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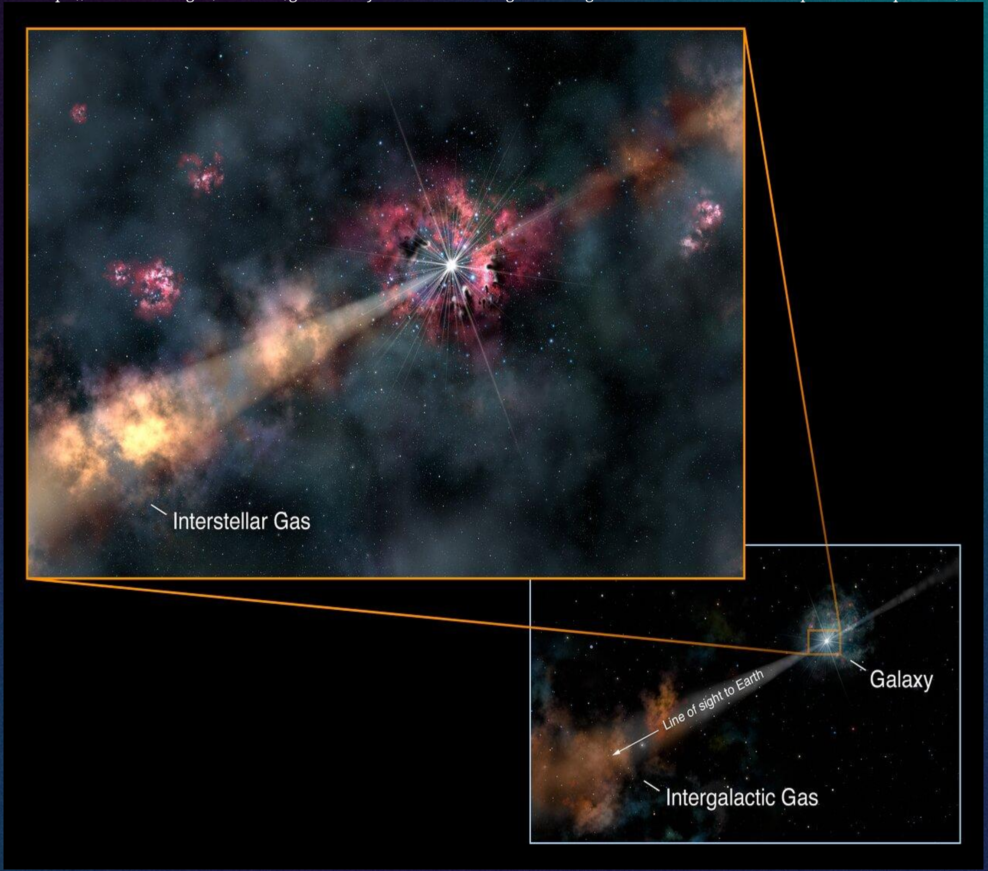
University of Johannesburg 20 Years 2005 2025

LATE-TIME SPECTROPOLARIMETRY OF GRB 250129A: EVIDENCE OF AN OFF-AXIS GAUSSIAN JET

https://science.nasa.gov/universe/gamma-ray-bursts-harvesting-knowledge-from-the-universes-most-powerful-explosions/



Date: 11.07.2025

PRESENTATOR: Ankur Ghosh
University of Johannesburg

Collaborators:

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Outline of the talk

Introduction

Afterglow emission of GRBs.
Polarisation in GRB afterglows and off-axis emission.

Photometry and spectropolarimetry

GRB 250129A detection. X-ray and optical light curves of different telescopes and spectropolarimetry using SALT.

Explain high polarisation through modelling

Explain late-time high polarisation through FS+RS and off-axis emission models.

Summary

A brief explanation of the possibilities, summary of the results, and future prospects.

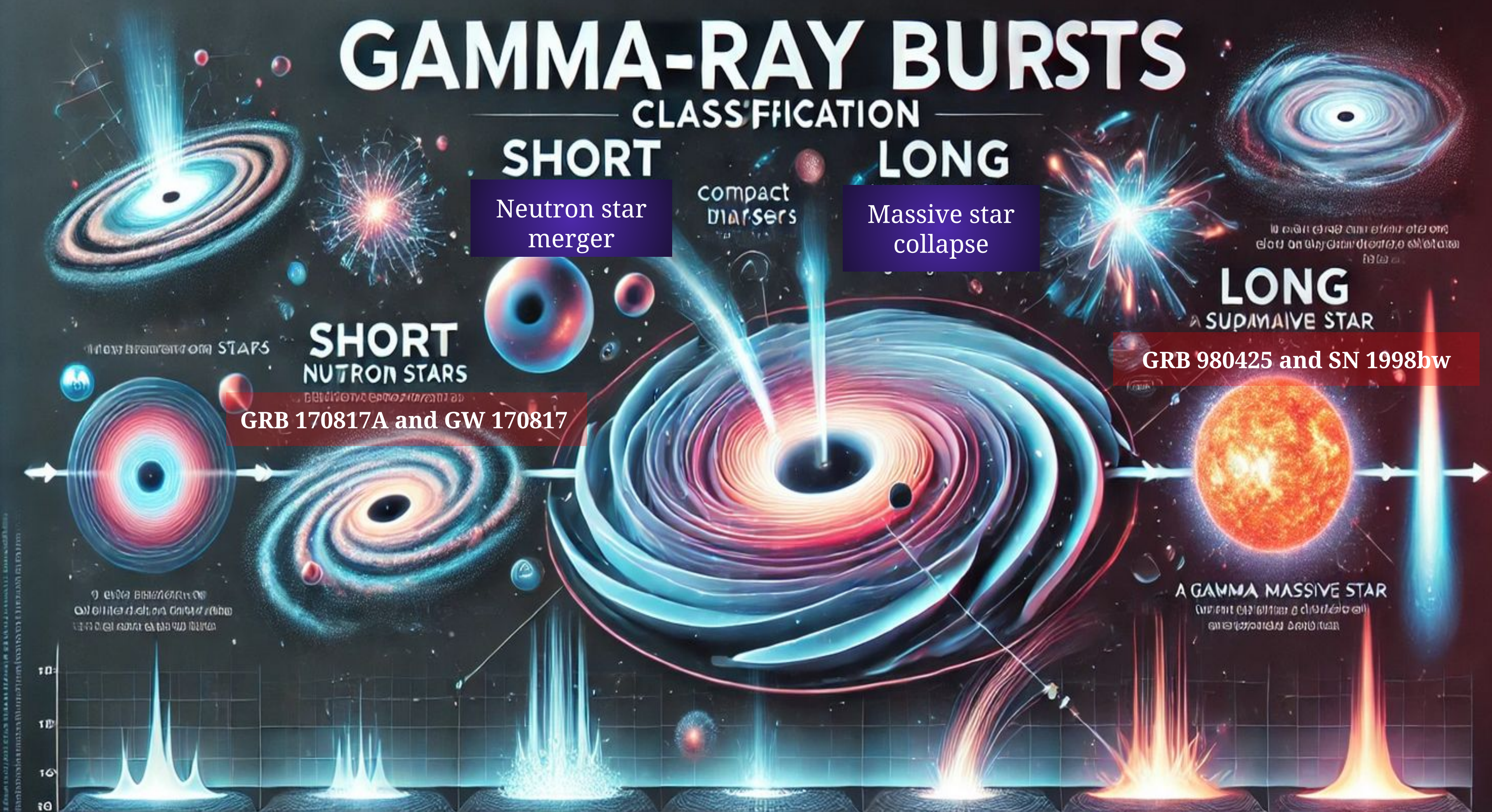
Most energetic explosion in the Universe

Gamma-Ray Bursts ???

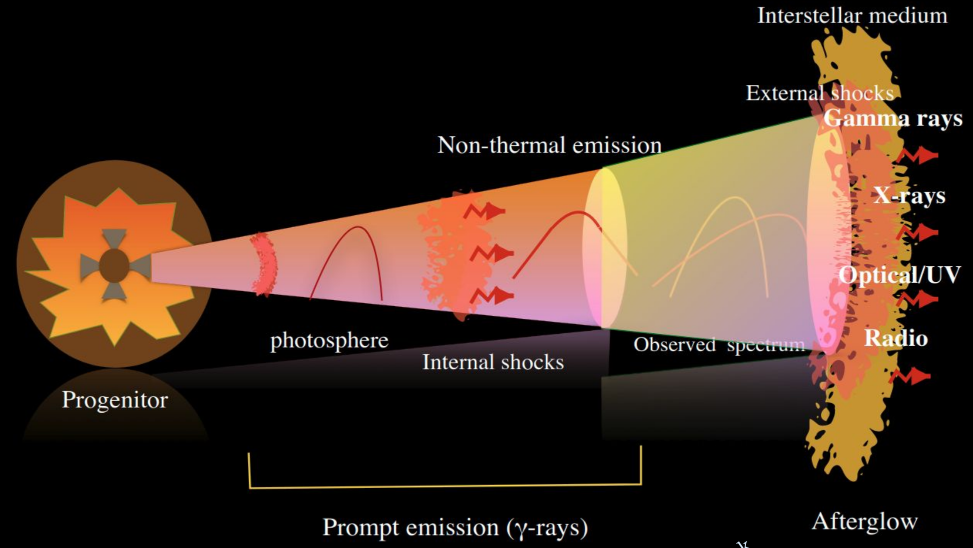
Energy in a blink: How powerful GRBs are?

