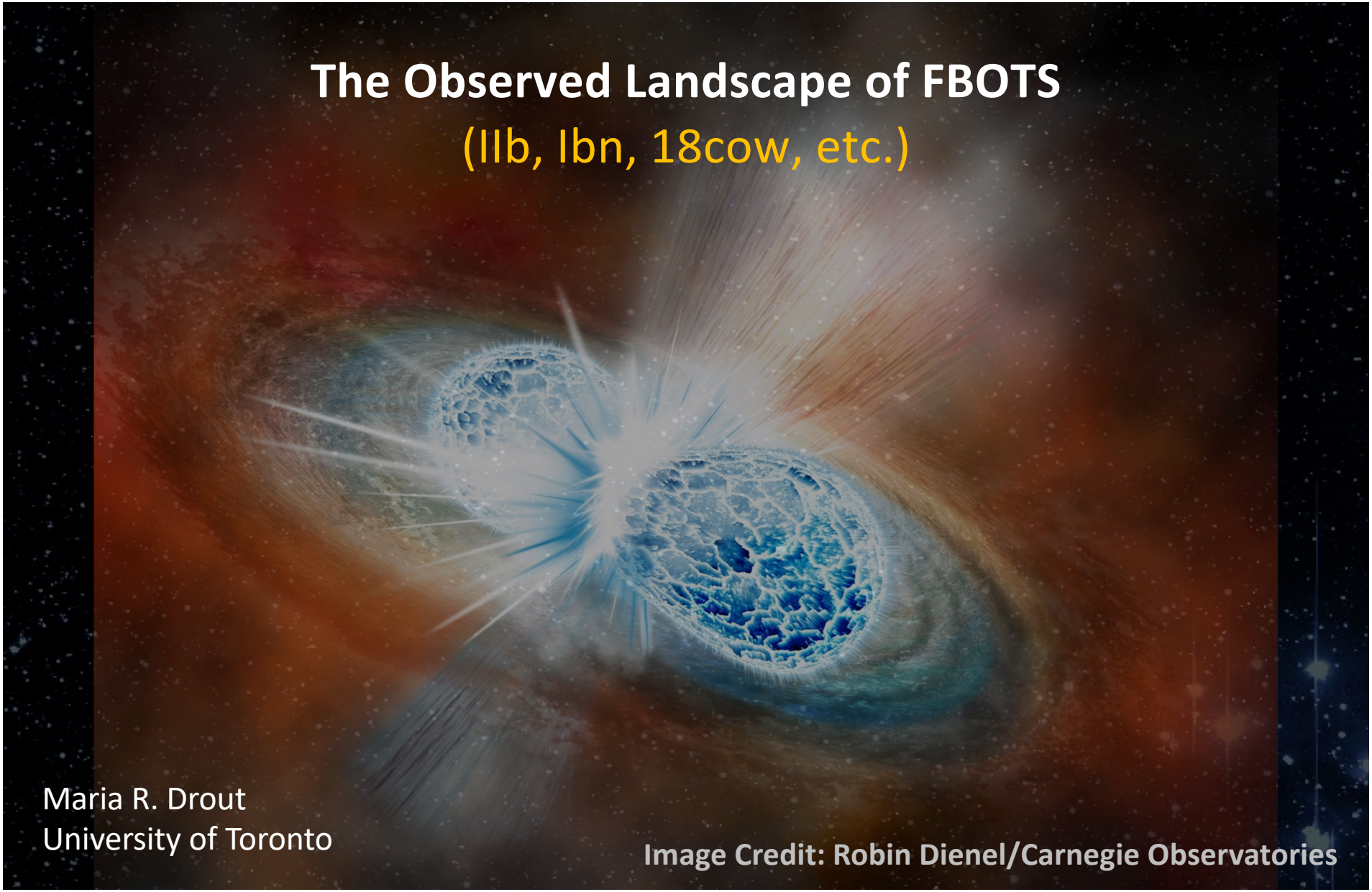
The Observed Landscape of FBOTS

(IIb, Ibn, 18cow, etc.)



Maria R. Drout
University of Toronto

Image Credit: Robin Dienel/Carnegie Observatories

What is an FBOT?

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“Fast Blue Optical Transient”

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First paper to use this specific term:

The Astrophysical Journal, 872:18 (32pp), 2019 February 10

https://doi.org/10.3847/1538-4357/aafa01

An Embedded X-Ray Source Shines through the Aspherical AT 2018cow: Revealing the Inner Workings of the Most Luminous Fast-evolving Optical Transients

R. Margutti[1], B. D. Metzger[2], R. Chornock[3], I. Vurm[4], N. Roth[5,6], B. W. Grefenstette[7], V. Savchenko[8], R. Cartier[9], J. F. Steiner[10,33], G. Terreran[1], B. Margalit[11], G. Migliori[12,13], D. Milisavljevic[14], K. D. Alexander[1,33], M. Bietenholz[15,16], P. K. Blanchard[17], E. Bozzo[8], D. Brethauer[1], I. V. Chilingarian[17,18], D. L. Coppejans[1], L. Ducci[8,19], C. Ferrigno[8], W. Fong[1], D. Götz[20], C. Guidorzi[21], A. Hajela[1], K. Hurley[22], E. Kuulkers[23], P. Laurent[20], S. Mereghetti[24], M. Nicholl[17,25], D. Patnaude[17], P. Ubertini[26], J. Banovetz[15], N. Bartel[16], E. Berger[17], E. R. Coughlin[2,33], T. Eftekhari[17], D. D. Frederiks[27], A. V. Kozlova[27], T. Laskar[28,29], D. S. Svinkin[29], M. R. Drout[30,31], A. MacFadyen[32], and K. Paterson[1]

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In last 5 years: used in 120 manuscripts

What is an FBOT?
"Fast Blue Optical Transient"

1. Have luminosities similar to supernova ($-15 \gtrsim M \gtrsim -21$)

2. Have short timescales (time above half light $\lesssim 12$ days)

3. Have relatively blue colors near maximum ($g-r \lesssim -0.2$)

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It has (retroactively?) been applied to transients with timescales shorter than "typical SN"

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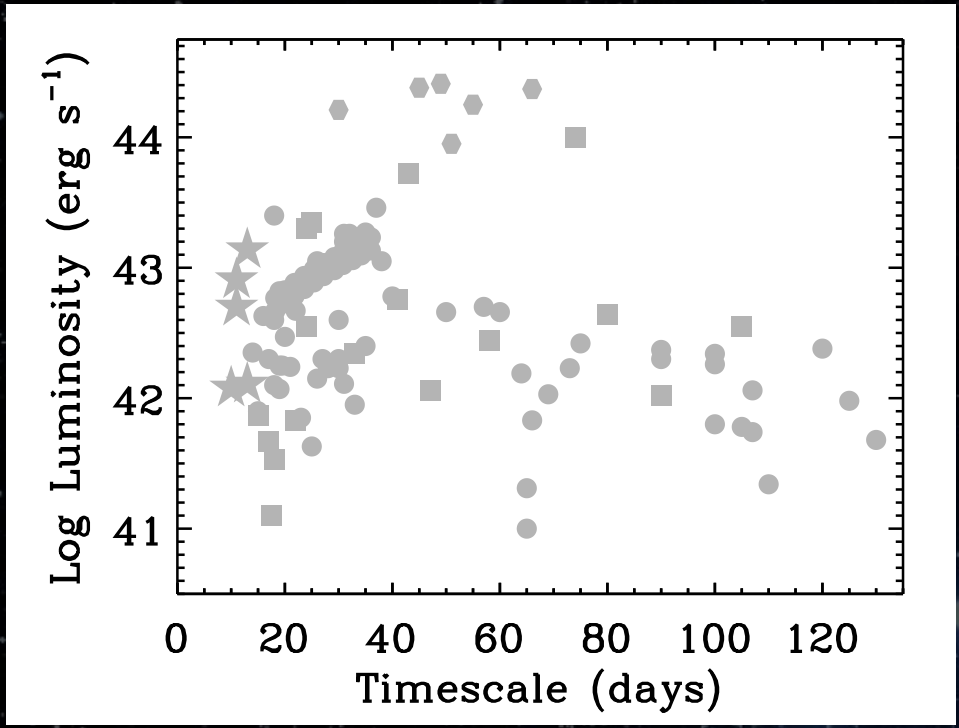

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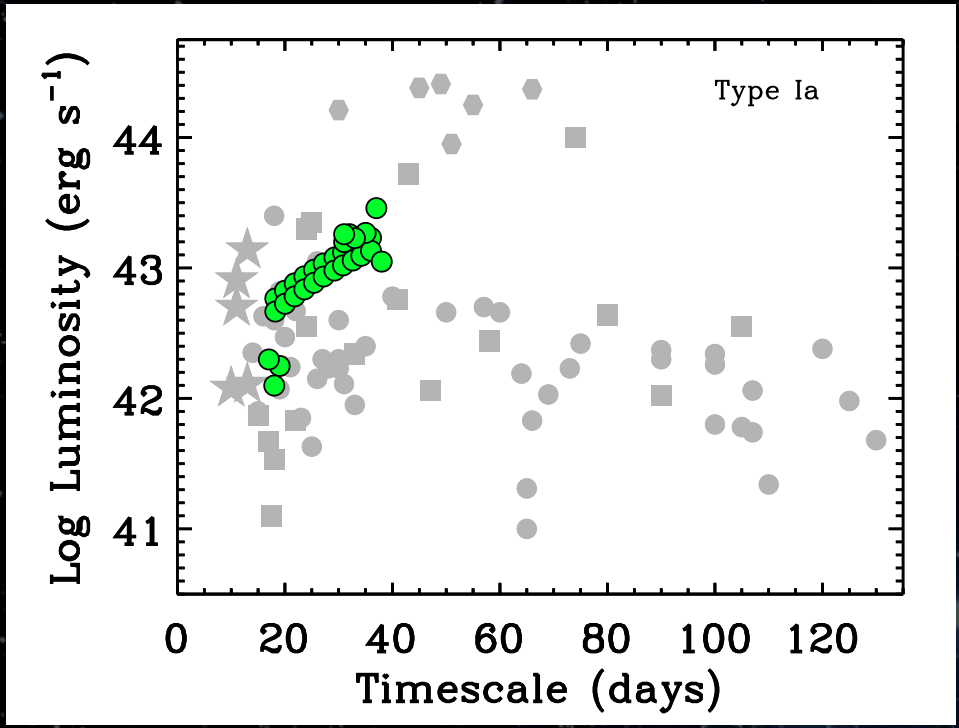

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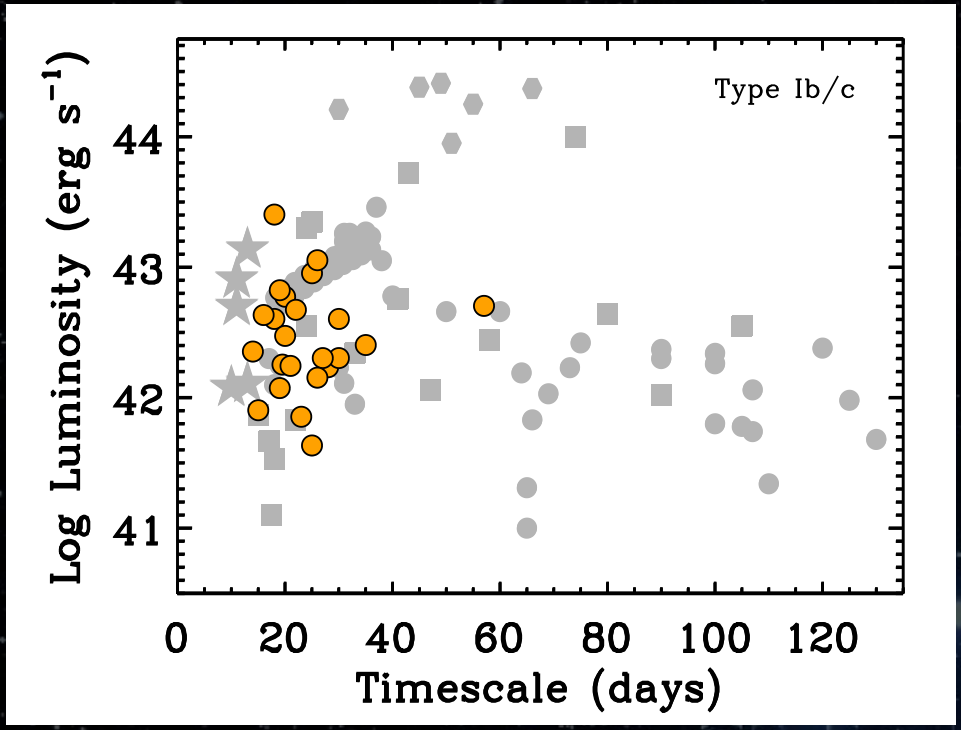

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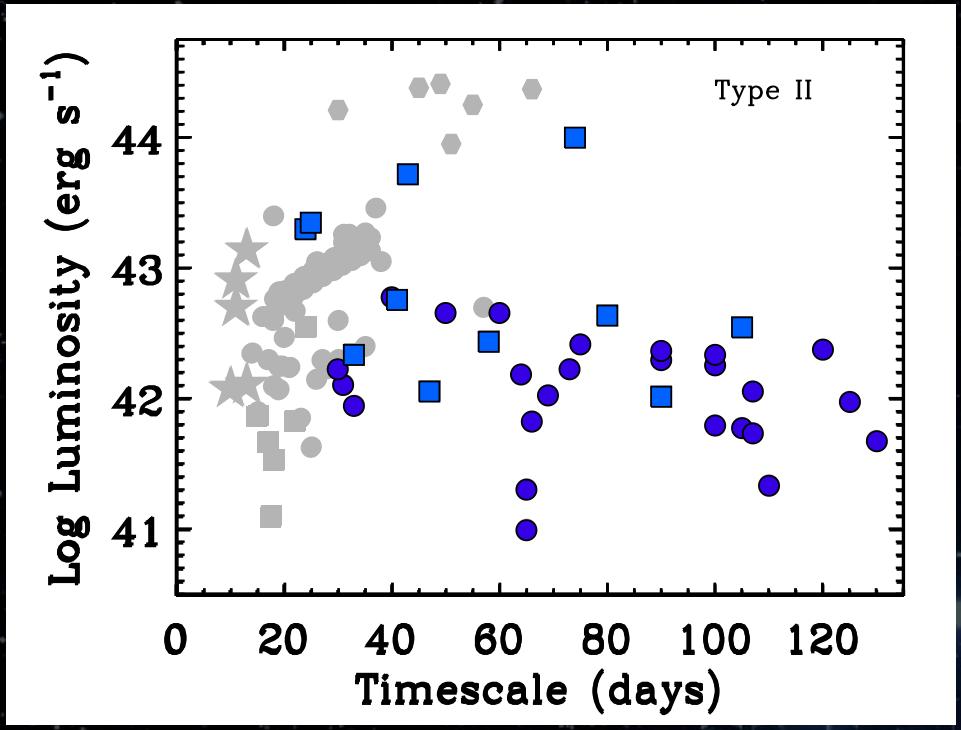

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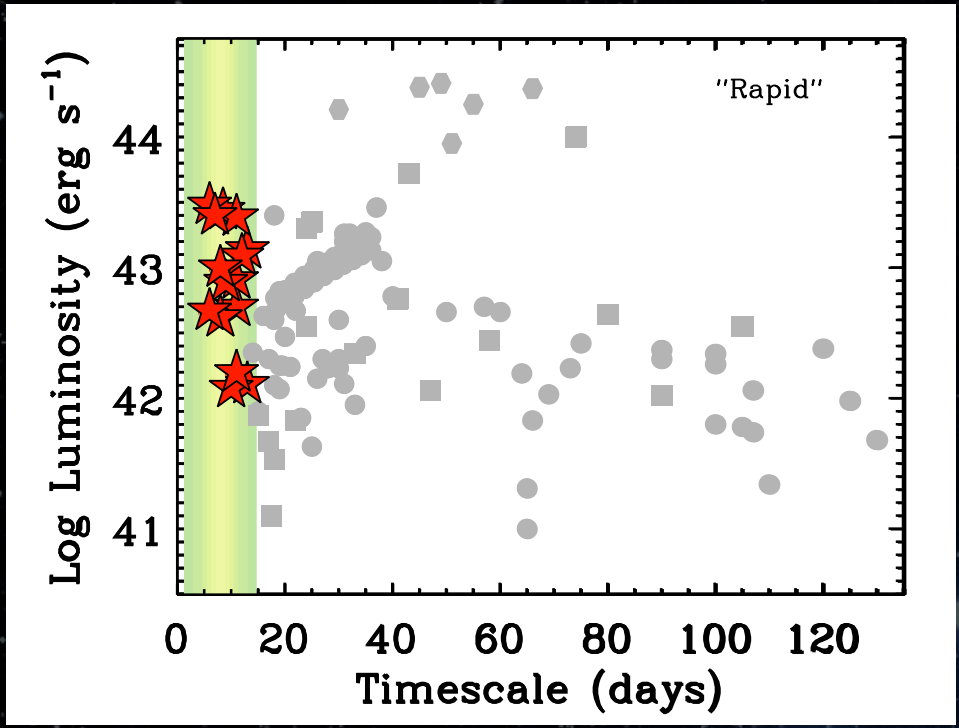

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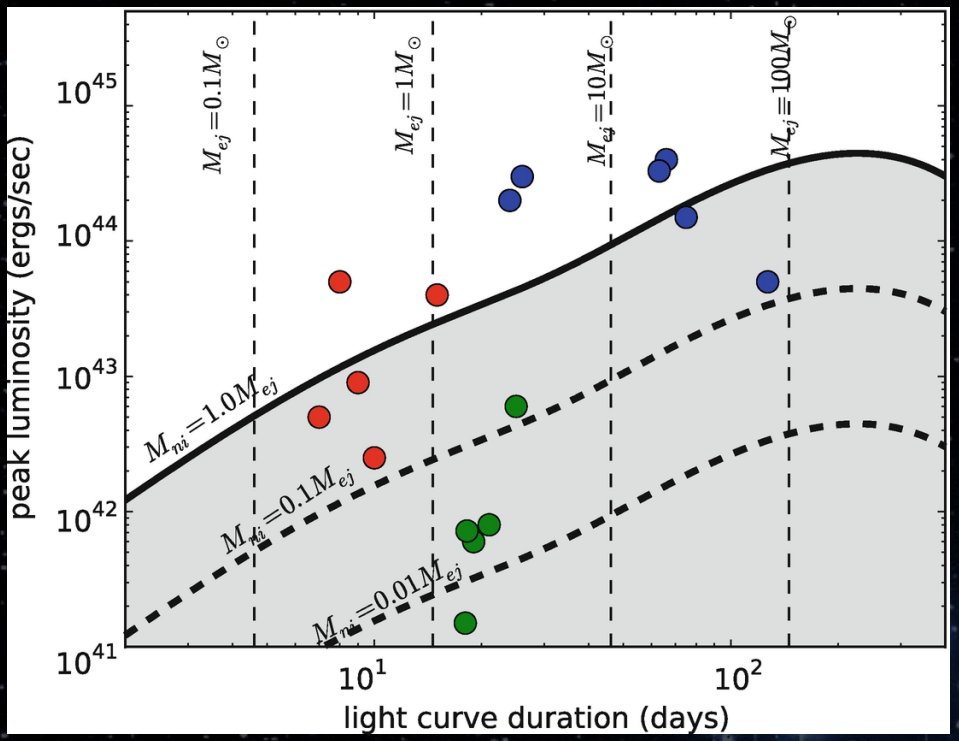

Kasen (2017)

Short timescales make it likely that a power source other than ^{56}Ni contributes

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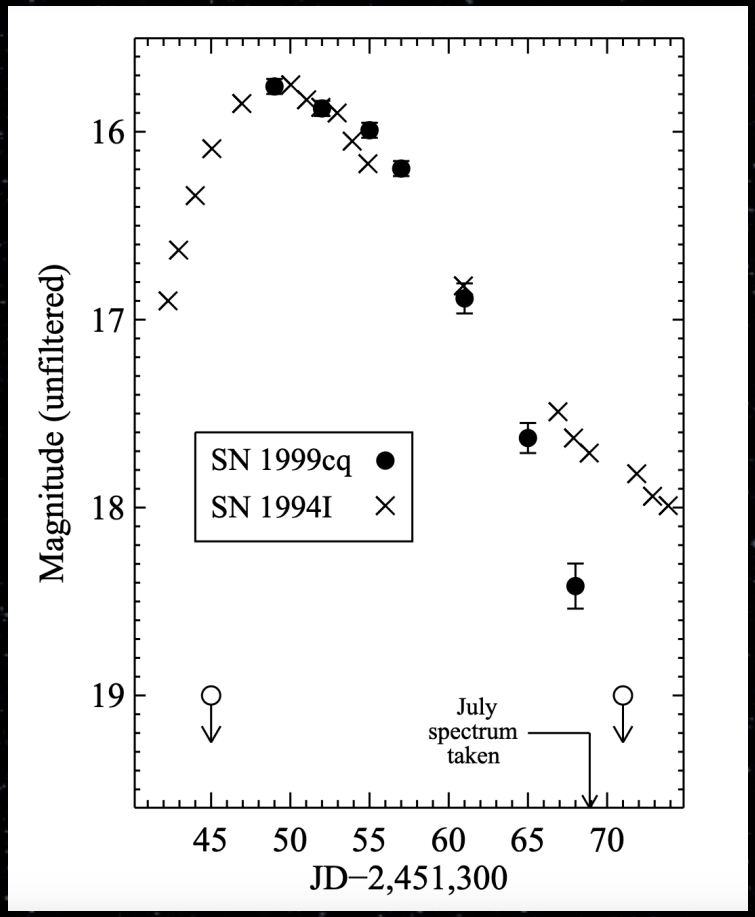
It was has retroactively been applied to transients with timescales shorter than "typical SN"

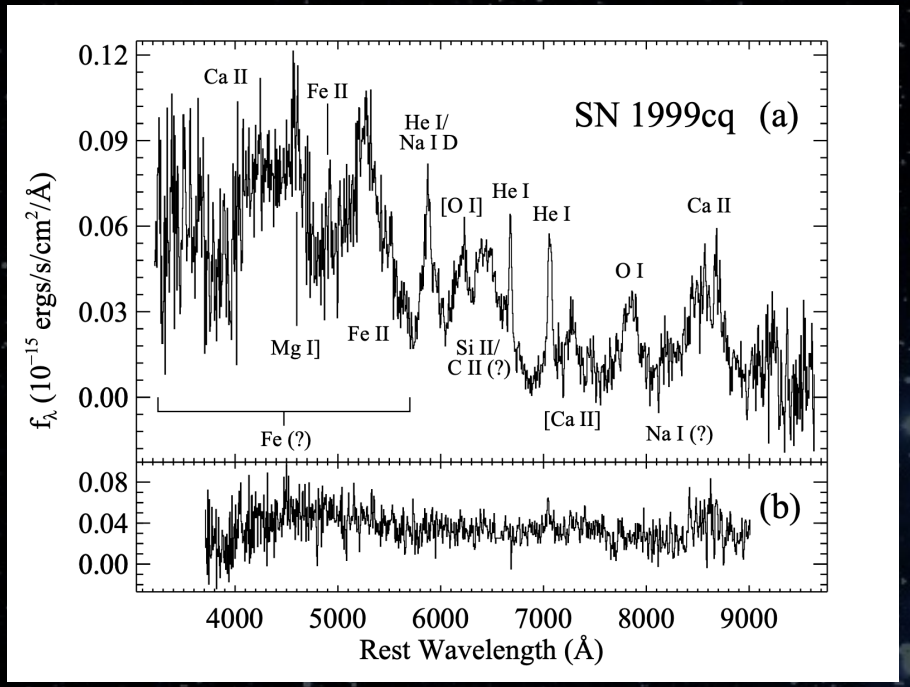
Likely encompasses multiple types of progenitors/explosions

