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Radiothermal Emission model of Venus

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Abstract

. The radio-thermal emission from Venus as observed by ground-based interferometric radio-telescopes shows a significant spectral variation, with a gradual increase in brightness temperature from 1 mm to 6 cm and a decrease thereafter at higher wavelengths. The first time GMRT observations beyond 70 cm wavelength also reconfirm this decreasing trend in T_b with the increase in wavelength [7]. Efforts have been made to model this spectral variation in T_b [1], [10], but these models fail to explain the low-frequency radio-thermal emission from Venus (decrease in T_b with the increase in wavelength) and the problem still remains unresolved.

The authors attempt to explain this problem using radiative transfer based model and radiometric observations of Venus focussing particularly on the higher wavelength T_b observations from the Giant meter radio telescope (GMRT). The GMRT brightness temperature (T_b) (at 0.21, 0.5, 0.9, 1.23 and 2 m) is observed to decrease with frequency. A radiative transfer modelwas developed and it is seen that a two layer Venusian surface model matches with the observations. Based on the simulation studies, the authors put forth a hypothesis that Venus may have an absorbing layer within the first few meter depth.

1. Introduction

Venus, also known as Earth's sister planet, owing to its similarities in size, mass, bulk composition and many physical properties, has aroused the curiosity of scientists due to its extremely warm, dry inhabitable environment. Despite the several successful explorations, many questions about Venus surface and geology and the different evolutionary processes which led to the extreme difference between conditions on Earth remain open. The dense atmosphere and clouds present on Venus block radiation from surface almost in the whole electromagnetic spectrum except radio and microwaves (where the atmosphere is completely transparent), and a few narrow transparent channels in near-infrared. Hence remote sensing using the radio waves and microwaves opens a vista of opportunities for atmosphere and surface/subsurface studies. The recent Magellan mission obtained near-global coverage of Venus surface by topography, radar images (using SAR, altimetry, and radiometry modes), and gravity field measurements.

Venus has been studied using ground-based radar and radio-telescopes. Radio thermal observations of Venus has shown that the brightness temperature spectrum of Venus increases at lower wavelengths up to 6cm and gradually decreases at longer wavelengths [1], [10], [3], [6]. The increase in T_b at lower wavelengths is attributed to a reduction in atmospheric attenuation and has been well modeled. But the decrease in T_b beyond 6 cm which has significant emission contribution from the surface and subsurface is still intriguing to the scientific community. Attempts to model the radio thermal emissions could not satisfactorily explain the decreasing trend in T_b at longer wavelengths. This paper is an attempt to model the radio thermal emission based on radio observations of Venus at longer wavelengths particularly focusing on the observations from the Giant Meterwave Radio Telescope (GMRT) at Pune, India. The observations from GMRT at frequencies from 1280 to 235 MHz also show a decreasing T_b with the wavelength which is consistent with earlier observations [7]. A radiative transfer based model has been developed to explain the radio-thermal emissions at longer wavelengths based on GMRT and other available observations. The paper highlights the simulation studies from the model and its inferences. The model gives an insight into the surface/subsurface thermo physical properties of Venus.

2. Observational data

This paper utilizes the brightness temperature observations of Venus at the inferior conjunction using the GMRT. GMRT is a synthesis radio telescope operating in the frequency range of 150 - 1280 MHz. It comprises of 30 antennas of a 45m diameter which can be operated at 5 different frequency bands centred near 150, 235, 325, 610, and 1280 MHz [9]. Venus was observed using the GMRT for 6 days between March 20 and 27, 2004 at 3 different frequencies centered close to 240 MHz, 323 MHz and 610 MHz, with an integration time of 16.8 seconds and a bandwidth of 125 kHz. For every observing day, the antennas were pointed at the right ascension (RA) and declination (Dec) of the Venus for that particular day. The diameter of Venus varied from 21.19 arcsec to 22.965 arcsec over the 6 days of observations. The 610 and the 240 MHz was analysed data using Common Astronomy Software Applications (CASA), (http://casa.nrao.edu), and the 333 and the 240 MHz data using the Astronomical Image Processing Software (AIPS) (http://www.aips.nrao.edu/index.shtml). Spurious data, arising from man-made interference was removed. The mean RA, Dec of Venus GMRT antennas tracked for every observing day. While Venus moved within the antenna beam over the course of the observations, self-calibration was performed by tracking the sidereal rate and the phase changes introduced by the GMRT electronics and the Earth's ionosphere was corrected. The background celestial radio sources seen in the field of view were used for this purpose. The emissions from all the background sources were subtracted from the self-calibrated visibility data using the statistically significant deconvolved (CLEAN) components in the field.

