INTRO

GRB-SN Association
within the Binary-Driven Hypernova Model

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for
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Motivation

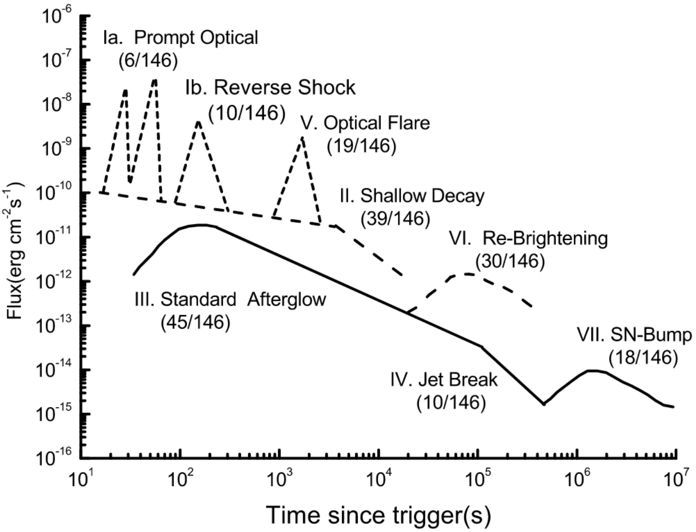
- Decades of observational data have established a solid connection between Long Gamma-Ray Bursts (GRBs) and Type Ic Supernovae (SNe).
- However, the classical "Collapsar" model (a single massive star collapsing into a black hole) struggles to explain the vast diversity in GRB energies versus the homogeneity of their associated SNe.
- We revisit the GRB-SN connection in light of the **Binary-Driven Hypernova (BdHN)** model, supported by statistical analysis and new extreme post-2023 observations.

The Fundamental Observational Tension

- **GRBs are extremely diverse:** Isotropic energies ($E_{\rm iso}$) span from 10^{48} erg (low-luminosity) to $> 10^{54}$ erg (ultra-long, ultra-energetic).
- **SNe are remarkably homogeneous:** The peak bolometric luminosities ($L_{p,\rm SN}$) and ejecta masses remain clustered within a very narrow range.
- If a single central engine powers both the GRB jet and the SN explosion, we should expect a strong correlation. *Do we see one?*

Overview of the Talk

1. Recap of the GRB-SN Sample & Analysis
2. Statistical Findings/Non-Findings
3. The Binary-Driven Hypernova (BdHN) Paradigm
4. The Post-2023 Observational Era (GRB 221009A, JWST)
5. Conclusions & Future Outlook



