COMBINED MICROSCOPIC RAMAN AND LIBS FOR PLANETARY SURFACE EXPLORATION USING A FAST TIME-GATED DETECTOR. J. Blacksberg[1], Y. Maruyama[1], E. Alerstam[1], M. Choukroun[1], E. Charbon[3], G.R.Rossman[2], [1]Jet Propulsion Laboratory, California Institute of Technology, 4800 Oak Grove Dr., Pasadena, CA 91109, Jordana.blacksberg@jpl.nasa.gov, [2]California Institute of Technology, Division of Geological and Planetary Sciences, Pasadena, California 91125, grr@gps.caltech.edu, [3]Circuits and Systems, Delft University of Technology, Delft, The Netherlands, e.charbon@tudelft.nl.

Introduction: We present a planetary mineralogy instrument that could potentially perform both phase and elemental analyses on rock, soil, and regolith in conjunction with microscopic imaging. Raman spectroscopy has long been a candidate for the next generation of *in situ* planetary instruments, as it provides mineralogical structure and composition of nearly all crystalline minerals [1-3]. It can be performed in concert with microscopic imaging, preserving the geological context of mineral phases. New developments in the field of time-resolved laser spectroscopy have made it feasible to perform fluorescence-free Raman spectroscopy combined with Laser Induced Breakdown Spectroscopy (LIBS) for elemental analysis. This combination yields a highly capable microscopic analysis tool suitable for diverse planetary surface environments. This versatile instrument would be operated close-range (e.g. on a rover arm) and could be considered for a host of planetary surface missions (e.g. Mars, primitive bodies, Venus, the Moon).

As we have demonstrated in previous work [4], time resolution is essential for fluorescence rejection, particularly when observing regions of aqueous alteration where minerals can be highly fluorescent (e.g. clays, sulfates, phosphates). The use of a small spot size (~ 1 µm) laser with high rep rate (40 KHz) and low pulse energy (1 µJ/pulse) allows us to rapidly collect high signal to noise Raman spectra while minimizing sample damage. Increasing the pulse energy by about an order of magnitude creates a microscopic plasma near the surface and enables the collection of LIBS spectra at an unusually high rep rate and low pulse energy. Recent progress in miniature sub-ns pulsed lasers and time-resolved solid state detectors provides a means for significant reduction in size, weight, and power as well as overall complexity of these instruments. We report on Raman and LIBS results from our newly developed detector module with a 1024 x 8 single photon avalanche diode array shown in figure 1.

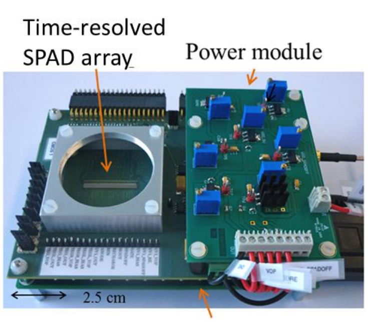

Figure 1. 1024 x 8 SPAD array integrated with the prototype FPGA board

Application to Small Primitive Bodies:
Microscopic Raman and LIBS are strong candidates for exploration of primitive asteroids and comets, where surface features tend to be dark and yield very weak spectral reflectance signatures. On-surface identification and mapping of mineral phases will be essential for understanding the histories and ultimately the

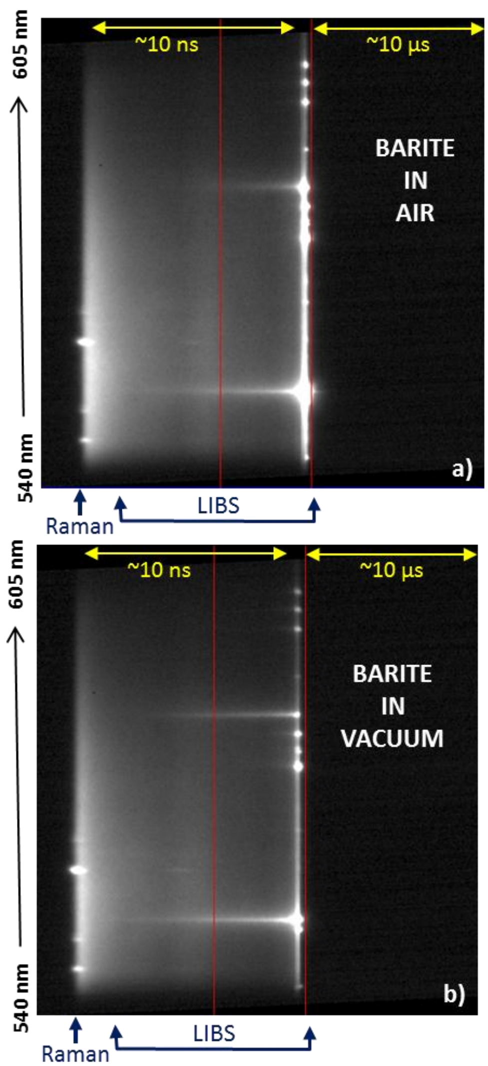

Figure 2. Streak camera images showing Raman and LIBS spectra of Barite in air and in high vacuum (10^{-5} mbar). The y-axis represents wavelength and the x-axis represents time. The Raman peaks coincide with the timing of the laser pulse, with LIBS occurring over a longer time scale.

