Multi-band analyses of the bright GRB 230812B and the associated SN2023pel

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PHENIICS Fest 16/05/2024

Gamma-Ray Bursts

-Very energetic events, happening since the earliest galaxies

-About one detected per day

2 categories:

- Short GRBs:
  Merger of compact objects (e.g. neutron stars)

- Long GRBs:
  Collapses of very massive stars

Supernovae

-Energetic events, mostly in closest few Gigaparsecs

-About one detected per day

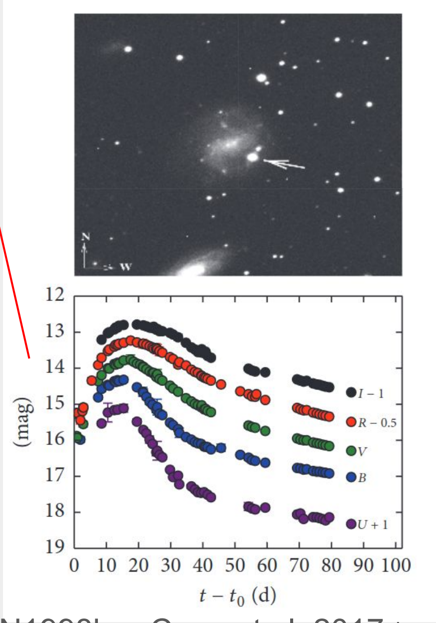
Categories:
- Type Ia:
  White dwarf accreting enough matter from companion to start runaway nuclear fusion

- Types Ib, Ic, II:
  Core- collapses of massive stars

Gamma-Ray Bursts associated to Supernovae

- First detected association is GRB 980425 and SN1998bw
- A dozen confident associations in the last 25 years
- Most events are long core-collapse GRBs with spectral features of Type Ic SNe

  Open question: Are all long GRBs linked to SNe ?



SN1998bw, Cano et al. 2017

- Long GRBs:
  Collapses of very massive stars

- Types Ib, Ic, II:
  Core- collapses of massive stars

GRB230812B - Timeline

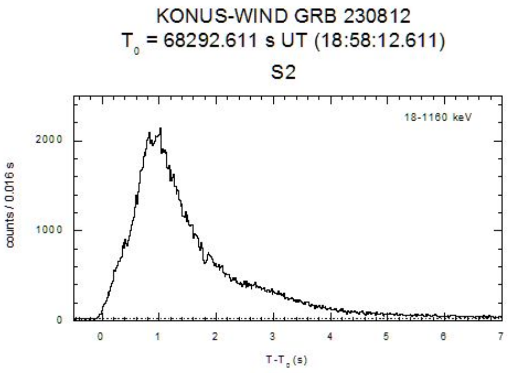
Initial detection of a Gamma-Ray Burst by gamma-ray telescopes in orbit

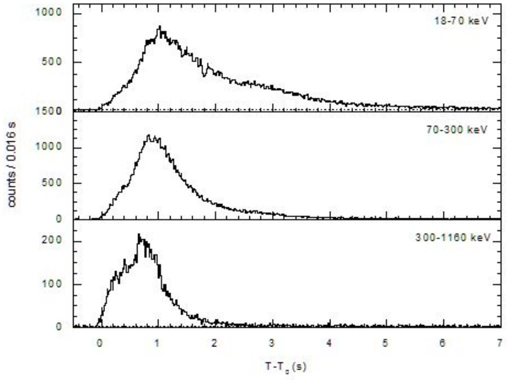
A lot of energy in few seconds: Top 5 brightest GRB ever

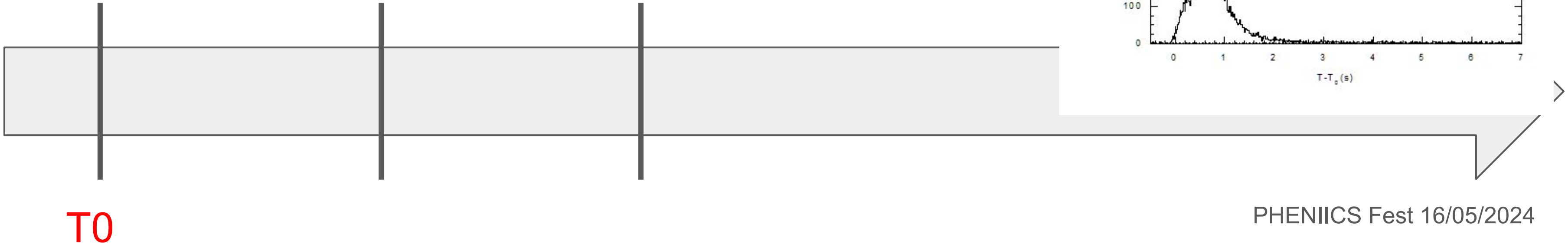
Fluence ([10-1000]keV band) ~ $2.5×10^{−4}$ erg $cm^{−2}$

