Measuring the brightness temperatures of Jupiter & Venus

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Abstract

This paper discusses the calculation of the observability of the planets in our solar system. It also covers the measurement of the brightness temperature of Venus and Jupiter with the HartRAO 26m telescope.

1 Introduction

Following the calibration of the telescope we wanted to observe familiar celestial bodies with the 26m HartRAO telescope. This required us to discover the observability of the planets and the minimal observable flux density of the receivers across all the wavelengths.

2 Theory

In reality any sophisticated equipment has a limit to its practical sensitivity. In the radio telescope this level is determined by the noise inherent to the individual receivers. The Calt[1] program available at HartRAO allowed us to calculated the noise temperature, T_{sys} of each receiver, over a set bandwidth $\Delta\nu$. This information was used in the following equation(Gaylard, 2005), to yield the minimum observable flux for the different wavelengths.

$$\Delta S_{min} = \frac{3K_R k T_{sys}}{A_e\sqrt{\Delta\nu t n}} \times 10^{26} \tag{1}$$

where k is Boltmann's constant, A_e is the effective aperture as discovered in Carr (2005) and K_R is the sensitivity constant of the receiver, which is 1 for a simple radiometer.

[1] Calibrate temperature

wavelength [cm]	18	13	6	3.5	2.5
S_{min} [Jy]	0.48	0.44	0.20	0.33	1.42

Table 1: The minimum observable flux for each wavelength

These values for S_{min} are averaged results for left and right circularly polarised light.

The observability of a planet depends on its flux density, phase, position in the sky and angular diameter. The flux densities of the planets are then calculated using

$$S = \frac{2kT\Omega_s}{\lambda^2} \tag{2}$$

where Ω_S is the solid angle subtended by the planet, T is the temperature of the planet and λ is the wavelength in question. Using planetary temperature information from NASA (2005) and diameter information from Gillard and Holdaway (2005) the following table was calculated.

wavelength [cm]	18	13	6	3.5	2.5
Mercury	0.03	0.05	0.25	0.74	1.45
Venus	0.21	0.40	1.71	4.56	7.15
Mars	0.07	0.13	0.61	1.79	3.51
Jupiter	0.16	0.31	1.47	4.32	8.47
Saturn	0.03	0.06	0.30	0.87	1.70
Uranus	0.00	0.00	0.01	0.03	0.06
Neptune	0.00	0.00	0.00	0.01	0.02
Pluto	0.00	0.00	0.00	0.00	0.00

Table 2: The calculated flux density of the satellites for the wavelengths

The flux density of a body is related to the antenna by the following equation.

$$S = 2K_sT_{Alcp/rcp}PSS \tag{3}$$

Due to the size of the planets, we cannot adopt the assumption that they behave as point sources. We therefore took the planets to have disc-like brightness (Gaylard, 2005) and therefore used

$$K_s = \frac{x^2}{1-e^{-x^2}} \tag{4}$$

The brightness temperature of the planet is related to the antenna temperature by

$$T_B = \frac{\Omega_A}{\Omega_S} T_A \tag{5}$$

where ΩA is the beam solid angle and ΩS is the solid angle subtended by the planet.

3 Procedure

We calculated the flux densities of the planets in our solar system for the various observation wavelengths, as discussed in the theory. We then measured the system temperatures of the individual receivers over defined bandwidths. These values were then used to calculate the minimum detectable flux density for each of the observation wavelengths.

We selected Jupiter and Venus for measurement, and took drift scans of both of these sources. This data was manipulated as discussed in Carr (2005).

We then used equation 5 to calculate the brightness temperature of the planets.

4 Results

Comparing table 1 & 2 reveals that Mercury,Venus,Mars,Jupiter and Saturn are visible at the 6cm, 3.5 cm and 2.5 cm wavelengths.