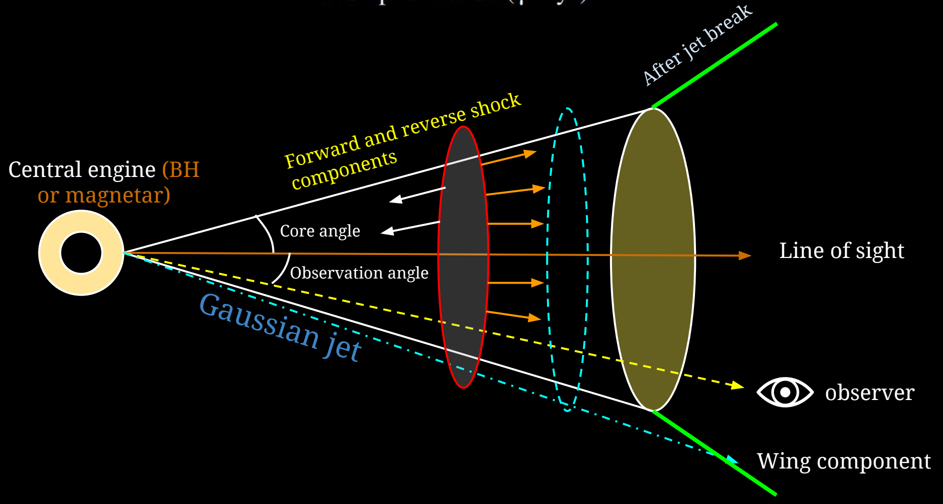
A window
to the
extraordinary & extreme Universe

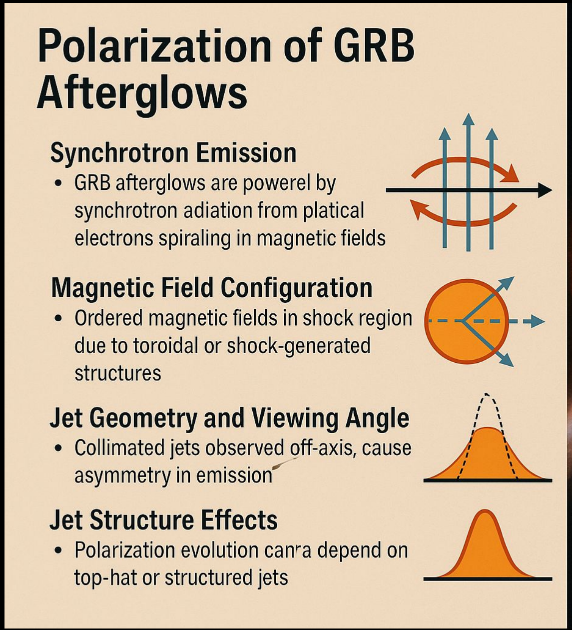
Thanks to Chat GPT



GRB afterglow emission







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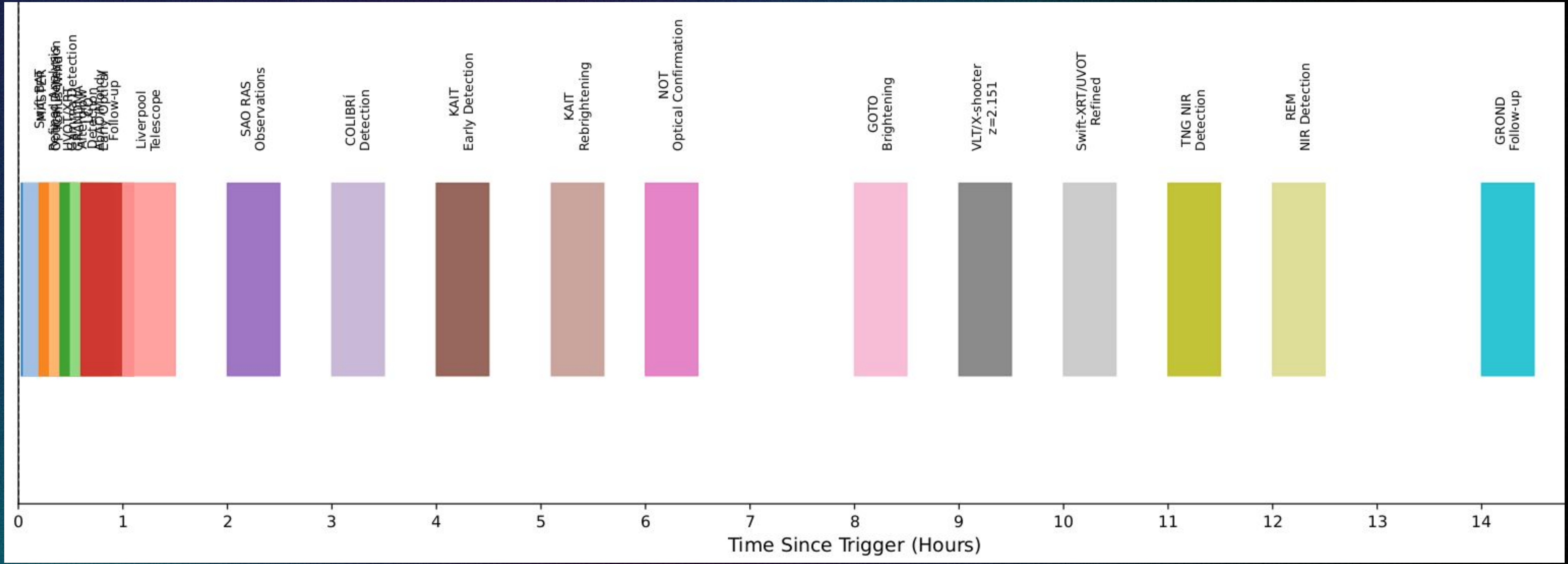
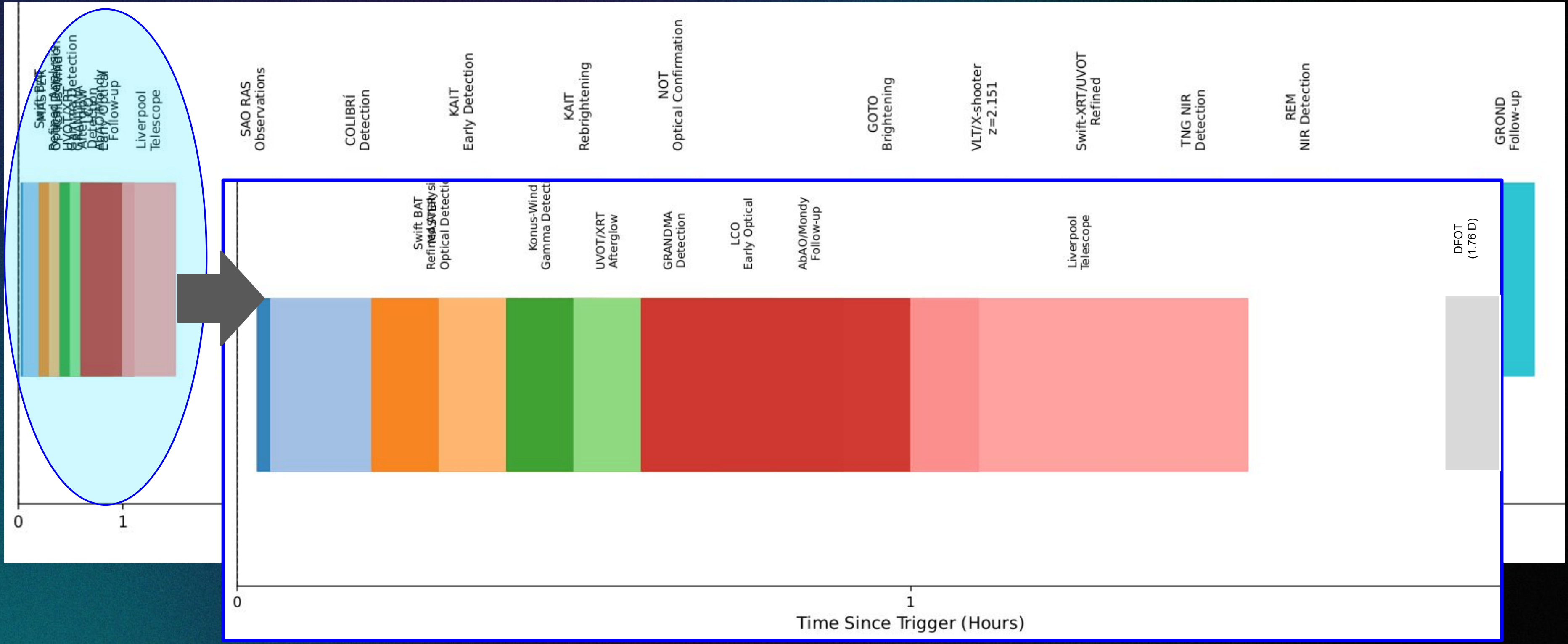


