JWST detection of a supernova associated with GRB 221009A without an r-process

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Outline

- Background Introduction
- Observation
- Conclusion

Where are the heavy elements come from?

- **Nucleosynthesis involving charged particles, photons, and neutrons during the Big Bang.**

  Like p, v, pv-process and such.

Very small amounts of heavy elements

- **s-process(slow neutron capture)**

  Environment: Low neutron density and moderate temperature.

  Time Scale: Thousands to millions of years.

  Products: Heavy elements up to bismuth(Bi), such as strontium(Sr), barium(Ba), and lead(Pb).

  Examples: The creation of elements like strontium, barium, and lead in AGB stars.

Relatively light heavy elements

- **r-process(rapid neutron capture)**

  Environment: High neutron density and high temperature

  Time Scale: Seconds to minutes.

  Products: Very heavy elements beyond iron, such as gold(Au), platinum(Pt), and uranium(U).

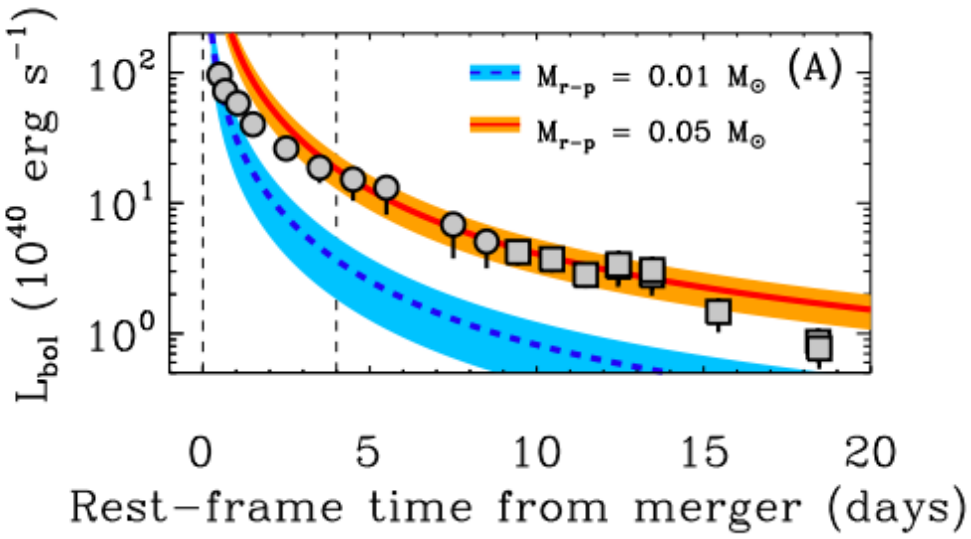
  Examples: The formation of heavy elements in neutron star mergers.

