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Observing the deep atmospheres of gas giant planets by spacecraft

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Abstract

Two outer-planet missions are presently underway that include microwave instruments capable of observing the subcloud atmospheres of the gas giants Jupiter and Saturn. The first is Cassini, which has orbited Saturn since 2004 and contains a 2.2-cm wavelength microwave radiometer incorporated in its RADAR instrument [1]. The second is the Juno mission, which was launched in 2011 and will reach Jupiter orbit in 2016. Among other instruments, Juno contains a multi-wavelength (1.4 to 50 cm) Microwave Radiometer (MWR) instrument specifically designed to probe Jupiter's atmosphere deep below the visible cloud deck [2]. In this paper we will present global maps of Saturn at 2.2 cm obtained by Cassini and discuss their implications. The capability and expectations for the Juno MWR will then be discussed.

1. Introduction

The extended deep subcloud atmospheres of the giant planets Jupiter and Saturn can only be observed in the microwave region, at wavelengths significantly lower than the ammonia rotational band around 1 cm. Earth-based observations at very long wavelengths are inherently limited in spatial resolution, sensitivity, and frequency coverage. Observation by orbiting spacecraft, although difficult, can overcome these limitations and uncover presently unknown compositional and dynamical properties.

2. Mapping Saturn

Saturn was imaged by the RADAR radiometer on board the Cassini spacecraft during five equatorial periapsis passes occurring between 2005 to 2011. The observations were centered around periapsis to obtain the best possible resolution achievable with the relatively large beamwidth (0.35°) of the radiometer. Continuous pole-to-pole scans were made through nadir throughout the pass, allowing the spacecraft trajectory and the rotation of Saturn to sweep the scan westward in longitude. The resulting scans were calibrated and processed into maps as shown in Fig. 1.

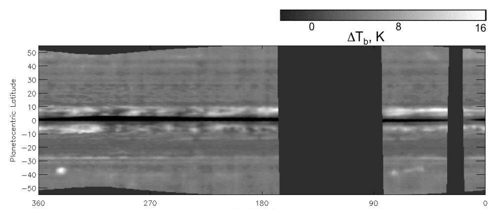

Figure 1: Saturn at 2.2-cm wavelength from observations obtained 9 Dec 2009.

The maps were absolutely calibrated to about 2K using observations of Titan [2]. The map is shown here in terms of residuals compared to a radiative transfer calculation for a model atmosphere with fully saturated ammonia. Among other things, the maps indicate a subsaturated cloud region with ~50% relative humidity in the midlatitudes, strong storm bands between about 3° and 10° latitude symmetric around the equator with ammonia depleted below the cloud deck, and a storm belt around 37° S.

3. Probing Jupiter

The Juno MWR is a six-channel radiometer with the characteristics given in Table 1. The Juno spacecraft will be placed into a highly eccentric polar orbit with an 11-day period and a periapsis altitude of about 4000 km, thereby avoiding the main radiation belts and allowing close observation of Jupiter by its several instruments. It is designed to achieve 33 orbits in all, at least six of which will be devoted to MWR observations. The MWR antennas are located on the sides of the spacecraft, which spins so that the antenna beams all sweep through nadir in a plane aligned with the Juno subspacecraft track. Each point along this track is thus observed multiple times at varying emission angles. Figure 2 depicts the half-power footprints of the antenna beams on Jupiter obtained during a pass.

Table 1: MWR Characteristics

Channel	Center Wavelength [cm]	NEDT [K/Hz$^{1/2}$]	Half-Power Beamwidth [°]
1	50	0.19	20.6
2	24	0.17	21.0
3	11.5	0.13	12.1
4	5.7	0.12	12.1
5	3.0	0.07	12.0
6	1.4	0.06	10.8

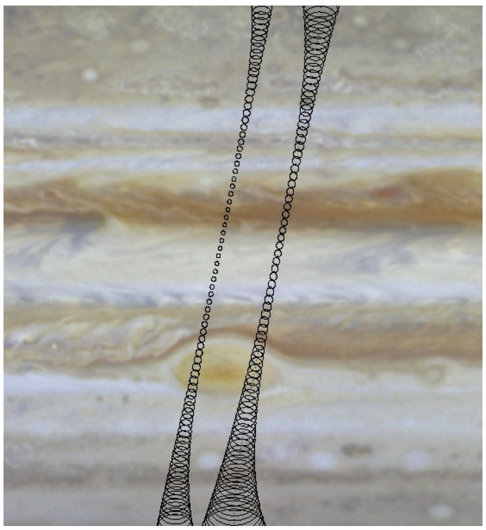

Figure 2: MWR footprints on Jupiter during a typical pass. The beamwidths of the six channels are either approximately 12° or 20°, the footprints for which are shown offset left and right respectively. Both sets of footprints actually lie on the same track but are shown separately for illustration here.

The MWR thus samples the atmospheric thermal radiation from depths extending from the ammonia cloud region at around the 1-bar pressure level to levels as deep as 1000 bars. Its primary scientific objectives are to determine the dynamical properties of Jupiter's subcloud atmosphere and to determine the global abundance of oxygen, present in the atmosphere as water deep below the visible cloud deck. The key to the experiment is the measurement of the emission angle dependence of the thermal radiation at each frequency relative to atmospheric local normal. Such a measurement can be made with with high accuracy and obviates the need for an extraordinary absolute calibration to recover atmospheric parameters.

4. Summary and Conclusions

Orbiting spacecraft provide a unique platform for the observation of gas giant atmospheres at wavelengths long enough to probe into regions that are otherwise inaccessible. Such observations can provide a new dimension for the development of general circulation models (GCMs), extending those based on cloud surface motions alone. Fundamental questions concerning deep circulations and composition may thereby be addressed.

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