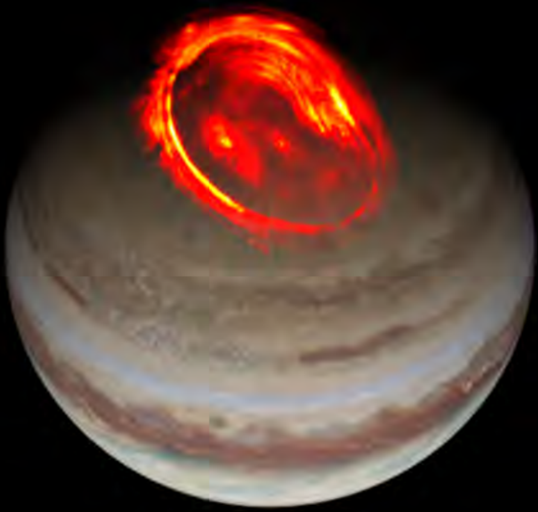
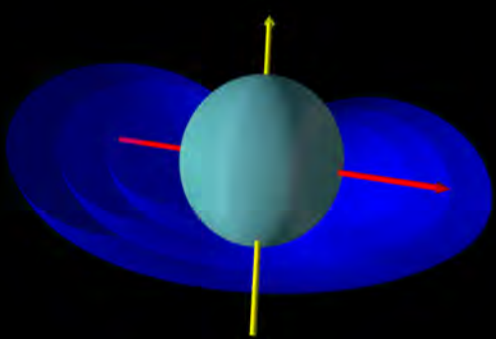
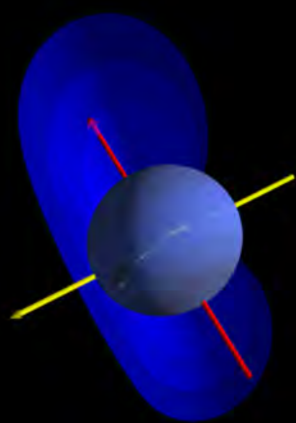
Magnetospheres of Outer Planets Virtual Meeting 2021

July 12 - 16 2021







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This is the 22-06-2021 version of the MOP21 program.

Contents

About 4

Magnetospheres of Outer Planets Meetings 4

Local Organizing committee 4

Science Organizing committee 4

Practical Information 5

Timetable 6

Monday, 12 July UTC 6

Tuesday, 13 July UTC 6

Wednesday, 14 July UTC 6

Thursday, 15 July UTC 7

Friday, 16 July UTC 7

Poster rooms maps 8

Mission updates - Monday July 12th 11

Mission updates - Tuesday July 13th 13

Tutorial talks 16

Posters - Day 1 20

Posters - Day 2 44

Posters - Day 3 73

Posters - Day 4 99

Up-coming event - MOP22 124

About

Magnetospheres of Outer Planets Meetings

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

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

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

Local Organizing committee

Denis Grodent (ULiège)
Alain Carapelle (ULiège, CSL)
Estelle Portassau (ULiège)
Jean-Claude Gérard (ULiège)
Kamolporn Haewsantati (ULiège)
Marie-Nöelle Chevalier (ULiège)
Viviane Pierrard (BIRA/IASB, UCL)
Bertrand Bonfond (ULiège)
Benjamin Palmaerts (ULiège)
Gilles Wautelet (ULiège)
Jean-Michel Dusoulier (ULiège)
Lauriane Soret (ULiège)
Ruilong Guo (ULiège)

Science Organizing committee

Bertrand Bonfond (ULiège, Belgium)
Abigail Rymer (Johns Hopkins University, USA)
Alessandro Mura (INAF, Italy)
Caitriona Jackman (DIAS, Ireland)
Marissa Vogt (Boston University, USA)
Tomoki Kimura (Tokyo University of Science, Japan)
Denis Grodent (ULiège, Belgium)
Adam Masters (Imperial College, UK)
Carol Paty (University of Oregon, USA)
Licia Ray (Lancaster University, UK)
Philippe Louarn (IRAP, France)

Practical Information

This virtual meeting will be held within the Gather.town interface. This interface is accessible via any up-to-date web browser (Firefox and Chrome are recommended) and only requires a microphone and a camera to interact with other attendees. This interface was chosen because it favors live discussions and informal interactions.

Apart from the pre-recorded tutorial talks and the two live "Mission Updates" sessions, all presentations will follow a poster format. The meeting will be split over 4 "meeting days". Depending on your timezone, a *meeting day* may spread over two of your own weekdays. For each *meeting day*, there will be 3 1-hour long poster presentation time slots. Depending on their time zone, the presenters are required to be present "near" their poster for 2 of the 3 slots on their designated *meeting day*, in order to be able to provide further information and answer questions. The time slots are set so that, whatever your time zone, there should be a suitable slot in your morning and one in your afternoon. The meeting interface and all the posters will be available 24 hours a day for the duration of the whole meeting, but attendees are expected to favor the designated time slots, in order to maximize the opportunity to interact with presenters and colleagues.

The posters will be provided in advance via a web form to the organizers who will then upload them into the interface. Only PNG and JPG files are accepted. The image size is not enforced, nor is the orientation (vertical or horizontal), but we highly recommend resolutions of 1920×1600 pixels or higher. Each *meeting day* will have its dedicated virtual poster room. Each poster is uniquely identified by a combination of a letter and a number, which corresponds to its location in the poster rooms.

More information will be provided in due time.

Timetable

Monday, 12 July UTC

7:00–8:00	PS	**Posters** Day 1	Asia - Europe
14:00 – 15:00	MU	**Welcome remarks & Mission Updates 1**	Live streaming
15:00–16:00	PS	**Posters** Day 1	Europe - America

Tuesday, 13 July UTC

00:00 – 01:00	PS	**Posters** Day 1	America - Asia
7:00–8:00	PS	**Posters** Day 2	Asia - Europe
14:00 – 15:00	MU	**Mission Updates 2**	Live streaming
15:00–16:00	PS	**Posters** Day 2	Europe - America

Wednesday, 14 July UTC

00:00 – 01:00	PS	**Posters** Day 2	America - Asia
7:00–8:00	PS	**Posters** Day 3	Asia - Europe
15:00–16:00	PS	**Posters** Day 3	Europe - America

Thursday, 15 July UTC

00:00 – 01:00	PS	**Posters** Day 3	America - Asia
7:00–8:00	PS	**Posters** Day 4	Asia - Europe
15:00–16:00	PS	**Posters** Day 4	Europe - America

Friday, 16 July UTC

00:00 – 01:00	PS	**Posters** Day 4	America - Asia
15:00	**End of meeting**		

Poster rooms maps

America	Europe	Asia

DAY 1

	1	2	3	4	5
A	Liuzzo	Bagenal	Marques	Dols	
B	Khurana	Paranicas	Smith	Grava	Clark
C	Regoli	Kivelson	Hue	Southwood	Janser
D	Nordheim	Addison	Harris	Mura	Louis (LOFAR)
E	Sakanoi	Kimura	Pontoni	Moirano	de Becker
F	Murakami	Tsuchiya	Haythom.	Cervantes	Huybrighs

DAY 2

	1	2	3	4	5	6
G	Kagitani	Yoshioka	Coffin	Nemey	Morgenth.	Damiano
H	Yamaguchi	Kita	Elliott	Crary	Lysak	West
I	Misawa	Nakamura (conductance)	Mendillo	Kurth	Gómez	Mauk
J	Lamy (Jupiter-Io)	Constable	Vogt (code)	Sinclair	Huscher	Schok
K	Zarka (Juno)	Zarka (Cassini)	Provan	Benmahi	Grodent	Dunn (ETO)
L	Louis (Juno)	Pensionerov	Kamran	Wiggs	Al Saati	

DAY 3

	1	2	3	4	5
M	McEntee	Wibisono	Tao	Promfu	Nakamura (electric field)
N	Weigt	Dunn (Jupiter)	Saito	Pan	Yao
O	Masters	Bonfond	Haewsantati	Szalay	Ebert
P	Roussos	Nichols	Sulaiman	Allegrini	Daly
Q	Ma	Rutala	Vogt (aurora)	Shen	Valek
R	Delamere	Montgomery	Wilson (overview)	Wilson (modelling)	

DAY 4

	1	2	3	4	5
S	Guo	Sun	Chowdhury	Xystouris	Holmberg
T	Felici	Zhang	Hunt	Provan	Cheng
U	Neupane	Ma	Millas	Zhang	Garton
V	Kollmann	Johnson	Nichols	Stallard	Jackman
W	Jasinski	Rusaitis	Weigt	Fischer	Gould
X	Olsen	Thomas	Dunn (Uranus)	Taubensch.	Lamy (SKR)

Mission updates - Monday July 12th

Io plasma torus and Jovian aurora activities seen by Hisaki and future icy moon UV observation platform

F. Tsuchiya*[1], *G. Murakami*, *A. Yamazaki*, *K. Yoshioka*, *T. Kimura*, *C. Tao*, *R. Koga*, *H. Kita*, *M. Kuwabara*, *K. Masunaga*, *S. Sakai*, *M. Kagitani*, *R. Hikida*, *T. Sakanoi*, *H. Misawa*, *Y. Kasaba*, *I. Yoshikawa*, *the Hisaki science team*, *and the LAPYUTA working team

[1] Tohoku University, Japan

Hisaki is an earth orbiting extreme ultraviolet spectroscope dedicated for observing solar system planets. Thanks to its monitoring capability, Hisaki has carried out unprecedented continuous observation of Io plasma torus and Jovian aurora since December 2013. A notable phenomenon which showed significant enhancements of neutral gas (sodium and oxygen) from Io occurred in the spring of 2015. Hisaki revealed that not only the plasma source, but transport, heating, and loss processes of magnetospheric plasma were influenced by the variation in the neutral source input. The presentation will include related topics from recent Hisaki publication. Since the autumn of 2016, the Juno spacecraft was in the orbit around Jupiter. Hisaki monitored activities of Jovian aurora and the plasma torus in the Juno era. These datasets will provide opportunities to compare in-situ observation by Juno with the global view by Hisaki. JAXA approved the Hisaki mission period by the end of March 2022. The operation after the next April is discussion in the Hisaki team. As a future remote observation platform, we are going to propose a UV space telescope, LAPYUTA (Life-environmentology, Astronomy, and PlanetarY Ultraviolet Telescope Assembly), a Japanese-leading mission using heritages of UV instruments for planetary science (e.g., Hisaki) and space telescope techniques for astronomy. One of goals of this mission is dynamics of our solar system planets and moons as the most quantifiable archetypes of extraterrestrial habitable environments in the universe. Water plume that gushes from the subsurface ocean of Galilean moons and tenuous atmosphere which is generated by bombardment of energetic charged particles to the surface are primary targets of LAPYUTA. As the plume activity and the atmosphere are not stable, continuous monitoring with high spatial resolution is essential. The icy moon's plume and ambient space will be deeply explored with the spacecraft by NASA's and ESA's icy moon missions in 2020s-2030s. The complementary remote sensing by LAPYUTA will visualize their global structure and temporal dynamics. We are studying the concept of LAPYUTA and preparing a proposal of it to JAXA M-class category.

Juno’s Magnetospheric Science Objectives for the Extended Mission

***George Clark*[1], *Rob Ebert*[2,3], *Scott Bolton*[2], *Barry Mauk*[1], *Fran Bagenal*[4], *Jack Connerney*[5,6], *Steve Levin*[7]**

[1]Johns Hopkins University Applied Physics Laboratory, USA
[2]Southwest Research Institute, USA
[3]University of Texas at San Antonio, USA
[4]Laboratory for Atmospheric and Space Physics, University of Colorado, USA
[5]Space Research Corporation, USA
[6]NASA Goddard Space Flight Center, USA
[7]Jet Propulsion Laboratory/Caltech, USA

The Juno mission and its unique trajectory throughout Jupiter’s space environment has led to a number of groundbreaking science discoveries (e.g., Bolton et al. 2017; Connerney et al. 2017; Mauk et al. 2018; Kotsiaros et al. 2019). The extended mission naturally continues this discovery theme as Juno visits new regions of Jupiter’s magnetosphere that have not or have only minimally been explored *in situ*. Remarkably, Juno’s evolving orbit does this without sacrificing the continued pursuit of Juno’s prime mission objectives as well (e.g., characterization of the internal magnetic field, dynamo, auroral acceleration and magnetosphere). Juno’s extended mission orbit will bring the spacecraft and its highly capable instrumentation to critically important regions of Jupiter’s magnetosphere, i.e., the Io and Europa torus and to very low-altitudes over the polar cap region, as well as to new and exciting areas yet to be explored such as the region near magnetospheric boundaries over Jupiter’s southern pole that are vital to understanding Jupiter’s unique magnetosphere and its coupling to the solar wind (Bagenal et al. 2017). Observations from Juno’s extended mission will also provide new insight into Io’s plasma torus and its variability with Io’s activity, the space environment near Europa as well as the highly debated topic of whether Jupiter’s polar magnetosphere is open or closed to the solar wind. In this presentation, we will briefly discuss the many scientific mysteries Juno has revealed and discuss the key magnetospheric science objectives for the extended mission in more detail.

Mission updates - Tuesday July 13th

JUICE: A European Mission to Jupiter and its Icy Moons

Claire Vallat, Olivier Witasse, Baptiste Cecconi, Corentin Louis, Norbert Krupp, Adam Masters, Ronan Modolo, Claudio Munoz, and the JUICE SOC team

JUICE - JUpiter ICy moons Explorer - is the first large mission in the ESA Cosmic Vision program. The spacecraft will be launched in 2022, 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 for almost a year. The main goal is to explore the emergence of habitable worlds around gas giants. The advanced instrumentation will permit new studies of Jupiter's magnetosphere and its interaction with the Galilean satellites, to further enhance our understanding of the evolution and dynamics of the Jovian system. The long-term magnetospheric science will push significantly beyond the capabilities of previous missions, and directly complement the results of the Juno mission. JUICE will explore Jupiter's magnetosphere covering a wide range of local times within the equatorial plane, as well as carrying out moderate excursions to higher latitudes. Three regions are of interest: the inner magnetosphere where the planetary magnetic field dominates, the middle magnetosphere where the effects of the magnetodisc controls the large-scale magnetic field and plasma populations, and the outer magnetosphere where the solar-wind effects are likely to be the largest. Remote sensing measurements of Jupiter's ring current and auroras will be provided, including energetic neutral atom imaging. The immediate space environment of the icy moons will be studied in detail; icy moons' ionosphere will be investigated not only in-situ with local plasma measurement, but also remotely by studying the Jovian radio emissions propagation through the moons' ionosphere. Io and Europa plasma tori will also be characterized remotely through radio occultation to derive an estimate of their total electron content and better understand the plasma distribution within this region. Interesting heliophysics measurements during the cruise phase could be performed and are being studied at the moment.

The Fields and Particles Investigations of the Europa Clipper Mission

Haje Korth [1]***, Robert T. Pappalardo*** [2]***, David A. Senske*** [2]***, James L. Burch*** [3]***, Sascha Kempf*** [4]***, Margaret G. Kivelson*** [5,6]***, Joseph H. Westlake*** [1]***, and the Europa Clipper Science Team.***

[1] Johns Hopkins University Applied Physics Laboratory, Laurel, MD, USA.
[2] Jet Propulsion Laboratory/California Institute of Technology, Pasadena, CA, USA.
[3] Southwest Research Institute, San Antonio, TX, USA.
[4] University of Colorado Boulder, Boulder, CO, USA.
[5] University of Michigan Ann Arbor, Ann Arbor, MI, USA.
[6] University of California Los Angeles, Los Angeles, CA, USA.

With a launch readiness date of late 2024, the Europa Clipper will set out on a journey to explore the habitability of Jupiter's moon Europa. The mission's science objectives will be accomplished using a highly capable suite of remote-sensing and in-situ instruments. The latter provide observations of the magnetic field and particle environments near Europa, providing a baseline throughout the sampled region of the Jovian magnetosphere. The Europa Clipper Magnetometer (ECM) investigation will measure magnetic fields generated by currents induced in Europa's subsurface ocean and in ionized material ejected from any plumes, and it will characterize electromagnetic coupling of the moon to Jupiter and its magnetosphere. The Plasma Instrument for Magnetic Sounding (PIMS) will measure ions and electrons in Europa's atmosphere to infer the contributions to the magnetic field from plasma currents and to understand the interaction and coupling of the plasma with the moon's surface and with Jupiter. The MAss Spectrometer for Planetary Exploration (MASPEX) measures trace neutral species to determine the composition in Europa's sputter-produced exosphere and potential plumes. Finally, the SUrface Dust Analyzer (SUDA) will map the chemical composition of particles ejected from Europa's surface and identify the makeup of potential plumes by directly sampling microscopic particles originating from the surface, entrained in plumes, or delivered from elsewhere within or outside the Jovian system. In addition, valuable scientific data on Europa's radiation environment can be inferred from the spacecraft's radiation monitoring system. The mission plan implements a synergistic set of observations among these instruments to characterize the ice-shell thickness, ocean thickness and salinity, composition of materials making up Europa's surface and subsurface ocean, and any current plume activity. The project completed its Critical Design Review (CDR) in December 2020, and flight hardware builds of instruments and spacecraft are well underway, with the System Integration Review scheduled for November 2021. We review the scientific instruments and objectives of the Europa Clipper mission with focus on fields and particles science and present updates on the hardware and the mission plan.

Ice Giant Mission Status: Awaiting with Bated Breath

Mark D. Hofstadter

Jet Propulsion Laboratory, California Institute of Technology

The scientific case for in situ exploration of the Ice Giant planets, Uranus and Neptune, is compelling. All components of those planetary systems (the planet's interior and atmosphere, the rings, satellites, and magnetosphere) present challenges to our understanding of the basic physical processes involved in planetary formation and evolution. Furthermore, planets similar in size to the Ice Giants are abundant in exoplanetary systems, being far more common than the Gas Giant planets. Despite being a highly-ranked mission in the 2013 Planetary Science Decadal Survey (Vision and Voyages), our only measurements from within these fascinating planetary systems remain those collected by the venerable Voyager 2 spacecraft in the 1980's. In this talk, I will briefly discuss some of the big-picture questions to be answered at the ice giants relevant to the magnetospheric community, and discuss the prospect for future missions.

Regarding those big-picture science questions, there are three areas that stand out: What can the magnetosphere tell us about the interior structure of the ice giants? What can the unique geometry between the solar wind and the ice-giant magnetic fields—in particular the rapid opening and closing of the planetary field relative to the solar field—¬teach us about the basic physics of plasmas? And are the ice giant bow-shocks useful analogs for shock fronts in the interstellar medium? These are questions that can only be addressed by detailed, in situ study of the ice-giant magnetospheres.

The best way to advance our knowledge of the ice-giant systems is with a dedicated mission. Only a large, Flagship-class mission can address questions across many disciplines, and would contain a large instrument suite capable of detailed follow-up of the unexpected discoveries sure to arise. But smaller missions (such as NASA Discovery and New Frontiers missions) are capable of addressing narrowly-focused science questions and making key discoveries. What mission path will we follow? It all hinges on the Decadal Survey on Planetary Science and Astrobiology currently underway, with recommendations scheduled for release in March 2022.

Tutorial talks

Magnetohydrodynamic simulations of the magnetospheres of the Ice Giants

Léa Griton

Institut de Recherche en Astrophysique et Planétologie (IRAP), University of Toulouse, France

Every planetary magnetosphere of our Solar System presents its own specificities, despite a common same physical origin: a strong planetary intrinsic magnetic field that creates a magnetic bubble of low density plasma around the planet, interacting with the supersonic solar wind. The unicity of Uranus in terms of magnetospheric physics comes from the wide range of values that the angle between the magnetic axis and the solar wind flowing direction takes over the day, and over the Uranian year. This results in the most dynamic magnetosphere within the Solar System, independently of the variability of the solar wind itself. In some extent, this is also true for Neptune's magnetosphere. In this tutorial, some of the key physics question about Uranus and Neptune's magnetosphere will be presented, especially the key questions that can be explored through numerical simulations. Magnetohydrodynamic (MHD) simulations are indeed one of the tools currently available to study the magnetospheres of the Ice Giants, Uranus and Neptune. This tutorial will start with a brief introduction to MHD simulations of magnetospheres, including a brief description of the different kinds of models and their respective advantages and limitations. The second half of the tutorial will present what can be learned about the magnetospheres of the Ice Giants from such simulations. In particular, the role of simulations in the preparation of a future exploration mission will be detailed.

An overview of radio and plasma waves in the magnetospheres of Jupiter and Saturn

Ali H. Sulaiman

Department of Physics and Astronomy, University of Iowa, Iowa City, USA

This tutorial will introduce some fundamental principles of radio and plasma waves and their application to Jupiter and Saturn. The emphasis will be on what we learn about these planets by measuring radio and plasma waves both remotely and in situ. The Gas Giants and their environments will be explored through the lens of these measurements and will span:

i **The interior**: Long-term remote-sensing observations of radio emissions track a magnetic rotation period, whether fixed like Jupiter or time-varying like Saturn. Accurate rotation rate is needed to determine internal structure and dynamics.

ii **The upper atmosphere and magnetosphere**: The role of plasma waves is to propagate and transfer electromagnetic energy through their interaction with charged particles across various scales. For this reason, plasma wave observations are used to diagnose highly dynamic phenomena from auroral processes to atmospheric lightning. Furthermore, the dependence of plasma wave frequencies on density and temperature means these basic plasma parameters can be inferred, enabling ionospheric/magnetospheric profiles to be constructed, as well as supporting plasma instruments in their calibration.

iii **The moons and rings**: Diverse interactions between moons, rings, and their host planets are revealed from measurements of electromagnetic waves, ionospheric profiles, and dust distributions.

iv **The solar wind**: The solar wind is a source of a variety of plasma waves, particularly near planetary bow shocks. These waves provide insight into the dynamical processes operating in the near-planet environments, as well as basic properties of the upstream conditions that are necessary for assessing solar-wind magnetosphere interactions.

Machine Learning and Data Science Methods: Applications for Advancing Understanding of the Magnetospheres of Giant Planets

Abigail Azari

Space Sciences Laboratory, University of California, Berkeley, USA

Recent planetary science missions are returning increasingly large datasets. The data volumes generated by modern missions have begun to necessitate the use of data science methods, including machine learning to engage in data analysis. It is advantageous to use these data-intensive methods to study planetary systems as they provide system-wide perspectives and open new avenues for scientific discovery, and exploration. However, there are several challenges that create difficulties when engaging in the scientific process with currently available data and methods. First, planetary science data, much like other data from natural systems, is inherently spatio-temporal, of multiple resolutions, and contains uncertainty. This creates a barrier for data processing when using traditional machine learning methods. Second, many planetary science questions require the use of interpretable models to pursue inference. In other words, answering these questions requires models that follow some underlying physical rules or constraints, or otherwise simple functional form that allows for human understanding of the model's form and outputs.

This tutorial presentation will provide an overview of machine learning and data science methods with relevant applications in planetary science and space physics. It will then discuss recent advances in addressing the challenges discussed above for applications in outer planets and magnetospheric studies. This presentation will additionally provide a discussion on best practices in pursuing data intensive research. Finally, this presentation will conclude by discussing insights for supporting data intensive research in the planetary research community broadly; building on recommendations submitted to the ongoing Planetary and Astrobiology Decadal Survey for the successful integration of machine learning for planetary sciences' challenges and needs.

Jupiter’s auroras: lessons from the comparisons with other planets

Zhonghua Yao

Key Laboratory of Earth and Planetary Physics, Institute of Geology and Geophysics, Chinese Academy of Sciences, Beijing, China

In the giant magnetospheres of Jupiter and Saturn, plasma and energy are potentially received from external (i.e., solar wind) and internal (i.e., moons and rings) sources. The rapid rotation of the planet, combined with highly variable solar wind conditions, continually perturbs the magnetosphere. The extremely complex particle acceleration associated with these perturbations leads to energy dissipation in the magnetosphere and ionosphere. At the planets, auroral emissions are consequences of these coupling processes. Therefore, remote sensing of aurora provides a global view for us to understand the energy dissipation in the magnetosphere-ionosphere dynamics, which strongly complements spacecraft in situ measurements. During the NASA Juno era, the remote sensing observations from the Hubble Space Telescope, Newton-XMM etc. are often coordinated with Juno’s in situ exploration, offering an unprecedented opportunity to advance the understandings of Jupiter’s auroras. Moreover, the Juno-UVS instrument provides the first opportunity to investigate auroral evolution from the nightside to dayside, and the first results have clearly demonstrated that Jupiter’s auroras may have much more in common with the auroral processes at Earth and Saturn than previously expected. Indeed, knowledge transfer can be highly valuable in understanding auroral morphologies and mechanisms in both terrestrial and planetary studies.

