MOP 2024
MINNEAPOLIS

MOP 2024

Minneapolis

2024 July 7th-12th

Contents

Local Organizing Committee

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- Bob Lysak
- Sadie Elliott
- Wondwossen Eshetu
- Greg Bocko
- Aaron West
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- Rob J. Wilson (LASP, CU)

Schedule

The following pages contain the schedule, then the list of posters.

Titles are click-able and will take you to the full abstract.
At the top left of the abstract is a link to click back to the schedule.

CT	Contributed Talk	15 minutes
IT	Invited Talk	20 minutes
TT	Tutorial talks	25 minutes
P	Poster	

Key for Presentation Type

Schedule for Sunday July 7th, 2024

Time	**Event**
17:00-19:00	*Ice Breaker at Campus Club*

Schedule for Monday AM July 8th, 2024

Time		1st Author	Title
08:45			*Opening Remarks by Associate Dean Joseph Konstan*
			Session Chair: Bertrand Bonfond
09:00	TT	**Ray, L.C.**	Magnetosphere-ionosphere-thermosphere at the outer planets
09:25	IT	**Kurth, W.S.**	Electron Densities in Jupiter's Topside Ionosphere
09:45	CT	**Valek, P.W.**	Survey of in situ observations of ions in the topside Jovian ionosphere
10:00	CT	**Agiwal, O.**	Jovian Radio Occultations: Spatial De-trending and A Magnetic Perspective
10:15	CT	**Sinclair, J.A.**	Stratospheric space weather on Jupiter: auroral-driven heating, chemistry and dynamics
10:30			Coffee
			Session Chair: George Clark
11:00	CT	**Benmahi, B.**	Exploring the Jovian auroral vertical structure: Juno's view.
11:15	IT	**Damiano, P.A.**	Electron Energization by Inertial Alfvén Waves in Density Depleted Flux Tubes at Jupiter
11:35	CT	**Kruegler, N.**	Electron Densities above Jupiter's Main Aurora and Implications on Auroral Acceleration
11:50	CT	**Clarke, J.T.**	HST UV High Spectral Resolution View of Jupiter's Aurora: Neutral Temperature and Search for Proton Aurora
12:05	CT	**Head, L.A.**	Effect of magnetospheric conditions on the morphology of Jupiter's UV main auroral emission, as observed by Juno-UVS
12:20			Lunch
13:50			End of Lunch, start of afternoon sessions ([on next page])

See next page for [Monday's afternoon schedule].

Schedule for Monday PM July 8th, 2024

Time		1st Author	Title
			Session Chair: Adam Masters
13:50	IT	**Clark, G.B.**	Energetic Particles in Jupiter's Polar Cap
14:10	IT	**Elliott, S.S.**	Evidence of the source of energetic electron beams over Jupiter's Polar Cap from Juno/Waves
14:30	CT	**Dunn, W.R.**	Identifying Connections between Jupiter's X-ray Aurorae and Radio, UV, Magnetic Field and Plasma Observations
14:45	CT	**Collet, B.**	A new type of Jovian hectometric radiation powered by monoenergetic electron beams
15:00	CT	**Martos, Y.M.**	Jupiter's magnetic field geometry and its relation with new decameter radiation events observed by Juno
15:15	CT	**Delamere, P.A.**	Is it possible to identify open magnetic flux in Jupiter's magnetosphere?
15:30			Coffee
			Session Chair: Jamie Jasinski
16:00	CT	**Hao, Y.**	Quasi-periodic flapping magnetodisk of Gas Giants: Cassini and Juno Observations
16:15	CT	**Joyce, H.S.**	Investigating the Effects of Clock Angle on Jupiter's Polar Aurora
16:30	CT	**Rutala, M.J.**	Revisiting the Form of the Jovian Bow Shock and Magnetopause: Most-Likely Locations based on Juno and MMESH data
16:45	CT	**Provan, G.**	Jupiter's dawnside magnetodisc: the force-balance context to Juno observations
17:00	CT	**Vogt, M.F.**	Juno Observations of Jupiter's Duskside Magnetospheric Structure, Dynamics, and Boundary Regions
17:15			End of day

See previous page for [Monday's morning schedule].

Schedule for Tuesday July 9th, 2024

Time		1st Author	Title
			Session Chair: George Clark
09:00	TT	**Yoshioka, K.**	The Io torus and highlights from 10 years operation of the Hisaki mission
09:25	CT	**Smith, H.T.**	Io's magnetospheric source rate extremes derived from neutral oxygen torus observations and 3-D modeling
09:40	CT	**Phipps, P.H.**	Variability of the Io Plasma Torus Through Juno Perijove 49
09:55	CT	**Moirano, A.**	The Io Plasma Torus State during the Juno Mission: Constrains from the Radio Occultations and the Io Auroral Footprint
10:10	CT	**Morgenthaler, J.P.**	Io Input/Output observatory (IoIO) observations of the Io plasma torus: evidence that IPT radial diffusion is driven by internal processes
10:25			Coffee
			Session Chair: George Clark
10:55	CT	**Nerney, E.G.**	Modeling Anisotropic Maxwellian and Kappa Field Line Distributions in Io's Plasma Torus using Multi-Fluid and Kinetic Approaches
11:10	IT	**Bunce, E.J.**	Magnetospheric Science Enabled by Coordinated JUICE and Clipper Investigations
11:30	CT	**Devinat, M.**	A self-consistent model of radial transport in the magnetodisks of gas giants including interhemispheric asymmetries
11:45	CT	**Paranicas, C.P.**	Plasma injections at Saturn and their local time of origin
12:00			Lunch
			Session Chair: Abby Azari
13:45	CT	**Zhang, B.**	Evolution of Interchange structures in rotating magnetospheres: the role of force balance within magnetodiscs
14:00	CT	**Wing, S.**	The roles of flux-tube entropy and effective gravity in the inward plasma transport at Saturn
14:15	CT	**Kamran, A.**	A new empirical plasma environment model of Saturn and its key moons
14:30	CT	**Ye, S.**	Dynamics of Planetary Magnetospheres Revealed by Wave Phenomena
14:45			*Future MOP*
15:00			*Transition to Posters in Tate Hall + Group Photo*
15:25			Poster Session A
17:25			End of day

Schedule for Wednesday July 10th, 2024

Time		1st Author	Title
			Session Chair: Licia Ray
09:00	TT	**Paty, C.S.**	Ice Giant Magnetospheres
09:25	CT	**Cohen, I.J.**	A localized and surprising source of energetic particles in the Uranian magnetosphere near Ariel
09:40	CT	**Zomerdijk-Russell, S.**	Seasonal, diurnal and solar wind driven variability in model-predicted reconnection voltages applied to Uranus' dayside magnetosphere
09:55	CT	**Jasinski, J.M.**	Uranus' magnetosphere was observed in an anomalous state by Voyager 2
10:10	CT	**Masters, A.**	Cosmic rays interacting with Neptune's asymmetric magnetic field
10:25			Coffee
			Session Chair: Licia Ray
10:55	CT	**Xystouris, G.**	Reanalysing, recalibrating, and archiving Voyager 2 Plasma Science data for Uranus
11:10	IT	**Thomas, E.M.**	The 30 year search for infrared aurorae at Uranus
11:30	CT	**Wibisono, A.D.**	The Search for Uranus with XMM-Newton
11:45	CT	**Melin, H.**	The ionospheres of Uranus and Neptune as observed by JWST
12:00	CT	**George, H.**	Mapping lightning generated whistler waves through near-Uranus space
12:15			Lunch
			Session Chair: Jamie Jasinski
13:45	CT	**Nichols, J.D.**	Simultaneous James Webb and Hubble Space Telescope observations of Jupiter's H_3^+ and FUV auroral emission
14:00	CT	**Tiranti, P.I.**	Jupiter's pole-to-pole vertical ionospheric profiles from JWST
14:15	CT	**Stallard, T.S.**	Jupiter's infrared aurora at unprecedented sensitivity: 1 day with JWST and 43 days with IRTF
14:30			*Future MOP vote*
14:45			Community codes
15:00			End of day

Schedule for Thursday July 11th, 2024

Time		1st Author	Title
			Session Chair: Yash Sarkango
09:00	TT	**Kollmann, P.**	Radiation Belts of the Outer Planets
09:25	CT	**Mauk, B.H.**	Auroral acceleration as the electron seed-population source for Jupiter's uniquely energetic radiation belts
09:40	IT	**Kao, M.M.**	Extrasolar Radiation Belts: Resolved Imaging and Occurrence Rate Statistics
10:00	CT	**Acevski, M.**	Asymmetry in Uranus' high energy proton radiation belts
10:15	CT	**Woodfield, E.E.**	A first step in combining diffusion and convection in Saturn's electron radiation belts.
10:30			Coffee
			Session Chair: Tom Nordheim
11:00	CT	**Roussos, E.**	Evidence for radial flows in Jupiter's inner radiation belts
11:15	CT	**Haynes, C.M.**	Global morphology of ENA emissions from the atmosphere-magnetosphere interactions at Callisto and Europa
11:30	CT	**Szabo, P.S.**	Observing Ion Precipitation onto Ganymede's Surface through Backscattered Energetic Neutral Atoms
11:45	CT	**Tippens, T.**	Influence of Titan's Variable Electromagnetic Environment on the Distribution of Energetic Neutral Atoms: Global Morphology and Observability
12:00	IT	**Liuzzo, L.**	Charged Particle Weathering of Europa and Callisto
12:20			Lunch
			Session Chair: Rob Ebert
13:50	CT	**Kinrade, J.**	Remote sensing of plasma flows in Saturn's magnetosphere using ENA imagery
14:05	CT	**Eshetu, W.W.**	Modeling of particle acceleration by ionospheric auroral resonator field in Jupiter
14:20	CT	**André, N.**	Temporal and spatial variability of the electron environment at the orbit of Ganymede as observed by Juno
14:35	CT	**Milby, Z.**	Local Electron Properties in Jupiter's Magnetosphere from Optical Aurora Observations of Io and Ganymede
14:50	CT	**Le Liboux, T.**	Characterizing Callisto's orbital environment with the Juno mission
15:05			*Transition to Posters in Tate Hall*
15:15			Poster Session B
17:15			End of day
18:30			*Banquet at the Weisman Art Museum*

Schedule for Friday July 12th, 2024

Time		1st Author	Title
			Session Chair: Jamey Szalay
09:15	IT	**Sarkango, Y.**	Field Line Resonances at the Galilean Satellites
09:35	CT	**Kivelson, M.G.**	Signatures of Io's Alfvén wing: I31 revisited
09:50	CT	**Ebert, R.W.**	Plasma Observations in Io's Alfvén Wing and Plasma Wake from Juno
10:05	CT	**Louis, C.K.**	Source of radio emissions induced by the Galilean moons Io, Europa and Ganymede: in situ measurements by Juno
10:20			Coffee
			Session Chair: Bertrand Bonfond
10:50	CT	**Rabia, J.**	Properties of electrons accelerated through moon-magnetosphere interaction: survey of Juno high latitude observations and modeling work
11:05	CT	**Allegrini, F.**	Electrons near Europa and in fluxtubes magnetically connected to Europa's footprint tail aurora at Jupiter
11:20	CT	**Jia, X.**	Multi-fluid MHD simulations of Europa's Plasma and Magnetic Field Environment during the Juno Close Flyby
11:35	CT	**Sharan, S.**	Electromagnetic induction at Ganymede during the JUICE mission
11:50	CT	**Winkenstern, J.**	Constraining Europa's Subsurface Ocean - A Revision of Galileo Flybys
12:05			Lunch
			Session Chair: Jamey Szalay
13:35	CT	**Saur, J.**	Analyzing the space environment of Saturn's moon Enceladus to possibly probe its interior
13:50	CT	**Dong, Y.**	Dust Impact Plasma Seen by the Cassini Plasma Spectrometer and Langmuir Probe in Enceladus' Plume
14:05	CT	**Molyneux, P.M.**	Mapping UV line ratios at Ganymede to constrain the atmospheric composition and distribution
14:20	CT	**Schlegel, S.**	The role of the electron thermal conductivity for Europa's auroral glow
14:35	CT	**Greathouse, T.K.**	Juno-UVS Observations of Io during the PJ58 Flyby
14:50			End of day

Posters

Posters A (Tuesday)

Poster		1^{st} Author	Title
A01	P	**Hamil, O.**	Fluid simulation of the Jovian low-latitude ionosphere
A02	P	**Gómez, D.W.**	Insights of Jupiter's equatorial airglow from Juno-UVS
A03	P	**Knowles, K.L.**	Unveiling Jupiter's Equatorial Ionosphere with JWST
A04	P	**Moore, L.**	Jupiter's ionosphere surrounding Juno PJ54: Model comparisons with Earth-based observations
A05	P	**Mohamed, K.**	Modeling Electrodynamics in Jupiter's Non-auroral Ionosphere
A06	P	**Roberts, K.**	Jupiter's Upper Atmosphere: Observations of Temporal Variations in Temperature
A07	P	**Smith, A.R.**	Magnetosphere-Ionosphere Coupling Sensitivity for Jupiter-Like GAMERA Simulations
A08	P	**Luo, H.**	Mapping of Jovian Magnetosphere-ionosphere System: Results from Three-dimensional Global Simulations
A09	P	**Moirano, A.**	Energy deposition in Jupiter's auroral regions: the vertical structure of Jupiter's ultraviolet aurora observed by Juno-UVS
A10	P	**Song, Y.**	A mechanism of the monoenergetic and broadband auroral acceleration
A11	P	**Kamran, A.**	Comparison of contemporaneous Juno magnetic and ultraviolet auroral observations with the Leicester Magnetosphere-Ionosphere Coupling Model
A12	P	**Leppard, F.**	Exploring the mechanisms behind Jupiter's x-ray auroral flares
A13	P	**Moral-Pombo, D.**	Characteristics of the Equatorward Emissions in Jupiter's UV Aurora
A14	P	**Daly, A.**	Jupiter's Auroral Response to Magnetospheric Injections: Insights from Juno Observations
A15	P	**Yao, Z.H.**	Auroral Injections and the Magnetospheric Processes at Jupiter
A16	P	**Parry, B.**	High Energy Ions in Jupiter's Aurorae
A17	P	**Sicorello, G.**	The Jovian ionospheric conductivity derived from a broadband precipitated electron distribution
A18	P	**Giles, R.S.**	Understanding the relationship between the size variations of Jupiter's magnetosphere, auroral brightness and solar wind pressure using Juno observations
A19	P	**Bonfond, B.**	North, South, East and West: the asymmetries in the Jovian UV aurorae
A20	P	**Skinner, E.**	Ion Cyclotron Waves as Drivers of Ionospheric Outflow in Jupiter's Auroral Zones

Poster		1st Author	Title
A21	P	**Boudouma, A.**	Characterization of the Jovian narrowband kilometric radio components: wave mode, frequency and sources locations from 3D numerical modeling of the Juno/Waves observations.
A22	P	**Collet, B.**	Characterization of bKOM sources
A23	P	**Jácome, H.R.P.**	Declination variation effect on characteristics of Jovian decametric radio emission
A24	P	**Palmer, V.A.**	Analysis of Standing Alfvén Waves in the Jovian Plasma Sheet: Insights from Juno Magnetometer Data Across the Dawn to Midnight Sector
A25	P	**Lysak, R.L.**	A new regime of plasma wave modes in Jupiter's polar cap
A26	P	**Rutala, M.J.**	Background Solar Wind Conditions during the Juno Mission: Results from the Multi-Model Ensemble System for the outer Heliosphere (MMESH)
A27	P	**Donaldson, K.**	Characterizing the solar wind-magnetosphere viscous interaction in the outer solar system
A28	P	**Devinat, M.**	Survey on interchange signatures in the Jovian magnetosphere using multi-instrument Juno data
A29	P	**Laffitau, U.**	A survey of proton and electron injections in the magnetosphere of Jupiter
A30	P	**Vogt, M.F.**	Juno-era updates to the Jupiter flux equivalence mapping model and implications for the predicted polar cap boundary
A31	P	**Provan, G.**	Juno Observations of Large-Scale Azimuthal Fields in Jupiter's Nightside Magnetosphere and Related Radial Currents
A32	P	**Wang, J.-z.**	Jupiter's plasma disk observed by Juno: Radial, vertical and local time structure
A33	P	**Wilson, R.J.**	Mapping the Jovian Magnetospheric Thermal Plasma
A34	P	**Spitler, C.E.**	Quantifying Transport Quantities in Jupiter's Magnetodisc Through Juno Data Analysis
A35	P	**Sarkango, Y.**	Electron distributions in the Jovian inner and middle magnetosphere measured by the Juno JADE instrument
A36	P	**Rogan, P.**	Soft x-ray emission from Saturn's magnetosheath: A comparison of two models
A37	P	**Yin, Z.-F.**	Trapped and Leaking Energetic Particles in Injection Flux Tubes of Saturn's Magnetosphere
A38	P	**Caggiano, J.A.**	Injection-driven rotational magnetospheric periodicity revealed at Saturn through combined MHD and test particle simulations.
A39	P	**Sicard, A.**	A new environment model framework for Saturn
A40	P	**Ma, X.**	Statistical survey of magnetic flux integral quantities in Saturn's magnetosphere

Poster		1st Author	Title
A41	P	**Xystouris, G.**	A simple spacecraft - vector intersection methodology and applications
A42	P	**Felici, M.**	Kronian ionospheric outflow in the magnetosphere of Saturn
A43	P	**Agiwal, O.**	SMITE: A New Saturn Ionosphere Model Including Ring-Planet Coupling and Electrodynamics
A44	P	**Taubenschuss, U.**	A Reinvestigation of Saturn Drifting Bursts
A45	P	**Pisa, D.**	Mapping of the possible source of Saturn Drifting Burst emissions
A46	P	**Wing, S.**	Periodic narrowband radio wave emissions and inward plasma transport at Saturnian magnetosphere
A47	P	**Hathaway, E.Y.**	Studying Saturn's Interchange Injection Events: Investigating Instabilities in the Kronian Inner Magnetosphere

Posters B (Thursday)

Poster		1^{st} Author	Title
B01	P	**Wilson, R.J.**	Internal and External Jovian Magnetic Fields: Community Code to Serve the Magnetospheres of the Outer Planets Community
B02	P	**Wang, J.-z.**	Juno-JADE Ion Parameters in Jupiter's Magnetosphere (10-50 R_J)
B03	P	**Bertucci, C.**	Preliminary Modelling of Magnetic and Plasma Conditions during Cassini's T21 Flyby of Titan
B04	P	**Fillingim, M.O.**	Currents in Titan's Ionosphere
B05	P	**Ledvina, S.A.**	Observed vs. Modeled Electron Densities in Titan's Ionosphere
B06	P	**Tippens, T.**	A Novel Backtracing Model to Study the Emission of Energetic Neutral Atoms at Titan
B07	P	**Pryor, W.R.**	Cassini UVIS Observations of the Enceladus Auroral Footprint in 2017
B08	P	**Le Liboux, T.**	Modeling the neutral and ionized environments of Callisto
B09	P	**Haynes, C.M.**	Observability of ENA emissions at Europa and Callisto: predictions for the JUICE mission
B10	P	**Krupp, N.**	The Particle Environment Package (PEP) onboard the JUICE mission: Science Perspectives and current status
B11	P	**Krupp, N.**	Energetic particle measurements near Ganymede: Galileo EPD data revisited, comparison with recent JUNO flyby and perspectives for Juice PEP
B12	P	**Liuzzo, L.**	On the Formation of Trapped Electron Radiation Belts at Ganymede
B13	P	**Santos, A.**	Characterising the magnetic and plasma environment upstream of Ganymede
B14	P	**Duling, S.**	Electron Impact Ionization of Ganymede's Atmosphere
B15	P	**Cervantes, S.**	Io's plasma interaction with the jovian magnetosphere: MHD modeling of the Juno flybys on orbits 57 and 58
B16	P	**Cervantes, S.**	MHD simulations of the plasma interaction between Europa and Jupiter's magnetosphere during the Juno flyby
B17	P	**Damiano, P.A.**	Kinetic simulations of standing Alfvén waves at Europa
B18	P	**Lovett, E.L.**	Europa's Alkali Exosphere During the 2022 Juno Flyby
B19	P	**Matsushita, N.**	Estimation of plasma parameters at Europa's orbit from the Hisaki observation
B20	P	**Satoh, S.**	Plasma Sheet Conditions at Europa's Orbit Retrieved from Lead Angle of the Satellite Auroral Footprints
B21	P	**Retherford, K.D.**	JUICE Ultraviolet Spectrograph Measurements of Icy Satellite, Jupiter, and Io System Environments
B22	P	**Becker, T.M.**	Europa Clipper Ultraviolet Investigations Will Constrain Interactions between Europa and Jupiter's Magnetosphere
B23	P	**Hospodarsky, G.B.**	Properties of Long Dispersion Jovian Lightning Whistlers and their association with the Io torus

Poster		1^{st} Author	Title
B24	P	**Kurth, W.S.**	Io Torus Electron Densities Inward of Io's M-shell
B25	P	**Vinci, G.**	Structure and dynamics of the Io Plasma Torus: from multi-spacecraft and multi-instrument observations to models
B26	P	**Kondo, H.**	Solar wind response of the dawn-dusk asymmetry in the Io plasma torus using the Haleakala T60 and HISAKI satellite observations
B27	P	**Tsuchiya, F.**	Overview of the LAPYUTA mission
B28	P	**Bagenal, F.**	Io Plasma Torus in the Juno Era
B29	P	**Dols, V.**	Io's atmospheric neutral loss by physical chemistry processes
B30	P	**Coffin, D.A.**	A multi-method examination of the Io-Jupiter Alfvénic connection
B31	P	**West, A.F.**	Multifluid Simulations of Kinetic Alfvén Waves in the Io-Jupiter Flux Tube
B32	P	**Loewe, R.**	Searching for ion cyclotron waves in the space region between Io and Europa
B33	P	**Sulaiman, A.H.**	Juno Plasma Wave Observations at Io
B34	P	**Szalay, J.R.**	Pickup ions from the atmospheres of Io, Europa, and Ganymede
B35	P	**Chang, M.S.**	Europa's Magnetic Environment from Juno and Galileo Flybys
B36	P	**Rabia, J.**	Influence of the Jovian current sheet models on the mapping of the UV auroral footprints of Io, Europa, and Ganymede
B37	P	**Santos-Costa, D.**	Latest advances in understanding Jupiter's high-energy electron dynamics from physics-based and public domain data-driven techniques
B38	P	**Santos-Costa, D.**	Magnetosphere-sourced energetic neutral atoms detection in the context of JUICE and future missions at the ice giant planets
B39	P	**Carr, N.A.**	X-ray optics development for studying the Jovian system and Galilean moons
B40	P	**Dunn, W.R.**	Why the MOP Community Should Care About the Next Generation of X-ray Observatory: the Line Emission Mapper
B41	P	**Dunn, W.R.**	Decadal Science Enabled by an X-ray Instrument on a Uranus Orbiter
B42	P	**Thomas, E.M.**	Is it cold or is it just Uranus?: Documenting infrared emission scans and temperatures at Uranus in 2023
B43	P	**Azari, A.R.**	Probabilistic Estimation of Uranus' Internal Magnetic Field for Future Exploration
B44	P	**Bale, S.D.**	Measurements Of Radio Emissions, Plasma Waves, And Dust At Uranus: Lessons From The PSP/FIELDS Instrument
B45	P	**Tsai, P.-C.**	Exploring Satellite-Magnetosphere Interactions at Uranus and Neptune
B46	P	**Merayo, J.M.G.**	Magnetic field mapping of Uranus and its major moons

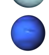
Abstracts

Abstracts follow, listed one per page (or two pages if many coauthors), with an *Index* following the Abstracts section that lists page numbers of their primary author presentations, and then separately any co-author presentations.

The top of the *Index* lists presentations by Planet, Team, then authors.

The Title, Authors, Affiliations and Abstracts are 'as provided by' the authors, mostly in plain text. Minimal editing has been carried out to fix anything obvious - however we had to re-insert super-scripts and sub-scripts, and some line-breaks.

The image(s) on the top right of each page indicate the planets[1] or Extrasolar[2] planet that the authors indicated were relevant to their abstract.

Planet	**Image**
Jupiter	
Saturn	
Uranus	
Neptune	
Extrasolar	

Key to Images

Authors are given in initial(s) and surname format as provided by the primary author (edited down if full names were provided), and where they provided fewer initials, we have expanded for the *Index*.
We assumed that everyone's first initial and surname is unique.

The day of week Link at the top left of each page is for PDF navigation to the schedule for that day, while that header describes if the abstract is oral (and what time) or a poster.

Links at the bottom of each page is for PDF navigation to the *Table of Contents* or *Index*.

[1] Images of planets from: [https://nineplanets.org]
[2] Extrasolar Image attributed to Andrew Z. Colvin, CC BY-SA 4.0, via Wikimedia Commons, see [Wikipedia].

Magnetosphere-ionosphere-thermosphere at the outer planets

L.C. Ray[1]

[1]*Lancaster University, Lancaster, UK*

Jupiter and Saturn host some of the most brilliant aurorae in the Solar System. Omnipresent, yet variable in intensity and planetographic extent, these emissions are just one sign of magnetosphere-ionosphere-thermosphere (MIT) coupling between giant planets and their surroundings. These rapidly rotating planets are coupled to their surrounding plasma discs through their planetary magnetic fields, which mediate the exchange of angular momentum and energy through a complex system of currents. Lorentz forces, Joule heating, and precipitating particles associated with MIT coupling modify the underlying atmosphere and affect magnetospheric flows.

In the magnetosphere, angular momentum drawn from each planet accelerates plasma as it is transported away from its source location, predominately Io at Jupiter and Enceladus at Saturn. Alfvén waves and quasi-static electric fields associated with MIT coupling accelerate particles into the planetary atmospheres, generating auroral emission. Energy is also deposited into the thermosphere through Joule heating associated with corotation enforcement currents. However, questions remain as to how this energy is redistributed across the planets to produce the observed thermospheric temperatures, which exceed predictions by 100s of Kelvin. This tutorial talk reviews the current understanding of MIT coupling at the outer planets, focusing primarily on the Jovian system in light of recent advances in understanding from Juno.

Electron Densities in Jupiter's Topside Ionosphere

W.S. Kurth[1], A.H. Sulaiman[2], S.S. Elliott[2], J.B. Faden[1], G.B. Hospodarsky[1], J.E.P. Connerney[3], P. Valek[4], F. Allegrini[4,5], J.H. Waite[6], F. Bagenal[7], S.J. Bolton[4]

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The Juno mission has provided a unique opportunity to explore the topside ionosphere of Jupiter. In this presentation we highlight recent observations by Juno's Waves instrument of plasma wave spectra that inform on electron densities over a latitudinal range of near equatorial to above 40 degrees. As with preceding occultation observations, the in situ data are accentuated by a myriad of variations with no clear geophysical explanation, although correlations with Jupiter's highly asymmetric magnetic field are enticing. Over the more than 50 perijoves analyzed to date, peak densities range from ˜100 to tens of thousands per cc. The density profiles can be highly variable from one perijove to the next and there can be sharp deviations from simple smooth increases and decreases with altitude within individual ionospheric passes. 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 about 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. We conclude it is unreasonable to construct a scale height from a single perijove pass as the trajectory is more horizonal than vertical. Spatial variations may be responsible for some of the variability, perhaps related to Jupiter's complex, higher order magnetic field. Temporal variations could also be at play. We show the variation in ionospheric density profiles and the distribution of peak densities as a function of latitude and System III longitude as well as other geometric parameters. Where appropriate, we refer to Cassini's Saturn's ionospheric observations for comparison.

Survey of in situ observations of ions in the topside Jovian ionosphere

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Juno's polar orbit enables in situ observations from a wide range of latitudes. At the beginning of the mission, Juno's closest approach was at the equator, but has moved northward by ˜ 1 degree of latitude each orbit. During the prime mission, this permitted in situ observations of the equatorial ionosphere (equatorward of the Io footprint) and the high latitude ionosphere (between the Io footprint and the auroral oval). In the extended mission, Juno's perijove is at high latitudes and low enough altitudes to directly sample the polar topside ionosphere. We present a survey of the in situ observations of the topside ionosphere at all latitudes (polar, high, and equatorial latitudes). During its perijove, the Juno spacecraft reaches altitudes down to ˜3500 km and velocities of 58 km/s, permitting regular observation of cold ions of the topside Jovian ionosphere. The cold ions are measured by the Jovian Auroral Distributions Experiment Ion (JADE-I) sensor. JADE-I measures ion composition over a mass range of 1 to 64 amu / q, and the high spacecraft velocity (with an equivalent ram energy up to ˜18 eV / amu) enables observations of low energy ions (< 1 eV / q). Here we will present distributions of the cold ions observed during the Juno prime and extended mission. This data covers a wide range of latitudes and longitudes, providing a global picture of the topside ionosphere.

