-electronvolts and relativistic electrons up to >50 mega-electronvolts. Such high energy thresholds and intensities of trapped radiation render Jupiter more in line with astrophysical systems, like the magnetospheres of pulsars and brown dwarfs, where electron synchrotron emissions represent a significant loss process that can be observed remotely from Earth. For this and several other reasons, Jupiter is an ideal stepping stone for bridging the knowledge gaps between Earth, planetary magnetospheres in general, and astrophysical systems. Despite several missions having been dedicated to studying different aspects of the Jovian planetary system, no observatory has yet been fully dedicated or sufficiently instrumented to understanding why exactly Jupiter in many ways acts as the Solar System's greatest particle accelerator. Understanding i) which acceleration processes are unique to a system and why, ii) which processes are universal, and iii) how those processes scale with the properties of the system are the fundamental science drivers for COMPASS.

COMPASS is a mission concept under development in advance of and for consideration during NASA's upcoming Heliophysics Decadal Survey. COMPASS is ideally instrumented for radiation belt physics, with a unique and unprecedented suite of instruments covering i) particle species from thermal plasma to 10s of MeV electrons and relativistic protons and heavy ions; ii) comprehensive magnetic and electric fields and waves; and iii) X-ray imaging. Combined, that suite will enable the COMPASS science team and greater scientific community to test existing hypotheses and make new discoveries of how Jupiter's radiation belts are sourced, accelerated, and lost within such a complex system. Jupiter's space environment is an ideal natural laboratory for enabling new discoveries and breakthrough progress on the topic of unique and universal radiation belt physics, particularly when put into context with results from previous Jovian missions (e.g., Juno, Galileo) and Van Allen Probes and other radiation belt missions at Earth.

In this presentation, we introduce the science and conceptual design of COMPASS: a dedicated radiation belt mission to Jupiter with the primary goal of exploring the distinctive and universal acceleration, source, transport, and loss processes that drive the most intense radiations belts in the Solar System.

Analysis of the sodium jets detected on Io with TRAPPIST

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Io is the solar system's most volcanically active body. This volcanic activity results in the ejection of material into Io's atmosphere. This material then escapes from the atmosphere to form various structures in the Jovian magnetosphere. These include the plasma torus and clouds of neutral particles. The physical processes involved in the escape of particles are not yet fully understood. Indeed, the study of the atmosphere and the volcanoes in the one hand and the study of the plasma torus on the other hand, lead to two different conclusions regarding the origin of the variability of the torus plasma content. Observations of Io, with a particular focus on the neutral sodium clouds, which are relatively easy to detect thanks to the D-doublet of sodium, could help solve the mystery surrounding the escape of those particles.

Observations with the TRAPPIST telescopes and their sodium filter have been carried out during 17 nights from December 2014 to April 2015 and 30 nights from April to October 2021. On those images, a particular attention was paid on the sodium jet, one of the neutral sodium clouds. The images from those two periods have been processed to highlight the presence of sodium in order to determine the presence or not of the sodium jet. From the 17 nights of the 2014-2015 period, the sodium jet has appeared for four nights, and it as appeared for three nights for the 2021 period. Among the images where the jet can be seen, it is visible that it does not always have the same size and brightness from one observation to another. The current goal is to establish the physical quantities, as the brightness, the size and the orientation of the jet that are observed. So far it can be established that the jet variation does not, or not only, depend on the phase angle of Io.

Moreover, we will show early results from a model of the plasma torus aimed at characterizing the influence of the variation of the sodium jet on it.

Io's Electron Beams

V. Dols

LASP/University of Colorado, Boulder

At Io, the Galileo spacecraft (GLL) detected intense energetic electron beams aligned along Jupiter's magnetic field in the wake, on the flanks and over the poles of the moon. The combination of the GLL PLS and EPD observations shows a continuous energy distribution between 100 eV and 150 keV, with a total energy flux 4 erg/cm2/s [Williams+, 1999; Frank and Paterson, 1999; Mauk+, 2001]. Like auroral electrons on Earth, each electron of the beam is capable of many ionizations along its path through the atmosphere, losing a few tens of eV per ionization. The beam ionization is important to estimate the local plasma supply close to Io, as they are probably the cause of the large electron density observed in the wake of Io along the Galileo J0 flyby (30,000 cm-3) [Saur+, 2002]. Their contribution to the ionization will also constrain the atmosphere distribution where the beams are present. As most ions are molecular SO_2^+, they will quickly recombine in fast atomic S and O neutrals, which will escape the system. We propose to compute the effect of field-aligned electrons on Io's plasma production based on Rees, 1989 empirical formulation and include this ionization process in a multi-species chemistry model of the plasma/atmosphere interaction [Dols+, 2012].

Latitudinal Variation of Io's Sublimation Atmosphere Explained by a Model Considering Thermal Inertia

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Whether and how strongly Io's SO_2 atmosphere is mainly driven by volcanic outgasing or the sublimation of SO_2 surface frost is still debated. Due to its high surface temperature dependence, the sublimation supported part of the atmosphere is assumed to collapse at night and when Io is in eclipse by Jupiter. Furthermore, the atmosphere is observed to be thicker in equatorial regions with decreasing column densities towards the poles. Here we present a time dependent surface temperature model including the effect of thermal inertia. Analyzing the conductive heat transfer from Io's surface towards its interior and vice versa, which is mainly determined by the thermal diffusivity α, allows us to show that observations can be well explained by assuming a sublimation dominated atmosphere. Simulations show that $\alpha = 3.1 \times 10^{-6}$ m^{2}s^{-1} yields an averaged atmospheric SO_2 column density decreasing from 10^{16} to $\sim 2.5 \times 10^{14}$ cm^{-2} from the equator to the poles. Further modeling indicates that assuming a thermal diffusivity lower by a factor of 12.5 leads to a maximum surface temperature (maximum atmospheric column density) shifted longitudinally by 30° against the sub-solar point.