The Observed Landscape of FBOTs

Examples have been known for 25+ years

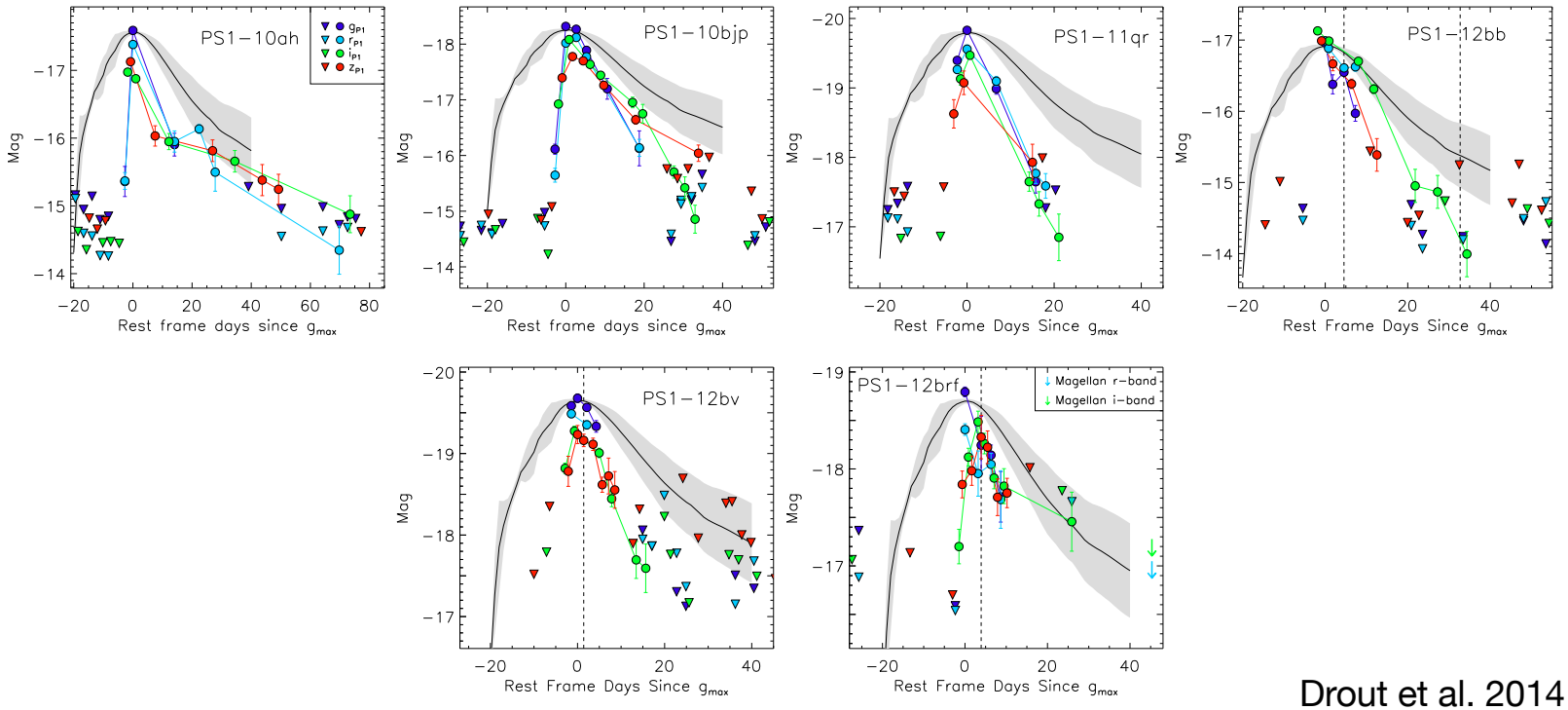


SN1999cq (Matheson+2000) was a rapid and luminosity transient with narrow HeI lines in its spectrum (Type Ibn)



The Observed Landscape of FBOTs

Wide-Field Surveys of the 2010s Grew Numbers



Drout et al. 2014

Systematic searches conducted in: PanSTARRS (Drout+2014), SNLS (Arcavi+2016), Subaru HSC (Tanaka+2016, Tampo+2020), DES (Pursiainen+2018), ZTF (Ho+2023), etc.

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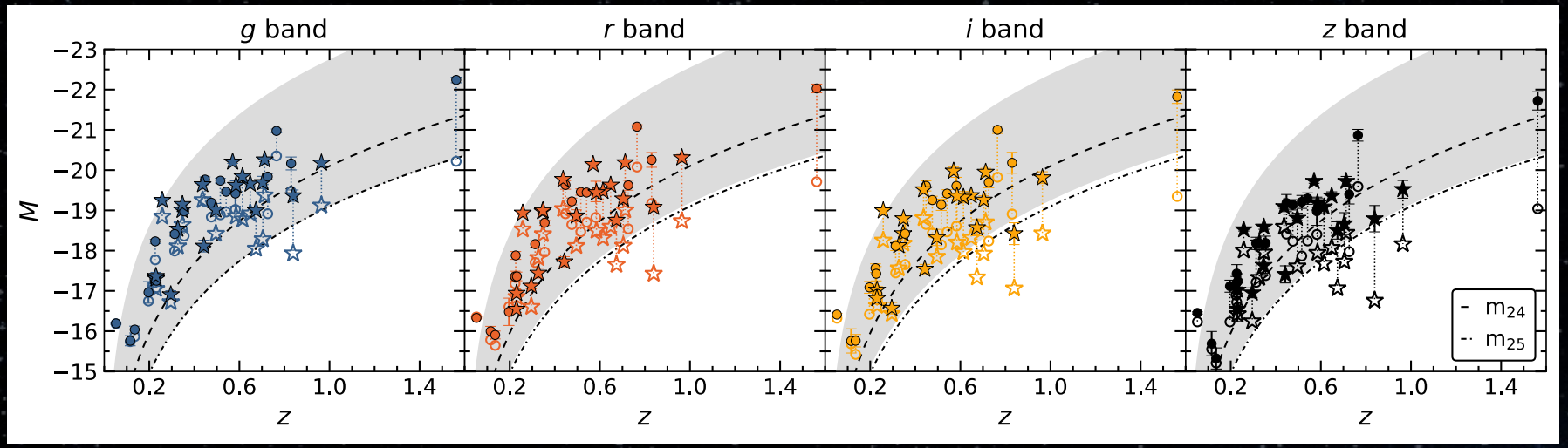

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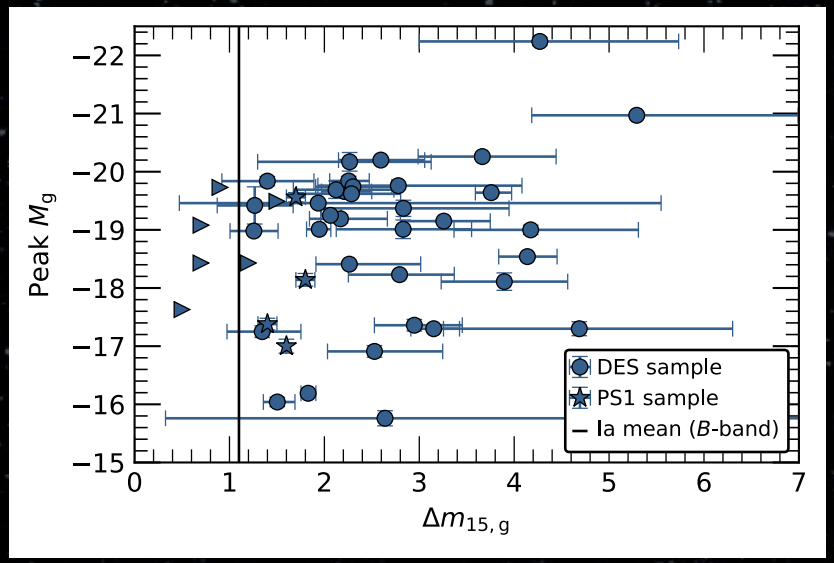

Pursiainen+2018

Key Takeaways:

Objects Span the Entire Luminosity Range of Supernovae

The Observed Landscape of FBOTs

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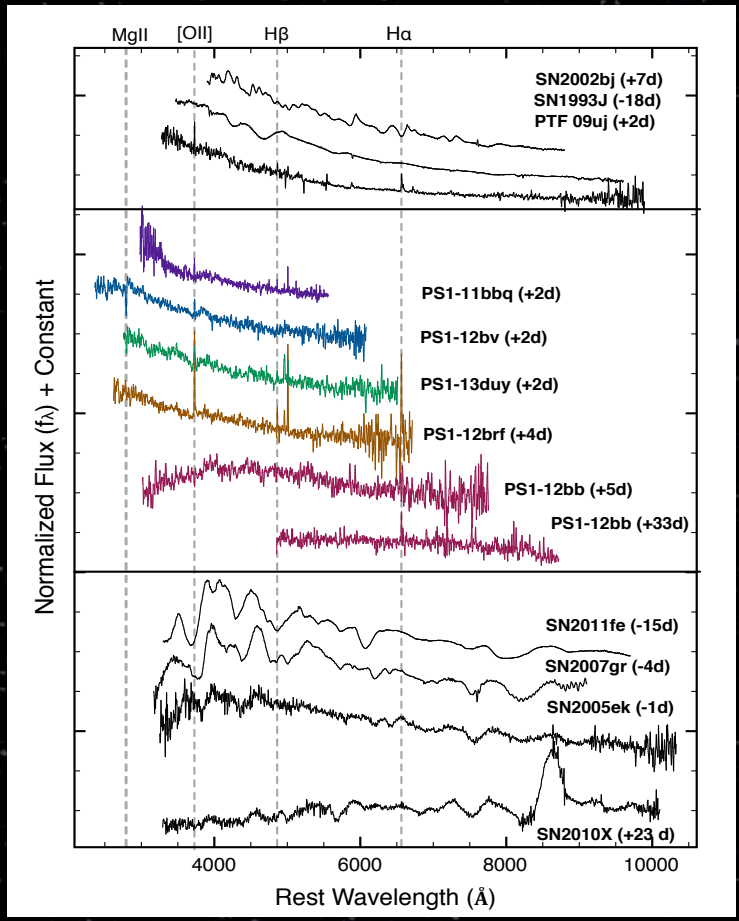

Drout+2014

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Many (but not all) showed featureless/blue spectra at maximum and expanding/cooling photospheres

The Observed Landscape of FBOTs

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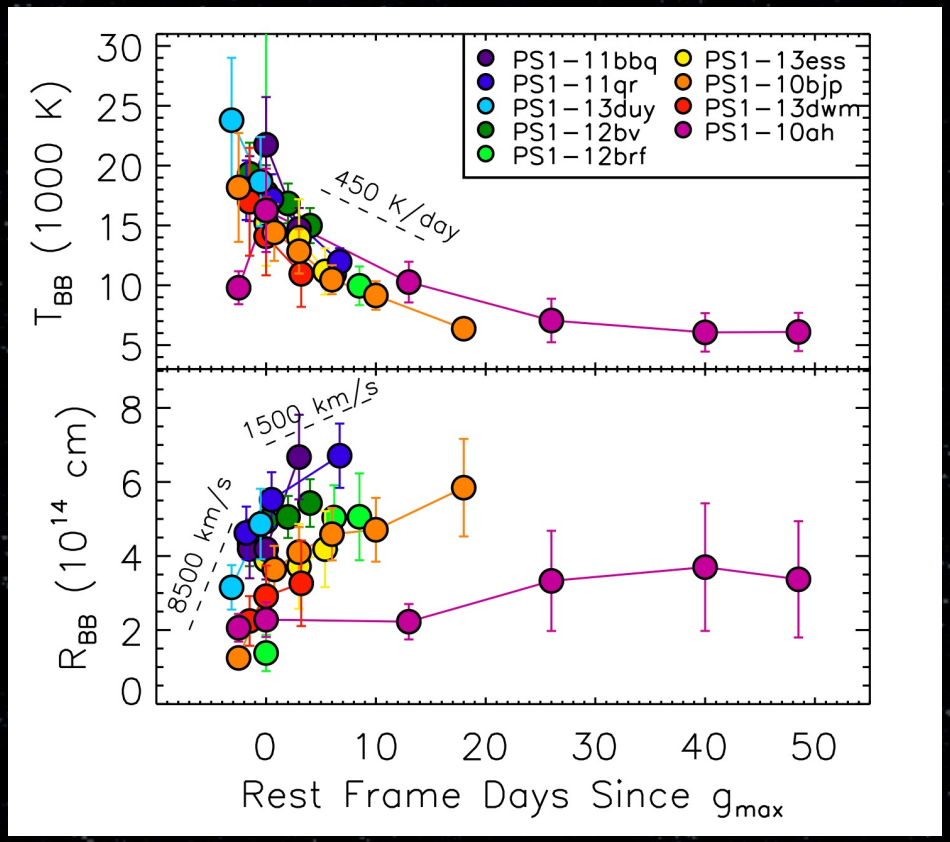

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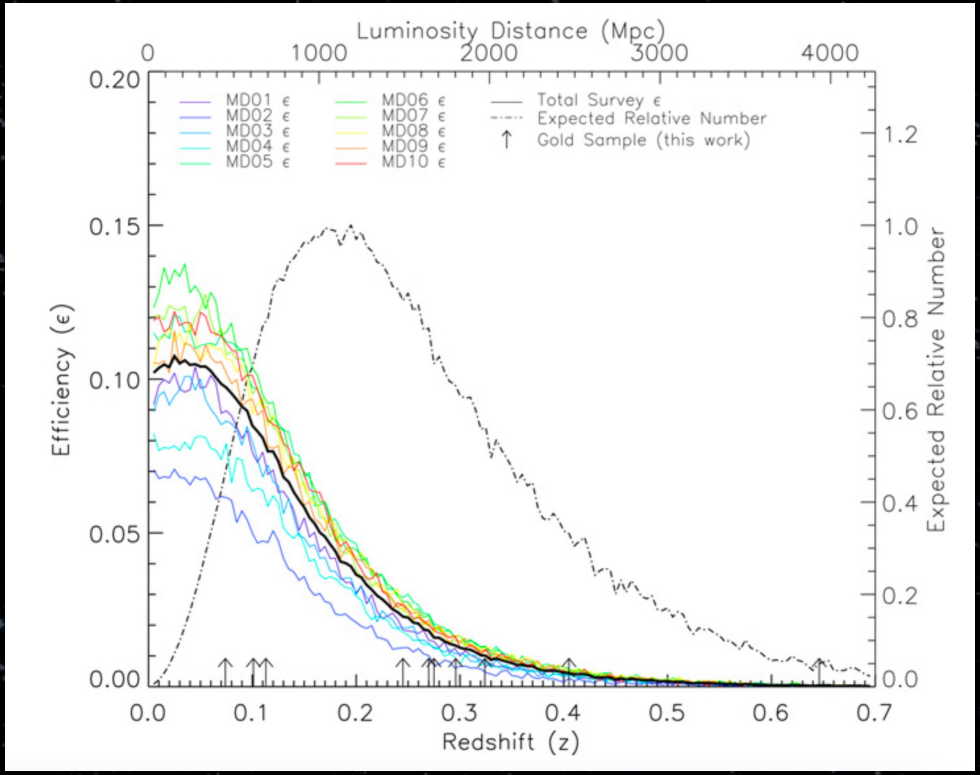

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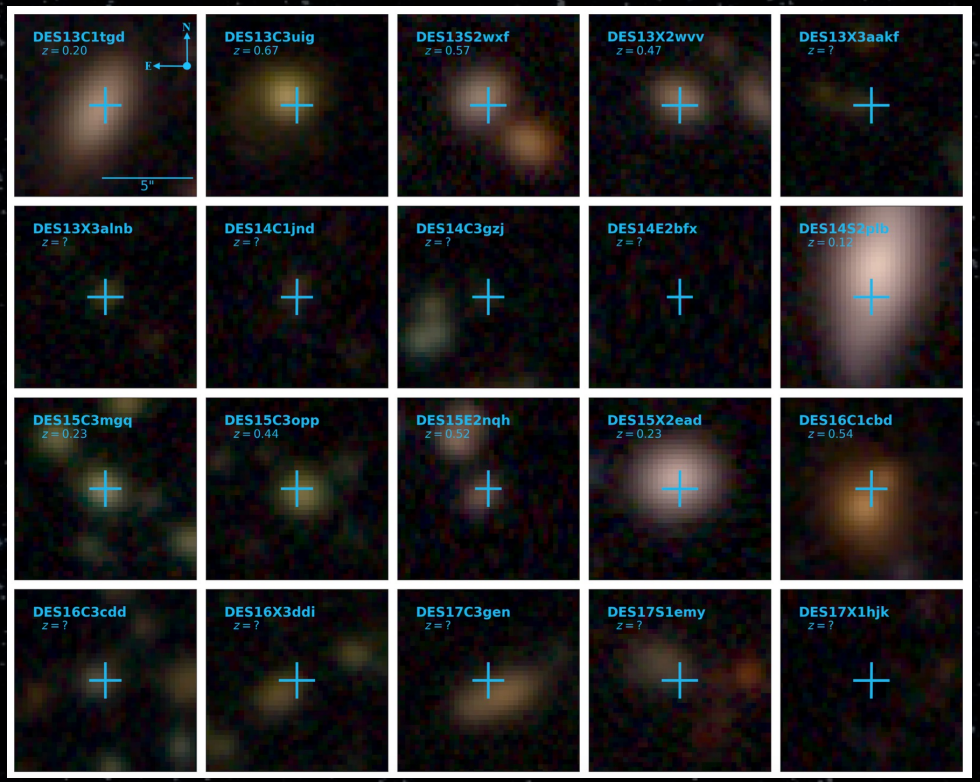

Wiseman+2020

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Host galaxies are star forming

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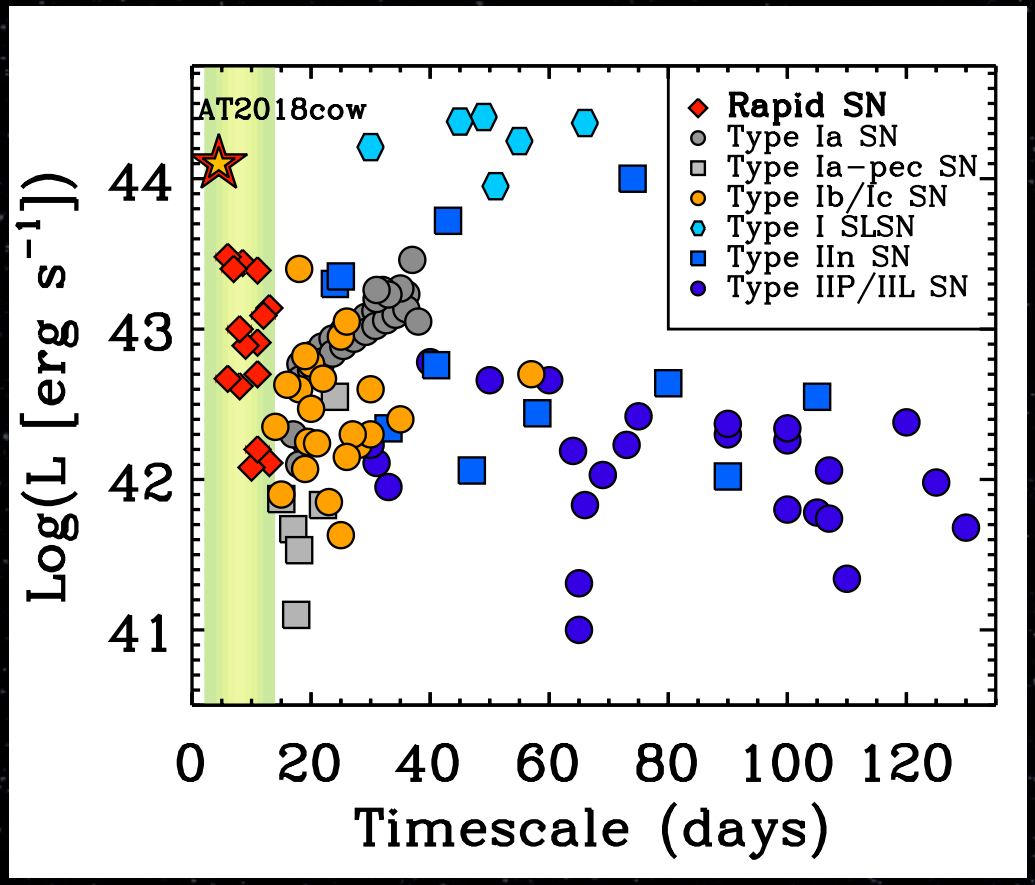

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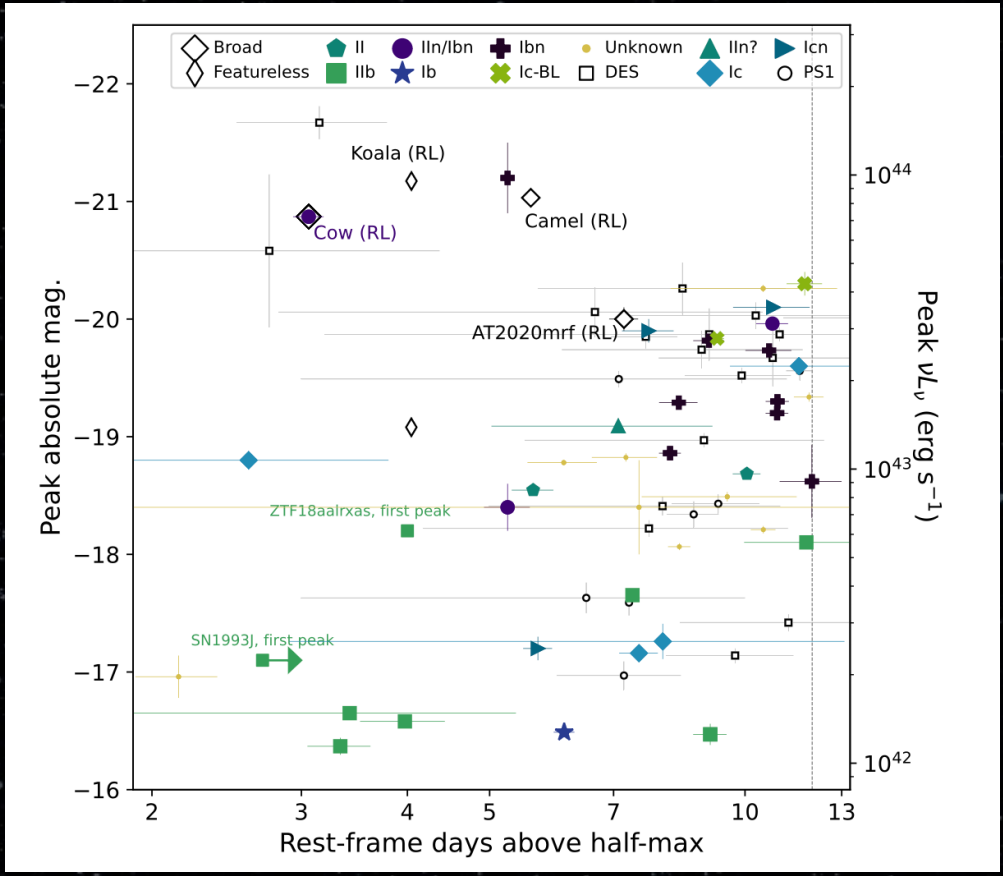

Ho et al. (2023)