Detection of GRB 250129A using telescopes globally



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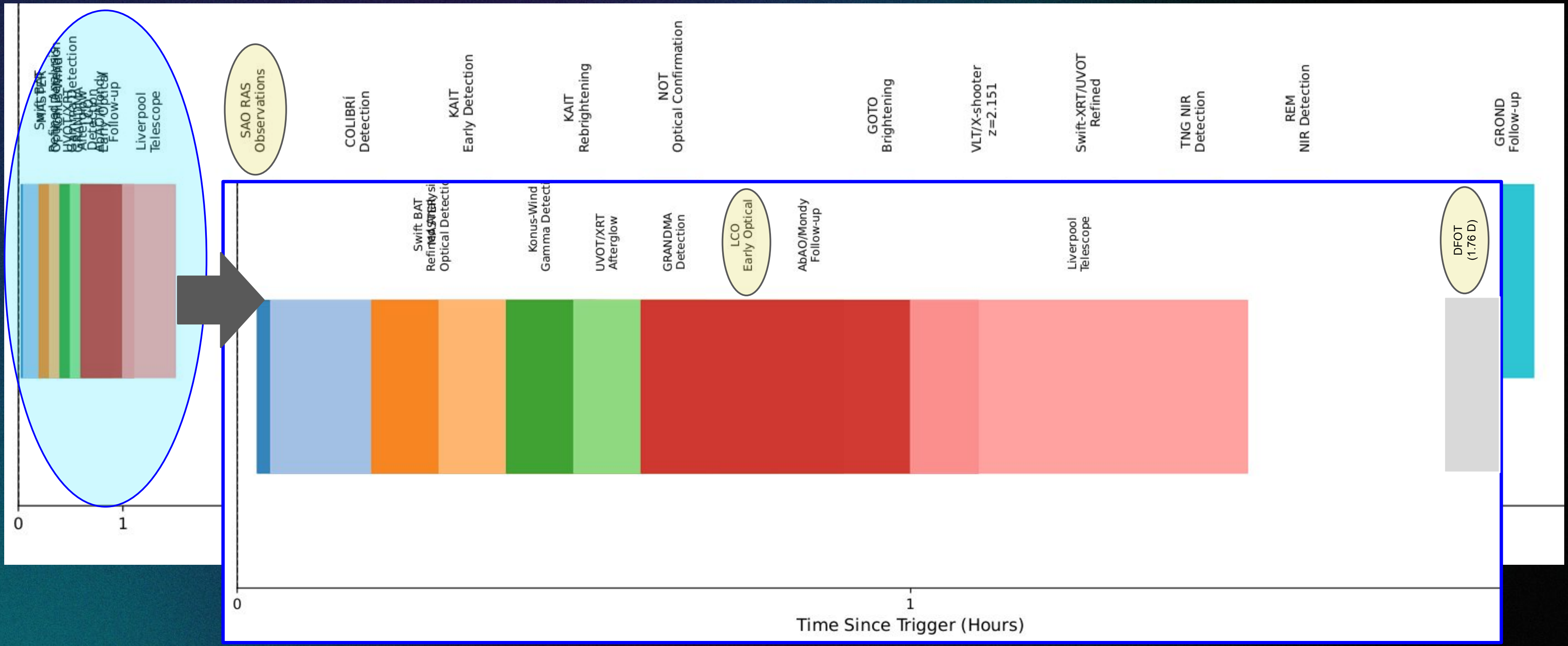
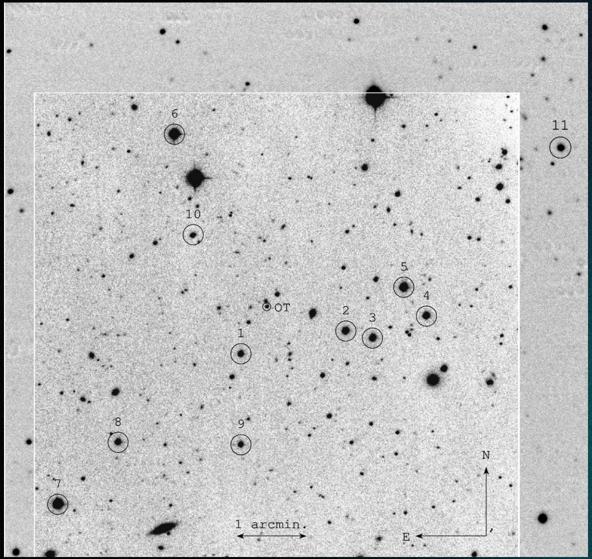
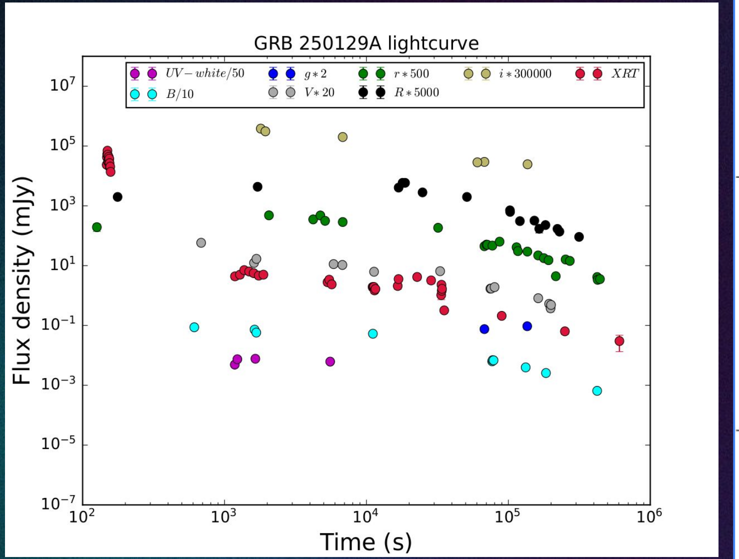


Temporal analysis of GRB 250129A





LCO photometry

JD	Time since burst (hours)	Filter	Magnitude (mag)
2460704.74678	1.17	r	17.05 ± 0.01
2460704.75724	1.42	r	17.17 ± 0.01
2460704.76597	8.88	r	17.75 ± 0.01
2460705.50914	19.46	r	19.16 ± 0.01
2460705.52102	19.75	r	19.17 ± 0.01
2460706.57392		r	20.06 ± 0.17
2460706.91924	53.30	r	20.46 ± 0.15
2460707.83711	75.33	r	20.52 ± 0.02
2460709.58845	117.37	r	21.87 ± 0.07
2460704.76597	1.63	V	17.34 ± 0.01
2460704.77642	1.88	V	17.41 ± 0.01
2460705.08089	9.18	V	17.93 ± 0.04
2460705.56264	20.75	V	19.39 ± 0.02
2460705.57450	21.03	V	19.38 ± 0.02
2460705.62376	22.21	V	19.26 ± 0.08
2460706.57684	45.09	V	20.19 ± 0.12
2460706.94115	53.83	V	20.67 ± 0.04
2460706.99403	55.10	V	21.03 ± 0.28
2460707.01144	55.52	V	20.75 ± 0.11
2460705.58815	21.36	B	19.93 ± 0.12
2460705.59446	21.51	B	19.84 ± 0.01
2460705.60864	21.85	B	19.85 ± 0.02
2460706.23123	36.80	B	20.44 ± 0.11
2460706.82903	51.14	B	20.91 ± 0.02
2460709.58604	117.31	B	22.40 ± 0.09

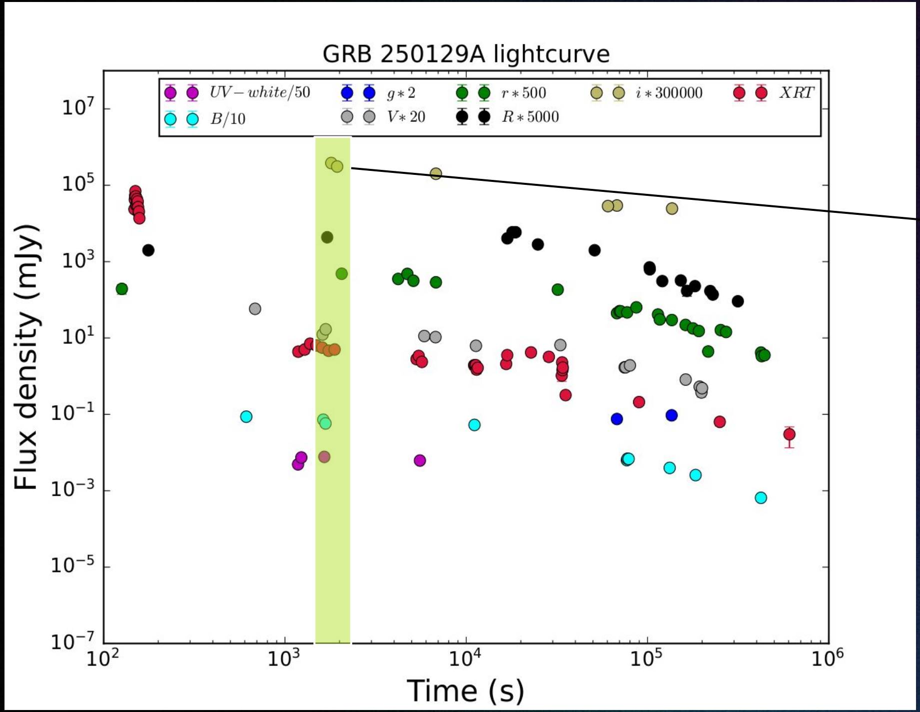
SAO-RAS ZEISS-1000 photometry

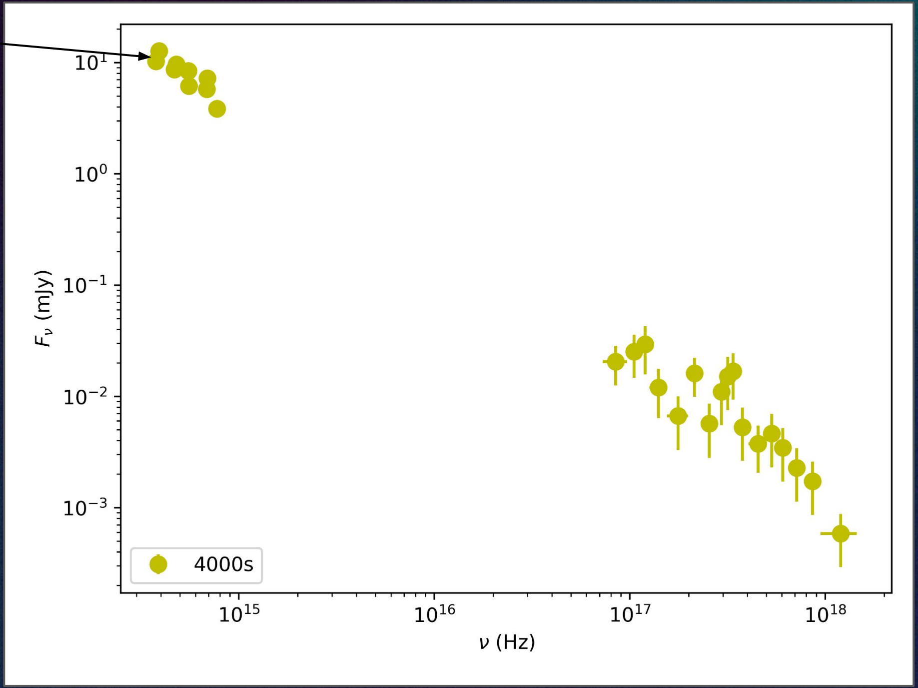
UT_{start}	UT_{end}	$t_{mid} - T0$, d	Exp. time, s.	filter	$mag \pm err$	Instrument
2025.01.30, 23:46:43	2025.01.31, 00:19:22	1.8041	5 × 300	Rc	19.806 ± 0.023	CCD-phot.
2025.01.31, 22:47:03	2025.02.01, 00:23:04	2.7847	5 × 300	B	20.981 ± 0.029	CCD-phot.
2025.01.31, 22:52:38	2025.02.01, 00:28:40	2.7885	5 × 300	V	20.524 ± 0.024	CCD-phot.
2025.01.31, 22:35:38	2025.02.01, 00:11:53	2.7768	5 × 300	Rc	20.189 ± 0.024	CCD-phot.
2025.01.31, 22:41:15	2025.02.01, 00:17:26	2.7807	5 × 300	Ic	19.733 ± 0.045	CCD-phot.
2025.02.02, 01:23:43	2025.02.02, 01:43:23	3.8669	3 × 300	Rc	21.248 ± 0.143	MAGIC
2025.02.27, 22:48:57	2025.02.27, 23:53:54	29.7752	12 × 300	Rc	> 24.0	CCD-phot.

