Metric Observations of Saturn with GMRT and LOFAR

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Abstract: We used the Giant Metrewave Radio Telescope (India) and the LOFAR array (The Netherlands) to observe Saturn in the metric domain – at 0.49 m (610 MHz), 1.28 m (235 MHz), and 2.0 m (150 MHz) with GMRT and at 1.25-2.7 m (110-240 MHz) with LOFAR – with the aim of constraining the deep atmospheric ammonia and water vapor concentrations around 10-20 kbar. We have obtained a clean detection at 610 MHz, with a disk brightness temperature T_b= 216 $\pm$ 32 K, and no significant emission outside of the disk, thus confirming model predictions about the weakness of synchrotron radiation by magnetospheric electrons (Lorenzato et al. 2012). A marginal detection was obtained at 235 MHz, with T_b= 404 $\pm$ 249 K, while an upper limit of 1210 K was set at 150 MHz. Unfortunately, some of the GMRT or LOFAR measurements were affected by strong ionospheric scintillation or RFI interferences. Although the reduction of the LOFAR measurements is much more complex, results are expected in the near future and will complement nicely those obtained with GMRT. We will discuss the constraints resulting from these observations on Saturn's deep atmospheric composition.

Scientific objectives: Observations of Saturn in the metric wavelength range offer a unique opportunity to probe deep atmospheric layers, much below the expected NH_3, NH_4SH, and H_2O condensation clouds. Unlike for Jupiter, Saturn's synchrotron radiation from the magnetospheric regions is very weak because most of the trapped electrons are absorbed by the rings (Fig.1 and Fig. 2). Consequently, Saturn's radiation in the metric range is expected to be almost purely thermal. The contribution functions peak between 100 bar at 100 cm and 20 kbar at 300 cm (Fig. 1), assuming that the opacity at these wavelengths is due to gaseous NH_3 and H_2O, with a potential contribution beyond 200 cm due to free electrons stemming from the weak ionization of water (Hofstadter and Gulkis, 2013).

