THE FIRST ORPHAN GRB DETECTED THROUGH ITS ASSOCIATED SN EMISSION

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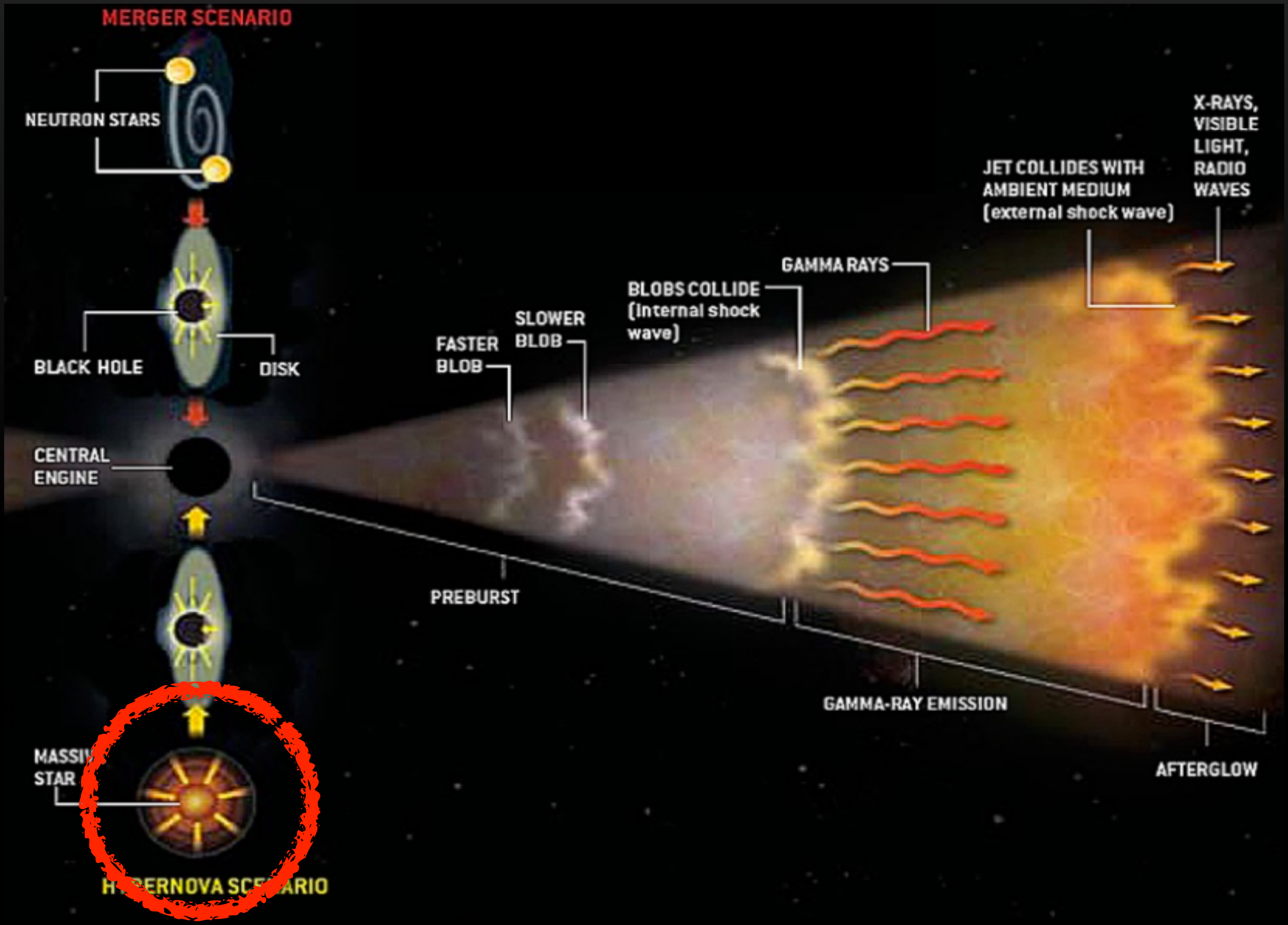
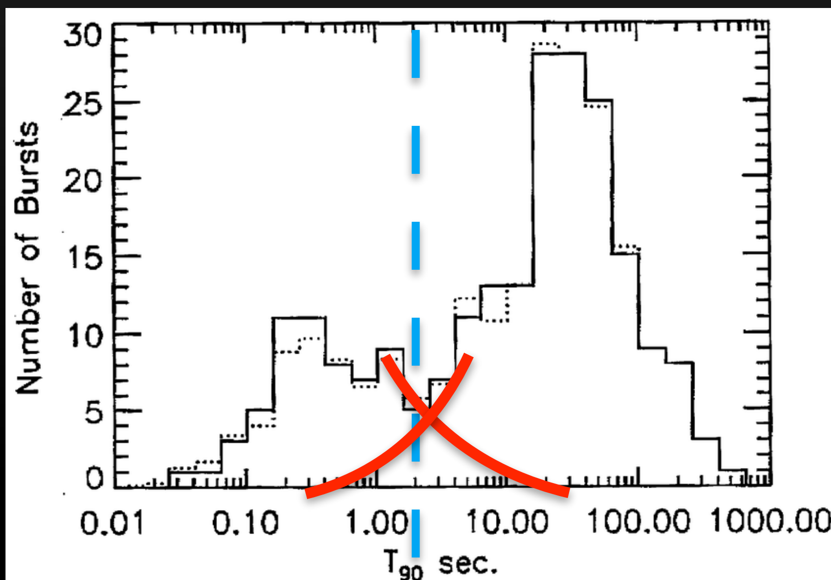
GRBV - September 13 - Trieste

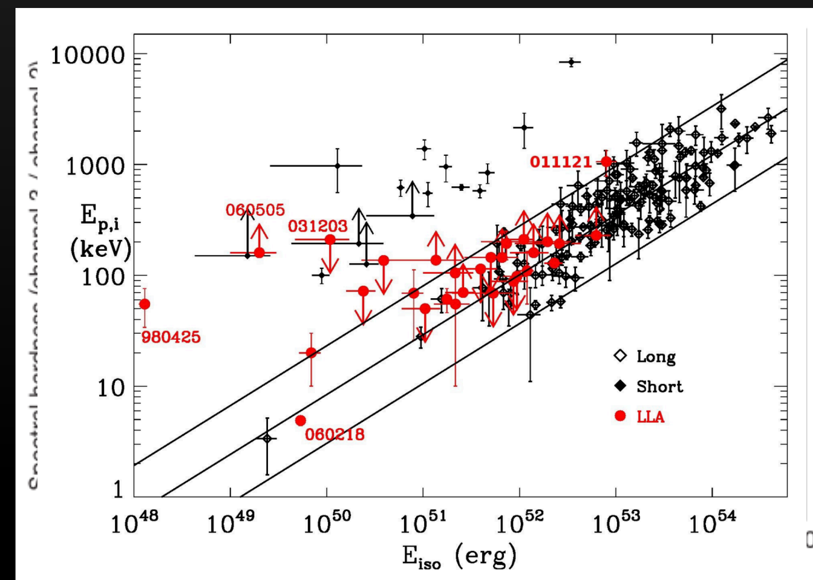
Gamma-ray bursts



Gamma-ray bursts

Two (?) "families" of GRBs





(courtesy T. Piran)

Short and Long GRBs

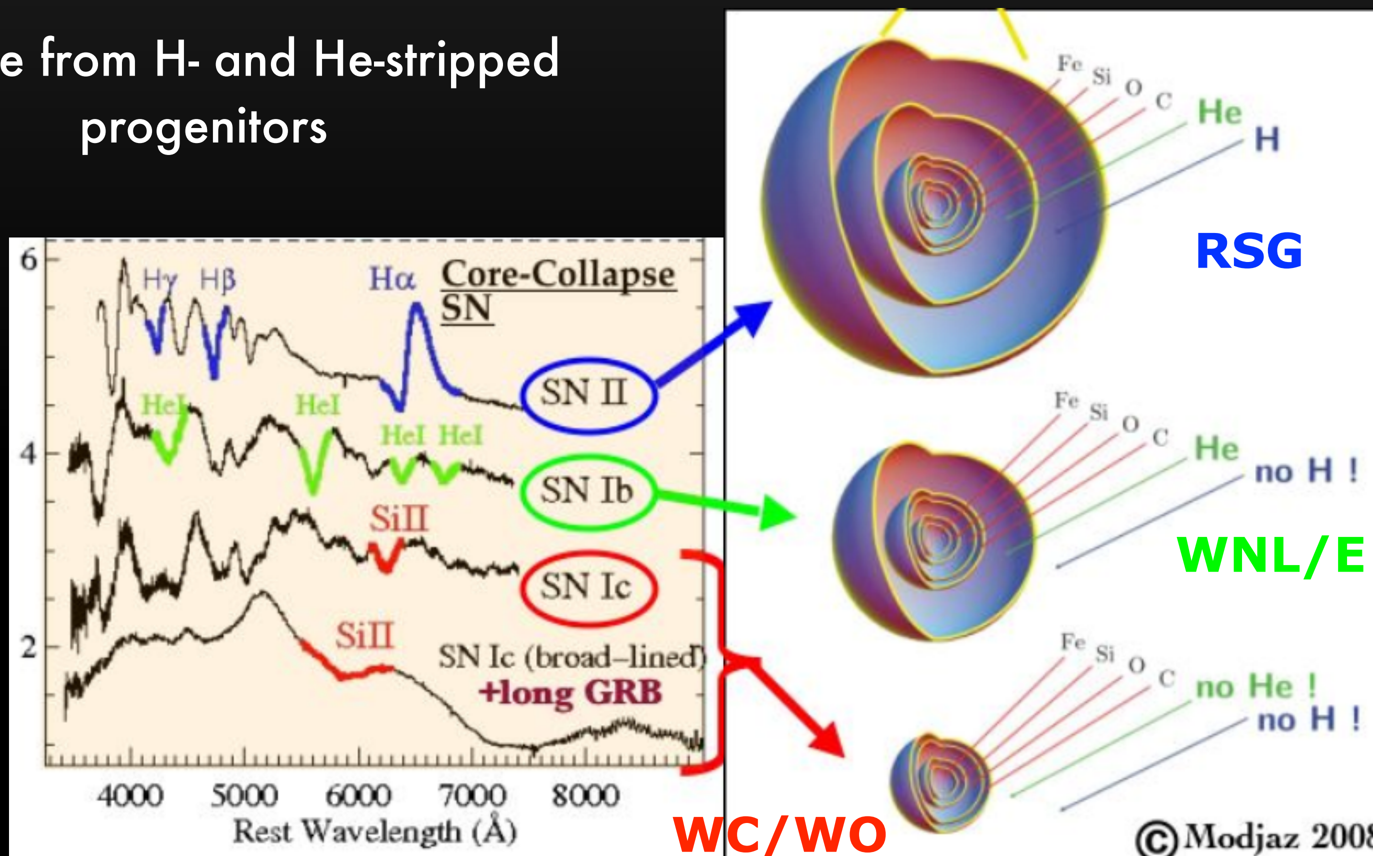
Short Long GRBs... and llGRBs

(Kouveliotou+ 1993, Hjorth+ 2005)