Oral [*Monday*] 10:00

Jovian Radio Occultations: Spatial De-trending and A Magnetic Perspective

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This study extends the research of Mendillo et al. (2022), which presented a spatial and temporal analysis of electron density profiles in Jupiter's ionosphere derived from radio occultation data obtained from the Galileo, Voyager, and Pioneer missions. These authors identify a number of outstanding questions concerning Jupiter's Ionosphere, such as the time-variable presence of a three-layer ionosphere, non-solar asymmetries in the peak electron density at dawn and dusk, and temporal variations in peak electron densities under similar solar cycle conditions. We investigate some of these outstanding questions by analysing the latitudinal and longitudinal differences in the observed electron densities during individual occultations, in conjunction with spatial variabilities in the magnetic field geometry and strength, which are evaluated using the JRM33 model. Preliminary findings indicate the electron density profiles exhibit organisation by latitudinal and longitudinal variations in the magnetic field geometry. For example, at a fixed longitude sector, the altitude profile of electron densities appears consistent at magnetically conjugate latitudes in the ionosphere, regardless of the latitude of the occultation; the three-layer ionosphere seems localised to low-latitude observations; and we observe distinct groupings in the altitude-electron density profile with occultation longitude. Although the physical mechanisms underlying these groupings require further investigation, our work provides new insights into Jupiter's ionospheric dynamics and lays the groundwork for Juno radio occultation and in-situ ionospheric measurements.

Stratospheric space weather on Jupiter: auroral-driven heating, chemistry and dynamics

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Jupiter has the largest and strongest planetary magnetic field and the most volcanically-active moon (Io) in the Solar System. This drives extreme space weather phenomena and makes Jupiter a unique target for studying the coupling between the atmosphere and external space environment. In this work, we present analyses of multiple datasets that capture the modulation of Jupiter's stratosphere by the magnetosphere and solar wind as well as support Juno's investigation of Jupiter's auroral emissions. Using a time series of mid-infrared images and spectroscopy recorded by Earth-based telescopes from 1994 to present, we demonstrate the magnitude and timescales over which stratospheric temperatures and abundances vary in response to external forcing. We also present analyses of high-resolution mid-infrared spectroscopy recorded on the IRTF and the SOFIA (Stratospheric Observatory for Infrared Astronomy) aircraft to determine the CH_4 homopause altitude (CHA) and its spatial and temporal variability at Jupiter's high latitudes. Improved constraints on the CHA support the analyses of Jupiter's ultraviolet auroral emissions recorded by Juno, Hisaki and Hubble. Using observations recorded at 65N, poleward of the main auroral emission (MAE) on July 6 2022 (near-contemporaneous with Juno's 43^{rd} flyby), we derive a CHA of 443^{+178}_{-51} km above the 1-bar level, which is approximately 70 km higher than the upper limit CHA derived from observations equatorward of the MAE. This demonstrates enhanced vertical transport inside Jupiter's main auroral oval compared to elsewhere on the planet and signifies a unique coupling between Jupiter's neutral atmosphere and external space environment.

Exploring the Jovian auroral vertical structure: Juno's view.

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Jovian auroras, the most powerful in the Solar System, result from the interaction between the magnetosphere and the atmosphere of Jupiter. While the horizontal morphology of these phenomena is widely studied, their vertical structure, determined by the penetration depth of the magnetospheric electron into the auroral regions, remains relatively unexplored. Previous observations, including those from the Hubble Space Telescope (HST), the Galileo probe, and the Subaru telescope, have addressed this question to a limited extent.

Thanks to observations from the UltraViolet Spectrograph (Juno/UVS), we have thoroughly examined the vertical structure of the auroral emissions. Building on the recent study by Benmahi et al. (2024), which mapped the average energy of precipitating electrons in auroral regions, we have developed a relationship between this average energy and the volume emission rate (VER) of H_2 for two types of electron energy distribution: monoenergetic and kappa distribution.

Using brightness maps, we derived the three-dimensional VER structure of Jovian auroras in both northern and southern regions, across multiple spacecraft perijoves (PJ). We found that the average altitude of the VER peak in the main, polar and outer emission regions, excluding the Io footprint emission, is approximately ~240 km for the case of monoenergetic distribution and ~190 km for kappa distribution case.

Our findings are, in average, consistent with measurements from the Galileo probe. This study contributes to a better understanding of the complexity of Jovian auroras and to highlight the importance of Juno observations to probe their vertical structure.

Electron Energization by Inertial Alfvén Waves in Density Depleted Flux Tubes at Jupiter

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Broadband energetic electron signatures dominate the UV aurora at Jupiter that in the terrestrial context are generally associated with the activity of dispersive Alfvén waves (Lysak and Lotko, 1996). While terrestrial Alfvénic energization usually peaks at a few keV (e.g. Chaston et al., 2002), broadband energy ranges at Jupiter reach relativistic MeV levels over the main auroral emissions (Allegrini et al. 2020). We illustrate, using a gyrofluid-kinetic electron model in curvilinear coordinates (Damiano et al., 2023), that high latitude inertial Alfvén waves (IAWs) are able to account for this extremely high energization owing to the very low densities that Juno JADE and JEDI observations illustrate accompany auroral flux tubes (e.g. Huscher et al., 2021; Sulaiman et al., 2022). These low densities imply that the IAWs must generate very large parallel electric fields (as also noted by Lysak et al. 2021) that energize electrons to these very high values in order to carry the parallel current. While IAWs can interact with electrons in both a resonant (Fermi) and non-resonant fashion (Kletzing, 1994), the relativistic Alfvén speed generally negates the applicability of the resonant energization at high latitudes and non-resonant energization naturally results in the production of highly field-aligned electron beams.

Electron Densities above Jupiter's Main Aurora and Implications on Auroral Acceleration

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Jupiter's Main Aurora has been classified into two distinct zones: an upward field-aligned current (FAC) region dominated by monodirectional electrons (Zone-I) and a downward FAC region with bidirectional electron beams (Zone-II). Wave-particle interactions have been theorized as the likely acceleration mechanisms to explain the broadband electron energies associated with the auroral zones. Alfvén waves and whistler-mode waves are the two leading candidates proposed to explain these observations. However, the interactions are highly dependent on the local plasma conditions in the low-altitude acceleration region. Here we present the distribution of auroral electron densities inferred from plasma wave spectra measured by the Juno/Waves instrument. We find that they remain persistently low, and we show trends and variabilities associated with the various auroral zones, altitude, and local time. Finally, we discuss the implications for auroral acceleration via wave-particle interactions, i.e. how conducive these conditions are to Alfvénic vs. whistler-mode interactions.

HST UV High Spectral Resolution View of Jupiter's Aurora: Neutral Temperature and Search for Proton Aurora

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The auroral current systems connecting the magnetosphere to Jupiter result in heating of the upper atmosphere. The deposited energy is 20-50 times the absorbed solar UV flux, so that this energy dominates the global energetics of the upper atmosphere. It is possible to measure the neutral atmosphere temperature in auroral regions at Jupiter through high resolution spectra of the H_2 emission bands. The ratio of band intensities can be modeled to reveal the ro-vibrational temperature of the emitting H_2. Recent (Jan. 2024) observations of the northern auroral region with HST / STIS and a high resolution grating were obtained with a slow scan of a long, narrow aperture across the emitting area. The field of view passed across most of the auroral region, including the magnetic footprint of Io and the downstream tail emission regions, with reasonable signal from the H_2 Lyman and Werner band emissions. The observations and subsequent modeling of the spectra will be presented.

Effect of magnetospheric conditions on the morphology of Jupiter's UV main auroral emission, as observed by Juno-UVS

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The jovian main auroral emission (ME) is known to be of variable size and morphology, though it is presently not fully understood in what way these properties depend on the state of the magnetosphere. A study of the variability in morphology of the jovian UV ME is presented, based on images from Juno-UVS from perijoves 1 through 54. Novel arc-detection techniques have been developed to automatically detect the ME in these images. The northern and southern ME are observed to expand and contract together, as are the day-side and night-side ME in both hemispheres, which indicates that the processes responsible for the variable expansion/contraction of the ME affect the magnetosphere globally and have timescales longer than 4 hours. The auroral footprint of Ganymede is observed to move poleward when the ME is contracted, which is not the case for the footprint of Io, which indicates that the expansion of the ME is predominantly caused by a stretching of magnetic field lines in the middle magnetosphere. This conclusion is supported by the correlation between increased magnetodisc current constant and the expansion of the ME. Finally, during periods of known compression of the magnetosphere, the ME is observed to be both contracted and brighter than average on the day side, as viewed by HST. These findings are then placed into the context of an Alfvénic generation of the ME.

Energetic Particles in Jupiter's Polar Cap

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One important, among the many, scientific discoveries that Juno made in its prime mission is the presence of upward energetic electron beams that fill Jupiter's polar cap auroral region. And in contrast, the sparse observations of downward electrons capable of producing the bright, patchy emissions routinely observed poleward of the main aurora. Together, these observations formed the basis for one of Juno's key magnetospheric science objectives in its extended mission—namely, revealing and understanding the low-altitude acceleration region over the polar cap. In this presentation, we report measurements from Juno's Jupiter Energetic particle Detector Instrument (JEDI) that suggest the spacecraft is beginning to traverse the low-altitude acceleration region in the northern hemisphere around 0.2 R_J. This conclusion is based on the energetic particle distributions exhibiting downward field-aligned angle beams with integral energy fluxes large enough to produce bright (i.e., 100s of kilo-Rayleigh) ultraviolet emissions. Plasma wave observations also provide key details that suggest Juno is crossing near the low-altitude source region (presentation by Dr. Sadie Elliott). The energetic particle observations and a more comprehensive analysis of the relevant extended mission orbits will be presented.

Evidence of the source of energetic electron beams over Jupiter's Polar Cap from Juno/Waves

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As Juno progresses into its extended mission phase, the spacecraft dips into lower altitudes above the northern polar region. Stemming from sparse observations of downward electrons capable of producing the bright polar emissions, one of Juno's objectives is to reveal and understand the low-altitude acceleration region over the polar cap. Here we show evidence of quasi-electrostatic plasma waves propagating along a resonance cone emerging from the northern polar cap during low altitude passes in the extended mission that are coincident with measurements of energetic electron beams. By virtue of the extremely magnetized plasma regime in this region, where fce/fpe is up to 10^4 (very rare in space plasmas), they are found to propagate up to the electron plasma frequency, enabling inference of electron densities of ~0.2 cm^{-3}. The wave generation mechanism and length scales are consistent with Landau resonance with the observed broadband-in-energy electron beams. Their quasi-electrostatic nature and frequency-time character imply a dispersion that is consistent with propagation along the resonance cone. As a result, we perform a statistical ray-tracing analysis to estimate the source of these plasma waves, which is assumed to be the location of the electron beam acceleration region. Our results demonstrate the reliable capability of utilizing plasma wave observations in this ultra-magnetized plasma regime to identify and estimate the distance to the electron acceleration region.

Identifying Connections between Jupiter's X-ray Aurorae and Radio, UV, Magnetic Field and Plasma Observations

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While the Voyager spacecraft were undertaking their paradigm-shifting explorations of the Jovian system in 1979, the Einstein X-ray observatory was also taking the first X-ray images of Jupiter (Metzger et al. 1983). Two decades later, the launch of the Chandra and XMM-Newton NASA and ESA Flagship X-ray observatories ushered in the modern era of X-ray astronomy. These complementary astrophysics platforms uncovered a variety of vibrant and dynamic X-ray aurorae, the majority of which mapped to sources beyond 50 R_J.

In this talk, through combined Hubble-Chandra, UV-X-ray auroral videos and XMM-Newton-Juno Waves time-series spectrograms we explore connections between these X-ray auroral emissions and what appear to be their UV and Radio counterparts. Exploring simultaneous Juno in-situ magnetic field and JEDI and JADE plasma data shows that the X-ray auroral pulsations share their pulsation rate with electromagnetic ion cyclotron waves, and anti-phase variations in the outer magnetosphere plasma and magnetic field data. The antiphase pulsations appear indicative of slow mode or mirror mode waves. We will speculate on how these shared multi-waveband periodicities may be causally linked, in an effort to unify connected auroral emissions and processes.

Finally, having noted connections between the X-ray and UV, we show preliminary analysis of the first spatially resolved XUV (60–170 Angstrom) observation of Jupiter, acquired through a technique we helped pioneer on Chandra. This shows up to an order of magnitude count-rate increase over typical X-ray observations. We discuss and show models that seek to identify the source of these enhancements.

A new type of Jovian hectometric radiation powered by monoenergetic electron beams

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In this study, we statistically analyze the Jovian auroral radio sources detected in situ by Juno/Waves at frequencies f below the electron cyclotron frequency f_{ce}. We first conduct a survey of Juno/Waves data over 1-40MHz from 2016 to 2022. The 15 detected HectOMetric (HOM) sources all lie within 1-5MHz and are both less frequent than the radio sources commonly observed slightly above f_{ce} and clustered in the southern hemisphere, within $\sim 90 - 270°$ longitudes.

We analyze these emission regions with a growth rate analysis in the framework of the Cyclotron Maser Instability (CMI), which we apply to JADE-E high cadence electron measurements. We show that the $f < f_{ce}$ emissions correspond to crossed radio sources, typically $\sim$ 800 km wide. They are located in a hot and highly depleted auroral plasma environment, along flux tubes colocated with upward field-aligned current and at the equatorward edge of the main auroral oval. The wave amplification is consistent with the CMI and its source of free energy consists of a shell-type electron distribution function (EDF) with characteristic energies of 0.2-5 keV. More energetic, 5-50 keV, shell-type EDFs were systematically observed at higher latitudes but without any radio counterpart. Various parameters for the $f < f_{ce}$ HOM sources, reminiscent of the ones at Earth/Saturn, are compared.

Other CMI-unstable EDFs, primarily loss cone ones, are systematically observed during the same intervals, giving rise to emission observed at $f_{ce} < f < f_{ce} + 0.5\%$. Our analysis thus reveals that different portions of the same EDF can be CMI-unstable and simultaneously amplify radio waves below and above f_{ce}.

Jupiter's magnetic field geometry and its relation with new decameter radiation events observed by Juno

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Decametric radio emissions (DAM) originating in Jupiter's polar aurorae ought to generate along magnetic field lines at the local electron gyrofrequency. The Io-related DAM have received particular attention since the 1980's, and it is expected that the maximum frequency of these emissions is bounded by the maximum magnetic field strength near the footprint of the instantaneous Io Flux Tube. DAM have been observed from Earth and spacecraft flybys before Juno, limiting the observation geometry to equatorial latitudes. Since 2016, and thanks to Juno, we have been able to observe Io-related DAM from a wide range of latitudes, leading to the observation of a new DAM feature that we preliminarily called "butterfly". We analyze the Waves data from May 2016 to June 2023 searching for these butterflies to catalog them and determine their relationship with Io and the Jovian magnetic field. Based on the observation geometries, we found that these events (˜ 135) are Io-related, they are always observed when Juno is in southern latitudes, they last for ˜5 hours and their maximum observed frequency is ˜20 MHz. As Juno is spending more time in southern latitudes as the mission progresses, the observation of butterflies keeps increasing over the years. Here, we study the role of the dipolar magnetic field of the southern hemisphere of Jupiter in the generation and observation of the butterfly events.

Oral [*Monday*] 15:15

Is it possible to identify open magnetic flux in Jupiter's magnetosphere?

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Numerical simulations have shown that Jupiter's magnetosphere has a very different magnetic field topology compared with the familiar terrestrial magnetosphere [Zhang et al., 2021]. The simulated open flux region is confined to crescent region, bounded by closed flux in the lower and higher latitude regions. On the dawn flank, the open flux region can exhibit anti-corotational flows, consistent with solar wind flow [Delamere et al., 2024]. However, the open flux is highly variable, so it is possible that open (closed) field lines, created through intermittent reconnection, can also exhibit corotational (anticorotational) flows and contain magnetospheric (solar wind) plasma. Numerical simulations can determine, via field line tracing, whether fields are open or closed (a consideration that is almost intractable from observational analysis alone). Therefore, a promising method to identify open flux signatures in Juno data, is through a careful data/model comparison approach. With this motivation in mind, we will discuss properties (e.g., flow shear, KH stability, magnetic reconnection) of the mid-mid-latitude open/closed boundaries in the Grid Agnostic MHD for Extended Research Applications (GAMERA) simulations and the implications for transport of mass, momentum, energy, and magnetic flux. To further quantify transport properties, we will review the results from test particle simulations, identifying properties of particles on open field lines for data comparison. Simulated parallel currents and Alfvénic Poynting flux at the ionospheric boundary will be used as proxies for auroral emissions [Zhang et al., 2021]. We will compare with Juno auroral images to determine potential auroral signatures of open vs. closed flux.

Quasi-periodic flapping magnetodisk of Gas Giants: Cassini and Juno Observations

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Quasi-periodic signals in the measurement of energetic particles, plasma waves, field-aligned current, and auroral activities throughout the magnetosphere of Saturn and Jupiter. The origin of modulations in the period of 60 minutes at Saturn (QP60) and 40-80 minutes at Jupiter (QP40-80) remains enigmatic. Based on in-situ observations taken by Cassini and Juno, we report multiple cases showing the quasi-periodic flapping motion of Saturnian and Jovian magnetodisk. One-to-one correlated modulations of energetic electron fluxes are also recorded. We also report the repeatingly observed QP60 flapping magnetodisk and electron flux oscillations modulated by planetary period oscillations (PPO) at Saturn. Our observations indicate quasi-periodic flapping motion of the magnetodisk as a new component of QP phenomena in the magnetosphere of gas giants. A comprehensive model explaining the QP activities of gas giants may need to include the near-equator region (flapping), mid-latitude (field-aligned current system), and magnetosphere-ionosphere coupling (auroral activities and bi-directional electron beams).

Investigating the Effects of Clock Angle on Jupiter's Polar Aurora

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Jupiter's aurora is the largest and most dynamic in the solar system. It is primarily driven by the rapid rotation of its magnetosphere and the internal plasma within. However, our understanding how the solar wind impacts Jupiter's aurora is still limited. Specifically, the relationship between interplanetary magnetic field clock angle and auroral intensity is not well-understood. Improving our comprehension of this can provide insight into the importance of magnetopause reconnection, which may occur at high magnetic latitudes, in driving Jupiter's aurora.

To explore Jupiter's interaction with the solar wind we investigate 12 visits of the Hubble Space Telescope during Juno's approach phase in 2016. Following Nichols et al (2017), we compare in situ Juno data of the solar wind to auroral images, focusing on the polar regions. The relationship between the IMF clock angle, solar wind ram pressure, and UV auroral brightness are analysed. We also investigate the shape of the polar region of Jupiter's northern aurora with varying solar wind parameters.

Revisiting the Form of the Jovian Bow Shock and Magnetopause: Most-Likely Locations based on Juno and MMESH data

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On the largest scales, the size and shape of Jupiter's magnetosphere is determined by the balance between the external solar wind dynamic pressure and the various internal pressure components driven by the rapidly rotating, plasma-laden magnetosphere. Both the external and internal pressures are highly dynamic, and can vary dramatically over timescales shorter than a Jovian day. Existing models for the magnetospheric boundaries, the bow shock and the magnetopause, are typically simplified by considering the effects of just one of these pressures. Such models, however, have to be used cautiously under the highly variable conditions of the Jupiter-solar-wind interaction. Here we present ongoing work into new, data-driven descriptions of Jupiter's bow shock and magnetopause as functions of ambient dynamic pressure, which have been found by fitting independently identified Juno boundary crossings to propagated solar wind conditions from MMESH (the Multi-Model Ensemble System for the outer Heliosphere) [Rutala et al., submitted, 2024]. Unique to this study, we consider both the varying internal and external pressures to determine statistically likely boundary locations by interpreting the fitted data (modeled dynamic pressure and boundary position) as probability distributions. The probability distribution for the dynamic pressure is obtained from MMESH, while probability distributions for the boundary position are estimated by comparison to the probabilistic location of a modeled boundary under constant solar wind conditions. A variety of functional forms for the boundaries are tested, and the resulting forms, coefficients, and distributions presented are compared to previous boundary models at different planets.

Jupiter's dawnside magnetodisc: the force-balance context to Juno observations

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We employ an iterative vector potential model of force balance in Jupiter's dawnside magnetodisc in order to examine the physics behind variations in the total azimuthal current previously observed by Juno. Specifically, we vary three key parameters that govern the force balance: a hot plasma parameter (=pV), the iogenic plasma mass outflow rate, and the ionospheric conductivity. We consider data obtained by Juno on orbits 1-12 as the spacecraft travelled inbound towards Jupiter and crossed the Jovian magnetodisc in Jupiter's middle magnetosphere. We fit the model to the residual component of the magnetic field and the density of the plasma sheet ions, finding the best-fit parameters for each orbit. We find orbit-by-orbit variations in the best-fit parameters, demonstrating a dynamic plasma sheet. We find a relation between the total azimuthal current in the magnetodisc and the hot plasma parameter, demonstrating that it is the hot plasma which predominantly governs variations in the total azimuthal current in the magnetodisc.

Juno Observations of Jupiter's Duskside Magnetospheric Structure, Dynamics, and Boundary Regions

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Jupiter's magnetosphere displays strong local time asymmetries in properties such as the magnetic field, plasma sheet thickness, and flows derived from energetic particles. Fully characterizing the nature of these local time asymmetries provides important observational constraints for conceptual models of plasma and energy circulation in Jupiter's magnetosphere. Juno's extended mission (EM) is providing an unprecedented view of Jupiter's high-latitude duskside magnetosphere, enabling studies of the duskside plasma sheet and tail lobe structure and the distribution of open flux across the magnetotail and placing new constraints on the magnetopause flattening. Here I will present new analysis using magnetometer data from Juno's primary and extended mission to create 2-D fits describing how the lobe magnetic pressure and plasma sheet magnetic and thermal pressures change with radial distance and local time. I will also use Juno magnetic field data to identify magnetopause crossings and to characterize the latitudinal dependence of the field bendback angle and its temporal variability, such as its response to a solar wind-induced magnetospheric compression. Near dusk in the middle magnetosphere (~30-60 Jovian radii, ~18:00-20:00 LT), the high-latitude Juno magnetic field measurements are typically bent forward, though the near-equatorial Galileo observations show a typically bent back field in that region. I will discuss implications of these findings on the expected field-aligned currents and local time asymmetries in Jupiter's M-I coupling system. Finally, I will examine how duskside magnetospheric activity observed by Galileo and Juno compares to the highly dynamic intervals of tail reconnection observed by those spacecraft in the pre-dawn magnetosphere and discuss implications for mass and flux transport in Jupiter's magnetosphere.

The Io torus and highlights from 10 years operation of the Hisaki mission

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The Io plasma torus (IPT), located in the Jovian inner magnetosphere (6-8 R_J from the planet), is filled with electrons and heavy ions such as sulfur and oxygen, a significant portion of which originates from the volcanoes on Io. The IPT serves as a crucial region connecting the primary plasma source (Io) with the middle and outer magnetosphere, where highly dynamic phenomena occur. Understanding the behavior of plasma in the IPT is essential for discussing the plasma dynamics in the whole Jovian magnetosphere. A comprehensive understanding of the IPT can be achieved through spectral analysis of ion emissions, which are generated by electron impact excitation. This method is called "plasma diagnostics." The emission lines from ions in the IPT are mainly in the extreme ultraviolet (EUV) region. Therefore, EUV spectroscopic data are important for the study of Jupiter's inner magnetosphere.

Hisaki, an Earth-orbiting spacecraft equipped with the extreme ultraviolet spectroscope EXCEED, has been providing high-resolution spectra of the IPT from 2013 to 2023. Here we present a summary of 10 years of operations for IPT spectroscopic observation by Hisaki. Ion and electron density variation, the relationship between the IPT and auroras, and responses to volcanic activity will be discussed.

Io's magnetospheric source rate extremes derived from neutral oxygen torus observations and 3-D modeling

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The Jovian system is very intriguing with extremely different particle sources. 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) sources,

Since its launch in 2013, the JAXA Hisaki mission has provided unprecedented observations of the Jovian system with its extreme ultraviolet spectroscope 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. These oxygen UV line of sight (LOS) observations revealed an intriguing amount of spatial and temporal data shedding 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 the range of Io's source of particles to Jupiter's magnetosphere and the resulting neutral tori populations during apparent quiet and active periods.

Variability of the Io Plasma Torus Through Juno Perijove 49

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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 Juno's extended mission, through Perijove 49. During Juno's extended mission the spacecraft's orbit is precessing in such a way that makes performing usable radio occultations difficult. Thus, the temporal spacing between data is becoming inconsistent. We show all orbits where there was a clean profile through Perijove 49. The temporal and longitudinal variability can be pulled out from the years of observations.

The Io Plasma Torus State during the Juno Mission: Constrains from the Radio Occultations and the Io Auroral Footprint

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The innermost Galilean moon of Jupiter - Io - orbits within the magnetosphere of Jupiter, and its volcanism supplies the material for the whole magnetosphere. The sulfur dioxide dispersed from Io supplies a torus-shaped plasma cloud called the Io Plasma Torus (IPT). The IPT material diffuses outward, and the presence of Iogenic plasma crucially determines the details of the ionosphere-magnetosphere coupling. The monitoring of the IPT is hence a fundamental tool to understand the details of the Io-Jupiter coupling and to shed light onto the mass and energy transfer between Io, the IPT and the magnetosphere.

Since 2016, the Juno spacecraft has been orbiting Jupiter in highly eccentric, polar orbits, hence (1) radio occultations of the IPT are performed when Juno is near the closest approach to Jupiter and (2) the Io footprint can be observed when the spacecraft flies over the polar regions. These two observables wrap information about the distribution of plasma around Io's orbit: the radio occultations are affected by the total electron content between Juno and the Earth's ground station – including the IPT – while the footprint position by the Io-ionosphere currents, whose path is affected by the plasma density along the magnetic field lines through the moon. Therefore, Juno observations represent an indirect, periodic monitoring of the IPT conditions. These observations are compared with a theoretical model based on Voyager 1 data. We will show the results obtained from this dataset from Juno orbit 1 to orbit 43.

Io Input/Output observatory (IoIO) observations of the Io plasma torus: evidence that IPT radial diffusion is driven by internal processes

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Two hypotheses have emerged as to the source of the superthermal electrons that control radial diffusion in the IPT (1) injection events from reconnection in the magnetotail (Louarn et al. 2014, Murakami et al. 2016) (2) Alfvén waves within the IPT (Copper et al. 2016, Coffin et al. 2020). In this work, we present comparisons between 7 years of IPT observations recorded by the Planetary Science Institute's Io Input/Output observatory (IoIO; Morgenthaler et al. 2019, 2024) and Multi-Model Ensemble System for the outer Heliosphere (MMESH) calculations of the solar wind at Jupiter (Rutala et al. 2024) to investigate these hypotheses. We use the fractional eastward shift, epsilon, of the IPT to measure the magnetospheric convection electric field and show that there is only a weak linear correlation to solar wind parameters on the longest timescales (300 days). Similarly, there is limited correlation between epsilon and IPT brightness. The only repeatable correlation is when the IPT brightness comes to a sharp local maximum, epsilon comes to a sharp local minimum. These results suggest that radial diffusion from the IPT fills and extends the magnetosphere, increasing epsilon, and plasma loss from the magnetosphere decreases epsilon. The lack of correlation between IPT brightness and plasma loss from the magnetosphere or the solar wind suggests that processes of reconnection are not involved in IPT radial transport, supporting hypothesis (2): Alfvén waves within the IPT provide the necessary heating to drive radial transport.

Oral [*Tuesday*] 10:55

Modeling Anisotropic Maxwellian and Kappa Field Line Distributions in Io's Plasma Torus using Multi-Fluid and Kinetic Approaches

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Static pressure or force balance along a magnetic field line in the MOP community has long been referred to as diffusive equilibrium, which gives the density distribution of a multi-species plasma along a given field line, given reference densities and temperatures. These models use different assumptions and starting points (kinetic vs fluid equations typically collisionless) that lead to diverging solutions. In this work, we will compare the work done by others and apply their theories using our nominal radial centrifugal equator reference densities and temperatures in the Io plasma torus along with the latest Juno-based JRM33 + Con2020 current sheet magnetic field model with various assumed anisotropies, and distribution functions (Maxwellian vs Kappa vs fried egg). Furthermore, we build on this work to correctly state the assumptions used and model the distributions starting from a kinetic or fluid perspective with and without collisional chemistry and the implications for the necessity of additional heating terms due to wave-particle interactions and turbulence. We will then compare our modeled range in torus conditions at Io and Europa throughout their orbit and implied Alfvén speeds and travel times throughout the torus.

