Instrument design and first data from the 3D-printed cruciform tunable heterodyne Raman spectrometer

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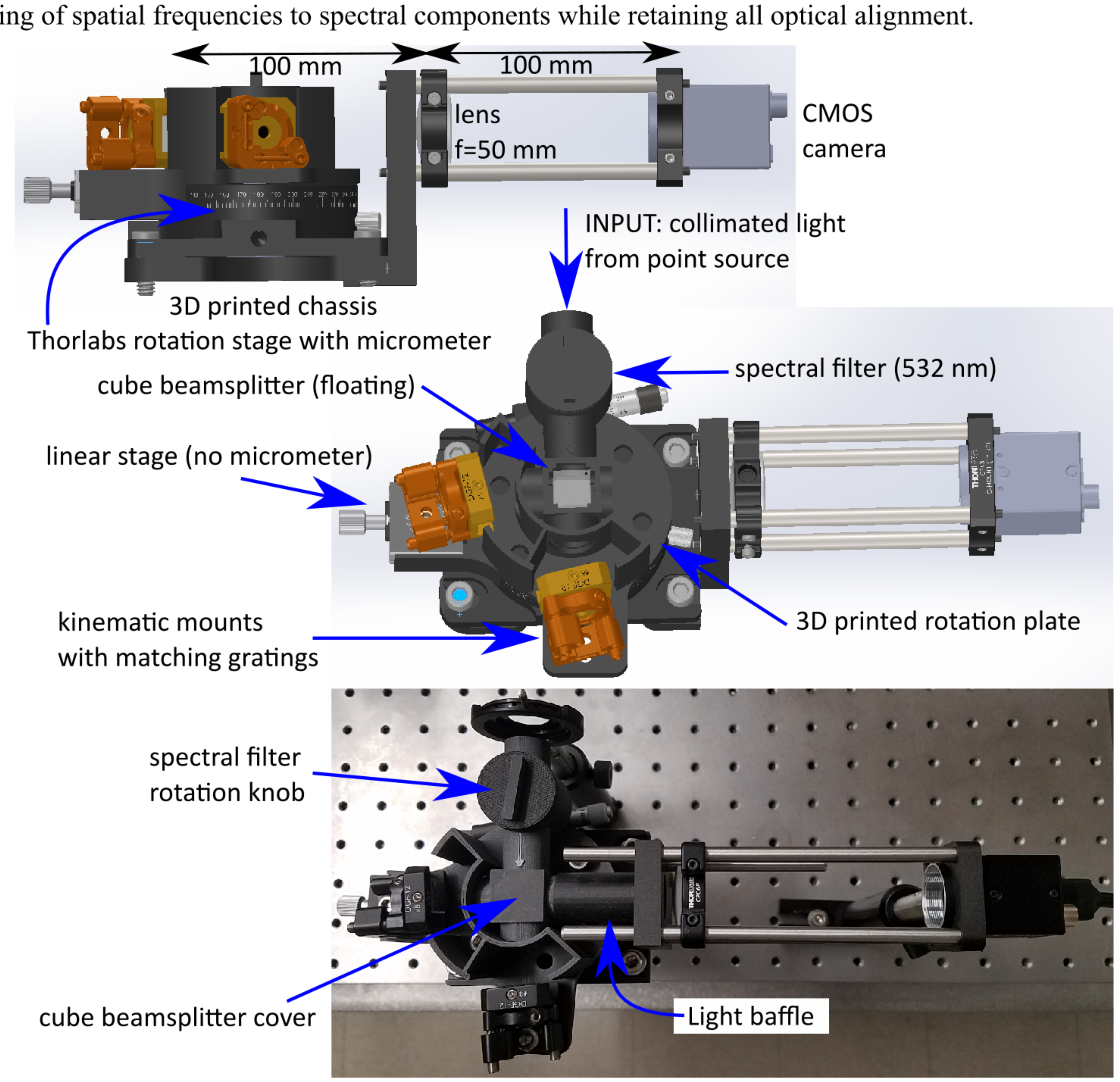
Introduction to the heterodyne Raman spectrometer