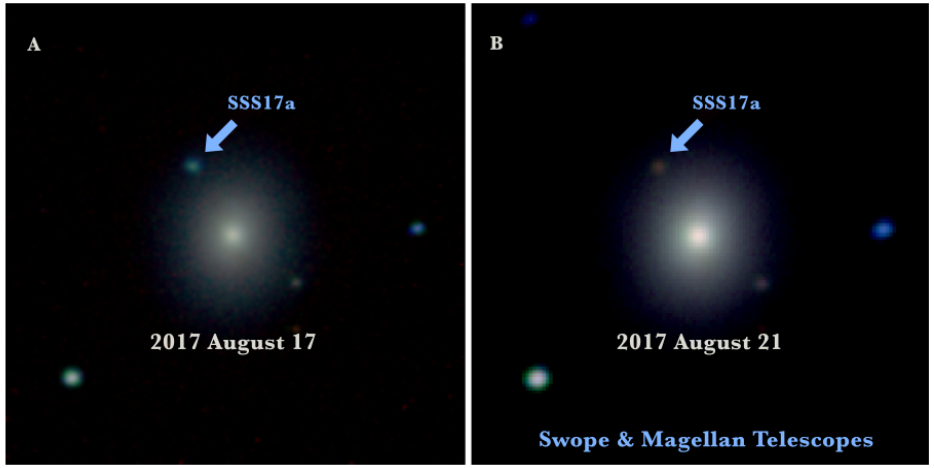
Heaviest elements

In the evolution of universe

Two theoretical model of r-process

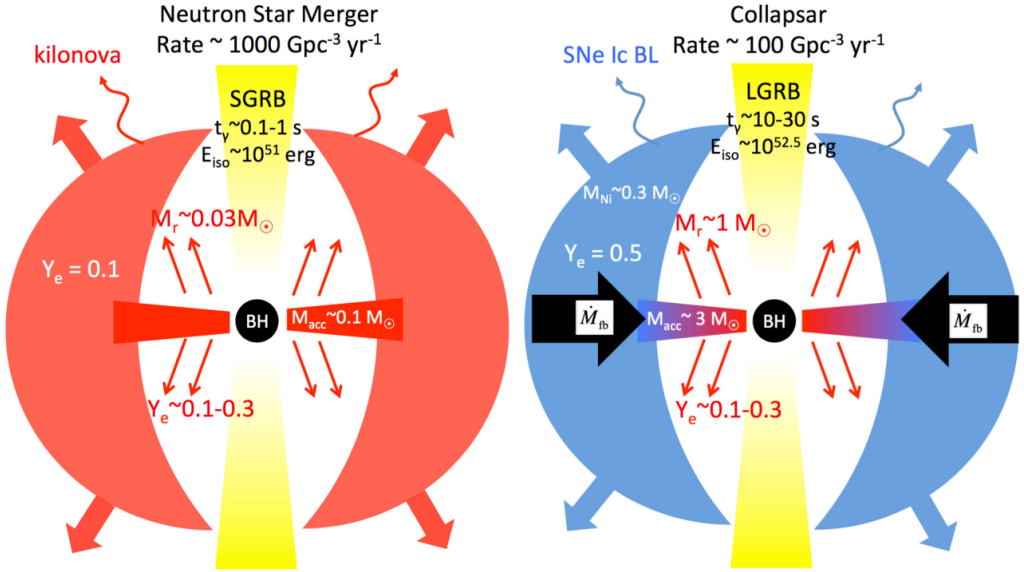
Light curve of GW170817





Drout, M. R, 2017, Science

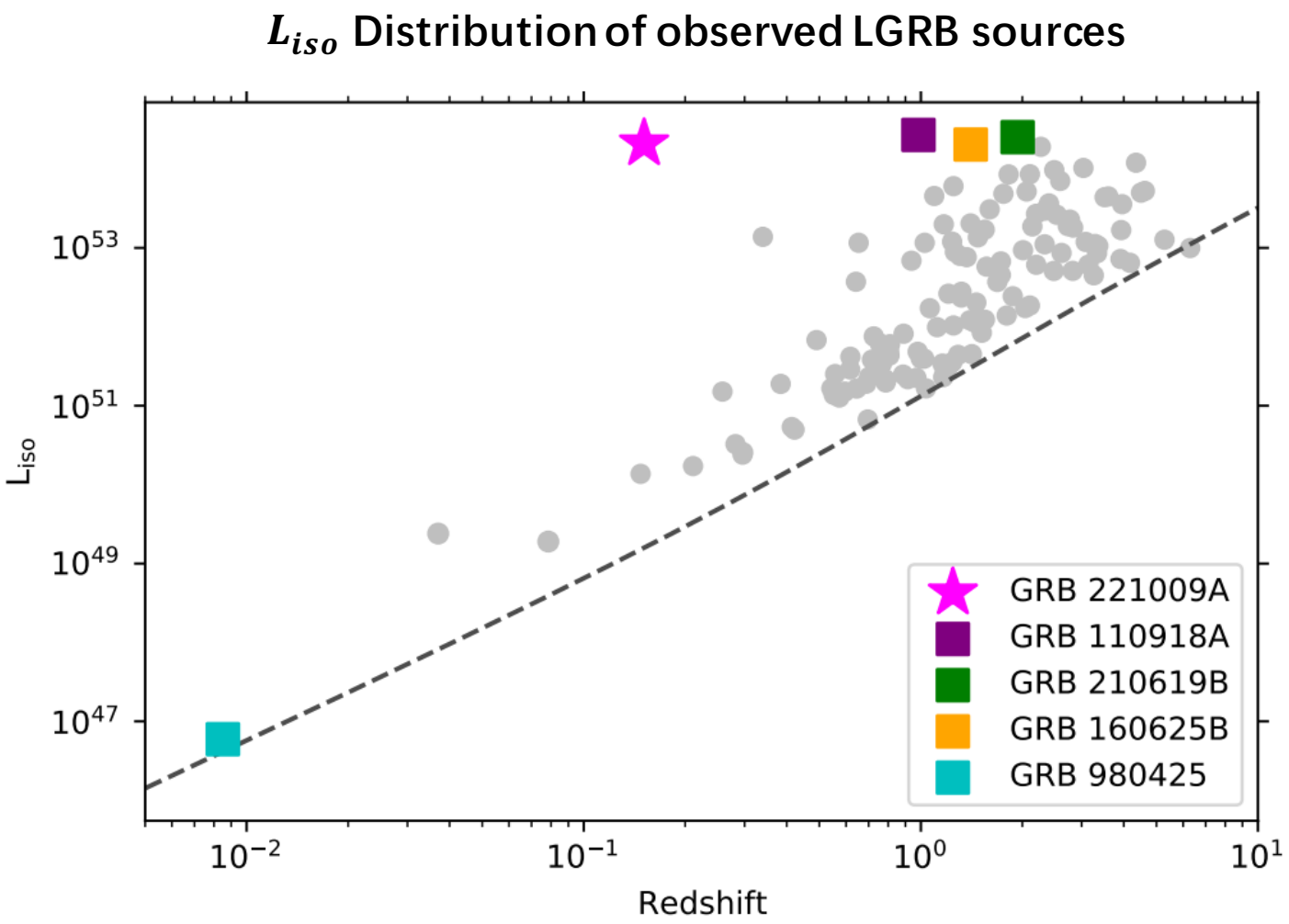
- Two theoretical assumption of the r-process origin is the kilonova or collapser.
- In 2017, with the observation of the neutron star merger event GW170817, Drout had demonstrated that the explosion of this source was accompanied by the r-process, confirming the first assumption can be a possible origin.



