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COMMISSION 16 — PHYSICAL STUDY OF PLANETS AND SATELLITES

ÉTUDE PHYSIQUE DES PLANÈTES ET DES SATELLITES

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TRIENNIAL REPORT 2006 - 2009

1. Introduction

This report is divided in four parts: the first part summarizes the activities of the Commission between September 2006 and June 2008; the second part reports on recent advances in the physical study of planets and satellites. However, instead of attempting to cover the large body of new knowledge gathered over the last three years, we have chosen to highlight just a few exciting results – on Mercury, the exploration of unchartered terrains with ground-based imaging and a new measurement of its libration parameters, some spectacular findings from the *Cassini* mission inside the Saturnian system, and the results of methane-band spectrophotometric monitoring of Saturn over the last 13 years; the third part summarizes future plans now being drawn by the various space agencies for the exploration of planets and satellites in the solar system; the last part tries to project the activities of the Commission over the period June 2008–August 2009, and to express a few thoughts concerning the future developments in the field, and the role of the Commission therein.

2. Activities during the past triennium (up to June 2008)

Members of the Organizing Committee met during the Annual Meeting of the Division for Planetary Sciences of the American Astronomical Society held in Orlando in October 2007. This was our first meeting since the IAU XXVI General Assembly in Prague. Besides regular organizing matters, we discussed the opportunity of proposing a Special Session at the next General Assembly (see below), as well as a recurrent concern which is the visibility of the Commission among the planetary science community, and especially the younger cohort. One idea put forward was to organize an informal event tentatively entitled *Meet the IAU/Commission 16* at the next AAS/DPS meeting to be held in Ithaca in October 2008, to present the objectives and activities of the Commission (and of the IAU in general) to those who are less informed about them. Another recurrent topic which was discussed is the idea of communicating with the membership through a regular electronic bulletin. There was a timid attempt at doing so with the first edition of *PS*^{2} *News* in May 2007. However, this attempt has not been re-iterated, as the incoming of publishable material was rather low. Nevertheless, the project is still on the table and will eventually be addressed in other ways in the future.

In response to the call for Scientific Meetings to be held during the IAU XXVII General Assembly in Rio de Janeiro, the Organizing Committee, in coordination with the Organizing Committees of Commission 51 on *Bioastronomy - Searchfor Extraterrestrial Life* and Commission 53 on *Extrasolar Planets*, put together a proposal for a Special Session devoted to planetary systems seen in the light of the emergence and sustainability of life. This is a rapidly evolving field for which a review of the most recent results would be of great interest to many of our colleagues attending the General Assembly. Moreover, one of the objectives of this meeting (and not the least) is a strengthening of the relationships between the three Commissions dealing with planetary systems within Division III. The Executive Committee has responded favorably to our proposal, advising us to merge with another similar proposal emanating from Commissions 51, 53, and 55 (*Communicating Astronomy with the Public*). Undoubtedly, the individuals involved in these two proposals will work together to design an exciting session in Rio de Janeiro.

As part of his duties, the President of the Commission participated in the activities of the Working Group for *Planetary System Nomenclature* (see the report from the WG-PSN) and responded to the call for ideas emanating from the Executive Committee about the opportunity of coining a new term replacing *dwarf planet*. In May 2008, the term *plutoid* was adopted by the Executive Committee to designate transneptunian dwarf planets, as required by Resolution B6 voted by the IAU XXVI General Assembly. We deplore, however, that a breakdown in communication led to this decision without formal votes by the WG-PSN and the Board of Division III.