In this presentation, I will briefly review the auroral characteristics at Jupiter, and particularly I will introduce recent progresses on (1) how does solar wind compression influence auroral emissions? (2) are dawn storms Jupiter’s substorms? (3) why is the near-pole aurora always bright? (4) are ultralow-frequency waves an important driver of the Jovian auroras; (5) why is Jupiter’s soft X-ray aurora pulsating?

The results in this presentation would demonstrate that the comparison of auroral morphologies between different planets is sometimes misleading, as a fundamental plasma process may give rise to different displays while similar morphologies may correspond to very different processes. A systematic comparison of the fundamental plasma processes amongst the Earth, Saturn and Jupiter is pivotal to improve our understandings of planetary auroral physics.

Posters - Day 1

Investigating the variability of Triton's interaction with Neptune's magnetospheric plasma – A1

***Lucas Liuzzo*[1], *Carol Paty*[2], *Louise Prockter*[3], *Karl Mitchell*[4], *Corey Cochrane*[4], *Tom Nordheim*[4], *Adrienn Luspay-Kuti*[3], *Kathy Mandt*[3], *Julie Castillo-Rogez*[4], *Krishan Khurana*[5], *Mats Holmstrom*[6], *Andrew R. Poppe*[1], *Peter Addison*[7], *and Sven Simon*[7]**

[1] Space Sciences Laboratory, University of California, Berkeley, USA
[2] Department of Earth Sciences, University of Oregon, USA
[3] Applied Physics Laboratory, Johns Hopkins University, USA
[4] Jet Propulsion Laboratory, California Institute of Technology, USA
[5] Institute of Geophysics and Planetary Physics, University of California, Los Angeles, USA
[6] Swedish Institute of Space Physics, Sweden
[7] School of Earth and Atmospheric Sciences, Georgia Institute of Technology, USA

The tilt between Neptune's magnetic and rotational axes, and the obliquity of Triton's orbit, cause the electromagnetic environment at Triton to be highly time-variable. To investigate the variability in Triton's resulting interaction with Neptune's magnetospheric plasma, we apply a hybrid (kinetic ions, fluid electrons) simulation that includes both an ionosphere and induced dipole at the moon. To represent the changes in Triton's local electromagnetic field environment over a synodic rotation, we model multiple orientations between the ambient magnetic field and flow velocity vectors. For each case, we first investigate how the superposition of an induced dipole at Triton with the magnetospheric background field perturbs the moon's local magnetic environment in the absence of any plasma interaction currents. Next, to constrain the effect of Triton's dense ionosphere on the local plasma currents, we model the interaction between the ionosphere and magnetospheric plasma in isolation from induced fields at the moon. Then, we investigate the perturbed environment for the coupled scenario of plasma interaction and induction at Triton. Finally, we explore the sensitivity of Triton's plasma interaction to changes in the upstream magnetospheric plasma density and changes to the strength of Triton's inductive response. We find that regardless of Triton's location within Neptune's magnetosphere, characteristic plasma interaction signatures dominate the electromagnetic field perturbations far from the moon (beyond approximately 3 Triton radii), whereas the induced field shapes the local field closer to the surface (within approximately 3 Triton radii). In addition, we show that the orientation of the ambient magnetic field and velocity vectors strongly affects features of Triton's plasma interaction, at times showing similarities to the moons of Jupiter or Saturn, while at others resembling the lunar interaction in Earth's magnetotail lobes.

Range of Plasma Conditions at Ganymede – A2

***Fran Bagenal*[1], *Marissa Vogt*[2], *Robert Wilson*[1], *and Chris Paranicas*[3]**

[1] University of Colorado, USA
[2] Boston University, USA
[3] Applied Physics Lab., The Johns Hopkins University, USA

We survey data from Ganymede's orbital distance (∼15 RJ) from Jupiter. We compare plasma parameters (density, temperature, composition, flow) from Voyager, Galileo and Juno spacecraft. These thermal populations are compared with the energetic particles measured by the Juno-JEDI instrument. Magnetic field models (e.g. Khurana, JRM09+Con2020) are compared with Galileo and Juno data. Statistics are derived for variations in the parameters with longitude and with time. Derived quantities (plasma thermal pressure, ram pressure, beta, Alfven speed, sound speed, etc) are found for typical conditions upstream of Ganymede.

Compilation of Jovian radio Decametric emissions with complete arcs in dynamic spectra observed by Wind/WAVES/RAD2 and the Nançay Decameter Array – A3

H. R. P. Jàcome[1], *M. S. Marques*[1], *E. Echer*[2], *L. Lamy*[3], *and P. Zarka*[4]

[1] Federal University of Rio Grande do Norte, Brazil
[2] National Institute for Space Research, Brazil
[3] LESIA, Observatoire de Paris, CNRS, PSL, UPMC, UPD, France
[4] LESIA, Observatoire de Paris, CNRS, PSL, SU/UPD, France

The plasma-satellite electrodynamic interactions that occur inside the Jovian magnetosphere with the Galilean satellites produce field-aligned electric currents that are carried by Alfvén waves towards Jupiter's ionosphere, accelerating electrons and causing auroral emissions at UV, IR and radio wavelengths. The Jovian Decametric (DAM) radio emissions are produced by electron-wave resonance through the Cyclotron Maser Instability (CMI) at the local electron cyclotron frequency. These emissions have frequencies from a few MHz to $\sim$40 MHz, and, therefore, are partially observed from the Earth >10 MHz.

The long-term monitoring of Jupiter by the Nançay Decametric Array has enabled to collect more than 40 years of daily observations of Jupiter between 10 and 40 MHz. The last 30 years of observations (since 1990) compose the NDA's extensive digital catalog, which based the in depth study of the various Jovian DAM components, and provided evidences of emissions driven by Io, Europa and Ganymede. However, radio observations from ground-based instruments such as the NDA are limited by the terrestrial ionosphere's cutoff frequency, of $\sim$10 MHz, and by Radio Frequency Interference (RFI) up to $\sim$20 MHz.

In this context, the complementary use of observations from spacecraft-based radio instruments emerges as an interesting possibility to improve the analysis of planetary radio emissions by overcoming the frequency limitation of terrestrial observations. Wind is a spacecraft that has been on space, at the vicinity of the Earth, since the end of 1994, collecting radio DAM emissions with frequencies up to 14 MHz through the onboard WAVES experiment, whose frequency range coverage comprises part of the Jovian DAM emission that is not detectable by the NDA. Jupiter is observed by Wind in some parts of the spacecraft's orbit, making it possible for WAVES receivers to occasionally detect Jovian DAM emissions at low frequencies.

Therefore, this work aims at producing a catalog of Jovian DAM emissions observed by both the NDA and Wind to improve the analysis of the emissions controlled by the Galilean satellites that have been observed on the NDA's catalog, by extending these emissions to their lower frequencies observed by Wind. This extension enables the visualization of the entire frequency range of the emissions and a more complete analysis of their arc shapes formed in the dynamic spectra.

The plasma interaction at Io: impact of the velocity dependence of ion-molecule charge exchange collisions – A4

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The Io plasma torus is mostly composed of singly and multi-charged S and O ions. These ions interact with the neutrals of Io's atmosphere (S, O, SO2 and SO) through symmetrical (i.e. O+ + O ⇒ O + O+) and asymmetrical (i.e. S++ + O ⇒ S + O++) charge-exchange collisions. Charge-exchange cross-sections were estimated in Johnson & Strobel, 1982 and McGrath & Johnson, 1989 at 60 km/s (the plasma corotation velocity in Io's frame), and are used in numerical simulations of the torus/neutral cloud interaction (i.e. Delamere and Bagenal, 2003).
Dols et al, 2008 presented numerical simulations of the multi-species chemistry interaction at Io using these cross-sections at 60 km/s. The plasma/atmosphere interaction at Io is strong and the flow velocity and ion temperature are drastically reduced close to Io (v<10 km/s). Thus, velocity-dependent charge-exchange cross-sections are critical for such numerical simulations and their effect on the local plasma and neutral supply at Io should be explored.
We revisit the calculation of ion/neutral charge-exchange cross-sections following Johnson & Strobel, 1982's approach for plasma velocities relevant to the local interaction at Io (v=10-120 km/s). When appropriate scaling to available laboratory data is used.
We illustrate the effect of using velocity-depend charge-exchange cross-sections in numerical simulations of the multi-species plasma/atmosphere interaction at Io.

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Detecting Triton's putative ocean from electromagnetic sounding from a single flyby – B1

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Triton, the largest satellite of Neptune is in a retrograde orbit and is likely a captured Kuiper Belt Object (KBO). It has a near circular orbit (with a mean radius of 14.3 R_N) which is tilted relative to Neptune's equator by 156.9 degrees. With a mean radius of 1353 km and a mean density of 2.061 gm/cm^3, Triton is believed to have a hydrosphere about 400 km thick. The young age of its surface and tectonically active surface hint at an internal heat source that could keep much of the hydrosphere in a liquid state. Triton is also one of the few outer planet satellites to possess a thick ionosphere (peak electron density > 2x10^4/cm^3). The height-integrated Pedersen conductivity exceeds 1x10^4 S and is expected to elicit a strong electromagnetic induction response complicating the sounding of Triton's subsurface. The magnetic field of Neptune near Triton's orbit has a peak strength of $\sim$ 10 nT and because of the large tilt of Neptune's dipole field axis relative to its spin axis (-47 degrees) is mostly cyclical in its form (the cyclical field is twice as strong as the non-cyclical field at Triton, whereas at Europa the cyclical field is 20% of the constant field). We show that the spectrum of the magnetic field at Triton is dominated by two frequencies, one at 14.5 hrs (amplitude $\sim$ 7 nT, at the synodic rotation period of Neptune in Triton's frame) and 140 hrs (amplitude $\sim$ 3nT, at the orbital period of Triton). We show that for most ionosphere conductivity models, the 14.5 hr wave is unable to penetrate deep into the putative ocean and is unable to elicit a response. However, the 140 hr wave penetrates the ionosphere almost unattenuated and can sound Triton's ocean.
We introduce a technique that allows us to determine the strength and phases of the magnetic moments generated at the 14.5 hr and 140 hr waves from the data from a single flyby. The technique uses the properties of the expected phase delays of the signals to constrain accurately the amplitudes of the magnetic moments of the two waves. The technique has been tested against several thousand models of the interior of Triton and found to provide accurate inversions of the dipole moments and discriminate between the oceans and no-oceans solutions in a robust manner.
Finally, Neptune's rotation period is not known accurately and therefore the phase of the 14.5 hr wave at the time of arrival would not be known a priori. We therefore test our technique with all possible phases of this wave and show that the detection of the ocean is possible for all arrival phases of Neptune's rotation.

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Interaction of Jupiter’s magnetosphere with Ganymede’s surface – B2

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Ganymede’s albedo is different in the polar and equatorial regions. The work of Khurana et al. (2007) suggests this is a weathering phenomenon, where Jovian field lines that connect to the polar regions of Ganymede would be populated by different levels of particle flux than the closed field lines with both footpoints on the moon. Earth-based observations suggest further that the equatorial region is not uniform, with much less water ice in the very top layer around the trailing hemisphere apex (Ligier et al. 2019). We suggest that, if the polar-equatorial albedo differences are a weathering phenomenon, the most likely agent is electrons, which are well organized by field topology due to their smaller gyroradii. Ions can become energetic neutrals atoms and hit the moon if they pass through the population of neutrals in bound Ganymede orbit, so their weathering patterns may be less coherent than electron ones. If the ENA conversion mechanism we propose allows substantial ion flux to reach the surface, i.e., vitiates the magnetic barrier, it may explain the lack of water ice on trailing apex as a sputtering phenomenon.

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Using Hisaki neutral oxygen observations and 3D modeling for insight into Io and its neutral torus – B3

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The Jovian system is very intriguing with extremely different particle sources ranging from the volcanic Io to the frozen world of Europa with both existing within Jupiter's relatively high radiation magnetospheric environment. While Voyager, Galileo and Cassini provided historic observations of this unique environment, they also raised numerous questions. As the dominant source of particles to Jupiter's magnetosphere, Io is of particular importance. However, this source is not well understood with total rate estimates varying from 700-2400 kg/sec and even the specific source mechanisms (ex. volcanic vs. sublimation) are under debate. Thus, characterizing the Io source is required to understand Jupiter's magnetosphere as well as enabling understanding of the minor (but extremely important) source. Since its launch in 2013, the JAXA Hisaki (SPRINT-A) mission offers the potential to answer some of these questions and help make future missions more successful.
The JAXA Hisaki mission has provided unprecedented observations of the Jovian system with its extreme ultraviolet (EUV) spectroscope (EXCEED) instrument. In particular, it's UV neutral oxygen line of sight observations provide the best glimpse so far of Jovian neutral particle populations. This is exciting in that for the first time, the neutral tori can be directly observed on time scales that constrain satellite sources. The current Hisaki oxygen UV line of sight (LOS) observations are already revealing an intriguing amount of spatial and temporal. This data can also shed unprecedented insight into neutral torus distributions which could subsequently provide essential information about the sources and mechanisms from Io. However, 3-D modeling is required to interpret the complex and dynamic observational geometries. Thus, for this presentation, we show preliminary research that combines Hisaki neutral oxygen LOS observations with computational modeling to identify and characterize Io's source of particles to Jupiter's magnetosphere and the resulting neutral tori populations.

A possible dust origin for an unusual emission feature in Io's sodium neutral clouds – B4

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We report the results of model simulations performed to explain the nature of a relatively new sodium emission feature observed in Io's Neutral Clouds. The feature was detected via high-resolution ($\Delta\lambda/\lambda \sim$ 115,000) spectroscopic observations from the 3.6-meter Italian telescope TNG (Telescopio Nazionale Galileo). The emission feature is blueshifted compared to the main emission (the banana-shaped Neutral Cloud loosely bound to Io) by a few tens of km s^{-1}, and it is most prominent when Io is a few tens of degrees before eclipse behind Jupiter's shadow. The feature's morphology changes with time, indicative of a geometrical effect. We constrained its direction, velocity, and brightness (i.e. column density) with a model of sodium atom trajectories under the influence of Io's and Jupiter's gravity and solar radiation pressure. The model that best explains this emission feature has the atoms injected into the exosphere from the leading/sub-Jovian hemisphere of Io (45-68° West longitude), with velocities from 50 to 90 km s^{-1} relative to Io. These trajectories are consistent with those of negatively charged particles moving through the co-rotational electric field of Jupiter's magnetosphere. We argue that the most plausible origin for this feature is dusty grains of size $\sim$10 nm, as shown by simulations of nanodust grains trajectories. The sodium atoms would be liberated by ion sputtering of Na-bearing molecules (most likely NaCl or Na_2SO_4, both detected by the Cassini Cosmic Dust Analyser) attached to these dust grains. Both modeling and observational constraints provide an order-of-magnitude estimate of the sodium production rate on the order of 10^{26} s^{-1}. We discuss alternative explanations for the blueshifed feature (negatively charged sodium ions) and why we find them less likely to the dust hypothesis. Our work provides another method to monitor the amount of material that Io is supplying to its Neutral Clouds and plasma torus.

Energetic ion signatures associated with Io's footprint tail – B5

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Juno's regular excursions of Io's low-altitude footprint tail provide us with comprehensive particles and fields measurements to probe the nature of the Io-Jupiter interaction region. Here, we present a survey of energetic (>50 keV) ion signatures from the Jupiter Energetic particle Detector Instrument (JEDI). We find that very near, or likely within the Main Alfvén Wing, ions are heated to high energies via wave-particle interactions and form upgoing conic distributions (Clark et al., 2020; Sulaiman et al., 2020, Szalay et al., 2020). More recent analyses, including a close inspection of Juno's first 26 orbits, reveal that ion acceleration is a persistent feature associated with Io's footprint tail. Whether or not the acceleration is active throughout the full extent of the tail region will be addressed in this presentation. We will also show observations of plasma waves, magnetic turbulence and lower-energy electrons accompanying the energetic ions in search for correlations and casual links.

Energy deposition by energetic electrons into Titan's atmosphere – C1

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Titan, Saturn's largest moon, is the only moon in the solar system known to harbor a significant atmosphere. Different processes contribute to the ionization of atmospheric particles, creating a complex ionosphere that acts as a conducting obstacle to the incoming plasma, thereby forming an induced magnetosphere, similar to those formed at Mars and Venus by their interaction with the solar wind. When located inside the magnetosphere, the interaction is subsonic, so no bow shock is formed in front of the moon, thus allowing magnetospheric particles to directly interact with the upper layers of the atmosphere. Energetic electrons play an important role in the creation of the nightside ionosphere, and in the ionization of atmospheric particles below the main ionospheric peak. Cassini was equipped with the necessary instrumentation to measure the influx of energetic electrons, with the Low Energy Magnetospheric Measurements System (LEMMS). In this contribution, we present a combination of the results from a test particle model used to trace energetic electrons upon electromagnetic fields generated by the AIKEF hybrid code and upstream measurements from the LEMMS instrument to estimate the local contributions of the precipitating energetic electrons to the ionization of Titan's atmosphere.

The Europa Clipper Magnetometer (ECM): Objectives and Progress – C2

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The icy surface of Jupiter's moon, Europa, is believed to hide a global scale ocean buried at relatively shallow depth. Considerable support for this model comes from the inductive magnetic response identified in data from multiple Galileo flybys; many surface features also support this assertion. However, the thickness of the ice layer and the depth of the ocean and its conductivity remain uncertain. Largely because a moon with a buried ocean is a good place to look for an environment capable of supporting life in some form, NASA has developed a mission, the Europa Clipper, designed to characterize the habitability of Europa. The spacecraft, now under construction by JPL and APL, will be launched on a commercial launch vehicle in late 2024 (launch window opens on Oct. 10) on a Mars-Earth gravity assist trajectory, arriving at Jupiter in April of 2030. After orbital adjustment through multiple encounters with Ganymede (and one or more with Callisto), the spacecraft will make multiple close flybys of Europa.

A key objective of the mission is to characterize the hidden ocean more completely. The amplitude of an induced field depends on the driving frequency of a time-varying field, with different frequencies penetrating the conducting ocean to different depths. Thus, by measuring the amplitude of the inductive signature at Europa at multiple natural frequencies including the synodic rotation period of Jupiter (11 hours) and its harmonics and the orbital period of Europa (85 hours), it will be possible to learn a great deal about the global averaged properties of the ocean and the ice layer. One might think that a continuous data set such as that collected by a spacecraft in orbit around Europa would be required to extract the multiple frequency response, but it is possible to patch together data segments from tens of close flybys to obtain the needed information. The Europa Clipper mission will provide the required information from a tour that passes close to the moon more than 40 times in different locations around its orbit.

The signal at the orbital period is not large, and extracting desired results will require collecting data of high precision, so a key requirement of instrument design, development, and operation is to assure as magnetically clean an environment as possible, operational stability and precise calibration. Three fluxgate magnetometers will be aligned near the end of an 8.5-m-long boom. The sensors themselves, now actual hardware, will be calibrated on the ground before being integrated into the spacecraft. Field gradients along the boom will be used to identify and remove the contribution of the spacecraft field at the outboard sensor. Spacecraft rolls will be used to calibrate the sensors periodically inflight. This report will provide updates on the hardware development, calibration procedures, and the science of the mission.

A Comprehensive Set of Juno In Situ and Remote Sensing Observations of the Ganymede Auroral Footprint during PJ30 – C3

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The Galilean satellite auroral footprints result from the interaction between the co-rotating iogenic plasma and the different satellites. Since its arrival at Jupiter in 2016, Juno continues to revolutionize the field of moon-magnetosphere interaction by providing, for each perijove, multi-instrument datasets combining in-situ and remote-sensing measurements of the magnetic fluxtubes connecting each satellite with their auroral footprints. So far, the Juno measurements favor an Alfvénic acceleration mechanism generating both the main auroral footprint spot and the footprint tail emissions. This work focuses on the Ganymede fluxtube crossing of PJ30 (8 Nov 2020), during which Juno appeared to be connected to Ganymede's Main Alfvén Wing (MAW) southern footprint. The peak MAW UV-brightness recorded by Juno-UVS was 472 +/- 40 kR, while JADE-E recorded a highly structured downward precipitating electron energy fluxes peaking at $\sim$300 mW/m^2 and an averaged downward precipitating energy flux of 51 mW/m^2. We present a multi-instrument characterization of this event.

Reflections from Io: I31 revisited – C4

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The Galileo I31 pass took the spacecraft over the northern pole of Io. The encounter takes place very close to perijove and the spacecraft orbit is closely aligned along the wake of the moon. The geometry of the pass is the first to firmly rule out the presence of any internal field at Io but also the long period where the spacecraft remained for a substantial time on flux tubes which would have passed through or near Io renders the pass also of great interest. Indeed, we show evidence of disturbance detected downstream of Io whose polarisation and apparent scale length resembles that of the Io disturbance itself. The signal amplitude is a factor of ten smaller than the disturbance at Io. Nonetheless, we examine the possibility that it is an Alfvén wave echo that has reflected back and forth from the southern ionosphere.

Properties of turbulent Alfvénic fluctuations and wave-particle interaction associated with Io's footprint tail – C5

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We investigate the small-scale magnetic field fluctuations and their associated turbulent nature in the Io flux tube connected to Io's footprint tail (IFPT). Our study is based on the recent magnetic field measurements by the Juno spacecraft during the PJ12 Juno flyby. Here we are interested in understanding what type of turbulence is consistent with the fluctuations in the quasi-dispersionless frequency range of 0.2 - 800 Hz as observed by Sulaiman et al, 2020. Knowledge of the turbulent fluctuations is important to constrain the acceleration mechanisms for ions and electrons in the Io flux tube.

In this work we first show that the observed fluctuations in the spacecraft frame correspond to Doppler-shifted spatial fluctuations structured perpendicular to the background magnetic field. Consequently, we reinterpret the spectral index of the observed magnetic power spectral density to be potentially the result of weak-MHD and sub-ion scale kinetic Alfvén wave turbulence in the low-frequency regime. Our theoretical modelings show that turbulence can be driven both in the torus region and at high latitudes rendering results in agreement with the Juno measurements. Calculated turbulence heating rates are consistent with observed energy fluxes in the Io flux tube and represent efficient drivers for particle acceleration. Moreover, a widening of the IFPT structure with respect to the Io flux tube extent is consistent with propagating dispersive Alfvén waves modified by kinetic effects on their group velocities.

Magnetospheric ion bombardment of Europa's surface – D1

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Jupiter's moon Europa is exposed to constant bombardment by magnetospheric charged particles, which are expected to be a major source of physical and chemical surface modification. We have investigated the flux of magnetospheric ions at Europa's surface by carrying out single-particle tracing within realistic electromagnetic fields from multi-fluid magnetohydrodynamic simulations of the moon's interaction with Jupiter's magnetosphere. We find that magnetic field line draping and pile-up leads to shielding and drastically reduced flux at low latitudes across Europa's trailing (upstream) hemisphere. Furthermore, we find that magnetic induction within Europa's sub-surface ocean leads to additional shielding when the moon is located at high magnetic latitudes. Overall, we find that the high latitude and polar regions receive the largest flux of magnetospheric ions.

Influence of Europa's Time-Varying Electromagnetic Environment on Magnetospheric Ion Precipitation and Surface Weathering – D2

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

Effects of Europa's atmospheric asymmetries on its plasma interaction: Insights from the Galileo E15 Flyby – D3

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Europa's neutral atmosphere is intrinsically coupled to the plasma interaction between Europa and Jupiter's magnetosphere through various mass-loading and momentum-loading processes. Models for the neutral atmosphere have predicted that an atmospheric bulge rotates around Europa with the illumination of the Sun, potentially leading to global-scale asymmetries in the atmosphere (Plainaki et al., 2013; Oza et al., 2019), but to date no models for the plasma interaction have investigated the effect of this variation on Europa's ionosphere and the resulting perturbations to the magnetic and plasma environment. We have used a multi-fluid MHD model (Harris et al., 2021) to simulate the E15 Galileo flyby, during which Europa's leading/downstream hemisphere was illuminated, to identify the effects of this atmospheric bulge on the plasma interaction. Our simulations indicate that an atmospheric bulge on Europa's leading hemisphere during the E15 flyby can well explain both the measured magnetic field and plasma density in Europa's wake. Our results are consistent with the analysis of Volwerk et al. (2001), who identified a source of mass-loading on Europa's leading hemisphere during the E15 flyby. Our results are also consistent with the atmospheric models of Plainaki et al. (2013) and Oza et al. (2019), who predicted that an atmospheric bulge should form on Europa's leading hemisphere during configurations similar to that of the E15 flyby. Our results demonstrate the crucial importance of taking into account variations in Europa's neutral atmosphere in understanding Europa's plasma interaction and have important implications for developing high-fidelity plasma interaction models for Europa.

