Transients upon Black Holes Born from Erupting Massive Stars

Daichi Tsuna

DT, Ishii, Kuriyama, Kashiyama, Shigeyama (2020), ApJL, 897, L44
DT, Kashiyama, Shigeyama (work in progress)

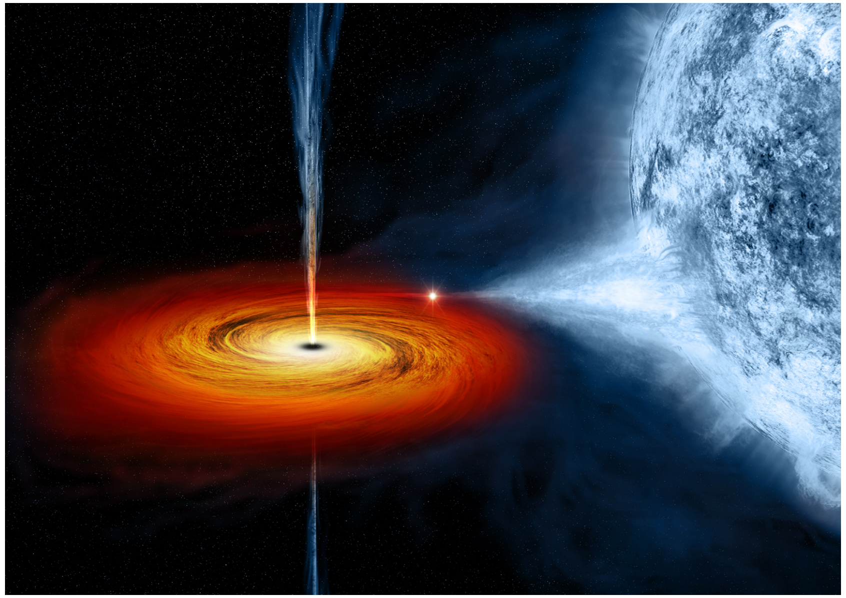
RESCEU Virtual Summer School. August, 2020

How can we probe newborn BHs?

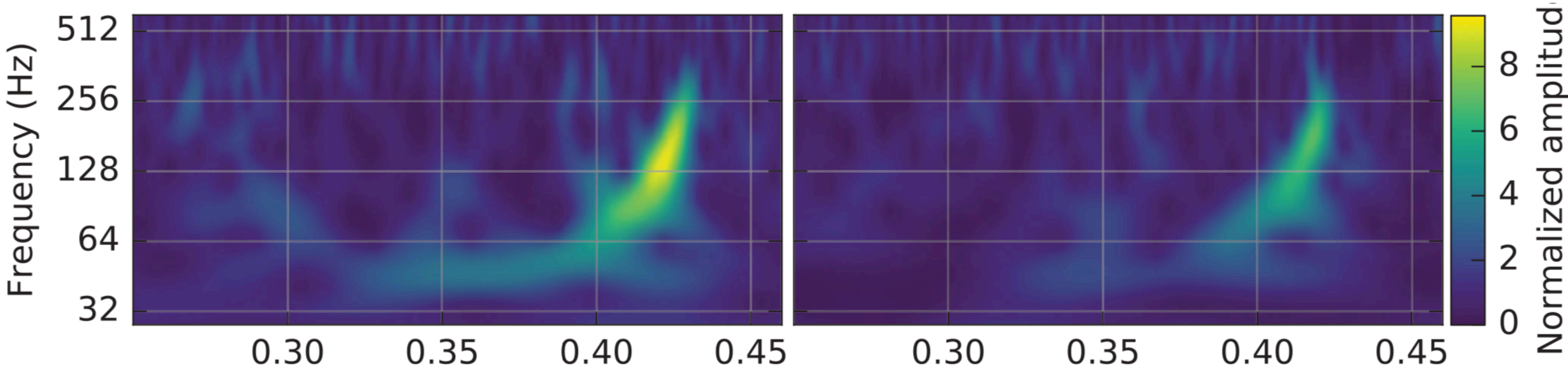
We know that stellar-mass BHs exist from X-ray & GW observations

But these are “old” BHs, and they don’t tell us much about their parental populations

How to find newborn BHs?



