National Aeronautics and Space Administration

OPTICAL DESIGN OF A NOVEL SPECTROSCOPIC INSTRUMENT FOR STUDYING FAINT, EXTENDED STRUCTURES IN THE UV

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Objectives

The objective was to verify the SHS Far UV instrument parameters and mature our instrument performance model studies to evaluate the abundance of the FUV C IV (1550 Å) lines in the Milky Way and other galaxies to formulate a mission concept to have a greater understanding of the formation and evolution of galaxies.

Background

Traditional far-UV (FUV) grating spectrographs lack the sensitivity to detect the line emission from faint and diffuse astrophysical targets. This presents a measurement gap in observing faint and extended astronomical environments that prohibits obtaining a detailed view of these targets' density, temperature, and kinematic structure and robustly test theoretical models for producing them.

Our science goal is understanding the formation and evolution of galaxies by high spectral resolution UV emission-line observations of the Circum-Galactic Medium (CGM) of nearby galaxies and the cycling of matter through the interstellar medium (ISM) in our galaxy. The PI Hosseini is developing a compact far UV Spatial Heterodyne Spectrometer (SHS) in JPL. However, due to the lack of an instrument performance model and verified instrument parameters, this opportunity cannot, at present, be used to estimate performance in obtaining CGM scientific measurements. SHS' high R~144,000 is required to map the fine thermal line-width of the C IV line (~ 6 km/s for T = $10^{4.5}$ - $10^{5.7}$ K gas) and obtain an unprecedented detailed view of the temperature, density, and kinematic structure of the ionized halo gas, and robustly test theoretical models for producing it.

Approach and Results

We employ the SHS design concept, flux, and noise propagation, and sensor properties to develop an instrument performance model (IPM) code developed by PI Hosseini. Our SHS IPM works in five steps: 1) the CGM emission simulation developed by C-I Raghvendra Sahai is used as a target of measurement, 2) the instrument resolving power, bandpass and FOV is selected and verified according to the target spectra requirements, 3) the sensor selections are chosen based on the bandpass and noise requirements, 4) the instrument measurements is modeled based on the instrument and electronic selections as well as flux levels and exposure times, 5) the simulated measurements are treated with the calibration process.

This IPM code was recently updated to handle multiple noise factors (dark and read noise). Previous versions of the code have focused on generating the fringes without the instrumentation noises modeling with corrections for bandpass, resolving power, and FOV. Initial testing of the code focused on the CGM spectra measurement scenario to map the C IV doublet (1548.20 Å, 1550.78 Å) in selected high-latitude regions of the Galactic halo (where the emission is uncontaminated by scattered UV, hot stars, and interstellar molecules) with a spatial resolution of 21 arcmins, a detector size of 1024 × 1024 and an e2v detector performance. Results are shown in Figures 1–3. The overall aim is to carry out an analysis sensitivity study to characterize error budgets and performance estimates for SHS measurements.

Significance/Benefits to JPL and NASA

The project has several benefits for NASA/JPL. The C IV doublet chosen to be studied in this project is an essential probe of the CGM's mass-budget and morphology in IWM. Absorption observations depend on the fortuitous presence of sufficiently bright background quasar continuum sources and then only probe the gas along the line-of-sight to the quasar, so no information is available about the lateral extent of the CGM. Emission-line observations complement absorption-line studies but are highly time-consuming for a traditional slit spectrograph because of the relatively faint line emission fluxes. SHS instruments with high E onboard of SmallSats with ample time can integrate the faint emission to provide unprecedented details by mapping the CGM in nearby galaxies.

The methods developed in this project thus position JPL to continue astrophysics FUV spectroscopy with state-of-the-art experimental methods. The SHS spectrometer is a novel technique that would significantly improve observations of Far UV astrophysics targets and many other targets from space. While our project focused on CGM, the lessons learned here will benefit any potential future applications of the SHS technique for astrophysics and planetary missions (e.g., for a cometary survey mission or lunar missions). Much of the project was dedicated to expanding the IPM to the instrument and electronic noises. The outcome of this project supports the maturation of a miniature, low-mass, low-volume, high-sensitivity science payload that is suitable for taking full advantage of compact satellite platforms and beyond.

