Powering Source of Gamma Ray Burst Associated Supernovae: Spin-down Millisecond Magnetar?

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GOTO
GRAVITATIONAL-WAVE OPTICAL TRANSIENT OBSERVER

2nd Astro-COLIBRI multi-messenger astrophysics workshop
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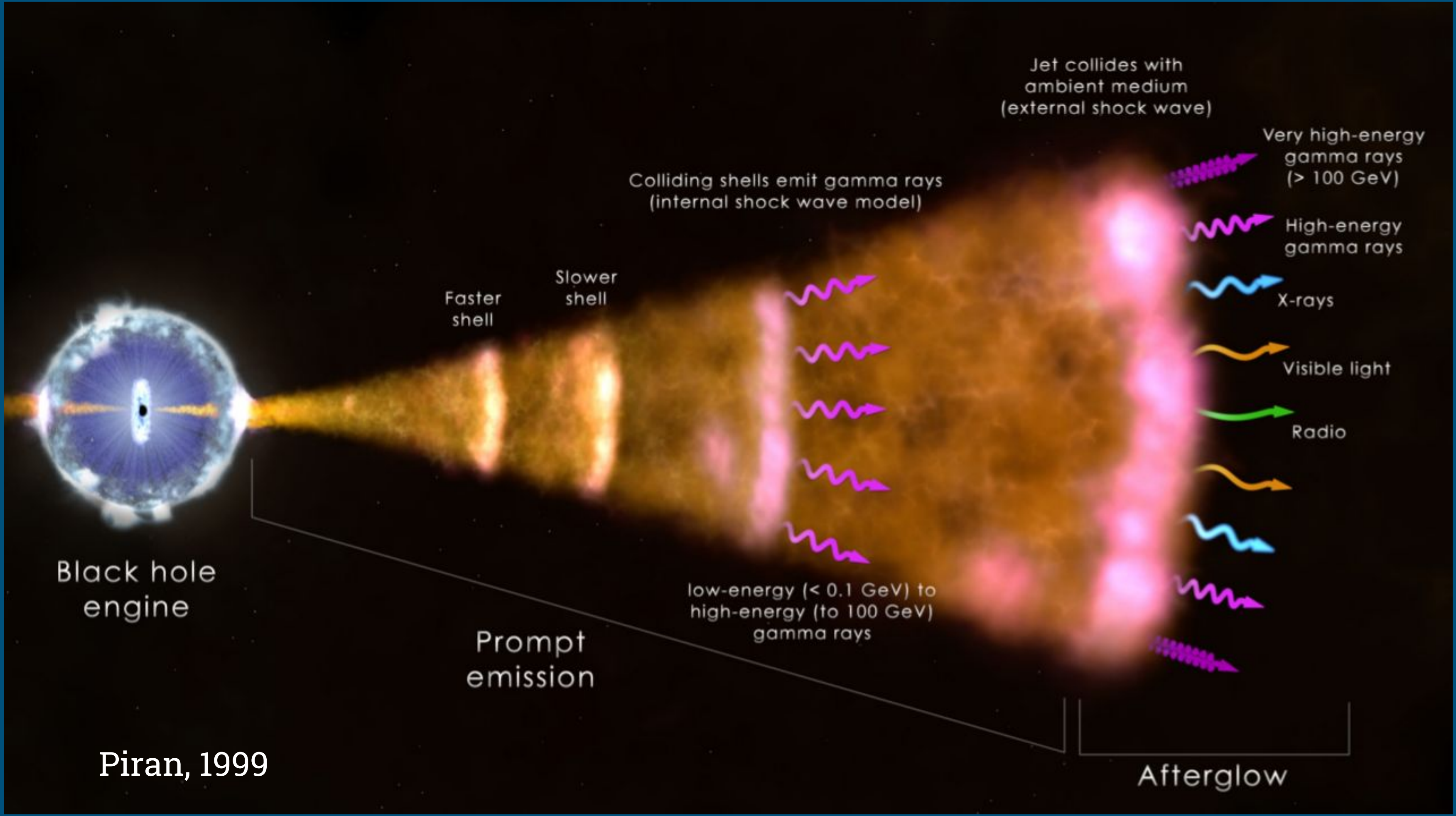
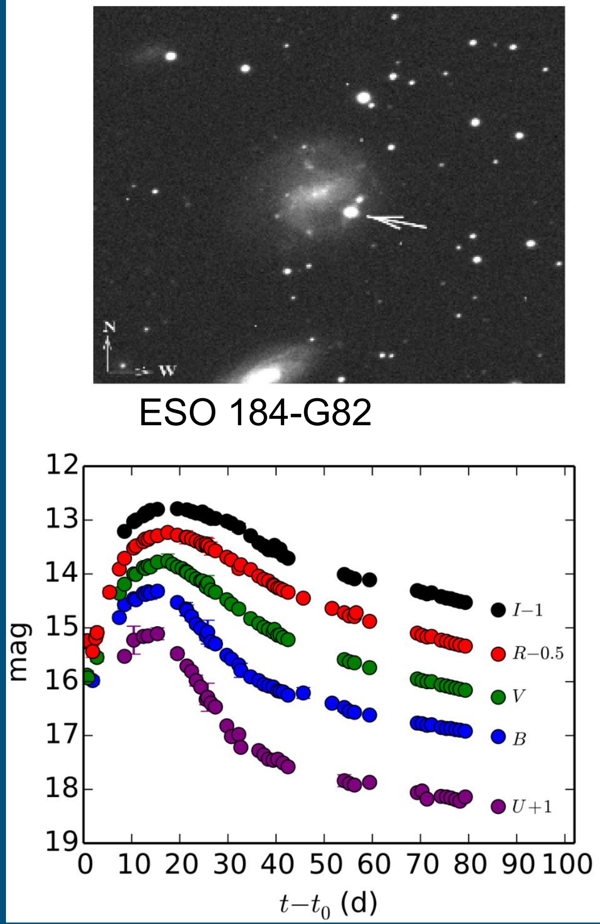
Formation of GRB and SN: Fireball Model

