SEARCH FOR ORPHAN GAMMA-RAY BURST AFTERGLOWS IN RUBIN LSST DATA WITH FINK

FINK Collaboration Meeting

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8 – 10 January 2024

BRIEF OVERVIEW

1- General context

2- Simulation of a population of GRBs

3- "Pseudo-observed" light curves and their analysis

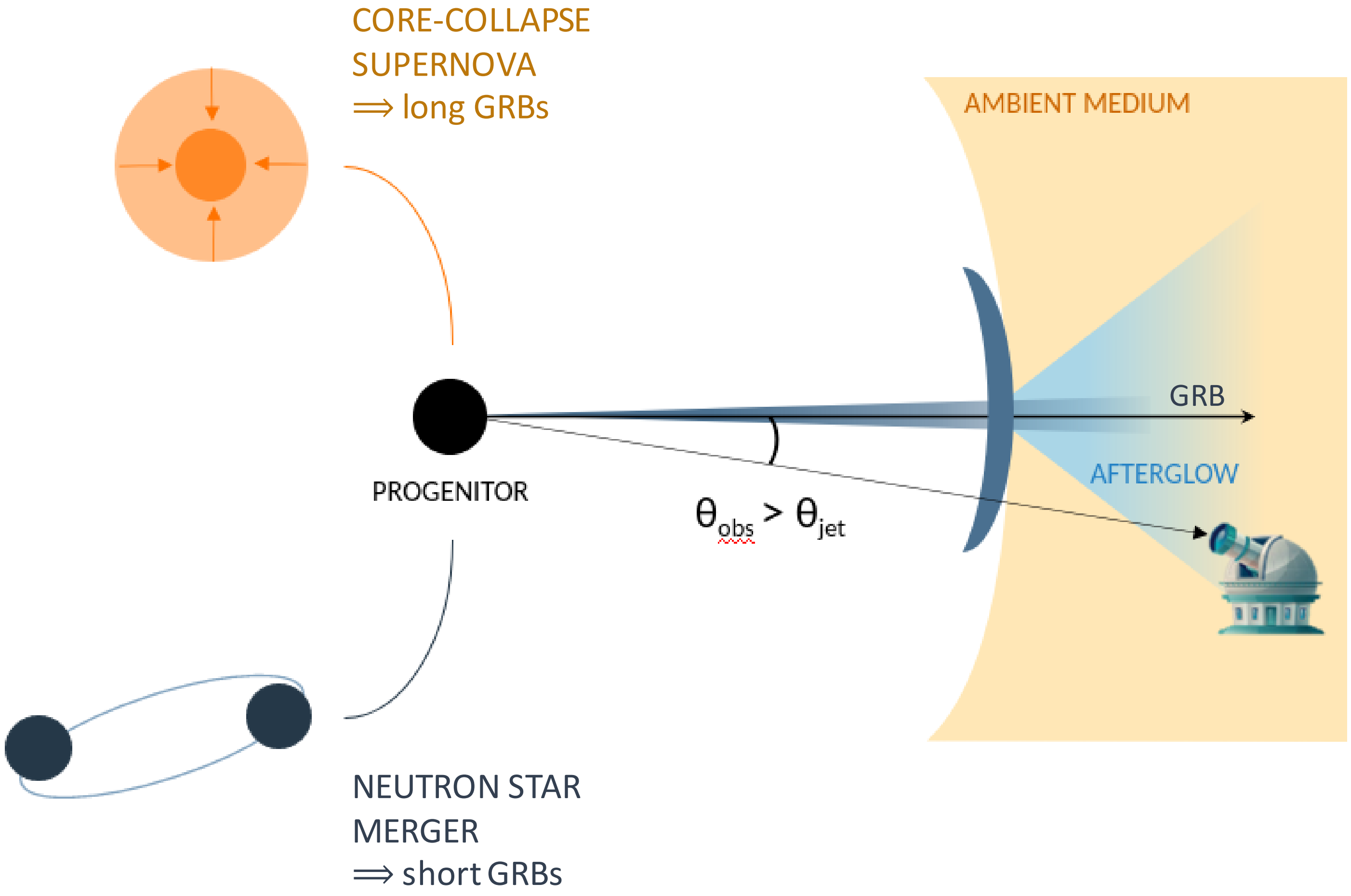
4- Light curve feature-based orphan selection

5- Overlap with supernova and kilonova light curves

6- Conclusions & perspectives

DESC project n°270

THE ORPHAN AFTERGLOW: A GRB VIEWED OFF-AXIS



Afterglow = long-lasting and fading emission following the gamma prompt emission

Orphan afterglow = afterglow observed off-axis (without gamma-ray emission)

⟹ **No orphan afterglow detected so far!**

(Some candidates but none confirmed)

Why study orphan afterglows?

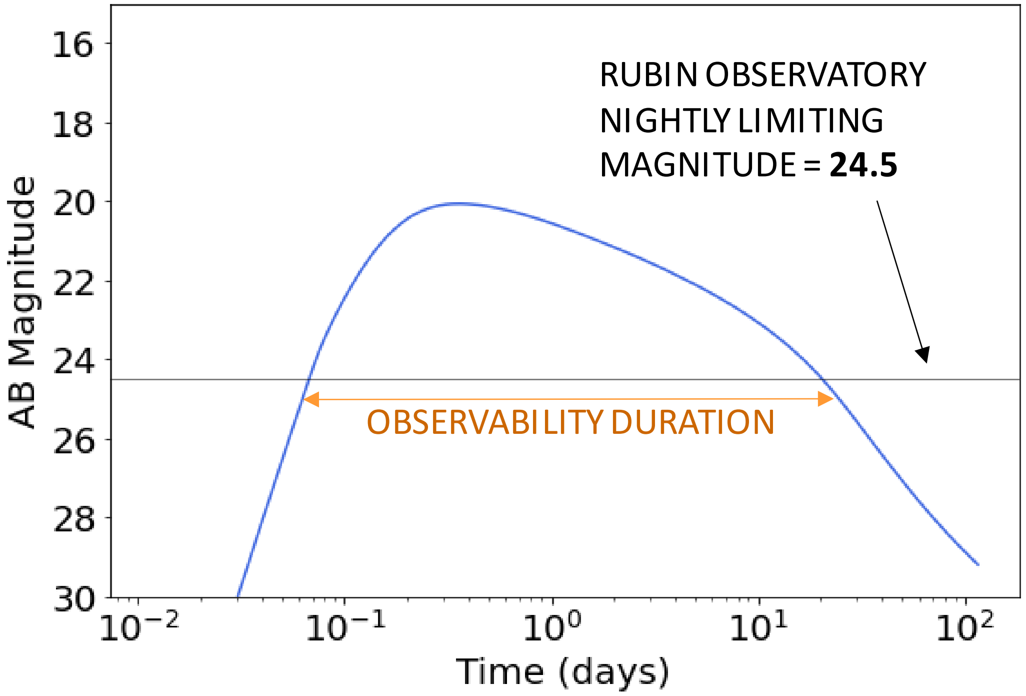
- More information on the GRB physics and their progenitors
- Multi-messenger analysis with gravitational waves