Very High Energy photons up to 72 GeV

Location constrained within 1 degree





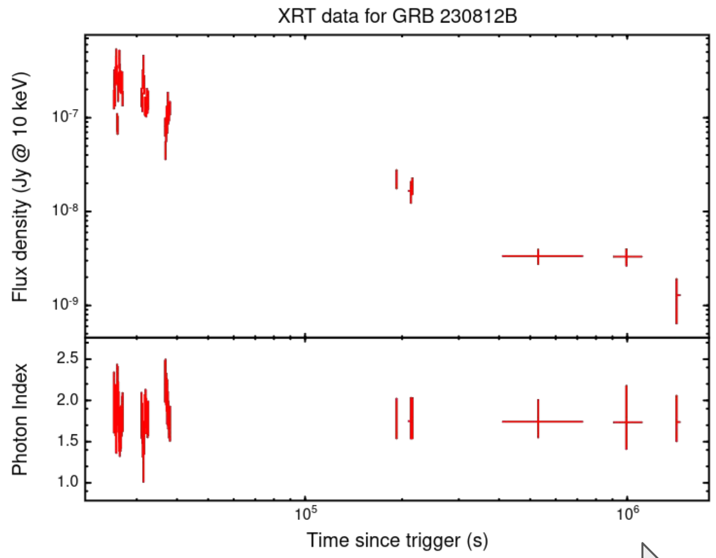


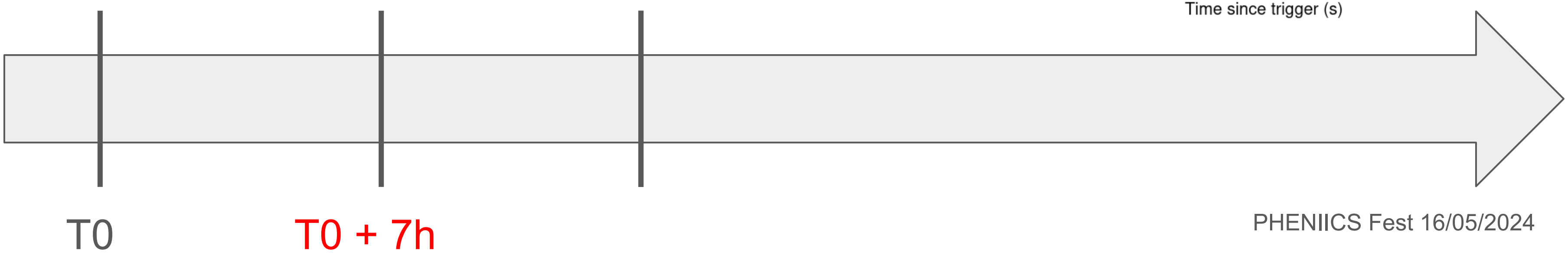
GRB230812B - Timeline

X-ray, UV and Optical telescopes search for a counterpart signal

Uncatalogued X-ray source detected in X-Ray Telescope of the Swift satellite

Improved localisation down to 4 arcseconds





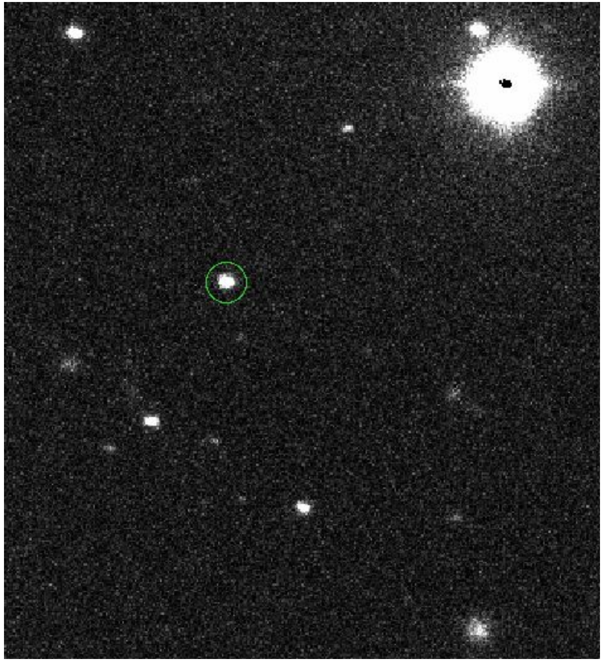
GRB230812B - Timeline

A corresponding optical transient is then discovered at that location

Spectroscopic observations by 10-meter Gran Telescopio Canarias (T0+1.1days)

-> Measured redshift : z ~ 0.360

-> Close-by source : 1.98 Gpc



Cutout from August 13 observation

T0

T0 + 7h

T0 + 8.5h

The GRANDMA collaboration

30 telescopes - 23 observatories - 29 institutes/groups - PI. S. Antier

Following transient sources
- Gravitational waves Counterparts
- Notable Transient phenomena

Partner programme with amateur astronomers:

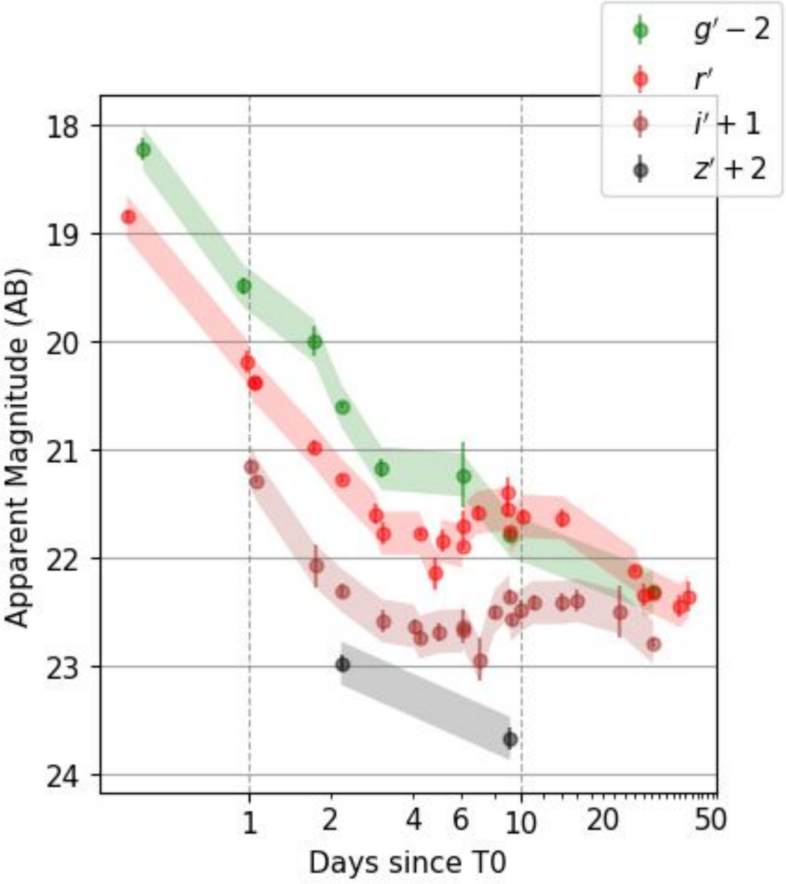
KILONOVA CATCHER

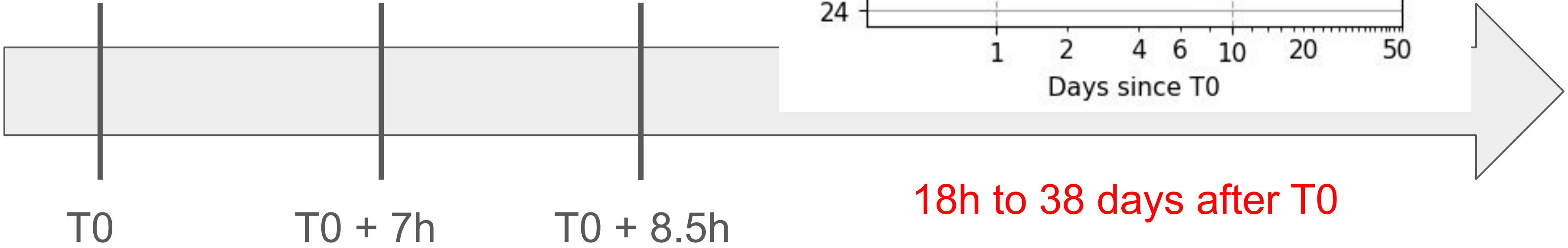
GRB230812B
GRANDMA observations

Optical observations with 20 GRANDMA observatories and several amateur astronomers → ~80 images