NASA



Abbott+16

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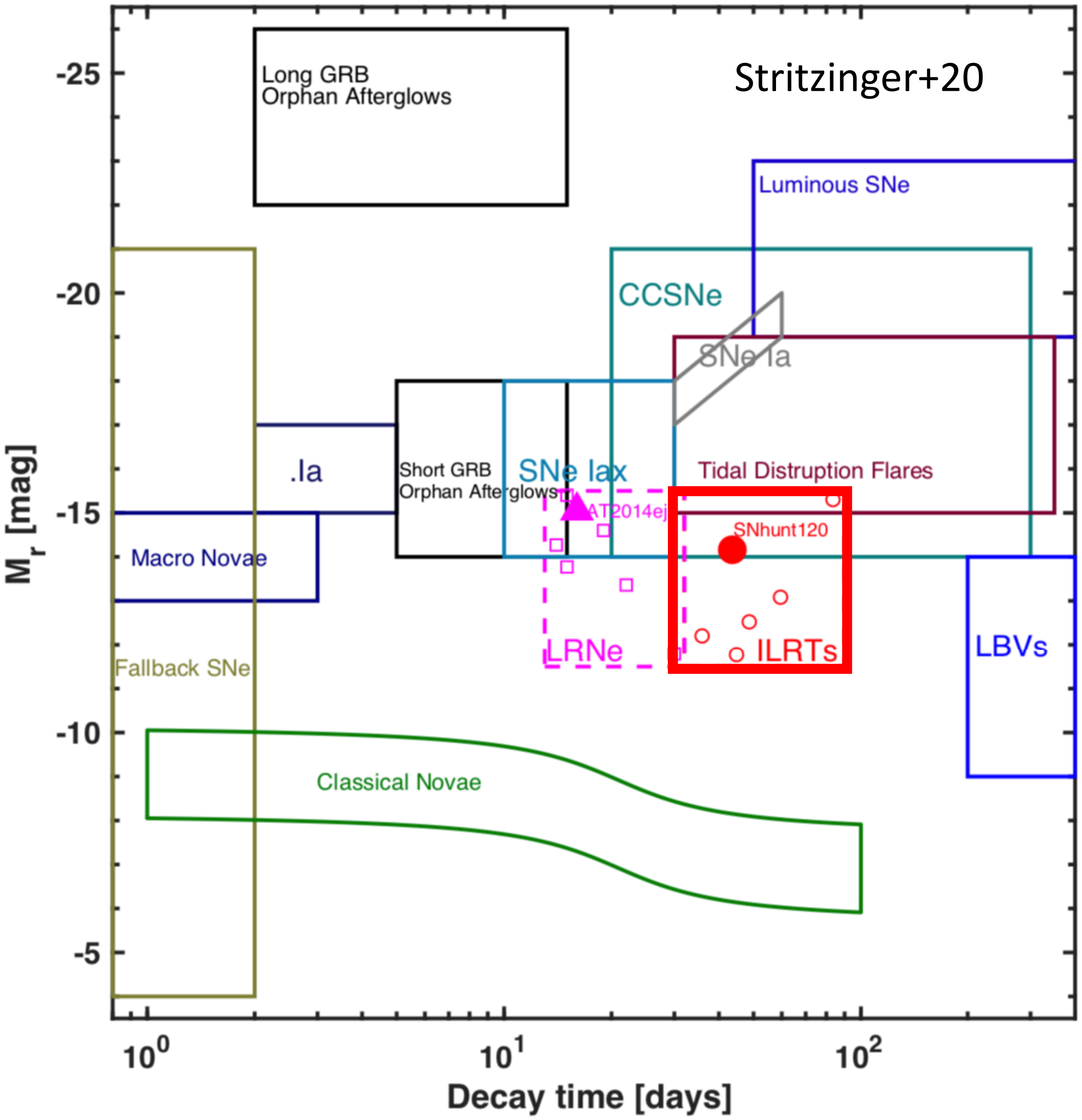
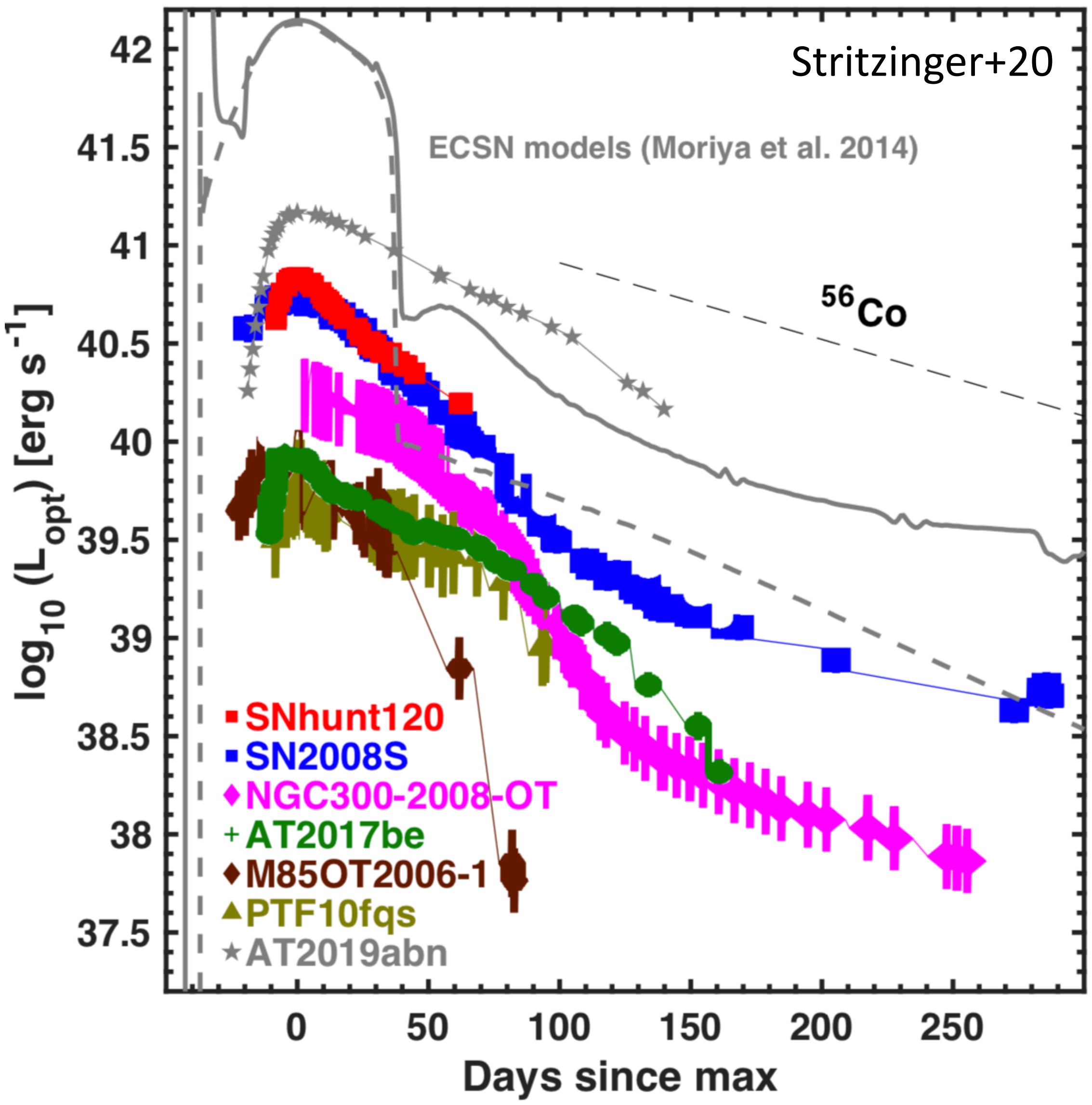
How to find newborn BHs?

Some may be in peculiar transients found by recent optical surveys

➢ Intermediate luminosity red transients?

