RADIATIVE TRANSFER SIMULATIONS TO EXPLAIN THE SUBSURFACE THERMAL RADIO-EMISSION OF VENUS Nithin Mohan[1,2] and Tinu Antony[2] and C. Suresh Raju[2] and Govind Swarup[3] and Divya Oberoi[3], [1]National Institute of Science Education and Research, HBNI, Bhubaneswar, India (nithin_mohan@niser.ac.in) [2]Space Physics Laboratory, VSSC, ISRO, India [3] National Centre for Radio Astrophysics, Pune, India

Introduction: Venus is like Earth in its size, mass and bulk density. Yet, the distinctions are much more pronounced, as the surface is extremely dry with a temperature of ∼750 K and pressure of ∼90 bar. The CO_2 dominated atmosphere and the globally covered H_2SO_4 clouds make the study of its lower atmosphere and surface thermo-physical properties extremely difficult. While the satellite-based remote sensing of its lower atmosphere has been limited to single polarization, the lander-based in-situ measurements were limited to localized regions and were severely affected by the planetary conditions. The Earth-based radio telescopes using interferometry have the potential for multi-frequency and dual-polarization (H and V) observations which can be used to study the thermo-physical properties of the surface and the lower atmosphere with reasonable spatial resolutions.

Scientific Problem: More than 100 observations were carried out on Venus over a wide frequency range between mm-cm wavelength spectra from the Earth-based platforms (eg. black filled circles in fig. 1). But, observations at decimetre (dm) wavelengths, especially, beyond 70 cm were limited due to increased background noise, system contamination and reduced planetary emission. Thermal emission from the Venus at microwave spectral regime, observed by several investigators, showed a monotonous decrease of radiometric brightness temperature (T_b) beyond ∼6 cm wavelength (black filled circles in fig. 1), which are expected to emanate from the subsurface layers of Venus [1, 2]. Hence, there have been several attempts to explain this emission even though none were satisfactory (eg. [2, 3, 4]). The reason for the continuous T_b decrease was hypothesised to a cooler subsurface [2], due to the change in emissivity with wavelength, and linked to the dielectric constant and subsurface properties.

Methodology: The observations of Venus using Giant Metrewave Radio Telescope (GMRT) interferometric techniques at 233.67 MHz - 1280.67 MHz (or ∼123 cm - 21 cm wavelength) channels were used to address this problem. GMRT is an interferometric array consisting of 30 antennas of 45 m aperture-diametre. The telescope operates in 5 frequency channels in the range of 150 MHz to 1280 MHz (or ∼200 cm - ∼21 cm). Later, the results from these observations were used in a zero-order radiative transfer simulation to explain the planetary thermal emission.

Results: Firstly, the archived data of GMRT observation of Venus carried out at 606.67 MHz, 332.9 MHz and 239.9 MHz (or ∼50 cm, ∼90 cm and ∼123 cm), conducted during 2004 were analysed. The results confirmed a further reduction of T_b beyond 70 cm wavelength [5] and the T_b values derived at the respective frequencies are 526 ± 22 K, 409 ± 33 K and <426 K. Further, based on these results, a dedicated, better SNR, GMRT observation campaign was conducted at multi-frequency and multi-stokes (I,Q,U) for a longer duration (10 hr for each channel), when Venus was near to its inferior conjunction in July-September of 2015. The T_b derived at the respective frequencies 1297.67 and 607.67 MHz were 622 ± 43 K and 554 ± 38 K, respectively. The derived value of the T_b at 233.67 MHz placed an upper limit of 321 K. The results of the two observations are shown as red filled circles in the fig. 1. Using the multi-stokes data of the 606.67 and 1297.67 MHz, the dielectric constant of Venus surface (globally averaged) was derived as ∼4.5 [6] which is in agreement with those derived from the orbiter-based radar (Pioneer Venus [7] and Magellan [8]) observations.

Radiative Transfer Simulation: The total emission simulation is accounted based on a zero-order radiative transfer (RT) model which accounts for the atmospheric and the surface thermal emission. The atmospheric part accounts for the induced absorption of CO_2 and N_2 based on [9], while the surface part accounts for the intensity of thermal emission from the surface/subsurface. The total brightness temperature (T_b) is the product of emissivity (e) and effective radiating temperature (T_{eff}) given by:

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

where p is the polarization, θ is the observing angle and f is the frequency of emission. T_{eff} is a function of physical temperature (T) and dielectric (ε) of the medium.