Oral [*Tuesday*] 11:10

Magnetospheric Science Enabled by Coordinated JUICE and Clipper Investigations

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ESA's JUpiter ICy moons Explorer (JUICE) launched on April 14, 2023, beginning an eight-year journey to the Jupiter system arriving in 2031. NASA's Europa Clipper is scheduled to launch in October 2024, and arrives in the Jupiter system in 2030, a year ahead of JUICE. Having two flagship-class spacecraft in close proximity in time and space affords unprecedented opportunities for synergistic observations of the overall Jupiter system, as well as opportunities for unique heliospheric and magnetosphere science during cruise and Jupiter approach phases.

Interplanetary cruise represents a rare opportunity to investigate the evolution of the solar wind plasma and interplanetary magnetic field and related structures such as Coronal Mass Ejections (CMEs) or Corotating Interaction Regions (CIRs) with two spacecraft beyond Mars orbit. The approach phase of JUICE while Europa Clipper orbits within the magnetosphere provides a unique opportunity to study longstanding questions relating to the solar wind-magnetosphere interaction and resulting aurora. These topics would be greatly aided by observations from other operational missions and ground- and space-based observatories.

Once JUICE and Clipper are both in orbit about Jupiter, multiple opportunities exist for joint magnetospheric science at several different targets within the Jovian system, including at Europa, Ganymede, and Callisto and as a result of a campaign of dual point measurements in the wider magnetosphere. In this presentation, we will discuss some of the potential combined science from JUICE and Clipper that can further enhance and inform our understanding of the Jupiter system and moon-magnetosphere interactions.

A self-consistent model of radial transport in the magnetodisks of gas giants including interhemispheric asymmetries

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The magnetospheres of gas giants are characterised by their strong magnetic fields, the fast rotation of the planet and the presence of embedded active moons (Io at Jupiter, Enceladus at Saturn), releasing neutral gas and plasma in the innermost regions of the systems. Their dynamics is controlled by a balance between the centrifugal force, plasma pressure gradients and magnetic forces. It results in the formation of an equatorial plasma disk and a global outward transport of plasma from the innermost regions to the outer magnetosphere where it is lost.

Until now, description of this transport has followed two different approaches in the literature: "corotation enforcement" models of angular momentum transport in a disk coupled to the planetary thermosphere/ionosphere via electric current systems; and models of radial diffusion of mass and energy assuming a certain state of turbulence in the magnetodisk.

We present a unifying approach of the radial transport of mass, angular momentum and energy, using turbulent diffusion and including sources and sinks of plasma with arbitrary radial distribution. Our set of coupled equations independently describes momentum exchange with the two conjugate ionospheres, thus allowing for the study of interhemispheric asymmetries, such as the ones revealed by Juno, in this coupling. We derive solutions that explore the possible causes and effects of interhemispheric asymmetries, with emphasis on the cases of latitudinally thin and thick disks, respectively corresponding to Jupiter and Saturn. We compare the outputs with recent observations by the Juno and Cassini missions.

Plasma injections at Saturn and their local time of origin

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Many injections detected in plasma and energetic charged particle data in Saturn's inner magnetosphere contain clues about their inflow speed and the local time and radial distance of their origin. These variables can potentially help separate injections that are signatures of plasma recirculation from those that result from large-scale, disruptive processes. Many techniques have been used to understand Saturn's magnetosphere and map injections across radial distances. For example, we have inferred characteristics of injections from phase space density conservation and drift-out patterns in the most energetic particles. In this presentation, we will review what has been established about injections and their local time of origin from multiple data sets and also present newer work.

Evolution of Interchange structures in rotating magnetospheres: the role of force balance within magnetodiscs

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Giant magnetospheres exhibit high levels of dynamic variations due to their rapid rotation and internal plasma sources from moons, which are characterized by complex physical processes. A quantitative analysis of the balance of forces within the magnetodisc is essential to understand the global dynamics of fast-rotating, giant magnetospheres. In this study, we conducted three-dimensional, high-resolution global MHD simulations of the Jovian and Kronian magnetospheres, focusing on the impact of internal force balance on the dynamic evolution of the magnetodiscs. Results demonstrate that the evolution of interchange structures is governed by the rate of internal mass loading, primarily by changing the ratio between the centrifugal force and the magnetic tension force. This theoretical study is of great significance in understanding the internal dynamics of planetary magnetospheres driven by rotation, with applications in both the Jovian and Kronian magnetospheres.

The roles of flux-tube entropy and effective gravity in the inward plasma transport at Saturn

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The inward plasma transport at Saturnian magnetosphere is examined using the flux tube interchange stability formalism developed by Southwood and Kivelson (1987). Seven events are selected. Three cases are considered: (1) the injected flux-tube and ambient plasmas are nonisotropic; (2) the injected flux-tube and ambient plasmas are isotropic and (3) the injected flux-tube plasma is isotropic but the ambient plasma is nonisotropic. Case (1) may be relevant for fresh injections while case (3) may be relevant for old injections. For cases (1) and (2), all but one events have negative stability condition, suggesting that the flux-tube should be moving inward. For case (3), the injections located at $L > 11$ have negative stability condition, while 4 out of 5 of the injections at $L < 9$ have positive stability condition. The positive stability condition for small L suggests that the injection may be near its equilibrium position and possibly oscillating thereabouts—hence the outward transport if the flux tube overshot the equilibrium position. The flux-tube entropy plays an important role in braking the plasma inward transport. When the stability condition is positive, it is because the entropy term, which is positive, counters and dominates the effective gravity term, which is negative for all the events. The ambient plasma and drift out from adjacent injections can affect the stability and the inward motion of the injected flux tube. The results have implications to inward plasma transport in Jovian magnetosphere as well as other fast rotating planetary magnetospheres.

Oral [*Tuesday*] 14:15

A new empirical plasma environment model of Saturn and its key moons

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As part of the ESA Testbed for Radiation and Plasma Planetary Environments Development (TRAPPED) project, we are developing an empirical model of the plasma environment at Saturn in support of researchers and industry for future mission planning at the ringed giant.

The 13-year Cassini mission has provided a wealth of multi-instrument measurements and multiple techniques to determine plasma moments obtained using the Cassini Plasma Spectrometer (CAPS), operational between 2004 and 2012, and the Radio and Plasma Wave Science (RPWS) instrument, operational for the full mission i.e., 2004-2017, including electromagnetic (EM) wave observations and the Langmuir Probe.

We present the first empirical model of Saturn's plasma environment that combines all publicly available plasma moment measurements determined from Cassini observations. We compute this model based upon the average plasma moments to provide a general illustration of Saturn's plasma population. We also investigate the variability of plasma moments with respect to L-shell, latitude, normal distance to the current sheet, and local time in order to identify potential plasma spatio-temporal dynamics.

Given that Enceladus' southern geysers and Titan's atmosphere act as source regions for the plasma in Saturn's magnetosphere and are therefore potential targets for future space missions, we include these moons and their respective local environments into our modeling framework.

We also aim to explore the possibility of expanding the application of this modeling framework to Uranus and Neptune, even if only Voyager 2 observations are available for the ice giants.

Dynamics of Planetary Magnetospheres Revealed by Wave Phenomena

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Rapid changes in solar wind conditions perturb the planetary magnetospheres, modifying the properties of the plasma within, providing energy for the generation of radio emissions and plasma waves. These waves reveal the dynamic processes in and around the planetary magnetospheres. The emissions often display periodicities caused by magnetic compressional waves induced by solar wind impact. Solar wind compressions increase the plasma density in the magnetosheath, keeping low-frequency radio emissions from escaping the planetary magnetosphere (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 the dynamics of planetary magnetospheres.

Oral [*Wednesday*] 09:00

Ice Giant Magnetospheres

C. Paty[1]

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The Ice Giant Magnetospheres provide some of the most interesting natural laboratories for studying the influence of large obliquities, rapid rotation, highly asymmetric magnetic fields, and large Alfvénic and sonic Mach numbers on magnetospheric processes. Uranus is subjected to extreme seasonal variations resulting from the nearly 98° tilt of its rotation axis. At both Uranus and Neptune, the solar wind-magnetosphere interaction varies dramatically on diurnal and seasonal timescales due to the apparent offset and large tilt of the dipole field. With in situ observations limited to a single encounter by the Voyager 2 spacecraft, a growing number of analytical and numerical models have been put forward to characterize ice giant magnetospheres and test hypothesis related to magnetospheric boundary layers, the solar wind interaction, the formation of the radiation belts, understanding charged particle precipitation, aurora, and energy deposition to the atmosphere, and quantifying potential plasma sources and the distribution of plasma observed. Yet despite these recent studies, many questions regarding the observations of the Ice Giant magnetospheres remain unanswered. This has led to great community interest in revisiting these distant worlds, with the Decadal Survey placing the Uranus Orbiter and Probe (UOP) as the highest flagship mission priority, and the Planetary Mission Concept Study Neptune Odyssey receiving tremendous support as well. In this tutorial I will describe the current understanding of the ice giant magnetosphere, as well as the key magnetospheric science questions motivating the UOP mission.

A localized and surprising source of energetic particles in the Uranian magnetosphere near Ariel

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A new survey of energetic particle observations from the Low Energy Charged Particle (LECP) instrument on Voyager 2 revealed a previously underappreciated signature. Specifically, LECP observed a significant discrepancy between the intensity of energetic particles (ions and electrons) observed during the outbound leg of the Uranus flyby encounter in the region between Miranda and Ariel compared to the inbound leg. Of particular interest are the pitch angle distributions measured by LECP, which display extremely steep gradients. Such a steep gradient in pitch angle is difficult to maintain since any waves would act to scatter the particles and isotropize the distribution. Maintaining such a steep PAD would require a significant and relatively constant source of energetic particles, specifically for those at near-90° pitch angles, at rates that can balance or even overcome any loss/scattering processes from waves. To assess whether such an energetic particle source is in fact present in the Uranian system, distributions of the phase space density profiles of the ions were investigated. A clear maximum between Miranda and Ariel at L˜7 suggests a source of energetic ions in this region. Potential energetic particle sources include particle injections, CRAND, and an active moon (i.e., a candidate ocean world). Both particle injections and CRAND are believed to be unlikely sources. However, an active moon source is potentially plausible as the narrow pitch angle source required matches that expected from newly created pickup ions. These results suggest the exciting possibility of the existence of a potential ocean world(s) in the system.

Seasonal, diurnal and solar wind driven variability in model-predicted reconnection voltages applied to Uranus' dayside magnetosphere

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Uranus provides a key missing piece for fundamental comparative planetary magnetospheres and solar wind-magnetospheric interactions due to its location in the outer solar system and its 'vacuum' magnetosphere with weak plasma sources. Currently, we do not know whether a viscous-like interaction will overtake global magnetic reconnection as the dominant process in solar wind-magnetospheric interactions at the outer planets, or if global magnetic reconnection will remain dominant as it does at the Earth. A link to resolve this paradigm with a Uranus mission would be to provide a step change in our understanding of one of these two processes at Uranus. It is possible to assess the effectiveness of magnetic reconnection between the interplanetary and planetary magnetic fields in driving Uranus' magnetosphere by quantifying the voltage that is applied to the magnetospheric system due to reconnection processes. Through analytical modelling, we present predictions of the dayside reconnection voltage at Uranus under different magnetospheric configurations. We find that the typical reconnection voltage applied at Uranus' dayside magnetosphere is ~10 kV, lower than that determined at Earth and other planets within the solar system. We will also explore whether the reconnection voltage exhibits dependence on diurnal, seasonal, or solar wind variabilities. This will allow us to investigate the role of reconnection processes in solar wind-driven magnetospheric dynamics and whether reconnection is driven in cycles at Uranus, helping us to better understand the 'open-closed' magnetospheric dynamics that have been observed in magnetospheric models of Uranus.

Uranus' magnetosphere was observed in an anomalous state by Voyager 2

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The Voyager 2 flyby of Uranus in 1986 revealed that the planet hosts an unusual magnetosphere with a highly oblique and off-centered internal magnetic field. The prevailing understanding of the Uranian magnetosphere is based on this single observation, leading to a description of the system as a canonical extreme case, with inexplicably intense electron radiation belts and a magnetosphere that is seemingly largely void of plasma. The properties of this complex magnetosphere, however, cannot be understood without carefully considering the role of external forcing by the solar wind. Here we show that Voyager 2 observed Uranus' magnetosphere in an anomalous, compressed state that we estimate to be present <5% of the time. Contrastingly, our findings show that had Voyager 2 arrived at Uranus just a few days earlier, the upstream solar wind dynamic pressure would have been ~20 times lower, resulting in the observation of a dramatically different magnetospheric configuration. Therefore, just prior to the flyby, the Uranian magnetosphere became severely compressed which would drive magnetospheric dynamics and consequently affect the findings from this single flyby. This includes increasing energetic electron fluxes within the radiation belts as well as emptying the magnetosphere of its internal plasma, providing possible explanations for the major mysteries that have surrounded Uranus since the Voyager 2 flyby. Furthermore, our results have significant effects with regards to detecting subsurface oceans at the planets icy moons by a future spacecraft.

Oral [*Wednesday*] 10:10

Cosmic rays interacting with Neptune's asymmetric magnetic field

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Cosmic rays are energetic charged particles of solar, galactic, and extragalactic origin that pervade the Solar System. Around each strongly magnetised planet the motion of these protons and alpha particles are affected by the planetary magnetic field, leading to different patterns of precipitation onto the planet for different particle energies. This precipitation contributes to atmospheric ionization and leads to cloud formation.

At Neptune, the weak flux of solar photons means that understanding the interaction between cosmic rays and the planetary magnetic field is particularly important for understanding the coupling between space and the planet's atmosphere, and we already have evidence that this precipitation controls long-term changes in global cloud cover.

Here we perform a detailed assessment of cosmic rays interacting with Neptune's asymmetric magnetic field. This assessment includes numerical solutions to the equation of motion for individual cosmic ray test particles of differing magnetic rigidity, a parameter that reflects how easily a particle can be deflected by a magnetic field. We compute the cut-off rigidity for vertical incidence onto the atmosphere at a range of latitudes and longitudes, and build maps of precipitating fluxes for different particle energies.

We show that asymmetry in Neptune's magnetic field structure produces results that differ significantly from those in a more dipolar field, with highest cut-off rigidities of order 10 GV as expected. The magnetic field asymmetry leads to north-south asymmetry in cosmic ray precipitation. We discuss possible implications for the interaction between these particles and Neptune's atmosphere, to be explored in further work.

Oral [*Wednesday*] 10:55

Reanalysing, recalibrating, and archiving Voyager 2 Plasma Science data for Uranus

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Both Voyager 1 and 2 are equipped with the Voyager Plasma Science (PLS) experiment: four Faraday cups that can measure the properties (temperature, density and charge) of the low energy ions and electrons. During the Voyagers journey towards the interstellar space and the flybys from the gas giants PLS gave us the first in-situ data of the solar wind in such great distances, the magnetospheric plasma composition of the gas giants, and the extent of our heliosphere along with the conditions of the interstellar medium.

Voyager was particularly important for the study of the gas giants, as it was the first time we had in-situ plasma measurements from inside the magnetospheres, and PLS helped in studying not only the morphology of the magnetosphere, but also the plasma sources, properties, interaction with the moons, and ultimately its interaction with the solar wind plasma.

Jupiter and Saturn were visited from both Voyager 1 and 2, but only Voyager two visited Uranus and Neptune. The PLS data for Jupiter have been re-calibrated and archived with the works of Bagenal+ [2017], Dougherty+ [2017], and Bodisch+ [2017]. They also developed an IDL package, VIPER (Voyager Ion PLS Experiment Response) for their analysis. For this work we re-analyze the Voyager PLS data for Uranus. We present our methodology, the incorporation and adjustment of VIPER for the Uranian conditions and the results of the analysis so far.

The 30 year search for infrared aurorae at Uranus

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Since the discovery of H_3^+ at Uranus in 1992 (Trafton, et al., 1993) the question of what Ice Giant aurorae would resemble (due to the planet's offset and tilted magnetosphere) has continued to haunt ionospheric exploration. Prior investigations (Lam, et al., 1997, Trafton, et al., 1999 and Melin, et al., 2019) were unable to detect the aurorae due either to the low resolution of 20th century telescopes or the long-term cooling of Uranus's upper atmosphere which reduced the H_3^+ signal by 97% (Melin, et al., 2019). So, our aim was to locate the infrared aurora using high spatial resolution data to assign latitude and longitudes, focusing on earlier data to mitigate the effect of Uranus's cooler temperatures.

A perfect situation presented itself in September 2006 close to the planet's equinox when both aurorae were observable. We extracted intensity, temperature, column density and total emission variables from the night's spectra by analysing fundamental H_3^+ emission lines. Assigning these values to mapped locations, our findings highlighted enhanced emissions that covered latitudes of the northern aurora (Q3mp model and Voyager II). When aligned in longitude, these emissions appeared to curve similar to a polar cusp edge like at Earth, Jupiter and Saturn. At these emissions we also identified raised column densities which could only be attributed to auroral activity. We hence concluded that, for the first time, a confirmed observation of Uranus's northern infrared aurora was observed, highlighting the need to document the southern aurora and investigate the infrared aurorae at Neptune.

The Search for Uranus with XMM-Newton

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Uranus was added to the list of local X-ray emitters in 2021 after analyses of data obtained by the Chandra X-ray Observatory in 2002 and 2017. Results gave a flux higher than expected if the emissions were only due to the planet's atmosphere scattering solar X-rays and showed hints of temporal variability. This suggests that there may be other processes at work, such as fluorescence from the rings and/or atmosphere and auroral emissions. To confirm Chandra's detection, and to determine how this mysterious Ice Giant generates X-rays, a campaign with XMM-Newton spanning a total of 364 ks (˜6 Uranus rotations) took place over three occasions in August 2022, January 2023 and February 2023. We present our initial results of the XMM-Newton dataset and highlight whether the European Space Agency's flagship X-ray observatory's superior sensitivity and spectral resolution can constrain the atomic composition of the Uranian rings and upper atmosphere and through detecting Solar Wind Charge Exchange X-rays, explore whether the Uranian aurorae are from the planet's cusps.

The ionospheres of Uranus and Neptune as observed by JWST

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Near-infrared observations of emission from the molecular ion H_3^+ obtained over the last 30 years revealed the physical properties of the ionospheres of Jupiter and Saturn, and how this region interacts with both the magnetosphere and the atmosphere below. The most striking manifestation of these processes is the aurora, occurring about the magnetic poles. However, similar studies of Uranus and Neptune has proven extremely challenging, given their small angular size in the sky and the large distances from the Sun. Whilst H_3^+ was detected at Uranus in 1992, any distinct auroral emissions have remained elusive, and at Neptune, emissions from the ion has never been observed, despite numerous attempts. Here, we present JWST NIRSpec observations of Uranus and Neptune, providing the most detailed data of the ionospheres of these planets to date. We present surprising features present in the data, including dark ionospheric regions at Uranus, and discuss how these kinds of data can provide science drivers for future robotic exploration.

Mapping lightning generated whistler waves through near-Uranus space

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The presence and occurrence rate of lightning can reveal fundamentally important information about the planetary environment. For lightning to occur, atmospheric convection must take place and there must be significant separation of charged particles within the atmosphere. Therefore, lightning provides critical insight to the convection patterns and constituents of planetary atmospheres.

When lightning strikes occur, they generate very low frequency plasma waves called 'whistlers' that propagate through the surrounding space environment. These whistlers travel along the magnetic field lines and can be detected by spacecraft with plasma wave instrumentation. The location and properties of these whistler waves can be used to evaluate both the location and intensity of the lightning strikes that generated the waves, and evaluate the magnetospheric plasma environment that the waves travelled through. Detection of lightning-generated whistlers at Uranus can therefore address multiple key science questions listed in the 2023 planetary decadal for the Uranus Orbiter and Probe.

We evaluate the propagation of potential lightning generated whistler waves through the Uranian magnetosphere. We use a simplified two-dimensional simulation of Uranus's magnetosphere and cold plasma environment, and perform ray tracing to evaluate the propagation of whistlers through near-Uranus space. The starting position of these waves is set at the location of the brightest storm ever observed at Uranus, and they propagate through a low-density plasma and a tilted dipole magnetic field. We map these whistlers throughout near-Uranus space and evaluate the probability of in-situ observation of lightning generated whistlers with a plasma wave instrument onboard a Uranus Orbiter.

Simultaneous James Webb and Hubble Space Telescope observations of Jupiter's H_3^+ and FUV auroral emission

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We present initial results from a recently-executed programme of observations of Jupiter's northern auroras including simultaneous JWST/NIRCam imaging or NIRSpec/IFU spectral imaging of Jupiter's near-infrared (NIR) H_3^+ emissions, and HST/STIS imaging or high-resolution spectral imaging of Jupiter's far-ultraviolet (FUV) auroral emissions. This programme provides the first imaging of Jupiter's H_3^+ emissions at 0.06"/pix resolution and 3s temporal resolution (respectively, ~1 and ~2 orders of magnitude greater than that typically achieved from the ground); the first simultaneous time-resolved imaging of Jupiter's FUV and H_3^+ emissions, and the first STIS/G140M spectral scan of Jupiter's FUV emissions with sufficient spectral resolution to resolve the H_2 lines. Movies of the H_3^+ emission exhibit Jupiter's auroras in a new light, revealing remarkable variability of the H_3^+ emission down to the 3 s resolution. We present an initial overview of the time-variable morphological features, highlighting differences and similarities between the morphologies of the H_3^+ and FUV emissions. These observations will enable a detailed study of the temperature, density and lifetime of H_3^+ in Jupiter's auroral ionosphere.

Jupiter's pole-to-pole vertical ionospheric profiles from JWST

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JWST programme #3665 successfully observed ionospheric emissions above Jupiter's limb in September 2023, December 2023 and January 2024, exploring the tenuous upper atmosphere of Jupiter. With a resolution of ~319 km/spaxel paired with NIRSpec's incredible sensitivity, it is possible to detect vertical ionospheric structures up to 9000 km of altitude. We use these NIRSpec IFU observations to retrieve pole-to-pole vertical profiles at both dusk and dawn for the first time ever. H_3^+ emissions at mid-to-low latitudes are produced by EUV photoionization by incoming solar radiation, however ion lifetime constraints remain uncertain, with only the lower boundaries defined. Hence, we analyse vertical H_3^+ temperature and ion density variations to probe the ionosphere as a function of latitude and local-time. The vertical extent of the JWST observations allows us to determine at which altitude is H_3^+ produced at dawn, and similarly how its morphology varies at dusk and after it. Dusk-dawn asymmetries allow us to look at the evolution of H_3^+ profiles across the dayside and explore this dynamical area. Further, we also present the vertical distribution of both H_3^+ temperature and density as a function of latitude, from the north pole to the south pole, at both dusk and dawn, showing strong temperature gradients away from the poles. This work has the potential to impact current 1D and 3D magnetosphere-ionosphere-thermosphere models, as well as supplementing the first Juno radio occultation occurred on the same date in September 2023, with the additional goal of providing context for the upcoming ones.

Jupiter's infrared aurora at unprecedented sensitivity: 1 day with JWST and 43 days with IRTF

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Our recent JWST clockwise scan of Jupiter's limb followed the rotating northern aurora as it turned through the northern pole, giving an incredible instantaneous view of the H_3^+ emission there at unprecedented sensitivity. With the small field-of-view of the NIRSPEC instrument, individual frames only measured a small subsection of the entire aurora, but the observations were timed such that the entire auroral region was observed, and a small sub-section was re-observed multiple times as the planet rotated past the slit.

Our previous investigation of Jupiter's equatorial ionosphere combined >13,000 images of Jupiter together into a highly sensitive ionospheric map, but that study ignored the auroral regions. Utilising hundreds of hours of integration, the depth of sensitivity allows the dataset to be split into three bins: latitude, longitude and local time, smoothing out temporal effects and allowing the first time-independent measures of the individual influence of magnetic field strength, local time and magnetic mapping on auroral brightness.

These two unique sets of observation unveil the infrared aurora in unprecedented depth, one highlighting short term variability, the other smoothing out variability almost completely. Here we compare and contrast what these unique observations reveal about Jupiter's aurora, and highlight how waves in the thermosphere and statistical bias imposed from the magnetosphere have comparable effects on the infrared auroral brightness.

Radiation Belts of the Outer Planets

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Planets with an intrinsic magnetic field trap and accelerate charged particles, and form radiation belts. These belts exist in a permanent interplay of different physical processes: Particles are initially provided, e.g., through erupted moon material, and accelerated to high energies, e.g., through transport into the stronger parts of the planet's magnetic field. Particle production is countered through the removal of particles, e.g., when they hit the planet. Particle acceleration in turn is balanced through slowing the particles down again, e.g., when emitting synchrotron radiation. The balance of the involved processes determines the structure and dynamics of the various radiation belts.

This presentation will discuss the processes that are currently considered as most important at Jupiter and Saturn, and illustrate them through examples. We will briefly review the current state of the relative importance of these processes, although that topic is far from being closed, even at well-explored planets.

Comparison with Earth will provide context and demonstrate how some physical processes are potentially better studied at one planet than another. We will discuss some of the limited data we have for the radiation belts of the moon Ganymede, as well as the Ice Giants. While these data are far from conclusive, they reveal open questions or even mysteries that are left for future missions, such as JUICE or an Ice Giant flagship. We will discuss how the study of radiation belts also has an impact on several other fields of planetary science and, e.g., how it informs on ring structure.

Auroral acceleration as the electron seed-population source for Jupiter's uniquely energetic radiation belts

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Jupiter's poleward (Zone II) main aurora exhibits bi-directional electron acceleration, with upward acceleration dominating but downward acceleration generating strong aurora. During Juno's first perijove (PJ1), the upward acceleration manifested as narrow electron angular beams (within ~5 degrees of the magnetic field) over the 30-1200 keV energy range of Juno's Jupiter Energetic Particle Detector Investigation (JEDI). These beams can be simply connected (non-uniquely) to >10 to >20 MeV electrons identified as having penetrated the radiation shielding of the camera head assembly of the Advanced Stellar Compass (ASC of the Magnetometer investigation). The most intense of those multiple MeV populations are shown to have been highly directional and propagating upwards. How auroral processes generate such beams is unknown. With azimuthal symmetry assumed, these beams provided ~2×10^{26} 1/s of >30 keV electrons to Jupiter's vast magnetosphere, a critical and possibly dominating source of energetic electrons to that region. This source appears to be acting as a primary seed population to Jupiter's uniquely energetic radiation belts.

Extrasolar Radiation Belts: Resolved Imaging and Occurrence Rate Statistics

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Planets host some of the most energetic plasma structures in the Solar System: extended radiation belts of relativistic particles up to tens of megaelectron volts in energy that can emit gradually varying radio emissions and affect the surface chemistry of close-in moons. In this era of comparative magnetospheric science, radio observations in the last decade demonstrated that brown dwarfs and very low mass stars, collectively known as ultracool dwarfs, can serve as magnetic analogs to gas giant planets. In addition to aurorae, ultracool dwarfs also exhibit a non-auroral radio component long hypothesized to trace stellar coronal activity or extrasolar radiation belt analogs. We present high resolution imaging of the ultracool dwarf LSR J1835+3259 at 8.4 GHz demonstrating that its quiescent radio emission is analogous to Jupiter's synchrotron radiation belts. We also present statistical studies examining the occurrence rate of extrasolar radiation belts around ultracool dwarfs as a function of temperature and system multiplicity. We discuss implications for exoplanet dynamo theory, searches for brown dwarf satellites, and the possibility of extrasolar volcanism.

Asymmetry in Uranus' high energy proton radiation belts

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Uranus is one of the least explored planets in our solar system, it exhibits a unique magnetic field structure which was observed by NASA's Voyager 2 mission nearly 50 years ago. Notably, Uranus displays extreme magnetic field asymmetry, a feature exclusive to the icy giant planets. We use the Boris algorithm to investigate how high energy protons behave within this unusual magnetic field which is motivated by Voyager 2's observation of lower-than-expected high energy proton radiation belt intensities at Uranus. We simulated full drift motions of high energy protons around Uranus and found that the azimuthal drift velocity can vary by as much as ± 15% around the planet. This results in areas around Uranus where particles will be more depleted (faster drift) and other regions where there is a surplus of particles (slower drift). This could provide a partial explanation for the "weak" proton radiation belts observed by Voyager 2. Furthermore, for the innermost high-energy proton radiation belts, the asymmetry of the magnetic field can be shown to cause a significant drift motion in the radial direction which can cause particles to hit the planets' upper atmosphere when they otherwise would not have. These findings highlight the need for a future mission to Uranus so we can better our understanding of the effects of extreme magnetic field asymmetry on the planets' local plasma environment.

