HIGH SPECTRAL RESOLUTION SPECTROMETRY IN COMPACT SIZES IN FUTURE INTERPLANETARY MISSIONS USING SPATIAL HETERODYNE SPECTROMETER

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Introduction: We can coarsely sort the performance of narrow bandpass imagers or traditional dispersive grating spectrometers into two classes of instruments with large effective aperture A_{eff} that emphasize spectral resolving power (e.g., HST-STIS or Keck-HIRES) and those with large étendue (e.g., Cassini UVIS). The most common instrument to obtain high spectral resolving power (R) in UV are the classical grating spectrometer, but their high R implementations are physically large and require large aperture telescopes to overcome the small field of view (FOV) of the apertures required. In grating spectrometers, R is derived from both the dispersion relation at the detector and the width of the aperture in the diffraction plane. This convolution drives the R lower if the size of the instrument is reduced and its FOV is increased. Thus, the typical high R (~50,000) spectrometer is quite large, has a very narrow FOV and is attached to a large telescope (2.4 m HST), while the typical low-resolving power spectrograph on a remote probe (e.g., Voyager-UVS or New Horizon-ALICE) is compact, has a wide FOV, and low R (<1000). The FOV in SHS is not convolved with the spectral response and therefore, to a large degree, the R is decoupled from the size of the area that is being sampled. Thus allows SHS to sample closer to the full theoretical R of the grating.

Interferometry is another technique that is used to obtain high étendue measurements at high R. They emphasize sensitivity for long-term temporal studying at high R from wide FOV (e.g., planetary disks, nebula, large galaxy structures, interstellar medium, etc.). Some technologies that demonstrate the utility for these targets include Hydrogen absorption cells (e.g., SOHO-Solar Wind experiment [2]), field-summing instruments such as FPIs (e.g., Wisconsin H-alpha Mapper [3]), and scanning Fourier Transform Spectrometers (FTSs). However, below 300 nm many commercially, available glasses begin to become opaque, and the transmitting optics issue dominates around 100-130 nm. The number of transmitting crystals, especially below 160nm, is sharply reduced, and performances degrade. The last known transmitter, LiF, becomes opaque at ~105 nm and is difficult to make optically flat beam splitter or etalon. Getting spectra below 100 nm requires Boron-Carbide or Silicon-Carbide coatings (≤35% reflectivity) [4] or multi-layer coatings for narrow-band filters. Therefore, these designs are limited at different points in UV by their use of transmitting optics, demanding low optomechanical tolerances, a narrow acceptance bandpass, and physical size [5, 6].

Spatial Heterodyne Spectrometer (SHS): SHS is a compact reflective two-beam cyclical interferometer that produces a 2-D fizeau fringe pattern from which the input spectrum can be obtained via a Fourier transform [5, 7, 8]. SHS-based instruments have been used in a series of ground and space-based project, or observations of atmospheric and interstellar emission line feature [9, 10]. To date, the majority of the SHS projects are in the Michelson SHS format [5] in which the mirror in each interferometer arm was replaced by a grating [5, 11], and a two-dimensional camera CCD detector imaged the fringes [5, 9, 12, 13]. But a major weakness of Michelson SHS instruments is their use of transmitting elements, which limits their usefulness in shorter wavelengths (UV). Reflective SHS [8] combines the high étendue (É= telescope effective area (A_{eff}) × FOV) and high R of FTS with higher optomechanical tolerance and simpler optomechanical design associated with grating spectrometers.

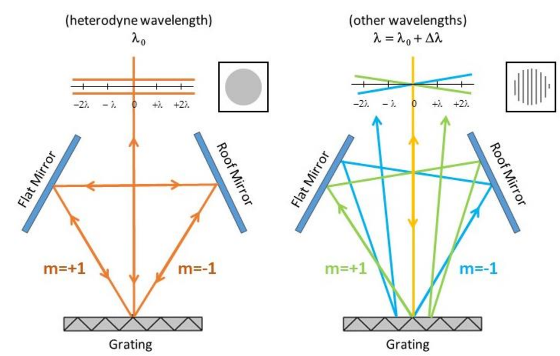

Fig 1. (Left) PHI is based on a remarkably simple cyclical design. The incoming collimated light hits the grating at normal incidence, splits to two orders, travel in opposite directions, and diffract off the grating before exiting. For the tuned wavelength λ_0 everything is symmetric, there is no path or phase differences between the emerging beams. **(Right)** However the exiting wave fronts of other wavelengths ($\lambda=\lambda0+\Delta\lambda$) are tilted in respect to each other producing a fringe pattern.

The significance of the FOV for SHS is that it increases the étendue of the instrument, the capability of an optical system to accept and gather light, and is the product of the collecting area A_{eff} and FOV (É = FOV×A_{eff}). Provided the source is aperture-filling, the FOV of the SHS can fill the same role that a large telescope does for a grating spectrometer. The quantity of

Étendue is widely used to express the sensitivity of an optical instrument. However, for practical reasons in building new instruments, usually the goal is to optimize grasp per cost. Grasp [8] is defined as G = É×R and it is used to quantify the overall potential of an instrument considering the input aperture, FOV, and resolving power. One of the implementations of low grasp in common high R spectrometers is the steep

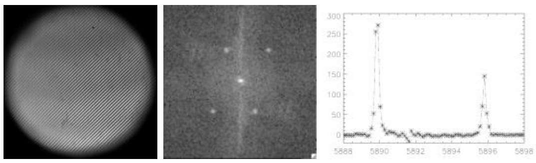

Fig 2. (Left) Fringe pattern from Na Hollow Cathode Lamp when the ground-based tunable reflective SHS built by PI at Mt. Hamilton [1]. The interferometer is tuned to the vicinity of the Na D lines at $\lambda_{\Delta 1}$= 5895.9 Å, $\lambda_{\Delta 2}$= 5889.9 Å . This image contains two set of fringe patterns each for one of the Na D lines. **(Middle)** The reduced power spectra shows both lines indicating both fringe pattern are present in the data. The top half of the 2D FFT is the repetition of the bottom half with an inverse wave-vector sign. **(Right)** The Na D lines' power spectra: the separation of $\Delta\lambda$=5.97 Å, indicates a resolving power of R~48000 which is same with the calculated R [1].

trade-off between R and FOV; by increasing the FOV, the instrument loses the R sensitivity.

Developing the SHS instrument has a wider significance to planetary science. SHS provides integrated spectra at high R, over a wide FOV in compact designs in which it offers the ability to make key science measurements for a variety of planetary targets. SHS could be implemented on a dedicated SmallSat or ISS that can sit and stare at its target for the long duration of time that cannot be done from the ground or on big missions. SmallSats are lower cost, faster to build, relatively easy to correct and upgrade. High R spectrometers are usually limited by the telescope aperture size and complicated optomechanical tolerances, but that's not the case for SHS. Preliminary SNR and flux calculation on extended targets show that the signal flux levels will allow robust measurements by SHS performing sequential high R observation in UV to IR from Earth's orbit. Such temporal studies on any one scientific objective would not be a practical request for any large-scale mission because of the high competitive subscription rates.

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