Daniel M. Siegel, 2019, Nature

Theoretically the r-process is primarily thought…

LGRB221009A

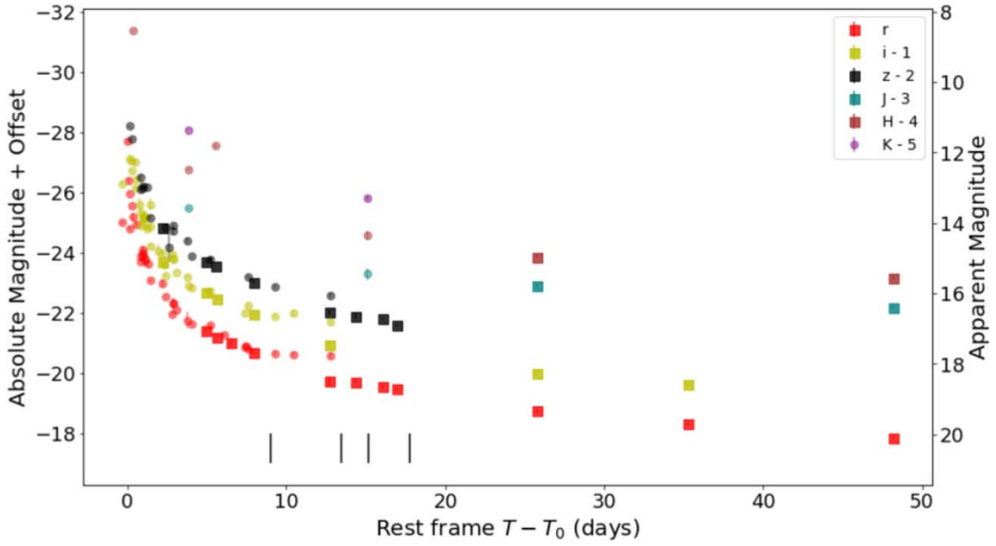


- Bolometric, *k*-corrected Liso for a nearly 100 observed GRBs The dashed line is an approximate, empirical detection threshold for GRBs as a function of redshift. Extreme GRBs are highlighted: GRBs 110918A and 210619B have higher $\boldsymbol{L_{iso}}$ than GRB 221009A. GRB 160625B is marked as it is an analog of GRB 221009A. GRB 980425, as measured by BATSE, as one of the lowest known $\boldsymbol{L_{iso}}$ values in a GRB. GRB 221009A is not the record holder.

