# Using CFHT's SITELLE to probe the long-sought shell in the Crab nebula

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## ABSTRACT

Supernova remnants and their associated pulsars have long fascinated astronomers. However, a persistent enigma remains; the absence of a supernova shell around certain young pulsar wind nebulae. Perhaps, the most famous example is the Crab Nebula, which after a decades-long search for its supernova shell with standard techniques in radio and X-rays is still "shell-less"', a long-standing puzzle in Supernova Remnant astrophysics. In this study, we address this question by employing the SITELLE instrument from the CFHT Canada-France-Hawaii-Telescope (CFHT) equipped with a large field of view and high-resolution spectroscopy of key emission lines. In particular, we aim to survey a large region around the visible nebula using the coronal emission line [FeXIV] λ5303 Å as a diagnostic for the search for the forward shock. Our methodology consists of integral field unit (IFU) spectroscopy with imagery to construct detailed flux and velocity maps of the [FeXIV] line outside of the visible nebula. Leveraging the emission modelling capabilities of the astrophysical code "MAPPINGS V"', we aim to discern the intricate interplay of physical processes within and outside the nebula. Our primary objective is to derive plasma temperature estimates and evaluate whether the observed emission properties align with theoretical predictions for the forward shock. By combining observational data with advanced modelling techniques, we aim to shed light on the long-standing puzzle around the missing shell in this iconic pulsar wind nebula.

## DATA ANALYSIS

- **Data:** Our data consists of two data cubes of adjacent regions extending out of the visible Crab Nebula (see Figure 2). The regions were observed with the integral field spectrograph SITELLE, mounted on the Canada-France-Hawaii Telescope (CFHT), in October and November 2023. Each data cube has a field of view of 11'x 11' and was taken using the C3 filter that covers 511-556 nm. The total integration time for both cubes is 11.42 hours.

- **Methodology:** Integral Field Unit (IFU) spectroscopy allows simultaneous data capture, of both spatial and spectral information, thus providing a detailed analysis of the physical properties of our target, across an extended region of the sky.