DOT and DFOT photometry

JD	Time since burst (hours)	Filter	Magnitude (mag)
2460706.50164	43.30	Rc	19.81 ± 0.02
2460707.47483	66.64	Rc	20.19 ± 0.02
2460708.56484	92.81	Rc	21.25 ± 0.14
2460734.47493	714.60	Rc	> 24.0
2460707.48267	66.83	B	20.98 ± 0.03
2460707.48655	66.92	V	20.52 ± 0.02
2460707.47870	66.74	Ic	19.73 ± 0.05

SED analysis of GRB 250129A





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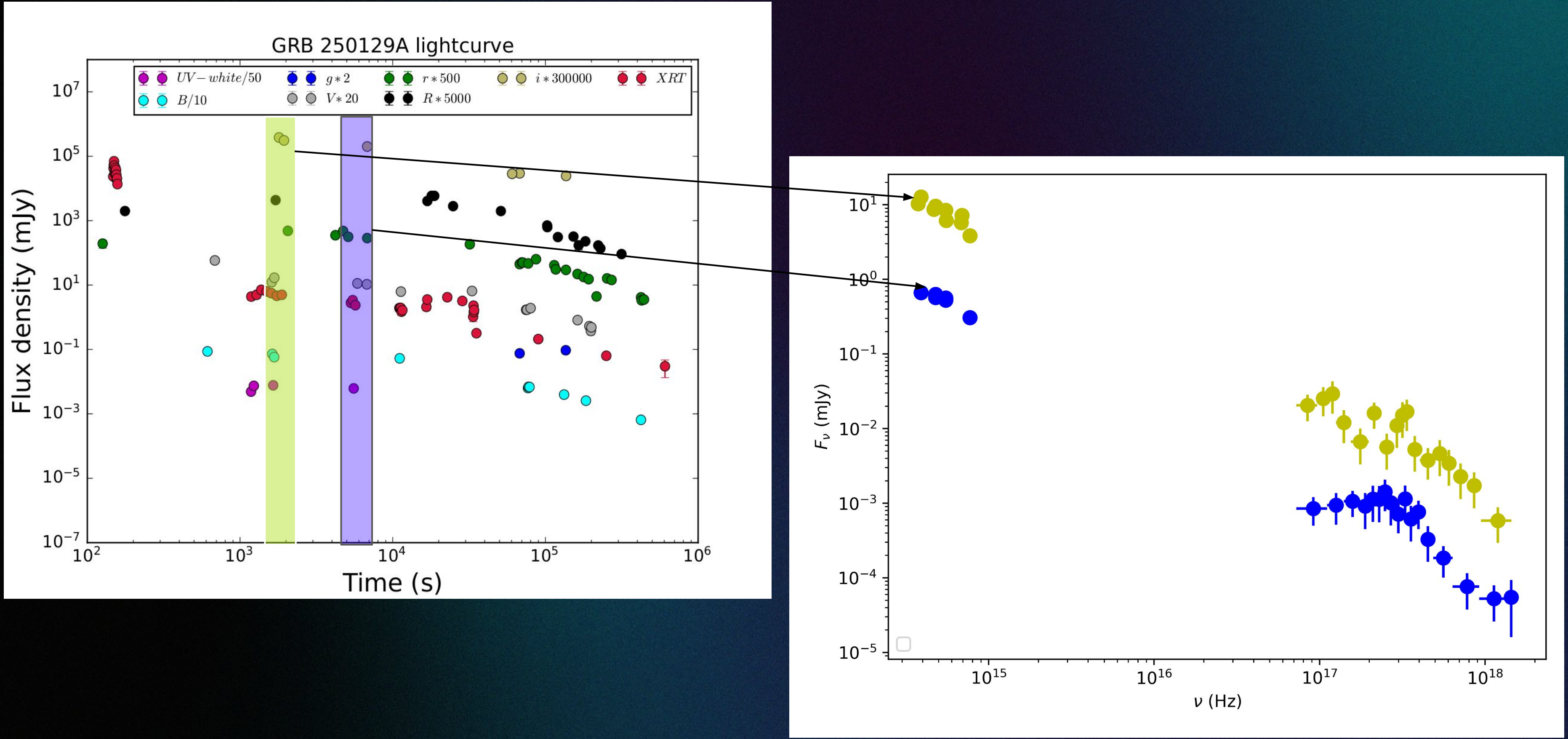

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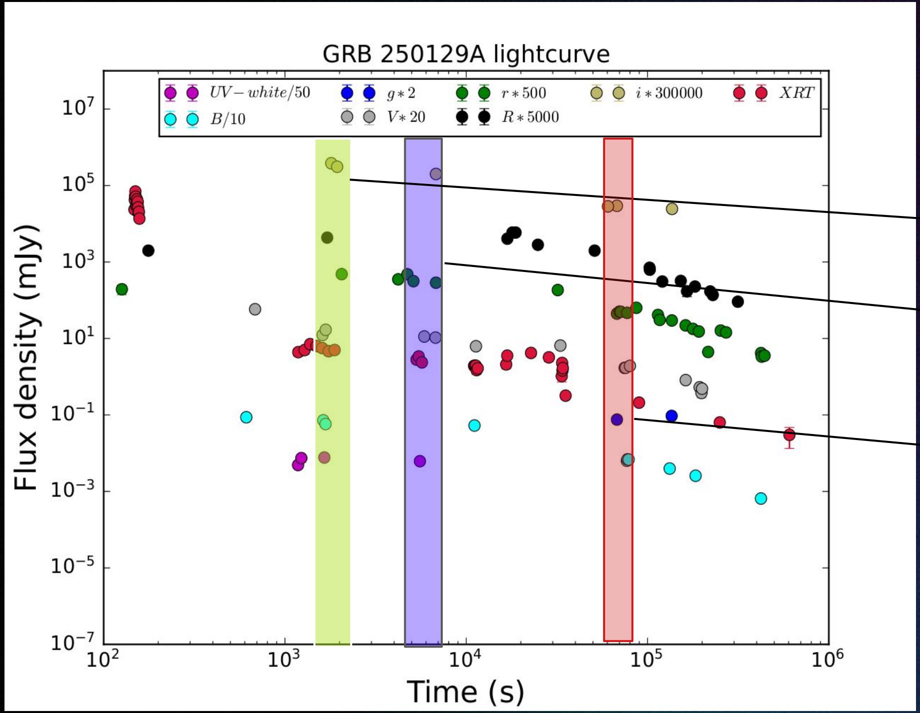