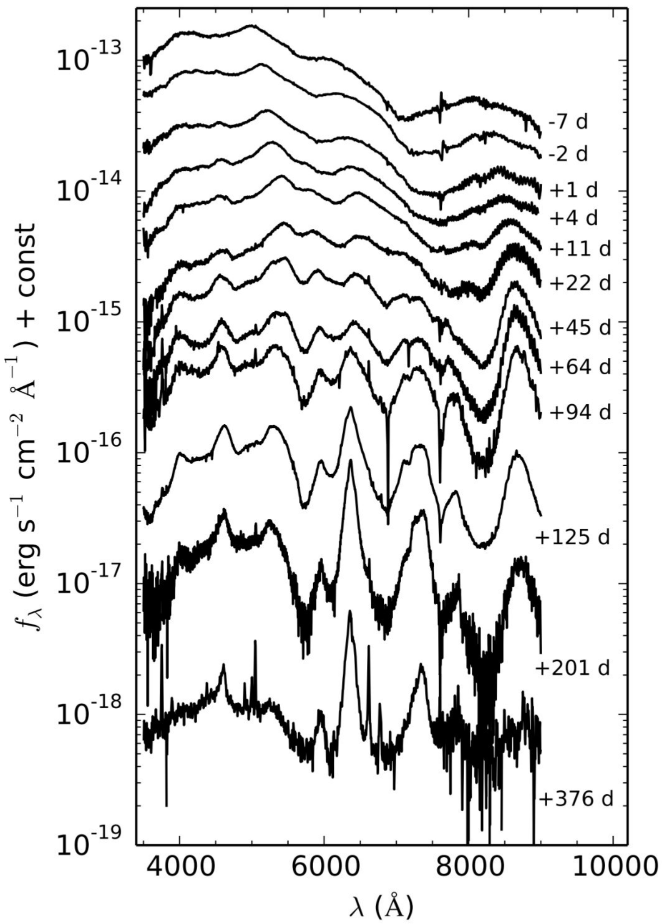


Piran, 1999

GRB 980425/SN 1998bw



Patat et al., 2001

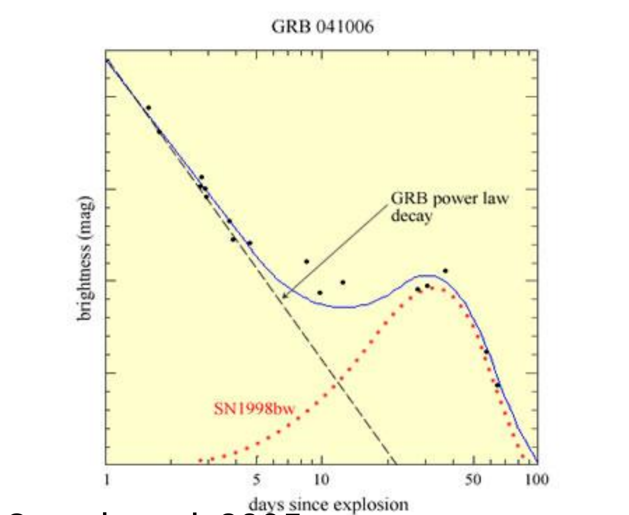


Clocchiatti et al., 2011

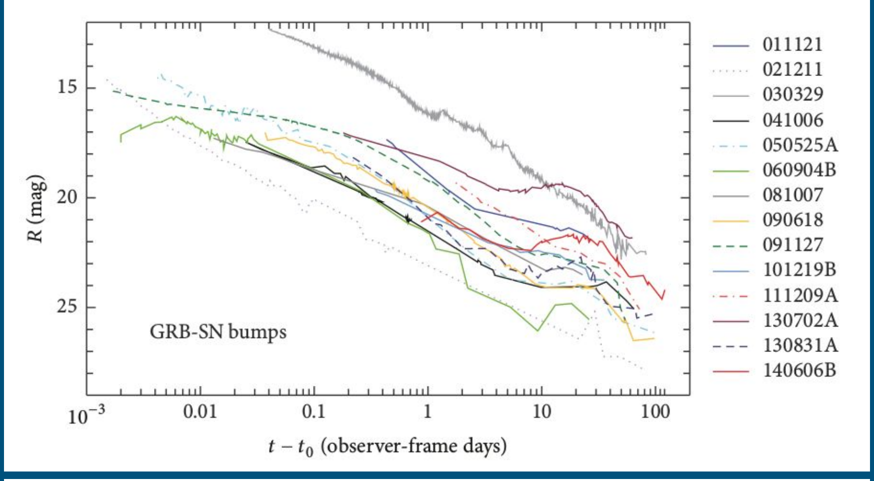
- The era of GRB-SNe connections started with the closest LGRB 980425 and broad lined SN 1998bw (at z = 0.00866).
- GRB 980425 appeared to have a low isotropic γ−ray luminosity relative to those of other cosmological LGRBs.
- Five years later, the discovery of GRB 030329 with a bright optical afterglow exhibited an isotropic γ−ray luminosity consistent with other cosmological LGRBs and associated SN 2003dh presented spectroscopic signatures similar to that of SN 1998bw, confirmed GRB-SNe association..

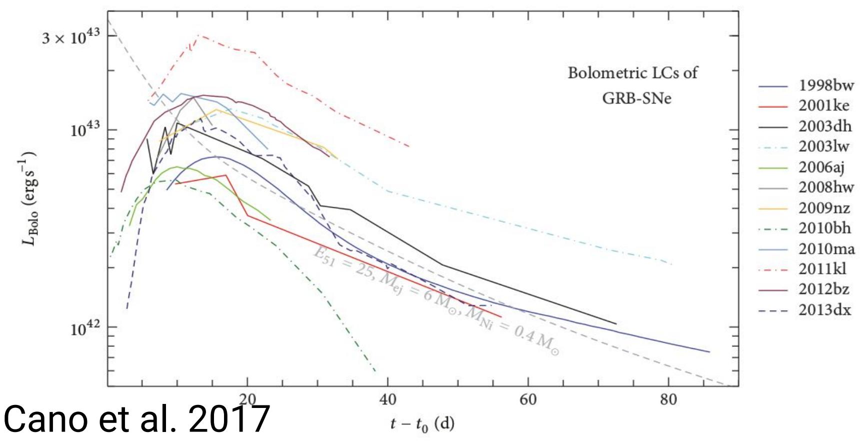
GRB-SNe connections

- To date, more than 50 LGRBs have been discovered with signatures of associated SNe and provide direct evidences of GRB-SNe connections.
- GRB-SNe light curves consist contributions from the Afterglow + SN + Host