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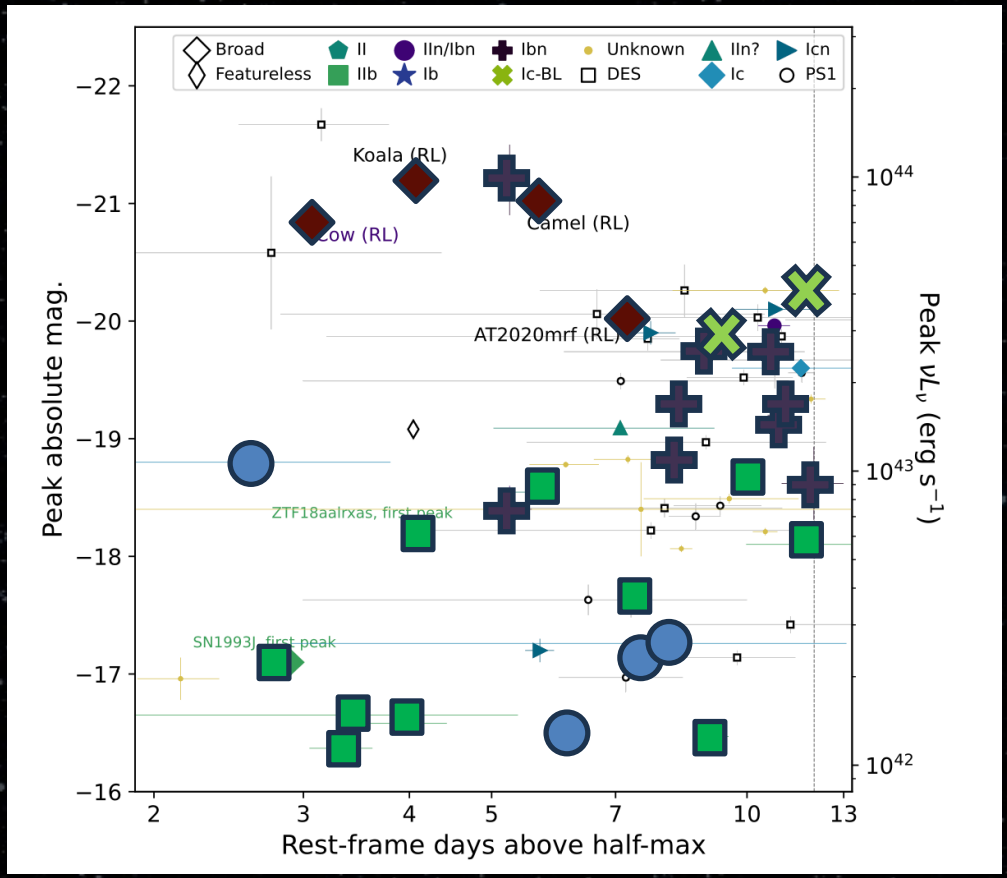

Ho et al. (2023)

- Luminous FBOTs
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- Various Core-collapse SN
- Fast and Faint Type I Supernovae

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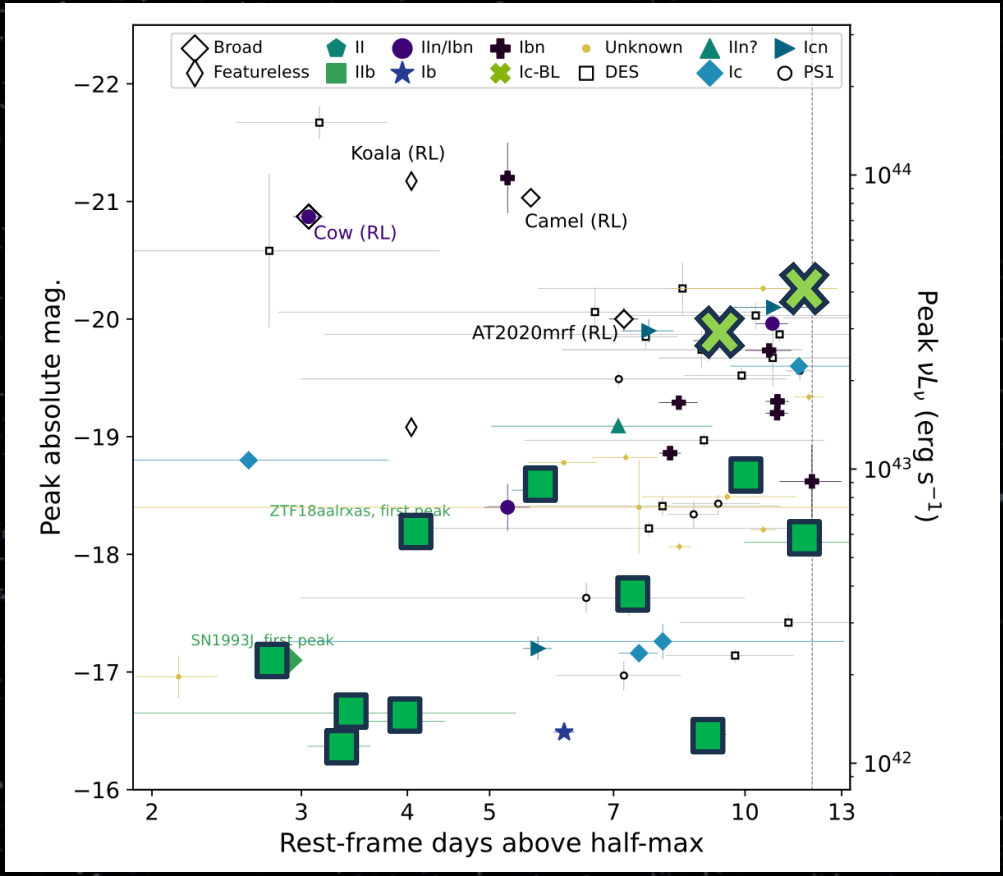

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Various Core-collapse SN

The Observed Landscape of FBOTs

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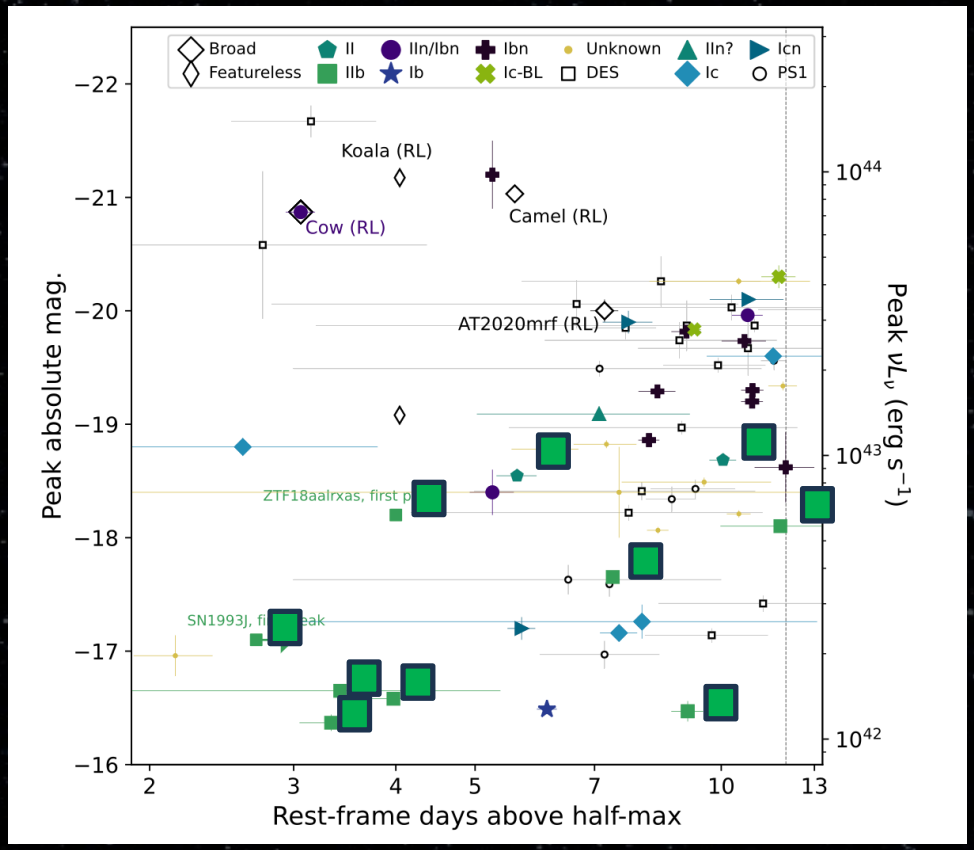

At lower luminosities, many have been classified as Type IIb

Ho et al. (2023)

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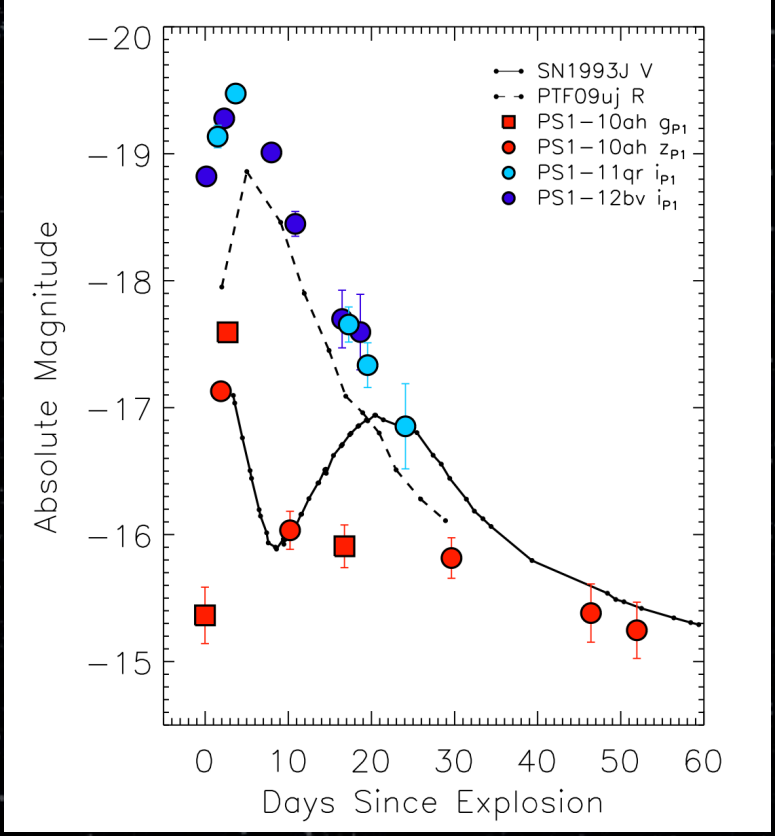

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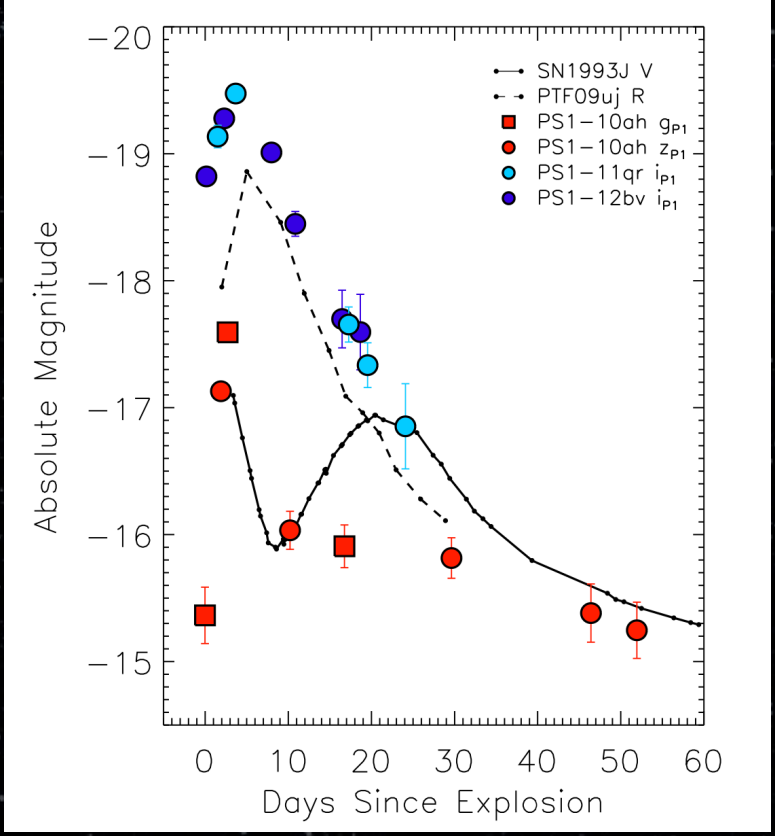

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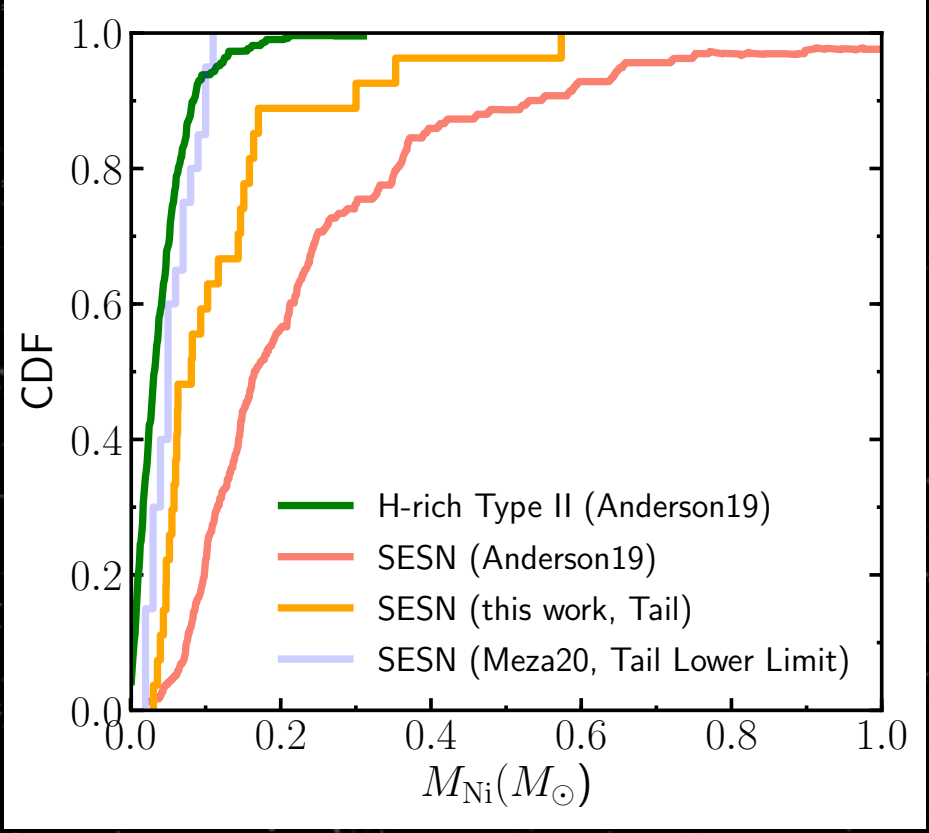

Afsariardchi et al. (2021)

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Upper limits of 0.02-0.03 Msun are lower than most SESN, but consistent with ~30% of Type II

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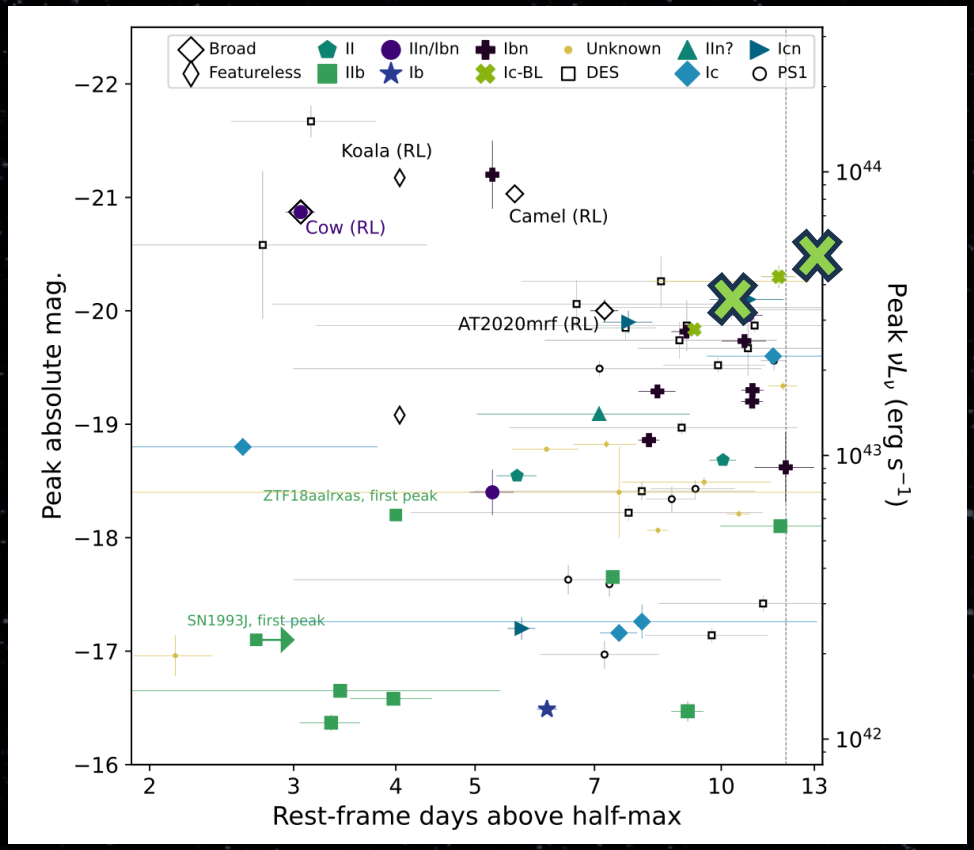

Ho et al. (2023)

At lower luminosities, a number of Type Ic-BL have now been identified (e.g. Whitesides+2017, Ho+2019)

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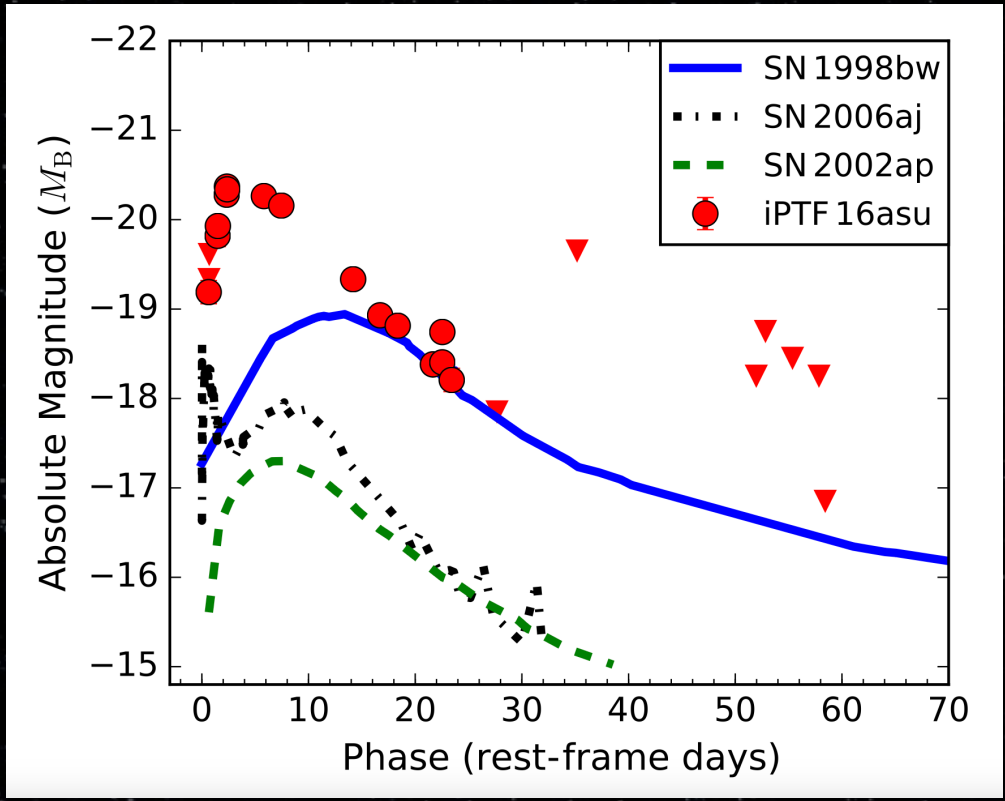

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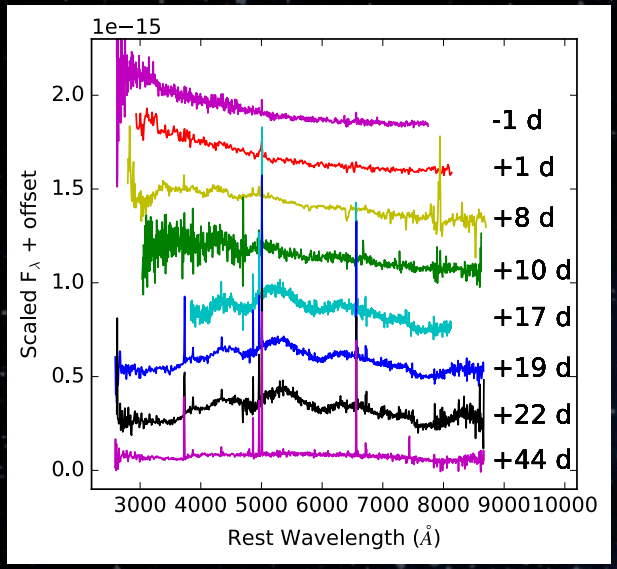

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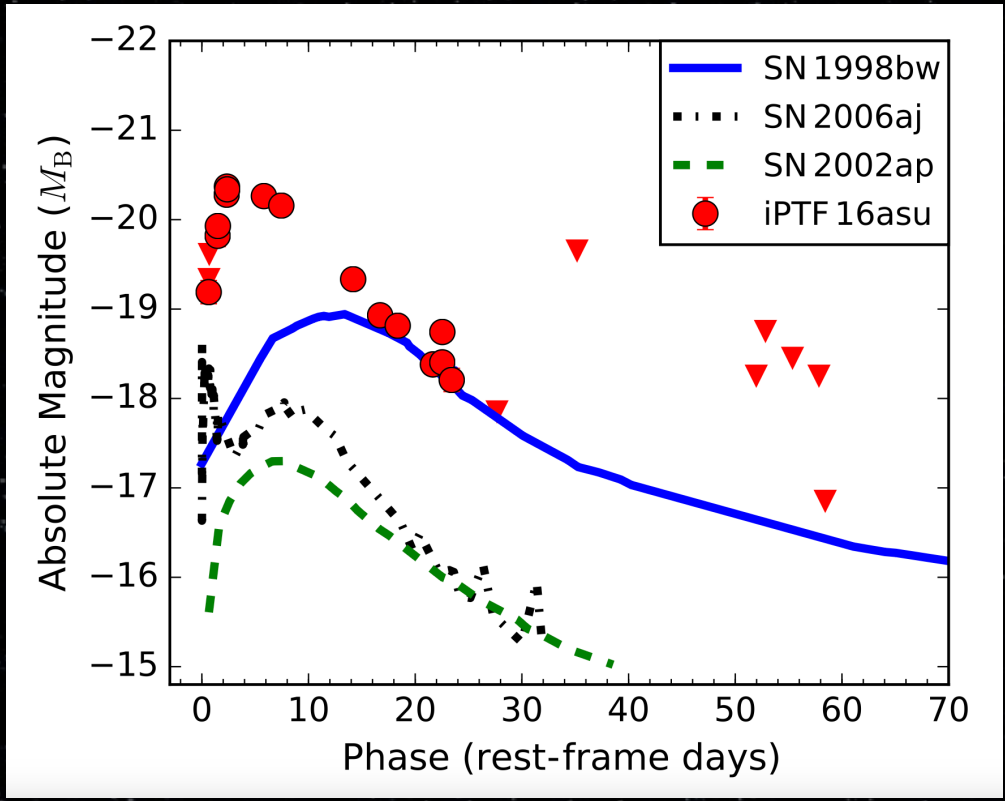

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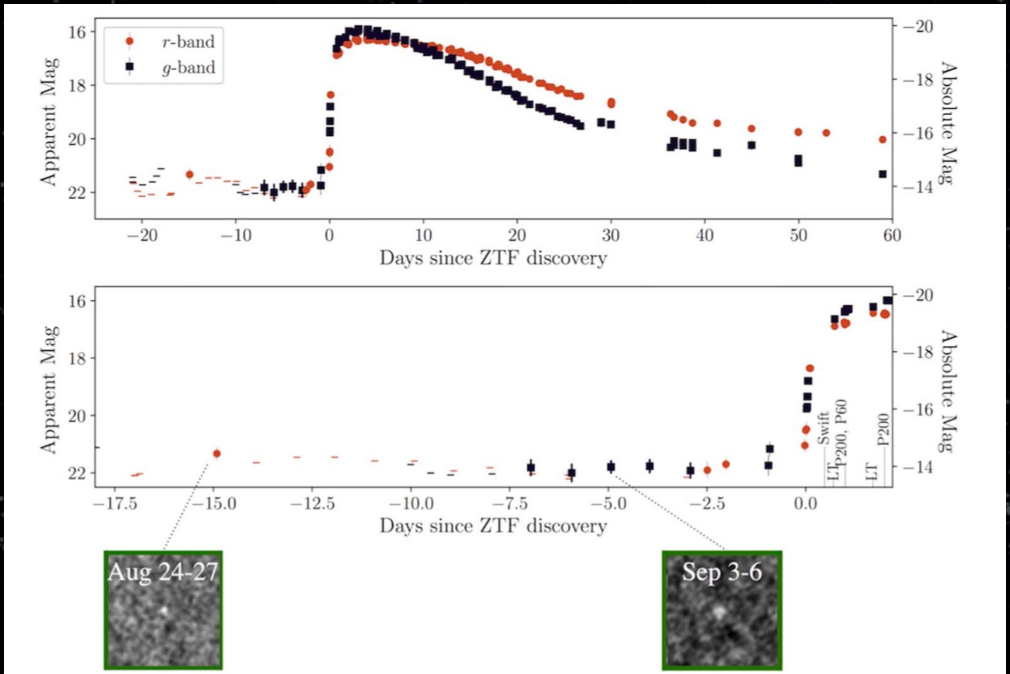

Figure 7. Full r and g-band light curves of SN2018gep. Horizontal lines show 3σ upper limits. Points at $t < 0$ are from 3 days stacks of ZTF/P48 data as described in Section 2.4. Sample subtractions from two of these stacks are shown in the bottom row.

