Single Pass X-band Radar Interferometry for Topographic Mapping of Venus. S. Hensley[1], S. Smrekar[1], D. Nunes[1], R. Seu[2], and P. Lombardo[2] and the VERITAS Science Team, [1]Jet Propulsion Laboratory, California Institute of Technology, 4800 Oak Grove Dr, Pasadena, CA 91109, [2]University of Rome La Sapienza, Roma, Italy

Introduction: Magellan, a NASA mission to Venus in the early 1990s, mapped nearly the entire surface of Venus with an S-band (12 cm) synthetic aperture radar and microwave radiometer and made radar altimeter measurements of the topography, [1]. Although these measurements revolutionized our understanding of the geophysical processes that have shaped the evolution of the surface of Venus, the lack of finer resolution imagery and topography of the surface than that obtained by Magellan has hindered finding the answers to key questions concerning the processes and evolution of the surface. The proposed Venus Emissivity, Radio Science, InSAR Topography And Spectroscopy (VERITAS) Mission is one of five NASA Discovery missions selected for Phase A studies. It is designed to obtain high resolution imagery and topography of the surface of Venus using an X-band radar configured as a single pass radar interferometer (called VISAR) coupled with a multispectral NIR emissivity mapping sensor, the Venus Emmissivity Mapper [2]. Here we describe the VISAR instrument.

Instrument Overview: The VISAR instrument is a single pass interferometric X-band radar with a wavelength of 3.8 cm designed to obtain both global imagery and topography measurements of the surface of Venus. Radar requirements were predicated on answering key questions about the evolution of the surface of Venus and how Venus evolved so differently than Earth [3].

Topographic mapping accuracy requirements are the driver for the VISAR design as a single pass radar interferometer. The operating frequency of X-band was dictated by two primary factors. First, attenuation in the Venus atmosphere goes as frequency squared in dB, which imposes a stiff SNR penalty for short wavelengths. Second, spacecraft accommodation restricted the baseline length (distance between the two antennas in the interferometer) to around 3 m, which drives the design to shorter wavelengths. A best comprise between these factors was used to set the operating frequency. Figure 1 shows the height accuracy as function of wavelength.

The radar operates with a bandwidth of 20 MHz that results in a range resolution of 7.5 m, which projects to a ground resolution of 15 m. The radar has a 0.6m×3.9m antenna resulting in a 14.5 km swath width and an azimuth resolution of 2 m. The radar is designed to generate 15 m imagery with at least 7 looks and topographic maps with a posting of 250 m and a height accuracy of 5 m.

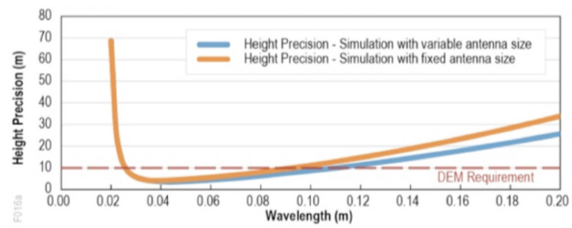

Figure 1. *Plot of the topographic mapping accuracy as a function of wavelength. Accuracy at small wavelengths is dominated by atmospheric losses whereas at longer wavelengths it is dominated by baseline length and antenna size constraints.*

See [3] for more details. Figure 2 shows a diagram of the instrument and the imaging geometry.

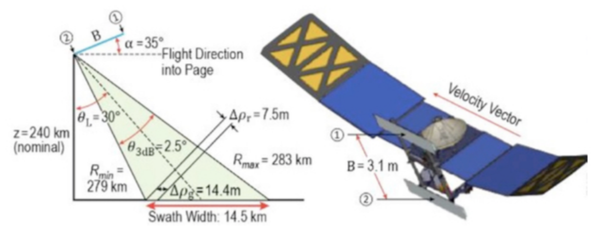

Figure 2. *VISAR flight configuration and observing geometry are optimized for InSAR DEM acquisition with baseline separation B = 3.1 m, look angle of θ_l=30°, range resolution of $\Delta\rho_r$=7.5 m, range of ρ=281 km and swath width of 14.5 km at an altitude of 240 km (high end of altitude range of platform).*

Radar Operations: The VISAR radar will operate from an average altitude of 220 km and have a look angle of 30°. Data will be collected on both ascending and descending orbits for about 11 orbits before turning to Earth for 5 orbits to downlink this data. The resulting gap will be filled in during the subsequent cycle (1 cycle=Venus sidereal day=243.015 days). Because the raw data volume is too large to downlink to Earth onboard processing of the raw data to interferograms reducing the data volume 1000 fold [4] is done prior to downlink. An exception to this is the raw data downlinked for targeted regions where inter-cycle repeat pass radar interferometry will be used to look for surface deformation either from volcanoes or tectonic deformation [5, 6]. The thick Venus atmosphere permits such observations, as shown in [7].