Spatial heterodyne spectrometers are a family of compact, high -throughput instruments that have been used for spectroscopic measurements across the visible spectrum, and have lately been of keen interest for fluorescence and Raman spectroscopy and other laser -based spectral probing of materials for both in situ and remote measurements. Spatial heterodyne spectrometers convert a narrow passband of spectral information into 2D field of spatial frequencies by converting a single spatial point or line source into a fan of spatially-diverging spectrally-resolved collimated beams which are then recombined and mutually interfered using a two-arm interferometer and imaged onto a 2D focal plane array. The 1D (and in some implementations, 2D) Fourier transform of each line of the field of spatial frequencies is computed independently which produces the spectrum of the point source. The spectral lines can then be added together to increase SNR and eliminate cumulative phase offsets between lines.

One of the fundamental limitations of heterodyne spectrometers is that the spectral passband of the instrument is limited to the spatial frequencies resolvable on the 2D focal plane array. Typically, the instrument is optically aligned to set the illumination laser wavelength to coincide with the DC spatial frequency. The maximum resolvable spectral width is then set by the resolution of the spectrometer and the Nyquist spatial frequency of the focal plane array. The spectrometer is built and aligned with a single central wavelength and passband, and altering this spectral response requires at the very least a highly precise optical realignment and often a replacement of the dispersive element and spectral filters to match the new laser wavelength. As part of the Project for Exploration Science Pathfinder Research for Enhancing Solar System Observations (Project ESPRESSO) SSERVI node, we report the development of a heterodyne spectrometer that uses a low-precision 3D printed chassis that permits the user to retune the central wavelength (and thus the resolvable spectral passband) by hand with a single actuator that shifts the mapping of spatial frequencies to spectral components while retaining all optical alignment.

