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Introduction: The extreme ~735K surface temperature and 9.2 MPa atmospheric pressure create a challenging environment for investigating Venus' surface. Quantitative chemical and mineralogical investigations are required to understand how surface minerals and rocks interact with Venus' atmosphere. In situ investigations must be completed within several hours before the lander is overcome by environmental conditions. Remote measurements made from within the safety of the lander are ideal and avoid many risks, including use of sampling hardware and the extended time required to deliver samples to instruments inside the lander.

The Venus Elemental and Mineralogical Camera (VEMCam) can make thousands of measurements within the first two hours on the surface, providing an unprecedented description of the Venus surface heterogeneity. VEMCam is based on the ChemCam instrument on the *Mars Science Laboratory* rover and the SuperCam instrument under development for the *Mars 2020* rover. VEMCam includes an integrated Raman and Laser-Induced Breakdown Spectrometer (LIBS) instrument capable of probing many disparate locations around the lander. VEMCam also includes a color Remote Micro-Imager (RMI) to acquire high-resolution context images of targets analyzed by Raman and LIBS spectroscopy. Finally, VEMCam includes a work-space multispectral imager to document the entire Raman and LIBS workspace. This paper provides an overview of this highly capable VEMCam Raman and LIBS integrated instrument.

Raman and LIBS Spectroscopy: Raman and LIBS are highly synergistic techniques. Raman spectroscopy is fundamentally sensitive to molecular vibrations from which the definitive mineralogy is determined and chemistry is inferred. LIBS provides quantitative chemical analyses from which mineralogy can be inferred.

LIBS experiments focus a Nd:YAG laser (1064 nm, 10 Hz, 60 mJ/pulse) laser onto a sample surface. The laser ablates material and generates an expanding plasma containing electronically excited atoms, ions and small molecules. These excited species emit light at wavelengths diagnostic of the species present. Some of this emission is collected with an 89 mm telescope and recorded with two reflection (275 – 500nm) and one transmission (535 – 800 nm) spectrometer. **Figure 1** contains a LIBS spectrum of BIR-1 under simulated Venus surface conditions.

For Raman analyses, a pulsed and frequency doubled Nd:YAG laser (532 nm, 10 Hz, 10 mJ/pulse) is directed onto the sample surface, stimulating Raman-active vibrational modes in the sample and producing Raman emission. Some of this emission is collected with an 89 mm telescope and recorded using the SuperCam transmission spectrometer noted above.

Limited turbulence effects on the laser: The possibility that turbulence could interfere with the laser as it propagates through the atmosphere have been considerd both theoretically and experimentally. We have characterized its magnitude and the impact it could possibly have on the laser. We have conclusively demonstrated that the Venus atmosphere has no impact whatsoever on Raman measurements of mineralogy [1], so our current work specifically addresses focusing the 1064 nm laser to create the LIBS plasma at the target.

After traveling through space and descending to the surface, the lander interior is far colder than the am-

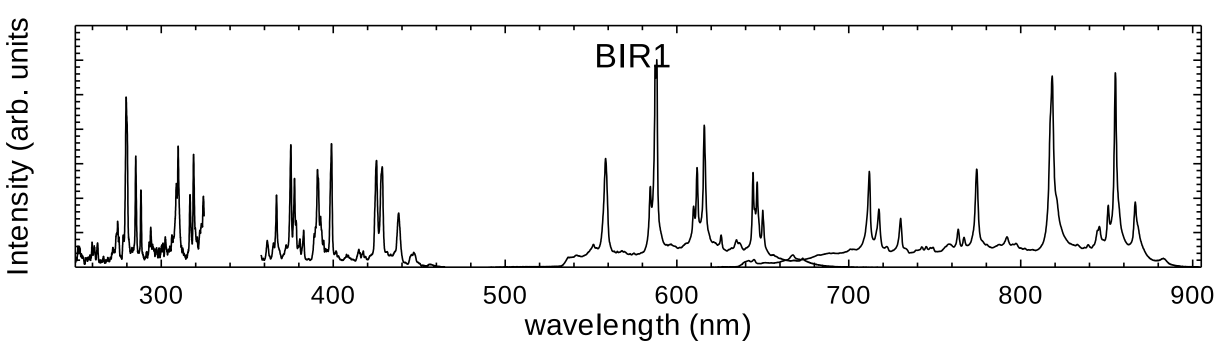

Figure 1: LIBS spectrum of the Islandic River Basalt (BIR-1) under simulated Venus atmospheric temperatures (465ºC) and pressure (92 atm).