The temperature profile of the Venus subsurface was generated using one dimensional heat transfer equations and was used to optimize the subsurface temperature profile which was then put into the RT equation. The profile revealed a near isothermal subsurface temperature within the depth of few 100 m depths [10]. The hypothesis is consistent with the logical assumption that a thick hot atmosphere would heat the subsurface to a uniform temperature over the period of 0.3 - 1 billion years [11, 12]. Thus it can be assumed that the subsurface temperature is near isothermal.

Thus the hypothesis of cooler subsurface could be rejected based on these assumptions, provided the exact subsurface composition of the Venus is still unknown. As reported by previous investigators (eg. [8]), the Venusian surface dielectric constant averages between 4.15–4.5 which is close to the dielectric value of basalt. Here, three Venusian regolith models are conceptualized in the simulations: (1) a homogeneous single layer with uniform thermal, dielectric properties having an infinite thickness (black square in fig. 1); (2) a two-layer subsurface where the dielectric property of the layers vary with the subsurface bulk density (black continuous line in fig. 1); and (3) similar to (2), but the second layer is considered to have large values of imaginary components of the dielectric permittivity (ε'') due to semi-conducting mineral deposit [13] (blue continuous line in fig. 1) [10]. All the models could very well explain the shorter wavelength (mm-cm) regime where the emission is dominated by the atmosphere. But, the first two models could not explain the decreasing T_b beyond $\sim$6 cm wavelength. In the third model, as ε'' increases (j100$\pm$50 [13, 14]), the T_b begins to show a decreasing trend at the dm wavelengths. Using Chisquare minimization, the best fit for the observed T_b values were obtained by optimising the top layer thickness and the dielectric constants (both ε' and ε'' of the two layers). The statistical analyses showed that the best fit for the observation was obtained for a top layer depth of 1.1 m and dielectric constant $4.5 + j0.1$, while the second layer was assumed a dielectric constant of $8 + j(120)$ (blue continuous line in fig. 1).

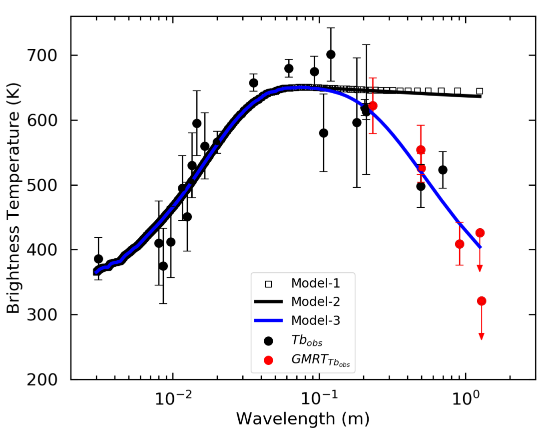

Figure 1: Summarizes the spectral variation of T_b of Venus. Previous observations and the GMRT observations are shown in black and red filled circles, respectively. The three regolith models are represented in black square boxes, black and blue continuous lines.

Many low land regions and certain highly elevated regions such as Maxwell Montes, Theia, Ovda have shown anomalously low value of emissivities. Radar measurements have shown that the high reflectivities of such regions could be likely due to semi-conducting minerals having conductivity of 13 mhos m^{-1} and ε'' j100$\pm$50, overlaid on normal volcanic terrain [13]. Also, the floors and ejecta of some craters such as Boleyn, Stanton, Stuart and Mead are observed to have anomalously high reflectivity, likely due to such minerals excavated from the subsurface. Hence the reduction in T_b could likely be due to the presence of a semiconducting subsurface layer with dielectric value ($\varepsilon' = 8.0$, $\varepsilon'' = \sim 120$) existing below the planetary surface basaltic soil of depth below $\sim$1.0 m. The mineral content in the deeper layer may be responsible for reflecting back or attenuating the thermal radiation from the deeper depths which are manifested as the reduced T_b at longer dm wavelengths. Thus, our hypothesis suggest the presence of 2-layer Venusian regolith consisting of a surface weathered layer (a mixture of anhydrite and basalt) overlaid over a lossy rocky layer [10].

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