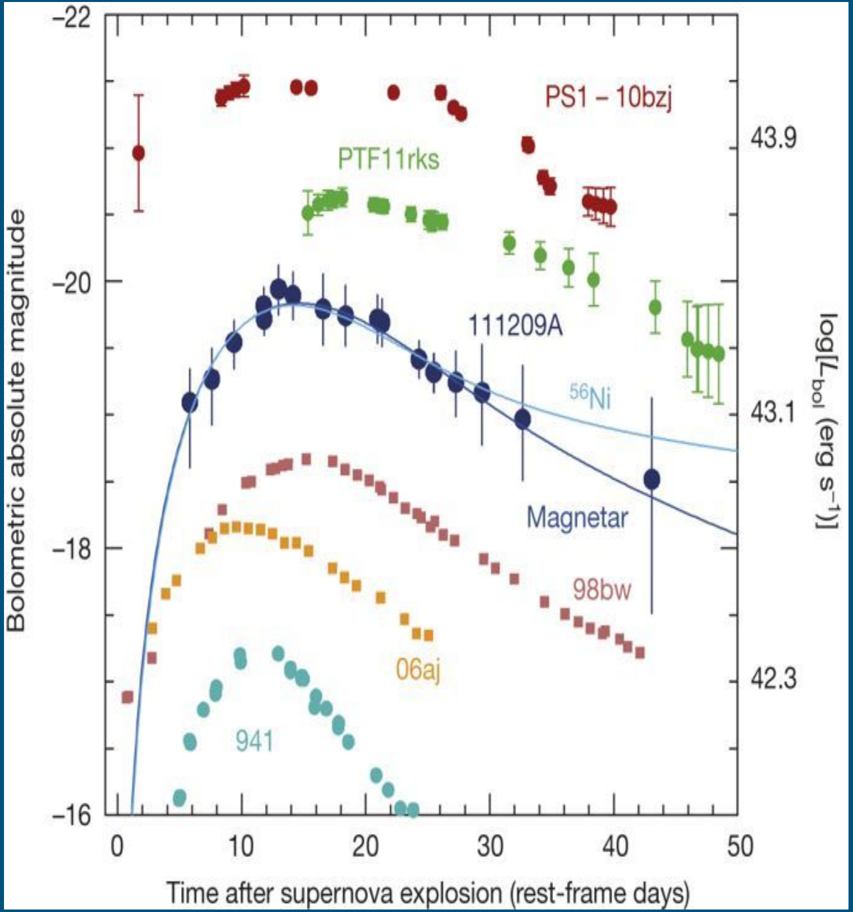
Stanek et al. 2005

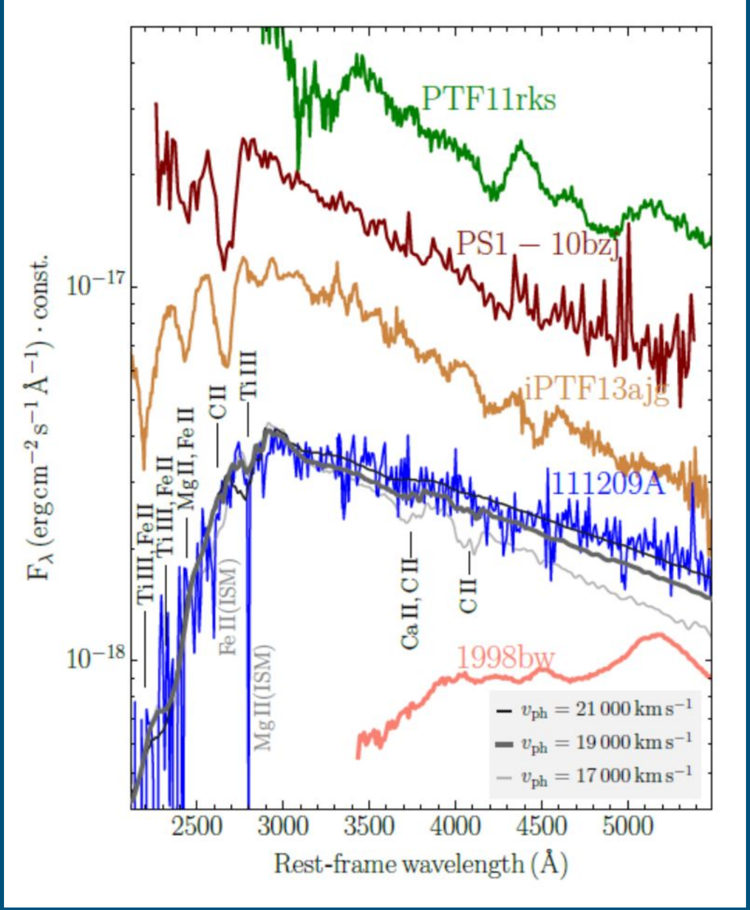




Cano et al. 2017

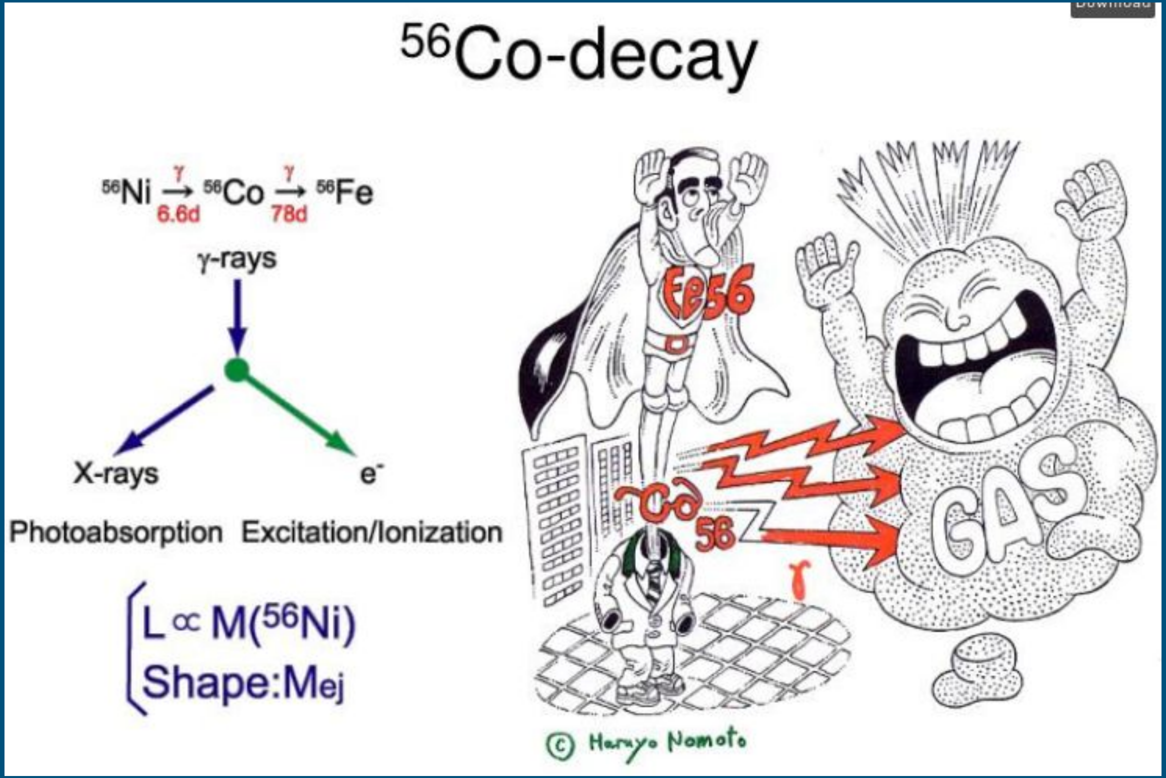
Light-curve & Spectral comparison





Greiner et al. 2015

Powering Mechanisms of SNe



Radioactive Decay

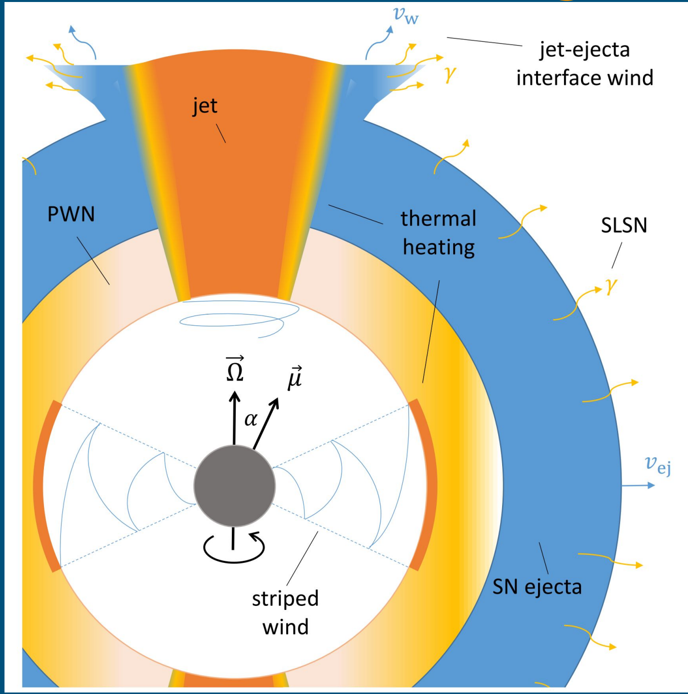
Pair-Instability SN

Spin-down Magnetar

CSM Interaction

Hybrid

Powering Mechanisms of SNe



Margalit et al. 2018

- Spin-down of a millisecond magnetar.
- Powered by rotation, energy extracted via magnetic field.

Power ~ B^2/P^4

Timescale ~ P^2/B^2

Radioactive Decay

Pair-Instability SN