GRB-SN connection

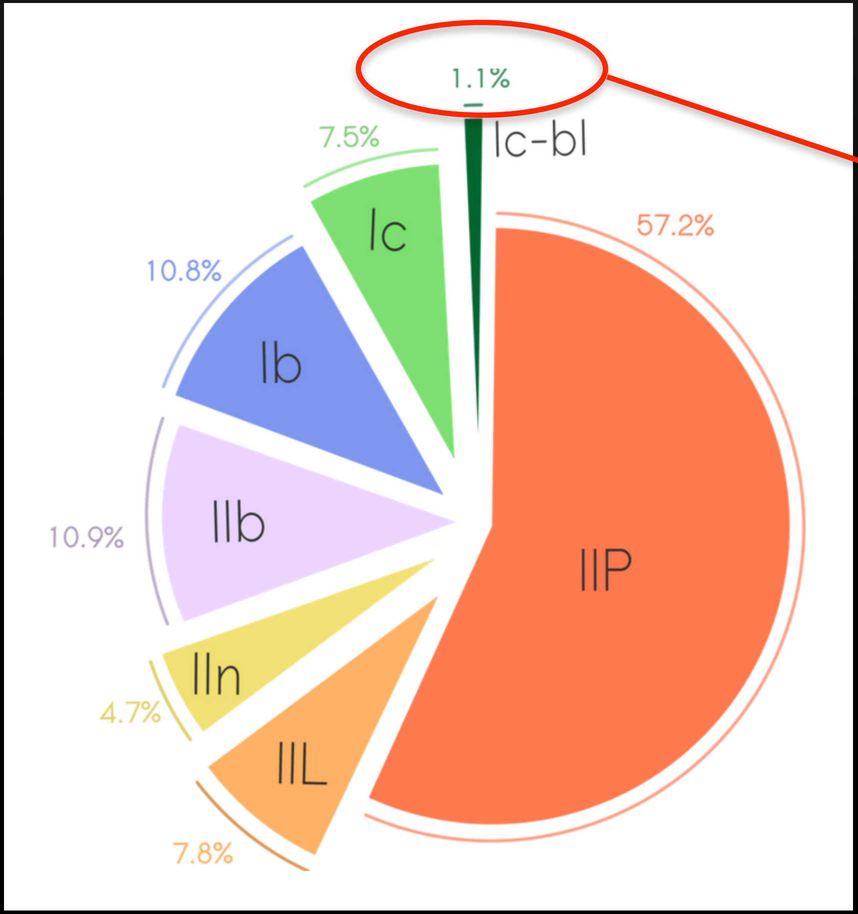
Type Ic-SNe

CC SNe from H- and He-stripped progenitors



Ic BL SNe w/o GRBs

Relative number of CC-SNe

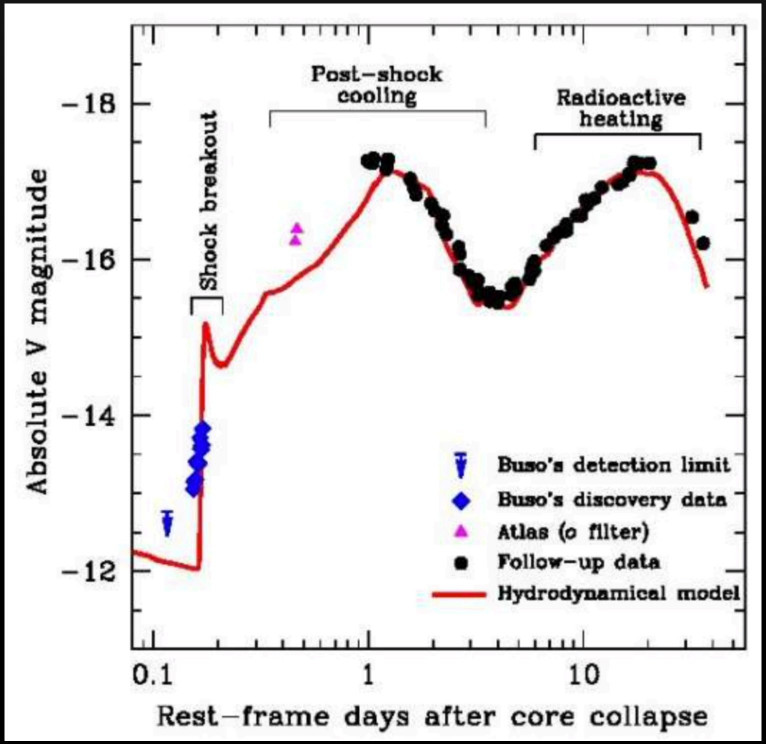


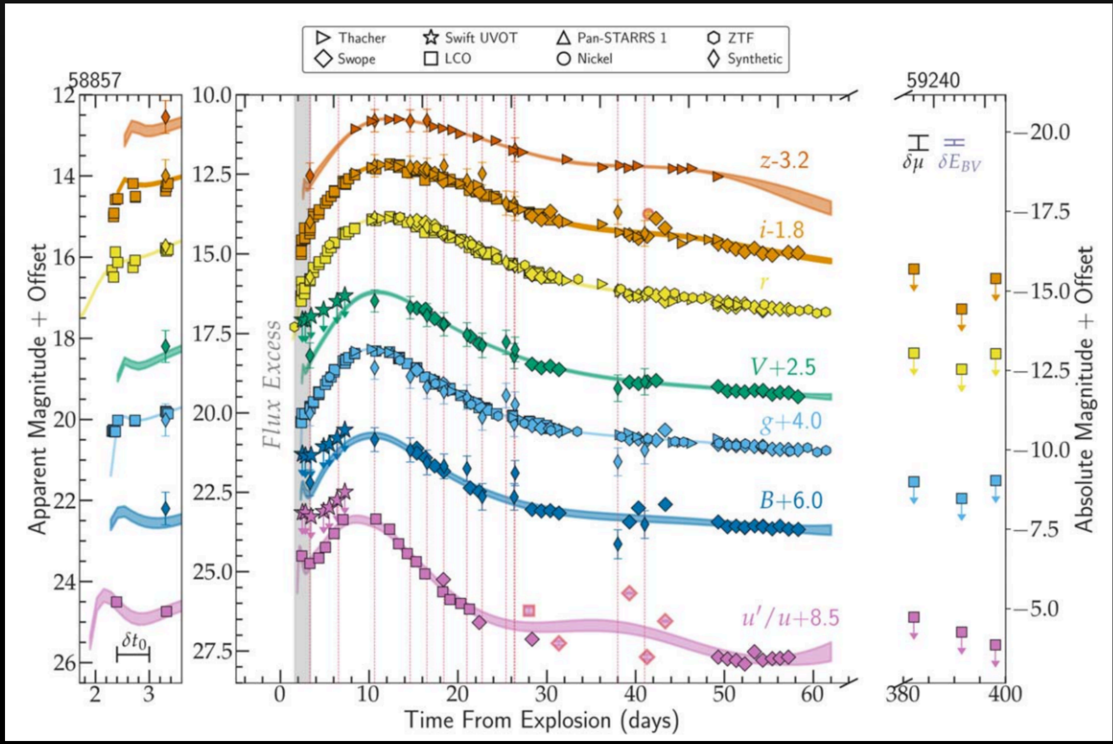
~10% of Ic-BL SNe are "apparently" associated with a GRB

What about the remaining 90%?

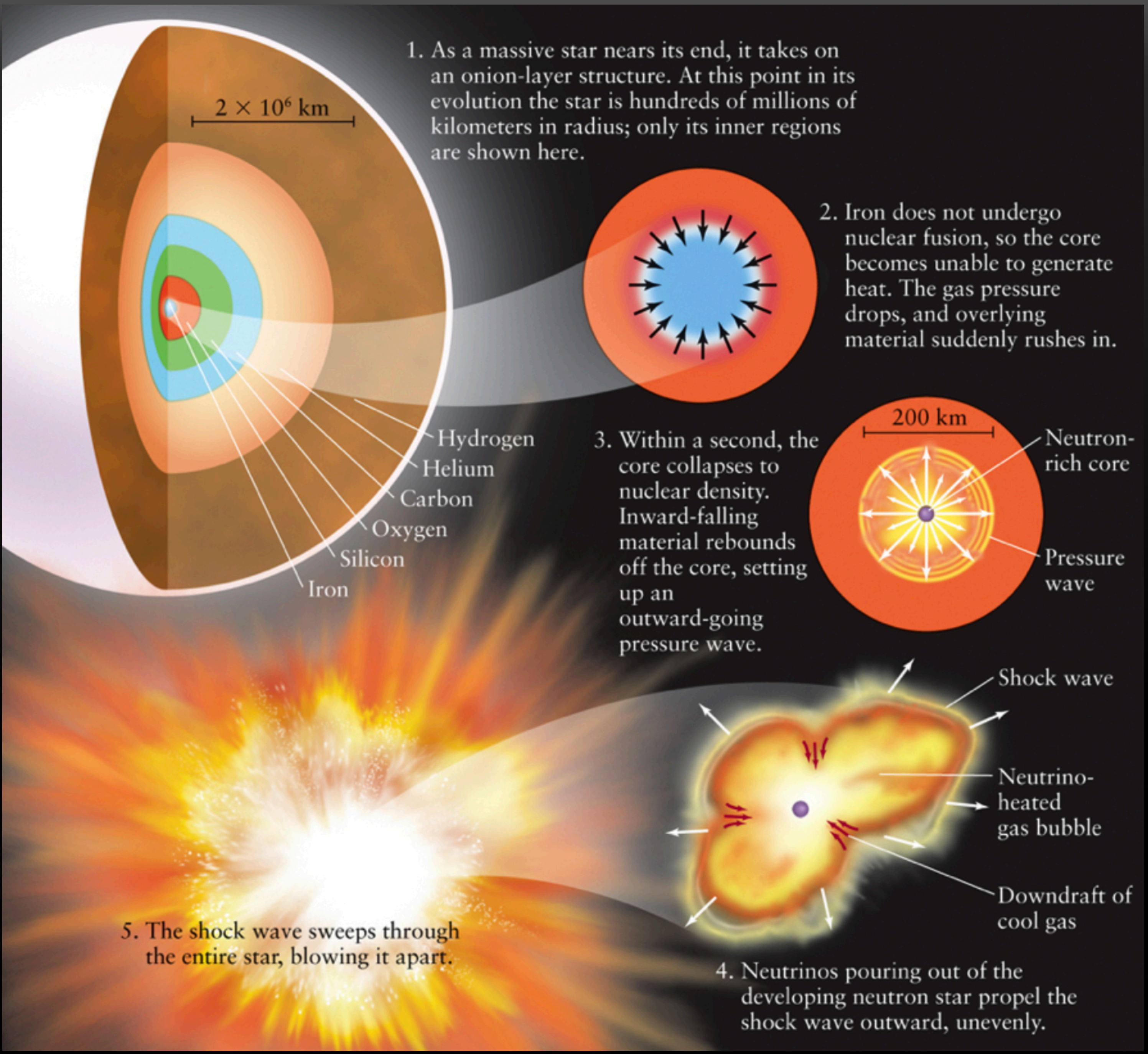
pre-SN emission

Cooling SBO emission + possible interaction with CSM





(Bersten+ 2018, Gagliano, Izzo+ 2022)

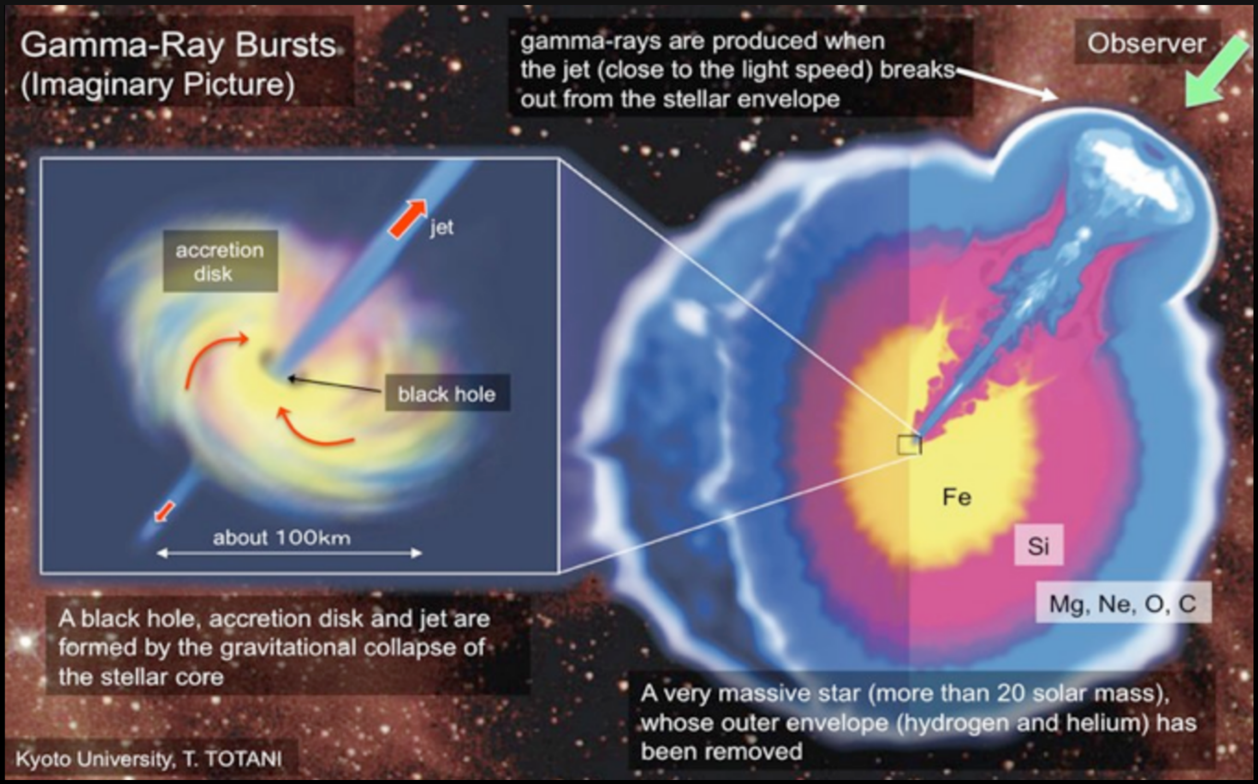


DARK

(courtesy Devor, Spurio)

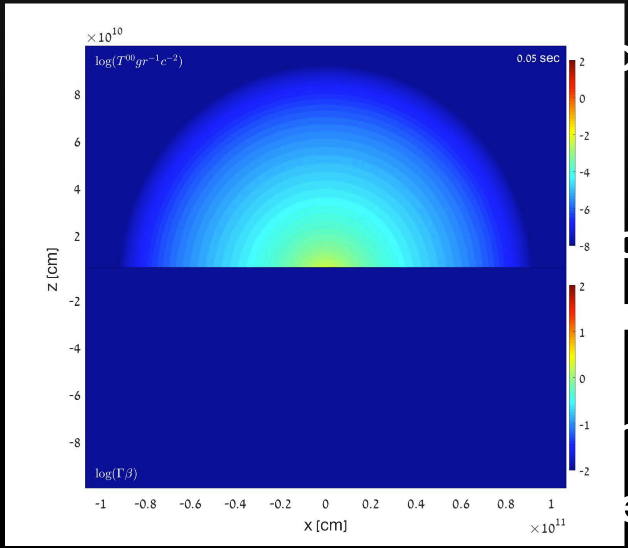
GRB-SN connection

- Fast-rotating Fe core
- H (and likely He) stripped-envelope progenitor
- Low metallicity (mass-loss is Z-dependent)



The Jet-Cocoon

➡ as the jet propagates within the stellar atmosphere it creates a cocoon composed of Newtonian shocked and a mildly-relativistic shocked jet material