Ho+2019

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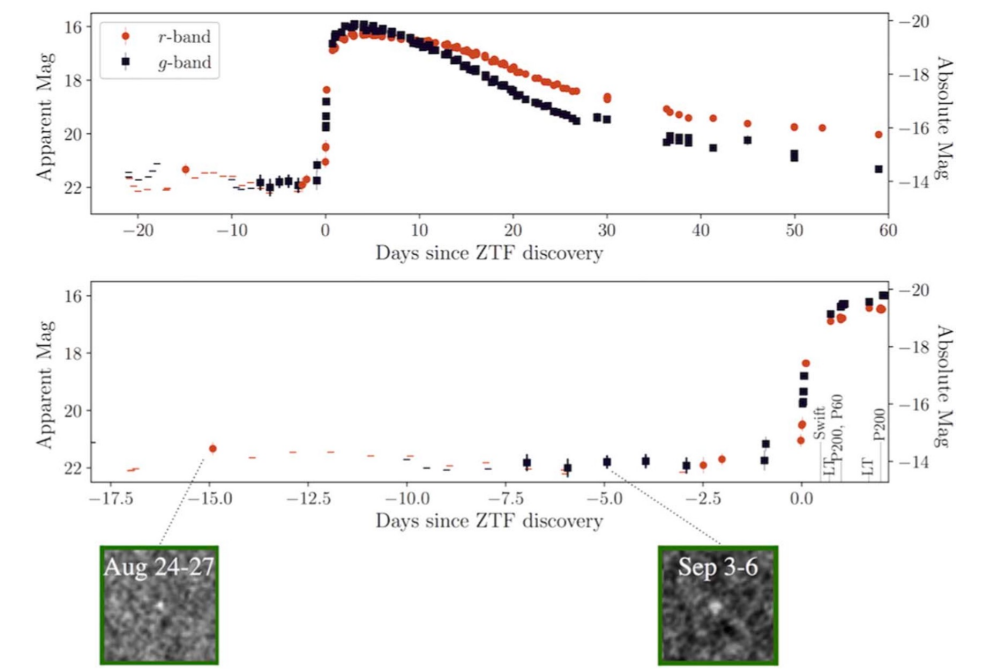

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Key Open Question: what causes the pre-explosion eruption/ejection?

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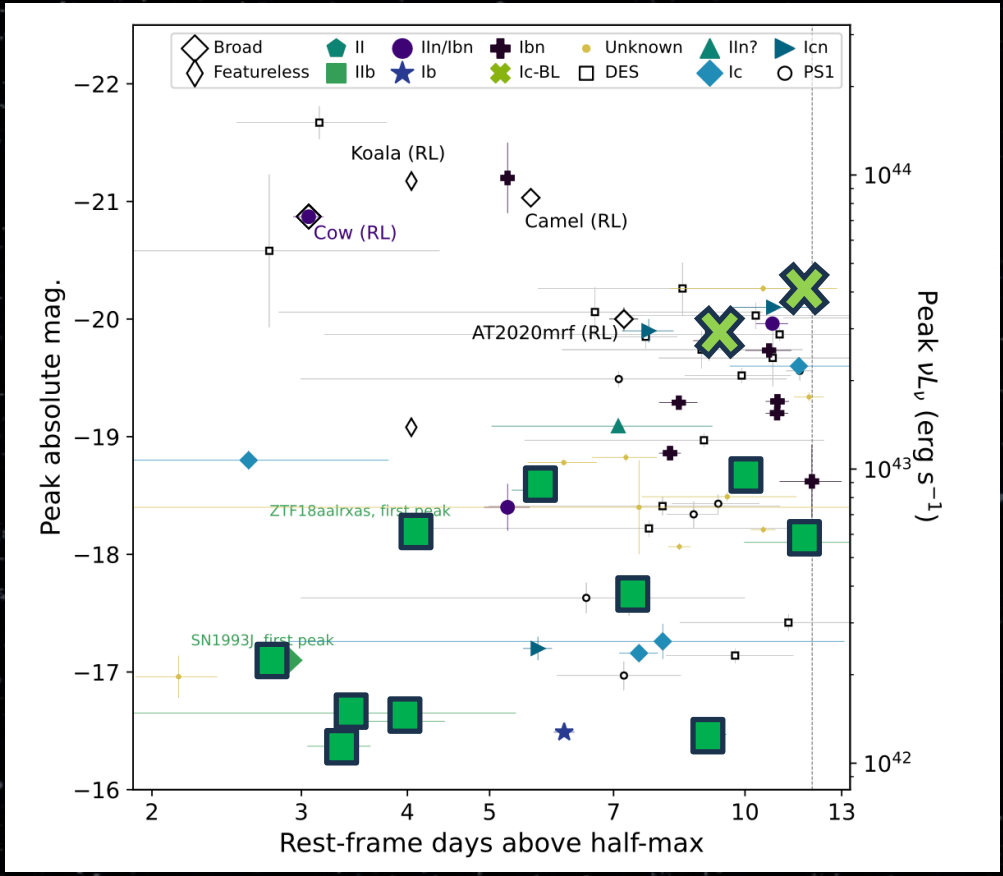

Ho et al. (2023)

Various Core-collapse SN

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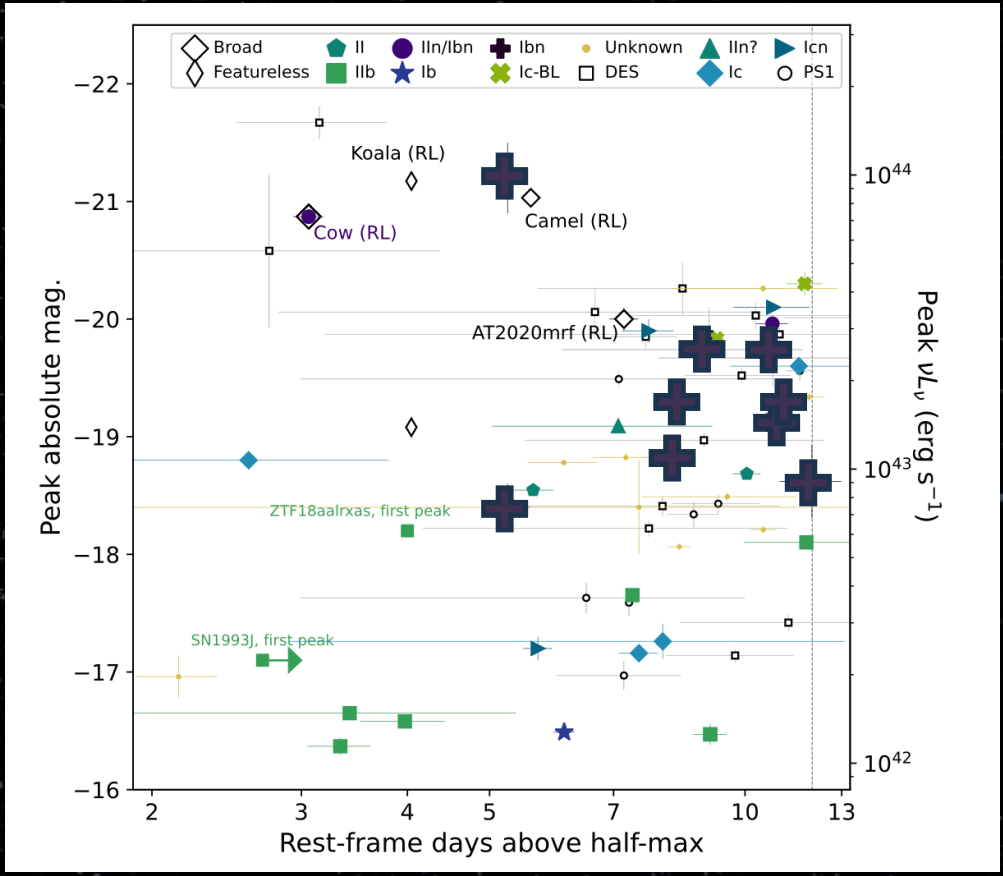
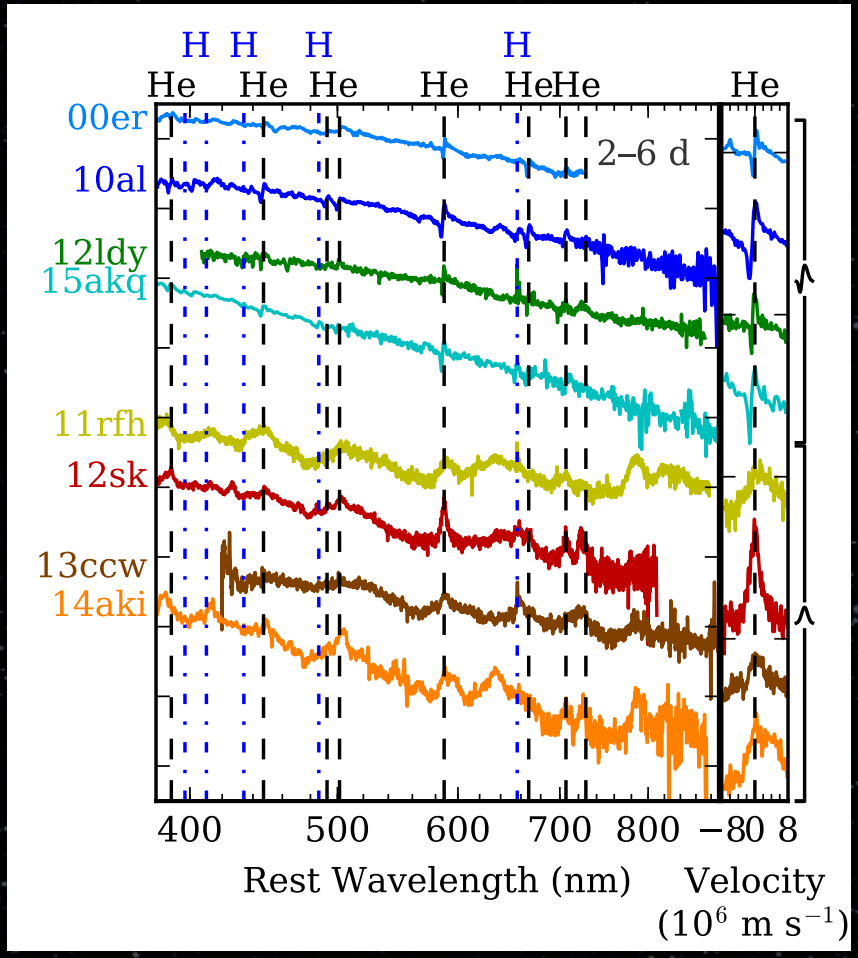


Type Ibn Supernovae

Ho et al. (2023)

The Observed Landscape of FBOTs

There is significant overlap between FBOTs and Type Ibn SN



Explosions with narrow HeI lines indicative of a blastwave interacting with He-rich (H-poor) circumstellar material

Hosseinzadeh et al. (2017)

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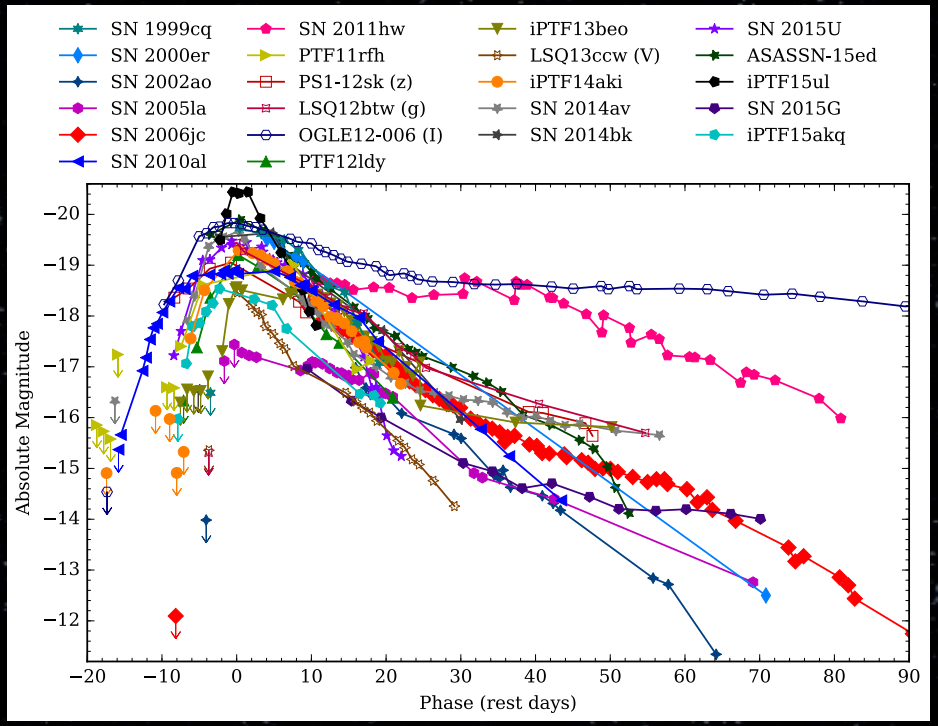

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Light curves are actually remarkably homogeneous (compared to Type IIn)

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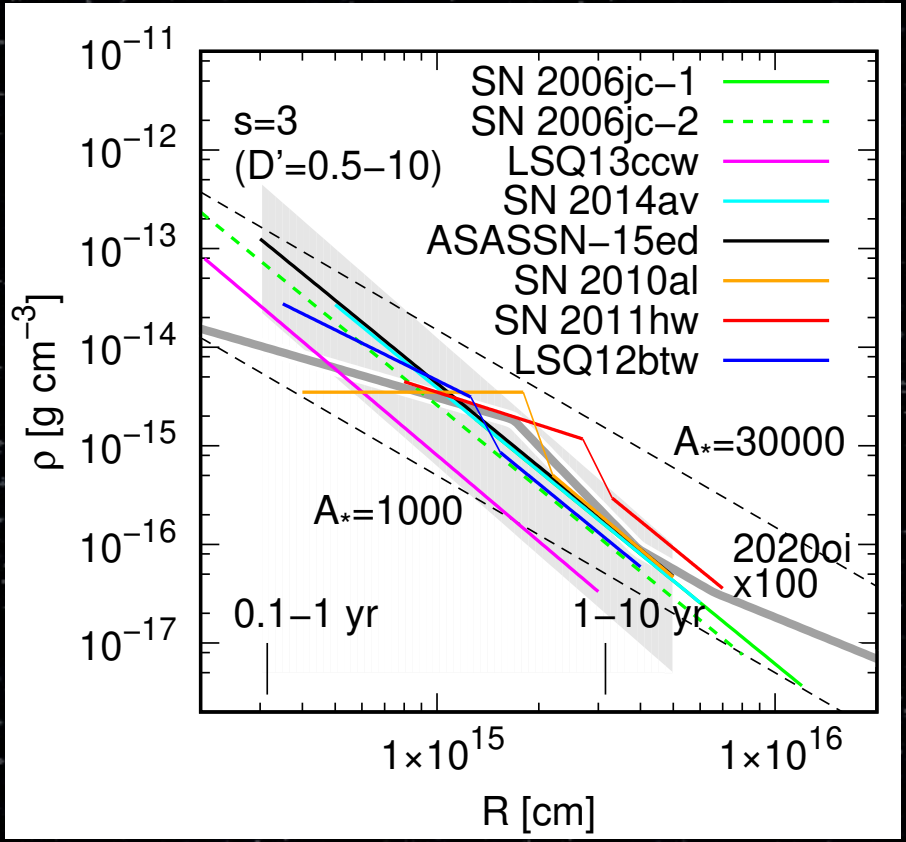

Maeda & Moriya (2022)

Explosions with narrow HeI lines indicative of a blastwave interacting with He-rich (H-poor) circumstellar material

Light curves are actually remarkably homogeneous (compared to Type IIn)

Typical CSM modelling implies ~0.1 Msun of He-rich material close to the progenitor star.

The Observed Landscape of FBOTs

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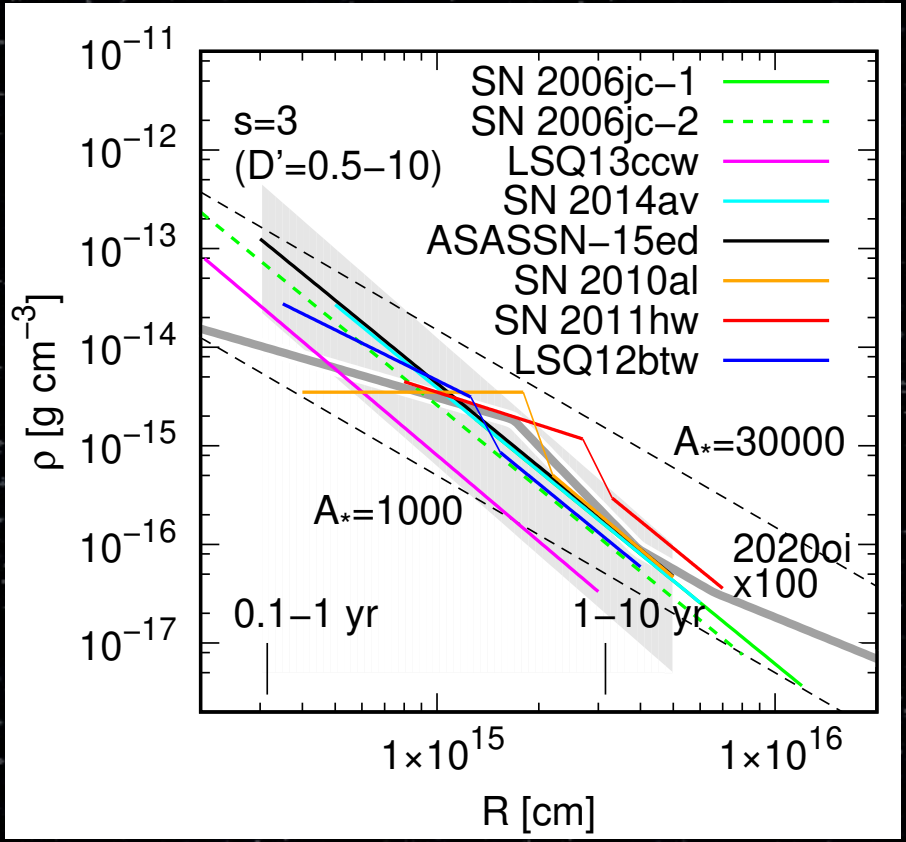

Maeda & Moriya (2022)

Key Open Question: what is the nature of the hydrogen poor progenitors?

Key Open Question: what is the mechanism by which this mass is ejected shortly before explosion?

The Observed Landscape of FBOTs

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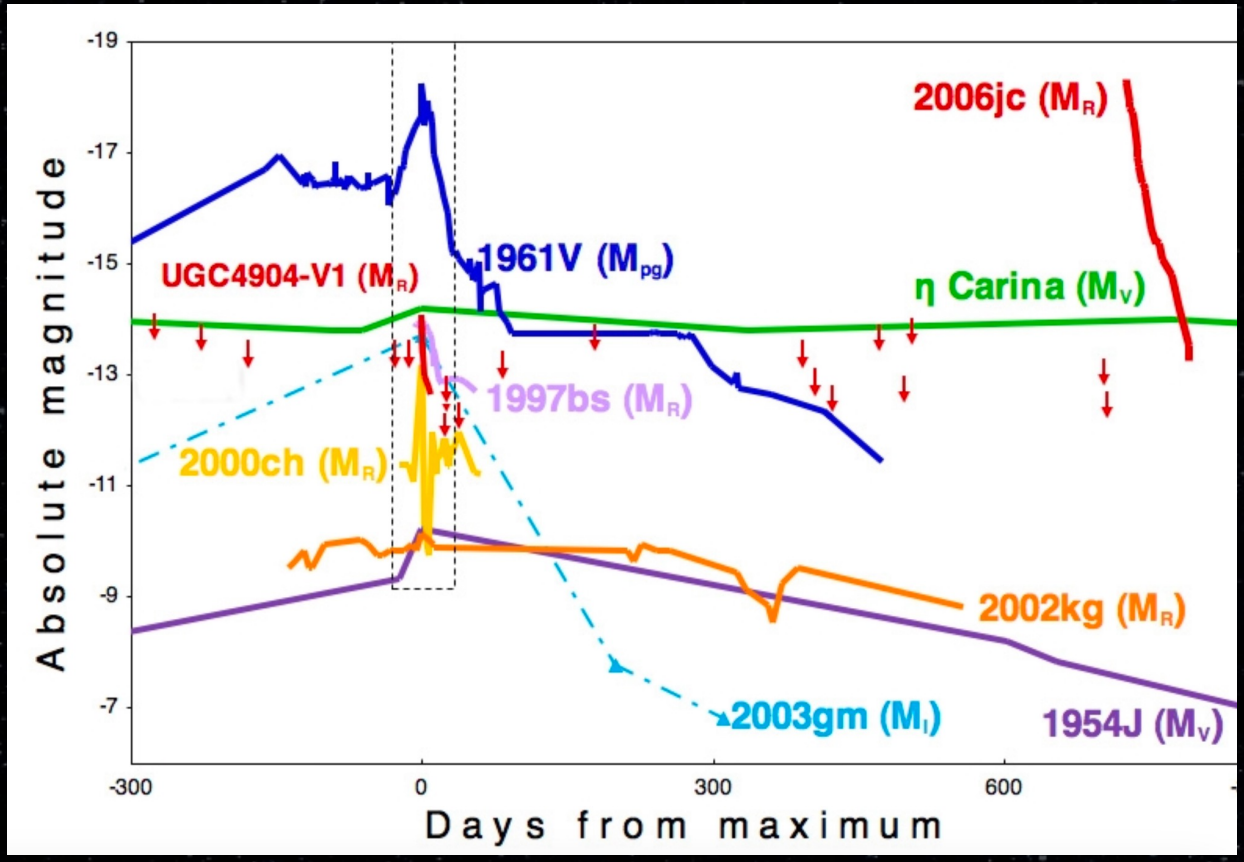

Pastorello et al. (2007)

There have been multiple observations of pre-explosion variability. Timescale of a few hundred days to a few years.