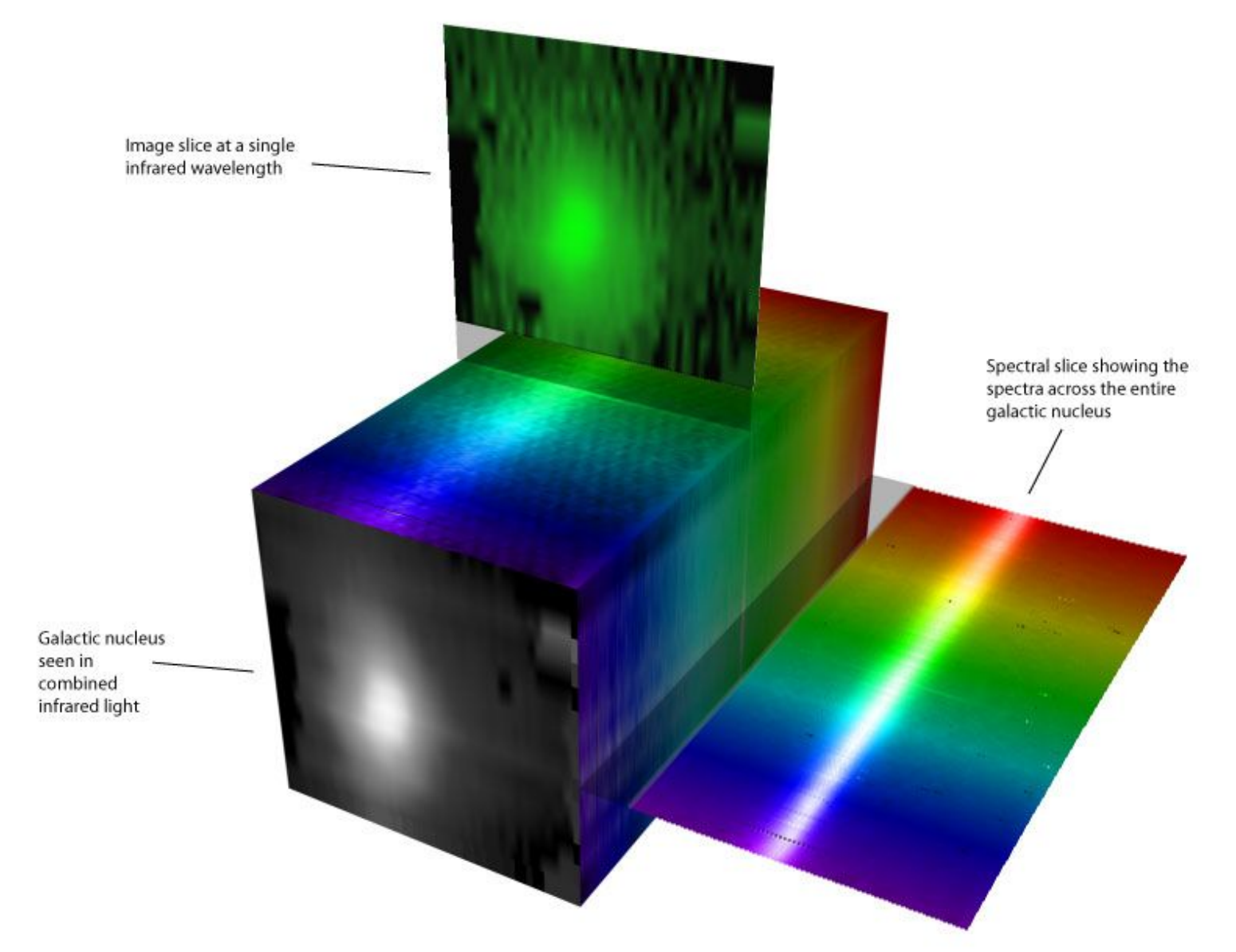

**Figure 1.** IFU data cube. Credit: Stephen Todd (ROE) and Douglas Pierce-Price (JAC)

- **Analysis:** The data analysis to date has been carried out using the code LUCI (Rhea et al. 2021), a Python module designed to facilitate the rapid analysis of SITELLE spectra. We obtained the image slices from the cubes corresponding to the target coronal line [FeXIV] λ5303 Å to verify the distribution of the iron emission throughout the fields (Figures 3 and 4). In addition, we selected regions (blue squares in Figures 5 and 6) that match the expected velocities of the shell: 2,000, 5,000, and 10,000 km/s. Assuming a distance of 2 kpc, these convert to 2.4, 5, and 10 pc (indicated by red circles in Figures 2, 5, and 6). We extracted the integrated spectra of these regions, as shown in Figures 7 and 8.