Timescales and vertical structure of the Io auroral footprint emission – D4

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The auroral footprints are peculiar features of Jupiter aurorae, and consist of bright spots (and associated tails) that appear in the ionosphere at the base of the magnetic field lines that swept past Io, Europa, and Ganymede. The moons are slow-moving obstacles in the path of Jupiter's rapidly rotating magnetospheric plasma and the resulting electromagnetic interaction launches Alfven waves along the magnetic field lines towards Jupiter. Such waves are associated with field aligned currents, whose electrons then precipitate onto the atmosphere, react with the hydrogen and make it to glow. However, Juno's close observations of such footprints revealed a fine structure, which in some way challenges the current knowledge and modelling for their formation. Here we focus on the temporal variability and the vertical structures of the footprints.

The inclusion of the Irish LOFAR station IE613 in the Jupiter observing program: a first multipoint observing case study of the Io-DAM emission – D5

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The Low Frequency Array (LOFAR) is an international radio telescope array, consisting of 12 international stations spread over Europe, with additional stations and a central hub in the Netherlands. I-LOFAR is the Irish complement to this network and the 12th international station to be built in Europe. It allows Irish astrophysical research to be integrated with one of the most sophisticated telescopes on the planet. Here, we want to study the Jovian decametric radio emission induced by Io, at high temporal and spectral resolution, from several LOFAR stations distributed in Europe, using the westernmost position of the Irish station. The objectives of these observations are multiple. As the stations are well distributed over Europe, we are able to measure a time difference between different observations of the same event. For example, between Letvia LV614 (the easternmost station) and Ireland IE613, the difference in observation time of an Io induced radio emission should be 6 ms. Since we have better time resolution than this (LOFAR stations can go down to 5μs), we are able to measure this offset. This gives us the rotation rate of this source, and also allows us to put constraints on the size of the emission beam. Using interferometry techniques, we are also able to put constraints on the source position (longitude + altitude of the sources), which we can compare with the theoretical source position. This should allow us to constrain the angle of attack in longitude between the active magnetic field lines (where the sources are located) and the instantaneous magnetic field lines connected to Io. This shift in longitude will allow us to determine an estimate of the electron density of the torus of Io (this shift being produced by the fact that the perturbation moves at Alfvén speed). A first set of observations using I-LOFAR in single station mode were taken in late 2020 to verify the processing pipeline and offer the opportunity to explore techniques to reduce RFI. Here we report early results and future plans from a significant campaign of multi-point LOFAR observations, starting in June 2021.

High-contrast imaging and spectroscopy in the visible and near-infrared range with a low-scattering off-set telescope PLANETS – E1

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We are carrying out a 1.8-m aperture off-axis telescope project PLANETS (Polarized Light from Atmospheres of Nearby ExtraTerestrial Systems). The PLANETS telescope is characterized by high-contrast imaging and spectroscopic capability thanks to low-scattering in the optical system by combining off-axis mirror, adaptive-optics (AO), and stable atmospheric conditions of an observatory site at a high-altitude. In particular, the off-axis system brings us no cross-shaped diffraction pattern caused by the secondary mirror support in the optical path, and thus the scattering light of PLANETS is estimated to be more than 10 times better than that of a normal large telescope. PLANETS Foundation (www.planets.life), whose board members are from Japan, USA, Germany, and Brazil, manages this project.
Our major scientific goal is to detect faint emission surrounding planet and satellite in the solar system as well as exoplanets, such as Jovian satellite Europa's plume and Martian ionosphere. These emissions are so faint (10^{-3} to 10^{-6} to the brightness of planetary or satellite disk) close to the main disk (less than a few arcsec) that the measurement of these distributions and time variabilities are difficult. PLANETS is appropriate to observe these targets by taking advantages of high-contrast imaging and spectroscopic capability and monitoring operation optimized for the targets.
The telescope optics has a Gregorian focus with a FOV of 6' (F/13). The main mirror is Clearceram Z-HS with a diameter of 1850 mm and thickness of 100 mm. So far, the glass blank of main mirror was made in 2010, the rough grinding was carried out by Harris/Excelis in 2012. In December 2019, the mirror was shipped from Hawaii to Japan for the final polishing. We glued 36 metal adapters on the backside of mirror to connect the mirror support. We adopted the mirror support with warping harness which is similar to TMT and the Seimei telescope. We made the elemental test of the whiffletree system, and confirmed that the performance for stress input is as expected by the structure model with a finite element method (FEM), and the repeatability (hysteresis) for stress change is in the acceptable range. We will carry out the final polishing using a dragging three probe method with a robot-arm system at Logist Lab./Astro-Aerospace within a year. Compared with a traditional CGH-type interferometric metrology, the dragging three probe method and polishing with the robot arm are characterized by the free-form metrology with three-probe. We expect to obtain the accuracy of main mirror better than 20 RMS nm by the final polishing. In addition, we will fabricate the telescope mount and structures using the proto-type mount Seimei telescope. We will assemble the whole PLANETS telescope sytem, and achieve the first light and technical demonstration, particularly on the high-contrast and low-scattering capability, in Japan within a few years. Further, we already have the construction permit at the summit of Haleakala (CDUP) from the State of Hawaii, and we plan to install PLANETS there as soon as we get the funding for the observatory construction.

Numerical simulation of the passive subsurface radar for Jupiter's icy moons – E2

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The subsurface ocean at icy bodies in our solar system is one of the most likely habitable environments except for Earth. While the subsurface ocean of Enceladus at Saturn has been already demonstrated with the Cassini explorer, it is still unclear that Europa and Ganymede at Jupiter have it although they are theoretically predicted to have greater amount of liquid water than Earth. The highest priority is placed on detections of the subsurface ocean and related water plume activities at Jupiter's icy moons in the Jupiter Icy Moon Exploration mission JUICE, which is going to start exploration in early 2030s. Here we numerically simulate the passive subsurface radar PSSR for the icy moon's ocean that is going to be observationally made by receiving Jupiter's auroral radio emissions with the radio and plasma wave instrument RPWI onboard JUICE. Based on the ray tracing method, we simulate propagation of Jupiter's radio emission in the icy moon's water plume, tenuous ionosphere, and interior assuming the plasma density and dielectric constant structures. The simulation indicated that some of the structures are clearly detectable by PSSR if the incident radio emission forms chirpy waveform packets at HF frequencies.

New estimates of sputtered Energetic Neutral Atoms from the surface of Ganymede – E3

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Surface weathering by precipitating Jovian plasma is thought to cause brightness asymmetries at the surface of Ganymede. One way to investigate this theory is to map ion precipitation through remote observations of Energetic Neutral Atoms (ENAs). Ion precipitation leads to the sputtering of Energetic Neutral Atoms that can be detected remotely by instruments such as the Jovian Neutral Analyzer (JNA) onboard the JUpiter ICy moon Explorer (JUICE) spacecraft. To help interpret the data to be collected by JNA, estimates of sputtered fluxes at Ganymede are needed. We combine results from hybrid simulations of ion precipitation at Ganymede with sputtering models derived in previous works to estimate sputtered fluxes of $\mathrm{H_2O}$, $\mathrm{O_2}$, and $\mathrm{H_2}$ from the surface of Ganymede. We then use a Thompson-Sigmund law to derive the energy distribution of the sputtered ENAs and simulate a simplified JNA observation at different places on the surface of Ganymede. Our global sputtering rates are in agreement with previous works, and our simulated observations show that the JNA instrument will be able to map ion precipitation at Ganymede.

Small Scale Morphology of the Footprint Tails of Io, Europa and Ganymede observed by JIRAM – E4

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The Jovian Infrared Auroral Mapper (JIRAM) on board Juno is a spectro-imager which is observing the atmosphere of Jupiter and its auroral emission using its two imagers in the L (3.3-3.6μm) and M bands (4.5-5.0μm) and a spectrometer (2-5 μm spectral range).
The high spatial resolution of the JIRAM imager allowed to observe the detailed structure of the auroral signature related to the Galilean moons. This phenomenon is caused by the jovian magnetic field sweeping past the satellites: such interaction generates Alfven waves that travel along the magnetic field lines as field aligned currents (FACs). The electrons associated to the FACs precipitate onto the ionosphere, where they trigger a chain of chemical reactions with the hydrogen and make the upper layer of the atmosphere to glow. The location where the main precipitation occurs is known as footprint, which is followed by a fading auroral arc known as footprint tail. JIRAM observed a dot-like substructure consistently in the footprint tails of Io, Europa and Ganymede using its L-band filter. The images acquired from perijove 4 to 30 where surveyed and analyzed quantitatively. We report that the typical distance between the sub-dots lies mostly between 200 and 500 km, with no apparent correlation with the phase of the moons or the hemisphere. This suggests that the origin of the observed morphology can be due to ionospheric processes. Furthermore, a sequence of images of the Io footprint tail lasting about 10 minutes on the southern hemisphere was captured during perijove 13 and it revealed that the sub-dots are corotating with the magnetic field of Jupiter. The same behaviour was observed during two shorter sequence (perijoves 14 and 26), therefore we believe that this feature is not transient.
The morphological characteristics we retrieved are incompatible with multiple reflection of the Alfven waves between the hemispheres. Instead, we suggest a feedback process between the ionosphere and the magnetosphere as a potential cause for the sub-dots. Such process is triggered the local increase of the ionospheric conductivity caused by the FACs in a region where Pedersen and Hall currents flow. We report order of magnitude estimates showing that the feedback process is compatible with the observed distance between sub-dots and their stillness.

Study of the sodium jet of Io with the TRAPPIST telescopes – E5

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Io is the solar system's most volcanically active body. This volcanic activity results in the ejection of material into Io's atmosphere, which then escapes from the atmosphere to form various structures in the Jovian magnetosphere. These include the plasma torus and clouds of neutral particles. The physical processes involved in the escape of particles are not yet fully understood. Indeed, the study of the atmosphere and the volcanoes in the one hand and the study of the plasma torus on the other hand, lead to two different conclusions regarding the origin of the variability of the torus plasma content. Observations of Io, with a particular focus on the neutral sodium clouds, which are relatively easy to detect thanks to the bright D-doublet of sodium, could help solve the mystery surrounding the escape of those particles.
Here we report on observations carried out during 15 nights in 2014 and 2015 with the 60 cm robotic TRAPPIST-South telescope and a narrow band sodium filter. On those images, a particular attention was paid on the sodium jet, one of the neutral sodium features. Among the images where the jet can be seen, we noticed that it does not always have the same size and brightness from one observation to another. The current study is to measure the physical quantities, as the brightness of the jet, its length and duration to be able to quantify these variations through time.
Furthermore, similar Io sodium observations are currently planned and carried out with both TRAPPIST telescopes. The images will be processed via different methods to highlight the sodium jets. Contrary to the observations made in 2014 and 2015, the new observations will be performed at moments chosen specifically to observe the jet. The configuration of Io with respect to Jupiter will be more or less the same from one observation to another in order to facilitate the comparisons. These new observations will be in the form of a monitoring, about two times a week for several months, to maximize the chances to catch the jet and have a more continuous data set to have a better understanding of its variation through time. In case a bright event is detected, more and dense observations will be carried for several hours continuously to follow the event.

Life-environmentology, Astronomy, and PlanetarY Ultraviolet Telescope Assembly (LAPYUTA) mission: instrument overview – F1

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The Life-environmentology, Astronomy, and PlanetarY Ultraviolet Telescope Assembly (LAPYUTA) mission aims to carry out spectroscopy with a large effective area (>300 cm^2) and a high spatial resolution (0.1 arc-sec) and imaging with a wide field of view in an ultraviolet spectral range (110-190 nm) from a space telescope. The main part of the science payload is a Cassegrain-type telescope with a 60 cm-diameter primary mirror. Two main instruments are installed on the focal plane of the telescope: a spectrometer and a wide-field imager. The spectrometer contains a movable slit with different slit width, a holographic toroidal grating with 2000 lines/mm, and an MCP detector coupled with CMOS imaging sensors. Spectral resolution of <0.01 nm and field-of-view of 100 arc-sec will be achieved. The wide-field imager located at the off-axis position close to the spectrometer slit consists of an array-type detector with 4 MCP sensors. It will achieve a field-of-view of 10 arc-min by 10 arc-min. A UV slit imager and hydrogen absorption cell are also under study as options. In order to achieve a high spatial resolution of 0.1 arc-sec, we will install a target monitoring camera at 0th order position inside the spectrometer and slit imager for both attitude control and image accumulation process. We are studying the concept of LAPYUTA and preparing a proposal of it to JAXA's M-class category. Here we present the LAPYUTA concept design and the overview of the spacecraft and instruments.

Future observations of Jovian system with LAPYUTA (Life-environmentology, Astronomy, and PlanetarY Ultraviolet Telescope Assembly) – F2

Fuminori Tsuchiya*[1], *Go Murakami*[2], *Tomoki Kimura*[3], *Ryoichi Koga*[4], *Chihiro Tao*[5], *Kei Masunaga*[2], *Shotaro Sakai*[1], *Jun Kimura*[6], *Masato Kagitani*[1], *Kazuo Yoshioka*[7], *Atsushi Yamazaki*[2], *and LAPYUTA WG

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Ultraviolet observation technique is one of the most powerful tools to cover wide science fields, from planetary science to astronomy. Here we propose a UV space telescope, LAPYUTA (Life-environmentology, Astronomy, and PlanetarY Ultraviolet Telescope Assembly), as a Japanese-leading mission, by using both many heritages of UV instruments for planetary science (e.g., Hisaki) and space telescope techniques for astronomy. We will accomplish the following four goals: (1) dynamics of our solar system planets and moons as the most quantifiable archetypes of extraterrestrial habitable environments in the universe, (2) transit spectroscopy of exoplanetary atmosphere, especially hydrogen and oxygen exospheres, to observe on-going atmospheric escaping predicted to occur on Earth-like exoplanets in the habitable zone of low temperature star system, (3) the unique UV map of the gaseous large-scale structures (LSSs) to test the structure formation scenario of the cold dark matter (CDM) model and to unveil galaxy growth and feedback processes in the LSSs, and (4) the time-domain survey for transient sky in the UV wavelength to witness the first moments of high-energy events such as compact-object mergers and supernovae with a great synergy of the growing facilities of multi-messenger astronomy including gravitational-wave observatories.

In this presentation, we focus on the first topic which includes sciences related with the Galilean moons and the Jovian magnetosphere. In our solar system, subsurface oceans of icy moons at gas giants are the most likely extraterrestrial habitable environment. Evolution and current situation of the subsurface oceans are essential unresolved problems to assess their habitability. Water plume that gushes from the subsurface ocean to the surface and ambient space is the only observable phenomena that tells us geological activity of the ocean. The energetic charged particle surrounding the icy moons is an essential energy source for chemistries at the icy moon's surface and interior. The energy input from the magnetosphere to the icy moons is caused by bombardment of energetic charged particles to the satellite atmosphere and surface and is visible through the auroral emissions in the satellite atmosphere. As the plume activity and the energy input are not stable, continuous monitoring with high spatial resolution is essential. The origin of energetic charged particles is heating and acceleration of plasma in the magnetosphere. The heating and acceleration phenomena are able to be visualized by the polar auroral emission that maps to the magnetosphere through the planetary intrinsic magnetic field. Monitoring capability of LAPYUTA will enable us to see dynamics of auroral morphology to uncover energy flows from the magnetosphere to the icy moons. The icy moon's plume and ambient space are deeply explored with the spacecraft by NASA's and ESA's icy moon missions in 2020s-2030s. The in-situ measurement with the spacecraft quantifies the gas density, molecular/atom species, and electromagnetic fields at the spacecraft location. The complementary remote sensing of the plume and ambient space by LAPYUTA will visualize their global structure and temporal dynamics.

Fast and Slow Water Ion Populations in the Enceladus Plume – F3

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Ion velocities have been measured during the Enceladus E3 and E5 flybys using the Cassini Plasma Spectrometer (CAPS) instrument on the Cassini spacecraft. Data from three sensors in the CAPS instrument have been examined from two flybys that occurred during 2008. Positive ion measurements from the CAPS Ion Beam Spectrometer and Ion Mass Spectrometer have been used to measure positive ion velocities. The CAPS Electron Spectrometer has been used to complement the positive ion findings with measurements of negative ion velocities. Two velocities for the positive ions are found, with the fast ions (2.3-5.8 km/s) originating from the high-speed neutral gas emission and slow ions (0.2-2.2 km/s) associated with the low-speed thermal gas emission from Enceladus. Negative ions were found to be near stationary or northerly traveling, implying a deceleration mechanism within the plume. A tentative detection of fast negative ions was also recorded for one of the flybys. These findings will aid in future modeling of plume dynamics.

Time-varying interaction of the Jovian magnetosphere with Europa: three-dimensional MHD simulations of the Galileo flybys – F4

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Europa, the smallest of the Galilean moons, is embedded within Jupiter’s magnetosphere where a rapidly flowing plasma interacts electromagnetically with the moon’s atmosphere and its surface. The magnetic field in the plasma is also affected by Europa’s induced magnetic field in a subsurface conducting layer. Between 1996 and 2000, the Galileo spacecraft executed eight close flybys of Europa for which magnetic field measurements were obtained. In this study, we investigate the environment of Europa and model the global three-dimensional interaction between the moon and the corotating Jovian plasma by means of a set of magnetohydrodynamic (MHD) equations. Our model accounts for electromagnetic induction in a subsurface water ocean, collisions between ions and neutrals, and plasma production and loss. The resulting magnetic field is compared with measurements performed by the Galileo magnetometer. We also present an analysis of the observations from these flybys taking into consideration the variable geometry of the trajectories. The model shows good agreement with the measured magnetic field and it reproduces the basic features of the plasma interaction in the vicinity of Europa.

The effect of Europa's induced dipole and plumes on energetic proton depletions in the Alfvén wings – F5

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We investigate energetic proton depletions during Europa flybys E17 and E25A* by the Galileo mission. Both of these flybys passed through Europa's Alfvén wings further away from the moon, where ionospheric effects are small. Energetic ion observations along trajectories like those of E17 & E25A are suitable for isolating the characteristics of the global configuration of the interaction region of Europa (or any Galilean moon) with the Jovian magnetosphere.
We simulate the measured flux with a Monte Carlo particle tracing code and investigate the effect of the following factors: inhomogeneous electromagnetic fields, Europa's induced dipole, atmospheric charge exchange and plumes.
We find that the homogeneous fields do not explain the Galileo data. We propose that the perturbed fields associated with the Alfvén wings affect the proton depletions. The inhomogeneous fields and induced dipole alter the pitch angle distribution of the depletion along the trajectory. The plumes that are investigated in this study have a minor effect on the proton depletions compared to the inhomogeneous fields and Alfvén wings. But, plumes with a surface density in excess of 2.5 10^15 m^{-3} could create a more pronounced depletion. The contribution of atmospheric charge exchange to the depletion is negligible for these flybys. Finally, we compare the simulations to the measured proton flux and discuss the contribution of the effects we have considered.
*E25A is a segment of the Io flyby I25

Structure and variability of Io plasma torus observed with the Tohoku 60-cm telescope – G1

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Volcanic gases (mainly composed of SO2, SO and S) originated from jovian satellite Io are ionized by interaction with magnetospheric plasma and then form a donut-shaped region called Io plasma torus. Ion pickup is the most significant energy source on the plasma torus though, distribution of pick-up region and its variability is still unclear. Density profiles of ions along the magnetic field line are determined under condition of diffusive equilibrium. Based on the equilibrium, plasma equator is close to the centrifugal equator though, higher ion anisotropy moves the plasma equator toward the magnetic equator. Measuring ion distribution with enough special resolution enables us to derive ion anisotropy which is tightly related to the amount of fresh pickup ion. On this study, we focus on variability of latitudinal structure of Io plasma torus as well as its radial structure using ground-based observation starting from 2018 through 2020.
The ground-based observation of sulfur ion emission, [SII] 671.6 nm and 673.1 nm was made at Haleakala Observatory in Hawaii during March 2018 through October 2020 using Tohoku 60-cm telescope. A monochromatic imager with coronagraph attached onto the telescope enables to measure distribution of singly charged sulfur ion with spatial resolution of 0.03 jovian radii. A digital micro-mirror device DMD was employed to block light from Jupiter disk and Galilean moons. Typical integration time of each frame was 20 minutes and total number of reduced images is about 1500. We also made observation of neutral sodium cloud extending up to several hundred of RJ as a proxy of supply of neutral particles from Io (Yoneda et al., 2015).
Based on observation over the past three years, we find several [SII] brightening events within a short period (< 2 days) over a small longitudinal region < 60 degrees. [SII] 671.6 and 673.1 nm emissions are sensitive to cold electron (1-10eV) rather than hot electron (>100eV). Thus, increase of cold electron temperature explains the observed [SII] brightening well as the EUV space telescope Hisaki observed brightening of Io plasma torus presumably associated with injection of hot electron. We also find variation of latitudinal structure of Io plasma torus. Latitudinal (north-south) peak of [SII] at the same system III longitude 279 degree are -0.73, -0.80 and -0.79 jovian radii on 26, 29 July 7 and August 2018, respectively. The magnetic-equatorward shift of sulfur ion density peak implies higher anisotropy on 29 July and 7 August compared with 26 July. One of the possible explanations of the latitudinal shift of [SII] is an increase of flesh pickup ion which makes higher anisotropy in the plasma torus.

Temporal variation of the Io plasma torus seen from Hisaki satellite – G2

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The temporal variation of ion and electron densities and electron temperature around IPT have been evaluated through the plasma diagnostic method using the EUV spectral data taken by Hisaki from 2013 to 2016. Within these years, several IPT brightness increases in the timescale of several weeks to months caused by the volcanic activity on Io have been detected by various observations by ground telescopes. During those events, the increase of the hot electron component has been confirmed after four of the five events. The dawn-to-dusk asymmetry in hot electron density are also seen in several events. In this presentation, we will summarize the Hisaki IPT data, and the procedure of the spectral analysis has also been shown. The temporal variation of IPT brightness from 2013 to 2021 (whole Hisaki operation) will also be shown.

Electron energization and the Io plasma torus energy budget – G3

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We use a self-consistent two-dimensional hybrid gyrofluid-kinetic electron (GKE) model to simulate the propagation of Alfvén wave energy along a Jovian flux tube and examine the resulting wave-electron interactions. At high latitudes the interaction of electrons with inertial Alfvén waves manifests as highly field-aligned broadband electron distributions (e.g. Damiano et al., 2019) that are qualitatively consistent with recent Juno satellite observations. Post-energization, the distribution functions maintain an elongated tail suggesting that energization of trapped electrons via dispersive scale Alfvén waves can be a source of suprathermal electrons critical to the torus energy balance (Bagenal and Delamere, 2011) and the torus physical chemistry (Coffin et al, 2020). The post-energization appearance of electron beams close to the Io torus also suggests that Alfvén-wave energized electrons could be a source of the observed trans-hemispheric beams (as proposed by Bonfond et al., 2008). We also explore the sensitivity of the model results to variations of the input parameters and compare these results with the energy budget calculations of Hess et al. (2011).

Using a 3D Physical Chemistry Model to Simulate Spectral Observations of the Io Plasma Torus – G4

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ESA's JUICE mission and NASA's Europa Clipper are sending UVS instruments to the Jupiter system that will view the Io plasma torus. In anticipation of these missions we have built a 3D Io plasma torus emission model in order to simulate what we would expect to see from both UVS instruments looking at the Io plasma torus. The Colorado Io Torus Emission Package 2 (CITEP 2) calculates the line of sight given the position of each spatial pixel and pointing of the spacecraft and produces a synthetic spectrum given plasma densities and temperatures along the line of sight using the CHIANTI atomic database (version 9) to compute volume emission rates. We compare our model with Cassini UVIS and Hisaki UV observations of the Io plasma torus. In addition we couple a 3D model of the physical chemistry to a neutral cloud model, and the local interaction. Output of this model will be a 3D distribution of densities and temperatures for all modeled species. This will then be used as input for CITEP 2 in order to predict what we expect to see when JUICE and Europa Clipper arrive at Jupiter.

