**Introduction:** The advent of ChemCam’s laser induced breakdown spectrometer (LIBS) [1] brought to fore the beginning of mid-range laser remote-sensing on the surface of another planetary body. Mid-range laser remote-sensing is superior to contact science instruments in that laser remote-sensing instruments can acquire spectral data without the need for sample preparation, can characterize a greater number of sample targets in a prescribed time period, and can acquire spectral data for sample targets that are inaccessible to a rover’s arm. While LIBS provides excellent spectral data characterizing the elemental composition of a sample, LIBS can only infer the arrangement of atoms in a given sample via stoichiometry, thus limiting the characterization of polymorph minerals that form in distinct environments. Raman spectroscopy, on the other hand, is highly sensitive to the arrangement of atoms with a given molecule, allowing for the unambiguous detection of polymorphs and isomers. Recently, we have developed a static Fourier transform spectrometer, known as a spatial heterodyne spectrometer (SHS), which is capable of interrogating Raman and LIBS samples remotely in a high-resolution, compact, light footprint design [2,3]. In this abstract, the authors present methods of increasing the wavelength coverage, and manipulating the signal to noise ratio properties of spatial heterodyne spectrometers in order to maximize sensitivity for analysis of planetary science materials via Raman and LIBS spectroscopy.

**Instrument Concepts and Results:** Spatial heterodyne spectrometers are a type of amplitude-splitting interferometer. In an SHS experiment, spectral input light is halved by a beam-splitter or grating, whereupon the halved spectral input is directed towards an optical element (e.g. grating or mirror), then recombines as crossed wavefronts. The wavefronts are called crossed because an angle exists between the two plane wavefronts caused by the interaction of the wavefront with the aforementioned optical element. The angle between the wavefronts defines the period of the resulting Fizeau fringe pattern. The greater the angle between the two wavefronts, the lesser the period of the oscillating pattern.

The most common SHS design consists of placing a stationary grating grating in each arm of the interferometer. In this design, each arm produces a tilted wavefront (for wavelengths other than the Littrow wavelength) that slowly diverge from one another. Spectral light in the overlapping region of these slowly diverging beams may produce interference patterns. Alternatively, a stationary mirror can replace one of the diffraction gratings within an arm of the interferometer, as depicted in Fig. 1. This modification has a few effects. First, all light that is incident upon the mirror arm of the interferometer reaches the detector. In other words, no light is lost to diffraction orders outside the free spectral range of the interferometer. Second, the light that strikes the mirror arm does not diverge from the optical axis of the interferometer, meaning that the area of overlap between the two beams within the interferometer is greater. Third, the angle between the crossing wavefronts is cut in half, thus doubling the bandpass. Modern intensified charge-coupled devices (ICCD) commonly have 26-micron pixel widths. When using the lowest groove density gratings available commercially off-the-shelf (i.e. 150 grooves per mm) and 26-micron pixel widths, the wavelength coverage for two-grating SHS is only 70 nm or ~2500 cm⁻¹ when exciting with a Nd:YAG 532 nm laser. Hence, a complete Raman spectrum (i.e. 100–3500 cm⁻¹) cannot be collected with the standard two-grating design at fixed grating angles with 26-micron pixels.

![Fig. 1 A depiction of a one-mirror, one-grating SHS.](image)

The authors acquired several Raman spectra of minerals using a one-mirror, one grating SHS at a remote distance of 2.845 m from the fore optic. The excitation source was a pulsed, frequency doubled Nd:YAG laser, operating at 532 nm with a 10 ns pulse.
width, 8.5 mJ pulse energy and 100 Hz pulse repetition rate. One-hundred one second accumulation spectra were acquired for each Raman analyte. For each Fourier bin, the median and median absolute deviation of the signal was calculated. Plotted in Fig. 2 are the results of this analysis where the solid line represents the median signal and the shading about this median line represents the median absolute deviation.

Sensitivity is limited in spatial heterodyne spectroscopy experiments by the multiplex disadvantage caused by uncorrelated photon noise in the interferogram. When recording a SHS interferogram, every pixel of the detector records every spatial frequency simultaneously, so photon noise created by any one spatial frequency is distributed to every other spatial frequency also. In effect, photon noise generated by prominent spectral features washes out weak spectral features. In order to supplant this limitation, the authors have developed a unique cross-dispersed spatial heterodyne spectrometer (xSHS) that correlates photon noise along one axis of the detector by coupling a low-resolution prism spectrometer in series with SHS.

The virtues of xSHS are manyfold. First, the multiplex disadvantage should be severely diminished. The authors have recorded interferograms where the spatial fringe patterns associated with Raman bands spaced just ~ 200 cm⁻¹ are completely resolved from one another. Hence, Raman modes spaced more than 200 cm⁻¹ apart should experience no multiplex disadvantage whatsoever. Second, the spatial fringe pattern associated with a particular spectral peak is localized onto a narrow region of the detector, meaning that fewer photons are necessary to reproduce the same fringe visibility when compared to traditional SHS measurements. Third, spectral features beyond the Nyquist limit do not contribute to the noise of spectral features within the Nyquist limit as a result of the cross-dispersion, diminishing the need for bandpass filtering. Fourth, spectral features beyond the Nyquist limit are recorded, albeit in low-resolution, by the cross-dispersion generated by the prism spectrometer. In Fig. 4, the authors present a cross-dispersed interferogram, and a cross-section of a nitrate Raman band of nitrate in water.

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