Emission of Energetic Neutral Atoms at Callisto and Europa

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Based on a combination of hybrid simulations and energetic particle tracing, we model the emission morphology of energetic neutral atoms (ENAs) that are generated by the interaction of the atmospheres around Callisto and Europa with energetic ions from Jupiter's magnetosphere. Since the trajectories of the energetic parent ions are strongly affected by the local electromagnetic field perturbations near Callisto and Europa, the ENA emission morphology contains an admixture of information on the particle distribution functions and the draped magnetic field configurations near both moons. Thus, the ENA emission pattern can be regarded as a snapshot of the moons' plasma interaction regions on a global scale. We apply the hybrid code to compute the three-dimensional structure of Callisto's and Europa's electromagnetic environments. By tracing the motion of several billions of energetic parent ions and their interaction with the moons' atmospheres, we then compute maps of the ENA flux through a concentric sphere around each moon. To isolate the influence of the draped fields near both moons, these ENA emission maps will be compared against the modeled emission patterns for homogeneous electromagnetic fields. The results allow to constrain the diagnostic potential of ENA images to characterize the moons' perturbed electromagnetic environments as a whole, in addition to local plasma and magnetic field observations along a spacecraft trajectory.

The satellite auroral footprints at Jupiter: A Juno perspective

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Jupiter's satellite auroral footprints are a consequence of the interaction between the co-rotating iogenic plasma and the Galilean moons. Since the disturbance caused by the presence of the moons in the plasma flow propagates along the field files in the form of Alfvén waves, the physical positions of the moons are magnetically connected to their respective footprint. The accurate determination of the footprint positions therefore provides an important physical reference point in Jupiter's auroral regions with respect to where they map in the magnetosphere. Over a decade of auroral footprint observations with the Hubble Space Telescope provided a first view of the footprint paths of Io, Europa and Ganymede, though with limited coverage in several SIII longitude ranges. More specifically, HST observations did not cover the 270°-90°(north) and 140°-290°(south) longitude ranges for the Ganymede and Europa footprints, and only provided a sparse coverage of the Io footprint there. Juno's polar and elliptical orbit around Jupiter now provides the opportunity to complete the picture and we present the work revising the satellite footpaths for Io, Europa and Ganymede recorded during Juno's prime mission.

The effect of perturbed fields, charge exchange and plumes on energetic proton depletions during the Galileo flybys of Europa

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The flux of energetic ions (protons, oxygen and sulfur) near the Galilean moons of Jupiter were measured by the Energetic Particle Detector (EPD) on the Galileo mission (1995 - 2003). During flybys of Europa such as E12, E17, E25A and E26, decreases of the energetic ion flux, of several orders of magnitude, were identified.

To interpret the ion losses in the EPD data, we conducted a Monte Carlo particle tracing simulation. The expected fluxes of the energetic ions are simulated under different scenarios including those with and without an atmosphere or plume, and magnetic field perturbations. We investigate the cause of the losses by comparing the simulated flux to the EPD data.

Regarding potential plume signatures during flybys E26 and E12 we report the following:

- In Huybrighs et al., 2020 we proposed that depletions (115–244 keV) are caused by perturbed electromagnetic fields combined with atmospheric charge exchange and possible plumes. One depletion feature identified as a plume signature was shown to be an instrument artifact (Jia et al., 2021, Huybrighs et al., 2021). Despite that, here we emphasize that Huybrighs et al., 2020 demonstrates that plumes can cause proton depletions and that these features should be sought after in the data. Furthermore, the conclusions on the importance of perturbed electromagnetic fields and atmospheric charge exchange on the depletions are unaffected. However, the artifact reported by Jia et al., 2021 prevents us from confirming or excluding that the detected depletion is caused by a plume (Huybrighs et al., 2021).

- We also discuss proton depletions during flyby E12 at energies 115–244 keV and 540–1,040 keV, coinciding in time with the plume detection reported by Jia et al., 2018. These depletions are not affected by the artifact and are best reproduced by a model with a plume located at the location from Jia et al., 2018. While no charge exchange occurs at 540–1,040 keV the depletions are best reproduced incorporating the field perturbations assuming that these indeed originate from a plume. Regarding flybys E17 and E25A (a segment of the Galileo orbit I25) which traversed the Alfvén wings we discuss the following:

- We report energetic proton depletions coinciding with the Alfvén wing encounters during these flybys.

- We find that the inhomogeneous fields associated with the Alfvén wing strongly affect the depletions of energetic protons. Whereas in the homogeneous case the depletion is focused on a narrow pitch angle range and has no structure, the depletion in the inhomogeneous case represents a wider and complex structure in pitch angle and along the trajectory. Furthermore, we also find that the induced dipole alters the structure of the depletion, most strongly so in the case of E25A, by shifting the minimum of the depletion along the trajectory.

- Finally, we compare the simulations to the measured energetic proton time series. We find that the simulations with inhomogeneous fields describe the data qualitatively better than the homogeneous case.

- This work emphasizes that energetic proton measurements could offer an additional way to probe the (sub-Alfvénic) moon-magnetosphere interaction from large distances of several moon radii away, which is of particular importance for interpreting measurements from data deprived moon encounters in the solar system.

A statistical view of the response of Saturn's radio emissions to solar wind driving

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Saturn has several components to its radio emission which can change in response to varying solar wind and magnetospheric conditions. These radio components include the Saturn Kilometric Radiation (SKR), a cyclotron maser instability-generated emission which occasionally displays Low Frequency Extensions (LFEs); and the Saturn narrowband emissions, typically below 40 kHz, which include n-SMR (narrowband Saturn Myriametric Radiation) and n-SKR. We utilise a list of all magnetopause and bow shock crossings by Cassini during its 13-year tour of the Saturn system [Jackman et al., 2019] to select out times when the Cassini radio (RPWS) instrument was sampling Saturn's radio emissions from the solar wind, magnetosheath and outer magnetosphere regions. We explore the hypotheses that the SKR is a good proxy for solar wind driving, and that narrowband emissions may link to dramatic magnetospheric reconfiguration events. We track the timeline between solar wind compressions observed during extended solar wind intervals and the occurrence of out-of-phase SKR bursts and LFEs (selected using a bespoke tool from Empey et al., 2021). Furthermore, we use boundary crossings in concert with magnetopause and bow shock models [Kanani et al. 2010; Went et al. 2011] to infer upstream solar wind dynamic pressure (DP) and pinpoint rapid large changes in DP which may indicate strong compressions - and their associated link to distinct radio signatures.