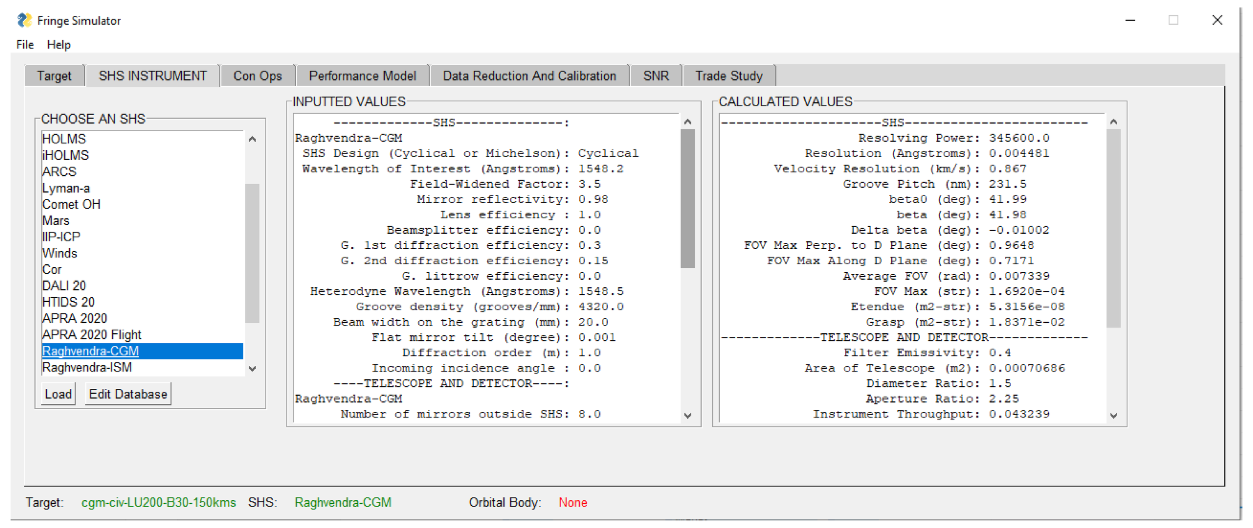

Figure 1: Instrument Performance Model interface showing the five steps in upper tabs.

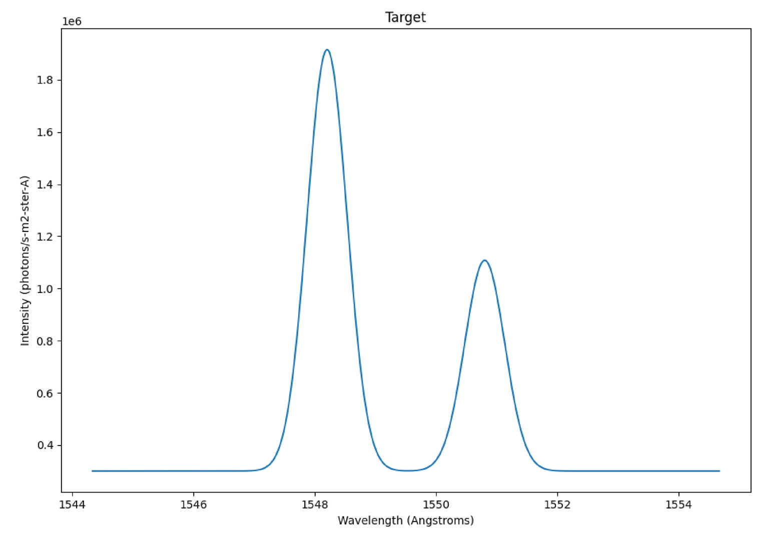

Figure 2: Simulated CGM emission spectra by Dr. Sahai is used as a test input in the code.