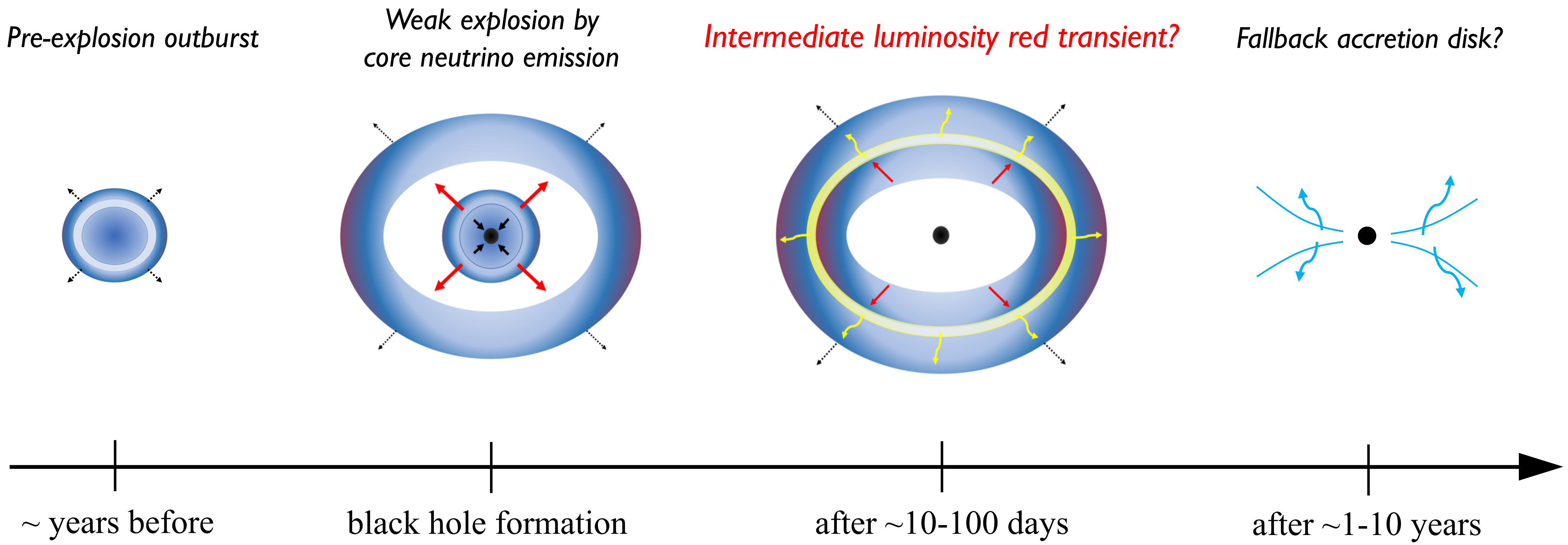


ILRTs = Electron-capture SNe? Or something else?