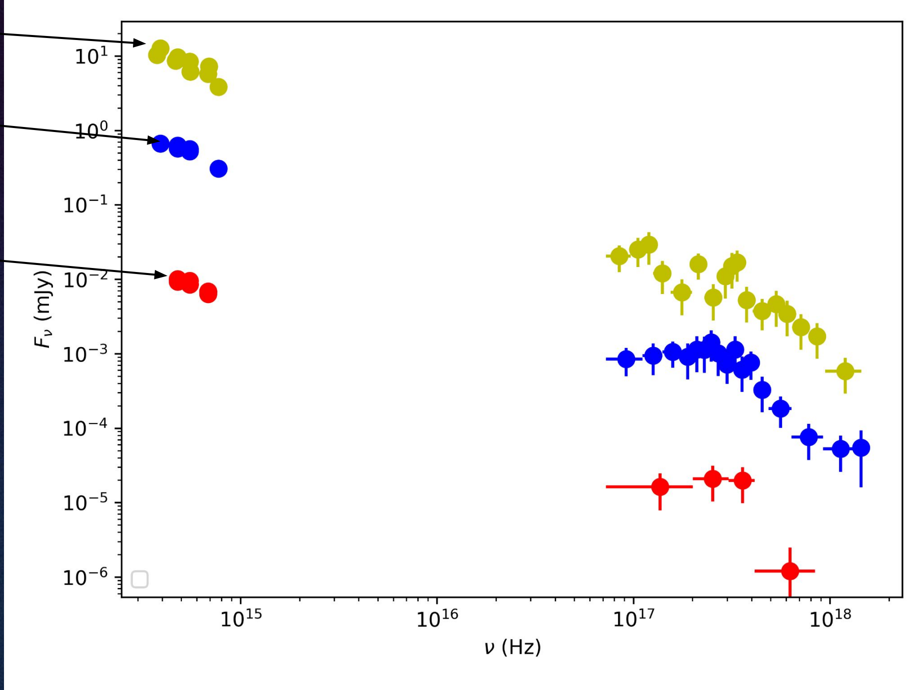

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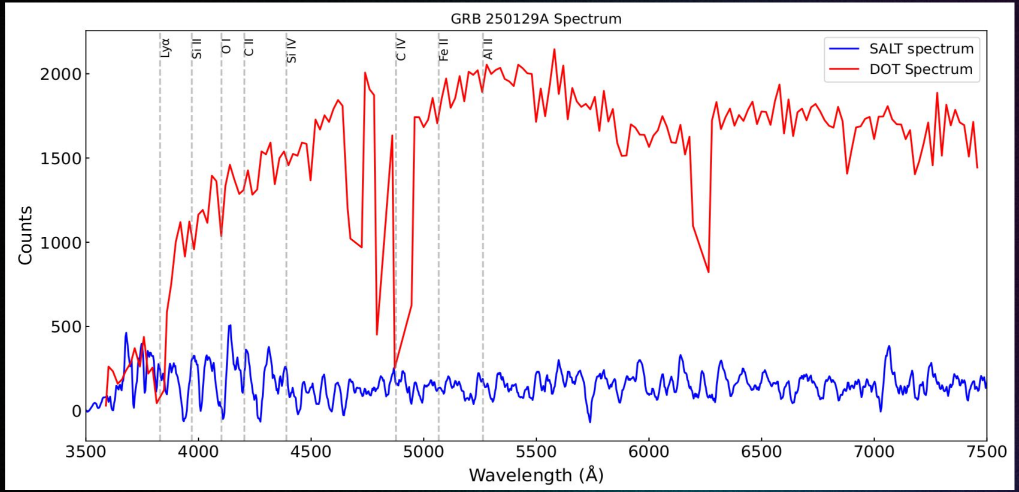
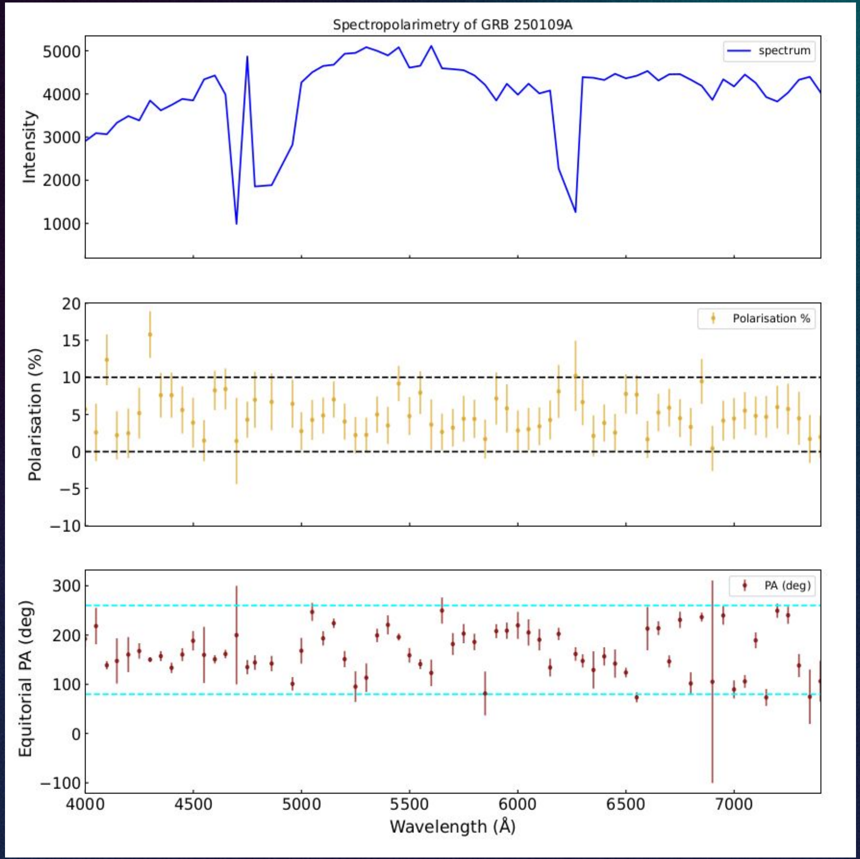
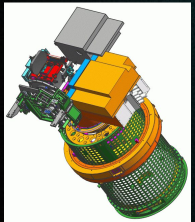
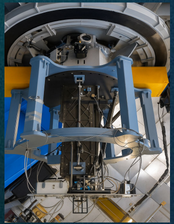
Spectroscopic and spectropolarimetric analysis of GRB 250129A





- ❖ SALT spectropolarimetry: ~19 hours since the burst.





- ❖ DOT spectroscopy: ~ 22 hours since the burst

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Statistics of polarisation detection

“

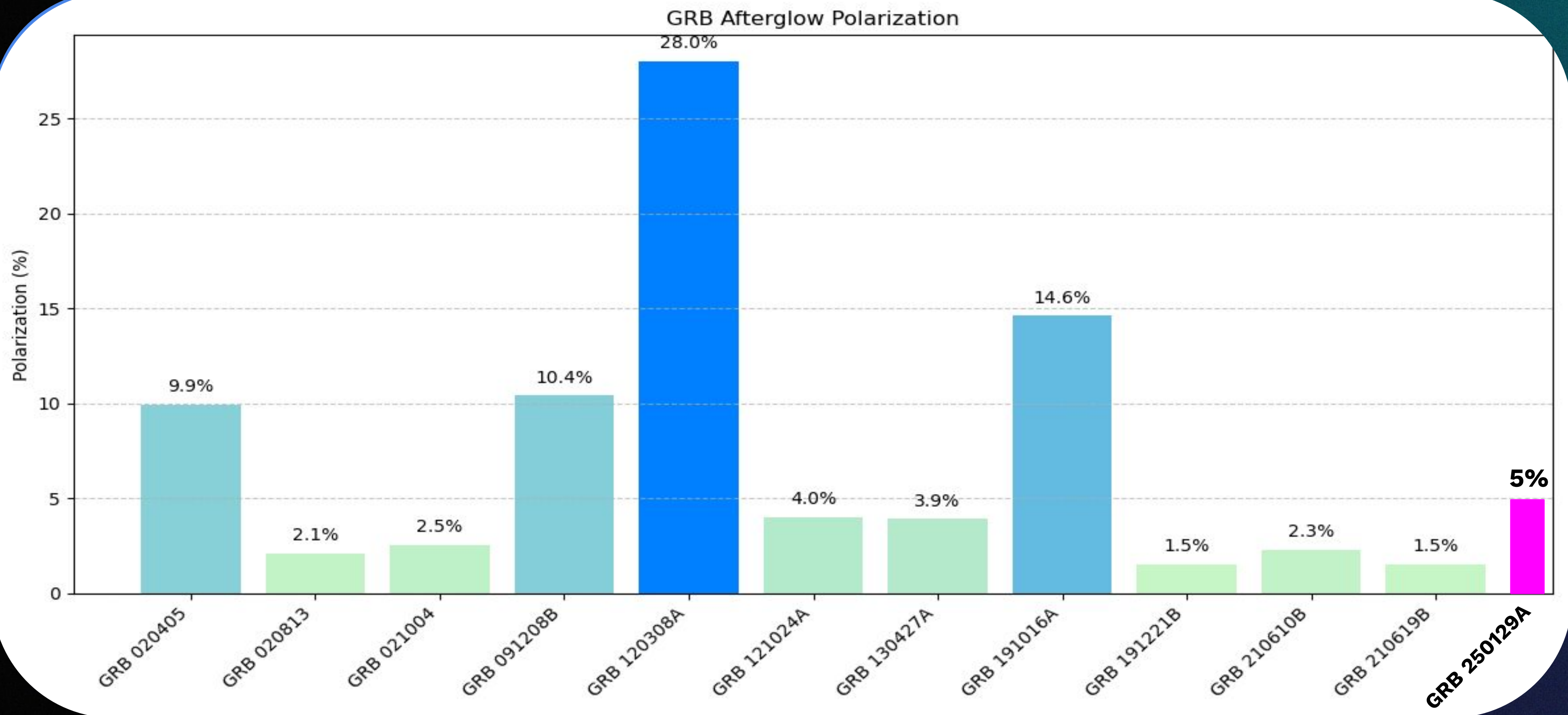
Color-coded Polarization Table (Green: Spectropolarimetry Yes, Red: No)

GRB	Time Since Burst	Polarization (%)	Spectropolarimetry
020405	~1.3 d	9.9	No
020813	4.7–7.9 h	2.1	Yes
021004	1–30 d	2.5	Yes
091208B	2–12 min	10.4	No
120308A	~4–10 min	28.0	No
121024A	~2–3 d	4.0	No
130427A	~6–12 h	3.9	Yes
191016A	1.1–2.1 h	14.6	No
191221B	2.9, 10.2 h	1.5	Yes
210610B	~0.12–0.26 d	2.27	No
210619B	~1.7–2.3 h	1.5	No

GRB250129A	~ 19 h	~ 5%	YES

Statistics of polarisation detection

“



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Explanation of polarisation through modelling

Forward shock

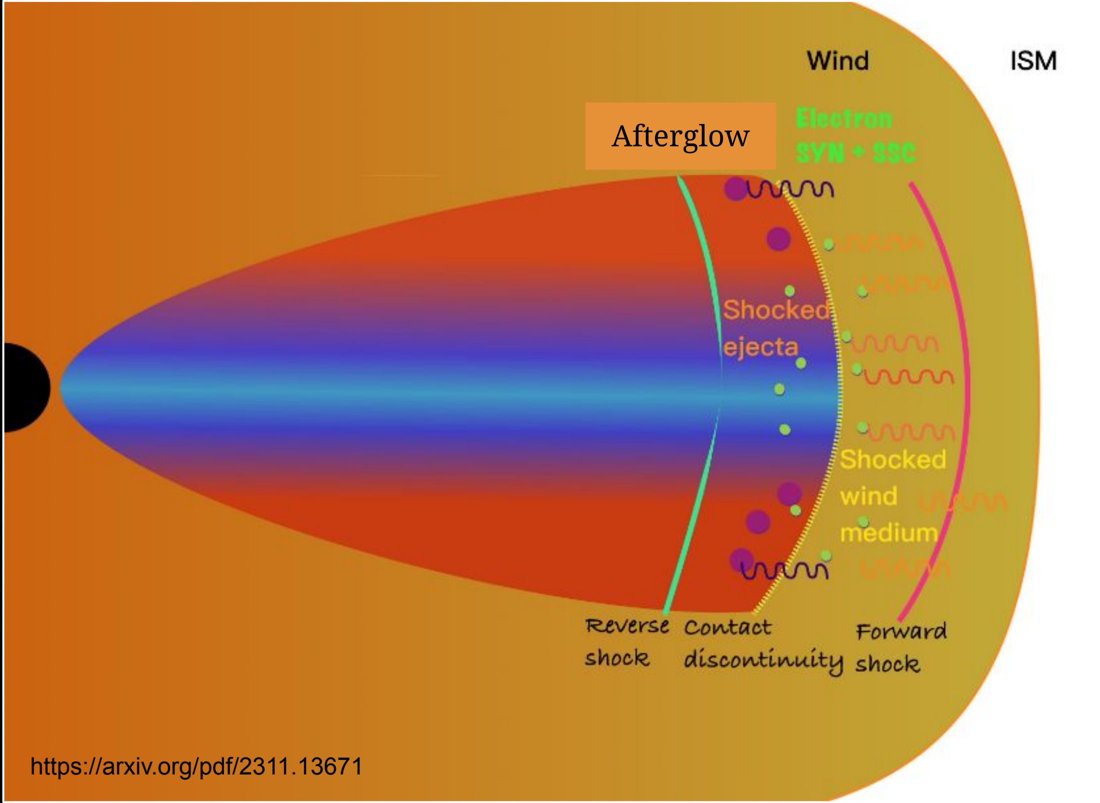
$$\nu_m = 3.3 \times 10^{14}\ \mathrm{Hz}\ (1+z)^{1/2}\ \epsilon_{B,-2}^{1/2}\ [\epsilon_e g(p)]^2\ E_{52}^{1/2} t_{\mathrm{obs,d}}^{-3/2}, \textit{ and}$$
$$\nu_c = 6.3 \times 10^{15}\ \mathrm{Hz}\ (1+z)^{-1/2}\ \epsilon_{B,-2}^{-3/2} E_{52}^{-1/2} n_p^{-1} t_{\mathrm{obs,d}}^{-1/2},$$