MODEL OF GRB AFTERGLOW EMISSION

afterglowpy package
https://github.com/geoffryan/afterglowpy

Identification of orphans based on their light curve

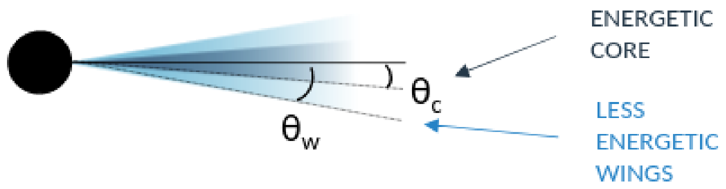
EXAMPLE OF AN ORPHAN LIGHT CURVE



Forward shock model
+ electron synchrotron model
(Van Eerten et al. 2010)

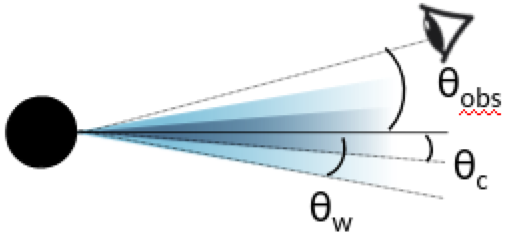
Studied parameters:

- Energy E_0
- Circumburst medium density n_0
- Redshift z
- Observer angle θ_{obs}
- Jet type (uniform or **structured**)
- Core angle θ_c
- Truncature angle θ_w



POPULATION OF SHORT GRBS (TEMPORARY)

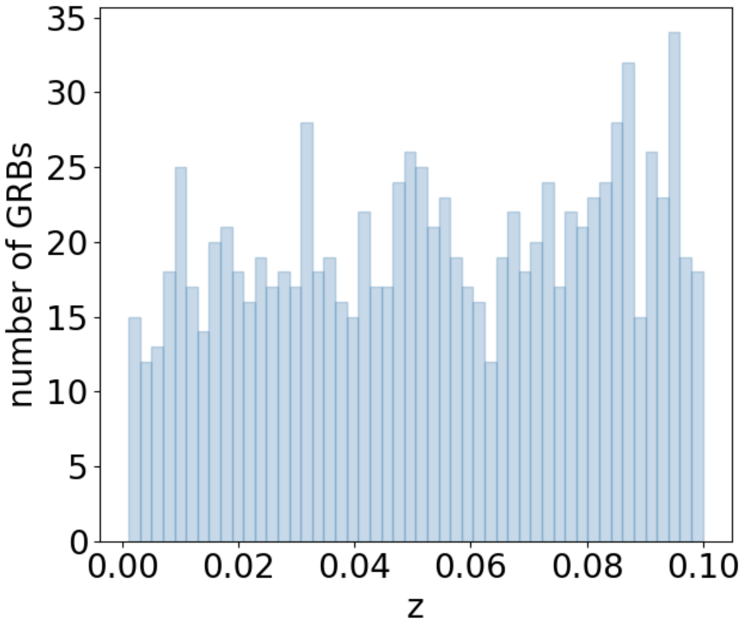
Goal: To simulate somewhat realistic distributions for short GRBs



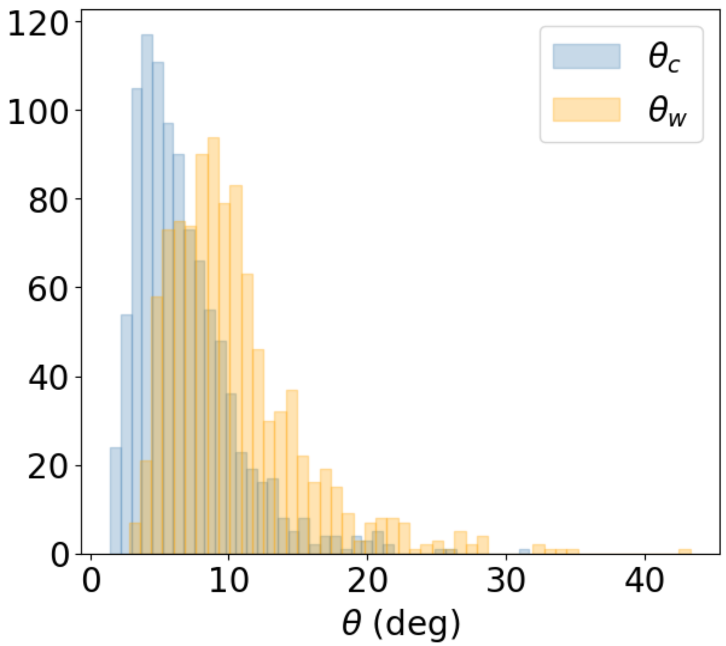
Studied parameters distributions:

