National Aeronautics and Space Administration

From Astrospheres to the Circum-Galactic Medium: Studying Faint, Extended Structures in the UV using a Novel Spectroscopic Instrument

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Program: Topic Area

Project Objective:

•Mapping the distribution and composition of key diagnostic species (e.g., molecules and atoms) is critical for improving our understanding of the structure and evolution of galaxies including our own. However, some of the most important structures that we need to map are extended and faint, with diagnostic lines that lie in the UV wavelength regime. These include the astrospheres around dying stars, supernova remnants (SNRs), the interstellar medium of our Galaxy, and the circumgalactic medium (CGM) around nearby galaxies.

•Traditional slit-spectrographs lack the sensitivity to disperse the low photon flux into a large number of spectral resolution elements (R~100,000) and cannot detect the faint UV emission spectra from these important astrophysical targets. We are therefore working on a novel spectroscopic instrument called AMUSS - a Spatial Heterodyne Spectrometer.

•SHS is a miniature, all-reflective two-beam cyclical interferometer that modulates and beats the photons (collected from large angular regions on the sky, ~1 arcmin) against themselves efficiently, enabling spectroscopy from targeted atomic and molecular gas spectral lines (UV to IR) at high spectral resolution (R~100,000) using small aperture telescope.

•Our objective was to develop models to allow quantitative predictions of emission lines and derive signal-to-noise ratios for each of the above investigations, using the SHS spectroscopic instrument onboard a Small SAT mission. Our first year objective of this 2-yeat task focussed on astrospheres (Fig. 1). We also installed the photoionisation plasma code CLOUDY, and made test models that will be used in the 2nd year, when we will focus on the ISM (Fig. 2) and CGM.

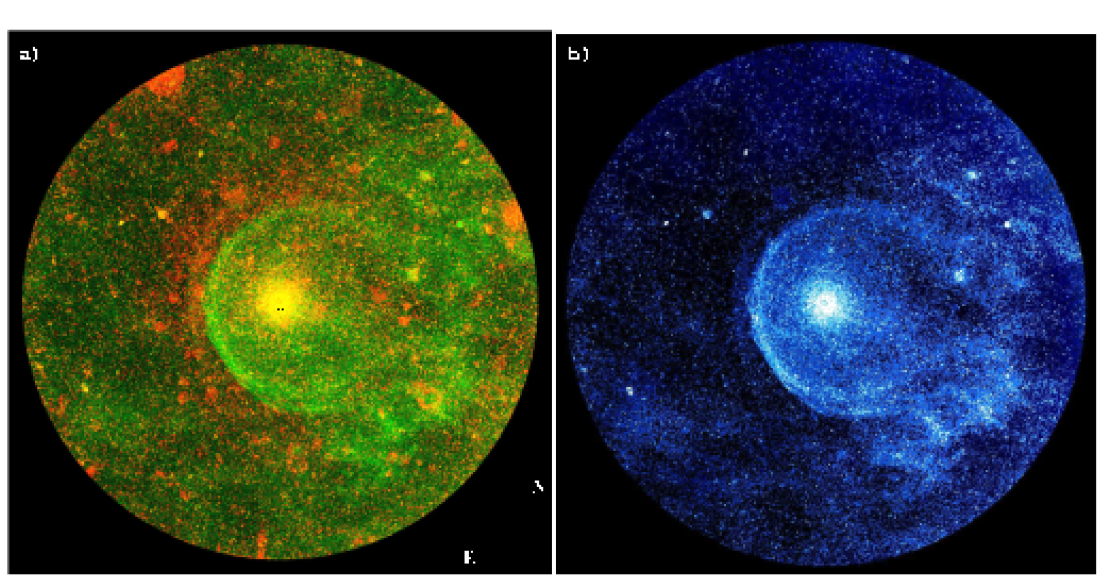

Fig. 1. Composite [NUV (red) & FUV (green)] GALEX image of the astrosphere of IRC+10216 (the box size is 65’×65’). The NUV (FUV) image was boxcar-smoothed using a 3 × 3 (2 × 2) pixel box, and displayed using a linear (square-root) stretch. The central star’s location is indicated by a ⋆ (from Sahai & Chronopoulos 2010).