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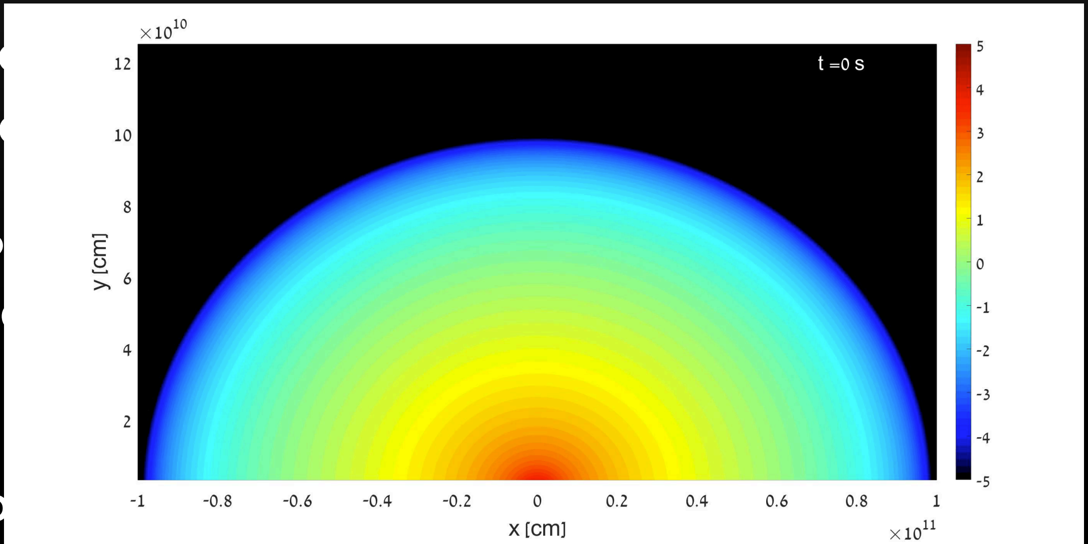
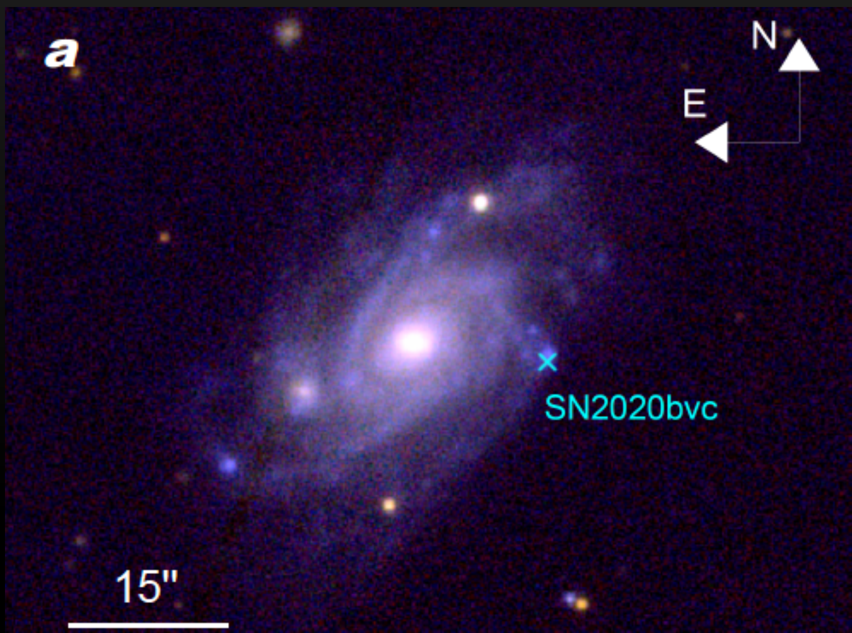
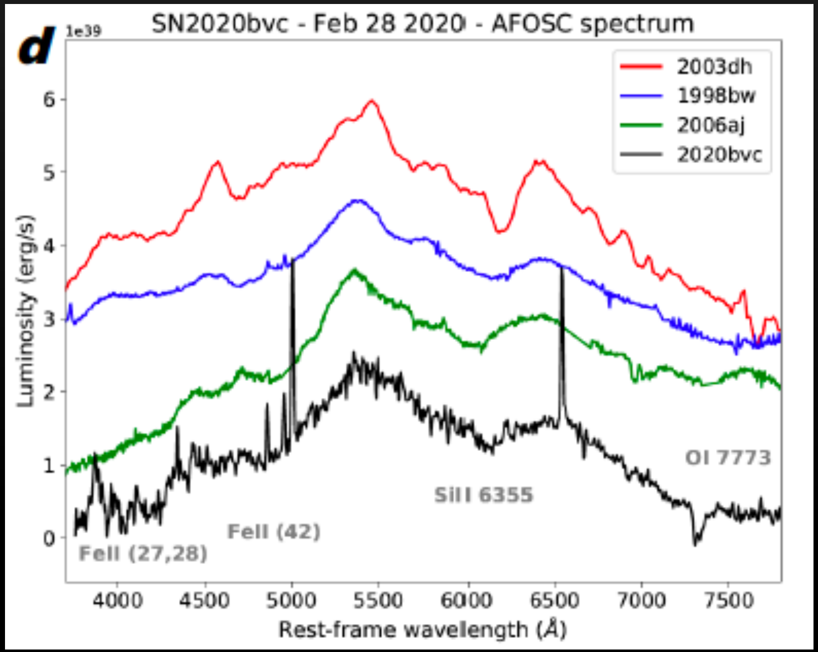


➡ The cocoon would eventually breaks out from the star, releasing sub-relativistic material in the circum-stellar environment

(courtesy Nakar)

SN 2020bvc

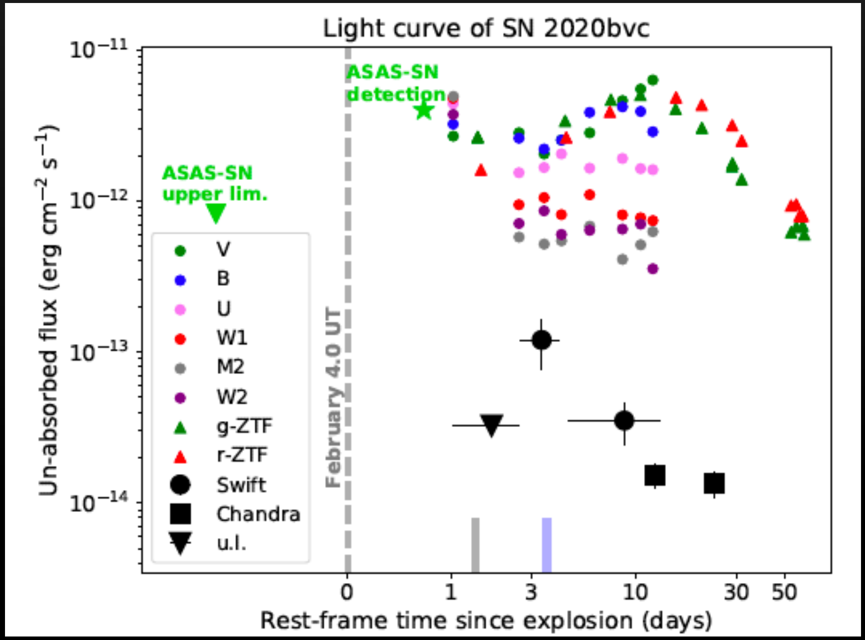


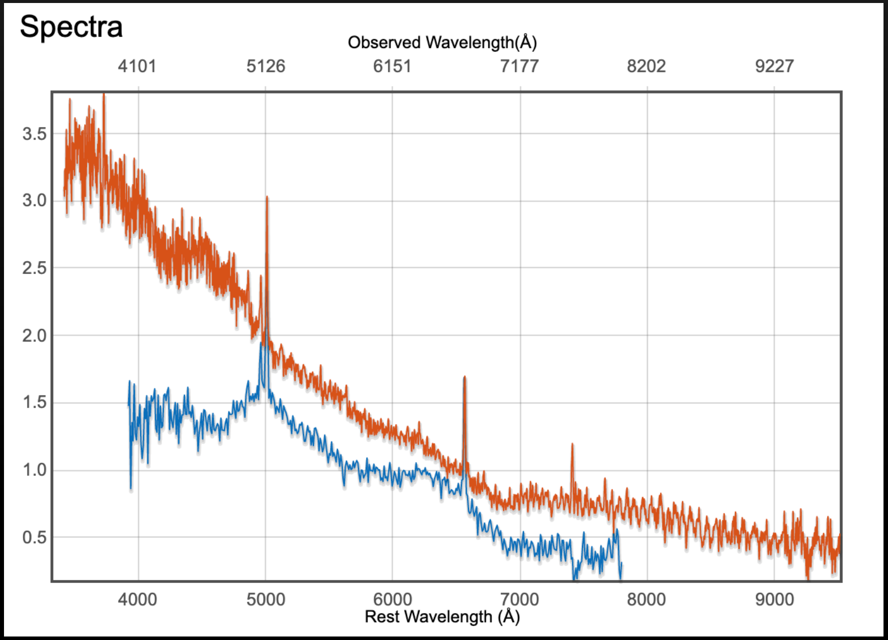


type-Ic BL SN @ z = 0.025235

(Izzo+ 2020)

SN 2020bvc





Early "blue" bump
Swift UVOT + ZTF

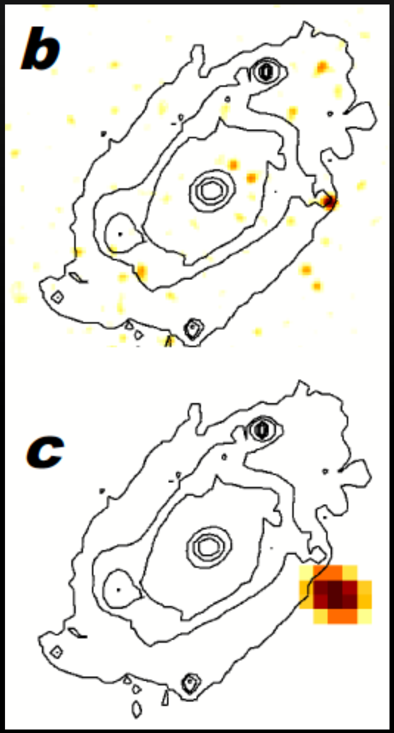
(Izzo+ 2020)

Floyds & SPRAT spectra

(TNS archive)

SN 2020bvc

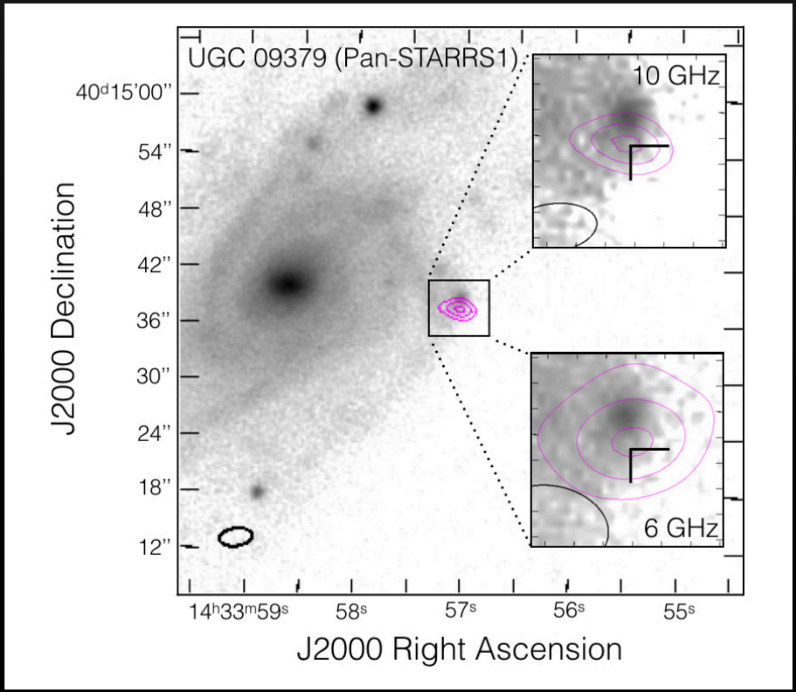
X-ray



Chandra

Swift-XRT

Radio

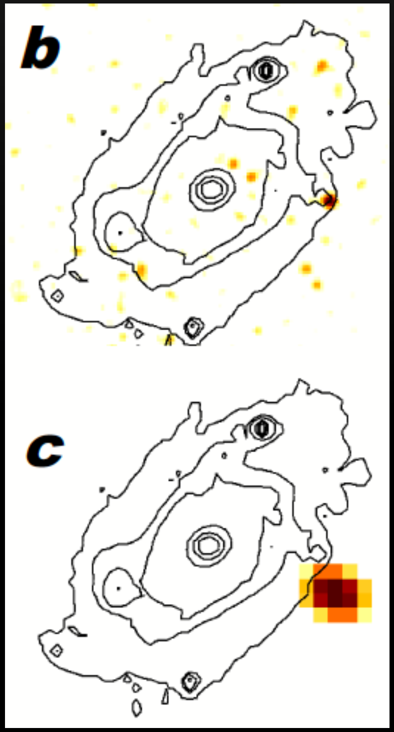


(Izzo+ 2020)

(Ho+ 2020)

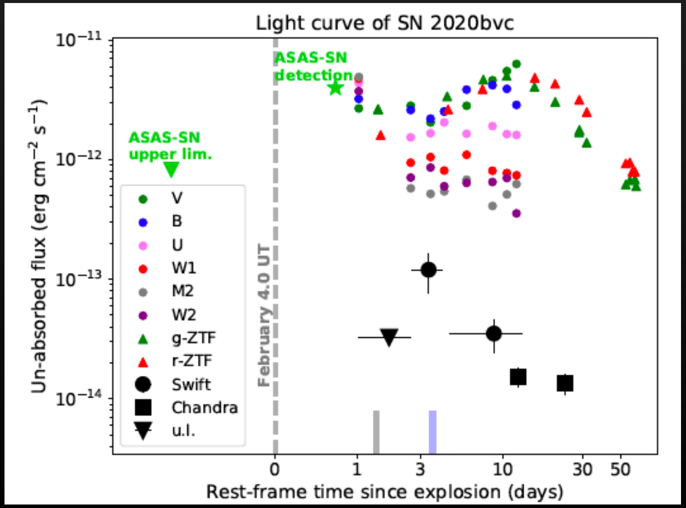
SN 2020bvc

X-ray



Chandra

Swift-XRT



Epoch (MJD)	flux (erg/cm^2/s)	error (erg/cm^2/s)	HR	error
58884.8	<3.23e−14	–	–	
58886.9	1.20e−13	8.65e−14	−0.99	0.71
58892.3	3.51e−14	2.19e−14	−0.93	0.56
58895.8	1.53e−14	0.54e−14	−0.39	0.32
58907.0	1.35e−14	0.51e−14	−0.77	0.30