## RESULTS

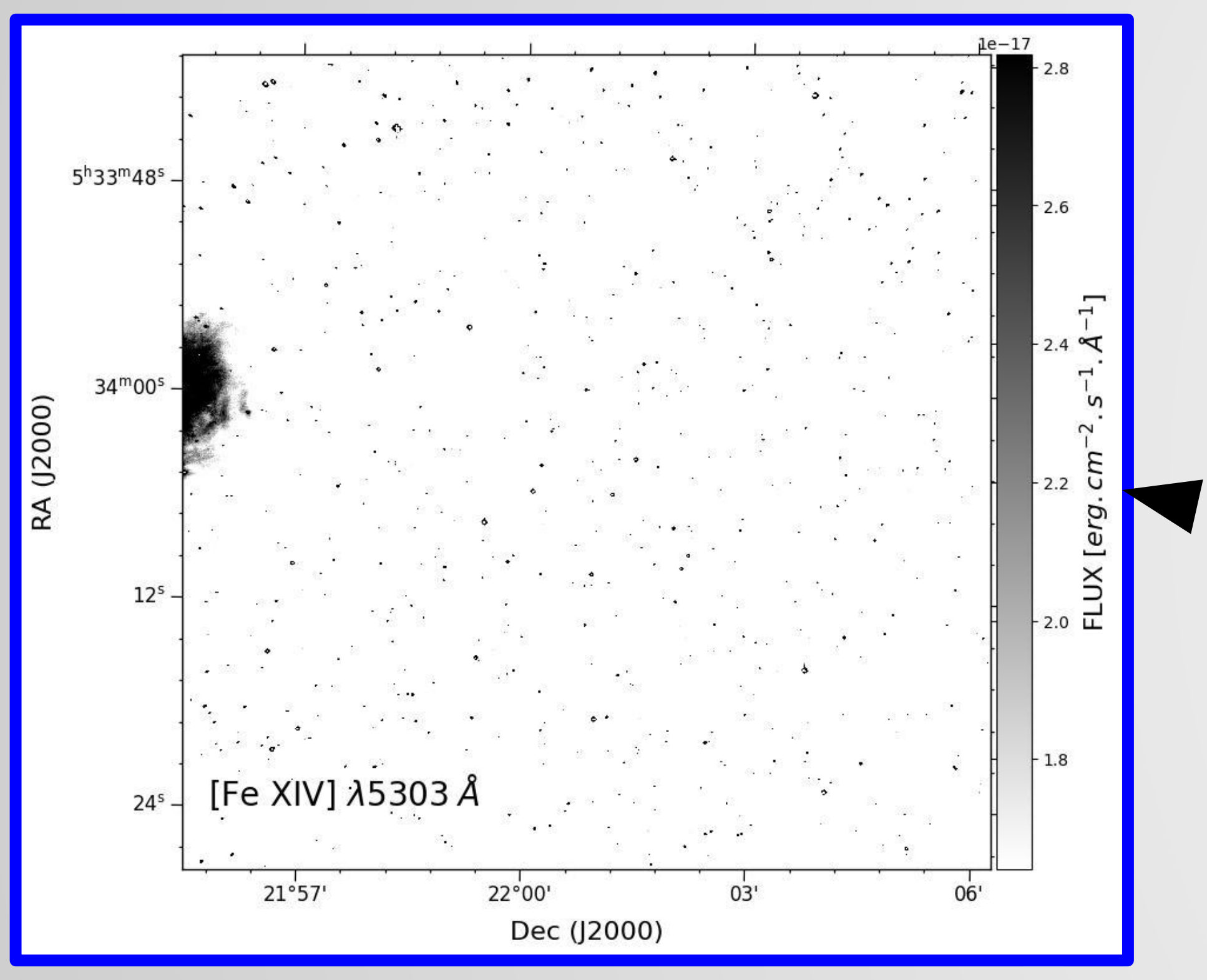

**Figure 3.** Background-subtracted [Fe XIV] slice for field 1.

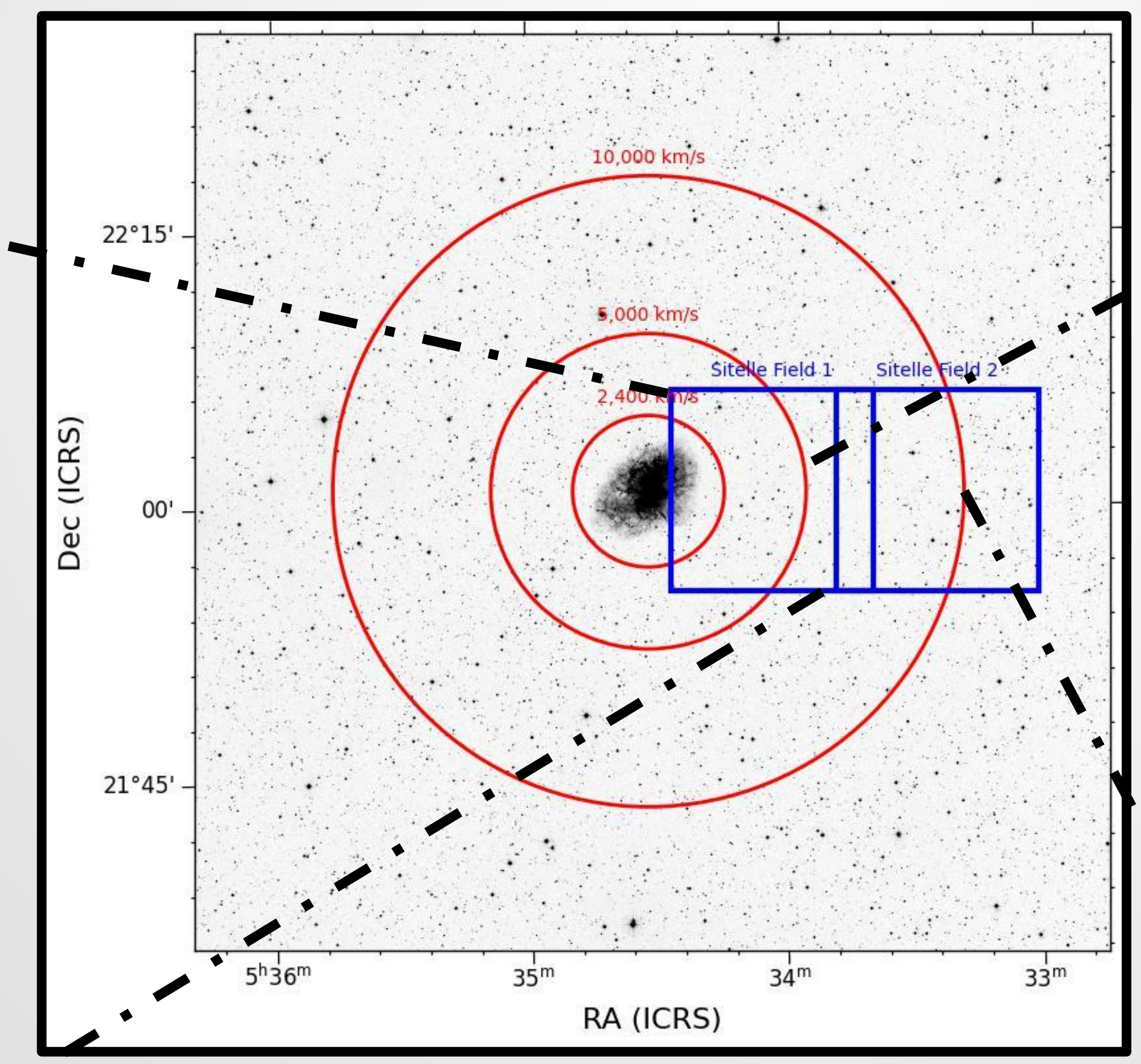

**Figure 2.** The sky map of Crab of our data cubes. The red circles represent the sought-forward shock location (2.4, 5, and 10 pc away from the pulsar, for 2,400, 5,000, and 10,000 km/s shell velocities). The blue squares (of 11'× 11' each) in Field 1 and Field 2 illustrate the SITELLE instrument coverage, with a small overlapping area.

