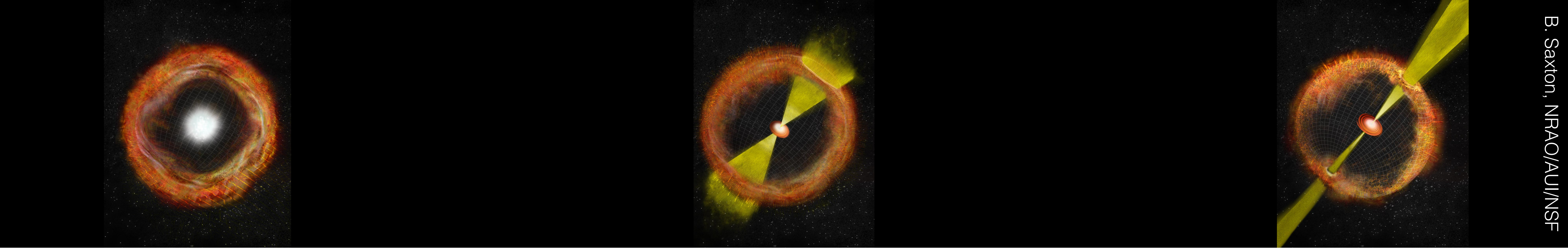
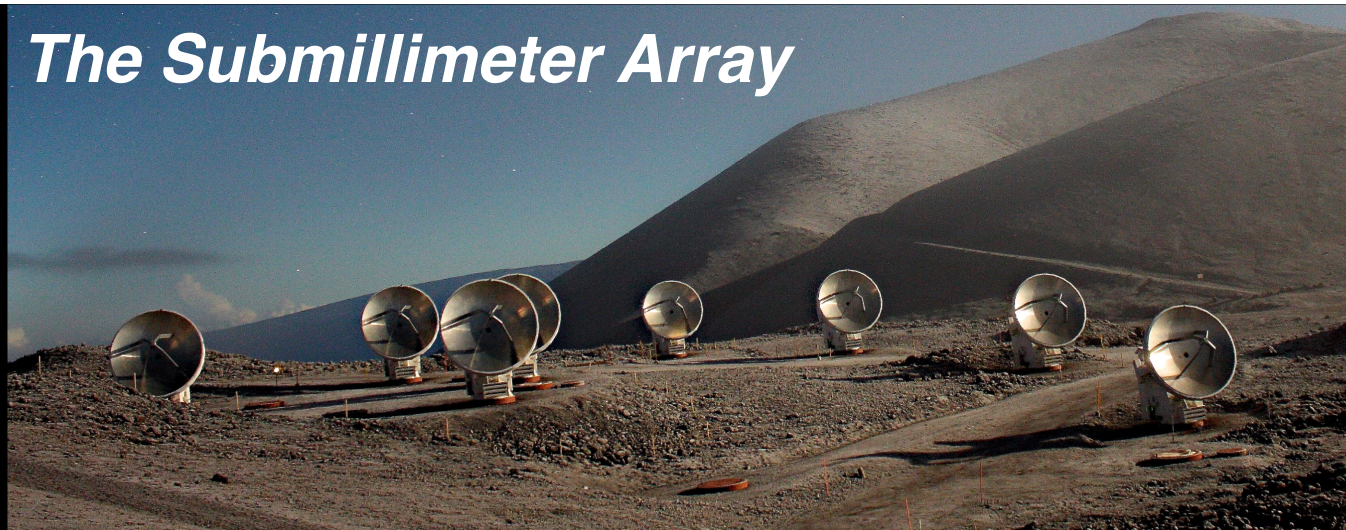


The Landscape of Fast & Luminous Transients

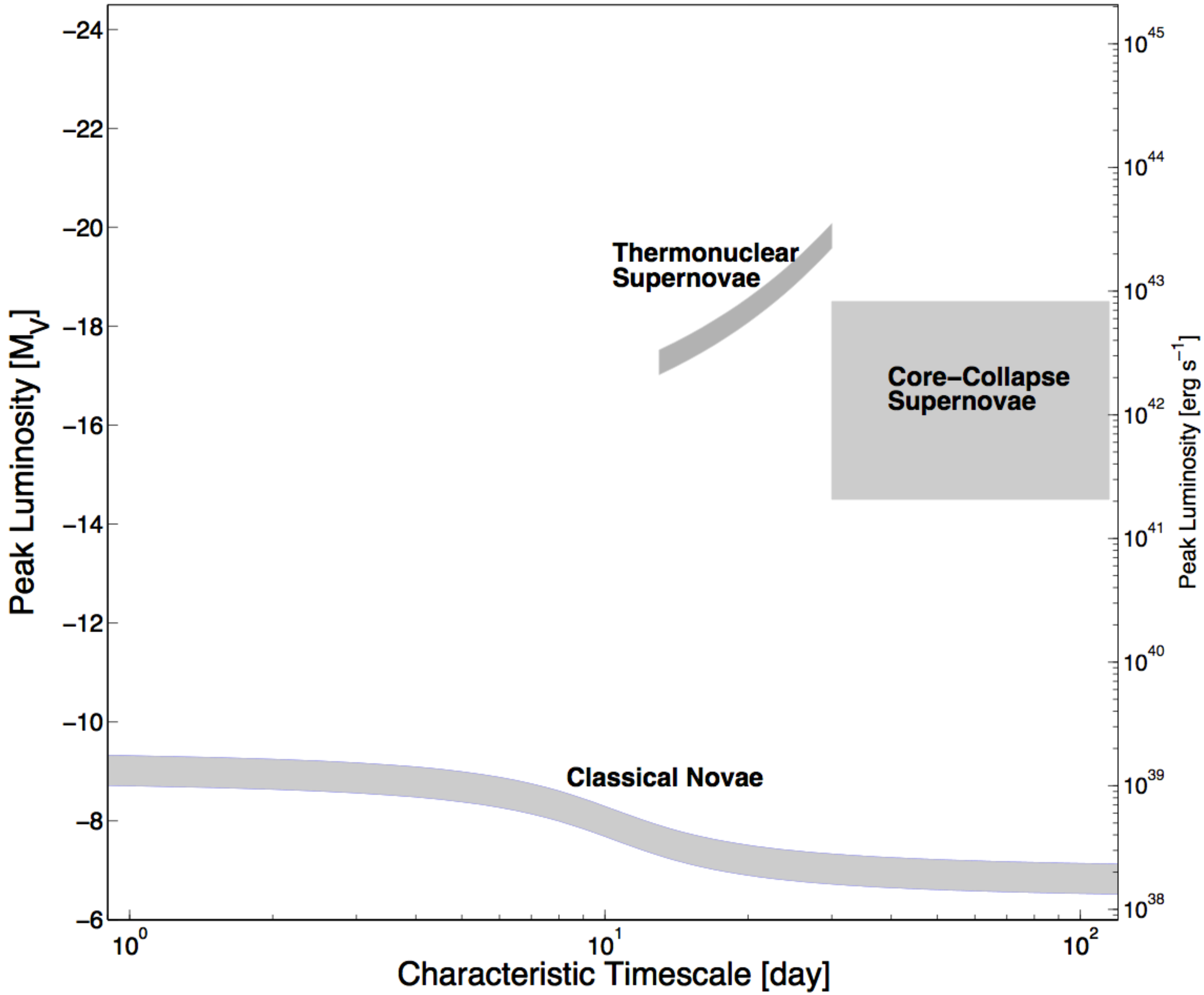
Anna Y. Q. Ho (Miller Fellow, UC Berkeley)