First Glimpse at Thermal Ion Properties of Individual Water Group Ions in Saturn's Magnetosphere

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The tectonic activity below Enceladus' surface releases tremendous amounts of neutral water through ice fissures at high speed such that some become gravitationally unbound and are injected to the magnetosphere. Then these neutral plumes are subject to interactions with magnetospheric ions and electrons. Through these physical chemistry interactions, the neutral plume gas becomes dissociated and ionized ultimately creating water group ions such as O+, OH+, H2O+, and H3O+, which eventually populate the entire magnetosphere of Saturn. After the arrival of Cassini spacecraft at Saturn in 2004, water group ions were discovered to be the most dominant magnetospheric ion group at Saturn. However, the plasma properties of the individual species could not be derived easily due to the complexity of the mass spectra of the Cassini Plasma Spectrometer (CAPS) Ion Mass Spectrometer (IMS). We are in the process of developing a sophisticated performance model for the CAPS/IMS time-of-flight (TOF) data that employs an advanced forward modeling technique successfully applied to measurements made by the JADE-I sensor aboard the Juno mission (Kim et al., 2020). This model allows us to resolve individual water group mass species more accurately than in the past, enabling us to calculate thermal ion properties such as number density, flow speed, and temperature of individual water group ions for the first time. Here, we will describe the new modeling procedure and present preliminary water group ion composition data to gain new insights into mass transport in Saturn's magnetosphere.

Determining the beaming of Io decametric emissions : a remote diagnostic to probe the Io-Jupiter interaction

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We investigate the beaming of 11 Io-Jupiter decametric (Io-DAM) emissions observed by Juno/Waves, the Nançay Decameter Array and NenuFAR. Using an up-to-date magnetic field model and three methods to position the active Io Flux Tube (IFT), we accurately locate the radiosources and determine their emission angle θ from the local magnetic field vector. These methods use (i) updated models of the IFT equatorial lead angle, (ii) ultraviolet (UV) images of Jupiter's aurorae and (iii) multi-point radio measurements. The kinetic energy E_{e-} of source electrons is then inferred from θ in the framework of the Cyclotron Maser Instability. The precise position of the active IFT achieved from methods (ii,iii) can be used to test the effective torus plasma density. Simultaneous radio/UV observations reveal that multiple Io-DAM arcs are associated with multiple UV spots and provide the first direct evidence of an Io-DAM arc associated with a trans-hemispheric beam UV spot. Multi-point radio observations probe the Io-DAM sources at various altitudes, times and hemispheres. Overall, θ varies a function of frequency (altitude), by decreasing from $75° - 80°$ to $70° - 75°$ over $10 - 40$ MHz with slightly larger values in the northern hemisphere, and independently varies as a function of time (or longitude of Io). Its uncertainty of a few degrees is dominated by the error on the longitude of the active IFT. The inferred values of E_{e-} also vary as a function of altitude and time. For the 11 investigated cases, they range from 3 to 16 keV, with a 6.6 ± 2.7 keV average.

Formation of a tilted plasma wake at Neptune's moon, Triton

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Due to the tilt between the rotational and magnetic axes of Neptune, along with the large orbital obliquity of Triton, the magnetospheric environment along Triton's orbit displays a substantial variability. This variability contributes to an ambient electromagnetic environment that is unlike those encountered by the moons of Jupiter or Saturn. On the one hand, the local magnetic field can at times be perpendicular to the direction of the magnetospheric flow across the moon's surface (as is also the case near moons of the gas giants). In this case, the signatures and perturbations associated with Triton's plasma interaction (e.g., magnetospheric field line pileup and draping, formation of Alfvén wings, and outflow of ionospheric plasma) resemble those observed near Jupiter's moon Callisto or Saturn's moon Titan during the Galileo or Cassini missions. On the other hand, the variability in the magnetospheric fields at times allows the orientation of the magnetic field near Triton to be tilted nearly 45° against the flow direction. In this case, signatures associated with Triton's interaction have never been directly observed and are unique when compared to Jovian and Saturnian moons.

This study uses a combination of hybrid modeling and analytical techniques to investigate Triton's interaction with its ambient magnetospheric environment. We illustrate that when the local magnetospheric field is strongly tilted against the ambient flow direction near Triton, one of the moon's Alfvén wings is tilted into the upstream hemisphere. This generates an unexpected signature near Triton: the magnetospheric flow is deflected toward the moon at a steep angle before being absorbed, thereby generating a wake cavity that is displaced against the direction of the geometric plasma shadow. Along the downstream-facing wing, the flow is directed away from the moon and is therefore unable to refill this wake. Alfvén wing absorption signatures may be common near all ice giant moons and may be detectable during future spacecraft encounters of these objects. Further details and additional results can be found in Liuzzo et al. (2021, JGR Space doi:10.1029/2021JA029740) and Simon et al. (2021, JGR Space, doi:10.1029/2021JA029958).

Flux tube entropy and Flux tube content of the Saturn's Magnetospheres

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The radial transport process in the giant magnetospheres (i.e., Jupiter and Saturn's magnetospheres) requires a net mass radial outward transport, and a two-way magnetic flux transport to maintain the magnetic flux in the inner magnetosphere. The dynamic of such process is mainly determined by the pressure gradient, magnetic field, and centrifugal force, which can be investigated by examining the magnetic flux integral quantities (e.g., flux tube entropy, flux tube content). Those quantities are conserved quantities under the frozen-in assumption. The change of these quantities often indicates the violation of the frozen-in condition (e.g., interchange instability, heating, drift out, etc.). The giant magnetospheres are stabilized by a radially increasing profile of flux tube entropy and destabilized by a radially decreasing profile of flux tube content. The traditional radial transport scenario suggested that the magnetic flux with heavy flux tube content moves from the inner magnetosphere to the outer magnetosphere, stretching the magnetic field into a magnetodisc configuration. Subsequently, magnetic flux with low flux tube entropy generated by magnetodisc reconnection circulates back to the inner magnetosphere. The flux tube entropy analysis suggests that energetic particles dominate the total flux tube entropy in the magnetodisc region, and newly closed field lines generated by magnetodisc reconnection are likely to be transported into the inner magnetosphere. Based on the flux tube entropy constraint, this study uses a steady state magnetodisc model to demonstrate that the radial transport process in Saturn's magnetosphere can also be achieved via middle-latitude double reconnection, driven by a low-latitude interchange instability. This process does not involve significant latitudinal convection of magnetic flux in the ionosphere, nor does it significantly modify the radial flux tube entropy profile. We also found the flux tube content decreases increasing radial distance, which suggests a non-ideal process (presumably magnetic reconnection) occurs during the radial transport process.