- r-process nucleosynthesis is more likely to occur in collapsars with large accretion disk masses which are thought to be linked with brighter GRBs, making GRB 221009A a particularly strong candidate to search for r-process.

Observation of GRB 221009A

Multi-band Light curve of GRB221009A

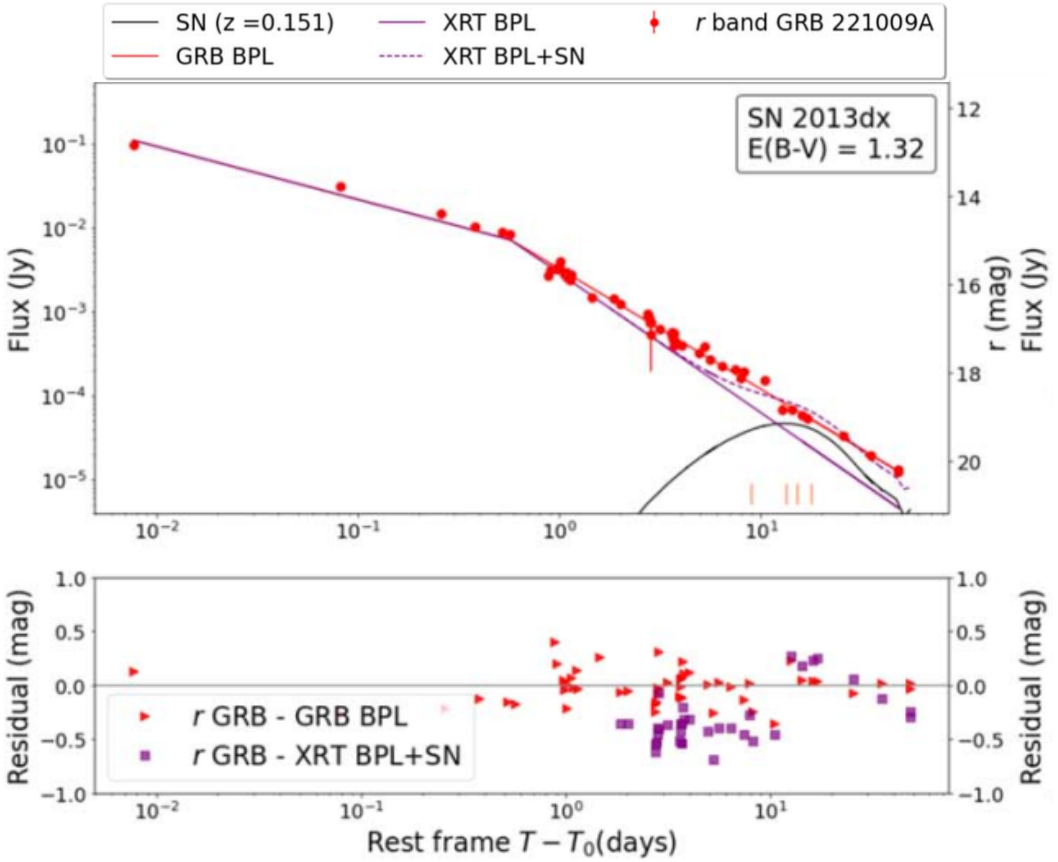


Optical light-curve data in r, i, z, J, H, K filter at the earlier rest frame phase(0 to 50 days)

Partial table of the data

Table 3
GCN Photometric Data of GRB 221009A

GCN	Telescope	$t - t_0$ (days)	r (mag)	i (mag)	z (mag)	J (mag)	H (mag)	K (mag)	References
32647	NEXT	0.0087	14.93 ± 0.05	...	...	...	...	...	Xu et al. (2022)
32645	AZT-33IK	0.01223	14.84 ± 0.09	...	...	...	...	...	Belkin et al. (2022c)
32662	GIT	0.094	16.16 ± 0.07	...	...	...	...	...	Kumar et al. (2022)
32646	MeerLICHT	0.17	17.76 ± 0.08	15.58 ± 0.03	14.89 ± 0.03	...	...	...	de Wet et al. (2022)
32644	BOOTES-2/ TELMA	0.19	16.57 ± 0.02	...	...	...	...	...	Hu et al. (2022)
32638	LT	0.29	17.00 ± 0.03	15.98 ± 0.03	15.32 ± 0.03	...	...	...	Perley (2022)
32755	REM	0.4	...	...	...	...	12.62 ± 0.02	...	D'Avanzo et al. (2022)

