Constraining Cas A's Shock Breakout with Infrared Echoes

Rodrigo Angulo (JHU)

Team: Armin Rest (STScI), Jacob Jencson (Caltech/IPAC), Joshua Peek (STScI)

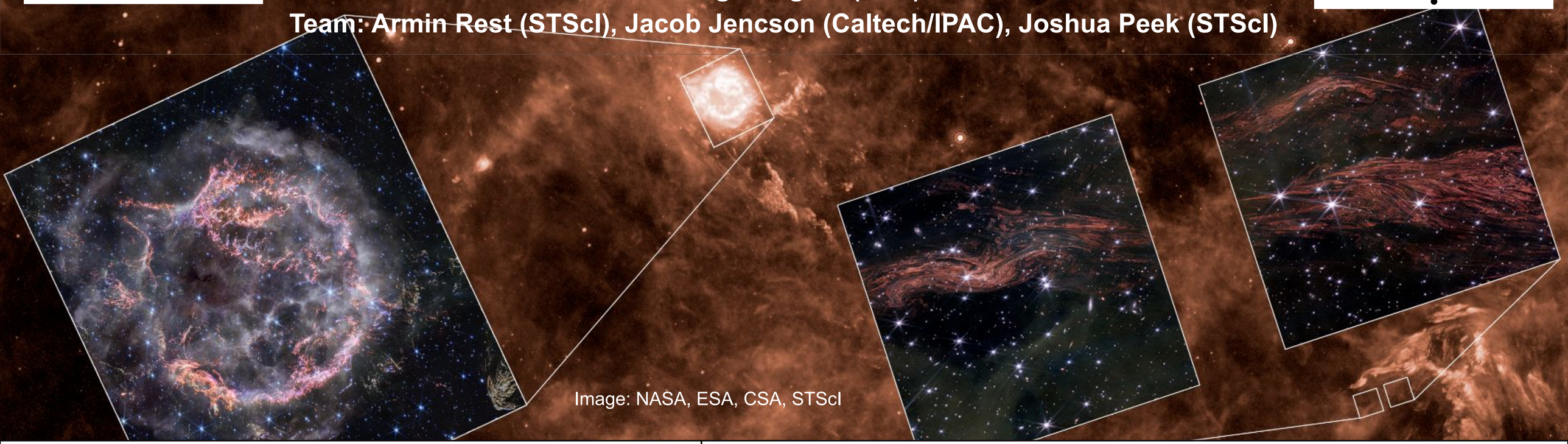


Image: NASA, ESA, CSA, STScI

Cassiopeia A (Cas A) is a well-studied supernova remnant (SNR) and the youngest core-collapse remnant in the Milky Way.

- The supernova (SN) occurred in the late 1600s.
- Hosts a system of infrared (IR) echoes and scattered light echoes (LEs; Krause+2005, Rest 2008).
- Spectra of LEs revealed that the SN was a type IIb (Krause+2008).
- IR echoes powered by EUV-UV radiation of the shock breakout and/or shock cooling of Cas A (Dwek and Arendt 2008).

Shock breakout refers to when the shockwave of an SN breaks through the surface of the star, resulting in an energetic flash of light dominated by X-ray and UV.

- The flash is short-lived, typically lasting seconds to hours, and up to days if interacting with circumstellar material.
- Highly dependent on the progenitor's radius.
- Rarely observed, but can produce **IR echoes**.
  - The energetic radiation heats up surrounding dust
  - Due to the longer path length from the SN to the dust, and then to Earth, these echoes can be observed long after the original event; a second chance to observe historical events!

Method: With a set of JWST images (JWST-GO 5451, 8527; PIs Jencson, Peek), we find an intricate and rich set of previously unseen and unresolved substructure in the Cas A IR echoes (in filter F444W). The flux profile of an echo is composed of the energetic flash of the shock breakout convolved with the PSF and the thickness of the dust sheet. Hence, we fit a flux profile for an IR echo with a input model describing a fast rise and slower decline, then convolved by the PSF and a Gaussian representing the dust width. Our method to translate the shape of echo profiles and their apparent motion on the sky to constraints on the duration of Cas A's shock breakout is illustrated in **Figs. 1-4.**