The Observed Landscape of FBOTs

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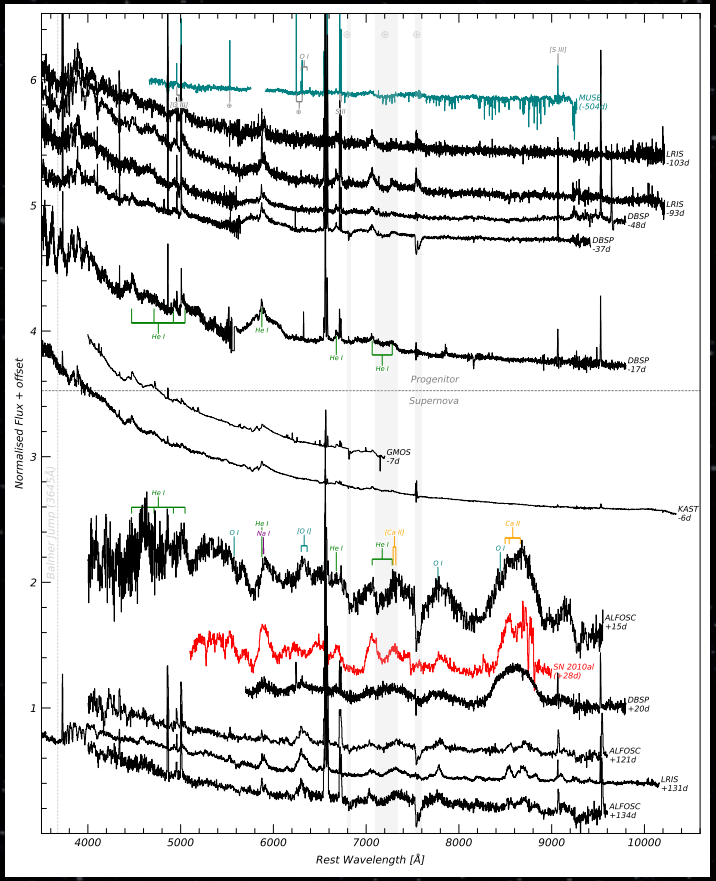

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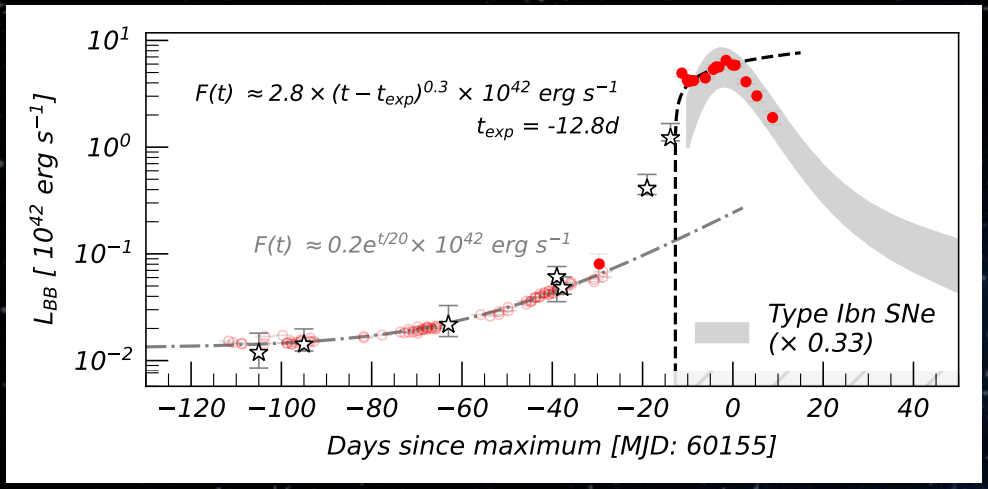

Brennan et al. (2024)

The Observed Landscape of FBOTs

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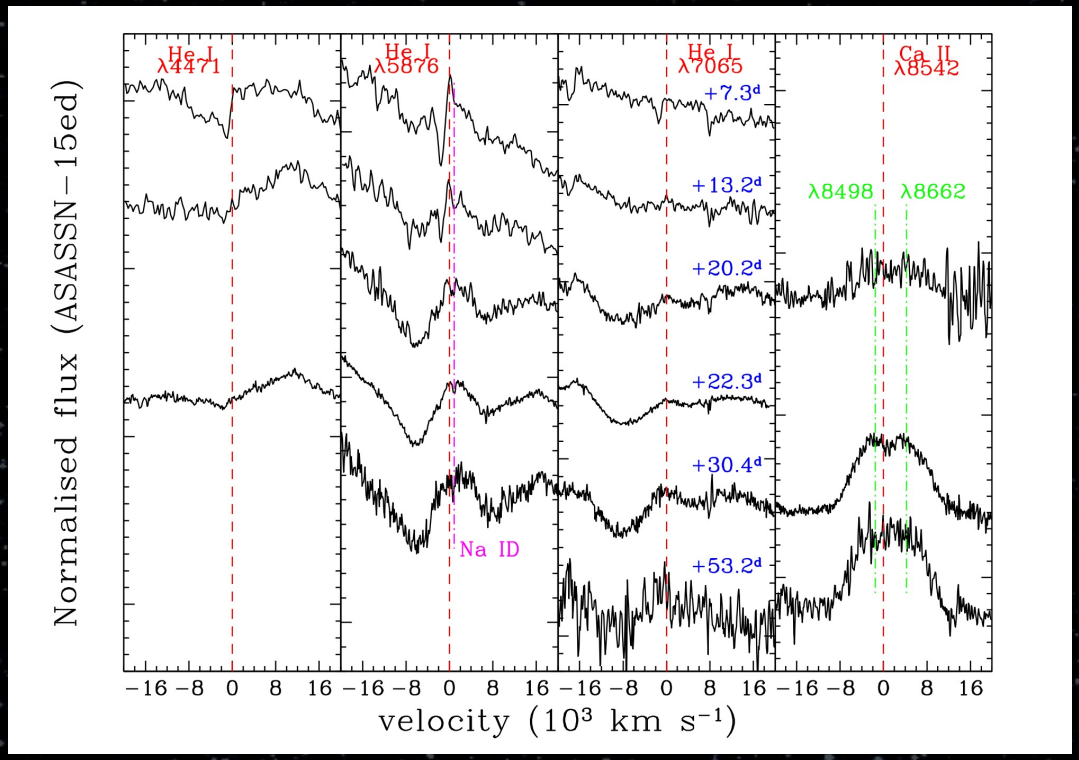

In several cases, broad emission lines have been detected at late times, confirming that they were genuine hydrogen-poor CCSN (e.g. Pastorello+2015, Matherson+2000, Brennan+2024).

Pastorello et al. (2015)

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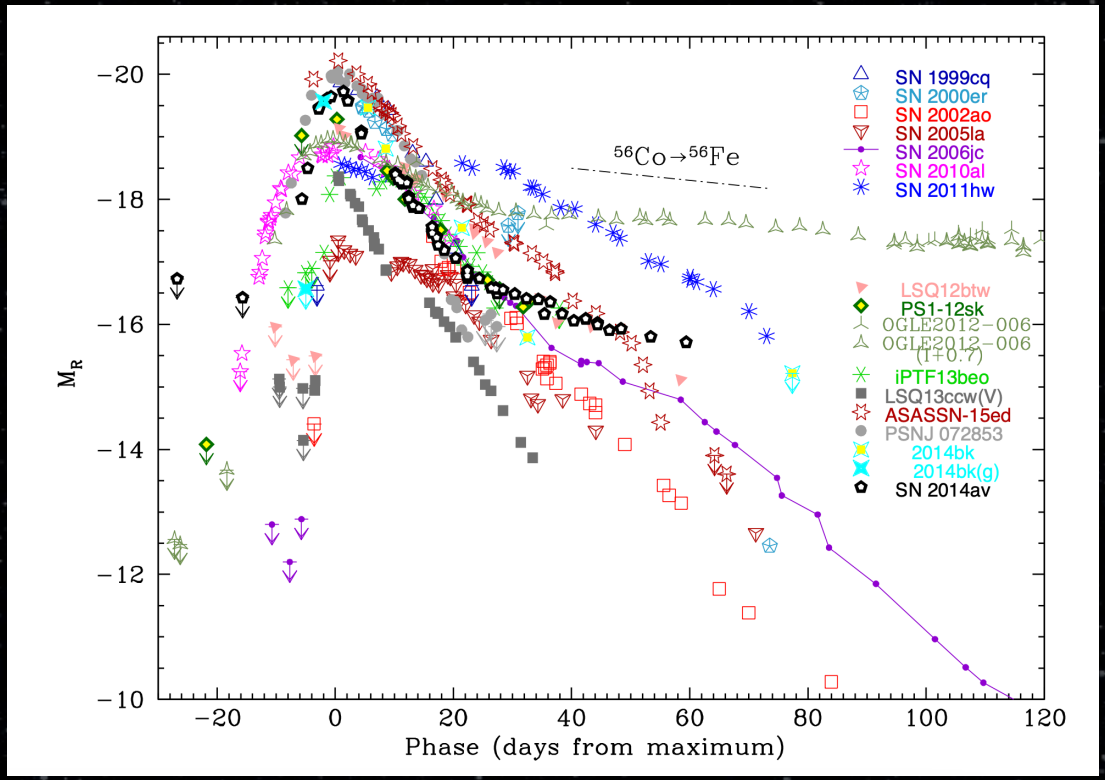

While some show flatter light curves at late-times, which could be interpreted as ~0.1 Msun of 56Ni, for others much deeper limits can be placed.

Pastorello et al. (2015)

The Observed Landscape of FBOTs

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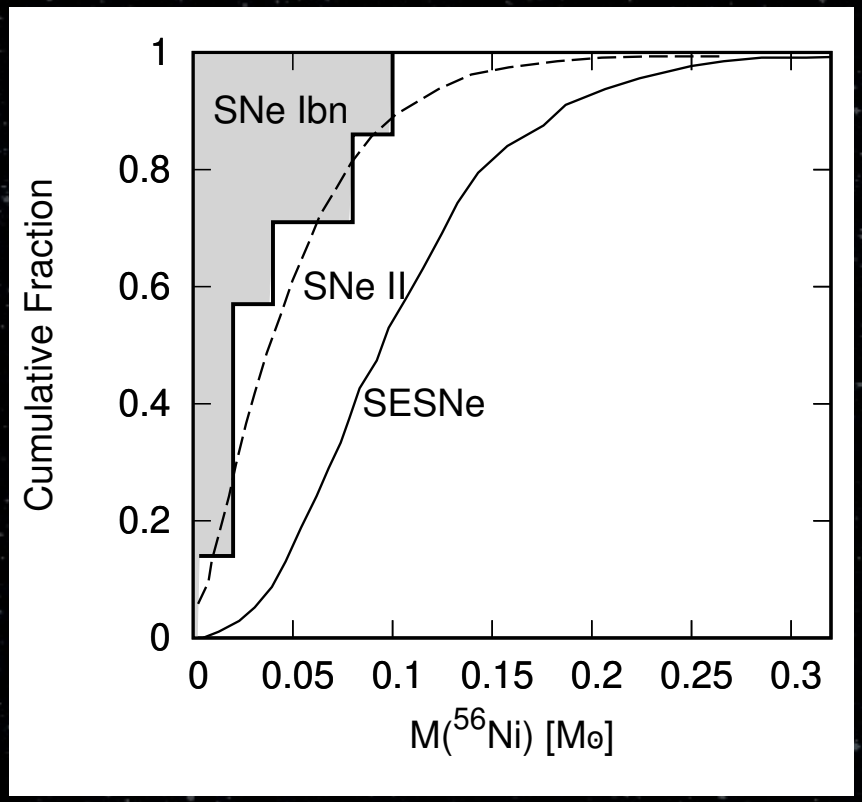
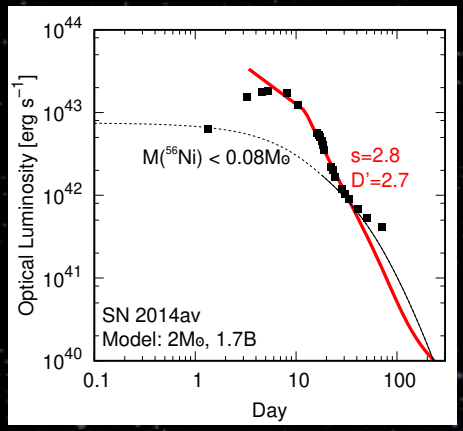
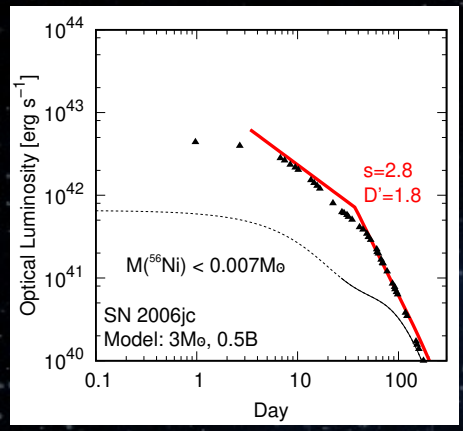


Maeda & Moriya (2022)

While some show flatter light curves at late-times, which could be interpreted as ~0.1 Msun of 56Ni, for others much deeper limits can be placed (e.g. Maeda & Moriya 2022; Chugai 2022).





The Observed Landscape of FBOTs

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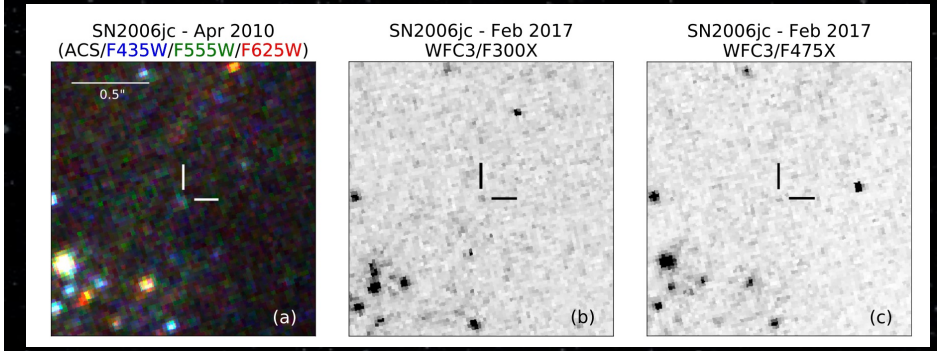
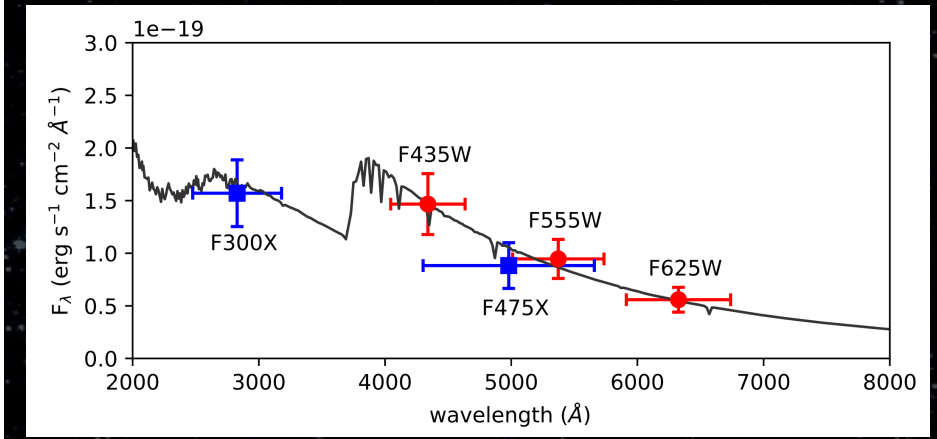
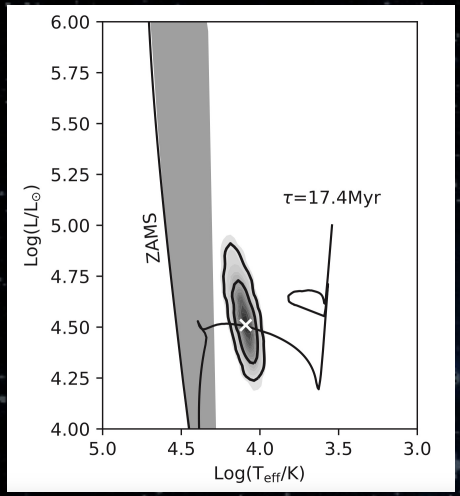


Other Interesting Progenitor Observations

Detection of a candidate binary companion to SN2006jc in post-explosion HST imaging (Maund et al. 2016, Sun et al. 2019)



Sun et al. (2019)



The Observed Landscape of FBOTs

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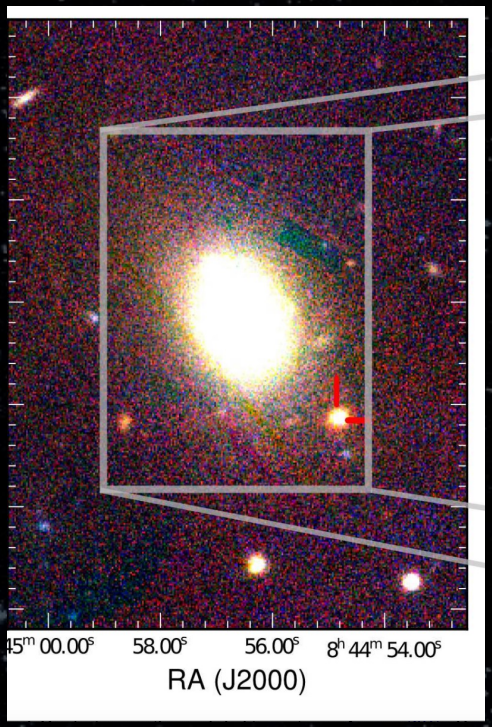
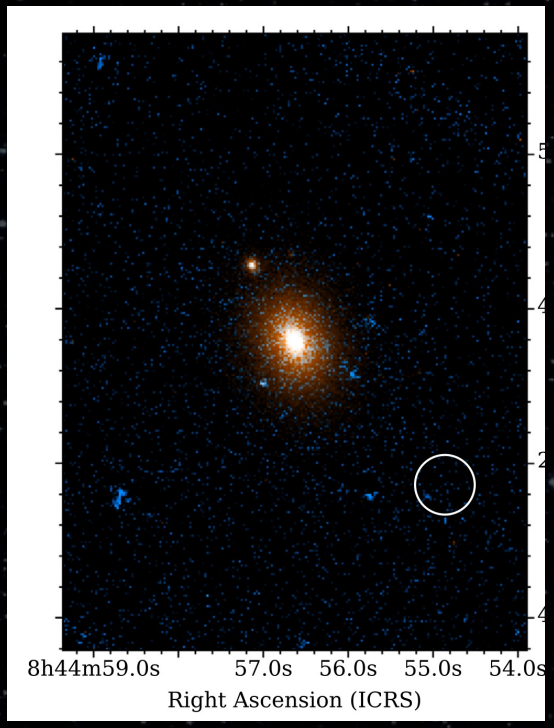


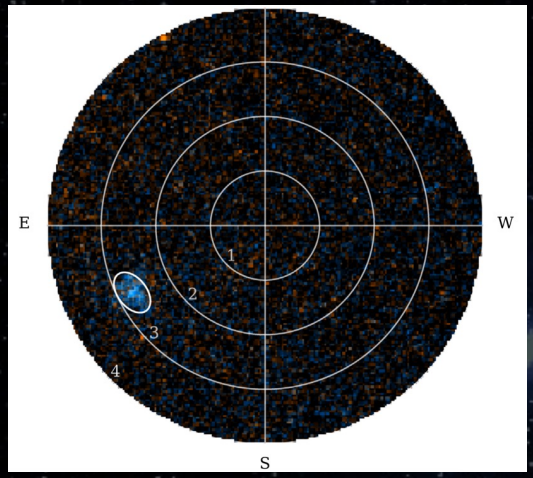
Sanders et al. (2013)



Hosseinzadeh et al. (2019)

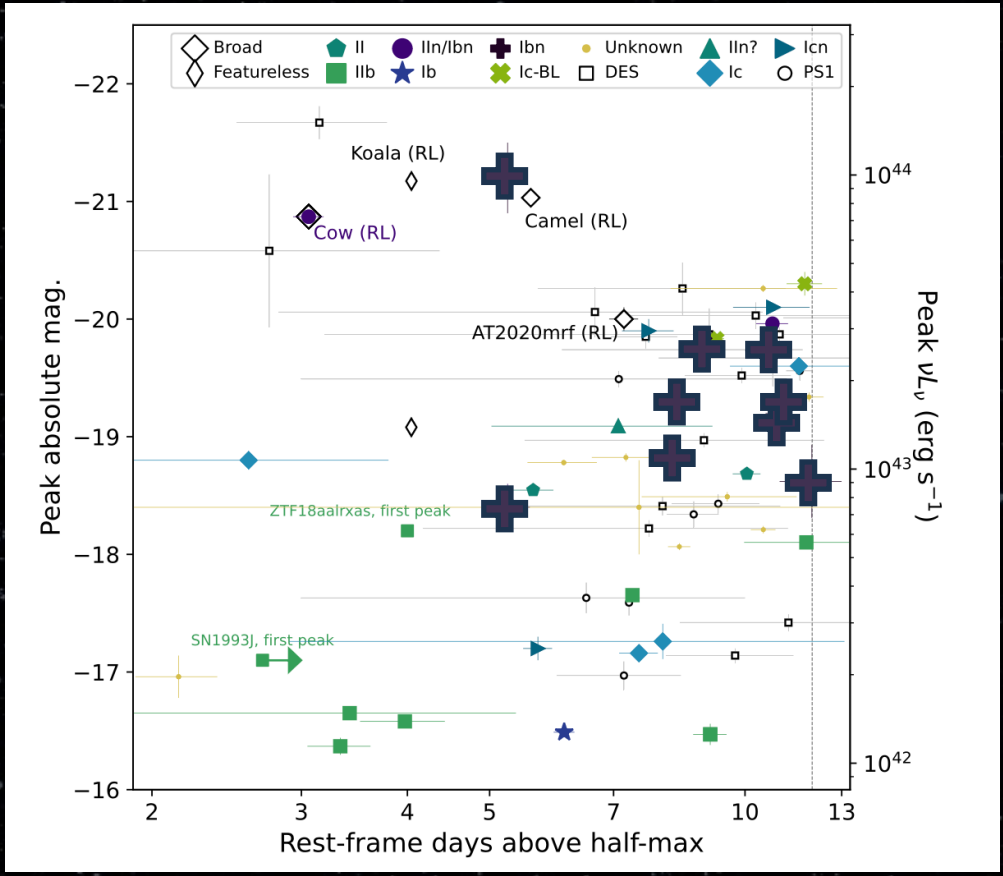
Other Interesting Progenitor Observations

There is an example of a Type Ibn exploding in an elliptical galaxy with no signs of nearby star formation



The Observed Landscape of FBOTs

Let's Sub-divide and Classify!



