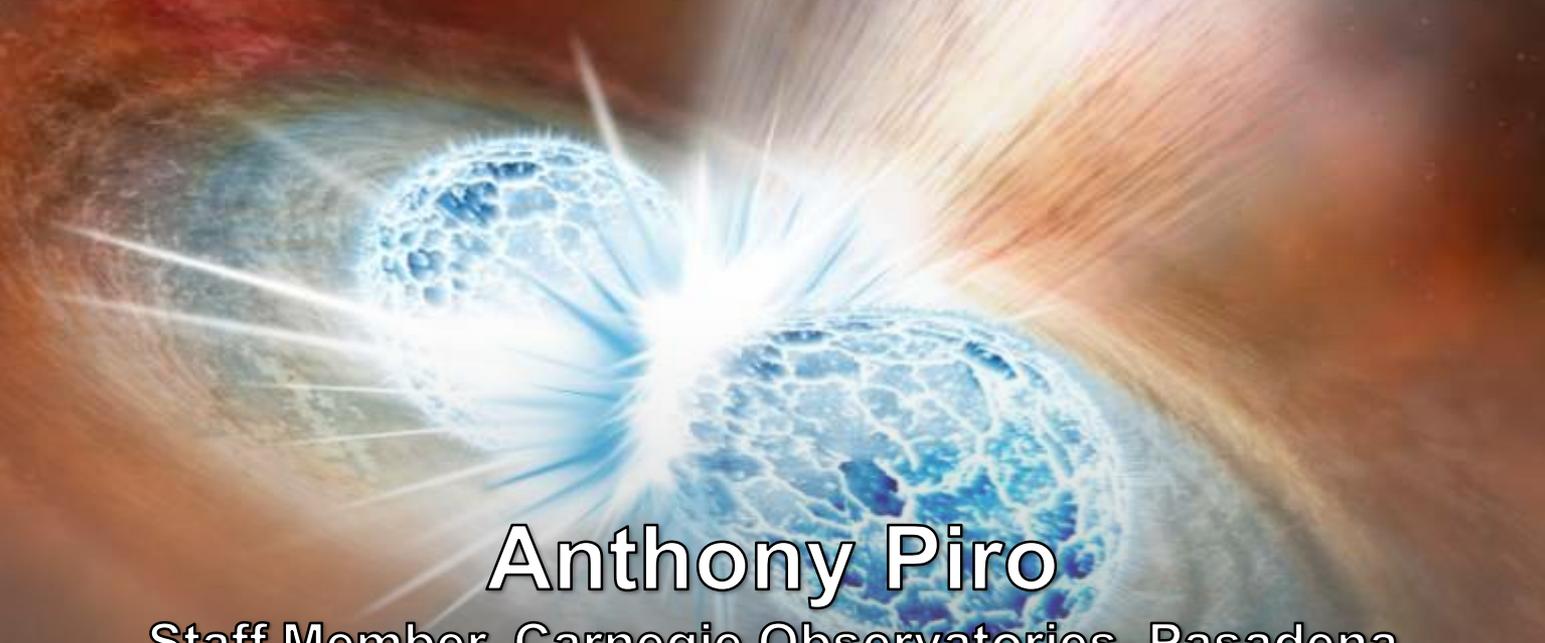


The Early Optical Emission from SSS17a

An artistic illustration of a double neutron star merger. Two blue, textured spheres representing neutron stars are shown in the process of colliding. A bright, multi-colored flash of light emanates from the point of impact, with rays of light extending outwards. The background is a dark, reddish-brown nebula with some faint star trails.