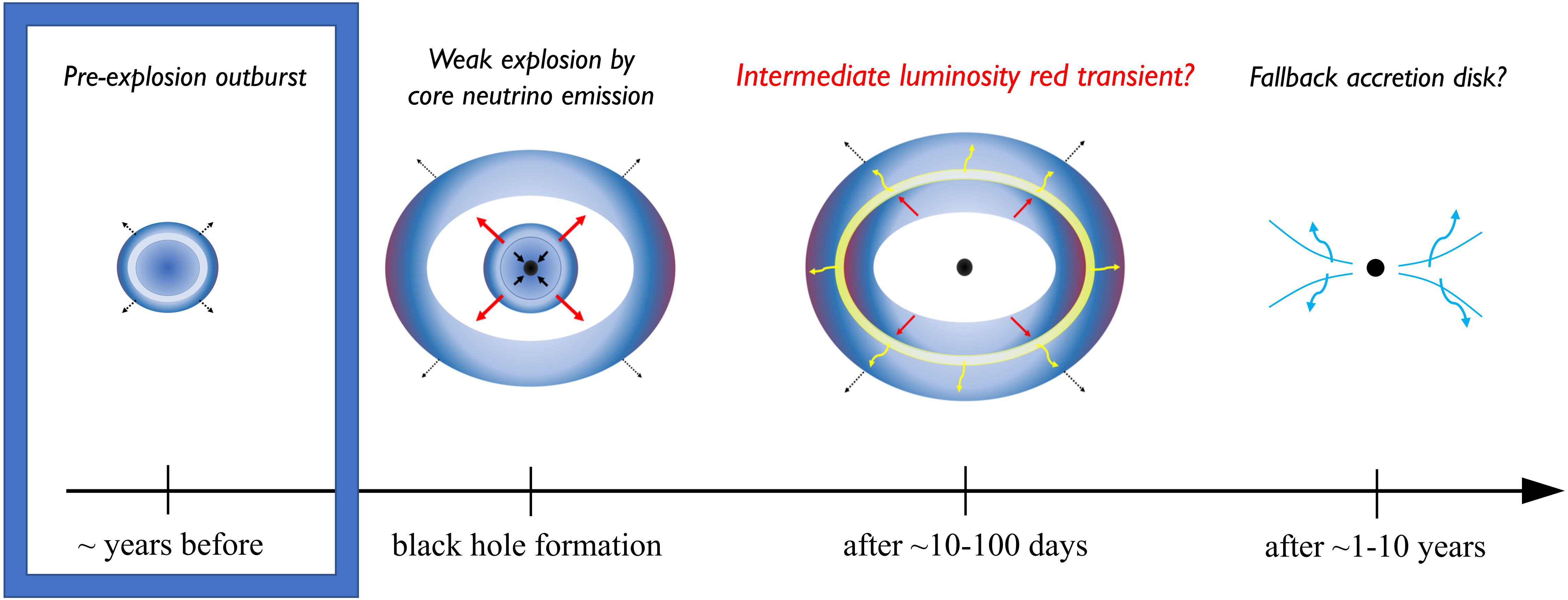
A Failed SN+CSM model for ILRTs

DT, Ishii, Kuriyama, Kashiyama, Shigeyama 2020

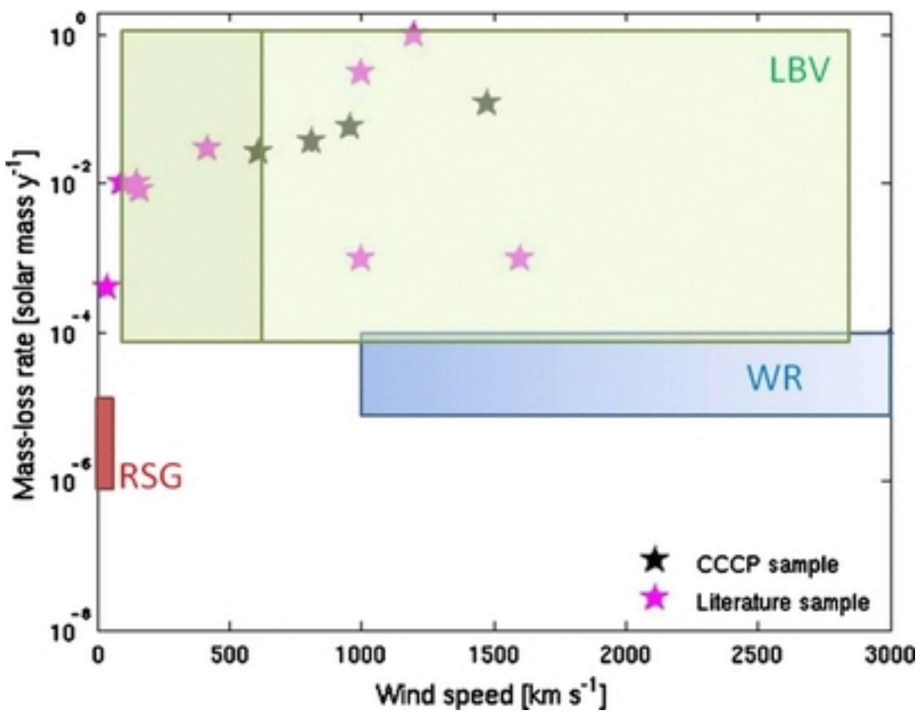


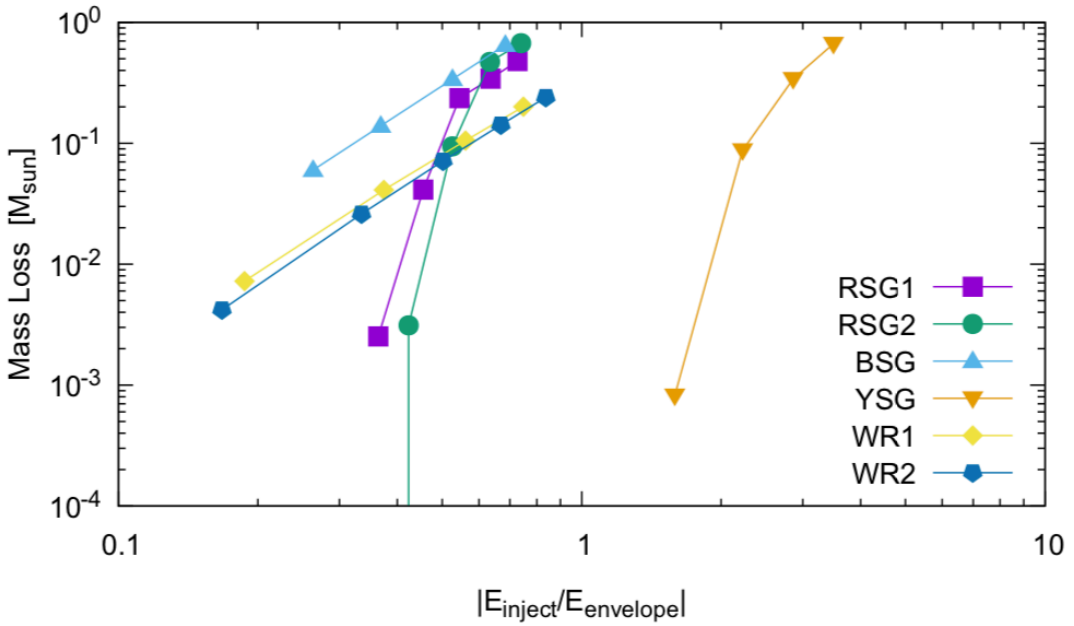
Our hypothesis: Transient is powered by the collision of ejecta from a failed supernova with a pre-ejected dense circumstellar medium

A moment before the BH forms...



Formation of circumstellar medium



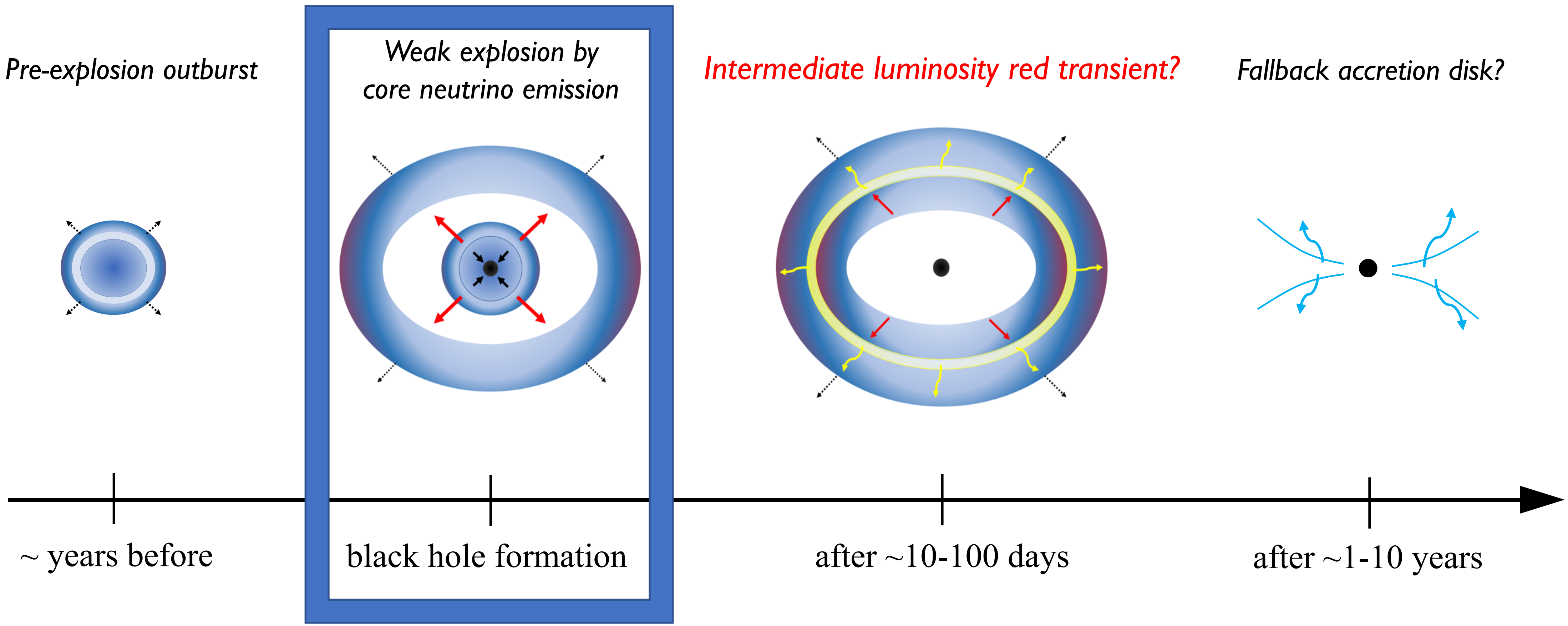


Core-collapse SN often show presence of huge mass loss just before explosion

This can be explained by mass eruption occurring years before core-collapse.