- **Circumburst density n_0:** uniform distribution [1.0 ; 100] cm^{-3}
- **Observer angle $\cos(\theta_{obs})$:** uniform distribution [0 ; 1] (isotropic)

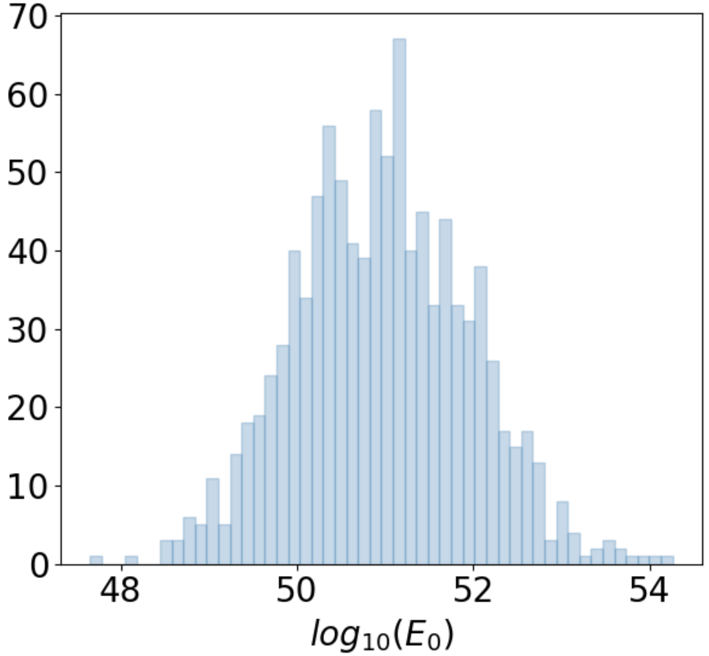
REDSHIFT



JET ANGLES



ISOTROPIC EQUIVALENT ENERGY



POPULATION OF SHORT GRBS BASED ON THE SBAT4 CATALOGUE

SBAT4 catalogue (D'Avanzo et al. 2014) = selected sample of short GRBs observed by the Swift satellite up to June 2013

- Short GRBs detected by the Swift BAT instrument in the **15-150 keV energy band**
- Selection criteria: peak flux $\mathbf{PF_{64} > 3.5\ ph/s/cm^2}$

Method = compute the flux of the prompt emission for a given configuration and applying the selection criteria of the SBAT4 catalogue

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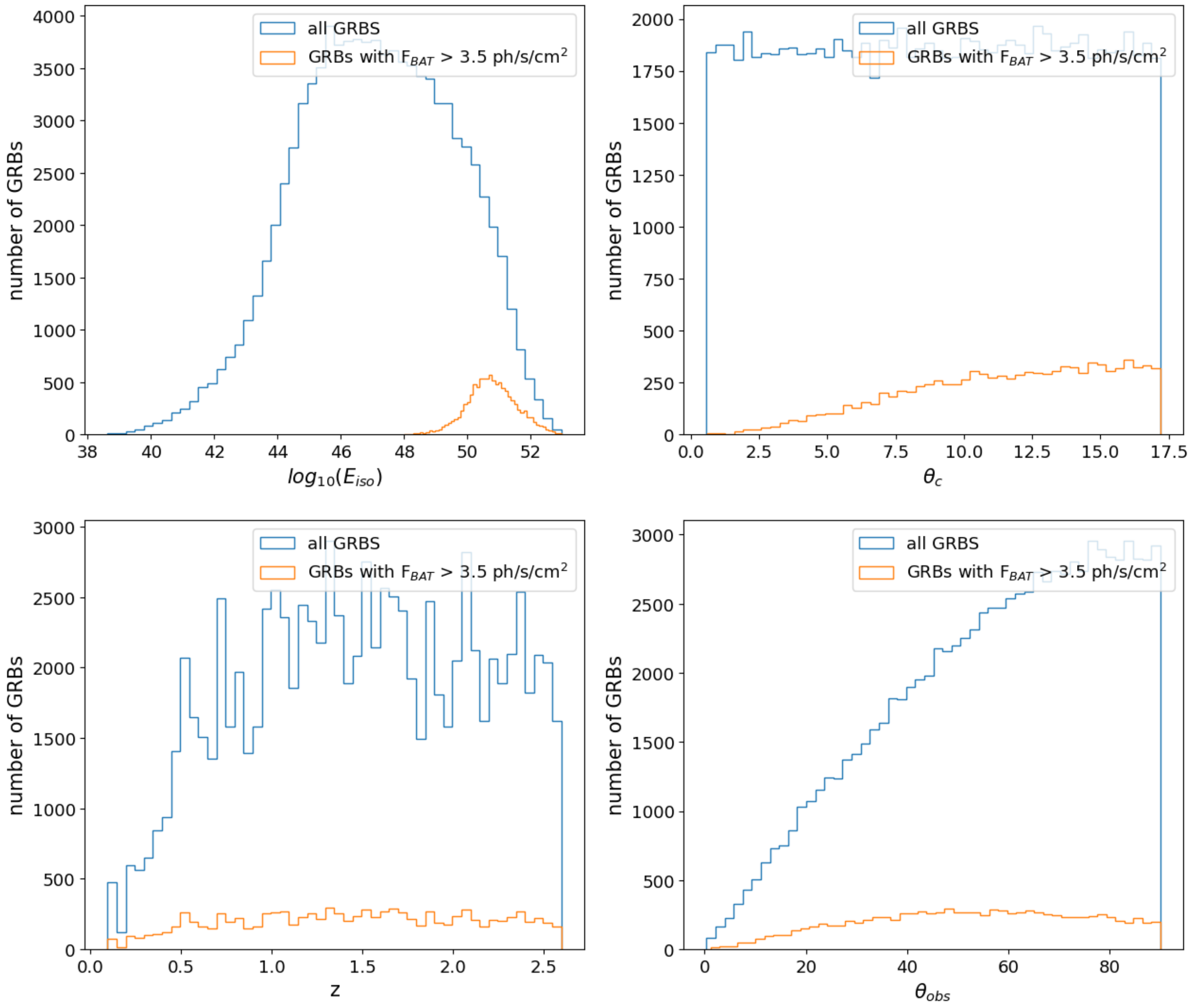
STILL IN PROGRESS