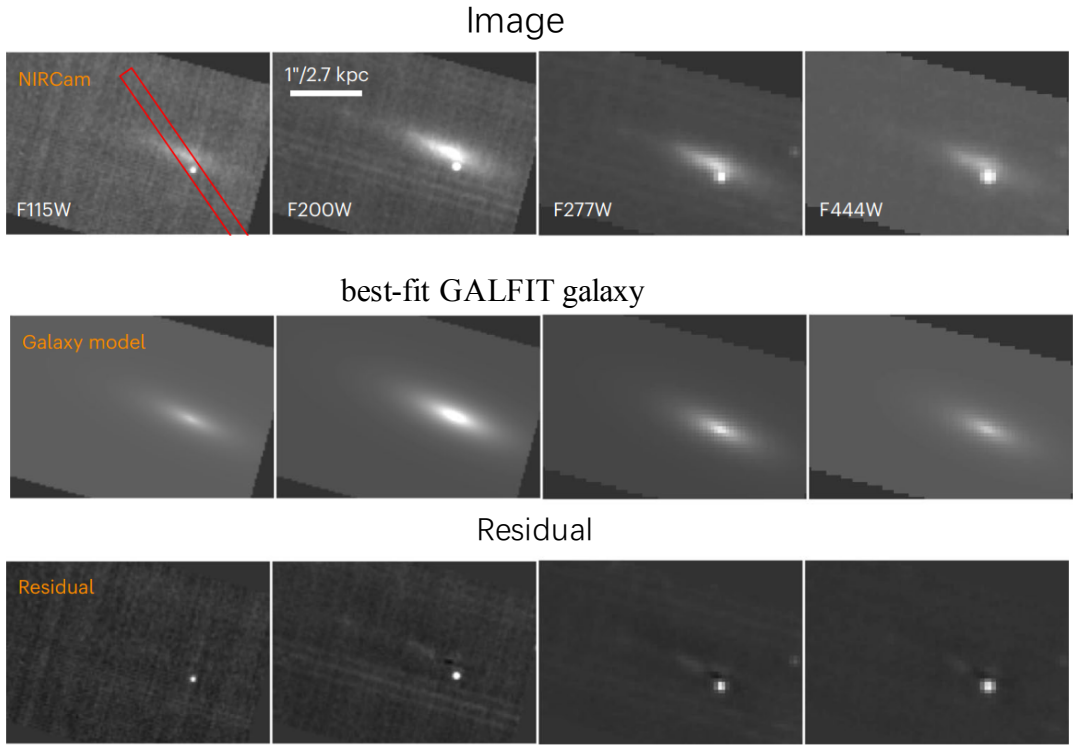


Light curves for the r filter with a broken power-law fit to the data. The red solid line shows the fitted afterglow by the r band data. The purple solid/dash line shows the fitted afterglow/afterglow+SN model(2013dx) (black solid line) by the X-ray data. The extinction value for r band is 1.32. We can`t see any evidence of exist of SN component.