3. Recent advances in the study of planets and satellites

3.1. *Mercury: Ground-based surface imaging and new libration parameters*

The work of Ksanfomality & Sprague (2007) presents results from the processing of images of Mercury acquired during the 2002 spring (evening) elongation to map districts containing the largest impact craters on the surface of Mercury. These impact craters show ringed structures with and without a system of rays. Craters are found in practically all areas of the 210-290°W sector. In all versions of the synthesized images, the Northern horn near the pole shows a large shock crater of about 280 km in diameter, with an extensive rim of debris and a 90 km wide dark central spot. The latitude of this large crater is 85∘N. Closer to the North pole by 2–3° is a smaller crater of about 60 km in diameter. At the time of the observations, the North pole was off by a few degrees from the limb, and was therefore in view. Because of the proximity to the pole and some blurring on the limb, the longitudes of craters near the pole are determined with a probable error no better than 5°. Nevertheless, their positions could be compared to independent data, i.e., a detailed radar map showing a group of large impact craters, with a resolution of up to 1.5 km (Harmon *et al.* 2001). Apparently, these craters are also visible in our synthesized images. The comparison with the radar map shows that the size and position of the 85°N crater coincide almost exactly with a crater in the radar map centered at 85.5°N, 292°W, with a diameter of about 80 km. Interestingly, the rim of debris on the radar map is seen only on the Northern side of the crater, without much detail, while in the optical image, a terrace of debris surrounds the crater, and the rim is visible as a bright formation. According to Harmon *et al.* (2001), craters at the pole are unusual in that at their bottom, under a layer of regolith, are apparently large amounts of ice. The bottom of these polar craters always remains in shadow and the temperature is low enough that ice could have subsisted on a cosmogonic timescale. Another hypothesis is

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that elemental sulfur, which in the decimeter radar range has scattering characteristics similar to that of ice, has been deposited at the bottom of these craters (Sprague *et al.* 1995).

As mentioned in previous works, expositions at morning elongations much improve the resolution of astronomical images. Although the use of short exposures to increase the resolution of astronomical images has existed for a long time, only the advent of high quantum efficiency CCD devices made it possible to obtain well-resolved images of Mercury, by processing a large number of electronic short-exposition frames. This is illustrated by new images of the longitude sector 270–330°W, which cover significant portions of Mercury's surface not imaged by *Mariner 10*. They seem to confirm that extended relief features are asymmetrically distributed on the surface of the planet (Ksanfomality 2005). Also, during the May and November 2007 elongations, new observations of Mercury were carried out at the SAO Observatory of the Russian Academy of Science, allowing to further document areas not imaged by *Mariner 10*. A continuous sequence of video frames was acquired with real-time A/D conversion and recording. The analysis of these new data is in progress.

On the basis of the Radar Speckle Displacement Interferometry (RSDI) method suggested by Holin (1988, 2004) , Margot *et al.* (2007) used the 'Goldstone/Green Bank' interferometer to derive the inclination and amplitude of the 88 d libration of Mercury from the radar-location components of its instant spin-vector. Simultaneously, they checked for the conformity of Mercury to the Cassini state 1 (no significant deviation was found). The values obtained for the inclination and amplitude are respectively 2.11'±0.1' and 35.8"±2" (compared to a previous determination of 60"±6"). Based on these results, they concluded that the libration of the shell occurs separately from the core, which would imply the presence of a liquid phase in the core (Margot *et al.* 2007). According to Holin, however, the precision of the amplitude determination is at odds with the theoretical limit he derived earlier. Therefore, this work should be carefully verified. The work of Margot *et al.* (2007) is the first practical use of Holin's method, which could bring forth considerable progress in solar system research. There are opportunities connected to the possible creation of a new planetary radar in Euro-Asia or North Africa where, due to the set of existing radiotelescopes (mainly in Europe), the accuracy of RSDI measurements would improve considerably (Van Hoolst *et al.* 2007). One of the suggested locations for the creation of a radar-tracking complex is Northern Caucasus.

3.2. *Findings from the Cassini mission inside the Saturnian system*

The Cassini spacecraft has now completed its nominal 4-yr mission at Saturn and entered a 2-yr extended mission to last until June 2010. The last two years, especially, have been rich in spectacular findings. For instance, on Saturn, the imaging experiment ISS showed that the South polar vortex shares some properties with terrestrial hurricanes: cyclonic circulation, a warm central eye surrounded by a ring of high clouds (the eyewall), and convective clouds outside the eye (Dyudina *et al.* 2008). Thermal mapping with CIRS showed that both poles exhibit similar tropospheric and stratospheric cyclonic hotspots, though only the North pole shows a coherent hexagonal structure below 100 mbar, whereas in the South polar vortex, a circumpolar jet at 87°S coincides with the eyewall and deep-cloud clearing (Fletcher *et al.* 2008). Also from CIRS data, Fouchet *et al.* (2008) found evidence for an equatorial oscillation like those on Earth and Jupiter.