Using Io Input/Output observatory (IoIO) observations to provide an new approach to resolving the question: Is mass flow in Jupiter's magnetosphere driven by internal or external processes? – G5

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The Io plasma torus (IPT) is the primary reservoir through which nearly all material in Jupiter's magnetosphere flows. Thus, regulation of mass flow in Jupiter's magnetosphere is ultimately controlled by mass flow through the IPT. Considerable work has been to determine the mechanism(s) which control mass flow in the IPT. In all cases, a small population of hot electrons (1% – 3%) has been shown to be critical. The question then becomes: where do these hot electrons come from? Theoretical evidence suggests electrons are heated by Alfven waves triggered partly by flux tube interchange in the IPT and partly by the flow of plasma around Io (e.g., Delamere et al. 2005, Copper et al. 2016, Coffin et al. 2020). Observational evidence suggests that the hot electrons are produced in the middle and outer magnetosphere during magnetospheric reconfiguration events and transported inward by flux tube interchange (e.g., Yoshikawa et al. 2016, Yoshioka et al. 2018, Hikida et al. 2020, Louarn et al. 2014). Because IPT hot electrons stimulate emission in the UV, observational studies have primarily been conducted at these wavelengths. Observed correlation between UV emissions and events in the middle and outer magnetosphere is the evidence for causality.
In this presentation, we describe a different observational approach being conducted by our team using the Io Input/Output observatory (IoIO). IoIO is a ground-based small-aperture coronagraph which contemporaneously observes the IPT S+ 673.1 nm line and the Jovian sodium nebula on a nightly basis. The S+ 673.1 nm line is excited by thermal electrons and is therefore a proxy for the bulk density of IPT plasma. The IoIO sodium images are of considerably higher spatial resolution than other synoptic studies (e.g., Mendillo et al. 2004, Yoneda et al. 2015), owing to IoIO's larger aperture. The IoIO sodium images allow study of detailed structures in the nebula (e.g., "banana," "jet" and "stream") which trace specific physical processes acting between the IPT and Io's atmosphere. These structures, together with the time history of the brightness of the IPT, enable solution of the mass balance equation governing material flow from the IPT. The astrometric position of the IPT ansas trace the cross-tail electric field, which is an indicator of middle-outer magnetospheric activity. Thus, IoIO collects all the information necessary to answer the question "Is mass flow in Jupiter's magnetosphere driven by internal or external processes?" without relying on observation of the hot electrons that are proposed to be critical in the process. In this way, the IoIO results will serve as an important independent verification of the relationship between hot electrons and mass transport in the IPT.
IoIO has collected over 7500 S+ and Na images and is entering its fourth year of operation. We will report on the status of IoIO data collection and analysis, including a reanalysis of the 2018 volcanic event reported by Morgenthaler et al. (2019) in light of our latest calibration results.

Kinetic Alfven wave propagation and electron energization in the Io plasma torus – G6

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Observations of the Galileo satellite have illustrated small scale magnetic field fluctuations near Io (e.g. Chust et al., 2005) suggesting the presence of kinetic Alfven waves in the Io plasma torus. In the terrestrial magnetosphere, both observations (e.g. Wygant, 2002) and simulations (e.g. Watt and Rankin, 2009; Damiano et al., 2016) have linked these waves to energized electron distribution functions elongated in the direction parallel to the background magnetic field. In this study, we present an overview of hybrid gyrofluid-kinetic electron model (Damiano et al., 2019) simulations of the interaction of electrons and kinetic Alfven waves in a heavy mass, high density torus. We highlight the resulting wave-particle interactions for both positive and negative field-aligned current regions and investigate the characteristics of the reflection/transmission of the waves through the torus boundary. We additionally explore what role these waves may play in the local generation of the supra-thermal electron population which has important implications for the System IV modulation in the Io plasma torus.

The response of Jovian inner magnetospheric plasma to the neutral source changes from Io: Comparison of a radial diffusion model with the HISAKI observation – H1

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We developed a time-dependent radial diffusion model to evaluate chemical reactions and radial transport of plasmas in the Io plasma torus(IPT). We compared equilibrium plasma distribution with the HISAKI observation to validate the model and investigated mass and energy flows in the magnetosphere when neutral sources from Io temporally changed. The radial distribution of the plasma has been examined based on steady state models and observations of Voyagers and Cassini spacecraft. However, comparison of the time dependent model with continuous observations have not been reported yet. The purpose of this study is to develop a time-dependent radial diffusion model and to compare the model with the HISAKI observation in 2015.
We solved mass and energy balances of major heavy ions of Io origin (O^+-O^{3+} and S^+-S^{4+}). The equation system is based on the mass and energy transport model by Delamere et al. [2005]. Nearby the Io's orbit, plasma parameters (temperature and density of ions and thermal electrons) are calculated by the physical chemistry model [Delamere and Bagenal 2003] and are used as the inner boundary condition. At the outer boundary (about 30R_J), the plasma parameters are fixed with extrapolated HISAKI observation. We considered several chemical interactions: ionization, recombination, charge exchange, Coulomb interaction and radiation. The initial values were given from the HISAKI observations in November 2013 when Io's volcanic activity was quiet. Since the plasma diffusion due to the interchange instability depends on the radial distribution of plasma, we adopted a non-limner diffusion coefficient based on Siscoe and Summers [1981]. To verify the validity of the model, the steady state temperature and density in the region of 6-10R_J were compared with the HISAKI observation [Yoshioka et al. 2014] and we got the parameters that best matched with the observation; at L=6, the hot electron fraction is 0.2%, the hot electron temperature is 60eV, the neutral source rate is 6.5 $\sim$10^{-4}/cc/s, p and k_Ω which characterize the radial diffusion coefficient are 2.0 and 8.0 $\times$ 10^{-16}, respectively. From comparison of the timescales for each chemical reaction and the diffusion at steady state, it is confirmed that O^+ and S^{2+} are the most dominant ions in IPT.
To investigate the time variations of the IPT, we compared the time-dependent model with the HISAKI observation during the IPT emission enhancement in 2015. We assumed the injection of neutrals started on the day of year (DOY) 10 in 2015. To reproduce the observation, it is needed to introduce increase in not only the neutral source rate but hot electron density. We examined the mass and energy flow among the neutrals, ions, and electrons. Neutralization through charge exchange and recombination is the most dominant loss process and 70% of the energy is provided from thermal electron heated by hot electrons, and 80% of loss process is caused by the UV radiation. While the radial diffusion coefficient was consistent with previous studies, the coefficient k_Ω was over 100 times

larger than the estimation based on the theory.

Long-term monitoring of Jupiter’s aurora and Io torus by Hisaki EXCEED – H2

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Hisaki is an Earth-orbiting spacecraft equipped with a UV spectroscope that primarily observes planetary atmospheres and magnetospheres. The spectrometer EXCEED (Extreme Ultraviolet Spectroscope for Exospheric Dynamics) has a unique dumbbell-shaped slit for observing the Io plasma torus and Jovian aurora simultaneously. Hisaki EXCEED can continuously observe the Jovian system along the 106 min orbit for several months, which is a feature never available for large facilities such as Hubble Space Telescope. Hisaki EXCEED began its monitoring of the Jovian system in December 2013 with the dumbbell slit. Because of the degradation of the Hisaki EXCEED field of view camera, it is more difficult to track the target with the guide camera after mid-2016. The location of Jupiter was set to in the narrow slit region, however, sometimes aurora moved away from the narrow slit region. Therefore, we use two observing modes, ’torus mode’ and ’aurora mode’ since 2017. The Jovian disk is located in the wide-slit region for the aurora mode. Both north and south auroras are observed, and only one side of the torus can be seen. For the torus mode, we set the location of Jupiter to the narrow slit region, and the torus fit within the wide-slit region. We have been developing a pipeline to correct the center position of the Jovian disk and derive the time series of the aurora and torus power. Several transient and solar wind induced brightenings were observed after 2016. We also found minor volcanic enhancement around the beginning of 2018 and 2019. In this study, we will show the time series of the total auroral power over 900-1480 A as well as the torus emission over 650-780 A.

Electron densities measured at high-latitudes on Io torus field lines: Observations from Juno Waves – H3

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This paper will present Jovian electron densities measured by the Juno Waves instruments at high-latitudes on magnetic field lines threading the Io torus and plasma sheet. Electron densities are obtained through identification of characteristic frequency cutoffs and resonances in plasma wave spectra. Often more than one of the characteristic frequencies of the plasma can be identified, whose consistency provides credibility to the plasma density estimate. Waves densities are also found to be consistent with partial electron densities measured by Juno's Jovian Auroral Distributions Experiment. Most of the density measurements are on magnetic field lines threading the Io torus and intersecting Jupiter's ionosphere between Io's M-shell and the main auroral oval, but there is evidence of density dropouts near and poleward of the auroral oval, which may be important in auroral particle acceleration. Sharp density gradients are found near field lines mapping to the inner edge of the Io torus M-shells. These observations demonstrate the extension of elevated Io torus densities along field lines to higher latitudes.

Plasma density along magnetic field lines connected to the Io plasma torus: Diffusive equilibrium models and their uncertainties – H4

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The distribution of ions and electrons along a magnetic field line determines many important aspects of magnetosphere-ionosphere coupling. In the case of the Io plasma torus, this distribution is only known, either empirically or theoretically, at low latitudes, and from initial Juno results at high latitudes. Connecting the low and high latitude measurements is an uncertain process. Above a certain latitude, 49 degrees in the case of field lines connected to Io's orbit, the assumptions of existing models break down and this can have profound effects for the density of ions at higher latitudes. The density distribution along a magnetic field line reflects a balance between centrifugal and gravitational forces, an ambipolar magnetic field and the particles' thermal motion. The traditional diffusive equilibrium model of the plasma density distribution works well at low latitudes, but there is a potential maximum at the mid-latitudes. Above this "choke point", the density distribution is poorly understood. Uncertainties include the proton abundance, the equatorial hot, heavy ion temperature anisotropy and the possible presence of a hole in phase space density above the choke point. These factors produce an order of magnitude uncertainty in the high latitude electron and mass densities. We will present a description of the diffusive equilibrium model, modified to account for phase space holes and applicable from the Io torus to the high latitudes. We will then show the sensitivity of the resulting high-latitude densities to poorly constrained quantities, and identify observations which can constrain these uncertainties.

Numerical Model of the Propagation of Io-generated Alfvén waves with Jupiter's Magnetosphere: First Results – H5

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Jupiter's moon Io (as well as Europa and Ganymede) acts as the generator of a field-aligned current system in the form of Alfvén waves that propagate to the ionosphere of Jupiter. The propagation of these waves is complicated by the strong inhomogeneities in the plasma density that lead to reflections from the gradients in the Io plasma torus as well as the Jovian ionosphere. This current system manifests itself in the formation of aurora not only on the footpoint of the Io flux tube but also in a tail that exhibits a great deal of structure, as observed by the JIRAM instrument on Juno. We present first results from a three-dimensional numerical full wave model of Alfvén wave propagation in the inner magnetosphere of Jupiter. This model takes into account the inclination of Io's orbit with respect to both the magnetic equator and the centrifugal equator where the density is concentrated. The density structure of this region has been determined by diffusive equilibrium models based on observations from Voyager and Galileo with various assumptions as to the plasma composition, temperature and anisotropy, and can be constrained by measurements of the electron density measured within 2 RJ of Jupiter's ionosphere by the Waves experiment on Juno.

Field Line Resonance Frequencies of Jovian Magnetosphere – H6

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Field line resonances (FLRs) form as eigenmodes of Alfven waves between conductive ionospheric boundaries along magnetic field lines. When kinetic Alfven waves develop along an FLRs, electron inertial effects can limit the width of the structure and lead to dispersive wave trains that in turn can accelerate particles. We present a numerical calculation of FLRs using the JRM09 magnetic field model (Connerney et al. 2018) and a plasma mass density model in a dipolar coordinate system modified to support Jupiter's magnetic deviations. This is compared to similar calculations of Earth's FLRs, to investigate the differences and commonalities of the systems. Radial (M-shell) maps of the frequency and local wave power are shown with their Earth counterparts. This model approach provides the framework for future investigations of kinetic plasma ULF wave dynamics at Jupiter.

Current status and future plan of the HF-UHF ground-based radio observation systems of Tohoku University for solar and extra-solar system explorations – I1

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The radio observation group of Tohoku University, Japan, has ground-based radio observation systems in the HF-VHF and VHF-UHF bands and has tried to make observations continuously since 1970's for solar system bodies such as the sun and Jupiter and extra solar system bodies such as pulsars, and also has supported planetary exploration missions. As major observational results in the HF-VHF band, we have observed Jupiter's decametric radiations (DAM) and identified the relationship between solar wind variations and Jupiter's magnetospheric activities and existence of Alfvenic resonating phenomena over Jupiter's ionosphere, and explained radio wave generation/propagation processes based on precise polarization analyses. On the other hand, in the VHF-UHF band, we have identified highly variable features of relatively low energy relativistic electrons in Jupiter's radiation belt using their synchrotron radiation, various fine structures of solar radio bursts and their generation/propagation processes, and also have explored characteristics of energy release processes of the Crab pulsar and newly identified magnetars.
The antennas of our current radio observation systems are stacked log-periodic dipole antennas in the HF-VHF band and a parabolic dish with the aperture of about 1000 m^2 (IPRT: Iitate Planetary Radio Telescope) in the VHF-UHF band. As near-future plans, we have examined development of a more sensitive new observation system with higher temporal and spectral resolution using an aperture array in the HF-VHF band, and that of wider frequency range system in the VHF-UHF band so as to connect the observation frequency range from HF-UHF band continuously. In addition, we have started examination of the participation in international VLBI observations using IPRT with connecting to larger radio observing systems, such as μ GMRT, India, MWA and/or SKA-Low (in future), Australia to make more sensitive investigation with higher spatial resolution especially for extra-solar system bodies. We would welcome and wait for further proposals of collaborative studies by using and connecting our current and future ground-based radio observation systems in the HF-UHF bands.

Effects of meteoric ions on Jupiter's ionospheric conductance – I2

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Ionospheric Hall and Pedersen conductivities are important parameters in determining plasma convection in a magnetosphere-ionosphere system. At Jupiter, meteoric ions deposited by meteoroid ablation are expected to play a major role in the ionospheric conductivities [e.g., Hinson et al., 1998]. This study evaluates the effects of meteoric ions on the ionospheric conductivities and on the plasma dynamics in the magnetosphere.
We have developed a meteoroid ablation model and a photochemical model. In our Jovian ionosphere model, we evaluated two cases, Case 1 without meteoric ions and Case 2 with meteoric ions. The contribution from meteoric ions is evident in the lower altitude (350 - 600 km) region of Case 2 ionosphere, with peak electron density of 10^{11} [m^{-3}], in good agreement with Kim et al. [2001]. In the middle latitude ionosphere of Case 2, meteoric ions modify the local time distributions of electron density. In Case 1, electron density below 800 [km] shows clear local time dependence. In Case 2, electron density still shows similar dependence at the altitudes of 600-800 [km] and below 350 [km], while local time dependence is not found at 350-600 [km] due to the long lifetime of meteoric ions ($\sim$0.5 Jupiter's day), which is consistent with Kim et al. [2001].
In Case 2, the ionospheric conductivity is enhanced and its distribution becomes axisymmetric by the contribution of meteoric ions, whereas there is clear local time dependence in Case 1. It is more evident in the middle- and low-latitude, in which both Hall and Pedersen conductivities have their peak at meteoric ion layer. Their peak values are 1×10^{-5} [S/m] and 3×10^{-6} [S/m], which are 20 and 6 times larger than Case 1, respectively. In the auroral region, Pedersen conductance is not largely affected, but the Hall conductance is 5 times larger in Case 2 than in Case 1. Although meteoric ions do not contribute to the ionospheric conductivities of Earth, they play a major role in Jupiter due to the strong magnetic field and strong gravity force of Jupiter.
We have calculated the azimuthal velocity of corotating plasma in the Jovian magnetosphere by using the corotation lag model of Hill [1979]. Plasma mass loading rate of 300 [kg/s] (Kimura et al. [2018]), and the ionospheric Pedersen conductance of the two cases of ionosphere are used as input parameters. In Case 1, corotation lag becomes significant at the distance 15-20 R_J away from Jupiter (R_J is Jupiter's planetary radius), and peak plasma azimuthal velocity is 120 [km/s]. In Case 2, corotation lag becomes significant at the distance 25-30 R_J away from Jupiter, and peak plasma azimuthal velocity is 250 [km/s]. Previous plasma observations by the Galileo satellite showed that plasma corotates almost rigidly within 25 R_J, and plasma azimuthal velocity becomes more than 200 [km/s] in the middle magnetosphere [Frank et al., 2002]. Our results suggest that the enhanced ionospheric conductance due to the existence of meteoric ions results in the more rigid corotating magnetosphere, which is consistent with the plasma velocity observations by the Galileo satellite.

Jupiter's Enigmatic Ionosphere: Re-assessment of Pioneer and Voyager Observations – I3

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The Pioneer and Voyager missions obtained the first observations of the ionosphere at Jupiter. Using radio occultation experiments, a total of seven electron density profiles N_e(h) were obtained: three in 1973-4 and four in 1979. These observations have solar zenith angle (SZA) between 82°- 98°, with three at dawn and four at dusk. The two profiles from Voyager-1 portrayed only topside ionosphere patterns (h $>$ 1500 km above the 1 bar pressure level). We use the five full N_e(h) observations to summarize patterns and processes arising from photo-chemical-equilibrium (PCE) theory, shown by modelling to be the domain below $\sim$1300 km.
As noted in previous studies, the N_e(h) profiles at Jupiter are highly structured and identification of the maximum electron density (N_{max}) and its height (h_{max}) do not follow PCE expectations for two distinct ionospheric layers produced by the Sun's soft X-rays and extreme ultraviolet irradiances, respectively. Moreover, pre-dawn profiles often show a more robust ionosphere than dusk-side profiles, inconsistent with simple chemical decay throughout the nighttime period. For the maximum electron density, no positive statistical correlations coefficients (CC $>$ 0) were found between N_{max} and PCE parameters.
In a new approach, we examined height-integrated plasma characteristics over two altitude spans: (1) the average electron density well within the PCE domain (h $<$ 1000 km) and (2) total electron content, defined as N_e(h) integrated up to a height of 3500 km. Using these integrated quantities, statistically significant results (CC $\sim$0.8) were found with solar fluxes over solar cycle time scales. To compare ionospheric morphologies at 5.2 AU with well-known SZA and solar cycle patterns at 1 AU, terrestrial ionosonde data confirm PCE dominance for the E- and F1-layers during the 'same day' periods of the Pioneer and Voyager observations at Jupiter.

Ionospheric Electron Densities Inferred from Juno Plasma Wave Observations – I4

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Juno's highly eccentric polar orbit takes it to perijove distances of ~ 1.06 R$_J$ on each orbit. For the first perijove, this occurred just north of the planetary equator, but has precessed north by about a degree per orbit over the prime mission. Typical altitudes at perijove are about 4000 km above the 1-bar level, but the minimum altitudes vary through the mission. The Waves instrument on Juno observes a number of plasma wave modes in and near the ionosphere that provide information on the local electron number density, including electron plasma oscillations that occur at the electron plasma frequency f_{pe} and whistler-mode hiss which has an upper frequency limit of f_{pe} in Jupiter's strongly magnetized inner magnetosphere. The electron plasma frequency provides the electron number density by $N_e = (f_{pe}/8980)^2$ where frequency is in Hz and N_e is in cm^{-3}. At times other characteristic frequencies of the plasma, such as the lower hybrid resonance frequency f_{LH} and the L=0 cutoff $f_{L=0}$ can be observed. Along with the electron cyclotron frequency f_{ce} given directly by the magnetic field strength measured by the Juno Magnetometer instrument, such characteristic frequencies provide multiple means of determining the electron number density. Where two or more of these characteristic frequencies can be found, simultaneously, and that they give the same value for N_e, we gain confidence in the inference. Where possible, we compare the Waves electron densities with ion densities measured by JADE, with assumptions about the charge state of the ions and charge neutrality.

Observations of Jupiter's Hydrogen Airglow by Juno-UVS – I5

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While the primary function of the Juno spacecraft's Ultraviolet Spectrograph (UVS) during perijoves is to observe Jupiter's auroral features, it is also capable of detecting and measuring Jupiter's airglow. Jupiter's airglow is caused, in part, by hydrogen emission signatures. The UV photons are emitted after photoionized gas in Jupiter's upper atmosphere returns to its ground state. Juno's low altitude perijove allows for UVS to detect Hydrogen Lyman-alpha emissions as a function of zenith angle. We search for variation in this emission, based on a variety of criteria, including spacecraft latitude, longitude, local time information, solar zenith angle, and location with respect to certain features (e.g., the "Great Blue Spot" magnetic anomaly, the magnetic equator). We will describe attempts to detect and characterize spectrally these emissions with Juno-UVS.

Loss processes of energetic ring current ions in Jupiter's inner and middle magnetosphere – I6

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The low-altitude-accessing, polar orbit of Juno allows the Jupiter Energetic Particle Detector Instrument (JEDI) to view into, and resolve, the loss cone of the energetic ions that comprise the low-altitude extension of Jupiter's ring current populations. For a region that extends from just inside Ganymede's orbit, to regions well beyond Ganymede's orbit, energetic ions (> 50 keV H^+, >130 keV Oxygen and Sulfur ions) are strongly scattered into the loss cone at the strong scattering or 'strong diffusion limit' at essentially all times. In analyzing the causes of this scattering, we have eliminated the hypothesis that the ions are scattered by the small radii of curvature of the magnetic field lines. We have concluded that the Alfvénic magnetic turbulence documented by Saur et al. (2003) likely causes the scattering. Scattering is weak or non-existent near the orbits of the moons Europa and Io, except for the regions just downstream of the co-rotating plasmas. For Io, we observe moderately strong scattering within roughly 20 degrees in azimuth from the moon's position, and weak scattering within up to 60 degrees downstream. The scattering near Io's orbit is never fully at the level of the strong diffusion limit. Significantly, scattering is weak or non-existent just upstream of Io's position, a finding that discriminates against a role for neutral gas pickup, and the associated generation of electromagnetic ion cyclotron waves, as the immediate cause for the scattering. A very preliminary accounting of the total scattering losses near Io's orbit yields loss rates no larger than several percent of the strong diffusion limit. Given the new role that Smith et al. (2019) has assigned to cool (< 100 eV) plasmas as the agents for charge exchange with energetic ions, charge exchange losses of energetic ions in the vicinity of Io may be an order of magnitude larger than traditionally calculated. We conclude that charge exchange losses are at least competitive with scattering losses for energetic ions near Io's orbit.

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Probing the Jupiter-Io interaction with synergistic radio and UV measurements from Juno, Nançay and HST observatories – J1

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The prominent component of Jovian decametric (auroral) emissions is induced by Io. Io decametric emissions (Io-DAM) have thus been monitored on a regular basis by Earth- or Space-based radio observatories for several decades. They display a typical arc-shaped structure in the time-frequency plane which results from the motion of the Io flux tube relative to the observer convolved with the anisotropic radio emission cone. Remote determination of the Io-DAM beaming pattern was used to check the emission conditions at the source (e.g. Queinnec & Zarka, 1998). It has been done at several occasions using various models of magnetic field/lead angles which introduce significant uncertainties. Nevertheless, Io-DAM arcs were shown to be consistent with oblique emissions triggered by the Cyclotron maser Instability from loss-cone electron distributions of a few keVs (Hess et al., 2008). The CMI validity for Jovian DAM and the prominence of loss cone electron distributions has been later confirmed by Juno in situ measurements (e.g. Louarn et al, 2017). In this study, we took advantage of simultaneous radio/UV or bi-point stereoscopic radio measurements provided by Juno/Waves, the Nançay Decameter Array and the Hubble Space Telescope to unambiguously derive the beaming pattern of several Io-DAM arcs and compare it with theoretical expectations. We then assess the energy of CMI-unstable auroral electrons at the source and discuss our results at the light of similar independent studies reaching different conclusions.

Numerical Investigation of Double Layer Stability in the Jovian Magnetosphere – J2

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At Earth, quasi-static potentials are one mechanism responsible for magnetic field-aligned acceleration of charged particles. These potential structures are often referred to as a double layer, owing to the separation of opposingly charged particles into "layers". Particles accelerated by these potentials can precipitate into the atmosphere, and can generate aurora when interacting with atmospheric constituents. Precipitating particle distributions can be characterised by an inverted-V structure. Such potential structures are well studied and have been observed by multiple spacecraft in the terrestrial magnetosphere. While theorised as one of the mechanisms for the generation of the UV aurora at Jupiter, few detections of field-aligned potential structures have been made by the JEDI instrument onboard the Juno spacecraft. However, Juno has observed the presence of bi-directional electron beams occurring on the same field line, indicating the occurrence of dynamic processes at varying altitudes.

In this work, we present results from a 1-D spatial, 2-D velocity-space, time-dependent Vlasov model of high-latitude magnetic field lines, extending to Jupiter's middle magnetosphere. Through the use of a non-uniform mesh, we can more finely resolve the region close to the ionosphere, where quasi-static potential structures may be expected to form. We investigate the stability of double layers extending from the ionosphere, as a function of an imposed ionospheric potential. Our simulations show that bi-directional electron beams can arise from the collapse of double layers close to the ionosphere, in-line with Juno's observations. We will also compare the simulation results to predictions on the theoretical stability of such double layers.