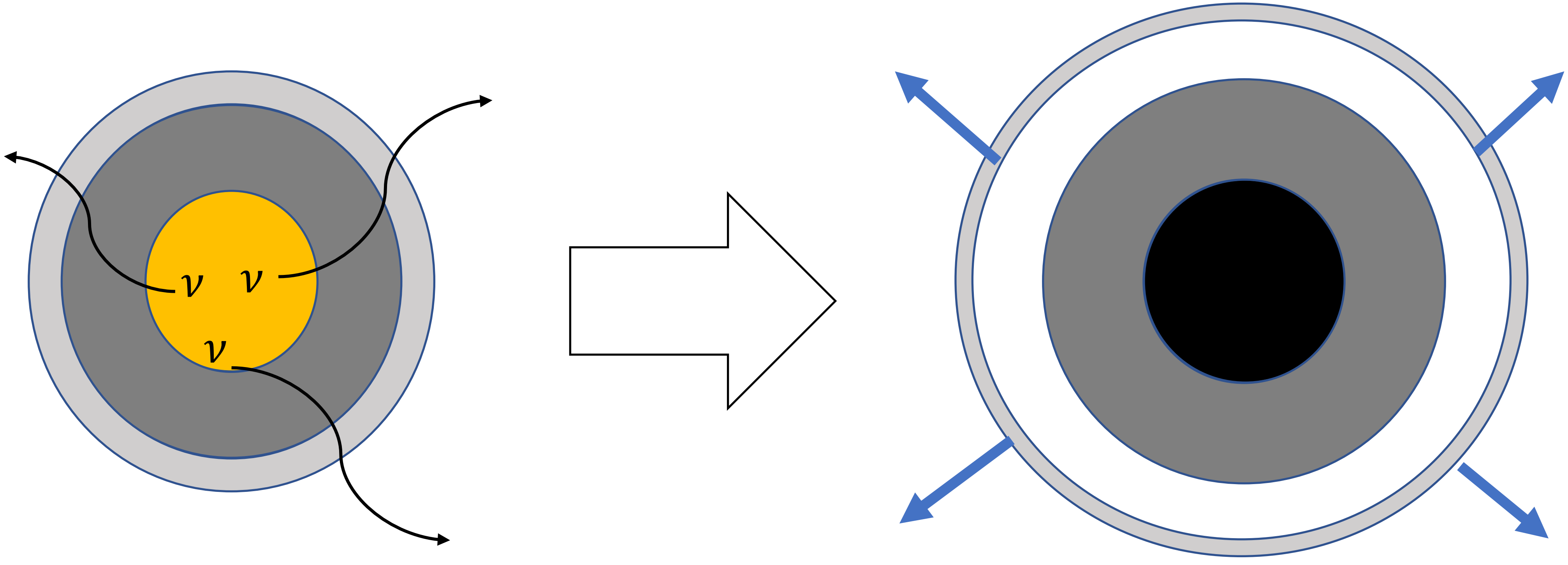
And this mass eruption naturally can happen for BH-forming cases too

The core collapses to a BH...



A mini-explosion!

Nadyozhin 80, Lovegrove & Woosley 13
Fernandez+18, Coughlin+18

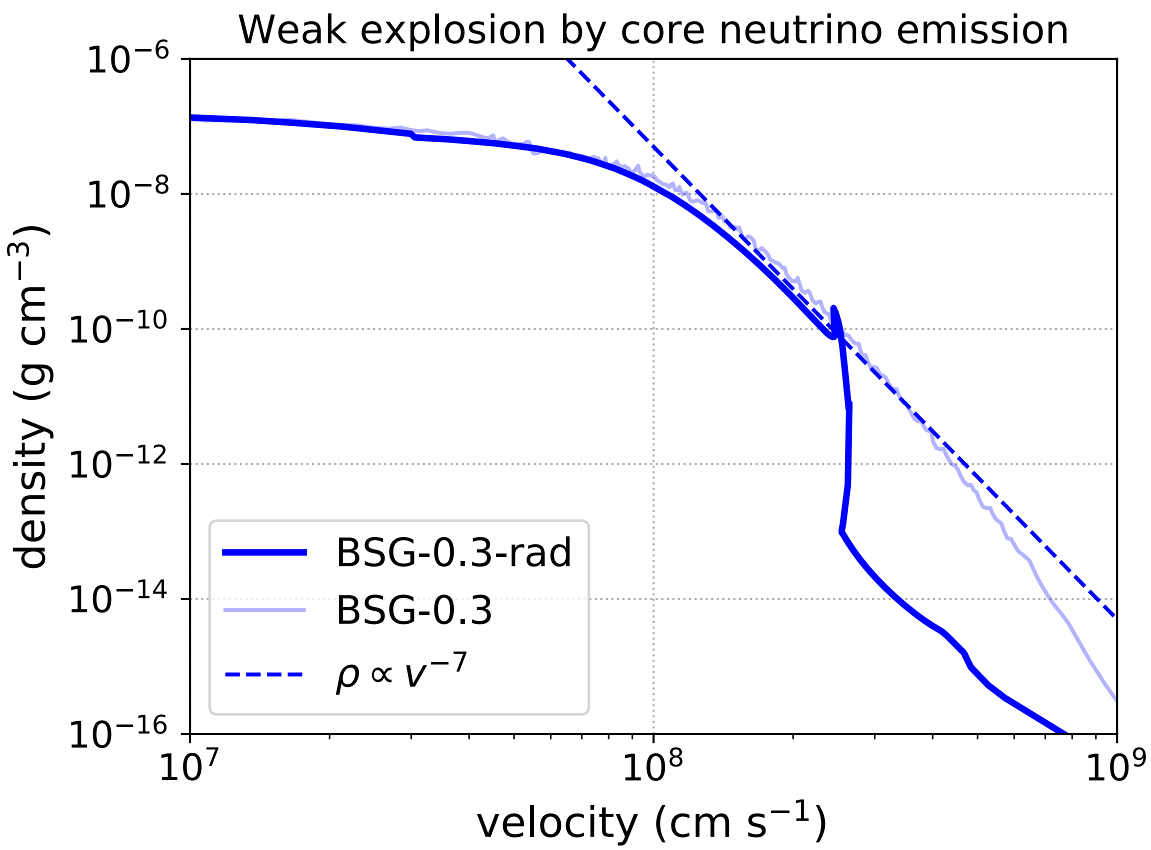


Neutrino mass loss during proto-NS phase can make a fraction of the outer envelope gravitationally unbound

We obtained the properties of the ejecta with hydro simulations.

