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METRIC OBSERVATIONS OF SATURN WITH THE GIANT METREWAVE RADIO TELESCOPE

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Abstract.
We used the Giant Metrewave Radio Telescope (GMRT, India) 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 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 Tb= 216 ± 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, Lorenzato et al. 2012). A marginal detection was obtained at 235 MHz, with Tb= 404 ± 249 K, while an upper limit of 1210 K was set at 150 MHz. Unfortunately, some of the GMRT measurements were affected by strong ionospheric scintillation or radio frequency interferences (RFI). Although the reduction of the LOFAR measurements is much more complex, results are expected in the near future and they will complement nicely with those obtained with the GMRT. We will discuss the constraints resulting from these observations on Saturn's deep atmospheric composition.

Keywords: Saturn; acceleration of electrons; atmosphere; numerical simulations; radio observations

1 Introduction

The bulk abundance of water in Saturn is very poorly known. Various estimates of the upper atmospheric H_2O mole fraction have been obtained in the infrared (Larson et al. 1980; Wilkenstein 1983; Chen et al. 1991; de Graauw 1997; Feuchtgruber et al. 1997) but they all refer to pressure levels above the water condensation cloud expected around 13 bar. Short of sending an atmospheric probe into Saturn to measure the gas composition below that level, we need to rely on remote sensing observations in the microwave domain, at wavelengths on the order of a few tens of centimeters. In the case of Jupiter, this particular method will be implemented during the JUNO mission with the MWR (Micro−Wave Radiometer) instrument (Janssen et al. 2005), which is expected to constrain the deep tropospheric abundances of both of NH_3 and H_2O down to at least 30 bar. For Saturn, however, no such mission is envisaged in the foreseeable future. Therefore, these remote observations must presently be carried out with ground−based radio−telescopes, such as the GMRT in India, the Very Large Array (VLA) in the USA, or the Low Frequency ARray (LOFAR) in the Netherlands, all three of which operate at metric wavelengths.

On the other hand, modeling of the thermochemistry occurring in Saturn's deep troposphere, based on the constraints provided by the observed mole fractions of CO, PH_3 and SiH_4, arrived at the conclusion that oxygen must be enhanced about 3−to−6 times compared to the solar abundance (Visscher and Fegley, 2005). However, the validity of the assumptions used in this model concerning the chemical reactions involved is rather uncertain.

At metric wavelengths, Saturn's radiation originates at deep tropospheric levels, as shown by the contribution functions plotted in Fig. 1. For instance, at 100 cm the contribution function peaks around 100 bar, while

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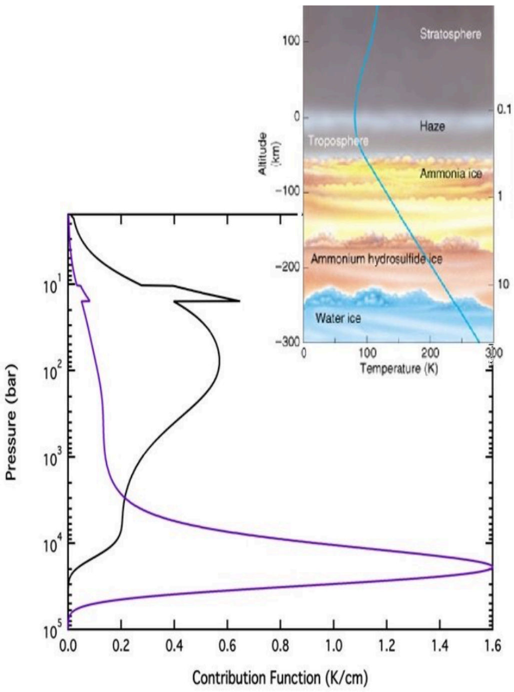


Fig. 1. Contribution functions computed at 1 m (black) and 3 m (purple). The humps at 10−20 bar correspond to the assumed location of the water cloud. Emission near 3 m originates mostly from the 20 kbar level, therefore much deeper than the water cloud.

