Millimeter-wavelength observations of Venus

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Abstract

Interpretive studies of the millimeter-wavelength emission spectrum of Venus can provide much information about its atmospheric motion, and climatology. Millimeter-wavelength observations of Venus made near the 3 mm-wavelength range show a significant day-night variation in the brightness temperature [*de Pater et al.*, 1991; *Sagawa*, 2008]. *de Pater et al.* [1991] made observations of Venus at 2.6 mm with the Hat Creek Interferometer and reported a nightside to dayside variation in the brightness temperature of approximately 30 K. More recent observations of Venus were made with the Nobeyama millimeter-wave array at 103 GHz ($\sim$ 3 mm) and a substantial (25%) diurnal variation in the millimeter-wavelength brightness was observed [*Sagawa*, 2008]. The observed diurnal variation in the brightness temperature in the millimeter-wavelength continuum is likely due to changes in opacity of the atmosphere because of spatial variations in the abundances of gaseous sulfuric acid and sulfur dioxide in a range of altitudes from just below the lower cloud base to the top of the lower cloud [*Sagawa*, 2008]. The sulfur dioxide abundance in and above the cloud region is a possible tracer of active volcanism. Interferometric mapping of Venus using CARMA can be used for studying its emission spectrum near the 3 mm-wavelength range to constrain any spatial and temporal variations in the abundances of these gases at the cloud base.

The atmosphere of Venus is composed mostly of CO_2 ($\sim$96.5%), with a small amount of N_2 ($\sim$3.5%), and trace amounts of SO_2, CO, H_2O, H_2SO_4, and other gases. Gaseous SO_2 and H_2SO_4 are highly opaque in the millimeter-wavelength region due to the presence of several rotational transitions in that spectral region. While maps of the cm-wavelength emission from Venus have indicated dark polar regions consistent with increased H_2SO_4 vapor abundance due to vaporization of cloud condensate from the downwelling characteristic of Hadley cell circulation [*Jenkins et al.*, 2002], the 3 mm-wavelength maps indicate much stronger variations over a range of different locations, with some indication of diurnal variation [*de Pater et al.*, 1991; *Sagawa*, 2008]. Hence, accurate interferometric mapping of Venus using the CARMA array can be used to study its emission spectrum in order to constrain temporal differences of the abundances of these gases and understand the dynamics of the atmosphere at the cloud base.

The peak of the weighting function at 3 mm-wavelength occurs at approximately 50 km altitude [*Fahd*, 1992]. The physical temperature of that region is not likely to be a strong function of local time [*Taylor et al.*, 1980]. Hence, the observed diurnal variation in the brightness temperature in the millimeter-wavelength continuum is most likely due to changes in opacity of the atmosphere at this wavelength. *Sagawa* [2008] attributes the variations in the brightness temperature to spatial variations in the abundances of gaseous H_2SO_4 and SO_2 in a range of altitudes from just below the

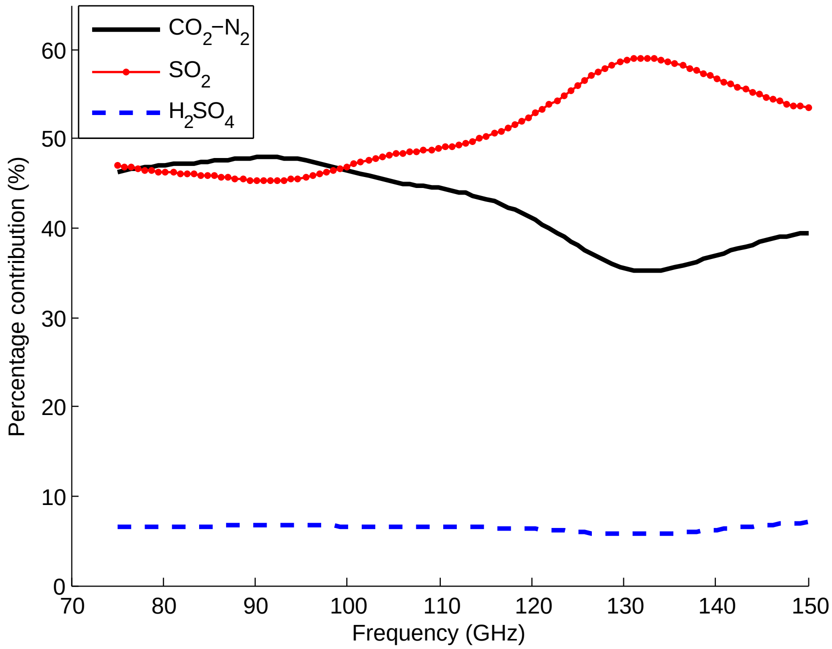

Figure 1: Percentage contribution to the total opacity under Venus conditions (P=2.5 bars; T=375 K; H_2SO_4=6 ppm; SO_2=150 ppm; N_2=0.035; CO_2=0.9648

lower cloud base to the top of the lower cloud (pressures 0.7–2 bars). The SO_2 abundance in and above the cloud region is a possible tracer of active volcanism.