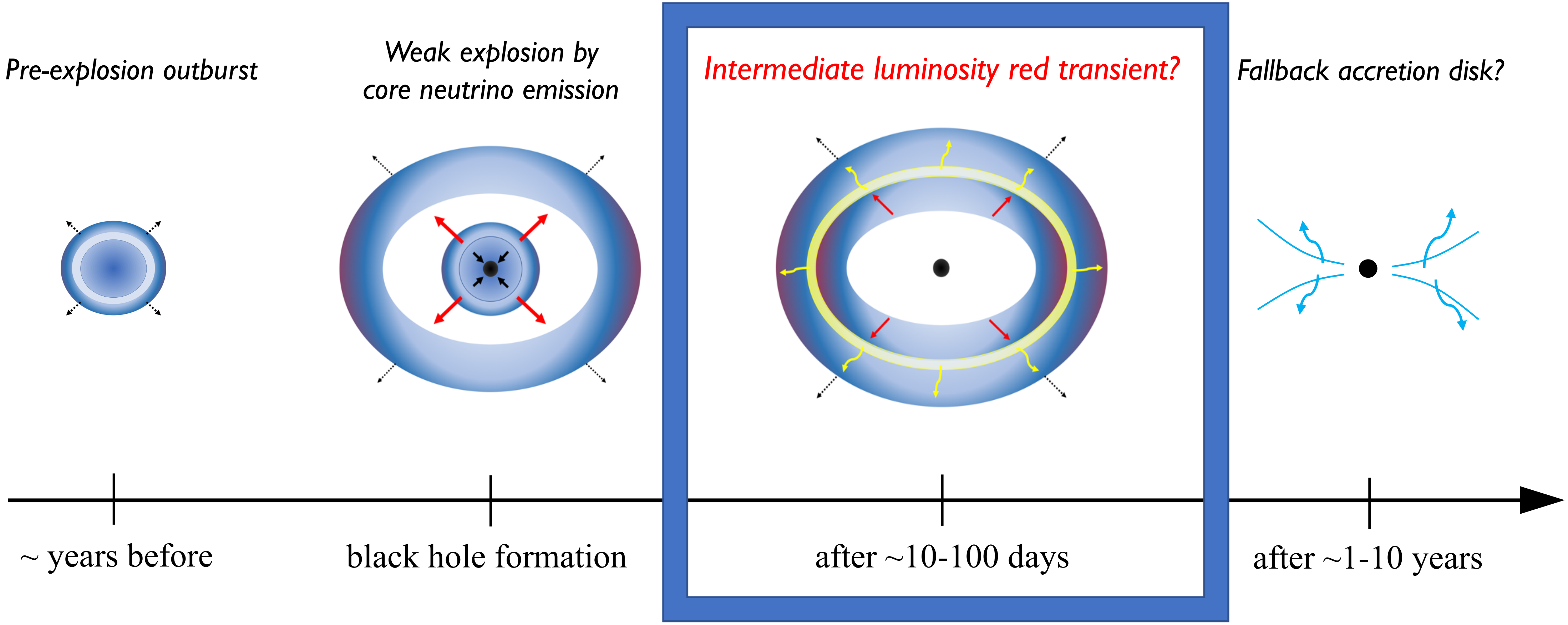
BSGs: $M_{ej} \sim 0.1\, M_{\odot}, E_{ej} \sim 10^{48}$erg

WRs: $M_{ej} \sim 10^{-3} M_{\odot}, E_{ej} \sim 10^{46-47}$erg



Name	R_{cc}	M_{cc}	R_{in}	M_{in}	$\delta M_G (M_\odot)$	M_{ej} $(M_\odot)$		E_{ej} (erg)
BSG–0.2	6.7×10^{12}	11.7	1.7×10^9	3.9	0.2	0.076	BSGs	4.0×10^{47}
BSG–0.3					0.3	0.11		1.1×10^{48}
BSG–0.4					0.4	0.16		2.2×10^{48}
BSG–0.3–rad					0.3	0.096		6.0×10^{47}
WR–0.3	2.9×10^{10}	10.3	2.2×10^9	8.9	0.3	4.0×10^{-4}	WR	1.9×10^{46}