UV reflectance spectra of Jupiter's icy moons: Spectral effects of surface processing by Jovian magnetospheric plasma

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At far ultraviolet wavelengths, the reflectance spectra of Jupiter's icy moons appear surprisingly different from those of other icy bodies, including Saturn's icy moons and rings. The spectra of the Saturnian moons contain a sharp absorption edge feature at 165 nm, characteristic of water ice and consistent with laboratory ice spectra, appearing dark at shorter wavelengths and undergoing a sharp increase in reflectance at the position of the H_2O edge. The icy Jovian moons, however, do not exhibit the same sudden reflectance change in the FUV, despite clear evidence for H_2O in the form of diagnostic near-infrared absorption bands. Instead, their reflectance increases gradually with increasing wavelength through the mid-UV. Here, we discuss how surface processing of the Jovian icy moons by Jupiter's magnetospheric plasma may alter their UV reflectance via the introduction of impurities or defects in the ice lattice, or through the production of UV-absorbing lag layers formed by preferential sputtering of volatiles from the ultraviolet sensing depth. We compare disk-averaged FUV (140 - 200 nm) reflectance spectra of Europa, Ganymede and Callisto obtained by the Hubble Cosmic Origins Spectrograph, and search for spectral trends related to differences in the Jovian plasma and the dust environments to which each moon is subjected.

Infrared images of Jupiter Aurora: 5 years of H_3^+ observations at Jupiter

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JIRAM (Jovian Infrared Auroral Mapper) is an imaging spectrometer on board the NASA/Juno spacecraft. The throughput of one of the imager channels (L band) is designed to observe the auroral emission due to the H_3^+ ion; the surface resolution, when Juno is close to Jupiter's poles, is down to 10 km. Combined with the unique vantage point provided by Juno, JIRAM observed the auroral emission of Jupiter with unprecedented details. Here we present a summary of the observations of auroral H_3^+ images after 5 years since the Jovian Orbit Insertion. Because of the constraints on the observing geometry, we put particular emphasis on the south Aurora, and on the auroral footprints of the Galilean Moons. These, when observed with high spatial resolution, consists of a regularly spaced array of emission features, extending downstream of the leading footprint. We discuss implications of the very small features of these signatures.

Life-environmentology, Astronomy, and PlanetarY Ultraviolet Telescope Assembly (LAPYUTA) mission: instrument overview and technical developments

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The Life-environmentology, Astronomy, and PlanetarY Ultraviolet Telescope Assembly (LAPYUTA) mission aims to carry out spectroscopy with a large effective area (>300 cm2) and a high spatial resolution (0.1 arc-sec) and imaging with a wide field of view in an ultraviolet spectral range (110-190 nm) from a space telescope. The main part of the science payload is a Cassegrain-type telescope with a 60 cm-diameter primary mirror. Two main instruments are installed on the focal plane of the telescope: a spectrometer and a UV slit imager. The spectrometer contains a movable slit with different slit width, a holographic toroidal grating with 2000 lines/mm, and an MCP detector coupled with CMOS imaging sensors. Spectral resolution of <0.01 nm and field-of-view of 100 arc-sec will be achieved. A UV slit imager consists of imaging optics, several bandpass filters with a wheel, and a same type of UV detector as the one installed in the spectrometer. In order to achieve a high spatial resolution of 0.1 arc-sec, we will install a target monitoring camera at 0th order position inside the spectrometer and slit imager for both attitude control and image accumulation process. We are studying the concept of LAPYUTA and preparing a proposal of it to JAXA's M-class category. Here we present the LAPYUTA concept design, the overview of the spacecraft and instruments, and the status of technical developments.

3D Physical Chemistry and Emission Simulations of the Io Plasma Torus

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ESA's JUICE mission and NASA's Europa Clipper are sending UVS instruments to the Jupiter system that will view the Io plasma torus. In anticipation of these missions we have built a 3D Io plasma torus emission model in order to simulate what we would expect to see from both UVS instruments looking at the Io plasma torus. The Colorado Io Torus Emission Package 2 (CITEP 2) calculates the line of sight given the position of each spatial pixel and pointing of the spacecraft and produces a synthetic spectrum given plasma densities and temperatures along the line of sight using the CHIANTI atomic database (version 9) to compute volume emission rates. We compare our model with Cassini UVIS and Hisaki UV observations of the Io plasma torus. In addition, we us a 3D model of the physical chemistry while varying the neutral source rate and diffusion coefficient in order to model the warm torus, ribbon, and cold torus. This produces a 3D model of densities and temperatures which we use in conjunction with CITEP 2 to simulate corresponding emission profiles.

Machine Learning for the Classification of Low Frequency Extensions of Saturn Kilometric Radiation

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Saturn Kilometric Radiation is an auroral emission that occurs between a few kHz to 1.2MHz, and peaks in the frequency range 100-400 kHz. It was detected quasi-continuously by Cassini from its arrival at Saturn in 2004 until mission end in 2017 and its properties have been extensively studied. SKR bursts which are global intensifications of SKR as well as extensions of the main SKR band down to lower frequencies, known as Low Frequency Extensions (LFEs), result from internally-driven tail reconnection and from solar wind compressions of the magnetosphere, which also trigger tail reconnection. LFEs have been selected by eye and also using a numerical criterion based on an intensity threshold [Reed et al., 2018]. In our work we propose to develop a supervised machine learning algorithm to select SKR bursts with an associated LFE from the entire Cassini dataset. The algorithm will be built using data from the Cassini radio instrument (RPWS), with LFEs selected by eye using a polygon selector tool by Empey et al., 2021 [zenodo.5636922] and will include examples of LFEs detected from a broad range of spacecraft locations. We plan to explore different types of algorithms that may be based on images, or on time series data e.g RNN, CNN, U-Net. We tried both a FFNN and a CNN to classifiy images of isolated LFEs and achieved preliminary testing accuracies of 89% and 87% respectively. Next steps will include the application of a mask to retain the shape of the LFEs (for interpretation of their frequency structure and its associated links to radio source location).

