Rotational phenomena in the Saturnian magnetosphere

**Leader:** David Andrews (IRFU, Sweden), **Co-Leader:** Georg Fischer (SRI, Austria)

**Abstract:** Rotational modulations near the planetary period were first detected in the Saturnian magnetospheric plasma, magnetic fields, and radio emissions during the Voyager era. Subsequently these phenomena have received significant international interest, having been extensively studied in the hope that they would provide some measure of the rotation period of the deep interior of the planet. However, despite the wealth of data obtained by the Cassini orbiter, theories of the origins of these modulations in Saturn's otherwise apparently perfect axisymmetric magnetic field remain highly contested. Proposed theories of their origin variously invoke as yet un-detected high-order anomalies in the planet’s magnetic field, stable rotating neutral wind systems in the thermosphere, or some intrinsic symmetry-breaking of the rotating magnetosphere favoring the observed $m=1$ mode. Following the past decade of extended study, in which available data sets were often studied in isolation, it has become evident that continued progress towards a complete understanding of these phenomena requires the collaborative atmosphere provided by ISSI, giving renewed impetus to this research. To that end, we have assembled a team of active researchers in this field willing to contribute to such a collaborative effort, bringing expertise in the analysis of magnetometer, radio, and particle data sets, as well as the development of theoretical models. Our focus would be on the synthesis and joint analysis of existing data sets, with a view to provide the best possible estimate of the periodicity, time-variability, phase relationships, response to solar wind variations, and global structure of these modulations. A complete theory of the origin of these periodic phenomena in an otherwise axisymmetric magnetosphere would be a significant development within space physics, and moreover is absolutely required for the refinement of models of Saturn's interior magnetic field (which may in turn yield a measure of the 'true' planetary rotation period, as new data becomes available). Finally, this work would have direct applications to the study of other rotating magnetospheres both inside and outside our solar system, where similar processes are likely occurring.

**Research Domain:** Space Sciences (Space plasma and magnetospheric physics)

**Team members**
14 scientists from 5 countries (Austria, France, The United Kingdom and Sweden from the ESA member states, as well as the USA) and 9 separate institutions. Furthermore, we also intend to include two young scientists in our meetings: Japheth Yates (Imperial College, UK) and Kate Ramer (UCLA, USA).

<table>
<thead>
<tr>
<th>Name</th>
<th>Institute</th>
<th>Nation</th>
<th>Role</th>
</tr>
</thead>
<tbody>
<tr>
<td>David Andrews</td>
<td>IRF-Uppsala</td>
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<td>Team Leader, magnetic field oscillations</td>
</tr>
<tr>
<td>James Carbery</td>
<td>APL/Johns Hopkins Univ.</td>
<td>US</td>
<td>Energetic particle periodicity</td>
</tr>
<tr>
<td>Georg Fischer</td>
<td>Space Research Institute</td>
<td>AT</td>
<td>Co-leader, Planetary radio emissions</td>
</tr>
<tr>
<td>Xianzhe Jia</td>
<td>University of Michigan</td>
<td>US</td>
<td>MHD Modeling</td>
</tr>
<tr>
<td>Krishan Khurana</td>
<td>UCLA</td>
<td>US</td>
<td>Magnetic fields &amp; modeling</td>
</tr>
<tr>
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<td>US</td>
<td>Theoretical development</td>
</tr>
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<td>William Kurth</td>
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<tr>
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<td>University of Leicester</td>
<td>GB</td>
<td>Infrared and UV auroral emissions</td>
</tr>
<tr>
<td>Donald Mitchell</td>
<td>APL/Johns Hopkins Univ.</td>
<td>US</td>
<td>Energetic particles</td>
</tr>
<tr>
<td>Gabby Provan</td>
<td>University of Leicester</td>
<td>GB</td>
<td>Magnetic field oscillations</td>
</tr>
<tr>
<td>David Southwood</td>
<td>Imperial College London</td>
<td>GB</td>
<td>Theoretical development</td>
</tr>
<tr>
<td>Sheng-Yi Ye</td>
<td>University of Iowa</td>
<td>US</td>
<td>Narrowband emissions</td>
</tr>
<tr>
<td>Philippe Zarka</td>
<td>LENS, Observatoire de Paris</td>
<td>FR</td>
<td>Radio emissions and solar wind control</td>
</tr>
</tbody>
</table>
Scientific rationale and goals of the project

Rotational modulations of Saturn’s magnetic field, plasma properties, and auroral radio and ultraviolet emissions near the ~10.7 h planetary period have been found to be ubiquitous throughout Saturn’s magnetosphere by all spacecraft that have studied it [see e.g., Carberry & Mitchell 2013, and references therein]. The presence of these rotating modulations in the magnetosphere of the planet with a near-perfect spin axis-symmetry in its magnetic field is one of the foremost problems in planetary magnetospheric physics. Surprisingly in the case of radio emissions, magnetic field oscillations and energetic electrons the rotational modulations exhibit two distinct periods, which both evolve differently with time over the years (Fig. 1). During southern summer conditions the Saturn kilometric radiation (SKR) measured by the Cassini Radio and Plasma Wave Science (RPWS) instrument showed two periods of ~10.8 h and ~10.6 h, attributed to SKR originating from the southern and northern auroral regions, respectively [Kurth et al. 2008; Gurnett et al. 2009]. Current understanding of the magnetic field oscillations measured by the Cassini magnetometer (MAG ~ Fig. 2) is that they are caused by two rotating current systems, one in each of the northern and southern hemispheres, with the relative phases of the magnetic field components providing direct measure of the locally dominant hemisphere [e.g., Provan et al. 2009]. It is then supposed that these two rotating current systems are responsible for the emission of modulated SKR from their respective hemispheres. Their two distinct rotation periods converged towards a common period of ~10.7 h following Saturn equinox in 2009 [Lamy, 2011], while the subsequent behavior of the system has been highly varied with intermittent appearances and disappearances of modulations associated with each hemisphere (cf. Fig. 1) [Provan et al., 2013]. Currently, there is no accepted consensus as to whether these results are echoed in all the available data sets (radio, magnetic, and plasma populations), and this is something we will seek to answer.