Anthony Piro

Staff Member, Carnegie Observatories, Pasadena

The First Double Neutron Star Merger, KITP- December 7, 2017

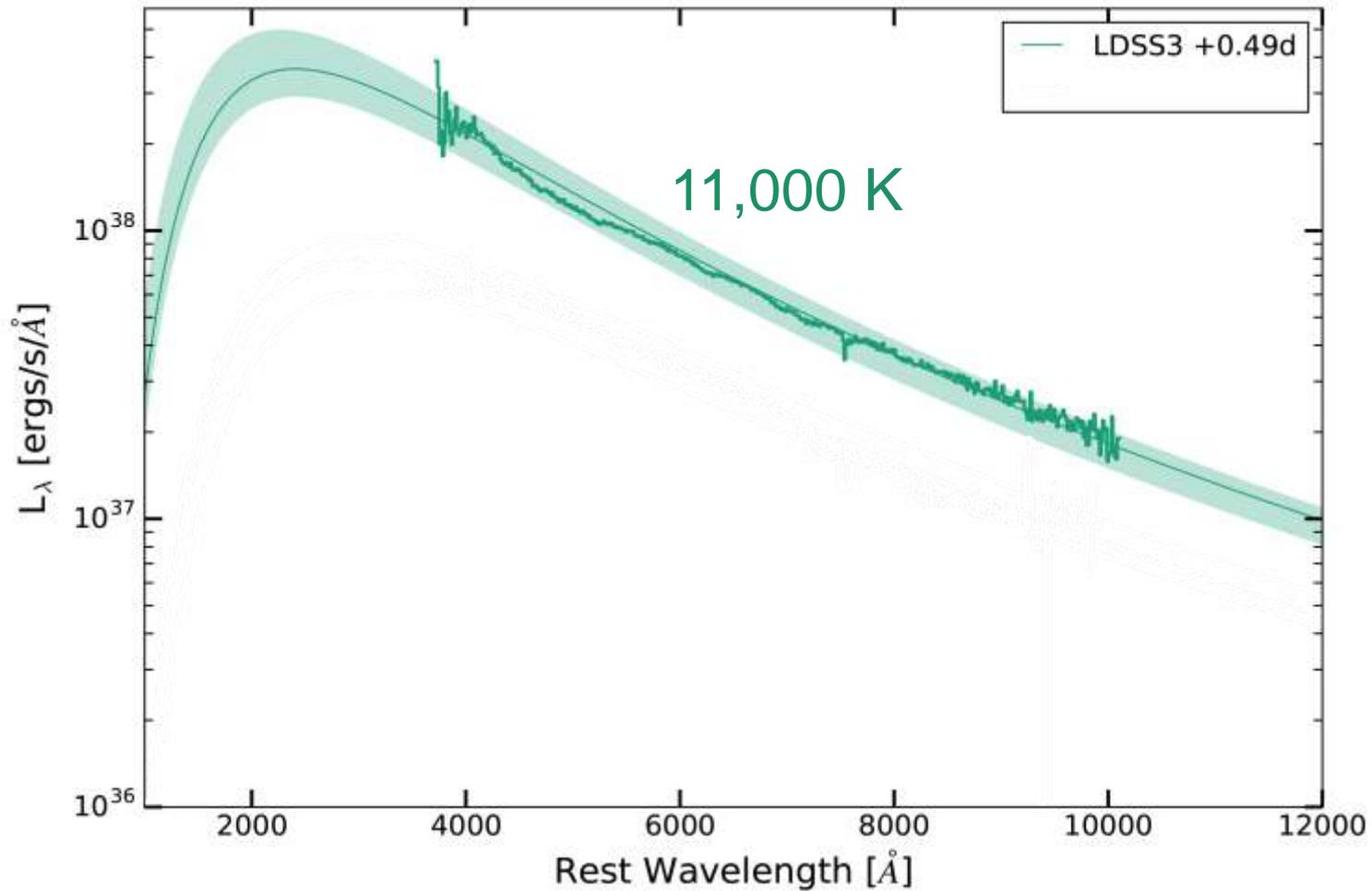


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SCIENCE

Illustration by Robin Dienel for the Carnegie Institution for Science

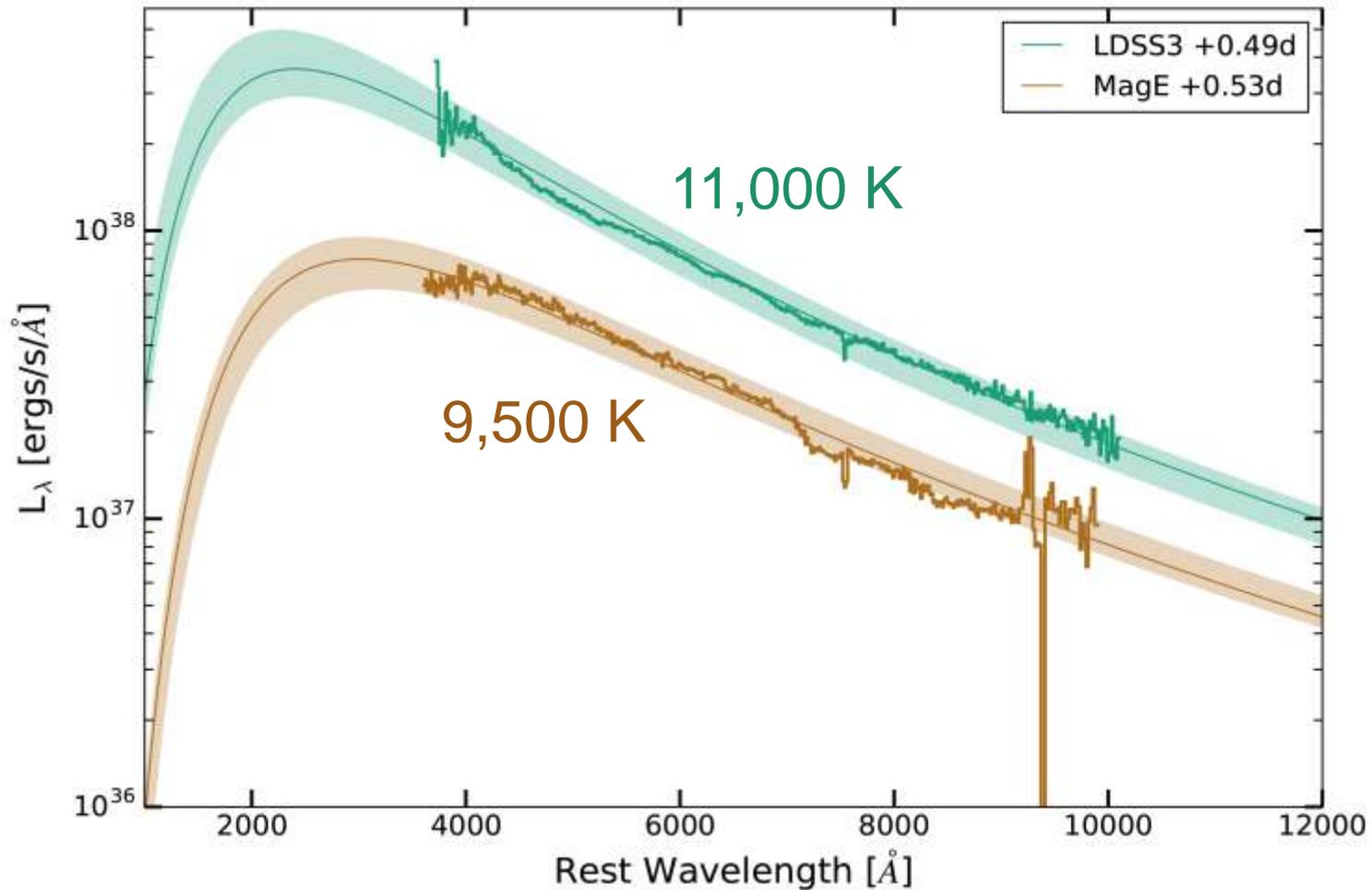
First spectrum of a GW source

Shappee, Simon, Drout, Piro, et al. (2017)



First spectra of a GW source

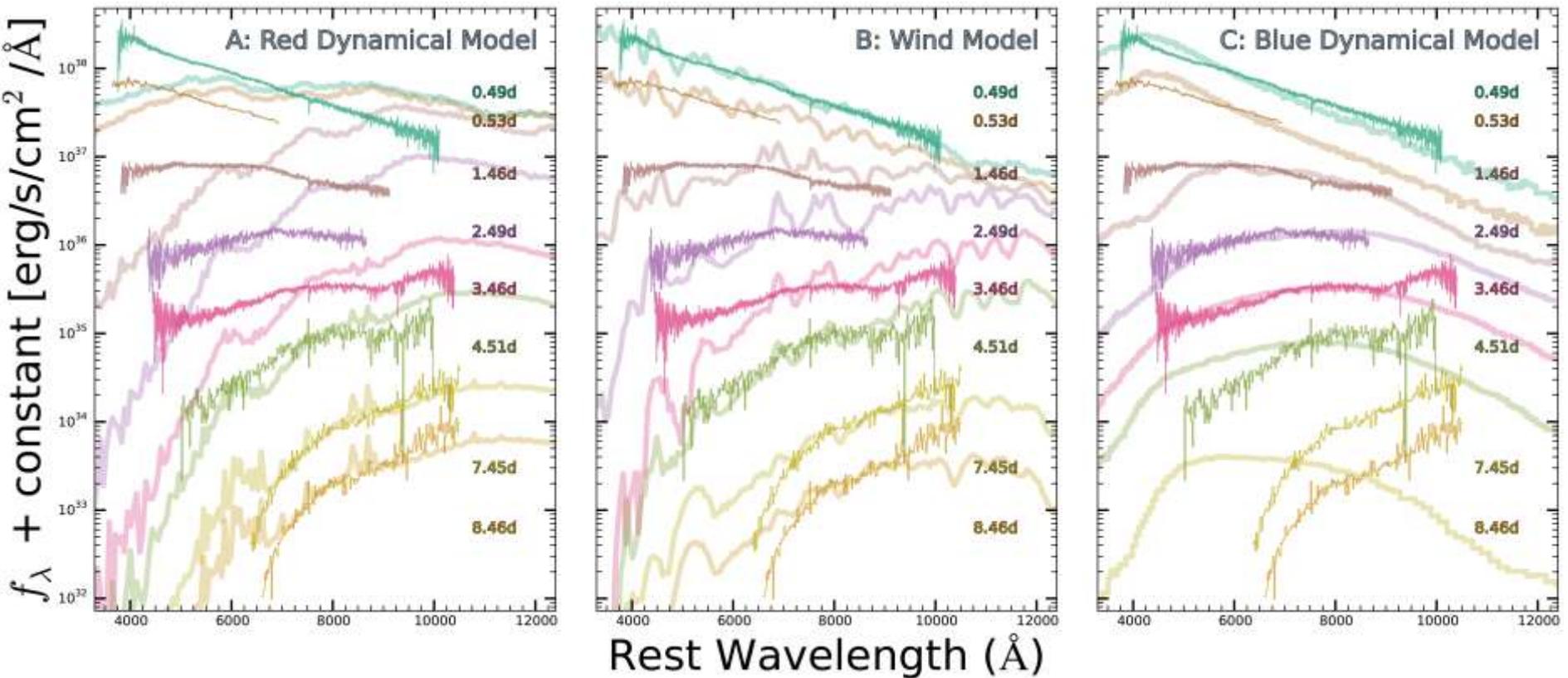
Shappee, Simon, Drout, Piro, et al. (2017)



