

REPORT on the LAM2002 WORKSHOP:

The LAM2002 workshop, which was held at the Laboratoire d'Astrophysique de Marseille in France on November 12-13, 2002, was dedicated to the remote-sensing of planetary auroral emissions and focused on Jupiter and Saturn. It gathered scientists with varied expertise (theory, modeling, data analysis, instrument development) in magnetospheres and ionospheres of the giant planets. The primary scientific goals of this workshop were to identify needs and to coherently strengthen the effort in auroral science within the scope of on-going and future space missions. The workshop was intended to initiate, to stimulate, and to consolidate collaborations between different groups from France, UK, and USA.

Studies of the aurora constitute a fundamental component of geophysical research. Auroral emissions, observed throughout the solar system, offer us unique and extremely valuable opportunities for remote-sensing different magnetic field configurations. They are a tracer of plasma interactions and an indicator of the atmospheric composition and energy source. But what is an aurora? An aurora is defined as any optical manifestation of the interaction of extra-atmospheric energetic electrons, ions, and neutrals with the atmosphere. For the giant planets, the energetic source is of magnetospheric origin. The players are then the magnetosphere, the upper atmosphere, the precipitating energetic particle source, and the resultant emissions. Even though not explicitly included in the definition, radio emissions associated with aurora are also under focus.

Jupiter was chosen as center of interest, because the Jovian auroral emissions are the most powerful in the solar system and therefore, the most studied after Earth's. They have been observed over the whole spectral range, from X-rays to infrared and radio. Several space missions have been proposed for improving our understanding of plasma processes in the Jovian magnetosphere. Jupiter is also the most massive planet of the solar system. Its study may be of interest for extrapolation to the exoplanets discovered to date. Saturn, which is an intermediate case between Jupiter and the Earth in terms of magnetospheric drivers, gathers all the focus in the dawn of the arrival of the Cassini probe in its environment in July 2004.

The workshop was articulated around the following topics: magnetic field and energetic particles in the inner magnetosphere; electrodynamics in the auroral regions; multi-spectral observations of the aurora; ultraviolet (UV) instruments recently developed; exoplanetary aurora; and on-going and future space missions. We do not want to provide a comprehensive review of the presentations here. The program of the workshop along with the oral presentations can be found at:
http://www.astrsp-mrs.fr/private/seminar/workshop_galand2002/marinaindex.html.

Here we present few of the collaborative projects, which emerged during the workshop and which need to be carried on.

(1) Magnetic field model for the interpretation of auroral images

Deriving the magnetospheric source region of auroral emissions from spectral images requires knowledge of the magnetic field configuration. The identification of the source region is thus very sensitive to the magnetic field model used. There is a real need for accurate magnetic field models over the high latitude regions. In particular, the Jovian

model needs to be extended to polar cap regions. This would help to differentiate between cusp and polar cap emissions and thus to identify the source region of the variable, dayside, auroral emissions seen in UV.

(2) MI coupling theory and auroral images

It has been quantitatively shown that the Jovian main oval is induced by MI coupling currents associated with the departure of the plasma from the rigid corotation in the middle magnetosphere [Cowley and Bunce, Planet. Space Sci., 2001]. Unlike the Jovian case, the main oval at Saturn, clearly asymmetric in UV, has an origin which is still not understood. Analysis of UV images has also shown that the incident particles have low energy. Further theoretical studies supported by a better knowledge of the auroral variability and by multi-spectral observations are needed to identify the different mechanisms and sources at the origin of the main oval at Saturn.

(3) Plasma model as input of auroral models

For describing the transport of precipitating energetic particles in the atmosphere or for modeling the ionospheric processes at high latitudes, one needs to know the characteristics of the energetic particles at the top of the atmosphere. For Jupiter, first estimates are derived from auroral images taken in different spectral windows. Emissions from one window undergo strong extinction by methane. The emissions from the other are not significantly affected by methane absorption. The ratio is a function of the mean energy of the incident particles. For Saturn, such an approach is difficult to apply. The incident particles have too low an energy to reach the hydrocarbon layer. Magnetospheric modeling could provide information on the high latitude ionospheric drivers, but currently large uncertainties on inputs and poor understanding as explained in (2) prevent such an approach for Saturn.

Another approach for estimating the particle energy auroral input appeals to in situ particle data from which a statistical plasma model can be derived. The first plasma model for Saturn was obtained from Voyager data. It will be of great relevance to modelers of the ionospheric auroral processes to develop a more comprehensive plasma model, extending to high latitudes, from the upcoming Cassini particle data.

(4) Trapped particles and low latitude X-rays

The model of trapped charged particles in the inner magnetosphere (radiation belts) has been applied to electrons and protons at Jupiter. Comparison of modeling results to the induced synchrotron emissions provides a better constraint to the model. To extend such a model to heavy ions (O^+ , S^+) will provide crucial information for the interpretation of the low latitude X-ray emissions seen at Jupiter. The auroral origin of these emissions is still under debate.

(5) Energetic Neutral Atoms (ENA) at Titan

Even though not the prime object of focus, Titan was discussed during the workshop. A global model of its upper atmosphere has been developed. The neutral escape computed at its upper altitude boundary is of use to exospheric models of Titan. Such a study would be supported by the ENA imaging from Cassini.