A first step in combining diffusion and convection in Saturn's electron radiation belts.

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The discovery of convection driven radial transport in the radiation belts of Saturn means that a new approach to the simulation of Saturn's electron radiation belt is required. Until now, the radiation belts at Saturn have been modelled using a diffusion-based, Fokker-Planck approach incorporating radial transport through diffusion along with local acceleration and loss due to wave-particle interactions. At the Earth, models of the ring current have combined the effects of convection and diffusive loss processes. One such model is RAM-SCB (ring current-atmosphere interactions model with self-consistent magnetic field); we have adapted this model to work at Saturn. Here we present our first results looking at the combined effect of Z-mode wave acceleration and convection in the inner radiation belt of Saturn.

Evidence for radial flows in Jupiter's inner radiation belts

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Jupiter's inner radiation belts constitute the most hazardous radiation environment of our solar system. The origins of this unique system are still unknown, in part because its contextual plasma environment is difficult to measure in-situ. In particular, the properties of plasma flows within Jupiter's inner belts are amongst the key parameters that remain to be resolved. Using data from the Juno/JEDI instrument, we report multiple detections of relativistic electron wakes (microsignatures) formed by Jupiter's inner moons (Metis, Adrastea, Amalthea and Thebe). Some microsignatures are found outside the moons' magnetically mapped orbital corridors, indicating that deep inside the radiation belts, plasma flows comprise a finite radial component with a velocity ranging between 1.5-15% of the rigid corotation. We discuss the origin of these radial ExB drifts and their importance for regulating the balance between electron transport, acceleration and losses in Jupiter's radiation belts.

Global morphology of ENA emissions from the atmosphere-magnetosphere interactions at Callisto and Europa

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We analyze the emission of energetic neutral atom (ENA) flux from charge exchange between Jovian magnetospheric ions and the atmospheres of Callisto and Europa. For this purpose, we combine the draped electromagnetic fields from a hybrid plasma model with a particle tracing tool for the energetic ions. We determine the ENA flux through a spherical detector that encompasses the entirety of each moon's atmosphere, thereby capturing the complete physics imprinted in these emission patterns. In order to constrain the modifications to the ENA emissions that arise from the periodic change of the ambient plasma conditions, we calculate the emission morphology at multiple positions during a Jovian synodic rotation. To isolate the influence of field line draping, we compare to the emission patterns in uniform fields. Our major results are:

(a) At Europa and Callisto, the majority of detectable ENA emissions are concentrated into a band normal to the Jovian magnetospheric field.

(b) The fraction of observable ENA flux that contributes to this band depends on the number of complete gyrations that the parent ions can complete within the moon's atmosphere.

(c) Field line draping partially deflects impinging parent ions around both moons, thereby attenuating the ENA flux and driving significant morphological changes to the emission patterns.

(d) The band of elevated ENA flux contains a local maximum and a local minimum in intensity, on opposite sides of each moon.

At Europa, detectable ENA emissions are maximized slightly west of the ramside apex. At Callisto, they maximize near the Jupiter-facing apex.

Observing Ion Precipitation onto Ganymede's Surface through Backscattered Energetic Neutral Atoms

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The interaction between the Jovian plasma and Ganymede's magnetosphere causes unique ion precipitation onto Ganymede's surface, which has been connected to the development of brightness patterns and radiolytic products. ESA's JUICE mission will measure ion fluxes at an altitude of around 500 km, which will leave uncertainties about the actual surface precipitation. The precipitation will instead be observable with Energetic Neutral Atoms (ENAs) that are created during the interaction of impacting ions with Ganymede's surface. In a similar manner, observations of backscattered ENAs from an orbiting spacecraft have been used at Earth's Moon to study the ion-surface interaction remotely. Recently, we verified the SDTrimSP code for modeling backscattered ENAs from the Moon and we were able to connect ENA signatures to properties of both the precipitating ions and the surface regolith.

We now present the first application of simulating backscattered ENAs from jovian magnetospheric H, O, and S ions at Ganymede to model the moon's ENA environment that will be observed by JUICE. Our simulation results suggest significant ENA emission from Ganymede's surface from backscattered H and O, with ENA fluxes and energies being directly related to those of the impacting ions. For energies above around 1 keV, backscattered H will also dominate over any H ENA components sputtered from surficial ice. This population is thus an ideal candidate for observing magnetospheric ion precipitation onto Ganymede's surface with JUICE's JNA and JENI instruments.

Influence of Titan's Variable Electromagnetic Environment on the Distribution of Energetic Neutral Atoms: Global Morphology and Observability

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We combine the electromagnetic fields from a hybrid model with a particle tracing tool to study the spatial distribution of energetic neutral atoms (ENAs) emitted from Titan's atmosphere when the moon is exposed to different magnetospheric upstream regimes. These ENAs are generated when energetic magnetospheric ions undergo charge exchange within Titan's atmosphere. The spatial distribution of the emitted ENA flux is largely determined by the parent ions' trajectories through the draped fields in Titan's interaction region. Since images from the ENA detector aboard Cassini captured only a fraction of the ENA population, we first provide context for such observations by calculating maps of the ENA flux through a spherical detector concentric with Titan to determine the global distribution of ENA emissions. We find that the ENA flux is highest in a band that encircles Titan perpendicular to the ambient magnetospheric field, which was strictly perpendicular to the moon's orbital plane during only one Cassini flyby. Field line draping strongly attenuates the emitted ENA flux, but does not alter the morphology of the global flux pattern. We then present a novel method which traces energetic magnetospheric ions backward in time to produce synthetic ENA images for a point-like model detector with a realistic, limited field of view. We present synthetic images for INCA's viewing geometry during several Cassini flybys under different magnetospheric conditions. Both the ambient magnetic field direction and field line draping can potentially influence the morphology of the observed ENA emissions, depending on the viewing geometry of the detector.

Charged Particle Weathering of Europa and Callisto

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Europa and Callisto are continuously exposed to ions and electrons from Jupiter's magnetosphere. These particles deposit energy onto the surface as they precipitate onto the moons, driving sputtering and radiolysis of the ice. However, the moons' local electromagnetic environments are perturbed by their interactions with the impinging magnetospheric plasma. These interactions generate non-uniformities in the electromagnetic fields (e.g., magnetospheric field line pileup, draping, Alfvén wings, and flow deflection due to mass loading) that alter the trajectories of these magnetospheric particles as they impinge onto the icy surfaces. Periodic variability to the moons' magnetospheric environments (and resulting plasma interactions) also drives variabilities in the sputtering, radiolysis, and weathering of the moons' surfaces. In this presentation, we will compare the roles that induction and plasma interaction at Europa and Callisto play on atmospheric generation and surface weathering of these moons, as driven by charged particle precipitation. We will highlight recent findings that emphasize how in-situ detections of the moons' atmospheres and pickup ions may be applied to derive properties of their surfaces.

Remote sensing of plasma flows in Saturn's magnetosphere using ENA imagery

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Energetic neutral atom (ENA) imagery reveals the dynamics of magnetospheric ions, with ENAs emitted from regions of ongoing ion-neutral charge exchange. At Saturn, the ENA emissions typically reveal discrete ion populations that sub-corotate about the planet, activated by global-scale injection events following tail reconnection. Additionally, the ENAs display planetary-period modulation over longer time periods (e.g., Mitchell+ 2009, Kinrade, Bader+ 2021). The key to decoupling and understanding these periodicities amidst transient injection features is better tracking of moving features in the Cassini INCA imagery. Keograms have been used to extrapolate the plasma flow speed from ENA images (e.g., Carbary & Mitchell, 2014) but the construction of azimuthal emission profiles requires averaging over radial distance, and information about the inward motion of the plasma is partially lost. Here we apply Voronoi segmentation (e.g., Guio & Achilleos, 2009) to ENA image projections (Bader, Kinrade+ 2021), whereby an image is divided into random segments and then recursively merged or split, cell-by-cell, depending on neighbouring cell intensity distributions. The segmentation process thereby hones in on the visible ENA emission morphology at each time step, producing a seed cloud that can be used to trace the motion of ENA features. The final Voronoi segmentation also provides a distribution of inherent scale sizes, allowing us to characterise the evolution of the ion population under gradient-curvature drift. We present azimuthal and radial drift speeds of ENA injection signatures derived from Voronoi segmentation, and compare them to similar estimates obtained from keogram analysis and in situ particle surveys.

Modeling of particle acceleration by ionospheric auroral resonator field in Jupiter

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Ionospheric Alfvén resonator (IAR) which is created as a result of strong density gradient in the planetary ionosphere is known to carry parallel electric field that fluctuates in frequencies of 0.1 -20 Hz. IARs are one possible cause of broadband acceleration of auroral particles, as the period of the fluctuation is about the same as the transit time of auroral particles through it. To explore this we combined ionospheric Alfvén resonator simulations in Jupiter, which give the electromagnetic fields, with test particle tracing. We traced test particles of different energy and pitch angle spectrum starting from an altitude above the IAR region as they move down. Results of the energy and pitch angle spectrum of the test particles below the IAR region after interacting with the IAR will be presented. The role of the IAR in producing broadband acceleration of auroral particles will also be discussed.

Temporal and spatial variability of the electron environment at the orbit of Ganymede as observed by Juno

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The thermal and energetic electrons along Ganymede's orbit not only weather the surface of the icy moon, but also represent a major threat to spacecraft. In this article, we rely on Juno plasma measurements to characterize the temporal and spatial variability of the electron environment upstream of Ganymede. In particular, we find that electron spectra observed by Juno have fluxes larger by a factor of 2 to 9 at energies above 10 keV than what was measured two decades earlier by Galileo. This result will advance our understanding of the surface weathering and may be a concern for the radiation safety of the JUICE mission. Furthermore, the June 2021 close fly-by of Ganymede reveals that the open field line regions of its magnetosphere attenuate electron fluxes at all energies by a factor of 1.6 to 5, thereby offering a natural shelter to visiting spacecraft.

Local Electron Properties in Jupiter's Magnetosphere from Optical Aurora Observations of Io and Ganymede

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The thin atmospheres of the Galilean satellites can be studied remotely through their auroral emissions, which reveal information about both their atmospheric compositions and the local plasma environment within Jupiter's larger magnetosphere. We used the HIRES instrument on the Keck I telescope at the summit of Maunakea to observe visible wavelength aurora on Ganymede during eclipse by Jupiter on June 8, 2021 and Io during eclipse by Jupiter on August 9, 2023. Observations of visible wavelength aurora are restricted to the sub-Jovian hemisphere during brief eclipse windows, but they achieve useful signal-to-noise in 5 minute integrations, which allow us to perform high-cadence temporal analyses of auroral line brightnesses. We will report on the discovery of both atomic neutral and ion emission lines at Io not previously observed at optical wavelengths. We will also present constraints on incident electron energy and density based on the ratios of several of these ion line brightnesses. On Ganymede, north-south asymmetries in the emission of neutral excited species reflect local electron scale heights relative to Jupiter's centrifugal equator, and we will show observational evidence for the canonical electron scale height at Ganymede's orbit of 2.78 Jupiter equatorial radii.

Characterizing Callisto's orbital environment with the Juno mission

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Callisto, second-largest Galilean moon, is orbiting at around 26.3 Jovian radii from its planet. During its orbit, the moon explores a wide range of magnetic latitudes, crossing environments with widely varying physical characteristics depending on its position relative to the current sheet, a region of increased plasma density. Although NASA's Juno mission did not do any flyby of the moon, it has crossed its orbit on several occasions and in a variety of configurations, offering the chance to characterize Callisto's orbital environment.

The aim of this work is therefore to characterize the variability of Jovian plasma and magnetic field properties at Callisto's orbit. After identifying time intervals where Juno crosses Callisto's orbit, we combine data from several instruments (JADE, JEDI and MAG) in order to build composite electron and ion energy spectra and derive their omnidirectional fluxes, densities, and pressures. In particular, we are observing the great variability of omnidirectional plasma fluxes, varying by almost two orders of magnitude depending on Juno's position. The intensity and direction of the magnetic field also vary greatly. These results are intended to be used as inputs for simulations of the interaction between Callisto's environment and the Jovian magnetosphere, in preparation for the arrival of the JUICE mission, planning to do several flybys of the moon.

Field Line Resonances at the Galilean Satellites

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The interaction of the Galilean moons with the Jovian magnetospheric plasma creates Alfvénic perturbations that propagate from the moon to the Jovian ionosphere, where they may be reflected. These Alfvén waves also interact with the ambient plasma both near the moons and near Jupiter's polar regions that are connected magnetically to the moons' orbits. In particular, enhanced electron and proton fluxes, and electromagnetic wave activity, have been observed simultaneously by Juno's JADE, JEDI, and Waves instruments within magnetic flux tubes connected to the satellite wakes. The broadband increase in electron flux could result from non-resonant interaction with inertial Alfvén waves. However, recent examination of the JADE energy spectra of protons and electrons within these flux tubes has revealed several intervals with flux enhancements at discrete energies that were linearly separated in particle speed, which hints at a resonant interaction. Since bounce periods for protons and electrons in the JADE energy range are comparable to eigenperiods of field-line resonances at the moons' orbits, and particle bounce frequencies under a dipole assumption are linearly related to the particle speed, it is likely that the energy banding observed in the satellite and satellite-wake flux tubes results from resonance between bounce motion of the particles and an eigenmode of a field-line resonance. The observed energy banding was limited to a short interval while crossing the satellite flux tube, providing indirect evidence of field-line resonances that are driven by the satellite-magnetosphere interaction.

Signatures of Io's Alfvén wing: I31 revisited

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Data obtained during the spacecraft encounter with Io on Galileo's I31 orbit reveal previously undocumented aspects of the plasma-moon interaction. This pass over the moon, the first ever polar pass, occurred when Io was near the northern edge of the plasma torus; the spacecraft orbit continued downstream along the Io wake. We show that on this pass the Alfvén wave launched by Io northwards returns to encounter Io itself again, recalling the early suggestions of Io behaving like a unipolar inductor. We further show that some 50 minutes after the transit of Io's northern polar cap, Galileo registered a localized signal whose scale and polarization resembles the disturbance seen at Io but with smaller amplitude. We show this disturbance cannot be a wave returning from the north; rather, it is a wave reflected from the southern hemisphere of Io returning after two transits of the torus to Io's latitude.

Plasma Observations in Io's Alfvén Wing and Plasma Wake from Juno

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Juno's extended mission includes close flybys of Jupiter's Galilean moons Ganymede, Europa, and Io. We report on plasma observations during Juno's two flybys of Io on December 30, 2023 and February 3, 2024. During the first flyby, Juno's trajectory went over the moon's northern hemisphere with a closest approach of ˜1500 km, providing a direct opportunity to explore Io's near space environment and the foot of its northern Alfvén wing, i.e., the region where the Alfvén wing starts to emerge. Enhancements in electron fluxes and energies characterize the moon-magnetosphere interaction in this region, with sharp transitions to low energy, low flux electrons in the bounding Io torus. The electron distributions near Io are primarily field-aligned, especially above ˜1 keV. They are bi-directional and asymmetric upon entering the Alfvén wing region on the anti-jovian side, and mono-directional traveling toward Io as Juno transits through this region, before exiting on the sub-jovian side. The ions decrease in energy within the Alfvén wing region and have a composition that reflects an Io source. During the second flyby, Juno's trajectory was south of the moon, in the plasma wake. Bi-directional, field aligned electron beams were observed in the plasma wake having enhanced fluxes and energies compared to the bounding Io torus. We place these measurements into context with previous observations (e.g. Galileo) and compare them to predictions from theory and modeling.

Source of radio emissions induced by the Galilean moons Io, Europa and Ganymede: in situ measurements by Juno

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At Jupiter, part of the auroral radio emissions is induced by the Galilean moons Io, Europa and Ganymede. Until now, except for Ganymede, they have been only remotely detected, using ground–based radio–telescopes or electric antennas aboard spacecraft. The polar trajectory of the Juno orbiter allows the spacecraft to cross the range of magnetic flux tubes which sustain the various Jupiter–satellite interactions, and in turn to sample in situ the associated radio emission regions. In this study, we focus on the detection and the characterization of radio sources associated with Io, Europa and Ganymede. Using electric wave measurements or radio observations (Juno/Waves), in situ electron measurements (Juno/JADE–E), and magnetic field measurements (Juno/MAG) we demonstrate that the Cyclotron Maser Instability (CMI) driven by a loss–cone electron distribution function is responsible for the encountered radio sources. We confirmed that radio emissions are associated with Main (MAW) or Reflected Alfvén Wing (RAW), but also show that for Europa and Ganymede, induced radio emissions are associated with Transhemispheric Electron Beam (TEB). For each traversed radio source, we determine the latitudinal extension, the CMI–resonant electron energy, and the bandwidth of the emission. We show that the presence of Alfvén perturbations and downward field–aligned currents are necessary for the radio emissions to be amplified.

Properties of electrons accelerated through moon-magnetosphere interaction: survey of Juno high latitude observations and modeling work

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In Jupiter's magnetosphere, the Galilean moons disrupt the flow of plasma in quasi-corotation. This interaction gives rise to a variety of physical processes, including the generation of Alfvén waves that propagate along magnetic field lines and accelerate charged particles. One manifestation of these phenomena is the parallel acceleration of electrons that precipitate into Jupiter's atmosphere, triggering the satellite auroral footprints. Such emissions are composed of a main spot, the Main Alfvén Wing (MAW) spot followed by an auroral tail extending in the direction of the magnetospheric plasma flow. Depending on the location of the moons within the Jovian magnetodisc, a spot created by a Trans-hemispheric Electron Beam (TEB) was also previously detected.

Thanks to its highly inclined orbit around Jupiter, the Juno spacecraft allows characterizing in-situ the charged particle populations accelerated through these interactions while remotely observing in the ultraviolet and infrared the resulting auroral emissions. In-situ measurements obtained within the magnetic flux tubes connecting the moons' orbital locations to Jupiter's atmosphere reveal the diversity of physical processes involved in the moon-magnetosphere interactions.

We present a comparison of the electron properties measured by the Juno-JADE instrument in the Io-, Europa-, and Ganymede fluxtubes at times when the UVS spectrometer observed their corresponding auroral emissions. In particular, we explore the energy distributions and show that for all three moons, the electrons creating the MAW spot and auroral tail always have a broadband distribution, whereas in the TEB flux tubes Juno has crossed, (Europa and Ganymede), the electrons are non-monotonically distributed, with a higher characteristic energy. We compare these observations to preliminary modeling work aiming to reproduce the propagation of waves and particles from the moons to Jupiter's ionosphere as well as additional wave-particle interactions that electrons may undergo during their propagation along the magnetic field lines.

Electrons near Europa and in fluxtubes magnetically connected to Europa's footprint tail aurora at Jupiter

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The interactions of the Jovian moons and Jupiter's magnetosphere create fascinating auroral emissions at the moons and Jupiter. The emissions are the visible result of electron-impact excitation of the atmosphere that are caused by precipitating electrons which are accelerated from those interactions. Juno's trajectory crossed multiple times fluxtubes that are magnetically connected to the auroral footprint tails of the moons near Jupiter. And later in its extended mission, Juno also flew near Ganymede, Europa, and Io. In this presentation, we summarize the plasma observations near Jupiter and the moons, with a focus on Europa. In particular, the Jovian Auroral Distributions Experiment (JADE) observed magnetic field-aligned electron beams near Europa. The energy and location of these beams are critical factors in better understanding Europa's space environment, as the beams are predicted to have an outsized influence on the ionization of the constituents of Europa's atmosphere and are accompanied with large magnetic field perturbations. The beams therefore play an essential role in shaping Europa's space environment and affect future attempts to diagnose Europa's interior.

Multi-fluid MHD simulations of Europa's Plasma and Magnetic Field Environment during the Juno Close Flyby

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On its PJ45 orbit, the Juno spacecraft conducted a close flyby of Europa passing through the moon's wake near the equator while potentially intersecting with Europa's Alfvén wings at higher latitudes. Particles and fields measurements acquired during this flyby provide new constraints on Europa's atmosphere and ionosphere and their interaction with Jupiter's magnetosphere. To place Juno observations in context, we simulate Europa's environment using a multi-fluid MHD model, which has been applied successfully to study various Galileo flybys. The MHD simulation separately tracks the bulk motions of several different ion species originating from Jupiter's magnetosphere and Europa's ionosphere, taking into consideration key mass-loading and momentum-loading processes such as photo- and electron impact ionization, charge-exchange, and recombination. Our expanded simulation model incorporates new constraints on Europa's neutral and plasma environments provided by Juno measurements. It tracks multiple neutral species to account for the presumably different spatial distributions around Europa of various atmospheric constituents and their resultant pickup ions. Simulations are performed with different models of Europa's atmosphere that acknowledge potential asymmetries arising from surface sputtering and solar illumination, thereby exploring the variability of Europa's plasma interaction and its resulting magnetic field perturbations. Through comparisons with Juno observations, the simulation will be iterated to obtain a realistic reconstruction of the near-Europa environment during the close encounter. The results from this modeling effort will provide a global context for interpreting Juno's in situ observations as well as for refining our understanding of the complex interaction of Europa's multi-species atmosphere with the Jovian environment.

Electromagnetic induction at Ganymede during the JUICE mission

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Jupiter's moons provide a window to understand the potential of habitability in our Solar System and beyond. The largest moon, Ganymede, is unique in possessing an intrinsic magnetic field in addition to a possible subsurface ocean. One of the main goals of the JUpiter ICy moons Explorer (JUICE) mission is to resolve the dynamo properties and confirm the ocean as well as gain a better insight into the moon's interior structure.

The most reliable method to understand the interior and confirm a subsurface ocean is through magnetic field measurements. Out of the five different fields observed at Ganymede, two of them, namely the internal-dynamo and external-magnetodisk fields originate at Jupiter. They create a time varying component due to the planet's fast rotation and the movement of the moon with respect to Jupiter. If Ganymede has a conducting ocean within its interior, we can model and predict its strength using this background field of Jupiter.

In this work, we use the JUICE trajectories in the flyby phase and compare them to the Galileo flybys to test their viability to potentially confirm the ocean. Subsequently, we use the orbital phase of JUICE to predict the induction signal assuming a perfect conductor response to Jupiter's background field and identify the different periodicities found in the signal. Observing the data at different frequencies will independently estimate the different properties such as the depth and conductivity of the ocean. Our results provide an understanding of expectations from the JUICE magnetometer observations on arrival at Ganymede.

Constraining Europa's Subsurface Ocean - A Revision of Galileo Flybys

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Since the Galileo spacecraft discovered a global subsurface ocean below its icy crust, the Galilean satellite Europa has been a primary target for the study of ocean worlds. Its ocean's salinity (electrical conductivity), thickness, and depth, however, are not well constrained and still subject of current research. In this study, we revisit a selection of Galileo's Europa flybys suitable for the study of the ocean's induced magnetic field. In addition to electromagnetic induction within the ocean, we also take plasma interactions into account to further constrain the ocean's parameters. In particular, we use the PLUTO code (Mignone et al., 2007) to solve the three-dimensional magnetohydrodynamic (MHD) single fluid equations and to model plasma interaction between the Jovian magnetosphere and Europa's atmosphere.

Analyzing the space environment of Saturn's moon Enceladus to possibly probe its interior

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Saturn's moon Enceladus is a moon generally considered to possess all necessary conditions for being a habitable planetary body. The Cassini spacecraft passed Enceladus on more than 20 close flybys within the time span 2005 to 2015. In our study, we revisit the measurements obtained during these flybys to investigate the time-spatial structure of Enceladus space environment. Despite no known deviations of Saturn's internal magnetic field from azimuthal symmetry, we show that the fields around Enceladus still contain time-variable components. Subsequently, we use Cassini's measurements to search for signatures possibly consistent with induced fields within the complex magnetic field environment generated by the plasma interaction with Enceladus' plumes.

Dust Impact Plasma Seen by the Cassini Plasma Spectrometer and Langmuir Probe in Enceladus' Plume

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Enceladus' plume, composed of water vapor and ice grains (dust) erupted from the south polar terrain, plays an important role regarding the moon-magnetosphere interaction at Saturn and the distribution of E ring particles. Furthermore, it provides important information about the potentially habitable subsurface ocean. Abundant ice grains micron-sized and smaller were suggested to be a significant plasma electron sink in the dusty plume. Our recent reanalysis of Cassini in situ plume measurements suggests that dust impact plasma, i.e., low-temperature plasma produced from high-speed dust impacts, has significant effects on both Cassini Plasma Spectrometer (CAPS) and Langmuir probe (LP) data. Taking impact plasma production into account, our analysis utilizes multiple in situ dataset over various plume crossings and provides direct constraints on the plume dust mass density agnostic to grain size distribution. We will also discuss how these results would affect our understanding of the variability of dust production, charge balance in the plume, and moon-magnetosphere interactions.

Mapping UV line ratios at Ganymede to constrain the atmospheric composition and distribution

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Far UV observations of Ganymede's auroral emissions allow us to monitor and map the major atmospheric constituents O_2, H_2O, and O. By comparing the intensities of the oxygen emissions at 130.4 nm, 135.6 nm, and 115.2 nm, we can constrain the relative abundances of these gases, while comparisons between the emission ratios observed at different positions on Ganymede's disk help us to determine whether the atmospheric components are more likely produced via sputtering of the surface or sublimation. In 2021 we performed high spectral resolution observations of Ganymede's leading and trailing hemispheres in the far UV using the Hubble Space Telescope Cosmic Origins Spectrograph (HST/COS) and detected the 115.2 nm emission for the first time, on the leading hemisphere only. Our measured 135.6 nm / 115.2 nm ratio was ~60% larger than expected based on laboratory measurements of the relevant emission cross sections. We discuss the implications of this result for the composition and distribution of Ganymede's atmosphere. Our HST observations were performed a few months after the Juno flyby of Ganymede, during which Juno UVS mapped the auroral emissions. We show that the 135.6 nm / 130.4 nm ratio map from the flyby data is consistent with the Roth et al. (2021) detection of a sublimated H_2O atmosphere concentrated at the sub-solar point.

The role of the electron thermal conductivity for Europa's auroral glow

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Europa's far ultraviolet (FUV) emissions have been observed over the last 30 years and have been used as a diagnostic for Europa's atmosphere and it's plasma environment. Hubble Space Telescope (HST) observations show the hemisphere of Europa facing the plasma sheet to be brighter in the OI1356 oxygen line than the opposite hemisphere.

To investigate the mechanism behind this asymmetry, we conducted a study of the plasma environment of Europa. The brightness of the OI1356 emission line is controlled by the atmospheric oxygen density, the electron density and the electron temperature along the line of sight. Previous studies often neglected the influence of a nonuniform electron temperature. Therefore, we investigated the electron temperature of Europa's environment using magnetohydrodynamic simulations of the system. In our study, the electrons are cooled by non-elastic collisions with atmospheric oxygen and are reheated by conductive heating along the magnetic field lines. Europa's hemisphere facing the plasma sheet has a larger energy reservoir for heating the electrons and can therefore maintain a higher electron temperature leading to a brighter emission. Using the simulated electron density and electron temperature as well as different atmospheric models, we created synthetic OI1356 HST images of Europa's FUV glow. These images show structures similar to the HST observations.

Juno-UVS Observations of Io during the PJ58 Flyby

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During its first extended mission, NASA's Juno spacecraft made several close flybys of Jupiter's Galilean satellites. The final of these was the Io flyby during the perijove (PJ) 58 orbit with closest approach at 17:48:35 UTC on 3 February 2024, about 3h59m prior to PJ58. We used Juno's UVS, a photon-counting far-ultraviolet (FUV) imaging spectrograph with a bandpass of 68-210 nm, to observe Io's numerous FUV emissions during the flyby. Due to the high speed and low altitude of the flyby, Io was only observable for a few minutes on either side of Juno's closest approach. Juno UVS utilizes a high countrate backoff mechanism to protect its MCP detector. Due to the high radiation background of penetrating (>10 Mev) electrons, UVS was only able to sustain its nominal voltage for 3 out the 20 spins of recorded data (± 5 min about closest approach). Out of those only one exhibited low enough radiation levels to allow for clear detections of oxygen and sulfur emissions. With a spatial resolution of ˜5 km at the limb, these observations offer a unique glimpse of the vertical distribution of the O and S emissions. The nadir time of the single low radiation spin was 17:48:09, just prior to closest approach. Juno was at an altitude of 1599 km and the sub spacecraft point was -35.7° latitude and -52.1° East longitude. We will present the observations and a comparison to earlier HST observations and the phenomenological model of Lorenz et al. (2014, DOI 10.1016/j.icarus.2013.10.009).