HR = (H-S) / (H+S) = -0.66 +- 0.21

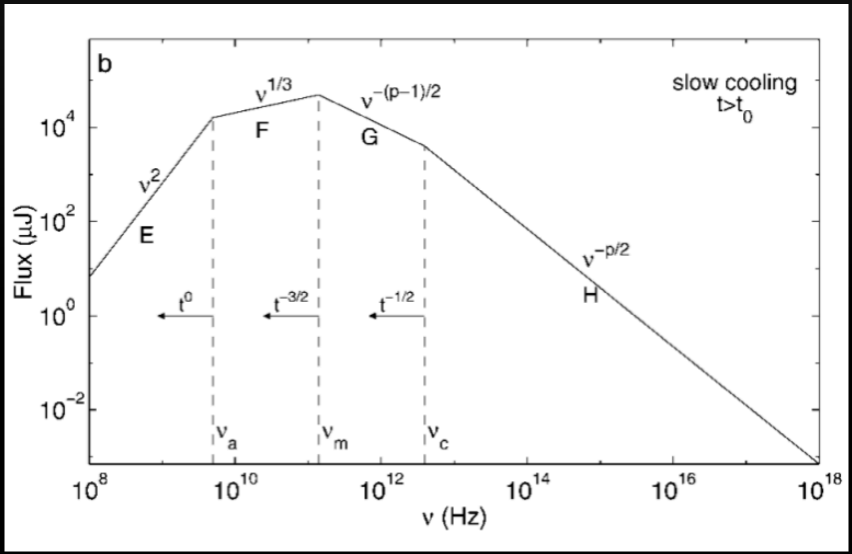
$1.9 < \gamma < 2.1$

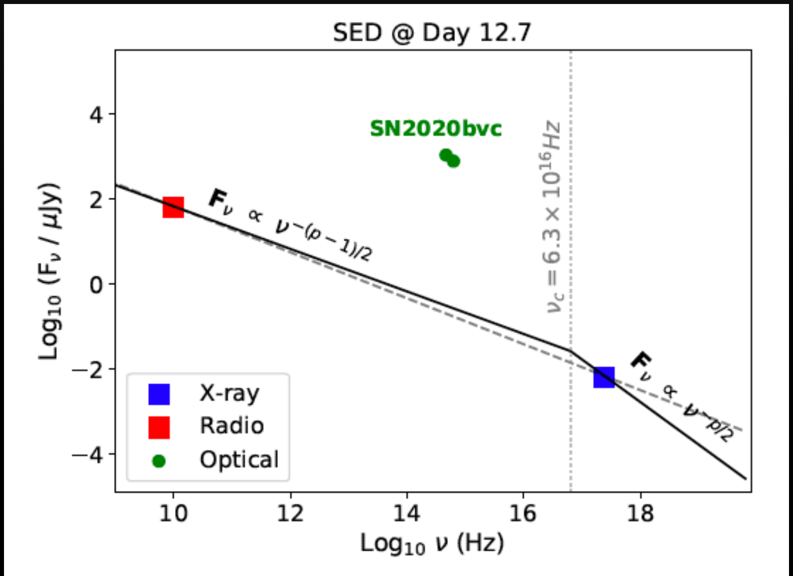
(Izzo+ 2020)

SN 2020bvc

Multi-wavelength SED

Match with a GRB afterglow

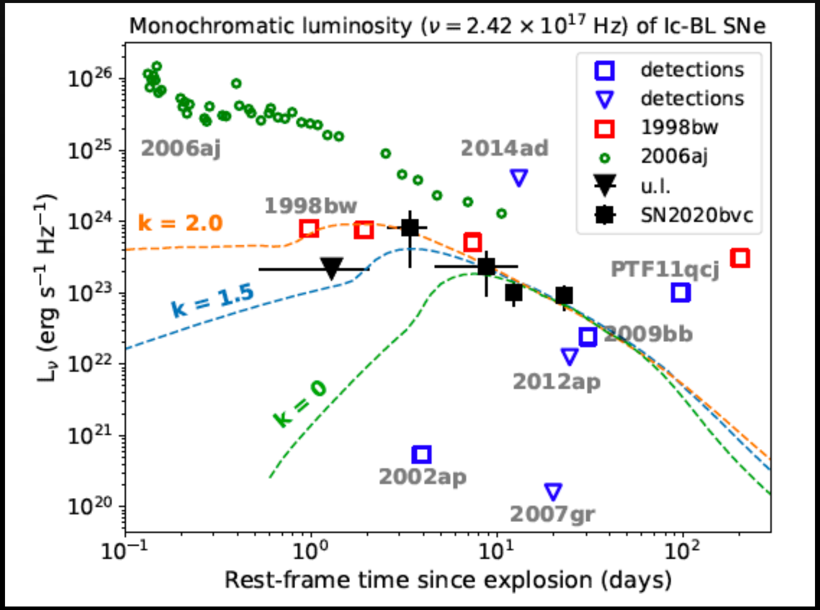


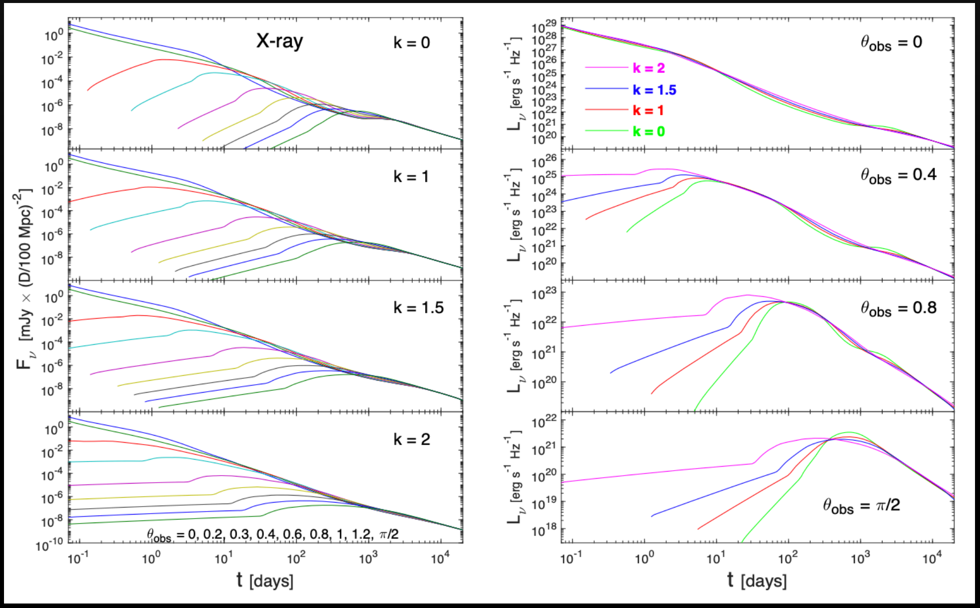


(Sari+ 1998, Izzo+ 2020, De Colle+ 2018)

SN 2020bvc

An off-axis GRB afterglow

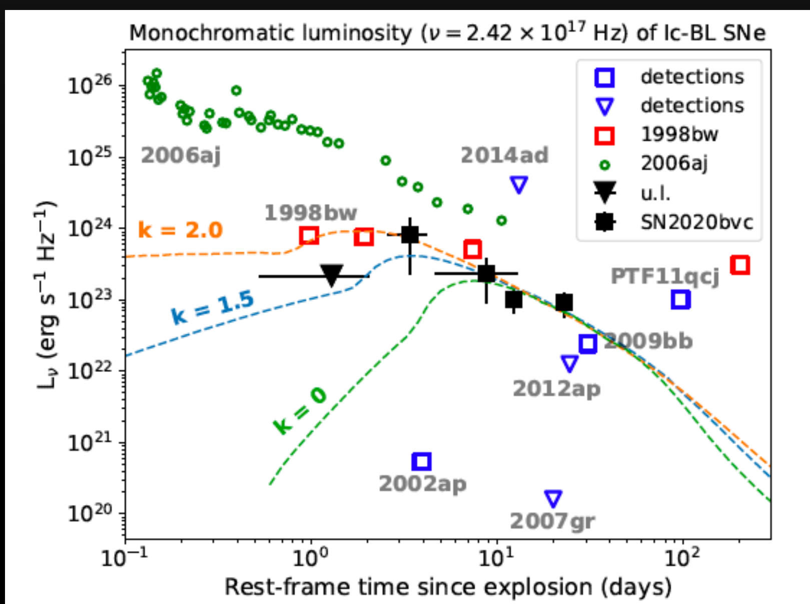




(Granot+ 2018, Izzo+ 2020)

SN 2020bvc

An off-axis GRB afterglow



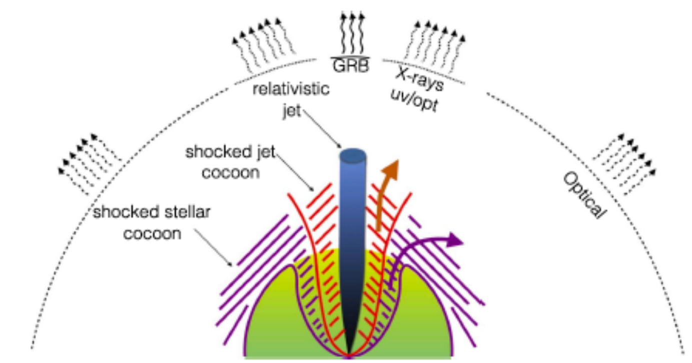


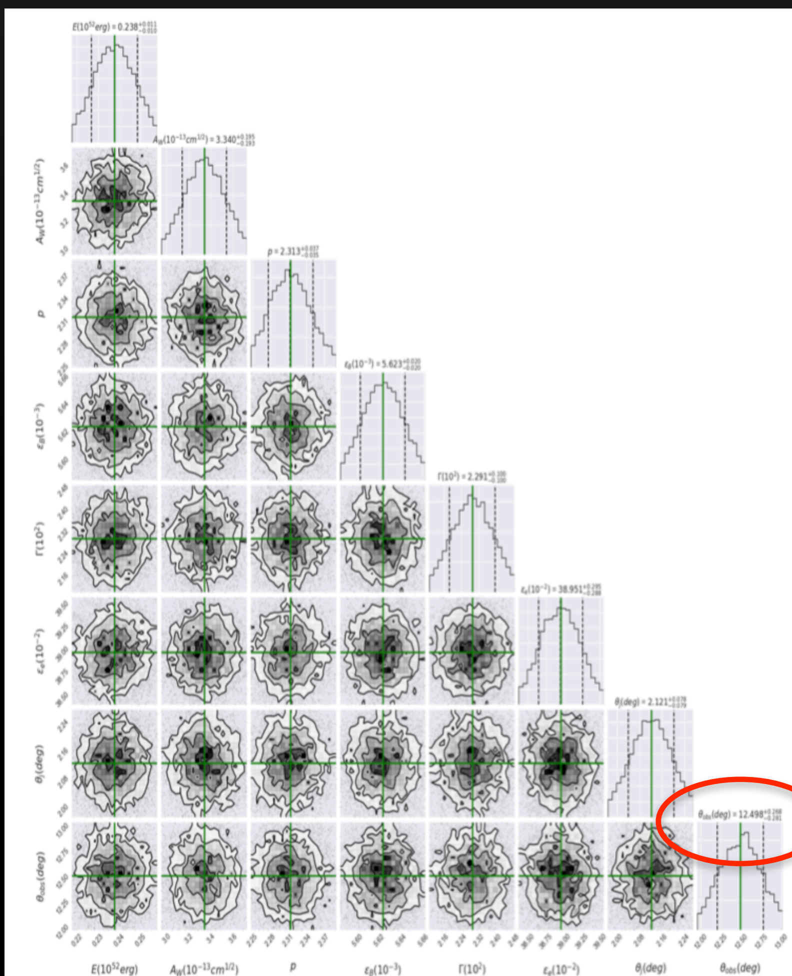
Figure 1. Schematic description of the Collapsar's jet and the cocoon. The cocoon is composed of two components: an inner "shocked jet cocoon" and an outer "shocked stellar cocoon." The jet cocoon is more dilute and hence it expands after breakout to faster, possibly relativistic, velocities. Also shown are the different emission components and their angular extent. A typical opening angle of the relativistic cocoon components (if exist) is ~0.5 rad. The stellar cocoon is sub-relativistic. As it gets out of the star it engulfs the star and its emission is practically isotropic.

