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FIFTH IAA SYMPOSIUM ON REALISTIC NEAR-TERM ADVANCED SCIENTIFIC SPACE MISSIONS

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FIFTH IAA SYMPOSIUM ON REALISTIC NEAR-TERM ADVANCED SCIENTIFIC SPACE MISSIONS

SOME RECENT RESULTS FROM THE CASSINI TITAN RADAR MAPPER*

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Several flybys of Titan have been successfully performed by the Cassini spacecraft. Among its instruments is a radar mapper, which can obtain images of the Titan's surface through its dense atmosphere. A complete scientific investigation will be conducted after the end of the mission, when all the data from all the instruments will be available, this paper aims summarize some of the preliminary results obtained by the Titan Radar Mapper.

Keywords: Cassini mission, Titan, Titan Radar Mapper

1. INTRODUCTION

July 1st, 2004: after a journey across the solar system lasting more than 6.5 years, the Cassini spacecraft successfully accomplished the Saturn Orbit Insertion maneuvers by approaching the planet from below its rings plane which has been crossed through the large gap between the F Ring and G Ring. This event marked the beginning of a four years tour, to explore Saturn and its moons, by making 74 orbits around the planet, using the flybys of Titan, the largest moon of Saturn, for gravity assists, changes in orbital paths and science data acquisition. The overall mission will include 74 orbits of Saturn, 44 flybys of Titan, 8 close flybys of other Saturn's moons (3 for Enceladus, one each for Phebe, Hyperion, Dione, Rhea and Iapetus), further 30 flybys of satellites at larger distances.

One of the most remarkable events of 2004 has been the release of the ESA's Titan probe Huygens towards the largest moon of Saturn on December 25th. The Probe coasted for 21 days en route to Titan and finally, on January 14th, 2005 successfully accomplished its descent mission and astonished the world with the images of an unexpected planet-like moon.

At the time of the *"4th Symposium on Realistic Near-Term Advanced Scientific Space Missions"*, on July 2005, the attention was mainly attracted by this first descent of a man made object on the surface of another planet's moon. Therefore a companion paper by the same author [1] was contributed to the symposium, aimed at tracking back the major events of the Cassini program, at describing the system and, in particular, the Italian contributions to it as well as their key role in obtaining two important scientific results on relativity testing [2, 3].

Since then, the Cassini mission is continued according to the plans, and several flybys of Titan, one of the most important targets of the program, have been successfully accomplished, allowing to gather a large amount of data on this intriguing moon, the view of which surface by optical instruments is prevented by the its thick atmosphere. Therefore, among the instruments of the Cassini payload there is a radar specially devoted to the investigation of Titan.

After a short review of the Cassini spacecraft, it is the purpose of this paper to concentrate on the radar instrument and on some of their results.

2. THE CASSINI SPACECRAFT

With a mass of 5712 kg (3132 kg of which being devoted to the propellant), Cassini carries 270 kg of scientific instruments, see Table 1, and 320 kg of the probe Huygens, which has already accomplished its descent mission on Titan.

The right column of the above table points out that the task of acquiring data on the morphology of the Titan's surface is assigned to the Titan Radar Mapper (TRM), during most of the planned 44 flybys of that moon, 31 of which have already been performed as of May 28th, 2007.

Of course during each flyby a small part of the Titan surface will be imaged, therefore the detailed investigations by the worldwide scientific communities will continue for years after the completion of the Cassini mission, when all the data will be available. Nevertheless some features of the Titan's surface are still evident, e.g. impact craters, fluvial channels, features that may be longitudinal dunes.

3. THE TITAN RADAR MAPPER

As anticipated in the introduction, the presence of a Radar on the Cassini spacecraft has been motivated by the mission objective of investigating the Titan's surface through its dense atmosphere, which does not allow the use of optical instruments, as it is evident in Fig. 1 [4]

Based on the agreements between NASA and ASI, the radar has been jointly developed by the Jet Propulsion Laboratory and Thales Alenia Space. Figure 2 [5] shows some members of the joint team during a test of the radar prototype.

* This paper was presented at the Fifth IAA Symposium on "Realistic Near-Term Advanced Scientific Space Missions" in Aosta, Italy on 2-4 July 2007.