On Titan, the ionospheric composition analysis with INMS shows that the most abundant species is $HCNH^+$ (m = 28), as predicted by pre-*Cassini* models. Other confirmed predictions include $C_2H_5{}^+$, $CH_5{}^+$, $C_3H_5{}^+$, $C_7H_7{}^+$, and $C_3H_3N^+$ (Cravens *et al.* 2006).

The spectral properties of the surface in the near-infrared has been investigated with VIMS (Barnes *et al.* 2007). The gas composition has been analyzed with CIRS (Coustenis *et al.* 2007; Teanby *et al.* 2007; de Kok *et al.* 2007). The surface morphology has been partially unveiled with RADAR, which detected volcanic features (Lopes *et al.* 2007), sand dunes (Lorenz *et al.* 2006), impact craters (Lorenz *et al.* 2007), as well as vast expanses of low-reflecting material near the North pole, most probably lakes of liquid methane (Stofan *et al.* 2007). That instrument also revealed a slowdown of Titan's rotation, suggesting the presence of a subsurface ocean (Lorenz *et al.* 2008).

On Enceladus, the first close flyby led to the detection of a dynamic atmosphere by the Magnetometer (Dougherty *et al.* 2006). ISS subsequently observed jets of fine icy particles emanating from the South pole and carried aloft by water vapor probably venting from subsurface reservoirs of liquid water (Porco *et al.* 2006). CIRS confirmed hot spots associated with the vents (Spencer *et al.* 2006). Chemical analysis of the plume with INMS (Waite *et al.* 2006) leads to an internal model in which aqueous, catalytic chemistry takes place within a very hot environment (Matson *et al.* 2007).

On Iapetus, especially in the equatorial regions, dark material tends to coat the equator-facing slopes of ridges and crater walls, as well as many crater floors. This strongly suggests the warming action of the Sun in removing bright ice from these sunward-facing surfaces and leaving behind the native dark material that is normally mixed with the ice.

A further extension of the mission is now under consideration by NASA, with the aim of reaching Northern summer solstice in 2017. No doubt such a *Cassini* Solstice Mission would gather an extraordinary body of data, the analysis of which could last many years.

3.3. *Methane band spectrophotometry of Saturn in support of Cassini*

The study of the variations of the methane absorption bands on Jupiter and Saturn has a long history at the Fessenkov Astrophysical Institute (Kazakhstan), beginning in the 1960s. During the last few years, these observations served as part of the ground-based astrophysical support of the *Cassini* mission at Saturn. The most interesting data were obtained during the period 1995 - 2008, thanks to the CCD-technique. The methane absorption, as well as other optical properties of the visible atmosphere and cloud cover, shows a clear North-South asymmetry, even at the time of the 'edge-on' viewing of the rings. During this event in 1995, we found that the CH_4 absorption bands were significantly more intense at temperate latitudes in the Southern hemisphere, compared with the Northern hemisphere. A reciprocal picture was observed for the limb-darkening coefficients in the continuum. In the Northern hemisphere, the coefficients were about 0.10–0.15 lower than in the Southern hemisphere, for similar latitudes. During the following years, up until 2008, the distribution of the CH_4 absorption with latitude varied as a function of the equator tilt, and for Northern temperate latitudes, a regular increase of the methane bands intensity was observed (Tejfel 2005; Tejfel *et al.* 2007). The depth of the 7252 nm band changed from 0.53 in 1995 to 0.74 in 2007 – 2008, with a linear trend that may be described as $R(Y) = 0.530 + 0.019 \times (Y–1995)$, where Y is the year. Spectrophotometric observations of Saturn in 2007 and 2008 have detected clear differences in the behavior of weak and strong methane bands in the Northern and Southern hemispheres. The equivalent widths of the relatively strong band at 725 nm are nearly the same in both hemispheres at temperate latitudes, but for weaker bands (619 nm and others), the equivalent widths in the Northern hemisphere are significantly larger than in the Southern hemisphere (Tejfel *et al.* 2008).

