JWST NIRCam Colors of Cas A Supernova Ejecta

Bon-Chul Koo[1], Jae-Joon Lee[2], Dan Milisavljevic[3], Robert Fesen[4], Seung-Hoon Jung[1], and John C. Raymond[6]

[1]Seoul National University, Korea, [2]Korea Astronomy and Space Science Institute, Korea, [3]Purdue University, USA, [4]Dartmouth College, USA, [5]Harvard-Smithsonian Center for Astrophysics, USA

Abstract

The young supernova remnant Cassiopeia A was observed by the James Web Space Telescope (JWST) under the Cycle 1 General Observers (GO) Program (ID: 1947, PI: Milisavljevic). The entire remnant has been mapped in near- and mid-infrared by using NIRCam and MIRI, and additionally, exploratory positions that can sample ejecta and circumstellar medium was observed with NIRSpec and MIRI/IFU. These observations reveal intricate details of the supernova ejecta and circumstellar medium that were not previously seen. We have explored the NIRCam F162M, F356W, and F444W images to study the physical and chemical properties of compact ejecta knots moving much faster than other ejecta material. It has been known that these knots are composed of newly-synthesized heavy elements, indicating that they are dense knots expelled from the inner layers of supernova during the explosion. The NIRCam images reveal numerous ejecta knots, most of which are < 1″ and often closely clustered together. We derived their NIRCam fluxes and analyzed their colors using NIRSpec spectra as a reference. We also examined the NIRCam colors of the unshocked ejecta in the interior. This poster presentation highlights our preliminary results.

1. NIRCam Images

NIRCam Observations and Image Processing The NIRCam images of Cas A were obtained on 2022 November 5 using three filters: F162M, F356W, F444W. These images capture both line and continuum emission (Milisavljevic et al. 2024; see also Figure 3). We reprocessed the images with the JWST pipeline version 1.13.3 with custom steps to reduce the 1/f noise.

JWST F162M Image: **Figure 1** shows the reprocessed F162M image where stars have been subtracted. In the F162M band, the dominant emission is [Fe II] lines and synchrotron radiation. There are also [Si I] 1.607 μm and 1.645 μm lines in the band, but they are in general much fainter than the [Fe II] lines. The F162M image in Figure 1 reveals numerous compact sources both inside and outside the main ejecta shell (see §2). The image also reveals intricate structures of unshocked ejecta that were not seen in ground-based observations (see §3.2).