Li et al. (2012) ApJ 758, 27

phenomenology of SN association

Two methods exist to detect a SN in association with a GRB

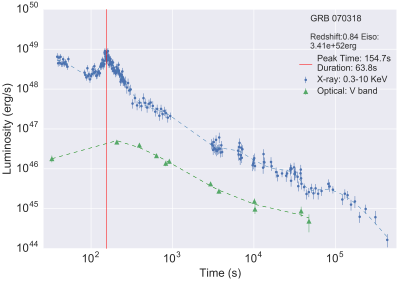
1) photometric identification

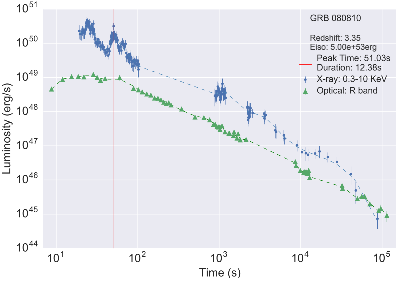
$\downarrow$

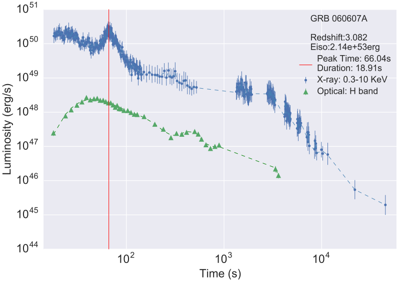
optical light curve behavior

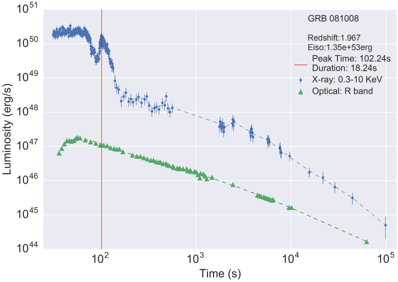
$\downarrow$

easier to obtain but usually (and unfortunately) the only to obtain



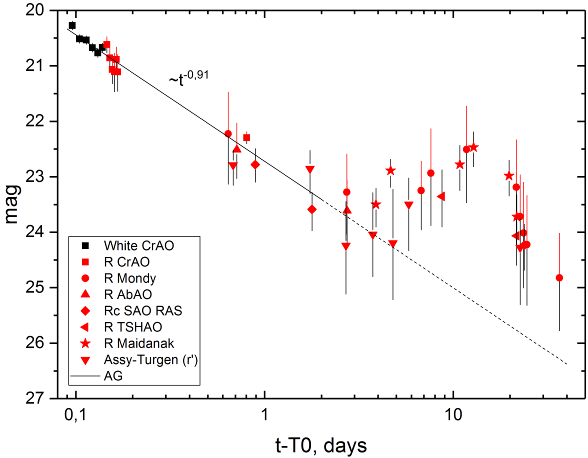




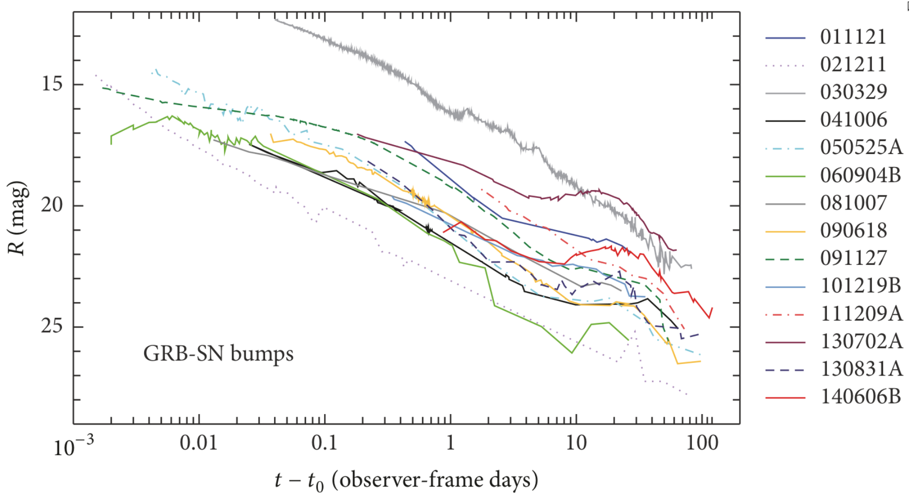


Ruffini et al. (2018) ApJ 852, 53

GRB 201015A optical afterglow light curve



Pozanenko et al. (2020) GCN, id 29033



Cano et al. (2017) AdvanAstr, id 8929054

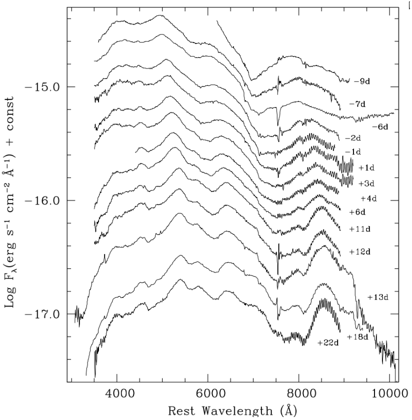
2) spectroscopic identification

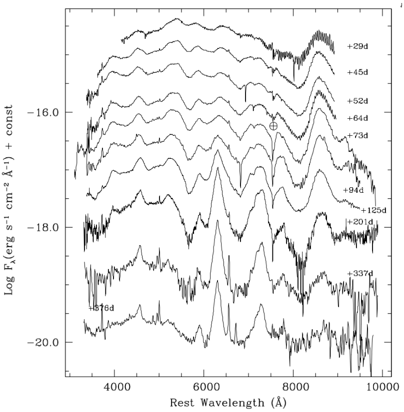
↓

tracks the absorption/emission lines in the spectra

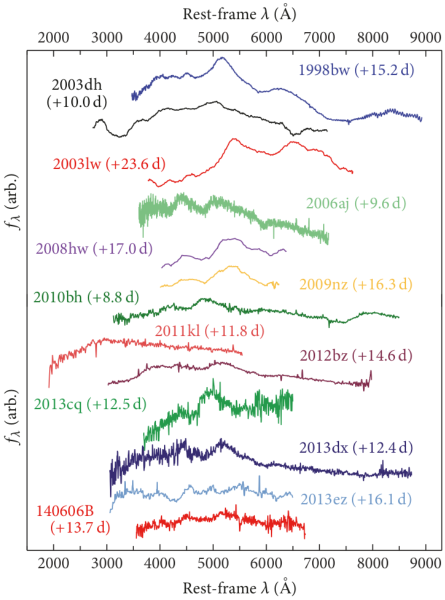
↓

harder to obtain due to needs of the largest telescopes
in order to collect more light in less amount of time