with D. Perley, Y. Yao, A. Corsi, S. Kulkarni, and many others



“Extreme” Observationally: The Landscape of Optical Transients

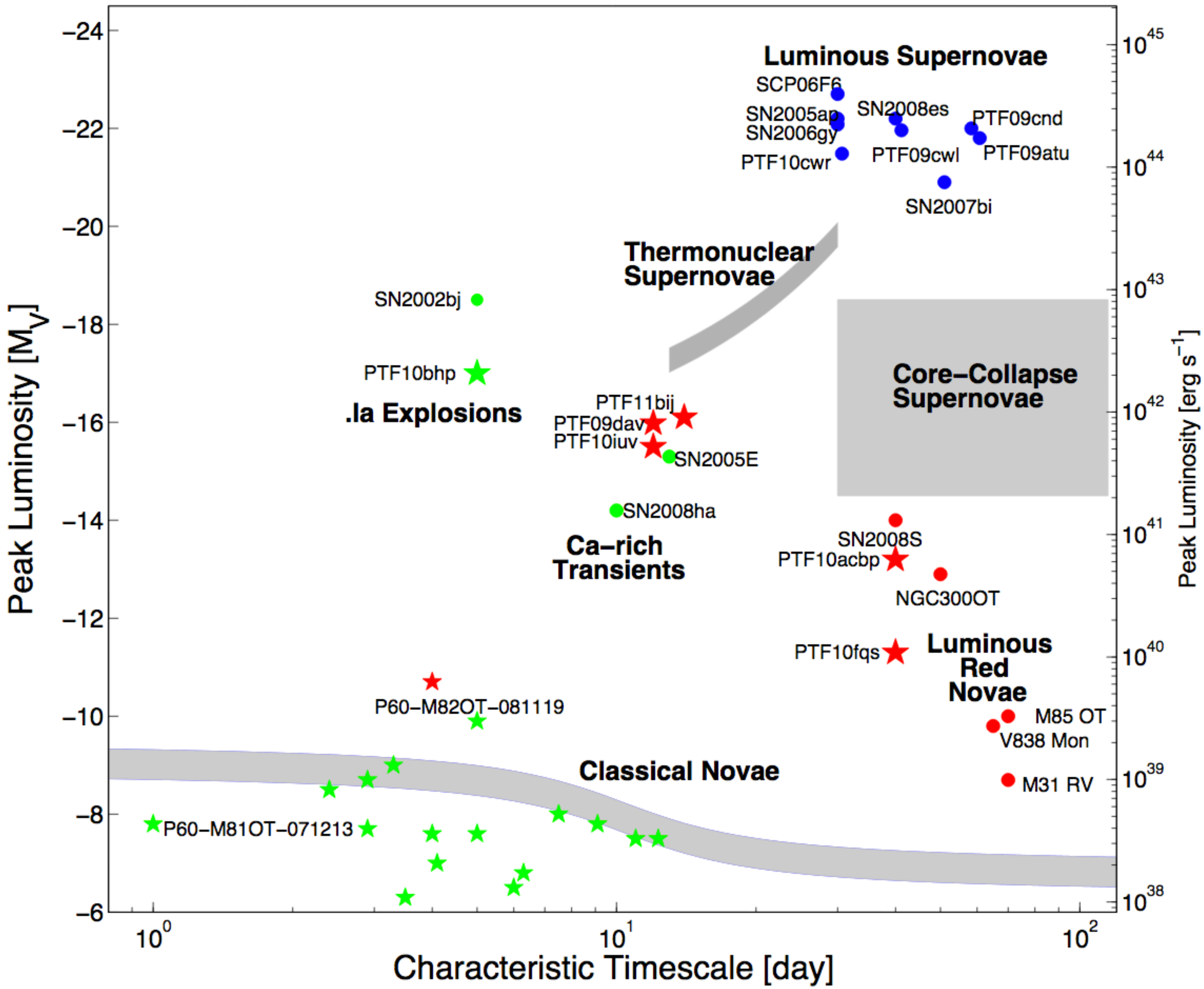
2005



Kasliwal (2011) PhD Thesis

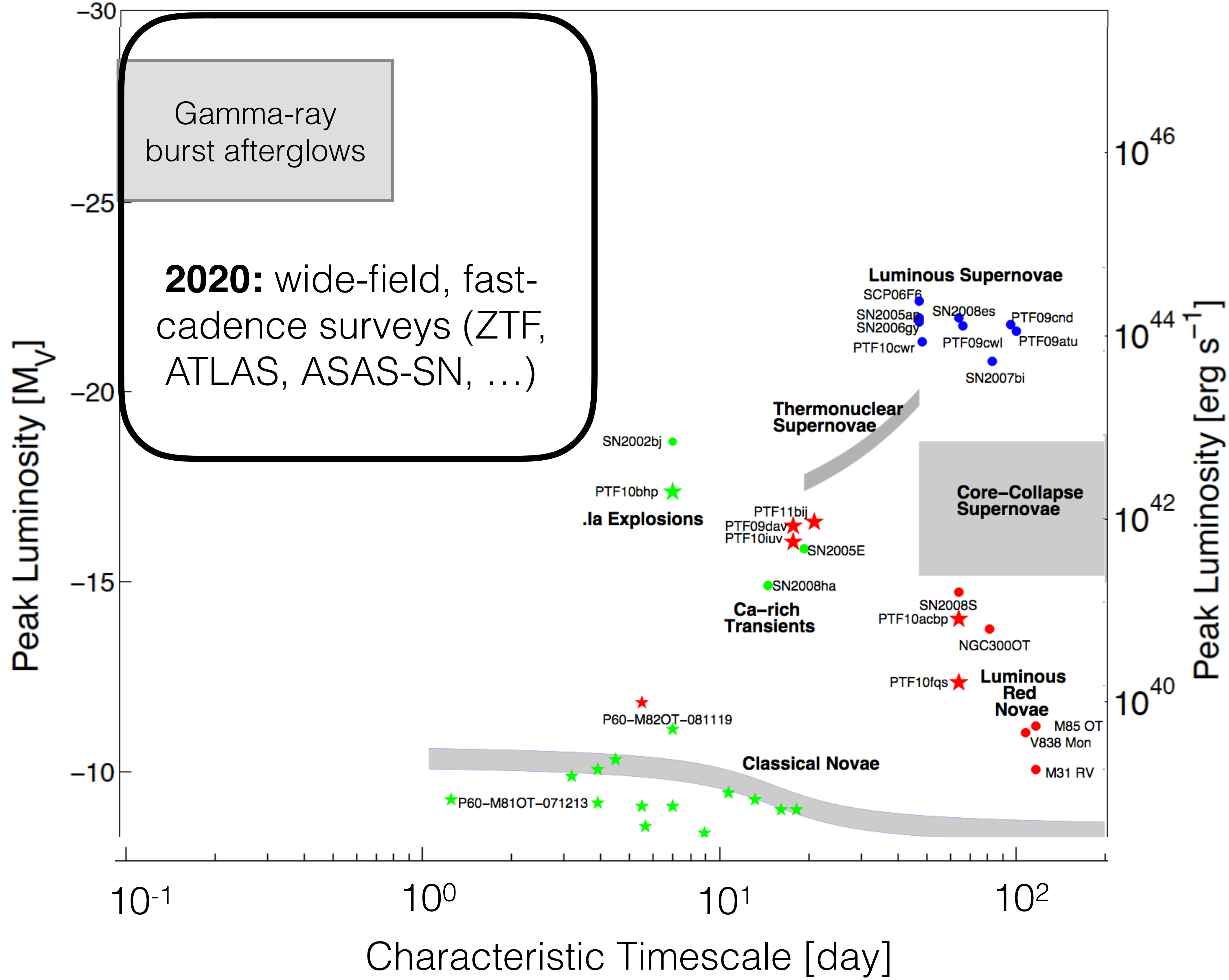
Wide Field-of-View, Untargeted, High-Cadence Surveys