TABLE 1: *Scientific Payload of the Cassini Spacecraft.*

Cassini Plasma Spectrometer (CAPS)	Explores plasma within and near Saturn's magnetic field
Composite Infrared Spectrometer (CIRS)	Studies temperatures and compositions of Saturn and its moons and rings
Cosmic Dust Analyzer (CDA)	Studies ice and dust grains in and near the Saturn system
Dual Technique Magnetometer (MAG)	Studies Saturn's magnetic field and its interactions with the rings, the moons, and the solar wind
Imaging Science Subsystem (ISS)	Takes pictures in visible, near-UV, and near-IR light
Ion and Neutral Mass Spectrometer (INMS)	Studies extended atmospheres and ionosphere of Saturn, Titan and icy satellites
Magnetosphere Imaging Instrument (MIMI)	Takes pictures of the distribution of charged particles in and near Saturn's magnetic field
Titan Radar (TRM)	Maps the surface of Titan and measures the height of its surface features
Radio and Plasma Wave Science (RPWS)	Investigates plasma waves, natural emissions of radio energy, and dust
Radio Science Subsystem (RSS)	Searches for gravitational waves: measures masses and structures of atmosphere
Ultraviolet Imaging Spectrograph (UVIS)	Studies structure, chemistry, and composition of atmospheres and rings
Visual and Infrared Mapping Spectrometer (VIMS)	Identifies chemical composition of surfaces, atmospheres, and rings

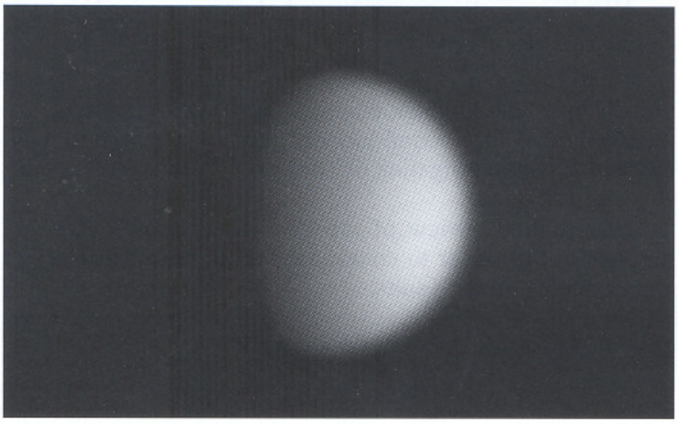

Fig. 1 The moon Titan. (JPL/NASA/Space Science Institute)

The radar has been described in several papers, e.g. [6]. A brief summary is given here below.

The selected operating frequency of 13.8 GHz is the result of several trade-off to optimize the instrument in terms of predicted atmospheric propagation loss, resolutions of measurements and detection sensitivity. The radar shares the 4 meters reflector of the High Gain Antenna, which hosts the instrument RF feed. In order to extend the illuminated area, a multiple radar feed structure has been adopted to generate five antenna beams adjacent to each other in the across-track direction (Fig. 3).

For scientific purposes, the TRM is a multimode radar, i.e. it can be used as an imaging instrument, an altimeter, a scatterometer and a radiometer. Furthermore, some key parameters, such as pulse width, bandwidth, receiver gain, pulse repetition frequency and other timing parameters, can be updated to adapt the instrument operations to the varying geometry of the flybys. All the above flexibility in operations results in a very robust instrument with respect to the uncertainties in the knowledge of Titan.

a) Imaging mode

The spacecraft can rotate around the along track axis, to illuminate, with the 5 antenna beams, the right or left side with respect to the motion direction. Of course the illuminated area depends on the distance between

JPL PHOTO LAB / P43638C

Engineers from Italy and JPL examine the Digital Subsystem (DSS) and the Radio Frequency Electronics Subsystem (RFES) of the Cassini Radar Instrument, built by the Italian aerospace firm Alenia Spazio for the Italian Space Agency. From left, Wai-chi Fang and Kevin Wheeler of Section 334, Enrico Zampolini, Roberto Chiappi, Leonardo Borgarelli and Marco Nati of Alenia Spazio; and Dr. Young Park, JPL's Cassini radar project manager.

Fig. 2 The joint JPL/Thales Alenia Space Team at work.