Developing a community code of Jupiter's current sheet magnetic field – J3

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We report on recent efforts to provide the MOP community with code that will calculate the magnetic field in Jupiter's magnetosphere using the "CAN" current sheet model updated for the Juno era (Connerney et al., 2020) and the JRM09 internal field (Connerney et al., 2018). Models of the magnetic field in Jupiter's magnetosphere are important tools for planning observations and interpreting data. One of the most commonly used models for Jupiter's current sheet field is the CAN model (Connerney et al., 1981), which represents the current sheet as an annular disk of current with adjustable parameters such as the disk inner and outer edge, thickness, and current density, and was recently updated to fit Juno magnetic field data. The updates include the addition of a radial current, which produces an azimuthal field, and new best fit parameters. Codes implementing the original CAN model and several others have been independently developed in several languages (IDL, FORTRAN, MATLAB, Python, etc.) by many people in the community but, confusingly, may not produce identical outputs because of different assumptions or approaches. With the new additions to the CAN current sheet model now is an opportune time to develop a community-wide "CAN2020" current sheet model code that can be combined with similar code for the internal field model (JRM09) to give the full modeled magnetic field in Jupiter's magnetosphere. We have developed such a code in the IDL programming language and are in the process of final testing and translating into Python and MATLAB. We will give a status update on our work and discuss lessons learned so far.

Spatial variations in the CH_4 homopause altitude at Jupiter's mid-to-high latitudes – J4

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The polar atmosphere of Jupiter is strongly influenced by the external magnetosphere and interplanetary environment. Previous studies have inferred that the CH_4 homopause, which denotes the level where eddy and molecular diffusion coefficients are equal, is higher in altitude inside Jupiter's main auroral ovals compared to elsewhere on the planet (e.g. Parkinson et al., 2006, JGRE 111, Gustin et al., 2016, 268, Clark et al., 2018, JGRA 123). The exact altitude of the CH_4 homopause is poorly constrained at Jupiter's high latitudes and is currently a large source of uncertainty in the analyses of Jupiter's ultraviolet auroral emissions, which are being measured regularly by Juno, Hisaki and Hubble. We present an analysis of IRTF-TEXES (Texas Echelon Cross Echelle Spectrograph, Lacy et al., 2002 PASP 114) spectra of Jupiter's mid-to-high latitudes in order to constrain the CH_4 homopause altitude and its spatial variation. The spectral emission features of H_2 S(1), CH_3 and CH_4 emission were measured on April 16th and August 20th 2019. The spectra were inverted using a family of atmospheric models with varying CH_4 homopause altitudes, and the goodness-of-fit to the observations was used to discriminate between models. At latitudes equatorward of Jupiter's main auroral ovals ($>$62°S, $<$54°N, planetocentric), the observations were adequately fit assuming a CH_4 homopause altitude lower than 360 km above 1 bar. At 62°N, using a mean of observations measured within the main oval, we derived a CH_4 homopause altitude of 461^{+147}_{-39} km. At the same latitude, but sampling longitudes outside the main oval, we derive a homopause altitude of 331 km, with a 1-σ upper limit of 370 km. Thus, we confirm the CH_4 homopause altitude is 70 - 130 km higher in Jupiter's auroral regions compared to elsewhere on the planet. This would suggest the deposition of energy from the magnetosphere ultimately drives vertical winds and/or turbulence, which transports CH_4 and its photochemical byproducts to higher altitudes. We found no evidence of statistically-significant spatial or temporal variability of the homopause altitude within the main oval however this may be a sampling artefact. We will also present preliminary analyses of IRTF-TEXES observations to be measured on June 28-29 and compare with previous TEXES measurements in order to search for temporal variability.

Survey of Juno Observations in Jupiter's Plasma Disk: Density – J5

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We explore the variation in plasma conditions through the middle magnetosphere of Jupiter with latitude and radial distance using Juno-JADE measurements of plasma density (electrons, protons, sulfur and oxygen ions) surveyed on orbits 5 to 26 between March 2017 and April 2020. On most orbits the densities exhibit regular behavior, mapping out a disk between 10-50 RJ (jovian radii). In the disk the heavy ions are confined close to the centrifugal equator which oscillates relative to the spacecraft due to the 10° tilt of Jupiter's magnetic dipole. Exploring each crossing of the plasma disk shows there are some occasions where the density profiles are smooth and well-defined. At other times, small-scale structures suggest temporal and/or spatial variabilities. There are some exceptional orbits where the outer regions (30-50 RJ) of the plasma disk show uniform depletion, perhaps due to enhanced ejection of plasmoids down the magnetotail, possibly triggered by solar wind compression events.

The structure of Jupiter's dawnside magnetodisc – J6

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The Juno spacecraft has provided an unprecedented view of Jupiter's dawn to midnight outer magnetosphere. The long spacecraft dwell time in the outer magnetosphere provides continuous sampling of the magnetic field that covers many days in the equatorial region (e.g., +/- 10 deg latitude). As a result, periodicities at multiple time scales can be investigated. Here we focus on three windows: 10-60 minutes, 1-10 hours, and 1-5 days. The first window is most likely to reveal eigenoscillations of the magnetodisc resonant cavity. The second window is tailored for the planetary rotation period, but it is possible that other, e.g., solar wind drivers can also modulate activity in this window. Finally, the multiple day time scale could reveal magnetotail periodicities, e.g., mass loss processes. We explore the Juno magnetometer data in the midnight to dawn sector to characterize the structure and/or temporal variability of Jupiter's outer magnetosphere. Turbulent heating rate densities will be used to identify active vs. quiet magnetic field conditions to determine the occurrence frequency and latitudinal distribution of disturbed magnetic field conditions following Neupane et al., [2021]. We will compare Juno observations with results from the GAMERA global simulation.

Latitudinal beaming of Jupiter's radio emissions from Juno/Waves flux density measurements – K1

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The observations from the Juno spacecraft in polar orbit of Jupiter provide for the first time a complete view of Jupiter's radio emissions from all latitudes. Characterizing the latitudinal distribution of radio emissions' occurrence and intensity is a useful step for elucidating their origin. Here we analyze for that purpose the first 3 years of observations from the Waves experiment on the Juno spacecraft (mid-2016 to mid-2019). Two prerequisites for the construction of the latitudinal distribution of intensities for each Jovian radio component are (i) to work with absolute flux densities, and (ii) to be able to associate each radio measurement with a specific radio component. Accordingly, we develop a method to convert the Juno/Waves data in flux densities and then we build a catalog of all Jovian radio components over the first 3 years of Juno's orbital mission. From these, we derive occurrence and intensity distributions versus observer's latitude and frequency for each component; these will be the basis for future detailed studies and interpretations of each component's characteristics and origin. First interpretations are proposed for the components produced at the local plasma frequency.

Jupiter's auroral radio emissions observed by Cassini: rotational versus solar wind control and components identification – K2

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Reanalyzing Cassini radio observations performed during the distant flyby of Jupiter in 2000-2001, we study the internal (rotational) control versus external (solar wind) control of Jupiter's radio emissions, from kilometer to decameter wavelengths, and the relations between auroral radio components.
For that purpose, we build a database of the occurrence of Jovian auroral (satellite-independent) radio components bKOM, HOM and DAM observed by Cassini, and from there we build synthetic frequency-versus-longitude stacked plots (or maps) of the polarized intensity of these radio components, that provide 'signatures' of each radio component.
Comparing the stacked plots obtained (i) along the two legs – inbound and outbound – of the Cassini-Jupiter flyby, and (ii) as a function of the spacecraft longitude or the Sun's longitude, we find that all auroral sources are controlled internally and externally, HOM & DAM being dominantly rotation-modulated (i.e. emitted from searchlight-like sources, fixed in Jovian longitude), whereas bKOM is dominantly solar wind modulated (i.e. emitted from strobe-like sources, fixed in Jovian Local Time).
We propose a simple model of internal versus external control of radio components, and determine ranges for its main parameters (the amplitude of each control) for HOM & DAM and for bKOM.
Comparing the inbound Cassini polarized stacked plots with similar plots built from the 29-years long database of Jupiter radio emissions observed by the Nançay Decameter Array (Marques et al. 2017), we find that HOM consists primarily of the low-frequency end of decameter emissions originating from the dusk – more active – sector of the Jovian magnetosphere (so-called non-Io-A and non-Io-C DAM), and is also related to the so-called lesser arcs identified in Voyager radio measurements, for which there is no interpretation to date.
bKOM consists of a main part above $\sim$40 kHz in antiphase with HOM occurrence, and detached patches below $\sim$80 kHz (especially intense in the south) in phase with HOM occurrence.

Magnetosphere-ionosphere coupling at Jupiter: Comparison of results from Juno Perijoves 1,3, and 6 with expectations from a steady-state axisymmetric physical model – K3

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We study magnetosphere-ionosphere coupling at Jupiter by comparing magnetic field observations from Juno perijoves 1,3 and 6 with modelled predictions from an axisymmetric physical model of magnetosphere-ionosphere coupling developed at the University of Leicester. This model predicts broadly distributed downward field-aligned current over polar regions mapping to the tail and outer magnetosphere, closed principally through a radial current mapping to the middle magnetosphere. Here we use Ampère's law to calculate the magnitude of the field-aligned coupling currents from the observed azimuthal magnetic field and compare our observations with expectations from the model. The Leicester model closely predicts the magnitude of the residual B_ϕ component observed across the middle magnetosphere region, the outer magnetosphere and the tail. However, we highlight two areas of discrepancy between the model and the data. On field lines mapping to the outer magnetosphere region, we observe an anti-correlation between the observed and the modelled B_ϕ component, such that when the observed B_ϕ increases with time the modelled B_ϕ decreases with time, and vice versa. We also observe a downward current, not the modelled upward current, at the boundary between the outer magnetosphere and field lines mapping to the tail. Currently the model includes a constant ionospheric conductivity. We suggest that the model can be improved by including a variable ionospheric conductivity.

Auroral stratospheric jets in Jupiter – K4

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The wind structure at the cloud-top of Jupiter's atmosphere consists of zonal superimposed eastward and westward winds with velocity peaks of up to 150 m/s around the equator. In the stratosphere, direct observations of the dynamics in the visible range, are not possible because there are no tracers such as clouds. With the ALMA interferometer we mapped Jupiter's stratospheric emission in HCN(4-3) at very high spectral and spatial resolutions. These observations allow us to retrieve the stratospheric winds from the Doppler shifts observed on the spectral lines. We detect zonal winds of up to 200 m/s around the equator, and non-zonal winds with speeds of 300-400 m/s in the polar regions below the auroral ovals. In the region of the South Polar Zone, we find that these non-zonal winds, form a vortex that seems to be lying under the southern auroral main oval. This stratospheric auroral vortex may be the lower extension of supersonic jets seen in the ionosphere.

Teaching Planetary Magnetospheres and Aurorae – K5

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Like many other specialised scientific fields that are taught to university master level students, planetary magnetospheres and aurorae may be a challenge as the field is missing a choice of text books that may be used as an accessible single reference. Accordingly, to build a complete course, teachers must often gather information from multiple sources, which are not always compatible in terms of format, level, background or purpose. As a result, the resulting assembly of parts may sometimes sound a bit rambling.

Fortunately, several of us were able to contribute to seminars or to series of seminars on the subject, that were recorded and made available to the public. These media are an important source of inspiration and may be directly used as part of a course. In addition, during these "covid years", some of us may have recorded their lectures and may be happy to share their experience and material.

Another complication, probably specific to the field of magnetospheres and aurorae, is the difficulty to find appropriate material for the practicum. In that regard, the Planeterrella experiment is a fantastic tool, sufficiently flexible to illustrate various parts of the course and to provide students with a hands-on experience in this complex field. Again, benefiting from each other's experience would be extremely useful.

It is suggested that an Education and Public Outreach (EPO) platform is set up in a way that would allow MOP participants (and others) involved in teaching planetary and magnetosphere sciences or regularly communicating on this subject with a wider audience, to share their experience and/or material.

Research In Schools Projects for the Outer Planets – K6

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We have been partnering with schools to involve students in MOP research.
In the UK, physics faces chronic diversity issues (e.g. only 20% of those studying physics beyond age 16 are girls), damaging shortfalls in subject-specialist teachers and 20% lower uptake beyond age 16 than in the 1980s. The ORBYTS programme is a movement that partners researchers with schools for long-term engagements that involve school students in active scientific research. Since 2017, ORBYTS has grown to 30 school-researcher partnerships, with 75% of ORBYTS school pupils being from groups historically-excluded from physics. While the first research projects were exoplanets focused, we now have researchers working with schools on: protostellar formation, molecular spectroscopy, planetary science, plasma physics, galaxy characterisation, AI, quasars, supernovae and more. Of particular note for the MOP community are the projects relating to terrestrial space physics and jovian aurorae, which 100+ school students have now taken part in.
Through the combination of involvement in research and partnerships with relatable science role models, ORBYTS is providing positive change in school students' attainment and is dispelling harmful science stereotypes. For example, schools involved in the programme at age 14-16 report 100% increases in post-16 uptake of physics by girls and by students from low income backgrounds. Since 2017, the programme has enabled more than 150 school students (the majority from historically excluded groups) to author published papers.
While my presentation in the Jupiter session will focus on the research aspect, this presentation will focus on the practicality of developing space physics research projects for school students. I'll walk through best practice development of research in schools projects in general, through my experiences overseeing and coordinating the delivery of 100+ of these projects over 4 years. I'll then move on to a detailed look at the development of the Jupiter's aurora school research projects (and, with sufficient time, the terrestrial magnetosphere projects) we have been running and how they have evolved through 3 years of school cohorts and iterations. These studies themselves led school students to contribute to JGR publications (e.g. Wibisono et al. 2020). Finally, I will talk about the diverse range of benefits that I think my involvement in these projects over 4 years has given me personally as a researcher. I will discuss how it has dramatically improved my proposal writing skills and physics teaching, while symbiotically offering a multitude of new insights into my research that have led to new research ideas beyond the school project itself.

Decametric emission induced by interactions between the Galilean moons and the Jovian magnetosphere: in-situ measurements by Juno – L1

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At Jupiter, part of the auroral radio emissions are controlled by the Galilean moons Io, Europa and Ganymede. Until now, they have been remotely detected, using ground-based radio-telescopes, or electric antenna aboard spacecraft. The polar trajectory of the Juno orbiter allows the spacecraft to cross the magnetic flux tube connected to these moons, or their tail, and gives direct in-situ measurements of the characteristics of these decametric moon-induced radio emissions (such as the electron population, size of the source, and beaming angle and growth rate of the emission). In this study, we focus on a few typical examples of the Io, Europa and Ganymede (Louis et al., 2020) flux tube crossings. The study of Juno/JADE-E (particle) and Juno/Waves (radio) data leads to an estimation of the source size, the electron population energy and the emission beaming angle. The additional use of Juno/MAG data brings us new constraints on the generation process (the Cyclotron Maser instability).

Asymmetrical steady state model of Jupiter's magnetosphere-ionosphere coupling – L2

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A steady state axially asymmetrical model of Jupiter's magnetosphere-ionosphere coupling is presented. We compare the radial magnetodisc currents in different local time sectors calculated using this model with those determined directly from magnetic field observations. We find that the observed radial currents require an average plasma mass transport rate of $\sim$2000 kg s^{-1}, while models employing the usually assumed value of 1000 kg s^{-1} underestimate the observed currents. We also consider the effect of field-aligned currents associated with the nightside partial ring current, and find that their inclusion in the model reduces the discrepancy between the model and the observed magnetodisc radial currents at radial distances beyond 40 Jupiter radii.

Azimuthal field signatures associated with magnetosphere-ionosphere coupling in the Jovian magnetosphere: Comparison between Juno observations and theoretical modelling – L3

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We present a comparison of magnetic field data collected by the NASA Juno spacecraft, with the magnetosphere-ionosphere (MI) coupling model for the Jovian system developed by the University of Leicester. We study the magnetic field of Jupiter, in the Northern Hemisphere, for Perijoves 1-13. By virtue of the offset of the magnetic field to the rotation axis and the subsequent 'wobble' of the Juno trajectory in magnetic coordinates, these northern hemisphere portions of PJs 1-13 see the spacecraft traversing magnetic field lines connecting to the inner, middle, outer and tail regions of the magnetosphere. As such, even away from the close Perijove period, the observations contain evidence of the expected magnetic field perturbations linked to field-aligned currents associated with this fundamental MI coupling. In this study, therefore, we focus on investigating the nature of the field-aligned current signatures evident in the residual azimuthal field (having subtracted the Connerney et al 2018 JRM09 internal magnetic field model) along the magnetic field lines outside of the close periapsides. We map the residual azimuthal field signatures into the ionosphere, and calculate the corresponding ionospheric Pedersen current on an orbit by orbit basis. We compare the magnitude and distribution of these field-aligned current signatures to those expected from the Leicester model, and consider the observed orbit-by-orbit variation as a function of ionospheric colatitude and longitude. We deduce estimates for the field-aligned current densities on auroral field lines for each observation using the Pedersen currents and their distribution in co-latitude, and compare to the previous work of Kotsiaros et al [2019]. We discuss possible reasons for the variations we see, and present the next steps of our broader analysis.

Jovian Magnetospheric Modelling using JERICHO: a Kinetic-Ion, Fluid-Electron Hybrid Plasma Model – L4

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Plasma in the Jovian magnetosphere is removed from Io's torus mainly via ejection as energetic neutrals and by bulk transport into sink regions in the outer magnetosphere. The physical process generally considered to be responsible for bulk transport is the centrifugal-interchange instability, analogous to the Rayleigh-Taylor instability, but with centrifugal force replacing gravity. This mechanism allows magnetic flux tubes containing hot, tenuous plasma to exchange places with tubes containing cool, dense plasma, moving material from the inner to outer magnetosphere whilst returning magnetic flux to the planet. In order to examine the transport we have developed a full hybrid kinetic-ion, fluid-electron plasma model in 2.5-dimensions, JERICHO. The technique of hybrid modelling allows for probing of plasma motions down to the ion-inertial length scale, considering constituent ion species kinetically as charged particles and forming the electrons into a single magnetised fluid continuum, allowing for insights into particle motions on spatial scales below the size of the magnetic flux tubes. Additionally, JERICHO provides a computational framework capable of capturing a wide range of flow dynamics, up to spatial scales on the order of planetary radii. Results from this model will allow for the examination of bulk transport on spatial scales not currently accessible with state-of-the-art models, improving understanding of mechanisms responsible for moving particles between flux tubes and from the inner to the outer magnetosphere. In this presentation we will examine the latest simulation results from JERICHO, initialised with Jovian parameters.

Magnetosphere-Ionosphere-Thermosphere Coupling study at Jupiter Based on Juno First 30 Orbits and Modelling Tools – L5

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The dynamics of the Jovian magnetosphere is controlled by the complex interplay of the planet's fast rotation, its solar-wind interaction and its main plasma source at the Io torus. At the ionospheric level, these MIT coupling processes can be characterized by a set of key parameters which include ionospheric conductances, currents and electric fields, exchanges of particles along field lines and auroral emissions. Knowledge of these key parameters in turn makes it possible to estimate the net deposition/extraction of momentum and energy into/out of the Jovian upper atmosphere. In this talk we will extend to the first thirty Juno science orbits the method described in Wang et al. (JGR 2021, in revision) which combines Juno multi-instrument data (MAG, JADE, JEDI, UVS, JIRAM and WAVES), adequate modelling tools and data bases to retrieve these key parameters along the Juno magnetic footprint and across the north and south auroral ovals. We will present preliminary distributions of conductances, electric currents and electric fields obtained from these orbits and will compare them with model predictions.

Comparing Jupiter's equatorial X-ray emissions with solar X-ray flux over 19 years of the Chandra mission – M1

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We present a statistical study of the X-ray emissions emanating from Jupiter's disk region using 19 years of observations from the Chandra X-Ray Observatory (CXO). Previous work has suggested that these emissions are consistent with solar X-rays elastically scattered from the planet's upper atmosphere, and that the Jovian disk emission is governed by solar activity. We showcase a new Pulse Invariant (PI) filtering method which was found to minimise the background and ensures consistency across the nearly-two-decade span of the observations, accounting for Chandra instrument degradation over this period of time. This filtering method ensures that any trends in photon counts have a real physical origin as opposed to an instrumental effect. We compare the CXO results with data from the GOES X-ray Sensor (XRS) in order to quantify the connection between the solar activity cycle and the count rates observed from Jupiter's disk. The high spatial resolution of the High Resolution Camera Instrument (HRC-I) on board the CXO also allows us to map the disk photons to their specific positions on Jupiter's surface. As a result, Voronoi tessellation diagrams were constructed to identify any spatial preference of equatorial photons, with a particular investigation into the region associated with the Great Blue Spot (GBS), a magnetic anomaly near the planet's equator. We also provide superposed epoch analysis on the CXO lightcurves to identify rare events, such as solar flares reaching Jupiter.

Jupiter's X-ray aurora during UV dawn storms and injections as observed by XMM-Newton, Hubble, and Hisaki – M2

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Many planets in our Solar System produce auroral emissions, but none are as large or as powerful as Jupiter's. The morphology of the gas giant planet's aurora consists of the bright main UV emission that is produced by atmospheric hydrogen atoms and molecules after they are excited by precipitating electrons. The same population of energetic electrons are also responsible for the hard X-ray (energy > 2 keV) emissions that are found along this main emission (Branduardi-Raymont et al., 2008). Diffuse UV and soft X-ray (energy < 2 keV) auroral emissions are located at higher latitudes. The low energy X-ray aurora arise from high charge state ions charge exchanging with native neutrals and often pulse quasi-periodically with periods of tens of minutes (Gladstone et al., 2002; Jackman et al., 2018; Dunn et al., 2016; Weigt et al., 2020; Wibisono et al., 2020).
Dawn storms appear in the UV aurora as brightenings in the dawn sector main emission that tend to last no longer than one Jupiter rotation. They may be accompanied by enhancements in the dusk sector found in between the main emission and Io footprint which are known as injection events. Previous studies show that magnetic reconnection in Jupiter's middle magnetosphere results in the dawn storms, while the injection events are a consequence of hot magnetospheric plasma being injected from the middle to the inner magnetosphere (Mauk et al., 2002; Dumont et al., 2018; Haggerty et al., 2019; Yao et al., 2020). Bonfond et al., 2021 demonstrate how dawn storms at Jupiter and substorms at the Earth share similar characteristics.
Here, we report our results from a multiwavelength observation of Jupiter's northern aurora using data from the Hubble Space Telescope, Hisaki satellite and XMM-Newton to determine how the X-ray aurora responds to the processes that produce dawn storms and injection events. We found that the hard X-ray and UV aurorae brightened when dawn storms were present leading us to the conclusion that more electrons precipitated into Jupiter's atmosphere, or that those that did precipitate were more energetic when compared to times when the aurora did not have these transient features. The soft X-ray aurora did not follow this behaviour indicating that there is an independency between ion and electron precipitation. We also found that the dawn storms did not 'switch on' the quasi-periodic pulsations of the ion emissions. Spectral analysis of the X-ray aurora agreed with previous observational and theoretical work that the precipitating ions that produced the soft X-ray aurora throughout the observation period were predominantly from the local environment rather than the solar wind (e.g. Cravens et al., 1995; Dunn et al., 2016; Houston et al., 2020). However, spectra extracted while dawn storms and injection events were present had enhanced bremsstrahlung tails,

suggesting that there was a second population of electrons precipitating into Jupiter's atmosphere at these times.

Quasi-Periodic Variation of Jupiter's Aurora Observed by Hisaki Compared with Magnetospheric Dynamics – M3

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Quasi-periodic variations of a few to several days are observed in the energetic plasma and magnetic dipolarization in Jupiter's magnetosphere. Variation in the plasma mass flux related to Io's volcanic activity is proposed as a candidate for the variety of the period. Using a long-term monitoring of Jupiter's northern aurora by the Earth-orbiting planetary space telescope Hisaki, we analyzed the quasi-periodic variation seen in the auroral power integrated over the northern pole for 2014-2016, which included monitoring Io's volcanically active period in 2015 and the solar wind near Jupiter during Juno's approach phase in 2016. Quasi-periodic variation with periods of 0.8-8 days was detected. The difference between the periodicities during volcanically active and quiet periods is not significant. Our dataset suggests that the difference of period between volcanically active and quiet conditions is below 1.25 days. This is consistent with the expected difference estimated from a proposed relationship based on a theoretical model applied to the plasma variation of this volcanic event. The periodicity does not show a clear correlation with the auroral power, central meridional longitude, nor Io phase angle. The periodic variation is continuously observed in addition to the auroral modulation due to solar wind variation. Furthermore, Hisaki auroral data sometimes shows particularly intense auroral bursts of emissions lasting <10 h. We find that these bursts coincide with peaks of the periodic variations. Moreover, the occurrence of these bursts increases during the volcanically active period. This auroral observation links parts of previous observations to give a global view of Jupiter's magnetospheric dynamics.