$$\nu_a = 1.0 \times 10^{8}\ \mathrm{Hz}\ \epsilon_{B,-2}^{1/5} \epsilon_e^{-1} E_{52}^{1/5} n_0^{3/5},\ \ \textit{for ISM}$$

$$\nu_a = 1.0 \times 10^{9}\ \mathrm{Hz}\ \epsilon_{B,-2}^{1/5} \epsilon_e^{-1} E_{52}^{-2/5} A_*^{6/5} T_d^{-3/5},\ \ \textit{for Wind}$$

$$f_{\nu,\max} = 1.6\ \mathrm{mJy}\ (1+z)\ \epsilon_{B,-2}^{1/2} E_{52} n_p^{1/2} D_{L,28}^{-2}, \quad n_p \propto R^0$$

$$f_{\nu,\max} = 7.7\ \mathrm{mJy}\ (p+0.12)(1+z)^{3/2} \epsilon_{B,-2}^{1/2} E_{52} A_* D_{L,28}^{-2} t_{\mathrm{obs,d}}^{-1/2}, \quad n_p \propto R^{-2}$$



Reverse shock Gao et al 2013

$$\nu_m = 8.5 \times 10^{11}\ \mathrm{Hz}\ z^{19/35} \left(\frac{G(p)}{G(2.3)}\right) E_{52}^{18/35} \Gamma_{0,2}^{-74/35} n_{0,0}^{-1/70} \epsilon_{e,-1}^{2} \times \epsilon_{B,-2}^{1/2} t_2^{-54/35}, \tag{10}$$

$$\nu_{\mathrm{cut}} = 4.3 \times 10^{16}\ \mathrm{Hz}\ z^{19/35} E_{52}^{-16/105} \Gamma_{0,2}^{-292/105} n_{0,0}^{-283/210} \epsilon_{B,-2}^{-3/2} t_2^{-54/35}, \tag{11}$$

$$F_{\nu,\max} = 7.0 \times 10^{5}\ \mu\mathrm{Jy}\ z^{69/35} E_{52}^{139/105} \Gamma_{0,2}^{-167/105} n_{0,0}^{37/210} \epsilon_{B,-2}^{1/2} \times D_{28}^{-2} t_2^{-34/35}, \tag{12}$$

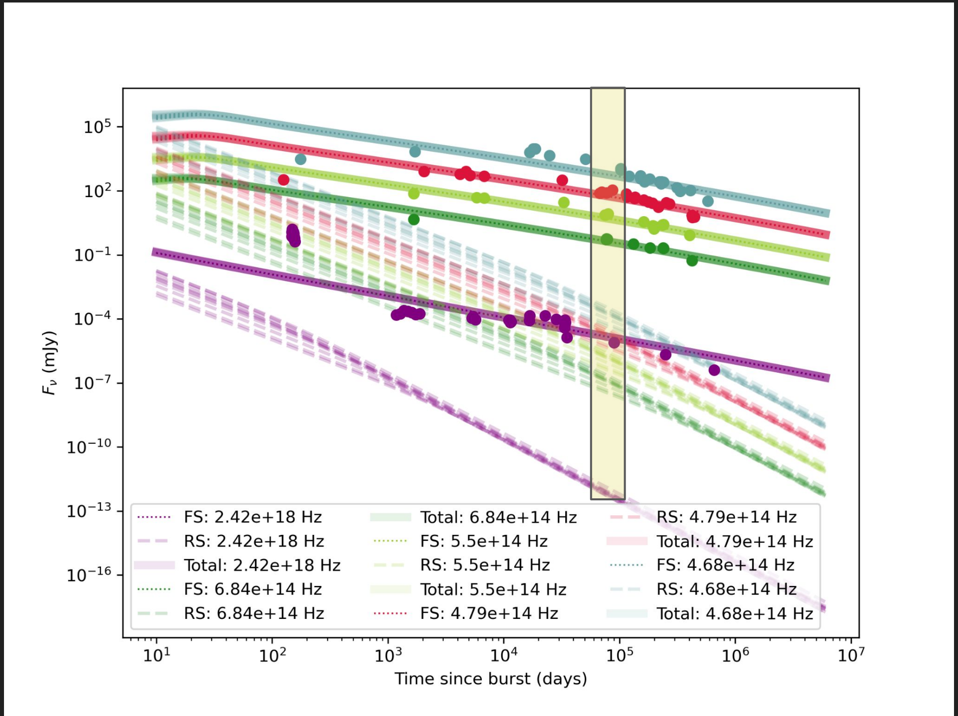
$$\nu_a = 1.4 \times 10^{13}\ \mathrm{Hz}\ z^{-73/175} \left(\frac{g^{\mathrm{XV}}(p)}{g^{\mathrm{XV}}(2.3)}\right) E_{52}^{69/175} \Gamma_{0,2}^{8/175} n_{0,0}^{71/175} \epsilon_{e,-1}^{-1} \times \epsilon_{B,-2}^{1/5} t_2^{-102/175}, \quad (\nu_a < \nu_m < \nu_c) \tag{13}$$

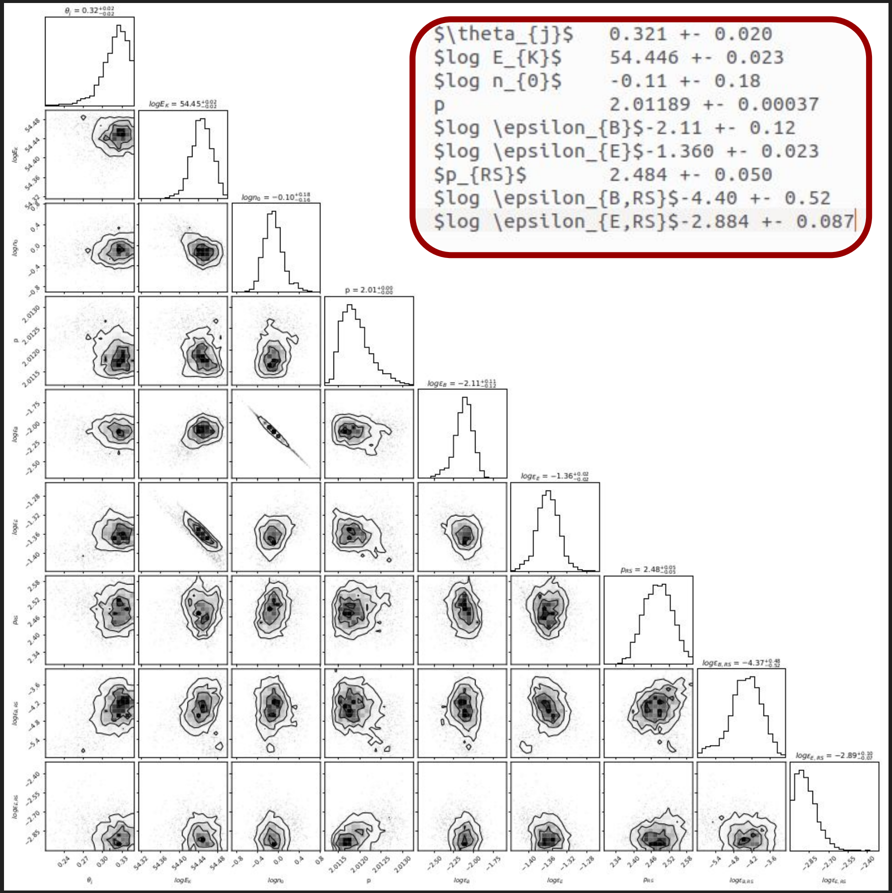
$$\nu_a = 3.7 \times 10^{12}\ \mathrm{Hz}\ z^{\frac{19p-36}{35(p+4)}} \left(\frac{g^{\mathrm{XVI}}(p)}{g^{\mathrm{XVI}}(2.3)}\right) E_{52}^{\frac{2(p+29)}{35(p+4)}} \Gamma_{0,2}^{\frac{-74p-44}{35(p+4)}} \times n_{0,0}^{\frac{94-70p}{70(p+4)}} \epsilon_{e,-1}^{\frac{2(p-1)}{p+4}} \epsilon_{B,-2}^{\frac{p+2}{2(p+4)}} t_2^{\frac{-54p+104}{35(p+4)}}, \quad (\nu_m < \nu_a < \nu_c) \tag{14}$$