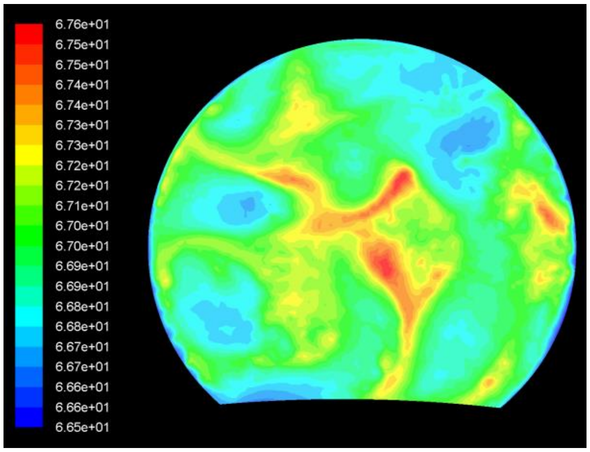

Figure 2: Contours of fluid density on the window. For reference, the window is approximately 87 mm in diameter. These contours represent only a **1.6%** change in density.

bient surface temperature. The sapphire window through which the laser propagates is thus cold relative to the atmosphere, so the window will have an adjacent layer of relatively cold fluid. This temperature difference causes changes in the density of the fluid which changes the index of refraction. In the presence of a mean surface wind, this atmospheric layer of fluid will fluctuate due to the shedding of turbulent eddies off the lander and window.

Computational fluid dynamics (CFD) calculations and a ZEMAX optical model have been integrated to characterize this dynamic shedding effect in the context of the laser beam propagation. **Figure 2** shows density variations determined from CFD calculations. It is important to note that these variations only represent a

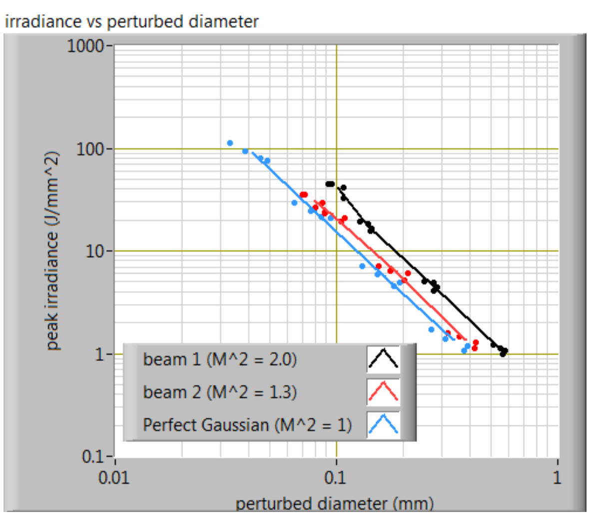

Figure 3: Changes in irradiance as a function of beam quality and distance. These results demonstrate that changes in irradiance due to turbulence are minimal.

1.6% change in density. Calculations were conducted with different wind speeds and angles relative to the window. One important conclusion is that increased wind speeds reduce the magnitude of the thermal gradients because the relatively cold fluid at the window exteral interface is rapidly mixed with the ambient fluid. Therefore, increased wind speeds reduce turbulent effects on the laser.

ZEMAX analyses depicted in **Figure 3** show that changes in irradiance due to turbulence, which are critical to plasma generation, are minimal out to 2 m. As expected from instruments that share the ChemCam and SuperCam architecture, the LIBS laser spot size increases as a function of distance, which results in a decrease in irradiance. The irradiance changes depicted in **Figure 3** are dominated by the expected changes in spot size and not by turbulence. Furthermore, laboratory investigations demonstrate that a LIBS plasma is repeatedly generated when the window temperature was more than 60°C lower than the ambient chamber temperature. This is 12× larger than the 5ºC difference expected on a Venus lander.

Figure 4. The 2 m long, 110 mm diameter Venus chamber capable of storing >92 atm of CO_2 at >465ºC.

Venus Chamber: Development of the VEMCam instrument and demonstration of its capabilities were accomplished using a Venus chamber at the Los Alamos National Laboratory depicted in **Figure 4**. The chamber can be capped with a sapphire window that enables the Raman and LIBS analysis of samples under simulated Venus surface conditions.

Reference: [1] Clegg S. M. et al. (2014) *Spectrochim. Acta B*, 68, 925-936.