Jupiter's main emission and Ganymede's magnetic footprint under the influence of magnetospheric plasma variability – M4

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The variation of Jupiter's magnetospheric plasma was driven partly by the mass outflow from volcanic eruptions on Io. The increasing plasma density in the magnetosphere affects the brightness of Jupiter's aurora. Jupiter's aurora consists of three regions which are main emission, satellite footprint, and polar emission. This work presents the brightness and location analysis of the main emission and Ganymede's magnetic footprint. Ganymede's orbit is about 15 RJ from Jupiter. The mapped location of Ganymede's magnetic footprint appears to be close to the main emission, while the footprint sometimes was embedded in the main emission. This could be an effect of plasma sheet density variation in the magnetosphere. The FUV auroral images in this work were detected by two instruments onboard the Hubble space telescope which are Advanced Camera for Surveys (ACS) and Space Telescope Imaging Spectrograph (STIS) in 2007 and 2016, respectively. The brightness of the main emission and Ganymede's footprint brightness will be used to study their connections with the variation of plasma in the magnetosphere. The fluctuation of magnetospheric plasma could affect the field-aligned current along the magnetic flux tube in which the enhancement of plasma could influence the footprint brightness. In the case of the main emission, while plasma density in the magnetosphere increases, the corotation breakdown region moves inward. This could result in the variation of brightness of the main emission. Moreover, the main emission boundary appears to expand equatorward as well as the location of Ganymede's magnetic footprint. In this study, we investigate the effect of volcanic eruption on Io and solar wind dynamic pressure on the location and the brightness of Ganymede's magnetic footprint in comparison with those of the main emission. Moreover, the aurora feature could change with respect to the modulation of Jupiter's magnetic field structure which responses to the variation of plasma density in Jupiter's magnetosphere as well.

Generation of dawn-to-dusk electric field in the Jovian inner magnetosphere via Region-2 like FAC – M5

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Due to Jupiter's strong magnetic field and rapid rotation, it is believed that the plasma dynamics of Jupiter's magnetosphere is dominated by corotation and the effects of the solar wind hardly penetrate deep into the magnetosphere [e.g. Brice and Ionnidis, 1970]. However, the evidence that the solar wind influenced the plasma dynamics in the inner magnetosphere was reported by Murakami et al. [2016]. Their results indicated that the strength of dawn-to-dusk electric field in the vicinity of Io's orbit changed in time and its variation coincided with the changes in solar wind dynamic pressure. Previous studies [Goertz and Ip, 1984; Murakami et al., 2016] suggested that the dawn-to-dusk electric field is generated by the M-I coupling process via Region 2-like field-aligned current (R2-like FAC), which is still not evaluated quantitatively. This study aims to evaluate the strength of dawn-to-dusk electric field in this process using numerical simulations.

We have developed a Jupiter's ionosphere model composed of a meteoroid ablation model, a photochemical model and an ionospheric potential solver. We found that meteoric ions can play a significant role in the ionospheric conductance in the middle- and low-latitude because of Jupiter's strong magnetic field and strong gravity force. The ionospheric Hall and Pedersen conductances become 1-2 orders of magnitudes larger in the case that considers meteoric ions (Case 2) than in the case that doesn't consider meteoric ions (Case 1), and their distributions become axisymmetric. We applied the conductance distribution to the ionospheric potential solver to investigate the dawn-to-dusk electric field in the inner magnetosphere. In Case 1, the calculated dawn-to-dusk electric field is 275 [mV/m] and 85 [mV/m] at 06:00 LT and at 18:00 LT of Io's orbit, respectively, In Case 2, the calculated dawn-to-dusk electric field is $\sim$25 [mV/m] at 06:00 LT and 18:00 LT, which is 10 times and 3.4 times smaller than in Case 1, and is closer to the observation (4-9 mV/m [Murakami et al., 2016]). We also tested the dependence of the dawn-to-dusk electric field on R2-like FAC strength, which could be affected by the solar wind conditions. The results show that the dawn-to-dusk electric field proportionally increases with the total amount of R2-like FAC. This result suggests that the dawn-to-dusk electric field enhances when the solar dynamic pressure increases, which agrees with the Hisaki observation [Murakami et al., 2016].

Comparing Jupiter's X-ray auroral emissions with in situ Juno data from the magnetotail – N1

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We present a case study of jovian X-ray observations from a Chandra campaign on July 18 2019 while Juno was in the plasmasheet $\sim$ 30 R$_J$ downtail near midnight, and had viewing of Jupiter's South pole. The Chandra observation lasted for $\sim$ 7 hours and was optimized to allow full viewing of the northern auroral region. With Juno near midnight in the magnetosphere, we can analyze in detail whether the dynamics in the magnetotail can have an effect on the temporal and morphological behaviour of the jovian X-ray aurora. We present 2-D histograms showing the location of the auroral X-ray emissions, identifying any unique morphological features and where the X-ray photons map to in the jovian system. We also provide timing analysis of significant quasi-periodic oscillations (QPOs) detected in both polar regions and compare both our mapping and timing analysis of the Chandra observation with Juno *in situ* data and other remote sensing datasets (such as Hubble Space Telescope data). We use a solar wind propagation model to infer the state of the magnetosphere during this time. Our preliminary results suggest that the morphology of the northern auroral region is unusual with respect to that found in previous studies with a possible bifurcation of the so-called "hot spot" emissions. The timing of the X-ray observation spans an interval where a dipolarization of the magnetic field in the tail is observed using the Juno magnetometer data. Both the North and South aurorae are found to exhibit similar QPOs during this time, suggesting that the same driver may be responsible for the pulsating X-ray production at both poles. Using a flux equivalence model, we find a dawn-dusk asymmetry with the northern and southern auroral X-ray photons mapping to the dawn and dusk flank respectively. We will compare these results with other *in situ* measurements (Juno WAVES and particle data) to identify correlations between the X-ray auroral emission and particle and plasma properties of the magnetotail.

Twenty-Two Simultaneous Chandra and Hubble Observations of Jupiter's X-ray and UV Aurorae – N2

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Jupiter possesses the most powerful UV and X-ray aurora in the solar system. Previous work has shown that hard X-ray emission (photon energy > 2 keV), which is produced by precipitating electrons, coincides with the UV main auroral emission (Branduardi-Raymont et al. 2008). In contrast, soft X-ray emission (photon energy < 2 keV), which is produced by precipitating ions, coincides with UV aurora flares that occur polewards of the main emission (Elsner et al. 2005). The known connections between these two wavebands are based on a single simultaneous Chandra X-ray Observatory (CXO) observation and Hubble Space Telescope (HST) orbit from 24 February 2003. Recent work (Gladstone et al. in prep and presented at recent MOP and AGU meetings) has shown several further connections. Here, we explore the 22 simultaneous HST and CXO Jupiter aurora observations taken between 2016 and 2019. This presentation will showcase the overlaid X-ray and UV auroral videos from Jupiter's Northern and Southern poles. By working with a group of school students, through the ORBYTS research in schools programme, we identified intervals of shared UV and X-ray auroral morphology between the observations. We present the examples of shared morphologies that were identified and explore a variety of time cadences to note how the morphology varies with integration time. This exploration is critical for our potentially misleading characterisation of a coherent 'X-ray hot spot' (Gladstone et al. 2002; Dunn et al. 2017; Weigt et al. 2020), which seems to be connected to several seemingly different UV auroral morphologies. We also note intervals when bright UV aurorae do not coincide with detections of X-ray emission. Grodent et al. (2018) and Nichols et al. (2019) both independently showed that the UV aurora appears to have 6 favoured 'families' of behaviour. For the simultaneous observations, we contrast the X-ray aurora morphology with each of these and explore possible trends between the two families. We close by attempting to interpret what the different shared auroral morphologies may mean for the driving processes responsible for Jupiter's polar aurorae.

Development of Plasma Distribution Solver for the field-aligned plasma distribution and its application to the Jupiter-Io system related to the auroral electron acceleration process – N3

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Juno revealed the significant roles of the Alfvenic acceleration in the Jupiter's auroral regions [e.g., Mauk et al., 2017; Szalay et al., 2018]. Despite the increasing attention to the Alfvenic acceleration process in considering the aurora formation of magnetized planets, physical processes controlling the characteristic energy and pitch angle distributions have been still unclear.
For the discussion of Alfvenic acceleration, the spatial distribution of electrons and multispecies ions along a field line is essential in understanding properties of Alfven waves. Matsuda et al. (2010) calculated the plasma distribution along the Jupiter-Io magnetic field line under the isothermal assumption. However, for the discussion of Alfvenic acceleration, the plasma pressure profile along the field line is not always isothermal and should be determined to be consistent with the plasma velocity distribution. In the present study, based on the model used in Ergun et al. (2000) and Matsuda et al. (2010), we developed a Plasma Distribution Solver for the plasma distribution along a magnetic field line between ionosphere of both hemispheres. The developed Plasma Distribution Solver computes both the plasma and their pressure distributions. We assume bi-Maxwellian distributions for the initial velocity distributions of plasmas at the Northern and Southern ionospheric ends and at the magnetic equator. By referring to both energy conservation law and adiabatic invariant, we determine the interval of integration in the velocity space for a certain location, and then integrate the distribution function at the boundary in the determined interval of the velocity space in order to obtain the number density and pressure.
We apply this model to the magnetic field line of Jupiter-Io system, and determine whether the dispersive Alfven wave will exhibit kinetic or inertial Alfven wave characteristics at each position. We assume the boundary conditions that protons and electrons originate from the Jovian ionosphere, and hot electrons, cold electrons, and ions (H^{+}, O^{+}, S^{+}, S^{2+}) from Io. The electrostatic potential difference between Jupiter and Io is initially assumed to be 30 kV. We obtain a result showing that the dispersive Alfven wave changes its characteristic from kinetic to inertial Alfven wave at about 20 degrees of the magnetic latitude.

Ultralow-Frequency Waves in Driving Jovian Aurorae Revealed by Observations From HST and Juno – N4

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Large-scale electrical currents and Alfvenic waves are the two main drivers responsible for producing planetary aurorae. The relative contribution of each process is a central question in terrestrial auroral science, and poorly understood for other planets due to the relatively rare opportunity of in-situ spacecraft measurements. Here, we present observations of Jupiter's aurorae from the Hubble Space Telescope (HST) contemporaneous with Juno magnetometer measurements in the magnetosphere. For three successive days, we found that the magnetospheric ultralow-frequency (ULF) wave activity (with periods of 1-60 min) was correlated with auroral power. This was especially true for the Alfvenic modes. We further performed a statistical analysis based on HST visits during Juno's third and seventh orbit, which revealed a systematic correlation between ULF wave and auroral activity. Our results imply that Alfvenic wave power could be an important source in driving Jupiter's aurorae, as theoretically predicted.

Recent Advances in Magnetospheric Drivers of Auroral Variations at Jupiter – N5

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Although mass and energy in Jupiter's magnetosphere mostly come from the innermost Galilean moon Io's volcanic activity, solar wind perturbations can play crucial roles in releasing the magnetospheric energy and powering aurorae in Jupiter's polar regions. The relative importance of solar wind and internal processes in driving Jupiter's auroras remains poorly understood. Recently, the contemporaneous measurements from NASA Juno mission and the Hubble Space Telescope provide an unprecedented opportunity to determine the magnetospheric drivers of auroral variations at Jupiter, and key evidence on how solar wind would affect the auroral brightening. In this presentation, we will discuss several important advances on several distinctive auroral morphologies at Jupiter, i.e., auroral dawn storm, the main auroral brightening and auroral injection processes. We find that magnetic reconnection and dipolarization play crucial roles in driving these auroras, and the auroral drivers for the Earth and Jupiter have more in common than ever expected.

Magnetic reconnection near the planet as a possible driver of Jupiter's polar auroras – O1

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The Earth, Jupiter, and Saturn all have appreciable atmospheres and predominantly dipolar magnetic fields, with the most common auroral emissions originating from regions encircling each magnetic pole. However, Jupiter's auroras poleward of its "main" emissions are brighter and more dynamic, and the driver of these mysterious "swirl" auroras has eluded identification to date. We propose the solution may stem from Jupiter's stronger magnetic field. We model large-scale Alfvénic perturbations propagating through the polar magnetosphere towards Jupiter, showing that the <0.1° deflections of the magnetic field could lead to magnetic reconnection as close as $\sim$0.2 Jupiter radii above the cloud tops. At Earth and Saturn this physics should be negligible, but reconnection electric field strengths above Jupiter's poles approach $\sim$1 V m-1, typical of the solar corona. We suggest such near-planet reconnection events could generate field-aligned beams of high-energy electrons capable of explaining Jupiter's brighter polar auroras.

Braving the Dawn Storm: February 7th 2018 in situ and remote observations from Juno – O2

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Thanks to its unique polar orbit around Jupiter, Juno offered us the first complete views of the aurora at Jupiter. By doing so, the spacecraft allowed us to track some of the most spectacular auroral events, the dawn storms, from their initiation to their decay. Its prowess does not stop there: on February 7th 2018, Juno flew right through the magnetic field lines connected to a dawn storm at a distance of 5 Jovian radii.
The JADE and JEDI particle instruments both recorded a sudden increase of the particle fluxes. This increase was also observed with the radiation monitors, indicating that even relativistic particles are involved in these events. This is consistent with the observation of particularly high color ratios in the UV auroral emissions. The intensity of the Alfvén waves also sharply increased at the same time as the particle fluxes increased, probably being the source of the particle acceleration. Moreover, Juno traversed several sources of bKOM radio emissions during this time interval.
Finally, observations of strong and opposite field aligned currents on each side of the dawn storm supports the idea that dawn storms are associated with a current wedge, further strengthening the similitude between dawn storms at Jupiter and substorms at Earth.

Juno in situ observations of waves and particles connected to UV polar bright spots in Jupiter's auroras – O3

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Since 2016, Juno observations have revealed key information to improve our understanding of Jupiter, and its powerful auroras, in particular. The unique combination of scientific instruments onboard the spacecraft allows studying auroral events on Jupiter synergistically through various mediums. This work presents results from in-situ observations related to an auroral "bright spots" in the Jupiter's polar auroral region. We focus on the time intervals during which the spacecraft flew above the polar regions close to the bright spot positions during perijove 3 (PJ3) and PJ15 observed by the Juno-UVS, JEDI, MAG, and Waves instruments. Our analysis shows that, during the bright spot emissions, the energetic particles were enhanced and dominated by the upward electrons. The northern bright spot in PJ3 displayed a higher emitted power than the southern bright spot found in PJ15. Similarly, the upward electron intensities observed by JEDI during PJ3 were higher than those observed in PJ15. In addition, we notice that the whistler-mode waves observed by the Waves instrument were first relatively intense during this time interval and then damped as the electron fluxes increased, suggesting the presence of wave-particle interactions. Since the bright spot emissions are found within these time intervals, our observations suggest that these wave-particle interactions contribute to the process that accelerates particles and produces UV emissions.

Proton Outflow Associated with Jupiter's Auroral Processes – O4

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Juno has determined that field-aligned proton beams are a systematic and identifiable feature associated with Jupiter's auroral emissions. We find these beams transport 3 ± 2 kg/s away from Jupiter's ionosphere. This mass loss occurs at all longitudes sampled by Juno around the southern auroral oval, while the northern hemisphere exhibits upward proton beams predominantly on one portion in System III, near the auroral kink region. These beams are associated with upward inverted-V structures indicative of quasi-static magnetic field-aligned parallel potentials. A lack of bidirectionality indicates these proton populations are pitch-angle and/or energy scattered and incorporated into the magnetospheric charged particle environment. We will discuss how this mechanism is a significant, and potentially dominant, source of protons in Jupiter's middle and outer magnetosphere.

Simultaneous UV Images and High-latitude Particle and Field Measurements During an Auroral Dawn Storm at Jupiter – O5

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We present Juno observations between 03:00 to 06:00 UT on day-of-year 86, 2017 that link particles and fields in Jupiter's polar magnetosphere to transient UV emissions in Jupiter's auroral region known as dawn storms. Juno ranged between 42°N - 51°N in magnetic latitude and 5.8 - 7.8 jovian radii (1 RJ $\sim$ 71,400 km) during this period. These dawn storm UV emissions consist of two separate, elongated structures which extend into the nightside, rotate with the planet, have enhanced brightness (up to at least 1.4 megaRayleigh) and high color ratios. The color ratio is a proxy for the atmospheric penetration depth and energy of the electrons that produce the UV emissions. Juno observed electrons and ions on magnetic field lines mapping to these emissions. The electrons are field-aligned, bi-directional, and, at times, exhibit sudden intensity decreases below $\sim$10 keV coincident with intensity enhancements up to energies of $\sim$1000 keV, consistent with the high color ratio observations. These more energetic electron distributions have characteristic energies of $\sim$120 - 280 keV and downward energy fluxes ($\sim$40 - 140 mW/m^2) that are a significant fraction of those required to produce the UV emissions for this event. The ions have similar energy distributions as the electrons. Whistler mode auroral hiss waves and magnetic field perturbations up to $\sim$0.7% of the local magnetic field ($\sim$1500 - 3700 nT) are also observed along Juno's trajectory. These high latitude observations are a result of dynamic processes in the equatorial magnetosphere that trigger the generation of these dawn storm emissions.

Energetic heavy ion observations in Jupiter's inner radiation belts by Galileo's Heavy Ion Counter – P1

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Jupiter's radiation belts constitute a multi-component system, trapping high intensities of electrons, protons and heavier ions. Observations and discoveries by the Juno/JEDI instrument and recent re-analysis of Galileo's Energetic Particle Detector (EPD) data have put back the spotlight on heavy ions as an important medium to understand the interplay between charged particle acceleration and losses as well as for probing the properties of different elements of the Jovian system (planet, moons, neutral tori, rings). We revisit measurements from Galileo's Heavy Ion Counter (HIC) instrument, a high-quality dataset that, on balance, has received much less attention compared to past observations by Galileo/EPD. HIC measurements partly overlap with the highest energies covered by Galileo/EPD and Juno/JEDI (<10 MeV/n) but extend up to $\sim$100 MeV/n, thus providing key complementary observations for those two instruments in the equatorial radiation belts. Thanks to HIC's large geometry factor and event-based measurement capabilities, HIC clearly resolves trace ions of both heliospheric and magnetospheric origin, such as Carbon, Nitrogen, Sodium, Magnesium, Iron and others, besides the much more abundant Oxygen and Sulfur. In this presentation we re-evaluate aspects of HIC's calibration, particularly for the analysis of measurements obtained at the innermost, intense radiation belts of Jupiter, which are currently monitored by Juno. We concentrate on previously unpublished observations from Galileo's last two orbits, reaching inward of Amalthea's orbit, including a close flyby of this moon. We show that the structure and composition of the heavy ion belts depends strongly on energy, L-shell and pitch angle. Major findings involve: (a) Above 50 MeV/n Jupiter's heavy ion radiation belts are dominated by oxygen, appearing stable and highly structured by strong losses at the orbits of Io, Thebe and Amalthea, a structure reminiscent of that observed in Saturn's proton radiation belts, (b) Pitch angle distributions at >50 MeV/n change twice from pancake to field-aligned and back to pancake across the L-shells of Thebe and Amalthea. In addition, we present our first estimates of heavy ion spectra and phase space density profiles in order to explore if heavy ions can be sustained in that region through adiabatic transport alone, and provide constraints on the MeV oxygen charge state based on observations of Amalthea's wake.

Relation of jovian main auroral emission intensity to magnetospheric currents during the Juno mission – P2

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We report on a study of the relation between the intensity of the dawnside jovian main emission as observed using the Hubble Space Telescope with the large-scale current systems in Jupiter's middle-outer magnetosphere as observed by the Juno spacecraft. Previous work has highlighted an association between these phenomena based on individual case studies, such as a disturbed interval in February 2018 (e.g. Nichols et al. 2020). Here we take a broad view of the relation between the two data sets over the course of the Juno mission prior to orbit 15. Specifically, we show that overall there is a significant correlation between the intensity of the dawnside main emission arc and the contemporaneous equatorial radial ("corotation enforcement") current as calculated from the azimuthal component of the magnetic field in the dawnside magnetosphere. We discuss the origin of the association along with the implications for the dynamics of Jupiter's magnetosphere.

Simultaneous fields and particles observations associated with Jupiter's auroral zones – P3

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The Juno spacecraft's polar orbits have enabled direct sampling of Jupiter's high-latitude, low-altitude auroral field lines. Jupiter's main aurora has been classified into distinct "zones", based on the repeatable characters of energetic electron and proton energy-time and pitch angle-time spectra. These are (i) Zone-I, where downward fluxes of energetic electrons dominate and is associated with the upward current region; (ii) Zone-II, where bidirectional fluxes of energetic electrons dominate and is associated with the downward current region; and (iii) the Diffuse Aurora, where magnetically trapped energetic electrons dominate [Mauk et al., 2020]. Here we combine datasets across all fields and particles instruments to examine the microphysical plasma processes at play in Jupiter's auroral zones. Specifically, we aim to: a) establish the role of plasma waves - as generators or consequences - of the unstable auroral particles distributions and identify distinctions between those associated with inverted-Vs and broadband distributions; b) constrain the direction of Poynting fluxes across the auroral zones. We anticipate our study to provide new insights into the microphysical processes sustaining Jupiter's uniquely powerful aurora.

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Electron partial density and temperature over Jupiter's main auroral emission using Juno observations – P4

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We present a survey of electron partial densities (i.e., the portion of the total density measured between $\sim$0.05 and 100 keV) and temperatures in Jupiter's main emission region using plasma measurements from the Jovian Auroral Distributions Experiment (JADE) on Juno. The electron partial density increases from $\sim$0.01 to 0.1 cm^{-3} near the main oval to a few cm^{-3} at the edge of the measurable part of the UV emission equatorward of the main oval. The electron temperature is highest near the main oval at $\sim$10-20 keV and decreases equatorward down to $\sim$0.3-2 keV. The JADE electron partial density agrees within a factor of $\sim$2 with the total electron densities derived from Juno-Waves when the comparison is possible. The electron density and temperature trends are consistent for all sampled longitudes, for the north and the south, and there is no significant trend with radial distance in the range examined in this study (1.25 to 1.96 RJ). The electron density is anti-correlated with the temperature and the characteristic energy. The ratio of the magnetic field strength to the electron density is maximum near the main oval.

Interchange Instability in the Jovian Magnetosphere Using Juno Observations – P5

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Interchange instability is one of the primary mechanisms that drives the radial transport of particles in Jupiter's magnetosphere. Interchange instability is often associated with sudden changes in particle distribution and plasma waves, but its occurrence rate, preferential location, and characteristics are not well understood. In this study, we perform a multi-event analysis to evaluate the relationship between energetic electrons and plasma waves in Jupiter's magnetosphere using Juno data. More specifically, particle data from the JEDI and JADE instruments, as well as plasma wave data from the Waves instrument, are used to evaluate the properties of energetic electrons and plasma waves (e.g., whistler mode waves) over 5<M<50 from 2016 to 2020. We present several representative examples of interchange events followed by multi-event analysis results revealing the occurrence rate, preferential location, and features of electron distributions (e.g., energy dependence, pitch angle distribution) and plasma wave properties (e.g., wave spectra, amplitudes). Our findings are important for understanding particle energy transport and the generation of plasma waves in the Jovian magnetosphere.

Energetic electron distributions and the implications on the efficiency of chorus-driven acceleration in Jupiter's radiation belts – Q1

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Previous studies have suggested the capability of relativistic electron acceleration by whistler mode chorus waves in Jupiter's radiation belts. The acceleration efficiency depends on a variety of factors, including the total electron density, chorus wave intensity, and the initial distribution of electron fluxes. Recent Juno data have provided direct measurements of chorus waves from 50 Hz to 20 kHz frequencies and electron fluxes from below 100 eV to $\sim$1 MeV energies. In this study, we evaluate the dependence of chorus-driven electron acceleration on the initial electron distributions in Jupiter's radiation belts using Juno observation and quasilinear modeling. The evolution of electron phase space density distribution is simulated using the electron and chorus wave distribution from Juno statistics or during an electron injection event. The simulation comparison indicates that electron injections can provide enhanced seed fluxes to facilitate faster relativistic electron acceleration due to chorus waves. Our results suggest the potentially important role of electron injections in the formation of Jupiter's radiation belts.

