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CARMA observations of Venus: 3-millimeter images of lower cloud continuum emission

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Abstract

We present initial results of data reduction and imaging for 3-millimeter CARMA observations of Venus near the terminator made in 2013. The resulting images from each observing date feature variations in disk brightness that are consistent with prior observations. These inhomogeneities are likely the result of horizontal variations in the abundances of sulfur-bearing molecules at Venus. For the first time, bright regions are observed on the dayside of the planet.

1. Introduction

The global cloud layer covering Venus limits the escape of thermal emission from the lower atmosphere. The existence of narrow emission windows in the infrared has enabled ground and space-based passive remote sensing of the lower atmosphere and surface on the nightside of Venus at high spatial resolution [1, 3]. Microwave and millimeter-wavelength observations of Venus, however, are sensitive to both dayside and nightside thermal emission from the lower clouds. The abundances of trace millimeter-wavelength absorbers, such as SO_2, H_2SO_4 vapor, and cloud aerosols, may change by orders of magnitude both vertically and horizontally across the Venus disk. To study the vertical and spatial distribution of these absorbers, as well as their change from day to night, near-terminator observations of Venus were made with the Combined Array for Millimeter-wavelength Radio Astronomy (CARMA) in 2013. In the following sections, we present our progress in the reduction and imaging of this dataset.

2. Observations

Venus was observed near elongation by CARMA in the 3-millimeter band on October 19th, October 31st, and November 12th, 2013. The six 10.4-meter and nine 6.1-meter CARMA antennas were arranged in the C configuration with a maximum baseline length of 372.49 meters and a minimum baseline length of 4.52 meters. For each day, Venus was observed for 5-6 hours to obtain sufficient uv coverage. 12 single polarization continuum windows with bandwidths of 487.5 MHz were observed within the 3-millimeter band with frequencies spanning 98-115 GHz. Following initial bandpass and flux calibrator observations, Venus was observed for 15 minute intervals with 30 second integrations, and J1733-130 was subsequently observed for three minute intervals as the phase calibrator.

3. Calibration and Imaging

The Venus datasets were retrieved from the archive and further processed using CASA. Following initial data inspection and flagging, delay and bandpass calibration are performed for each continuum window, and the 39 channels comprising each window are subsequently averaged together. Flux scaling and a phase calibration step is then applied to each averaged window. For the October observations, flux-scaling determined from flux density measurements of MWC349 (accurate to 15%) at 103 GHz were scaled with frequency as $\nu^{0.6}$ [4], and flux-scaling from Mars measurements takes advantage of the Butler-JPL Horizons 2012 solar system reference standard. Figure 1 shows the real part of the observed visibilities following this calibration procedure

For imaging, a limb-darkened disk starting model is subtracted from the visibility data, and the residuals are used as inputs to the CLEAN algorithm with a Briggs weighting scheme. For the CLEAN process, a finite support is specified as a circular region extending 4" radially beyond the Venus disk on the observation date.

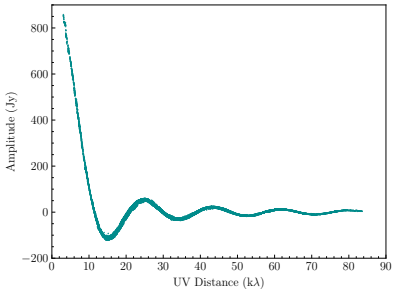

Figure 1: Real part of the calibrated visibilities for the October 19th observation in a single spectral window as a function of the projected baseline lengths in units of kilowavelengths

4. Results

Figure 2 shows a brightness image of Venus derived using the aforementioned imaging procedure. Brightness variations on the order of 30 Kelvin can be seen across the disk, in agreement with prior observations [2]. Unlike prior observations, however, bright regions are observable on the near-terminator dayside of Venus for the October 19th observations. Images from the October 31st observations show the expected nightside bright regions.

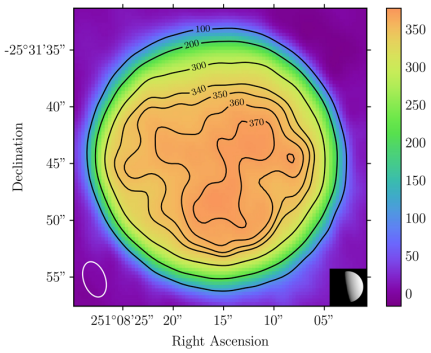

Figure 2: Image of Venus at 101.7 GHz created from October 19th observations in brightness temperature units (K). Variations of 20-30 Kelvins are visible across the disk. The illumination of Venus is shown in the bottom right corner of the figure

5. Summary and Conclusions

3-millimeter images of Venus have been made from CARMA observations in late 2013. These images confirm spatial brightness variations consistent with prior observations and provide evidence that variations are not limited to the nightside. Future work will focus on the application of a Venus microwave radiative transfer model to constrain the abundances of sulfur species in the lower cloud using this dataset.

Acknowledgements

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