BRIEF OVERVIEW

SIMULATION OF AN OBSERVATION: METHOD

`rubin_sim` package ⟹ Realisation of the scheduler simulation for the 10 years of LSST (https://github.com/lsst/rubin_sim)

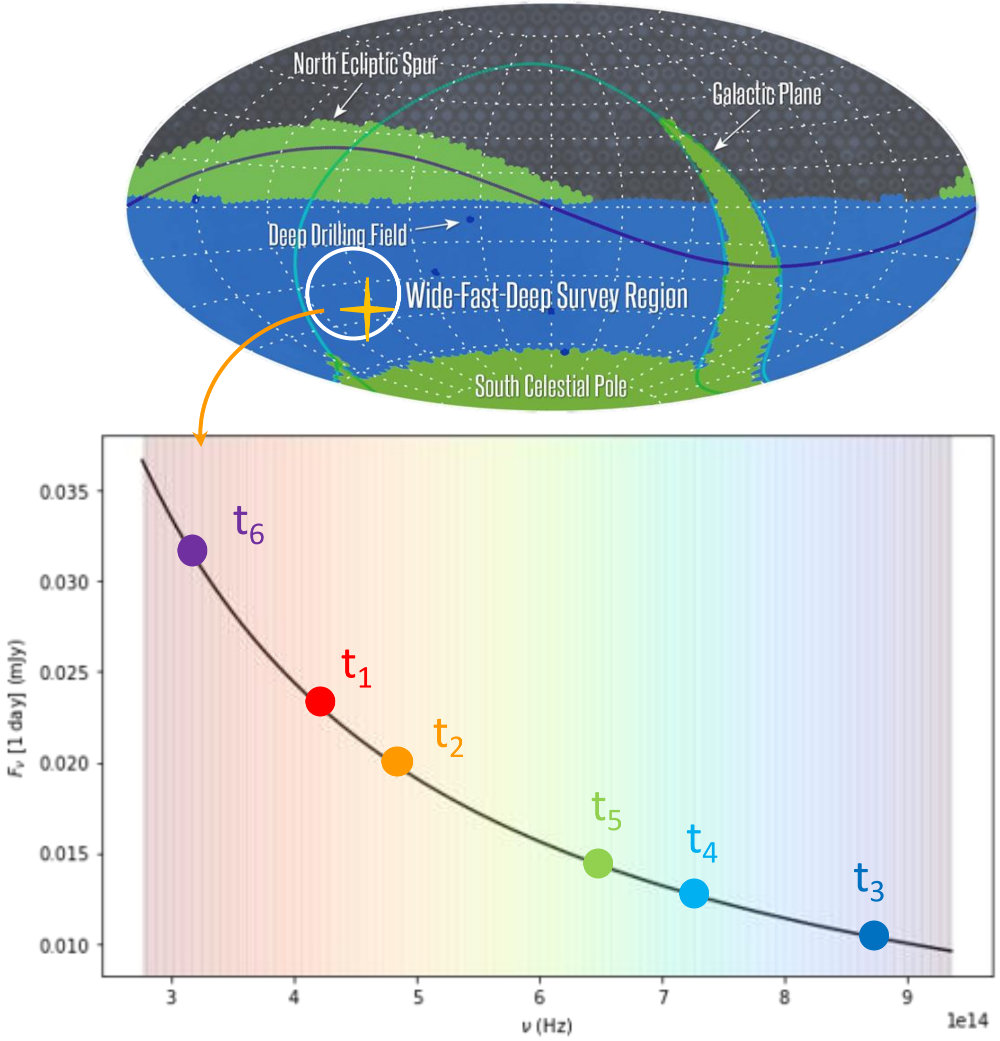
1- Take time and coordinates of a GRB

2- Keep only observations inside the Rubin/LSST field of view

3- Compute spectra at observation time bins in magnitude with **`afterglowpy`** (Ryan et al. 2020)

4- Keep only "real" observation for the right filter

5- Plot pseudo observed light curve



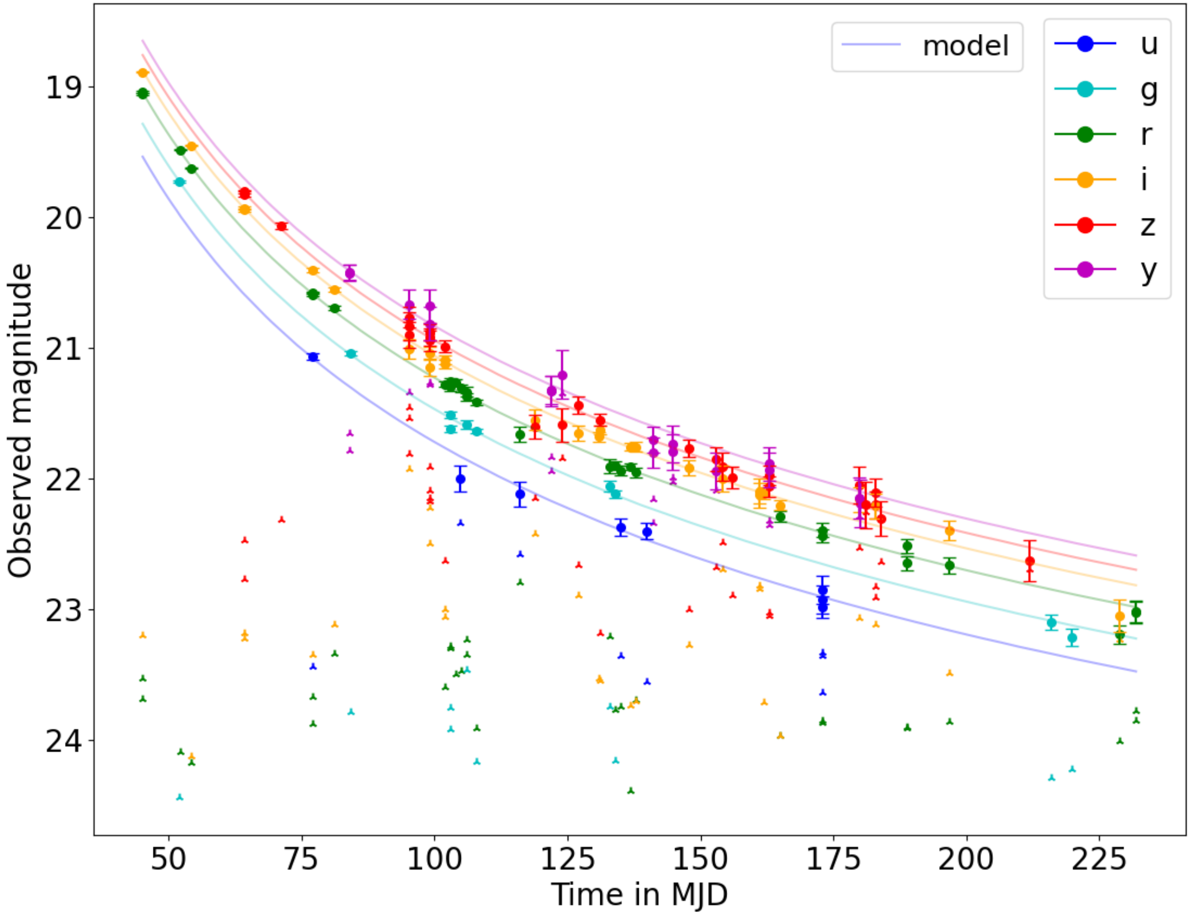
EXAMPLE OF A "PSEUDO-OBSERVATION"