[Poster A01]

Fluid simulation of the Jovian low-latitude ionosphere

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A model of the low-latitude ionosphere of Jupiter is used to interpret data from the Juno mission. Quasi-one-dimensional fluid equations for several ion species are numerically solved along several lower-latitude ($\pm 20^{\circ}$) magnetic field lines. Densities and flow velocities are determined for different times of day along the field lines. Appropriate neutral densities and ionization rates are adopted as well as a rather simple chemical scheme. Our initial results focus on ionospheric protons in the topside ionosphere and in the inner magnetosphere. Some low-latitude periapsis Juno JADE data indicates that some higher mass ion species could be present, and we will show some model runs for that case. We will use the model to test the hypothesis that heavy species transported from the Io plasma torus could be important. Model results will be compared with available Juno data from several instruments (e.g., electron and ion densities).

[Poster A02]

Insights of Jupiter's equatorial airglow from Juno-UVS

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Jupiter's hydrogen (H) airglow emission is created by Lyman alpha (Lyα) photons produced when solar photons scatter off of H atoms in the thermosphere. During each perijove (PJ), NASA's Juno spacecraft flies through the upper atmosphere about 3500km above the 1-bar level. This allows us to use Juno's UltraViolet Spectrograph (UVS) to observe the Lyα photons all around the Juno spacecraft during perijove. Juno's rotation allows the UVS to see the atmosphere in a wide range from near nadir to near zenith. This includes the crucial observation range close to the limb where the observed Lyα airglow is brightest. We present a variety of calibrated brightness maps, including spacecraft viewing angle and local position and time. These results will then be compared to models created using a resonance line radiative transfer program in order to determine reasonable estimates about the structure, density, and characteristics of Jupiter's H atmosphere, particularly about the presence of energetic H atom fragments that we call "hot" H. The presence or absence of large quantities of "hot" H will have implications on the structure of Jupiter's airglow, including Jupiter's Lyα bulge, a consistent feature in the atmosphere where there is increased brightness in Lyα at roughly 100 degrees System III longitude.

Unveiling Jupiter's Equatorial Ionosphere with JWST

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Despite extended periods of observation, the interplay between Jupiter's ionosphere and magnetic fields away from the poles remains enigmatic. Spectral analysis of near-infrared (NIR) emissions from the major upper-atmospheric ion, H_3^+, give us a unique window into this coupling at the Giant Planets. However, emissions from the low latitudes are ~10 times weaker than the auroral regions and are difficult to spectrally disentangle from bright neutral species. Here, we present JWST NIRSpec observations on the disk of the planet, providing the most detailed view of the Jovian mid-to-low latitude ionosphere to date. JWST carried out a clockwise scan of the entire limb of Jupiter (Cycle 2 - GO 3665), revealing both the auroral and the non-auroral regions in incredible spatial detail.

For the first time, this scan provides us with unprecedented measurements of several highly localised features in the NIR emissions, which appear to trace out the long-term magnetic influence on the equatorial ionosphere. We also highlight an incredible array of small-scale brightness variations which may indicate either dynamic wave activity, or highly filamented manifestations of the Jovian magnetic field within the ionosphere.

Jupiter's ionosphere surrounding Juno PJ54: Model comparisons with Earth-based observations

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We present observations and modeling of the state of Jupiter's non-auroral upper atmosphere surrounding Juno perijove 54. Juno radio occultations sampled Jupiter's dawn ionosphere near 38N planetocentric latitude around 12 UTC on 7 September 2023. Simultaneous IR spectroscopy was obtained by JWST/NIRSpec, Keck/NIRSPEC, and IRTF/iSHELL. Analysis of IR spectra yields maps of H_3^+ density and temperature in altitude, latitude, and local time, providing spatiotemporal context for Juno PJ54 observations. Model reproductions of the measured diurnal variation of H_3^+ also provide key insight into unconstrained giant planet ionospheric chemistry (the conversion of H^+ to H_3^+ by an intermediate reaction with vibrationally-excited H_2). We find that Jupiter's mid-latitude ionosphere during this epoch was reasonably well-behaved in comparison to the range of dynamic plasma distributions seen in prior giant planet observations. H_3^+ temperatures are roughly 700 K, densities a few thousand ions/cc, and loss rates for $H^+ + H_2$ reactions are line with prior estimates in the literature.

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[Poster A05]

Modeling Electrodynamics in Jupiter's Non-auroral Ionosphere

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We present initial results from a Jovian low-latitude ionospheric code in development, JAMMIES (Jovian Atmospheric Models Making Ionospheric Estimates). This code will complement the Juno mission, which has provided a steady stream of observational data to a community with a dearth of modeling for comparative analysis. JAMMIES is adapted from the Earth-based ionospheric code SAMI2 and its derivative Saturn-based ionospheric code SMITE (2D). These codes evaluate plasma chemistry and dynamics over a dipole magnetic field-aligned grid, and are advantageous for ionospheric modeling as they incorporate interhemispheric transport of plasma along magnetic field lines. We first present a longitude-varying dipole approximation of the JRM33 Jovian magnetic field model. This approximation follows the approach used by SAMI2 at Earth, and defines the model's computational grid. We then simulate the spatiotemporal generation, distribution, and evolution of plasma in the Jovian ionosphere across different longitude sectors. Finally we investigate if our model can reproduce the still unresolved, persistent localized H_3^+ emission minima coincident with the magnetic equator (known as the H_3^+ Dark Ribbon). JAMMIES is the first model to include low-latitude electrodynamics at Jupiter, and will elucidate our understanding of magnetically correlated atmospheric phenomena at Jupiter. Such a model is essential for increasing the science return from active and future missions as well as in interpreting remote observations of Jupiter's ionosphere from Earth-based facilities.

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[Poster A06]

Jupiter's Upper Atmosphere: Observations of Temporal Variations in Temperature

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For decades, we have known that the equatorial upper atmospheres of the giant planets are significantly warmer than solar heating models predict, and heat sources which would bridge this gap in energy are not well constrained. By mapping temperatures and densities in the upper atmosphere of the archetypal giant planet, Jupiter, we look to gain insight on this Giant Planet "Energy Crisis" by better understanding sources of heat and their transfer processes. Possible sources include Jupiter's aurorae and propagating waves from the lower atmosphere. Evidence of these processes include monotonic aurora-to-equator temperature gradients and sporadic hotspots, respectively. To investigate their impacts we seek signatures indicative of their presence on timescales of hours, months, and years. Additionally, we investigate Jupiter's overall equatorial temperature variability in time.

We present preliminary maps of H_3^+ temperature in Jupiter's upper atmosphere from ground-based, infrared observations using Keck Observatory's NIRSPEC instrument. These three nights, December 2022 and November and December 2023, were taken as part of a Juno support campaign. They offer a comparison of similar central meridional longitudes from which an estimate of average equatorial temperature (~800K) has been calculated with individual nights having averages ±50K of the overall average. Other qualitative notes include a smooth aurora-to-equator gradient and no significant hotspots.

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[Poster A07]

Magnetosphere-Ionosphere Coupling Sensitivity for Jupiter-Like GAMERA Simulations

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The magnetosphere of Jupiter, characterized by its rapid ten-hour rotation and the presence of Io as an internal heavy plasma source, offers a complex and dynamic setting for scientific exploration. It serves as a unique natural laboratory, providing invaluable insights into the functioning of magnetospheres. Understanding the intricacies of Jupiter's magnetosphere holds great potential for enhancing our ability to model and forecast space weather phenomena at the Earth. Many models have been used to study Jupiter's magnetosphere, one such being the Grid Agnostic MHD for Extended Research Applications (GAMERA), a modern update of the high-heritage LFM code. Leveraging simulations from the GAMERA model of a Jupiter-like magnetosphere, we delve into the behavior of the magnetosphere with different constant ionospheric conductances, ranging from 0.5 to 10 mho, as well as a million mho case, as well as other simulation constraints. The radial density profiles in the equatorial tail from these simulations will be compared with data and empirical models. The radial profile of azimuthal flow will be presented as well, where the breakdown in corotation is highly dependent on the ionospheric conductance, some conductances comparing to data more favorably than others. Meridional cuts will also be investigated in the midnight-dawn local time region, which will allow for comparisons with Juno spacecraft observations.

Mapping of Jovian Magnetosphere-ionosphere System: Results from Three-dimensional Global Simulations

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The interaction between solar wind and planetary internal magnetic field (i.e., magnetosphere) of the earth is has been extensively studied in recent decades. By combining empirical geomagnetic field models with satellites data, such as the Tsyganenko model and THEMIS, a relatively accurate representation of the earth's magnetosphere-ionosphere (M-I) connections can be achieved. However, for the Jovian system, the applicability of such terrestrial methodologies becomes questionable due to the limited availability of observational data, especially for the middle and outer Jovian magnetosphere. Recent numerical modeling suggests a Jovian magnetosphere with a largely closed polar cap and helical lobe magnetic field lines. This unusual magnetic topology is significantly different from earth and induces distinctive auroral morphology. This unique configuration is due to Jupiter's fast rotation period and strong internal magnetic field, suggesting that that the mapping between ionospheric activity (e.g., aurora) and magnetospheric source region may not be as linear as our experience with earth indicates. In this study, we perform a series of three-dimensional global Magnetohydrodynamics (MHD) simulations of the Jovian magnetosphere to investigate the local time (LT) mapping between Jovian magnetosphere and ionosphere. The Jovian magnetospheric simulations use different interplanetary field orientations and both dipole and JRM33 Jupiter magnetic field model for the inner boundary M-I mapping. Results show that unlike the earth, the LT relation of the Jovian MI system is very nonlinear and north-south asymmetric. The difference between LT in the ionosphere and its magnetospheric origin increases as the magnetospheric distance from Jupiter increases (i.e., poleward of the main oval), due to rotational effect. Such feature is stronger in southern hemisphere for eastward IMF and in northern hemisphere for westward IMF. For region far away from the planet (>100 R_J), the LT relation becomes unpredictable.

Energy deposition in Jupiter's auroral regions: the vertical structure of Jupiter's ultraviolet aurora observed by Juno-UVS

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Jupiter hosts the most powerful magnetosphere among the planets in the Solar System. Magnetohydrodynamic waves and electric currents transfer energy and angular momentum between Jupiter and its magnetosphere, leading to the precipitation of charged particles nto the atmosphere and generating auroral emissions coming from an extended area around the magnetic poles of Jupiter. Among the auroral features, we will focus on (1) the main mission (a thin, bright and almost continuous stripe of emissions), and (2) the auroral footprint of Io, which originates from the moon-magnetosphere interaction.

Since 2016, the Juno spacecraft has been orbiting Jupiter in highly-elliptical, polar orbits, carrying, among its payload, an ultraviolet spectrograph (UVS) to observe the UV emission from the excited atmospheric hydrogen. As Jupiter and Juno spin, the instrument can observe the aurora at the planetary limb: this is the opportunity to investigate the atmospheric structure and the precipitating particle distribution. Indeed, the vertical profile of the emission reflects the energy distribution of the precipitation, and the UV emission below 130 nm is strongly absorbed by methane below the homopause, hence limb observations can be used to constrain its altitude. We aim at characterizing the main emission and the Io footprint: the Io footprint is powered by electrons with typical energy ˜1 keV, which are accelerated by wave-particle interaction with Alfvén waves, while the main emission is associated to either wave-particle interaction and quasi-static acceleration by magnetospheric potentials, and the typical electron energy of the precipitation is a few kiloelectronvolts.

A mechanism of the monoenergetic and broadband auroral acceleration

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Juno spacecraft frequently observes Alfvénic aurorae which are associated with the broadband acceleration of electrons, as well as the inverted-V type of monoenergetic electron precipitation which is commonly seen at the Earth. We suggest that quasistatic parallel electric fields which are generated in plasma structures such as double layers (DLs) may play an important role in the acceleration of both monoenergetic and broadband electrons. The localized parallel electric field results from the displacement current complying with Ampere's law for the dynamic case. The double layers are embedded in low density cavities surrounded by enhanced magnetic stresses, while the Poynting flux carried by Alfvén waves continuously supplies the energy to maintain strong electric fields.

In the acceleration process, the amount of energy gained by the electrons passing through the double layers may differ depending on the time the electrons spend in the double layers and the strength of the DL's potential drops. When a spacecraft traverses through a relatively large region where a cellular distribution of double layers exists, it is likely that the spacecraft would see a broad energy range of accelerated electrons leading to Alfvénic aurorae. In the case that the active region is relatively narrow or the acceleration occurs in a relatively concentrated double layer distribution, the spacecraft may then observe monoenergetic electrons. The fact that bidirectional electrons are observed during the broadband acceleration indicates that the parallel potential drops associated with the charge separation may also be bidirectional.

[Poster A11]

Comparison of contemporaneous Juno magnetic and ultraviolet auroral observations with the Leicester Magnetosphere-Ionosphere Coupling Model

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We present an analysis of contemporaneous observations of magnetometer (MAG) data and ultraviolet (UV) images obtained during the first 10 data-taking northern inbound orbits of the NASA Juno spacecraft. Guided by the Leicester Magnetosphere-Ionosphere coupling (L-MIC) model (see Cowley et al., 2017, `https://doi.org/10.1002/2017GL073129`, and references therein), we identify a total of eight high-altitude field-aligned current (FAC) signatures, which are associated with the main oval auroral emission. Kamran et al. (2022, `https://doi.org/10.1029/2022JA030431`) have previously identified two sets of FAC signatures found at radial distances of 7-16 R_J (T1) and 4-7 R_J (T2), respectively. In this study, we identify an additional set of lower-altitude crossings magnetically mapping to 2-3 R_J (T3). Three of the four T2 signatures and all T3 signatures occur during simultaneous Juno MAG-UVS observations and correspond to intervals of full traversals of magnetic field lines mapping to the L-MIC model middle magnetosphere as Juno travels from the inner to outer magnetosphere. The T2 and T3 signatures correspond to mean ionospheric Pedersen current per radian values of $\sim$3.0 MA rad^{-1} and $\sim$5.4 MA rad^{-1}, respectively, compared with L-MIC model value of $\sim$8.5 MA rad^{-1}. We find a positive correlation with R$\sim$0.7 between the concurrent FAC magnetic field values and ionospheric Pedersen current per radian with respect to the peak UV intensity measured by UVS. We also compare our results with previous Juno-era magnetosphere-ionosphere coupling studies and investigate reasons for the observed variations.

[Poster A12]

Exploring the mechanisms behind Jupiter's x-ray auroral flares

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Jupiter's strong and rapidly rotating magnetic field provides a natural laboratory which we can use to better understand the dynamics of high energy plasmas. These plasmas play a pivotal role in generating Jupiter's spectacular auroral x-ray flares whose mechanism was largely unknown for many years. Recent investigations have uncovered a possible mechanism wherein planetary scale compressional mode waves modulate EMIC waves in the outer Jovian plasma sheet. This modulation leads to the scattering and subsequent precipitation of heavy ions into Jupiter's polar regions, facilitated by a previously identified megavolt potential. Building upon prior research, our study embarks on a comprehensive statistical analysis coupled with the development of test particle simulations to combine the many complex mechanisms and test their validity. The success of this study would not only advance our understanding of Jupiter's magnetosphere but also shed light on similar phenomena in the magnetospheres of other planets.

Characteristics of the Equatorward Emissions in Jupiter's UV Aurora

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Characteristics of the Equatorward Emissions in Jupiter's UV Aurora

Previous investigations into Jupiter's diffuse equatorward emissions have associated certain auroral features embedded in this region to injection events (Gray et al., 2017) and magnetic reconnection (Guo et al., 2021). However, these equatorward emissions have not been quantified in a statistical analysis across an extensive set of HST campaigns yet.

This new study uses a novel automatic identification algorithm to help separate, categorize, and pinpoint the different types of auroral emissions occurring, often simultaneously, beyond the main emission arc. This survey reviews all the HST images of the Jovian Southern hemisphere between 2016 and 2022. By quantitatively assessing the occurrence of the secondary oval and its location, while combining these results with the examination of Juno-JADE data from crossings of field lines mapping to these regions (Nichols et al., 2022), we get a comprehensive picture about the characteristics of both these features and the particles that originate them.

To get an understanding as complete as possible of these processes, this statistical study has calculated both the frequency and the latitude of these emissions by local time and longitude, and compared the obtained results between the different auroral morphological families (as defined by Grodent et al., 2018). The results show a high prevalence of the secondary oval in the range of 300-0° (left-handed System III) longitude, a higher frequency in the dusk sector, and a relative decoupling of the latitude of both the main and secondary emission with respect of said morphological families.

Jupiter's Auroral Response to Magnetospheric Injections: Insights from Juno Observations

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Previous studies have linked magnetospheric injections to isolated auroral patches equatorward of the main emission at Jupiter. However, the critical characteristics of injection events leading to auroral signatures are not well understood. In this study, we examine two injection events associated with isolated auroral enhancements measured equatorward of the main emission using Juno data. We analyze the variations of particle flux distributions at low altitude that are directly related to the observed auroral emissions, along with the near-equatorial Juno observations within the same M-shell range to identify their potential driver. For these events, the JEDI and JADE instruments are used to evaluate the properties and variations of energetic particles in the injection region, and the wave data from the Waves instrument are used to examine the properties of various types of plasma waves, including whistler-mode and electron cyclotron harmonic (ECH) waves. Moreover, Juno UVS measurements are used to provide the intensity and color-ratio of aurora. Our findings indicate that the relationship between magnetospheric injections and auroral brightening is more complex than previously thought. Notably, not every injection is linked to isolated auroral patches; instead, isolated aurora likely intensifies when multiple key factors, including particle injections and plasma waves facilitating electron precipitation, enhance simultaneously. This study offers valuable insights into auroral phenomena and their connection to the Jovian magnetospheric dynamics.

[Poster A15]

Auroral Injections and the Magnetospheric Processes at Jupiter

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Jupiter's powerful auroral emissions include a substantial component from the region at lower latitudes than the main auroral oval, named outer auroral emission. Besides the persistent auroral footprint of Jupiter's natural moon Io, auroral injection are often observed in the outer auroral region, manifesting the magnetospheric plasma injection from middle/outer magnetosphere to the inner magnetosphere. Magnetospheric plasma injections sometimes have auroral counterparts, while sometimes have not. It is yet to be understood what controls the auroral counterparts of magnetospheric plasma injections. In this presentation, we show a long-lasting auroral injection events captured by the Hubble Space Telescope, together with simultaneous particle measurements from the Juno spacecraft. Multiple auroral substructures were identified in the injection region, which are likely associated with the observed filament plasma injections. Highest ever global numerical simulation, for the first time reproduced the massive auroral injection event. The multiple datasets and mesoscale-resolving global simulation provides key insights to understand the plasma injection processes and associated auroral emissions.

High Energy Ions in Jupiter's Aurorae

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Magnetospheric plasma precipitating in the polar regions of Jupiter produce the observed aurorae. However, the ion composition and processes are still an area of active investigation. Co-adding legacy data from the XMM Newton telescope, a high energy X-ray spectrum has been created to investigate the precipitating ions. We see hints of S15+ showing that relativistic (~10MeV) sulphur ions precipitate in the auroral zone. The spectral lines at ~4.0keV, 7.46keV, 8.7 – 8.8keV and 9.3keV are also characterised and the potential processes are discussed.

The Jovian ionospheric conductivity derived from a broadband precipitated electron distribution

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The Pedersen and Hall ionospheric conductivities and altitude-integrated conductivities (conductances) are important parameters to study the exchanges of energy and momentum between Jupiter and its magnetosphere. These quantities can be inferred from UV auroral spectra in the auroral region by assuming a particular distribution for the precipitated auroral electrons. Until now, only mono-energetic electron distributions have been used with this method. In the present study, Pedersen and Hall conductivities/conductances have been computed using a kappa distribution, a choice justified by the Juno spacecraft measurements showing the dominance of broadband energy distributions in the polar aurora. Hence, the input kappa distribution used in this study is obtained by fitting the electron flux measurements from the Juno-JEDI instrument. The altitude distributions of H, H2, He and CH_4, included in the atmosphere model, are taken from Grodent et al's (2001) model.

In a first approach, the Pedersen and Hall conductances have been computed using mono-energetic and kappa distribution for different values of the mean energy of the precipitating electron population. It appears that the conductances computed with a kappa distribution can show large differences with the one inferred from a mono-energetic distribution, depending on the mean energy. To evaluate the impact of these findings on the Jovian aurorae, Pedersen and Hall conductance maps have been computed for each hemisphere from perijove 1 to 58. These maps show that the Pedersen conductance can be up to 2 times larger in the case of a kappa distribution, especially in the main and polar emission regions.

Understanding the relationship between the size variations of Jupiter's magnetosphere, auroral brightness and solar wind pressure using Juno observations

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The size of Jupiter's magnetosphere and the total power emitted by the planet's auroras both vary considerably with time. Two potential drivers of this variability are the upstream solar wind conditions and the internally-driven mass loading/unloading of the magnetosphere, but the relative contributions of these external and internal mechanisms are not clear. In this work, we present ongoing work which uses data from multiple instruments on the Juno spacecraft to investigate the relationship between the location of the magnetopause, the brightness of the auroras and the dynamic pressure of the solar wind. Four in-situ instruments on Juno (JADE, JEDI, MAG and Waves) are able to detect magnetopause crossings during the apojove period of the spacecraft's orbit. Over the eight years of the mission there has been significant evolution in the orbital geometry, which means that a large segment of three-dimensional space has now been probed. We use the entire Juno trajectory thus far to fit a parameterized surface representing the magnetopause in its most expanded state. For each detected magnetopause crossing, we then compare the spacecraft position with this fitted surface to quantify the level of compression that the magnetosphere was experiencing. These results will be compared with simultaneous measurements of the total auroral power obtained by the Juno UVS instrument and with solar wind model predictions. The presence or absence of any correlations between these three datasets will help us to build a more cohesive picture of how different elements of Jupiter's magnetosphere interact with one another.

[Poster A19]

North, South, East and West: the asymmetries in the Jovian UV aurorae

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Asymmetries in the auroral brightness and morphology carry key information about the origins of these auroral features and allow us to test theoretical models relating magnetospheric processes to their auroral counterpart. In this study, we use Hubble Space Telescope Imaging Spectrograph and Juno-UVS observations of the Jovian UV aurora, separately or in combination, to quantify these asymmetries. For example, focusing on the main emissions, we find that auroral arcs in the dusk side are 3 to 5 times more powerful than in the dawn side (Groulard et al. 2024).

We also show comparisons between aurorae in the northern and southern hemispheres and we show that, on average, their emitted powers in the UV are broadly equivalent. However, when we separate the auroral emissions into three regions, the polar emissions, the main emissions and the outer emissions, we find that polar emissions are brighter in the north, while main emissions are brighter in the south, essentially compensating each other. Zooming in on individual features, we find a good correspondence between features in both hemispheres, except in the polar region, where some features have a clear simultaneous counterpart while others do not.

Ion Cyclotron Waves as Drivers of Ionospheric Outflow in Jupiter's Auroral Zones

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The outflow of ionospheric protons plays a significant role in supplying Jupiter's magnetosphere with ions. To investigate this ionospheric outflow, we look to the auroral zones of Jupiter, where intense, upward, field-aligned proton beams have been observed by the JEDI and JADE instruments. These proton beams indicate the presence of potential structures which accelerate ionospheric ions into the magnetosphere. However, the potential structures themselves exist at high altitudes not easily accessible to the ionospheric particles. Therefore, we consider a pre-acceleration mechanism by which ionospheric ions would escape Jupiter's gravitational potential up to the altitudes where the potential structures exist. We propose that ion cyclotron waves act as the initial mechanism of the ionospheric outflow of protons. To investigate this proposed mechanism, we look for coincidence between the upward, field-aligned proton beams and ion cyclotron waves during auroral zone crossings using Waves, JADE, and JEDI data. Finally, we discuss potential mechanisms that lead to the generation of these waves.

[Poster A21]

Characterization of the Jovian narrowband kilometric radio components: wave mode, frequency and sources locations from 3D numerical modeling of the Juno/Waves observations.

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Measurements by the radio and plasma waves (Waves) instrument on board the Juno spacecraft suggest the generation of the narrowband kilometric radiation (nKOM) at 20-141 kHz and the narrowband low-frequency radiation (nLF) at 5-70 kHz, in the Io plasma torus (IPT) in low latitudes regions [Imai et al. 2017, Louis et al. 2021, Boudouma et al. 2024].

Although the generation of radio waves in the IPT is attributed to conversion of the natural modes of the plasma into escaping radio waves, at the fundamental or the harmonic, there is no consensus on the specificity of the mechanisms involved.

Using electron density and magnetic field measurements by the Jovian Auroral Distribution Experiment (JADE) and the FluxGate Magnetometer (FGM), we identify the range of frequencies accessible to the different wave modes as Juno passes through the plasma.

We classify the nKOM and nLF based on their observation modes: trapped (Z-mode or Whistler), escaping (X-mode or O-mode), and indeterminable (either trapped or escaping).

We apply the modeling method proposed in Boudouma et al. [2024] to the escaping and indeterminable modes of nKOM and nLF observations, leading to macroscopic constraints on the generation mechanism, wave mode, characteristic frequency, beaming and radio sources locations.

Our analysis supports the idea that high-latitude nKOM is consistent with O-mode, while low-latitude nKOM is X-mode compatible. We find that nKOM and nLF are consistent with radio waves produced near the plasma frequency fundamental, but only nLF is consistent with radio waves near the first harmonic, suggesting nonlinear generation mechanisms.

Characterization of bKOM sources

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This work focuses on the in situ analysis of the source region of Jovian broadband KilOMetric (b-KOM). b-KOM are auroral radio emissions produced from 300 kHz to a few MHz, hence at lower frequencies and therefore larger distances than decametric/hectometric emissions, along Jupiter's magnetic flux tubes mapping to atmospheric UV aurorae.

We identify in situ crossings of bKOM sources with Juno/Waves and JADE-E measurements, following the methodology adopted by Louarn 2017, Louis 2019, Collet 2024 for HOM and DAM sources.

These source crossings are analyzed in the framework of the Cyclotron Maser Instability. This wave-plasma instability has been validated in situ to be at the origin of AKR (Earth), SKR (Saturn), and HOM/DAM (Jupiter) and shown to operate in variable plasma environments from different sources of free energy.

This study aims at unravelling the specificities of bKOM. Indeed, while HOM & DAM are dominantly rotation-modulated (and mostly driven by loss cone CMI-unstable electron distributions functions), bKOM is thought to be modulated more strongly by the solar wind than by the rotation.

Declination variation effect on characteristics of Jovian decametric radio emission

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The variation of the Jovicentric sub-latitude (declination - DE) of a radio observer of Jupiter is long known to affect the observation of Jovian Decametric (DAM) radio emission due to these emission's anisotropic nature. The DE effect, however, is still not clearly understood. For ground-based observations of Jupiter, the DE effect is combined with the effects of the cyclic variation of the distance to Jupiter and Jupiter's elongation angle. We analyze Jovian DAM emission detected with the Nançay Decameter Array (NDA) from 1990 to 2020 and suggest a selection of these emission by intensity and maximum frequency thresholds to obtain an unbiased set for the analysis of the pure DE effect. We, then, investigate the Earth's DE effect on the maximum frequency, duration, average Io phase and average CML of Io-induced DAM emission. Also we redo the analysis with matching Io-DAM simulations obtained with the Exoplanetary and Planetary Radio Emissions Simulator (ExPRES). From both the NDA data and the ExPRES simulations, it is observed that the pure DE effect on the Io-DAM emission characteristics is minor, yet a clear proportionality of the maximum frequency and duration of the northern Io-DAM emission with DE is noticed. The northern Io-DAM emission seem to be more importantly affected by the DE variation than the southern emission. ExPRES can predict Io-DAM emission consistently, so the current understanding of the emission generation and propagation is reasonable. Then, EXPRES might contribute to improve our understanding of the DE effect.

[Poster A24]

Analysis of Standing Alfvén Waves in the Jovian Plasma Sheet: Insights from Juno Magnetometer Data Across the Dawn to Midnight Sector

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Magnetometer observations from the Galileo mission suggest evidence of standing Alfvén waves (also known as Field Line Resonances - FLRs) in the Jovian magnetosphere (e.g. Manners & Masters, 2019). The Juno spacecraft mission began orbiting Jupiter in 2016 and is currently on its extended mission. This project uses Juno's magnetometer observations to identify these standing waves in the dawn to midnight sector. These waves, which are an electromagnetic analogue to waves on a string, are a common feature of Earth's magnetosphere and are thought to be correlated with mono-energetic electron energization that drives some terrestrial discrete auroral arcs. Periodic auroral emissions at Jupiter have also been observed using the Hubble Space Telescope (e.g. Nichols et al., 2017) suggesting these waves participate in generating some auroral emissions at Jupiter as well. This, along with the findings from Galileo, motivates our search for standing Alfvén waves in Jupiter's magnetosphere. The goal of this project is to find and characterize waves of short periodicities within Jupiter's plasma sheet for time scales ranging from a few minutes to one hour. To do this, our approach lies in analyzing continuous wavelet transformations (CWT) of the perturbed perpendicular magnetic field where the Juno spacecraft crosses–or skims–Jupiter's current sheet where there is evidence of small-period standing waves. Preliminary simulation studies, informed by this observational analysis, will also be briefly reviewed. The results of this study will contribute to understanding the role of field line resonances in the broader study of magnetospheres and heliophysics.