Illuminating the Physics behind the Motions of Jupiter's Auroral Dawn Storms – Q2

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The enigmatic dawn auroral storms are a distinctive feature of Jupiter's main emission. These features can grow in intensity to dwarf the rest of the main emission, occasionally reaching brightnesses beyond $10,000$ kR, nearly an order of magnitude increase over the mean main emission brightness. Dawn storms with these intensities are rare, historically occurring in $\sim 5\%$ of Hubble Space Telescope (HST) observations of the Jovian aurorae. Dawn storms are not just brighter than other main emission features, but are also noted to markedly lag behind rigid corotation by $30\%\sim 100\%$– meaning they occasionally remain entirely fixed in local time. This is unusual, as the main emission as a whole essentially corotates with Jupiter; despite this, dawn storms have frequently been identified by the intensity of their emission alone, rather than in conjunction with their motion. We have taken the opposite approach, and identified and characterized dawn storms in archival HST observations by their corotation rates first and intensities second. The result is a clear increase in the frequency of dawn storms at Jupiter: roughly 50% of dawn auroral features at Jupiter lag behind corotation, but only $\sim 10\%$ are significantly brighter than other regions of the main emission in our analysis. The discovery of faint auroral dawn storms, or "quasi-dawn storms", across the decade of archival HST observations used here confirms that the Jovian dawn storms are driven by a common process, in contrast to the picture of the rare dawn storm painted by previous studies. While an analysis of HST observations is limited to surveying the earth-facing side of Jupiter's main emission and thus cannot track the entire lifespan of individual dawn storms, we are able to relate auroral features to the processes in the dawn-sector magnetosphere which must control their behavior. Finding and measuring these features was made possible by a statistical analysis of 150 hours of HST observations, one of the largest composite studies of the Jovian aurorae and the first to systematically measure the corotation rates of individual auroral features.

Variability of Jupiter's main auroral emission and satellite footprints: A survey of Galileo-era HST observations – Q3

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HST images of Jupiter's aurora show that the main emission occasionally contracts or expands, shifting toward or away from the magnetic pole, by several degrees (e.g. Grodent et al., 2008). These latitudinal shifts have been linked to both changes in the solar wind dynamic pressure (Grodent et al., 2003) and Io's volcanic activity (Bonfond et al., 2012). They are sometimes accompanied by motion of a satellite footprint, indicating a change in the magnetic field configuration that shifts the ionospheric mapping of a given radial distance in the equatorial magnetosphere. As a field line becomes increasing radially stretched its ionospheric footprint shifts equatorward compared to its initial mapping. However, in some cases, the main emission has been observed to shift independently of the satellite footprints, indicating that the variability stems from some other change in the corotation enforcement current (CEC) system that is responsible for the main auroral emissions at Jupiter. Here we analyze HST auroral images from the Galileo era (1996-2003) and compare how latitudinal shifts of the Ganymede footprint compare to concurrent shifts in the main auroral emission. We focus on images with overlapping Galileo measurements because concurrent information is available about the current sheet strength, which indicates the amount of field line stretching that can affect the position of both the main emission and satellite footprints (Vogt et al., 2017). We find that the Ganymede footprint and main auroral emission typically, but do not always, display similar poleward or equatorward motion. Additionally, we find that the auroral shifts are weakly linked to changes in the current sheet strength measured by Galileo. We discuss implications of the observed auroral shifts in terms of the expected changes to the CEC system and magnetospheric mapping.

Global Distribution of Energetic Protons in Jovian Magnetosphere – Q4

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Jupiter has intense proton fluxes beyond Io's orbit ($\sim$5.9 RJ), since volcanic eruptions and associated activities at Io are the main source of energetic protons in Jovian magnetosphere. However, the global distribution of these energetic protons is still not well understood, especially the latitudinal distribution, pitch angle distribution, and phase space density distribution. In this study, we take advantage of Juno's JEDI measurement, which provides the pitch angle distribution of energetic protons from tens of keV up to several MeV at various magnetic latitudes and M shells, to systematically evaluate the global distribution of energetic protons in the Jupiter's inner and middle magnetosphere (M < 50). Specifically, (1) we construct a global empirical model of energetic proton flux at various M shells (M < 50) and magnetic latitudes (-80 to 80 degrees) from tens of keV to several MeV; (2) we evaluate the pitch angle distribution of these energetic protons in various regions; (3) we analyze the radial profile of phase space density of energetic protons in the plasma sheet, which is selected near the magnetic field dips close to the magnetic equator. These results are important for improved understanding and modeling the proton dynamics in the Jovian magnetosphere and are critical for identifying the source of energetic protons at Jupiter.

In situ observations of the ion moments above the equatorial ionosphere made by the Juno JADE-I instrument – Q5

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The orbit of Juno enables repeated in situ observations above the Jovian ionosphere. The spacecraft typically reaches altitudes of $\sim$4000 km above the 1 bar level and is traveling at speeds of $\sim$58 km/s. The low altitude and high velocity of Juno at perijove permits direct sampling of ionospheric ion populations by the Jovian Auroral Distributions Experiment Ion sensor (JADE-I) that otherwise would be outside its measurement range. When looking into the spacecraft ram direction, JADE-I can measure composition separated, ion energy distributions to below 1 eV/q. At equatorial latitudes, the low energy ions consist of protons and heavier ions, protons being the dominant species. Heavy ions (primarily oxygen and sulfur likely originating from the magnetosphere) are seen most passes, but their intensity varies. Other trace light ions - H3+ and He+ - are observed during some of the perijoves. These ionospheric ions are observed up to altitudes of $\sim$7,000 km. We present here the in situ observations of ions above the Jovian equatorial ionosphere. Forward modeling results of these observations are used to determine properties of the ion distributions. When available, we will compare the ion density values to the electron densities determined by the Juno Waves instrument.

Kelvin-Helmholtz waves on Jupiter’s dawnside magnetopause boundary – R1

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Jupiter’s dawnside outer magnetosphere can be characterized as the battleground between internally-driven sunward flow and solar wind-driven tailward flow. The Juno mission has provided detailed observations of this region, including 100 magnetopause boundary crossings. We have conducted a statistical analysis of the boundary crossings to determine the distribution of boundary normal directions. The broad distribution of normal directions is consistent with a Kelvin-Helmholtz (KH) unstable magnetopause boundary. Turbulent heating rate densities were calculated to further identify potential KH activity [Delamere et al., 2021; Burkholder et al., 2020], and select case studies were conducted to investigate particle transport at the magnetopause boundary using both JADE and JEDI data. In addition, we have modeled KH waves using local MHD and hybrid simulations and the global GAMERA simulation [Zhang et al. 2021]. Simulation results are compared with Juno data to investigate energetic particle and magnetic flux transport.

Identifying the Occurrence of Magnetic Reconnection at Jupiter's Dawn Magnetopause – R2

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Limited observations and modeling of magnetic reconnection along Jupiter's dawn magnetopause have given many insights into the properties of the plasma in that location; however, there are still many open questions regarding the occurrence of magnetic reconnection at Jupiter's magnetopause and its impact on magnetospheric dynamics. It is known through theoretical approaches that a multitude of conditions are likely necessary for magnetic reconnection to occur. However, now that Juno has provided several observations of dawn magnetopause crossings at Jupiter, identifying conditions for reconnection there can be solidified. In this study, observations from the JADE, JEDI, and MAG instruments on Juno are used to identify signatures of magnetic reconnection at Jupiter's dawn magnetopause based on the characteristics of the local plasma environment. Specifically, we apply the Swisdak relation (e.g. Swisdak et al. 2010) to determine the susceptibility of reconnection through observations of magnetic shear angle and the change in plasma beta (β) in the intervals immediately before and after a magnetopause crossing. Identifying magnetopause crossings that include accelerated ions, plasma energization, and a change in polarity of at least one component in the local magnetic field show more extensive evidence for reconnection. Initial findings show that a large majority of dawn magnetopause crossings at Jupiter have a low likelihood for local magnetic reconnection (are diamagnetically suppressed) because of high $\Delta\beta$ values and low magnetic shear angles across the magnetopause boundary.

Overview of the Thermal Plasma: Juno's First 30 Orbits – R3

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This poster shows thermal plasma data over the first 30 Juno orbits (all data in the PDS as of MOP2021) with a series of 'whole orbit' plots. PDS Level 3 data from both the JADE and MAG instruments are shown: Thermal ions, thermal electrons, and the magnetic field magnitude and the radial component. It's rare to see this much raw data on one plot and gives a sense of how vast and time-variable the Jovian magnetosphere is. This poster's focus is to encourage discussion of the whole magnetosphere and potential future science investigations.

Partitioning Jovian Thermal Ions: Forward Modelling Using Coincident Juno JADE Datasets – R4

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The ion detector on JADE is an electrostatic top hat analyzer with a Time-of-Flight (TOF) section. This measures co-incident signals (not ‘singles’) of incoming ions and separates them out by mass per charge (m/q). ≈80% of the Jovian magnetosphere is O^{+} and S^{++}, which both have m/q of 16, making them difficult to separate in the data. But there are also protons, and O^{++}, O^{+++}, S^{+} and S^{+++} ions. We won a NFDAP proposal to use forward modeling to split out the ions by species to gain composition, densities, velocities and temperatures, utilizing the TOF and ion species data sets. The main obstacle to overcome is using fundamentally different data sets simultaneously to separate out ion distributions that overlap with each other; one data set has directional information but greatly restricted ion species separation, while the other data set can separate species but has no directionality. This is an update of progress during the first year of this study.

Rotating auroral current system and reconnection sites on Saturn – S1

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Energetic charged particles trapped in a planet's magnetosphere can produce stunning aurorae when they travel along the magnetic field lines and eventually collide with the planet's atmosphere. Magnetic reconnection is one of the key processes in driving plasma and energy transport in the magnetosphere, and also a fundamental plasma process in energizing charged particles. Here, using in-situ measurements from the Cassini spacecraft, we report multiple small-scale reconnection sites that rotated with the magnetosphere. The spatial distribution of the identified long-standing multiple small reconnection site sequences shows no significant preference on local times. A chain of field-aligned currents is also found in Saturn's magnetosphere that generates separated auroral patches. Both the multiple currents and their energy sources in the magnetodisc are azimuthally separated and rotate with the planet. The generation of the rotating azimuthally distributed field-aligned currents might be associated with the rotating long-standing small-scale reconnection processes.

Saturn's inner magnetospheric convection in the view of zebra stripe patterns in energetic electron spectra – S2

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Banded structures observed in energetic particle spectrograms in the Earth's inner radiation belt and slot region, i.e., "zebra stripes", have been resolved also in the Saturnian magnetosphere with Cassini. This paper implements a large-scale statistical analysis of Saturnian zebra stripe properties in association to the noon to midnight electric field of the inner magnetosphere, to which the stripes' origin was recently established. Cassini has detected zebra stripes extending between L-shells (L) of 5 to 9 for more than half of the orbits that crossed inward of L=9. The amplitude of the stripes is $15-20\%$ on average above the background differential energy flux, while their age is estimated to be 20-60 hours. The regular observation of zebra stripes suggests that their trigger should recur over time scales comparable to their estimated lifetime (days). The flux-enhanced stripes are traced back to the dayside, preferentially from post-noon, indicating an electric field orientation from post-noon to post-midnight in agreement to past studies. Our results further suggest that the electric field's offset from the noon-midnight line may be subject to both L-shell and temporal dependencies.

Evidence for a neutral thermosphere-driven planetary period current at Saturn – S3

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One of the abiding mysteries that remain following the advent of the Cassini mission to Saturn is also one of the first discoveries the flagship spacecraft made at the planet: that Saturn's rotation rate changes with time, with the magnetic fields above the planet somehow slipping relative to those generated deep within the interior. An array of wide-ranging models have attempted to explain this variable rotation rate, but the solution to what generates Saturn's variable radio rotation pulse has remained hidden for the best part of nearly two decades.
One of the most-cited theories suggests that the radio pulse could be driven by rotating twin-vortex flows within the polar upper atmosphere, effectively a form of weather-driven aurora. If the atmosphere is the driver, then at a planetary period phase of 0°, the ionosphere would be expected to move towards us over the pole (in the observer's line-of-sight), with a corresponding return flow occurring away from us near the auroral oval. If, however, the magnetosphere is the driver of these currents, then these same flows are expected to be reversed.
Using spectral data of Saturn's northern infrared auroral emissions - obtained with the Keck-NIRSPEC instrument (situated at Mauna Kea, Hawaii) during the summer months of 2017, when the Cassini spacecraft was performing its final Grand Finale orbits - binned into planetary phase groupings (0°, 90°, 180°, and 270°) we can now demonstrate evidence that the variable rotation rate of Saturn is produced by a previously proposed twin-vortex within the thermosphere of the planet.
In the difference between our measurements at phases of 0° and 180°, we clearly observe ion wind patterns across the pole that are consistent with the behavior of a twin-vortex driving currents out into the magnetosphere and producing a radio pulse. Based on these observations, the variations in rotational period seen within the radio emission, and indeed throughout Saturn's magnetosphere, must result from localised variations in the rotation speed of this twin-vortex.
In this work, we will present the ion wind structures observed by Keck and reveal the evidence for the twin-vortex that is proposed to drive the variable rotation rate of Saturn. We will also look ahead to what this ongoing investigation in the context of the planetary period oscillations intends to reveal about Saturn's thermosphere-ionosphere-magnetosphere interaction at large.

Cassini Langmuir Probe observations during solar eclipses by Saturn and its rings – S4

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The motivation for this work is to understand the effects of photoelectrons on Langmuir Probe measurements. By biasing the Langmuir Probe to a range of positive and negative potentials a current-voltage relationship can be measured and can be used to measure properties of the surrounding plasma, such as temperature, density, and mass (for the ions). As the bias voltage can be both negative or positive, the LP has the capability to measure both ions and electrons.
Eclipses provide an opportunity to study how the spacecraft-plasma interaction changes in darkness following the simple logic that when there is no sunlight hitting the spacecraft there are no new photoelectrons generated. Hence, we focus our study in periods where Cassini was eclipsed by Saturn, i.e. Cassini was in Saturn's shadow. We also studied the impact of the rings' shadow.
This poster describes our analysis method and some results of our analysis.

Surface charging and ion wake of Cassini: implications for in-situ data analyses and ion temperature estimates in Saturn's inner magnetosphere – S5

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We have used Spacecraft Plasma Interaction Software (SPIS) simulations to study the spacecraft-plasma interaction of Cassini at 4.5 to 4.7 R$_S$ and at 7.6 R$_S$. The interaction between the spacecraft and its environment will alter the local environment around the spacecraft and might impact scientific measurements. One important interaction between the spacecraft and its environment is the ion wake that will be formed behind the spacecraft when the relative speed of the spacecraft exceeds the ion thermal speed of the ambient plasma. Cassini Langmuir probe (LP) measurements in Saturn's inner magnetosphere shows that a strong ion wake is formed, with ambient ion densities a factor 5, or more, larger than ion densities observed in the wake. The radial distance 7.6 R$_S$ is close to the maximum distance where a clear ion depletion, i.e. an ion wake, can be detected in the Cassini LP data. This is due to lower ion densities and higher ion temperatures for increasing radial distances from the planet. At 7.6 R$_S$ the ambient ion density is up to a factor 1.9 larger than ion densities observed in the ion wake. We have used SPIS simulations to show that the LP ion density measurements can be well reproduced, both outside and inside of the ion wake. Comparison between simulated and measured spacecraft potentials also shows a good agreement. This is an important result that shows that SPIS simulations can be used, with high accuracy, to simulate the spacecraft potential and spacecraft-plasma interaction in plasma regimes similar to the inner and middle magnetosphere of Saturn. Hence, SPIS can be used with advantage for preparatory studies for future missions like e.g. JUICE and Europa Clipper.
Our simulations also show that the best agreement with the ion densities is found using ion temperatures of 8 eV at 4.5 to 4.7 R$_S$, and 300 eV at 7.6 R$_S$. The results for the inner magnetosphere, at 4.5 to 4.7 R$_S$, indicated that many earlier ion temperature estimates are overestimated. This shows that SPIS simulations also can be used in order to better constrain environmental parameters in regions where significant perturbations prevent accurate measurements.

Cassini observations of ionospheric plasma in Saturn's magnetosphere – T1

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It is well known that the ionosphere is an important mass source for the magnetosphere at Earth, but lesser attention has been dedicated to study the ionospheric mass source at Saturn.
Felici et al. (2016) presented evidence of ionospheric outflow from Saturn's ionosphere, detected when Cassini was located at $\simeq$ 2200 h Saturn local time, 36 R_S far from Saturn. During several entries into the magnetotail lobe, tailward flowing cold ions were observed; the ions appeared to be dispersed in energy and the Ion Mass Spectrometer/Time Of Flight instrument revealed a ion composition dominated by light ions. Ultraviolet auroral observations showed a bright and extended aurora, and the heliospheric model ENLIL suggested that the magnetosphere was being compressed by a region of high solar wind dynamic pressure. Felici et al. (2016) considered several configurations for the active atmospheric regions and estimated the corresponding source and mass rates outflowing the ionosphere.
We have now identified 247 instances in the Cassini Plasma Spectrometer Singles (CAPS/SNG) data, in which the ions appear dispersed in energy. For two of these events, we conducted an investigation of the location of the spacecraft in respect to the plasma sheet, flow direction, ion composition, ionospheric and solar wind activity at the times of detections, utilizing the Cassini Magnetometer data, CAPS Time of Flight data, Cassini Ultraviolet Imaging Spectrograph data, and ENLIL model results. We interpreted these additional events as ionospheric outflow, estimated the number flux, and lastly, compared these results to the estimates by Felici et al. (2016) and the models for ionospheric outflow at Saturn presented in Glocer et al. (2007) and Martin et al. (2020).
We will present these new results that show ionospheric outflow events with different characteristics and number fluxes, underlining the variability of this phenomenon and its importance for improving our understanding of ionosphere-magnetosphere coupling, the ionosphere as a source of plasma for the magnetosphere, how much upstream conditions drive the system, and extrapolating ionospheric escape rate at Saturn.

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Cassini’s Plasma Interaction with Saturn’s Ionosphere during the Grand Finale: 3-D Particle-In-Cell Simulations – T2

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Cassini’s Grand Finale was the first time Saturn’s ionosphere had been sampled in-situ. Here, the ionospheric plasma was dominated by charged dust grains and depleted of free electrons. Understanding how the spacecraft potential is affected by its environment is important for interpreting the surrounding plasma conditions and on-board plasma measurements. In this paper, we describe three dimensional Particle-In-Cell simulations of a model Cassini employing plasma conditions representative of those observed in Saturn’s equatorial ionosphere at 2500 km altitude. The simulations reveal complex interaction features such as a highly structured wake containing spacecraft-scale vortices, and electron wings associated with propagating Langmuir waves, which extend into the pristine plasma ahead of Cassini. Despite the high electron depletions, the electron temperature is found as a significant controlling factor for the spacecraft potential together with the magnetic field orientation which induces a potential gradient across Cassini’s asymmetric body. This study reveals the global spacecraft-plasma interaction experienced by Cassini during the Grand Finale in a plasma environment dominated by a class of physics quite different to those considered within the classic view of spacecraft charging in space plasmas.

The response of Saturn’s dawn field-aligned currents to magnetospheric and ring current conditions during Cassini’s Proximal Orbits – T3

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The Proximal orbits of the Cassini spacecraft during 2017 have given us the opportunity to examine the auroral field-aligned currents in the northern hemisphere dawn sector in relation to wider magnetospheric conditions. Here we will combine the results of three recent studies on the properties of the auroral field-aligned current, magnetospheric ring current, and the overall compressional state of Saturn’s magnetosphere due to solar wind conditions. Using these results, we will examine the response of the auroral field-aligned currents in combination with the magnetospheric ring current to compressions and expansions of the Saturnian magnetosphere. We will show that for a compression of Saturn’s magnetosphere the current within in the downward current sheet, located equatorward of the main auroral oval, increases in strength with increasing total ring current. While the inverse relation occurs during an interval of quiet or expanded magnetospheric conditions. We observe within the magnetic field region which carries the downward current that during compression events there is an increase in hot plasma intensity, in particular, in the protons (35-506 keV). This response is akin to an Earth-like ‘region 2’ field-aligned current within Saturn’s dawn magnetosphere, with a partial nightside ring current closing via a downward current within the dawn sector. We will further discuss the implications of these observations for Saturn’s magnetospheric current systems and dynamics.

Saturn’s nightside ring current during Cassini’s Grand Finale – T4

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During Cassini’s Grand Finale proximal orbits, the spacecraft traversed the nightside magnetotail to $\sim$21 Saturn radii. Clear signatures of Saturn’s equatorial current sheet are observed in the magnetic field data. An axisymmetric model of the ring current is fitted to these data, amended to take into account the tilt of the current layer by solar wind forcing, its teardrop-shaped nature and the magnetotail and magnetopause fringing fields. Variations in ring current parameters are examined in relation to external driving of the magnetosphere by the solar wind and internal driving by the two planetary period oscillations (PPOs), and compared with previous dawn and dayside observations. We find that the relative phasing of the PPOs determines the ring current’s response to solar wind conditions. During solar wind compressions when the PPOs are in antiphase, a thick partial ring current is formed on the nightside, dominated by hot plasma injected by tail reconnection. This partial ring current should close partly via magnetopause currents and possibly via field-aligned currents into the ionosphere. However, during solar wind compressions when the PPOs are in phase, this partial ring current is not detected. During solar wind rarefactions an equatorial ‘magnetodisc’ configuration is observed in the dayside/dawn/nightside regions, with similar total currents flowing at these local times. During very quiet intervals of prolonged solar wind rarefaction, a thin current sheet with an enhanced current density is formed, indicative of a ring current dominated by cool, dense, Enceladus water group ions.

Automated plasma region classification and magnetic field statistics in Saturn's magnetosphere – T5

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Statistical studies of different plasma regions found near the edge of planetary magnetospheres require knowledge of boundary crossings for purposes of classification, for example, by visual inspection, the plasma regions sampled by the spacecraft. Automation of this type of activity would improve the efficiency of boundary studies and could also have implications for onboard data processing pre-downlink.
The Cassini mission at Saturn (2004-2017) provided an invaluable dataset to test the viability of automated region classification. While both magnetic field and plasma data are available for most or all of the mission timeline, in this ongoing work we have focussed on the magnetometer dataset to investigate how effectively magnetic data statistics can inform classification.
In this investigation, we used the latest catalogue of bow shock and magnetopause crossings for the time period 2004 to 2016 (Jackman et al. (2019)) to train a LSTM recurrent neural network classifier, using only magnetometer data to classify plasma regions. Data are pre-selected using models of the bow shock and magnetopause to reduce the variance. Given a 60-min window of magnetic field measurements, the network predicts the region for each timestep, within that window, as either magnetosheath (SH), magnetosphere (SP) or solar wind (SW). A prediction accuracy of 94.0% was obtained on unseen test data, with over 90% precision and recall for each region, thus closely aligning with relevant 'ground truth' class labels (Figure 1, left). The performance of the network is poorest for SH points, very likely due to highly variable conditions and potential mixing with SP and SW plasmas (Figure 1, right). An example of a previously unidentified bow shock crossing is predicted on 2016-03-03 14:00:30. This demonstrates the viability of such techniques for potential use in on-board data selection for future missions and boundary physics studies.
To further illustrate the role of effective classification for science, we also present preliminary work in progress related to mirror mode structures in Saturn's magnetosheath (adapting identification criteria for the Jovian system from Joy et al (2006)). The occurrence rate of different types of mirror modes is examined and their evolution from the bow shock to the magnetopause is analysed using structure functions and Fourier analysis.

Temperature and density fluctuation on Saturn's Magnetosphere – U1

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The outward radial transport in Saturn's magnetosphere occurs due to the centrifugally driven interchange instability, determined by the radial gradient of flux tube content and flux tube entropy. Electron density and temperature fluctuations were observed in the outer magnetosphere of Saturn by Voyager-1 and Voyager-2. Goertz [1983] suggested that these fluctuations are due to the formation of plasmoids via a flute type instability. Similarly, the Cassani CAPS/ELS data also shows a similar fluctuation on the dawn side of the magnetosphere. Also, both the CAPS ion and ELS data show asymmetry in temperature where the dawn side is hotter than the dusk side. This dawn-dusk asymmetry in the magnetosphere could be associated with the generation of low-density flux tubes in the midnight to dawn sector. Multi-fluid Lyon -Fedder -Mobarry (MFLFM) global simulations suggest that a Rayleigh Taylor (RT) type instability, a Kelvin-Helmholtz instability, or tail reconnection in the midnight to dawn sector, could lead to the injections. We will compare the observed electron density fluctuation with MFLFM simulations. Also, we will use the information theory and wavelet transportation to understand the observed density fluctuation on the dawn side of the magnetosphere.

Magnetic Flux Integral Quantities in the Giant Magnetospheres – U2

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Magnetic flux integral quantities (e.g., flux entropy, flux 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). Therefore, examining the change of different flux integrals quantities can help us better understand the dynamical processes in the giant magnetospheres (i.e., Jupiter's and Saturn's Magnetospheres). The giant magnetospheres are stabilized by a radially increasing profile of flux tube entropy and destabilized by a radially decreasing profile of flux tube content. The traditional radial transport scenario suggested that the magnetic flux with heavy flux tube content moves from the inner magnetosphere to the outer magnetosphere, stretching the magnetic field into a magnetodisc configuration. Subsequently, magnetic flux with low flux tube entropy generated by magnetodisc reconnection circulates back to the inner magnetosphere. The flux tube entropy analysis suggests that energetic particles dominate the total flux tube entropy in the magnetodisc region, and newly closed field lines generated by magnetodisc reconnection are likely to be transported into the inner magnetosphere. Based on the flux tube entropy constraint, this study uses a steady state magnetodisc model to demonstrate that the radial transport process in Jupiter and Saturn's magnetosphere can also be achieved via middle-latitude double reconnection, driven by a low-latitude interchange instability. This process does not involve significant latitudinal convection of magnetic flux in the ionosphere, nor does it significantly modify the radial flux tube entropy profile.