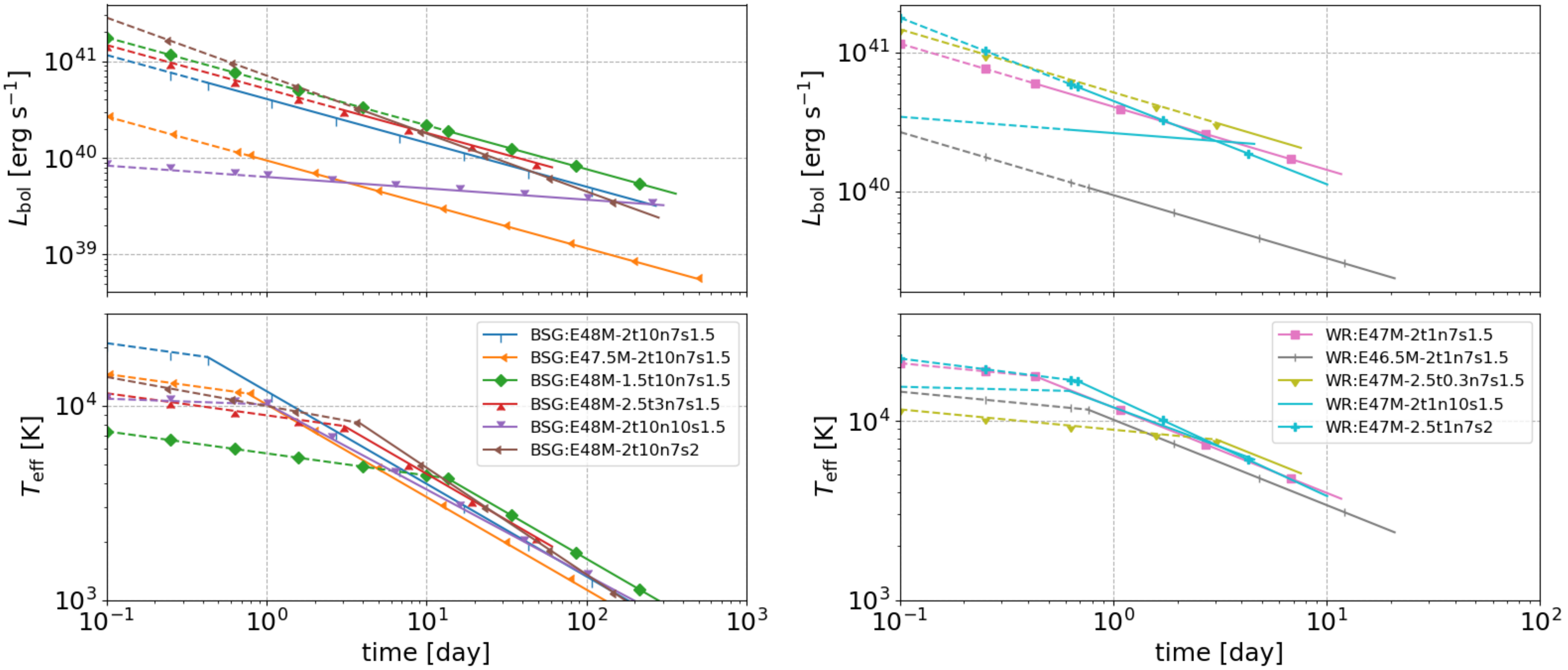
Ejecta & CSM collides for 10-100 days…



Shocks form and heats gas, creating photons via bremsstrahlung

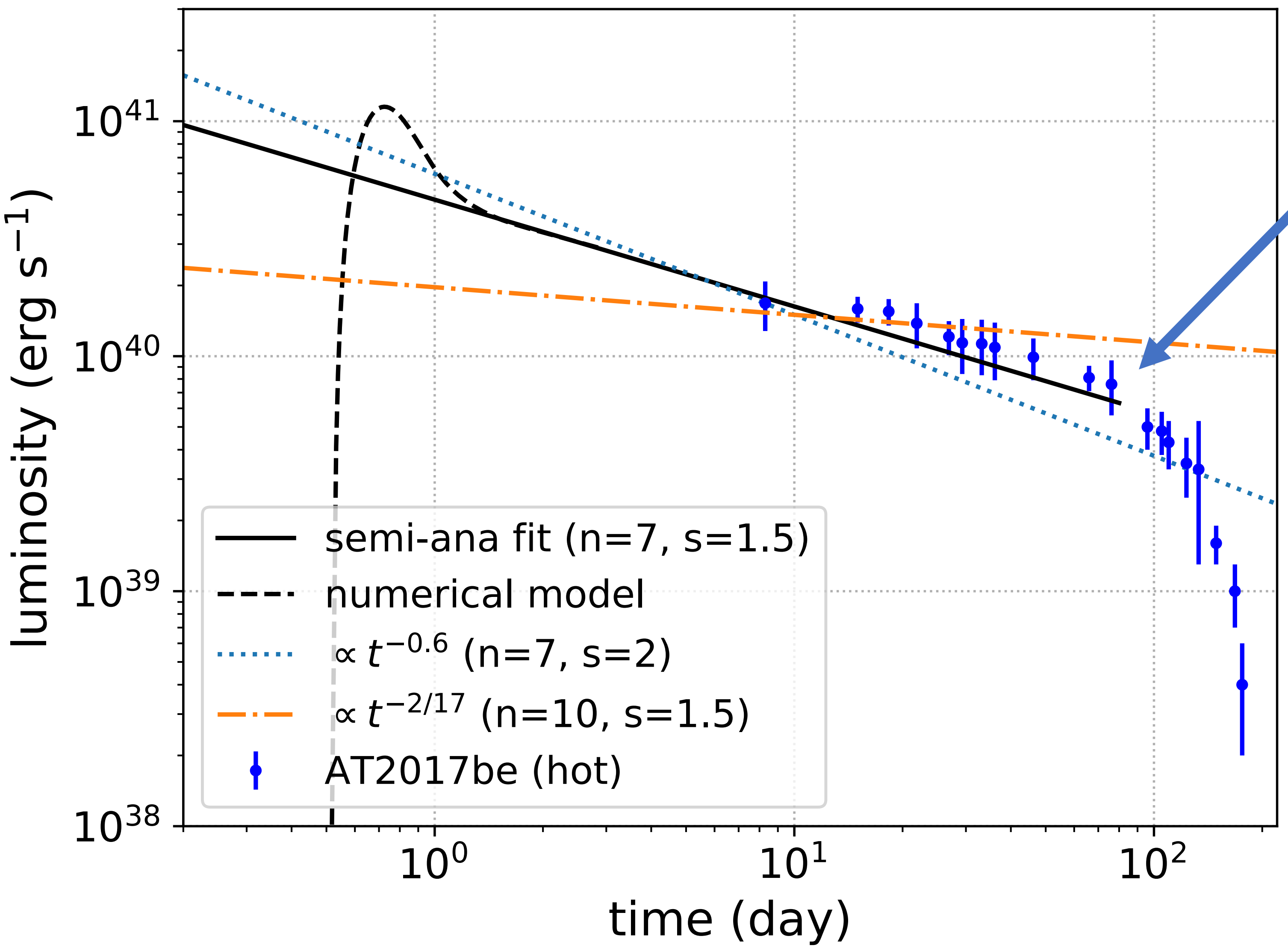
We use the light curve model by Tsuna+19, adopting reasonable ejecta & CSM params