1. Forward and reverse shock model

Forward + reverse shock

ISM model





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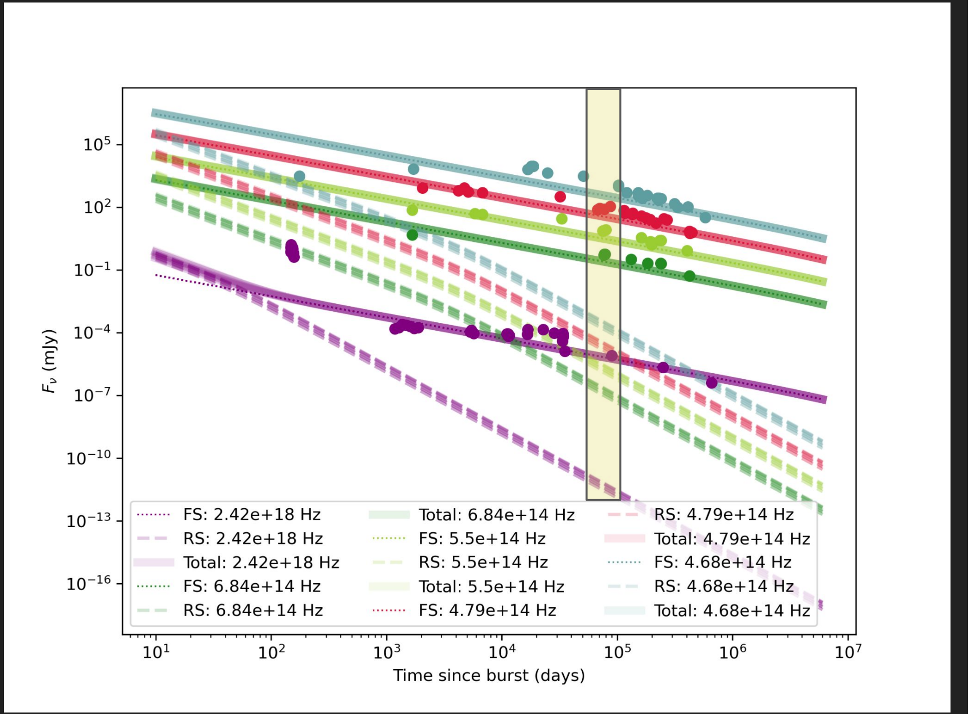
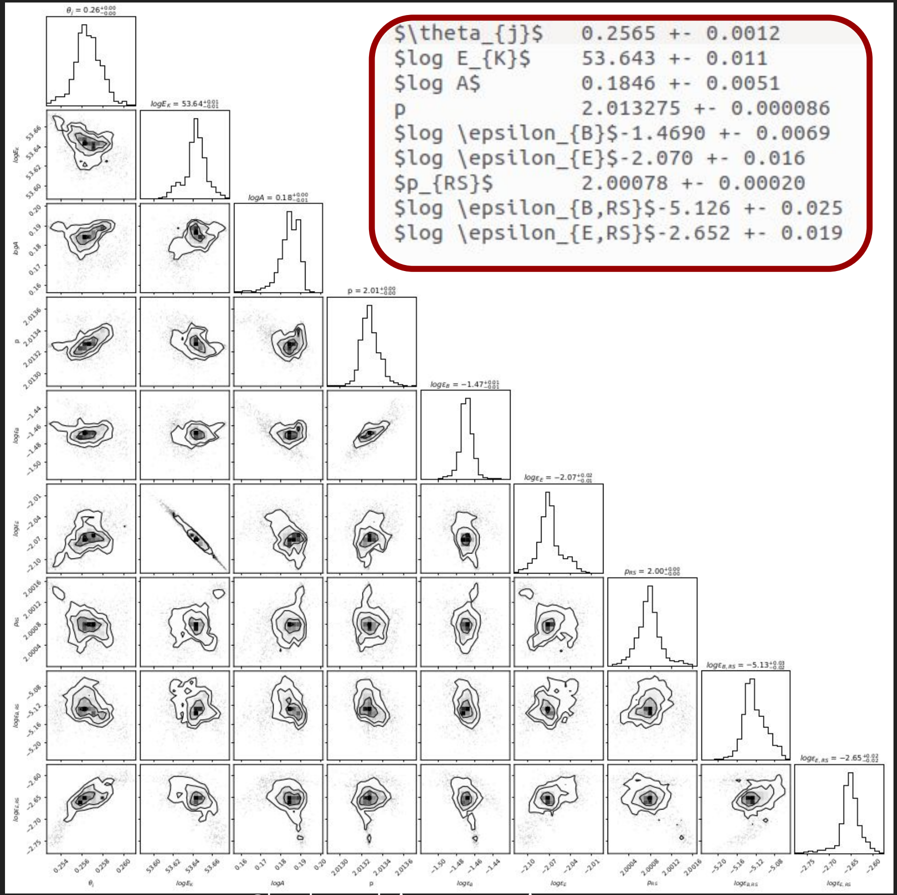
1. Forward and reverse shock model

Forward + reverse shock

Wind model





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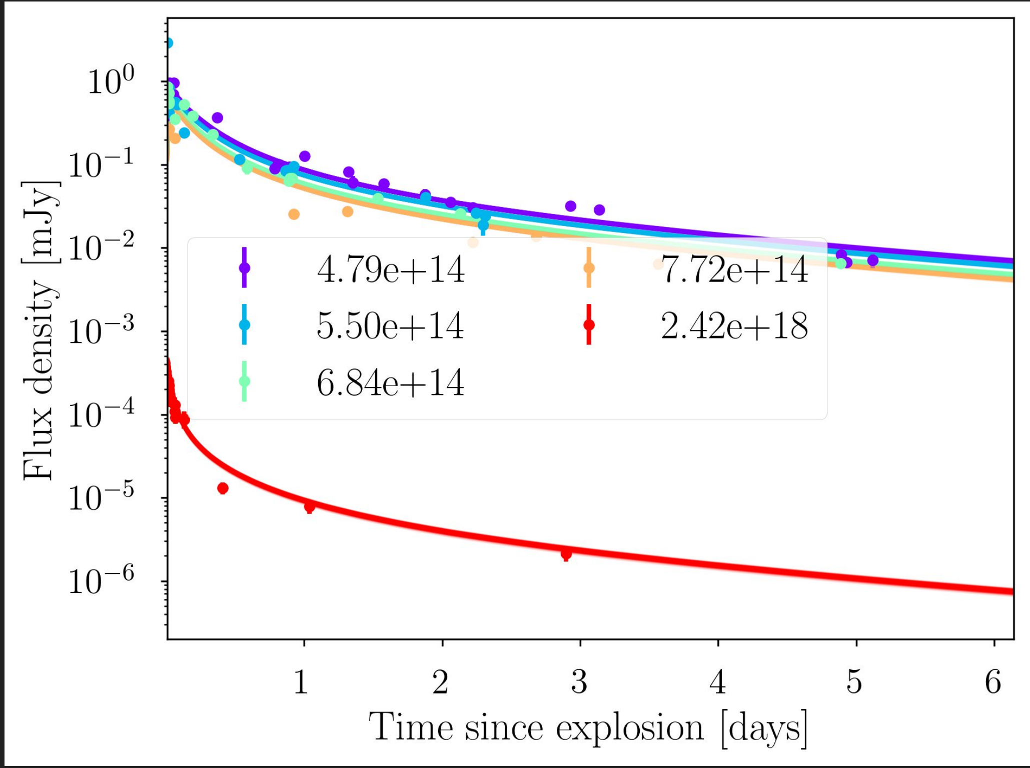
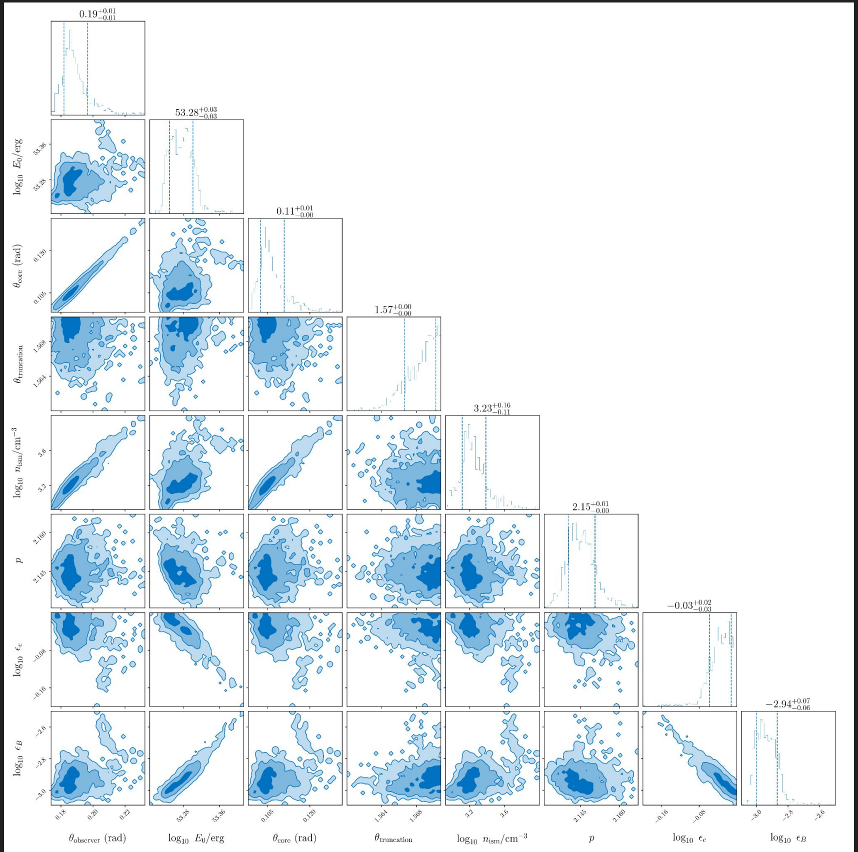
2. Off-axis scenario