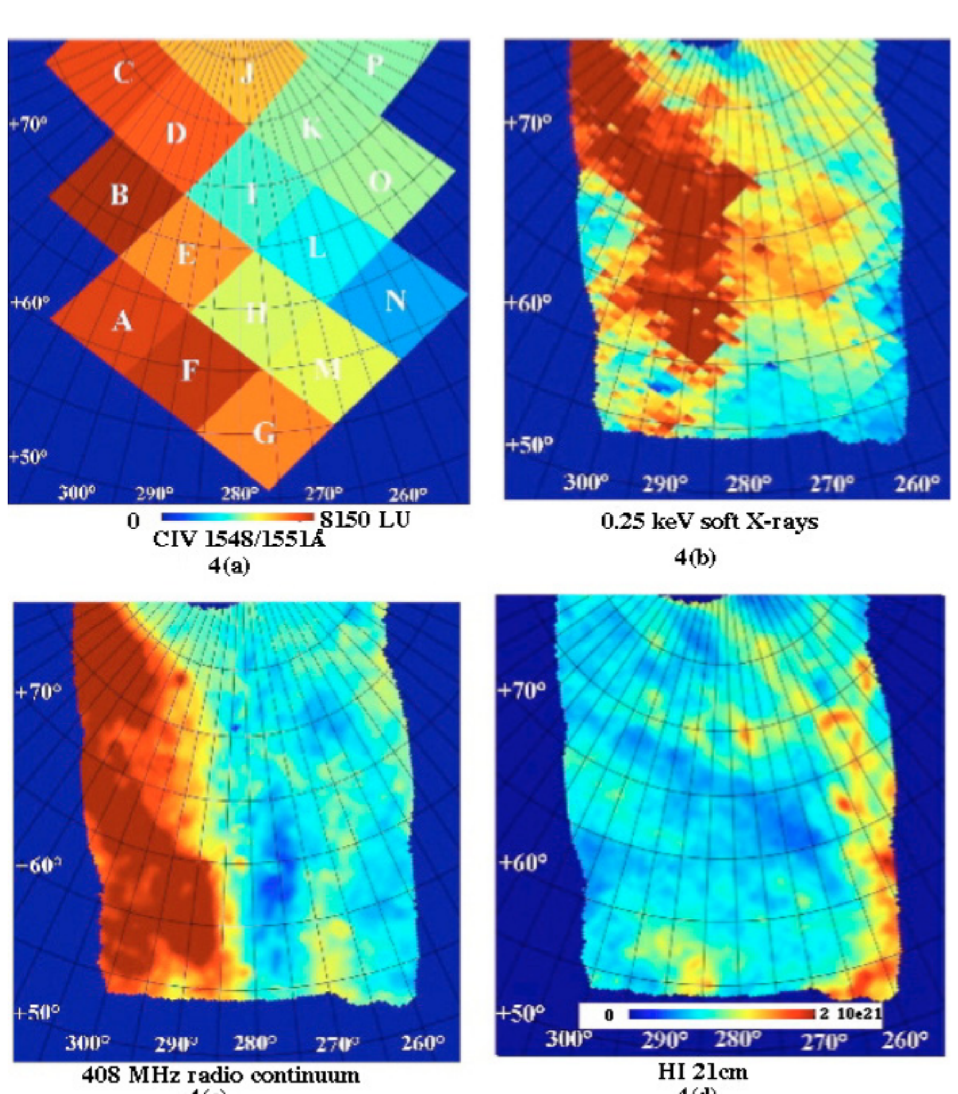

Fig. 2. SPEAR observations of the CIV (1550 Å), compared with emission at other wavelengths from the Galactic halo (from Welsh et al. 2007). The very faint UV line emission, binned to 15-arcmin resolution, appears roughly correlated with the X-ray and radio emission that probes the hot gas in the halo, but the low angular resolution is too coarse to provide a robust comparison. An SHS instrument like AMUSS with ∼ 0.8-arcmin resolution, will allow us to compare the CIV emission with the radio and X-ray emission with much higher fidelity

Benefits to NASA and JPL

The results of this work are essential for us to be able to propose to future NASA proposal calls such as Strategic AstrophysicsTechnology (SAT) and APRA in order to raise the TRL level for SHS technology. SHS can be proposed to SmallSat payloads and/or mission calls such as AS3, or can be proposed as a small secondary payload on Explorer Astrophysics missions. The outcome and the published papers are vital to inform the community of the new observation capabilities we are developing in JPL for these important science targets.

FY18/19 Results:

(a) We approached our first year objective of determining the emission line fluxes of Lyman-Werner band lines of H2 from astrospheres excited by hot electrons as follows:

•(A) We used use-precomputed normalized H2 spectra computed for specific electron impact energies and H2 temperature (provided by Dr. Xianming Liu/ SpaceWx), and integrated them over the FUV GALEX band (using the response function of this band) in which astropheres have been detected, A new code using updates cross-sections and line lists was developed by Dr. Liu nd delivered to JPL.