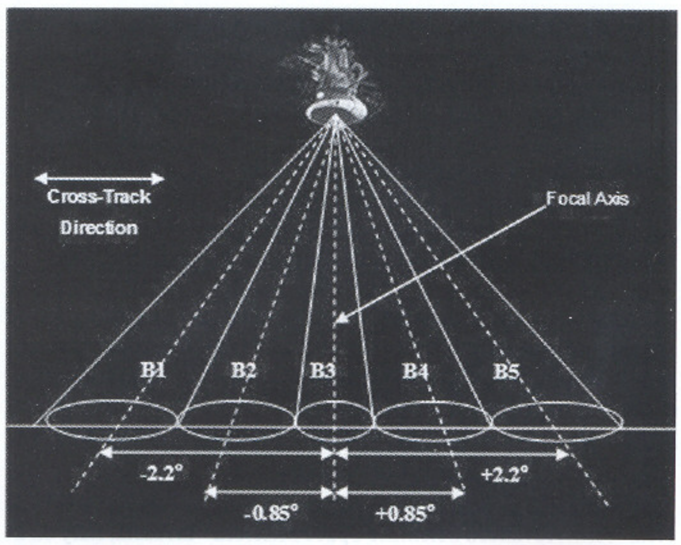

Fig. 3 Antenna beam configuration.

the spacecraft and the Titan surface, ranging from about 120 km for a distance of 1,000 km to about 460 km for a distance of 4,000 km. In the along track direction, the image resolution is obtained by synthetic aperture processing techniques being in the range of 350-720 m. In the cross track direction the resolution is obtained by pulse compression of a linearly frequency modulated (chirp) signal, which depends on the signal bandwidth and on the angle of incidence with the Titan surface. When the distance is lower than 1600 km, a bandwidth of 850 kHz is used and the corresponding resolution is in the range of 480-640 m; with a distance between 1,600 and 4,000 km and a bandwidth of 425 kHz, the resolution is 420 m-2.7 km.

b) Altimeter

This mode is used for topographic characterization of the Titan's surface. Only the quite circular central beam, the one looking at nadir with a -3dB beamwidth of 0.35°, is used in this mode. Also depending on the mission planning dictated by the resources sharing with the other instruments, the altimeter mode is not activated during all the flyby opportunities, therefore the altimetry maps will be limited in terms of Titan's coverage. The performance of this mode is a vertical resolution of about 50 m and a horizontal resolution (pulse limited techniques) in the order of 24-27 km.

c) Scatterometer

Used to characterize the different types of Titan's surfaces by measuring their radar reflectivity at different incidence angles, this mode is only activated at altitudes preliminarly estimated between 9,000 and 100,000 km. A small bandwidth of 106 kHz is used in this mode in order to ensure a sufficient signal detection with an anticipated radar backscattering coefficient as low as -35 dB (depending on the distance)

d) Radiometer

It is used to measure the emissivity of Titan at 13.8 GHz, in order to complement the data obtained by the active modes by providing additional inputs to the radar backscattering model of the Titan's surface. A very accurate calibration procedure has been included in the instrument to improve the accuracy of the measurements. The good performances of this mode of operation have allowed the detection of the Synchrotron Radiation around Jupiter [3].

Based on all the above considerations, and taking into account the geometry of a Titan fly-by, the different modes are activated according to a typical sequence as the one depicted in the Fig. 4.

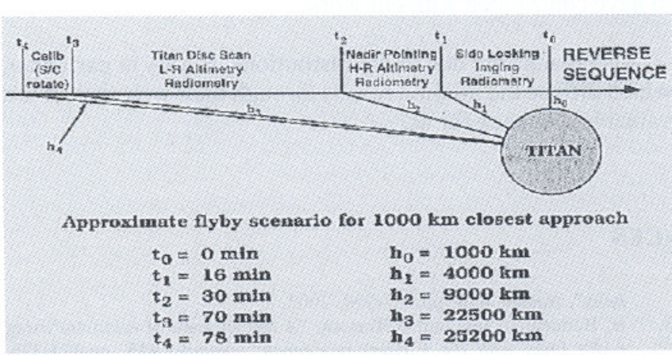

Fig. 4 The fly-by trajectory.

4. SOME RESULTS

Radar images of the Titan' surface have unveiled its face, showing an unexpected world exhibiting planet-like characteristics. Even if a lot of time will be needed for a exhaustive scientific investigation, several images have been diffused on web sites of the participating space agencies.

Some of them are given here below to show a sample of interesting features of Titan.

a) A possible impact crater

Impact craters play a key role in helping the scientific community to estimate the age of the surface of a celestial body. Up to now few impact have been detected on Titan: does it means that the surface of Titan is young?