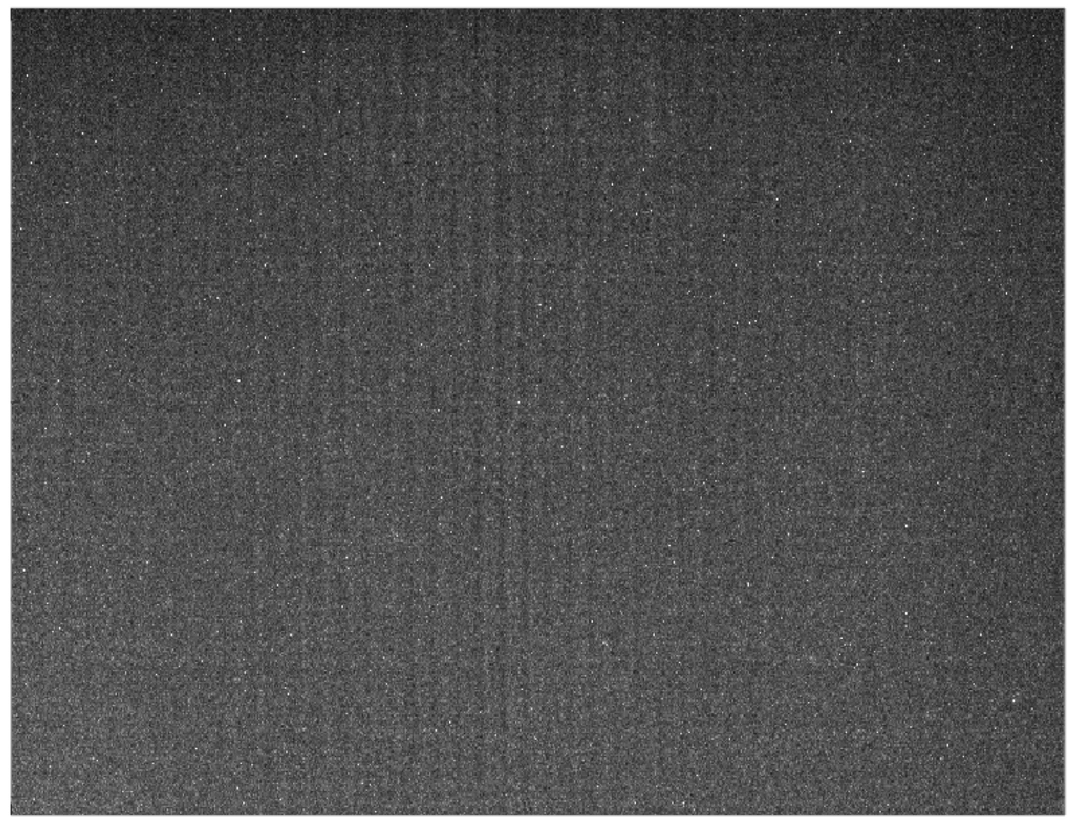


Instrument alignment, operation and first experimental results

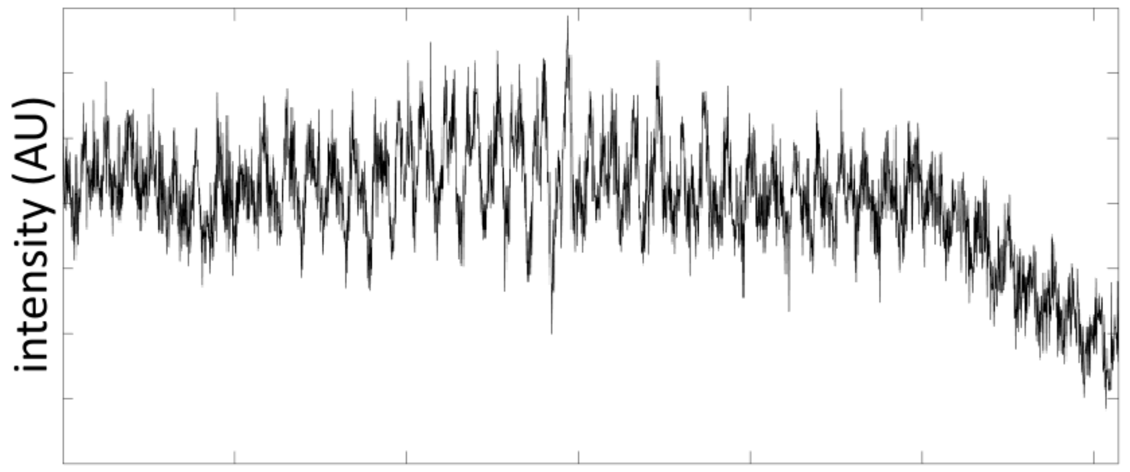
Instrument Alignment Procedure

1. Align imaging optic and camera to image surface of grating
2. Align gratings with laser without filter to produce no fringes
3. Insert filter, and switch to strong incoherent light source with multiple spectral lines (mercury lamp)
4. Maximize strength of the interference fringes by pathlength matching using linear stage
5. Switch back to laser and fine tune pathlength matching using source with strong Raman response (sulfur)