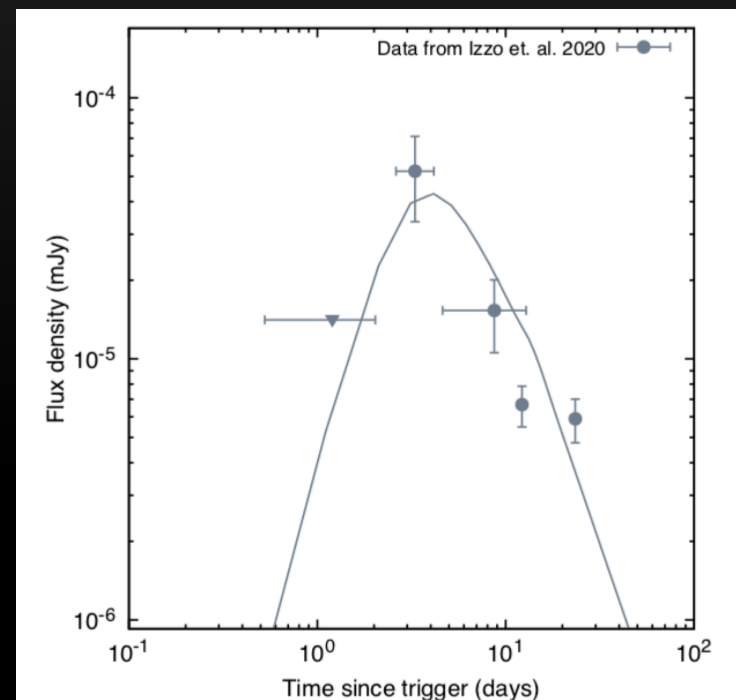
(Granot+ 2018, Izzo+ 2020)

(Nakar & Piran 2017)

SN 2020bvc

More detailed analysis confirm the off-axis jet nature





θ = 12.5 deg

(Fraija+ 2022)

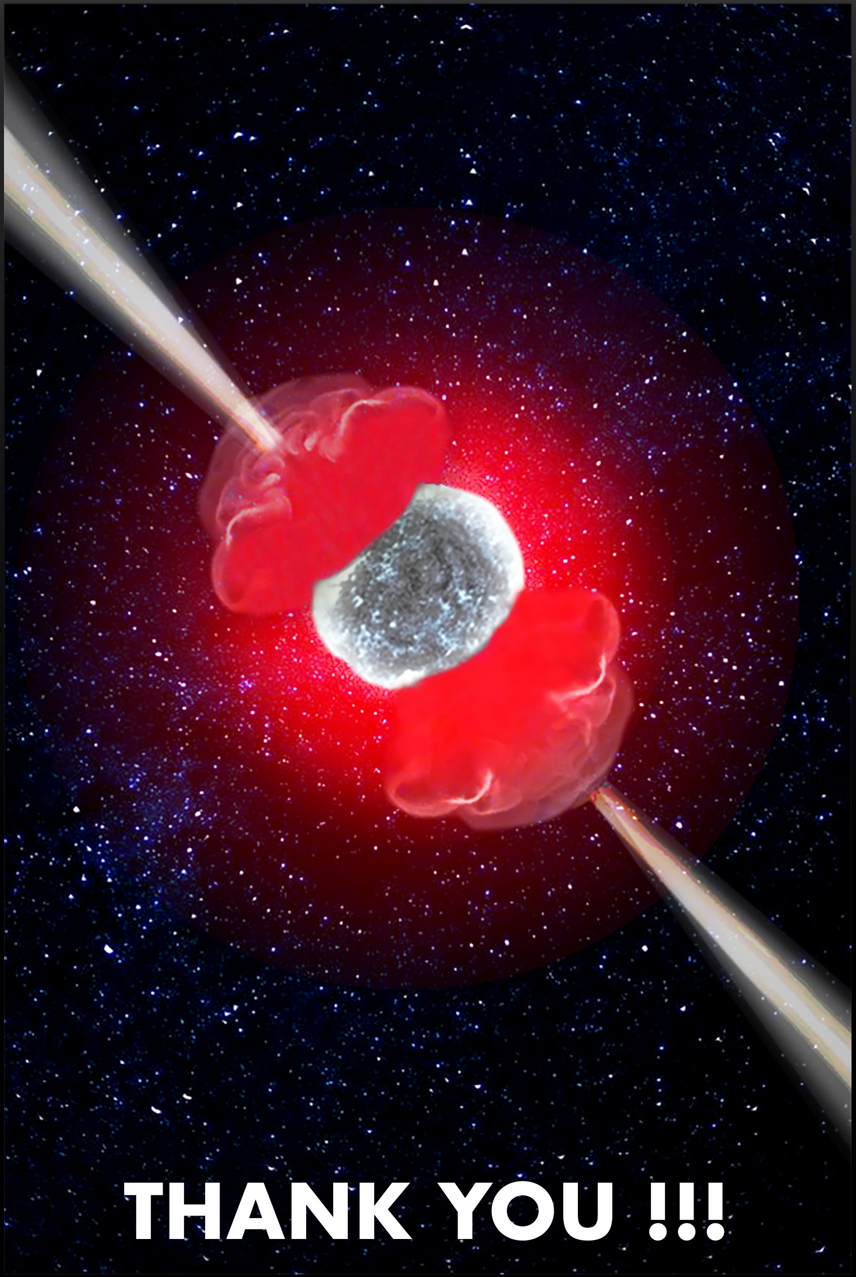
Summary

➡ jets, and then rotation, can play a fundamental role in the processes by which massive stars explode

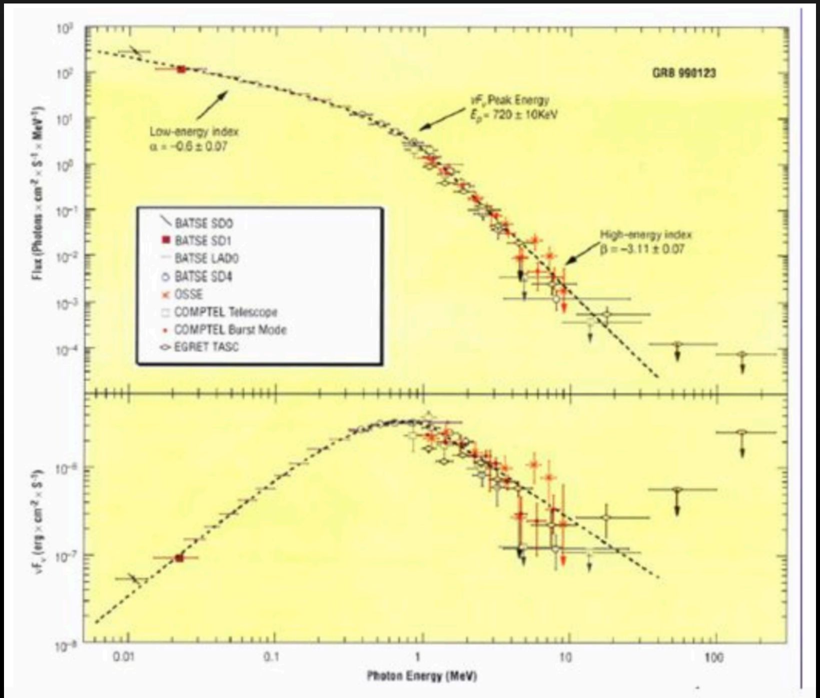
➡ jets are indeed Poynting-flux dominated and neutrino annihilation processes are likely not adequate in driving jets and very energetic SN explosions in general

➡ evidences of cocoon emission induced by the GRB jet in the Ic-BL SN 2017iuk associated with GRB 171205A support the existence of choked-jets in Ic-BL SNe not accompanied by GRBs

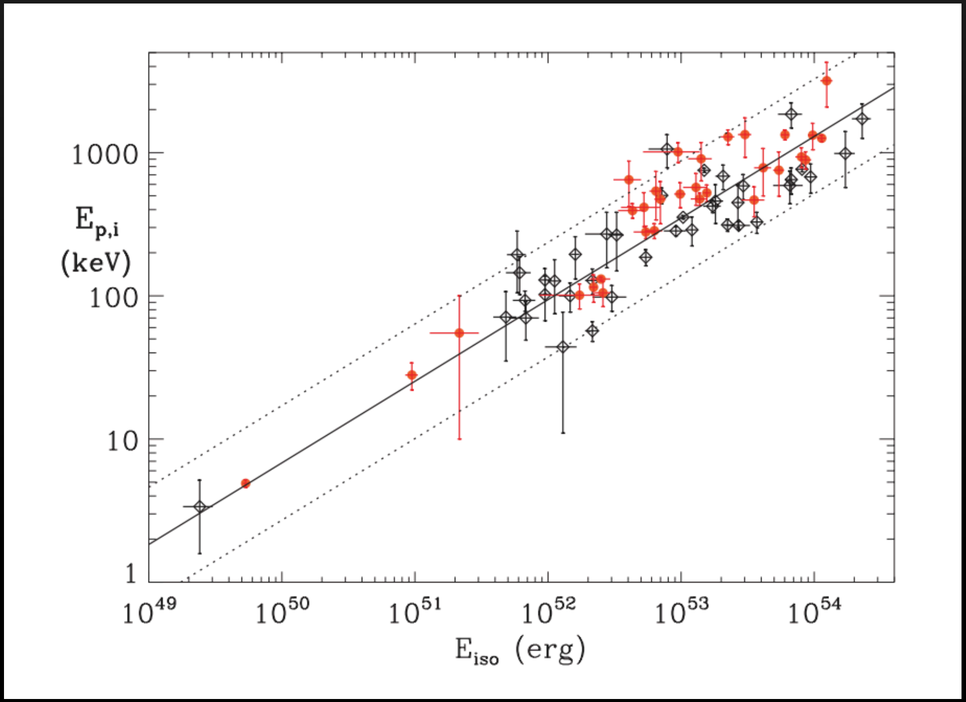
➡ cocoon/SN emission can also pinpoint off-axis afterglow, as proposed (and demonstrated) for the Ic-BL SN 2020bvc


THANK YOU !!!

Gamma-ray bursts



The "prompt" spectrum



Correlation between E_{peak} and E_{iso}

(Amati+2002, 2008)

Metallicity indicators

Nebular gas emission lines can be used as indicators for gas Z

Since Ic-BL SN progenitors have short (~10 Myr) lives, the metallicity of the surrounding gas is a proxy for the progenitor Z

$$\mathrm{O3N2} = \log\left(\frac{[\mathrm{O\,III}]\lambda5007}{\mathrm{H}\beta} \times \frac{\mathrm{H}\alpha}{[\mathrm{N\,II}]\lambda6583}\right)$$

$$12 + \log(\mathrm{O/H}) = 8.743[\pm0.027] + 0.462[\pm0.024] \times \mathrm{N2},$$

$$\mathrm{N2} = \log\left(\frac{[\mathrm{N\,II}]\lambda6583}{\mathrm{H}\alpha}\right).$$

$$12 + \log(\mathrm{O/H}) = 8.533[\pm0.012] - 0.214[\pm0.012] \times \mathrm{O3N2}.$$

$$y = \log[\mathrm{NII}]/[\mathrm{SII}] + 0.264\log[\mathrm{NII}]/\mathrm{H}\alpha,$$

$$12 + \log(\mathrm{O/H}) = 8.77 + y + 0.45(y + 0.3)^5$$

SN 2020bvc
12 + log(O/H) = 8.16 +- 0.18

(Marino+ 2013, Dopita+ 2016)

DARK

Shocked stellar material (SSM)

The physics of the emission from the shocked stellar material is similar to the envelope surrounding an SN cooling after the passage of SBO => similarities between the two phenomena

(Nakar & Piran 2017)

Assuming canonical values for k, and considering cooling shocks equation, we have that the SSM peaks at

$$t_{c,s} \approx 1.2\, E_{51.5}^{-1/4} \theta_{10^\circ}^{3/2} M_{10}^{3/4} \kappa_{0.05}^{1/2}\ \mathrm{day},$$

Time

$$L_{c,s} \approx 10^{42} E_{51.5} \theta_{10^\circ}^{-4/3} R_{11} M_{10}^{-1} \kappa_{0.05}^{-1}\ \mathrm{erg\ s^{-1}}$$

Luminosity

$$T_{c,s} \approx 9000\, E_{51.5}^{1/8} \theta_{10^\circ}^{-7/12} R_{11}^{1/4} M_{10}^{-3/8} \kappa_{0.05}^{-1/2}\ \mathrm{K}$$

Temperature

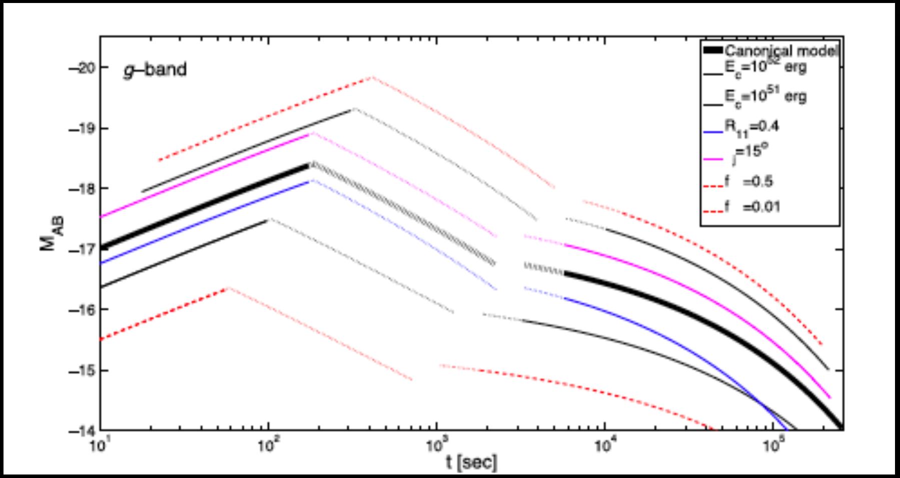
"...cocoon emission from a GRB will produce an isotropic signal a day after the event... at an absolute magnitude ~ -16 and is dominant over the orphan afterglow..."