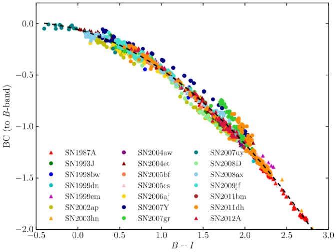
Patat et al. (2001) ApJ 555, 900



Cano et al. (2017) AdvanAstr, id 8929054

Recap: The GRB-SN Sample

- We compiled a comprehensive sample of GRB-SNe spanning the pre-*Fermi* and *Fermi* eras.
- Selected objects with well-sampled optical light curves to accurately model the SN bump.
- **Methodology:** Convert photometric magnitudes in various bands to bolometric luminosities using established K-corrections and bolometric corrections (e.g., Lyman et al. 2014, 2016).



Sampling:

GRB-SN = pre-Fermi + Fermi era

60 (ph+sp) = 30 + 30

We cross-correlate information from:

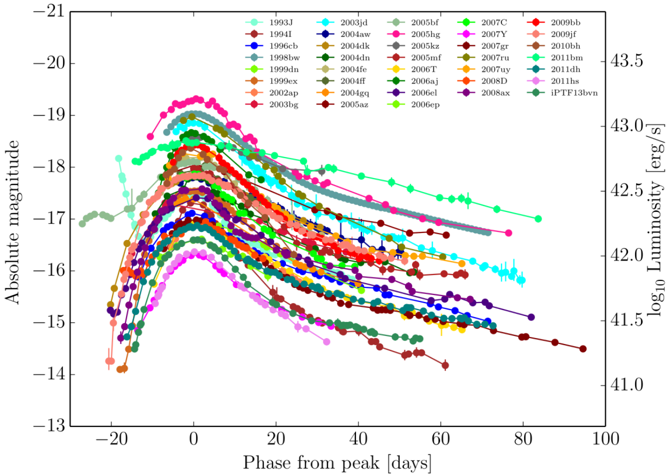
- catalogues on GRBs detected by *Fermi*-GBM
- catalogues on GRBs detected by *Fermi*-LAT
- GCN circulars (since the first GRB-SN association)
- Big table on GRB data by Dr. Greiner
- GRBweb catalogue by Dr. Coppin
- Transient Name Server website
- Simbad Strasbourg database
- + dozens of articles on GRB-SN

60(+) objects of GRB-SN sample

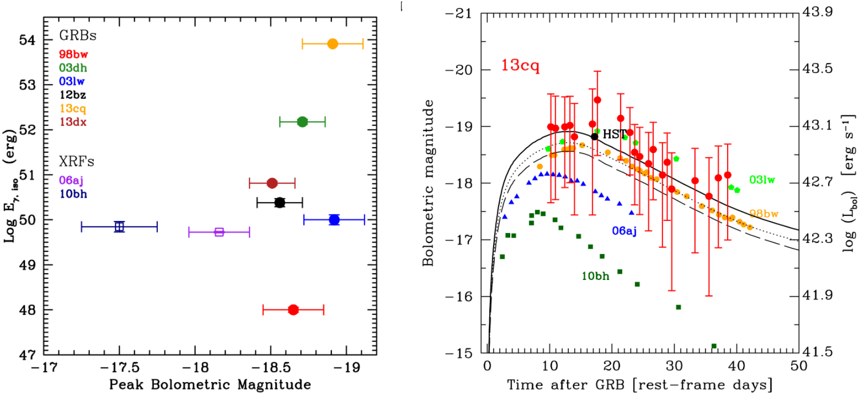
GRB	SN	Redshift
201015A	bump	0.4260
200826A	AT2020scz	0.7481
181201A	bump	0.4500
171010A	bump?	0.3285
161219B	2016jca	0.1475
150818A	bump	0.2820
150518A	bump	0.2560
140606B	bump	0.3840
130831A	2013fu	0.4790
130215A	2013ez	> 0.597
120729A	bump	0.8000
120714B	2012eb	0.3984
120422A	2012bz	0.2825
111228A	bump	0.7140
...	...	...
...	...	...