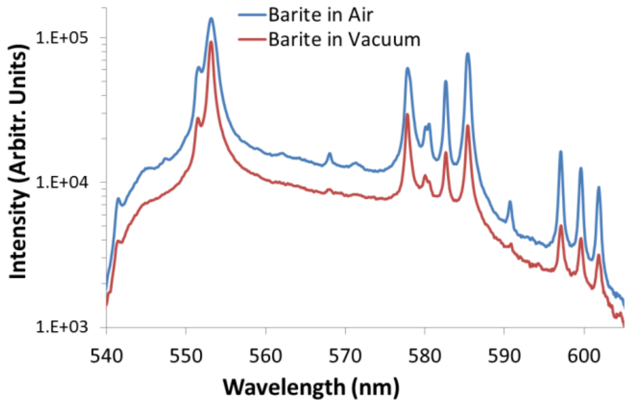

Figure 3. LIBS spectra of barite in air and under high vacuum (10^{-5} mbar). These spectra represent the sum of spectra within the time region between the red lines in figure 2.

origins of these bodies. We have performed some preliminary tests simulating Raman and LIBS operation on an airless body, using a custom-built optical chamber connected to a turbomolecular pump, achieving high vacuum of ~ 10^{-5} mbar. Although the formation and explansion of a LIBS plasma are altered by the surrounding atmosphere or lack thereof, our results indicate that vacuum operation does not significantly affect the signal to noise of LIBS spectra. Results for Barite comparing spectra in vacuum and air are shown in figures 2 and 3. These early results underscore the versatility of laser spectroscopic techniques in exploration of highly varied planetary environments.

Time-Resolved Laser Spectroscopy Instrument Development:
We will present recent developments in time-resolved spectroscopy instrumentation leading to miniaturization. Instrument capability will be demonstrated using natural mineral samples of relevance to planetary exploration. We present a newly-developed solid state Single-Photon Avalanche Diode (SPAD) sensor array based on Complementary Metal-Oxide Semiconductor (CMOS) technology [5,6]. Using this new SPAD array that is compact and similar in size to a standard uncooled CMOS or CCD image sensor, we have demonstrated that we can achieve equal or greater sensitivity to that achieved with traditional photocathode-based detectors such as streak cameras. The use of a solid state time-resolved detector offers a significant reduction in size, weight, power, and overall complexity, putting it on par with instruments that do not have time resolution, while providing enhanced science return. Some preliminary Raman and LIBS spectra collected using the new 1024 x 8 detector are shown in figure 4.

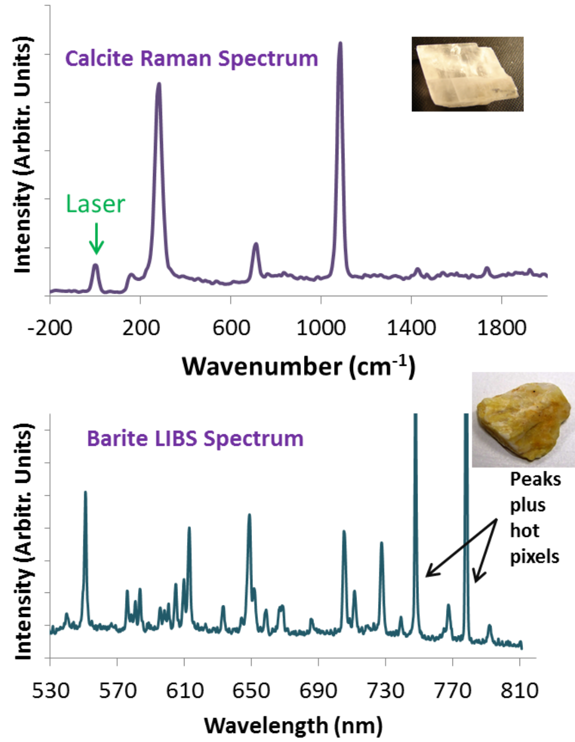

Figure 4. Time-resolved Raman and LIBS spectra using the 1024 x 8 SPAD array.

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