Europa-induced emissions in the Nançay Decameter Array's catalog

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The satellite control of part of the Jovian Decametric (DAM) radio emissions is long known and studied. This control is set through field-aligned electric currents and Alfvén waves generated by the interaction between Jupiter's magnetospheric plasma and magnetic field and the large Galilean satellites. The electric currents or Alfvén waves accelerate electrons that are thought to cause radio wave amplification through the Cyclotron Maser Instability mechanism, resulting in part of the observed Jovian DAM emissions. The partial control of the emissions by Io was first suggested in the 1960s, but no statistically significant evidence of control by the other Galilean satellites was detected until recently. Thanks to the compilation of extensive digital catalogs of Jovian radio emissions in the last years, such as the Nançay Decameter Array's (NDA) catalog, evidences of partial control of those emissions by Ganymede were finally detected, and Ganymede-induced emissions were analyzed. In this work, we present a search of the NDA's catalog for evidences of control of the Jovian DAM emissions by the satellite Europa. We have detected Europa-induced emissions in the A, C and possibly D components of the Jovian DAM. We also present general characteristics of these emissions and analyze their energetics (duration and intensity) in comparison to that of the Io-induced and of the Ganymede-induced emissions in the catalog.

Io Plasma Torus Properties Through Perijove 25 from Juno Radio Occultations

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The innermost Galilean satellite, Io, is the dominant source of plasma in Jupiter's magnetosphere. About a ton of material per second is released into the area surrounding Jupiter and ionized. This material, mainly sulfur and oxygen, once ionized into a plasma is picked up by Jupiter's magnetic field and distributed into a torus around Jupiter called the Io plasma torus. This plasma can be detected by radio occultations in which the plasma's total electron content affects the path delay properties of the spacecraft's radio signal as it propagates through the plasma on the way to a Deep Space Network station, and vice-versa. The total electron content of the Io plasma torus is derived from the dual frequency (Ka and X-band) uplink and downlink radiometric tracking data of the Juno spacecraft during perijoves 17-25. From these measurements, the longitudinal variability is undeterminable in all variables except the offset from VIP4 models. Thus, the variability is more likely related to temporal variability in the Io plasma torus plasma distribution.

The Grand Finale: Cassini's last view of Saturn's magnetosphere-ionosphere dynamics including the Planetary Period Oscillations.

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Cassini's 2017 proximal orbits provided a uniquely rich dataset, allowing us to study Saturn's magnetosphere-ionosphere system close to the planet and at high cadence. Here we will present the latest results from a number of papers, examining how Saturn's magnetosphere-ionosphere system is driven both externally by the solar wind and internally by the ubiquitous Planetary Period Oscillations (PPOs). We report the occurrence of tail reconnection events when Saturn's magnetosphere is compressed and the Northern and Southern PPOs are in anti-phase. These reconnection events result in the injection of hot plasma, the formation of a partial ring current, and the modulation and formation of field-aligned currents systems including an Earth's like 'Region 2' current system at local dawn. We have further studied Saturn's equatorial ionospheric electron densities and report that Northern and weaker southern PPO modulations occur in the ionospheric diffusive layer and transport region (2500-10,000 km) but not at lower altitudes. The maxima in electron density occur near the rotating principal meridians for both the Northern and Southern PPOs. Finally, we focus on a new study reporting modulations in equatorial plasma velocity by the PPOs as observed in CAPS/IMS equatorial ion velocity data from 2004-2012.

Transient Flashes on Saturn's UV Aurora

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Transient flashes in Saturn's auroral images correspond to $\sim$1 h quasiperiodic pulsations (or QP60) in in situ particle and wave measurements at high latitudes. A previous investigation by Bader et al. (2019) showed these events mostly take place near dusk and link to magnetodisc reconnection. In this study, we examined northern auroral images from Hubble Space Telescope (HST) 2013-2017 campaigns, identified 29 short-lived, recurrent features and examined simultaneous magnetometer (MAG) data collected by the Cassini orbiter. We found, when HST observation cadence permitted, the flash lifetime $\sim$4-17 min (subject to uncertainties related to exposure times), and a 40-70 min periodicity in occurrence. A heat map was constructed to illustrate the aggregate occurrence of transient auroral signatures, and it shows a strong preference in both local time, 14-19 LT, and latitude, 75-85°. These transient flashes are identified in either the presence or absence of Saturn's main auroral oval, indicating the lacking of dependence on the main emission power. The concurrent magnetic field pulsations generally take a sawtooth shape rather than a sinusoid, and the local field strength can experience a change varying significantly from 0.5 to 5.0 nT (depending on the range of Cassini). The QP pulsation events were all detected when the spacecraft was at the southern hemisphere and are usually seen with a less bent-back field, suggesting closed field lines in a more dipolar configuration. One of the identified field pulsation events (2014-100) indicates that these features could occur at the $\sim$21 LT region, in agreement with the spatial location of an identified, atypical flash (2016-232). We also found the ionospheric footprint of the spacecraft must be close to the region of flashes for magnetic field pulsations to be detected, indicating a localised rather than global driving process.