Fast cooling means ejecta is traveling **30% of the speed of light!**

Comparison to Kilonova Models

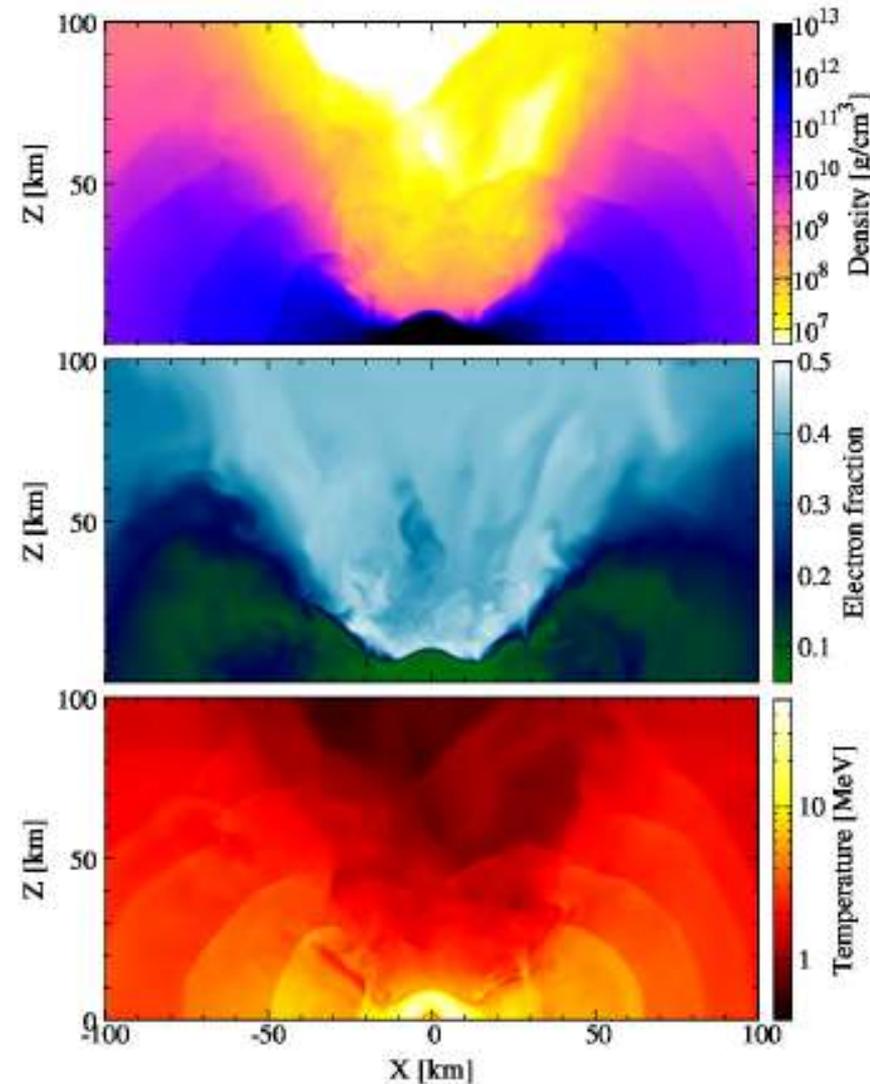
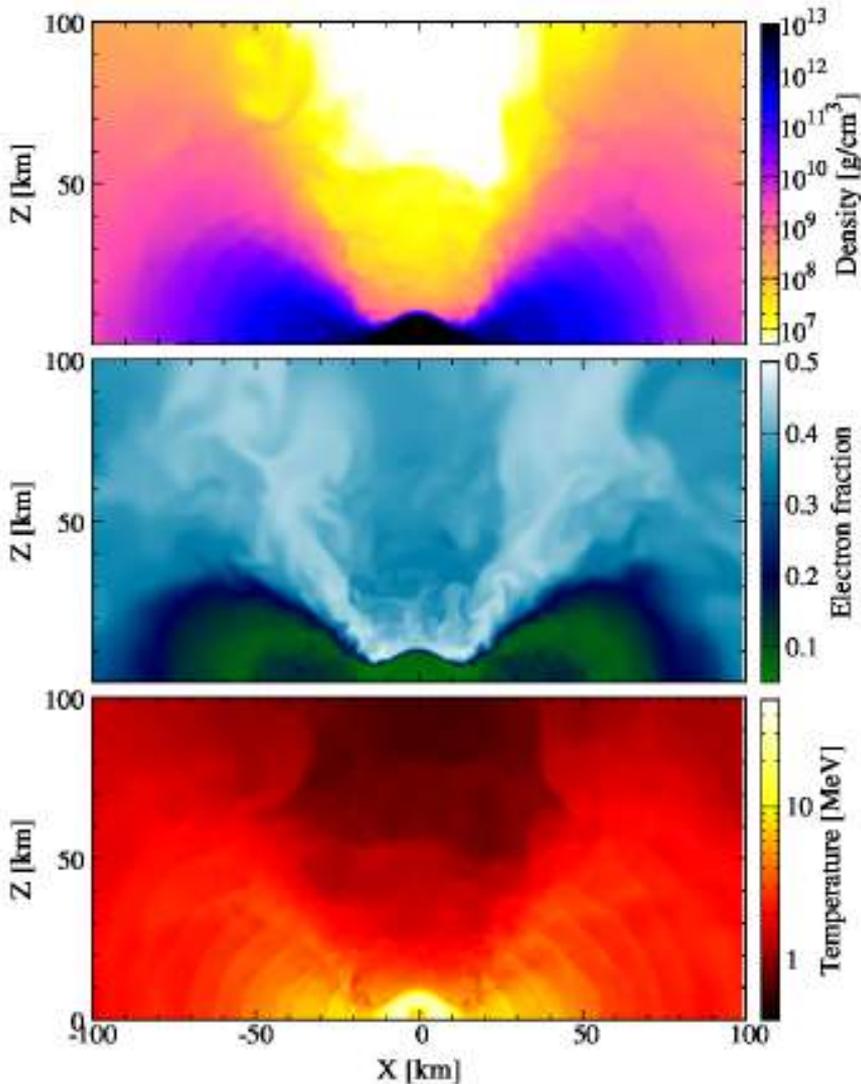
Shappee, Simon, Drout, Piro, et al. (2017)



Blue component needs to be fast and potentially massive (~ 0.01 - $0.03 M_{\text{sun}}$)

Dynamical Ejecta Masses

Sekiguchi, Kiuchi, Kyutoku, Shibata, and Taniguchi (2016)

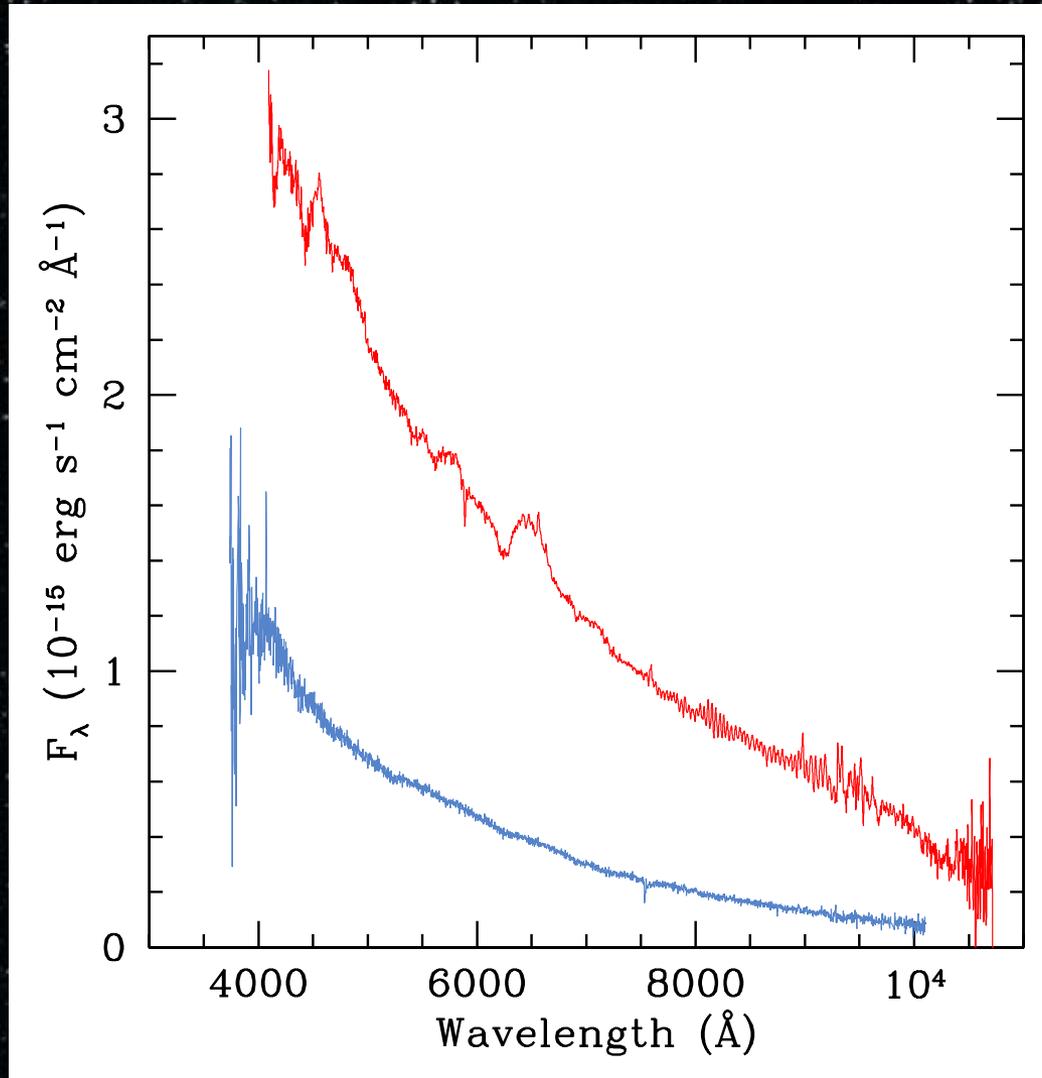


Dynamical Ejecta Masses

Sekiguchi, Kiuchi, Kyutoku, Shibata, and Taniguchi (2016)