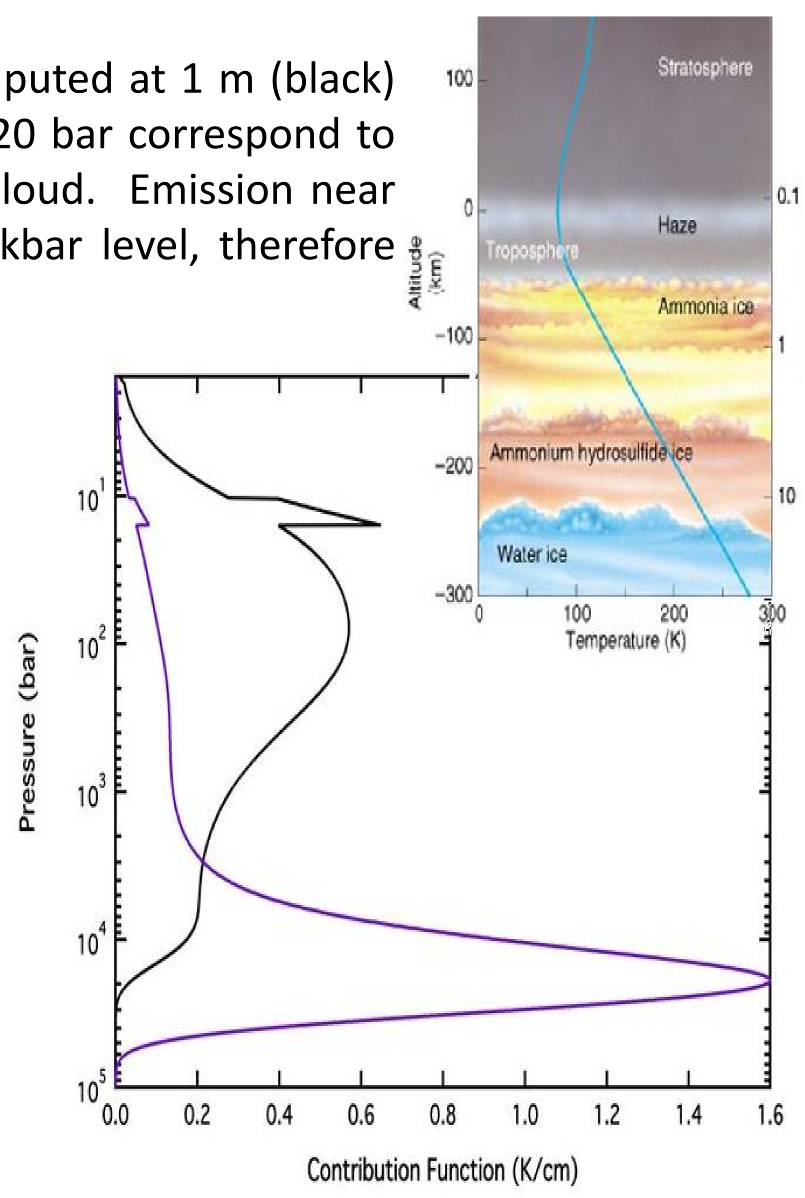

Figure 1: Contribution functions computed at 1 m (black) and 3 m (purple). The humps at 10-20 bar correspond to the assumed location of the water cloud. Emission near 3 m originates mostly from the 20 kbar level, therefore much deeper than the water cloud.

The main objective of the observing program is to constrain the deep atmospheric concentrations of NH_3 and H_2O, which in turn would allow a determination of the bulk N/H and O/H ratios. The O/H is especially important in terms of cosmogonical implications and for constraining interior models of Saturn. Other objectives include the confirmation of a weak-to-negligible magnetospheric synchrotron emission, and that of a possible opacity contribution from weakly-ionized water beyond 2 m wavelength.

Instrument facilities: The Giant Metrewave Radio Telescope (GMRT), about 80 km north of Pune, India (see Fig. 2), consists of 30 fully steerable parabolic dishes of 45-m diameter spread over distances of up to 25 km. It operates within four frequency bands in the metric domain (see table below). The 610 MHz and 235 MHz bands can be used simultaneously.

The Low Frequency Array (LOFAR) is a large radio telescope distributed across Europe (see Fig. 2), consisting of phased antenna stations that are combined in an aperture synthesis array. It operates in two frequency domains – LBA: 10-80 MHz, and HBA: 110-250 MHz (see de Vos et al., 2009 for more details).