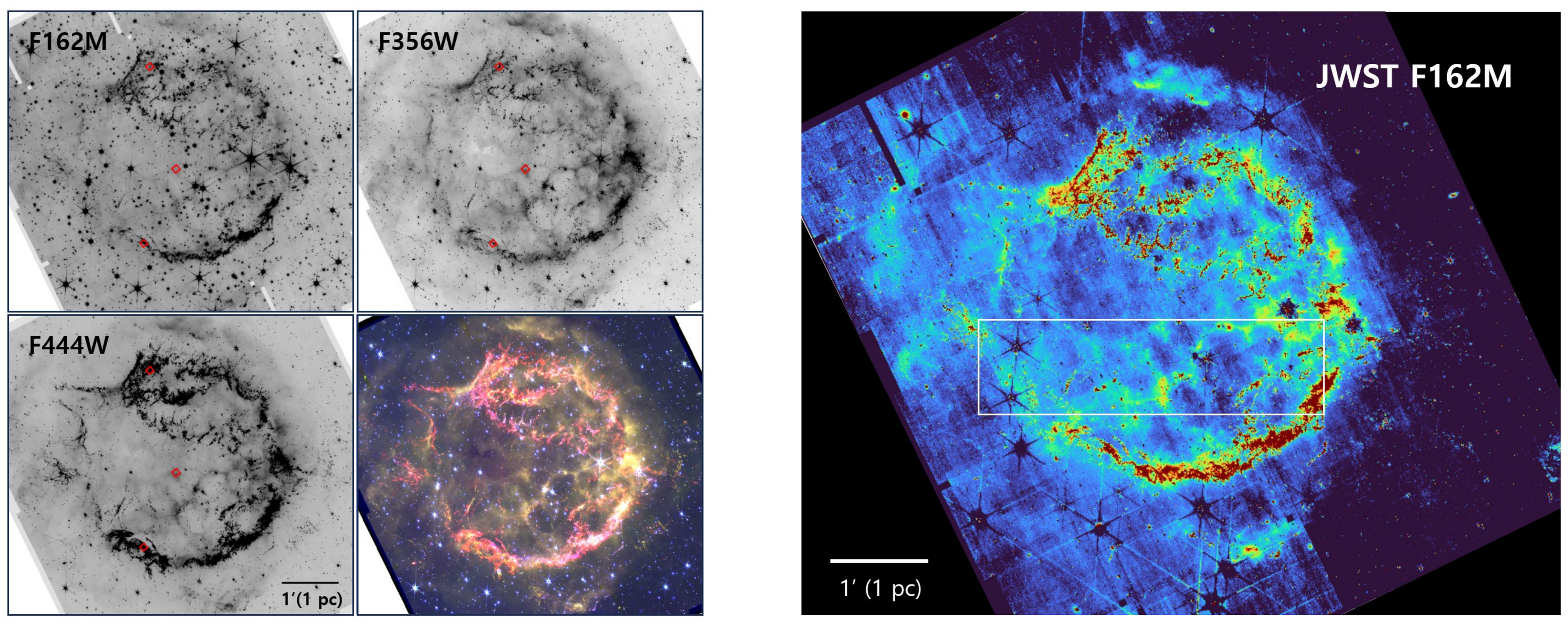

Figure 1. Left: JWST NIRCam mosaic images of Cas A. The color version at lower right is an F444W(R), F356W(G), F162M(B) three-color composite image. **Right:** Reprocessed and star-subtracted JWST F162M image of Cas A.

2. Compact F162M Sources

Catalog of Compact Sources: Our source catalog is based on the output of the stage 3 pipeline (calwebb_image3), but we ran the pipeline without the deblending option and manually applied a watershed algorithm for deblending afterwards where the local peaks are found from a PSF-deconvolved image.

Result: We have identified about 30,000 ejecta knots, the majority of which are the dense clumps in the main ejecta shell (**Figure 2**). The ejecta knots of F162M flux density ≥10^{-7} Jy have been cataloged in the outer area.