A multi-instrument, multi-event study of the interactions between Galilean moons and the magnetosphere of Jupiter

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NASA's Galileo mission taught us that Galilean moons interactions with the magnetosphere of Jupiter are the main source of plasma of this magnetosphere. However, the mechanisms involved in these interactions are diverse and poorly understood. The Juno mission, in orbit since 2016 and originally designed to study the auroral processes occurring in Jupiter's vast magnetosphere, was recently extended to explore the Galilean moons, making it possible to investigate moon-magnetosphere interactions and especially interactions between moons and the plasma frozen into the nearly-corotating magnetospheric field. The moons, which orbit with a Keplerian velocity slower than the plasma flow speed, constitute an obstacle to the co-rotating plasma. This obstacle generates disturbances in plasma flow, particle distributions, current systems, magnetic perturbations and wave emissions, including the generation of Alfven wings which propagate to the Jovian ionosphere and trigger auroral emissions. The amplitude and geometry of these disturbances strongly depends on each moon's specific properties. Io creates the spatially broadest interaction region, which encompasses its full neutral and ionized torus along its orbit and generates the largest plasma source of the Jovian magnetosphere. In contrast, the three icy moons Europa, Ganymede and Callisto correspond to radically different types of interactions: Ganymede's intrinsic magnetosphere offers the largest obstacle to the plasma flow and may therefore induce the largest perturbations. Europa and Callisto's surfaces, without the protection of an intrinsic magnetic field, interact directly with Jovian magnetospheric flows and energetic particles. These diverse interactions induce space weathering and chemical alteration of the three moons icy surfaces. These disturbances are also thought to be space and time dependent: because Jupiter's magnetic axis is tilted with respect to its rotational axis by roughly 10○, the moons wobble up and down through Jupiter's plasma sheet and encounter different plasma and field conditions during their wobbling motion. Juno crossed the magnetic shell of each moon at least twice per orbit during its forty first orbits, generating a huge observational dataset that witnesses the diversity of physical processes involved in moon-magnetosphere interactions. In this communication, we study these mechanisms, with a primary focus on icy moons, using data from four instruments: the two charged particle spectrometers JADE and JEDI, the magnetometer MAG and the electromagnetic waves investigation WAVES. We use this multi-instrument and multi-event approach to highlight the different signatures of magnetosphere-moons interactions and their space and time variations. Finally, in a focused comparative study of Ganymede and Europa interactions using electron data, we identify the differences between plasma interactions with an intrinsic magnetosphere near Ganymede and with an induced wake and magnetic field near Europa.

An exploration of the Saturn magnetosphere using pitch angle distributions

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The Saturnian magnetosphere is home to a wide variety of processes that involve charged particles and their study is essential for understanding of magnetospheric physics at giant planets. Enceladus is the source of neutral water molecules which pervade the magnetosphere and ice grains which form the E ring, and pickup ions are produced when the neutral molecules are ionised and interact with Saturn's corotating plasma and magnetic field. Pitch angle distributions provide us with a great tool for studying these interactions. In this study we build upon the work done by Tokar et al. (2008), reproducing their radial v_{perp} vs $v_{parallel}$ plots and applying them to the entire Cassini mission and looking at more processes. We use data from the Cassini CAPS and MAG instruments and cover the mission from the Cassini Orbit Insertion in 2004 to 2012 when the CAPS instrument stopped working. These plots give us a good idea of the pitch angle distribution of ions as well as their velocity distribution above the corotation speed allowing us to gauge the amount of acceleration they have undergone. We look at pickup ion signatures around the orbits of Saturn's moons, banded ions and plasma waves and their interaction with charged particles. Our results show that these plots are effective in identifying pick-up ions within the inner magnetosphere.

Transient heavy ion radiation belts at the orbits of Europa, Ganymede and Callisto

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Due to their high mass and large sputtering yield, heavy ions with energies above 1 MeV/nucleon could be an important weathering agent of icy moon surfaces in the magnetosphere of Jupiter. However, the way these heavy ions have been treated in space weathering simulations is limited by several simplifying assumptions: oxygen and sulfur are considered to be the dominant species, while their flux spectrum is assumed to be stable over both short and long-time scales. In this work we put these assumptions to test, using reprocessed energetic heavy ion measurements by Galileo's Heavy Ion Counter (HIC), measuring $Z>4$ ions from $\sim$5 MeV/nucleon and well into >50 MeV/nucleon and contextual information by Galileo's Energetic Particle Detector (EPD) and the Plasma Spectrometer (PLS) instruments. We identify about ten instances, all in the vicinity of the three Galilean moons to be visited by the JUICE mission (Europa, Ganymede, Callisto), during which the energetic heavy ion signal intensity increases by at least a factor of five and up to several orders of magnitude with respect to the nominal levels. We demonstrate that several of these increases contain significant amounts of carbon, probably of solar wind origin, at large concentrations compared to sulfur. The most intense transient is observed during Galileo orbit C22 when also an extreme ultra-relativistic electron storm was observed. Its ion spectra, dominated by oxygen and carbon, extend well above 50 MeV/nucleon. Short- and long-term variations in ion fluxes and ion composition information will be used to identify the drivers of these dynamical changes. The implications of these findings with regards to the weathering of the Galilean moons will be also discussed.

A Test Particle Simulation of Jovian Magnetospheric Electrons Precipitating into Europa's Oxygen Atmosphere

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Europa has a tenuous atmosphere composed mostly of molecular oxygen generated through sputtering of the water-ice surface by Jovian magnetospheric ions. The oxygen OI] 135.6 nm emissions have been detected in Europa's atmosphere. Roth et al. [2016] found that there is north-south asymmetry of the 135.6 nm brightness when Europa is far from the plasma sheet center. Since the main source of the 135.6 nm emissions is the electron impact dissociative excitation of O2, they concluded that the asymmetry is the result of an inequality of electron energy flux into Europa's atmosphere. The electron energy flux into the atmosphere depends on (a) the bounce period of magnetospheric electrons moving along a field line, (b) the velocity of the corotating plasma flow, and (c) the magnetic latitude of Europa. Retherford et al. [2003] explained that when the corotating plasma flow slows down by the moon-plasma interaction, most electrons in an intersecting flux tube collide with Europa: the electrons above Europa precipitate into the northern hemisphere and those below Europa precipitate into the southern hemisphere. This creates a pronounced asymmetric electron energy flux into the atmosphere when the moon is far from the plasma sheet center. The theory, however, has never been evaluated for the case of Europa quantitatively. To derive the electron flux into Europa's surface, we trace the motion of Jovian magnetospheric electrons around Europa with a test particle simulation. We assume that Jupiter has a tilted dipole magnetic field and a corotational electric field. The motion of each magnetospheric electron is treated as a superposition of the cyclotron motion around a field line, the bounce motion along the field line and the longitudinal convection in the Jovian magnetosphere. We use a model of the moon-plasma interaction by Ip [1996] to describe the deceleration of the corotating plasma flow near Europa. To reduce the computational costs, we use the equation of motion for the guiding center of the gyration (Northrop and Birmingham [1982]) and trace the trajectories backward in time (e.g., Cassidy et al. [2013]). We calculate the spatial distribution of electron precipitation and derive the electron flux to Europa's surface. We found that the corotation velocity relative to Europa, 100km/s at Europa's orbit, is required to be decelerated to below 5km/s in order to create a north-south ratio of electron flux larger than 2. We also calculate brightness of the 135.6 nm emissions with the derived electron flux. We found that the scenario suggested by Retherford et al. [2003] can explain the observed north-south brightness ratio of 135.6 nm on Europa (< 5). This suggests that the interaction between Europa and magnetospheric plasma can be considerably strong near the moon. Our study demonstrates how the asymmetric morphology of the 135.6 nm aurora is created on Europa. The results could be a constraint for the study of energy transportation from the Jovian magnetosphere to Europa's environment.