![Figure 1: Time-evolution of the N and S SKR periods showing a convergence after Saturn equinox [Gurnett et al., 2010]. Estimates for the rotation period of the interior of the planet are indicated for comparison.](image1)

![Figure 2: Rotating equatorial magnetic field vectors projected onto the equatorial plane [Andrews et al., 2010]. Each vector rotates with the same period as the SKR. The curl of the field indicates the presence of the rotating SKR current system.](image2)

If funded, this team of international experts will focus its efforts in addressing the three science questions that follow, through the activities outlined below each.

**Question 1: What are the underlying relationships between rotating phenomena at Saturn?**

1. Analyze the common periodicity and phase relations between various phenomena, especially between MAG and SKR phases.
2. Perform periodicity analysis under the assumption of common northern and southern periods and fixed phase-differences between different phenomena.
3. Perform the first multi-instrument analysis in which data are combined at a low level and analyzed in a single process, rather than as disparate data sets.
4. Characterize the consequences of changing spacecraft trajectory and signal amplitudes on the periodicity analysis.
While considerable progress has been made, significant gaps remain in our understanding of the relationships between these periodic phenomena, which reduces our ability to model accurately and understand the whole system, and thereby address the underlying cause of these periodicities. A novel joint analysis of magnetic and radio emission periods and relative phases may resolve the issue of apparent differences in their periodicity following Saturn equinox \cite{Fischer et al., 2015}. The synthesis and joint analysis of data we plan for this project can avoid some issues arising from differing treatments of the available data, instead providing combined estimates of the independent N and S periods based on all available data. Conversely, if a true difference in the modulation periods of these various phenomena exists, this will also become clear through a failure to obtain a complete or unique solution across all data sets. Furthermore, with this approach it can be found if SKR phases need a correction due to the beaming and visibility of the radio sources along the quasi-periodic Cassini orbit.

Once the joint analysis of MAG and SKR is established, we will seek to supplement this analysis by considering additional rotating periodic phenomena for which suitable data exist (e.g., narrowband emissions \cite{Ye et al., 2010}, auroral hiss, hot and cold plasma densities \cite{Gurnett et al., 2007}, energetic neutral atom (ENA) emissions \cite{Carbary et al., 2008}, and UV and IR auroral intensities \cite{Badman et al., 2012; Lamy et al., 2013}) to find fixed phase relations, e.g. between the H and O signals of ENA emissions and SKR \cite[e.g.,][]{Carbary et al., 2011}. If fixed phase differences between these phenomena are found (which is to be expected), our new approach would be to apply our novel periodicity analysis to the combined data set, rather than as disparate data sets. This approach will enable us to establish unique N and S periods throughout the Cassini mission, which hopefully will be of great value to the wider Saturn science community.

**Question 2: What drives short- and long-term changes in rotational modulations?**

1. Study the effects of solar wind variations and shocks on rotating phenomena.
2. Determine the effects of other phenomena like transient changes in the size and shape of the magnetosphere or the parameters of its plasma population.
3. Investigate the consequences of coupling between northern and southern systems.
4. Characterize seasonal change in the properties of rotational phenomena. Could the seasonal evolution of thermospheric wind systems be responsible, or can a seasonal current sheet tilt produce the observed periodicities in Saturn’s magnetosphere?

Using a model for solar wind propagation to Saturn, the short-term effect of solar wind changes and shocks can be investigated. It is well known that SKR intensity and solar wind ram pressure are correlated, and systematic SKR period variations by ±1% with a characteristic time scale of 20-30 days were attributed to solar wind speed variations \cite{Zarka et al., 2007}. However, further correlation studies between the solar wind properties at Saturn and the short-term SKR phase variations are needed to fully understand this influence, and will be performed here. Other transient internal influences in Saturn’s magnetosphere may play a role as well, such as possible variations in mass-outflow rate.

Here, one of our major activities will be the deployment of an existing, tested MHD simulation code to study the expected influence of the passage of a sudden solar wind dynamic pressure increase on the rotational phenomena. These model results will be compared to suitable observations, to address in particular the apparent stability of the phase of the rotational phenomena to such shocks.

**Question 3: What is the ultimate cause of these rotating phenomena, and what are the wider implications of this process?**

1. Discuss existing theoretical descriptions of these phenomena, and refine them where necessary in view of new evidence arising from addressing Questions 1 & 3.
2. Investigate the applications of these models to other magnetospheres, such as the Jovian “System-IV”, and other astrophysical objects if deemed relevant.

It has been shown that the plasma and magnetic fields in the inner region of Saturn’s plasma disk rotate in synchronism with the time-variable modulation period of SKR \cite[e.g.,][]{Gurnett et al., 2007}. It is still unknown what the primary cause for these modulations is, and what causes the...
seasonal changes in period [e.g., Gurnett et al. 2007, Southwood & Kivelson 2007]. Is it simply the seasonal tilt of the current sheet [Khurana et al. 2009], or a complex centrifugally driven convective instability in the equatorial plasma disk of Saturn’s magnetosphere [Goldreich & Farmer, 2007], or is it Saturn itself and its neutral atmosphere which is in the driver’s seat [Smith, 2011; Jia et al., 2012a]? Testable predictions of these models that we can address include the relative phases of the modulated phenomena and their seasonal evolution, their response to changes in the solar wind, and the structure of the electrodynamic current systems within in the magnetosphere. Aspects such as these can be explored in future global MHD simulations [e.g., Jia & Kivelson 2012b], and by further study of the dynamical behavior of the planet’s neutral atmosphere [e.g., Melin et al., 2006]. Recently, [Southwood & Cowley, 2014] have suggested that the ultimate source of these scale Alfvénic perturbations may be an effective ionospheric dynamo in each polar cap, transmitting energy and angular momentum from the central object.