3. Theory and model

The total thermal emission from the planetary body comprises of emission from the surface and the intervening atmosphere. The microwave emission spectra of Venus are observed to decrease in the millimeter range, which is attributed to absorption by the Venus dense atmosphere. The atmospheric contribution to the total emission from the planet is accounted based on a radiative transfer model for the atmosphere, wherein induced absorption by carbon dioxide and nitrogen are considered [3]. A radiative transfer model (zero-order RT model) based on the intensity of emitted radiation from a soil medium, which computes the subsurface emission (effective radiating temperature of the soil). The Fresnel reflections at the air-surface interface and the first order reflections from interfaces of the stratified media with different dielectric properties are incorporated in the model. The total brightness temperature (T_b) for a particular polarization (p) and frequency (f) is the product of emissivity (e) and effective radiating temperature (T_{eff}), which in turn depends on the temperature and dielectric profiles of the soil medium.

$$T_b(p,\theta,f) = e(p,\theta,f)\ T_{eff}(\theta,f) \qquad (1)$$

One dimensional heat transfer equations are used to account for the Venus surface temperature profile. The analysis reveals that the surface temperature is near isothermal within the first few 100 m depths. The temperature slightly increases by 2 K within this depth. The hypothesis is on par with the logical assumption that a thick hot greenhouse atmosphere would heat the subsurface to its temperature over millions of years. Thus it can be safely assumed that the ground temperature is near isothermal or very slightly increasing with depth. Cooler subsurface would have existed at time scales of few millions of years after the Venusian global resurfacing event which had buried much of the previous rock record and leaving the Venus surface relatively young (compared to other terrestrial planets). Thus, the decline in brightness temperature observations at longer wavelengths as observed by GMRT cannot be explained on the basis of a cooler subsurface. Also, the exact surface and subsurface composition and hence the soil dielectric profiles of Venus is unknown.

3.1 Surface emission model

The mineral composition of the surface material has not yet been determined by any conclusive technique. The surface dielectric constant varies from 3 to 8 with an average dielectric constant of 4.5 – 5 close to basalt dielectric constants. The abundances of atmospheric sulphur reported for the Venera and Vega landers are <2%. The low sulphur contents propose the possibility of formation of anhydrite due to chemical weathering of basalt. If all the sulphur in the atmospheric sulphur dioxide of 185 ppm were utilized for weathering, then the surface would have been weathered to a depth of 1 m, and even deeper by penetrating through cracks and pore spaces. The surface weathering is also apparent from images from the panoramic cameras of Venera 10, 13 and 14 missions.

Low-frequency microwaves have large penetration into a low dielectric constant medium, such as basalt or mafic rocks (volcanic origin as is the case of Venus) or anhydrites. The penetration depth varies with wavelength and dielectric constant of the medium. The penetration depth (PD) is 4.45 m at 240 MHz for $\epsilon'' = 0.1$ as in the case of basalt rock, while the PD increases to 445 m for $\epsilon''=0.001$ as for anhydrite (a possible compound due to chemical weathering of basalt under Venusian atmospheric conditions) for a constant value of $\epsilon''= 5$. Thus emission at low frequencies will have substantial subsurface contribution.