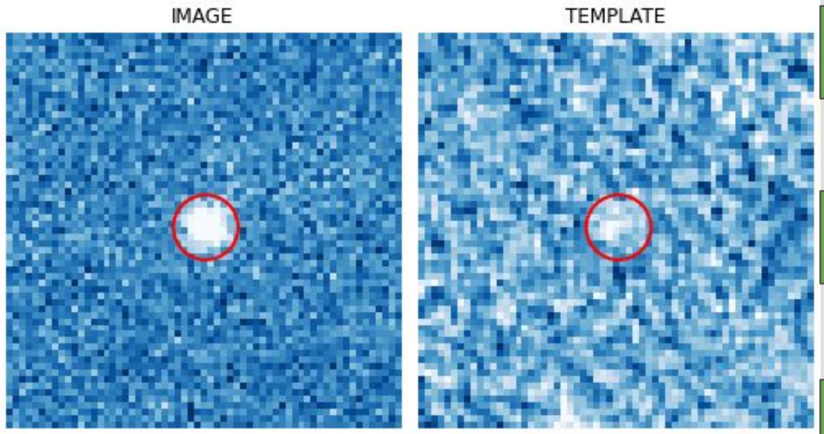
+ Data from partner observatories

= Many observations in different optical and infrared filters





Behind the scenes: Data analysis steps

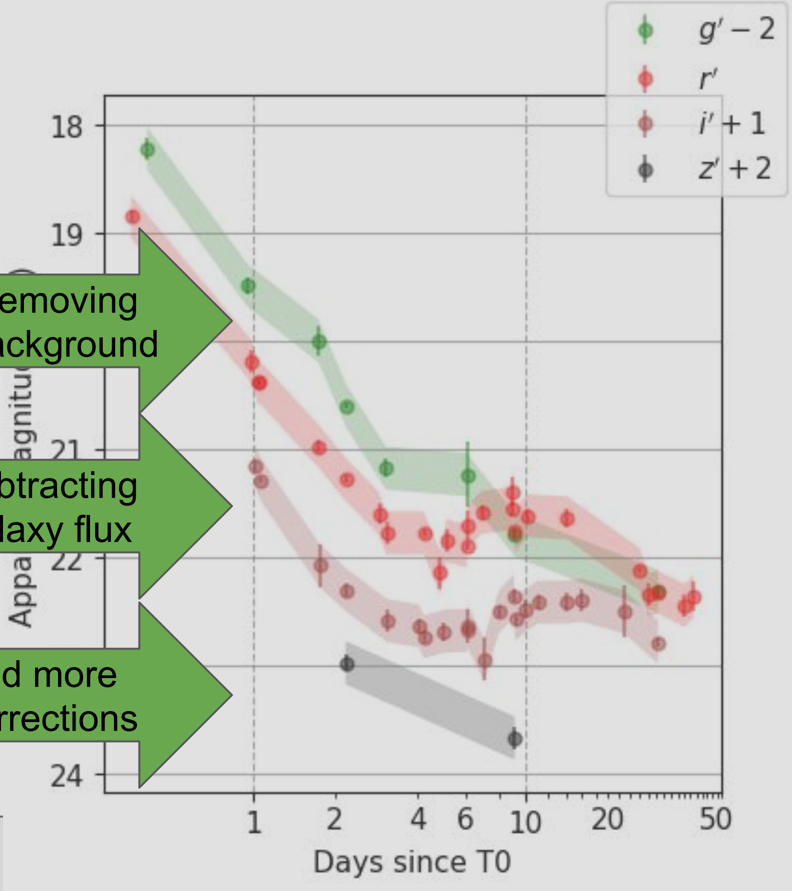


Example: GRB230812B - Cutout from GMG observation T+18h

removing background

subtracting galaxy flux

And more corrections



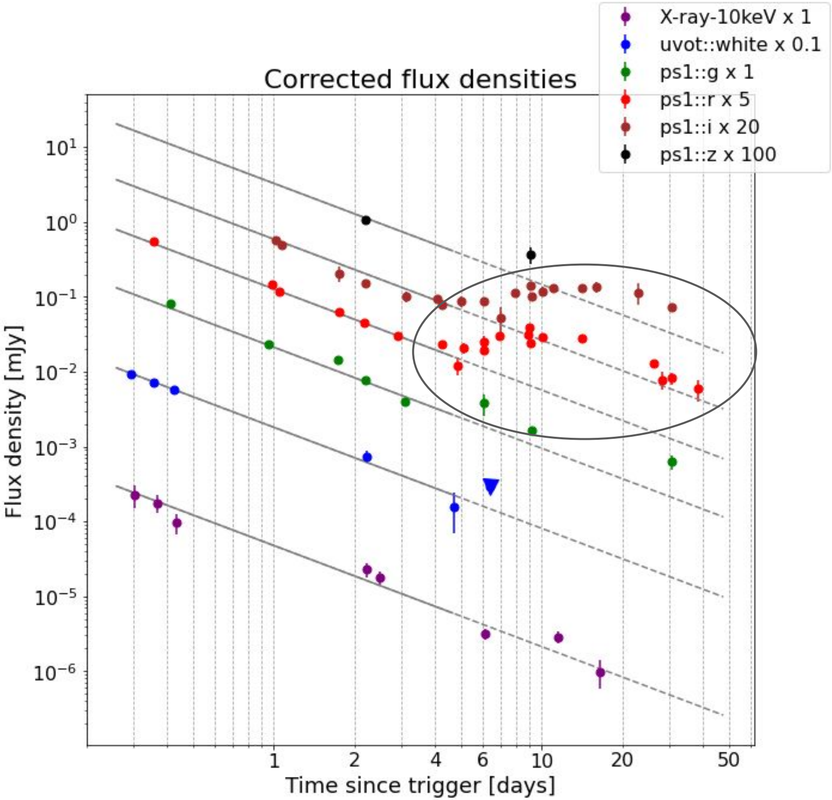
T0

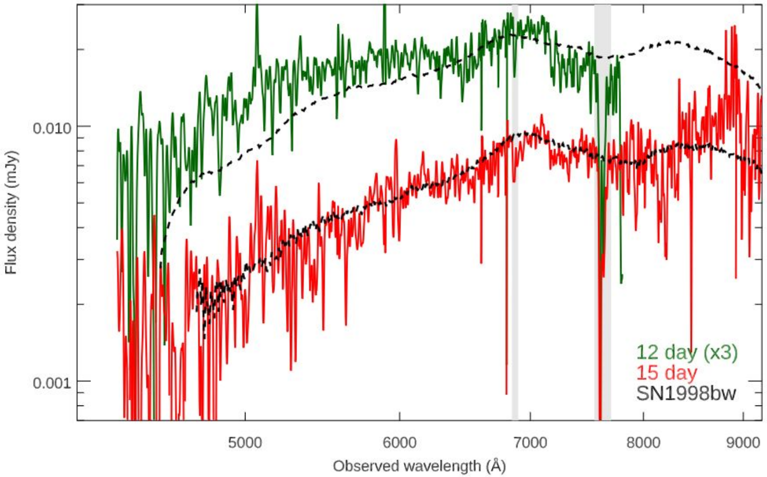
T0 + 7h

T0 + 8.5h

18h to 38 days after T0

Observing the Supernova