Cassini will end its mission at Saturn in 2017 following an interval of low-altitude, highly inclined ‘proximal’ orbits. Crucially, determining the ‘true’ rotation period of Saturn’s interior may be possible during this interval, by measuring any non-symmetric high-order magnetic fields that may be detectable only at these low altitudes [e.g., Burton et al. 2010]. However, doing so will necessarily require a robust understanding of the periodic phenomena we propose to study, including the external rotating current system responsible, in order to accurately remove their effects and facilitate the search for such a high-order magnetic anomaly.

Finally, our new understanding of the Saturnian periodic phenomena resulting from these efforts will naturally enable us to consider its applications to other rotating planetary and astrophysical magnetospheres. For example, is a direct counterpart to these phenomena present in the Jovian system? Can these particular phenomena only persist in an axisymmetric system? Could the ~1.5% difference between the rotation period of Jupiter and the non-Io decametric radiation emission – the so-called ‘System IV’ period – be a manifestation of a related processes acting at Jupiter [Sandell & Dessler, 1988]? Likewise, are the somewhat similar modulations in the radio emission from pulsars, with various short and long-term changes in their periodicity (so called ‘glitches’) and abrupt absolute cessation (‘nulling’) of their emission possibly related [e.g., Lyne et al. 2010]?

Data sets to be studied
For these investigations we plan to use the following data sets and tools. These data products are already in existence, and the team has collective expertise in their processing and analysis.

<table>
<thead>
<tr>
<th>Data set</th>
<th>Comments</th>
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<tbody>
<tr>
<td>RPWS</td>
<td>Integrated intensities of SKR, narrowband and auroral hiss emissions, separated by source hemisphere. Local electron densities from both the Langmuir probe and the upper-hybrid frequency measurement.</td>
</tr>
<tr>
<td>MAG</td>
<td>Processed and filtered magnetic field in three components</td>
</tr>
<tr>
<td>CAPS</td>
<td>Ion and electron count rates (up to June 2012 when disabled)</td>
</tr>
<tr>
<td>MIMI</td>
<td>Ion and electron measurements, and energetic neutral atom images</td>
</tr>
<tr>
<td>UVIS &amp; VIMS</td>
<td>Auroral ultraviolet and infrared emissions, e.g. via the Auroral Planetary and Imaging Spectroscopy data base at <a href="http://apis.obspm.fr">http://apis.obspm.fr</a></td>
</tr>
<tr>
<td>Solar wind</td>
<td>In-situ measurements where available, substituted by proxy data obtained at Earth and propagated to Saturn’s orbit using e.g. the Michigan Solar Wind Model (see <a href="http://mswim.engin.umich.edu/index.php">http://mswim.engin.umich.edu/index.php</a>)</td>
</tr>
<tr>
<td>MHD Simulations</td>
<td>Statistical results and virtual spacecraft fly-throughs obtained from a global MHD simulation (either existing model runs already performed, and later in the project the results of a new time-dependent run).</td>
</tr>
</tbody>
</table>

Project schedule and expected output
If this proposal is accepted, we anticipate two meetings to be held at ISSI (Berne) during 2015 and 2016, with the aim that all activities and publications undertaken by the team will be completed by mid 2017. We outline our anticipated timeline in the table below.
The central output of this ISSI team will be the development of a best-possible estimate of the slowly-varying rotation period of a number of magnetospheric phenomena, based on a synthesis of all available data sets. A systematic survey of the rapid changes observed in these phenomena, and their correlation to external drivers such as solar wind changes, will be archived for future use as a simple event-list. Finally, we intend to develop a more complete understanding of the process that produces these oscillations, and if possible apply this to other astrophysical objects.

We anticipate that several papers would arise from this activity, with clear acknowledgements to ISSI. Previous work on this problem has yielded some of the most frequently cited recent papers within the planetary magnetospheres community. We expect that the hopefully conclusive results of this proposed collaboration will be of similarly high scientific value, both in the near future in the analysis of data obtained during the end of the Cassini mission, and in the longer-term as understanding of other rotating magnetospheres grows.

**Timeliness of the project**

This project will take place during the final years of the Cassini mission. For more than a decade Cassini has provided new discoveries about the Saturn system, among which these periodic phenomena have been a top-10 highlight¹. The finale of the mission will be the ‘proximal’ orbits, where the spacecraft periapsis will be lowered inside the rings, before disappearing finally into the clouds in September 2017. The understanding developed in this ISSI team will greatly assist in the interpretation of these last moments. Furthermore, we look forward both to the arrival of the NASA Juno mission at Jupiter in 2016 and the preparations for ESA’s JUICE mission, where aspects of this proposal will likely remain highly relevant.

**Relevance to ISSI, and added value provided by ISSI**

If selected, this would be the first ISSI team to address this unique physical problem of periodic field and plasma signatures at periods close to, but distinct from, the internal rotation period of the planet. The collaborative environment provided by ISSI is an ideal setting for fruitful work on what has often been a contentious topic. No such extended round-table discussions have been had on this topic at any stage. Study of these periodic modulations also addresses physics fundamental to all rapidly rotating magnetospheres (including those beyond our solar system) as well as magnetosphere-ionosphere-neutral atmosphere coupling in a more general context.