Model	(m_1, m_2)	$q = m_2/m_1$	Δx_9 (m)	N	$M_{\text{ej}} (10^{-2} M_{\odot})$	$\langle Y_c \rangle$	V_{ej}
SFHo-135-135h (high)	(1.35, 1.35)	1.00	150	285	1.1	0.31	0.22
SFHo-135-135l (low)	(1.35, 1.35)	1.00	250	160	1.3	0.32	0.21
SFHo-133-137h (high)	(1.37, 1.33)	0.97	150	285	0.9	0.30	0.21
SFHo-130-140h (high)	(1.40, 1.30)	0.93	150	285	0.6	0.27	0.20
SFHo-130-140l (low)	(1.40, 1.30)	0.93	250	160	0.6	0.27	0.21
SFHo-125-145h (high)	(1.45, 1.25)	0.86	150	285	1.1	0.18	0.24
SFHo-125-145l (low)	(1.45, 1.25)	0.86	250	160	1.2	0.19	0.23
DD2-135-135h (high)	(1.35, 1.35)	1.00	160	285	0.2	0.30	0.16
DD2-135-135l (low)	(1.35, 1.35)	1.00	270	160	0.2	0.30	0.15
DD2-130-140h (high)	(1.40, 1.30)	0.93	160	285	0.3	0.26	0.18
DD2-125-145h (high)	(1.45, 1.25)	0.86	160	285	0.5	0.20	0.19

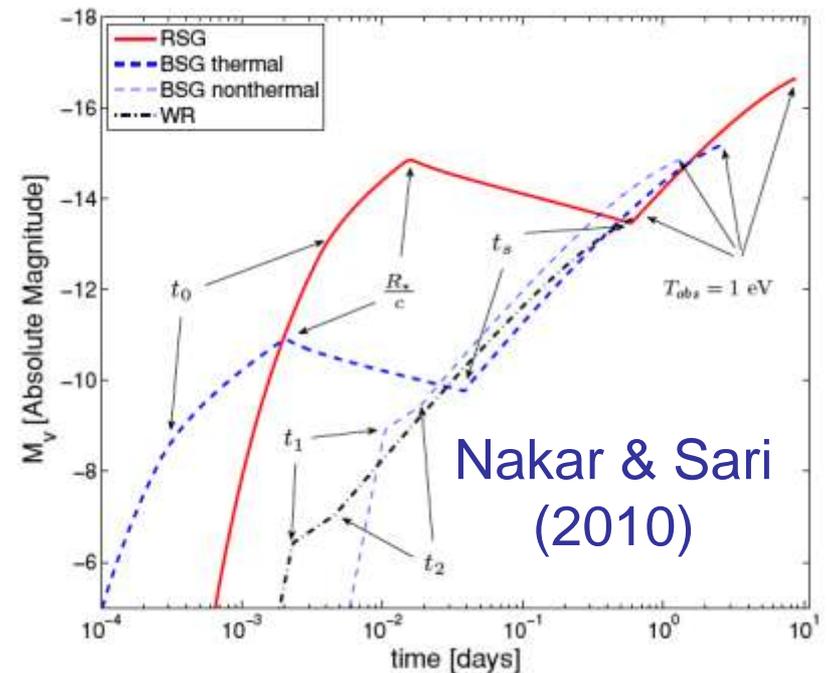
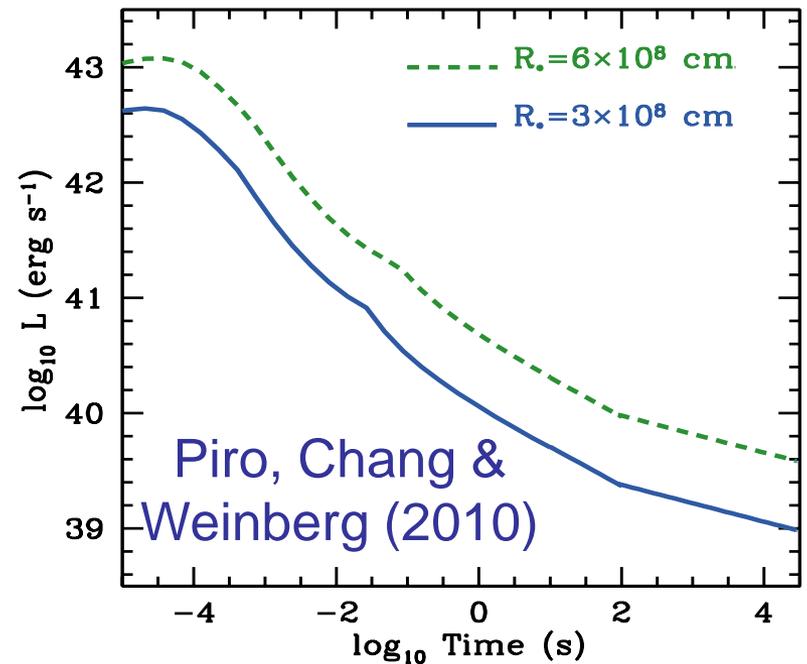
SSS17a versus Early Supernova



Following Breakout is Shock Cooling

- Early UV/optical dominated by cooling of shock-heated material
- Luminosity proportional to initial radius

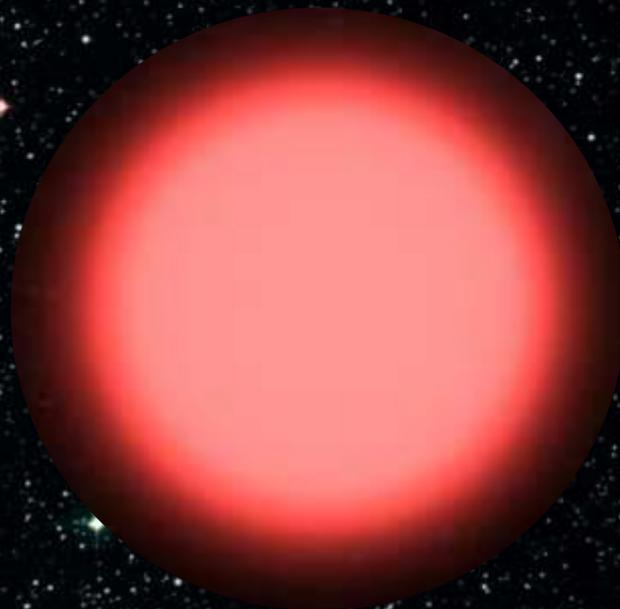
$$L \sim \frac{4\pi c R_0}{\kappa} \frac{E}{M}$$