VISAR Products: Planned products to be generated by the VISAR radar include:

- Global 30 m medium resolution X-band backscatter imagery of the surface at 31° incidence angle (30° look angle).
- High-resolution 15 m resolution imagery of targeted areas covering approximately 23% of the planet surface. See Figure 3 for a comparison of Magellan and VERITAS imagery for various science investigations.
- Topographic maps with a spatial resolution of 250 m and a height accuracy of 5 m. The estimated height accuracy includes atmospheric losses, radar backscatter variations (estimated by converting S-band Magellan measurements to X-band) and the radar imaging geometry. During Phase A we will estimate performance spatially based on Magellan backscatter and topography and generate histograms of expected performance as a function of backscatter, elevation and various terrain types. Different terrain types have different combinations of slope and backscatter.
- Topographic precision maps are derived from the interferometric correlation and the interferometric imaging geometry.
- Repeat pass interferometric maps of surface deformation for approximately 12 targeted regions with dimensions of 200km×200km. Allowable numbers and target dimension are being further investigated during Step II.
- Repeat pass correlation maps, which after correcting for SNR correlation (that can be estimated from the single pass data), can be used to generate bounds on the amount of temporal and volumetric correlation. Temporal correlation can be used to infer sub wavelength (3.8 cm) scale changes on the surface.

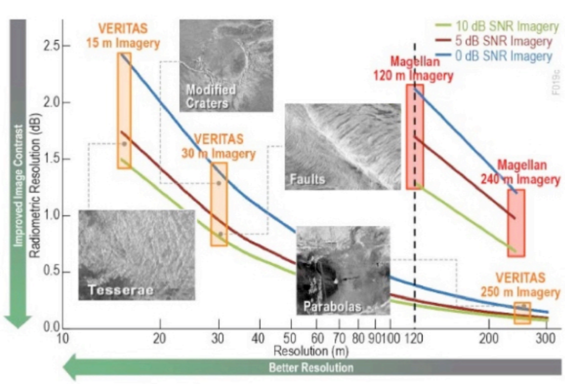

Figure 3. *Radiometric resolution of Magellan data is insufficient to look for subtle variation in of radar backscatter in very radar dark regions, e.g., parabolas. The spatial resolution is also an order of magnitude too coarse to understand the history of crater modification, tesserae, and faults.*

Tie points between overlapping mapping strips will be used to improve the ephemeris and in a bundle adjustment procedure to remove residual cross-track elevation tilts due to baseline and other sensor calibration errors prior to mosaicking the strips. Figure 4 shows a diagram of how VISAR will be used in conjunction with other VERITAS and Venus data products to support various science investigations.

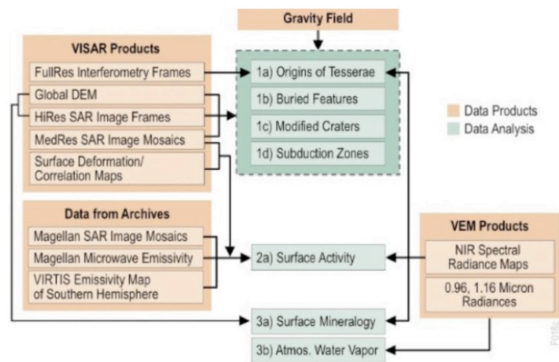

Figure 4. *High-level data products flow into data analysis led by Science Team members to address each of the proposed VERITAS Science Objectives.*

One of our key science objectives will be to assess if Venus is geologically active. One means of looking for recent activity will be comparison of VISAR imagery to Magellan imagery. Differences in wavelength, incidence angle and look direction (for some imagery since Magellan alternated look direction between cycles) will complicate this assessment. To mitigate these problems we plan to look for changes in regions with distinct morphological boundaries above a particular area threshold (conservatively ~25 km^2). Additionally, DLR's airborne F-SAR radar has acquired simultaneous radar interferomertric data at X-band and S-band over representative volcanic surfaces to provide actual X to S-band backscatter comparisons that can be used to tune change detection algorithms.

References:

[1] Saunders, R. et al. (1992) *JGR*., 97:13,06713,09 [2] Helbert, J. et al. (2016) LPSC XLVII [3] S. Smrekar, et al., (2016) LPSC XLVII. VERITAS Mssion [4] Hensley, S. et al. (2015) Proc Asia Pacific SAR [5] Smrekar, S.E., et al. (2010) Science, 328, xx. [6] Shalygin, E.et al. (2015) GRL, 42. [7] Hensley, S., and S. Shaffer (2010), LPSC XLI, Abstract #2369.

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