**Financial support and facilities required**

We plan on having two one-week meetings, and therefore request financial support for 24 person-weeks (per diem and living expenses in Bern). Due to the large size of the team, some members will likely participate in person in only one meeting while others could cover their expenses by themselves or participate remotely. We ask for the usage of the facilities made available by ISSI, specifically one meeting room with projection facilities, white board, wireless internet, and simple video-conferencing facilities for members who may be unable to travel to Berne.

Annex A: Relevant publications


### Annex B: Names, addresses and emails of confirmed participants

<table>
<thead>
<tr>
<th>Name</th>
<th>Address</th>
<th>Phone/Email</th>
</tr>
</thead>
<tbody>
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<td>Margaret Kivelson</td>
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<td>Henrik Melin</td>
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<td>Gabby Provan</td>
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<tr>
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</tr>
</tbody>
</table>

Note: We plan to include two young scientists, Japheth Yates (Imperial College, UK; japheth.yates@imperial.ac.uk) and Kate Ramer (Univ. of California at Los Angeles, USA).
Annex C: CVs of committed participants

Dr. David J. Andrews
Swedish Institute for Space Physics (IRF), Uppsala Division, Box 537, SE-75121, Uppsala, Sweden
Tel: +46 184715922
Email: david.andrews@irfu.se

Research Interests
Induced magnetospheres and ionospheres, particularly applied to Mars as studied with the MARSIS radar on Mars Express and the Langmuir Probe & Waves instrument on MAVEN
Planetary-period oscillations at Saturn, as studied with Cassini magnetometer data
Magnetosphere-ionosphere coupling

Education
Oct. 2004 – Sep. 2008: MPhys, Physics, Department of Physics & Astronomy, University of Leicester, UK

Employment
Jan. 2015 – Present: Research scientist (Forskare) at the Swedish Institute for Space Physics, Uppsala, Sweden. Position jointly funded by the Swedish Research Council Vetenskapsrådet and the Swedish National Space Board Rymdstyrelsen.

Selected Relevant Publications
26 publications, 8 as first-author, 400+ citations, h = 13


Professional Affiliations and Awards
2008 – Present: Membership of the Institute of Physics, London, UK; The American Geophysical Union, Washington, USA; The European Geosciences Union, Munich, Germany.
2011 – Runner-up, Keith Runcorn Thesis Prize, Royal Astronomical Society
## Curriculum vitae Dr. Georg Fischer

### Contact information

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Tel: +43 316 4120664 (office); Fax: +43 316 4120690  
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### Personal information

Date and place of birth: 22 October 1971, Klagenfurt, Austria  
Nationality: Austrian

### Education

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<thead>
<tr>
<th>Year</th>
<th>Institution</th>
</tr>
</thead>
<tbody>
<tr>
<td>1982-1990</td>
<td>High school at 1. Bundesgymnasium Klagenfurt</td>
</tr>
<tr>
<td>1990-1999</td>
<td>Graz University of Technology, MSc in Technical Physics</td>
</tr>
<tr>
<td>2001-2004</td>
<td>Graz Karl-Franzens University, PhD in Geophysics and Meteorology</td>
</tr>
</tbody>
</table>

### Employment

<table>
<thead>
<tr>
<th>Year</th>
<th>Position</th>
</tr>
</thead>
<tbody>
<tr>
<td>04/2015</td>
<td>Researcher at the Institute of Physics, University of Graz, Austria</td>
</tr>
<tr>
<td>09/2008-03/15</td>
<td>Research Scientist at the Space Research Institute in Graz, Austria.</td>
</tr>
<tr>
<td>02/2006-07/2008</td>
<td>Postdoctoral Research Scholar at the Dept. of Physics &amp; Astronomy</td>
</tr>
<tr>
<td>07/2008</td>
<td>at the University of Iowa, Iowa City, USA.</td>
</tr>
<tr>
<td>02/2000-12/2005</td>
<td>Research scientist and doctoral student at the Space Research</td>
</tr>
<tr>
<td>before 2000</td>
<td>Institute (SRI) of the Austrian Academy of Sciences in Graz, Austria</td>
</tr>
<tr>
<td></td>
<td>Work on diploma thesis at Siemens-Matsushita; industrial practicals at</td>
</tr>
<tr>
<td></td>
<td>Sony, Siemens and Semikron during college</td>
</tr>
</tbody>
</table>

### Scientific interests

- Lightning on planets  
- Magnetospheric radio emissions of Saturn  
- Periodicity, polarization and direction-finding of radio waves  
- Atmospheres and ionospheres of giant planets  
- Calibration of radio antennas on spacecraft: Cassini/RPWS, Stereo/Waves, Juno/Waves, Solar Orbiter/RPW, Jupiter Icy Moons Explorer/RPWI

### Projects

- Project leader of 3 projects with total funding amount of 491 k€ (2 Austrian Science Fund (FWF) projects about Saturn lightning, 1 Austrian Research Promotion Agency (FFG) project about JUICE/RPWI antenna optimization)  
- Collaborator in 5 projects (2x CDAP, 2x FFG, 1x ESA)

### Scientific teams and memberships

- Co-Investigator of Cassini RPWS (Radio & Plasma Wave Science) instrument  
- Co-Investigator of JUICE RPWI (Radio & Plasma Wave Investigation)  
- Member of EGU and AGU (European and American Geophysical Union)  
- Participation in three ISSI (International Space Science Institute, Bern, Switzerland) international teams

### Publications

- Publications in refereed journals: 38 (11 of them as first author)  
- Refereed articles currently submitted: 1 (1 of them as first author)  
- Proceedings papers: 21 (6 of them as first author)  
- Other publications: 1 book chapter and 8 internal SRI reports