- 30(+) GRB-SN occurred within *Fermi* era (since mid-2008)
- 30 GRB-SN occurred in pre-*Fermi* era (since 1998)

Bolometric Light Curve Reconstruction

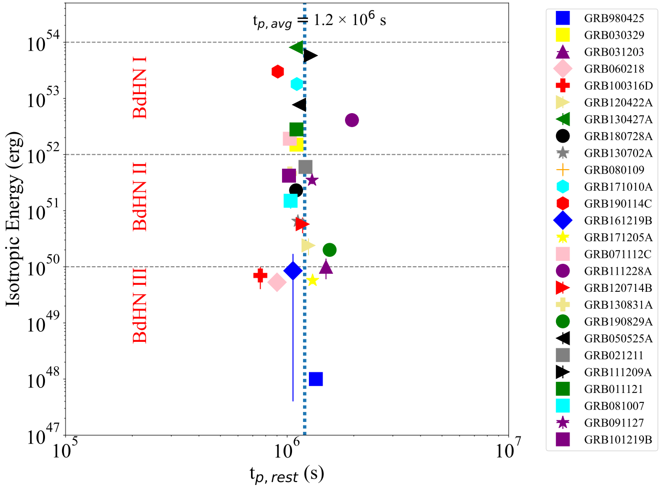


Lyman et al. (2016) MNRAS 457, 328



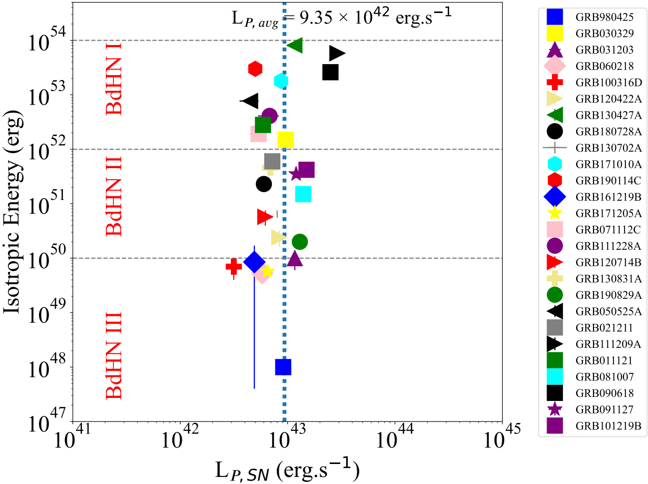
Melandri et al. (2014) A&A 567, A29

Universality of SN Peaking Time



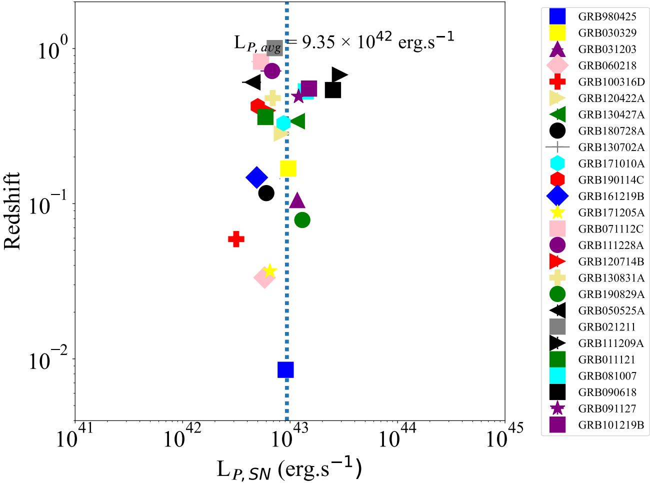
Aimuratov et al. (2023) ApJ

Narrow Scatter of SN Luminosity



Aimuratov et al. (2023) ApJ

Lack of Redshift Correlation



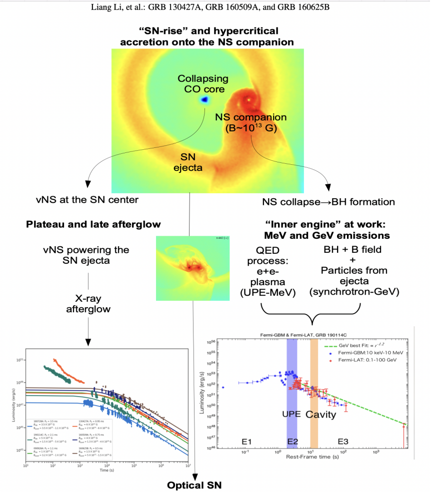
Aimuratov et al. (2023) ApJ

Summary of Empirical Tensions

- SN peaking times strongly cluster around $t_{p,\mathrm{avg}} \approx 13.8$ days (rest-frame).
- SN peak bolometric luminosities cluster tightly around $L_{p,\mathrm{avg}} = 9.35 \times 10^{42}$ erg/s.
- Meanwhile, GRB E_{iso} varies by ~ 6 **orders of magnitude**.
- The GRB energy is entirely decoupled from the SN energy.