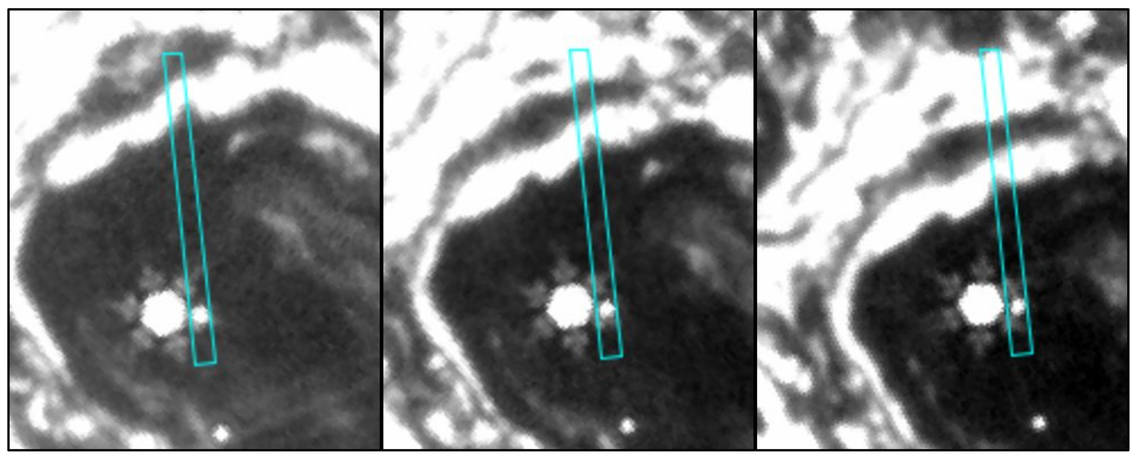


Fig 1: Find thin and fast moving echo structure. Then define a light echo flux profile box (perpendicular to apparent motion) to obtain the flux curve for the IR echo at each epoch. These observations are ~2 weeks apart.

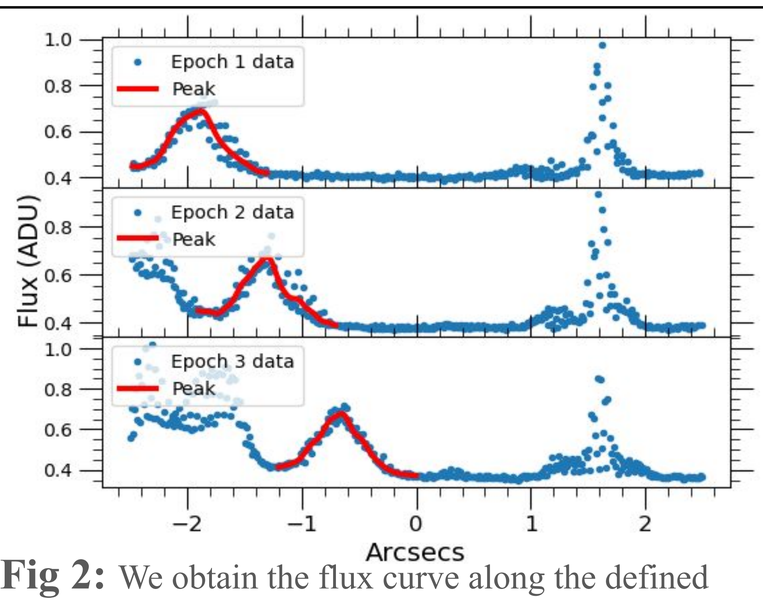


Fig 2: We obtain the flux curve along the defined profile box for each epoch. The peaks of the IR echo of interest are in red.