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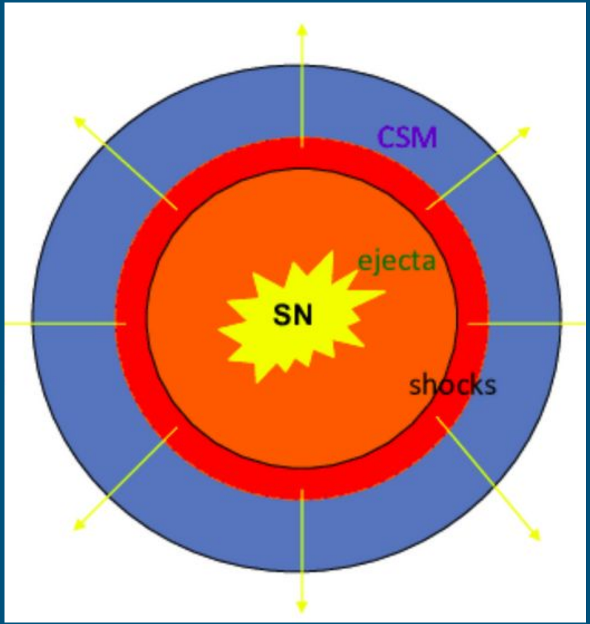
Powering Mechanisms of SNe



- Mass loss and build-up of circumstellar matter around the massive stars are generic features of stellar evolution.
- SN ejecta collides & violently interacts with the CSM.
- Interaction with enshrouded CSM can boost the luminosity of SNe.
- Light curves of Type I SNe generally lack interaction signatures in their spectra.

Radioactive Decay

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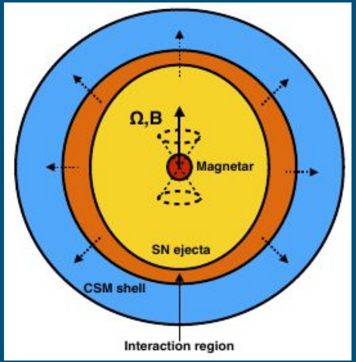
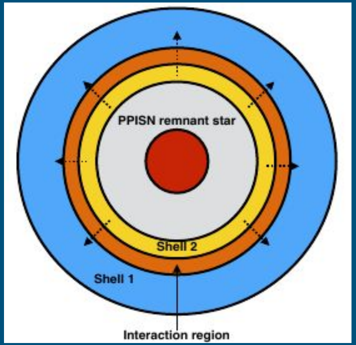
Chatzopoulous et al. 2016