GRB date: 12 March, 2030

GRB (RA, Dec) coordinates:
(19h00m55.04s, -53d23m42.38s)

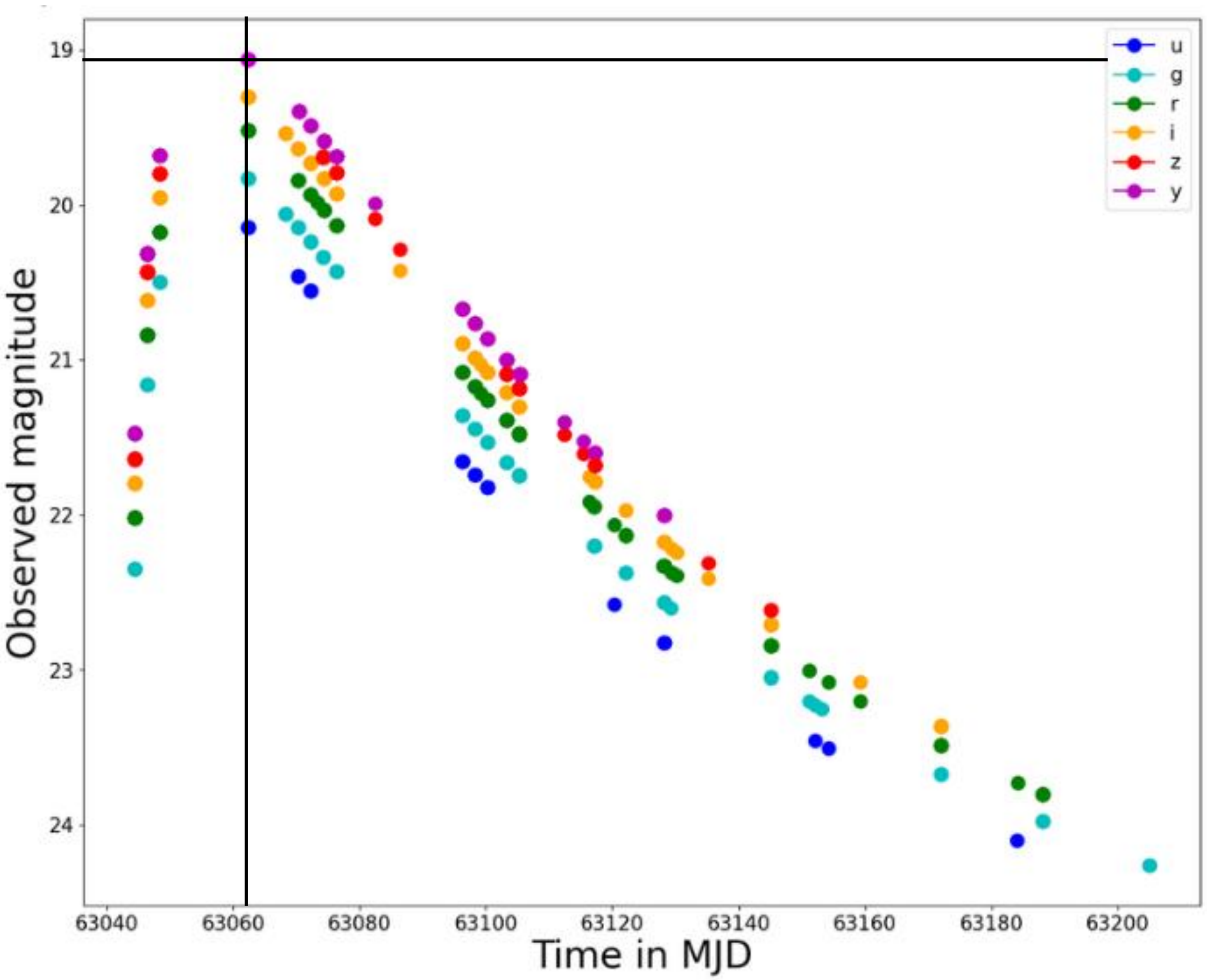
Parameters:

- Power-Law jet
- $E_0 = 1.3 \times 10^{52}$ erg
- $\theta_{obs} = 21.2$ °
- $\theta_c = 2.9°$
- $\theta_w = 8.6°$
- $n_0 = 0.45$ cm^{-3}
- z = 0.001