2011



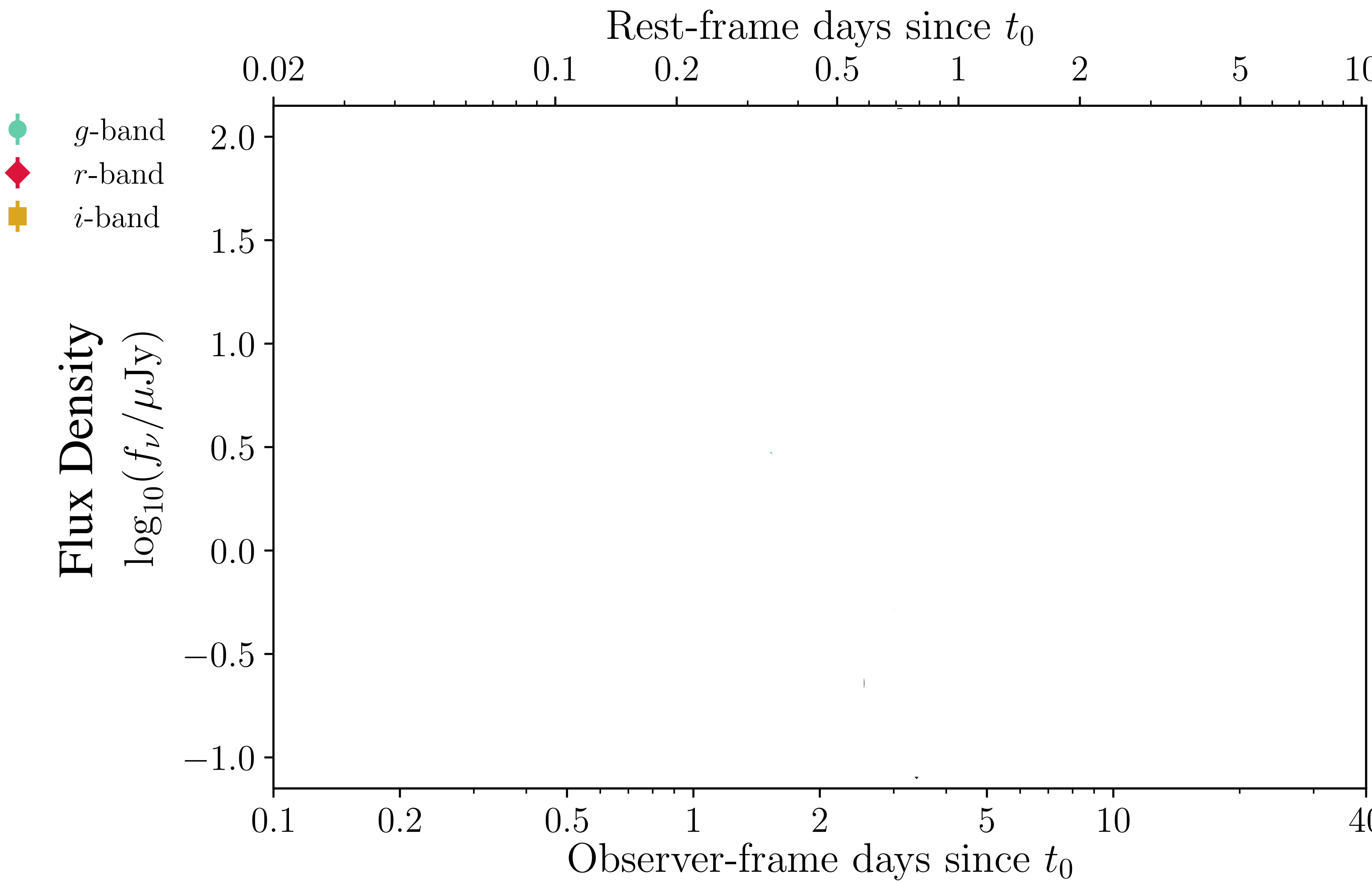
Kasliwal (2011) PhD Thesis

The Next Frontier: Fast & Luminous Transients



Challenge: need to discover and follow up transients shortly after explosion

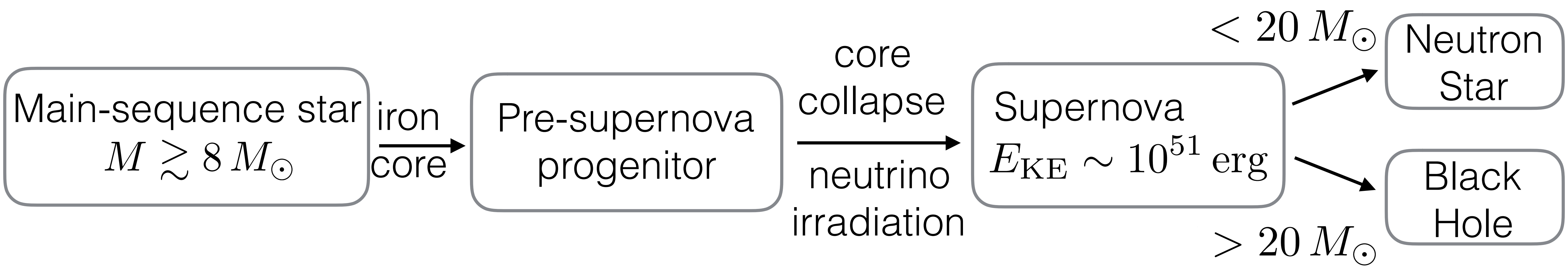
AT2020blt, an afterglow at *z*=2.9 with no detected GRB (Ho+2020d)



modified from (Ho+2020d)

“Extreme” Physically: Unusual Stellar Endpoints

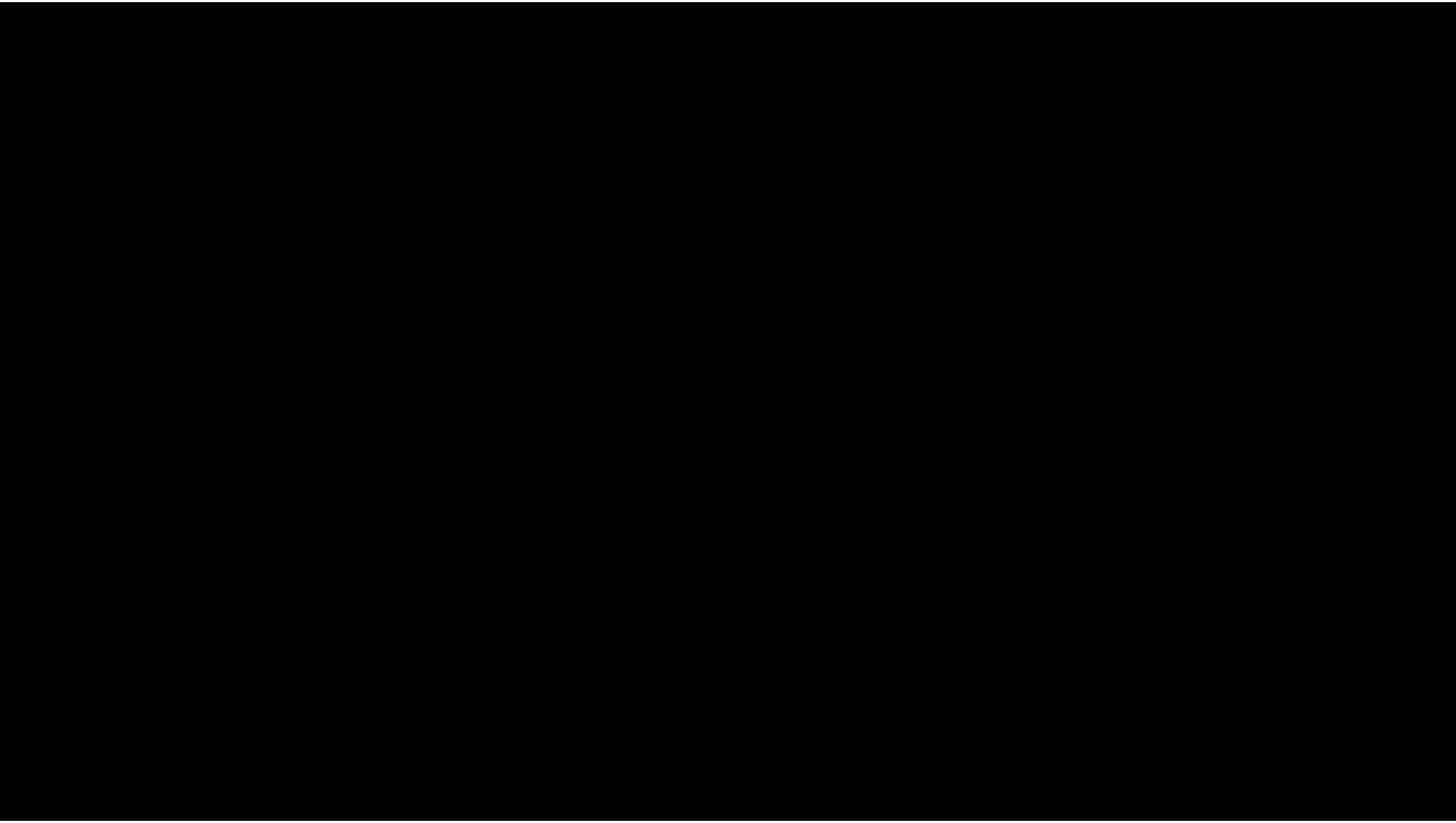
Traditional story of stellar evolution:



Phenomena: relativistic jets (compact object accretion/rotation; “central engine”), circumstellar interaction (recent intense mass-loss; “death omens”)

Scientific Motivation: stellar evolution (rotation, metallicity, binarity, mass-loss), explosion physics, jet physics