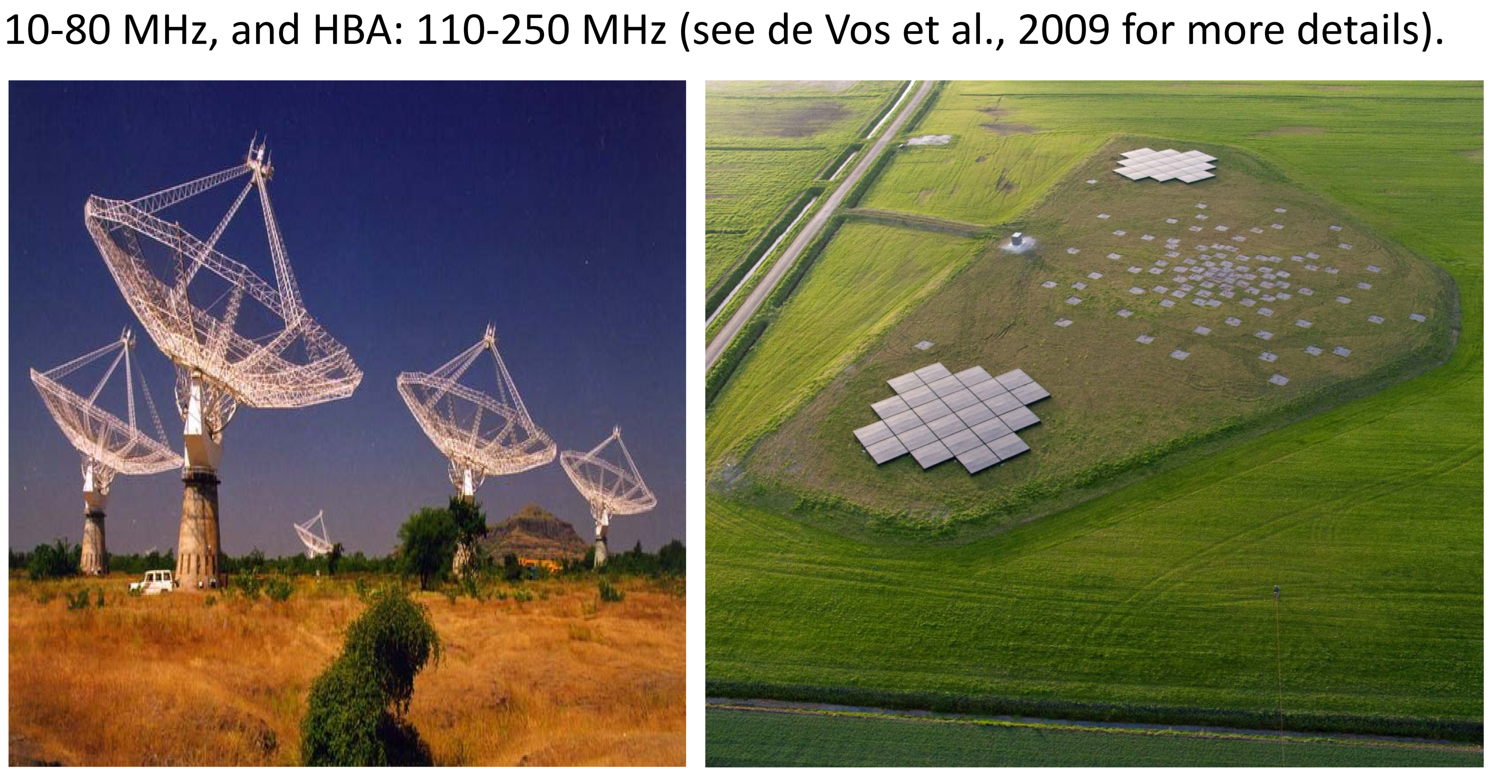

Figure 2: The Giant Metrewave Radio Telescope operated by NCRA in India (left) and one of 48 LOFAR antenna stations run by SRON in The Netherlands (right).

Characteristics of the GMRT radiotelescope

Central frequency (MHz)	Central wavelength (cm)	Frequency range (MHz)	Field of view (degree)	Maximum resolution (arcsec)	Sensitivity rms (mJy/beam)	Detectable source size (arcmin)
610	49	590-630	0.72	5	0.02	17
325	92	315-335	1.35	9	0.3	32
235	128	232-244	1.90	13	0.6	44
150	200	149-156	3.10	20	1.5	68

Characteristics of the LOFAR array (HBA only)

Central frequency (MHz)	Central wavelength (cm)	Field of view (sqr. degree)	Maximum resolution (arcsec)	Sensitivity (mJy) (with 36 stations 1h/4MHz)
120	250	28.8	5.2	0.4
150	200	18.4	4.1	0.3
180	167	12.8	3.4	0.4
210	143	9.4	3.0	0.4
240	125	7.2	2.6	0.5

Observations: The tables below summarize the Saturn observations carried out in 2014 with GMRT and in 2013 with LOFAR. Unfortunately, the March 1 (150 MHz), March 21 (235 MHz), and June 20 (150 MHz) GMRT observations, as well as the May 21 (150 MHz) LOFAR one, suffered from substantial noise due to ionospheric scintillation and/or radio-frequency interferences (RFI).