### Relevant publications

## Curriculum vitae Dr. James Carbary

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Tel.: +1-858-342-2706 (cell)  
Email: james.carbary@jhuapl.edu |
|---------------------|----------------------------------------------------------------------------------|
| Personal information | Date and place of birth: 5 June 1951, Pennsylvania, USA  
Nationality: United States |
| Education | 1974-1977 Rice University, Houston, TX, USA MS & PhD Space Physics  
1969-1973 University of Illinois, Champaign, IL, USA, BS, Physics |
| Employment | 1985-now Senior Staff Scientist, JHU/APL, Laurel, MD  
1983-1985 Research Scientist, Mission Research Corp, Santa Barbara, CA  
1978-1983 Postdoctoral Research Assoc., JHU/APL, Laurel, MD  
1977-1978 Postdoctoral Research Assoc., Rice Univ, Houston, TX |
| Scientific interests | Charged particles in Saturn’s magnetosphere.  
Energetic neutral particles from Saturn’s magnetosphere.  
Periodicities of all kinds at Saturn, including kronoseismological. |
| Projects | 2005-present, Magnetospheric Imaging Instrument (MIMI) on Cassini  
1995-2004, Ultraviolet Imaging and Spectrographic Instrument (UVISI) on MSX  
1995-2000, Ultraviolet Imager (UVI) on Polar (as data analyst only)  
1986-2003, plasma detectors on DMSP (as data analyst only)  
1978-1985, Low Energy Charged Particle Program (LECP) on Voyager 1 & 2  
1978-79, Charged Particle Measurement Program (CPME) on IMP 1 & 2 |
| Scientific teams and memberships | Co-Investigator of Cassini MIMI (Magnetospheric Imaging Instrument)  
Member of AGU (American Geophysical Union)  
Saturn in the 21st Century Book Team (lead author, chapter 5) |
| Publications (as 1st author only) | Saturn/Cassini Publications in refereed journals: 33  
Saturn/Cassini articles currently submitted: 1  
Dr. Xianzhe Jia  
Department of Atmospheric, Oceanic and Space Sciences, University of Michigan  
2455 Hayward Street, Ann Arbor, MI 48109-2143, USA  
Tel: +1 734-764-7220  
Email: xjia@umich.edu

Research Interests
- Large-scale structure and dynamics of the giant planet magnetospheres  
- Rotational periodicities at Saturn  
- Plasma interactions with Jupiter’s Galilean satellites  
- Solar wind interaction with Mercury and its magnetosphere

Education
- Ph.D. (Geophysics and Space Physics) University of California, Los Angeles 2009  
- M.S. (Geophysics and Space Physics) University of California, Los Angeles 2004  
- M.S. (Geophysics and Space Physics) University of Science and Technology of China 2002  
- B.S. (Geophysics and Space Physics) University of Science and Technology of China 1999

Employment
- Assistant Research Scientist University of Michigan, Ann Arbor 2010 – present  
- Research Fellow University of Michigan, Ann Arbor 2009 – 2010

Relevant Publications

Awards and ISSI-related Activities
- University of Michigan Research Faculty Recognition Award 2014  
- Eugene B. Waggoner Scholarship, Department of Earth and Space Sciences, UCLA 2007  
- Invited participant of the following ISSI workshops:  
  - Plasma sources in solar system magnetospheres 2013  
  - Giant planet magnetodiscs and aurorae 2012  
  - Planetary magnetism 2008
- Member of the following ISSI international teams  
  - Towards a global unified model of Europa’s exosphere in view of the JUICE mission 2014-2015  
  - Modes of radial plasma motion in planetary systems 2013-2014  
  - Investigating the dynamics of planetary magnetotails 2010-2011
Krishan Khurana received his first Ph.D. degree from Osmania University, Hyderabad, India in 1981 in the field of developing automated data processing techniques for exploration magnetic data. He subsequently embarked on a second Ph.D. program in the field of magnetohydrodynamics of rotating fluids at Durham University, England, which he successfully completed in 1984. From 1985, he has been working at the Institute of Geophysics and Planetary Physics at UCLA as a Research Geophysicist and is currently a Co-investigator on the Magnetometer experiments onboard Cluster, THEMIS and Cassini spacecraft missions.

He has worked on many theoretical and empirical investigations relating to the magnetospheres of Venus, Earth, Jupiter and Saturn. Some of the recent problems he has studied include inferring oceans in the icy satellites of Jupiter, interactions of the icy satellites with the Jovian and Saturnian plasma, magnetospheric convection driven by the solar wind, maintenance of corotation in the Jovian magnetosphere and the development of global models of Jupiter’s and Saturn’s magnetospheric fields.

Khurana has advised NASA through committees such as the Committee on Planetary and Lunar Exploration (COMPLEX), the Solar System Exploration Survey (known as the Planetary Decadal Survey) and the NRC committee on Solar and Space Physics (CSSP).


Selected Publications


Professor Margaret G. Kivelson
Department of Earth, Planetary, and Space Sciences, UCLA, Los Angeles, CA 900951567, USA
Also: Atmospheric, Oceanic and Space Science Department, University of Michigan, Ann Arbor, MI, USA
Tel: +1 310-825-3435
Email: mkivelson@igpp.ucla.edu

Research Interests
Magnetohydrodynamic processes in planetary magnetospheres
The source and consequences of planetary-period oscillations at Saturn
Magnetospheric dynamics at Earth, Jupiter, Saturn and their moons

Education
Ph.D. (Physics) Radcliffe College, Harvard University, Cambridge, MA – 1957
(Advisor: Professor Julian Schwinger; dissertation: Bremsstrahlung from Ultrarelativistic Electrons.)
A.M. (Physics) Radcliffe College, Harvard University, Cambridge, MA – 1951
A.B. (Physics) Radcliffe College, Harvard University, Cambridge, MA – 1950 (Magna cum Laude)

Employment
1967-2009: from Assistant Research Geophysicist to Distinguished Professor of Space Physics in various departments at UCLA, Los Angeles, CA, USA.
2009-present: Distinguished Professor of Space Physics, Emeritus, Department of Earth, Planetary, and Space Sciences, UCLA, Los Angeles, CA, USA.
2010-present: Research Professor, Department of Atmospheric, Oceanic, and Space Sciences, University of Michigan, Ann Arbor, MI, USA.