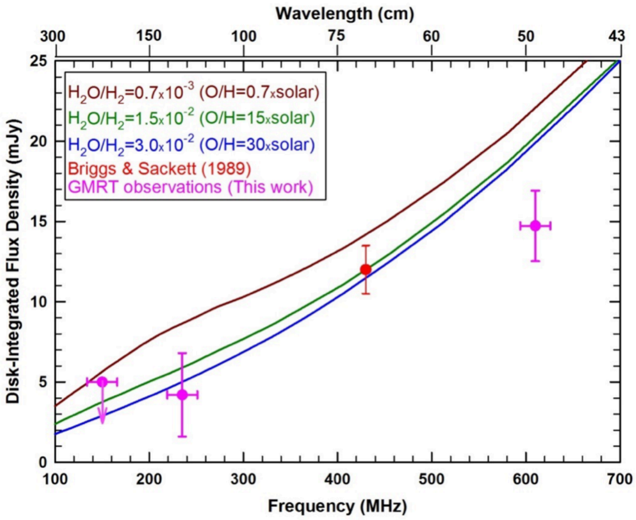
at 300 cm, the maximum is located around 20 kbar. These contribution functions are calculated under the assumption that the temperature profile follows an adiabat and that the dominant opacity is that of a NH_3-H_2O mixture with mole fractions consistent with those predicted by the Visscher and Fegley model (Gulkis and Hofstadter 2013). Given these assumptions, Saturn's flux density spectrum corresponding to thermal emission can be calculated as a function of the deep−tropospheric water abundance, as shown in Fig. 2.

The absolute level of flux density varies between ∼4 and 20 mJy in the 150−610 MHz frequency range that is accessible with the three ground−based instruments mentioned above. Given the sensitivity of the present detection systems, the expected signal−to−noise ratios are expected to decrease from several hundred at 610 MHz to a few at 150 MHz. But most importantly, we need to measure the flux density with enough accuracy, i.e. less than 10%, to differentiate between the two extreme models, one corresponding to a roughly solar O/H ratio and one with a 30−times enhanced ratio. An impediment to Earth−based remote sensing of Jupiter's deep tropospheric layers at decametric or metric wavelengths stems from the fact that the thermal radiation component is overwhelmed by the synchrotron radiation due to energetic electrons in the Jovian magnetosphere. Such is not the case for Saturn. In modeling the distribution of energetic electrons inside Saturn's magnetosphere, Lorenzato et al. (2012) have shown that losses due to absorption by the dense ring system and icy satellites are the dominant processes. Thus, their model predicts a very weak level of synchrotron emission, on the order of a few tenths of mJy in the 100−300 cm range, whereas the thermal emission is expected to be on the order of a few mJy (see above).

2 Observations

The GMRT observations at 610 and 235 MHz were carried out in order to constrain Saturn's thermal flux density spectrum, and hence the deep tropospheric NH_3 and H_2O concentrations. The measurement of NH_3 and H_2O concentrations allow us to determine the bulk N/H and O/H ratios. The O/H is especially important in terms of cosmological implications and for constraining interior models of Saturn. Other objectives includes the confirmation of a weak−to−negligible magnetospheric synchrotron emission, and that of a possible opacity contribution from weakly ionized water.

Table in Fig. 2 summarize the Saturn observations carried out in 2014 with the GMRT. Unfortunately,



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

Fig. 2. (Panel 1): 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 is constrained by another result from Briggs & Sackett (1989) at 1450 MHz. (Panel 2): Log of radio observations on Saturn.

the March 1 (150 MHz), March 21 (235 MHz), and June 20 (150 MHz) GMRT observations, suffered from substantial noise due to ionospheric scintillation and/or radio-frequency interferences (RFI). The on-source time during the observations varied between 3.0 to 4.0 hrs. A total bandwidth of 33.3 MHz (RR correlations only), split into 512 channels, was recorded at 610 MHz. In the case of 235 and 150 MHz the bandwidth was 6 MHz. NRAOs Astronomical Image Processing System (AIPS) was used to carry out the initial calibration of the visibility dataset. The primary calibrator was used to set the flux density scale and derive the bandpass solutions for all the antennas. About 40% of the data, mostly from short baselines, were affected by RFI and subsequently flagged. Gain solutions were obtained for the calibrator sources and together with the bandpass solutions applied to the target field. Channels showing flat bandpass calibration response were used and the rest were discarded as they were too noisy due to the bandpass roll-off. The clean channels were averaged in 10 in order to reduce the size of the data. Cleaned set of averaged channel UV data were used to produce images using 3D technique. Self calibration was applied to the data in order to produce final phase corrected images.

The March 21st 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 source was detected at a level of 14.73±1.64 mJy (Tb= 216±32 K) at 610 MHz and 4.2±2.24 mJy at 235 MHz. The error in the flux density measurement is a combination of rms noise in the field, system error and the calibration error in flux density estimate. Note that the noise in 235 MHz is very high as the data was severely affected by RFI and observation was performed when the source was at low elevation. Further deep observations are needed to confirm the detection at 235 MHz.

