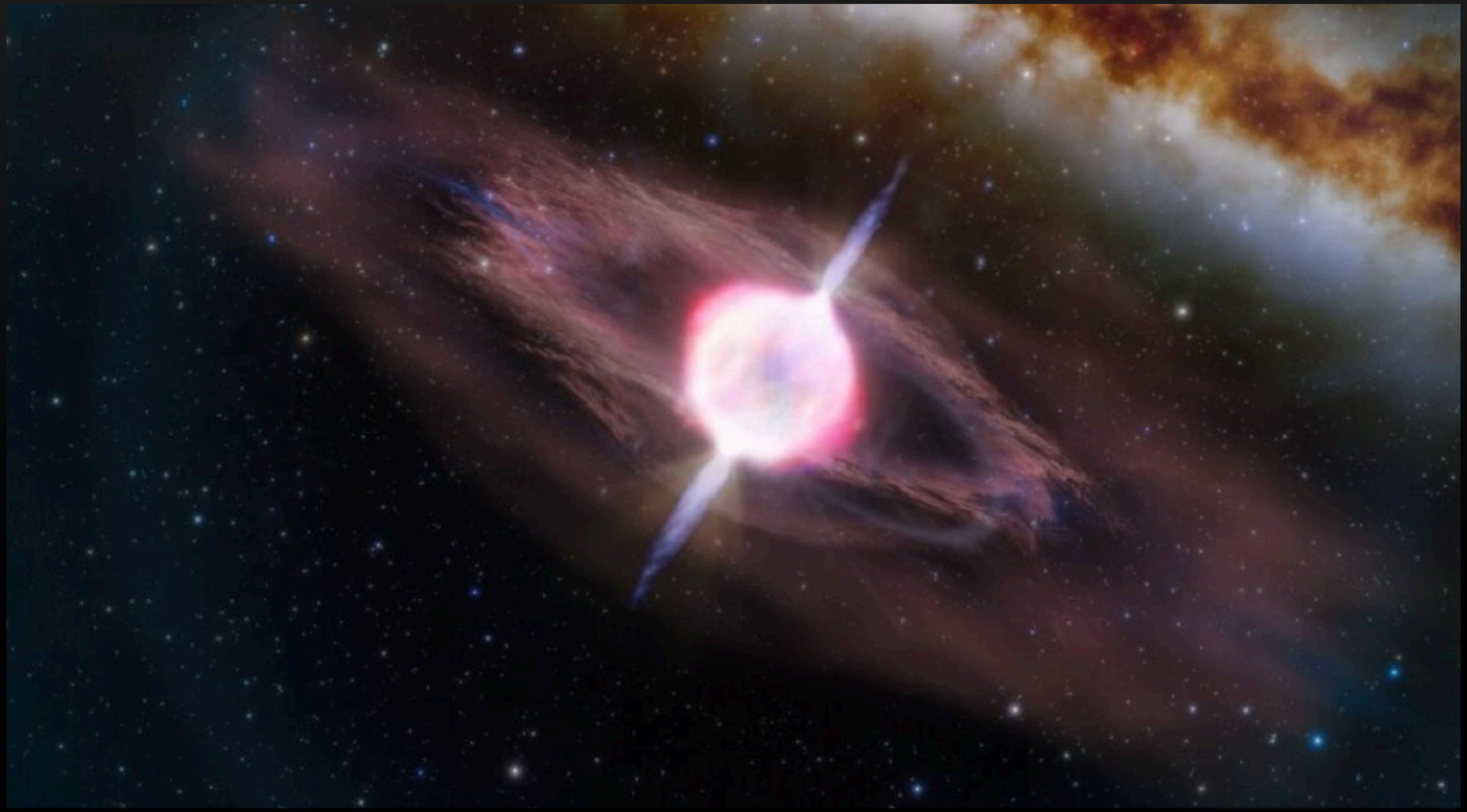
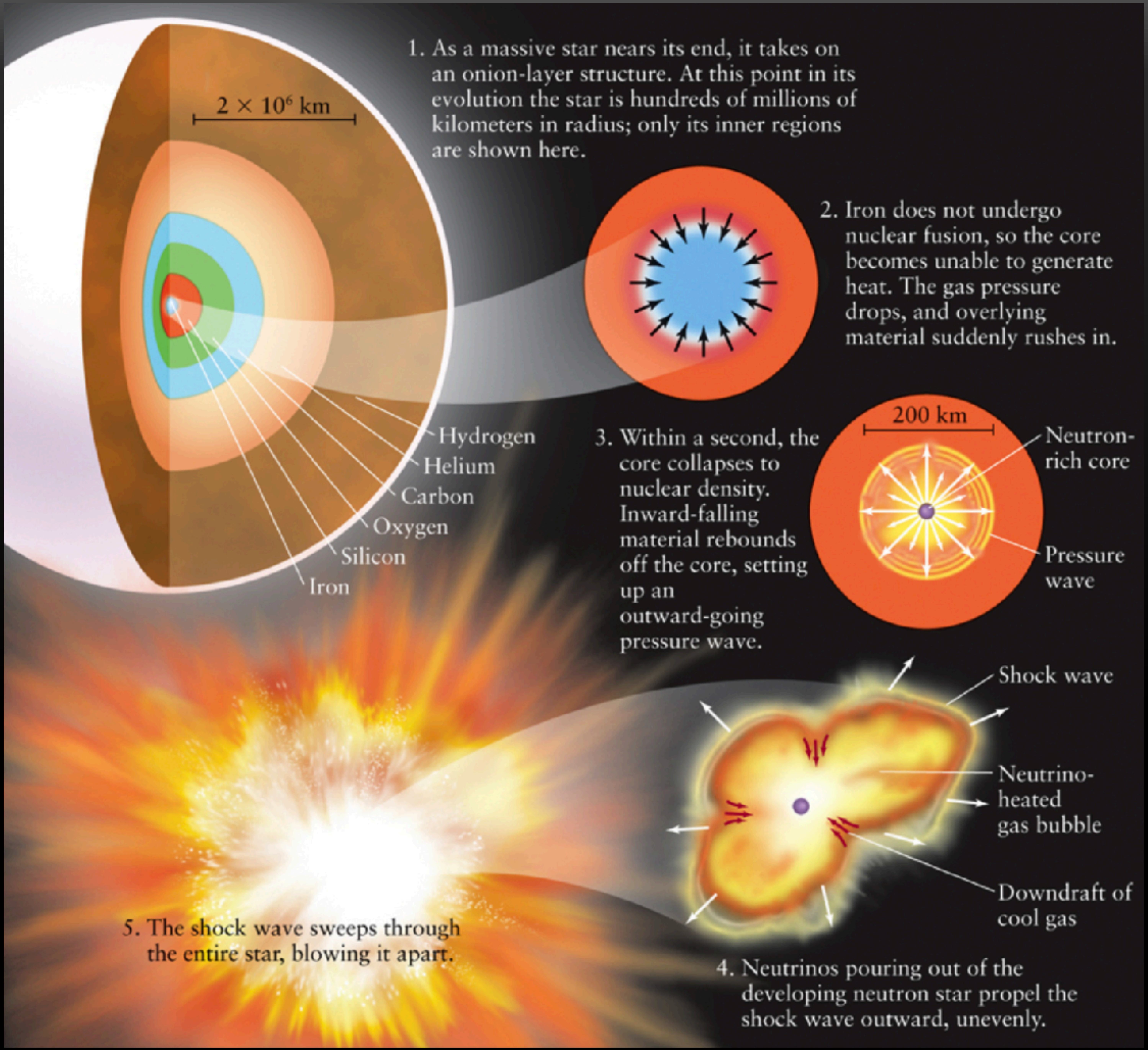
SIGNATURES OF COCOON IN GRB/SN



L. Izzo (INAF-OACN & DARK/NBI)

GRB+CE2024 - PI



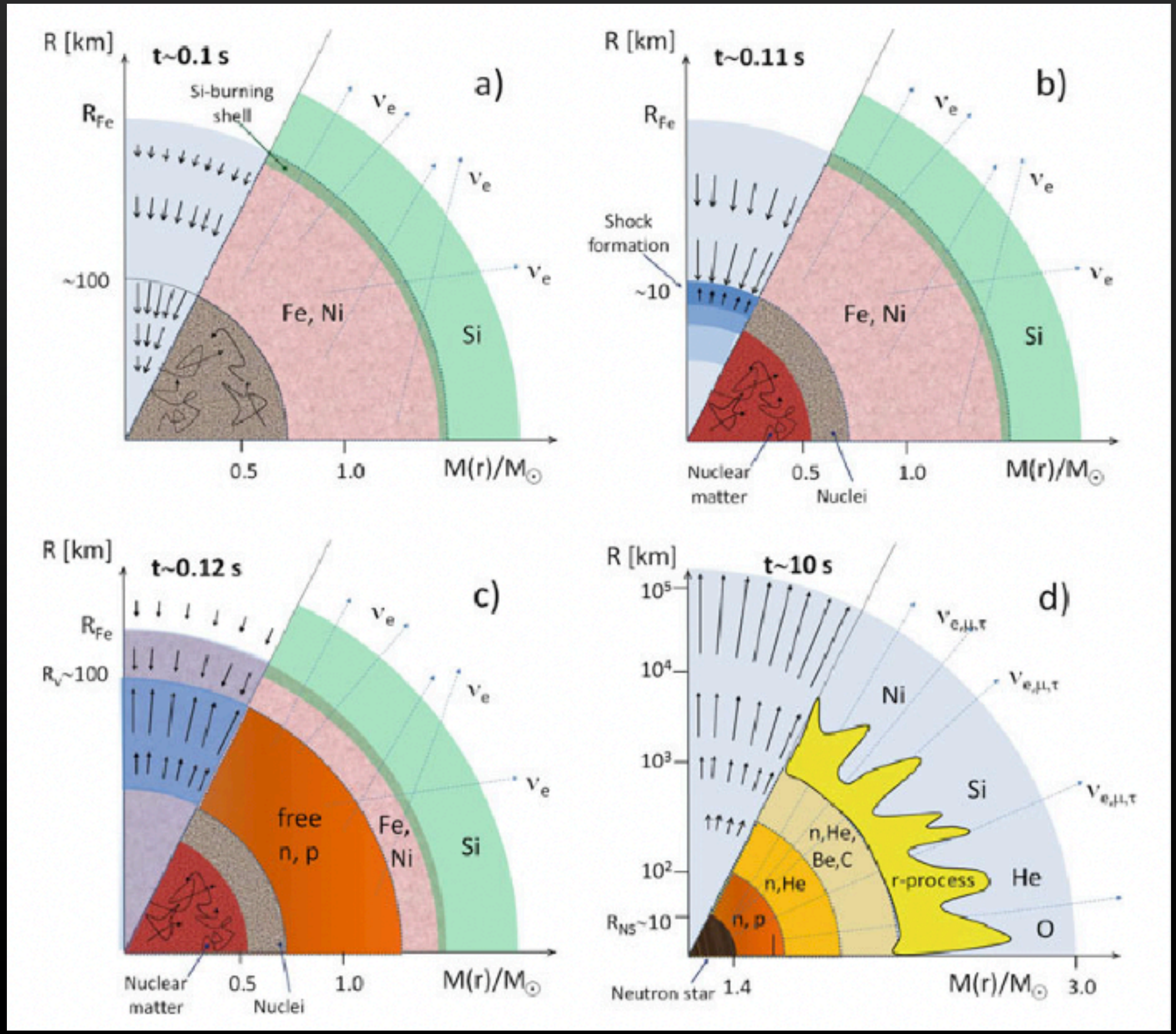
1. As a massive star nears its end, it takes on an onion-layer structure. At this point in its evolution the star is hundreds of millions of kilometers in radius; only its inner regions are shown here.

2. Iron does not undergo nuclear fusion, so the core becomes unable to generate heat. The gas pressure drops, and overlying material suddenly rushes in.

3. Within a second, the core collapses to nuclear density. Inward-falling material rebounds off the core, setting up an outward-going pressure wave.

4. Neutrinos pouring out of the developing neutron star propel the shock wave outward, unevenly.

5. The shock wave sweeps through the entire star, blowing it apart.

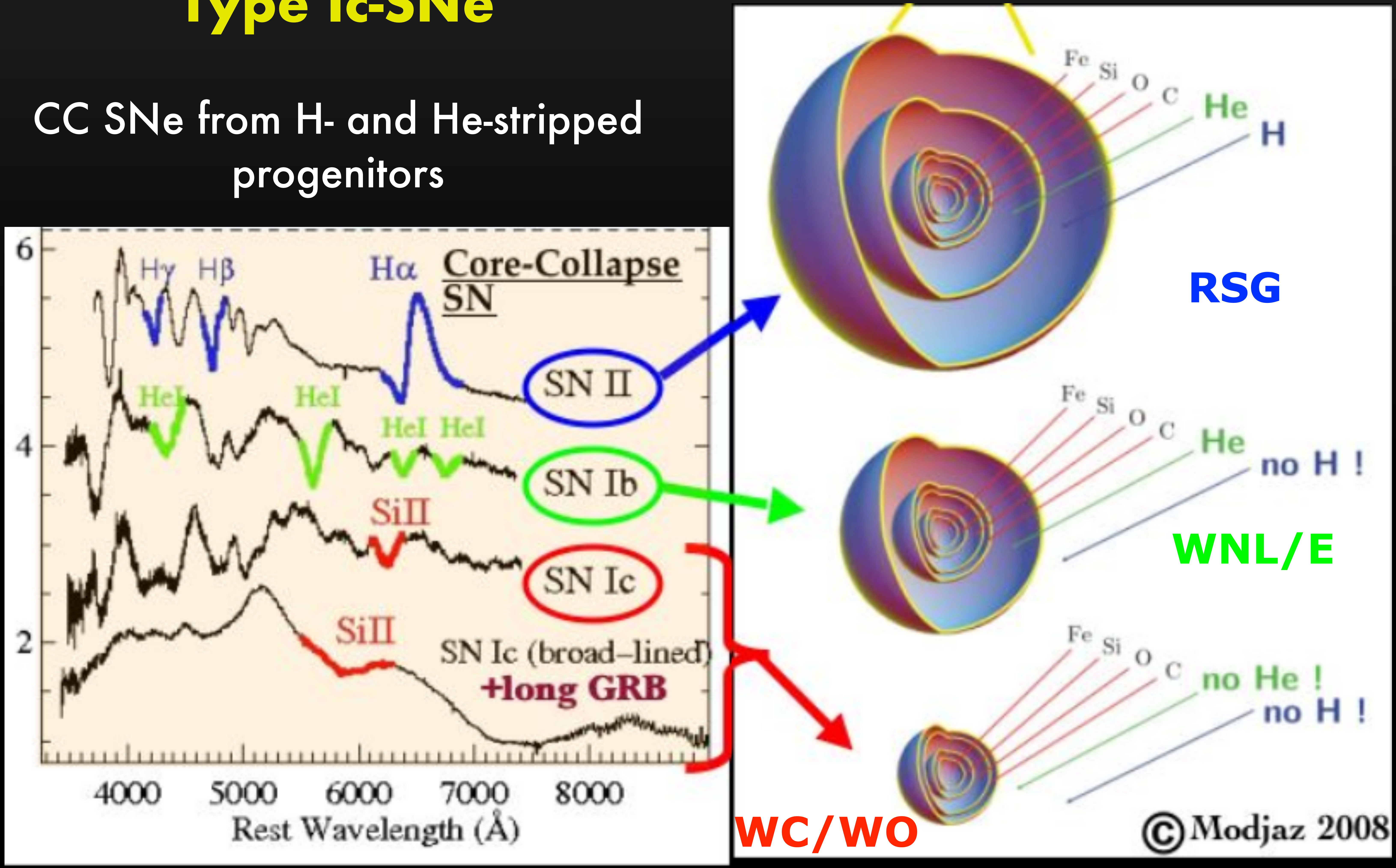


(courtesy Devor, Spurio)

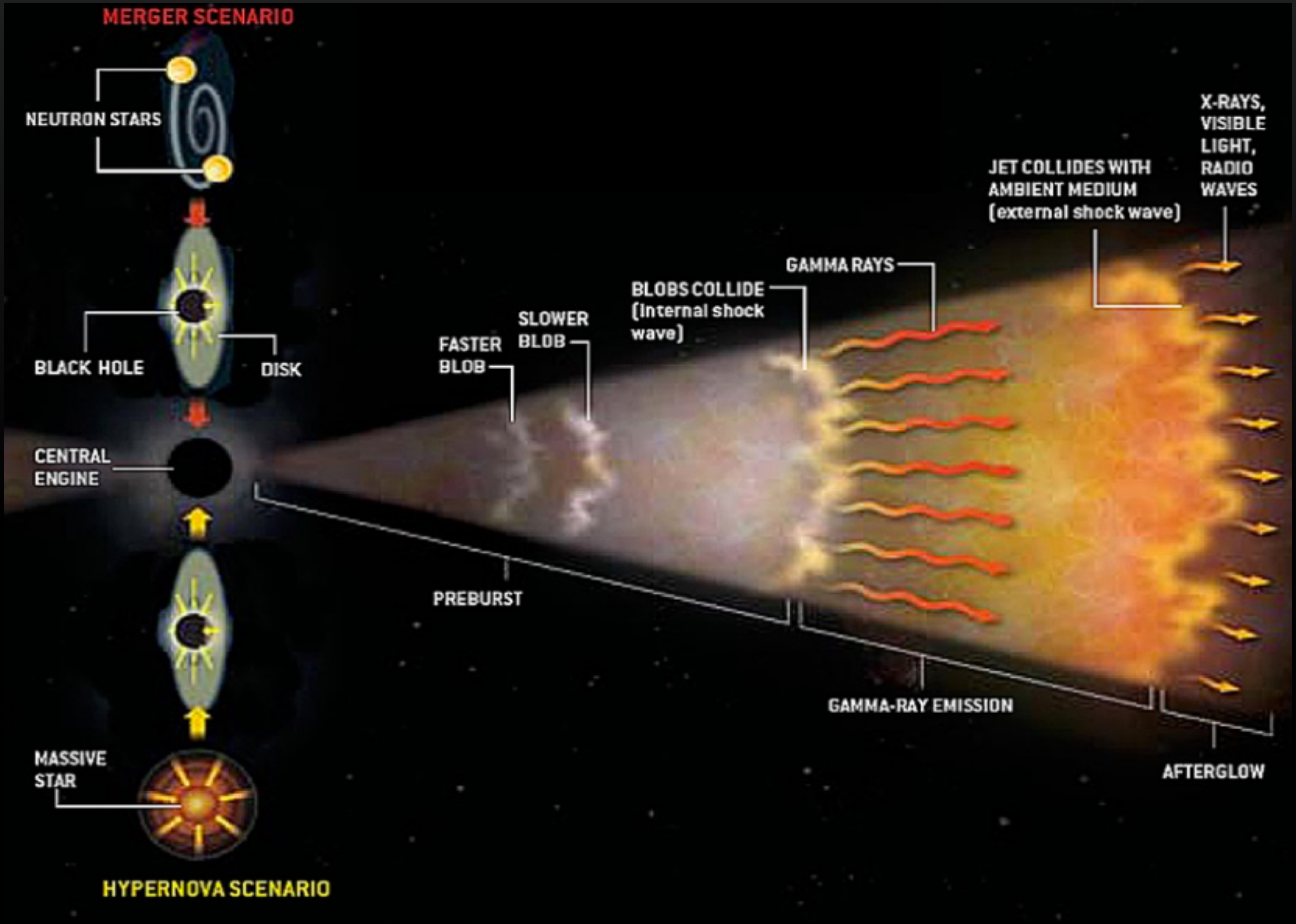
SN types and progenitors

Type Ic-SNe

CC SNe from H- and He-stripped progenitors



Gamma-ray bursts



GRB-SN connection

WC/WO star => loss of consistent mass

Fast-rotation

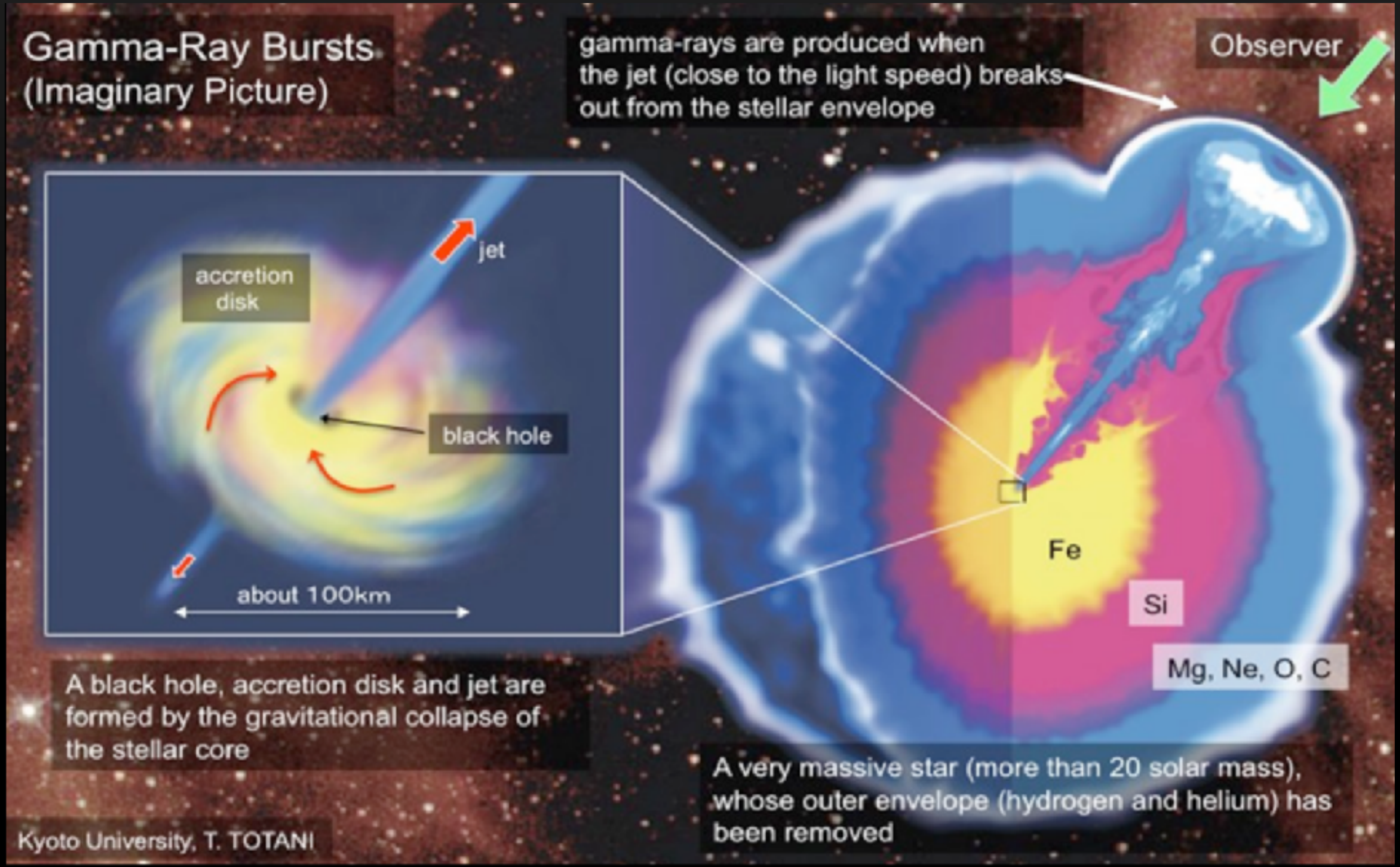
Low metallicity:

- weak stellar winds (low L losses)
- strong mixing
- homogeneous evolution

(type Ic events without losing large mass)

Binarity => L values similar to single scenario

(Maeder & Meynet 2001, 2007,
Woosley & Heger 2006, Yoon+ 2010)



Gamma-Ray Bursts
(Imaginary Picture)

gamma-rays are produced when the jet (close to the light speed) breaks out from the stellar envelope

A black hole, accretion disk and jet are formed by the gravitational collapse of the stellar core

A very massive star (more than 20 solar mass), whose outer envelope (hydrogen and helium) has been removed

Kyoto University, T. TOTANI

(courtesy Totani)

The jet cocoon

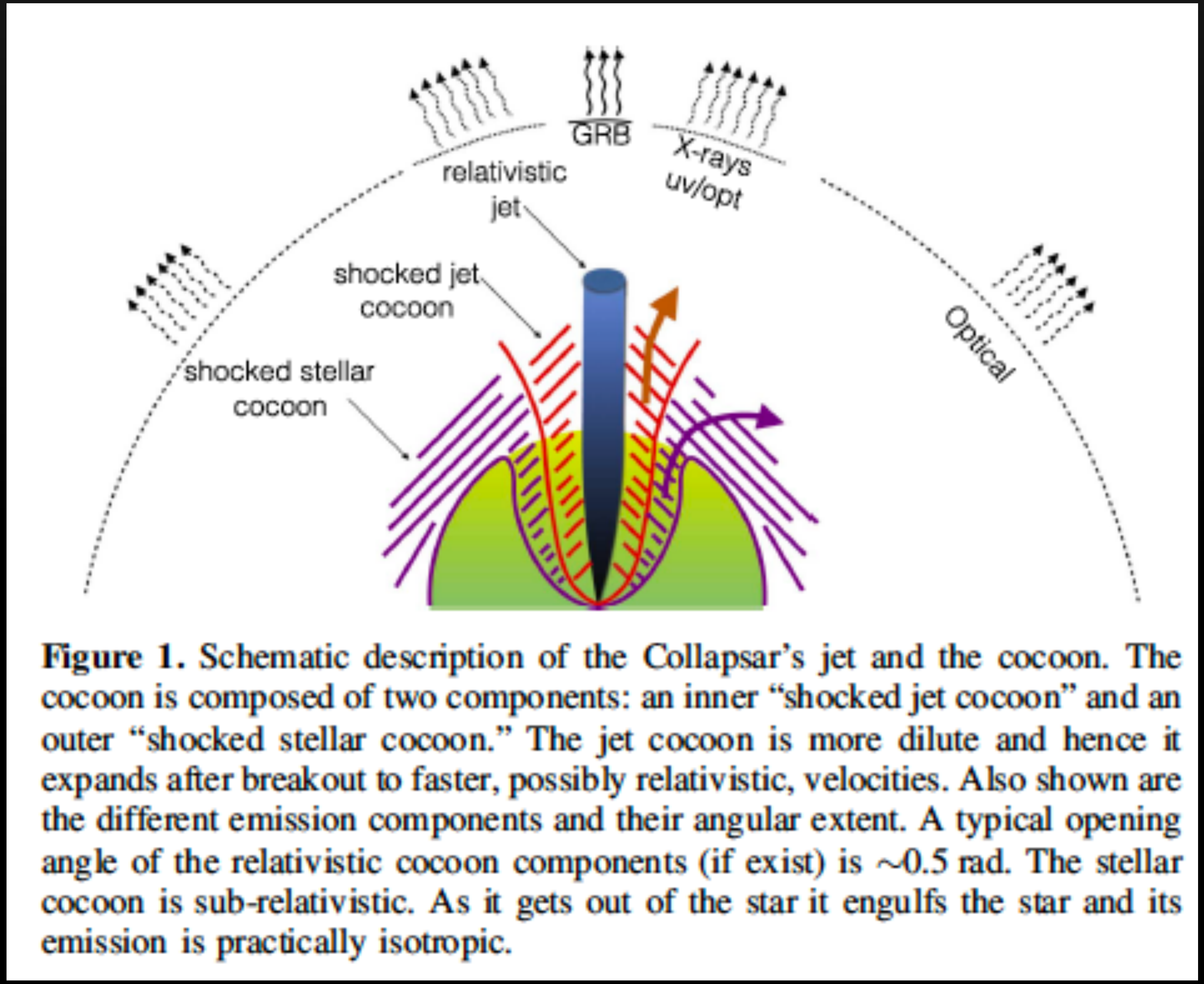
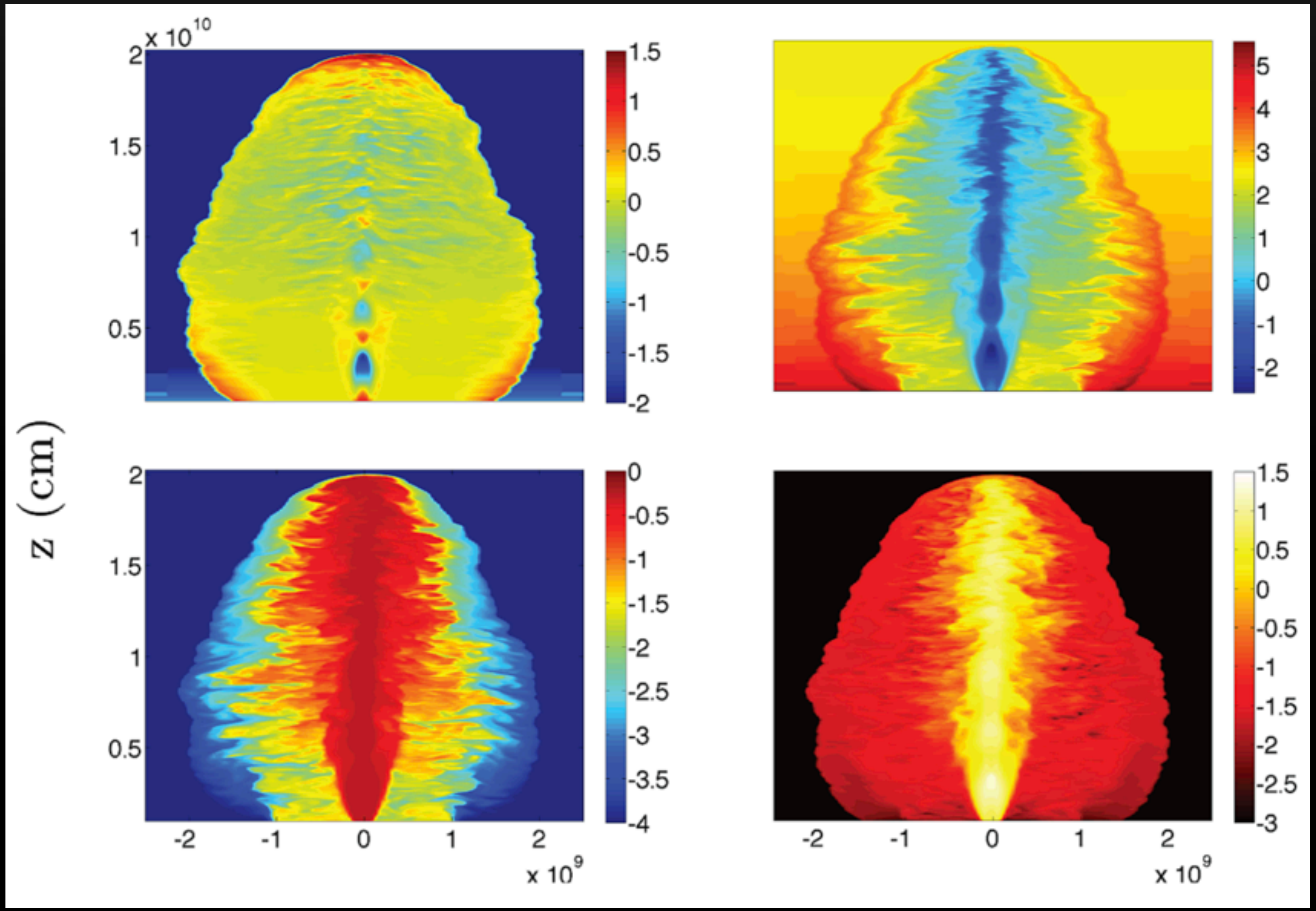
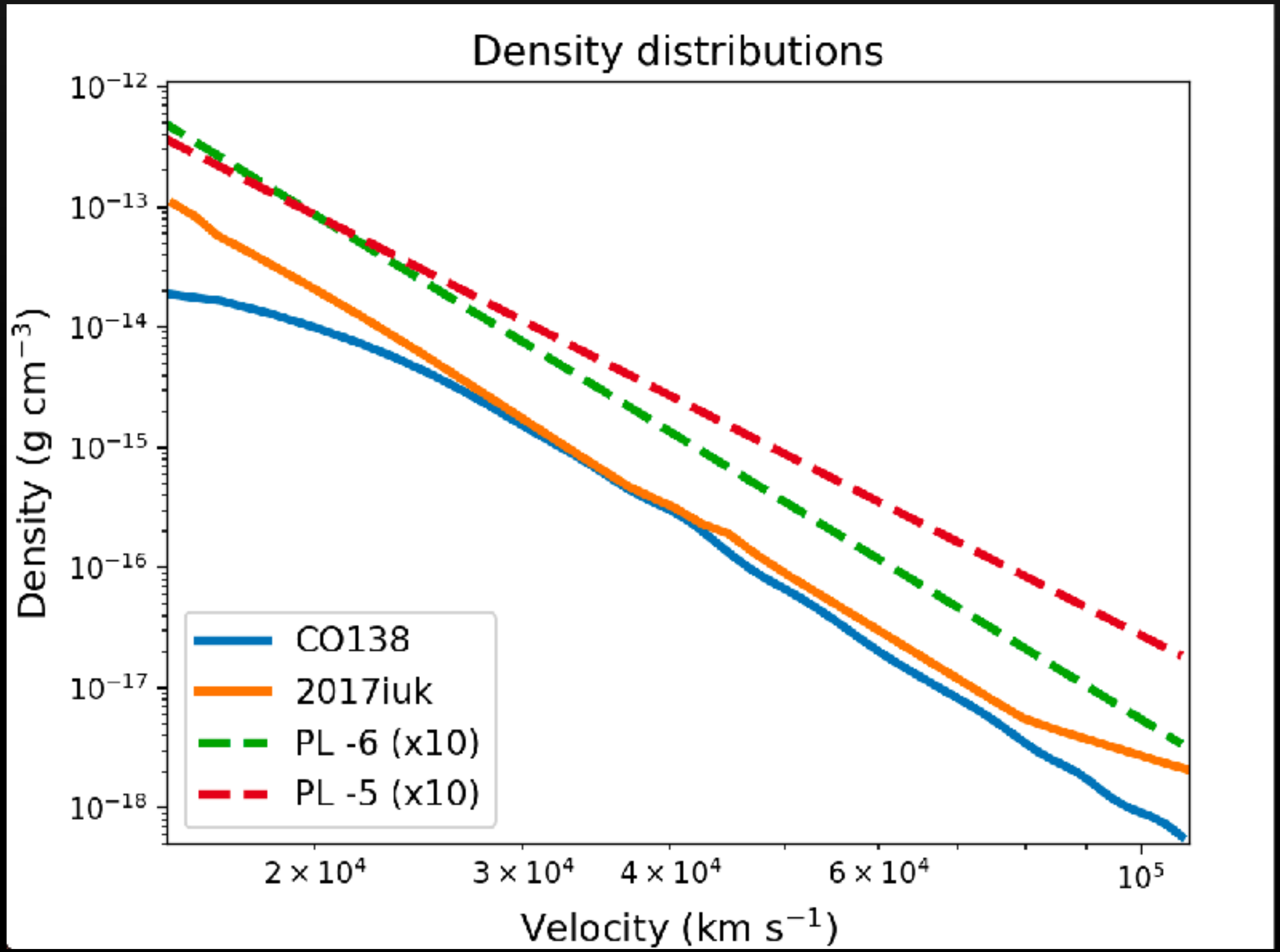


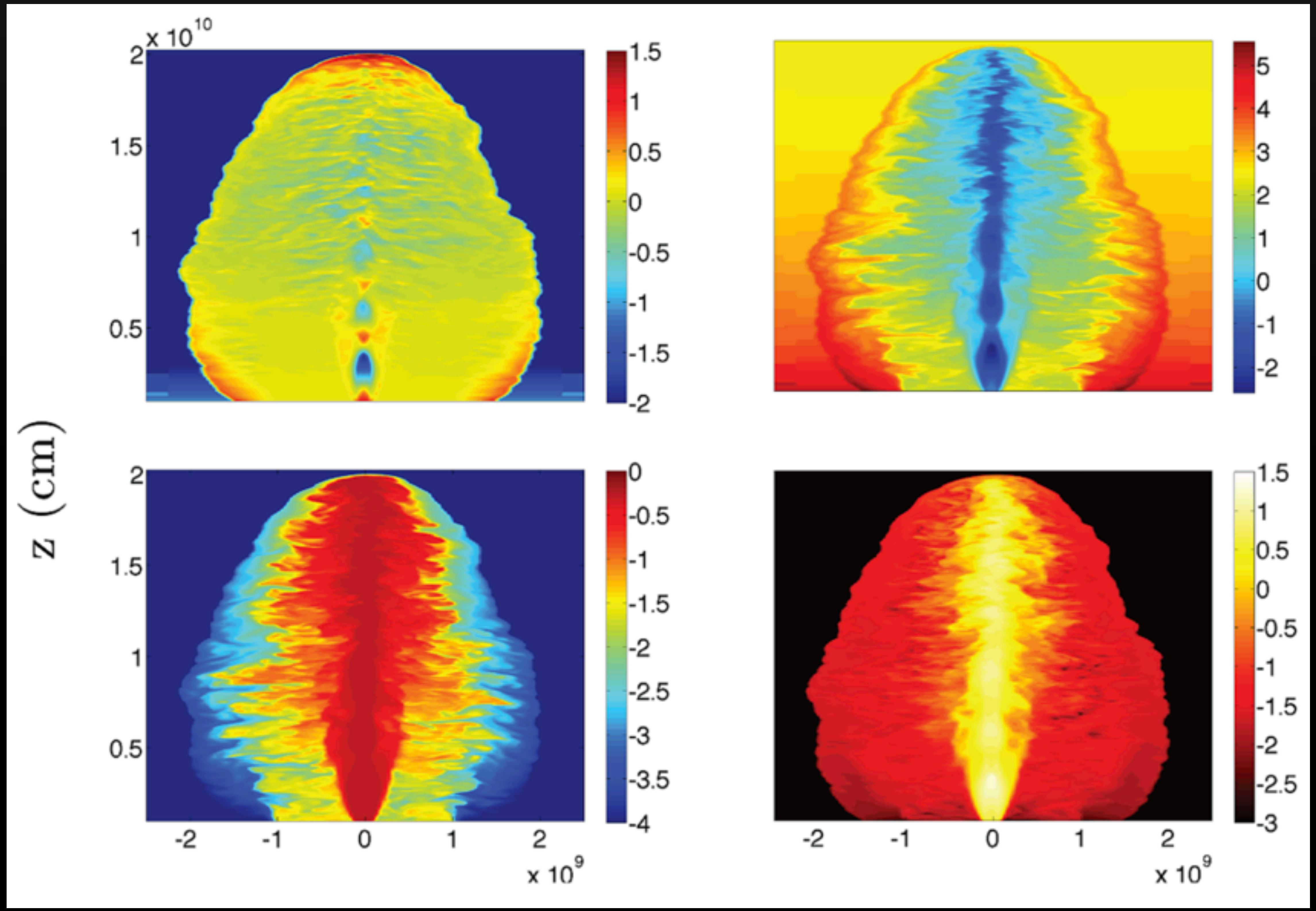
Figure 1. Schematic description of the Collapsar's jet and the cocoon. The cocoon is composed of two components: an inner "shocked jet cocoon" and an outer "shocked stellar cocoon." The jet cocoon is more dilute and hence it expands after breakout to faster, possibly relativistic, velocities. Also shown 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.



(Nakar & Piran 2017, Harrison+ 2017)

