Observations of the Diffuse Far-UV Sky with SPEAR

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Abstract. The Spectroscopy of Plasma Evolution from Astrophysical Radiation (SPEAR) instrument, aboard the STSAT-1 satellite mission, is now observing emission from the cosmic far ultraviolet background. The primary science objectives of the mission are to characterize the Galactic interstellar medium and particularly to study interfaces of hot interstellar plasma. The mission plan is to map most of the sky and then to conduct pointed observations of selected targets. We describe the mission and examples of observations of the Vela supernova remnant and the Eridanus Loop superbubble. The SPEAR results provide unprecedented imaging spectra of diffuse emission from highly ionized species including HeII, CIII, CIV, OIII], and OVI, and from molecular hydrogen.

1. The Instrument, Mission and Data

SPEAR is an imaging, dual band spectrograph (S band: λλ 900 – 1150 Å, L band: λλ 1350 – 1750 Å) optimized for diffuse-radiation measurement (Edelstein, et al. 2003). This bandpass includes many strong atomic emission cooling lines from N, C, O, Si and S, as well as H2 fluorescence lines. The instrument obtains ∼5' imaging resolution along the 7.5° / 4.5° (L/S) field of view and a spectral resolution of λ/Δλ ∼ 500 HEW. SPEAR is the primary payload on the 3-axis stabilized STSAT-1 (S-1) satellite launched into a 700 km low-earth orbit in late 2003. Astrophysical observations are taken for 20 minutes of eclipse during 10 of 15 daily orbits.

The S-1 mission is operated from the SaTReC Ground Station in South Korea. Data reduction of each photon includes: pulse height selection, correction of electronics drift and spectral and imaging distortions, and association with time and attitude information. Efficiency was calibrated by measuring known bright stars. In 12 ksec of exposure over its full slit, SPEAR can measure 650 photons cm⁻²sr⁻¹s⁻¹ (hereafter Line Units or LU) of CIV λ1550 and 5 000 LU of OVI λ1032 emission. Spectral scale (∼ 1 Å error) and resolution were calibrated using aurora and day glow emission lines. Imaging scale and distortion were found by measuring bright stars. The reconstructed attitude resolution is 10' FWHM.
2. SPEAR Observation of the Vela SNR

SN explosions are the principal engine producing shock-heated gas in the Galaxy. Our understanding of shock-ISM interactions and the global distribution of ionized gas in galaxies are far from complete. SNRs are among the brightest far ultraviolet (FUV) emitting diffuse objects with emission line intensities that depend on the shock velocity, the ambient medium, and the thermal structure of post-shock cooling regions \( (e.g., \text{Hartigan et al. 1987}) \). The important high-ionization lines of \( \text{CIII, CIV and OVI} \) sample gas temperatures from \( \sim 5 \times 10^4 \) to \( 1 \times 10^6 \) K and shock velocities between those of the bright optical filaments \( (\sim 100 \text{ km/s}) \) and the main X-ray blast wave (typically \( > 300 \text{ km/s} \)).

Vela is a middle-aged SNR that can be studied in detail due to its proximity. It shows pronounced optical filaments, X-ray knots, and non-thermal radio emission. SPEAR has obtained FUV spectral images of the entire Vela SNR, the first such detailed spectral images of any SNR. The Vela spectra (Fig.1) show strong FUV emission lines. The FUV line luminosities, assuming an \( 8^\circ \) diameter and 250 pc distance, can exceed the soft X-ray (0.1 – 2.5 keV) luminosity \( (\text{Lu and Aschenbach 2000}) \) by more than an order of magnitude. The SPEAR spectrum and line ratios of Vela vary across the remnant, indicating varying physical conditions such as plasma temperatures, shock velocities, and densities.

![Figure 1](image_url)

Figure 1. Left: Vela SNR contours of C IV \( \lambda 1550 \) intensity from 16 scans \( (\sim 10 \text{ ksec}) \). Contour Levels are 3.3, 7.5 and \( 11.5 \times 10^5 \text{LU} \). Right: FUV spectrum from a bright knot in Vela. Strong lines include He II \( \lambda 1640 \), C III \( \lambda 977 \), C IV \( \lambda 1550 \), O III \( \lambda 1663 \), and O VI \( \lambda 1032 \) with intensities from \( 3 - 30 \times 10^5 \text{LU} \)

Spectral maps of diffuse emission were derived by differencing an image with a waveband including an emission line and one including only a continuum band. Stars were eliminated using a thresholding procedure. The Vela C IV image (Fig. 1) shows the SNR spherical structure although areas of enhanced emission are offset from enhanced soft X-ray emission features. In some instances, enhancement in C IV do not have corresponding X-ray features. We find the Vela C IV bubble to be surrounded by dust and neutral hydrogen with
some interesting and distinct correlations. Future analysis is in progress to compare the SPEAR Vela FUV data with that from other bandpasses, to determine the physical conditions and to derive shock conditions across the SNR.

3. SPEAR Sees the Orion-Eridanus Superbubble

The nearby (~155 pc) Orion-Eridanus superbubble, a large cavity in the ISM, may be due to stellar winds from hot stars or to SN explosions excavating the surrounding local material. This superbubble has a complex structure resulting from the interaction of a variety of interstellar phases. SPEAR observed two Eridanus Loop positions near the edge of a shell structure and one toward a hot bubble, as visualized by soft x-ray, H-α and radio continuum. These FUV emission spectra (Fig. 2) of a superbubble are unique and unprecedented. The various atomic lines can originate from plasma with temperatures of $10^4$-$10^6$ K, or from shocks with velocities of 100-180 km/s. This suggests the simultaneous sampling of several different gas components. The line strengths are characteristic of emission measures of $2 - 5 \times 10^{-4}$ cm$^{-6}$ pc (CIII at $10^5$ K) and $2 - 4 \times 10^{-3}$ cm$^{-6}$ pc (OVI at $10^{5.3}$ K). Differences in important diagnostic line ratios (e.g. CIII/CIV, CIV/OVI) exist among the different regions. The presence of H$_2$ fluorescence is a puzzle unto itself if it is part of the bubble structure. Can the H$_2$ survive the shock conditions, or is it swept up in the shell? Future work will examine FUV spatial correlations with other bands and model the plasma and H$_2$ conditions.

Figure 2. SPEAR UV spectra of a shock region in Eridanus Loop from a ~20 ksec observation. Strong L-band emission lines include HeII λ1640, CIV λ1550, OIII | λ1663, and and H2. S-band lines include CIII λ977 and OVI λ1032, visible as shoulders on the geocoronal Lyman series lines (arrows). Line intensities range from 200 to over 3600 LU.

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References

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