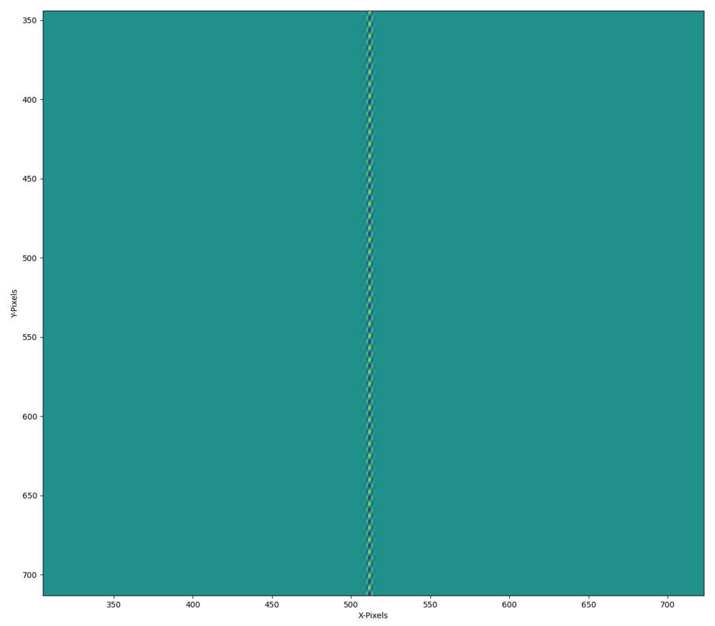

Figure 3: Simulated fringe pattern without any noise parameters.

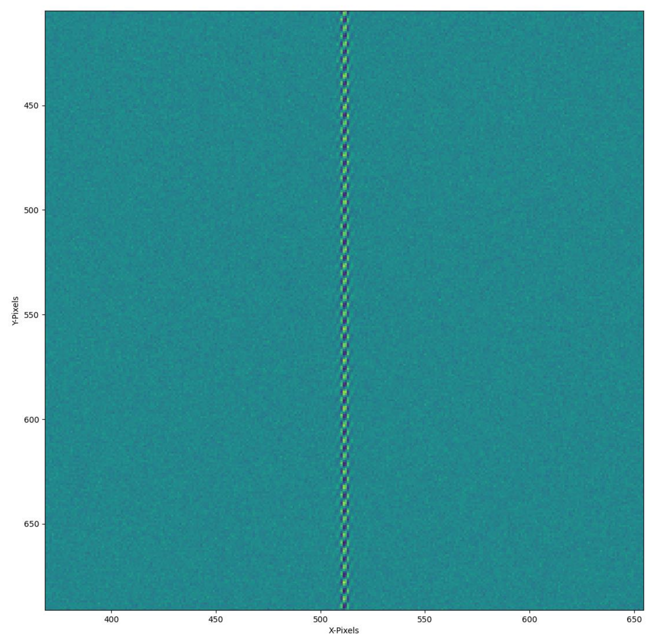

Figure 4: Simulated fringe pattern with noise parameters (sensor dark noise, and electronics readout noise).

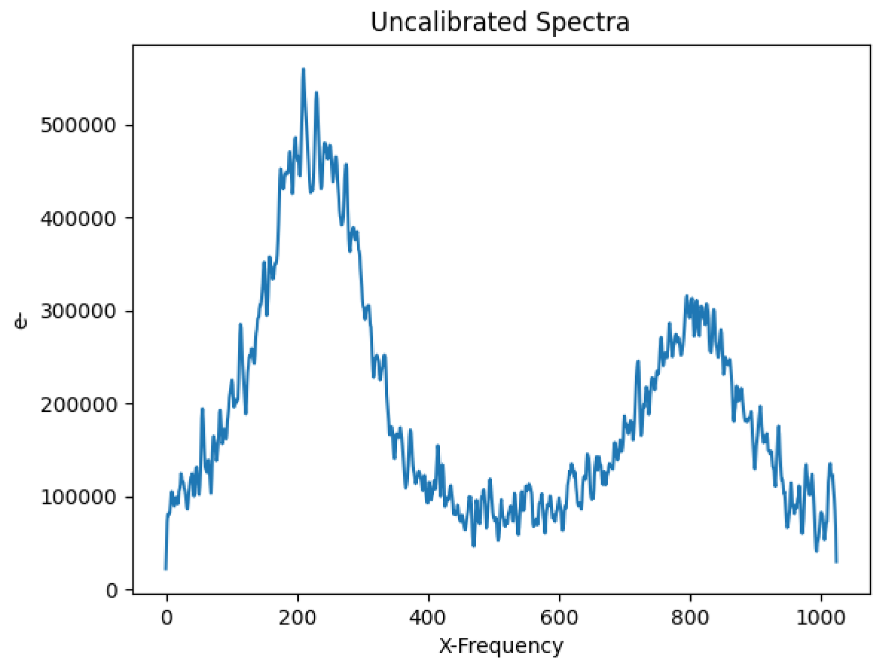

Figure 5: Simulated spectra recorded by the instrument.

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