Figure 5 [7] shows an area in the northern hemisphere of Titan, with feature, having a size of about 180 km, similar to those characterizing impact craters. It has been detected by the TRM during the fly-by of January 13th, 2007 (T23)

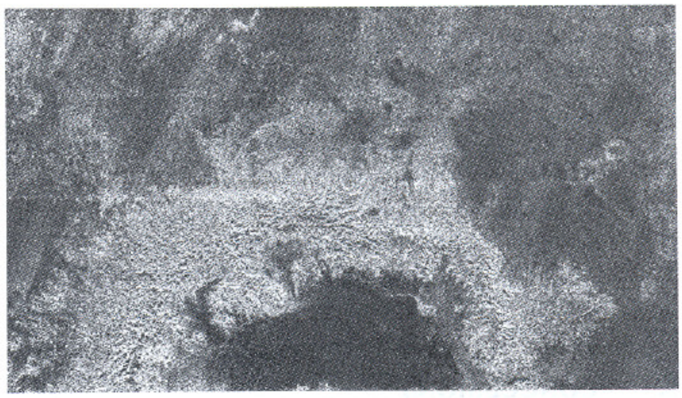

Fig. 5 An impact crater on Titan? **(NASA/JPL)**

b) An intriguing surface

Dunes are a quite common feature on the Titan's surface, in fact they appear in several radar images.

Figure 6 [8], taken by the TRM on the same T23 flyby of Fig. 5, shows some interesting features. The largest part of the image is covered by dunes, they are well detected by radar which is particularly suitable to identify morphologic features.

On the right side there is a brighter area, which seems to create an obstacle to the progress of the dunes. It is likely to be a surface feature at a different altitude with respect to the level of the dune field. A possible measurement with the radar in altimeter mode could confirm this interpretation.

Very interesting are the circular features on the top right side of the image. They could be impact craters. The dune like pattern on their borders seems to indicate that dunes are covering them.

c) Lakes

The evidence of "lakes" on Titan, gained with the flyby on July 2nd 2006 (see Fig. 7 [9]), confirms a prediction which dates back to the 80's.

In this figure, the black areas represents low backscattering targets, as it is in general the case for calm liquid surfaces, the white/light-grey represent higher radar backscattering zones, darker grey is intermediate between the two.

Fig. 6 Dunes, craters and highland. **(NASA/JPL)**

Fig. 7 A region of lakes. **(NASA/JPL/USGS)**

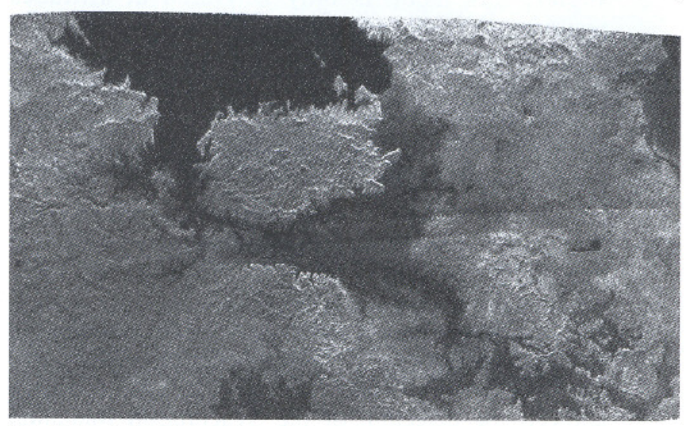

Fig. 8 An island in a large lake. **(NASA/JPL)**

Figure 8 [10] puts into evidence the dimension of some lakes of Titan.

In this radar image, taken during the flyby T25 on February 22nd, 2007, the lake contains a very large island of 90 km x 180 km.

Of course, the term "lake" is used here to mean a depression of the surface containing liquid, which, if confirmed by further analysis, and given the temperature of Titan (-180°C), could consist of hydrocarbons (e.g. methane).

5. CONCLUSIONS

The images in Section 4 represent only a very limited sample of those diffused by the entitled entities, NASA in particular. They have been selected as representative of some very interesting planet-like features of Titan.

Also radar altimetry measurements have been made during the fly-bys. First analysis, based on data from limited regions of the moon, has allowed a preliminary estimation of the Titan's radius at 2575.5 km +/-0.1 km, in good agreements with the estimation from the Voyager data. Titan appears characterized by flat regions.

It is most likely that several years will be necessary after the end of the Cassini mission to evaluate, analyze and correlate the large amount of data gathered by the payload's instruments. It is in any case evident that the preliminary results have already exceeded expectations.

ACKNOWLEDGMENTS

I wish to acknowledge all the persons involved in the operations and scientific activities of the Cassini mission: they give value to the work performed by those in charge of developing the instruments they use. It is indeed a strong motivation for us to follow their scientific investigations to which we are proud to have contributed with our work.

Also thanks are due to the institutions, NASA in particular, which diffuse the mission results through their web sites. It is a valuable feedback for us.

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