⟹ Fraction of "pseudo-observable" orphans by the Rubin Observatory: a few %

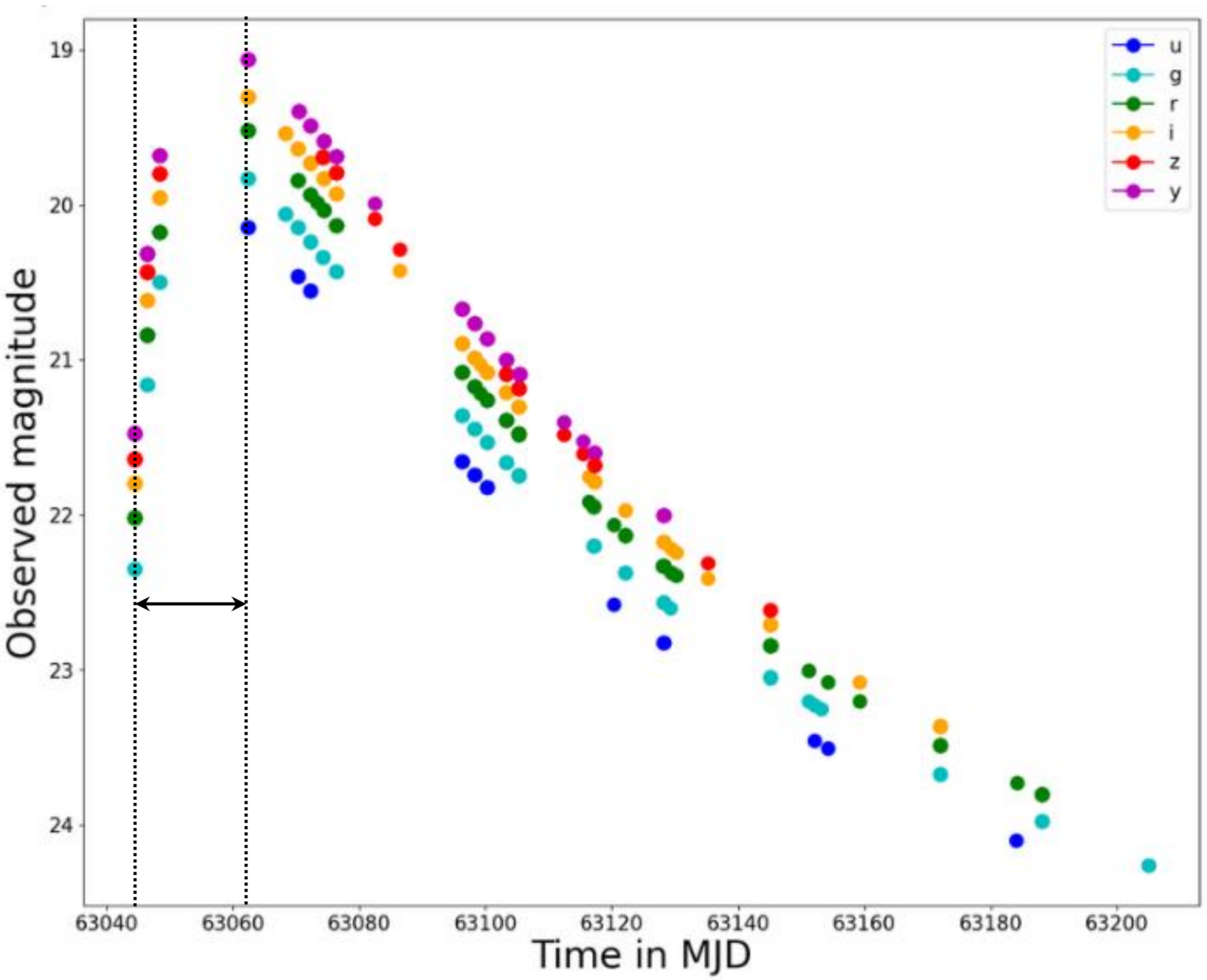
CHARACTERIZATION OF LIGHT CURVES



Defined features:

- **Minimal magnitude**
- **Time of the minimal magnitude**

CHARACTERIZATION OF LIGHT CURVES



Defined features:

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- **Duration between the first detection and the peak**