- The independence of GRB and SN energetics is pointing for the posible binary nature of the progenitors.
- A single-star collapsar, where the central BH accretion drives both the jet and the explosion, should naturally produce correlated energies.
- Two independent, decoupled energy scales require **two independent physical components**.

The Binary-Driven Hypernova (BdHN) Paradigm



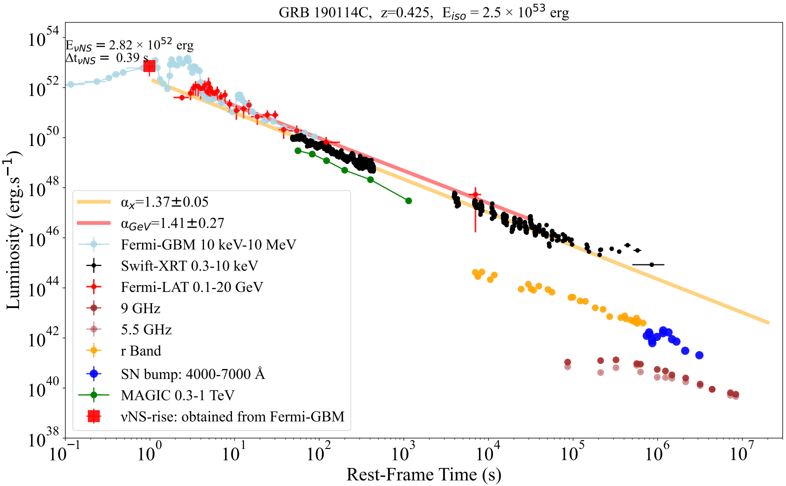
Ruffini et al. (2016) ApJ

BdHN Phases

1. **Progenitor:** A tight binary system consisting of a Carbon-Oxygen (CO) core and a Neutron Star (NS) companion.
2. **Phase 1 (The SN):** The CO core collapses, forming a new neutron star (νNS) and ejecting the outer layers (the Supernova).
3. **Phase 2 (The GRB):** The SN ejecta falls onto the NS companion. If the binary is tight enough, this *hypercritical accretion* pushes the NS past its critical mass, collapsing it into a Black Hole (BH) and powering the GRB jet.

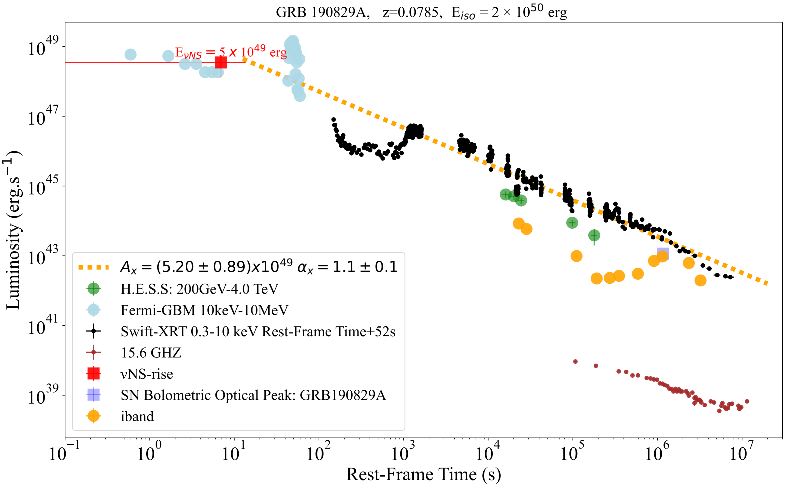
Result: The SN is powered by the CO core collapse (standard energy), while the GRB is powered by accretion onto the companion (variable energy dependent on binary separation).