[Poster A25]

A new regime of plasma wave modes in Jupiter's polar cap

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Observations from Juno have indicated very low densities, as low as 10^{-3} cm^{-3}, on polar cap field lines at Jupiter (Sulaiman et al., 2023). This region is strongly magnetized, with surface magnetic fields up to 20 G, or 2 mT (Connerney et al., 2022), leading to the unusual situation that the electron plasma frequency is less than the ion gyrofrequency. For example, in a 1 G (100 μT) field, the proton gyrofrequency is about 1.5 kHz, corresponding to the electron plasma frequency for a density of 0.03 cm^{-3}. In a more typical plasma where the ion gyrofrequency is lower than the plasma frequency, the Alfvén mode transitions to an electromagnetic ion cyclotron wave, sometimes called the Alfvén-ion cyclotron mode at large wave number. However, in this extremely low-density plasma, the Alfvén wave becomes a plasma oscillation at the plasma frequency. Analysis of this mode with a kinetic low-frequency dispersion solver indicates that at large wave number, this mode has the characteristics of the Langmuir wave. Thus, this mode can be called an Alfvén-Langmuir mode. Below the plasma frequency, the high-wave number behavior of this mode exhibits a resonance cone, with frequency determined by the angle of the wave vector with the background magnetic field.

Connerney, J. E. P., et al. (2022). Journal of Geophysical Research: Planets, 127, e2021JE007055. `https://doi.org/10.1029/2021JE007055`

Sulaiman, A. H., et al., (2023), in Planetary, Solar and Heliospheric Radio Emissions IX, editors: Fischer, G., Jackman, C. M., Louis, C. K., Sulaiman, A. H., Zucca, P., doi: `https://doi.org/10.25546/103098`

Background Solar Wind Conditions during the Juno Mission: Results from the Multi-Model Ensemble System for the outer Heliosphere (MMESH)

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As in-situ solar wind measurements near the outer planets are rare, and those simultaneous with magnetospheric measurements are even rarer, propagation modeling is essential to understanding the important interactions between outer planet magnetospheres and the solar wind. Propagation of solar wind conditions from the inner solar system, where measurements are available, to the outer planets introduces significant uncertainties in propagation models. These uncertainties are often difficult to quantify and compare across the different models available. Here we present a statistical, time-varying hindcast of the solar wind conditions (namely: density, speed, pressure, and magnetic field) near Jupiter during the Juno mission (2016/03/01 - 2024/03/01) using MMESH: the Multi-Model Ensemble System for the outer Heliosphere. The MMESH framework allows for: (1) individual solar wind propagation models to have their uncertainties and biases quantified by comparison to available in-situ data; (2) uncertainties and biases to be modeled using multiple linear regression; (3) biases to be corrected for; and (4) a multi-model ensemble prediction to be created. These results thus represent an ensemble of multiple solar wind models which have been optimized to provide best estimates for the arrival times of solar wind structures to Jupiter. The results are ideally suited for comparison to in-situ Juno measurements and deeper investigations into solar wind driving at Jupiter, and allow for a more complete statistical view than previously available, owing to self-consistent propagation of uncertainties. We will conclude by discussing potential applications of MMESH to planets beyond Jupiter.

Characterizing the solar wind-magnetosphere viscous interaction in the outer solar system

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Currently, theories of magnetospheric interaction with the solar wind have been primarily studied on Earth, Jupiter, and Saturn, which interact with the solar wind predominantly through reconnection. The magnetohydrodynamic plasma description suggests that solar wind conditions in the outer solar system encourage magnetosphere boundaries at Uranus and Neptune to be more Kelvin-Helmholtz (KH) unstable, but no quantitative assessment has been performed.

Kelvin-Helmholtz instabilities (KHIs) occur when there is a velocity shear across the interface between two fluids. Viscous interactions between the solar wind and magnetospheric plasma occur because the KHIs allow for plasma mixing and momentum transfer through KH vortices at the magnetopause boundary. Localized regions of magnetic reconnection can occur in KH vortices, creating an intermittent mode of plasma transport very different from global magnetic reconnection.

This study employs an analytical model to test the condition for KHI growth at the outermost planets in the solar system. We evaluate the points along the magnetopause surface where the growth of KHIs is possible and use this to determine the most favorable conditions for KHI growth at Uranus and Neptune.

The results of this analytical model indicate that the ice-giants are environments where KHIs may play a more dominant role in controlling the flow of plasma in the magnetosphere. The model provides a valuable insight into the processes that may take place at Uranus and Neptune's magnetopause as a function of rotation phase, season, and the interplanetary magnetic field strength.

Survey on interchange signatures in the Jovian magnetosphere using multi-instrument Juno data

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The interchange instability is thought to be the driver of slow plasma transport in the inner magnetospheres of Jupiter and Saturn.

Case detections have been reported at Saturn using Cassini magnetic field and plasma data (e.g. André et al. 2007), and at Jupiter using Galileo magnetic field, waves, and high energy plasma data (e.g. Bolton et al. 1997).

Russel et al. 2005 conducted a survey of interchange signatures using Galileo magnetic field data only, which led them to set an "interchange occurrence rate" of 0.32% in the Jovian magnetosphere. More recently, Kurth et al. 2023 published a multi-instrument analysis of multiple interchange events seen by the Juno mission in the inner Jovian magnetosphere from Mshell 5 to 10 and magnetic latitude -35 to 35°. In particular, they explicitly describe the various expected signatures of interchange in the Juno/WAVES (B and E sensor), Juno/JADE (E and I sensors) and Juno/MAG data. Based on this presentation, we verify their catalog and extend it. We perform a systematic mining of Juno WAVES-E, WAVES-B, JADE-E, JADE-I and MAG data, selecting as interchange event, time intervals when unambiguous interchange signatures are seen with two or more of those instruments.

From this catalog, we derive the distribution and properties of interchange events in the inner magnetosphere of Jupiter as observed by Juno.

André, N., et al. (2007), GRL., 34, L14108, doi:10.1029/2007GL030374. Bolton, S. J. et al. (1997), GRL., 24, 2123-2126, doi:10.1029/97GL02020. Russell, C. T. et al. (2005), doi:10.1016/j.pss.2005.04.007. Kurth, W. et al. (2023), EGU 2023, doi:10.5194/egusphere-egu23-4260.

A survey of proton and electron injections in the magnetosphere of Jupiter

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Injections of energetic particles in planetary magnetospheres are dynamical phenomena that have been intensively studied in the past years. However, the processes responsible for these injections are still poorly understood. At Jupiter, the data obtained by the Galileo Energetic Particle Detector (EPD) during the first four years of the mission revealed many substorm-like injections [Mauk et al., 1999]. A full survey of the Galileo-EPD dataset still remains to be conducted. In this study, we therefore present a complete analysis of Galileo-EPD electron and ion injections at M<30 based on the dataset recently released on PDS [Kollmann et al., 2022]. We confirm that injections occur at all local time as suggested by Mauk et al. [1999]. In addition, we use measurements from the JADE instrument onboard the Juno spacecraft to characterize the plasma properties at $E < 100$ keV during injection events. These results provide important insights to better understand the plasma transport in Jupiter's magnetosphere and can also contribute to a better evaluation of the impact of energetic particles on the weathering of moon surfaces.

Juno-era updates to the Jupiter flux equivalence mapping model and implications for the predicted polar cap boundary

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The Juno spacecraft has now completed nearly 60 orbits, collecting a wealth of information about Jupiter's polar magnetosphere and aurora. However, there are still many unanswered questions about the size, location, and variability of Jupiter's polar cap or region of field lines that are open to the solar wind. These questions are difficult to answer without a clear link between polar auroral features and source regions in the magnetosphere. Therefore, as a first step, we have updated the flux equivalence mapping model (Vogt et al., 2011, 2015) that allows users to relate a point in Jupiter's middle and outer equatorial magnetosphere to the polar ionosphere. Specifically, we have incorporated new Juno-era Jovian magnetic field models (Connerney et al., 2018, 2020, 2022) and the temporal variability observed in the magnetodisk that is known to influence the mapping of the satellite footprints (Vogt et al., 2017, 2022a, 2022b). The result is an updated flux equivalence mapping model that can be adjusted on an orbit-by-orbit to best interpret the relationship between Juno in situ observations in the polar magnetosphere and the source regions in the equatorial magnetosphere. We will present results from the updated model, including initial predictions for the location of the open/closed field line boundary on each Juno perijove and an initial search for a relationship between Juno's mapped equatorial position and measured ionospheric properties like auroral brightness or plasma composition.

[Poster A31]

Juno Observations of Large-Scale Azimuthal Fields in Jupiter's Nightside Magnetosphere and Related Radial Currents

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We combine magnetic data from the first 46 data-taking periapsides of the polar orbiting Juno spacecraft spanning dawn to dusk via midnight to investigate azimuthal fields and related currents in Jupiter's nightside magnetosphere. Data are binned by perpendicular radial distance ρ from the magnetic axis over 4-32 R_J along empirical poloidal model field lines spanning from tail to middle magnetosphere regions (dipole ionospheric colatitudes θ_i~5°-17°), and by local time (LT). The data was found to be well organized by these parameters. On southern tail field lines ($\theta_i \leq 11°$) the azimuthal field is well represented as the sum of sweepback fields falling as $1/\rho$ that are near-independent of θ_i and LT, and a near-constant field consistent with ~3.5 nT pointing sunward. The combination is swept back at dawn/midnight but swept forward at dusk outside ~5 R_J. Outer magnetosphere (θ_i~12°-15.5°) azimuthal fields are instead swept back near-independent of LT, near-continuous with the tail field in the dawn sector, but with large shear at the tail interface and across outer magnetosphere field lines in the dusk-midnight sector. The $1/\rho$ field is associated with a nightside inward polar axial current ~5.8 MA located within θ_i~5° of the magnetic axis, while the dusk-midnight field shear measured near the ~30 R_J study boundary provides an inward current ~15.4 MA, related to the near-constant field. Azimuthal fields fall to small values across middle magnetosphere field lines (θ_i~15.5°-17°), associated with outward currents ~21.2 MA per hemisphere near-independent of LT forming the nightside equatorial current sheet, balancing these inward currents.

Jupiter's plasma disk observed by Juno: Radial, vertical and local time structure

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The ionized plasma originating from Io's escaping atmosphere forms a thin disk region near the equator of the Jovian magnetosphere. The Juno spacecraft traverses the plasma disk frequently with its orbit moving from the dawnside through midnight to the duskside. Based on plasma observations from the JADE instrument and a newly developed forward modeling method, we perform a survey of the plasma disk properties between 10-40 R_J using data from 274 plasma disk crossings occurring between PJ5 and PJ44. Plasma is heated from 1.5 keV to 6 keV between 15 R_J and 30 R_J. Strong outflows with velocity >100 km/s are observed frequently outside 25 R_J. Plasma corotates around Jupiter and the rigid corotation breaks down outside 15-20 R_J. From disk center to edge, the plasma temperature increases by a factor of 10. Heavier ions with lower charge states are more confined near the equator and vice versa. The field-aligned observations are consistent with the multi-species diffusive equilibrium model. The dawn-dusk asymmetry is predominantly modulated by the Vasyliūnas cycle featuring super-corotating hot flows (˜10 keV) in the pre-dawn sector. On the dawnside, the flux tubes are depleted characterized by low density, low temperature, and near rigid corotation velocity. On the duskside, the flux tubes are mass-loaded characterized by high density, high temperature, and sub-corotation velocity. The hotter inflows are coupled with swept-forward magnetic fields, whereas the colder outflows are coupled with swept-back magnetic fields. Thermal plasma beta exceeds one beyond 20 R_J and contributes to increased instabilities. The centrifugal instability related cold, dense plasma is commonly observed near the midnight sector.

Mapping the Jovian Magnetospheric Thermal Plasma

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Juno's prime mission covered 36 flybys, each giving new insights to the jovian magnetosphere. Here we examine the ion composition of the jovian magnetospheric plasma utilizing the JADE-I sensor on Juno. Proton properties are determined by numerical moments, while the heavy ion properties are from forward models of Maxwellian fits of multiple ion species with a shared velocity but separate densities and temperatures. The later requires simultaneous model fitting of Time-of-flight data (good for composition, little to no directional information) and the JADE-I Species data set which has coarse mass resolution (protons, 'lights' and 'heavies') but has excellent directional information. Fitting two fundamentally different data products simultaneously is challenging and the fitting is computational expensive, requiring careful pruning of the data to retrieve suitable intervals for analysis. In this presentation, we determine the thermal plasma properties and map out the trends in location, and derived locations (e.g. centrifugal latitude), including relative abundances and per-species temperatures.

Quantifying Transport Quantities in Jupiter's Magnetodisc Through Juno Data Analysis

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Radial transport of plasma and magnetic flux is important in giant planet magnetospheres, such as Jupiter, where the system is internally driven. The strong rotational flows associated with the rapid rotation period of Jupiter confines plasma into the equatorial region forming what is known as the magnetodisc. A significant portion of the plasma found in the magnetodisc originated from Io and is traveling through the magnetodisc on its way down the tail until the composition becomes primarily solar wind-like. In order to elucidate plasma transport in this region, mass transport and magnetic flux transport is examined. In addition, vertical pressure balance is verified. These quantities are derived from two separate methods, forward fits as determined by J.-z. Wang and numerical moments as determined by R.J. Wilson. The comparison gives validity to both methods and the quantities they produce. Both methods demonstrate similar magnetic flux conservation indicating a net outward transport. This could imply implications such as unresolved small-scale inward transport. Mass transport is examined using a scale height given by Bagenal and Delamere, 2011 for both methods. Additionally, mass transport is also examined using the numerical moments with an integration over the magnetodisc. The results of all three methods are compared with physical chemistry models outlined by Delamere and Bagenal, 2013 which approximate a mass transport rate of 300-1200 kg/s.

Electron distributions in the Jovian inner and middle magnetosphere measured by the Juno JADE instrument

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The JADE instrument onboard the Juno spacecraft has comprehensively sampled a range of M-shells in the Jovian magnetosphere and collected vast amounts of data on plasma distributions in the magnetosphere. In particular, JADE-E measured electrons between roughly 30 eV and 35 keV using two operational electron sensors that measured a range of pitch angle at a cadence of 1 s in high data-rate mode or between 30 s to 600 s in low data-rate mode. In this study, we conduct the first comprehensive survey of electron plasma populations in the Jovian inner and middle magnetosphere between M-shells of 6 and 40. We will show the variation of energy and pitch angle spectra with latitude and radial distance, as well as the variation of parameters derived from observations, such as the thermodynamic kappa and temperature of electrons. Results from this new survey will be useful to study electron transport, acceleration, and interaction with other plasma and neutral species, for example, due to electron-impact ionization or recombination.

[Poster A36]

Soft x-ray emission from Saturn's magnetosheath: A comparison of two models

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Soft X-ray emission generated by charge exchange is a potential probe of regions with mixed neutral and charged particle populations. Saturn's magnetosheath is one such region, with several in-system sources providing neutrals that can interact with sheath plasma. Local x-ray emission enables imaging of the active magnetosheath and cusp regions by instruments like the SMILE SXI, which will perform this role at Earth.

We present results from two simple models of soft x-ray emission in Saturn's magnetosheath to determine if a SMILE-like instrument could image emission structures in a reasonable time frame. The first model builds on earlier work by Sulaiman et al. (2017), characterising soft x-ray emission using 3-D MHD simulation data of Saturn's magnetosheath from Jia et al. (2012), further constrained by an empirical magnetopause and imposed bow shock surface. This model assumes steady solar wind conditions.

The second model applies 2-D magnetopause and bow shock surfaces from Kanani et al. (2010) and Went et al. (2011), respectively. Magnetosheath conditions, including location and the abundance of heavily stripped oxygen are modified with solar wind variations. Neutral hydrogen densities extrapolated from Smith et. al. (2021) are used in both models. We find similar volumetric emission rates of $10^{-10} - 10^{-12}$ photons cm^{-3} s^{-1} between the two models. Integration timescales are explored for a variety of detector locations.

Trapped and Leaking Energetic Particles in Injection Flux Tubes of Saturn's Magnetosphere

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In Saturn's magnetosphere, the radially-inward transport of magnetic fluxes is usually carried by localized flux tubes with sharply-enhanced equatorial magnetic fields. The flux tubes also bring energetic particles inward, which are expected to drift azimuthally and produce energy-dispersive signatures. Spacecraft observations, however, indicate the occurrence of energy-dispersionless signatures for perpendicular-moving particles. These unexpected features are attributed to the sharp magnetic gradient at the edge of the flux tubes, which significantly modifies the drift trajectories of perpendicular-moving particles to enable their trapping motion within the flux tubes. The bouncing particles are less affected by the gradient, and therefore, still display energy-dispersive signatures. It is the distinct particle behavior, together with different spacecraft traversal paths, that underlies the observational diversity. The results improve our understanding of particle dynamics in the magnetospheres of giant planets and indicate that pitch-angle information should be considered in the extraction of flux-tube properties from energetic particle observations.

Injection-driven rotational magnetospheric periodicity revealed at Saturn through combined MHD and test particle simulations.

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Cassini observations reveal an intriguing ˜11 hour quasi-periodic variation across the magnetic field, kilometric radiation, energetic particle and Energetic Neutral Atom (ENA) measurements in Saturn's magnetosphere. However, the underlying driver of this recurrent behavior remains unresolved. Observational studies have suggested this periodicity is related to a rotating partial ring current associated with enhanced dipolarization and ENA activity. However, as of yet global modeling attempts to provide context for this periodicity has been unable to establish a causal origin for this mechanism.

We employ a two-pronged computational approach combining global magnetohydrodynamic (MHD) simulations and test particle tracing to investigate the physical mechanism responsible for this periodicity. Using the Grid Agnostic MHD for Extended Research Applications (GAMERA) model, we simulate Saturn's global magnetosphere including internal planetary magnetic field sources, planetary rotation, and mass-loaded plasma from the moon Enceladus. Injections of sample test particles in our MHD simulations reproduce the periodicity in the magnetic field structure and plasma flows. Periodic magnetic reconnection in the magnetotail drives the observed ˜11-hour periodicity, generating particle injections from the tail towards the Enceladus plasma torus, modulating global particle distributions. Test particles exhibit periodic energization and transport consistent with Cassini Type-1 ENA observations.

[Poster A39]

A new environment model framework for Saturn

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As part of the ESA Testbed for Radiation and Plasma Planetary Environments Development (TRAPPED) project, a new easy-to-use environment model framework for gas giant planet moon systems is developed. This framework is targeted at deriving specifications for future science mission engineering purposes. To date, environment models are being developed for Saturn but could be extended to Uranus and Neptune in future work.

The 13-year Cassini mission has provided a wealth of multi-instrument measurements and multiple techniques to determine energetic particles fluxes obtained using LEMMS (Low Energy Magnetospheric Measurements System), CHEMS (Charge Energy Mass Spectrometer) and INCA (Ion Neutral Camera). In the scope of the TRAPPED project, a new calibration for LEMMS was developed, that improves the description of the electron and proton spectral shapes and fluxes at MeV energies, the cross-calibration between CHEMS, INCA and LEMMS proton measurements has been re-evaluated, and a new global magnetic field model of Saturn's magnetosphere has been introduced.

Based on Cassini data, a new average empirical model of Saturn's radiation environment is presented here. The dynamics of energetic electron and proton fluxes (> few keV) with respect to L-shell, equatorial pitch angle and local time is investigated. This new model will provide the energetic particle mean flux but will also take into account the temporal dynamics through a confidence level.

Statistical survey of magnetic flux integral quantities in Saturn's magnetosphere

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Magnetic flux integral quantities (e.g., flux tube entropy, flux tube content) 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). In this study, we combine the Cassini CAPS and CHEMS Moments Data as well as a steady state magnetic field model (i.e., Caudal model) to estimate the flux tube content and flux tube entropy in Saturn's magnetosphere. Our statistical survey found the flux tube content rapidly decreases with the radial distance away from Saturn in the inner magnetosphere and roughly levels out in the middle magnetosphere, indicating the radial transport processes occurring in the inner magnetosphere and the middle magnetosphere could be fundamentally different. Notice, Saturn's magnetosphere is stabilized by a radially increasing profile of flux tube entropy and destabilized by a radially decreasing profile of flux tube content. In this study, we also estimate the expected penetration location by using the flux tube interchange stability formalism developed by Southwood and Kivelson 1987. The results show that flux tube entropy can play a crucial role in braking the injections, while the flux tube content has a relatively smaller influence on the injected flux tube, being consistent with our previous case study (Wing et al., 2022).

A simple spacecraft - vector intersection methodology and applications

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Observations with spacecraft-mounted instruments are usually limited by their field-of-view and are often affected by the spacecraft's shadow or wake. Their extent though can be derived from the spacecraft's geometry.

In this work we present a robust method for calculating the field-of-view as well as the extent of a spacecraft shadow and wake from readily available spacecraft CAD models. We demonstrate these principles on Cassini, where we give examples of vector-spacecraft intersection for the Cassini Langmuir Probe , as well the field-of-view of the Langmuir Probe and the Cassini Plasma Spectrometer.

Kronian ionospheric outflow in the magnetosphere of Saturn

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Felici et al., 2016 described an ionospheric outflow event from Saturn's magnetotail, when Cassini was located at $\simeq$ 2200 h Saturn local time at 36 R_S from Saturn. During several entries into the magnetotail lobe, a tailward flowing cold ion beam were observed directly adjacent to the plasma sheet and extending deeper into the lobe. The ions appeared to be dispersed, dropping to lower energies with time. The ion composition showed mainly H^+. Ultraviolet auroral observations showed a dawn brightening, and upstream heliospheric models suggested that the magnetosphere was being compressed by a region of high solar wind ram pressure. The authors considered several configurations for the active atmospheric regions and estimated the corresponding mass rates outflowing the ionosphere. We found 247 new instances of dispersed ions in the Cassini Plasma Spectrometer Singles (CAPS/SNG) data. Investigating the location of the spacecraft in respect to the plasma sheet, flow direction, and ion composition utilizing the Cassini Magnetometer data, and the CAPS Time of Flight data, we confirm the nature of some of these events and map them in the magnetosphere of Saturn.

Aurora and solar wind activity during the events were also investigated, utilising the Cassini Ultraviolet Imaging Spectrograph data, and ENLIL model results.

Future work will include an analysis of ionospheric outflow in the Jovian system, and a comparison with models of ionospheric outflow at the Gas Giants [Glocer et al., 2017, Martin et al., 2020 a,b], and between the two planets.

[Poster A43]

SMITE: A New Saturn Ionosphere Model Including Ring-Planet Coupling and Electrodynamics

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Decades of observations have shown that Saturn's ionosphere has many morphologies that cannot be understood by solar influence alone. The Cassini Grand Finale revealed the presence of inter-hemispheric electromagnetic coupling at Saturn, electromagnetic coupling between Saturn and its rings, and volatile ring compounds and grains flowing into Saturn's equatorial atmosphere, finally giving us a peek at the complex dynamics which may drive the ionosphere. Thus, we present the Saturn Model of the Ionosphere, Thermosphere, and Electrodynamics 'SMITE', which is the first giant planet ionospheric model to include the effect of non-auroral electrodynamics on the upper atmosphere and self-consistent, inter-hemispheric, plasma transport. It derives its heritage from Saturn Thermosphere-Ionosphere Model 'STIM', a global circulation model, and 'SAMI2/3', a well-known terrestrial ionospheric model suite that successfully captures complex ionospheric morphologies observed at Earth due to electrodynamics driven by the interactions between the terrestrial magnetic field and the ionosphere. This presentation will showcase the latest SMITE results, which include photochemistry, analytic approximations of Earth-like electrodynamics (e.g., the equatorial fountain effect), ring material influx, and seasonally variable inter-hemispheric plasma transport driven by the 'ring shadow' on Saturn's atmosphere. We will also present a comparison between the SMITE results, and in-situ and remote observations of Saturn's ionosphere, to constrain the dynamics that give rise to the spatial and temporal variability in the observed plasma distributions. Furthermore, we will discuss the applicability of Saturnian dynamics to the other giant planets in our solar system, highlighting the adaptability of SMITE to giant planet ionospheric studies.

A Reinvestigation of Saturn Drifting Bursts

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Soon after the arrival of the Cassini spacecraft at Saturn in July 2004, the Radio and Plasma Wave Science (RPWS) instrument detected a new type of low-frequency radio emissions below 50 kilohertz, which were later named Saturn Drifting Bursts (SDBs). Although SDBs have a very characteristic spectral structure in the shape of single drifting elements (drift rates around 1 kHz per minute), they received little attention so far. From an early study of the first 5 years of RPWS data from Cassini's orbital tour, it has been shown that SDBs are radiated mainly in the ordinary mode, and occurrence statistics indicated source regions located in the outer layers of the Enceladus plasma torus. However, a conclusive analysis using the direction-finding capabilities of Cassini/RPWS has not been successful so far. We will present results from a reinvestigation of SDBs based on the later years of the Cassini mission, including the Grand Finale orbits, during which Cassini spent more time at medium and high latitudes, thus increasing the chances to detect more SDB events. Existing statistics will be refined with new data, trying to narrow down the source regions, and to gain new insights into the generation mechanism of SDBs.

Mapping of the possible source of Saturn Drifting Burst emissions

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Saturn Drifting Bursts (SDBs) are radio emissions detected at frequencies below 50 kHz with very characteristic spectral features of a drifting element. From the early phase of Cassini's mission, it has been shown that SDBs are radiated mainly in the O-mode, and occurrence statistics indicated source regions located in the outer layers of the Enceladus plasma torus. Although a conclusive analysis using the direction-finding capabilities of Cassini/RPWS has not been successful, we present an attempt to map a possible source location. The propagation characteristics of SDBs are studied using a ray-tracing simulation incorporating a semi-empirical model of Saturn's magnetized plasma environment. The model presented by Dougherty et al., 2018 is used for the magnetic field. For electron plasma density, the expanded model including existing models of Persoon et al., 2019 for the ionospheric model, and Persoon et al., 2020 for the inner magnetosphere and Enceladus plasma torus has been used. The Langmuir Probe proxy data expands these models into higher latitudes and distances. The ray-paths for the O-mode waves at several discrete frequencies and propagation directions are simulated. The possible SDBs source location and wave properties including possible mode conversion along the ray path are discussed.

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 Saturnian 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 R_S (R_S = 60,268 km) in the midnight or postmidnight region; (2) the brightening of a smaller cloud usually seen at distances < 10-12 R_S 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 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 density gradient at the outer edge of the Enceladus plasma torus, can mode convert to the Z mode and then to O mode. The 5 kHz narrowband waves commonly propagate in the O mode

[Poster A47]

Studying Saturn's Interchange Injection Events: Investigating Instabilities in the Kronian Inner Magnetosphere

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We investigate the plasma mass transport process known as the interchange instability. Injections resulting from this process have been observed by the Cassini spacecraft within Saturn's inner magnetosphere with multiple plasma particle, magnetic field, and wave instruments. It is not well understood how these interchange injections, relatively small in spatial scale and similar to Rayleigh-Taylor instabilities, are potentially triggered by larger-scale injections caused by current-sheet collapse processes. We investigate this potential connection with two main avenues: data analysis and modeling.

First, we analyze 26 interchange events which have each been independently identified as co-occurring across Cassini plasma instruments. Our aim is to provide a unifying review of interchange injections seen in all previous statistical surveys with a particular focus on observations from the Radio and Plasma Wave Science instrument. Second, we investigate the conditions within the inner magnetosphere of Saturn with HEIDI (Hot Electron and Ion Drift Integrator), a kinetic model that solves the gyro- and bounce-averaged Boltzmann equation for the plasma population in the inner magnetosphere. Originally designed for Earth, we will present steps taken towards adapting this model for Saturn. Early efforts in understanding interchange injection events at Saturn include the study of ring current evolution with changing global magnetic field magnitudes and orientations, associated electric field, and the modification of the co-rotation flow. Future efforts include adding source and loss terms and coupling HEIDI to SWMF-BATSRUS to create a comprehensive physical model of the Kronian environment.