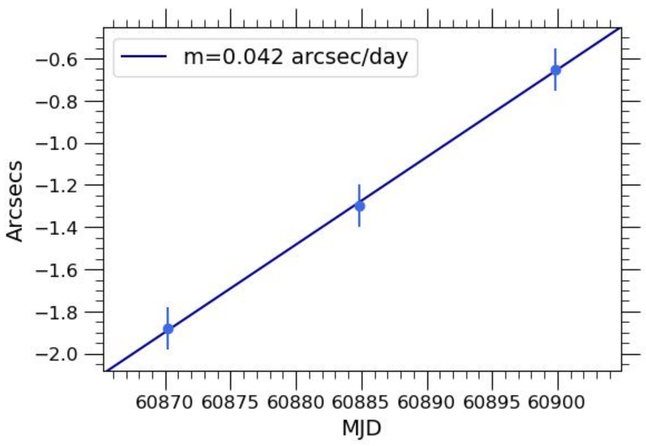
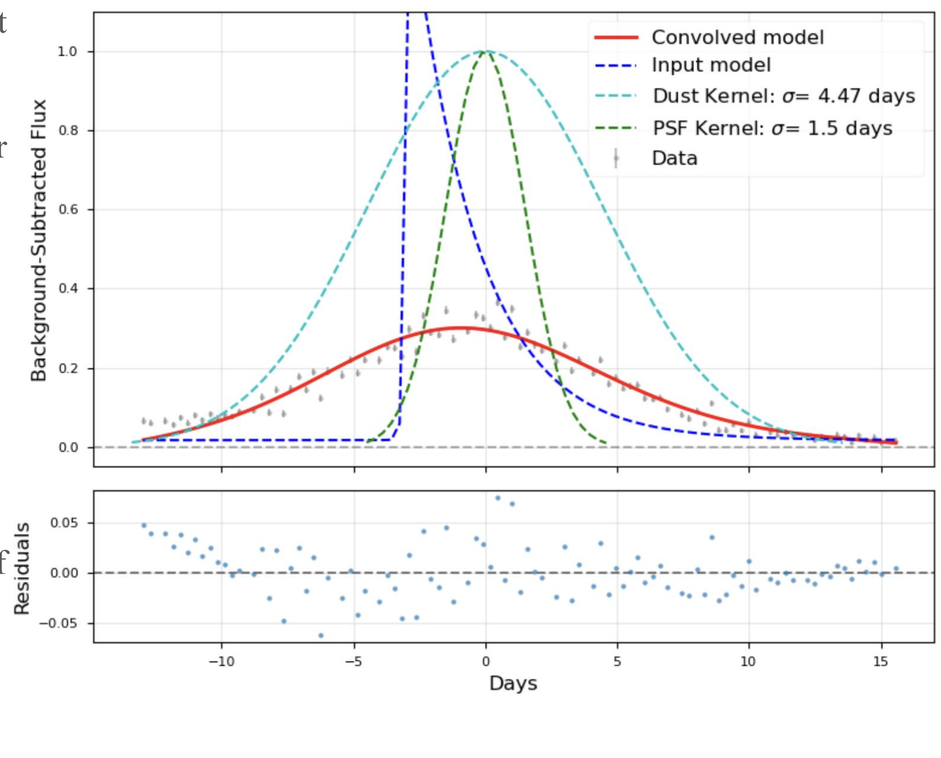


Fig 3: We calculate the apparent motion to get the conversion between spatial coordinates and light-curve phase.

Fig 4: After converting from spatial coordinates to phase, we fit the peak for one of the epochs with an input light curve consisting of a fast rise and slower decline, and convolve it with the PSF kernel and a Gaussian kernel representing the impact of the dust. The free parameters are the normalization and peak location for the input model, and the dust kernel. The PSF kernel is determined by JWST empirical PSF size. We check the fits for different rise times with a range of fall times.
This figure shows a fit for a rise time of 6 hours and a 44 hour fall time.



Status: Work in progress:

- We have fitted the our test light echo profile with a Bazin function that has a rise time of 6h, a conservative upper limit of the rise time based on theoretical considerations (Goldberg+2022), as well as observational constraints from SN IIb (Armstrong+2021 , Wang+2023) observed with Kepler and TESS, respectively.
- We have now all the software in place to run on many different IR echoes
- We will look for the IR echoes that give us the tightest constraints

Future work: The following are areas we can improve our analysis:

- Test multiple echoes – investigate varying dust structure and/or asymmetry of the breakout
- Include other filters for analysis – bluer filters with smaller PSF, though echoes are fainter.
- Improve background subtraction
- Test other input models and optimizers – improve computational limits
- Improve error propagation to include reliable uncertainties
- Angulo et al. (in prep)
- 2nd paper: Constraints on asymmetry of shock breakout using this analysis on different IR echoes