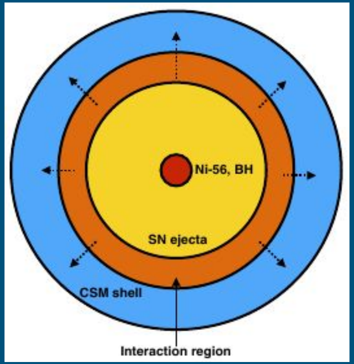
Powering Mechanisms of SNe



- Massively, rapidly rotating CCSN interacting with the CSM



- Multiple CSM interactions of a H-poor ejecta



- Interaction of a radioactively powered H-poor ejecta with a CSM

Radioactive Decay

Pair-Instability SN

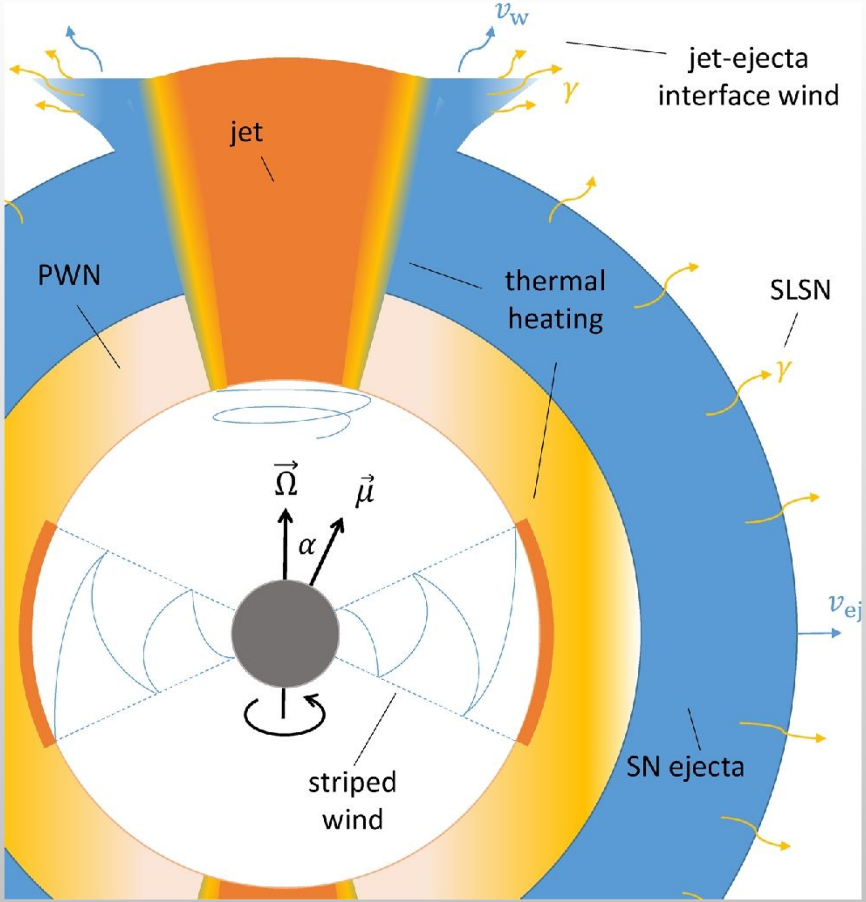
Spin-down Magnetar

CSM Interaction

Hybrid

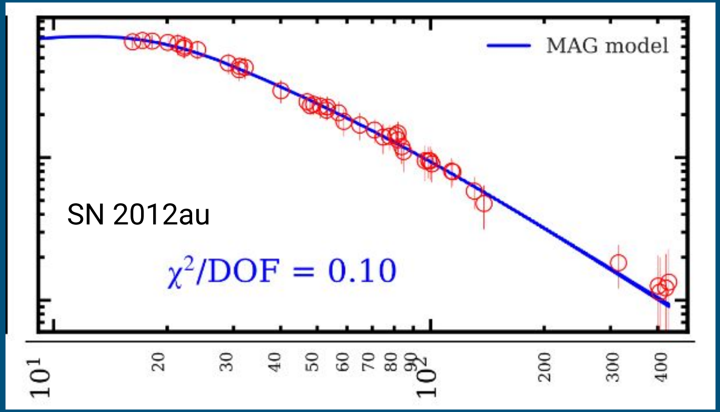
Chatzopoulous et al. 2016

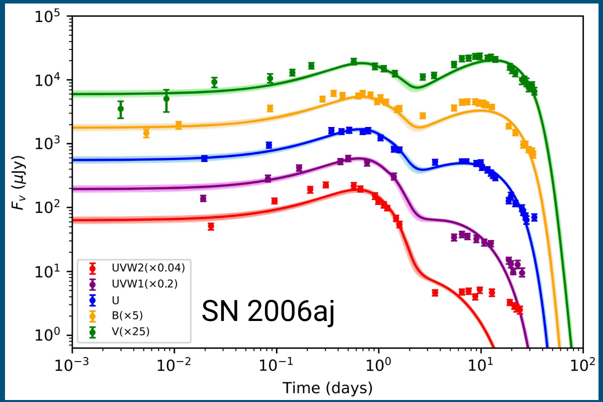
Magnetar as powering source of GRB-SNe

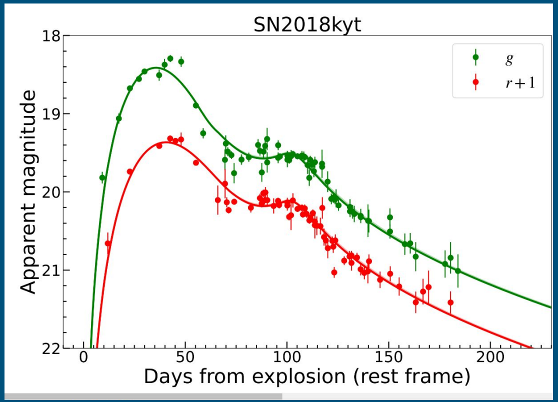


Margalit et al. 2018

Light-curve modelling of SNe







Ib

Pandey & Kumar et al., 2021

- Analytical light-curve modelling insinuates a spin-down millisecond magnetar as a likely powering source for SN 2012au, which is also explain its other photometric and spectral properties.

GRB+SN

Zhang et al., 2022

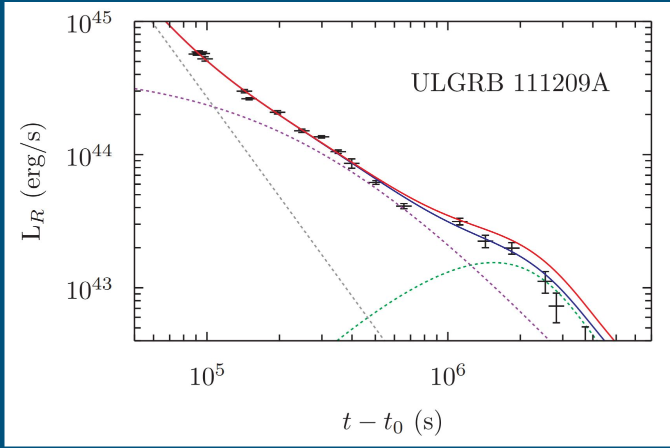
- The best fit of the multiwavelength double-peaked light curves of SN 2006aj by using the model including a magnetar wind-driven significant shock breakout emission and a magnetar-aided supernova emission

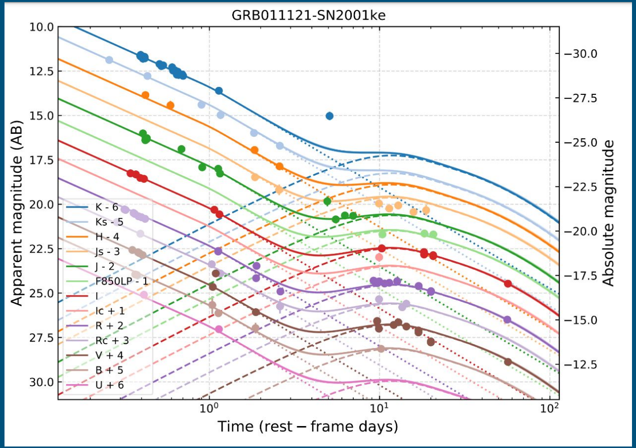
SLSN

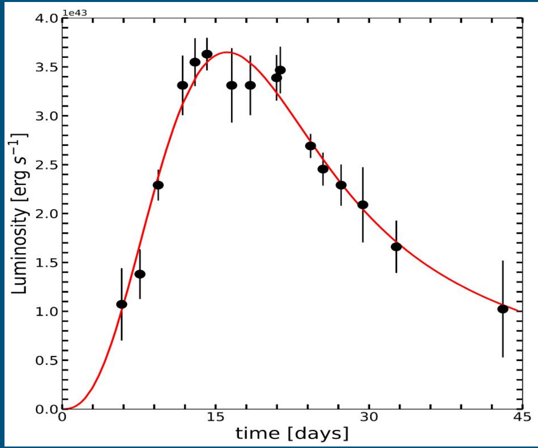
Dong et al., 2023

- Magnetar Flare-driven Bumpy Declining Light Curves in Hydrogen-poor Superluminous Supernova 2018kyt. Multiwavelength observations (dots) with the best magnetar-powered fitting (solid line) for SLSN 2018kyt.