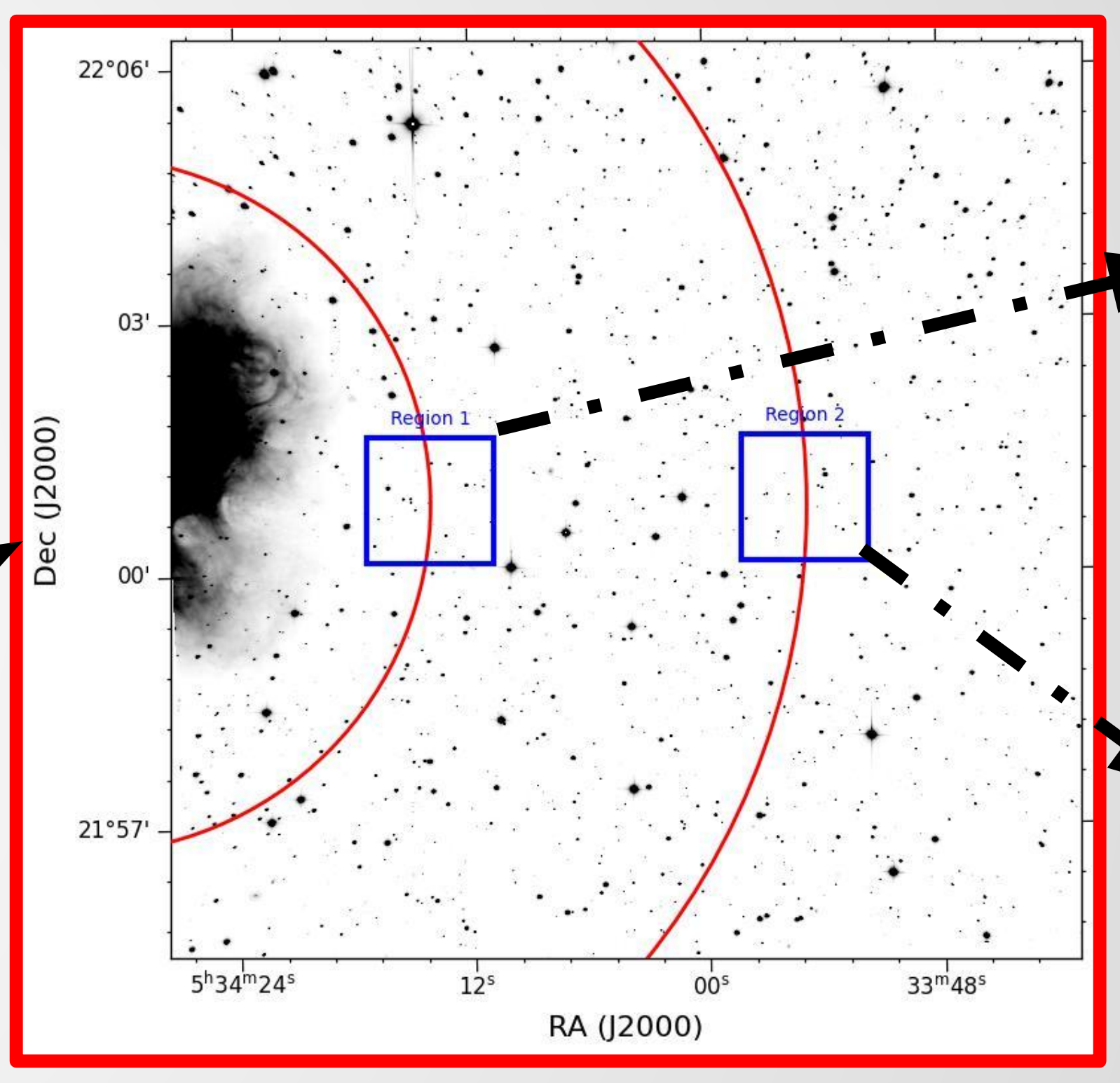

**Figure 5.** Field 1 observed with SITELLE.

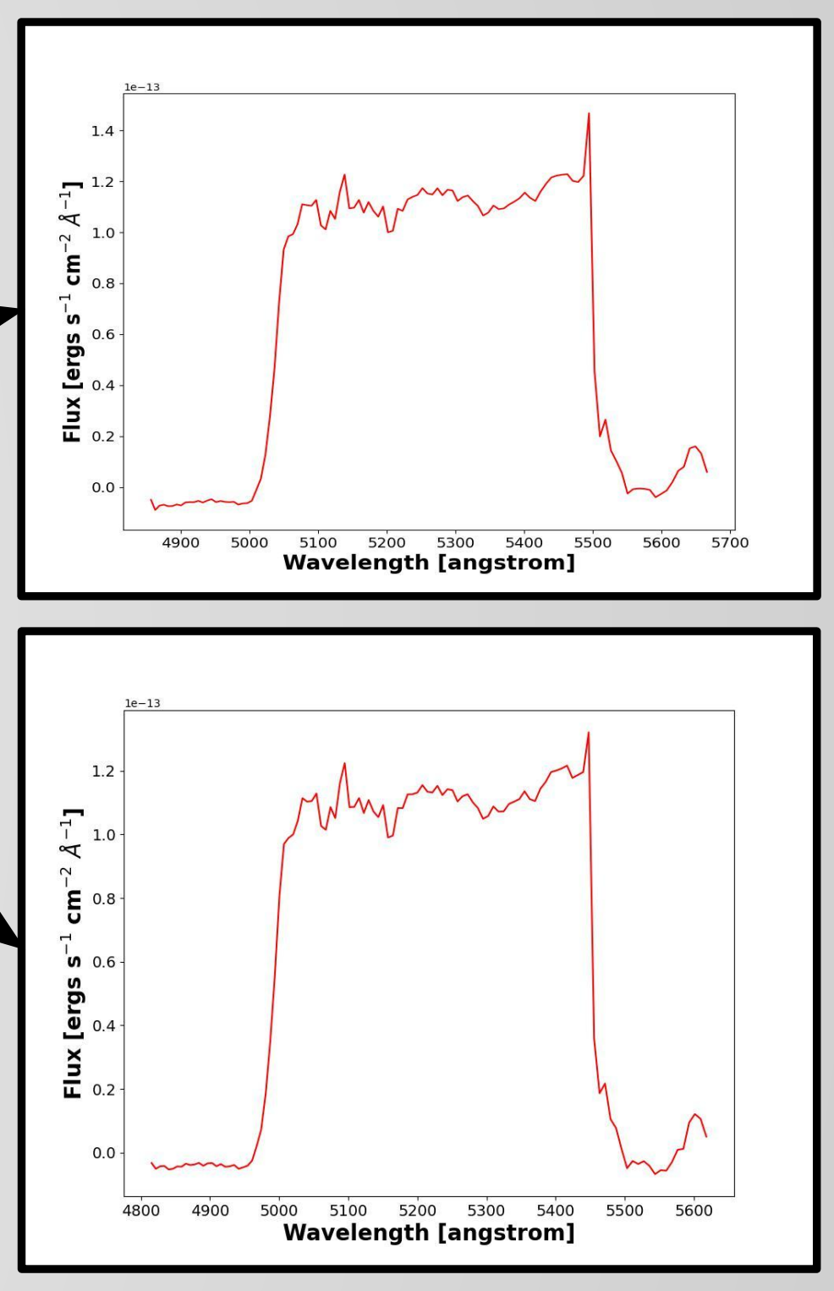

**Figure 7.** Integrated spectra for the selected regions 1 and 2 (blue squares) in field 1.

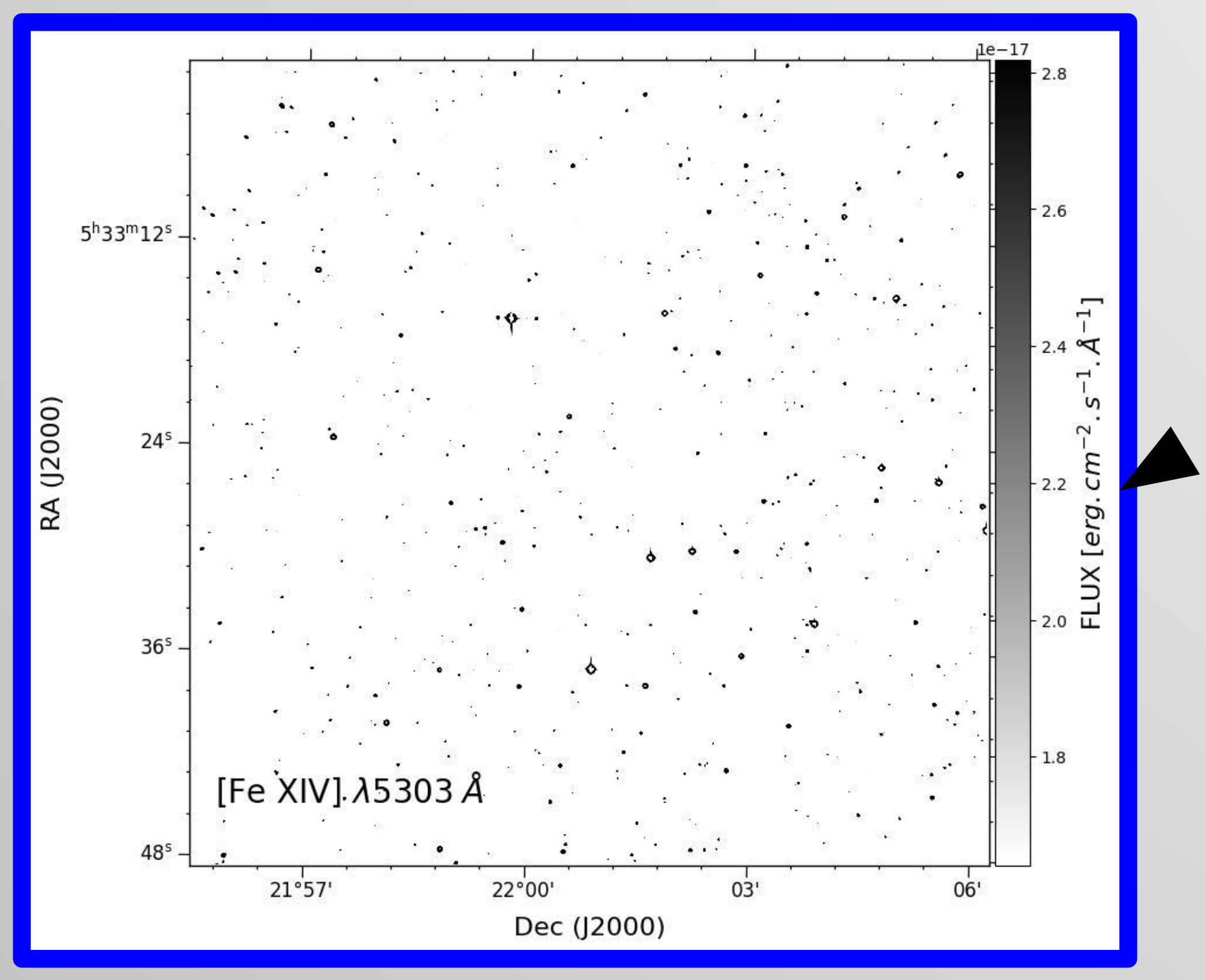

**Figure 4.** Background-subtracted [Fe XIV] slice for field 2.

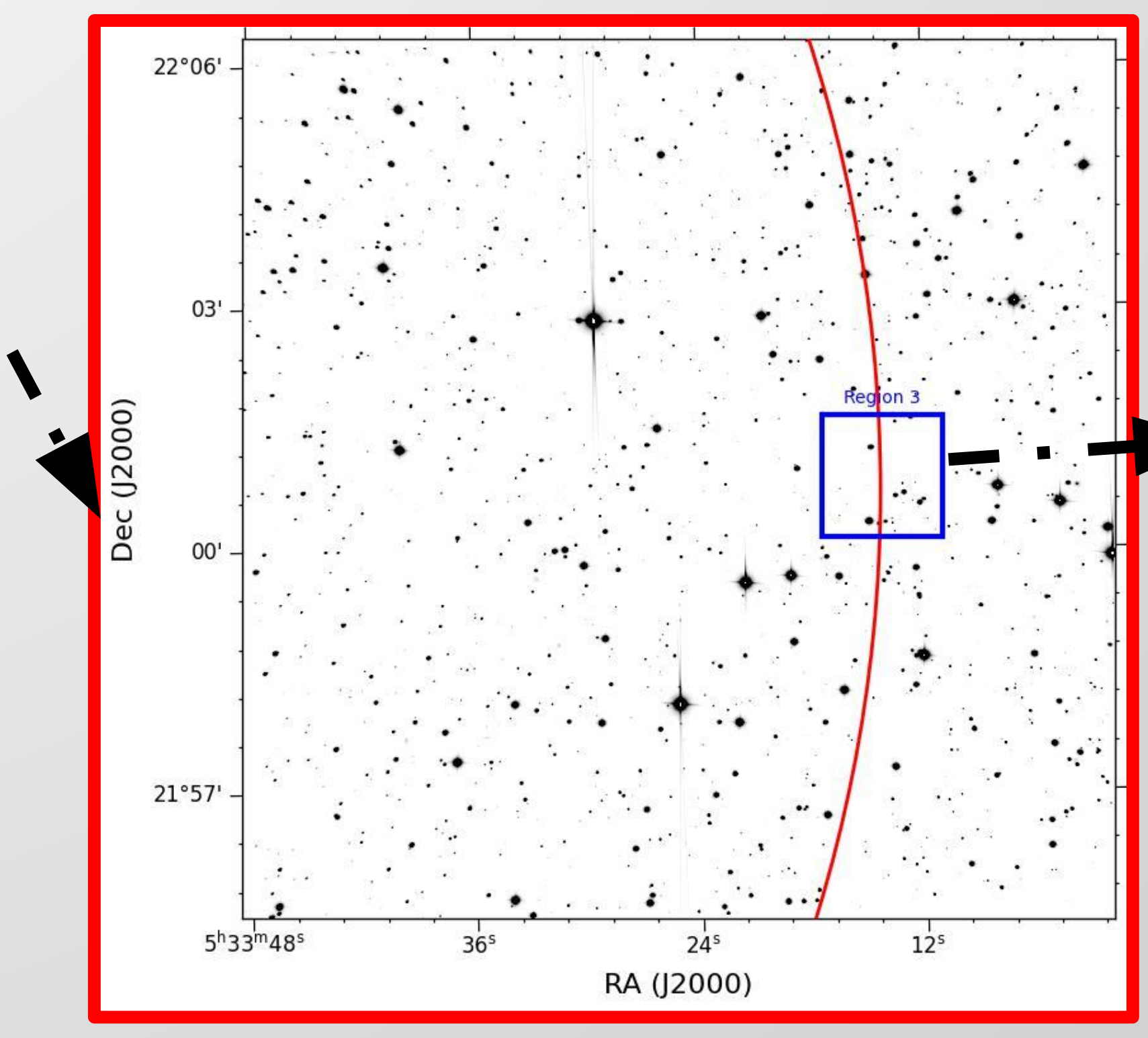

**Figure 6.** Field 2 observed with SITELLE.

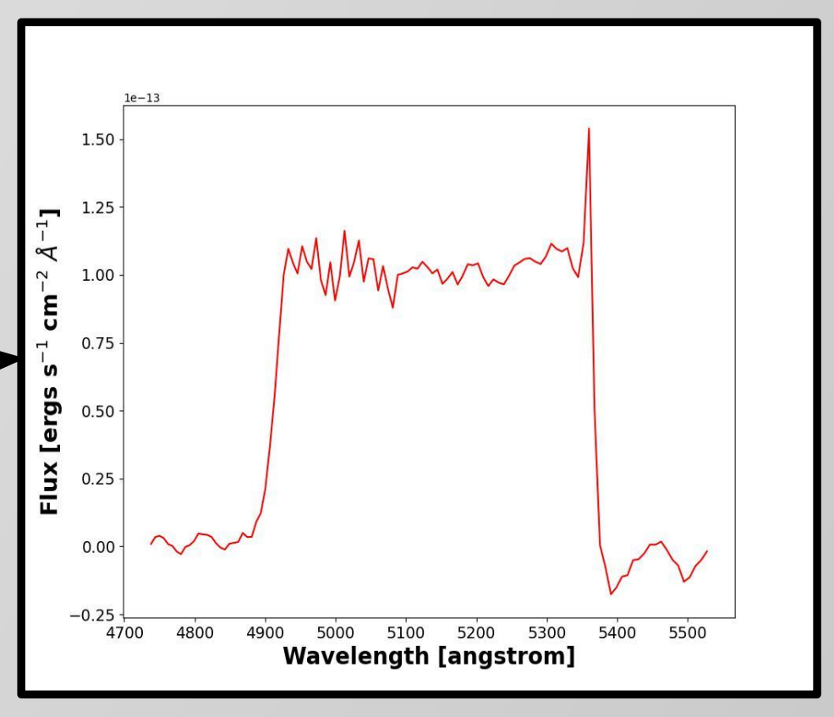

**Figure 8.** Integrated spectrum for the selected region 3 (blue square) in field 2.