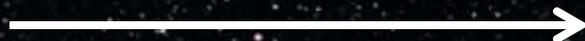
Shock Cooling Proportional to R_0



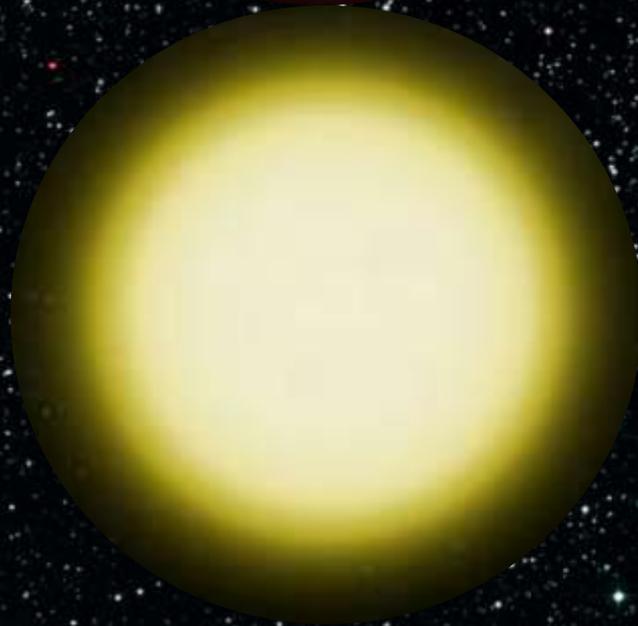
Expands and cools



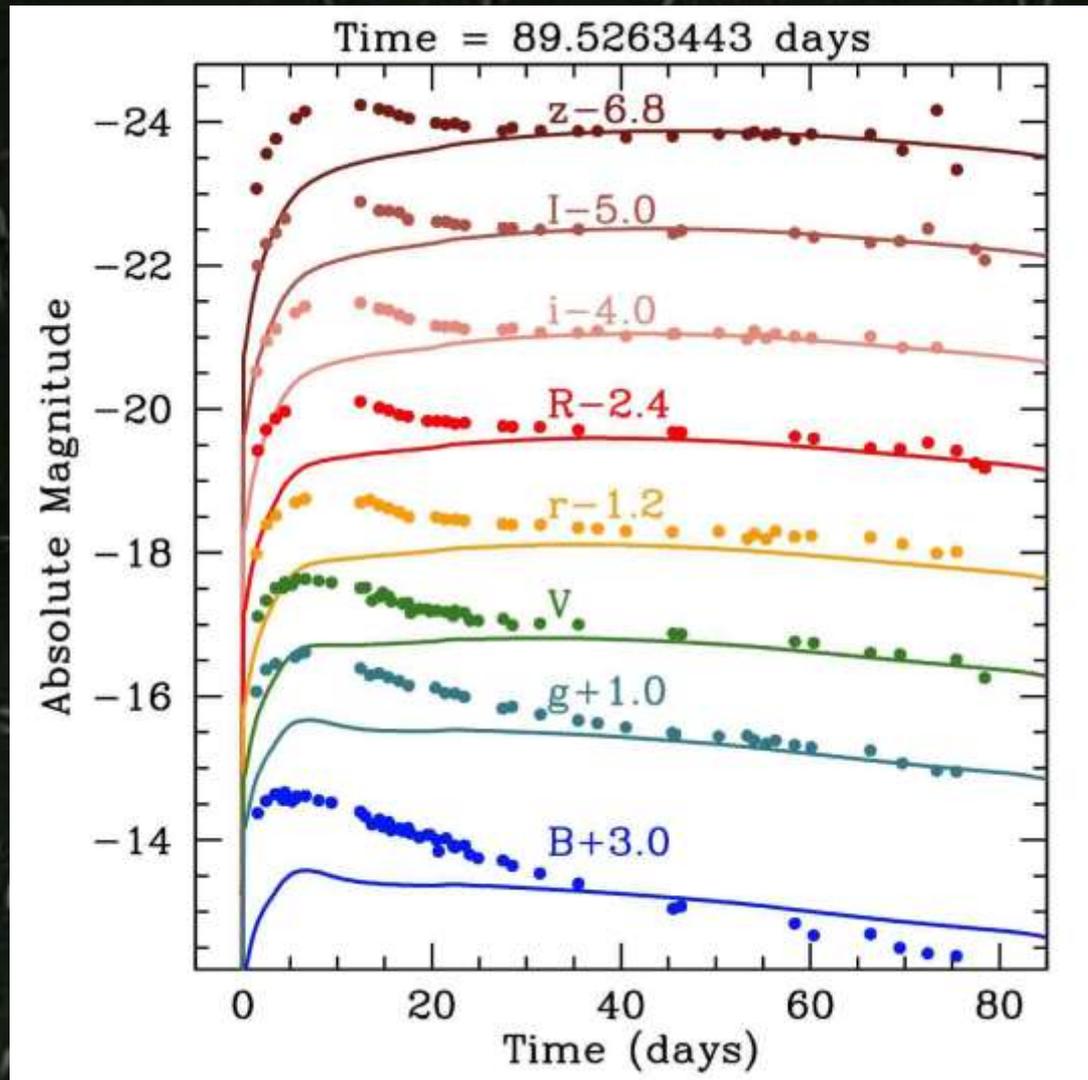
Expands and cools



...but not as much

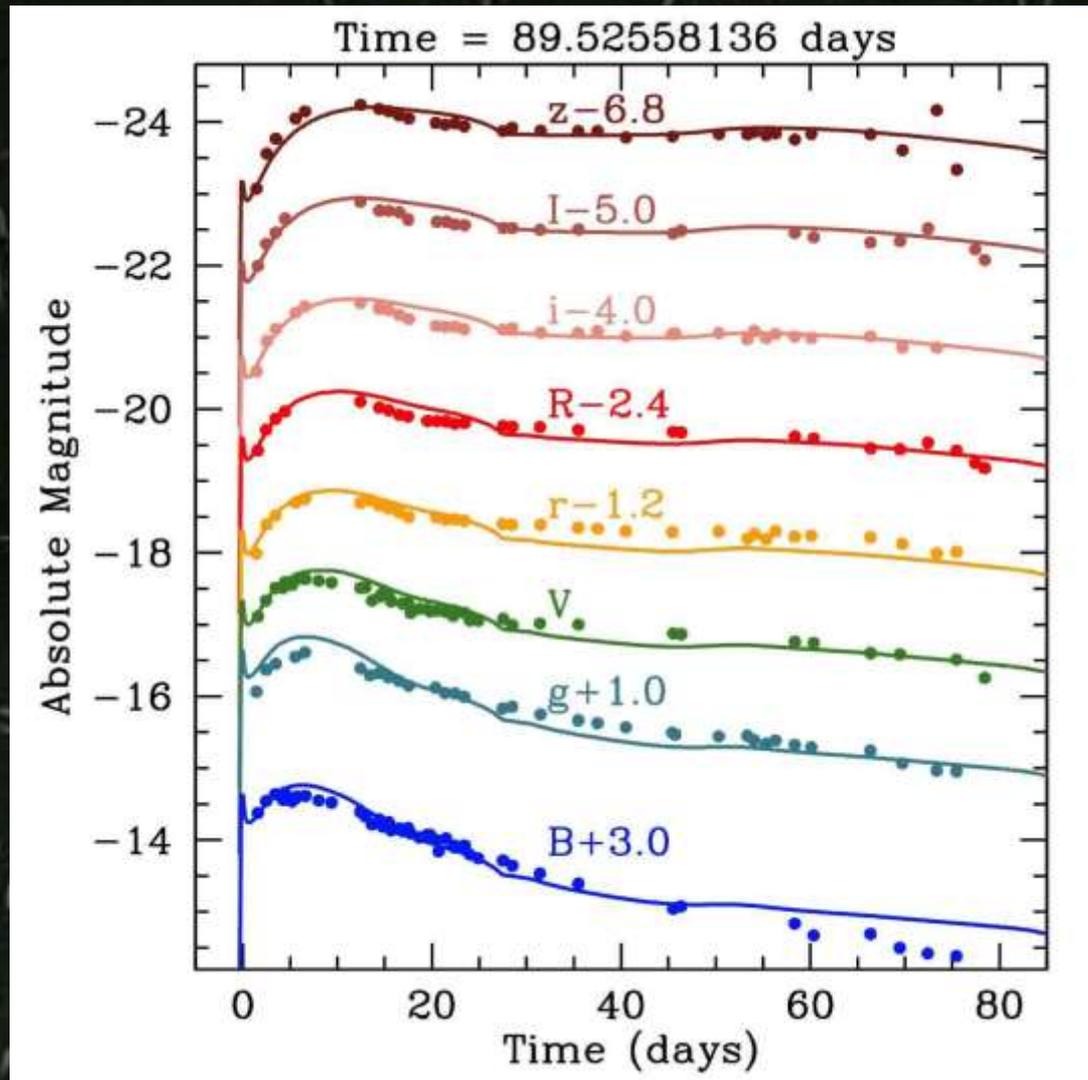


Type II SNe with standard progenitors



Morozova, Piro, & Valenti (2017)