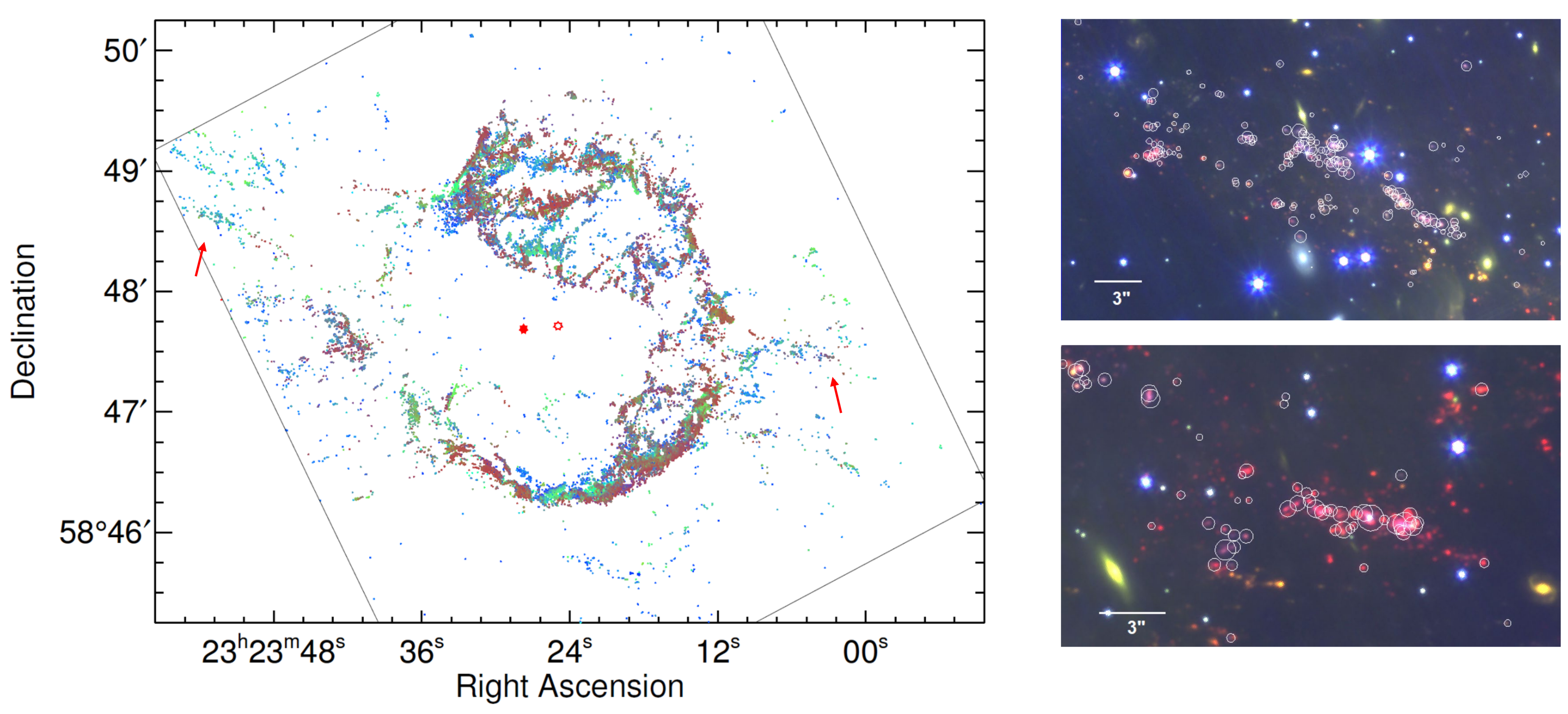

Figure 2. Left: Compact ejecta knots identified in the F162M image of Cas A, with their NIRCam brightness color-coded. The filled and empty symbols in the central area represent the explosion and geometrical centers, respectively. **Right:** Zoomed view of the area marked by red arrows in the left frame figure.

3. NIRCam Colors of Supernova Ejecta

3.1 Shocked Dense Ejecta

Color-color diagram (CCD): The supernova ejecta knots are distinct in NIRCam colors from background stars and galaxies (**Figure 3**). They have F444/F356 ratios greater than 1 whereas most stars and galaxies have the ratios less than 1. The majority of the ejecta knots have the ratios as high as those of P1 and P3, while there are many knots with the ratios close to that of P2 (Rho et al. 2024; De Looze 2024). We are investigating the color properties of the ejecta knots and their nature (Koo et al. 2024). The spatial distribution of the ejecta knots are shown in **Figure 2**, with their NIRCam brightness color-coded.