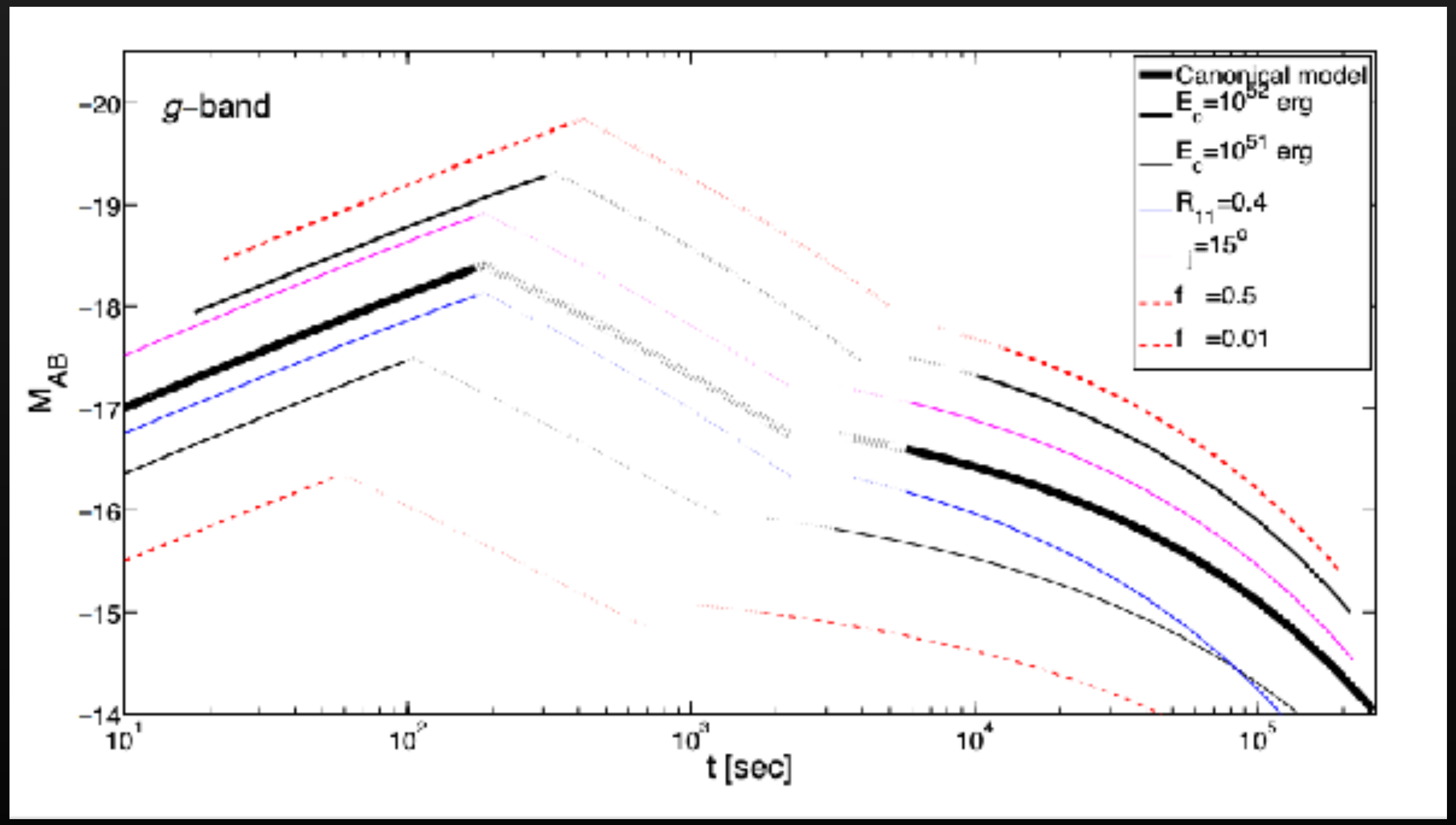
The jet cocoon

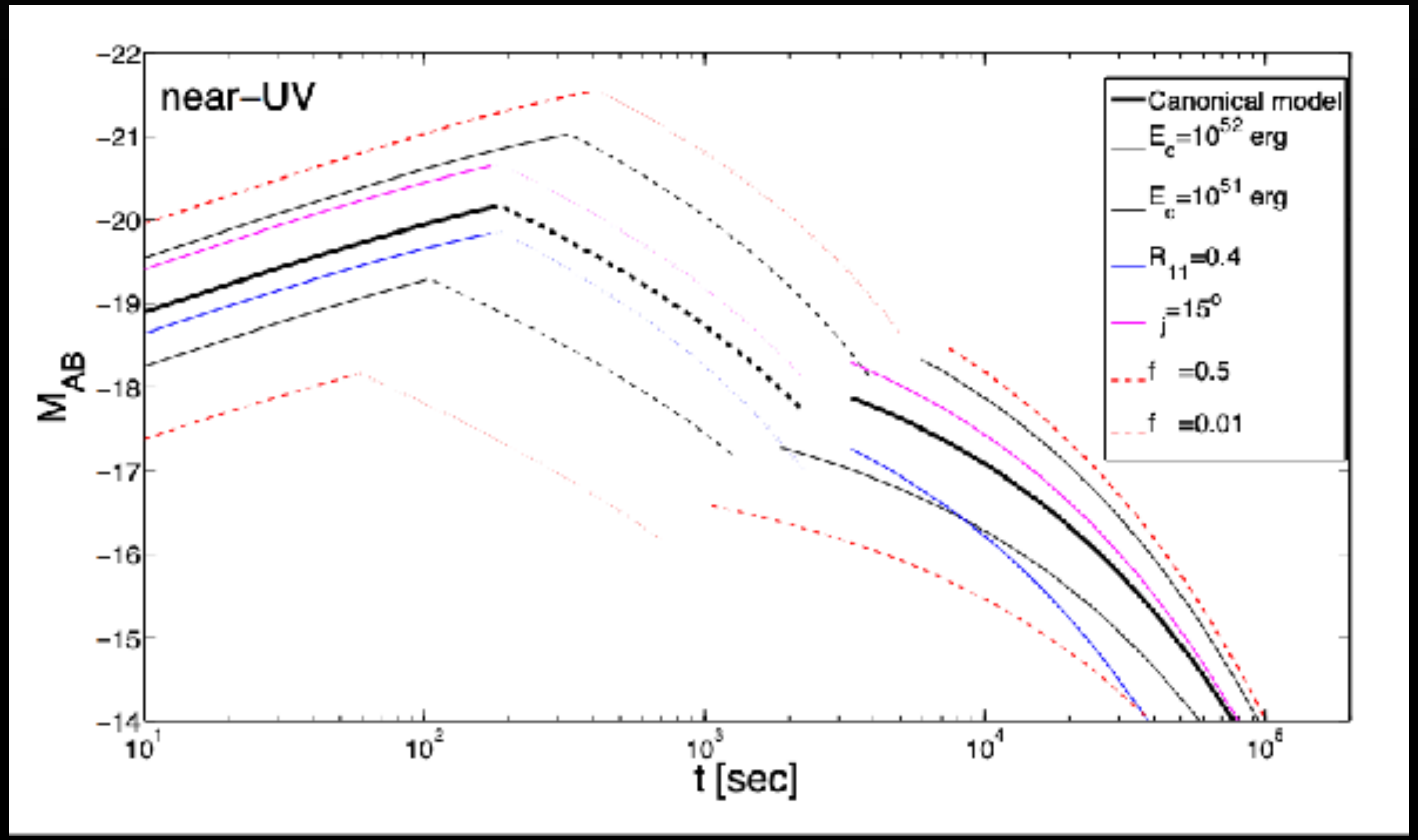


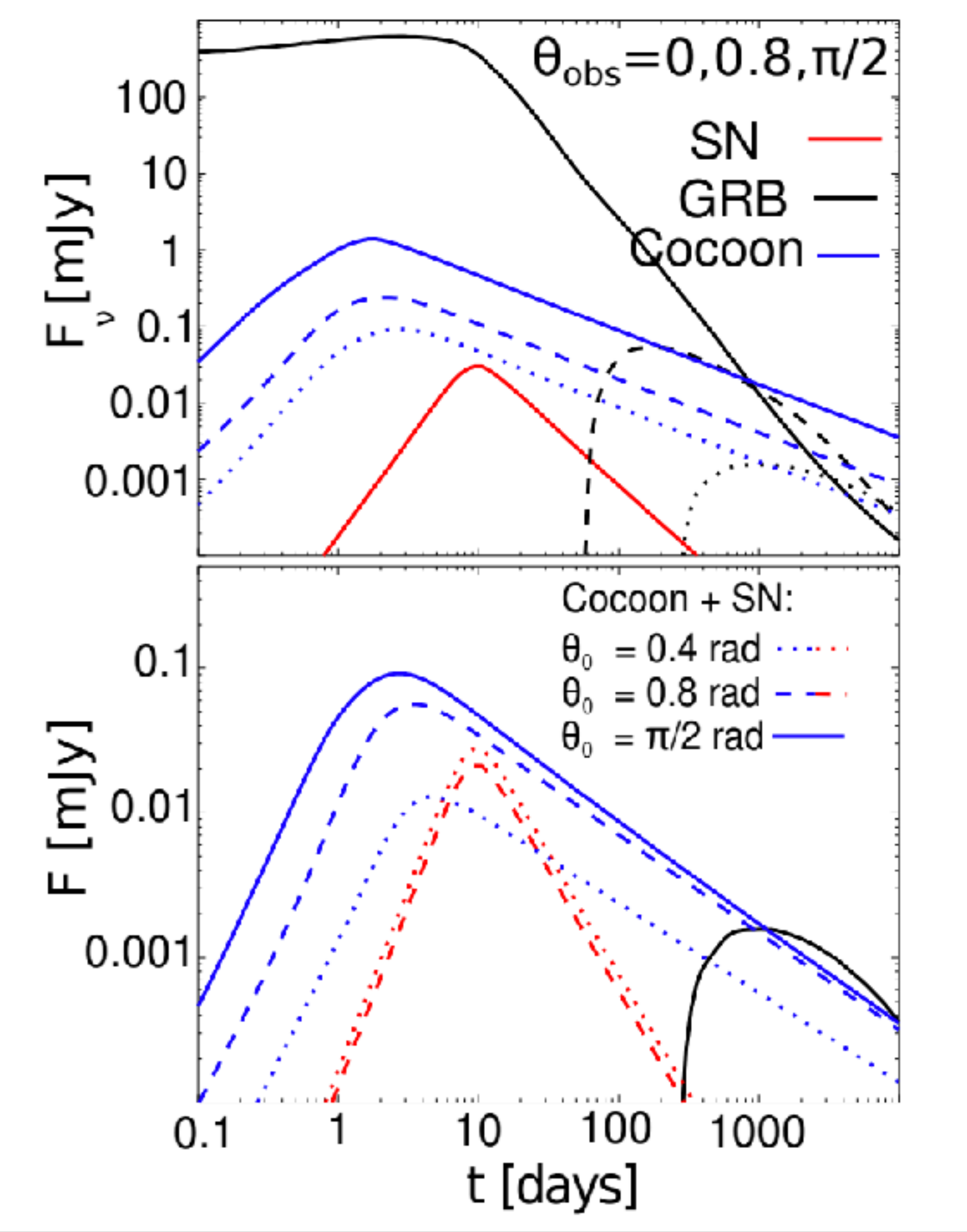


(Iwamoto+ 1999, LI+2019, Maeda+2023, Harrison+ 2017)

The jet cocoon

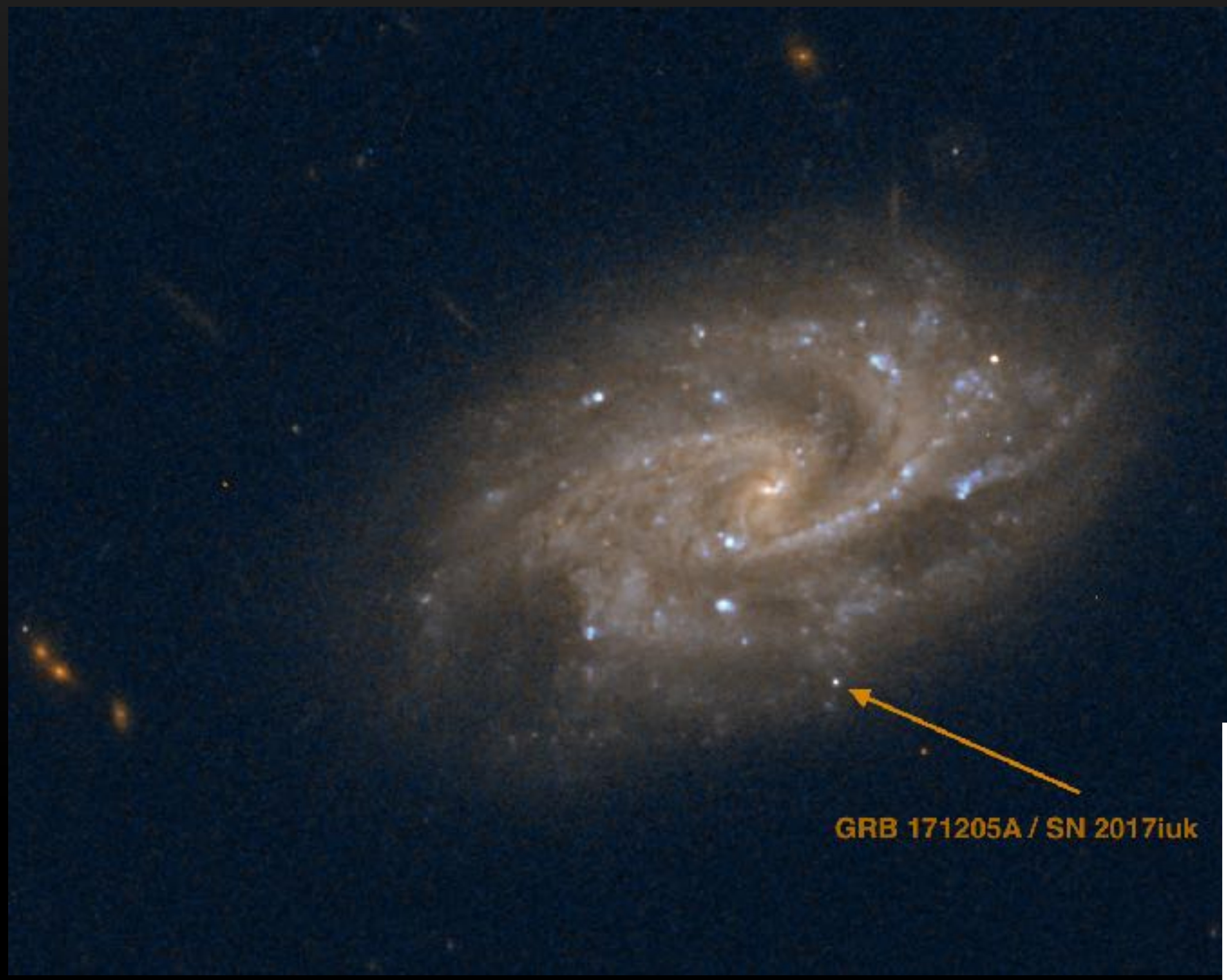


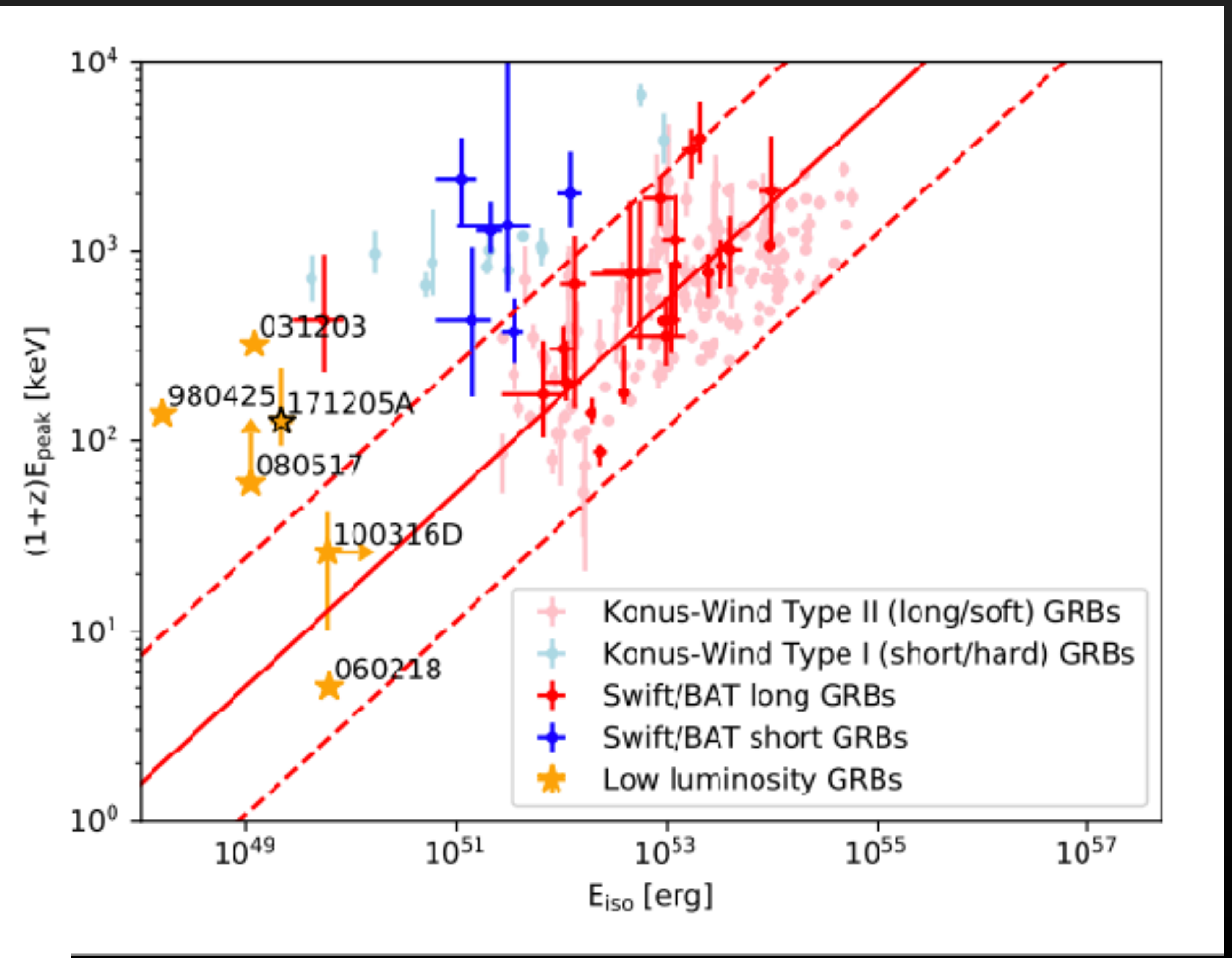


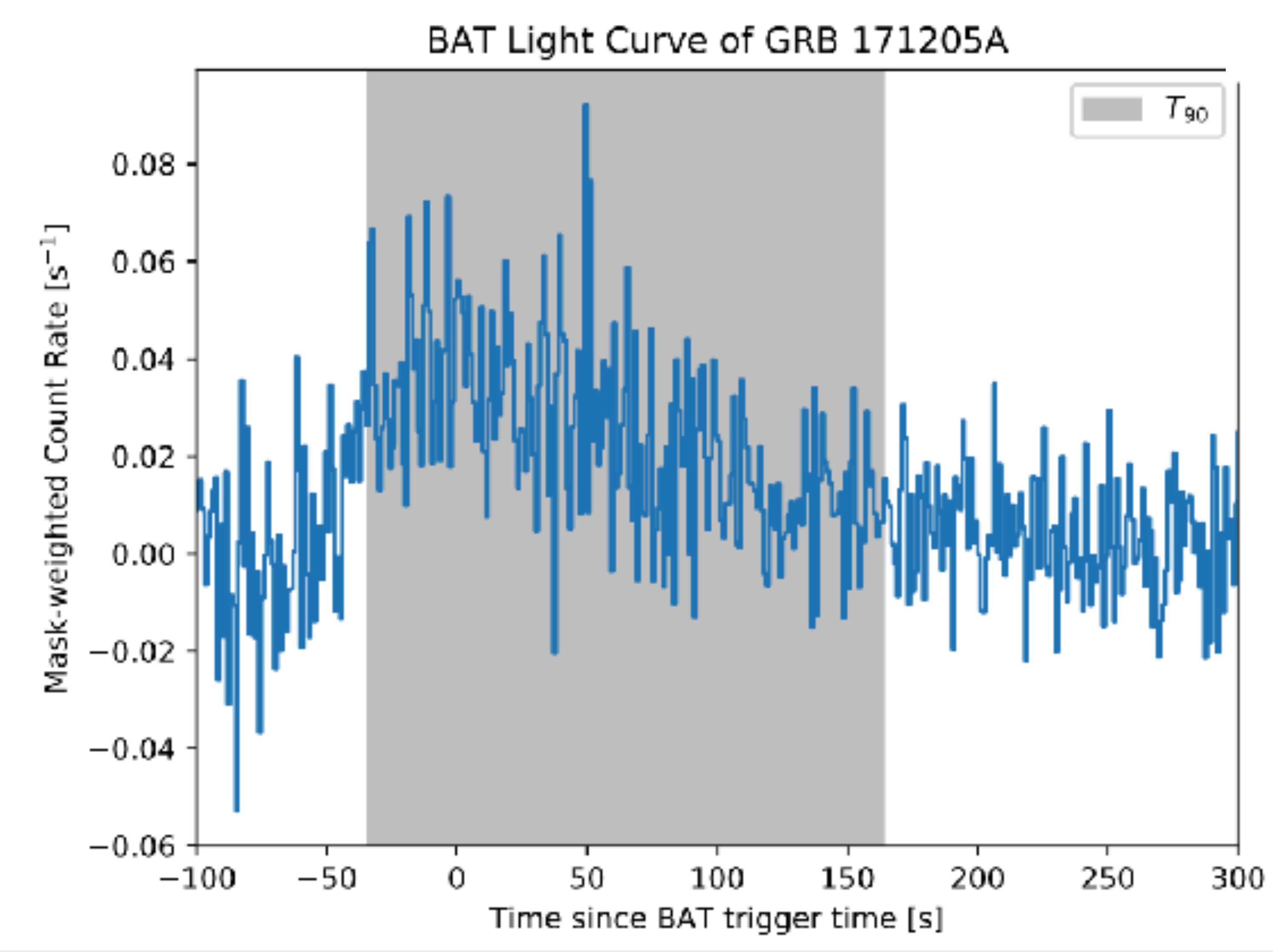


(Nakar & Piran 2017, De Colle+ 2021)

GRB 171205A/SN 2017iuk







(LI+ 2019, D’Elia+ 2018)

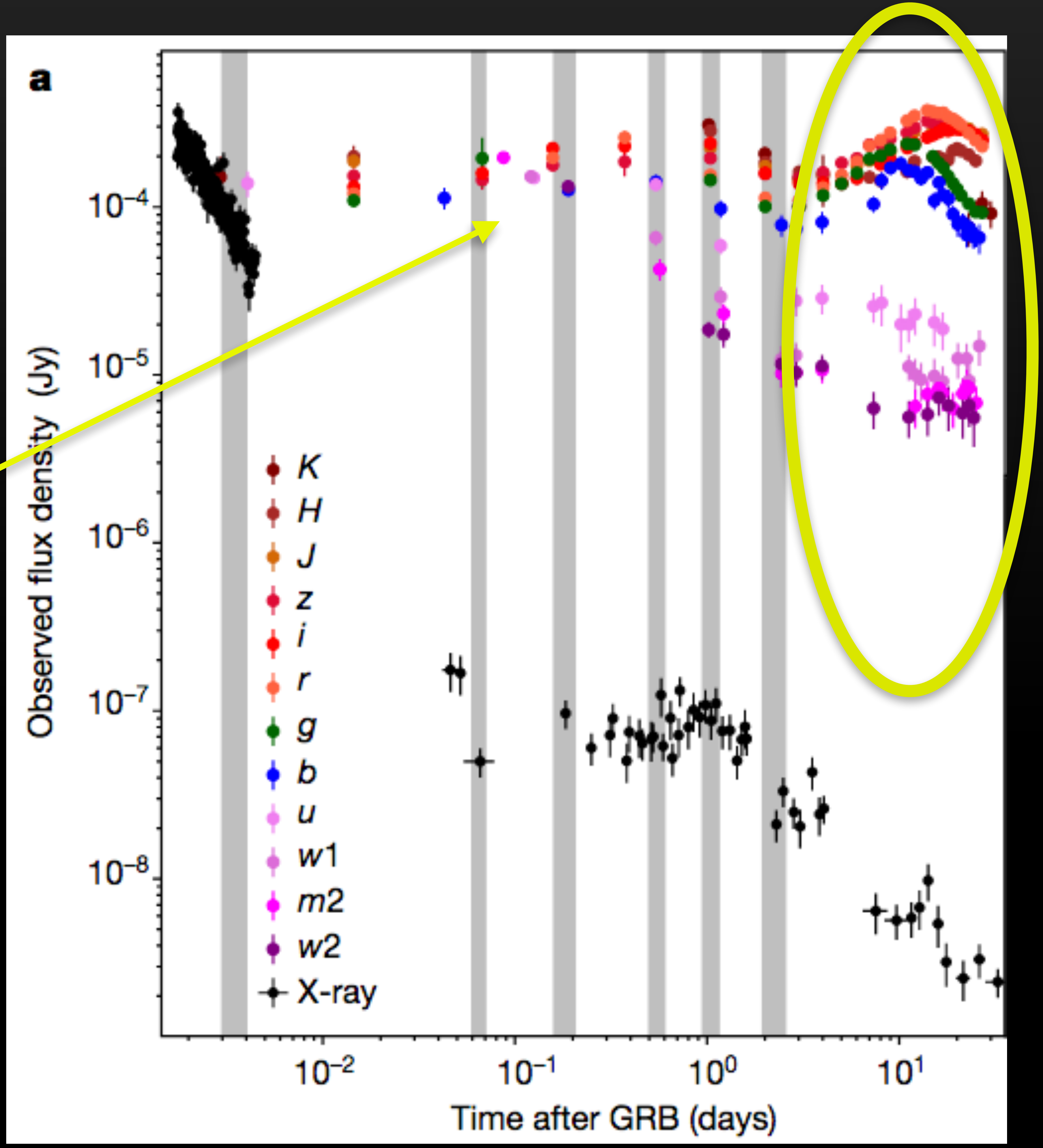
GRB 171205A/SN 2017iuk

rapid decay in the X-ray
afterglow emission

> faint afterglow

anomalous behaviour in the first
day at UV-optical freqs

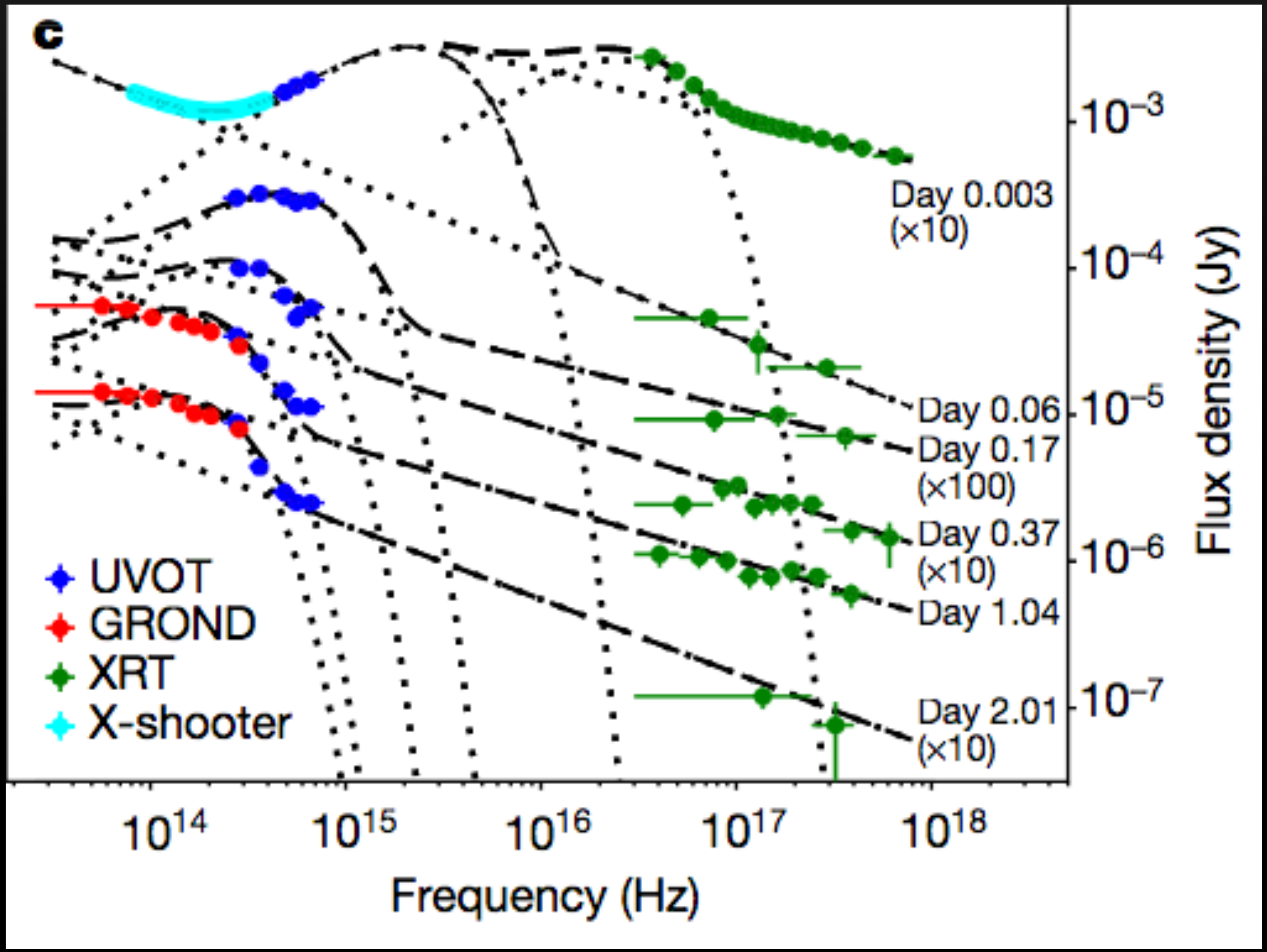
multi-wavelength photometric
& spectroscopic campaign
(Swift, VLT, GTC, GROND,
PST2, OSN, GOTO, ...)