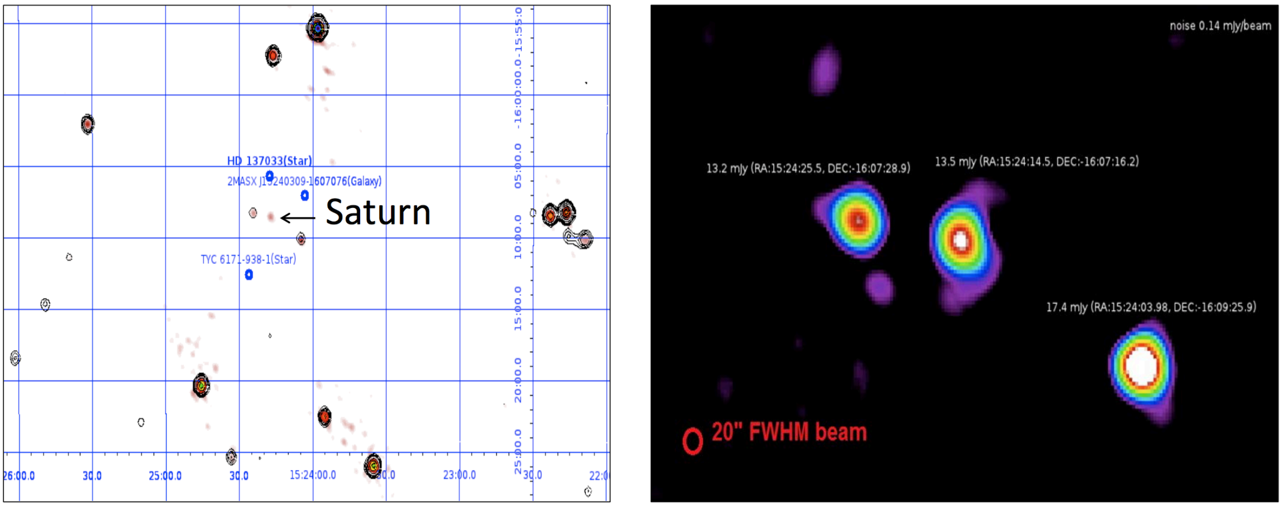


Fig. 3. (Panel 1): GMRT field−of−view for the March 21 observation at 610 MHz. The black contours correspond to known sources in the NVSS catalog. (Panel 2): Zoom on the central part of Panel 1. The size of Saturn's image is consistent with a 18 arsec disk convolved with a beam of 20 arcsec FWHM.

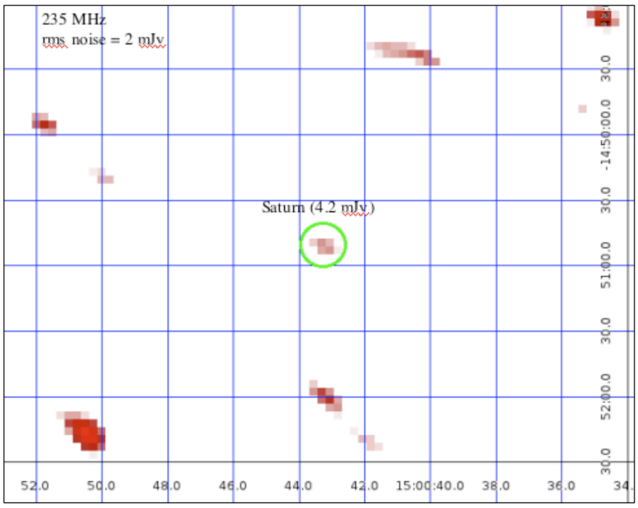


Fig. 4. GMRT field−of−view for the August 16, 2014 observation at 235 MHz (128 cm).

3 Discussion and Conclusion

A 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. 2). This very tentative conclusion needs to be confirmed with additional observations in the metric range. More measurements spread out within the 150-600 MHz interval are needed to confirm the shape of the spectrum and arrive at firmer conclusions. Deeper LOFAR observations will also provide important constraints for the models at frequencies that are complementary to the GMRT ones.

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References

Briggs, F. H. and Sackett, P. D.; 1989; Icarus 80; 77-103

Chen, F. et al.; 1991; J. Geophys. Res.; 96; 17519

deGraauw,T. et al.; 1997; Astron. Astrop.; 321; L13
de Vos, M.; Gunst, A.W.; Nijboer, R; 2009; IEEE Proceedings 97; 1431
Feuchtgruber,H. et al.; 1997; Nature; 389; 159
Gulkis, S. and Hofstadter, M; 2013; Private communication
Janssen, M. A. et al.; 2005; Icarus 173; 447
Larson, H. P. et al.; 1980; Astrophys. J.; 240; 327
Lorenzato, L.; Sicard, A.; Bourdarie, S.; 2012; J. Geophys. Res.; 117; A08214
Lorenzato, et al.; 2012; Thesis 'Modlisation des ceintures de radiation de Saturne'; Univ. Toulouse
Visscher, C. and Fegley B.; 2005; Astrophys. J.; 623; 1221
Wilkenstein, P.; et al.; 1983; Icarus 54; 309