Fitting the lightcurve with simple empirical afterglow powerlaw model $F\nu \propto t^{-\alpha} \nu^{-\beta}$

-> SN bump is clearly visible after T+5days

Spectra at 12 and 15 days, GRB afterglow has become negligible under SN component

Spectral features are in good match with other Type Ic SNe: SN2006aj, SN2002ap, SN2005ek, SN1998bw

Bayesian Analysis - Finding the best fitting model

Lightcurve models:

-GRB afterglow: afterglowpy model

-SN: template based on SN1998bw lightcurve

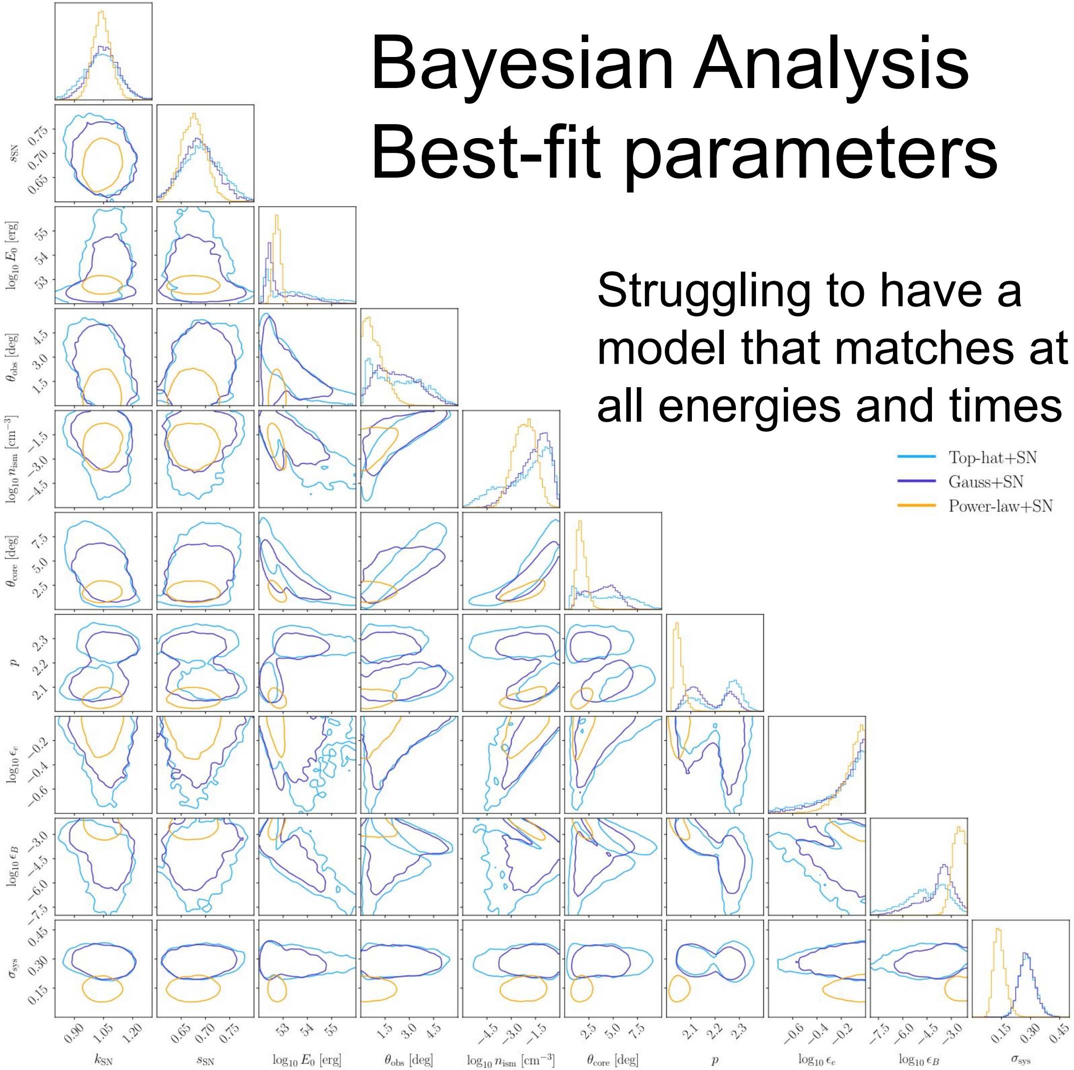
-Other astrophysical events (Kilonovae, Collapsars)