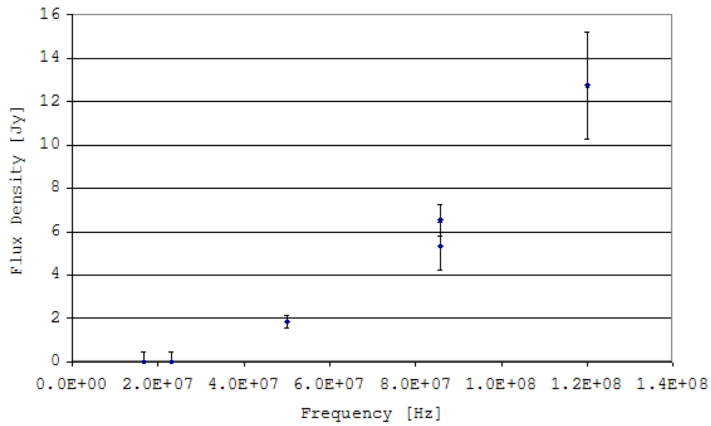

Figure 1: flux density for Venus : lcp receiver

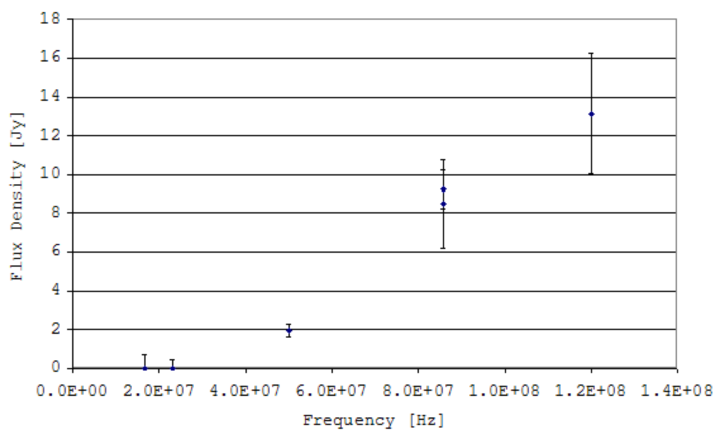

Figure 2: flux density for Venus : rcp receiver

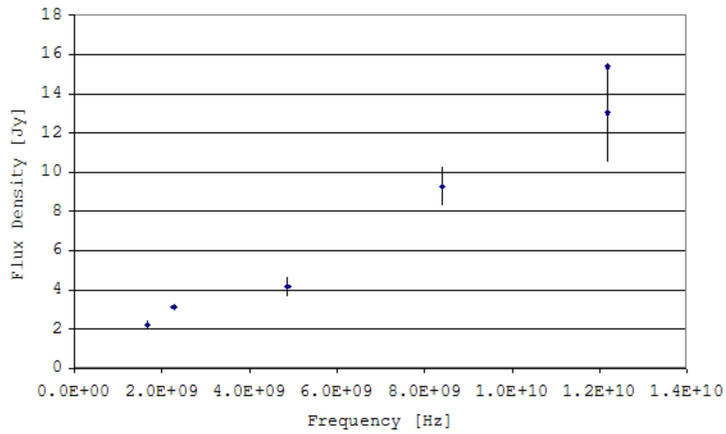

Figure 3: flux density for Jupiter : lcp receiver

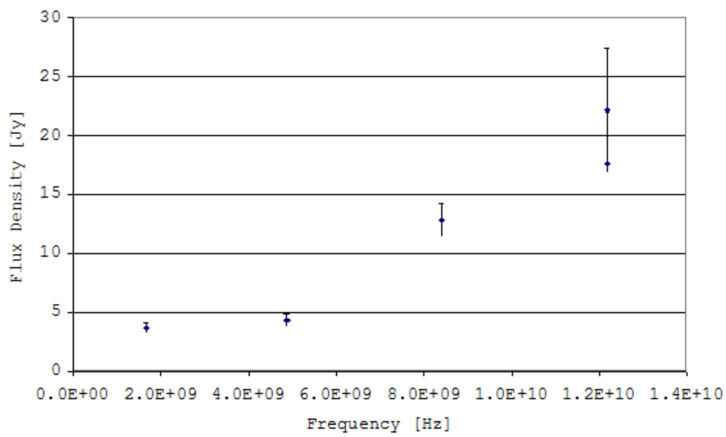

Figure 4: flux density for Jupiter : rcp receiver

wavelength [cm]	lcp [K]	rcp [K]
18	-	-
13	-	-
6	617	567
3.5	826	1049
2.5	4276	4834

Table 3: Brightness temperatures for Venus

wavelength [cm]	lcp [K]	rcp [K]
18	1570	2238
13	1059	-
6	311	272
3.5	258	323
2.5	200	229

Table 4: Brightness temperatures for Jupiter

5 Discussion

While comparing table 1 & 2 suggests that none of the planets were observable for our wavelengths greater then 6cm, we were able to successfully manipulate the data associated with Jupiter, and therefore calculate a brightness temperature, at 13cm and 18cm. Only the 13 cm data received from Jupiter by the right hand circularly polarised receiver was too noisy to fit a gaussian to, and there is therefore no brightness temperature associated with this combination.

Venus obeyed the predictions we made and the data was therefore too noisy to analyse at 13cm and 18cm.

Brightness temperature is identical to physical temperature in a blackbody radiator, and therefore uniform across the various wavelengths. The variation of brightness temperatures across the wavelengths shows that the planets can not be regarded as blackbody radiators.

6 Conclusion

The flux densities of the various planets in our solar system were calculated. The minimum detectable flux density was calculated across the range of receiver wavelengths. Jupiter and Venus were selected from the observable planets and drift scans were taken across all the wavelengths. The brightness temperatures of Jupiter and Venus were then calculated, and the observability was compared with the earlier predictions of observability.

References

Carr, D. (2005), *The calibration of the 26m HartRAO telescope*.

Gaylard, M. J. (2005), *Practical Radio Astronomy a hi-math introduction*, Hartebeesthoek Radio Astronomy Observatory.

Gillard, D. and Holdaway, R. (2005), *Astronomical Almanac*, US Nautical Almanac Office.

NASA (2005), *http://nssdc.gsfc.nasa.gov/planetary/planetfact.html*.