Manisha Shrestha, 2023, ApJL

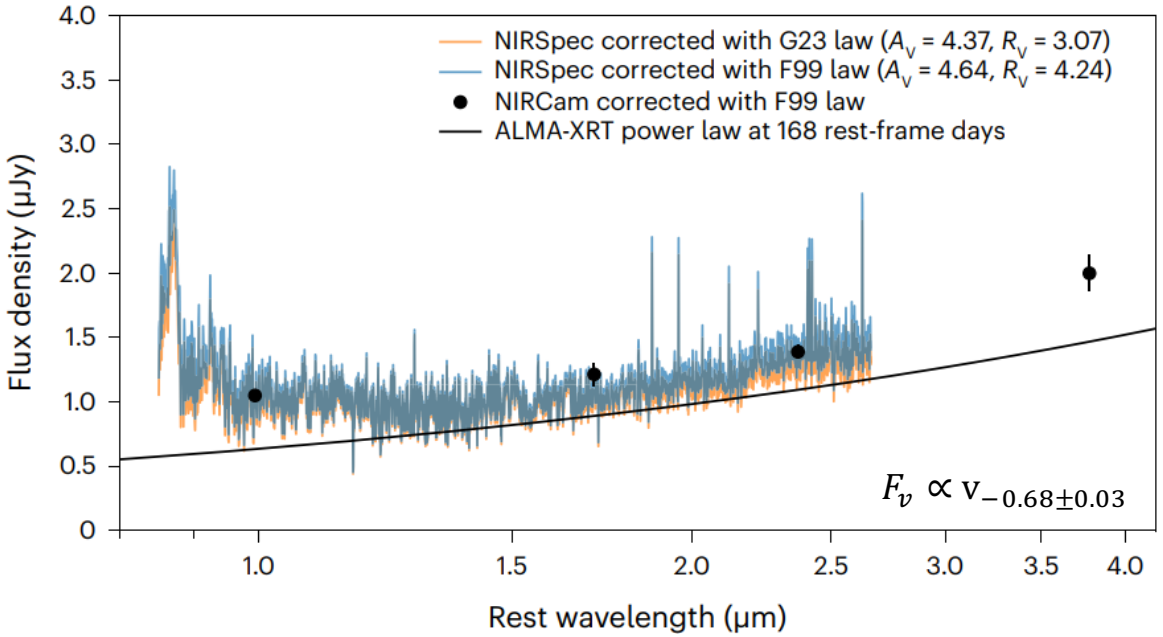
JWST Spectrum Analysis of GRB 221009A

Multi-band JWST NIRCam imaging



Images of GRB 221009A (top row) obtained by JWST Near Infrared Camera(NIRCam), best-fit GALFIT galaxy models (middle row) and GALFIT model subtracted images (bottom row) in four band(F115W, F200W, F277W, F444W)

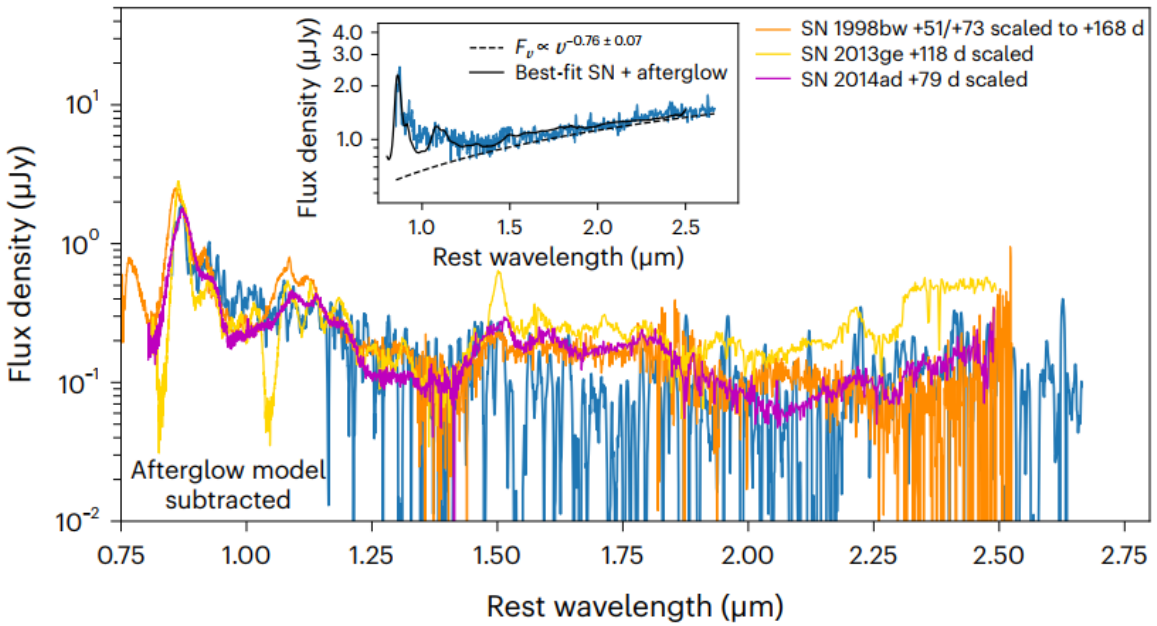
JWST NIRSpec spectrum



+168 rest-frame phase JWST Near Infrared Spectrograph (NIRSpec) spectrum of GRB 221009A corrected for extinction with two methods(orange and blue line). The results shows very slightly different with essentially the same pattern, where the short and long wave parts are respectively dominated by the explosion and GRB afterglow(which obey the classical power-law spectrum) , black solid line shows the fitted afterglow model based on the observational data from ALMA and Swift.