Relativistic jet in collapsing star: Long-duration gamma-ray burst + supernova
Spectroscopic Type Ic-BL (no H/He), “broad-lined” (high velocities)



Video credit: NASA’s Goddard Space Flight Center

Relativistic jet in collapsing star: Long-duration gamma-ray burst + supernova
Spectroscopic Type Ic-BL (no H/He), “broad-lined” (high velocities)

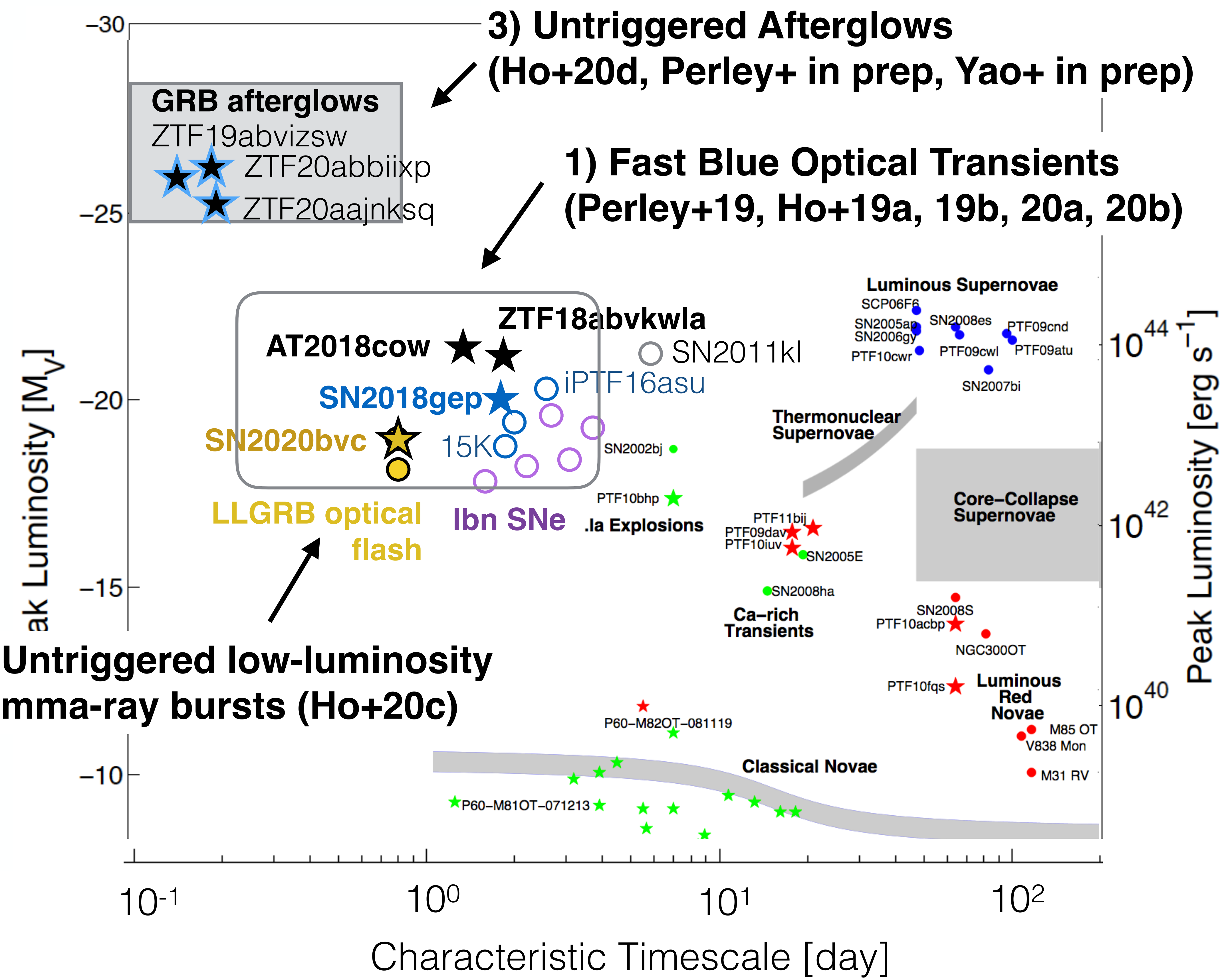
Conditions (break-out, hyper-relativistic velocities) are contrived:
perhaps GRBs are the extreme of a continuum?

“Dirty fireball” (Dermer 1999): low Lorentz factor jet, afterglow lacking GRB

Choked jets (Mészáros & Waxman 2001, Nakar 2015)

Can’t rely on GRB satellite $\longrightarrow$ Search for fast & luminous optical transients

Summary of Fast & Luminous Transients in ZTF Phase I



modified from Kasliwal (2011)

1) A Detour: Fast Blue Optical Transients (FBOTs)

Motivation **Status** **Future**

- Originally identified in Pan-STARRS (Drout+2014)
- Fleeting ($t_{1/2}$ < 12d) common (4-7% CC SN rate) explosions with -16 < M < -21
- Starforming host galaxies suggest massive-star origin
- 100 additional events from Dark Energy Survey (Pursiainen+2018)
- No spectroscopic classifications (no information on composition)

1) A Detour: Fast Blue Optical Transients (FBOTs)

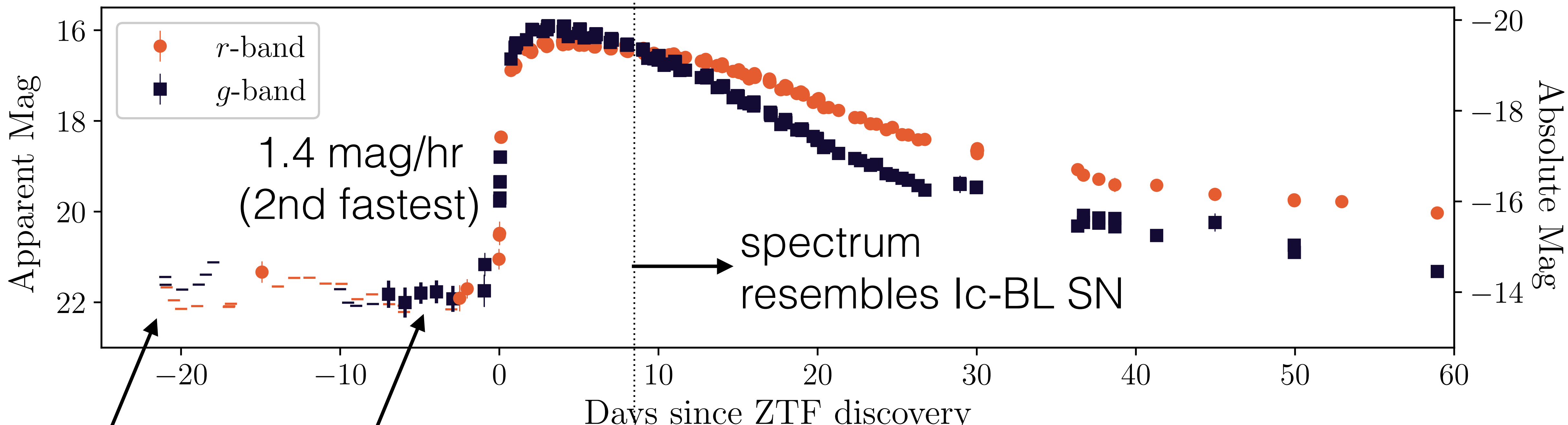
Motivation **Status** Future

- Notable individual events in ZTF:

Ic-BL: Ic (no H/He), “broad-lined” (high ejecta velocity), associated with GRBs

luminous and
blue: 18cow?