The Nuclear Multi-Messenger Astronomy (NMMA) analysis software searches the model that matches best the full observation dataset (Xray, UV, optical, infrared and radio)

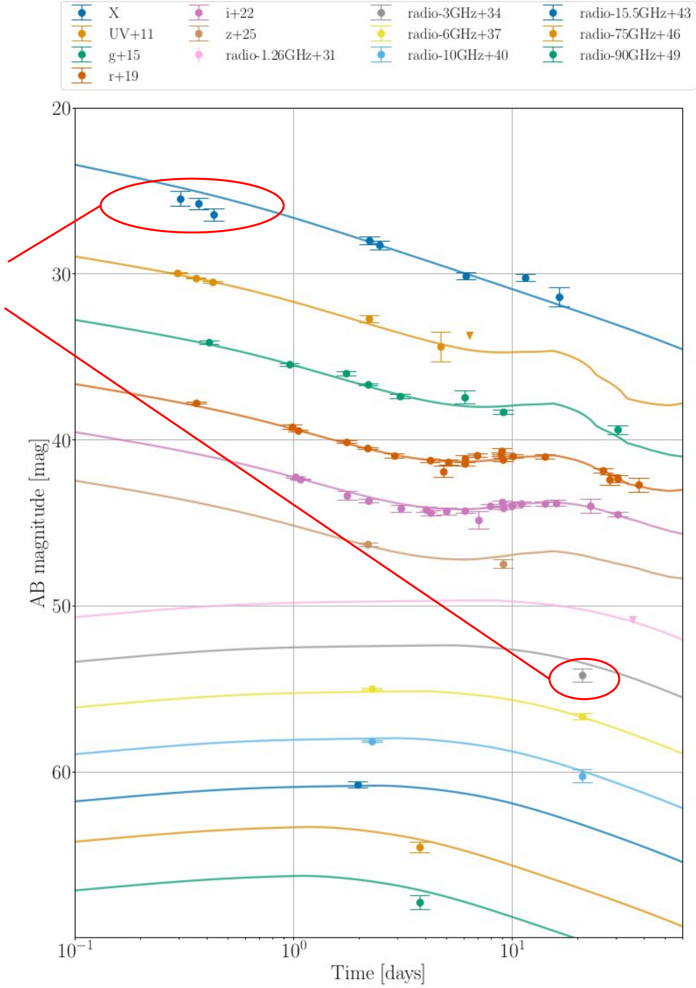
-> We confirm that <u>GRB afterglow + SN is the best-match scenario</u>

Bayesian Analysis
Best-fit parameters

Struggling to have a model that matches at all energies and times



Powerlaw best fit lightcurve

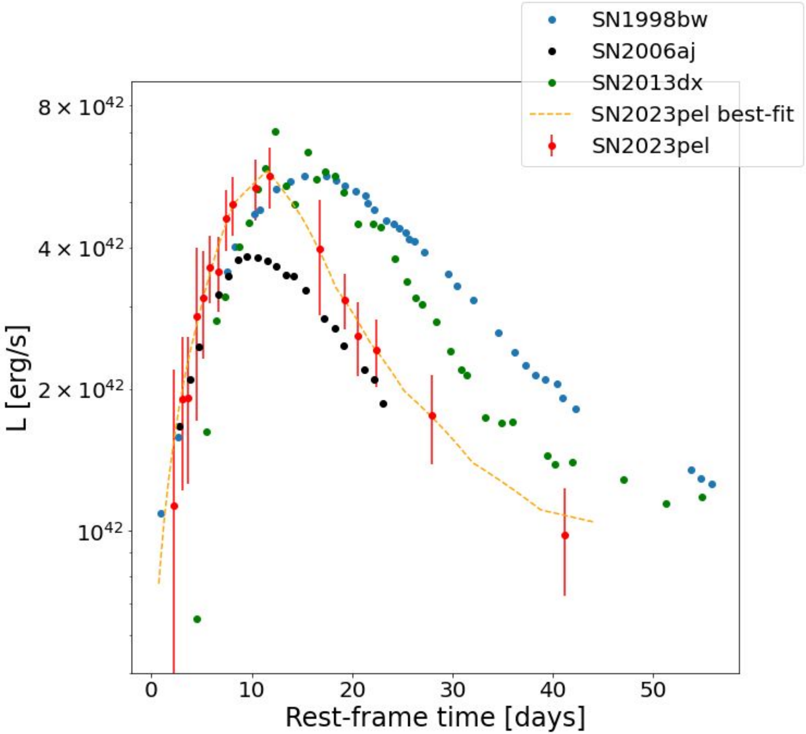


Comparing the SN to other GRB-associated events

Studying the bolometric lightcurve:

SN2023pel has a similar rising time and brightness to other GRB+SN events, but seems to fade quicker

SN	L_{max} (erg s^{-1})	Peak time (d)	Half-max time width (d)
SN2023pel	5.75×10^{42}	11.6	16.2
SN1998bw	5.67×10^{42}	15.3	36.0
SN2006aj	3.80×10^{42}	9.50	26.9
SN2013dx	7.10×10^{42}	12.3	25.1



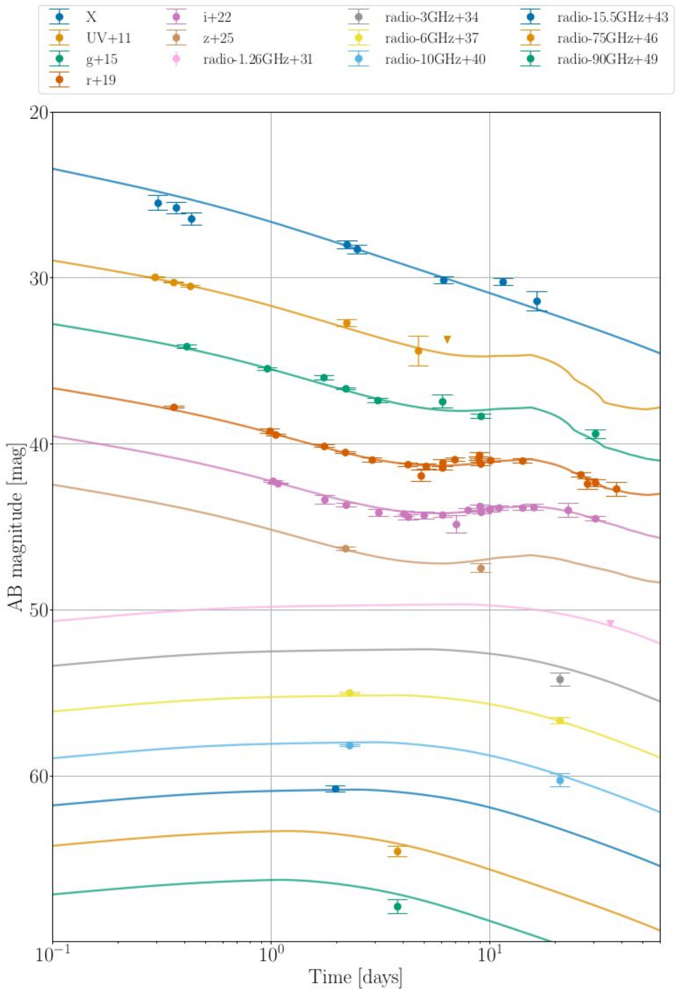
Conclusion

GRB230812B was a bright and rather nearby "long" GRB. Extensive follow-up by GRANDMA and partners in optical and infrared.
-> Strong association to a supernova component

Adding X, UV and radio we modeled a GRB+SN:

- Type Ic SN parameters, in line with previously studied GRB+SN events
- GRB afterglow, with a power-law jet angular structure. Some parameters (Narrow jet angle, Low density of interstellar medium) unusual for this class of events.

Highlighting limitations of literature models for all-encompassing description
-> Call for further modeling



Thanks for listening!

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Hussenot-Desenonges et al.
MNRAS 530 (2024) 1, 1-19