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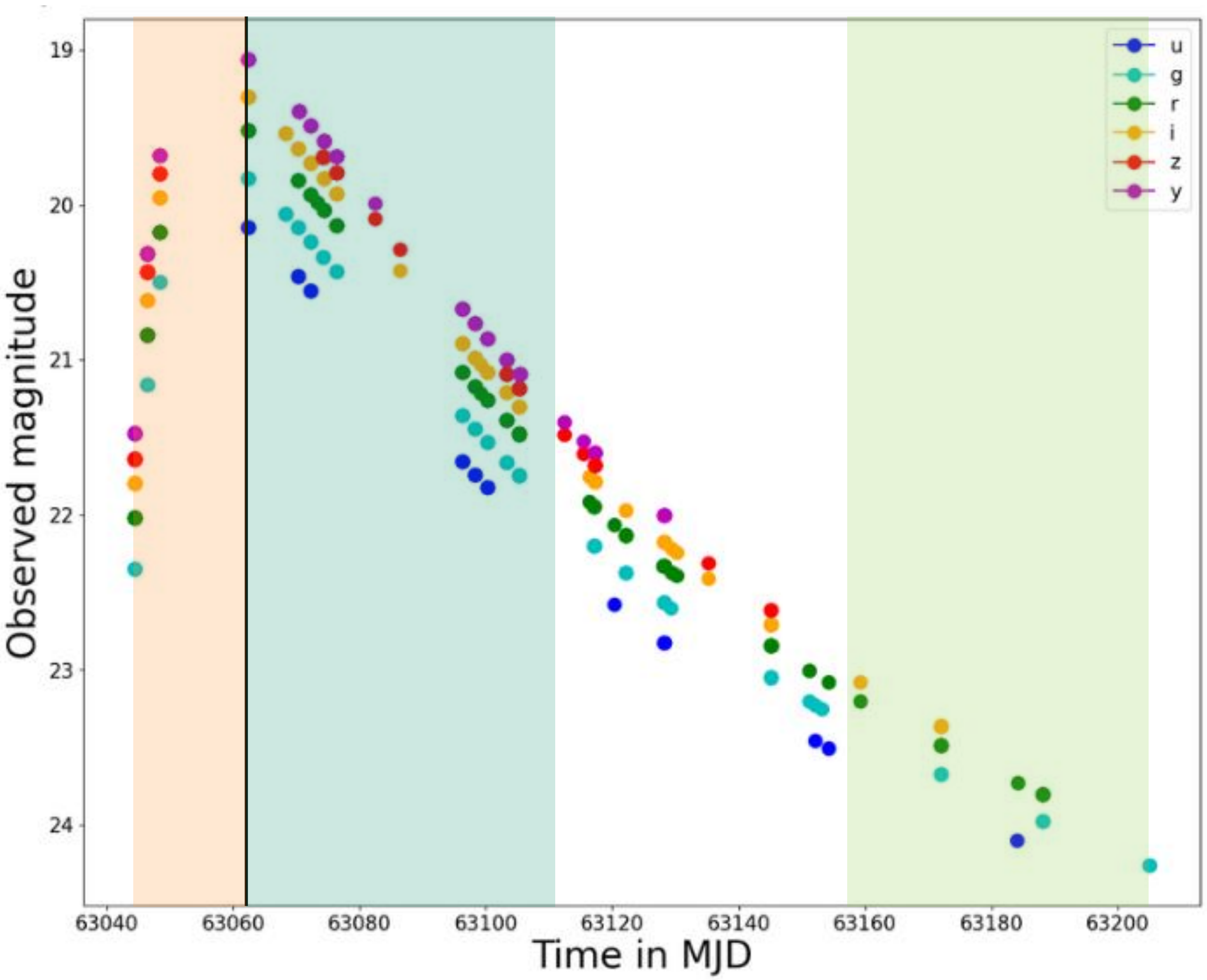

Defined features:

- Minimal magnitude
- Time of the minimal magnitude
- Duration between the first detection and the peak
- **Increase rate of the magnitude**
- **Decrease rates of the magnitude in the 1st third and the last third of the light curve**