## DISCUSSION

In this work, we analyzed the two Crab fields observed using SITELLE. We searched for the iron coronal line [Fe XIV] λ5303 Å, which recent optical studies have demonstrated can effectively trace the SNR shell (Dopita et al., 2016; Vogt et al., 2017). Our preliminary analysis of the SITELLE data suggests that the signal from the [Fe XIV] line, if present, is quite faint and will require alternative methods to distinguish it from the current contaminating noise in the data cubes. Figures 3 and 4 show the background-subtracted image of the [Fe XIV] line of both regions. There is no obvious structure corresponding to the iron emission. From the integrated spectra of the selected regions coincident with the expected velocities of the shell, shown in Figures 7 and 8, we notice that there are several possible emission-line-like features on the bluer side of the spectra. To confirm whether these are related to our target emission line, and to further separate them from the noise, we would need to do additional analysis and employ binning techniques. We plan to implement the Weighted Voronoi Tessellation (Rhea et al. 2020b) as the next step to enhance the signal. In the case of a positive detection, we aim to model the forward shock using photoionization and shock modeling (e.g. MAPPINGS V; Sutherland et al., 2018). Otherwise, we will proceed with the non-flux detectability calculation to estimate an upper limit for the expected flux for this line emission. This will help us constrain the explosion energetics and mechanism of the SN that created the Crab Nebula.

Contact Information
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**References**
[1] Dopita et. al (2018), ApJS, , 237(1):10, [2] Rhea et al. (2021), 5, 208, [3] Sutherland et al. 2018, ASCL, 1807.005, [4] Vogt et al. (2017), A&A, 602:L4, [5] Rhea et al. 2020b, ApJ, 901, 152.