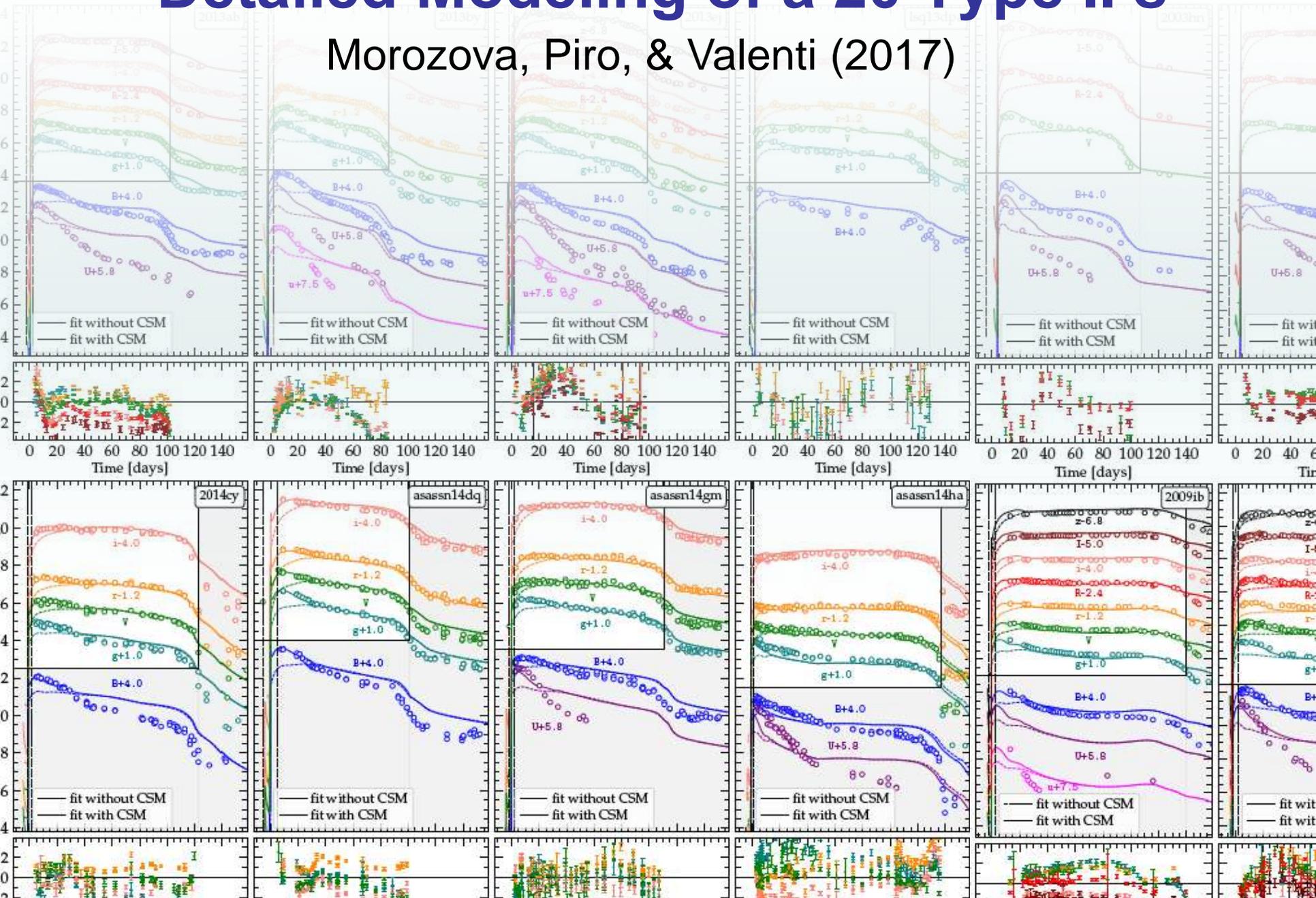
Type II SNe with dense CSM



Morozova, Piro, & Valenti (2017)

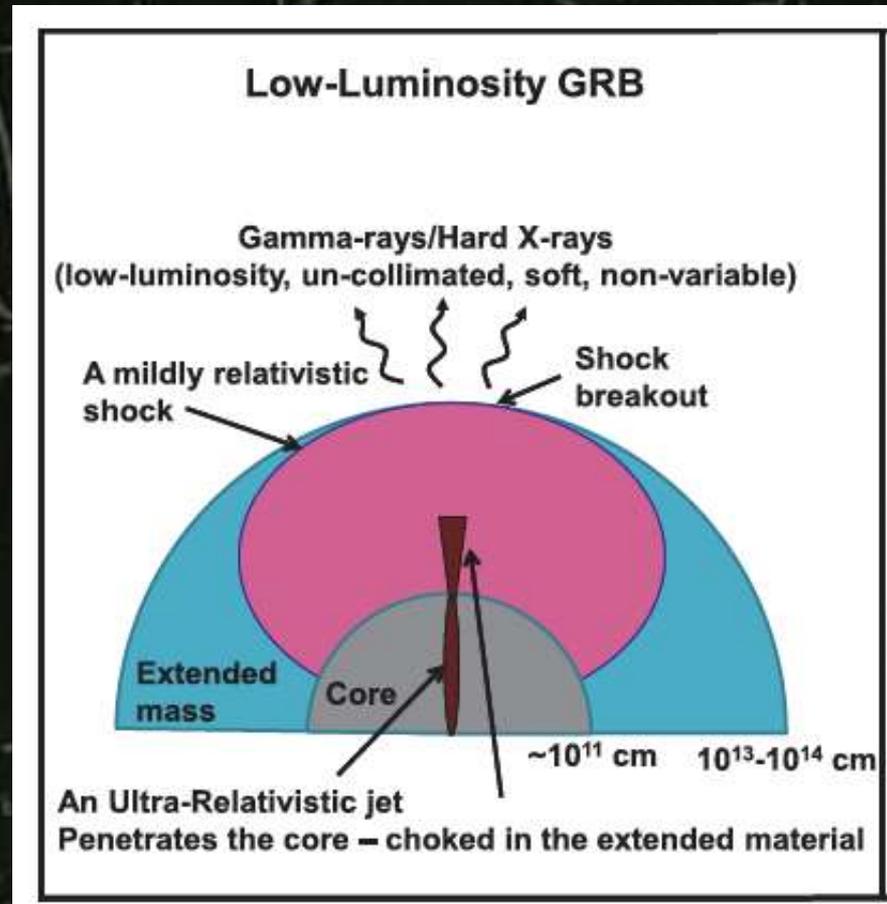
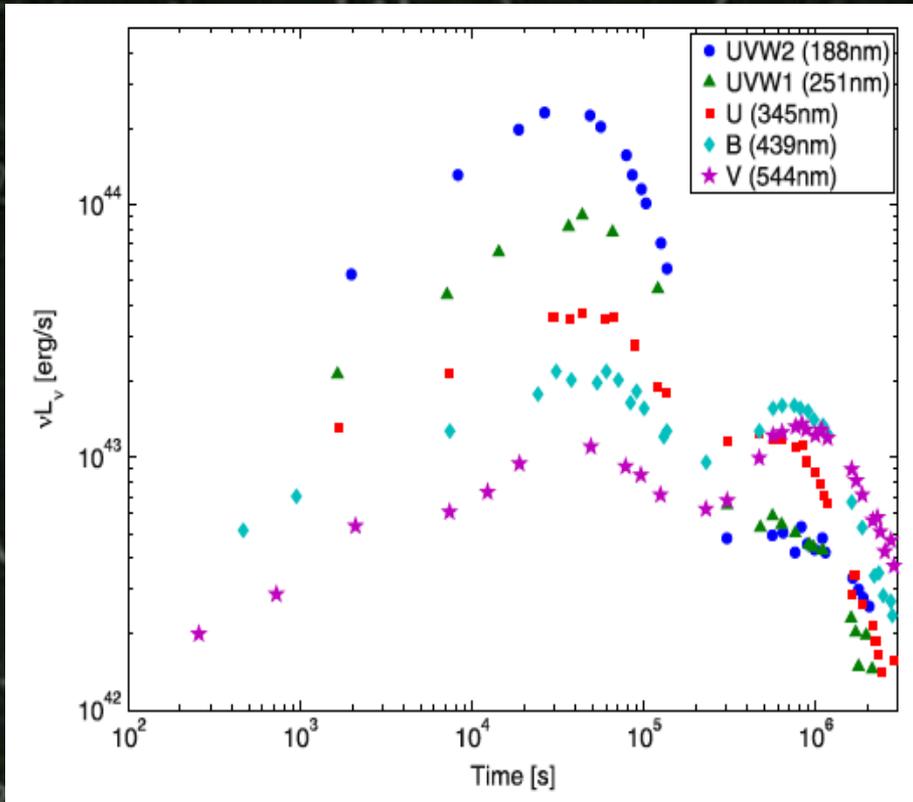
Detailed Modeling of a 20 Type II's

Morozova, Piro, & Valenti (2017)