Type Ibn Supernovae

Ho et al. (2023)

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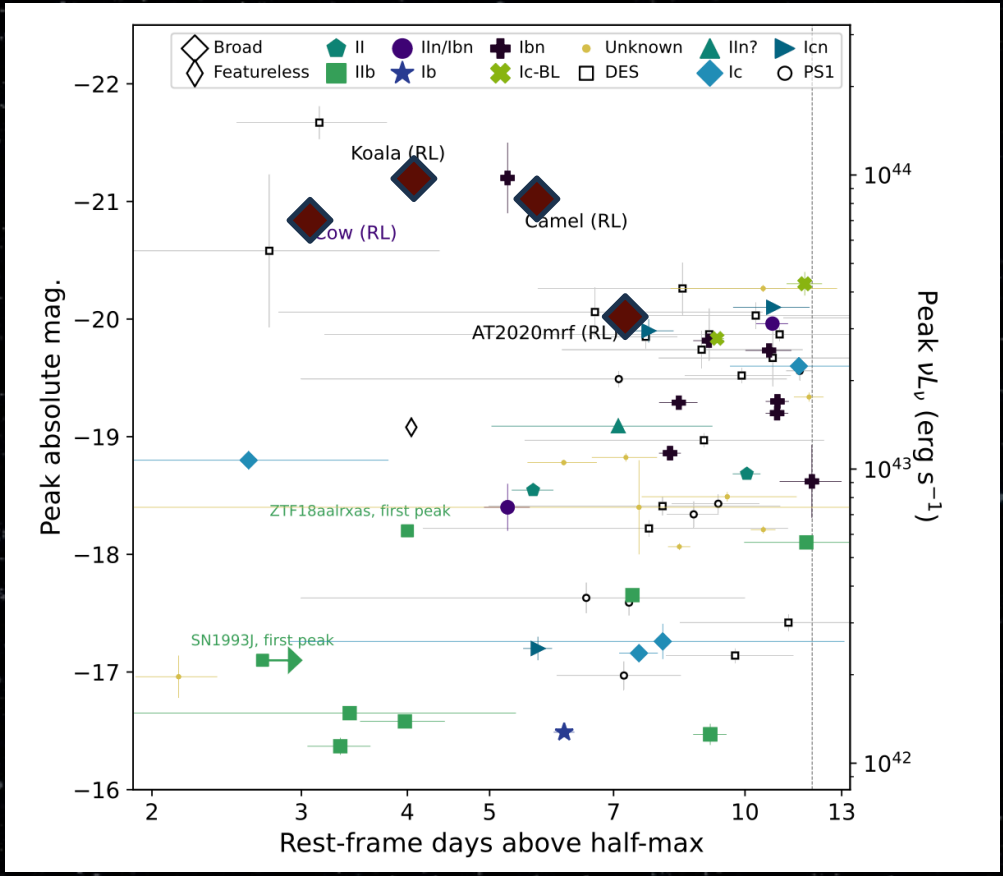
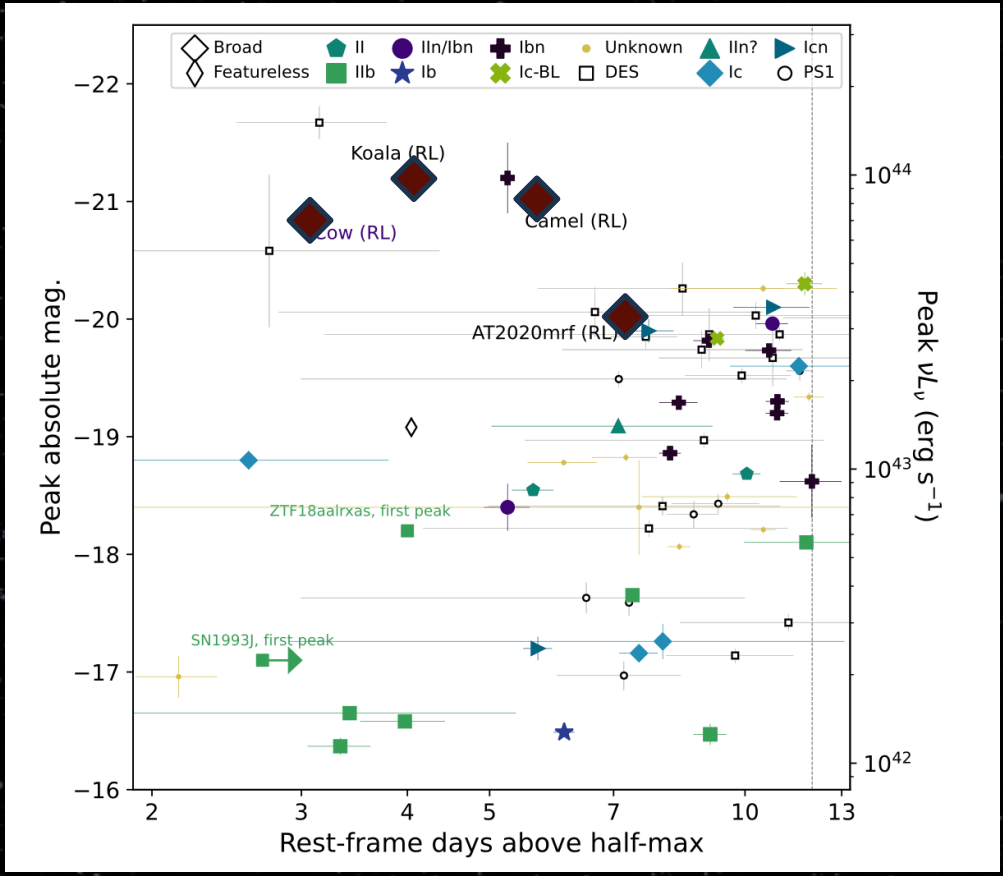


Luminous FBOTs

Ho et al. (2023)

The Observed Landscape of FBOTs

A New Type of Beast Has Emerged at High Luminosity



These are more extreme in both timescale and luminosity

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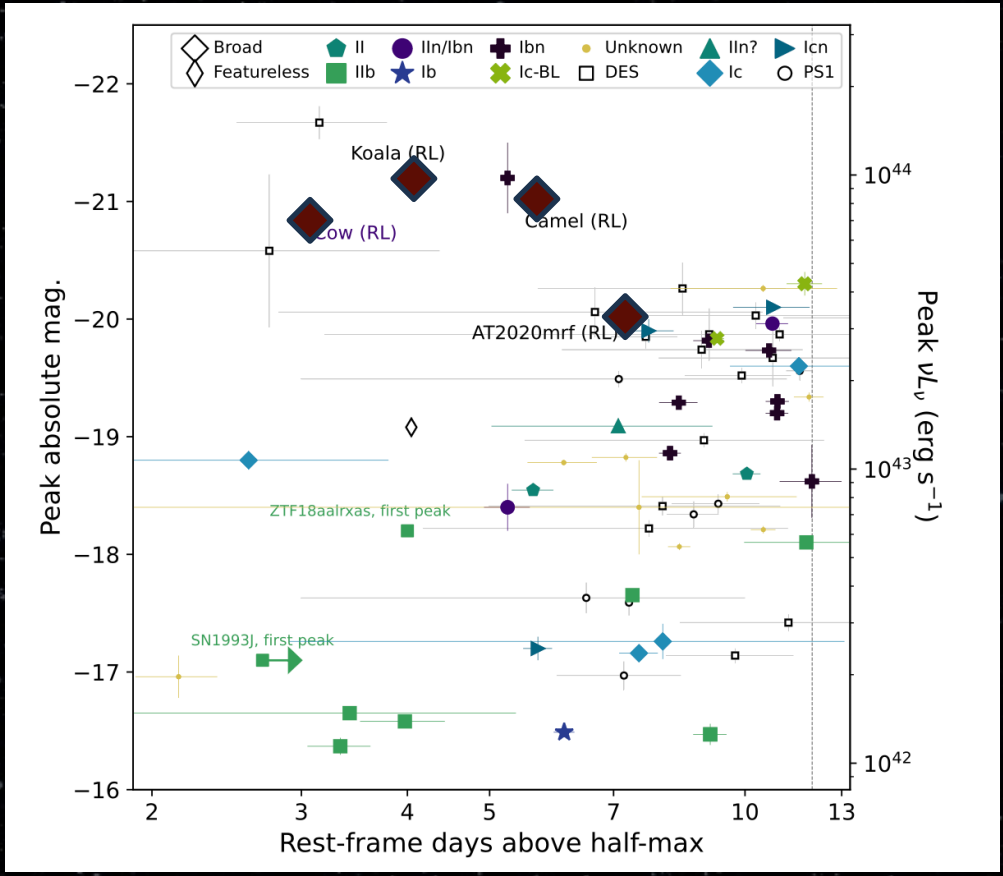

These are more extreme in both timescale and luminosity

They are significantly rarer than FBOTs as a whole (<0.1% of the CCSN rate; Ho+2023)

Ho et al. (2023)

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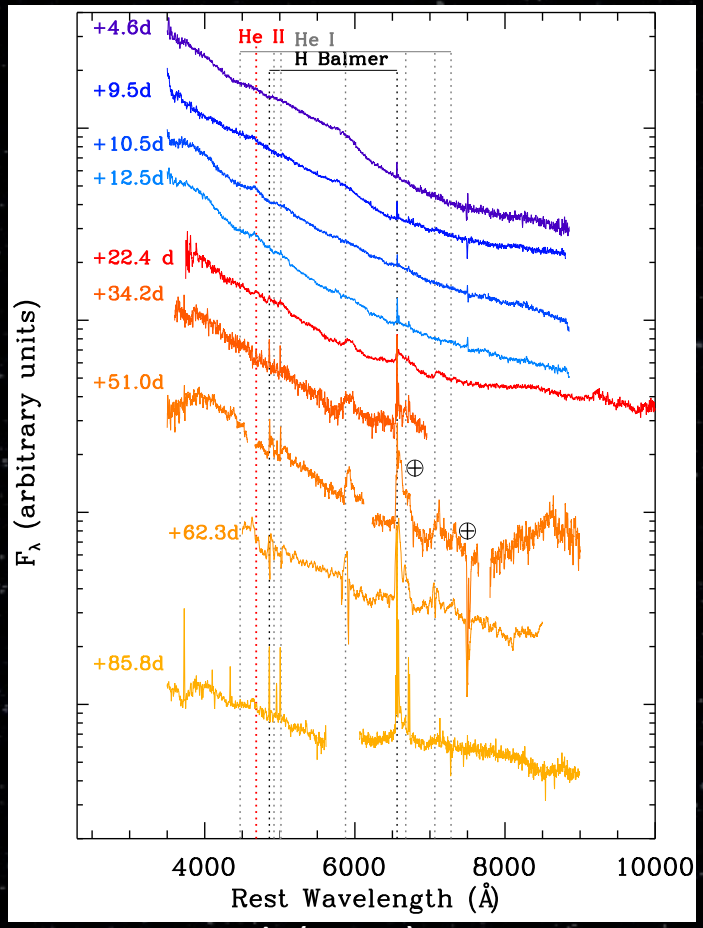

Margutti et al. (2018)

Some luminous FBOTs show signatures of interaction: there is CSM around

The Observed Landscape of FBOTs

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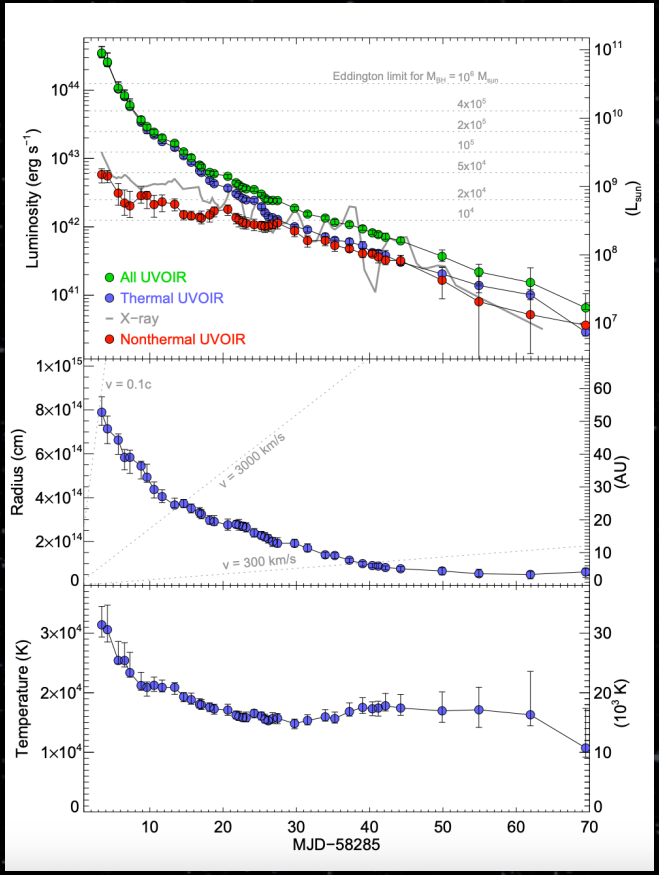

Perley et al. (2018)

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They have rich multiwavelength (X-ray and radio) behavior

The Observed Landscape of FBOTs

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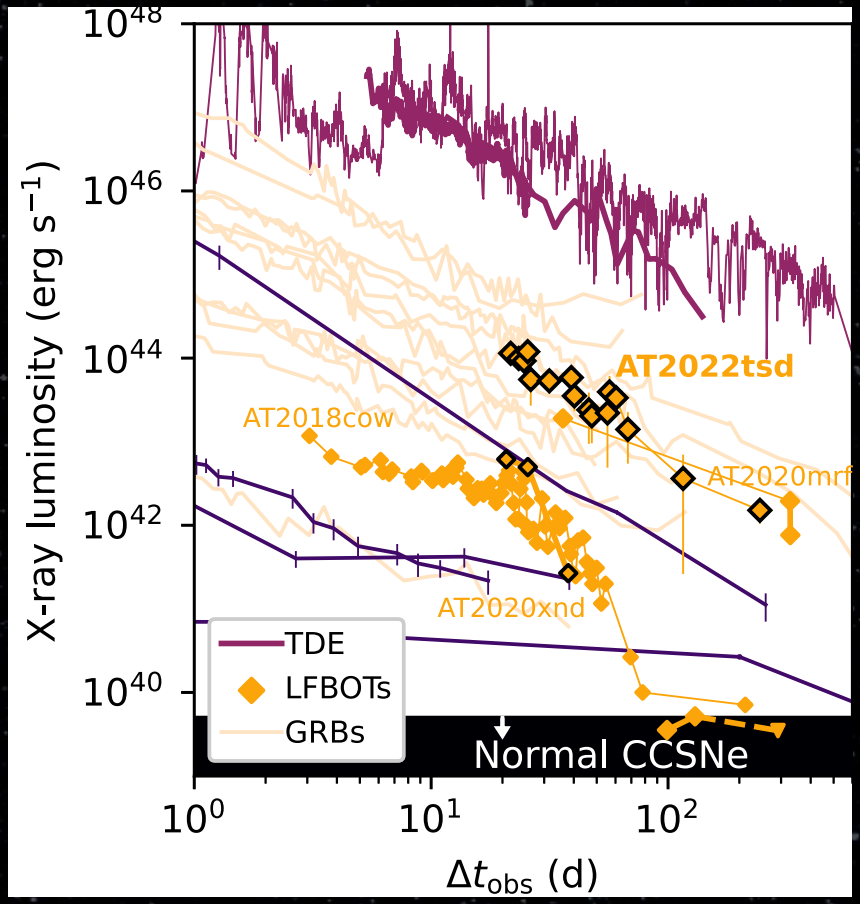

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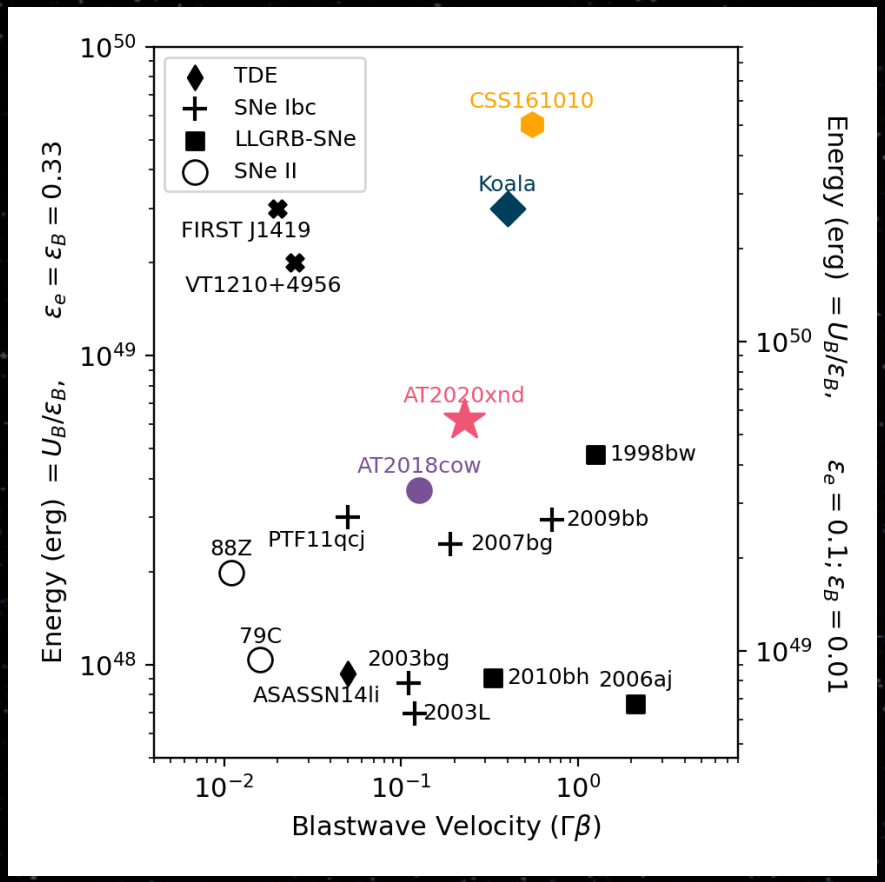

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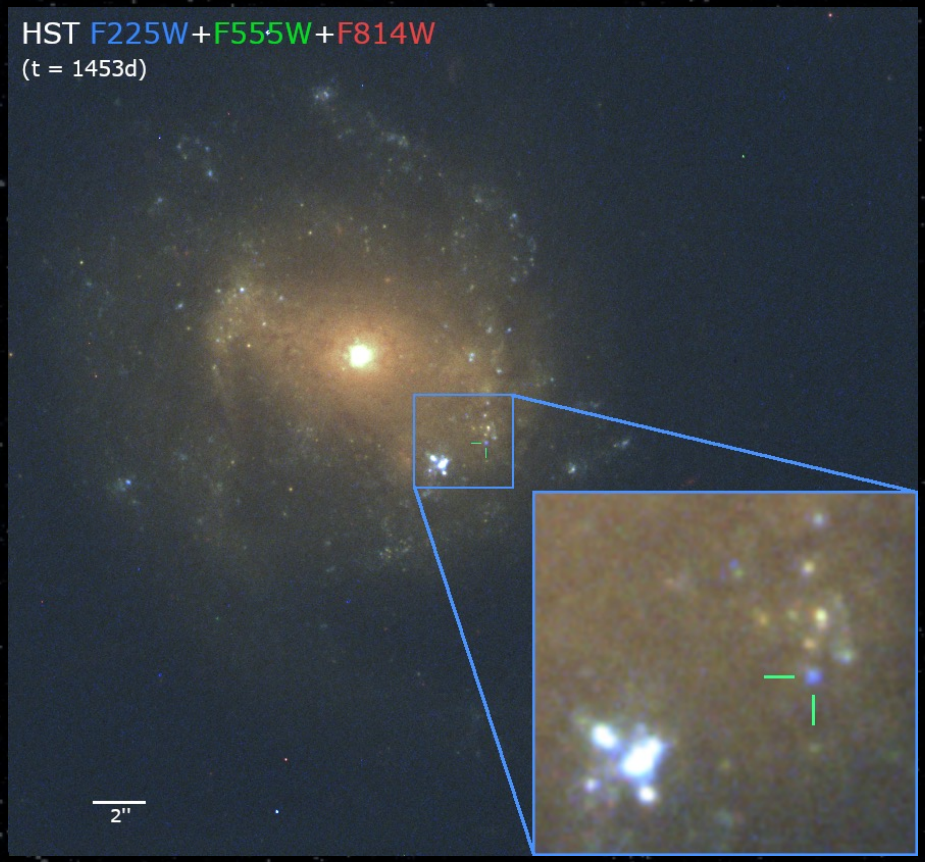

Chen, Drout, Piro et al. 2023b

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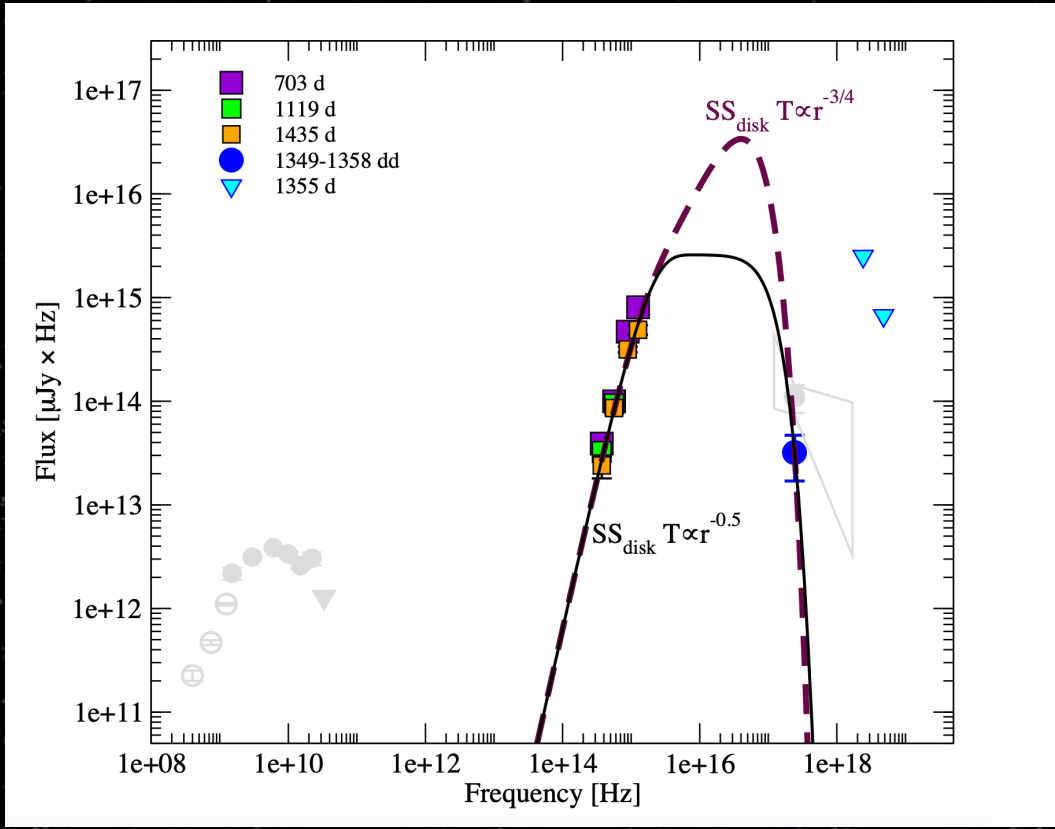

