

SPATIAL HETERODYNE RAMAN SPECTROSCOPY. T. A. Nathaniel¹ and C. I. Underwood¹, ¹Surrey Space Centre, University of Surrey, Guildford, UK GU2 7XH t.nathaniel@surrey.ac.uk, c.underwood@surrey.ac.uk

Overview: A Spatial Heterodyne Raman instrument (SHERA) has been developed at the University of Surrey. SHERA is the first Raman spectrometer to incorporate spatial heterodyne spectroscopy (SHS). Raman spectroscopy is actively proposed as a tool for the Martian surface[1]. SHERA research is focused on developing a compact Raman spectrometer that achieves performance appropriate for remote analysis of Martian minerals.

SHS is a novel method to use in a Raman instrument. Described in depth by Harlander [2], SHS is an interference-based spectroscopic technique that requires no moving parts. The basic design in SHS is based on a Michelson interferometer wherein the mirrors are replaced with reflective gratings and the detector is a CCD-type array. By imaging the gratings, crossed wavefronts are superimposed on the detector forming interference fringes. A standard SHS diagram is depicted in Figure 1.

SHS diagram

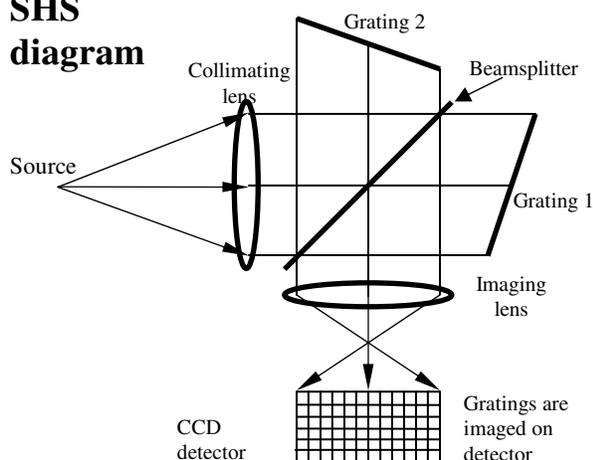


Figure 1. Standard SHS configuration

SHS retains the high throughput advantage of other Fourier transform spectroscopy (FTS) techniques but eliminates the sensitive moving parts in a classical Michelson design. Incoming wavefronts are mixed with the Littrow wavelength of the gratings and interference fringes are captured on the CCD. For the spectral input $B(\sigma)$, intensity as a function of position $I(x)$ on the array detector is given by equation 1:

$$I(x) = \int_0^{\infty} B(\sigma) (1 + \cos[2\pi(4(\sigma - \sigma_0)x \tan \theta)]) d\sigma \quad (1)$$

Where σ_0 is the Littrow wavenumber and θ is the Littrow angle of the grating. The Fourier transform of $I(x)$ will then recover the input spectrum.

Experimental Setup: The SHERA breadboard was assembled from all commercial components. Key design parameters of the SHERA breadboard are listed in Table 1 with a picture of the breadboard is shown in Figure 2. Raman scattered radiation is captured by a collimating lens at a distance of 70mm. Laser energy is filtered using an Iridian Spectral Technology ultra steep edge filter. The edge filter prevents shorter wavelength light from entering the instrument and aliasing with the scattering wavelengths of interest.

Table 1. SHERA instrument parameters

Parameter	Value / Description
Resolving Power	~2500 resolution (~7.25cm ⁻¹)
Bandpass	~535.4 – 700nm (100-4500 Δcm ⁻¹)
Littrow wavelength	520.7nm (19205cm ⁻¹)
Laser	532nm, cw
Edge filter	OD6 at 532nm, T>90% at 535.4nm
Beam splitter	25mm cube, nonpolarizing, fused silica
Gratings	150 lines/mm
Exit optics	1x magnification Linos macro lens
Detector	SonyICX285 CCD, 1360x1024 pixels

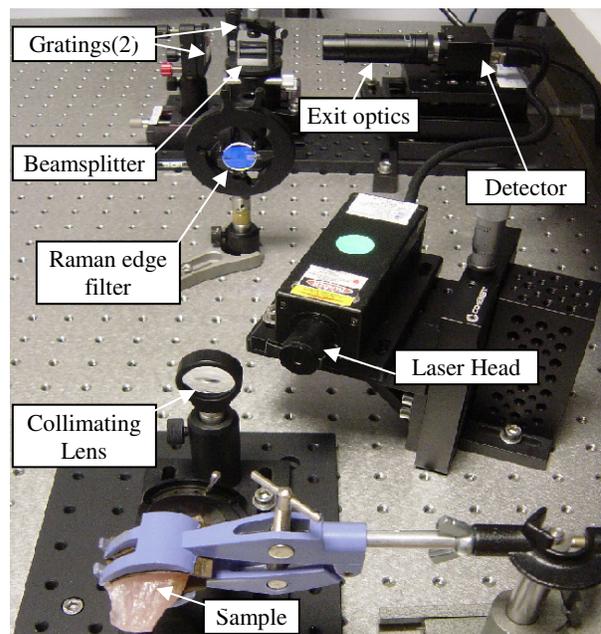


Figure 2. SHERA instrument setup

SHERA Calibration. The resolving power and resolution of the instrument were calculated using a mercury calibration lamp. A section of the image from the mercury interferogram and a plot of one row is shown in Figure 3. The bottom panel shows the fast Fourier transform of the interferogram revealing the 3 mercury lines expected within the bandpass.