modified from Ho+2019b

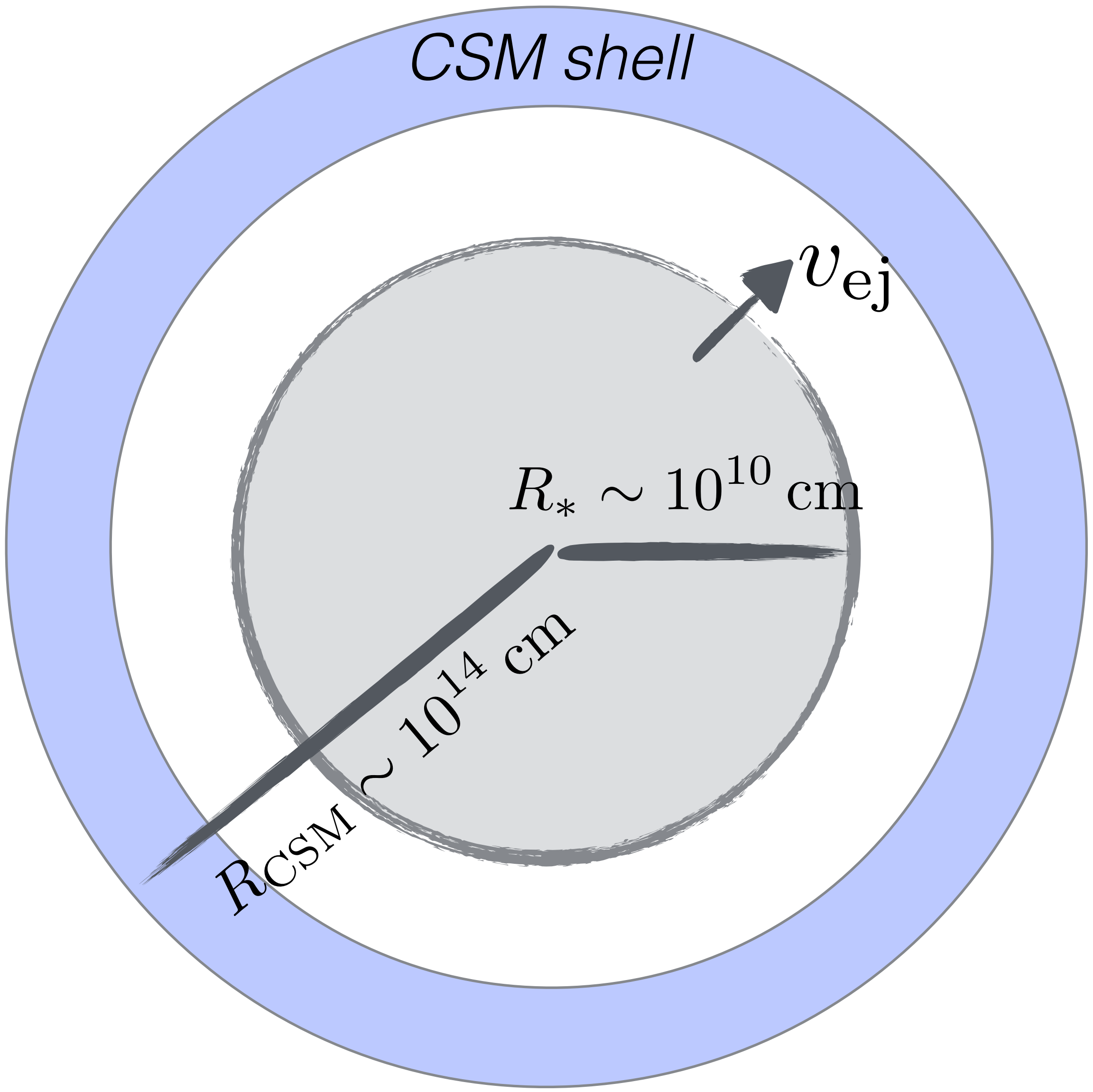


(upper limits)

First pre-explosion emission from a Ic-BL (Danny Goldstein’s image coaddition pipeline)

Rich dataset enabled by early discovery
- Earliest spectral sequence of a stripped-envelope SN (9 spectra in first 5 days)
- Velocity evolution
- Detailed UV & optical LCs
- Early UV grism spectrum
- Radio, millimeter, & X-ray limits

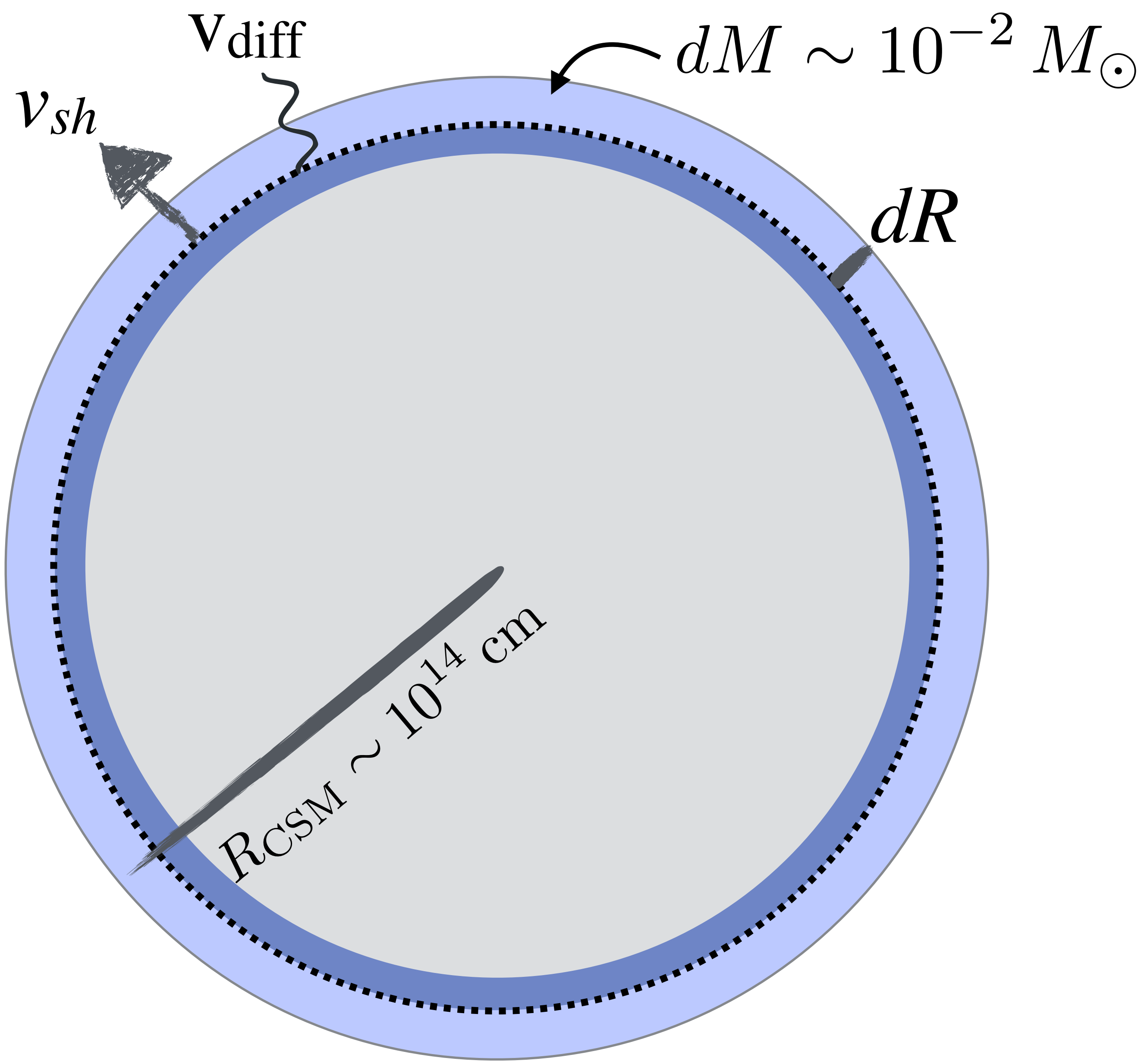
Likely mechanism: shock-interaction with a shell of CSM



$L_{\rm peak} > 10^{44}$ erg/s

$t_{\rm peak} < 1$ day

Likely mechanism: shock-interaction with a shell of CSM



$L_{peak} > 10^{44}$ erg/s

$t_{peak} < 1$ day

No EM radiation until CSM breakout:

$$\tau \sim c/v_{\rm sh}$$

$$t_{\rm cross} \sim dR/v_{\rm sh} \text{ (\textasciitilde day)}$$

$$L_{\rm peak} \sim \frac{E_{\rm dep}}{t_{\rm cross}} \quad >10^{44} \text{ erg/s}$$

Easily explains what we observe

1) A Detour: Fast Blue Optical Transients (FBOTs)

Motivation ***Status*** ***Future***

- Notable individual events in ZTF:

  Engine-driven explosions: AT2018cow analogs
  (Prentice+18, Perley+19, Margutti+19, Ho+19a)

    ZTF18abvkwla (GRB-like radio luminosity; Ho+20b)

    AT2020xnd (ATel #14105—stay tuned!)