Compressibility of the Jovian magnetosphere – U3

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The effect of the solar activity on a magnetosphere, as an external driver, can be studied via the compressibility index; this index is calculated via changes in the magnetopause due to variations in the external pressure and quantifies the overall response of the magnetosphere.
The system size, composition and morphology of the magnetospheres of Jupiter and Saturn make them ideal targets for such studies. We report on a numerical study of the compressibility of the Jovian magnetosphere, using an implementation of Caudal's iterative scheme to create an axisymmetric magnetodisc structure. We create an ensemble of models, treated as virtual observations or "crossings", using a different system size (parametrized by the magnetopause distance) and hot plasma content (parametrized by the hot plasma index) for each case.
We evaluate different methods to obtain the compressibility index and discuss the effects of the system size, compare the results with observations of the Jovian magnetosphere and with similar studies focused on the magnetosphere of Saturn. Furthermore, as a complementary step, we implement Pontius' algorithm to update the plasma angular velocity using the equatorial magnetodisc structure in a consistent way and examine the major differences with a simple dipole model.

The Open Polar Cap of Rotating Magnetospheres – U4

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The classic Dungey cycle plays an essential role in understanding the dynamics of the terrestrial magnetosphere. However, its direct applicability to planetary magnetospheres is limited, especially when the planetary rotation is much faster than the Earth. In this study, we use a series of numerical experiments to show the transition of the terrestrial magnetosphere from a classic Dungey cycle, convection-dominated system to rotation-dominated configurations. The numerical experiments use the Earth's magnetosphere-ionosphere system as a testbed, with modified rotation speed to increase the influence of planetary rotation over solar wind driving, characterized by the ratio between the solar wind merging potential and the polar cap rotation potential. Results show that when the rotation potential of the polar magnetosphere becomes comparable to the merging potential of the solar wind, the classic Dungey cycle is modified by azimuthal transport of magnetic flux, resulting in a more closed polar magnetosphere with a crescent-shaped open flux region in the ionosphere. These numerical experiments provide a theoretical framework for understanding the fundamentals of magnetospheric physics, which is potentially applicable to Saturn, Jupiter, and exo-planetary systems.

Statistics of Saturn's Magnetotail Reconnection Events – U5

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Magnetic reconnection is a fundamental physical process in planetary magnetospheres, in which plasma can be exchanged between the solar wind and a planetary magnetosphere, and material can be disconnected and ultimately lost from a magnetosphere. Magnetic reconnection in a planetary magnetotail can result in the release of plasmoids downtail and dipolarizations planetward of an x-line. The signatures of these products include characteristic deflections in the north-south component of the magnetic field which can be detected by in-situ spacecraft. Identification of these signatures has been performed by eye, semi-automated algorithms, and more recently machine learning methods. Here, we apply statistical analysis to the most thorough catalogue of Kronian magnetospheric reconnection signatures created through machine learning methods to improve understanding of magnetospheric evolution. This research concludes that no quasi-steady position of the magnetotail x-line exists within 70 R_S. This research introduces prediction equations to estimate the yearly distribution of duration for plasmoid passage over the in-situ spacecraft ($N = 300\Delta t^{-1.3}$, bin width = 1 min), and the yearly distribution of north-south field deflection ($N = 52\Delta B_\theta^{-2.1}$, bin width = 0.25 nT) expected to be identified by an orbiting spacecraft. Furthermore, this research finds a local time asymmetry for reconnection identifications, with a preference for dusk-side over dawn-side. This may indicate a preference for Vasyliunas style reconnection over Dungey style for Saturn's magnetosphere. Finally, through these distributions, the reconnection rate of Saturn's magnetotail can be estimated as 3.22 reconnection events per day, with a resulting maximum mass loss from plasmoids of 34.4 kg s^{-1} on average, which is comparable with the magnetospheric mass loading from Enceladus (8-250 kg s^{-1}). However, this still leaves open the possibility of magnetospheric mass loss through other methods, such as Kelvin-Helmholtz instabilites.

Spectra of Saturn's proton belts revealed – V1

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Saturn is permanently surrounded by 6 discrete proton radiation belts that are rigidly separated by the orbits of its inner moons and dense rings. These radiation belts are ideal environments to study the details of radial diffusion and CRAND, yet progress on this has been hindered by the fact that the energy spectra of these protons are not known with certainty: Reanalysis of the response functions of the LEMMS instrument on-board the Cassini orbiter has shown that measurements of $\lesssim 10$ MeV protons may be easily contaminated by $\gtrsim 10$ MeV protons and that many available measurements characterize a very broad energy range, so that the calculation of an energy resolved spectrum is not as straightforward as previously assumed.
Here we use forward modeling of the instrument response and combine it where useful with numerical modeling of the proton belt physics in order to determine Saturn's proton spectra with more certainty. While earlier studies reported on proton spectra roughly following a power law with exponent ≈ 2, our more advanced analysis shows much harder spectra with exponent ≈ 1. The observed spectra are consistent with what is expected from the CRAND process, potentially occurring in combination with cooling of the protons in tenuous gas originating from Saturn or Enceladus.
These new spectra can be used in the future for studying space weathering of Saturn's moons and rings, and to further our understanding of Saturn's proton belts and the respective physical processes that also occur at other magnetized planets.

Shear-Driven Aurora – V2

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Velocity shears serve as effective voltage generators in planetary magnetospheres and drive field-aligned currents, coupling the magnetosphere-ionosphere system and powering auroral emissions. We present a quasi-static magnetosphere-ionosphere coupling model that relates solar wind and ionospheric parameters to the strength and thickness of field-aligned currents in a region of sheared velocity, such as the boundary layer between the solar wind dominated magnetosheath and magnetosphere. Instabilities in the shear layers often lead to the development of small-scale vortex structures. We compare vortex induced current structures with those induced by shear-flow. We find that the strength of the maximum currents are comparable, but the structure is significantly different in that there is a preferred spatial scale for vortex structures. This preferred scale results from the balance of 2D current convergence (which increases currents with decreasing scale) and mirror-force resistance (which chokes out the currents as the vortex size decreases). Auroral bright spots have been observed at Earth, Jupiter, and Saturn in regions that map to the boundary layer. It has been suggested that the bright spots are associated with Kelvin-Helmholtz vortices. We utilize our model to determine how the field aligned current structure depends on ionospheric and boundary layer parameters for vortex structures. We present observations from Earth and Saturn that suggest that the size of observed auroral beads in planetary magnetospheres is consistent with the predictions of the preferred scale of vortex structures for typical magnetospheric parameters.

A Tail of Two Giants: Observations of Saturn's FUV auroras in Jupiter's magnetotail – V3

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In late November 2020, Saturn passed through the projected location of Jupiter's magnetotail. No other planet experiences such an event, which occurs for Saturn once every 19 years. It presents a unique natural experiment to capture the behaviour of a planet's magnetosphere under such unusual conditions. We report on the results of a programme of Hubble Space Telescope observations of Saturn's UV auroras, which provide an indication of the state of the magnetosphere, during this interval, and compare the auroral morphology with projections of the solar wind and location of Jupiter's tail.

Observations of Saturn’s aurora inside Jupiter’s magnetotail – V4

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Once every two decades, Jupiter, Saturn and the Sun move into close alignment with each other, so that Saturn moves periodically into Jupiter’s extended magnetotail. Observations from Voyager 2 show that this rare alignment results in dramatic changes to Saturn’s aurora, with the radio emission decreasing by two orders of magnitude. However, since that observation, we have no measurements of this event and no real understanding of how the auroral region changes in brightness or currents, or how the thermosphere might change as a result of changing auroral inputs.

A statistical view of the response of Saturn's radio emissions to solar wind driving – V5

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Saturn has several components to its radio emission which can change in response to varying solar wind and magnetospheric conditions. These radio components include the Saturn Kilometric Radiation (SKR), a cyclotron maser instability-generated emission which occasionally displays Low Frequency Extensions (LFEs); and the Saturn narrowband emissions, typically below 40 kHz, which include n-SMR (narrowband Saturn Myriametric Radiation) and n-SKR.

We utilise a list of all magnetopause and bow shock crossings by Cassini during its 13-year tour of the Saturn system [Jackman et al., 2019] to select out times when the Cassini RPWS instrument was sampling Saturn's radio emissions from the solar wind, magnetosheath and outer magnetosphere regions. We explore the hypotheses that the SKR is a good proxy for solar wind driving, and that narrowband emissions may link to dramatic magnetospheric reconfiguration events. Solar wind intervals give a direct measure of the upstream environment to compare against. Magnetosheath intervals can be used to infer solar wind velocity via CAPS measurements of proton temperature [Thomsen et al., 2019] and to infer the state of magnetospheric compression by the location of local boundary crossings.

We explore how the detection of radio emissions is highly sensitive to observer position (especially latitude and local time), and how the passage of radio waves through the dense magnetosheath can alter the detected signal. We explore case studies of extreme solar wind compression where Cassini had direct traversals of the magnetosheath in < 300 minutes, implying dynamic motion of the boundaries, and present superposed epoch analyses of the radio emission during such intervals. With the wide span of Saturn season and solar cycle conditions, we further explore how the phasing of the SKR radio bursts can be altered by changing solar wind. Lastly we focus on the narrowband emissions, and quantify their link to dramatic SKR bursts and LFEs, and track their recurrence and associated quasi-periodicities.

Flux Ropes at the reconnection-suppressed magnetopause of Saturn: Cassini observations – W1

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We will present the recently reported discovery and analysis of seven new flux rope observations at Saturn's dayside magnetopause by the Cassini spacecraft and analyze the measurements of all eight known flux ropes (Jasinski et al., 2021). Since the high plasma-beta conditions at Saturn's magnetopause are likely to suppress reconnection from occurring we investigate how flux ropes will differ in comparison to other planets. The measured ion-scale flux ropes have diameters close to or above the ion inertial length $d_i \sim$1-27 (median and mean values of 5 and 8), considerably lower than typical flux ropes found at Earth's magnetopause. The magnetic flux contents are 4-461 kWb (median and mean values of 16 and 77 kWb), considerably smaller (<0.1%) than average flux opened during magnetopause compression events at Saturn. This is in contrast to Earth and Mercury where dayside flux ropes contribute significantly to magnetospheric flux transfer. Therefore, at Saturn, flux ropes represent a negligible proportion of the amount of open magnetic flux transferred. Due to the likely suppression of the two main growth-mechanisms (continuous multiple x-line reconnection and coalescence), we conclude that adiabatic expansion is the likely (if any) candidate to grow the size of flux ropes at Saturn. Electron energization is observed inside, due to either Fermi acceleration or parallel electric fields. Due to diamagnetic suppression of reconnection at Saturn's magnetopause, we suggest that the typical size of flux ropes at Saturn is most likely very small, and that there may be more di-scale flux ropes present in the Cassini magnetometer data that have not been found due to their brief and unremarkable magnetic signatures.

The 1-Hour Ringing in Saturn's Magnetosphere: Analysis of Quasi-periodic Perturbations in the Magnetic Field Measurements and Comparison to Alfvén Wave Resonances in a Realistic Field and Plasma Density Model – W2

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In this study, we analyze the observations of the quasi-periodic 60-minute (QP60) perturbations in the magnetic field in Saturn's outer magnetosphere, and compare them to the recent models of Alfvén wave resonances in a realistic magnetic field with realistic plasma densities [Rusaitis et al., 2021]. Many observations of these waves during Cassini's flybys have been previously reported [Palmaerts et al., 2016; Roussos et al., 2016], but none of the studies have included data from the entirety of the mission or compared data with field line resonance models in realistic plasma/field configurations. This presents us an opportunity to validate the field line resonance mechanism that is often suggested as the source of these perturbations. Analyzing hundreds of QP60 events throughout the 13-year period, we find that the observed wave frequency is independent of invariant latitude, agreeing with earlier studies. As shown in Rusaitis et al. [2020], the plateau in field line eigenfrequencies in the outer magnetosphere (especially 10 to 20 RS) is explicable with a realistic field and density model. Additionally, we observe a higher occurrence rate of events in mid-to-high latitudes, compatible with the magnetic perturbation amplitude variations in the field line resonance model. Such amplitude variation is very different to that seen in magnetospheric box models with a step-function density models [e.g., Yates et al., 2016], which show high relative magnetic field perturbation amplitudes only near the magnetic equator. We suggest that our analysis of the QP60 events and comparison with the predictions of the realistic field line resonance model demonstrates that the field line resonance mechanism is likely responsible for at least a large fraction of the observed 1-hour periodic waves in the magnetic field measurements.

Searching for Saturn's X-rays during a rare Jupiter Magnetotail Crossing using Chandra – W3

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Every 19 years, Saturn passes through Jupiter's 'flapping' magnetotail. The structure and motion of the tail are governed by the variable solar wind dynamic pressure surrounding the jovian magnetosphere. Here, we report Chandra X-ray observations of Saturn planned to coincide with this rare planetary alignment. We analyze three Director's Discretionary Time (DDT) $\sim$ 10 ks observations from the High Resolution Camera (HRC-I) on-board Chandra, taken on November 19, 21 and 23 2020 with the aim to find auroral and/or disk emissions. We infer the conditions in the kronian system by looking at coincident soft X-ray solar flux data from the Geostationary Operational Environmental Satellite (GOES) and Hubble Space Telescope (HST) observations of Saturn's ultraviolet (UV) auroral emissions within 2 days of the Chandra observations. The GOES data show a C-class flare that may have impacted Saturn just prior to the November 23 observation while the planet was most likely immersed in the solar wind. However, there was no significant detection of Saturn's disk or auroral emissions in any of the DDT observations. We estimate the upper limit to the energy flux of Saturn at this time which is agreement with the results found from previous modelled spectra of the disk emissions. We conclude our study by discussing the implications of this non-detection and how it is imperative that the next fleet of X-ray telescopes (such as Athena and the Lynx mission concept) continue to observe Saturn with their improved spatial and spectral resolution and very enhanced sensitivity to help us finally solve the mysteries behind Saturn's apparently elusive X-ray aurora.

Fine structures of Saturn kilometric radiation at low and medium frequencies – W4

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The fine structures of Saturn kilometric radiation (SKR) are best investigated with the Wideband Receiver (WBR) of Cassini's Radio and Plasma Wave Science (RPWS) instrument. Spectral features are displayed in so-called dynamic spectra as a function of time and frequency with resolutions of $\sim$0.1 s and $\sim$0.1 kHz, respectively. We introduce 7 different classes of SKR fine structures ranging from dots (1 class for 0-dimensional objects) over lines (4 classes of 1-dimensional objects being horizontal, vertical, or with positive or negative slope) to areal features (1 class for 2-dimensional objects). Additionally, the 7th class contains special structures which are named according to their appearance in the dynamic spectra like rain, striations, caterpillars, or worms. About 20% of SKR features cannot be classified with our classification scheme.

We classified SKR spectra from the 80 kHz WBR (low frequencies) and from a 25 kHz band centered at 325 kHz (medium frequencies). We found several differences in the occurrence of various structures at low and medium frequencies. For example, the particular fine structure of striations is quite common below 80 kHz, but rarely appears at 325 kHz. However, we can see groups of short and thin lines of negative slope looking like "rain" or interrupted striations. Striations are one of the few fine structures which have been investigated for Auroral kilometric radiation (AKR) at Earth, where they also tend to appear at lower frequencies and are less common at medium frequencies (Menietti et al., 2000, JGR 105, A8, 18,857-18,866). Until today, no classification scheme exists for the fine structures of auroral radio emissions, and here we attempt to introduce one. Furthermore, we still do not know which processes are responsible for the multitude of fine structures, and many different theories exist.

Using Saturn Kilometric Radiation as a proxy for the solar wind – W5

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Due to a lack of upstream monitors, the effects of the solar wind on Saturn's magnetosphere are not well understood. Consequently, previous investigations of this relationship have been restricted to time limited case studies. However, it is known that the solar wind plays an important role in magnetosphere dynamics. With the conclusion of the Cassini mission in 2017, we present a large-scale statistical study of the Saturnian kilometric radiation as a proxy for the solar wind. Due to the lack of direct solar wind monitoring at Saturn, we use a solar wind propagation model, to explore several solar wind parameters and their relationship with the Saturnian Kilometric Radiation.

To assess the strength of the relationships between solar wind parameters and Saturnian kilometric radiation, we use mutual information. Mutual information is a measurement of how strong the relationship is between two variables, and by extension, how much we can infer from one about the other. In this study, that is how confident we can be of the Saturn Kilometric Radiation's strength when measuring a given solar wind parameter value from the propagation model. Additionally, we present rigorous testing of the technique, before drawing conclusions from the physical data.

Evaluating Solar Wind-Magnetosphere Interactions at Neptune: A Modeling Study of Solstice Conditions – X1

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At a distance of ∼30 AU from the Sun, the interaction of Neptune's tilted and off-centered magnetic dipole moment with the solar wind is far from typical. Recent studies have indicated that with increasing distance from the Sun, a viscous interaction between the solar wind and magnetosphere may be prevalent over a more standard picture of reconnection in terms of driving energy and mass flow into the magnetosphere. The viscous interaction would arise from a transfer of momentum between the solar wind plasma and magnetospheric plasma at the magnetopause boundary due to the reflection and refraction of magnetohydrodynamic waves, an effect enhanced by the Kelvin-Helmholtz instability. In this study we adapt a multifluid magnetohydrodynamic simulation previously implemented at Uranus for an offset tilted dipole and apply it to Neptune's magnetosphere. We examine a range of potential upstream solar wind conditions for Neptune's solstice configuration to quantitatively assess how these characteristics affect conditions at the bow shock, magnetosheath, and magnetopause boundary layers and how those characteristics evolve during planetary rotation. The probability of reconnection along the magnetopause will be assessed based off two criteria. For the diamagnetic drift condition, the difference between plasma beta in the magnetosheath and magnetosphere will be determined to assess potential reconnection sites. The flow shear condition will be evaluated by considering the magnetosheath and magnetosphere magnetic fields, in addition to the magnetosheath plasma mass density. The strength of the reconnection electric fields will be calculated when the reconnection criteria are met. Several simulations will be run to cover a range of Alfvén Mach numbers characterizing the upstream flow.

Unmasking the Infrared Aurorae of Uranus – X2

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How the aurorae of Uranus are produced and what processes drive these phenomena are two fundamental questions in understanding the Ice Giant planets. With an offset and tilted magnetic field from the planet's unusual 98-degree rotational tilt, Uranus's magnetosphere presents a planetary environment unlike those of our own at Earth or Jupiter and Saturn. Since 1986, where Uranus was visited by a single fly-by from Voyager II, we have continued to work with a snapshot of data that provided the first glimpse into the ultraviolet aurorae. This went onto to discover a most peculiar asymmetric set of aurorae (Herbert and Sandel, 1994), thought to result due to the 0.3 planetary radii offset of the magnetic dipole.

Since these findings, the Hubble Space Telescope (HST) has continued to observe auroral emissions at Uranus (Lamy, et al., 2012, 2017) but only in the ultraviolet wavelength. These observational campaigns have, however, been unable to map the full spatial extent of the aurorae as observed in 1986, and highlighted a need for further investigations. Similar observations have also been carried out in the infrared spectrum, with the use of H_3^+ a molecular ion which acts as an energy probe of a planet's upper atmosphere. Over the 30-year history of infrared observations at Uranus (Trafton, et al., 1993) there has been a similar difficulty in observing the planet's aurorae, with only one possible auroral event documented in 2016, but this was unable to be confirmed (Melin, et al., 2019).

By analysing multiple infrared datasets for H_3^+ emissions during and after the planet's equinox (2007), we have successfully revealed two broad regions of H_3^+ emission that closely resemble the latitudinal positions of the UV northern and southern aurorae as was first observed by Voyager II. Spectral analysis shows these peaks in H_3^+ intensities are not driven by thermal processes, but instead due to increased column densities of H_3^+. The combination of these results presents an increase in localised ionisation rates across the surface of Uranus, hence indicating the presence of infrared aurorae which have now been observed for the first time in history.

Seeing X-rays from Uranus for the First Time (a low signal) – X3

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We present three Chandra X-ray Observations of Uranus (each 24-30 ks duration). One of these observations shows a low signal but statistically significant detection of X-rays from Uranus, with measured X-ray fluxes that are consistent with upper limits and modelling predictions in previous work (Ness & Schmidt. 2000; Cravens et al. 2006). The probability chance of occurence of this signal being randomly generated in the location of Uranus is of the order of 1 in 1 million. The detection also shows an energy clustering of the photons that is consistent with observations of Jupiter and Saturn. The other two observations, when considered in their entirety, constitute non-detections. However, one of these observations shows intriguing short timescale brightenings that raised the X-ray brightness of Uranus above 99.9 percent of the field of view. Given that the Sun's X-ray brightness was reasonably constant and dim at this time, it seems unlikely that the change in brightness was caused by the scattering of solar flares in the planets atmosphere (as seen for Jupiter and Saturn). A plausible alternative cause of this brightening could be aurorae (given its co-location with the expected UV aurora location at this time). We also observe X-ray emission clustered along the rings of the planet, which may hint at fluorescent emissions triggered by collisions from energetic particles (e.g. Mauk & Fox 2010). For Saturn, the rings can often rival the planet for X-ray brightness (e.g. Bhardwaj et al. 2005). It therefore may be plausible that Uranus could undergo a similar fluorescence process. To better explore these hints, longer observations are required beyond the exploratory nature of these first attempts.

Saturn Kilometric Radiation observed near its source by the Cassini Wideband Receiver – X4

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Towards the end of the Cassini mission, the spacecraft performed regular crossings of auroral magnetic field lines at high latitudes and low altitudes. In these magnetospheric regions, Saturn kilometric radiation (SKR) is typically generated. SKR is monitored by the Cassini-RPWS High-Frequency Receiver (HFR) in the survey mode and by the Wideband Receiver (WBR) in the burst mode. We present WBR observations obtained during Cassini's Grand Finale orbits while the spacecraft was within or very close to the SKR source region. The fine structure of SKR is discussed, and we compare WBR recordings to HFR spectra. Whereas the HFR shows SKR at frequencies slightly below the local electron cyclotron frequency (fc) within the source region, the WBR shows SKR being amplified at fc or slightly above fc. We will discuss these discrepancies in terms of receiver characteristics and address possible modifications to the theory of SKR generation needed for explaining the observations.

The peak frequency source of Saturn's Kilometric Radiation – X5

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Before to ultimately plunge into Saturn's atmosphere, the Cassini spacecraft explored between 2016 and 2017 the auroral regions of Saturn's magnetosphere, where rises the Saturn's Kilometric Radiation (SKR). This powerful, nonthermal, radio emission analog to Earth's Auroral Kilometric Radiation, is radiated through the Cyclotron Maser Instability (CMI) by mildly relativistic electrons at frequencies close to the local electron gyrofrequency. The typical SKR spectrum, which ranges from a few kHz to $\sim$1MHz, thus corresponds to auroral magnetic flux tubes populated by radiosources at altitudes ranging from $\sim$4 kronian radii (Rs) down to the planetary ionosphere. During the F-ring orbital sequence, Cassini probed the outer part of both northern and southern auroral regions, ranging from $\sim$2.5 to $\sim$4 Rs altitudes, and crossed several SKR low frequency sources ($\sim$10-30 kHz). Their analysis showed that the radiosources strongly vary with time and local time, with the lowest frequencies reached on the dawn sector. They were additionally colocated with the UV auroral oval and controlled by local time-variable magnetospheric electron densities, with importants consequences for the use SKR low frequency extensions as a proxy of magnetospheric dynamics. Along the proximal orbits, Cassini then explored auroral altitudes below $\sim$2.5 Rs and crossed numerous, deeper, SKR sources at frequencies close to, or within the emission peak frequency ($\sim$80-200 kHz). Here, we present preliminary results of their survey analysis, taking advantage of HST remote UV observations coordinated with Cassini in situ radio and magnetic measurements. Understanding how the CMI operates in the widely different environments of solar system magnetized planets has direct implications for the ongoing search of radio emissions from exoplanets, ultracool dwarves or stars.

Up-coming event - MOP22

Unfortunately, the pandemic forced us to change our initial plan to organize the MOP meeting in Liège (Belgium) in 2021. However, we are looking forward to welcoming you in-person for the MOP2022 meeting from July 11 to 15, 2022. The meeting will take place at the Academic Hall of the University of Liège, which is located in the city centre and within walking distance from most downtown hotels.

For more information and updates, please visit our website.