Density Model of the Io Plasma Torus Constrained by the Io Footprint Positions

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The electromagnetic interaction between Jupiter and its innermost Galilean moon Io is a prime example for moon-planet and star-planet interaction. Io's movement relative to the plasma in Jupiter's magnetosphere creates Alfvén waves that propagate along the magnetic field lines towards Jupiter's ionosphere. There, these waves are subject to wave-particle interaction, accelerating particles towards Jupiter and creating auroral emissions, called footprints, in the process. The positions of these footprints depend on the magnetic field and the total travel time of the waves, which in turn are determined by the plasma density along the travel path. Therefore, we can use the footprints as a diagnostic for the magnetic field and density profile in Jupiter's inner magnetosphere. In our work, we use the JRM33 magnetic field model and the observed positions of the Io footprints to constrain a Io plasma torus density model along the magnetic field lines. In our inversion, we obtain torus positions, peak densities and scale heights that are consistent with models in the general literature.

Callisto's moon-magnetosphere interaction: MHD parameter studies for Galileo's C03 and C09 flyby

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We investigate the influence of selected parameters on Callisto's moon-magnetosphere interactions within Jupiter's magnetosphere using an MHD model. Callisto experiences a time-varying magnetic field and is subject to the subcorotational flow of the magnetospheric plasma. The time-varying magnetic field induces a secondary magnetic field within conductive layers of Callisto, such as a subsurface ocean or the ionosphere. The interactions between Callisto and the plasma flow additionally affect the ambient magnetic field. The magnetic field in Callisto's vicinity thus depends on properties of Callisto and of the magnetospheric plasma, which generally are not fully constrained. By applying an MHD model, we study the influence of selected parameters such as upstream plasma properties or the density of the atmosphere on Callisto's space plasma environment. Our model allows to include an induced dipole field in the simulation of the moon-magnetosphere interactions. The model results are directly compared with the magnetometer measurements of Galileo's C03 and C09 flyby. For the C03 flyby, we find the induced dipole field to be strong and the magnetic disturbances due to moon-magnetosphere interactions to be comparatively weak. For the C09 flyby, we find induction and moon-magnetosphere interactions to have a somewhat similar magnetic signature.

Small-scale signatures of Io's flux tube: Evidence of filamentation?

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The Juno spacecraft routinely traverses high-latitude magnetic flux tubes connected to Io's orbit, affording assessment of the Io-Jupiter interaction in unprecedented detail. Recent works have made significant progress in this area by providing observational constraints and highlighting the diversity of fields and particles that play a role in mediating the coupling, namely, energization/acceleration features of electron, proton, low- and high-frequency electromagnetic wave, and magnetic field spectra [Clark et al., 2020; Gershman et al., 2019; Paranicas et al., 2019; Sulaiman et al., 2020; Szalay et al., 2018; 2020a; 2020b]. While the large-scale picture is understood to be inherently non-linear and non-steady state, the nature of acceleration and power transmission remains an ongoing topic of research. Since the particle acceleration is understood to occur at high-latitudes, Juno's high-resolution instruments are well placed to investigate the small-scale features of the Io-Jupiter interaction. Here we present evidence of correlated small-scale variations in field-aligned currents, charged particle fluxes, and high-frequency electromagnetic emissions. We investigate the possibility of a chain of causality and place our findings in the context of whether Io's flux tube is filamented.

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LAPYUTA (Life-environmentology, Astronomy, and PlanetarY Ultraviolet Telescope Assembly) mission

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Ultraviolet observation technique is one of the most powerful tools to cover wide science fields, from planetary science to astronomy. Here we propose a UV space telescope, LAPYUTA (Life-environmentology, Astronomy, and PlanetarY Ultraviolet Telescope Assembly), as a Japanese-leading mission, by using both many heritages of UV instruments for planetary science (e.g., Hisaki) and space telescope techniques for astronomy. We will accomplish the following four goals: (1) dynamics of our solar system planets and moons as the most quantifiable archetypes of extraterrestrial habitable environments in the universe, (2) transit spectroscopy of exoplanetary atmosphere, especially hydrogen and oxygen exospheres, to observe on-going atmospheric escaping predicted to occur on Earth-like exoplanets in the habitable zone of low temperature star system, (3) the unique UV map of the gaseous large-scale structures (LSSs) to test the structure formation scenario of the cold dark matter (CDM) model and to unveil galaxy growth and feedback processes in the LSSs, and (4) the time-domain survey for transient sky in the UV wavelength to witness the first moments of high-energy events such as compact-object mergers and supernovae with a great synergy of the growing facilities of multi-messenger astronomy including gravitational-wave observatories. The first topic which includes sciences related with the Galilean moons and the Jovian magnetosphere. In our solar system, subsurface oceans of icy moons at gas giants are the most likely extraterrestrial habitable environment. Evolution and current situation of the subsurface oceans are essential unresolved problems to assess their habitability. Water plume that gushes from the subsurface ocean to the surface and ambient space is the only observable phenomena that tells us geological activity of the ocean. The energetic charged particle surrounding the icy moons is an essential energy source for chemistries at the icy moon's surface and interior. The energy input from the magnetosphere to the icy moons is caused by bombardment of energetic charged particles to the satellite atmosphere and surface and is visible through the auroral emissions in the satellite atmosphere. As the plume activity and the energy input are not stable, continuous monitoring with high spatial resolution is essential. The origin of energetic charged particles is heating and acceleration of plasma in the magnetosphere. The heating and acceleration phenomena are able to be visualized by the polar auroral emission that maps to the magnetosphere through the planetary intrinsic magnetic field. Monitoring capability of LAPYUTA will enable us to see dynamics of auroral morphology to uncover energy flows from the magnetosphere to the icy moons. The icy moon's plume and ambient space are deeply explored with the spacecraft by NASA's and ESA's icy moon missions in 2020s-2030s. The in-situ measurement with the spacecraft (JUICE & Europa clipper) quantifies the gas density, molecular/atom species, and electromagnetic fields at the spacecraft location. The complementary remote sensing of the plume and ambient space by LAPYUTA will visualize their global structure and temporal dynamics.