Light-curve modelling of GRB-SNe:







Cano et al., 2016

- Presented an analytical model that considers energy arising from a magnetar central engine for 7 GRB+SNe.
- Successfully described all phases of ULGRB 111209A/SN 2011kl, from the early afterglow to the later SN.

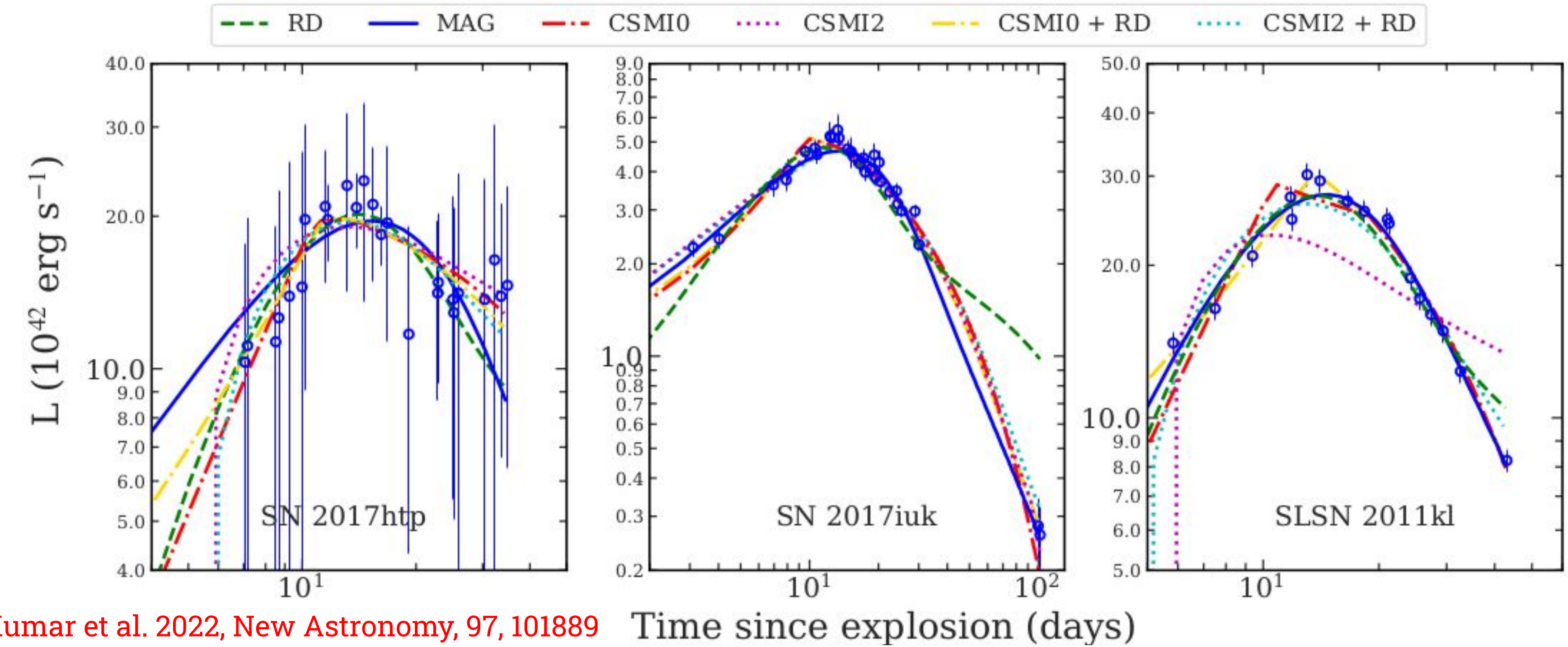
Lian et al., 2022

- Used the multi-band broken power-law plus Ni-56 model to fit the multi-band light curves of three afterglows and SNe.
- They found that the model can account for the multi-band light curves of the three discussed GRB+SNe.

Lin et al., 2020

- Presented light-curve modelling of SLSN 2011kl using the Blandford & Payne (Blandford & Payne 1982) mechanism.
- The light curve is well explained by the magnetar model.

Light-curve modelling of GRB-SNe:

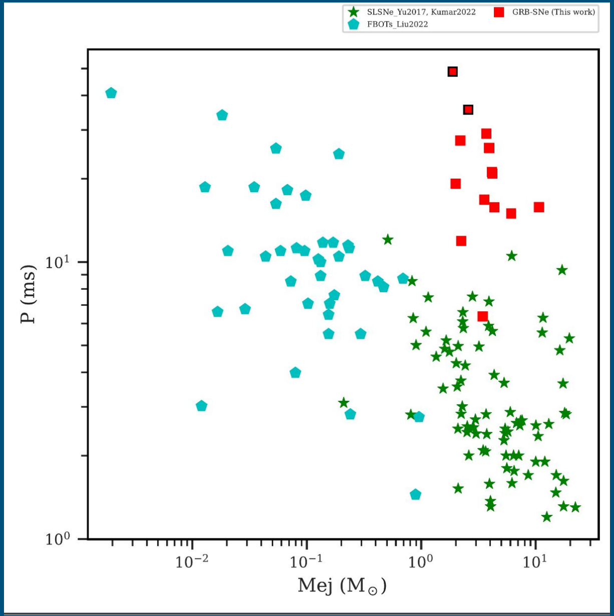


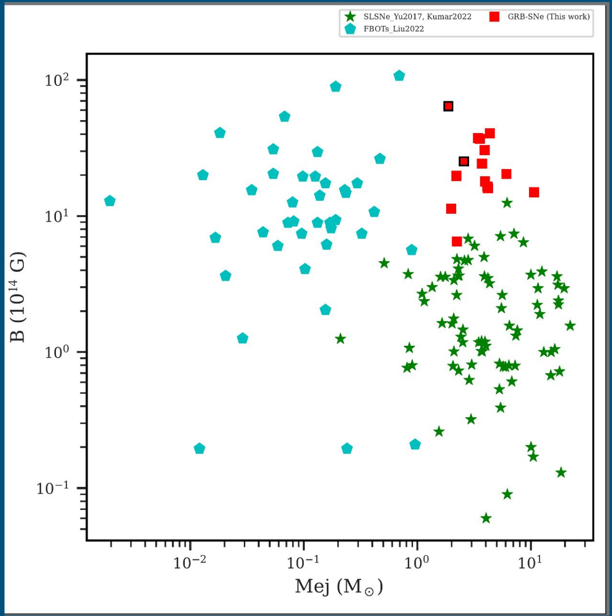
Kumar et al. 2022, New Astronomy, 97, 101889