[Poster B01]

Internal and External Jovian Magnetic Fields: Community Code to Serve the Magnetospheres of the Outer Planets Community

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Community Code for both internal and external jovian magnetic fields has been created to model various internal fields (including O6, VIP4, VIT4, VIPAL, ISaAC, JRM09 and JRM33), and the Con2020 external field. These open source tools are available in IDL, MATLAB, Python and C++, with different packages, led by different authors, all available on GitHub. This poster will summarize the different Community Code tools and give examples of how to use them and how to cite them in publications. The 2023 SSR paper (DOI: 10.1007/s11214-023-00961-3) provides in depth details, but since that publication further enhancements have been made to the codes to account for more situations. For a list of our Community Codes, and other some other public codes, see `https://lasp.colorado.edu/mop/missions/juno/community-code`.

We welcome others to use and improve on these Community Codes, by suggesting code improvements directly in to the GitHub repositories.

Reference:

Wilson, R.J., Vogt, M.F., Provan, G. et al. Internal and External Jovian Magnetic Fields: Community Code to Serve the Magnetospheres of the Outer Planets Community. Space Sci Rev 219, 15 (2023). `https://doi.org/10.1007/s11214-023-00961-3`

[Poster B02]

Juno-JADE Ion Parameters in Jupiter's Magnetosphere (10-50 R_J)

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After its arrival at Jupiter in July 2016, Juno conducted a global survey of Jupiter's magnetosphere (especially the equatorial plasma disk region) with its highly eccentric polar orbit. Since then, the JADE instrument has accumulated a large amount of plasma measurements. Using a developed forward modeling method and the Alpine supercomputer cluster at CU Boulder, we fit all ion measurements between 10-50 R_J from PJ5 to PJ56, obtaining a dataset with 71,224 good fits that consists of a set of plasma parameters: abundances of different heavy ions, density, temperature, and 3-D bulk flow velocity of heavy ions. An overview of the dataset is presented to illustrate its effectiveness and usefulness. This dataset has the potential for many applications.

Preliminary Modelling of Magnetic and Plasma Conditions during Cassini's T21 Flyby of Titan

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The Cassini spacecraft was immersed in the Southern lobe of Saturn's plasmasheet for several hours before and after its closest approach to Titan during the T21 flyby (2006, 12 December at 11:41:31 UT). T21 was an upstream encounter, significantly inclined with respect to Saturn's equatorial plane. It thus presents a good opportunity to model the field and plasma conditions upstream of Titan, particularly for the 'quiet' lobe region in which Titan was immersed during closest approach. Following a similar approach to a previous study by Achilleos et al (GRL, 2014), we use an equilibrium model of a rotating plasmadisc, in conjunction with a configurable geometrical model of the current sheet morphology, in order to obtain best fitting parameters, including the effective magnetodisc radius in the relevant pre-dawn sector of local time (˜50 R_S) and the characteristic distance at which the current sheet shows significant tilting or hinging upwards from the equatorial plane (<˜40 R_S). We also demonstrate how a reasonable fit to the observed magnetic field can also be used, within the model framework, to make predictions of the thermal and dynamic pressure of the disc plasma, both along the spacecraft trajectory and at selected points in the near-Titan space.

[Poster B04]

Currents in Titan's Ionosphere

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Changing magnetic field configurations experienced by Titan as it orbits Saturn can induce currents in the conductive ionosphere of Titan. These induced currents in turn generate ionospheric magnetic fields that deflect the incident plasma and shield out the external magnetic field. By measuring magnetic field perturbation, we can calculate the current densities necessary to create the observed perturbations (with some restrictive assumptions). We determine horizontal currents in the ionosphere of Titan from magnetic field perturbations during Cassini flybys closer than 1500 km, i.e., within the collisional ionosphere. By grouping the flybys by external magnetic field and plasma conditions and Titan orbital position, we attempt to determine how ionospheric currents change with respect to external conditions. These currents induced in Titan's ionosphere are but one way Saturn's magnetospheric environment impacts ionospheric processes and dynamics at Titan.

Observed vs. Modeled Electron Densities in Titan's Ionosphere

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Saturn's largest moon, Titan, has a chemically complex atmosphere that upon ionization forms a complicated ionosphere. The ionosphere consists of several species such as electrons, H^+, CH_4^+, N_2^+ and several heavy hydrocarbon ions. In-situ observations by the Cassini spacecraft have led to a significant improvement of our understanding of Titan's ionosphere. However, the electron densities calculated by various models below ~1200 km altitude are typically larger than those observed by Cassini. Many of the models have tried to address this discrepancy, as a chemistry issue, either an over production of some of the ion species or missing loss process. While incomplete chemistry schemes are a likely candidate to explain this issue, there are however, other suspects that need examination. We examine if the underlying asymmetric 3-d structures and processes, such as the neutral densities, ionization rates, negative ion distribution and electron temperature can lead to the density discrepancies. Finally the hypothesis that the electron density discrepancies are due to transport effects from Titan's interaction with Saturn's magnetosphere and ion-neutral interactions with atmospheric winds will be tested.

To examine these hypotheses we use and combine a series of models. These include models for ion-neutral chemistry, electron impact ionization, negative ions, the 3-d density and winds from the T-GITM code and the HALFSHEL hybrid code for plasma interactions. The combination of all of the models are used to simulate Titan's plasma interaction to test the effects of transport on the electron density below ~1200 km altitude.

A Novel Backtracing Model to Study the Emission of Energetic Neutral Atoms at Titan

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To study the emission of energetic neutral atoms (ENAs) at Titan, we have developed a novel model that takes into account a spacecraft detector's limited field of view and traces energetic magnetospheric particles backward in time. ENAs are generated by charge exchange between Titan's atmospheric neutrals and energetic magnetospheric ions. By tracing these ions through the draped electromagnetic fields in Titan's environment, we generate synthetic ENA images and compare them to Cassini observations from the TA flyby. Our model can reproduce the intensity and morphology of the observed images only when field line draping is included. Using a realistic detector geometry is necessary to determine the influence of this draping on the ENA images: the non-uniform fields eliminate a localized feature of increased ENA flux, which is a different effect than in models utilizing an infinitely extended detector. We demonstrate that ENA observations from TA contain signatures of the time-varying Saturnian magnetospheric environment at Titan: the modeled ENA emission morphology and the effect of field line draping are different for the background field vectors measured during the inbound and outbound legs of TA. The visibility and qualitative effect of the draping on observed ENA images vary strongly between different detector locations and pointings. Depending on the viewing geometry, field line draping may add segments of elevated flux to the synthetic ENA images, remove such segments, or have no qualitative effect at all. Our study emphasizes the challenges and the potential for remote sensing of Titan's interaction region using ENA imaging.

Cassini UVIS Observations of the Enceladus Auroral Footprint in 2017

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Ultraviolet Imaging Spectrograph (UVIS) observations show the Enceladus auroral footprint on Saturn on September 14, 2017, near the end of the Cassini mission (Pryor et al., PSJ 5, id.20, 2024). A series of Saturn north polar auroral images were obtained by slowly slewing the Cassini spacecraft at right angles to the UVIS long slit. The images were limb-fit to improve the spacecraft geometry. Enhanced Extreme Ultraviolet (EUV) 88-118 nm channel emissions due to electron impact on atomic and molecular hydrogen were seen in the expected location for the Enceladus auroral footprint on five successive images spanning almost 4 hours. Enhanced emissions were also seen in simultaneously obtained Far Ultraviolet (FUV) 111-165 nm images in at least two of these images, with the spectral signature expected for auroral emissions. While most Cassini UVIS auroral images do not show the Enceladus auroral footprint, these 2017 images support the earlier detection of an Enceladus-linked spot on Saturn in 2008 Cassini UVIS data (Pryor & Rymer et al., 2011).

Modeling the neutral and ionized environments of Callisto

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Callisto is the most distant of the four Galilean moons, orbiting at around 26.3 Jovian radii from its planet. Composed of equal parts rock and ice, the moon has a tenuous atmosphere composed mainly of O_2 [Cunningham et al., 2015] and CO_2 [Carlson, 1999], as well as an ionosphere characterized by densities of up to 10^4 cm^{-3} [Kliore et al., 2002]. During flybys of Callisto, NASA's Galileo mission detected an induced magnetic field compatible with the signature of a subglacial ocean. The moon's environment interacts with the Jovian magnetosphere (surface erosion, Alfvén wings, etc.), whose physical characteristics vary greatly during its orbit, with a wide excursion in magnetic latitude.

While the JUICE mission plans to carry out several flybys of Callisto, the interaction between the moon and Jupiter's magnetosphere remains poorly understood. Simulations describing the neutral and ionized environments of the Jovian satellite must therefore be set up. These simulations will use the LatHyS hybrid multi-species parallel 3D model [Modolo et al., 2016; 2018] already used to describe the environment of Ganymede in particular. The Larmor radii of freshly generated pick-up ions of O_2^+ and CO_2^+ being larger than the moon radius, a kinetic approach for the ion dynamic is more appropriate than a fluid model and is enable to capture asymmetries in Callisto's plasma interaction. Simulation results will be compared with Galileo in-situ observations.

[Poster B09]

Observability of ENA emissions at Europa and Callisto: predictions for the JUICE mission

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We analyze the emission of energetic neutral atom (ENA) flux from Callisto and Europa as a tool to probe moon-plasma interactions on a global scale. In situ ENA detectors sample a two-dimensional snapshot of the entire interaction region, as opposed to observations that provide magnetic field and plasma data only along one-dimensional trajectories. Charge exchange between energetic magnetospheric ions and cold atmospheric neutrals results in ENAs that propagate along rectilinear trajectories. Since the distribution of ENA flux is resultant from the interaction between the ambient plasma, the magnetospheric field configuration and the neutral gas distribution, ENA images can contextualize and quantitatively constrain these aspects of the moon-magnetosphere interaction on a local as well as a global scale. We combine the perturbed electromagnetic fields from a hybrid plasma model with a particle tracing tool to model ENA generation for the energetic ions interacting with Europa's and Callisto's neutral envelopes. By taking into account the point-like size (on scales of the plasma interaction) and limited field of view of a spacecraft detector, we apply our model to investigate which features of the emitted ENA flux will be observable by the JUICE spacecraft during its close flybys of both moons.

The Particle Environment Package (PEP) onboard the JUICE mission: Science Perspectives and current status

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JUICE is the first large mission in the ESA Cosmic Vision program. The spacecraft was launched in April 2023 and will arrive at Jupiter in 2031. It will spend three years characterizing the Jovian system, the planet itself, its giant magnetosphere, and the icy moons Ganymede, Callisto, and Europa. JUICE will then orbit Ganymede as the first spacecraft in history for almost a year. The main goal of the mission is to explore the emergence of habitable worlds around gas giants. While Gany¬mede is in the focus of the JUICE-mission also the magnetosphere of Jupiter will be studied in great detail. The long-term magnetospheric science will push significantly beyond the capabilities of previous missions. JUICE will explore Jupiter's equatorial magnetosphere covering a wide range of local times and radial distances to study the global and local magnetospheric parameters, but the spacecraft will also study higher latitudes up to 30 degrees to explore the regions above and below the magnetodisc, study remotely the ring current and the Jovian aurora.

One of the scientific payloads onboard JUICE is the Particle Environment Package PEP which consists of six different sensors to measure electrons, ions, and neutral particles in a variety of energy ranges. The scientific objectives of PEP range from the global configuration and the dynamics of the Jovian magnetosphere, the local plasma parameters near the moons and the interaction of the magnetospheric corotating plasma with the icy Galilean moons as well as characterizing the composition of the exospheres of the Galilean moons.

We will summarize all the instrument parameters, their detailed science goals for each sensor, and the current status in flight.

Energetic particle measurements near Ganymede: Galileo EPD data revisited, comparison with recent JUNO flyby and perspectives for Juice PEP

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The Galileo spacecraft performed close flybys of the moon Ganymede between 1996 and 2001. We reanalysed data of the energetic particles detector EPD onboard Galileo and derived the particle fluxes, energy spectra, and pitch angle distributions in the energy range of several keV to MeV during Ganymede flybys G2, G7, G8, G28, and G29.

We find sharp dropouts in ion and electron fluxes as signatures of the loss cones inside the Ganymede magnetosphere as well as trapped electron distribution. Additionally, bi-directional field-aligned and butterfly distributions were found as well.

We discuss these findings compared with results from the recent JUNO flyby and with simulation results in charactering Ganymede's magnetosphere and in the context of future measurements with the Particle Environment Package PEP onboard the Juice mission which will be in orbit around Ganymede in 2032.

On the Formation of Trapped Electron Radiation Belts at Ganymede

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We present evidence of stably trapped electrons at Jupiter's moon Ganymede. We model energetic electron pitch angle distributions and compare them to observations from the Galileo Energetic Particle Detector to identify the origin of the pancake distributions seen during the G28 encounter. We trace electron trajectories to show that these particles enter Ganymede's mini-magnetospheric environment, become trapped, and drift around the moon for up to 30 minutes, in some cases stably orbiting the moon multiple times. Conservation of the first adiabatic invariant partially contributes to energy changes throughout the electrons' orbits, with additional acceleration driven by local electric fields, before they return to Jupiter's magnetosphere or impact the moon's surface. These trapped particles manifest as an electron population with an enhanced flux compared to elsewhere within the mini-magnetosphere that may be detectable by future spacecraft.

Characterising the magnetic and plasma environment upstream of Ganymede

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We present an application of the latest UCL-AGA magnetodisc model (MDISC) to the study of the magnetic and plasma conditions in the near-Ganymede space. By doing this, we provide a comparison with measurements from Juno's most recent flyby of the Jovian moon, perijove 34 (PJ34). We find good agreement between the model results and the magnetometer data, pointing towards a hot plasma index value and an effective magnetodisc radius of the Jovian magnetosphere, for the duration of the trajectory, consistent with a configuration with middling levels of expansion. We also predict the plasma conditions observed by Juno during the same flight-path, as well as the typical conditions over the orbit of Ganymede, with the magnetic and hot plasma pressures assuming dominant roles. Finally, these results are compared with functional fits of a compilation of Galileo flyby data obtained in the vicinity of Ganymede's orbit, suggesting Juno experienced somewhat similar conditions, despite a systematic overestimation in magnetic field intensity in the near-Ganymede space.

Electron Impact Ionization of Ganymede's Atmosphere

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Ionization of neutrals in Ganymede's O_2 dominated atmosphere is expected to play a major role in populating Ganymede's magnetosphere with plasma. While photo-ionization processes are reasonably understood, a quantitative assessment of electron-impact-ionization usually requires assumptions about electron densities and temperatures within the ionosphere that have not been measured yet. In our study, we use a new approach to investigate the total ionization rate and constrain its spatial structure. We further analyze the impact of ionization on the space environment around Ganymede.

Io's plasma interaction with the jovian magnetosphere: MHD modeling of the Juno flybys on orbits 57 and 58

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Io, the innermost of the Galilean moons, was recently targeted on two close passages of NASA's Juno spacecraft as part of its extended mission. These flybys took place on 30 December 2023 and 3 February 2024 on Juno's orbits 57 and 58, respectively. Both encounters reached a closest approach altitude of approximately 1500 km, and they were the closest flybys of Io since Galileo in over 20 years.

In this study, we apply the three-dimensional magnetohydrodynamic (MHD) single fluid PLUTO code (Mignone et al., 2007) and model the plasma interaction of Jupiter's magnetosphere with Io and its SO_2 atmosphere for the conditions of the Juno flybys. The model includes plasma production due to electron impact ionization, loss due to dissociative recombination, and collisions between ions and neutrals. We explore the effect of longitudinal and latitudinal variations of Io's global atmosphere on the magnetic field and plasma perturbations around the moon. Furthermore, we apply our parameterization of electron beams previously developed for Europa to Io's plasma interaction, whose presence were already reported by Williams et al. [1996] and Frank and Paterson [1999]. Finally, we compare our MHD simulations with the magnetic field measured by the magnetometer onboard Juno.

[Poster B16]

MHD simulations of the plasma interaction between Europa and Jupiter's magnetosphere during the Juno flyby

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Europa is situated within Jupiter's magnetosphere, where a rapid flow of magnetized plasma interacts with the moon's atmosphere and its icy surface. The magnetic field in the environment of Europa is also affected by Europa's induced magnetic field in a subsurface water ocean. On 29 September 2022, NASA's Juno spacecraft performed a close flyby of Europa, at a distance of approximately 350 km. This was the first close flyby since Galileo's last encounter on January 2000.

In this work, we model the plasma interaction of Jupiter's magnetosphere with Europa and its atmosphere for the conditions of the Juno flyby. We apply the three-dimensional magnetohydrodynamic (MHD) single fluid PLUTO code based on Mignone et al., [2007]. Our model considers electromagnetic induction in a subsurface water ocean, collisions between ions and neutrals, plasma production due to electron impact ionization, and loss due to dissociative recombination. Furthermore, we include the recently detected electron beams by Allegrini et al. [2024] as sheets of locally enhanced electron impact ionization. We also study the effects of density variations in Europa's neutral atmosphere and of asymmetries in electron temperature around the moon on its plasma and magnetic field environment. We compare our simulations with the magnetic field and the total ion number density measurements from the magnetometer and the JADE detector onboard Juno, respectively. Our results show that the electron beams are essential in the plasma interaction by producing large variations of the magnetic field and by filling the wake with newly ionized plasma downstream of Europa.

Kinetic simulations of standing Alfvén waves at Europa

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Recent observations of the Juno spacecraft have illustrated energetic particle signatures connected to the flux tubes of the innermost three Galilean satellites and their wakes that exhibit banded structures in energy (Sarkango et al., 2024). These banded structures have been attributed to bounce resonance interaction with the electrons and protons within standing Alfvén waves (also known as field line resonances) that form as a result from the moon-magnetosphere interactions. Self-consistent kinetic simulation studies of electron energization within field line resonances in the terrestrial magnetosphere also exhibit a banded structure on top of the background electron energization signature that has also been attributed to a bounce resonance interaction (Damiano et al, 2012, 2019). We close the gap between the terrestrial simulations and the Juno observations by using the same simulation model to study the case of the moon-magnetosphere interaction at Europa. In the execution of the simulations, we assume a background density profile that includes an equatorial torus and the simulation domain is centered along field lines that transect Europa's orbit. Modeling the initial moon-magnetosphere interaction as an Alfvénic perturbation imposed within the torus results, after some time, in the formation a spectrum of standing modes that oscillate along the field line. In this presentation, we summarize the electron response and corresponding wave energy dissipation that are evident in the simulation results and discuss them in the context of the recent Juno observations.

[Poster B18]

Europa's Alkali Exosphere During the 2022 Juno Flyby

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Ground-based measurements of Europa's extended Na and K exosphere were taken during the 2022 Juno flyby using Keck/HIRES. Preliminary maps of column density show that Na originates largely from the satellite's trailing hemisphere where Iogenic Na is sputtered due to continuous plasma bombardment. Less Na was detected than previous measurements reported by Leblanc et al. (2005) despite neutral enhancements from Io's volcanic activity. This data thus shows that Iogenic neutrals have little effect on Europa's alkali exosphere, and that Na on Europa remains superthermal even during times of increased neutral transport—an indication that the exosphere remains collisionless.

[Poster B19]

Estimation of plasma parameters at Europa's orbit from the Hisaki observation

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Europa (9.4 R_J from Jupiter) has a tenuous molecular oxygen atmosphere produced by magnetospheric plasma sputtering on its surface. To improve understanding of the production and loss of the atmosphere, the density and temperature of the magnetospheric plasma around the satellite must be known. The Jovian magnetosphere is filled with plasmas originated from the satellite Io (5.9 R_J). However, plasma observations at Europa's orbit are still limited. In this study, we use JAXA's Hisaki satellite data to determine the plasma properties from Io's to Europa's orbits.

We used the Hisaki observations of Io plasma torus from February to May 2015. An ultraviolet spectrograph onboard the satellite (EXCEED) measured sulfur and oxygen ion emission lines in the extreme ultraviolet (EUV) wavelength range.

The torus emission intensity is peak at around Io's orbit and decays with increasing the radial distance. At Europa's orbit, the brightness is so weak that contaminations from the terrestrial radiation belt and scattering light of foreground emissions (geocorona) were carefully removed. As a result of long-term exposure (over 1080 minutes), the sulfur and oxygen ion emission lines were identified at Europa's orbit, and their brightness were about one-fiftieth of those at Io's orbit. The brightness of S_3^+ and O^+ relative to S_2^+ are both brighter than those at Io's orbit. We plan to derive plasma parameters at Europa's orbit through a plasma diagnosis analysis to study higher ionization state there and search for oxygen ion population escaped from Europa's atmosphere.

Plasma Sheet Conditions at Europa's Orbit Retrieved from Lead Angle of the Satellite Auroral Footprints

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The electromagnetic interaction between Europa and the corotating plasma in the Jovian magnetosphere generates Alfvén waves, triggering auroral footprints and a diffuse auroral tail in Jupiter's atmosphere. The equatorial lead angle, i.e. the angular separation between Europa and the position of the main auroral footprint magnetically mapped onto the orbital plane, is related to the travel time of the Alfvén waves. We investigated FUV images of Jupiter obtained by the Hubble Space Telescope in 2014 and 2022 and found that the equatorial lead angle of Europa's main footprint was larger in 2022, which indicates that the Alfvén-wave travel time was longer in 2022 due to increases of ion mass density and/or temperature in the plasma sheet at Europa's orbit. We retrieved the ion mass density and temperature by tracing the Alfvén waves in the plasma sheet and predicting the footprint lead angle, assuming a given plasma sheet condition. We found that both ion density and temperature of the plasma sheet were larger in 2022 than 2014. The retrieved plasma sheet parameters are in good agreement with the previous in-situ observations by the Galileo spacecraft. This study shows that the temporal variation in the plasma sheet parameters at Europa's orbit accounts for the changes in the observed footprint lead angle.

JUICE Ultraviolet Spectrograph Measurements of Icy Satellite, Jupiter, and Io System Environments

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The Jupiter Icy Moons Explorer (JUICE) mission's Ultraviolet Spectrograph (JUICE-UVS) is operating nominally in cruise, following launch in April 2023. Planned JUICE-UVS investigations utilize a variety of observational techniques including nadir push-broom imaging, disk scans, limb stares, stellar and solar occultations, Jupiter transit observations, and neutral cloud/plasma torus stares to perform a comprehensive study of icy satellite atmospheres, plumes, surfaces, and local space environments; Jupiter's atmosphere and aurora; Io and its Io Plasma Torus; and other Jupiter system targets (rings, small moons, etc.) as available. We present recent commissioning and payload checkout calibration data to provide examples of our expected data products at Jupiter. Other calibration and JUICE-Clipper science opportunities during cruise are also planned. We will report our plans to 1) Explore the atmospheres, plasma interactions, and surfaces of the Galilean satellites; 2) Determine the dynamics, chemistry, and vertical structure of Jupiter's upper atmosphere, from equator to pole, as a template for giant planets everywhere; and 3) Investigate the Jupiter-Io connection by quantifying energy and mass flow in the Io atmosphere, neutral cloud, and torus.

[Poster B22]

Europa Clipper Ultraviolet Investigations Will Constrain Interactions between Europa and Jupiter's Magnetosphere

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The Europa Ultraviolet Spectrograph (Europa-UVS) onboard NASA's Europa Clipper spacecraft will detect interactions between Jupiter's magnetosphere and its icy satellite Europa. We discuss the planned observational campaigns that will serve as indicators for how Europa alters/is altered by Jupiter's magnetosphere.

Atmosphere: Europa-UVS will perform stares and scans to observe auroral emissions resulting from the interaction of atmospheric gasses with the charged particles in Jupiter's magnetosphere. This technique can be used to infer the presence of water vapor plumes, when present. The intensity and relative position of Europa's aurora depend on the plasma environment, Jupiter's magnetic field orientation, and Europa's atmospheric density. Measurements of how the aurora responds to the plasma will compliment the magnetometer and plasma instrument constraints on Europa's interior ocean. Stellar occultation and transit observations will characterize the global structure and composition of the neutral atmosphere.

Local Space Environment: Dedicated neutral cloud and torus stares are designed to search for and map the structure of clouds/torii produced by materials sputtered or erupted from Europa that then feed into the magnetosphere of Jupiter.

Surface: Impacts from charged particles onto the surface break molecular bonds and drive reactions (i.e., radiolysis), modifying the reflectance properties of surface material. UV surface reflectance maps are therefore indicative of the past and present distribution of charged particle interactions. Comparisons with spectra at longer wavelengths can constrain their intensity and penetration depths. Regions with less radiolysis may indicate fresher ice deposits. Europa's surface is also marked by Iogenic particles that were erupted into Jupiter's magnetosphere.

Properties of Long Dispersion Jovian Lightning Whistlers and their association with the Io torus

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Juno Waves has detected thousands of lightning whistlers at Jupiter providing valuable information about the properties of both the source lightning and the plasma environment along the whistler propagation path. The majority of these lightning whistlers exhibit dispersive curves with time scales of a few to 10s of milliseconds, suggesting a lightning source in the same hemisphere as the spacecraft (short propagation path), which has been verified from wave propagation direction analysis. A subset of the Juno lightning whistler observations display much longer dispersion (up to ˜8 seconds) and are only detected when Juno is located on magnetic field lines that map back to the equator near the orbit of Io. This longer dispersion is due to the lightning whistler propagating through the higher density plasma of the Io torus. We will discuss the conditions under which that these emissions are detected, the properties and statistics of the emissions, and compare the density profile of the Io torus to the densities needed to produce the observed spectral characteristics of these whistlers.

Io Torus Electron Densities Inward of Io's M-shell

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Various characteristic frequencies observed in the plasma wave spectrum inward of Io have revealed a durable electron density profile that includes a localized relative maximum near M = 4.8 with a local minimum between this and the much greater densities closer to Io. In this paper we show evidence of the low-frequency cutoff of the z-mode at the L=0 frequency, a polarization change at the local electron plasma frequency and low-frequency cutoff of ordinary mode waves. The determination of the electron plasma frequency and electron cyclotron frequency from the measured magnetic field strength also allow the calculation of the upper hybrid resonance frequency and R=0 cutoff of the extraordinary mode. Often, all of these spectral features can be found in the Juno plasma wave spectra obtained in the inner Io torus. Hence, these spectral features allow the determination of the electron density inward of Io over a range of latitudes, a region heretofore poorly characterized by its plasma density. Scale heights relative to the centrifugal equator are of order one Jovian radius, thought to be too large for a cold heavy ion population leading to the conclusion that protons are likely responsible for the determined scale height.

[Poster B25]

Structure and dynamics of the Io Plasma Torus: from multi-spacecraft and multi-instrument observations to models

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A number of spacecraft have flown by Jupiter or have been put into orbit around the planet. Some of them crossed the Io Plasma Torus, which is the main source of charged particles for the magnetosphere of Jupiter. We use publicly available plasma data obtained by the Voyager, Galileo, and Juno (up to PJ 50) in order to describe the radial, latitudinal, longitudinal and local time variations of the plasma moments in the torus. We also search for signatures of dynamical events connected to plasma transport through the interchange instability mechanism. We will finally present a new simplified mathematical model of the Io torus aimed at describing the links between generation and loss mechanisms of the atmosphere and neutral cloud, chemical processes, torus ions pickup and plasma exchange with the magnetodisk, which will assimilate observational data in the model. We will discuss our preliminary modeling results and their implications on the role of the Io source on Jovian magnetosphere dynamics.

Solar wind response of the dawn-dusk asymmetry in the Io plasma torus using the Haleakala T60 and HISAKI satellite observations

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Plasma originating from the satellite Io forms a dense plasma region known as the Io plasma torus (IPT) in the Jovian inner magnetosphere. Slightly inside the Io-orbit is a distinct structure called the "ribbon," where Io-originated plasma spreads along the magnetic field lines. The ribbon moved dawnward owing to the dawn-to-dusk electric field. Extreme ultraviolet (EUV) observations of the IPT showed that the electric field was enhanced under compressed conditions of the magnetosphere caused by solar wind. However, no reports have been published on the influence of solar wind on the radial position of the ribbon. Here, we show the correlation between the temporal variation in the ribbon's position and solar wind. We analyzed the visible ([SII] 6716, 6731 Å) IPT images observed by the Tohoku 60-cm telescope (T60) and the EUV emissions observed by the Hisaki satellite. We found that the position of the ribbon shifted dawnward when the solar wind dynamic pressure was enhanced. The dawnward shift was more significant on the dawn side than on the dusk side, indicating that the change in the electric field was inhomogeneous. The simultaneous observations of T60 and the Hisaki satellite on February 19–23, 2016 indicated that the averaged intensity of the electric field derived from T60 was 3.9 ± 0.9 mV/m, consistent with that of 2.8 ± 1.2 mV/m derived from the Hisaki satellite. Our results demonstrate how solar wind affects the nonuniformity of the electric field in the inner magnetosphere.