Light curves



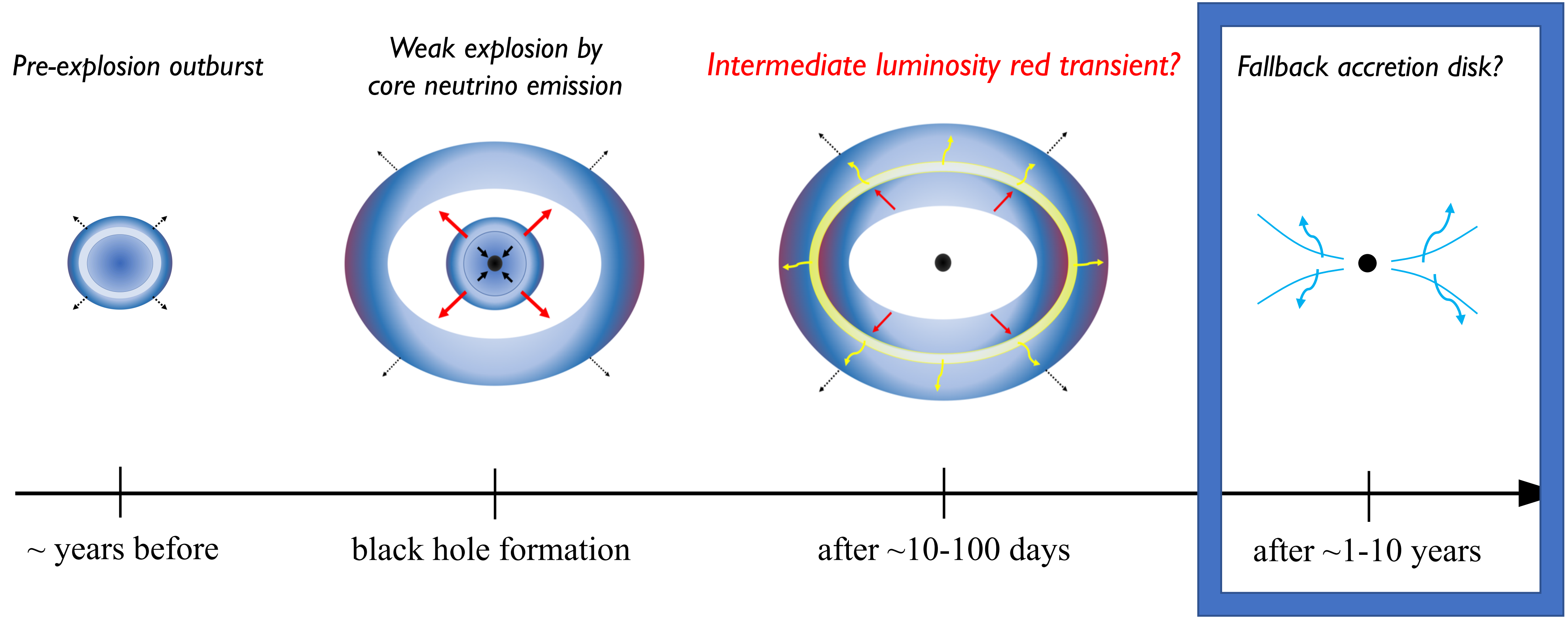
10^{40}~10^{41}erg/s, 10-100 days, ~5000 K

Our model reproduces ILRT AT2017be!



The outer ejecta is completely used, and the light curve will cutoff from here

We predict that years later…



An accretion disk can form?

Specific angular momentum required to circularize outside ISCO

$$j_{circ} \sim (2\sqrt{3}GM_{BH})/c \sim 10^{17}\ \mathrm{cm^2 s^{-1}} \left(\frac{M_{BH}}{10\mathrm{M_\odot}}\right)$$

Specific angular momentum at star's surface

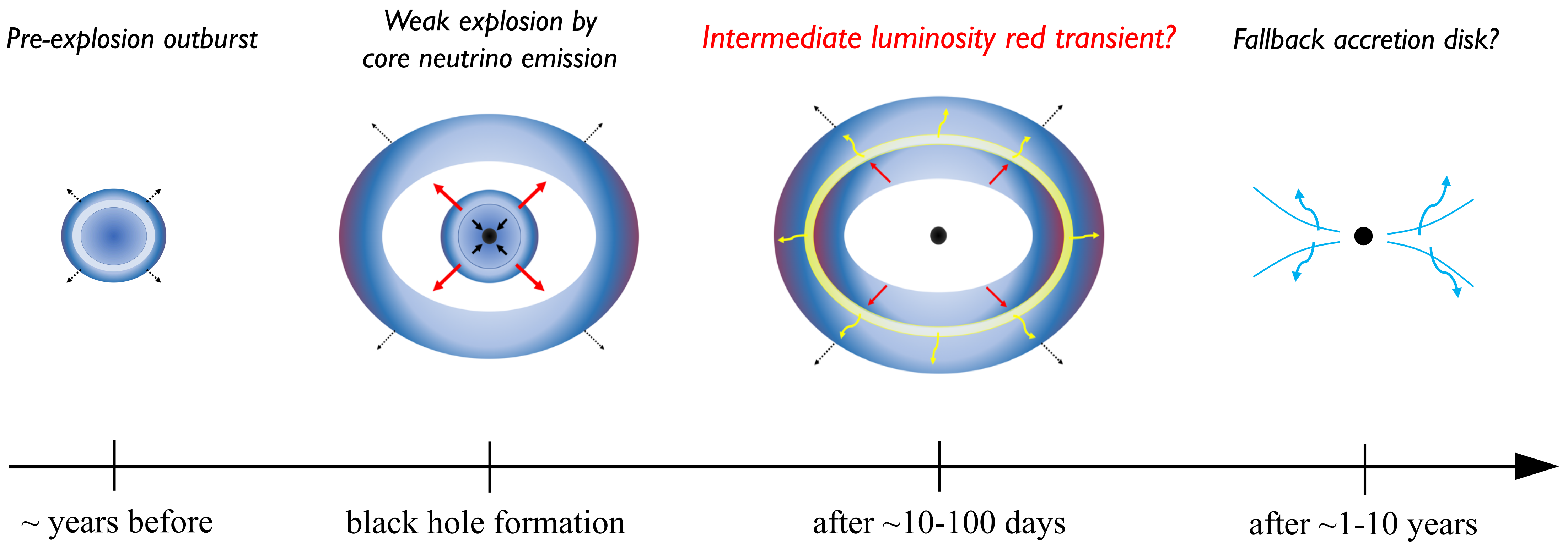
$$j_{surf} \sim R_{surf} v_{rot} \sim 7{\times}10^{17}\ \mathrm{cm^2 s^{-1}} \left(\frac{R_{surf}}{10\mathrm{R_\odot}}\right)\left(\frac{v_{rot}}{10\mathrm{km/s}}\right) > \boldsymbol{j_{circ}}!$$

Flux if BH radiates at Eddington luminosity (can last ~30yrs for BSGs, ~1yr for WRs)

$$F_{Edd} \sim \frac{L_{Edd}}{4\pi d^2} \sim 10^{-13}\mathrm{erg\ s^{-1}\ cm^{-2}} \left(\frac{M_{BH}}{10\mathrm{M_\odot}}\right)\left(\frac{d}{10\mathrm{Mpc}}\right)^{-2}$$

- ➢X-rays from BH accretion disk can be detectable ~years after BH formation

Summary



1) (Some) ILRTs may be powered by collision of a failed SN ejecta with a CSM
2) X-rays from fallback accretion years after the transient may be a smoking gun