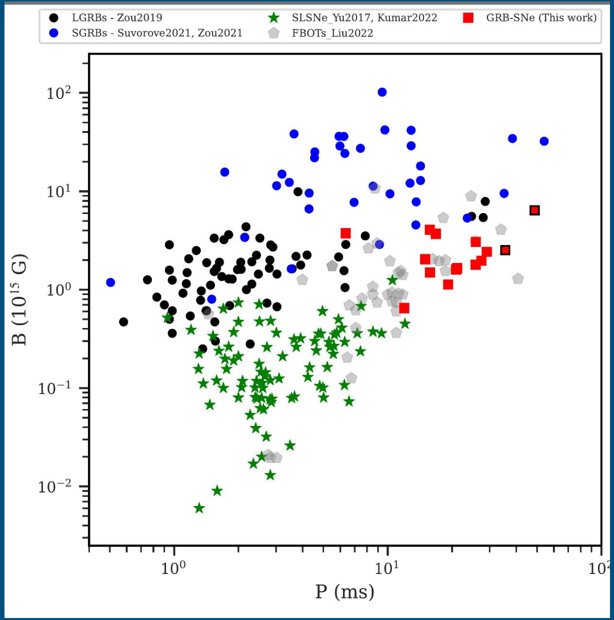
SN	Type	M_{ej} ($M_\odot$)	v_{exp} (10^3 km s^{-1})	P_i (ms)	B (10^{14} G)	R_0 (10^{13} cm)	Best-fit model
SN 2017htp	Ic BL	2.5-6.3	13.5-15.4	12.9 ± 0.1	8.7 ± 0.3	0.01–0.11	RD/MAG/CSM
SN 2017iuk	Ic BL	5.6 ± 0.1	29.0 ± 3.5	26.4 ± 0.1	18.4 ± 0.3	0.04 ± 0.02	MAG
SLSN 2011kl	SLSN I	3-5.8	14.4-35	11.9 ± 0.1	6.5 ± 0.1	0.01–0.13	MAG/CSM

Magnetar as a central engine:

Kumar et al. 2023, in preparation







- ❑ The present comparison of magnetic fields and the initial spin periods of GRB-SNe with those of SLSNe and Long and short GRBs shows that GRB-SNe seem to consist of a different parameter space. It also shows that magnetars with different B and Pi values can govern different types of transients.

- ❑ The luminosity of a magnetar-powered SN is directly related to how long the central engine is active, where central engines with longer durations give rise to brighter SNe.

GOTO

GRAVITATIONAL-WAVE OPTICAL TRANSIENT OBSERVER

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MANCHESTER 1824 The University of Manchester

The University Of Sheffield.

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UNIVERSITY OF PORTSMOUTH

ARMAGH OBSERVATORY & PLANETARIUM EXPLORING THE COSMOS SINCE 1790

UKRI Science and Technology Facilities Council

https://goto-observatory.org

Slides courtesy: Prof Danny Steeghs

GOTO network

WARWICK

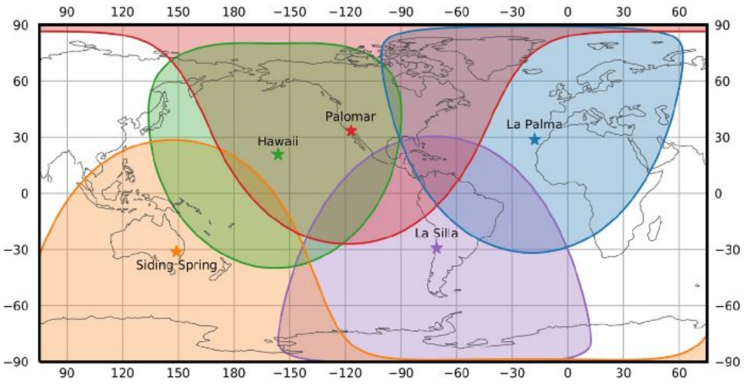
Autonomous telescope arrays

Full node = 16 x D=40cm covering 80 deg^2
(~ 10,000 sqr.deg / night)

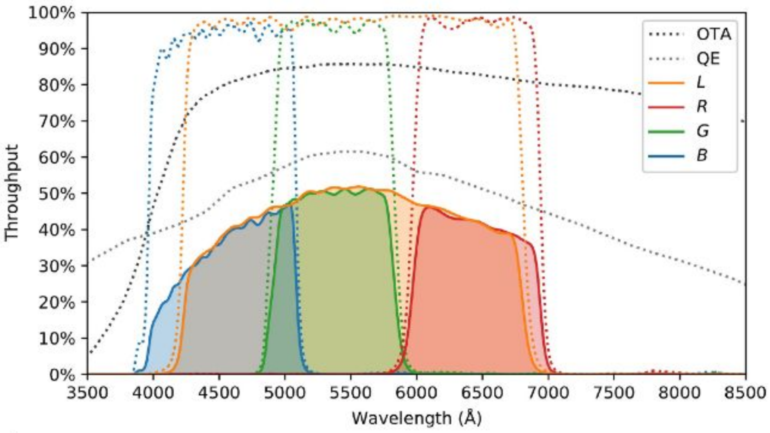
Two antipodal sites

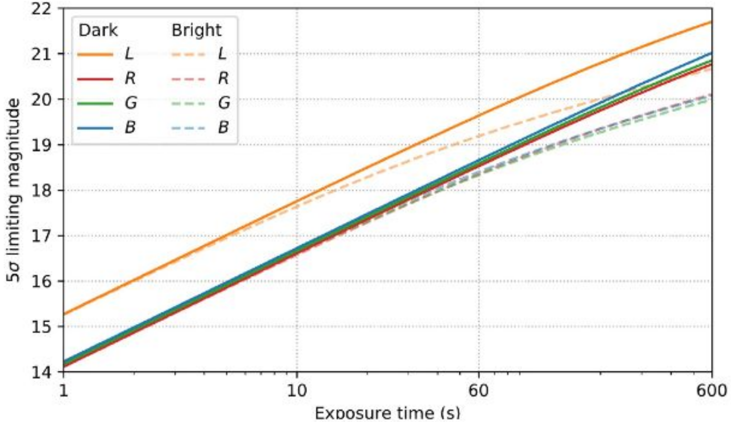
Sky survey patrol mode
Responsive mode

Steeghs et al. (2022)