Redback
https://github.com/nikhil-sarin/redback

Forward shock + Gaussian jet scenario

ISM model





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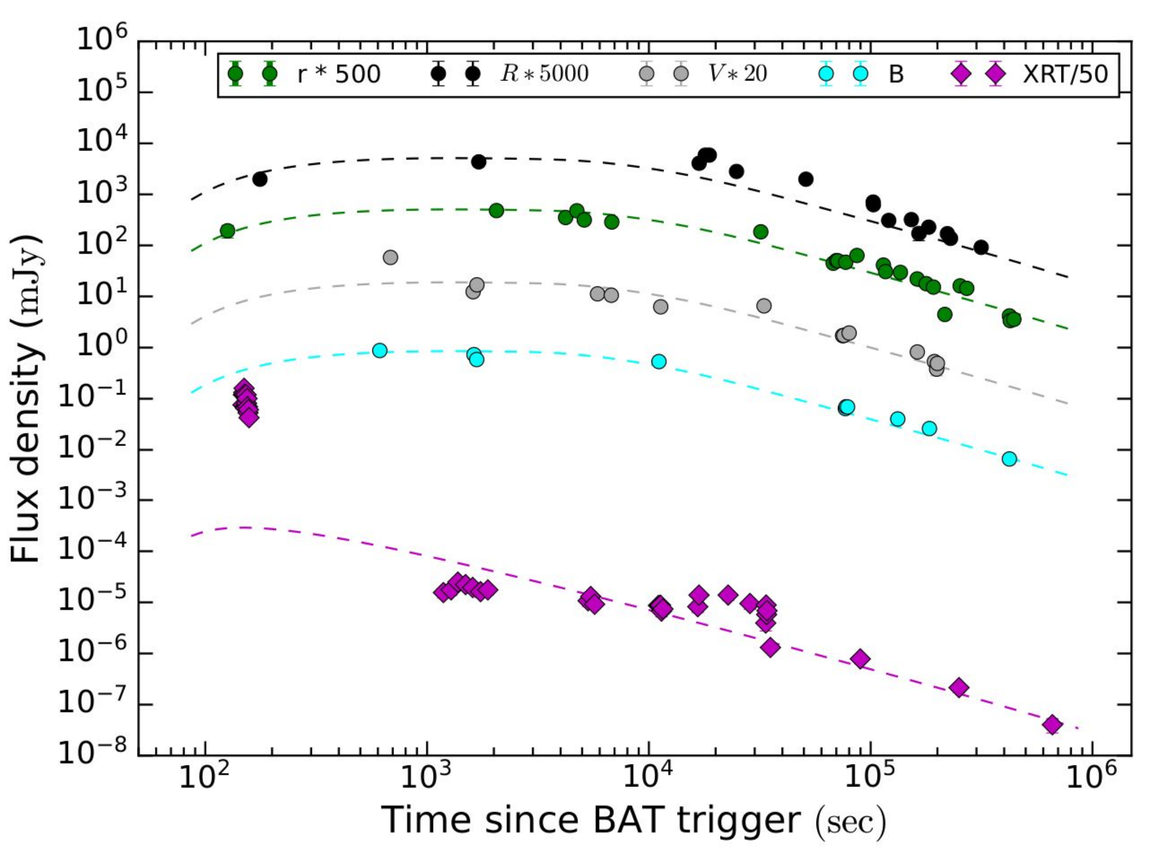


2. Off-axis scenario

Including flare and high latitude emission

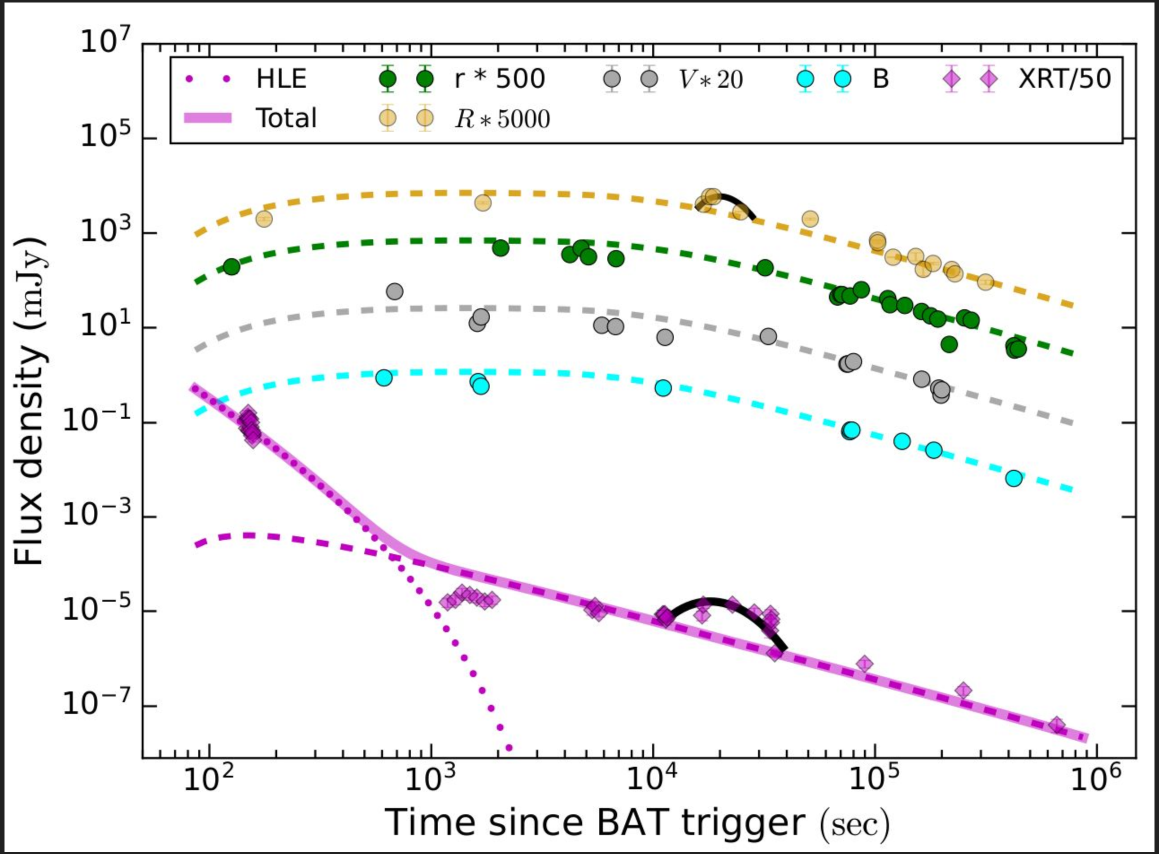
ISM model

Norris model

$$I(t) = A\lambda \exp\left(-\frac{\tau_1}{(t-t_i)} - \frac{(t-t_i)}{\tau_2}\right)$$

High latitude emission

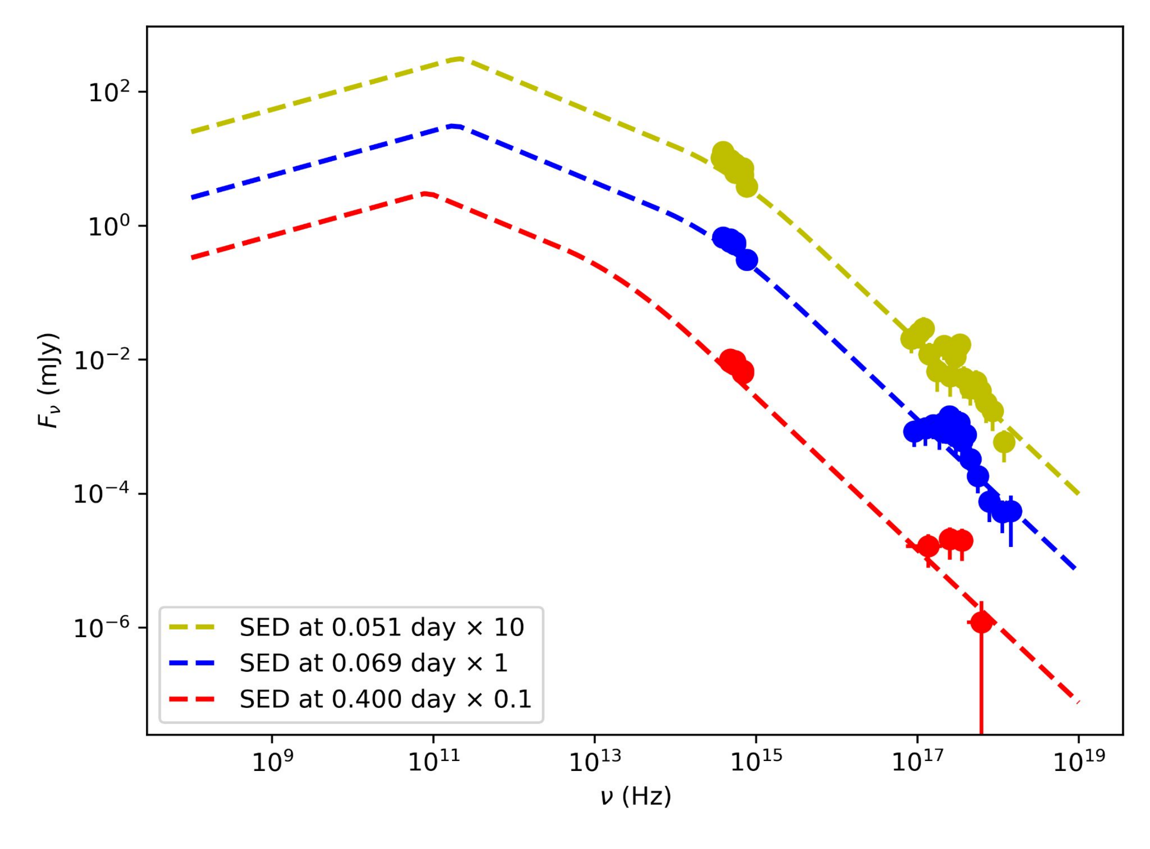
$$F_\nu(t) \propto t^{-(2+\beta)}\nu^{-\beta}$$



2. Off-axis scenario

SED modelling

ISM model



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GRB 250129A exhibited a **very bright optical counterpart** observed at **early times**.

This burst is notable for exhibiting **late-time polarization**, with:

- **Polarization degree**: ~5%
- **Polarization angle rotation**: **180°** across the observed wavelength range

We tested several models combining **forward shock (FS)** and **reverse shock (RS)** components:

- The **reverse shock** was found to **dominate the early-time emission**.

Afterglow modeling was performed using **Afterglowpy**, considering:

- **Gaussian jet**
- **Jet + wing structure**

These models provided a **satisfactory fit in an off-axis configuration**, which can naturally explain:

  - The **high degree of polarization**
  - The **rotation in polarization angle** at late times

To explain the **early-time X-ray excess** and the **mid-time excess** in both X-ray and optical bands, we incorporated:

- **High-latitude emission** for the steep decay phase
- A **Norris function** to model the prompt and residual emission features

THANK YOU

Ankur Ghosh

11.07.2025

SAIP-2025

UNIVERSITY OF JOHANNESBURG

20 YEARS 2005-2025

Our Future. Reimagined.