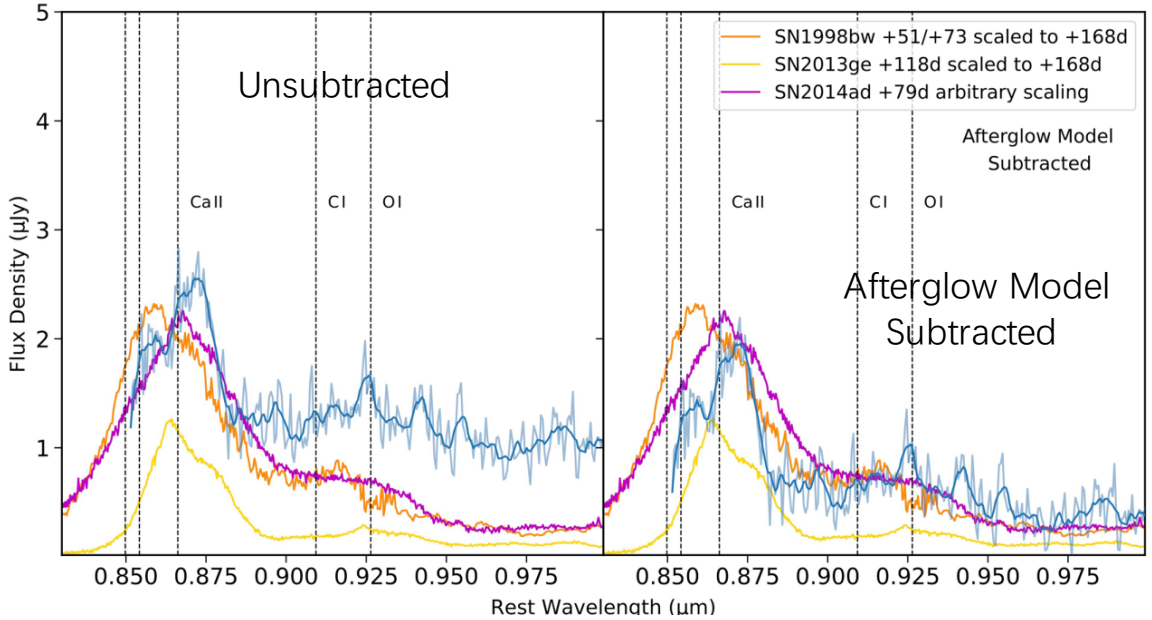
Evidence of Supernova Association

Afterglow model subtracted spectrum



Comparing with other 3 SN sources` subtracted spectrum, It shows a high degree of consistency, which indicate that the GRB221009A is a classical GRB-SN source.

Spectrum(0.825-1μm)