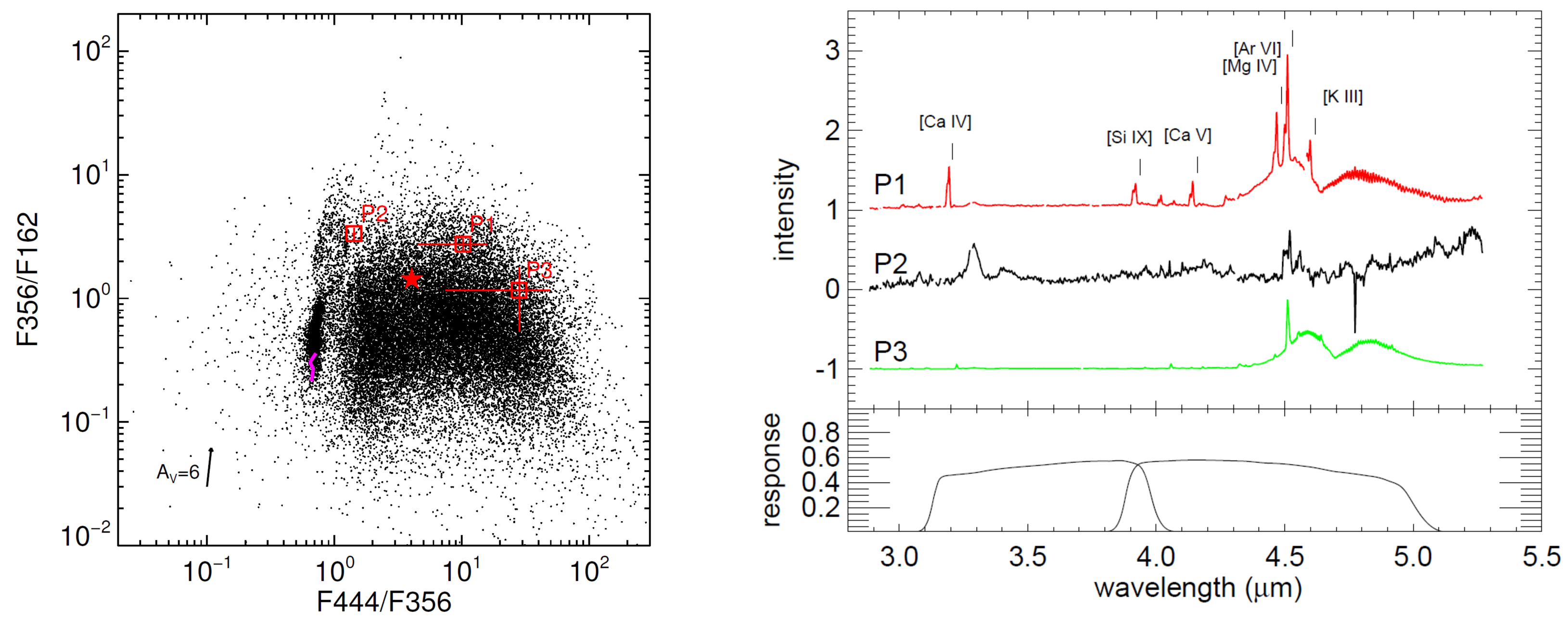

Figure 3. . Left: JWST NIRCam CCD of F162M compact objects. The red squares represent the average colors of the three IFU positions marked in Figure 1, while the red star symbol marks the average color of the entire main ejecta shell.. The magenta line represents the color of main sequence stars. **Right:** JWST NIRSpec Spectra of three IFU positions marked in Figure 1. The bottom frame shows the response function of F356W and F444W filters.

3.2. Unshocked Ejecta

Limb-brightened pillars of unshocked ejecta: The NIRCam images of the interior of Cas A is dominated by synchrotron emission. But SN ejecta material can be seen because their NIRCam colors are different from the synchrotron emission material. The structure shown in **Figure 4**, which looks like the ``pillars of creation'' in the Eagle Nebula, is particularly interesting. The limb-brightened morphology suggests that the unshocked ejecta is encountering a reverse shock. We are exploring the origin of the structure (Koo et al. 2024).