Selected Publications
360+ refereed publications (Web of Science lists 391), many as first-author, 12,867 citations, h = 62

Professional Affiliations and Awards
Kivelson was awarded a Guggenheim Fellowship (1973-74), the Radcliffe Graduate Society Medal (1983), the Harvard University 350th Anniversary Alumni Medal (1986), several NASA Group Achievement Awards, the Alfvén medal of the European Geophysical Union, the Fleming medal of the American Geophysical Union and memberships in the American Academy of Arts and Sciences, the National Academy of Sciences (Councilor 2007-2010) and the American Philosophical Society. She is an elected Fellow of the American Geophysical Union, the American Physical Society, the International Academy of Astronautics, the American Association for the Advancement of Science and an Honorary Fellow of the Royal Astronomical Society (Great Britain).
William S. Kurth  
Research Scientist, Dept. of Physics and Astronomy, University of Iowa, Iowa City, IA 52242  
Tel: 319-335-1926; Email: william-kurth@uiowa.edu

**Education**  
Ph.D. (Physics), University of Iowa, 1979  
M.S. (Physics), University of Iowa, 1975  
B.A. (Physics and Mathematics), University of Iowa, 1973

**Research Interests:**  
Plasma waves in planetary magnetospheres and in the heliosphere.  
Planetary and heliospheric radio astronomy  
Dust in planetary systems

**Project participation:**  
Cassini Radio and Plasma Wave Science Investigation *Deputy-Principal Investigator*  
Juno/Waves investigation *Lead Co-Investigator*  
Van Allen Probes/EMFISIS/Waves investigation *Lead Co-Investigator*  
Voyager Plasma Wave Investigation *Co-Investigator*  
Galileo Plasma Wave Investigation *Co-Investigator*  
Polar Plasma Wave Investigation *Co-Investigator*  
Planetary Data System Planetary Plasma Interactions *Outer Planets Subnode Manager*

**Professional Affiliations and Awards:**  
Fellow of the American Geophysical Union; International Academy of Astronautics, American Physical Society  
NASA Outstanding Public Leadership Medal for Juno; NASA Group Achievement Awards for Voyager (4); Galileo (5); Polar (1); Cassini (9); Juno (8); Van Allen Probes(1); NASA Silver Achievement Award for Voyager; U. Iowa Outstanding Staff Award; U. Iowa Distinguished Research Professional Award

**Selected Publications** of more than 400:  
Laurent LAMY
Born on 3 February 1980, Montpellier (France)

Assistant Astronomer
Laboratoire d'Etudes et d'Instrumentation Spatiales en Astrophysique (LESIA)
Observatoire de Paris, 5, Place Jules Janssen, 92195 Meudon
Tel: 01-45-07-76-61
Courriel: laurent.lamy@obspm.fr

ACADEMIC EDUCATION
------------------------------------
2012-… Permanent assistant astronomer, LESIA, Observatoire de Paris, CNRS, Meudon.
2010-2011 Post-doctoral CNES researcher, LESIA, Observatoire de Paris, CNRS, Meudon.
2009-2010 Research Associate, Blackett Laboratory (Space physics), Imperial College London.
2008-2009 Research Teaching Associate, Observatoire de Paris, Meudon.
2005-2008 PhD at the Pierre et Marie Curie University (UPMC), Paris Observatory, Meudon.

TEACHING AND RESEARCH
-----------------------------------------
- Field of research: comparative planetary magnetospheres, plasma physics, radio- and UV astronomy.
- Teaching: general physics and astronomy, superviser of 9 internships and 1 PhD thesis
2012-… 66h / year (Observatoire de Paris, UPMC, level L1 to M2).
2009-2010 112h (Imperial College London, undergraduate level).
2008-2009 60h (Observatoire de Paris, L3 level).
2005-2008 64h / year (UPMC, level L1 to M1).

PUBLICATIONS ET COMMUNICATIONS
----------------------------------------------------------
51 refereed publications, >100 first-authored communications at international conferences.

RESPONSABILITIES
---------------------------------------
- Scientific responsibilities:
- Observation services (tasks for the community):
  (iii) Modeling of plasma-satellite interactions for the preparation of Solar Orbiter/RPWI.
- Community:
  organizer of several colloquium (EPSC sessions >2010, Cassini MAPS in 2010, LOC of LOFAR TKP in 2011, SOC of MOP in 2013, National workshop on planetary thermospheres in 2010, Uranus international conference in 2011, National workshop on planetary magnetospheres in 2015), regular referee (journals, applications).
- Administrative tasks:
  elected at the administration council of the Observatory of Paris (2014-2018), member of the scientific council of the PNST (Sun-Earth physics) and PNP (Planetology) CNRS programs (2015-2019).
Dr. Henrik Melin  
Department of Physics & Astronomy, University of Leicester, University Road, Leicester LE1 7RH, UK  
Tel: +44 7429 424 529  
Email: hpm5@leicester.ac.uk

Research Interests
Processes of the upper atmospheres of Jupiter, Saturn, Uranus, and Neptune  
Ultraviolet and infrared remote sensing of auroral phenomena using spacecraft  
Comparative aeronomy using ground-based infrared telescopes