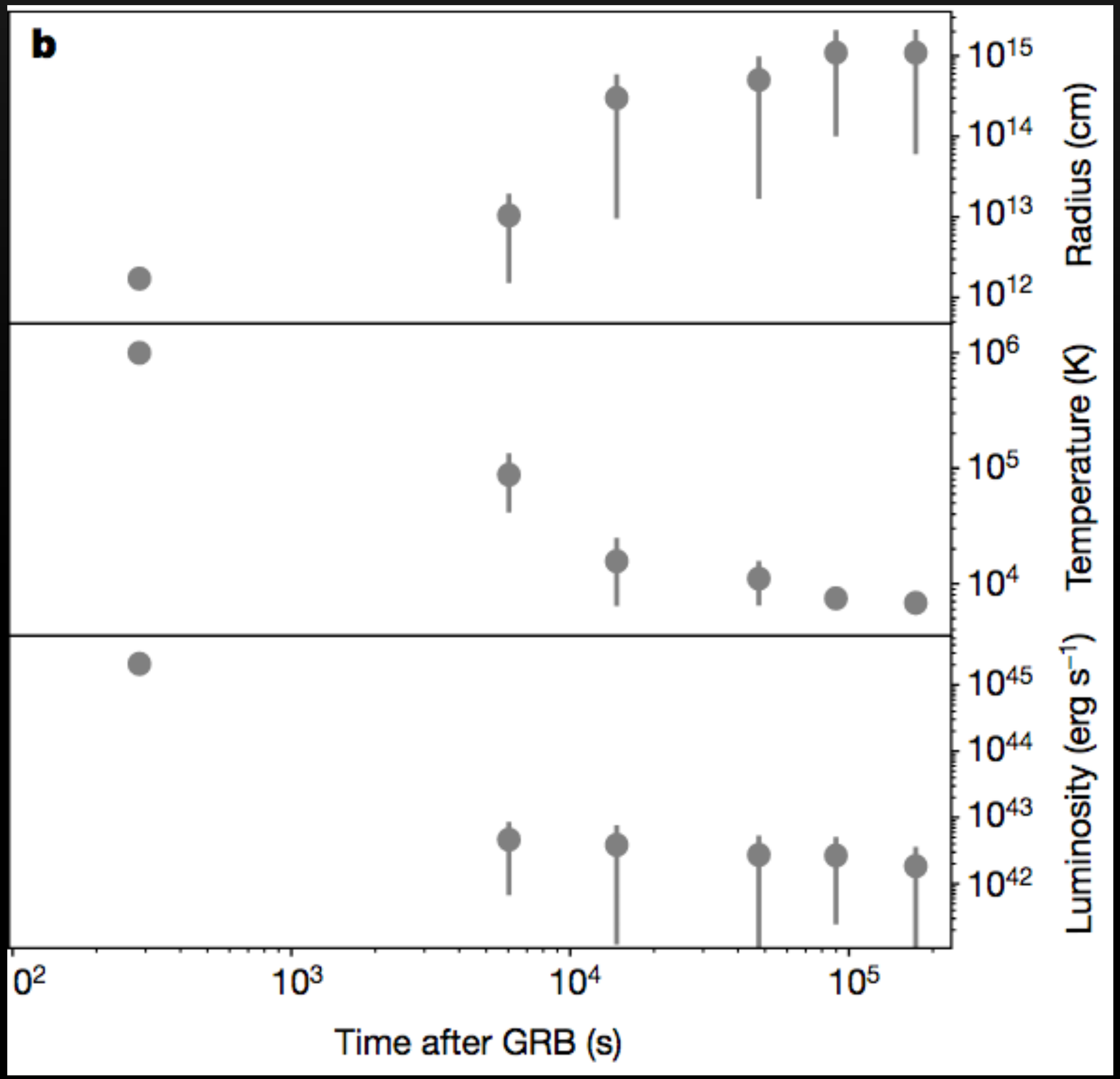


(LI+ 2019)

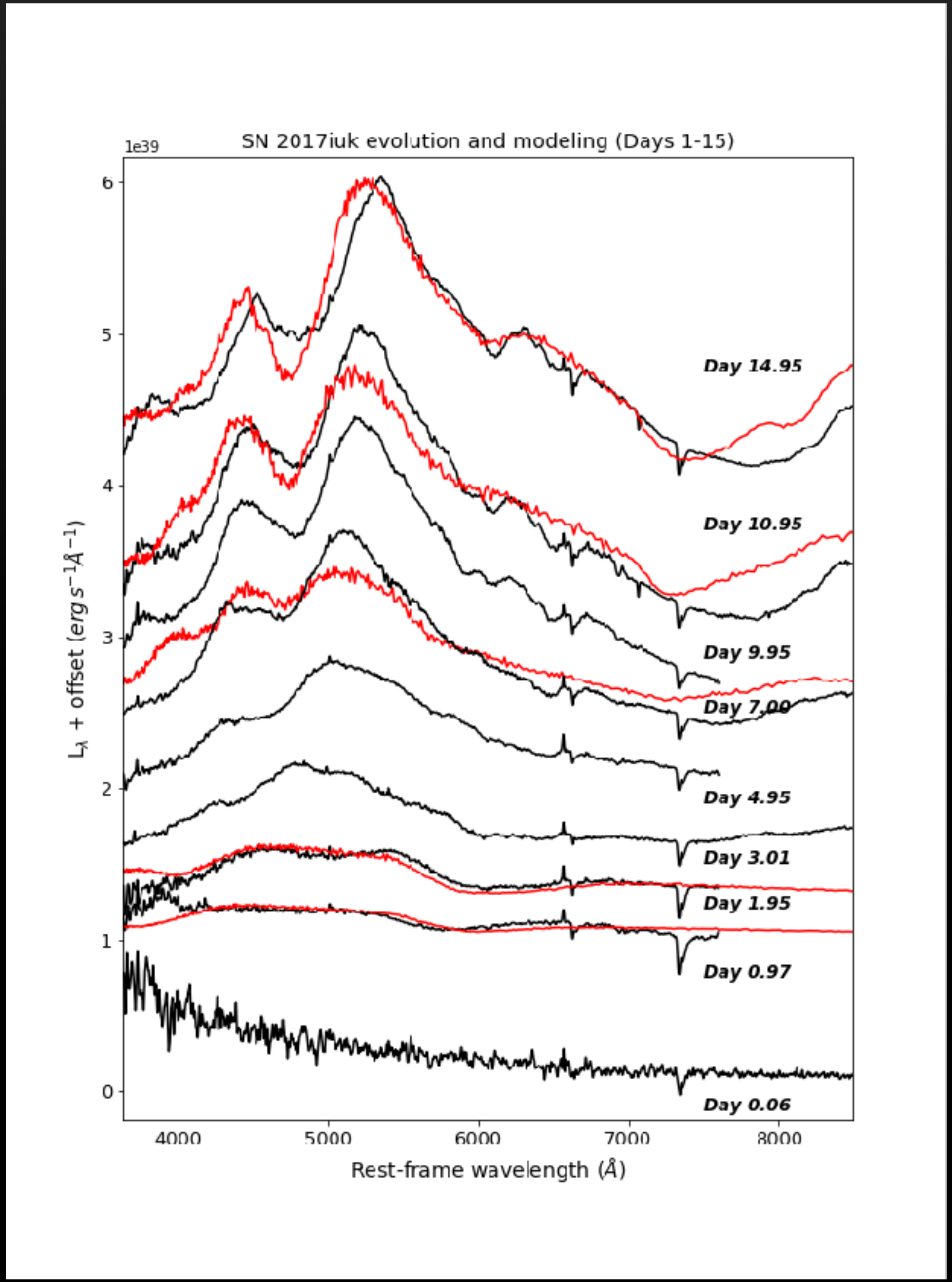
GRB 171205A/SN 2017iuk

from near-IR to X-rays

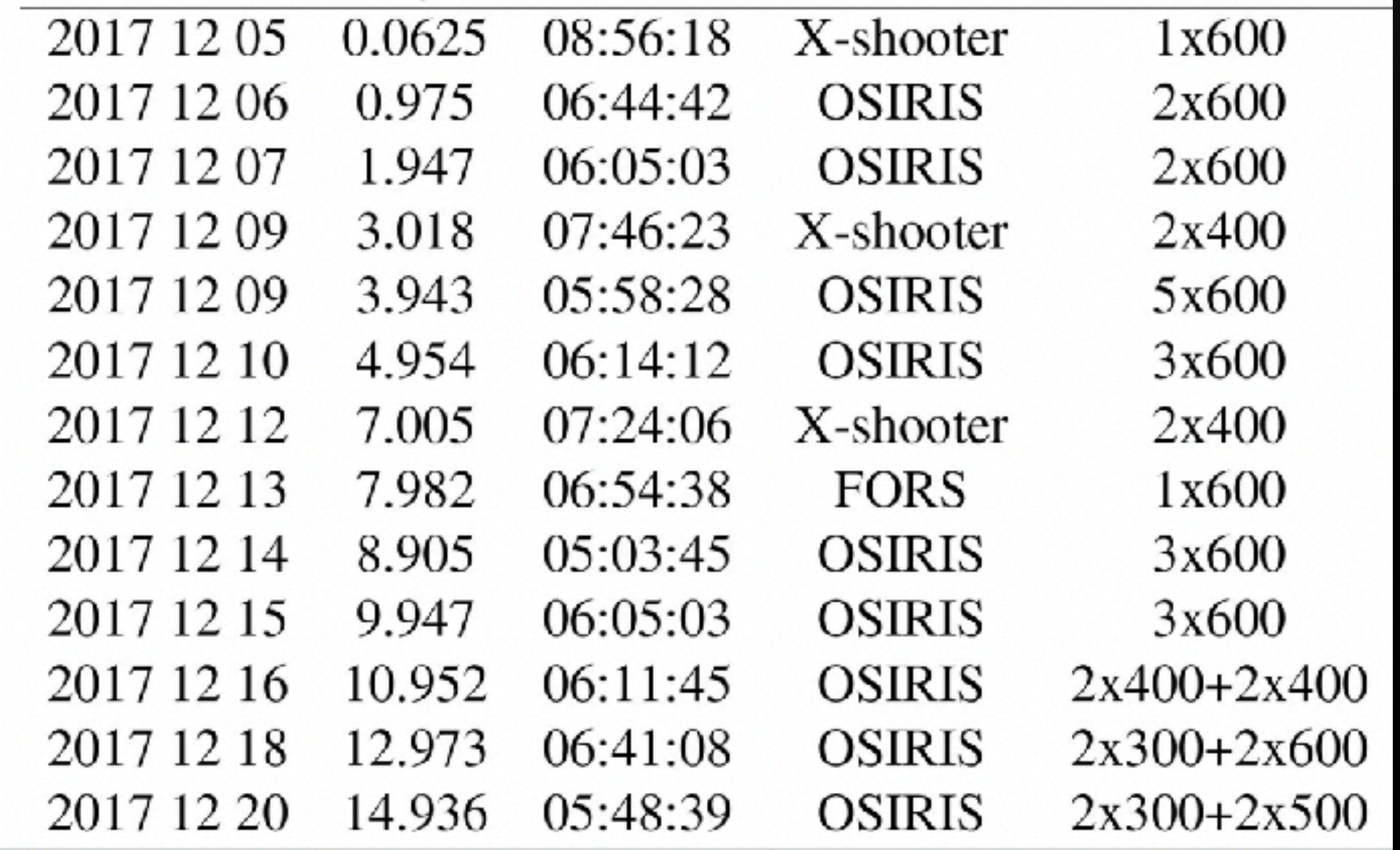




GRB 171205A/SN 2017iuk



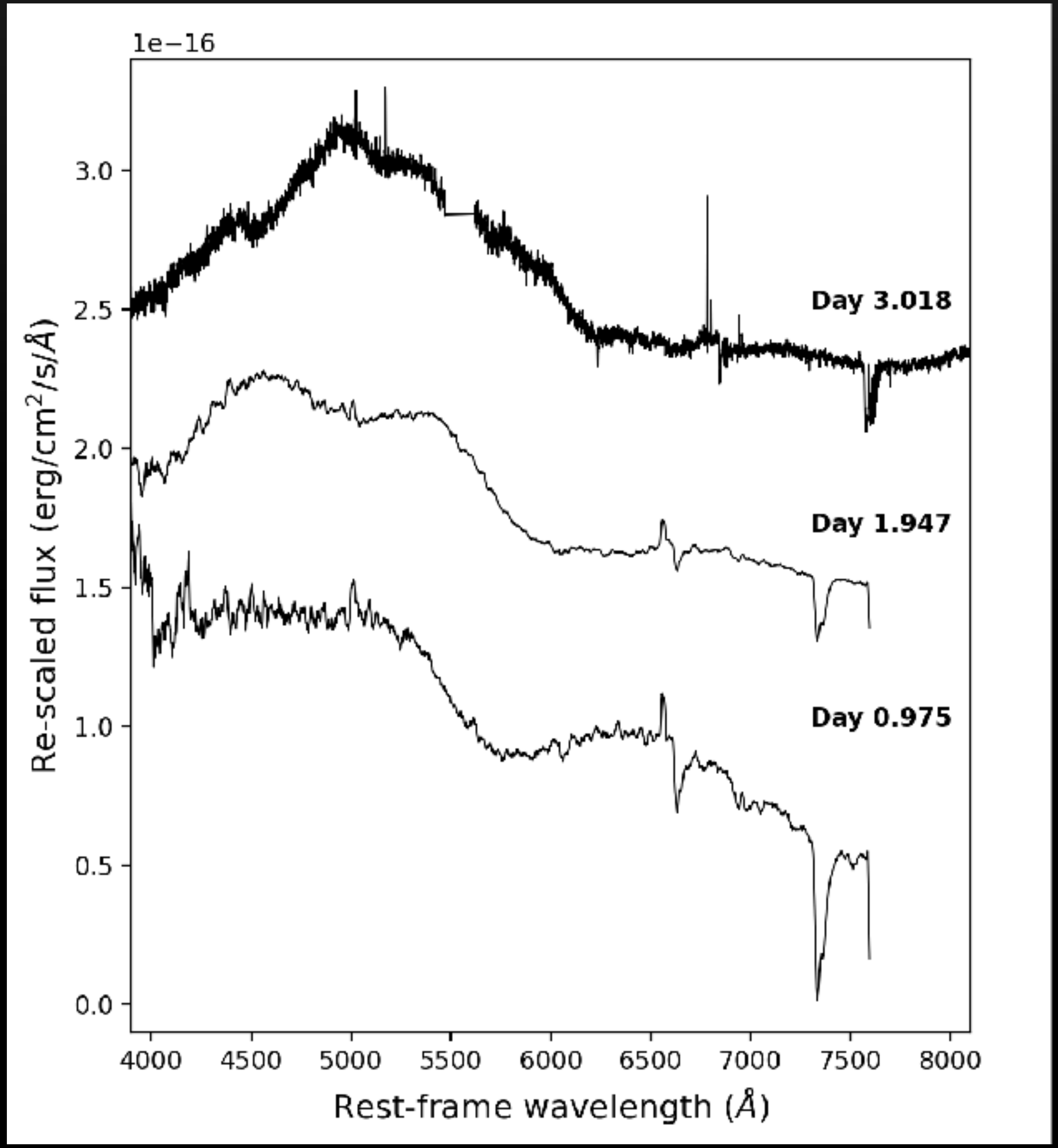
~Daily Spectroscopy monitoring

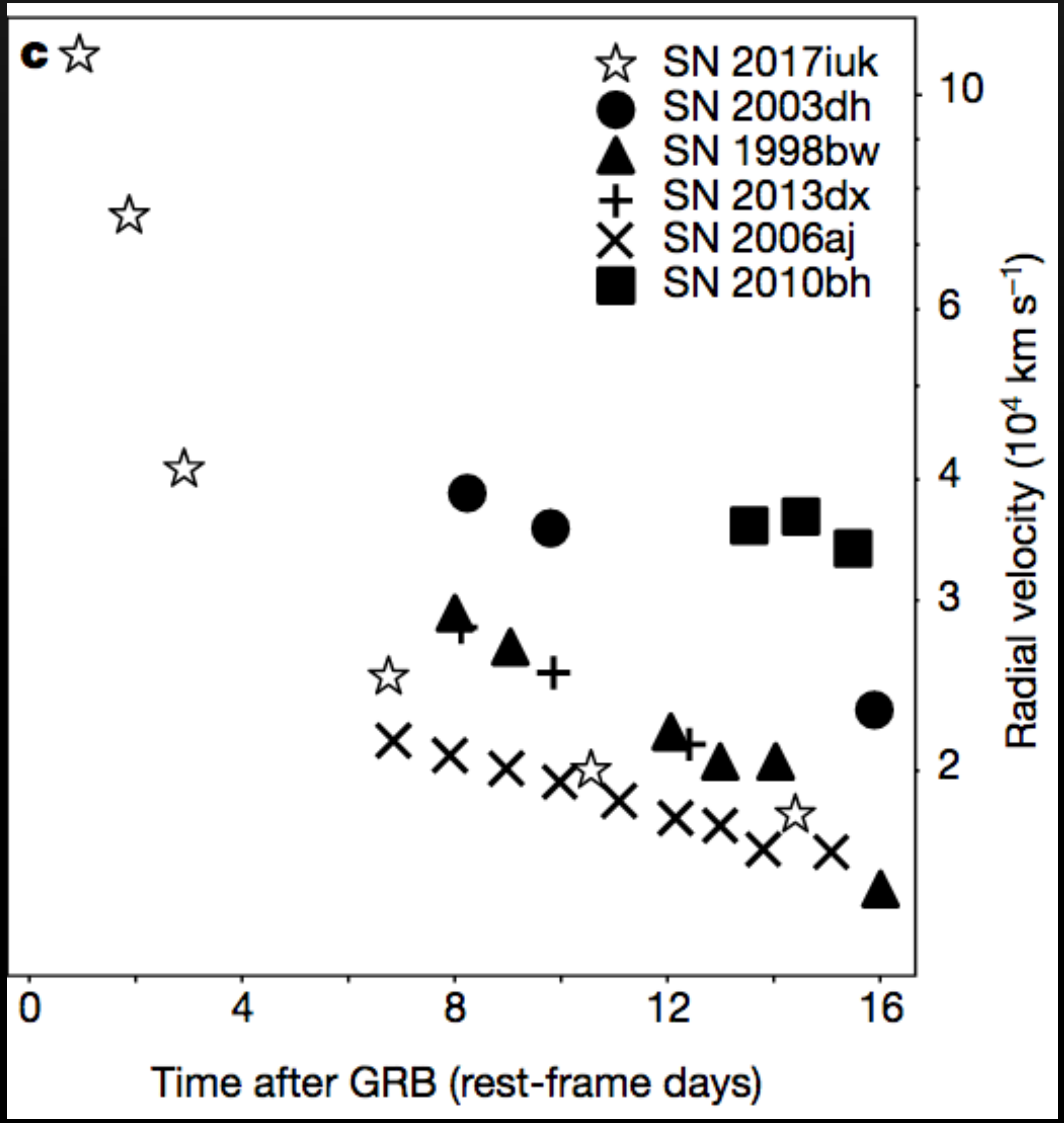


2017 12 05	0.0625	08:56:18	X-shooter	1x600
2017 12 06	0.975	06:44:42	OSIRIS	2x600
2017 12 07	1.947	06:05:03	OSIRIS	2x600
2017 12 09	3.018	07:46:23	X-shooter	2x400
2017 12 09	3.943	05:58:28	OSIRIS	5x600
2017 12 10	4.954	06:14:12	OSIRIS	3x600
2017 12 12	7.005	07:24:06	X-shooter	2x400
2017 12 13	7.982	06:54:38	FORS	1x600
2017 12 14	8.905	05:03:45	OSIRIS	3x600
2017 12 15	9.947	06:05:03	OSIRIS	3x600
2017 12 16	10.952	06:11:45	OSIRIS	2x400+2x400
2017 12 18	12.973	06:41:08	OSIRIS	2x300+2x600
2017 12 20	14.936	05:48:39	OSIRIS	2x300+2x500