Case Study 1: GRB 190114C (BdHN I)



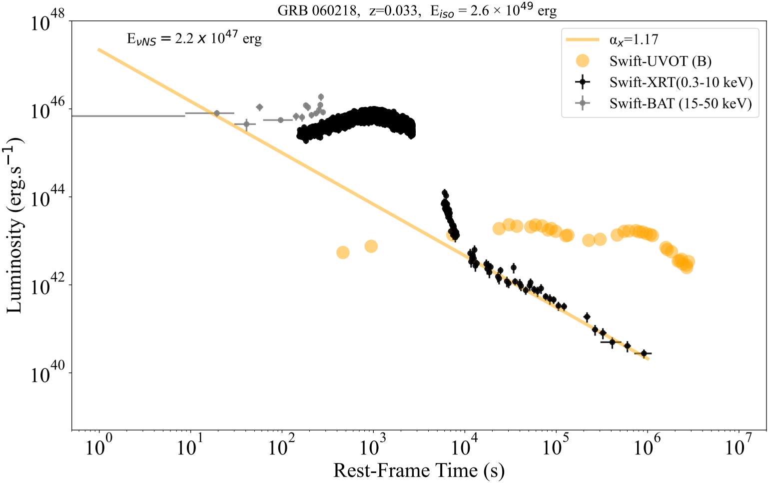
Ruffini et al. (2019) ApJ

Case Study 2: GRB 190829A (BdHN II)



Aimuratov et al. (2023) ApJ

Case Study 3: GRB 060218 (BdHN III)

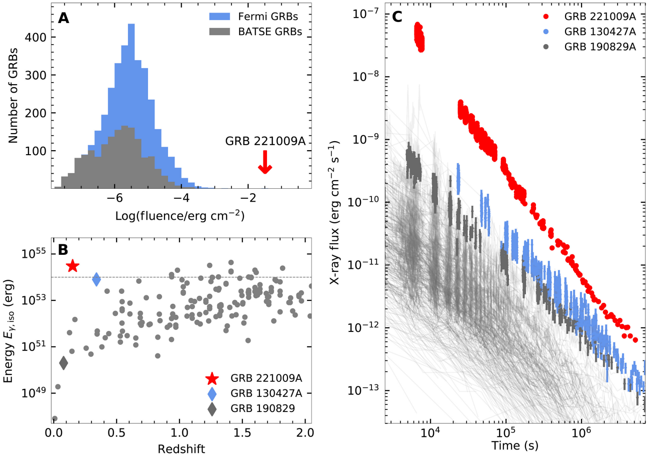


Aimuratov et al. (2023) ApJ

The Post-2023 Observational Era

- The BdHN model has been stringently tested by new observations in the post-2023 era.
- High-cadence surveys, multi-messenger networks, and instruments like *JWST* and *SVOM* are breaking old paradigms.

GRB 221009A: "The BOAT"



O'Connor et al. (2023) Science Advances

The BOAT's Supernova (SN 2022xiw)

- GRB 221009A is the brightest of all time, with $E_{\mathrm{iso}} > 10^{54}$ erg.
- Under a single-star collapsar model, such an extreme central engine should have produced a hyper-energetic supernova.
- **Reality:** JWST and HST observations revealed SN 2022xiw was shockingly *ordinary*, nearly identical in luminosity and evolution to SN 1998bw

SLSN-GRB Associations

- Recent years have also revealed rare associations between GRBs and Superluminous Supernovae (SLSNe).
- These events suggest a highly magnetized, rapidly spinning newborn neutron star (a *magnetar*) powering the prolonged, luminous SN emission.
- Within the BdHN framework, this aligns with the dynamics of the νNS formed from the CO core collapse, offering a unified physical origin for diverse transients.

The "Missing Progenitor" Puzzle

- Classical SN physics faced a "missing progenitor" problem: we rarely saw the massive Red Supergiant (RSG) progenitors before they exploded.
- Pre-explosion imaging often turned up empty for the most massive stars.

JWST Pure-SN Field Observations

- *JWST*'s infrared capabilities have recently resolved this puzzle.
- Observations of recent SNe (e.g., SN 2025pht) show massive progenitors were hidden inside thick, carbon-rich dust shells.
- These dense, complex circumstellar environments are exactly what is expected and required for tight interacting binaries in the BdHN model!

Future Outlook

- JWST observations of pre-SN dust shells continue to reveal the complex binary environments of these progenitors.
- The upcoming decade of gravitational wave and multi-messenger astronomy will allow us to probe the BH formation and νNS dynamics directly.
- The BdHN model with unified framework is going to test the future of transients.

Thank You!