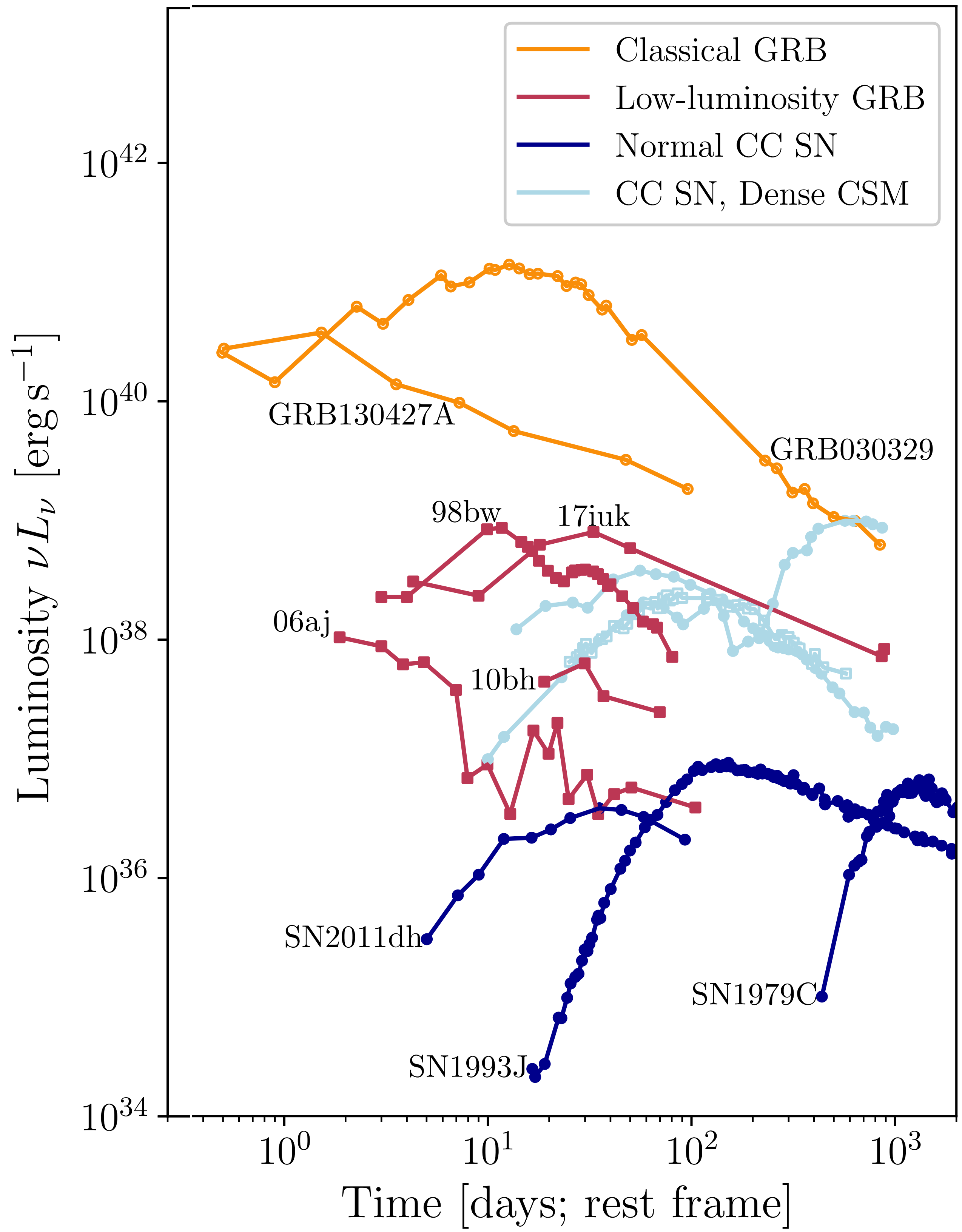
- Large sample paper in prep
  - 20 FBOTs with spectra: diverse compositions
    (H-rich, He-rich, H/He-poor, engine-powered…)

2) "Low-luminosity gamma-ray bursts" (LLGRBs) in the local universe

Key characteristics:

- Prompt emission: subluminous, smooth, low peak energy ("X-ray flash")
- Ic-BL SN (like classical GRBs)
- X-ray & radio emission (central engine)
- May be 10-100x more common than classical GRBs (Soderberg+06)

Radio (<10 GHz) light curves

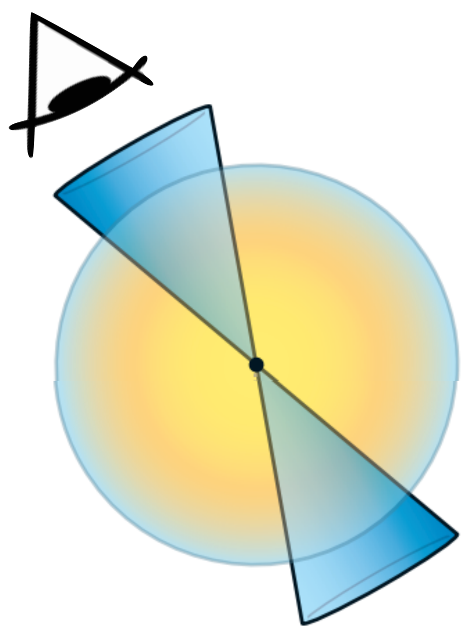


What is the relationship between LLGRBs and classical (cosmological) GRBs?

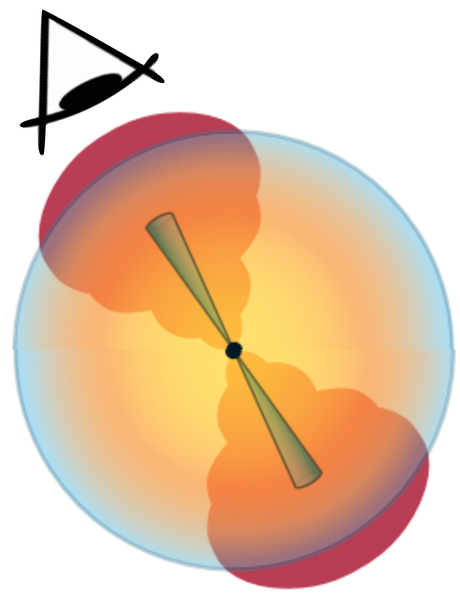
- Ingredients: shock breakout + central engine (Kulkarni+98, Campana+06, Waxman+07)

Possibilities:

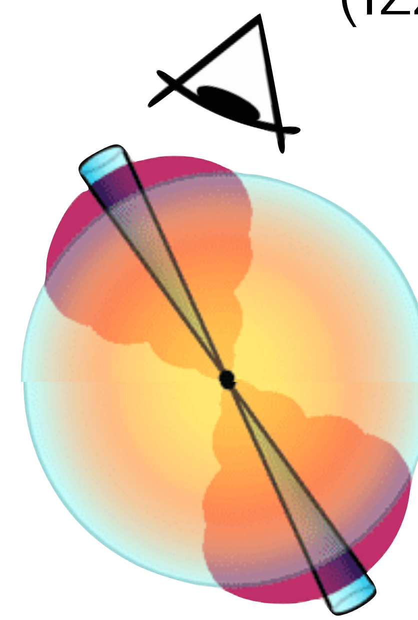
Low-luminosity jet
(Irwin+16)?



Jet choked in CSM?
(Nakar+15)



Off-axis jet
(Izzo+19)?