GRB 171205A/SN 2017iuk

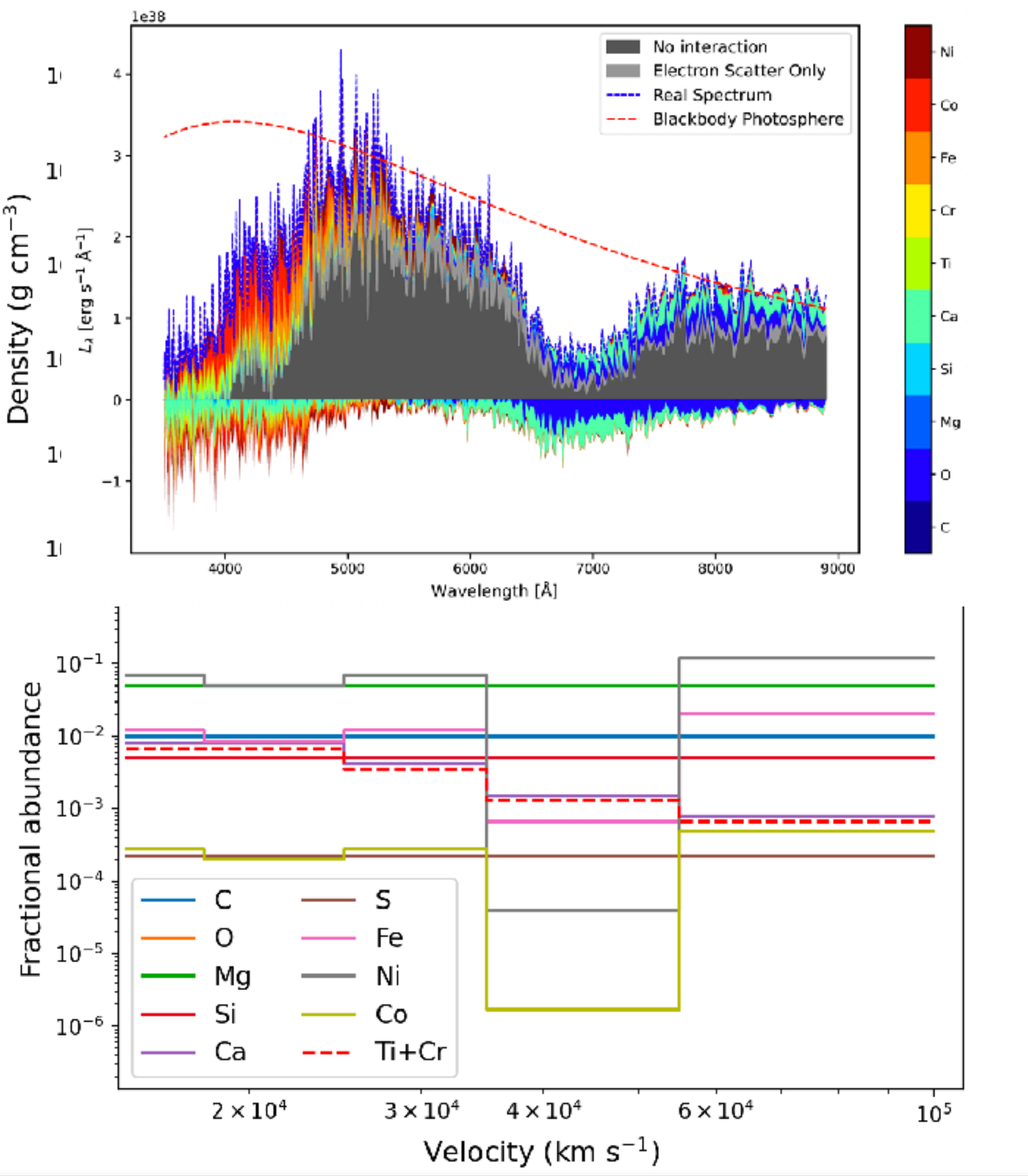
Very early spectra - modeling





GRB 171205A/SN 2017iuk

Spectral synthesis model (TARDIS code)



- CO138 model (1998bw)

+

- flat distribution at high velocities

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

M_{ejecta} ~ 2.9 MSun

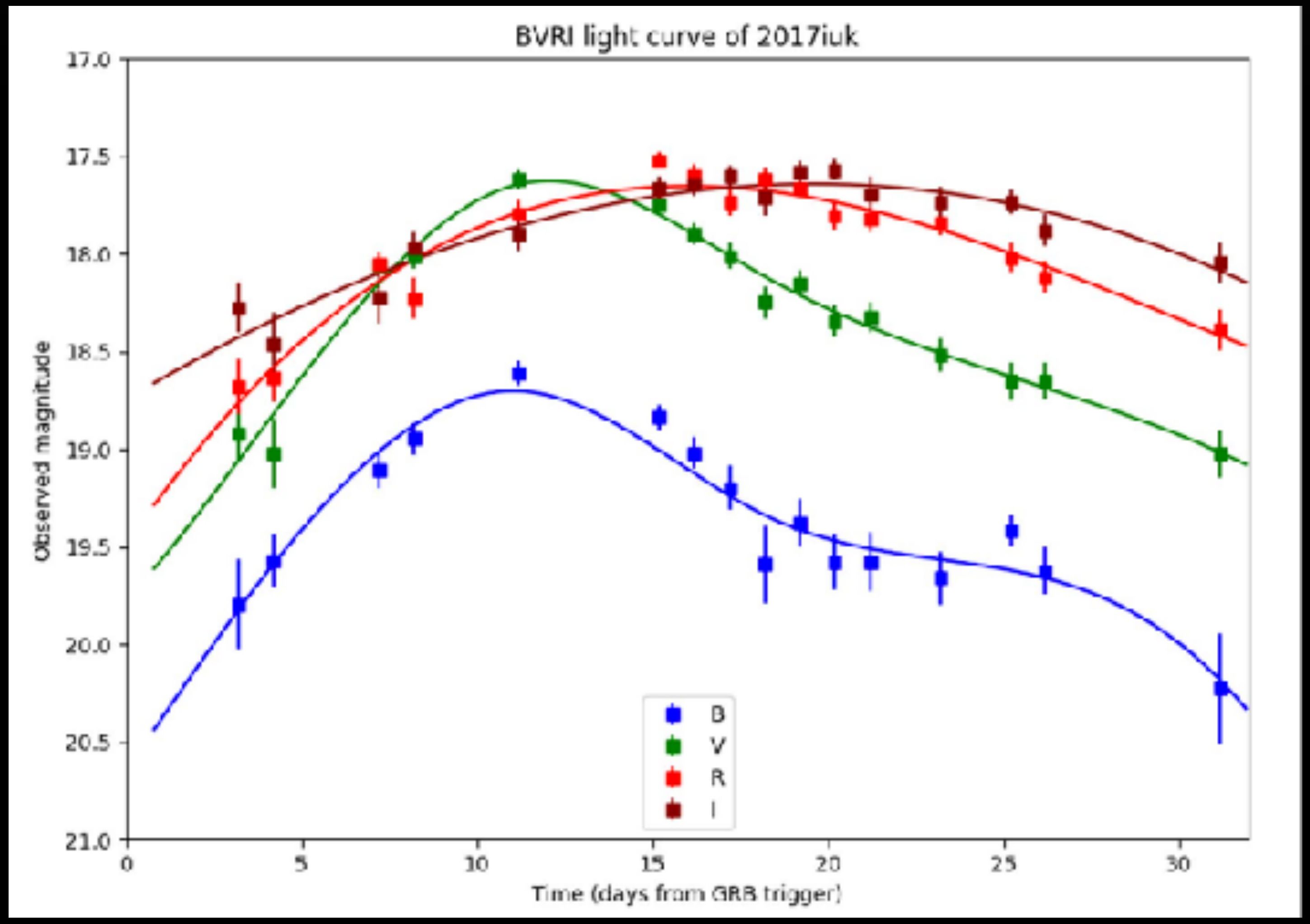
(Kerzendorf & Sim 2014, Iwamoto+ 1998, Maeda+ 2002, LI+ 2019)

Arnett model

Homologous expansion, spherical symmetry, constant optical opacity, Ni & Co as energy sources and… self-similar energy distribution

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

(Kasen 2017, Arnett 1982,Valenti+ 2008)



M_{ejecta} = 4.9 MSun

M_{56Ni} = 0.18 MSun

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

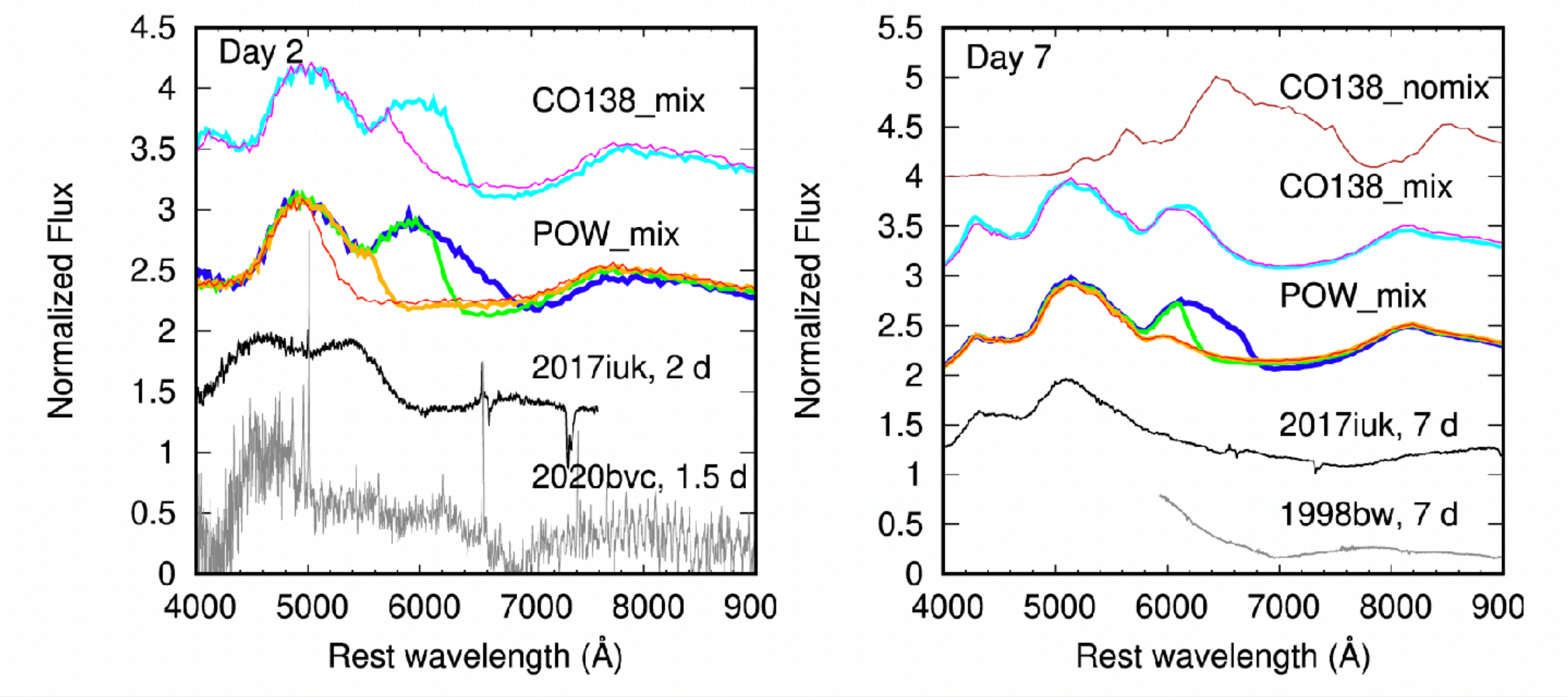
(but see Khatami & Kasen 2019, Woosley+ 2021)

GRB 171205A/SN 2017iuk

Check with other density model configurations

80,000 km/s
100,000 km/s

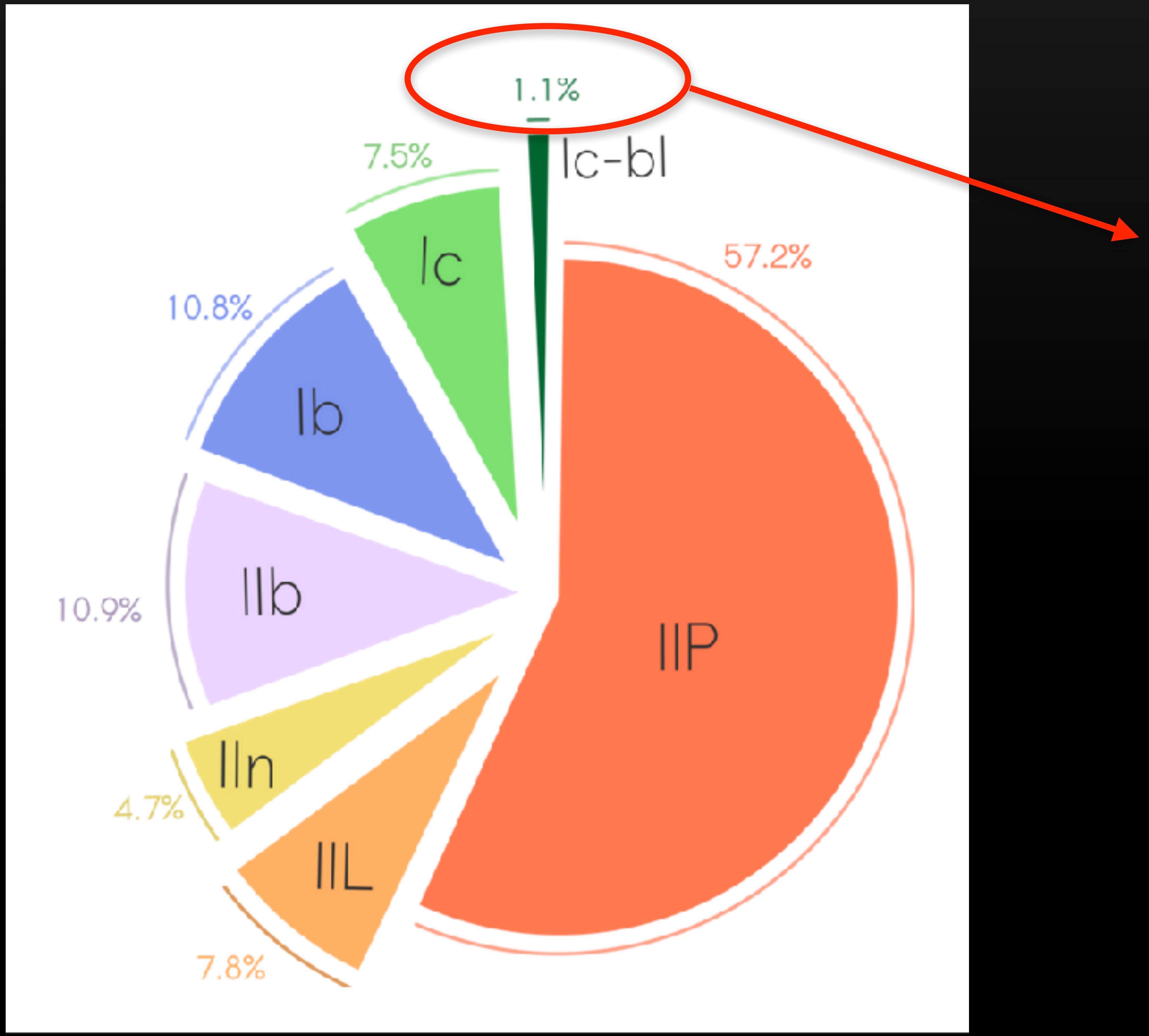
60,000 km/s
80,000 km/s
100,000 km/s
120,000 km/s



(Maeda+ 2023)

Ic BL SNe w/o GRBs

Relative number of CC-SNe



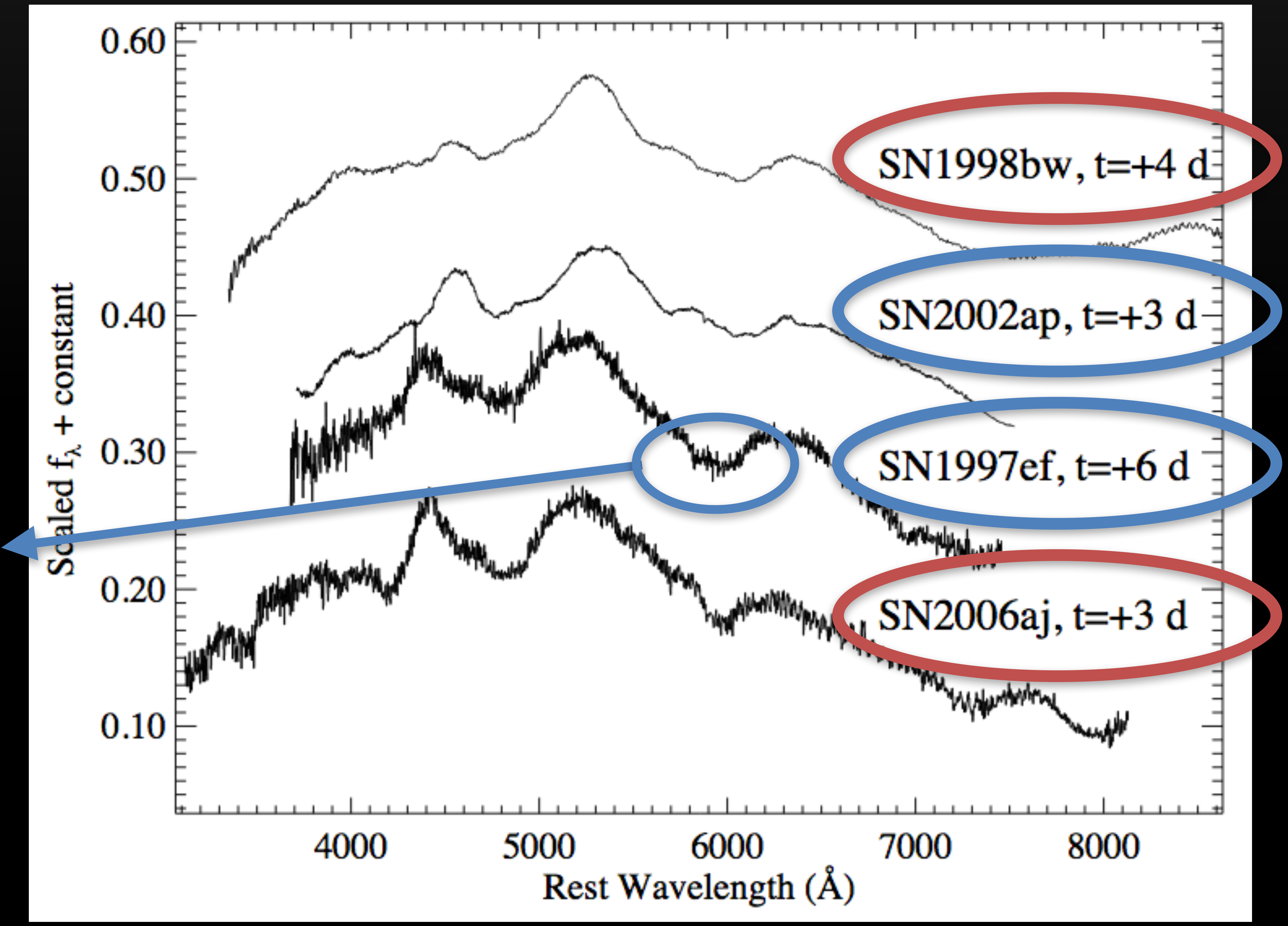
~10% of Ic-BL SNe are “apparently” associated with a GRB

What about the remaining 90%?