Extended Material In Long GRBs

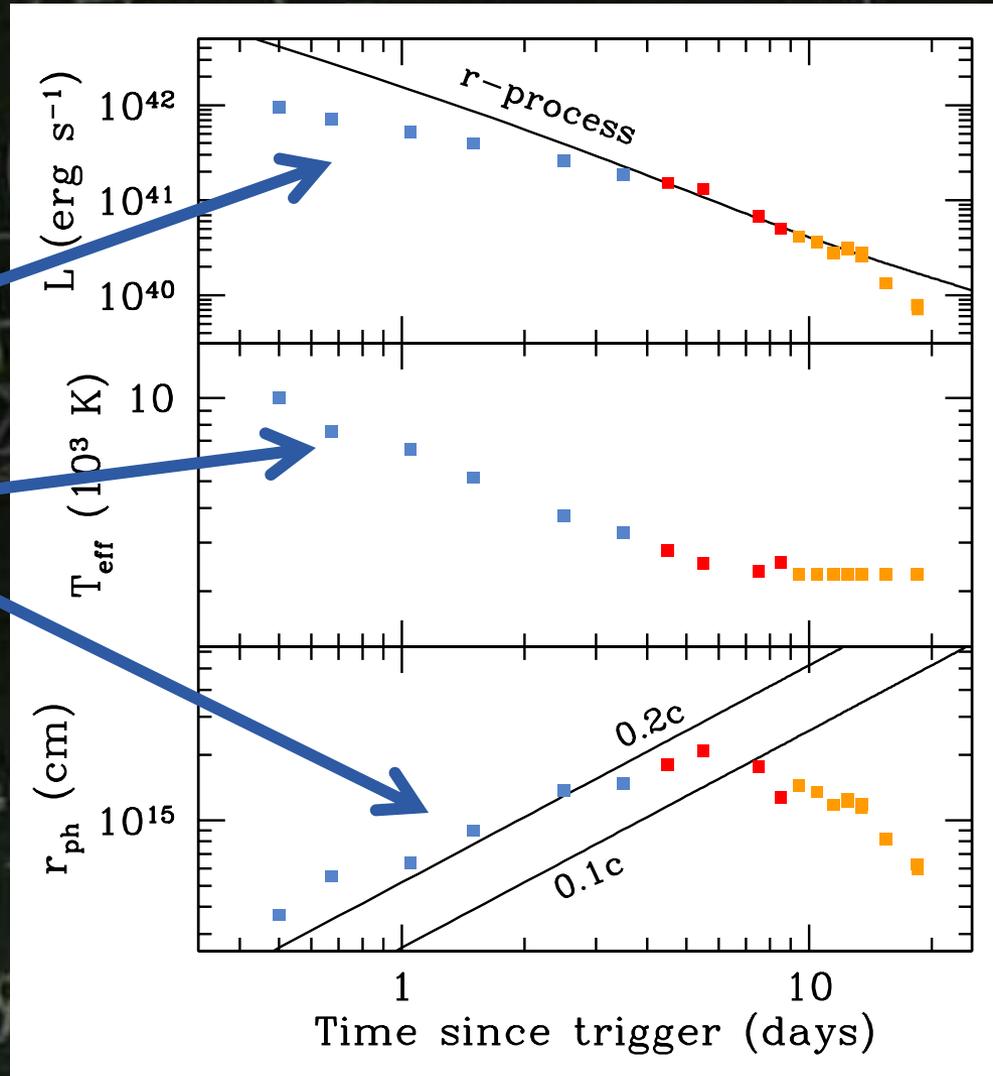
Nakar (2015)



Closer Look at Early Blue Emission

Piro and Kollmeier (2017)

Early power-law emission really from a kilonova?



Energetics of Shock Cooling

Luminosity of shock cooling is (Piro & Nakar 2013)

$$L \approx \frac{4\pi cR}{\kappa} \frac{E}{M}$$

Associated energy of a shock is

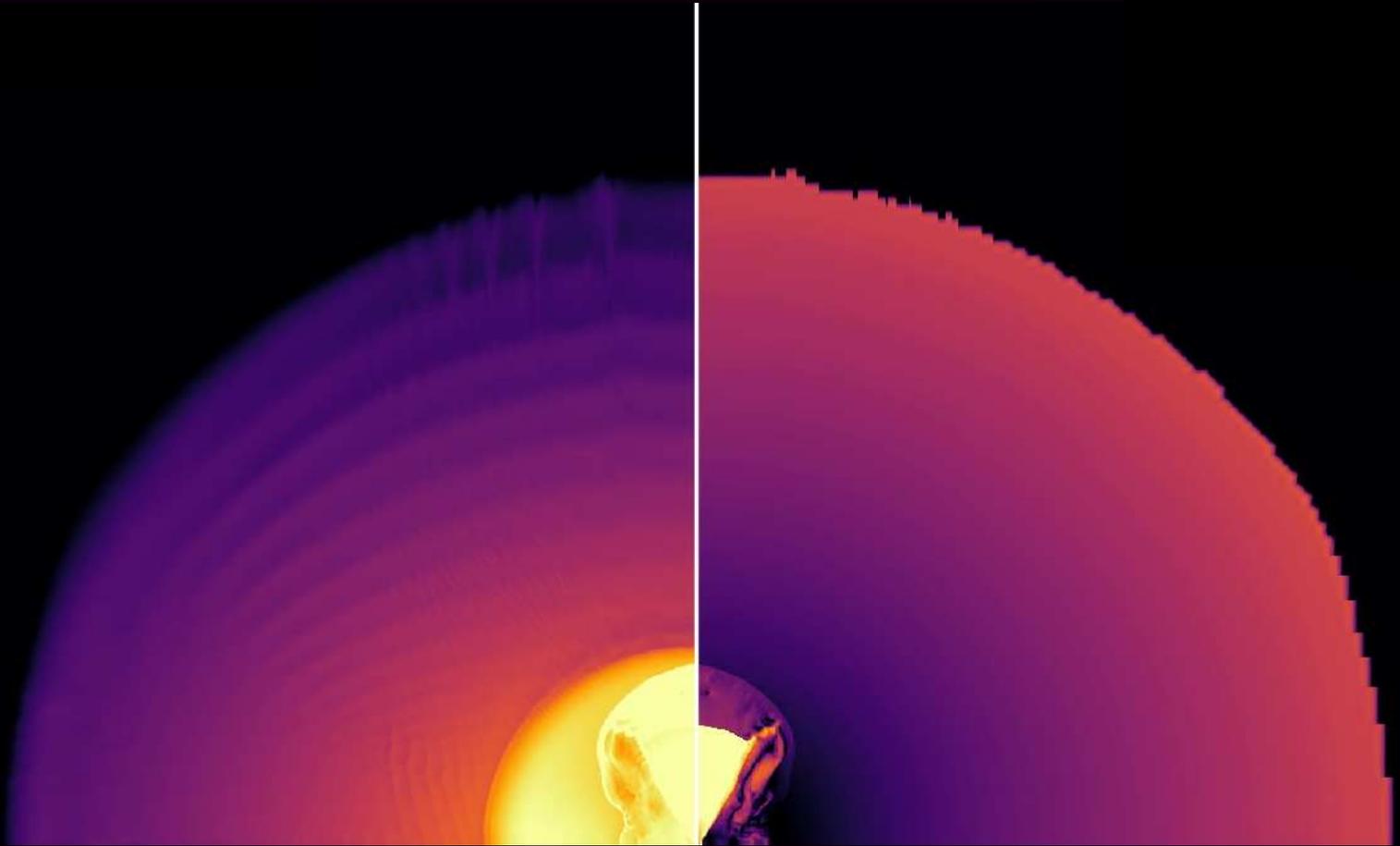
$$E \approx \frac{L\kappa M}{4\pi cR} \approx 10^{50} \text{ erg}$$

The kinetic energy of early component is

$$E \approx Mv^2/2 \approx 10^{50} \text{ erg}$$

Does this near equality suggest shock cooling?

Cocoon Heating



Nakar & Piran ('17), Gottlieb, Nakar & Piran ('17), Kasliwal, Nakar, et al. ('17)

Cocoon Heating Model

GRB inputs power law distribution of energy (Nakar & Piran '17)

$$dE/dv \propto v^{-s}$$

Power laws for luminosity, effective temperature, and photospheric radius (Piro & Kollmeier 2017)