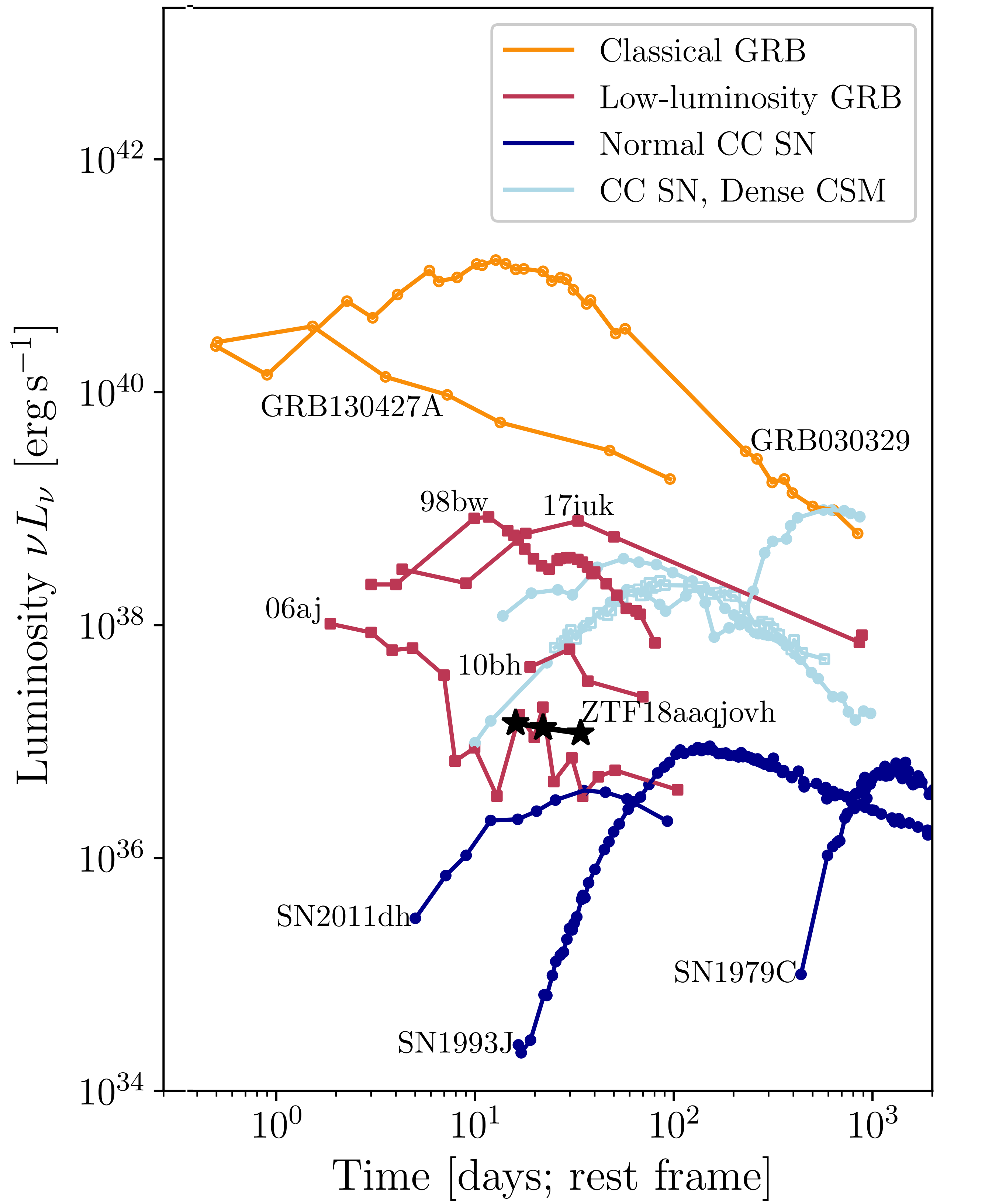
(cartoons modified from Kasliwal+2017)

Why are LLGRBs poorly understood?

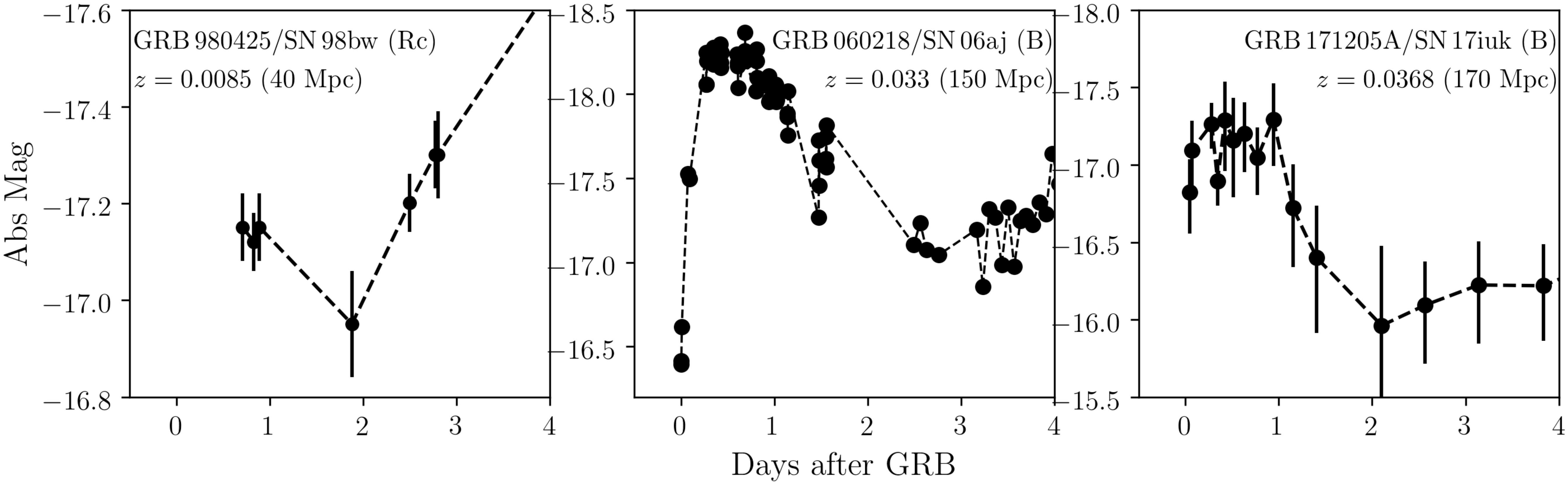
- Low discovery rate by GRB satellites (one every few years)

- Brute-force radio follow-up of Ic-BL SNe is limited by sensitivity (e.g. Corsi +2016, **Ho+2020a**)