4. Future plans for the in-situ exploration of planets and satellites

In the USA, NASA has two different programmes for the in-situ exploration of the planets and their satellites:

(i) New Frontiers missions, ranging in cost from 500 to 800 M$, and responding to strategic targets specified in the Solar System Roadmap, i.e., from Venus to giant planets, but limited in scope in terms of the complexity of operational capabilities (for instance, robotic exploration is not envisaged within the frame of these medium-class missions). Within this program, the Venus in-situ *Explorer* (VISE, launch 2020), if selected, will study the composition and surface properties of Venus. It will acquire and characterize a core sample from the surface to study the mineralogy of surface materials. On the other hand, Jupiter *Polar Orbiter* (launch in August 2011, arrival in 2016) will map the gravity field, magnetic field and atmospheric structure of Jupiter from polar orbit. Furthermore, a Jupiter *Multi-Probes* mission and a Saturn *Multi-Probes* mission are in the conceptual design phase, both with a 2020 launch timeline.

(ii) *Flagship* missions, ranging in cost from 800 to 1400 M$ or from 1400 to 2800 M$. These missions will be crucial in reaching and exploring difficult but high-priority targets: complex missions to the surface of Venus, the lower atmosphere and surface of Titan, the surface and subsurface of Europa, the deep atmosphere of Neptune and the surface of its moon Triton. Besides the *TandEM/TSSM* (to Titan and Enceladus) and *Laplace/EJSM* (to Jupiter) international missions (see below), two more are contemplated by NASA: *Enceladus Explorer* (in the planning stage and likely to be part of the *TSSM* mission), and *Europa Astrobiology Lander* (in conceptual design with a 2030 launch timeline).

Within the European Space Agency, the massive response by the scientific community to the 2004 call for themes has been synthesized into the Cosmic Vision 2015 - 2025 plan. To address the fundamental questions delineated in this programme, Announcements of Opportunities for missions were issued in March 2007, and candidate missions were selected in October 2007 for further assessment and consideration for launch in 2017/2018. For the study of planets and satellites, two missions were selected: *TandEM/TSSM* (to explore Titan and Enceladus), and *Laplace/EJSM* (to explore Jupiter and the Galilean Satellites). These are L-class missions, with a cost at completion to ESA below 650 million euros. The assessment studies are carried out jointly with NASA, and with NASA and JAXA, respectively, since both these agencies currently envisage a mission to the outer Solar System. The *TandEM/TSSM* mission aims at an exhaustive in-situ exploration of Titan and Enceladus with an orbiter (NASA responsability), a montgolfiere-type balloon, and two landers (ESA responsability). The study of Jupiter and the Galilean Satellites with *Laplace/EJSM* was conceived as a set of three satellites for which ESA, NASA and JAXA would share responsabilities: *Jupiter Europa Orbiter* (*JEO*), *Jupiter Magnetospheric Orbiter* (*JMO*) and *Jupiter Planetary Orbiter* (*JPO*). ESA is expected to make a selection between these two missions in consultation with its foreign partners in the coming years.

For its part, the Japanese space agengy JAXA is planning the exploration of Venus with the *PLANET-C* (or *Venus Climate Orbiter*) mission. The main objectives are: to elucidate the mechanism of 'super-rotation' of the atmosphere through 3-D mapping down to the surface (at UV, IR and radio wavelengths), and to search for active volcanism and lightning. The probe is scheduled to be launched in June 2010 and orbit insertion is expected in December 2010.

5. Projected activities and future developments

In the coming months, Commission 16, together with Commissions 51 and 53, will be active in preparing a Special Session for the IAU XXVII General Assembly. The scientific program has already been outlined, but the task of securing the participation of considered speakers needs to be rapidly completed, as well as the promotion of the session among the planetary science community. The latter would be an excellent motivation to implement a new attempt at editing an electronic bulletin. The Commission will also work towards a significantly stronger participation from younger researchers in its activities. This will include encouraging the new generations of planetary scientists to become members of the IAU, with a main affiliation to Commission 16.

The next decade will see the begining or the completion of a number of space missions, to Mercury, Venus, Mars, Jupiter, Saturn, and Pluto. The role of the Commission should be significant in fostering effective ground support for these planetary missions, as well as a wide participation in the interpretation of the data that will be harvested.

In the area of communicating astronomy with the public, the Commission intends to be active in encouraging and sponsoring Saturn Observing Night events, particularly during the *International Year of Astronomy* in 2009, and in the following years.

Régis Courtin
president of the Commission

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