Shocked jet emission

In case of no complete mixing (e.g. partial or null mixing) the shocked jet material is characterised by a relativistic and non-relativistic emission

The relativistic emission would peak at NUV frequencies ~100-1000 s after the collapse

The newtonian emission has a shallower emission, being more isotropic, then it should be visible in the first few days after the collapse



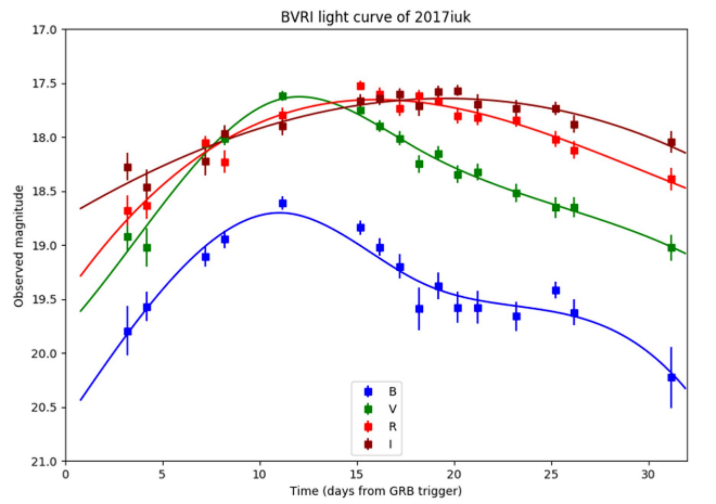
(Nakar & Piran 2017)

Arnett model

Homologous expansion, spherical symmetry, constant optical opacity, Ni & Co as energy sources.

$$L_{^{56}\mathrm{Ni}}(t) = 2 \times 10^{43}\left(\frac{M_{\mathrm{Ni}}}{M_{\odot}}\right)[3.9e^{-t/\tau_{\mathrm{Ni}}} + 0.678(e^{-t/\tau_{\mathrm{Co}}} - e^{-t/\tau_{\mathrm{Ni}}})]\,\mathrm{erg\ s^{-1}},$$

(Kasen 2017, Arnett 1982,Valenti+ 2008)



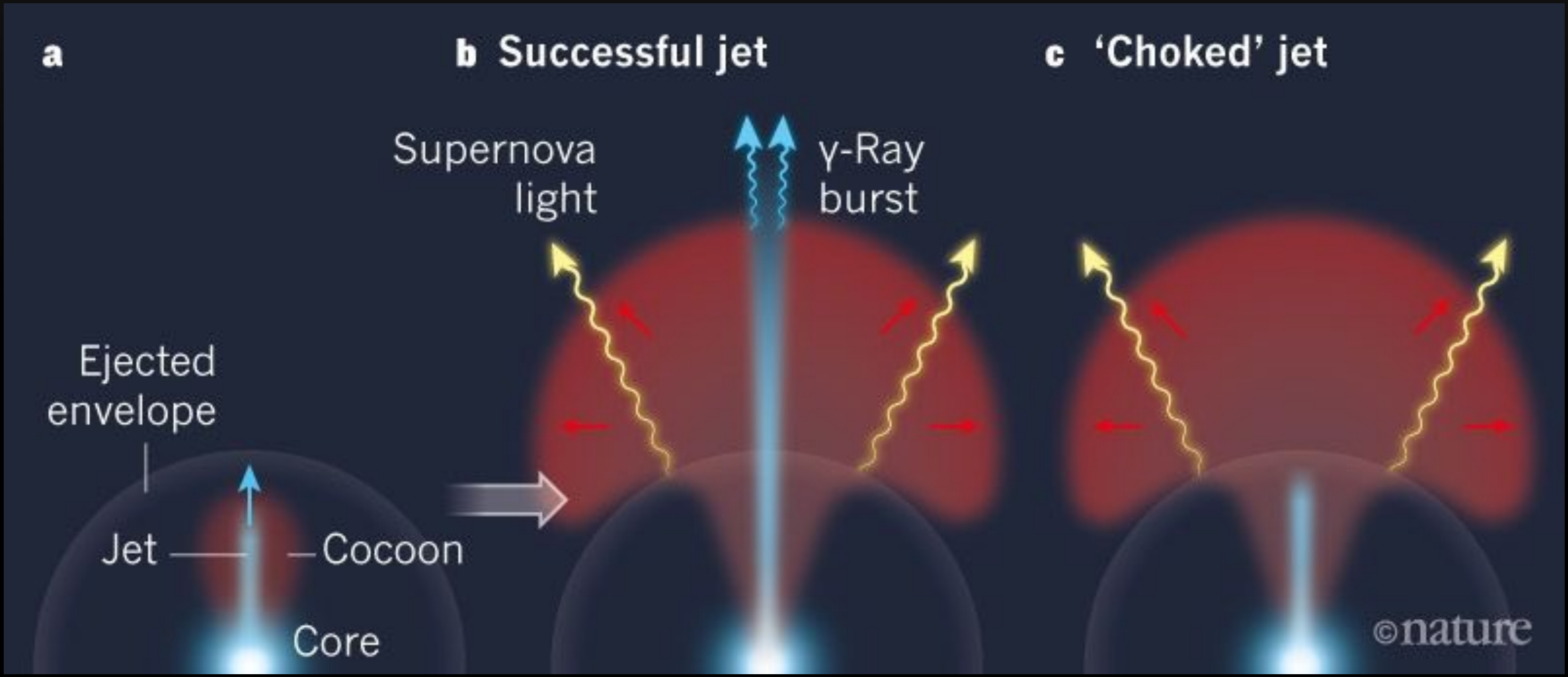
M_{ejecta} = 4.9 MSun

M_{56Ni} = 0.18 MSun

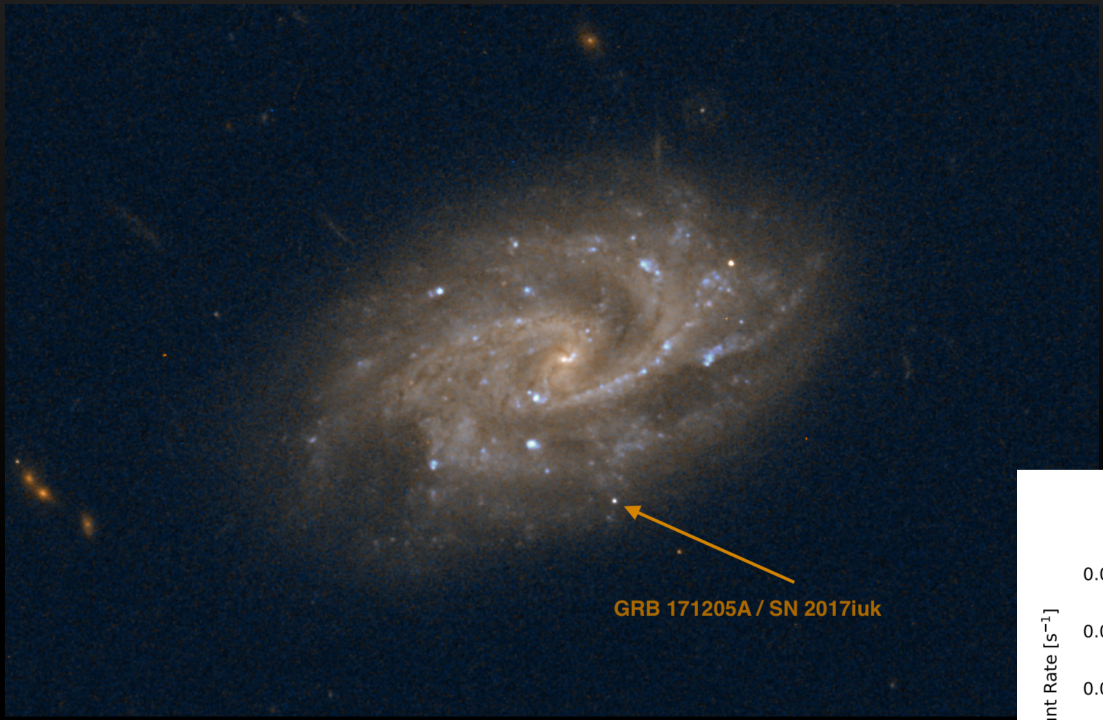
E_{kin} = 2.4 x 10^{52} erg

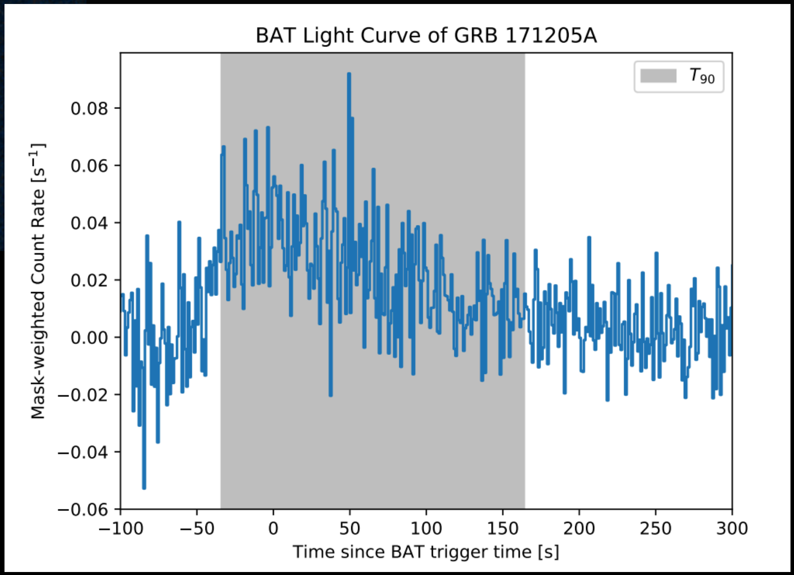
The Jet-Cocoon

- early thermal cooling emission from X-rays to UV-opt
- velocity shocked material ~ 0.1-0.3 c
- significant level of mixing (no mixing, no party !!!)



GRB 171205A/SN 2017iuk





(Izzo+ 2019, D'Elia+ 2018)

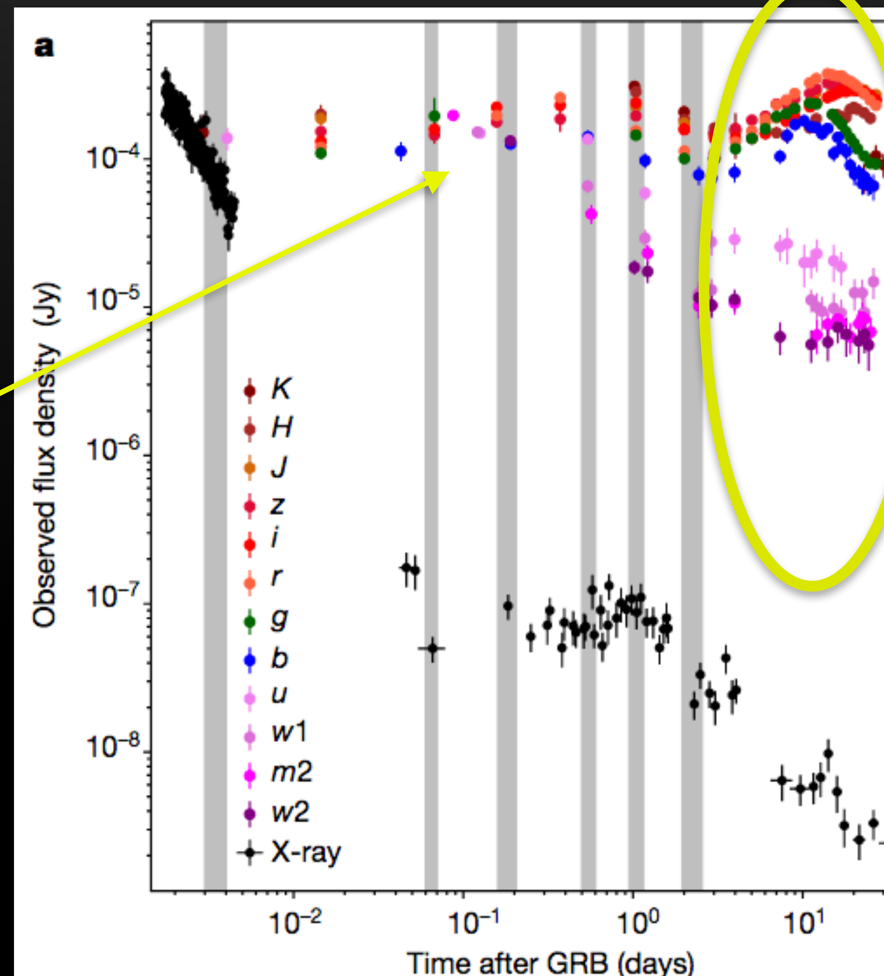
GRB 171205A/SN 2017iuk

rapid decay in the X-ray afterglow emission

> very faint afterglow

anomalous behaviour in the first day at UV-optical freqs

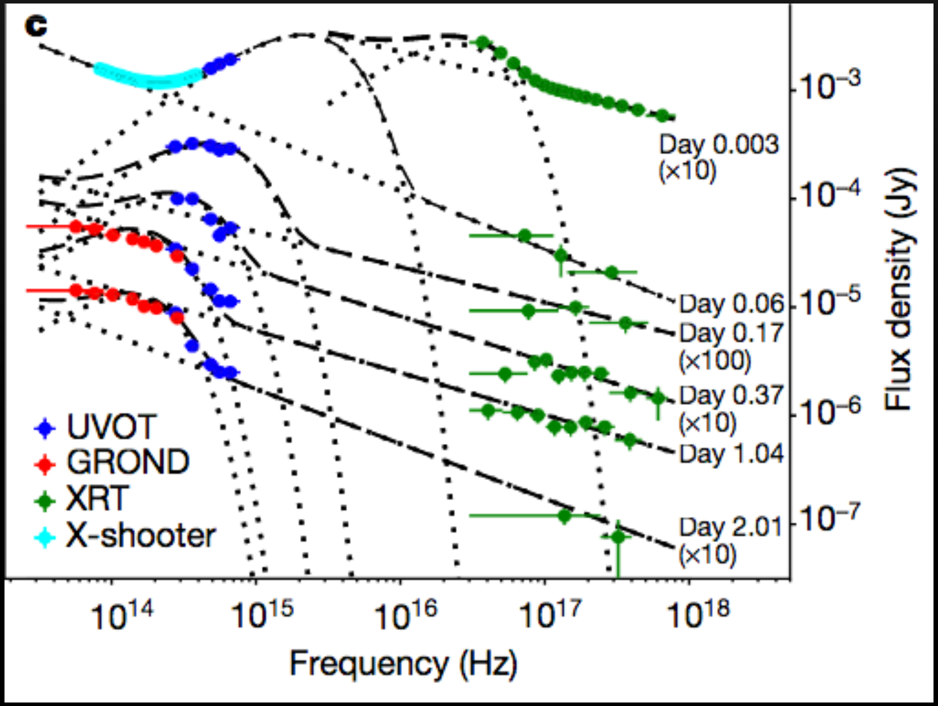
multi-wavelength photometric & spectroscopic campaign (Swift, VLT, GTC, GROND, PST2, OSN, GOTO, ...)