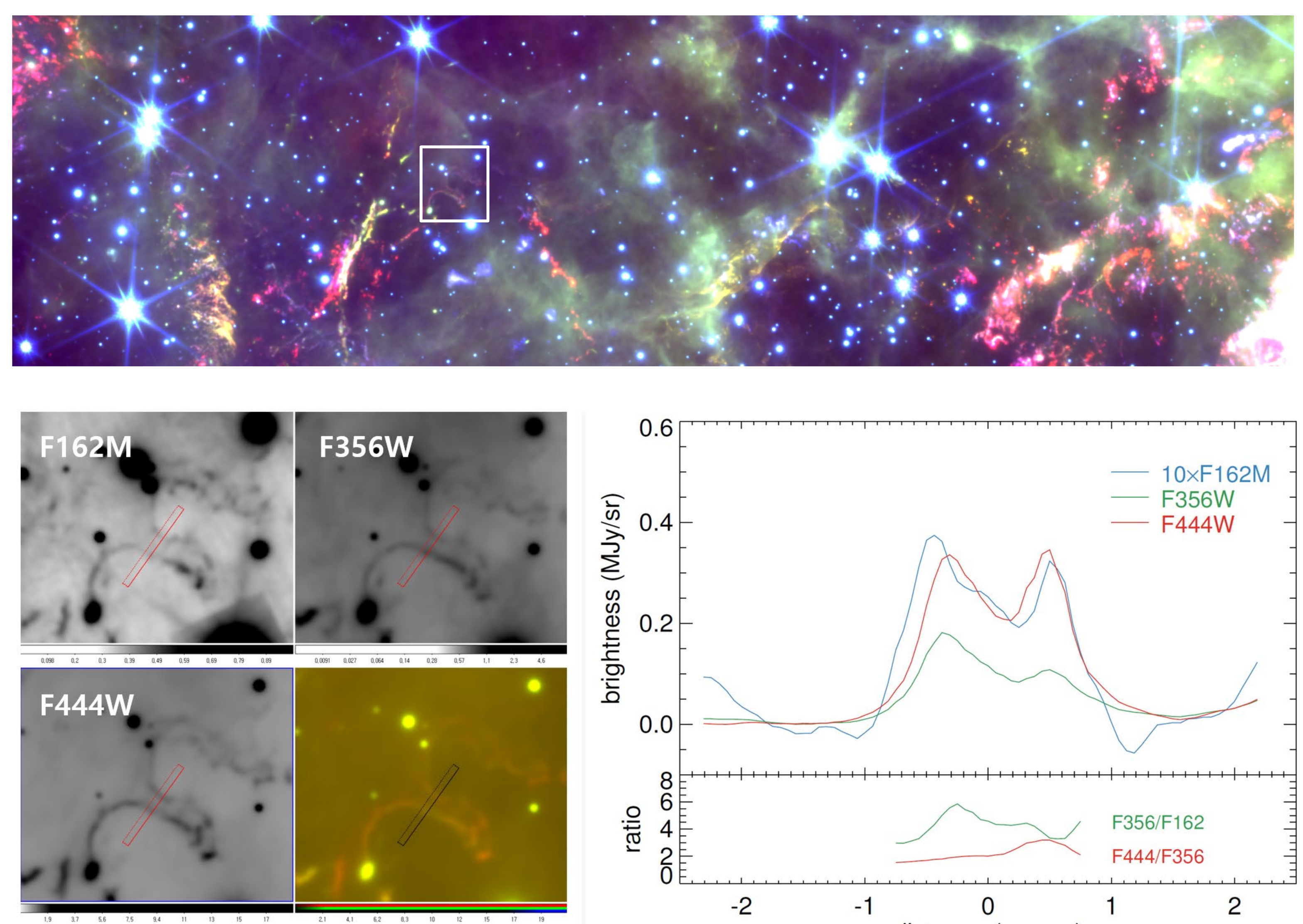

Figure 4. Top: Three color image of the white box area in Figure 1 produced from F162M, F356W, and F444W images. **Bottom Left**: Zoomed view of the white box area in the top frame. **Bottom Right:** Brightness profiles along the slit in the left and their ratios.

Reference:

De Looze, I., Milisavljevic, D., Temim, T. et al. 2024, in preparation
Koo, B.- C., Lee, J.-J., et al. 2024, in preparation
Milisavljevic, D., Temim, T., De Looze, I. et al. 2024, arXiv:2401.02477 (To appear in ApJL)
Rho, J., Park, R., Arendt, R. et al. 2024, ApJ accepted

+ references therein