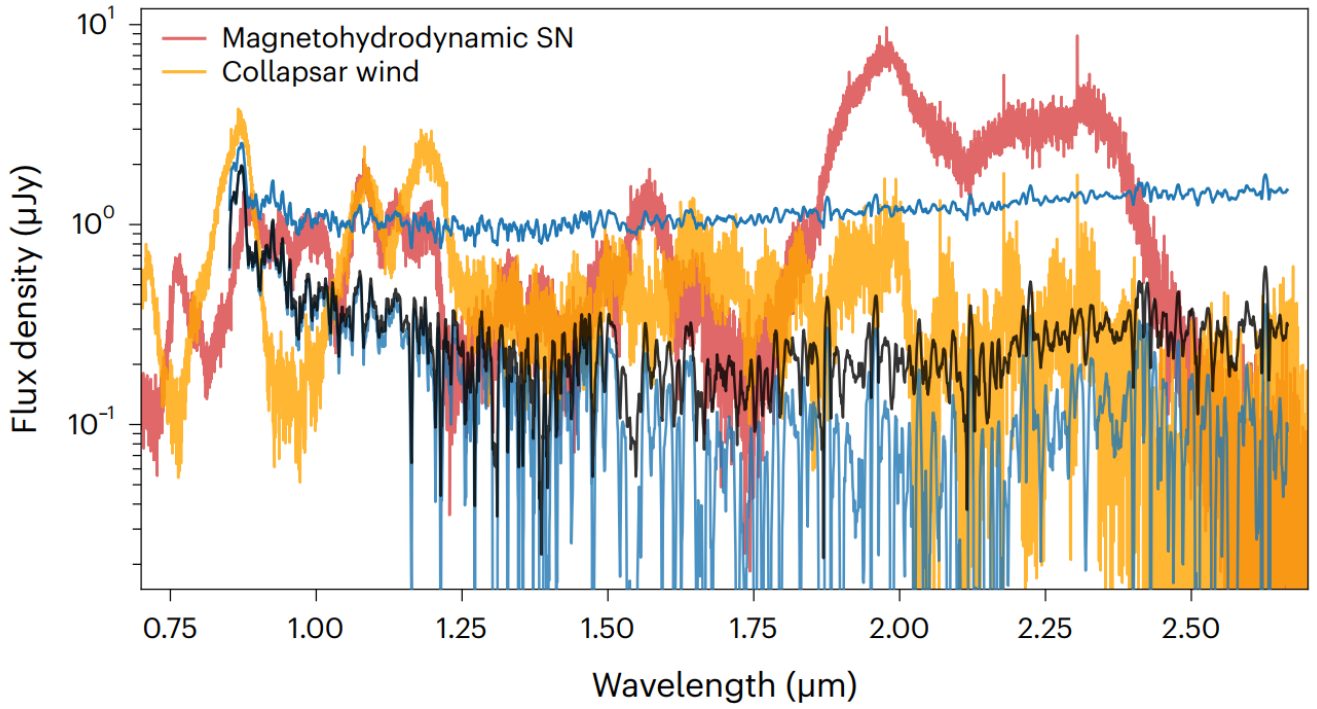
The unsubtracted and subtracted spectrum with the range in 0.825 to 1 μm. The observation of the typical nebular-phase emission lines(like Ca II, CI and OI) in corecollapse supernovae further demonstrate that the GRB221009A is truly associated with a supernova.

The subtracted spectrum is not unusually bright compared to other GRB-SNs, but this source is accompany with an extremely bright GRB, which is suggesting that the mechanisms of supernova explosions and GRB might be decoupled.

To confirm whether the

Additionally,

Distinction from theoretical r-process spectrum



Comparison of our NIRSpec spectrum of GRB 221009A with r-process enriched SN models. The red and orange lines correspond to theoretical spectra with two different models (MHD SN and Collapsar wind model). The upper flat blue line represents the spectrum without afterglow subtraction, and the lower blue and black lines respectively correspond to the subtracted spectra fitted from ALMA-Swift and JWST NIR data.

- The spectrum, even after subtracts for the afterglow, is still clearly distinct from the predictions of an MHD SN or Collapsar wind model, which means the absence of r-process
- The absence of r-process signatures in such a bright GRB supernova challenges the collapsar origin model. It encourages us to continue searching for evidence of r-process in other bright GRB-SNe. This also drives us to reconsider whether the collapsar environment can be a primary source of heavy elements in the universe, or whether there might be other potential physical environments that could serve as an alternative.

To determine if this source is accompanied by the r-process

Conclusion

- This study compared the subtracted spectra of GRB221009A with several other typical GRB-SN spectra and found that they have very similar spectral shapes. They also exhibit emission lines typical of the supernova phase, confirming the association of this source with a supernova.

- GRB221009A has a relatively faint supernova brightness but is accompanied by a very bright gamma-ray burst, indicating a decoupling between the supernova and gamma-ray burst explosion mechanisms.

- The study compared the theoretically predicted spectra corresponding to the r-process with the actual observed spectra and found significant discrepancies between the two. This proves that the r-process was not accompanied by GRB221009A.

Thanks for listening!

The end