Log of GMRT observations of Saturn

Date	Central frequency	Duration	Quality / rms noise
March 1, 2014	150 MHz	3 h	Poor (RFI noise)
March 21, 2014	235 MHz 610 MHz	4 h 4 h	Poor (scintillation) / 2 mJy Good / 0.15 mJy
June 20, 2014	150 MHz	4 h	Poor (RFI noise) / 5 mJy
August 16, 2014	235 MHz	4 h	Mediocre (RFI noise) / 2 mJy

Log of LOFAR observations of Saturn

Date	Central frequency	Duration	Quality
May 21, 2013	116 MHz / 166 MHz	5 h	Poor (scintillation)
May 22, 2013	216 MHz / 244 MHz	5 h	Good
August 25, 2013	216 MHz / 244 MHz	5 h	Good
August 26, 2013	116 MHz / 166 MHz	5 h	Good

The March 21 GMRT observation at 610 MHz resulted in a high S/N detection of Saturn, along with several extragalactic sources that were used for flux calibration (Figs. 3 and 4). The flux density was measured at 14.7 $\pm$ 2.2 mJy (T_b= 216 $\pm$ 32 K) where the error bar is essentially due to a 15% uncertainty on the absolute flux scale.

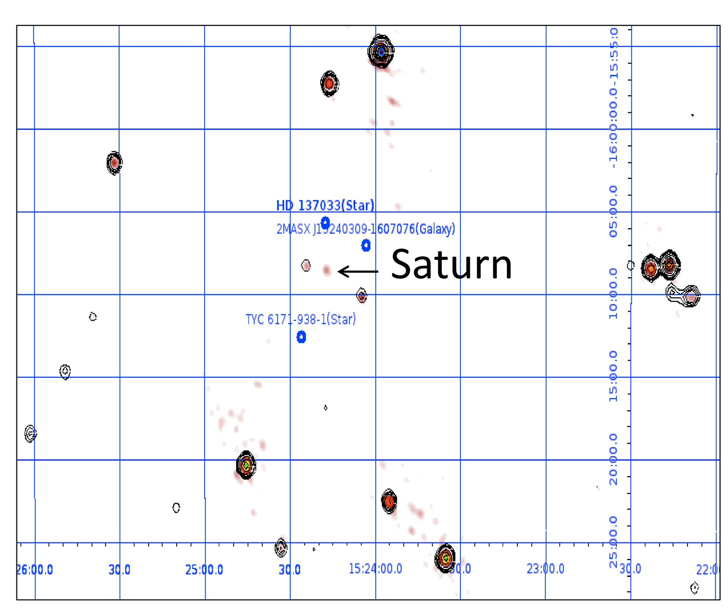

Figure 3: GMRT field-of-view for the March 21 observation at 610 MHz. The black contours correspond to known sources in the NVSS catalog.

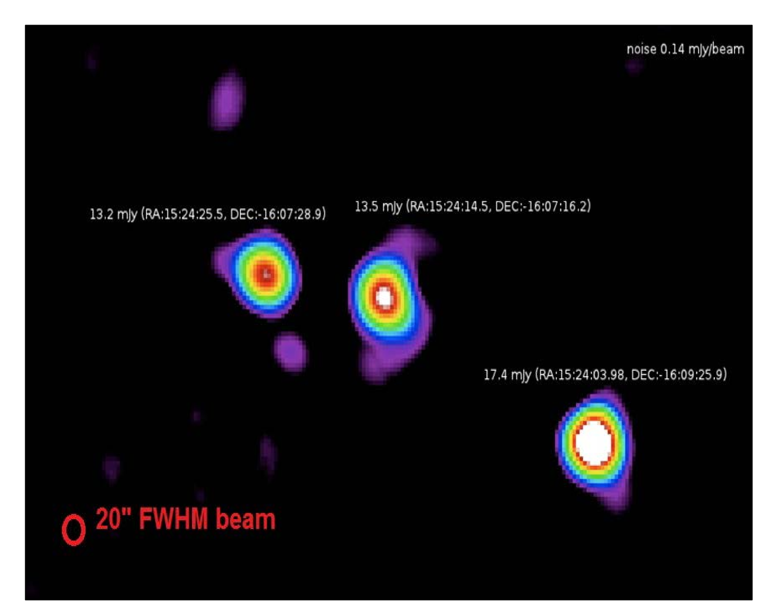

Figure 4: Zoom on the central part of Fig. 2. The size of Saturn's image is consistent with a ∅18" disk convolved with a beam of 20" FWHM.