(courtesy Stevance)

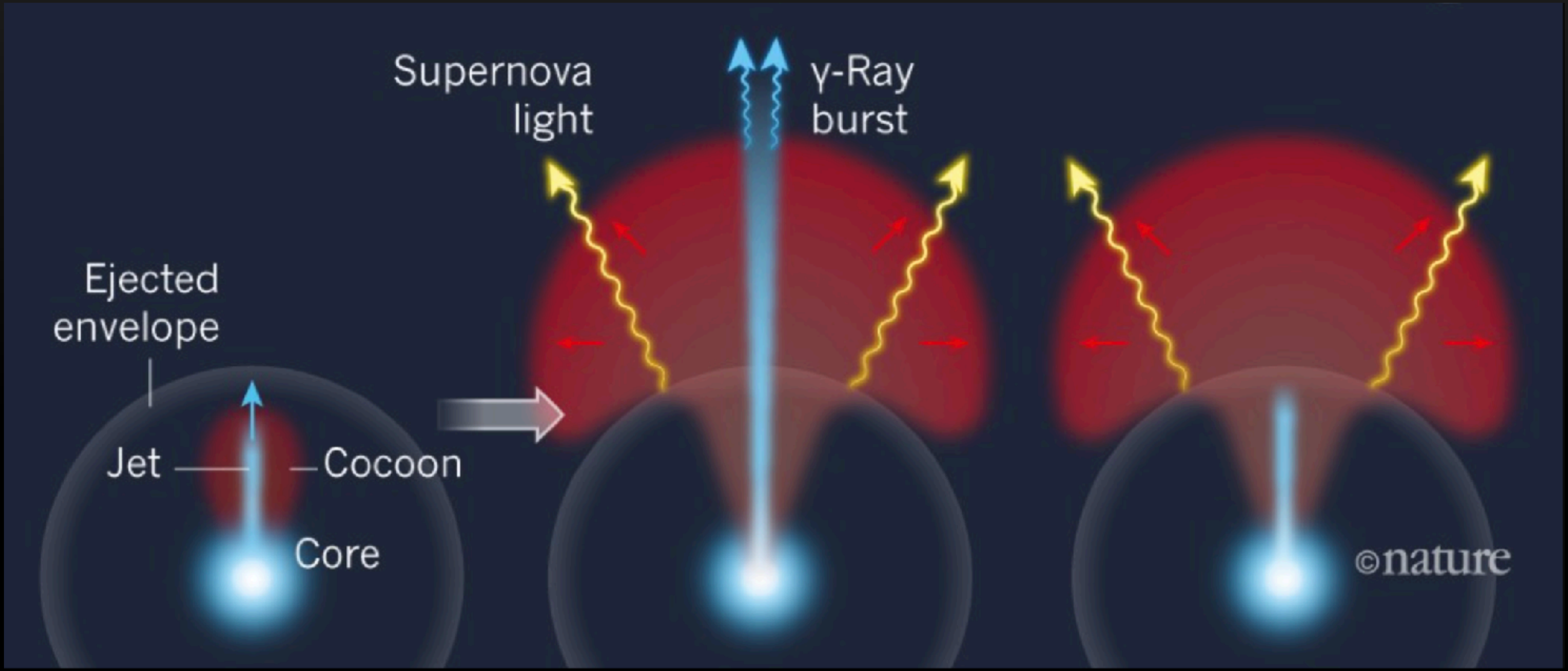
Ic BL SNe w/o GRBs

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



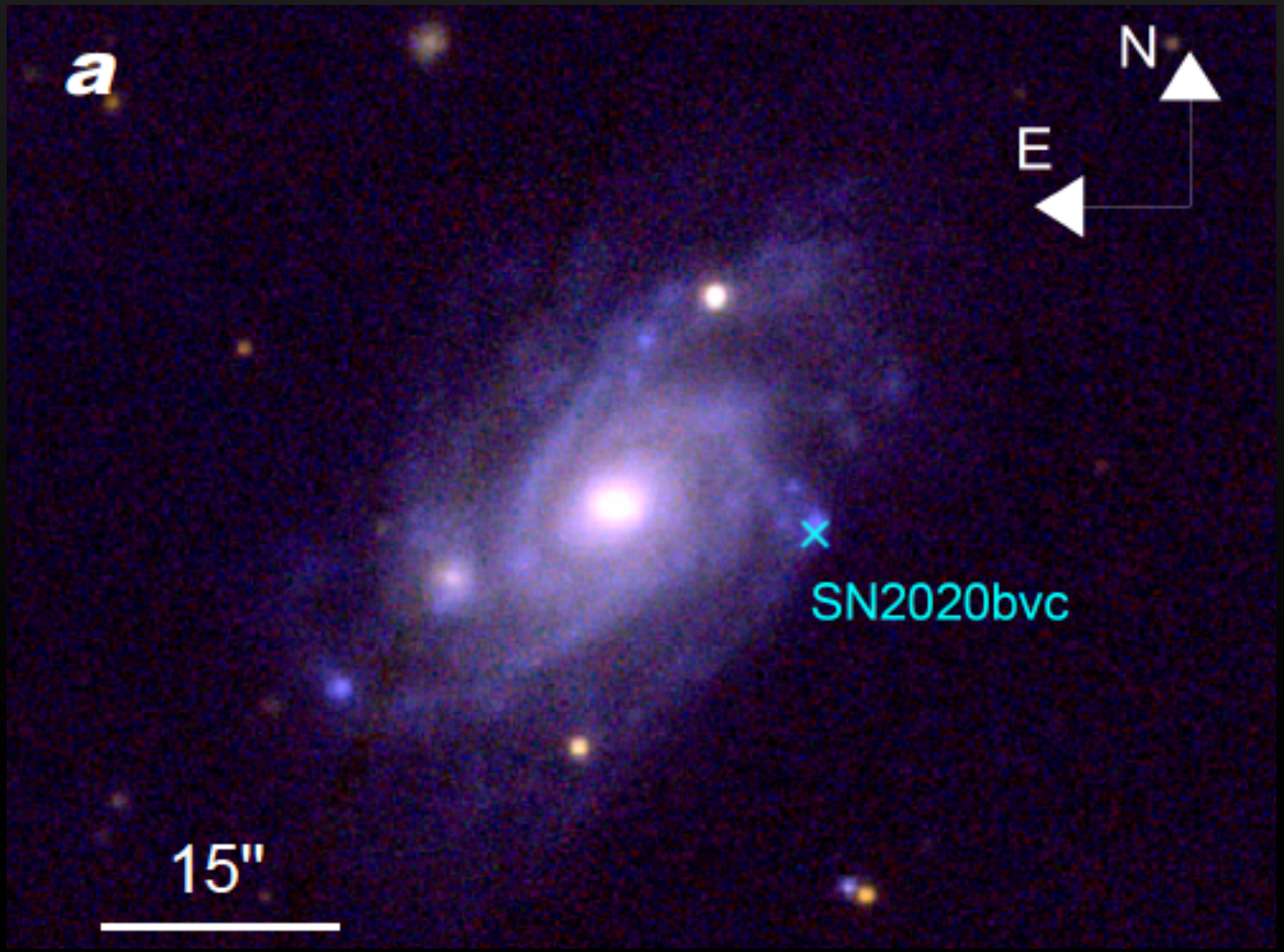
(Mazzali+ 2000)

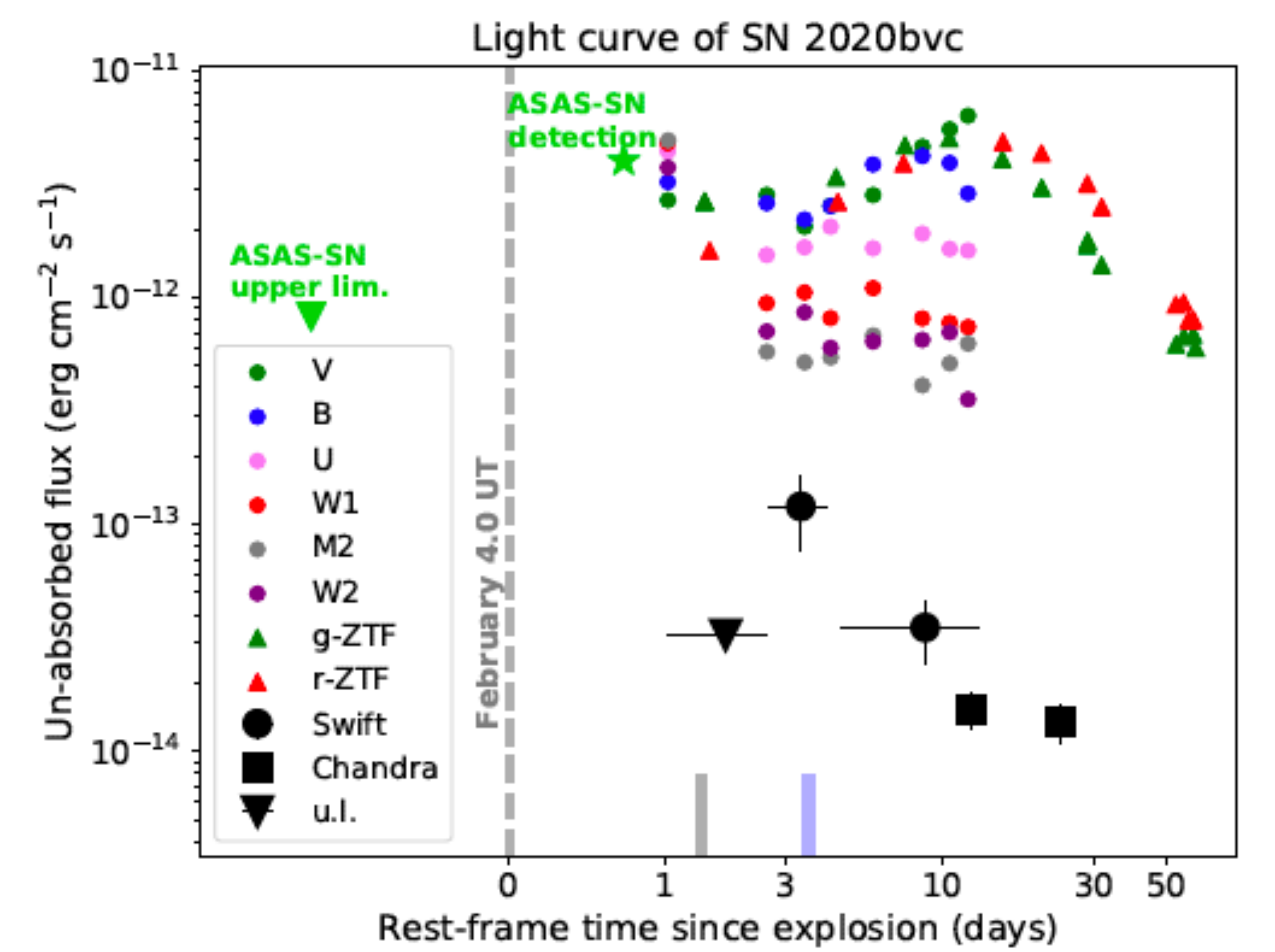
Ic BL SNe w/o GRBs



(Nakar 2019)

SN 2020bvc

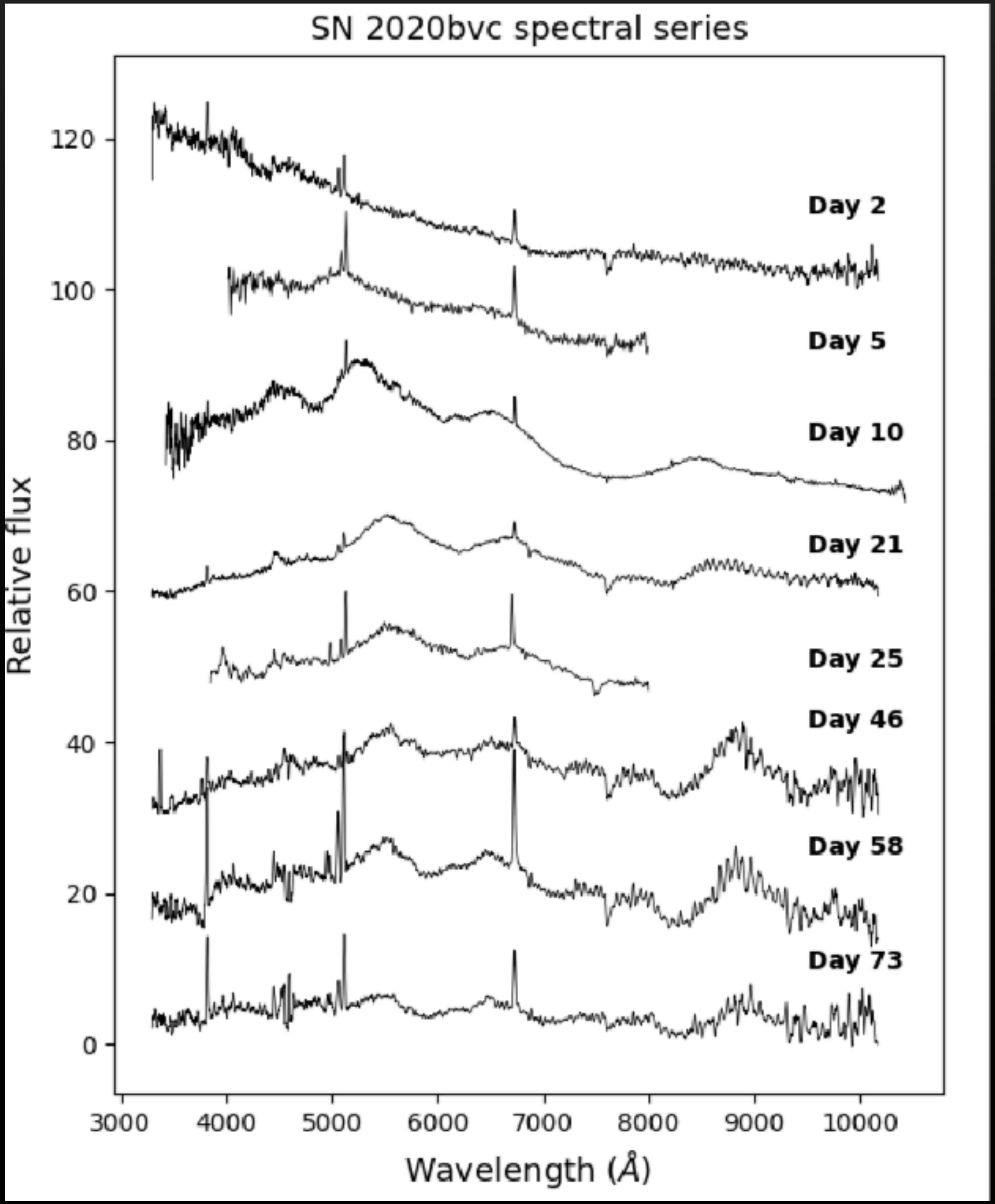


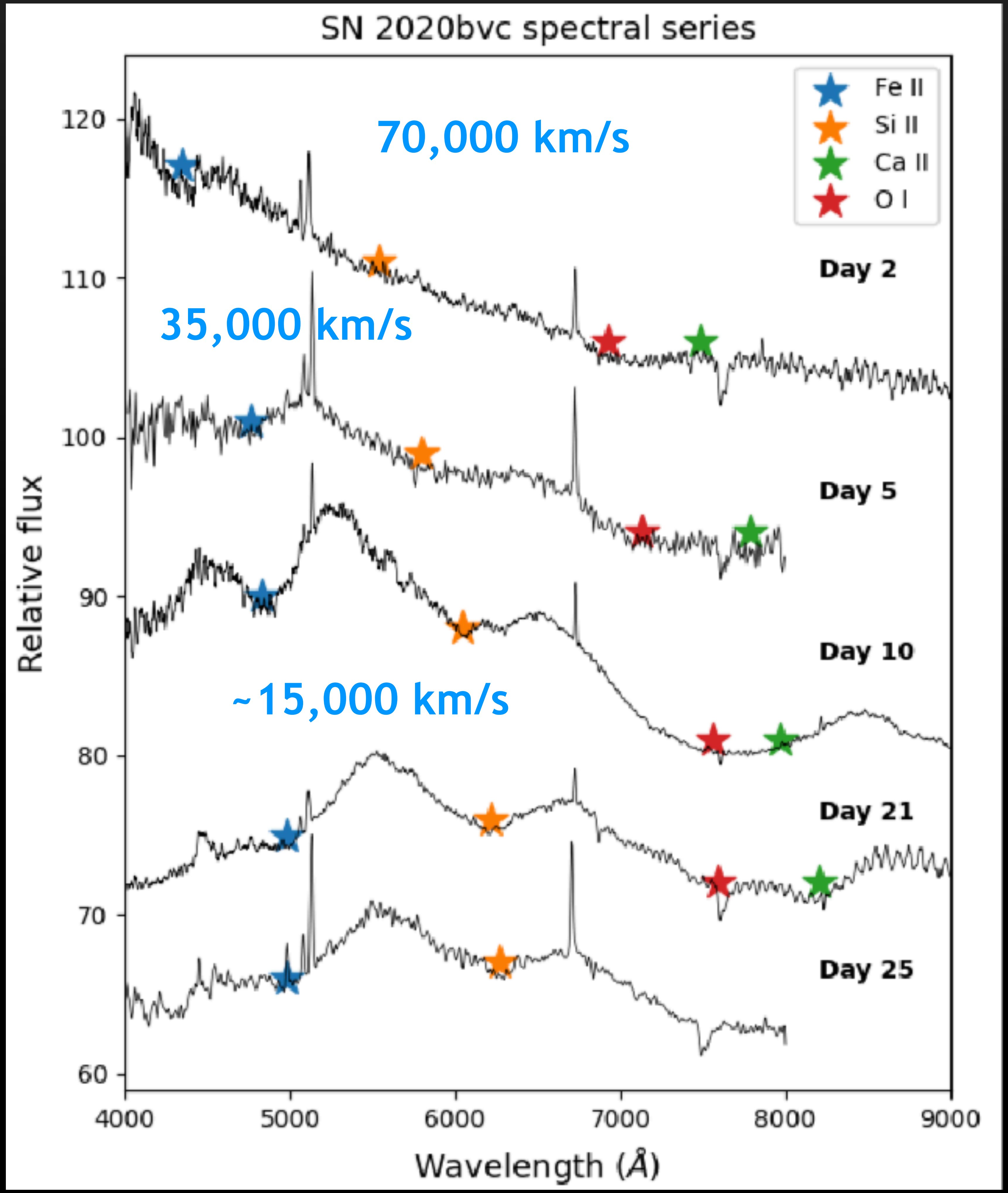


type-Ic BL SN @ z = 0.025235

(LI+ 2020, Ho+ 2020)

SN 2020bvc


SN 2020bvc spectral series


SN 2020bvc spectral series

70,000 km/s

35,000 km/s

~15,000 km/s

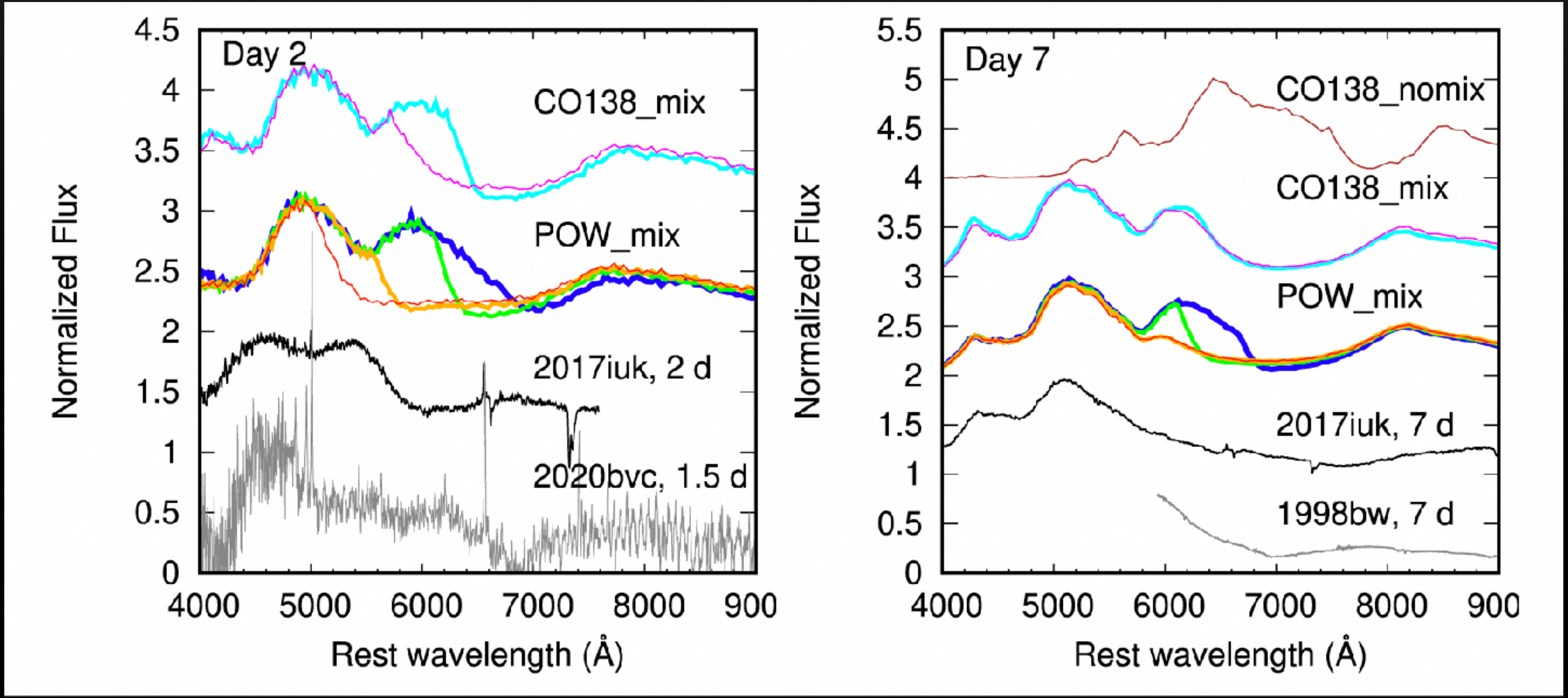
(TBS)

SN 2020bvc

Check again with density model configurations

80,000 km/s
100,000 km/s

60,000 km/s
80,000 km/s
100,000 km/s
120,000 km/s



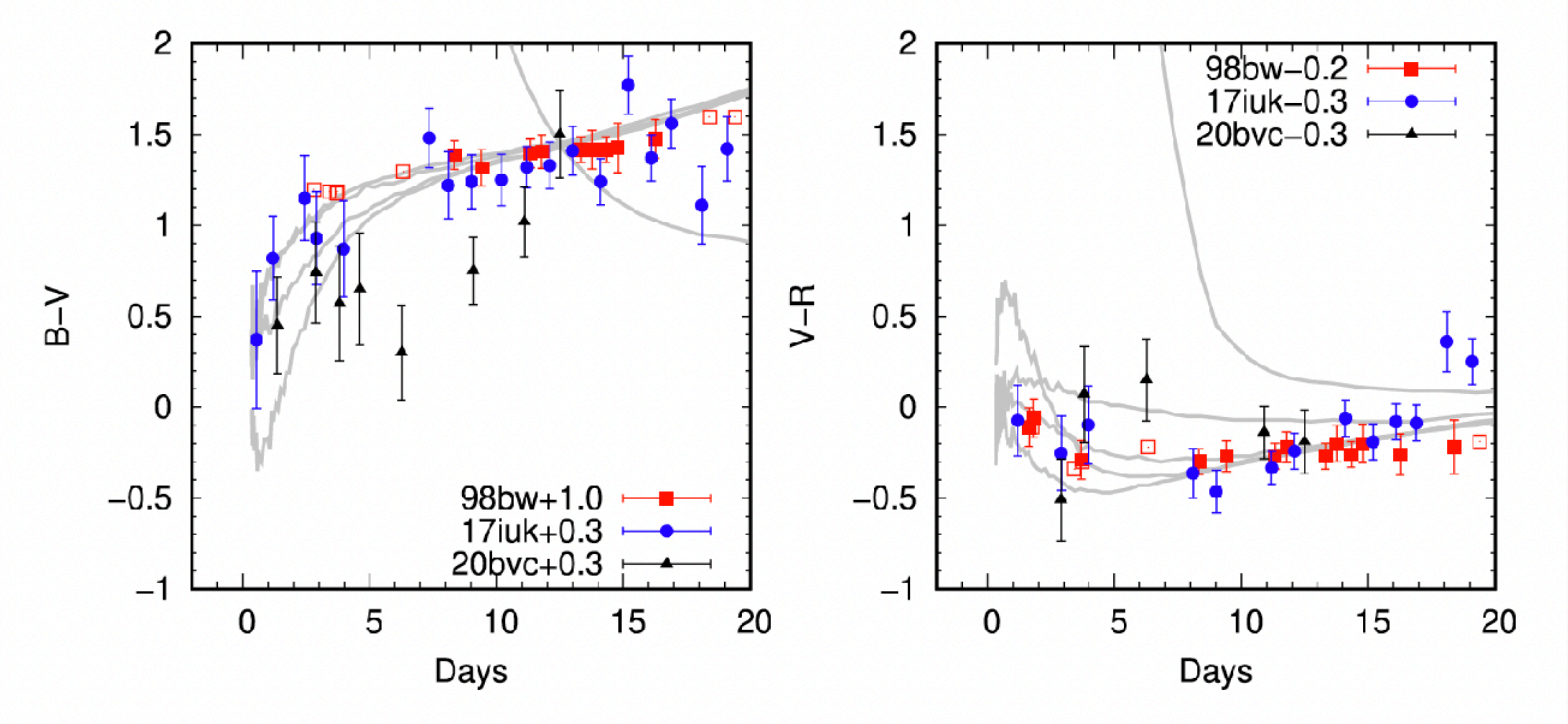
(Maeda+ 2023)