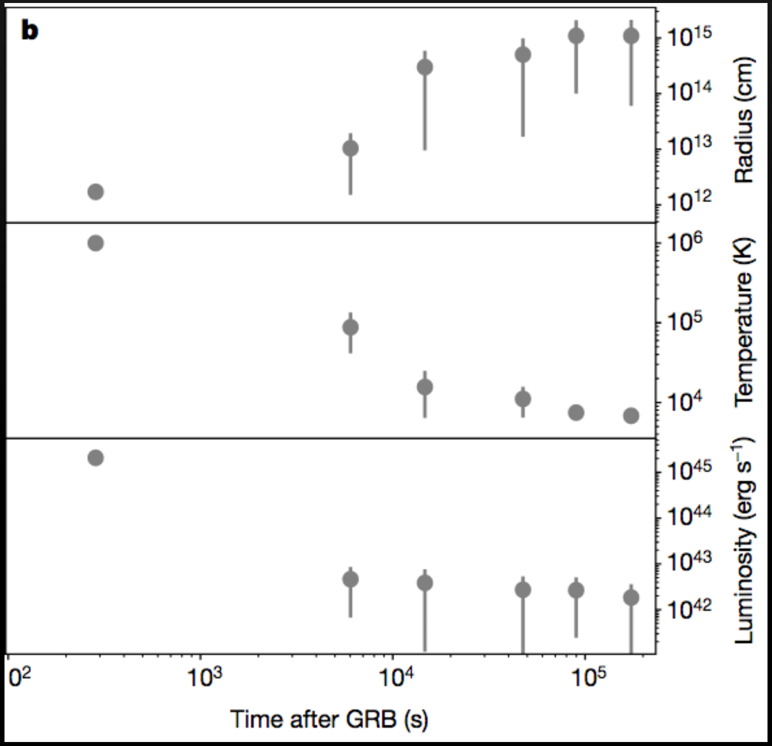


(Izzo+ 2019)

GRB 171205A/SN 2017iuk

from near-IR to X-rays

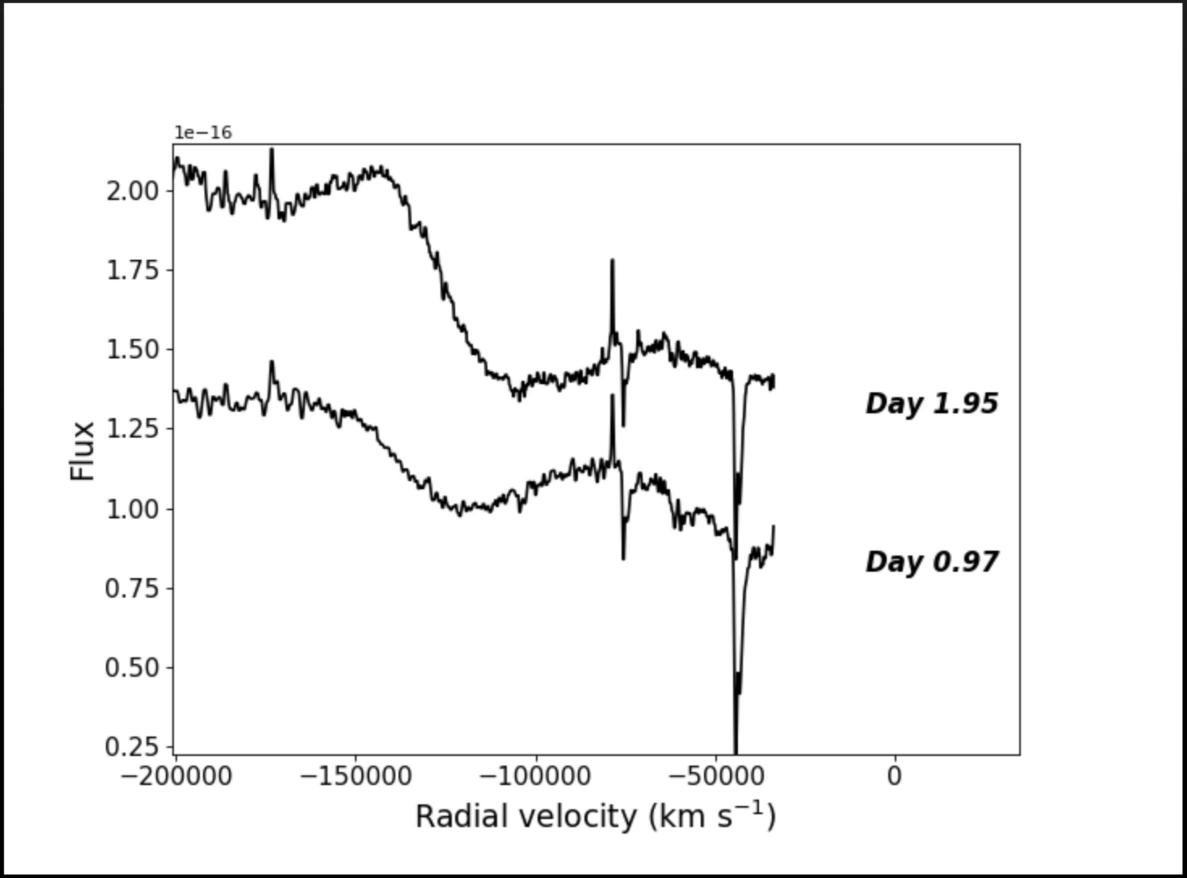




cooling thermal component

GRB 171205A/SN 2017iuk

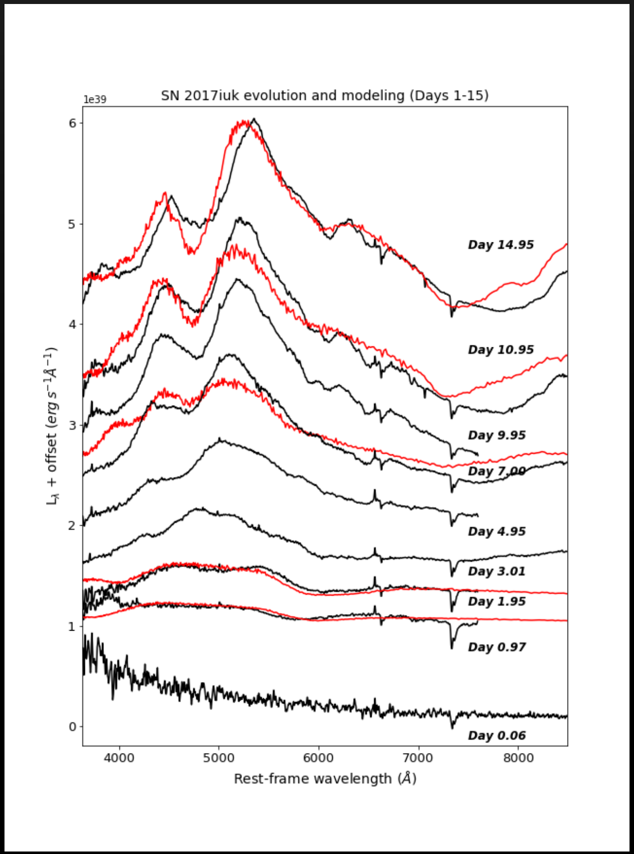
Ca II near-IR triplet



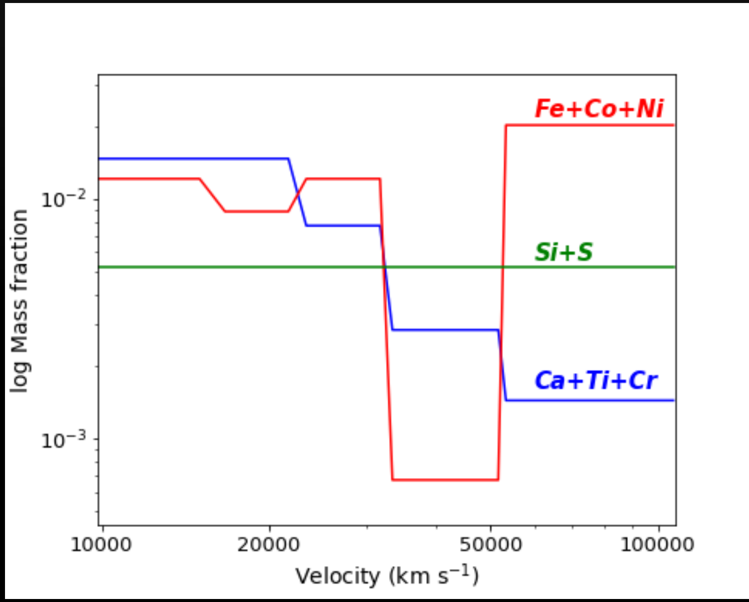
expanding velocities for the ejecta of ~ 0.3c
Huge KE for the cocoon -> 10^{51} - 10^{52} erg !!!

GRB 171205A/SN 2017iuk

Spectral synthesis model (TARDIS code)



- CO138 model (1998bw)
- flat distribution at high velocities
- Fully-mixed chemical composition



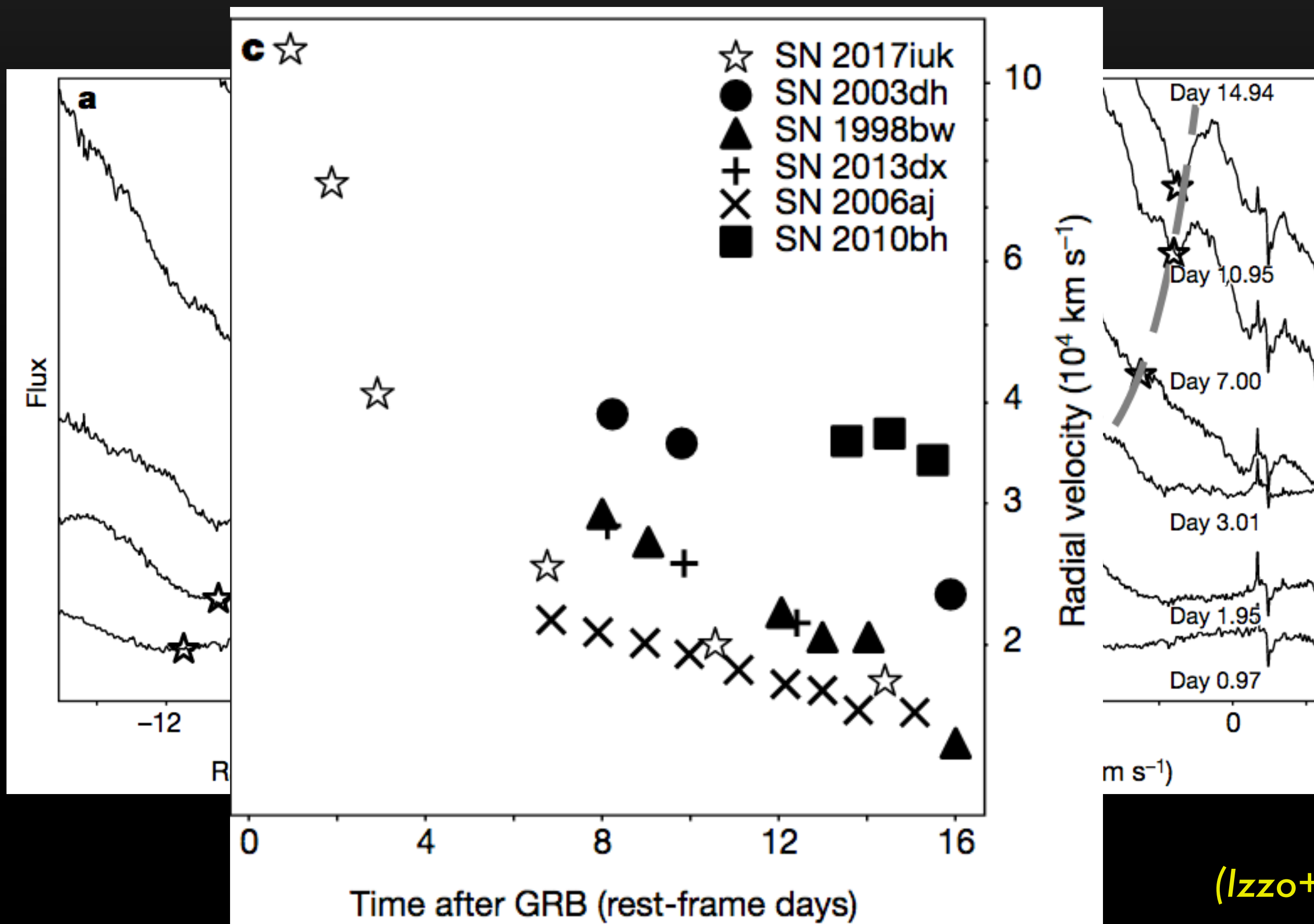
Significant level of mixing

M_{cocoon} ~ 0.13 MSun — E_{kin} ~ 10^{52} erg

(Iwamoto+ 1998, Nakamura+ 2001, Maeda+ 2002, Izzo+ 2019)