For a uniform dielectric medium, under isothermal conditions, RT simulations show that the effective temperature is very close the surface temperature for a basaltic ($\varepsilon = 8 \pm 0.1$), mafic ($\varepsilon = 7.5 \pm 0.03$) and anhydrite ($\varepsilon = 6.2 \pm 0.001$) medium for all frequencies, however, the surface reflectivity (which is equal to emissivity) is different. Hence, the resultant T_b varies between 580 K and 605 K at all GMRT frequencies for basaltic, mafic and anhydrite medium. From these simulations it can be concluded that a uniform dielectric medium even up to 1 km cannot capture the decrease in T_b with the decrease in frequency as obvious from GMRT and other radio-thermal observations of Venus.

In the present RT based model, Venus surface is assumed to be composed of two layers, with surface weathered layer (mixture of anhydrite and basalt) with an effective dielectric of 5 overlain over higher dielectric constant (real part of dielectric constant of 8) and lossy second layer, with an imaginary part of dielectric constant of 100 ± 50. The reflection coefficient at the interface of the first and second layer is found to be 0.65. Figure 1 shows the simulated and observed T_b at different frequencies. The simulated T_b is represented by solid lines. The simulated T_b also shows a similar decrease in with increase in wavelength compatible with the observations from GMRT. The simulated T_b values for surface basaltic layer ($5\pm i0.1$) and the second layer with real part 8 and imaginary part of 50 (upper line) and 150 (upper line) are respectively. The GMRT observations are within the error limits of the model input parameters (dielectric constant).

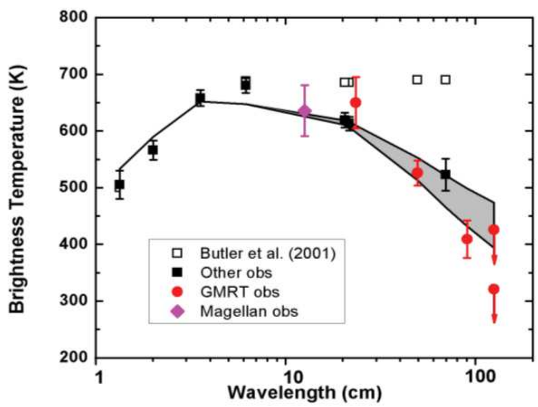

Figure 1. Brightness temperature of Venus at different wavelengths. The symbols represent the observations and the solid line is the modeled T_b. The open squares are modeled T_b by [1].

The observations from VLA (Very Large Array radiotelescope) are also shown as black filled squares apart from GMRT observations (red circles).The measurement uncertainties are represented as error bars. The best fit to GMRT observations is found when the first basaltic layer ($5\pm i0.1$) has a thickness of 1 m overlain over a lossy layer with an imaginary dielectric constant of 100 or even more.

Many low lying plain regions on Venus surface have exhibited abnormally high Fresnel reflectivities apart from the elevated regions such as Maxwell Montes, Theia, Ovda, Atla, Gula and Sif Mons. From the bistatic radar measurements, the elevated regions may be composed of a surface layer of semiconducting material of conductivity 13 mhos m^{-1} likely to have an imaginary dielectric constant of $100\pm i50$ [8] overlain over normal volcanic or tectonically deformed terrain. The floors and ejecta of some craters such as Boleyn, Stanton, Stuart and Mead are observed to have anomalous low emissivity, which appears to be high dielectric constant crustal material excavated from beneath. Thus, as seen from radar observations, materials of high radar reflectivity may underlie lower reflectivity surficial materials [4], [5] which supports our simulations.

5. Conclusion

A two layer radiative transfer model has been proposed to explain the decrease in T_b observations from GMRT and other radio telescopes. The model captures the decreasing trend in emission with increase in wavelength only when the Venus surface is hypothesized to be a two layer medium with an inner absorbing layer. There are evidences on existence of such materials on the surface and interior of Venus, from orbiter and ground based radar observations. However, future missions should have dedicated radiometric observations of the surface and atmosphere to prove the hypothesis.

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7. References

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