Diagnostics

Photometric behavior

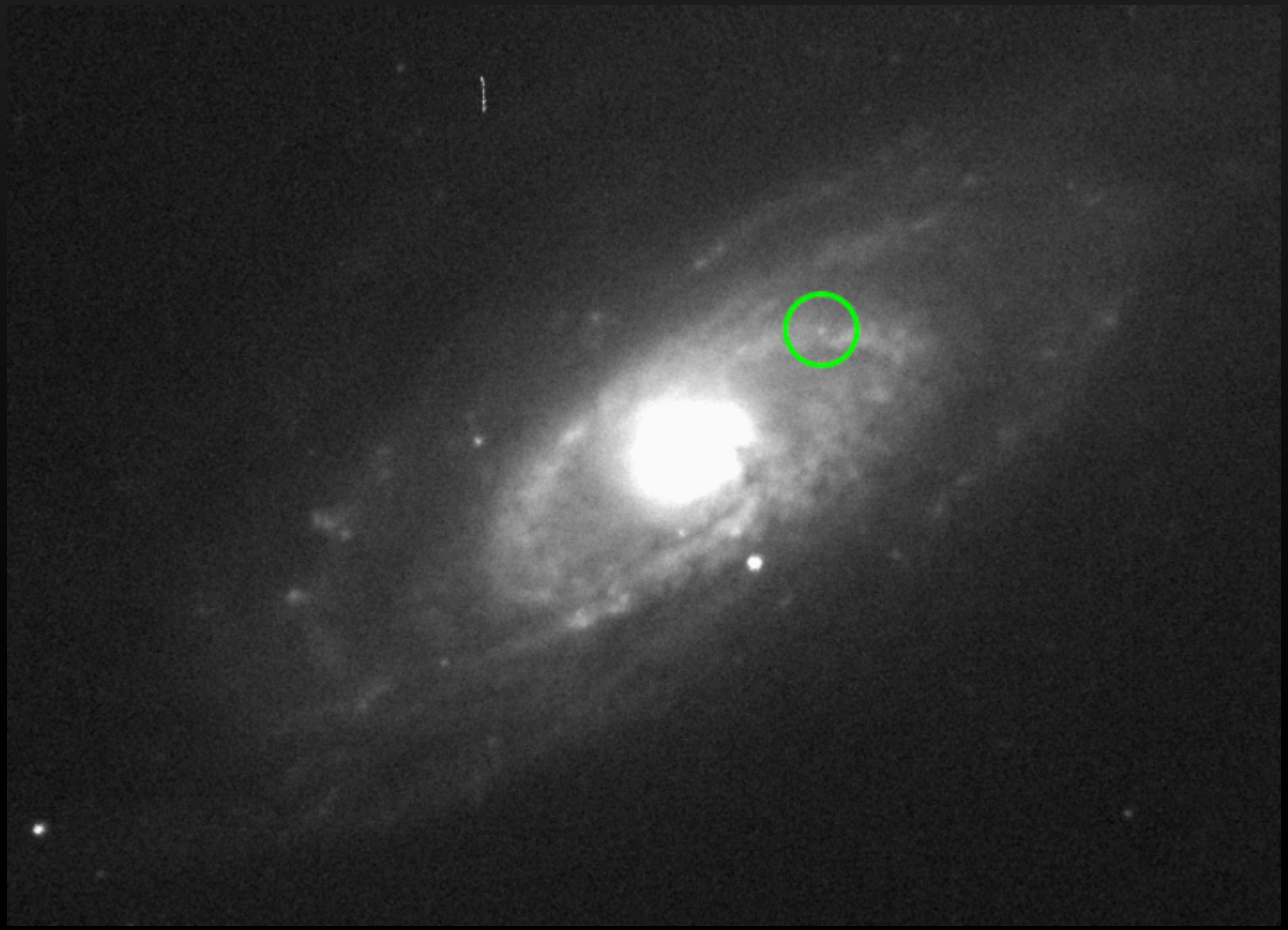
80,000 km/s
100,000 km/s

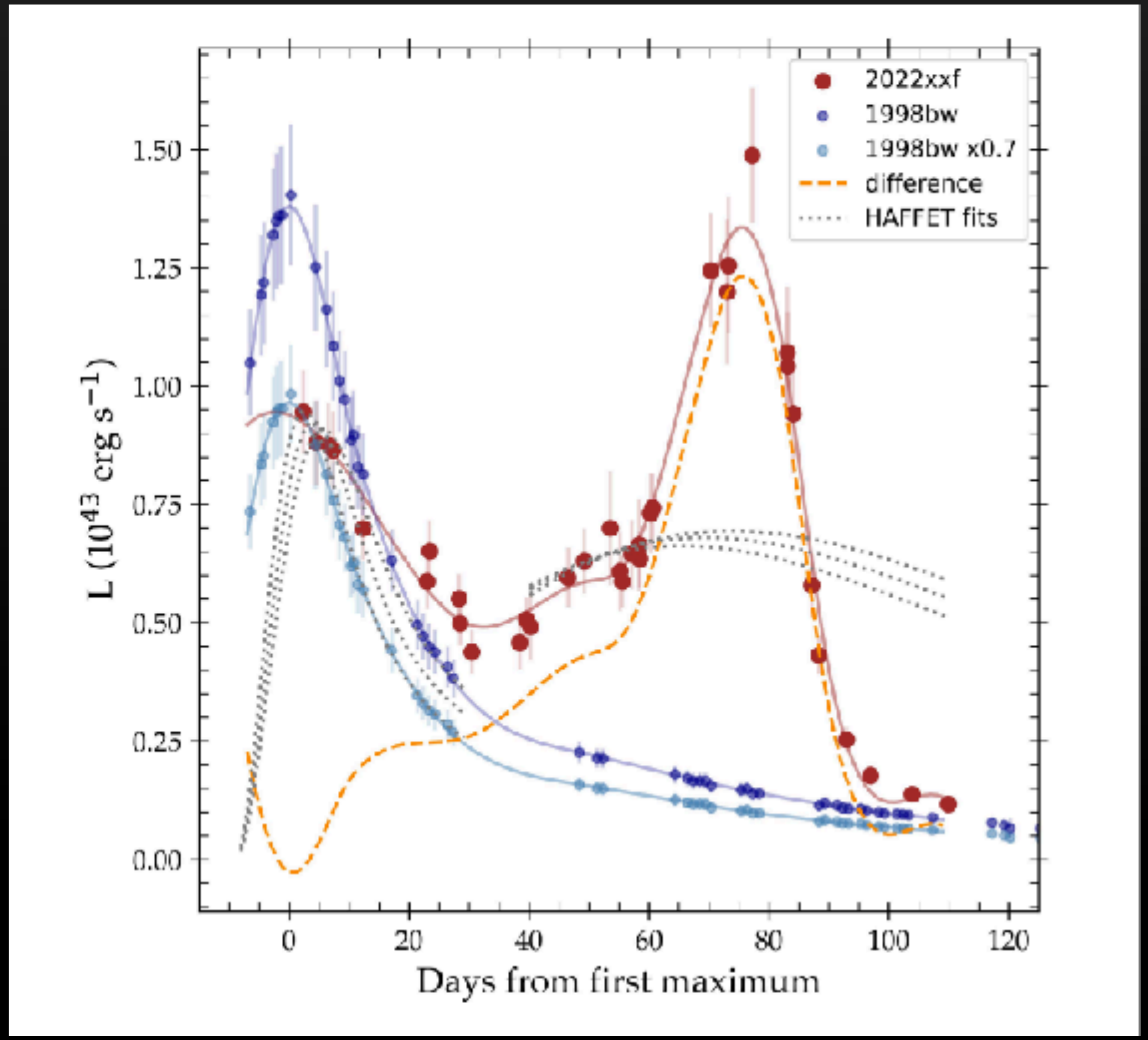
60,000 km/s
80,000 km/s
100,000 km/s
120,000 km/s



(Maeda+ 2023)

SN 2022xxf





Most nearby type-Ic BL SN @ d = 15 Mpc

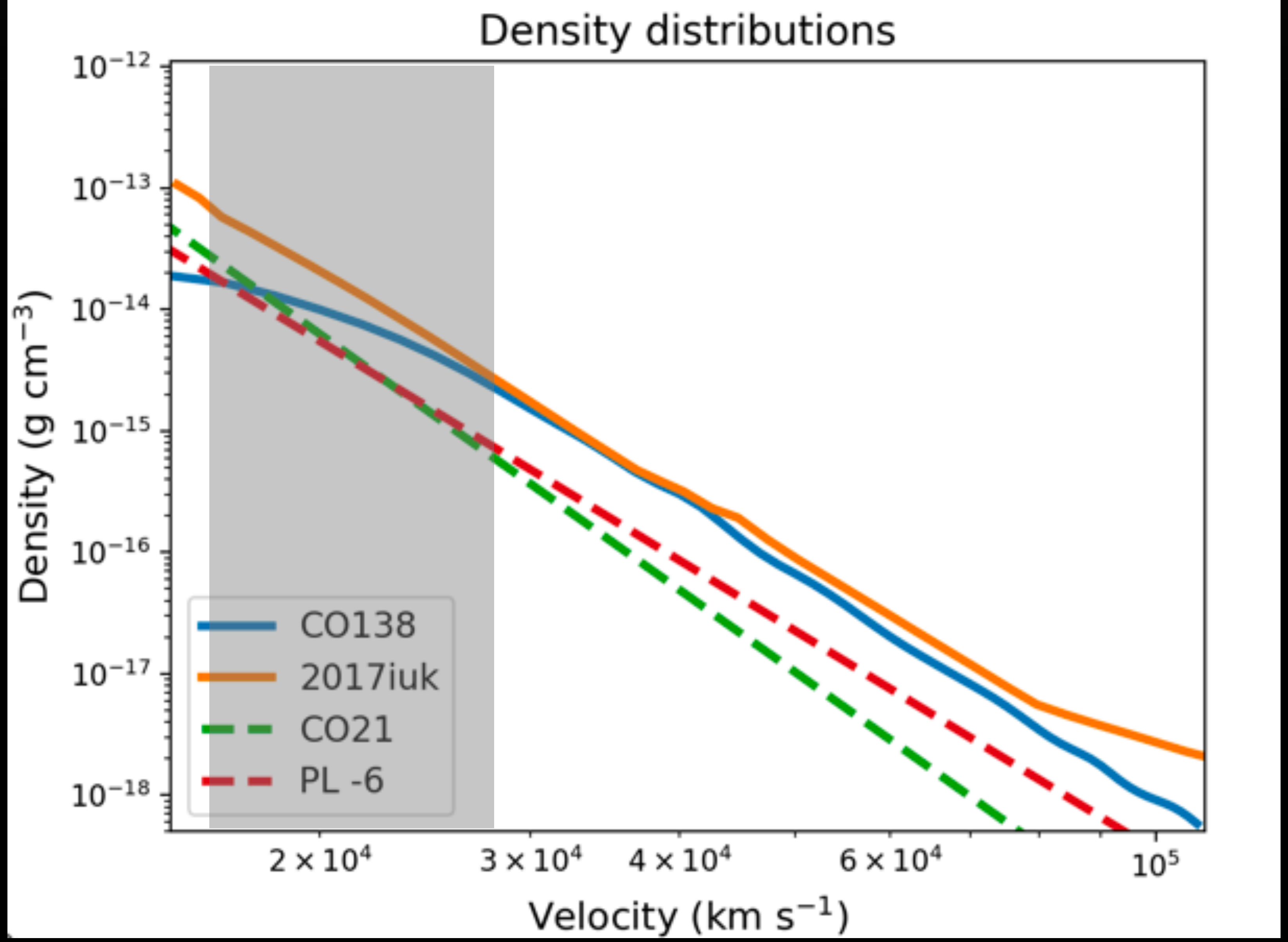
(Kuncarayakti+ 2023)