The Salinity of Europa's Subsurface Ocean and the Implications on its Conductivity and Resulting Induction Amplitude

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The chemical composition of the subsurface ocean harboured within the Jovian satellite Europa is an ongoing research question. Past literature hinted toward multiple possible constituents, e.g. $NaSO_4$ and $MgSO_4$ (Orlando et al., 2005). Research efforts in the recent years however favour NaCl as the main compound (Trumbo et al., 2019). Given the correlation between chemical composition and conductivity, this topic has a direct impact on our studies of induced magnetic fields, as the conductivity is one of two fundamental parameters governing the induction amplitude, the other one being ocean's thickness. A better understanding of the expected conductivities will help us in further constraining the parameter range for the thickness. We present a parameter study, showing the induction amplitude reached for different conductivities and fixed thicknesses, and connect these results to the salt compounds which possibly make up the salinity of Europa's subsurface ocean.

Wave-Particle Interactions at Saturn: The Impact of Multiple Wave Types on the Dynamics of Saturn's Electron Radiation Belt.

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In recent years, the importance of wave-particle interactions with electrons on the dynamics of the electron radiation belt at Saturn has been increasingly apparent. Thanks to the wave surveys processed from the NASA Cassini mission we are now able to work out the combined effect of the interactions of different waves with the electron population in the inner magnetosphere. In this presentation we investigate how the acceleration and scattering we expect from individual wave types are affected by combining the individual wave effects. Z-mode, whistler mode chorus and hiss and have all been shown to accelerate electrons whilst ion cyclotron waves scatter them into the atmosphere. However, the strength and location of all these waves vary greatly and their impact on the electron population depends on the underlying plasma properties at any given location. We present our analysis of the effects of combinations of whistler-mode chorus and hiss, Z-mode and ion cyclotron waves on energetic electrons across the inner magnetosphere of Saturn. In particular we show remarkable similarities between the simulated and observed pitch angle distributions of very high energy electrons.

Rotational Modulation of the 20 kHz Saturn Narrowband Emissions

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The rotational modulation features of the 20 kHz narrowband emissions at Saturn are studied for the first time, and they are compared to the modulations of 5 kHz narrowband emissions and Saturn Kilometric Radiation. A least-square analysis reveals that the modulation rates of 20 kHz narrowband emissions are similar to the 5 kHz narrowband emission, displaying dual periodicities in each hemisphere, which can be explained as Z mode waves crossing the hemisphere before mode conversion to L-O mode. Seasonal variations of the modulation rates are also observed. The relative phase differences between the narrowband emissions and the Saturn Kilometric Radiation reveal a phase lock relation, suggesting that these three clock-like rotationally modulated emissions are triggered at different local times and in sequence of the phase relation.

Numerical radar simulation for the explorations of the ionosphere at Jupiter's icy moons

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Jupiter's icy moons such as Europa and Ganymede may harbor subsurface liquid water oceans and have ionospheres created from the oceanic water materials. While only Earth has the ocean on the surface in the current solar system, multiple icy bodies like the icy moons of giant planets have oceans in their subsurface under the icy crust. The icy bodies' oceans are potentially more universal habitable environment than the Earth-type surface ocean. Structures of the ocean and the ionosphere of the icy moos are essential information for understanding the universality of habitable environments. However, the structures of the oceans are unknown because in-situ or lander explorations on the surface of icy objects, the most effective method for exploring the structures, are still at technically conceptional level at present. The structures of ionospheres are still unclear as well because the ionospheric radio occultation and other effective explorations have difficulties of limited observing opportunities. Here we are going to uncover the structures of the ocean and the ionosphere of Jupiter's icy moons by the radar exploration with the Radio & Plasma Wave Investigation (RPWI) and the Radar for Icy Moon Exploration (RIME) onboard the Jupiter ICy moons Explorer (JUICE). For the investigations of radio wave sounding in and around the icy moons with RPWI and RIME ranging in tens KHz to tens MHz, we developed a numerical simulation code that models the propagation of electromagnetic (EM) waves and emulated occultation of the Jovian radio waves by the icy moon's ionospheric structures during the flybys of the Galileo spacecraft to Jupiter's icy moons. In this presentation, we will propose the vertical ionospheric profiles and day-night asymmetry of its structure in our result. As the next step, we will also simulate the reflection and transmission of the EM waves in the icy crust and underlying ocean. After completing these studies, we will be able to elucidate icy moon's ionospheric and subsurface structures by combining our model with the JUICE radar explorations. The combination of our model and the JUICE radar explorations would also constrain the pressure and temperature of the subsurface, which finally lead to deep understandings of the icy moon's habitability.

Secondary electron emission from the Cassini spacecraft in Saturn's ionosphere: An alternative to charged dust?

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In-situ observations of Saturn's ionosphere inferred large populations of charged dust that dominate the plasma dynamics. Significant questions remain, however, as to how much dust is present as Cassini's Plasma Spectrometers were offline and the Langmuir Probe only measures bulk currents. In this letter, we use three dimensional Particle-in-Cell simulations [Zhang et al., 2021] to further constrain how the plasma currents control the spacecraft floating potential. We focus on the phenomenon of Secondary Electron Emission (SEE) arising through collisions with the neutral atmosphere, and show how this significantly enhances the phenomenon of electron wings and is also capable of charging Cassini to positive potentials, a phenomenon also associated with charged dust. The SEE simulations predict a positive potential for even small neutral densities and can potentially be used to infer new information on the neutral composition of Saturn's atmosphere.