•(B) we developed a code to measure flux in the GALEX FUV band from specific regions of astrospheres, which included finding and remove background/ foreground point-sources (stars and compact galaxies),

•(C) we determined the appropriate scale factor to make the flux determined in A equal to than in B, and this obtained a prediction of the astrosphere spectrum (Fig. 3). Since the noise in a spectrum obtained with AMUSS varies as the square-root of the total band-pass, it is advantageous to limit the band-pass as much as possible, while still being able to detect the line(s) of interest. The lower panel of Fig. 3 shows an expanded view of the spectrum, with black arrows indicating the centers of two wavelength windows covering lines that would be optimum for observations with AMUSS. Although there are a plethora of strong lines at shorter wavelengths (i.e., less than 1300 Å), AMUSS would be less sensitie to them because of the steep decrease in the quantum efficiency of UV detectors at shorter wavelengths

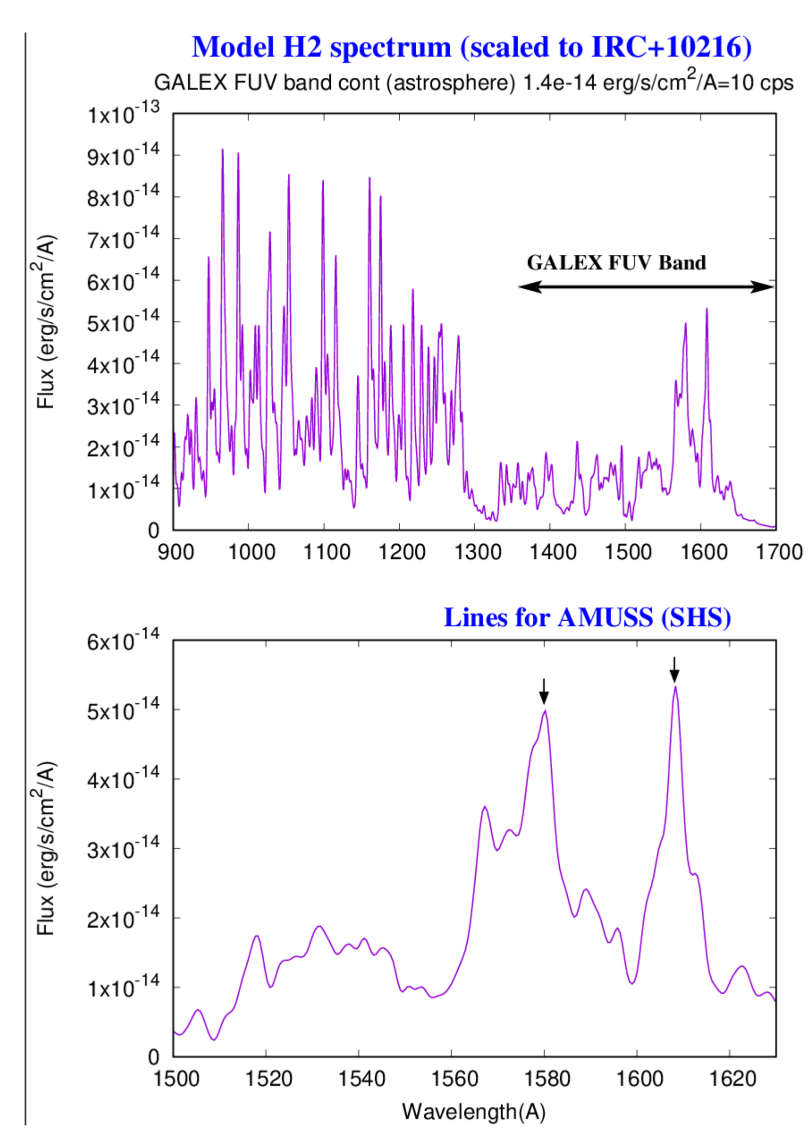

Fig. 3. A plausible FUV-band spectrum due to electron excitation of H2 in the astrosphere of IRC+10216. Top panel shows the full spectrum of Lyman-Werner bandlines; whereas the bottom panel shows an expanded view of the spectrum indicating the centers of two wavelength windows that would be optimum for observations with AMUSS