(6) Jupiter and exoplanets

The hundred or so exoplanets discovered to date can be considered either as low-mass, cold stars, or as massive, hot Jupiter-like planets. The latter can be studied by extrapolation of solar system bodies, as has been illustrated for radio emissions [Zarka, et al., *Astrophys. Space Sci.*, 2001]. A better understanding of the processes occurring at the giant planets, especially at Jupiter, will provide a solid basis for exoplanetary studies. The coming years, or perhaps the more distant future, should provide unambiguous observations of transmission spectra of the star light through the exoplanetary atmosphere and direct detection of atmospheric emissions from the exoplanet. The presence of a magnetosphere is expected to be detected through cyclotron radio emissions in the near future. All these remote-sensing observations, some of possible auroral origin, will offer crucial information about these distant planets.

TABLES

Jovian aurora has been observed over the whole spectral range. With a fruitful set of multi-spectral observations, it appears timely to gather prime characteristics of the main features identified so far. This information was collected during the meeting and is summarized in Tables 1 (Jupiter) and 2 (Saturn). Most of the auroral features seen in different spectral windows overlap well within the actual spatial resolution of each spectral range. This multi-spectral information may provide clues to the magnetospheric source, which is still under debate.

In order to better define the needs for future missions, measurement characteristics over the different spectral ranges were gathered for Jupiter (Table 3), for Saturn (Table 4), and, for comparison, for the Earth (Table 5). Even though not yet complete, this survey was constructive. Recent observations from HST to Chandra, from Galileo to IRTF, have revealed the main auroral features. These different auroral regions are now well identified (which does not exclude the finding of new features at higher spatial resolution and sensitivity). Despite the difference in spatial resolution over the spectral window, the prime focus for the years ahead was unanimously given to the dynamics of the auroral features through long time coverage and, when possible, time resolution. On HST or Chandra it is not possible to get extended observation time. This makes it difficult to study the time variability of the auroral emissions and their connection to the environment (such as to a CME). Dedicated instruments/missions offering a large coverage over time seem to be essential for further understanding of the auroral features of Jupiter and Saturn.

SPACE MISSIONS

- **Earth-orbiting satellites: JMEX and m-OUVRAJES**

Advantages:

- Large time coverage (compared with other Earth-orbiting satellites, such as HST and Chandra), because the instruments are primarily dedicated to the observations of Jupiter and Saturn

- The observations of the global structures over long time intervals are suitable for the study of the dynamics of auroral features. The time resolution needs to be sufficient for the understanding of the origin of the variability.

Note that a radio experiment requires a rotating platform for polarization, whereas the classical UV imaging needs a fixed platform. Tomographic techniques applied to UV imaging may be the answer.

- **Space probes: Cassini, JPO, JASSI**

Advantages:

- Due to the proximity of the probe to the planet, the spatial resolution of the images is excellent. Remote-sensing observations can have improved temporal or spectral resolution.
- Such a mission offers viewing geometry not reachable from Earth orbits, such as a polar view (the most suitable for global view of the auroral regions) and nightside viewing (crucial for full longitudinal coverage; required for the detection of auroral emissions in the visible)
- In-situ measurements: with close orbits, in-situ measurements of particles and fields associated with the auroral regions are of great relevance. For example, it will help to track waves and to look for the acceleration region at the origin of the auroral emissions.
- Access to micro-physics, whereas from an Earth-orbit only the global structure can be studied.
 - **Cassini** will arrive at Saturn in July 2004. It will spend 80 hours above the auroral zone ($R < 5R_S$) + 44 Titan flybys (for studying Titan-Saturnian magnetosphere interaction). Auroral campaigns are planned with UV, visible, and IR observations along with in-situ measurements (particles and fields). Data will be released after one year. Earlier access may be possible through the instrument PI.
 - **JPO** (Jupiter Polar Orbiter) is a candidate for “New Frontiers” mission at NASA and was recommended by both Planetary and Space physics NRC reports. Close orbits would be of use to in-situ measurements (especially in the radiation belts), whereas high altitude orbits ($\sim 20R_J$) would allow polar imaging of the entire auroral oval.
 - **JASSI** (Jupiter Deep Atmospheric Sounding System and Imager), a Jupiter polar flyby, is a candidate for “Discovery” mission at NASA. The workshop participants unanimously agreed auroral science should be incorporated in the polar flyby which offers a very interesting viewing geometry. Remote-sensing imaging has the highest priority. The in-situ instruments should only be considered if the flyby reaches low altitudes, which imposes a shorter mission life.

There was a consensus among the attendants of the workshop for a need for multi-spectral imaging in UV, IR, X-rays, and visible, by decreasing order of priority.

Hope that this workshop has been useful to some of you and will lead to fruitful collaborations!

With our best wishes for a bright future in auroral science,

Marina Galand and Michel Blanc.

P.S.: If you need further information on the workshop or if you have any comments regarding this report, please contact Marina Galand (mgaland at bu.edu) or Michel Blanc (Michel.Blanc at oamp.fr)