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Backup slides

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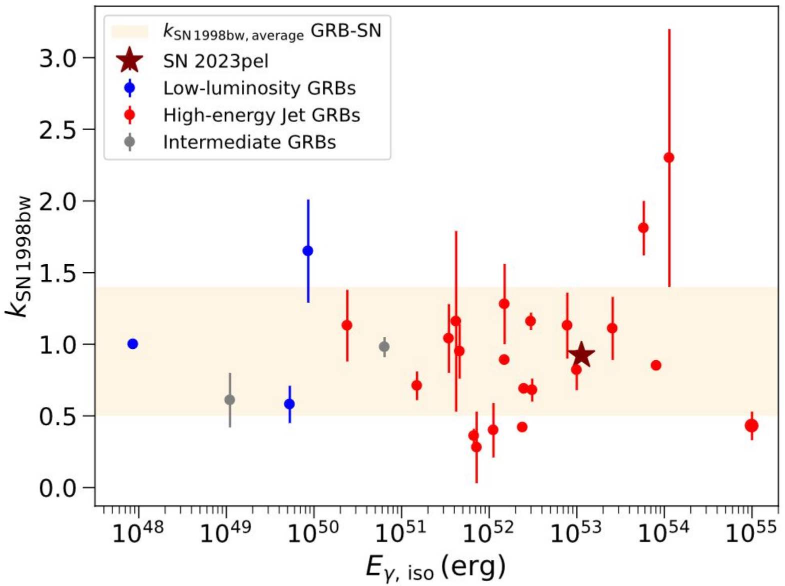
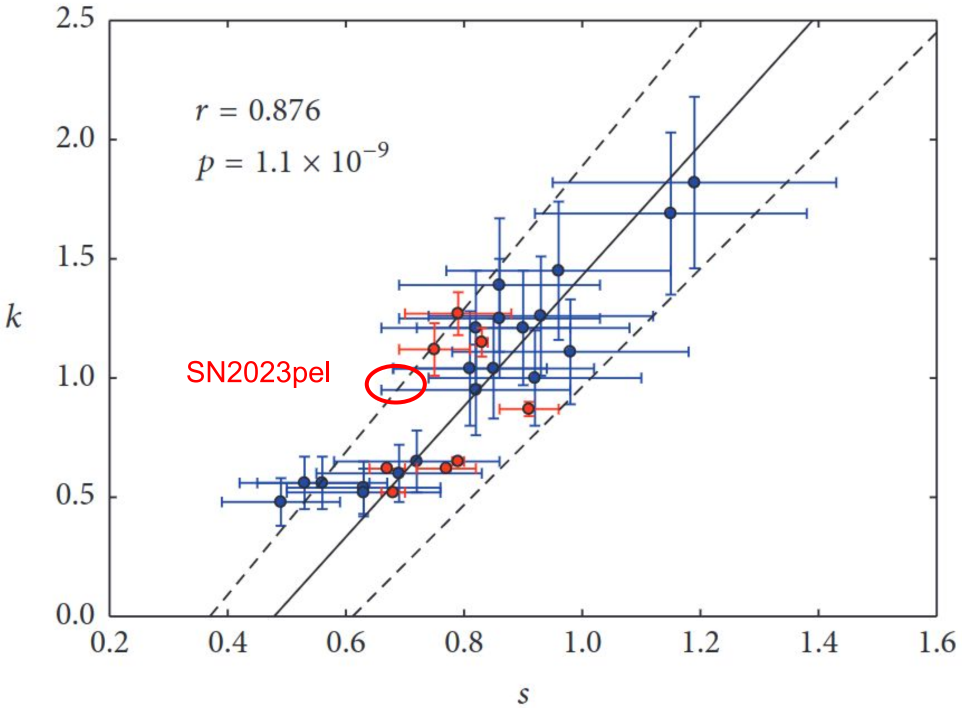
More comparisons with the GRB+SN population



SN brightness against GRB energy (Srinivasaragavan et al 2023)



SN brightness against SN timescale (Cano et al 2017)

Bayesian Analysis Parameter Estimation

Parameter	Prior	Prior range	Power-law+SN
(log-) Isotropic afterglow energy E_0 [erg]	Uniform	[47, 57]	$52.76^{+0.28}_{-0.26}$
(log-) Ambient medium's density n_{ism}[cm^{-3}]	Uniform	[−6, 3]	$-2.16^{+1.21}_{-1.30}$
(log-) Energy fraction in electrons ϵ_e	Uniform	[−5, 0]	$-0.09^{+0.09}_{-0.23}$
(log-) Energy fraction in magnetic field ϵ_B	Uniform	[−10, 0]	$-2.44^{+0.83}_{-0.83}$
Electron distribution power-law index p	Uniform	[2.01, 3]	$2.05^{+0.04}_{-0.02}$
Viewing angle θ_{obs} [degrees]	$\mathcal{N}(0, \theta^2_{core})$	–	$0.75^{+1.27}_{-0.75}$
Jet core's opening angle θ_{core} [degrees]	Uniform	[0.6, 18]	$1.70^{+1.00}_{-0.71}$
"Wing" truncation angle θ_{wing} [degrees]	Uniform	[0.6, 45]	$20.82^{+18.94}_{-11.93}$
Power-law structure index b	Uniform	[0.1, 7]	$1.66^{+0.51}_{-0.42}$
Angle ratio $\theta_{obs}/\theta_{core}$	–	–	$0.44^{+0.76}_{-0.44}$
Supernova boost k_{SN}	Uniform	[0.01, 100]	$1.04^{+0.09}_{-0.09}$
Supernova stretch s_{SN}	Uniform	[0.1, 5.0]	$0.68^{+0.05}_{-0.05}$
Systematic error σ_{sys}	LogUniform	[0.01, 2.0]	$0.14^{+0.06}_{-0.05}$

Supernova parameters: quicker but about as bright as SN1998bw, consistent with the values estimated in the ZTF paper

SN peak at 22.0 in r and 22.8 in i at ~16 days after trigger, consistent with parameter space of strong GRB-SN associations

Low ISM density is uncommon for case where SN implies a massive progenitor

Narrow core angle, high electron energy fraction