The August 16 GMRT observation at 235 MHz resulted in a marginal detection of Saturn (Fig. 5), with a flux density of 4.2 $\pm$ 2.6 mJy (T_b= 404 $\pm$ 249 K), while the June 20 observation at 150 MHz set an upper limit at 5 mJy (T_b<1210 K).

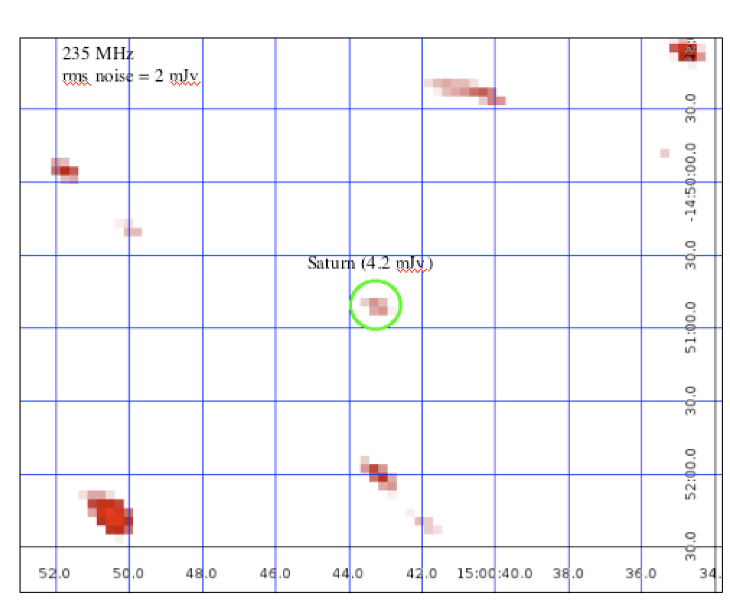

Figure 5: GMRT field-of-view for the August 16, 2014 observation at 235 MHz (128 cm).

Implications and prospects: The comparison of the GMRT results at 150, 235, and 610 MHz with models of Saturn's thermal radiation assuming different values for the water vapor concentration seems to favor water-rich models with an O/H ratio of at least 15 (Fig. 6). This very tentative conclusion needs to be confirmed with additional observations in the metric range. Deeper (8h-long) GMRT observations (at 150, 235 and 325 MHz) are planned in March 2015. The LOFAR measurements will also provide important constraints for the models at frequencies that are complementary to the GMRT ones.

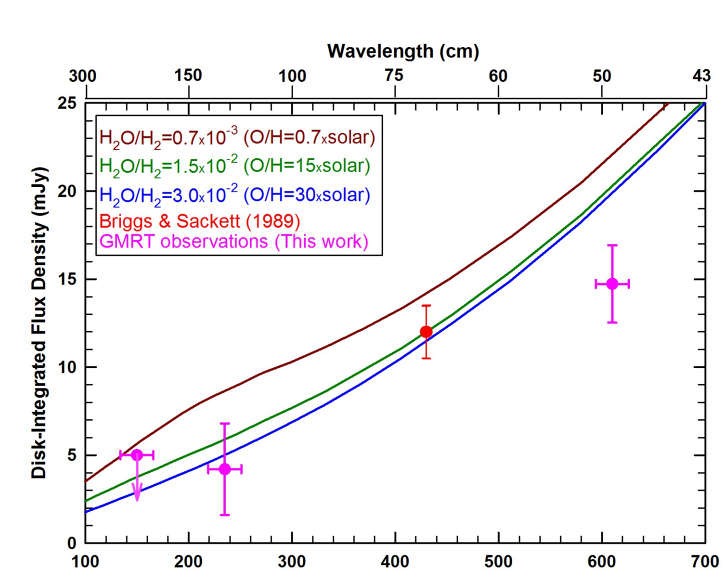

Figure 6: The GMRT flux densities at 150, 235, and 610 MHz are compared with models of Saturn's thermal radiation assuming various H_2O concentrations. The flux density measured by Briggs and Sackett (1989) at 430 MHz is also shown. In all models, the NH_3 concentration ($5{\times}10^{-4}$) is constrained by another result from Briggs & Sackett (1989) at 1450 MHz.

References

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