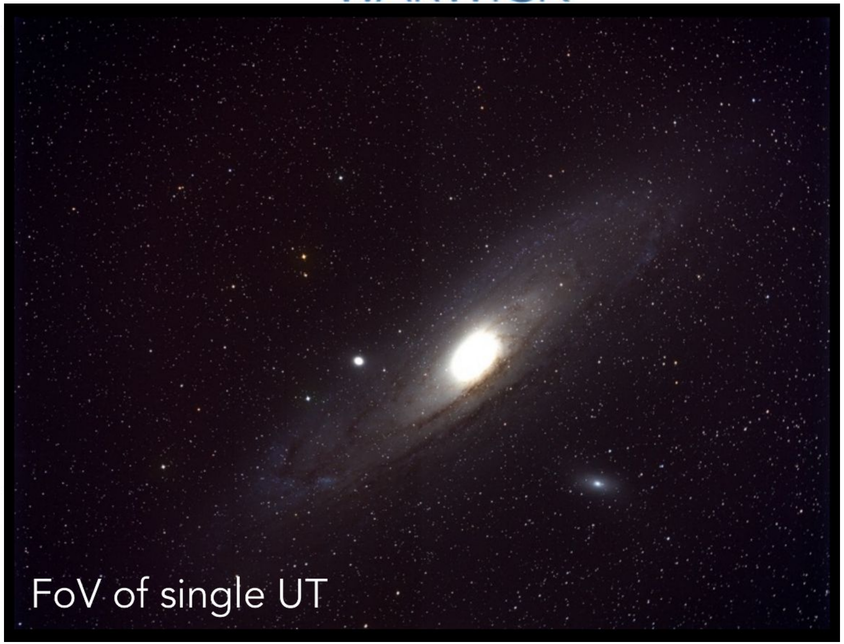


GOTO Prototype Performance





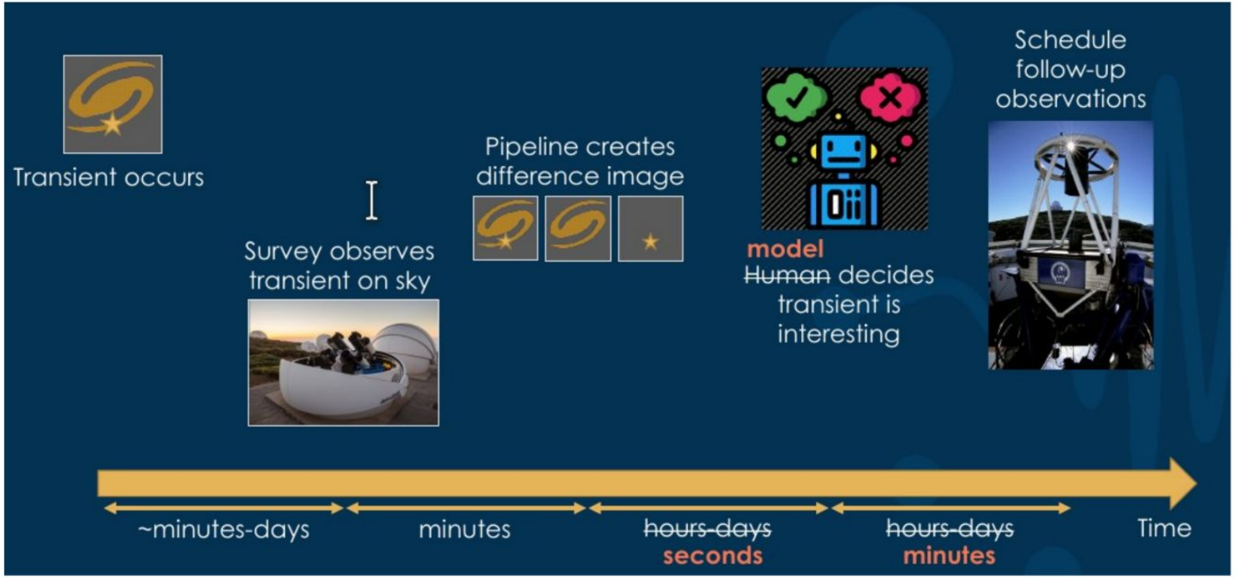
Steeghs et al. (2022)   L-band ~ g+r



- 4x40cm f/2.5 unit telescopes (UT)
- 8176 x 6132 pixels, 1.25”/pixel, 2.8 deg x 2.1 deg
- FLI MicroLine (50 Mpixel CCD)
- 5-slot filterwheel (currently Baader LRGBC)
- Total FoV (4 UT): ~20 sq. deg.
- L ~ 19.8 mag in 60 s

Rapid localisation to enable follow-up

- EM searches straddle GW detection and follow-up with our fleet of telescopes and satellites
- Needs low-latency end-to-end dataflow to permit timely alerting and triggering of follow-up
- Automate as much as possible, but needs to be robust



courtesy Joe Lyman

Science with GOTO

GW triggered & blind kilo-nova searches

Luminous transients in the SN arena

Fast transients

TDEs

New AGN

GRB triggers, particularly short

Neutrinos from IceCube

Pulsar binaries via Fermi cross-matches

Blazar monitoring with CTA link

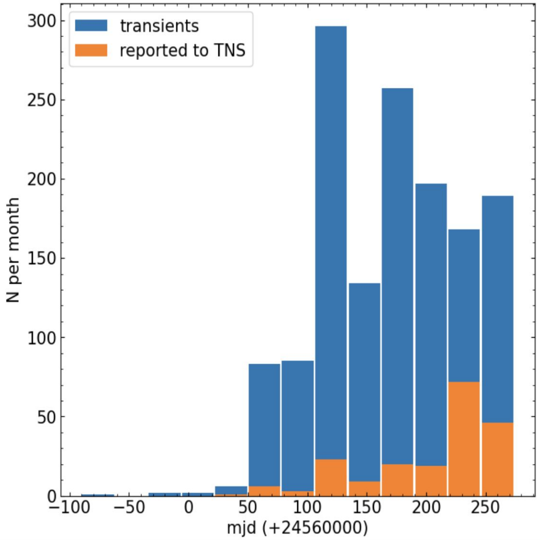
Galactic variables and compact binaries

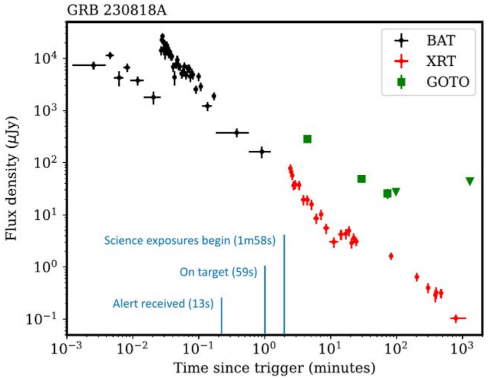
Moving objects

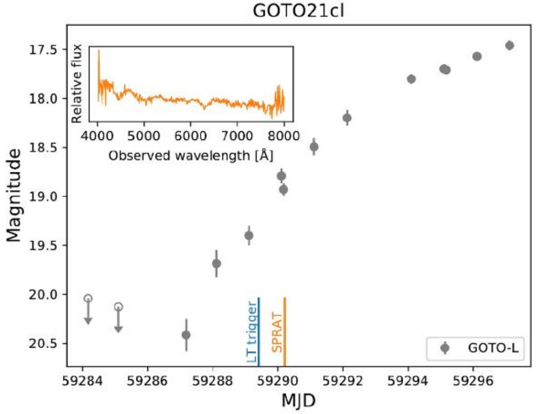
Rapid discovery allows rapid follow-up

Spectroscopically target early stages

Rare bright events offer key insights







Steeghs et al. (2022)

Public engagement

Thank you!