Migliori, Margutti et al. (2023)

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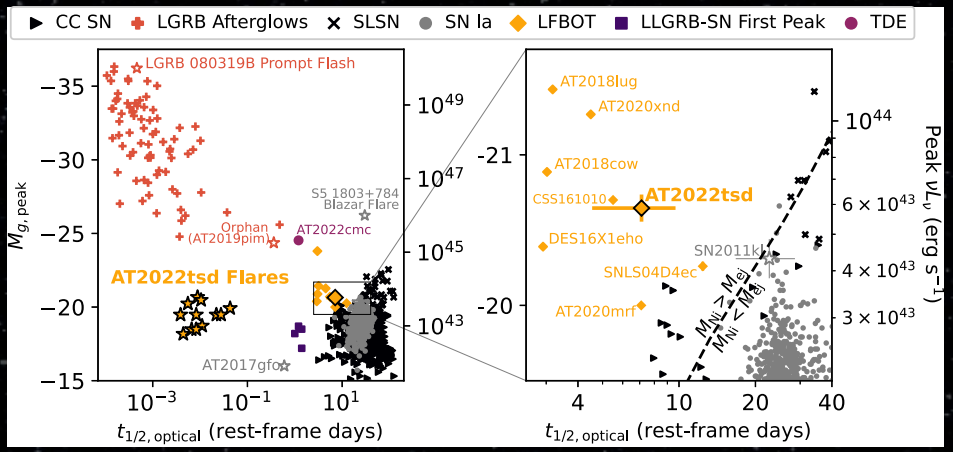

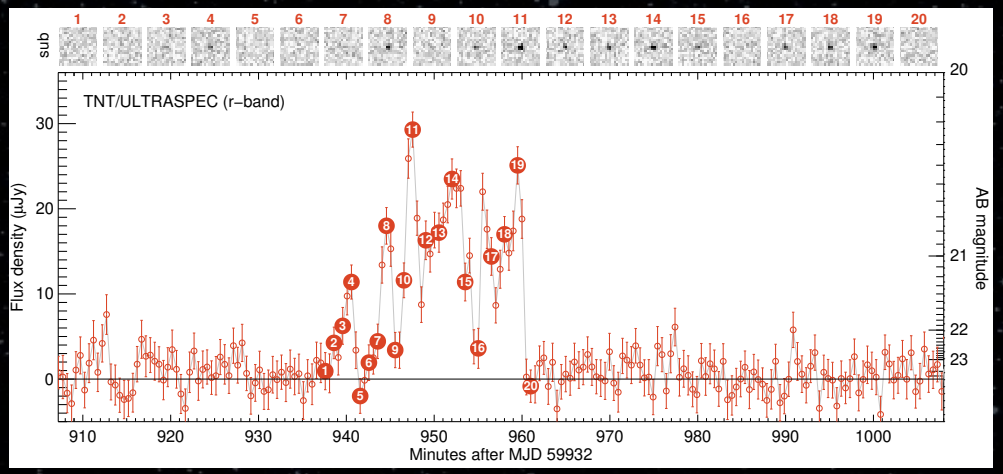

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Ho et al. (2023)

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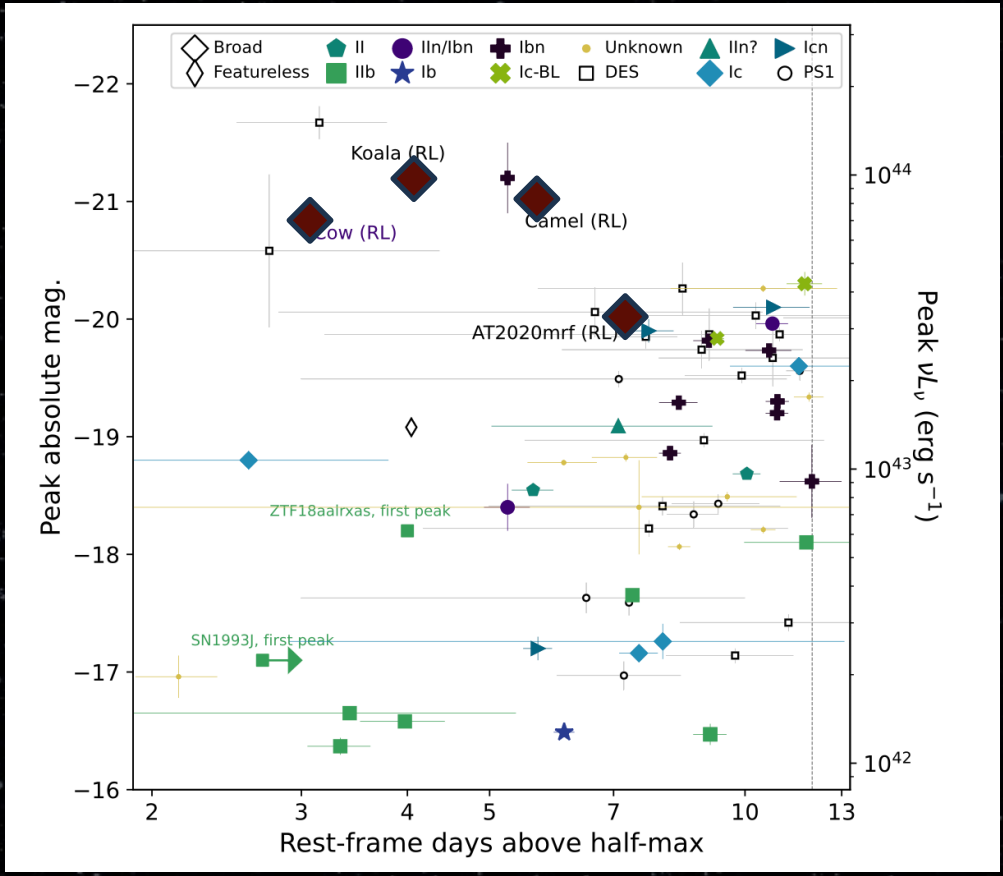

Ho et al. (2023)

Key Takeaways:

- CSM must play some role
- There is a central engine
- Accretion onto a compact object is important

The Observed Landscape of FBOTs

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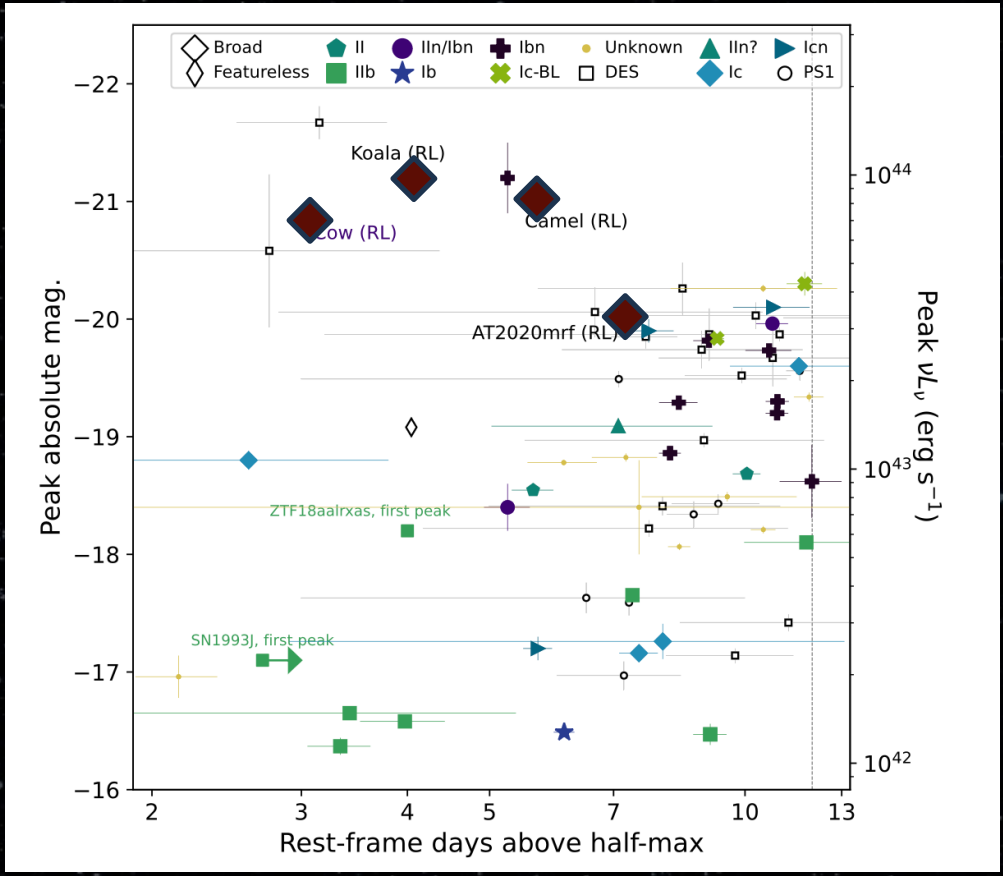


Ho et al. (2023)

Key Takeaways:

CSM must play some role

There is a central engine

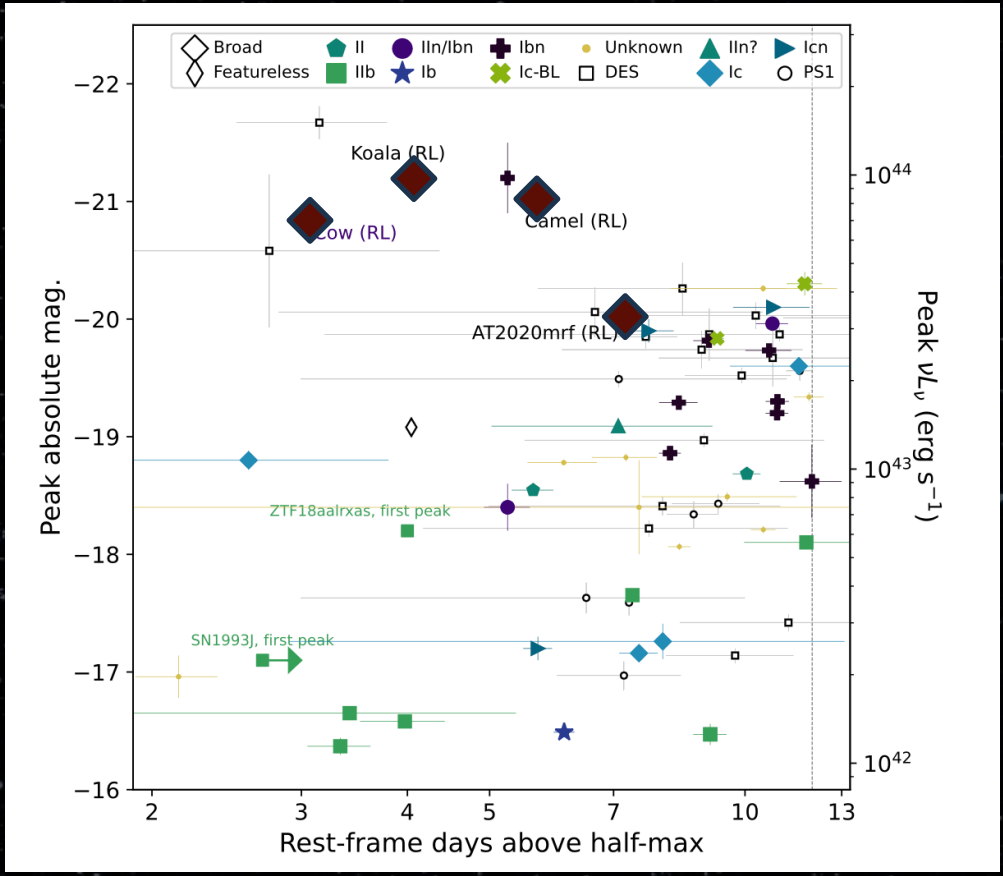
Accretion onto a compact object is important

Key Question: what is the nature of the compact object and explosion?

Key Question: Do luminous FBOTs launch jets or some other kind of outflow?

The Observed Landscape of FBOTs

Let's Sub-divide and Classify!



Luminous FBOTs

Ho et al. (2023)

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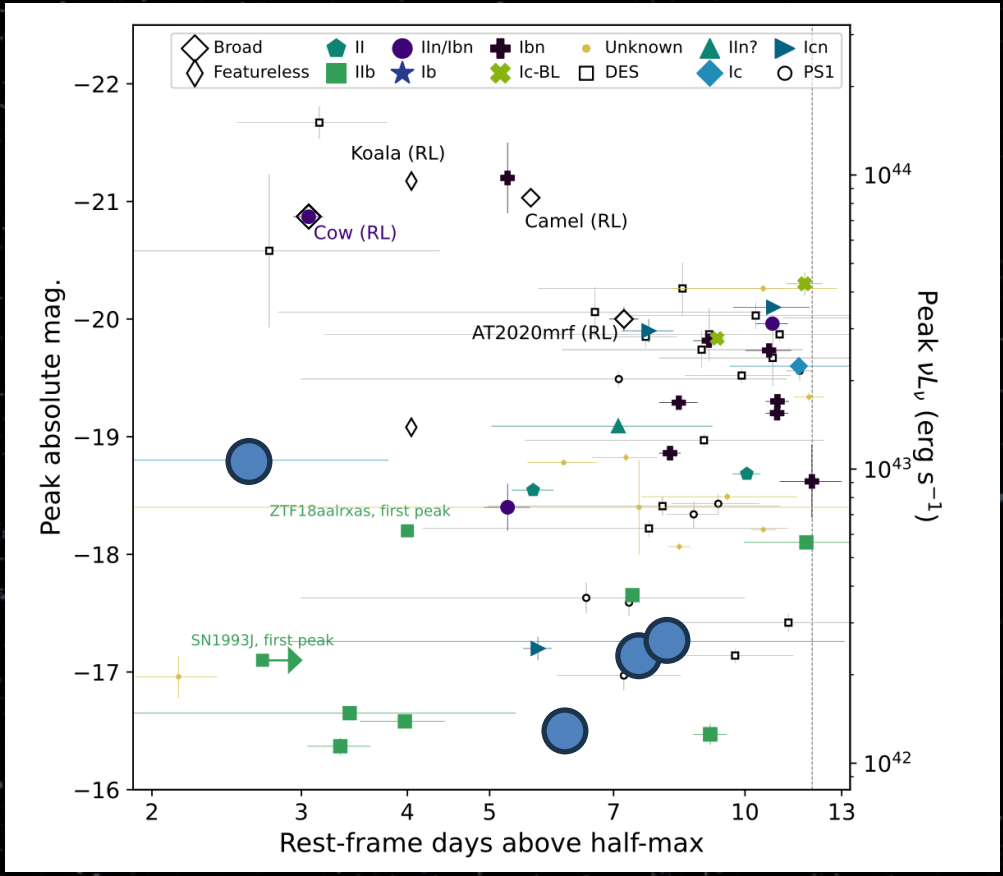
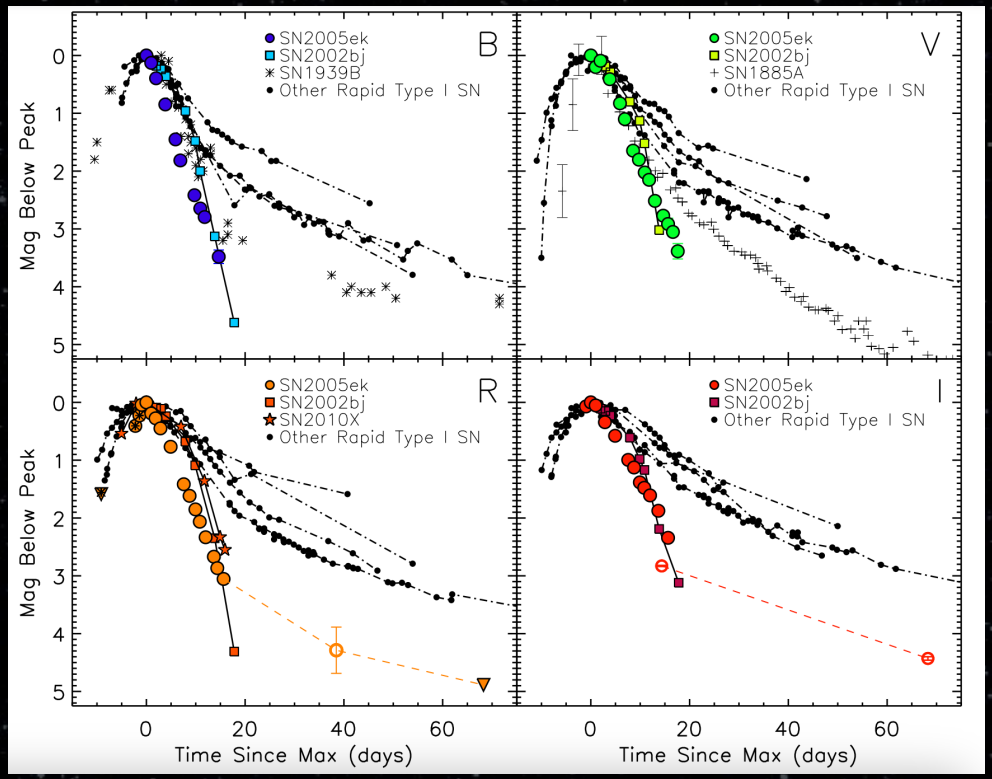


Ho et al. (2023)

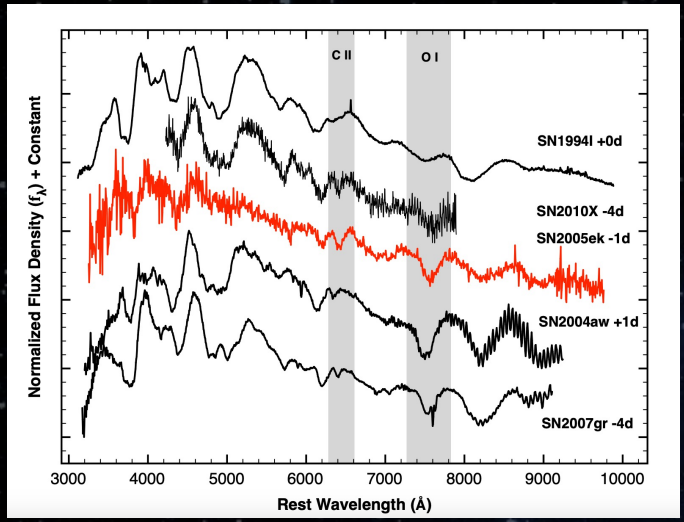
Fast and Faint Type I Supernovae

The Observed Landscape of FBOTs

Fast and Faint Type I SN

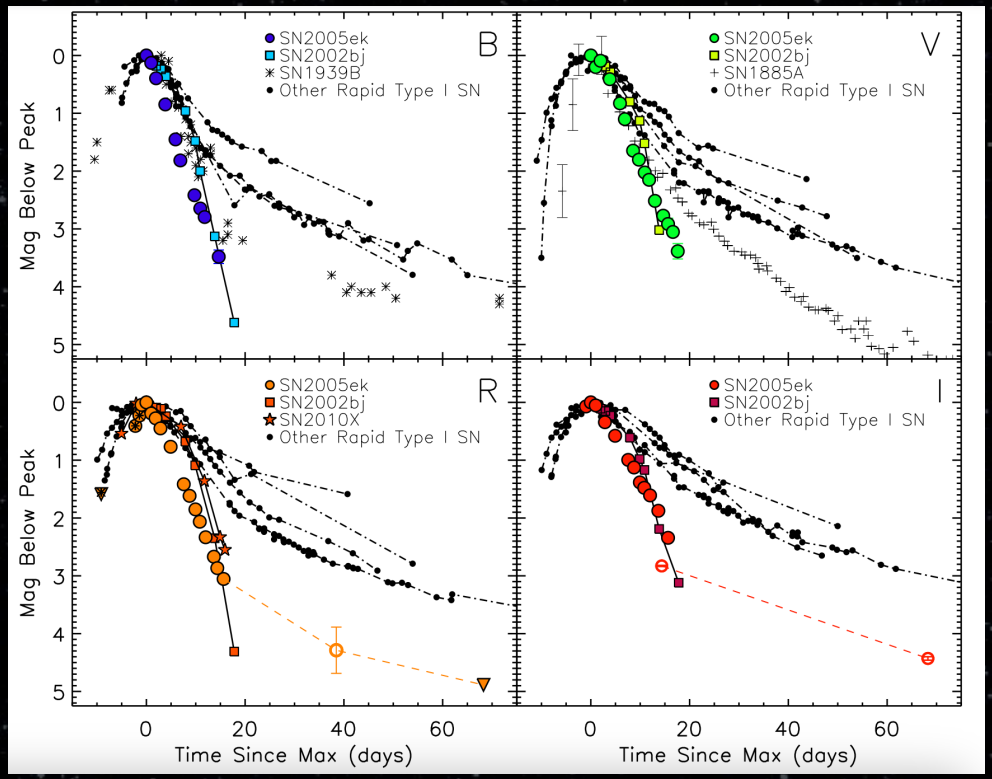


Objects with very spectra that look like normal Ic (or Ib) SN. But just have very fast light curves. Note: not all of the them are technically 'blue'.



Drout et al. (2013)

The Observed Landscape of FBOTs
Fast and Faint Type I SN

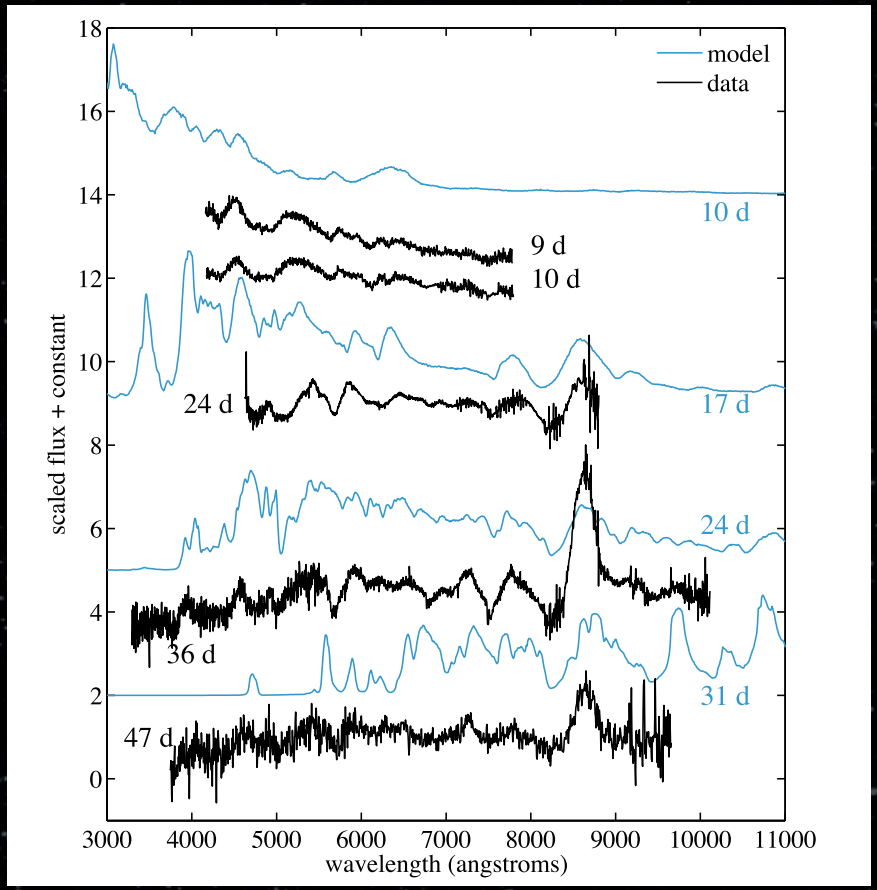


Key Question 1: Are these core-collapse, thermonuclear, or other?