Radio (<10 GHz) light curves

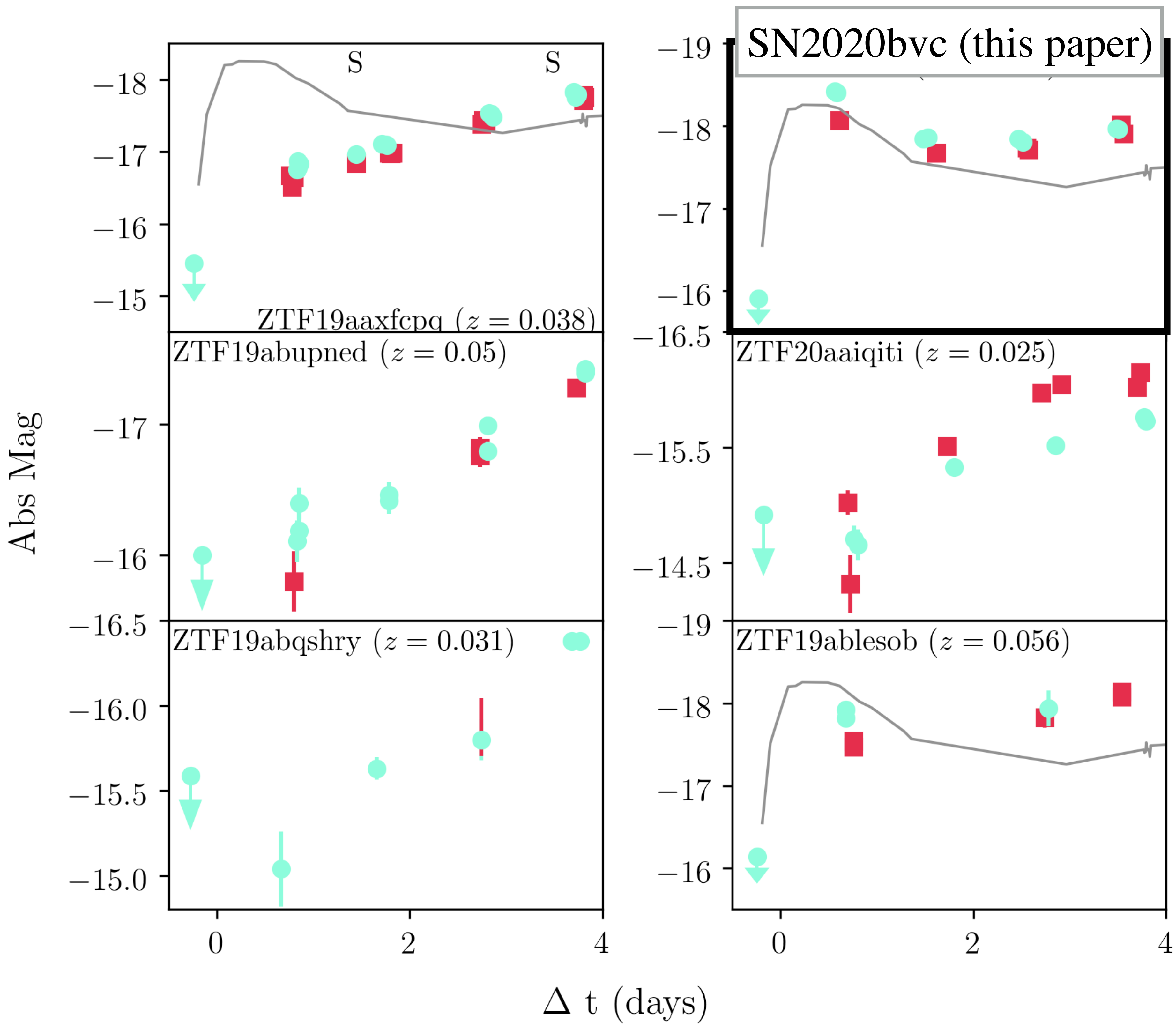


Possibility for optical discovery: double-peaked Ic-BL SNe



Optical avenue: many Ic-BL SNe in ZTF lack a first peak (Ho+2020c)

comparison: GRB 060218 / SN2006aj



Double peaked event also showed luminous radio emission…

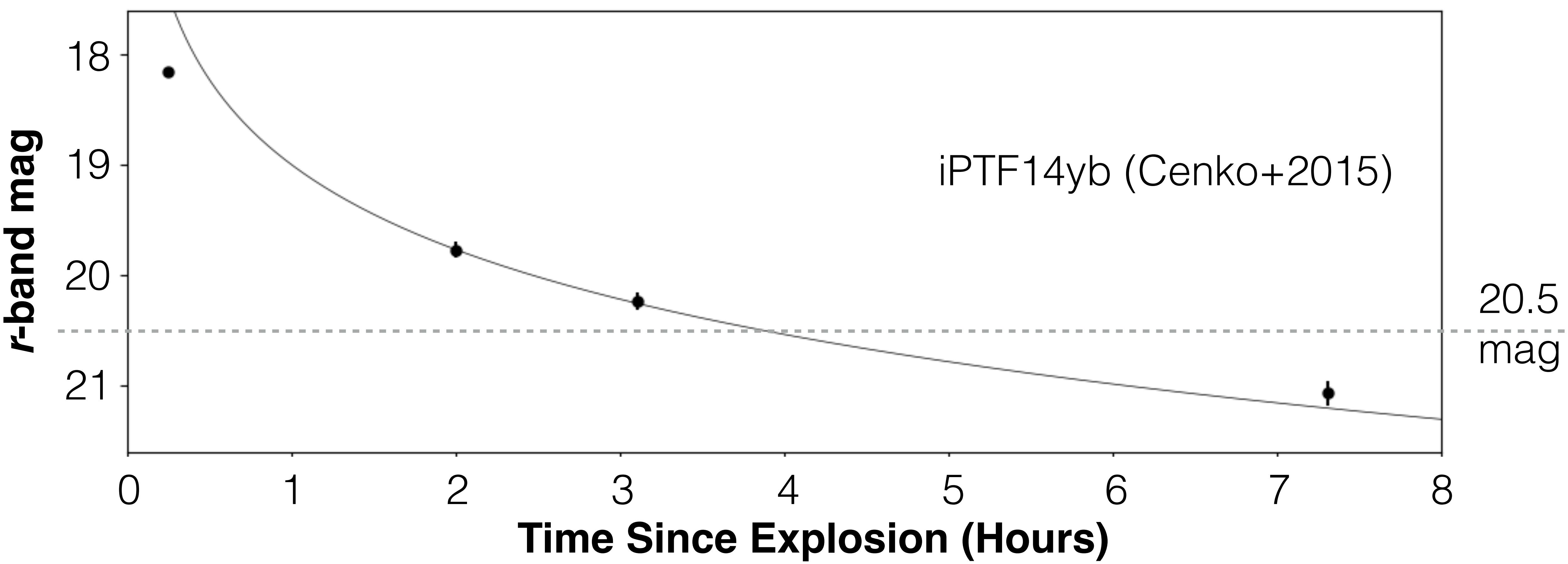
Intriguing suggestion that radio & optical are linked

3) Untriggered Afterglows

Motivation

Does a successful jet have to be clean? Do dirty fireballs exist?

Prior to ZTF, only three untriggered optical afterglows had been found, and the only one with a redshift measurement turned out to be a normal GRB



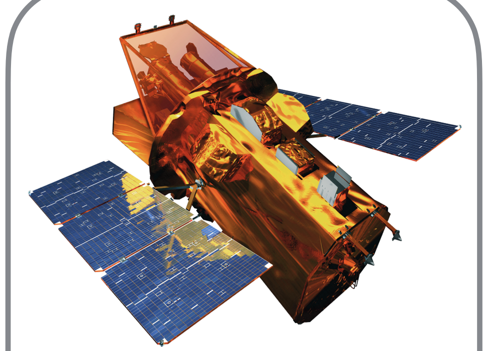
Status

Search has yielded two afterglows to-date: afterglow at z=2.9 lacking a detected GRB (Ho+2020d), and a Fermi LAT GRB (Yao et al. in prep)

4 afterglows found in ZTF in total (two below nominal threshold; Perley+, Andreoni+)

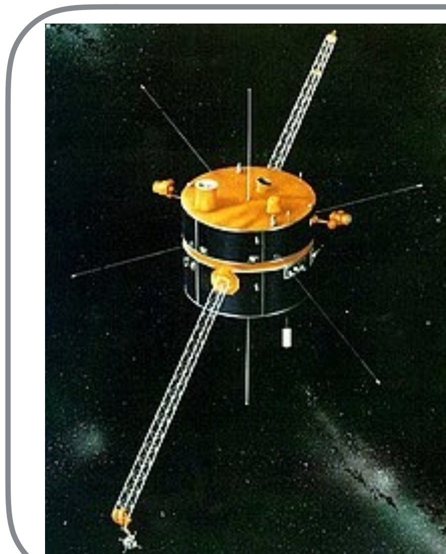
Future

Was there a GRB in AT2020blt (z=2.9)? Impossible to know



Swift:
not in FOV

Fermi:
65% in FoV



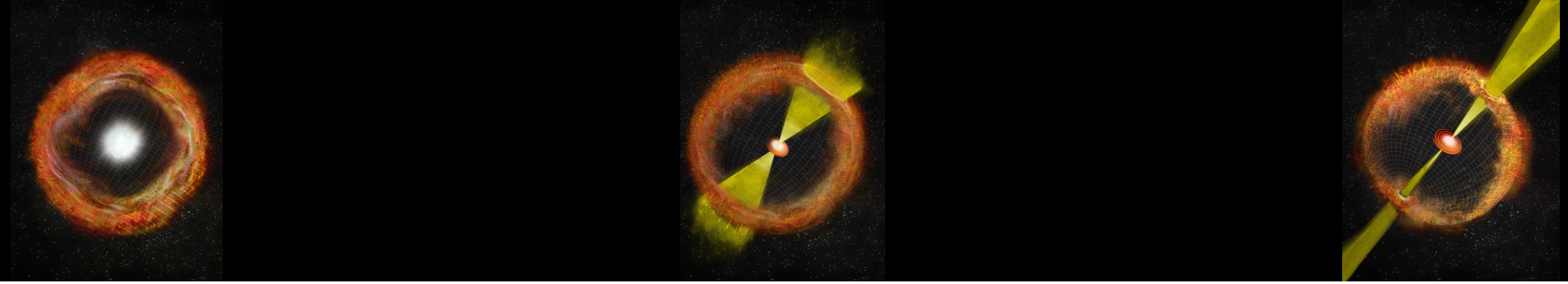
Konus-*Wind*:
100% in FoV

Difficult to distinguish dirty fireball from slightly off-axis jet

No evidence that dirty fireballs exist (if they look the same as classical afterglows)

Population: could use

- luminosity function,
- probabilistic statements about coverage by GRB satellites,
- shape of the optical light curve



B. Saxton, NRAO/AUI/NSF

Questions?

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