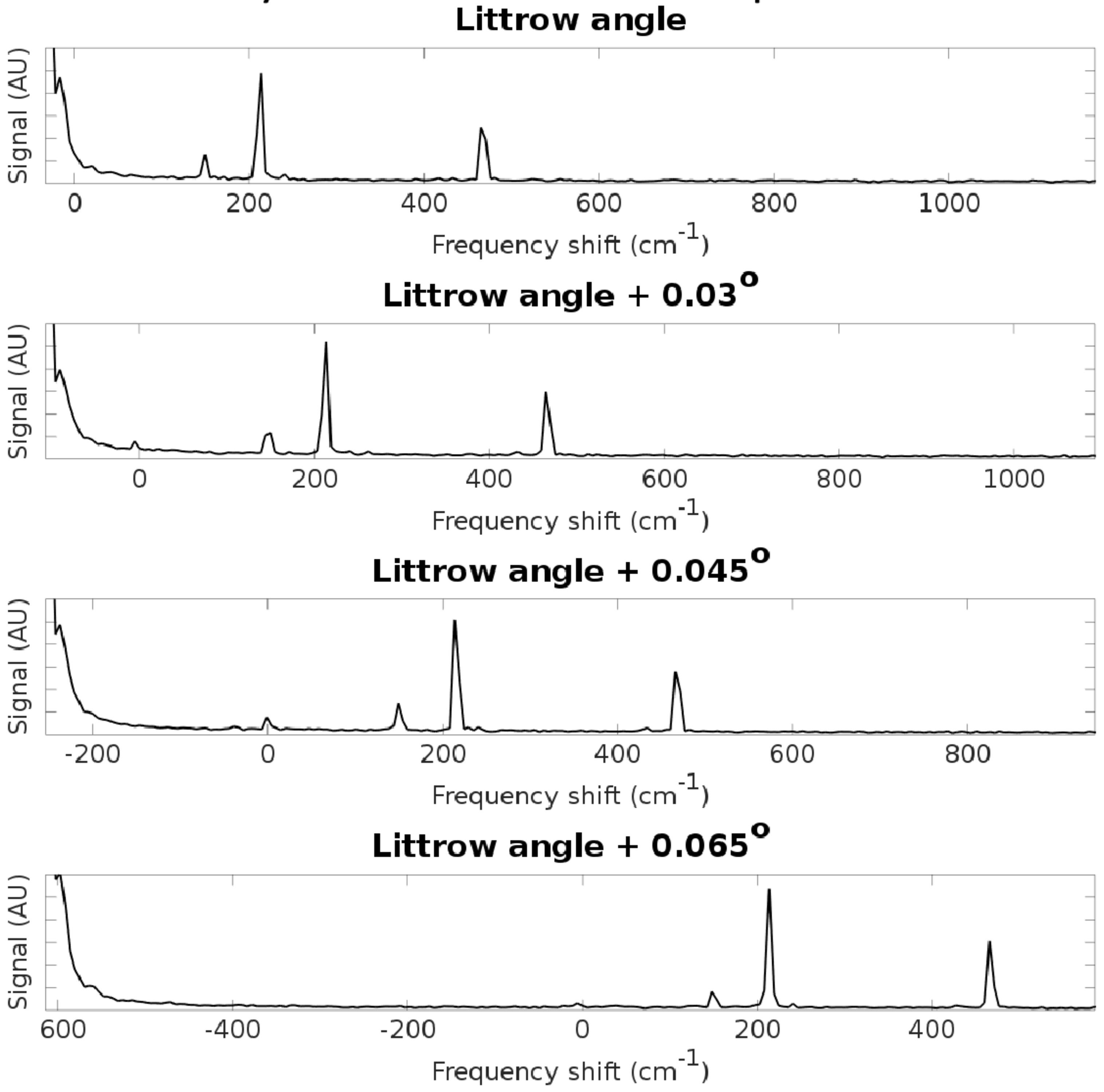
1.5 s raw exposure of crystaline sulfur



column average of raw image



Crystaline Sulfur Raman Spectrum



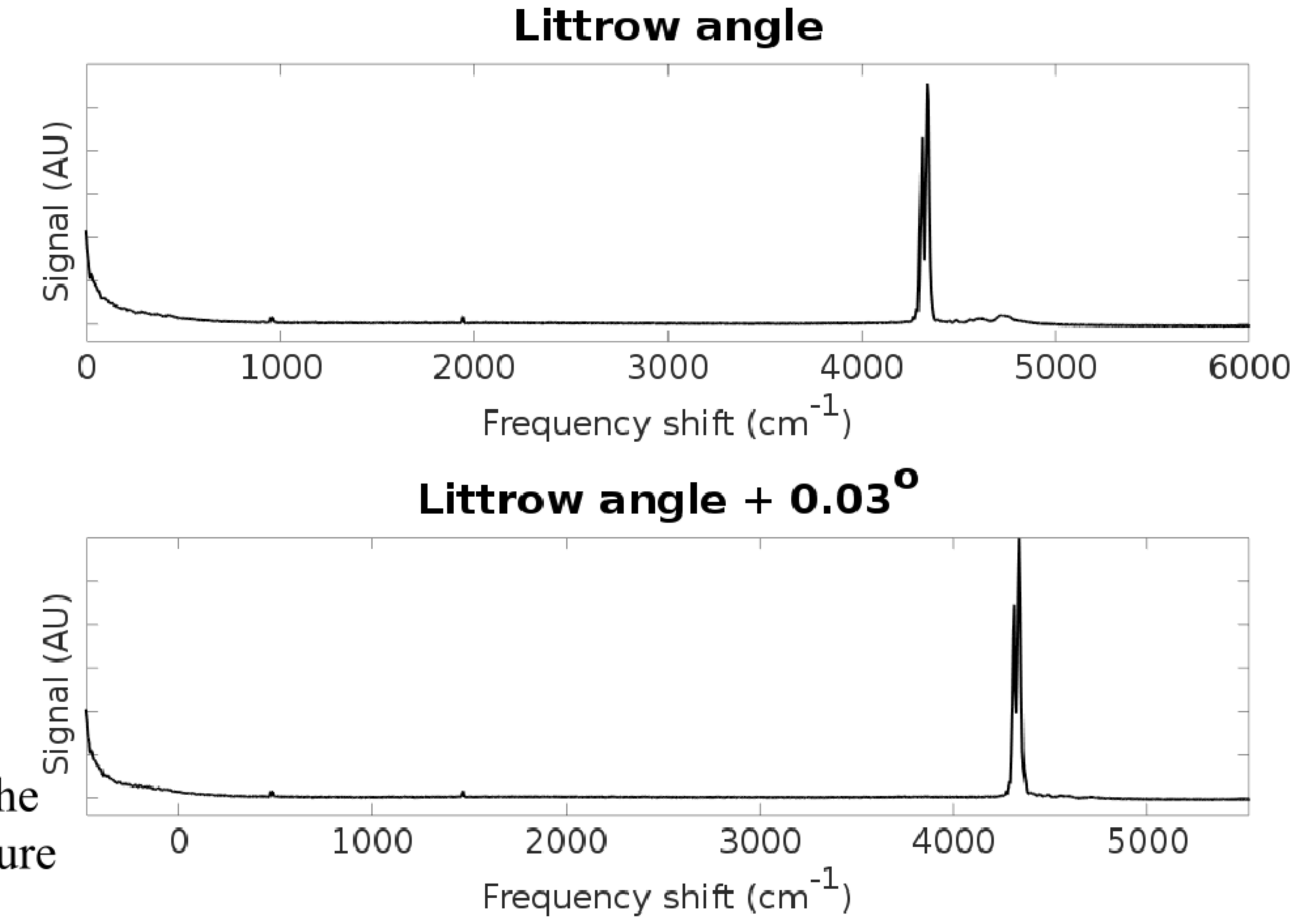
Sulfur Raman spectrum

The image above was taken of a single crystal of natural sulfur. The exposure was 1.5 seconds and the optics were aligned for unity magnification.

Each row of the image is 1D Fourier transformed individually to eliminate the summation errors due to inter-row phase offsets. The absolute magnitude of all of the 1D FTs are added together in order to maximize SNR.

Each of the plots represents a small co-rotation of the 3D printed rotation plate on which the 2 gratings are mounted. The cube beamsplitter, spectral filter, light baffle and camera all remain stationary. Small rotation of gratings around the center of the cube beamsplitter allow the spatial frequencies of the interferogram to shift while the fundamental light from the laser remains blocked by the stationary filter - thus allowing the Raman shifted lines to move away from the DC signal peak of the FT, or other systematic noise.

Ruby Fluorescence Spectrum



Ruby fluorescence spectrum

The spectrometer also functions as a fluorescence spectrometer. Shifts of the fluorescence double peak of ruby is seen moving across a stable noise feature at 4750 cm^{-1}.