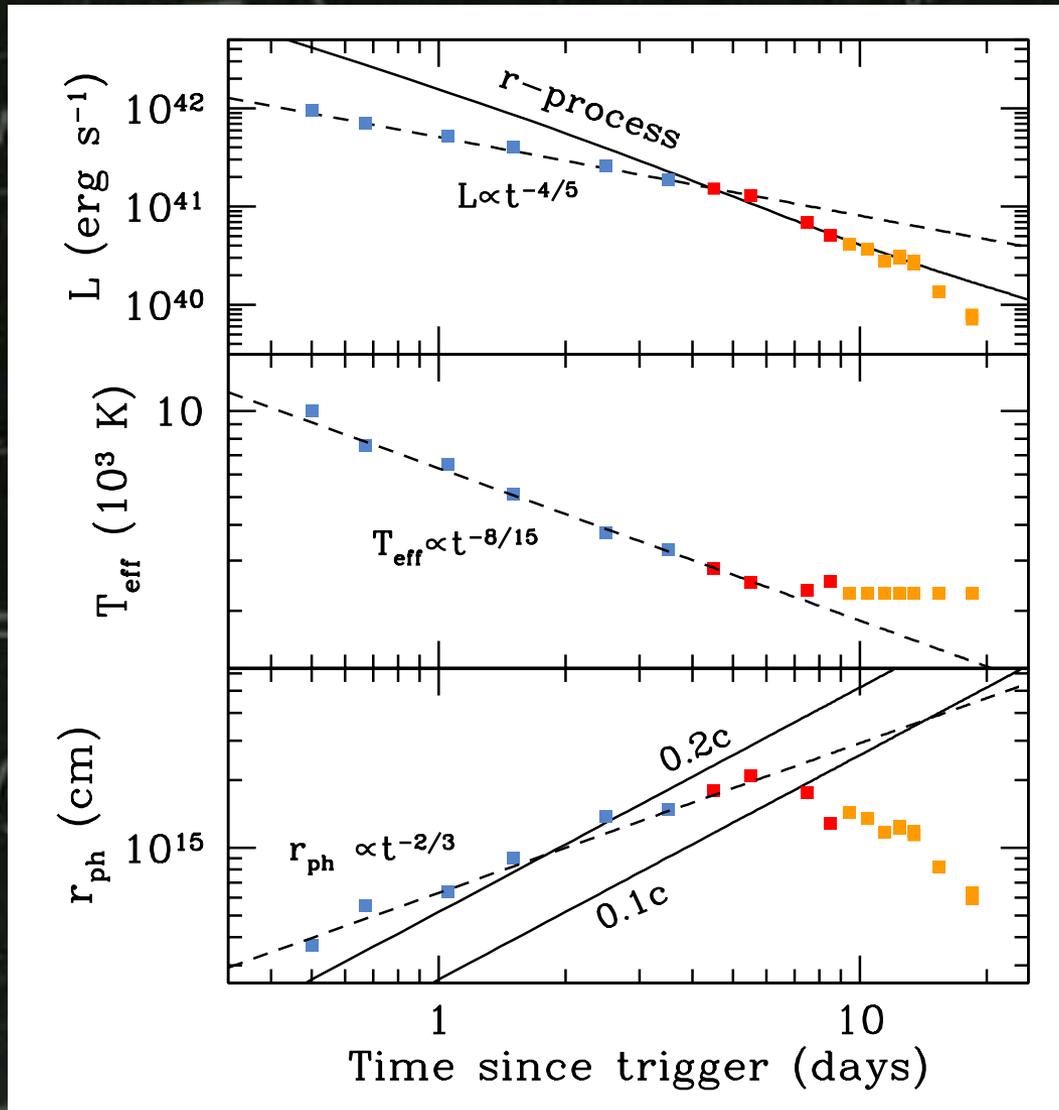
$$L \propto t^{-4/(s+2)}$$

$$T_{\text{off}} \propto t^{1/(s+3) - 1/(s+2) - 1/2}$$

$$r_{\text{ph}} \propto t^{(s+1)/(s+3)}$$

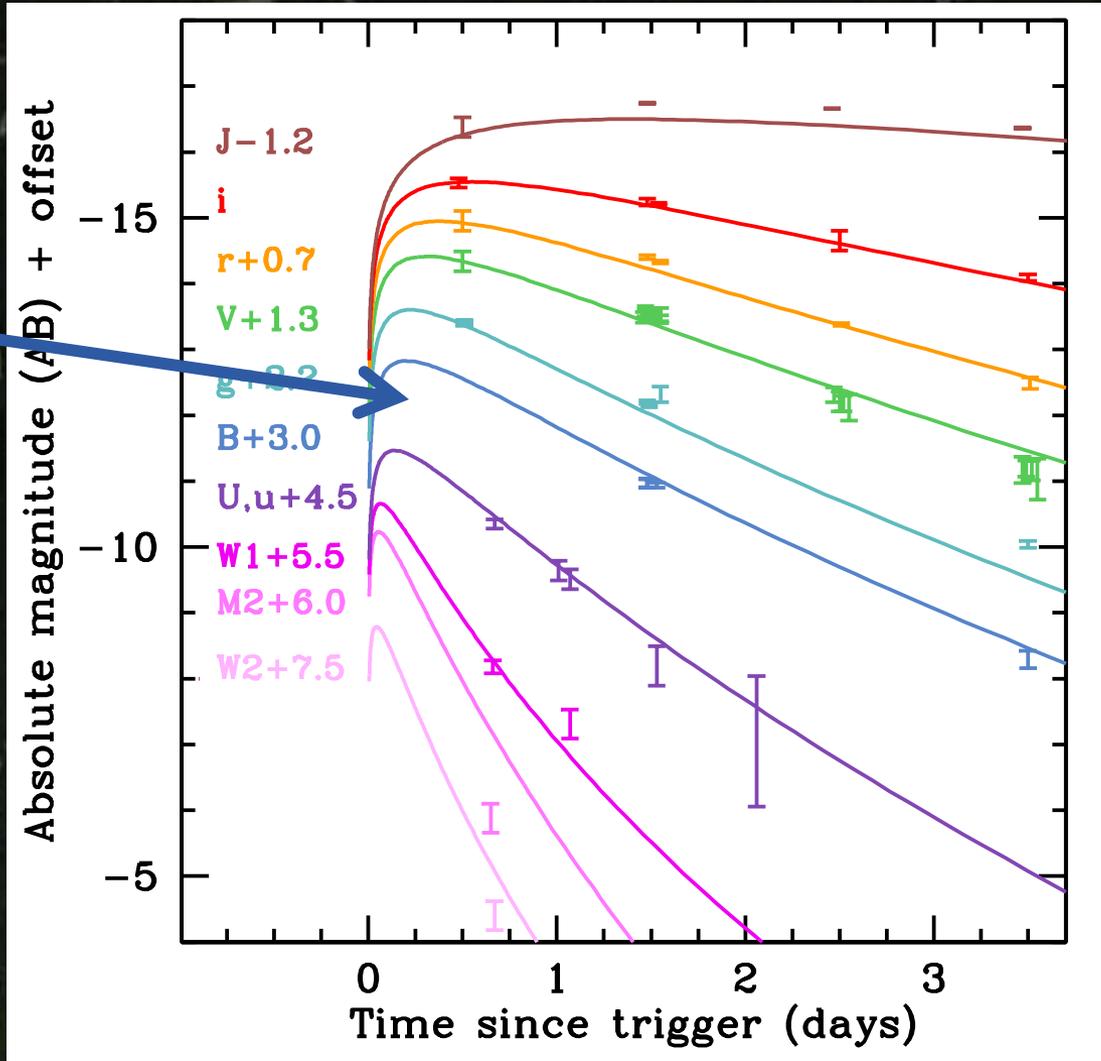
Cocoon emission with $s=3$

Piro and Kollmeier (2017)



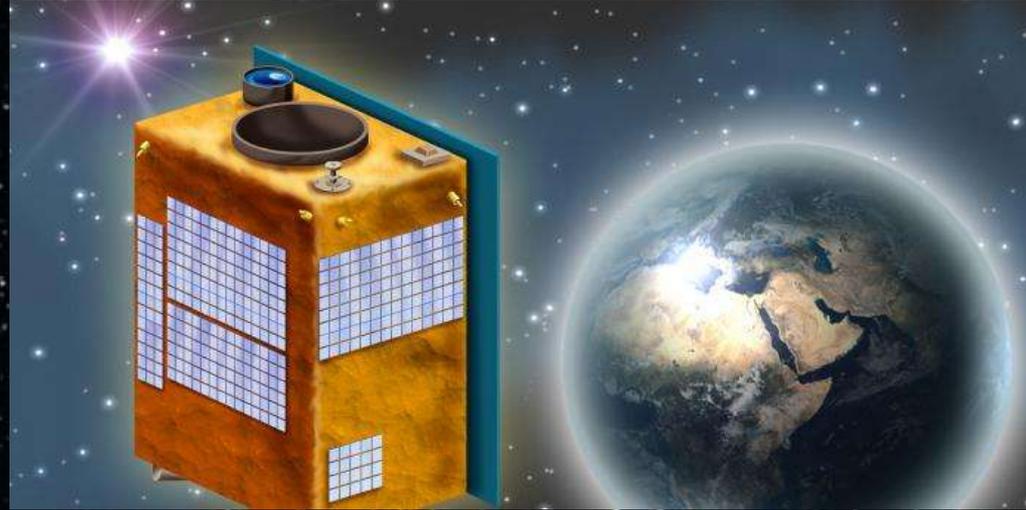
Cocoon emission with $s=3$

Piro and Kollmeier (2017)



Even brighter and bluer during first ~3-6 hrs

Finding Neutron Star Mergers



- UV survey down to ~ 19 mag (Cenko et al.) would find $\sim 0.1-1$ NS mergers per year
- UV survey down to ~ 21.5 mag (Sagiv et al. 2014) would find ~ 20 NS mergers per year

Conclusions

- On day 0.5, SSS17a was $\sim 10^{42}$ erg/s with a hot, featureless spectrum and $v \sim 0.3c$
- Shock cooling of extended material may explain these features
- This is an exciting opportunity!-- shock cooling can provide more information about geometry of the ejecta
- Shock cooling predicts even brighter and bluer at $\sim 3-6$ hours--what are the best survey strategies to catch NS mergers as soon as possible?