The abundances of sulfur compounds in the 40–50 km altitude range in Venus have been established by various remote sensing methods, with SO_2 abundance estimated to be 130±40 ppm [*Bézard et al.*, 1993], and H_2SO_4 abundance between 2–10 ppm depending on the latitude [*Kolodner and Steffes*, 1998]. Figure 1 shows a plot of the percentage contribution to the total opacity under Venus atmospheric conditions. Collisionally induced dipole moments of CO_2 and N_2 are modeled as per *Ho et al.* [1966]. Collisionally induced absorption from SO_2 is modeled as per *Suleiman et al.* [1996], and H_2SO_4 is modeled using a Gross lineshape and using a self-broadening parameter of 21.6 MHz/torr and a foreign gas broadening parameter of 7.2 MHz/torr. This plot only shows the prediction of contribution to the total 2–4 mm-wavelength opacity from the different constituents in the Venus atmosphere and does not represent the actual millimeter-wavelength opacity. It should be noted that predicted contributions to the opacity from H_2SO_4, and more importantly SO_2, are significant.

A complete understanding of this measured variation in the emission spectra requires accurate modeling of the effects of the atmospheric constituents of Venus. This requires accurate data concerning the opacities of the constituents. The Planetary Atmospheres Lab at the Georgia Institute of Technology has been continuously involved with measuring the cm- and mm-wavelength properties of various gases under simulated Venus atmospheric conditions. Laboratory measurements are currently being conducted of 2–4 mm-wavelength properties of H_2SO_4 and SO_2 under Venus conditions and will be used to develop accurate models of the millimeter-wavelength properties of

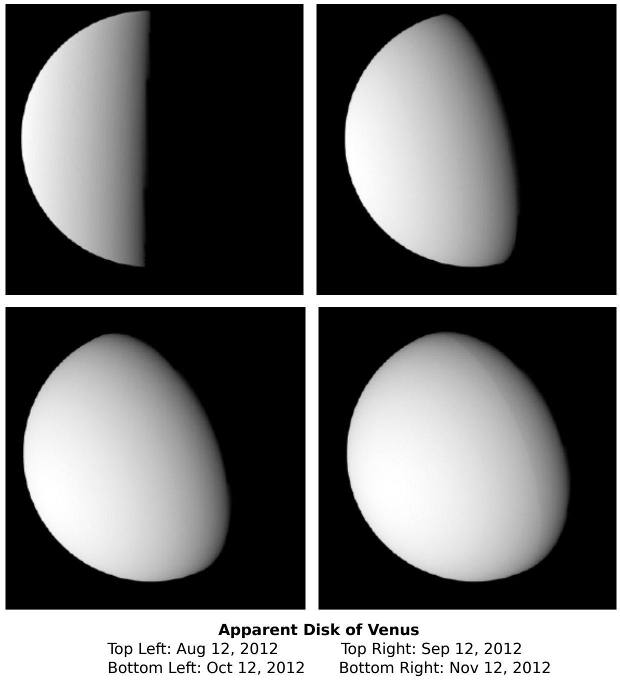

Figure 2: Apparent Disk of Venus

these gases. These measurements will be used to interpret the CARMA observations and derive planet-wide abundances of those constituents.

We propose to observe Venus at 103 GHz and 112 GHz in order to study possible spatial and temporal variation in the brightness temperature. Figure 2 shows the apparent disk of the planet between August and November 2012. Table 1 gives some ephemeris information for Venus during the CARMA observing period for semester 2012b along with some telescope parameters of interest. We would like to observe Venus once every month between August and November in order to study its emission spectrum near the 3 mm-wavelength range to constrain any spatial and temporal variations on the abundances of millimeter-wavelength absorbing gases such as sulfuric acid vapor and sulfur dioxide at the cloud base.

Table 1: Ephemeris for Venus

Parameter	August	September	October	November
Percentage Illumination	50%	60%	70%	80%
Angular Diameter	26”	20”	15.7”	13.3”
Sun-Earth-Venus Angle	46°	44°	40°	35°
Frequency	103 GHz and 112 GHz			
Bandwidth	4 GHz/sideband			
Array Configuration Required	C			
Array Spatial Resolution	2.2”			

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