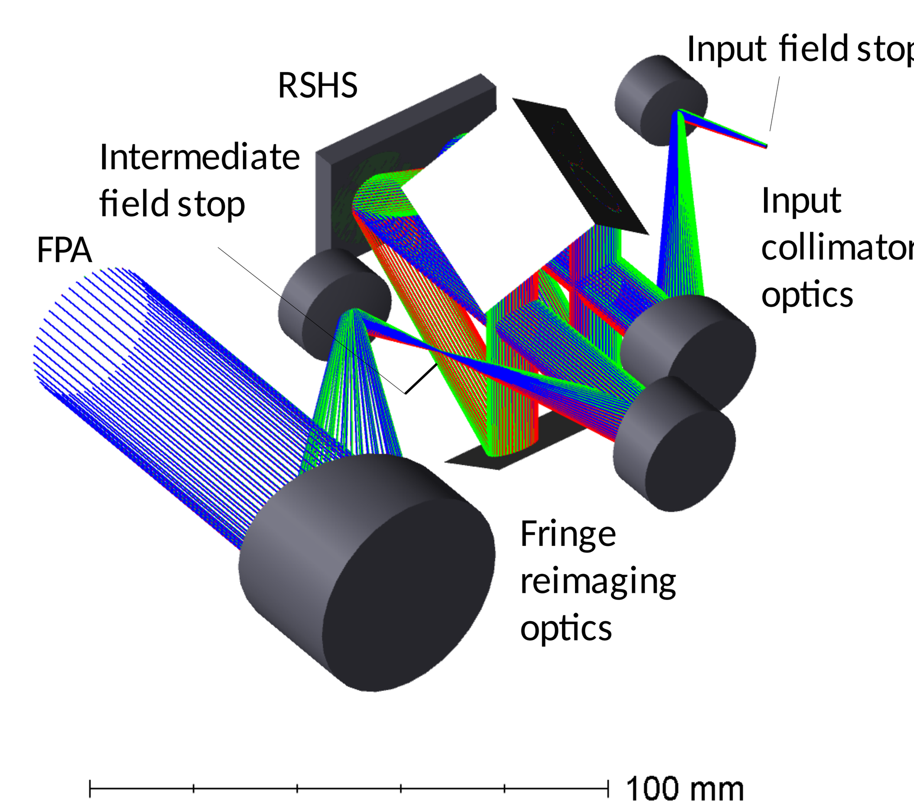

Fig. 4. The AMUSS istrument desig concept: its ultra-compact form factor fits SmallSats or allows it to be a small payload on a larger UV mission

Technical results:

Instrument optical design concept is developed and completed (Fig. 4). Bandpass, resolution and FOV trade study is studied and the desired parameters has been set. Optical parts, coatings and grating items are identified and chosen.we present a summary of instrumental parameters below, together with a comparison of AMUSS performance with other UV spectrographs on GALEX and HST. Instrument SNR, radiometric and performance model is developed. The preliminary SNR study indicates the detector noise is dominant. A SAT proposal was submitted using early results from our task in 2019

	GALEX	HST - STIS	HST - COS	AMUSS
				
Spectroscopy Technique	Grism and bandpass filters	Dispersive grating	Dispersive grating	Cyclical interferometric
Telescope Aperture	0.5 m	2.4 m	2.4 m	0.03 m
Wavelength	FUV band = 1344–1786 Å	“140M” channel = 1140–1741 Å	“G160M” channel = 1405–1775 Å	1541-1556 Å
Spatial Resolution	4.3 arcsec (FUV), 5.3 arcsec (NUV)	0.2 arcsec	2.5 arcsec	45 arcsec
Spectral Resolving Power	250–300	10,000	20,000–24,000	144,000
Instrument mass	~280 kg	~318 kg	~200kg	~ 3kg
Detector QE	MCP, 12%	CsI, 25% @ 1216 Å	MCP 32% @ 1216 Å	CCD, 40–50%

Beam width on the grating (mm)	10
Heterodyne wavelength	1595.227 Å
Wavelength of interest	1608 Å
G (grooves/mm)	3200
Resolving power	128000
Resolution	0.012 Å
Detectable velocity	2.34 km/s
Wavelength range	1560.454 - 1630.000 Å
Max acceptance FOV (SHS)	23’ 22”
FOV on the sky (with the 3cm telescope)	7’ 47”

Publications:

•[A] "Faint But Not Forgotten: Stellar Astrospheres", Sahai, R., 2019, The Realm of the Low-Surface-Brightness Universe, IAU Symp. 355 (proc), eds. D. Valls-Gabaud, I. Trujillo & S. Okamoto

•[B] "AMUSS – Astrophysics Miniaturized UV Spatial Spectrometer for spectroscopic studies of diffuse astrophysical objects", Hosseini, S. & Sahai, R. 2019, The Realm of the Low-Surface-Brightness Universe, IAU Symp. 355 (proc), eds. D. Valls-Gabaud, I. Trujillo & S. Okamoto

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