Overview of the LAPYUTA mission

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LAPYUTA (Life-environmentology, Astronomy, and PlanetarY Ultraviolet Telescope Assembly) is a future UV space telescope, which is selected as a candidate for JAXA's 6th M-class mission in 2023. Launch is planned for the early 2030s. LAPYUTA will perform spectroscopic and imaging observations in the far ultraviolet spectral range (110-190 nm) with a large effective area (>300 cm2) and a high spatial resolution (0.1 arcsec). LAPYUTA has the following four objectives:

(1) atmospheres of solar system planets,
(2) the atmospheres of exoplanets around the habitable zone,
(3) the structures of present-day galaxies,
(4) the synthesis process of heavy elements from observations of neutron star mergers.

The Jovian system is one of the primary targets. LAPYUTA will have capabilities to monitor water plumes from icy mooons, moon-plasma interactions through observations of auroral emissions of moons and Jupiter, and mass loss from Io's SO_2 atmosphere to Io' neutral cloud and plasma torus. Some of them are similar to but enhancing the successful observations of Hisaki.

Io Plasma Torus in the Juno Era

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We present preliminary analyses of the state of the Io plasma torus during the Juno mission based on (a) predictions derived from physical chemistry models; (b) in situ data from Juno Waves and JADE instruments; and (c) ultraviolet emissions observed by HST and Juno. We note that the Juno spacecraft and instruments were not designed to explore the Io plasma torus and the high plasma densities and high radiation environment pose serious challenges to such measurements.

Io's atmospheric neutral loss by physical chemistry processes

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Io's atmospheric loss is an outstanding issue: it is the source of neutrals and ions to the whole jovian magnetosphere. It is casually claimed to be ˜1 ton/s but the physical processes leading to this loss and their quantitative estimates are surprisingly poorly constrained (Roth et al., 2024, ISSI review paper, submitted to JGR):

• The ion loss (100-300 kg/s) is estimated from a single Galileo flyby through the wake (J0) based on creative assumptions of the ion flux volume and ion composition (SO_2^+ for Saur et al., 2003 and Dols et al., 2008).

• The neutral loss results from different physical processes but their relative rates have yet to be estimated and each provides neutrals with specific velocity distributions and escape directions.

1. The sputtering of the neutral atmosphere might provide slow neutrals (McGrath & Johnson 1987).
2. The physical chemistry processes (charge exchange, molecular dissociation, molecular ion recombination) provide slow and fast atomic and molecular escaping neutrals (Dols et al., 2012)
3. The photochemistry provides slow atomic neutrals with very low escape rates (Huang et al., 2023)

We propose numerical simulations of the physical chemistry loss processes (2) in Io's atmosphere of S, O, SO_2 and SO. We estimate the rate of escaping neutrals, their velocity distribution and directions. Our simulations include both the processes around Io and in its wake (Dols et al., 2024). We also explore the sensitivity of our results to newly published velocity-dependent charge exchange cross sections (Dols and Johnson, 2023).

[Poster B30]

A multi-method examination of the Io-Jupiter Alfvénic connection

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The intense volcanism of Io, the innermost Galilean moon of Jupiter, produces a permanent torus of material along its orbit that is thoroughly ionized, setting up a fruitful laboratory for plasma interactions. The passage of Io through its plasma torus induces an Alfvén wing to the high-latitude ionosphere of Jupiter that serves as the main conduit of energy and momentum between the torus and the planet. I quantify the magnitude and efficiency of the energy flow via the Alfvénic coupling through a combination of models looking at specific components of the interaction: the torus dynamics in response to Alfvénic energy deposition (Coffin et al, 2020) and the energy efficiency of the propagation of Alfvén waves along the wing (Coffin et al, 2022). I demonstrate effects of this energy transfer into Jupiter's high-latitude ionosphere in the context of recent Juno observations of the high-latitude ionosphere and fine structure of the Io footprint tail.

Multifluid Simulations of Kinetic Alfvén Waves in the Io-Jupiter Flux Tube

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We present a 3d time-domain multifluid plasma simulation of kinetic Alfvén wave behavior of the inner Jovian magnetosphere environment centered on the Io flux tube. The model assumes modified dipole coordinates and a dense plasma torus aligned with the centrifugal equator. Heavy plasma ion populations of Sulfur, Oxygen, Helium, Sodium, and H_3^+ are represented by a singular heavy ion fluid, assuming relative stability of heavy ion fluid densities over the relevant timescales. A finitely conducting Jovian ionosphere and a conducting Io surface bound the simulation domain. Finite electron and ion temperatures recreate the transition from the warm plasma of the torus to the cold plasma of Jupiter's ionosphere. The model adopts a 3d finite-volume 2nd order high resolution spatial integration scheme propagated forward in time through a 4th order Runge-Kutta predictor-corrector algorithm. Simulated Alfvén Poynting fluxes are compared to prior work by Sulaiman et al. (2023) across several field line plasma density and ionospheric coupling scenarios.

Searching for ion cyclotron waves in the space region between Io and Europa

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We are searching for signatures consistent with ion cyclotron waves on magnetic field lines connected to the torus region between Io and Europa. This is a widely understood to be responsible for the production of pickup ions in Jupiter's magnetosphere. To do this, we are generating an integrated dataset between Juno's WAVES and MAG instruments to identify plasma waves in the polar and equatorial regions, respectively. We employ a continuous wavelet transform (CWT) on parallel and transverse magnetic field perturbations, calculated using a fitted background field of degree 4, measured by MAG. This approach allows us to observe waves in heavy ion bands in the torus. Using this integrated dataset, we aim to identify features in WAVES and/or MAG data near/at the various ion cyclotron frequency bands that potentially suggest wave-particle interactions.

Juno Plasma Wave Observations at Io

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The Juno spacecraft performed two close Io flybys before its 57th and 58th perijoves on 30 Dec 2023 and 03 Feb 2024, respectively. Both flybys brought Juno to an altitude of ˜1,500 km at closes approach, with Io located at centrifugal latitudes of 2.7° and –4.5°, respectively. Here we present an overview of plasma wave measurements made during the flybys. We report dramatic changes in the power of magnetic field fluctuations, extending up to a few times the proton cyclotron frequency, that are consistent with Juno crossing Io's Alfvén wing during both flybys. Simultaneously, intense high-frequency/small-scale substructures in the electric field are present and reminiscent of those reported from the Galileo/PWS measurements during Alfvén wing crossings. These have been proposed to be signatures of strong filamentation that bridge the large-scale Alfvén wave disturbances to kinetic scale at the high latitudes where electrons are accelerated. However, the ambiguity between spatial and temporal variations due to single-point measurements precluded a definitive conclusion. Recently, we have combined high-latitude Juno observations of the Io flux tube to confirm that these substructures are indeed spatial in nature, supporting the filamentation hypothesis. Finally, we report whistler-mode "saucers" outside the Alfvén wing during PJ58. Their generation is understood to be via Landau resonance with electron beams. We discuss potential explanations for the source.

Pickup ions from the atmospheres of Io, Europa, and Ganymede

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Juno recently performed close flybys of Io, Europa, and Ganymede, providing unprecedented plasma composition measurements with JADE, the Jovian Auroral Distributions Experiment. We will summarize the pickup ion composition observations from Juno's satellite flybys, providing comparisons of the three innermost Galilean moons. These recent Juno observations provide new insights on the evolution of the surfaces and atmospheres of these bodies. At the icy moons, we will provide direct constraints on the radiolytic production of hydrogen and oxygen, as well as their subsequent losses from these bodies, and compare these to model expectations. At Io, we will discuss the extent to which we may constrain the local plasma composition given the specifics of the Juno flyby geometry and observations in this intense region. Finally, we will discuss how the Galilean moons interact with their plasma environments, providing sources of pickup-ions to the Jovian magnetosphere and highlight how these interactions provide analogues for satellite-moon interactions applicable to other planetary systems.

Europa's Magnetic Environment from Juno and Galileo Flybys

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Europa is located deep within Jupiter's magnetosphere. Due to its interaction with the Jovian magnetic field and plasma environment, and electromagnetic induction from its subsurface ocean, Europa's interaction is multi-faceted. In Dec. 1996, Galileo provided the first magnetic field measurements near Europa, and in 2022, Juno performed a new close flyby (PJ45) that came within 0.23 R_E of the moon's surface. Here we analyze the Juno PJ45 magnetometer data in conjunction with those measured during several of Galileo's close flybys to model Europa's magnetic environment. We visualize the magnetometer data of PJ45 against trajectory and time to delineate regions of magnetic enhancement and depression. Along PJ45, depression appears to be located in the geometric wake while enhancement persists in the upstream. Moreover, it is expected that the planetary magnetic field would drape around Europa upon contact with the obstacle. The X-component of the magnetic field in EphiO coordinates is expected to be negative above the equator and positive below. Linking these observations to the upstream plasma and Jovian magnetic field conditions aids in contextualizing the Juno and Galileo measurements. This would also provide a generalized picture of how Europa's magnetic environment varies with changing upstream conditions.

Influence of the Jovian current sheet models on the mapping of the UV auroral footprints of Io, Europa, and Ganymede

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The powerful intrinsic magnetic field of Jupiter is generated by an internal dynamo, which gives rise to the largest planetary magnetosphere in the Solar system. In addition to this internal magnetic field, Pioneer 10 was the first spacecraft to reveal the presence of a plasma disk confined near the magnetic equator where electric currents flow and induce an external magnetic field that adds up to Jupiter's intrinsic magnetic field. The external magnetic field greatly distorts the shape of the magnetic field lines at the orbital distances of the Galilean moons. This contribution to the total magnetic field strength becomes increasingly significant as we move from the orbit of Io to that of Ganymede.

A precise knowledge of the current sheet and intrinsic magnetic field contributions is therefore critical in order to model the motion of charged particles, the path of electromagnetic waves in Jupiter's magnetosphere and the mapping of moon auroral footprints onto the Jovian ionosphere. In this study, we compare the ability of two widely-used current sheet models, Khurana-2005 (KK2005) and Connerney-2020 (CON2020) combined with the most recent internal magnetic field model of Jupiter (JRM33) to match representative Galileo and Juno measurements acquired at low, medium, and high latitudes.

We show that in the inner magnetosphere ($R < 15\ R_J$), JRM33 + CON2020 maps more accurately the UV auroral footpath of Io, Europa, and Ganymede. The JRM33 + KK2005 model predicts a local time asymmetry in the position of the moons' footprints, which is however not detected in Juno's UV measurements. This could indicate that local time effects on the magnetic field are marginal at the orbital locations of these moons

[Poster B37]

Latest advances in understanding Jupiter's high-energy electron dynamics from physics-based and public domain data-driven techniques

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We present our latest understanding on how high-energy electrons populate different regions of Jupiter's magnetosphere and how they evolve as a function of time. We focus on the magnetic region close to the planet (L shells of 1-5) and the population magnetically trapped between Io and Europa (L = 6-9). Specifically, the diverse roles of magnetospheric mechanisms and the heliospheric environment in governing the dynamical behavior of energetic electrons are reevaluated for those two regions. Our methodology is to combine public domain data products from planetary missions with a physics-based modeling of Jupiter's radiation belts. We describe how multi-datasets assist in our investigation and are incorporated into our modeling approach. Our simulation results of Jupiter's electron belts dynamics are ultimately tested by comparing simulated electron-belt emission with Juno/MWR data collected over time. Our combined physics-based and public domain-driven techniques provide a method for predicting the radiation environment at Jupiter over time and space.

Magnetosphere-sourced energetic neutral atoms detection in the context of JUICE and future missions at the ice giant planets

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We present our computational capabilities to investigate the sources of Energetic Neutral Atom Emission (ENAE) from the giant planets of our solar system. Our numerical results are based on models of Charged Trapped Particle Environments (CTPE) and neutral environments coupled with ENAE simulators. We describe our modeling approach for the Saturnian case. For Jupiter, the detectability and discernibility of ENAE from the different icy moons during JUICE approach, its orbit insertion and while touring the jovian magnetosphere at large distances from the Galilean moons are of particular interest for the science community and are here discussed in more detail. In the same way, we present ENA simulations from an orbiter viewpoint in the context of future planetary missions at Uranus and Neptune.

X-ray optics development for studying the Jovian system and Galilean moons

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The Jovian system is host to a unique magnetic environment which generates X-rays through several processes, and understanding these emissions allows us to uniquely address a wide range of science questions. X-ray images can distinguish the ion and electron aurorae, characterising magnetosphere-ionosphere coupling and plasma populations. Relativistic particles in Jupiter's radiation belts produce X-rays, and global X-ray imaging can track variability of the production processes, providing understanding of extreme particle acceleration in the Universe. X-rays can image charge exchange processes that are key for mass transportation in Io's torus. Giant planets couple to the solar wind but these interactions are not well understood – X-rays could image the cusp of Jupiter. Particle precipitation to the surfaces of moons produces fluorescent line emission and thick-target bremsstrahlung X-rays, which provide elemental compositional maps of the moons - breaking IR molecular degeneracies - and characterise the precipitating population.

The development of Micro Pore Optics has enabled the creation of smaller, lighter X-ray telescopes using lobster eye arrangements to allow wider fields-of-view. This permits an instrument, similar to BepiColombo MIXS or SMILE SXI, to perform in-situ X-ray observations of the systems of the outer planets – a recent, transformational development allowing science that would not have been possible with the high mass of traditional X-ray telescopes.

We present an X-ray instrument concept for a Jupiter mission, with applications on missions to other outer planetary bodies. This concept draws on the extensive history and heritage of lobster eye telescopes developed at the University of Leicester.

Why the MOP Community Should Care About the Next Generation of X-ray Observatory: the Line Emission Mapper

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Currently NASA has an open call for a future $bn X-ray or IR observatory. One of the concepts in contention is the Line Emission Mapper (LEM - `https://www.lem-observatory.org`). LEM will have unprecedented spectral resolution (~1 eV) and leading effective area for an X-ray telescope (~1500cm2) that will open new research domains in Astrophysics, Planetary Science and Heliophysics. Particularly, for our community, LEM will provide step-change capabilities X-ray studies of the outer planets and provide invaluable remote diagnostics of the plasma population.

The observatory will enable novel X-ray measurements of historically inaccessible line species, thermal broadening, characteristic line ratios and Doppler shifts - a universally valuable new plasma diagnostic toolkit. LEM observations will be possible for comets, Venus, Mars, Earth's magnetosheath, the moon, Jupiter and the Io Torus, Saturn, Uranus and Kuiper Belt Objects and the Heliosphere as a whole.

This poster will include simulated LEM spectra from many of these bodies, showcasing the paradigm-shifting capabilities of the observatory for solar system CX science. This will highlight:

identification of the ion composition responsible for the auroral CX at Jupiter and remote measurement of their collisional and thermal velocities through precise line characterisation. Spectral modelling shows that this would enable remote identification of precipitation by solar wind ions, which produce characteristic charge exchange lines. Alongside this, neutral fluorescence lines will probe atmospheric and surface atomic and molecular compositions for the outer planets, their rings and moons. The poster will show simulated LEM spectra and open discussions on other possible observations by the next generation of X-ray telescope.

Decadal Science Enabled by an X-ray Instrument on a Uranus Orbiter

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X-ray observations offer a reservoir of interdisciplinary X-ray science for the Uranian system, ranging from ring and satellite composition to the complex interface and interplay between the solar wind (SW), exosphere, magnetosphere and atmosphere. These will address key questions from the Uranus Orbiter study and planetary decadal:

1. When and where did Uranus form in the protosolar nebula?
2. How does the SW interact with Uranus's magnetosphere?
3. What external factors are altering the planet, satellites and ring compositions?

For the satellites, atmosphere and rings, energetic particle collisions produce X-ray fluorescence that maps the elemental composition and impact of energetic particles. These insights are key to characterise the formation and evolution of the moons and the plasma loss processes.

X-rays from SW charge exchange (CX) enable direct imaging ('videos') of the magnetosheath and cusps, where SW ions CX with neutrals to produce characteristic X-ray emissions - revealing the global nature of the SW-magnetosphere interaction and the distribution of neutrals in the system. For Uranus, we show models for SWCX from the magnetosheath(Ray & Dunn+) and note the importance of the moons as neutral sources.

The recent technological revolution in X-ray instrumentation, such as miniaturized X-ray optics and radiation-hardened detectors, enables compact, light-weight (~kg), low-power (~W), wide-field instruments suited to the Uranian system, enabling the diverse science cases above with a single high-feasibility, low-risk instrument.

Based on Chandra observations of Uranus, with SMILE-SXI or BepiColombo-MIXS-like instruments, we calculate planetary count-rates of ~10000-100 /second from a few 2-17 R_U. For the magnetosheath SWCX scenario, we calculate Earth-magnetosheath-like count-rates.

Is it cold or is it just Uranus?: Documenting infrared emission scans and temperatures at Uranus in 2023

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Thomas, et al., 2023 successfully located the northern aurorae of Uranus so an investigation to fully document the southern aurorae was considered as the next key step in understanding the magnetosphere-ionosphere coupling at this planet.

We present a series of half disk scans of Uranus focusing on and around the southern rotational pole to identify the southern aurora with both NASA Keck NIRSPEC and IRTF iSHELL. Spatial analysis shows significant variation across the planet's disk, with the dusk enhancement observed by Melin, et al., 2019 remaining as a distinct feature possibly before 2016 and up to 2023. We believe this is due to the increased half-life of H_3^+ as also suggested by Moore, et al., (2018). In contrast to Lamy, et al., (2018), we identified a pronounced depletion of H_3^+ intensity close to the southern pole. This suggests spatial variation of H_3^+ at the rotational poles though further work is required to conclude this statement. We also highlight the lack of intense temperature difference between aurora and expected aurora locations compared with the magnetic equator. Prior investigations at Jupiter have observed a 300 to 500 K difference between these regions, so the lack of temperature difference suggests that the aurorae may not be what drives the higher than expected temperatures of Uranus's atmosphere (Yelle and Miller, 2004).

[Poster B43]

Probabilistic Estimation of Uranus' Internal Magnetic Field for Future Exploration

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The recently released Origins, Worlds, and Life: A Decadal Strategy for Planetary Science and Astrobiology 2023–2032 recommended a large-class mission to Uranus. Our current understanding of the Uranian system however is data sparse and often based on a single fly-by of the Voyager II spacecraft in 1986. Current knowledge indicates a highly variable system in which seasonal dynamics and Uranus' gravitational and magnetic fields drive physical processes throughout the planetary system. Understanding these fields therefore offers insights into the Uranus system and improves our understanding of icy giant formation and interiors. It is reasonable then that a primarily goal of a future mission is to collect data for accurate estimations of the magnetic field of Uranus.

Current estimations of Uranus' internal magnetic field based on Voyager II data, pose this as a linear inverse problem based on spherical harmonic expansions. The spherical harmonic coefficients are estimated via a singular-value decomposition for a (severely) truncated series [Connerney et al., 1987, 1991], or an overparameterized approach in which regularization is applied to ensure smooth solutions [Holme and Bloxham, 1996]. Both approaches indicate an internal field with substantial contributions from non-axial-dipole terms. Since Voyager II, computational advancement has enabled full estimation of probability distributions that account for the range of probable models that represent solutions to limited observations. We will review these previous representations of Uranus' magnetic field and discuss a Bayesian approach to the inverse problem. We will conclude with examples where we compare the present approach to previous models.

Measurements Of Radio Emissions, Plasma Waves, And Dust At Uranus: Lessons From The PSP/FIELDS Instrument

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Uranus is a known source of radio emission associated with auroral processes and solar wind-magnetosphere interactions. The spectrum, polarization, and dynamics of the emission provide a powerful, remote-sensing diagnostic of dynamics deep within the magnetosphere. Broadband transient radio events were measured by Voyager 2 and thought to be associated with lightning. The role of plasma (whistler) waves associated with electron acceleration and diffusion in the uranian radiation belts can be measured for studies of the origins and dynamics of the trapped particles. Plasma (Langmuir) waves upstream of the uranian bow shock [10] and near the moons will be indications of energetic/suprathermal electrons and may generate plasma radio emission. Dust impacts on the Uranus Orbiter spacecraft will generate small voltage spikes that can be used to study the distribution of dust in the uranian system. Antenna floating voltage is a sensitive, high-cadence measurement that can be used to infer electron density and density fluctuations. We describe the FIELDS instrument suite [1] onboard the NASA Parker Solar Probe (PSP) mission, PSP/FIELDS and some of its measurement capabilities and how such an instrument might be adapted for a mission to the uranian system.

[Poster B45]

Exploring Satellite-Magnetosphere Interactions at Uranus and Neptune

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The interaction between satellites and magnetospheres plays an important role in the magnetospheres of the outer planets. One of the most intriguing phenomena is that the Cassini spacecraft captured the so-called "Pac-Man" thermal distribution pattern in infrared images of the Saturnian icy moons Mimas and Tethys. Subsequent studies revealed that these unique leading/trailing-side asymmetries were the result of energetic particle bombardment, leading to increased thermal inertia in the impacted regions. In contrast to Saturn's nearly symmetrical dipole field, Uranus and Neptune each possesses an offset-tilted dipole (OTD) field, characterized by highly tilted magnetic axes that are displaced from their rotational axes. Considering this, it becomes interesting to determine if similar radiolysis effects might still be observed on Uranian and Neptunian icy moon. This research will employ the simplified OTD models for Uranus and Neptune, and multiple numerical models to trace the trajectories of energetic particles, such as ions and electrons with different energies, aiming to understand particle impact flux distributions on these satellite surfaces and the subsequent radiation micro-absorption signatures.

[Poster B46]

Magnetic field mapping of Uranus and its major moons

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The magnetic mapping of Uranus will allow us to study the interior of the planet and understand the dynamo processes that create its large multipolar and highly non-axisymmetric magnetic field. This is one of the three principal scientific goals proposed for the Uranus Orbiter and Probe (UOP) mission. In addition, a magnetometer experiment will collect measurements in the Uranus system to investigate the structure and dynamics of Uranus's magnetosphere, as well as the compositions and internal structures of the major moons and whether they contain subsurface oceans. These are the other major goals of the UOP.

In this paper, we present a proposal for a heritage magnetometer package that can exceed the requirements described in the Decadal Survey for a nominal payload for the UOP. This package includes a boom-mounted magnetometer that measures the three-axis magnetic field with a range of $\pm$20,000 nT and an instrument sensitivity of 0.1 nT. The instrument performance and measurement requirements will be presented to address the UOP science in various operational scenarios and how these scenarios can influence the determination of key science parameters.

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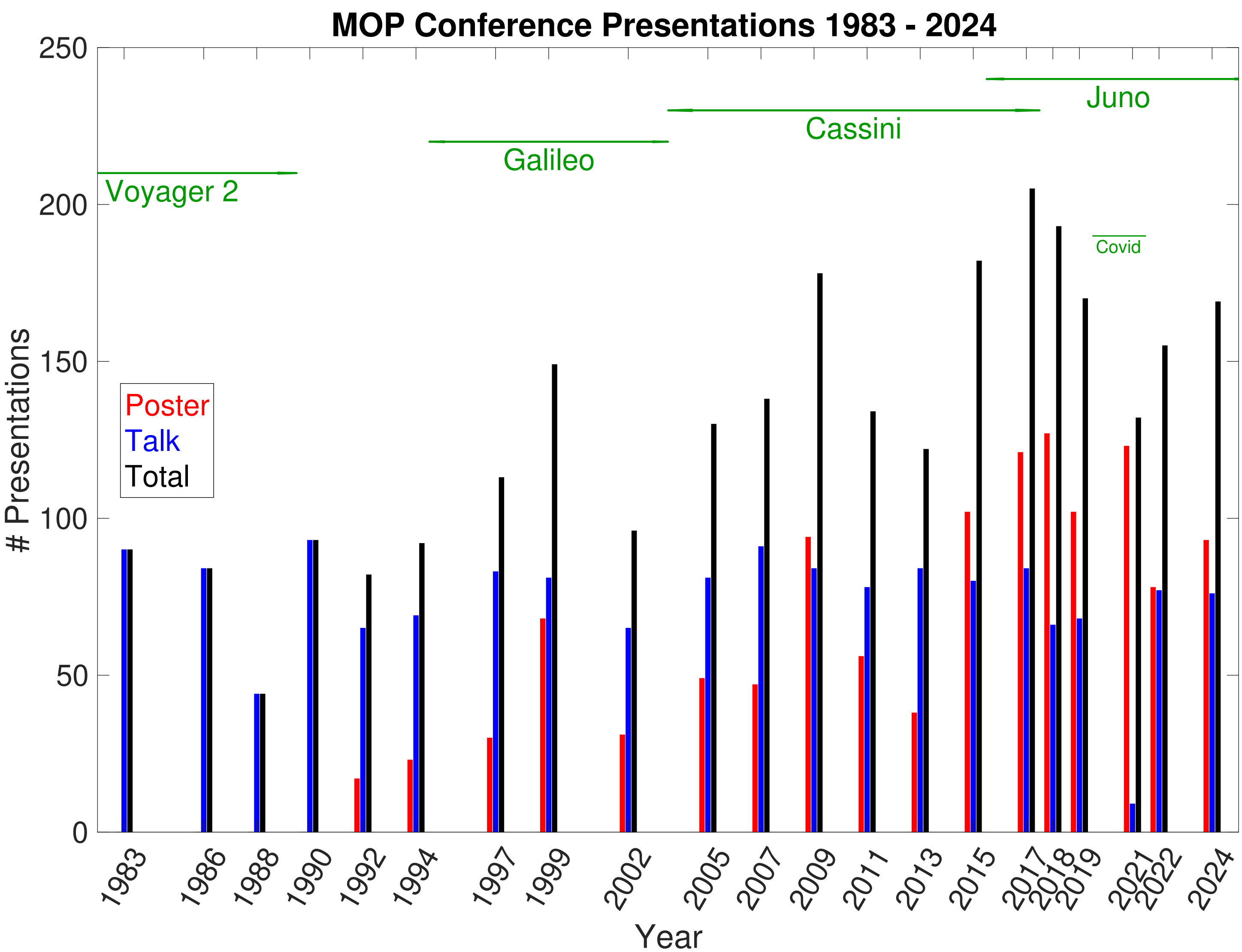
Appendix A: History of MOP Conferences Locations

- 1974 Frascati, Italy
  The Magnetospheres of Earth and Jupiter, Neil Brice Memorial Symposium
- 1977 Lindau, Federal Republic of Germany
  Workshop on the Structure and Dynamics of the Jovian Magnetosphere
- 1980 Houston, Texas, USA
  Physics of the Jovian Magnetosphere
- 1981 Laurel, Maryland, USA
  Physics of the Magnetospheres of Jupiter and Saturn
- 1983 Cambridge, Massachusetts, USA
  The Fifth Conference on the Physics of Jovian and Saturnian Magnetospheres
- 1986 Iowa City, Iowa, USA
  Second Neil Brice Memorial Symposium on the Magnetospheres of Outer Planets
- 1988 Lindau, Federal Republic of Germany
  Third Neil Brice Memorial Symposium on the Magnetospheres of Outer Planets
- 1990 Annapolis, Maryland, USA
  Fred Scarf Memorial Meeting on Magnetospheres of Outer Planets
- 1992 Los Angeles, California, USA
  Goertz-Smith Memorial Meeting on Magnetospheres of Outer Planets
- 1994 Graz, Austria
- 1997 Boulder, Colorado, USA
- 1999 Paris, France
- 2002 Laurel, Maryland, USA
- 2005 Leicester, England, UK
- 2007 San Antonio, Texas, USA
- 2009 Cologne, Germany
- 2011 Boston, USA
- 2013 Athens, Greece
- 2015 Atlanta, USA
- 2017 Uppsala, Sweden
- 2018 Boulder, USA
- 2019 Sendai, Japan
- 2021 Liège, Belgium (Virtual)
- 2022 Liège, Belgium
- 2024 Twin Cities/Minneapolis, USA

Appendix B: History of MOP Presentations

The MOP Conferences began in 1974 (and were not called MOP at the time), although we do not (*yet?*) have copies of the programs for the MOP in 1974, 1977, 1980 or 1981 to know how many presentations there were in those first four conferences. See Appendix A for a list of past MOP locations (and names). There were no poster sessions before 1992, and 2021 was held virtually due to the Covid Pandemic (and restricted travel). The number of talks per conference does not vary much, but non-parallel sessions for a week limits that. But from the years we do have...



Number of Presentations for each MOP Conferences. Horizontal lines shown for years when spacecraft were at an Outer Planet, and for the Covid Pandemic when travel was restricted.