Education & Employment

<table>
<thead>
<tr>
<th>Year</th>
<th>Position/Institution</th>
<th>Details</th>
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<tbody>
<tr>
<td>2009 - present</td>
<td>Post Doctoral Research Associate (PDRA), University of Leicester, UK</td>
<td></td>
</tr>
<tr>
<td>2006 - 2009</td>
<td>Research Scientist, Planetary and Space Science Division, Space Environment Technologies, USA</td>
<td></td>
</tr>
<tr>
<td>2002 - 2006</td>
<td>University College London, PhD, Astronomy (‘Comparative aeronomy of the upper atmospheres of the giant planets’, Dr Steve Miller, supervisor)</td>
<td></td>
</tr>
<tr>
<td>1996 - 2000</td>
<td>MSci Astrophysics, University College London</td>
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</tbody>
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Selected Publications

33 publications, 9 as first-author, 548 citations, $h = 15$


Award and Distinctions

<table>
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<th>Year</th>
<th>Details</th>
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<tbody>
<tr>
<td>April 2013</td>
<td>Awarded the role as a Cassini Participating Scientist</td>
</tr>
<tr>
<td>December 2011</td>
<td>Invited keynote presentation at the Fall AGU meeting in San Francisco</td>
</tr>
<tr>
<td>2009 to present</td>
<td>Visiting Astronomer at the NASA Infrared Telescope Facility (IRTF)</td>
</tr>
<tr>
<td>August 2009</td>
<td>NASA Group Achievement Award for outstanding Cassini research</td>
</tr>
<tr>
<td>July 2009</td>
<td>NASA Group Achievement Award for excellence in mission planning</td>
</tr>
</tbody>
</table>
Donald G. Mitchell  
Research Scientist, Physicist  
Principal Professional Staff, JHU/APL

EDUCATION
Ph.D. Space Physics, 1975, University of New Hampshire.  
B.A. Physics, 1971, University of Michigan.

WORK EXPERIENCE
1985-present: JHU/APL – Space Physics Group, Space Department  
Lead Investigator: HENA instrument, IMAGE MidEx Mission  
Instrument Scientist: Magnetospheric Imaging Instrument, Cassini Saturn mission  
Instrument Scientist: Radiation Belt Science of Protons and Ion Composition Experiment, RBSP Mission  
Instrument Scientist: EPI-Lo -- Solar Probe Plus; JENI -- JUICE

Instrument Design:
Design of small, low power energetic particle time of flight - energy analyzer (now flying on MESSENGER, New Horizons, and selected for flight on MMS, JUNO, and RBSP);  
Design of instrumentation for the imaging of the magnetosphere in energetic neutral atoms including the Cassini MIMI Ion and Neutral Camera (INCA), the IMAGE Mission High Energy Neutral Atom imager (HENA), and JENI for JUICE  
Design of advanced ENA imagers and Ion Mass Spectrometers under Internal Research and Development grants, as well as NASA funded instrument development grants.  
Design of full-sky energetic particle composition and angular distribution instrument. (Solar Probe Plus, ISIS EPI-Lo)

Research Interests:
Analysis and interpretation of energetic neutral atom images of magnetospheric ion-neutral gas interaction regions at Saturn;  
Heliospheric physics, especially heliosheath and interstellar medium  
Magnetospheric interactions with Titan and Enceladus at Saturn;  
Image processing, analysis and interpretation of energetic neutral particle emissions from Earth's magnetosphere;

Service To Community:
NRC-Space Studies Board Committee on Solar and Space Physics, 1994-1996  
NRC-Space Studies Board, Committee on International Programs, 1996-1997  
Magnetospheric Multi-Scale Science Definition Team, 1999-2000  
Radiation Belt Mappers Study Team, 2000  
SEC Roadmap 2002, GSRI Mission Design  
Heliophysics Subcommittee of the Nasa Advisory Council, 2008-2010  
Heliophysics Decadal Survey, SWMI subcommittee

Professional Associations:
Member AGU, AAAS, IAA  
AGU Fellow
# Curriculum Vitae: Dr Gabrielle Provan

**Nationality:** British  
**Address:** Department Physics and Astronomy, University of Leicester, University Road, LE1 7RH  
**Telephone number:** 01162522083  
**Email:** gp3@ion.le.ac.uk

## Employment

<table>
<thead>
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<th>Year</th>
<th>Position</th>
<th>Institution</th>
</tr>
</thead>
<tbody>
<tr>
<td>1998-</td>
<td>Research scientists</td>
<td>Department of Physics and Astronomy, University of Leicester</td>
</tr>
</tbody>
</table>

## Research Interests
- Solar wind-magnetosphere-ionosphere interaction at the Earth and Saturn.
- Aurora of the Earth and Saturn.
- Magnetospheric dynamics of the Earth and the giant gas planets.

## Scientific Responsibilities Held
- Elected councillor on MIST council*, serving from 2008-2011. Examples of duties performed include co-organizing several conferences, representing the MIST community by providing input to the House of Commons Science and Technology Select Committee on astronomy and particle physics and speaking to MPs concerning funding cuts.

* Magneto-Ionosphere-Solar-Terrestrial (MIST) council represents the UK solar-terrestrial and space-plasma physics community. The council act as champion for and representative of the MIST community.

## Main Collaborators
- Co-authors of recent Provan et al. papers and first-authors of recent papers on which I have collaborated:

## Conference & Seminar
- 2015: Proposed and will be convening the session ‘Magnetic fields of planets and cool stars’ at the National Astronomy Meeting, 2015.
- 2011: Proposed and co-convened the session ‘Magnetospheres and ionospheres throughout the Universe’ at the National Astronomy Meeting, 2011.
- 2011: Invited talks at the AGU Fall Meeting and the Magnetosphere of the Outer Planets workshop.
- 2008-2011: Co-organized the twice-annual MIST conference meeting.
- 2007: Invited to present a seminar at Laboratory for Atmospheric and Space Physics, University of Colorado, Boulder.