GRB 171205A/SN 2017iuk

Spectral evolution

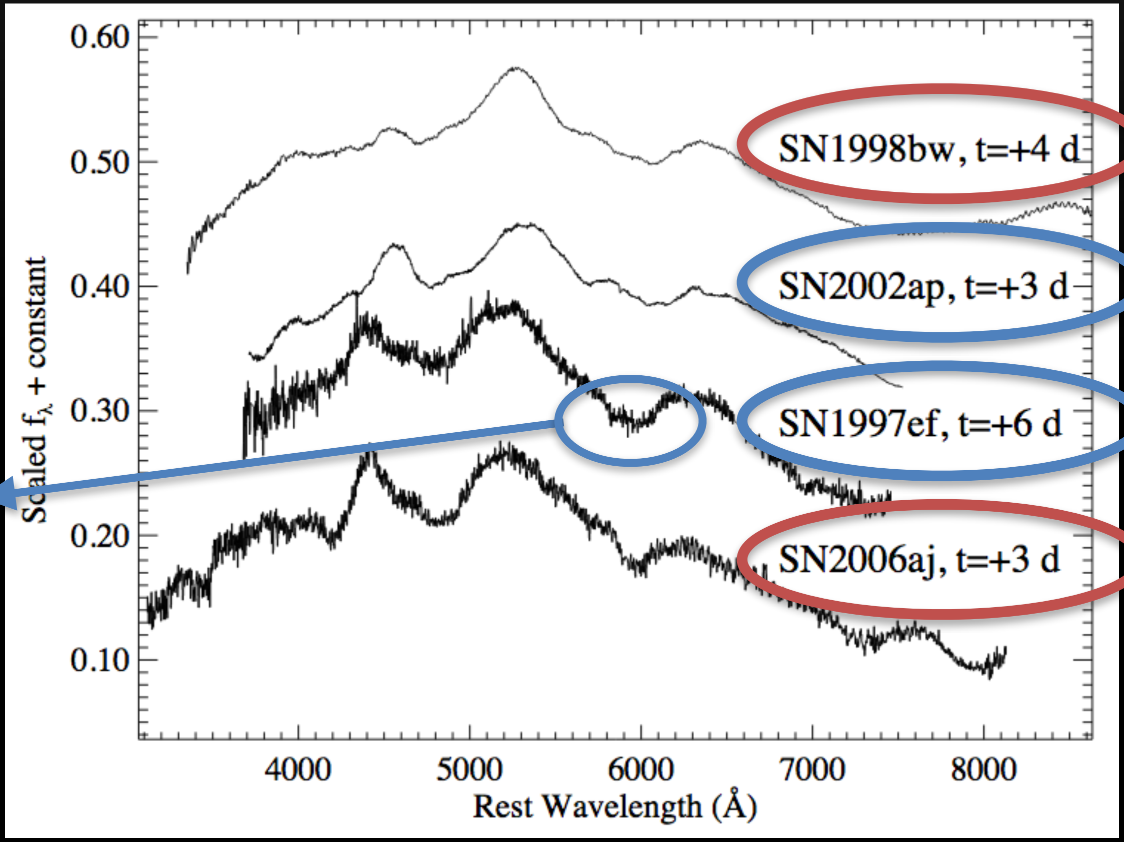


(Izzo+ 2019)

Ic BL SNe w/o GRBs

GRB-SN are Ic-BL SNe, but not all type Ic-BL SNe are associated with a GRB => no relativistic jet emission

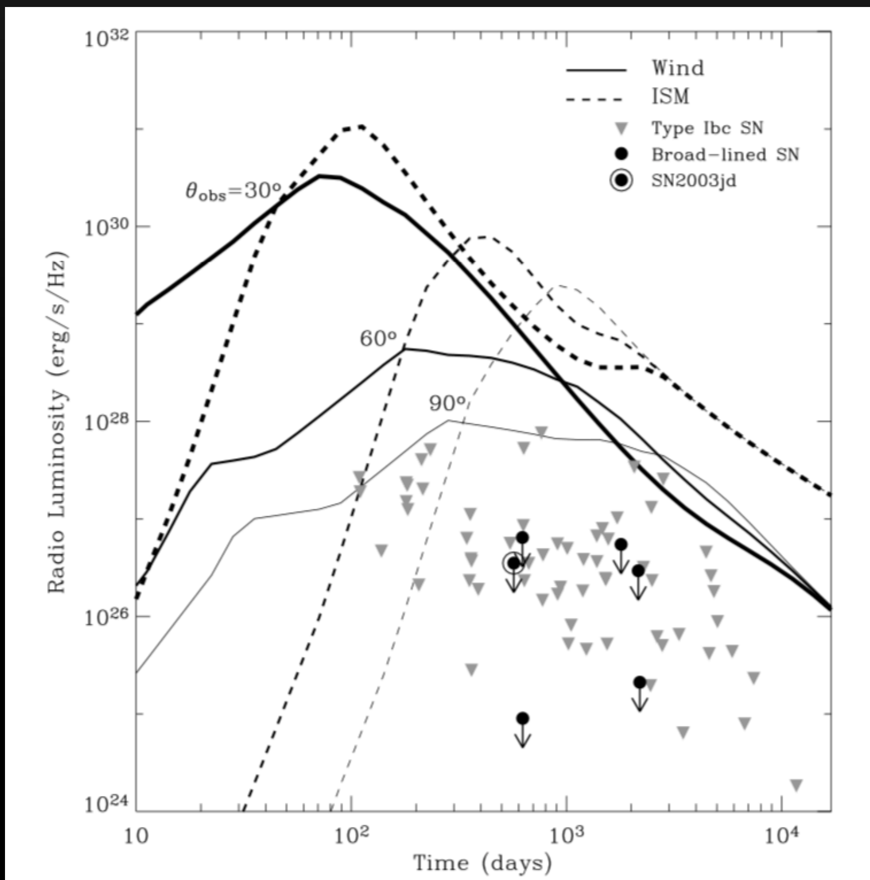
V_{ej} ~ 25,000 kms



(Mazzali+ 2000)

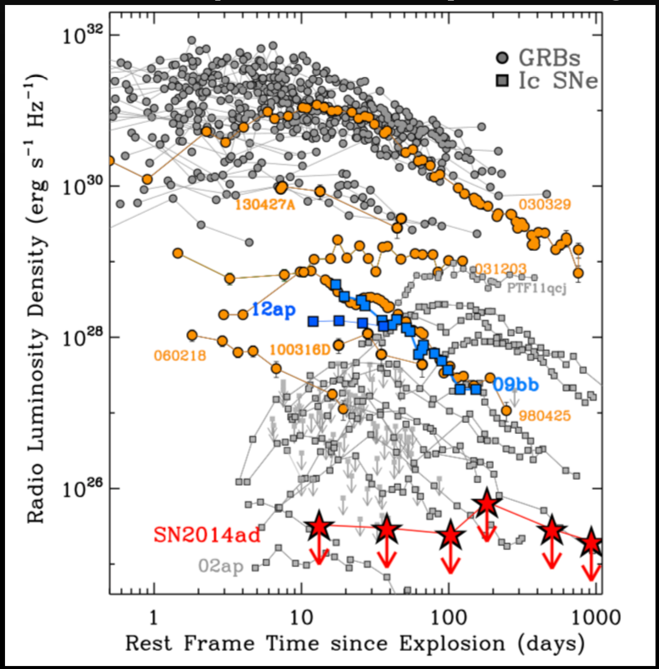
Ic BL SNe w/o GRBs

radio observations of a sample of six Ic-BL without GRB have revealed no association with an off-axis jet



(Soderberg+ 2006)

For the nearby SN2014ad it cannot be excluded a narrow jet offset by 30deg

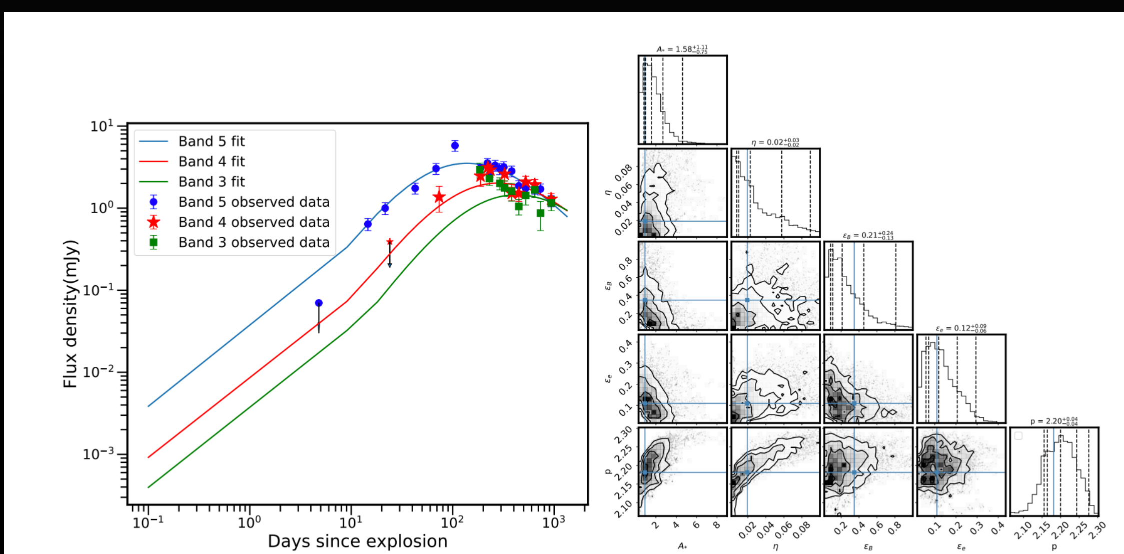


(Marongiu+ 2019)

GRB171205A @ radio

No jet break observed up to >3 years after the GRB
=> radio emission from a quasi-spherical afterglow (SBO or cocoon)

Enhancement of energy at late time in radio LC
=> energy injection from the central engine

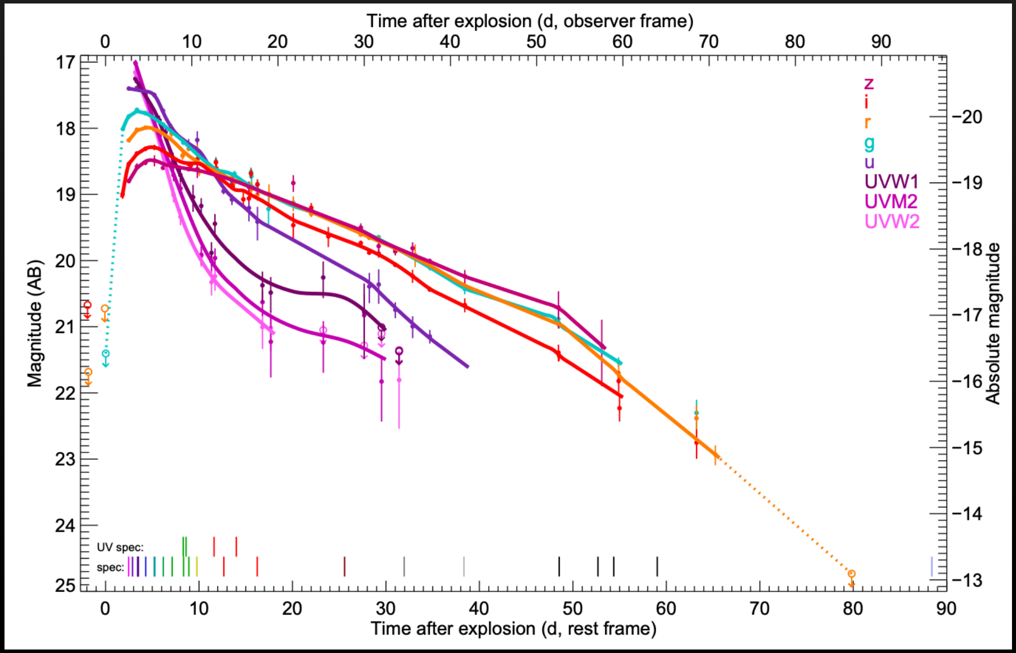


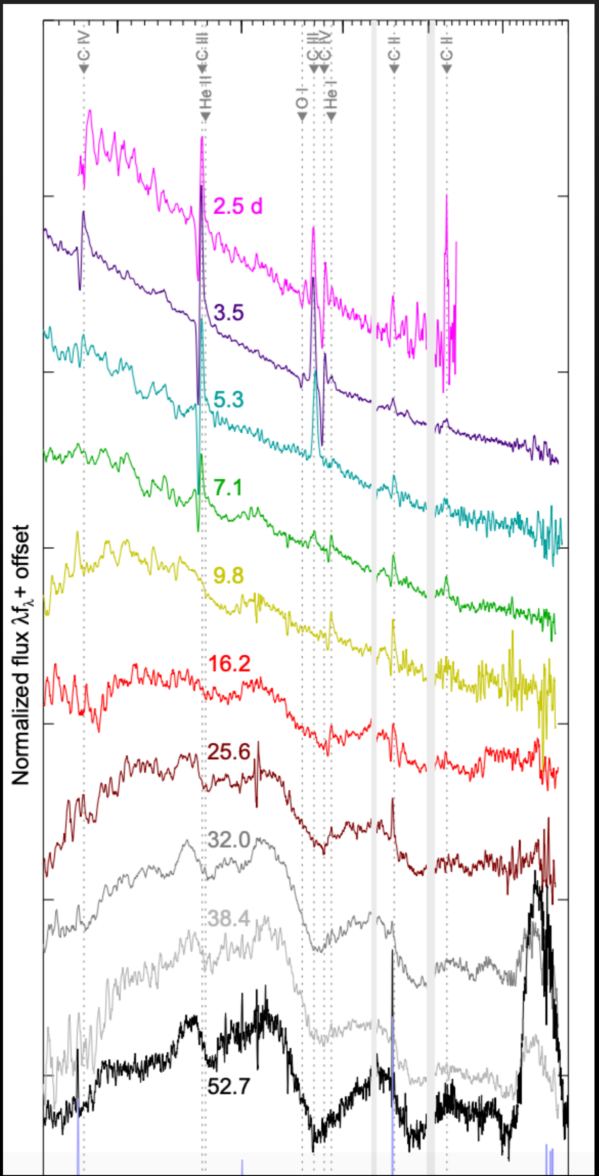
Two component

- early radio from cocoon

- late rise from afterglow of a jet observed slightly off-axis

Type Icn SNe





WR surrounded by a CO(Ne) massive wind

Early spectra show P-Cygni of "interacting" C II lines

(Perley+ 2021, Gal-Yam+2022)