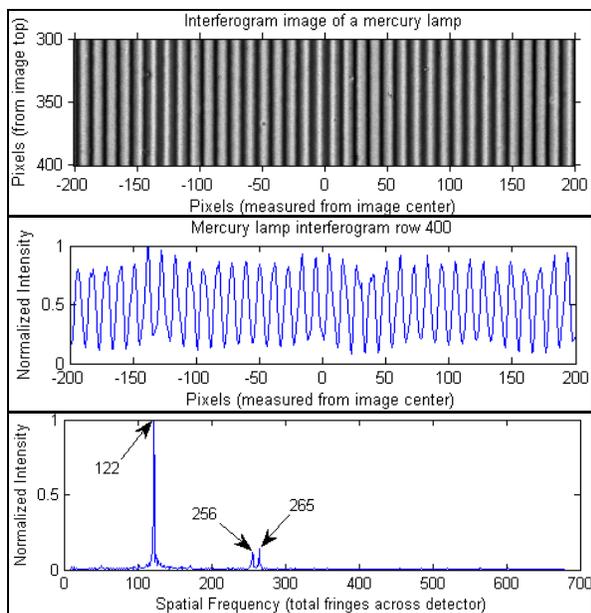


Figure 3. Top Panel-SHERA interferogram image from a mercury lamp. Middle Panel-Single row plot of interferogram. Bottom panel shows the mercury lamp FFT. 546.075nm appears at 122, 576.961nm at 256 and 579.067nm at 265 fringes.

The fringes measured from the mercury lamp were then used to establish the performance parameters of the spectrometer according to equations 2-5 as in Englert et al[3].

$$\lambda_0 = \frac{f_2 - f_1}{(f_2 / \lambda_1) - (f_1 / \lambda_2)} \quad (2)$$

Where λ_0 is the Littrow wavelength, λ_1 and λ_2 are the known wavelengths from the calibration source, f_1 and f_2 are the measured fringe cycles across the detector width and obtained from the fft of the interferogram.

$$\Theta_L = \arcsin\left(\frac{\lambda_0 \times G}{2}\right) \quad (3)$$

Where Θ_L is the Littrow angle (rads) and G is the grating groove density.

$$w = \frac{f_1}{4(1/\lambda_0 - 1/\lambda_1)\tan(\Theta_L)} \quad (4)$$

Where w is the width of the interferogram imaged on the detector.

$$\lambda(f) = \frac{\lambda_0}{1 - \frac{f}{2 \times G \times w}} \quad (5)$$

Equation 4 gives the wavelength as a function of spatial frequency. Converting equation 4 to units of wavenumbers(cm^{-1}) yields a linear relationship, as in traditional FTS.

Control Data. Control data was obtained using a Renishaw System 2000 microRaman Spectrometer using a 514nm excitation laser. Although 514nm is not an exact match for the 532nm laser used in the SHERA instrument it was deemed appropriate for the purposes of this demonstration.

Results: Single Raman bands were detected on several mineral samples. Four Raman bands were detected on a sample of Celestine, SrSO_4 . Detecting multiple Raman bands allowed verification of not only the peak location but also the relative spacing and amplitude, confirming that a Raman signal was collected. The collected signal is compared to the control Raman signal and presented in Figure 4. The peak locations of both control data and SHERA data are labeled. The measured Stokes shift was an average of 18.5cm^{-1} above the control peaks with a standard deviation of 3.8cm^{-1} . To the best of the authors knowledge, this is the first Raman signal collected using SHS.

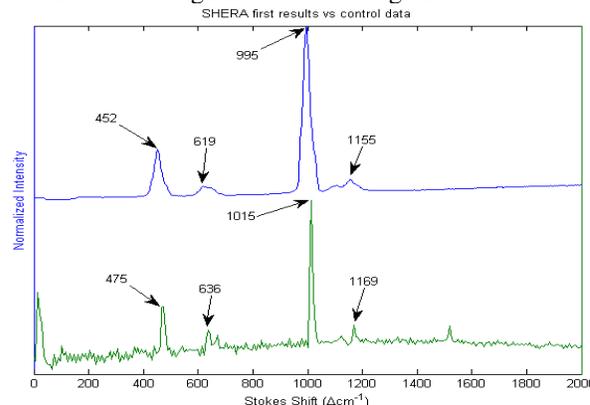


Figure 4. Top spectrum collected on Renishaw Raman instrument. Bottom spectrum collected on SHERA.

Because SHS scans all elements simultaneously, fluorescence can be avoided by implementing a pulsed laser and gated detector approach as shown by Sharma et al[1]. Future design work on SHERA will incorporate fluorescence avoidance and focus on achieving the higher resolution ($\sim 2\text{cm}^{-1}$) necessary for planetary exploration while striving to minimize the instrument footprint and power consumption.

SHERA is a Fourier transform Raman spectrometer with no moving parts. Given the constraints on rover mass and power budgets, the SHERA concept offers a high performance, compact Raman spectrometer.

References: [1]Sharma, S.K., et al., (2009) 40th Lunar and Planetary Science Conference, Abstract #2398 [2]Harlander, J.M., (1991), PhD Thesis, University of Wisconsin-Madison, p. 179 [3]Englert, C.R., et al., (2005), ADA524407, N.R.L. WashingtonDC, p. 22.