Drout et al. (2013)

The Observed Landscape of FBOTs

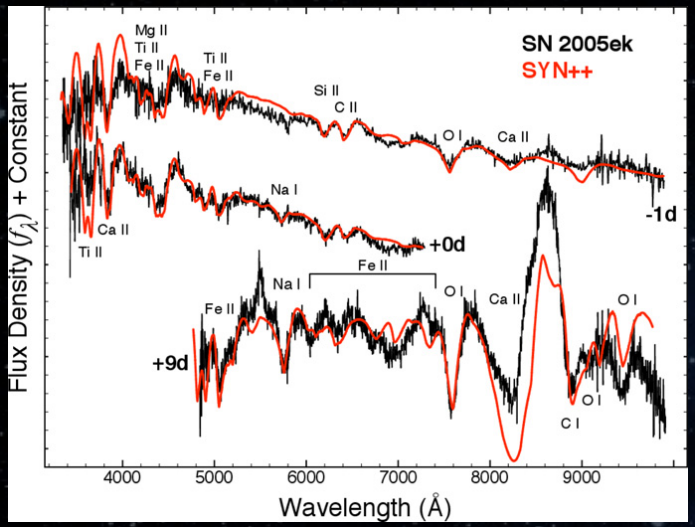
Fast and Faint Type I SN



Kleiser & Kasen (2013)

Key Question 1: Are these core-collapse, thermonuclear, or other?

Spectral modelling for two (2005ek, 2010X) showed ejecta dominated by oxygen, consistent with CCSN.



Drout et al. (2013)

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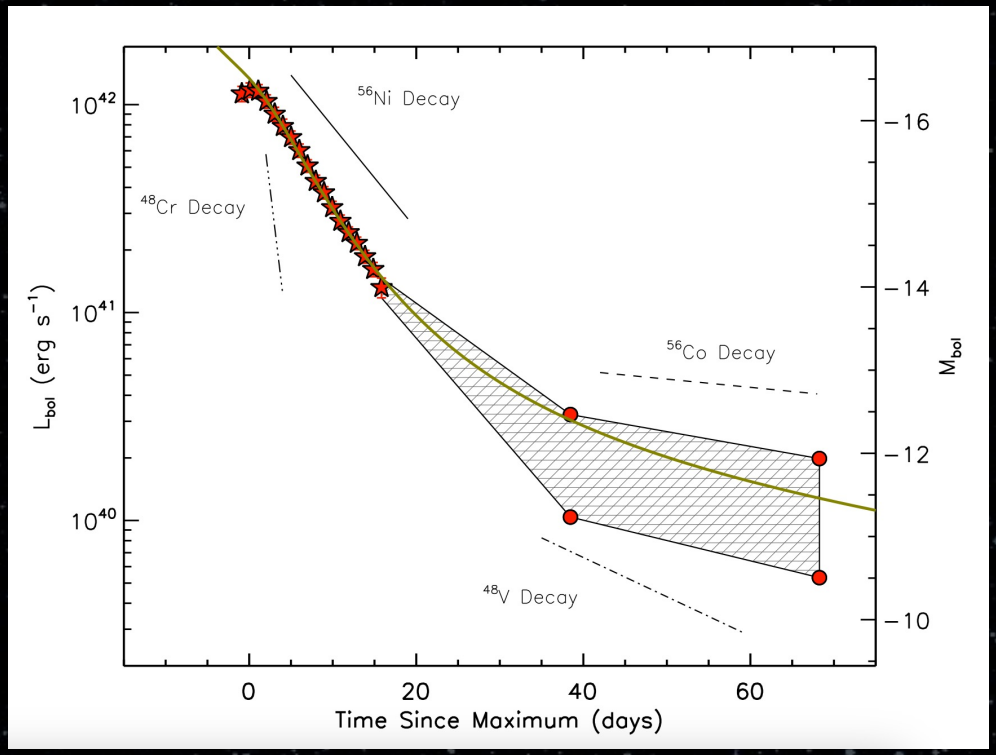
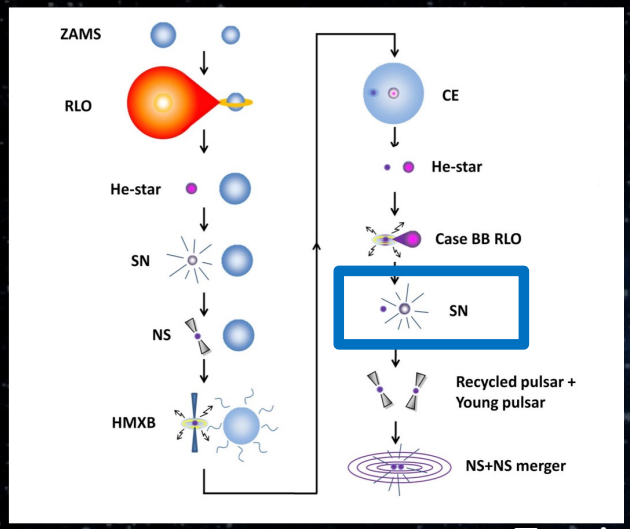


Drout et al. (2013)

Key Question 2: what is the origin of their emission? Several options:

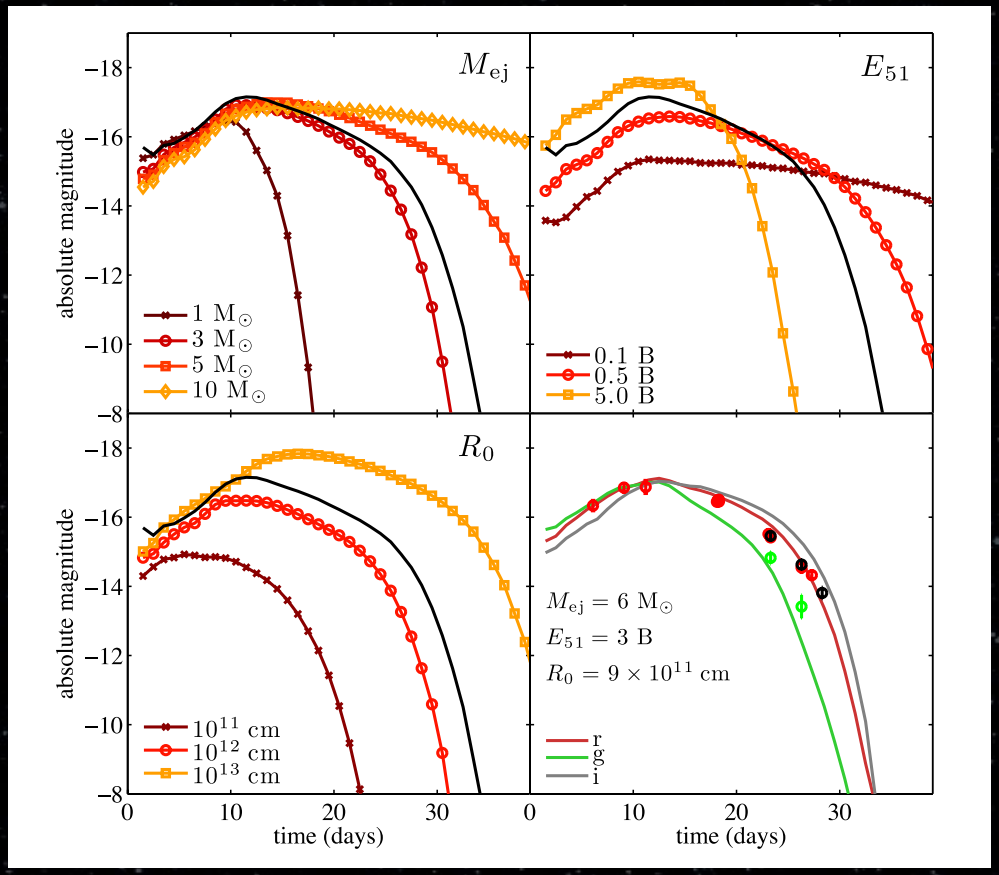
Radioactive decay of 56Ni in a very low ejecta mass (~0.2-0.3 Msun) explosion. “Ultrastripped SN”.



Tauris

The Observed Landscape of FBOTs

Fast and Faint Type I SN



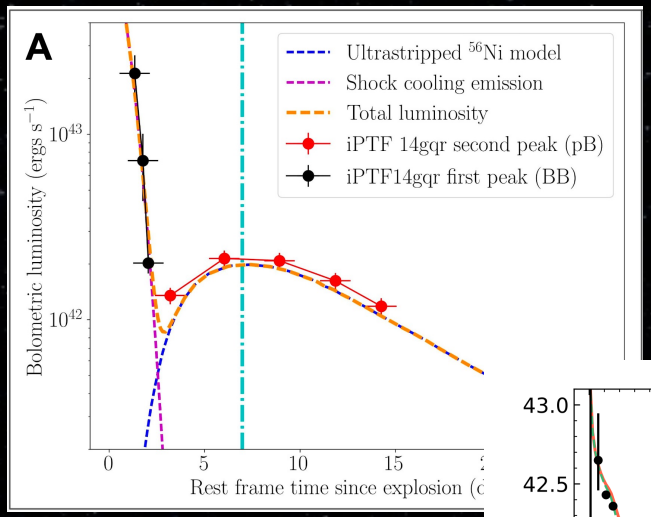
Kleiser & Kasen (2013)

Key Question 2: what is the origin of their emission? Several options:

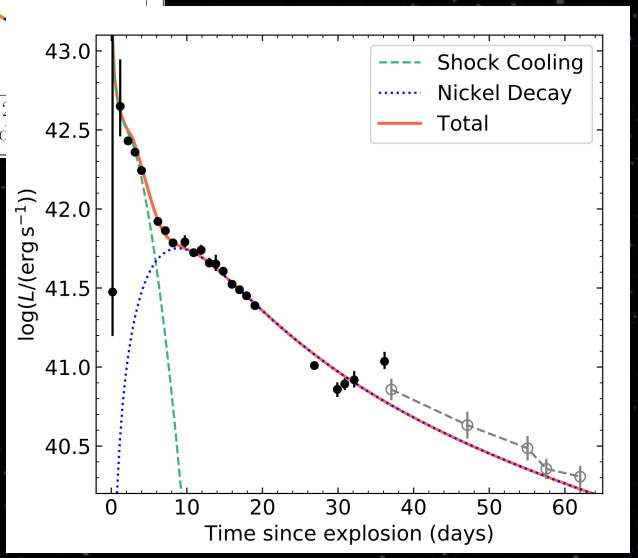
Cooling of an inflated oxygen envelope in an explosion that ejects almost no 56Ni. “Oxygen Plateau SN”.

The Observed Landscape of FBOTs

Fast and Faint Type I SN



De+2018

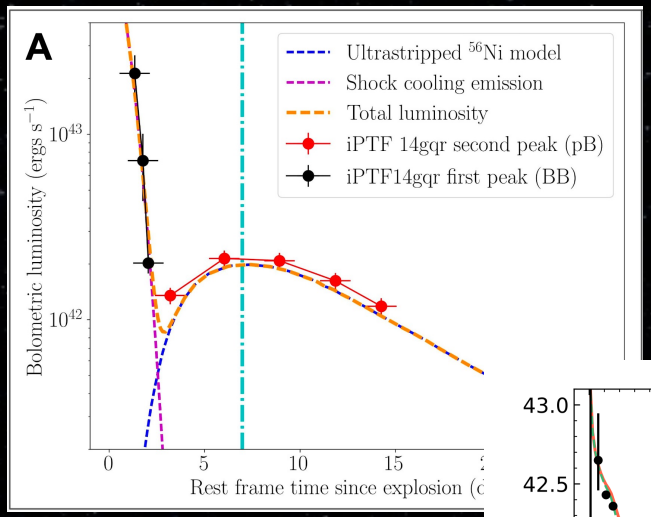


Yao+2020

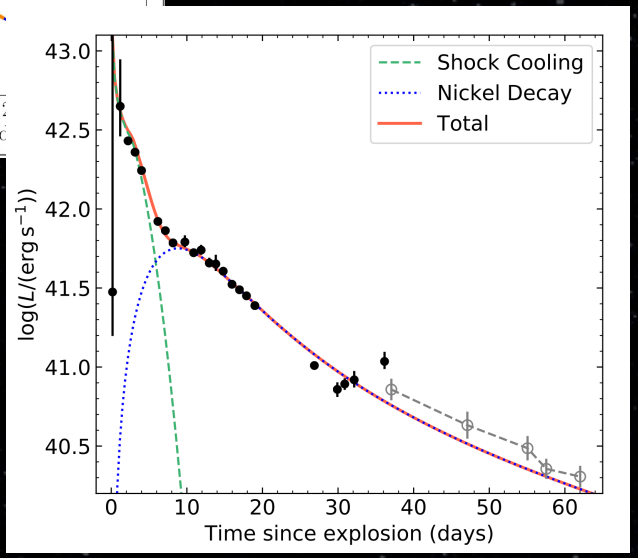
A handful of new events (De+2018, Yao+2020, Agudo+2023, Yan+2023). Interesting features: early shock cooling peaks, early HeII emission in spectra, late-time constraints on 56Ni

The Observed Landscape of FBOTs

Fast and Faint Type I SN



De+2018



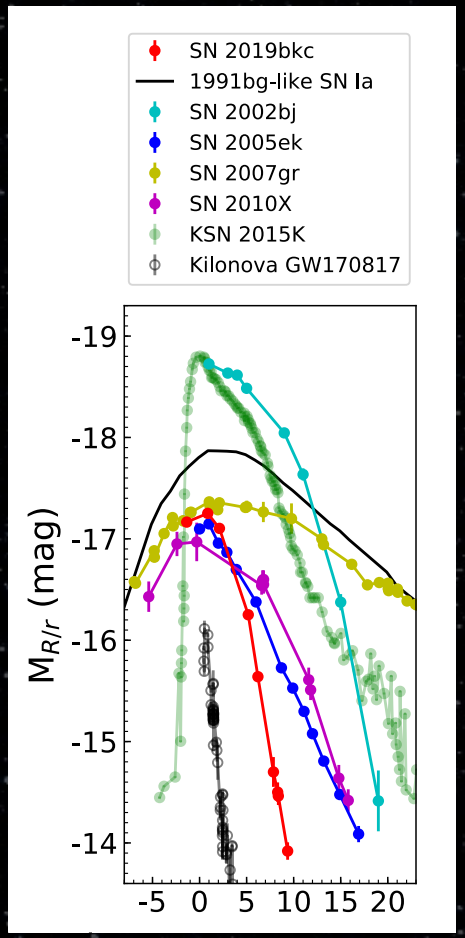
Yao+2020

A handful of new events (De+2018, Yao+2020, Agudo+2023, Yan+2023). Interesting features: early shock cooling peaks, early HeII emission in spectra, late-time constraints on 56Ni

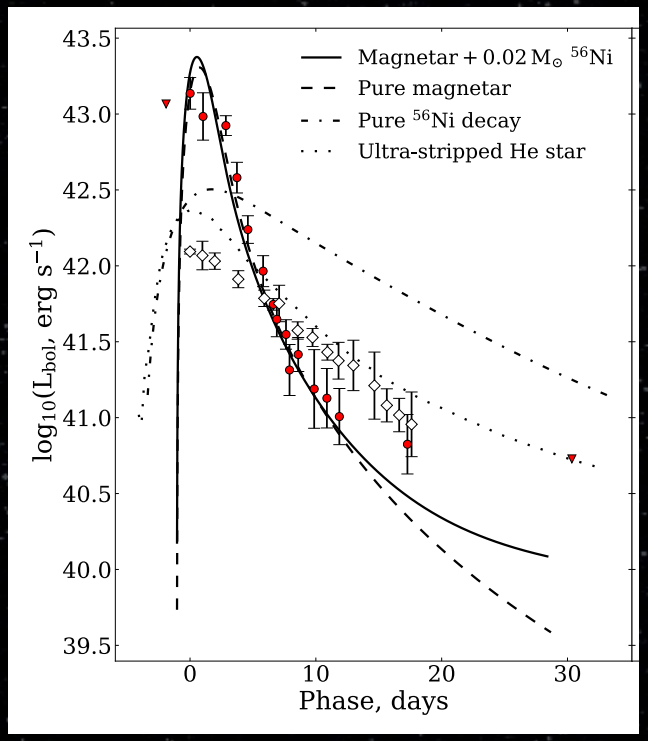
Generally consistent with ultrastripped SN with inflated He-rich envelopes

The Observed Landscape of FBOTs

Fast and Faint Type I SN



Chen+2020



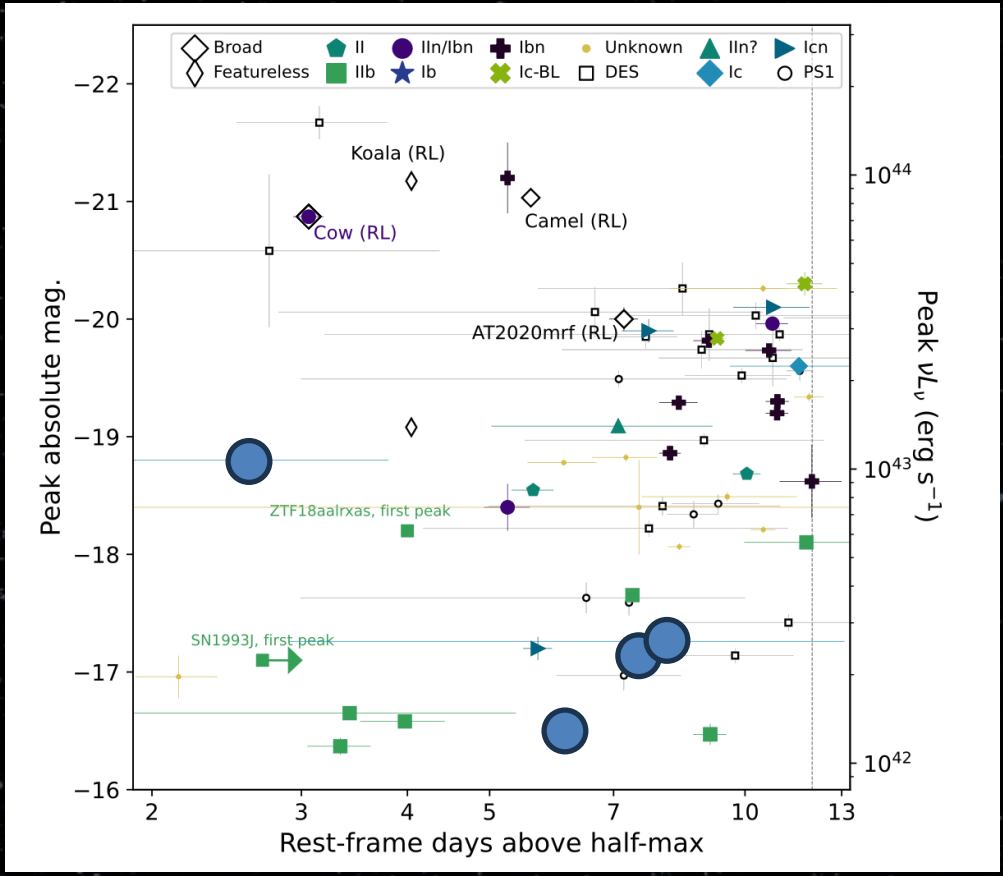
McBrien+2019

There have also been events that push the envelope even further; SN2018kzr (McBrien+2019) and SN2019bkc (Chen+2020)

Both are too fast to be fit with 56Ni, but neither show distinct features of cooling emission near peak.

The Observed Landscape of FBOTs

Let's Sub-divide and Classify!

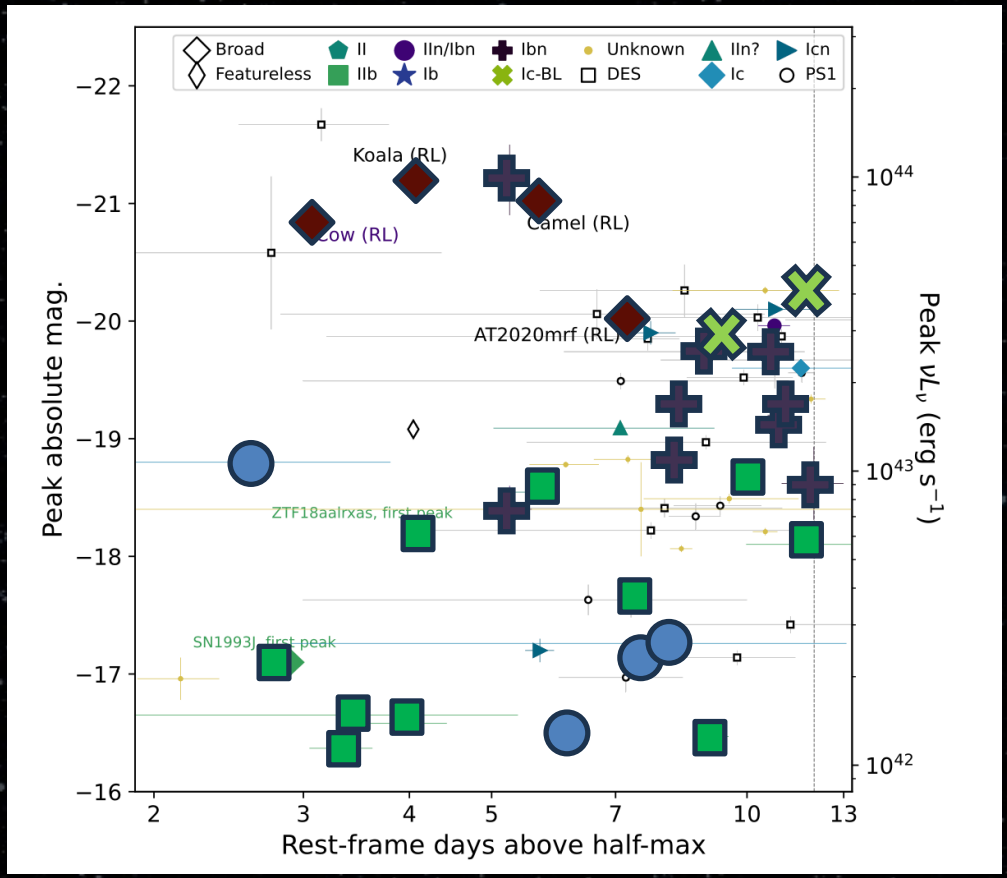


Ho et al. (2023)

Fast and Faint Type I Supernovae

The Observed Landscape of FBOTs

Let's Sub-divide and Classify!



Ho et al. (2023)

- Luminous FBOTs
- Type Ibn Supernovae
- Various Core-collapse SN
- Fast and Faint Type I Supernovae

The Observed Landscape of FBOTs
Key Takeaways (for now)

1. There is large diversity.

2. Many FBOTs can be understood as examples of previously known classes of transients (IIb, Ibn, Ic-BL, Ibc)

3. However, these events raise questions about:
   - Mechanism by which envelopes are inflated/mass ejected in the final stages before core-collapse.
   - Implications of the relatively paucity of 56Ni in some cases for the masses of the progenitors.

4. At the same time, new explosion mechanisms/types of phenomena are likely required at both the high and low luminosity end.