## Selected Publications

Short biographical note on Professor David Southwood – November 2014

David was born in Devon UK and had an academic career in Britain and USA. He is at present a Senior Research Investigator at Imperial College (UK), Honorary Professor at the U. Lancaster (UK), Visiting Fellow, KULeuven (Be)

Research interests: Magnetohydrodynamic waves, MHD of Jupiter and Saturn magnetospheres, Radio emission from astrophysical objects

Recent employment:
2011-present: Non-Executive member, UK Space Agency Steering Board. (Member of UK ESA Council delegation)
2001 to 2011 the Director of Science and Robotic Exploration at the European Space Agency (ESA) in Paris.
1997-2000, Head of Earth Observation strategy at ESA.
1994-7, Head of Physics Department, Imperial College (UK).

Despite a high level administrative career, scientific publications were maintained throughout (often first authored).

Other honours/positions: Past President of the Royal Astronomical Society of London, Fellow of the Royal Aeronautical Society (UK), a visiting professor at the Universities of Plymouth and Lancaster (UK) and KULeuven (Belgium), Honorary degrees: Queen Mary University of London, Plymouth University (UK), U. Bern (CH). Distinguished Visiting Scientist, NASA Jet Propulsion Laboratory, USA. Arthur C. Clarke award (UK), Gold Medal, Confederation of European Aeronautical Societies, Silver Medal, Royal Aeronautical Society, Patron, British Science Fiction Foundation. 1981 Macelawane Award (AGU)

Key publications


Japheth Nesta Yates

Address
Space and Atmospheric Physics
Imperial College London
South Kensington, London, SW7 2AZ, UK

Telephone: +44 (0)20 7594 1155
Email: japheth.yates@imperial.ac.uk

Research Interests
Comparative planetology, in particular
- Gas giant magnetosphere-ionosphere-thermosphere (MIT) coupling
- Periodicities at Saturn: separating the northern and southern magnetic field oscillations
- The Jovian and Kronian magnetic and plasma environment

Employment
Postdoctoral research associate
Sept 2013 – Present
Imperial College, London, UK

Postdoctoral research associate
Feb 2013 – Aug 2013
University College London, London, UK

Education
University College London
PhD in Astrophysics
Title: Influence of solar wind on the Jovian thermosphere.
Physics MSci – First Class Honours
Sept 2004 – June 2008

Technical skills
Theoretical and numerical modelling; Data analysis; Signal Processing; Machine Learning; Programming with FORTRAN, C++, Java, Python, OpenMP, MPI, Matlab and LaTeX. Experience with Microsoft Windows, Mac OS X, Linux distributions and High Performance Computing.

Professional Memberships
Fellow of the Royal Astronomical Society
Member of the European Geosciences Union
Member of the American Geophysical Union

Professional Achievements
Co-Leader of the ‘Coordinated numerical modeling of the global Jovian and Saturnian systems’ ISSI team
2013, 2014: Convener of ‘Aeronomy of giant planets’ session at EPSC
2013: Invited seminar at University of Leicester
2012: Invited seminar at Imperial College London

Relevant Publications
Four publications (3 published, 1 accepted), three as first author

Shengyi Ye
203 Allen Hall, Iowa City, IA, 52242
Office: 319-335-1699
shengyi-ye@iowa.edu

EDUCATION
Ph.D., Physics, Dartmouth College, Hanover, NH, USA (2007)
B.S., Physics and Economics, Tsinghua University, Beijing, China (2000)

AREA OF SPECIALIZATION
Space physics

WORK EXPERIENCE
Associate Research Scientist, University of Iowa, 2014 - present
Assistant Research Scientist, University of Iowa, 2009 - 2014
Post-Doctoral Scholar, University of Iowa, 2007 - 2009

PROJECT EXPERIENCE
Cassini Radio and Plasma Wave Science (RPWS) experiment
Rocket and Ground-based observation of auroral radio emissions

PROFESSIONAL SERVICE

HONOR AND AFFILIATION
Member of American Geophysical Union
Outstanding Student Paper Award, AGU fall meeting, 2004
Dartmouth Teaching Fellowship, 2001-2005

RELATED PUBLICATIONS
Fischer, G., D. A. Gurnett, W. S. Kurth, S.-Y. Ye, and J. B. Groene, Saturn kilometric radiation periodicity after equinox, under review ICARUS.
Brief CV

ZARKA Philippe
Senior Research Scientist (Directeur de Recherche de 1ère classe) at CNRS
LESIA (Laboratoire d'Etudes Spatiales et d'Instrumentation en Astrophysique), Observatoire de Paris, 92195 MEUDON, France
E-mail: Philippe.Zarka@obspm.fr

PhD in Astrophysics, 1984, Université Paris VI.

Fields of Interest: Low Frequency Radioastronomy (ground-, space-, and moon-based), Plasma Physics & Signal and Data Processing, mainly applied to Planetary Physics (atmospheres, ionospheres, magnetospheres) and Extrasolar planets (theory and search of radio emissions) + Sun and Pulsars.

Involved in the missions:
- Voyager, Ulysses, Cassini, Stereo, JUNO, BepiColombo, JUICE ... (in space) + Moon, Earth & Uranus projects
- Nançay Decameter Array, Kharkov Decameter Array, LOFAR (PI of Planets WG), PI of NenuFAR project (on the ground)

>180 publications in international peer-reviewed journals (>4300 citations in ADS, H-factor 35), 2 books and >10 book chapters.


Supervisor of 9 PhD students, 4 post-docs, many Master students.

Responsible for reasearch programs (INTAS x2, ANR x2, PICS).

SOC & LOC member of > 25 national and international conferences.


Member of several scientific councils, national (Nançay, LESIA, CNRS/INSU, French LOng Wavelengths consortium) & international (LOFAR builders list & Transients Key Project, SKA WG)

Vice-Director of the Nançay Radioastronomy Observatory.

Selected Relevant Publications