SN 2022xxf

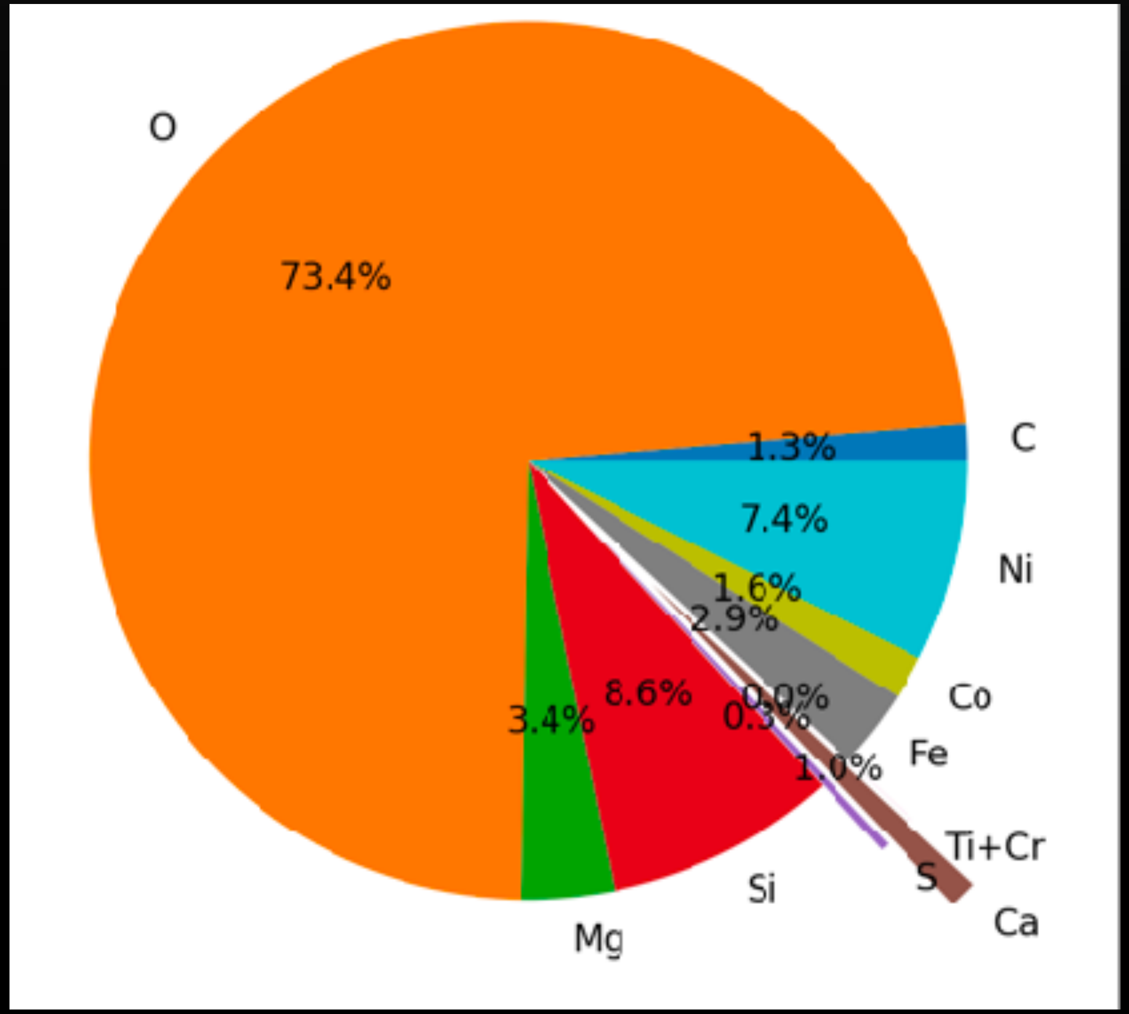
Best model with PL -6

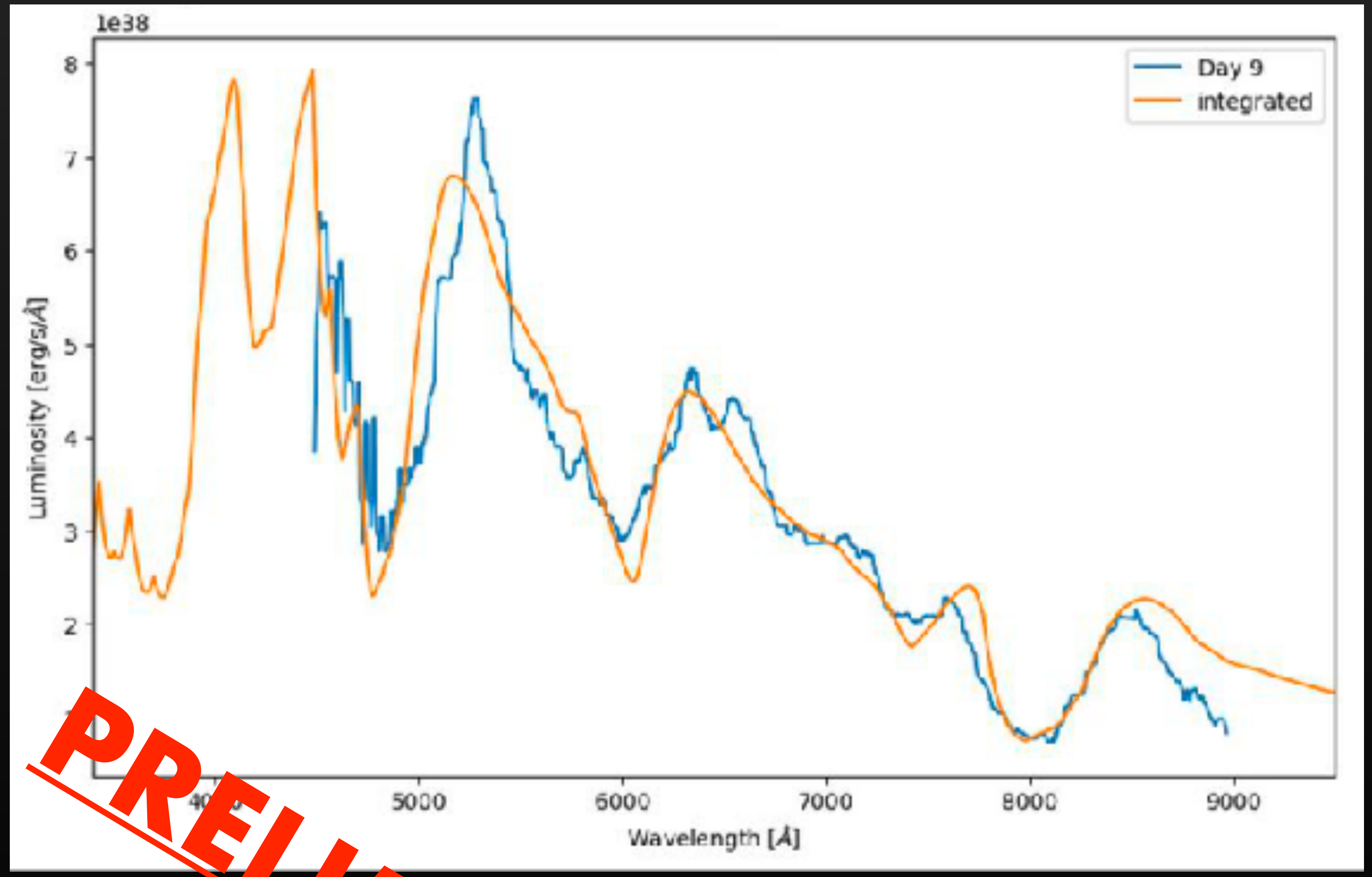
0.12Msun 56Ni

Vmax = 27,000 km/s

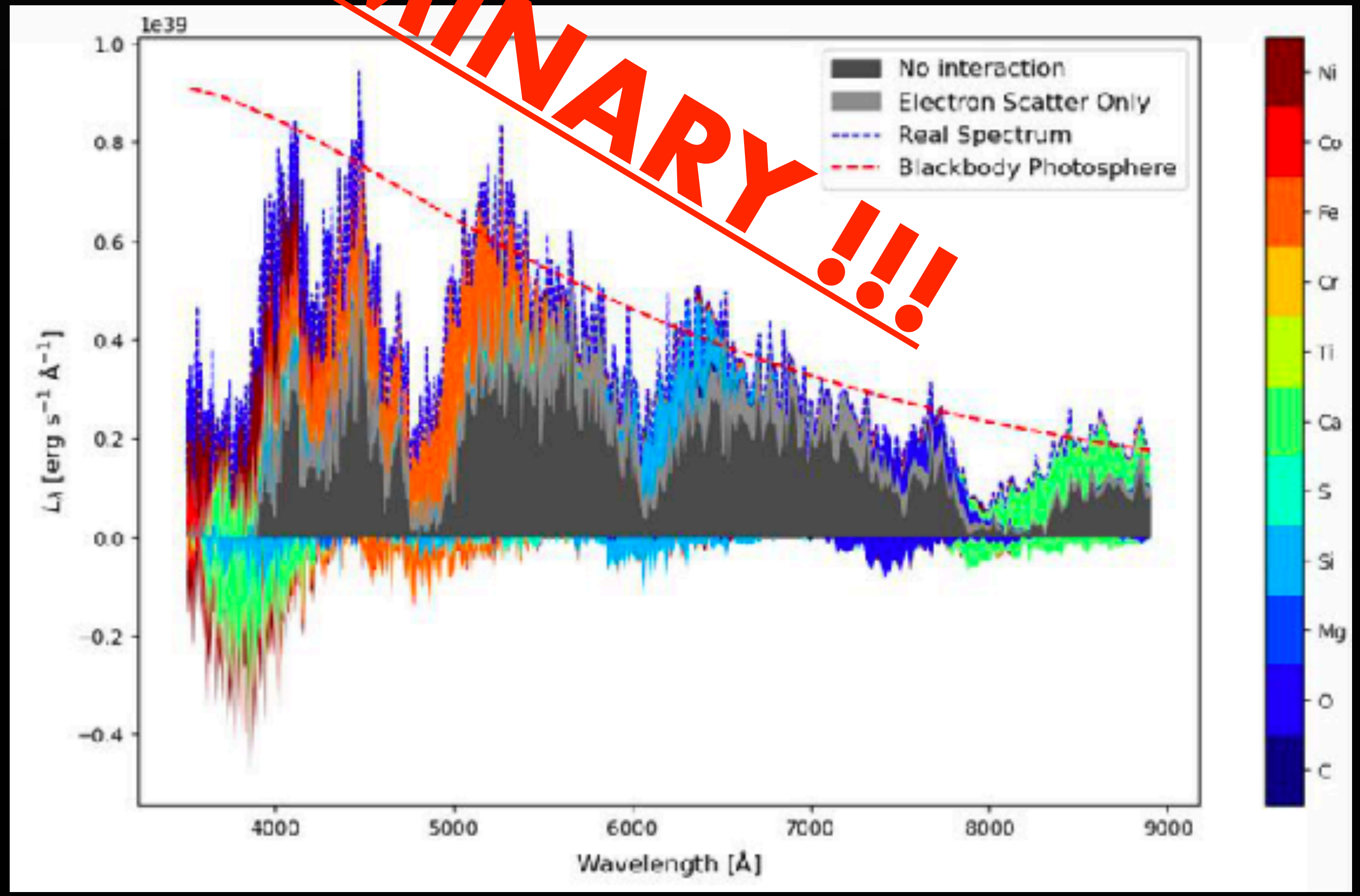


TARDIS!
Exploring supernovae made easy



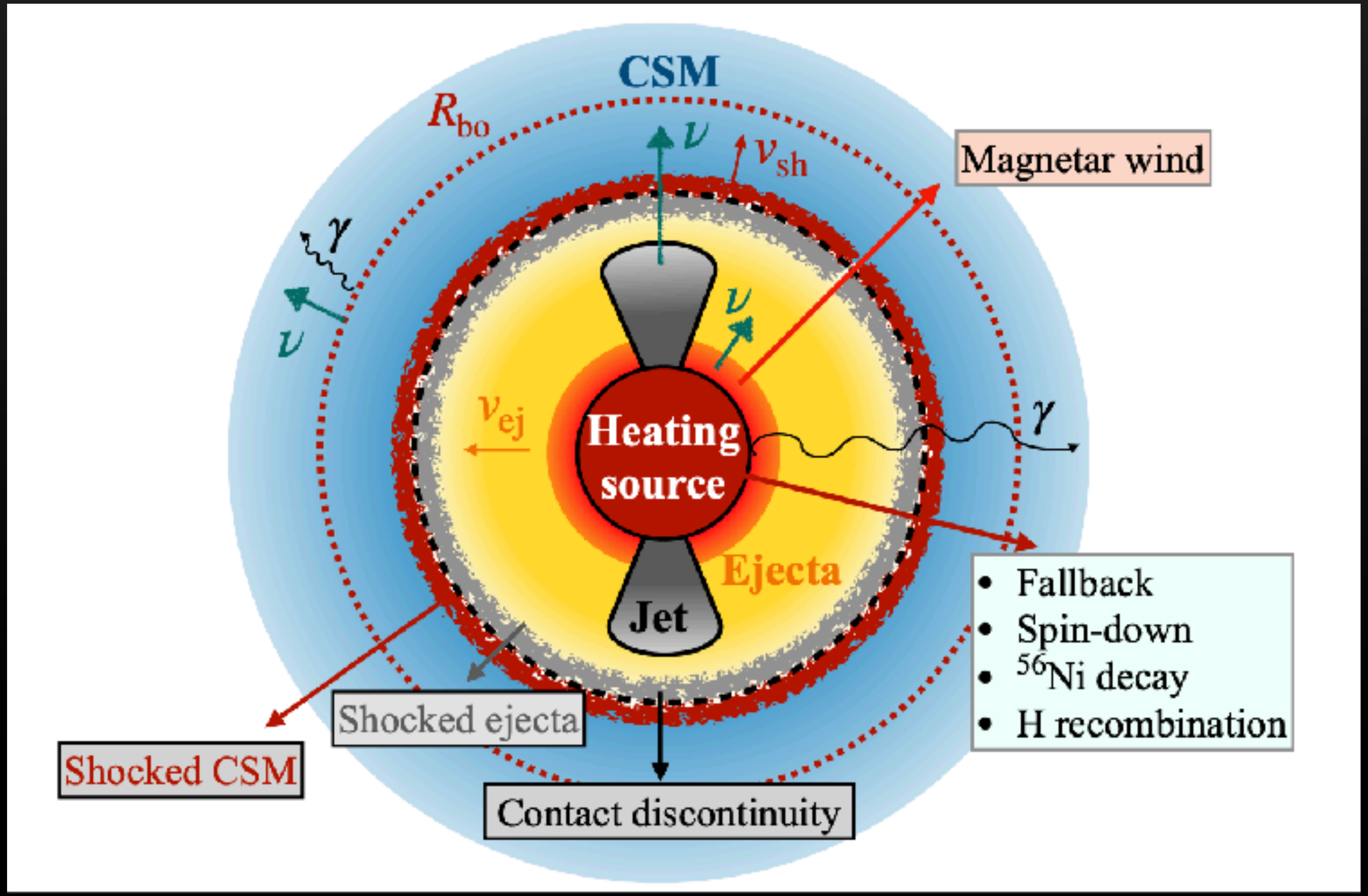


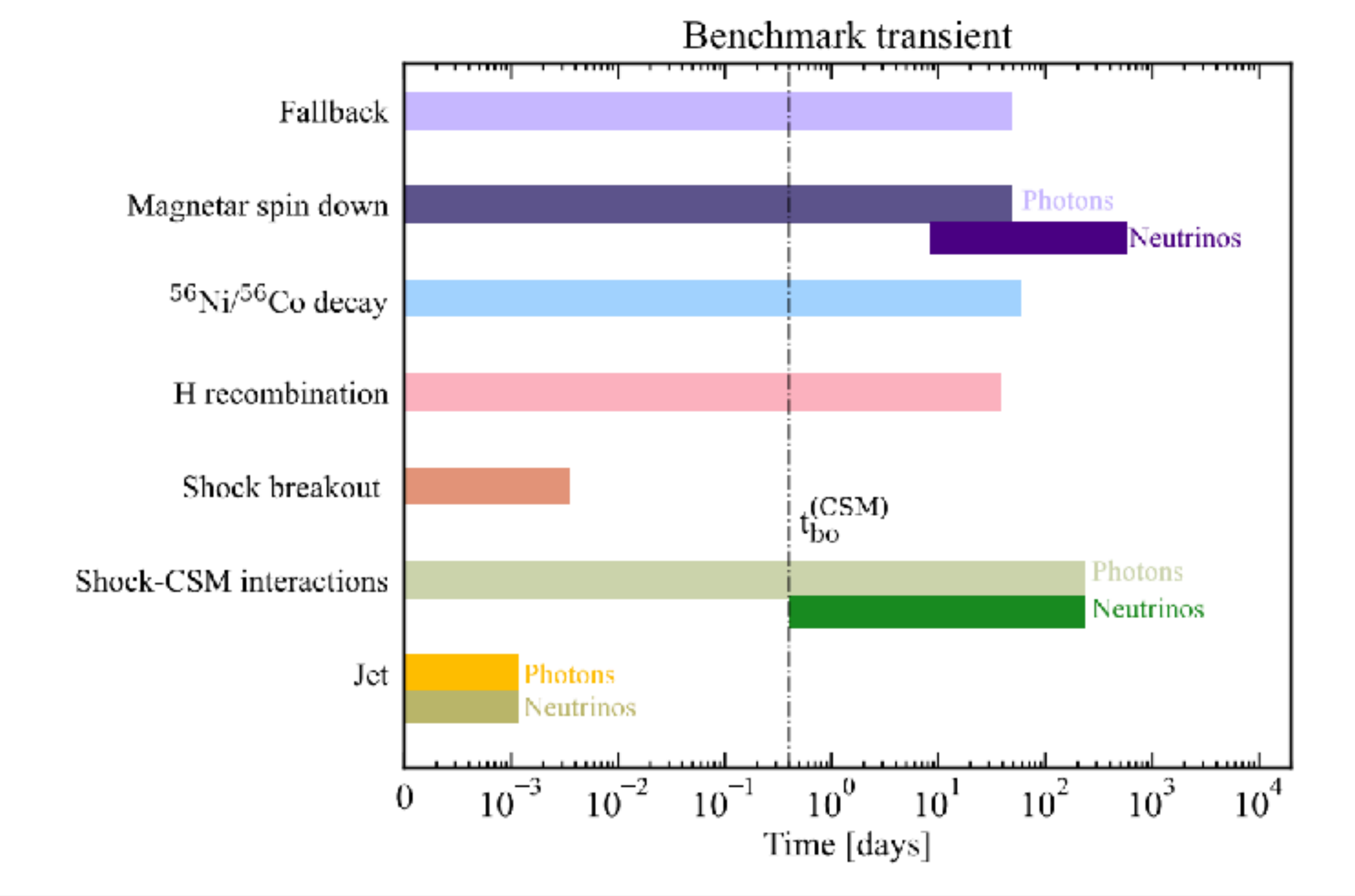
PRELIMINARY !!!



(Izzo+ in prep.)

Neutrinos from Ic-BL

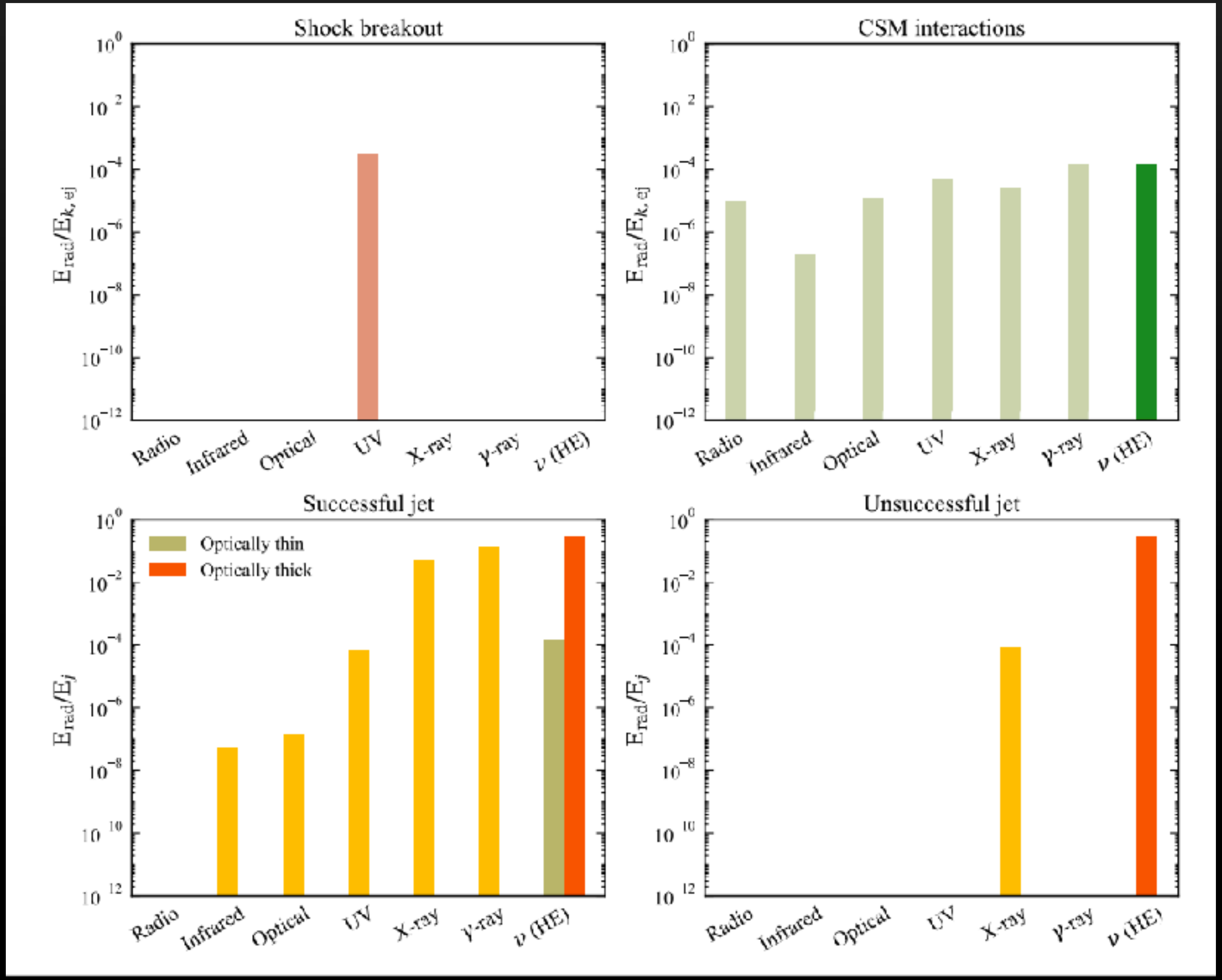


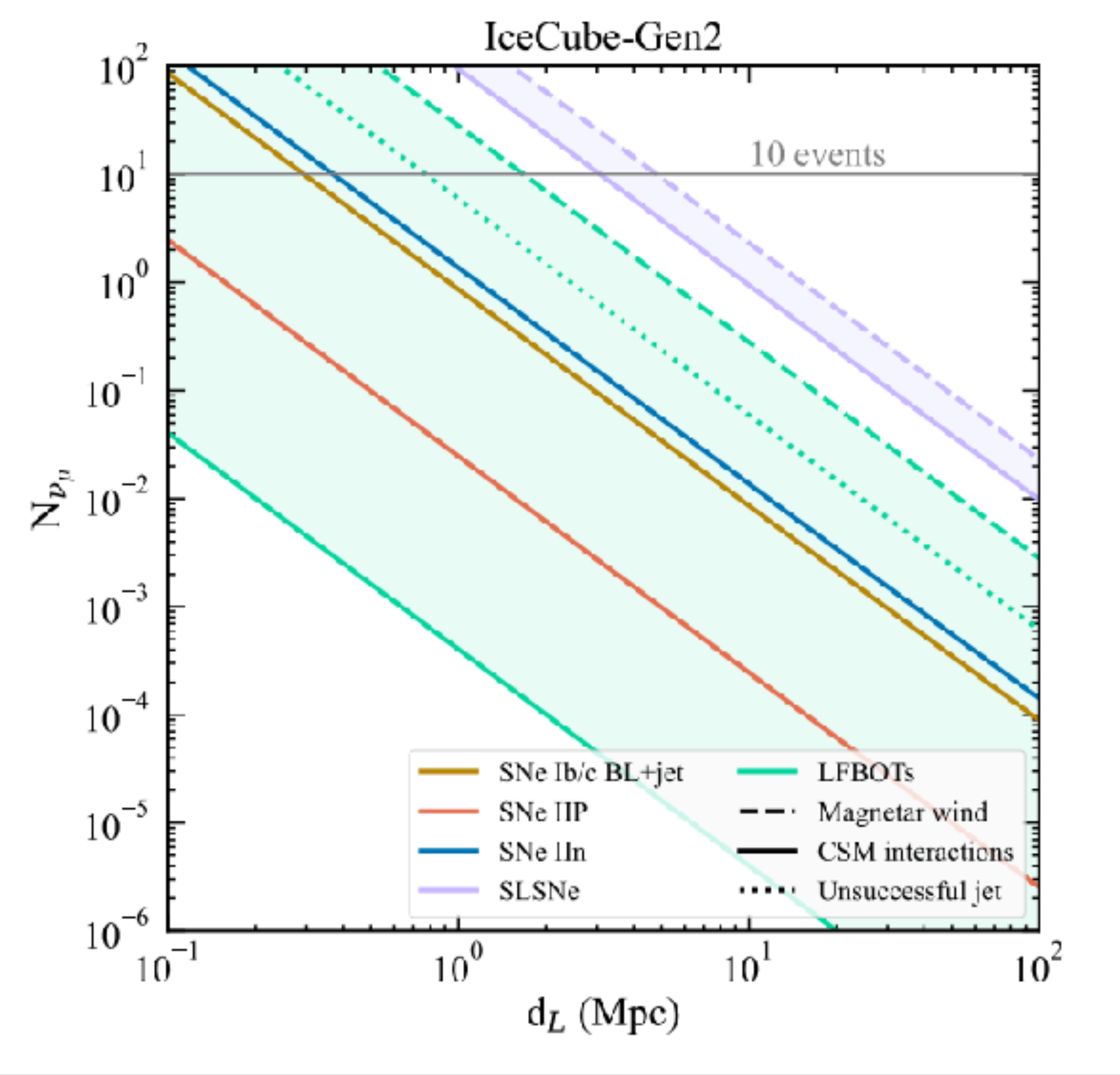


Ic-BL SNe as the most promising sources of neutrinos (SNe)

(Guarini+ 2023)

Neutrinos from Ic-BL





Jet (successful or choked)
CSM interaction
More efficient processes for neutrinos

(Guarini+ 2023)

Summary

Jet-driven SNe give rise to jet-cocoon stellar shocked emission @ UV-optical & radio

High-velocity broad absorptions in very early spectra

Synthesis modeling points out to:
- flat, high densities at $v_{exp} > 50{,}000$ km/s
- enhanced IME and Fe-peak abundances due to shock nucleosynthesis

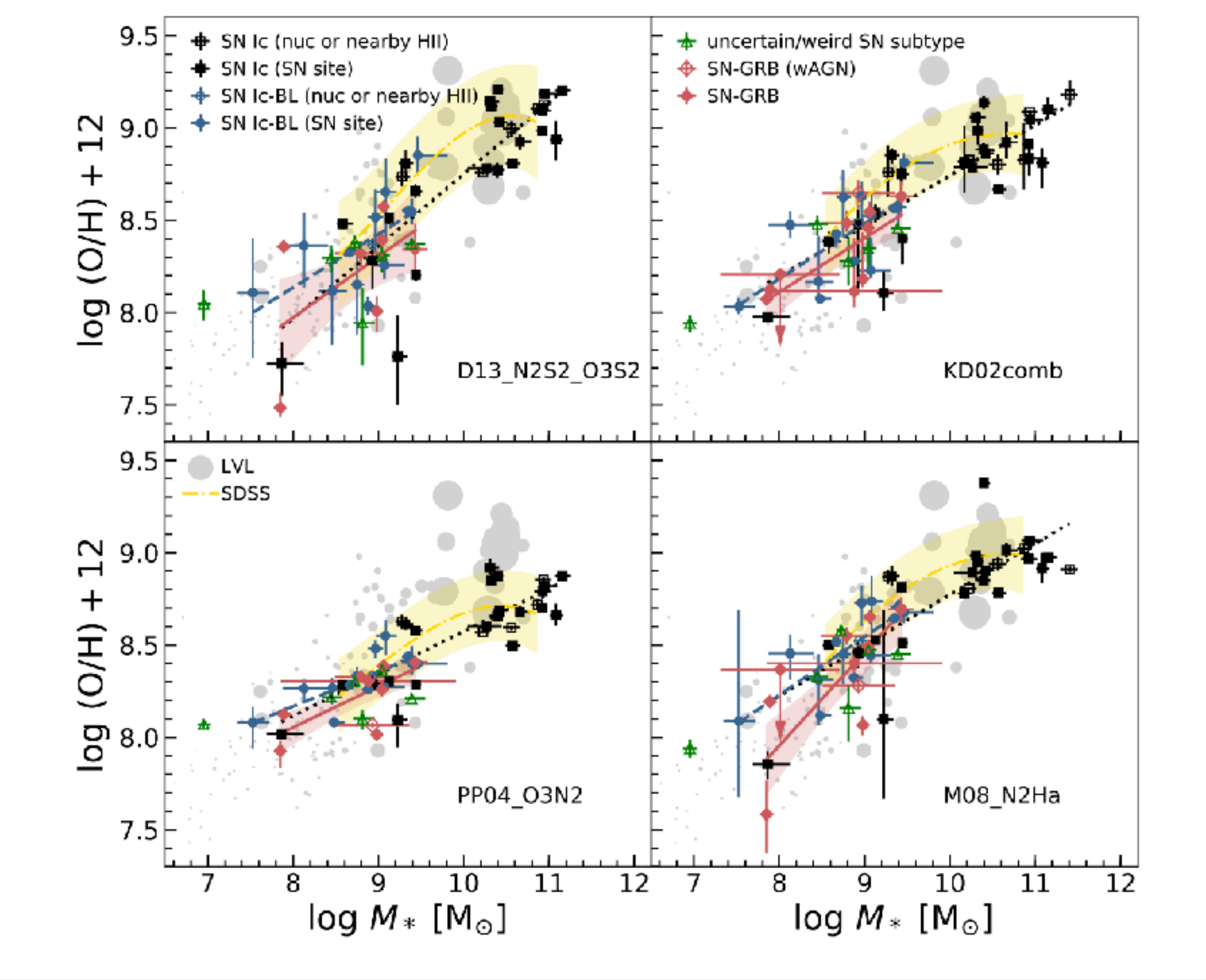
GRB-less Ic-BL SNe could be also powered by choked-jet explosions

Early radio observations suggest high-velocity expanding component

Smoking gun: neutrinos? GWs? High-energy?

So long, and Thanks for All the Mezcal

Host galaxies of Ic-BL



(Modjaz+ 2019)

Slightly higher average Z for Ic-BL

vs

SN-GRB host galaxies