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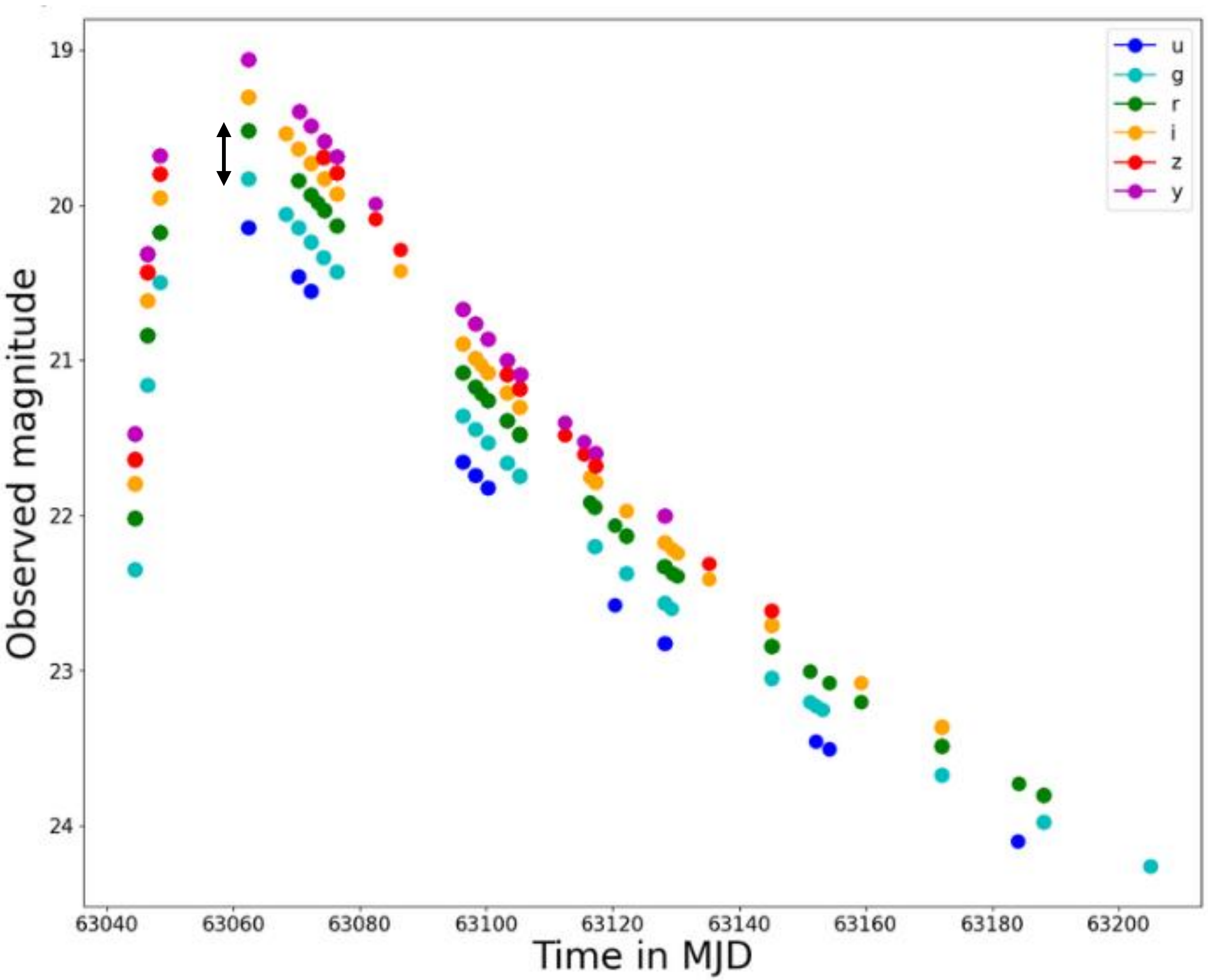
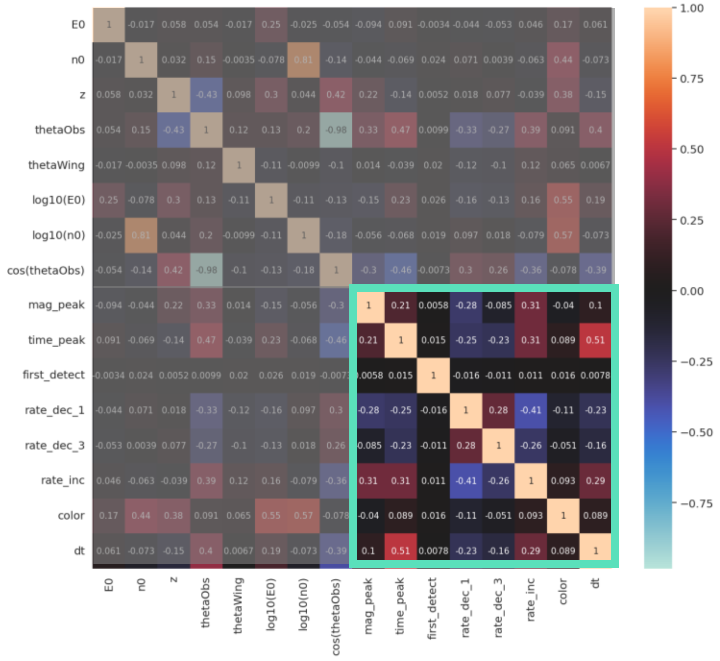
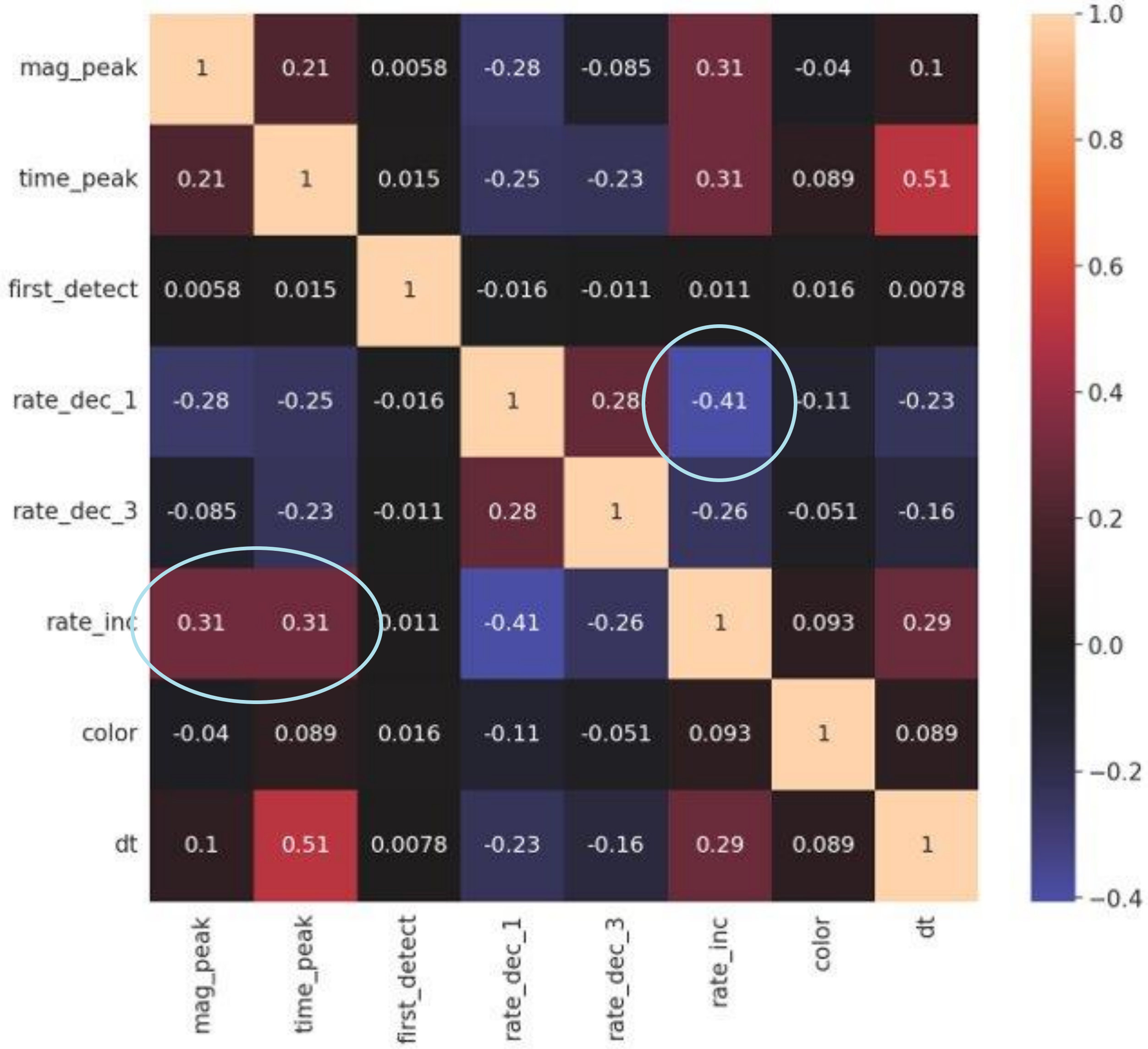


Defined features:

- Minimal magnitude
- Time of the minimal magnitude
- Duration between the first detection and the peak
- Increase rate of the magnitude
- Decrease rates of the magnitude in the 1st third and the last third of the light curve
- **g-r color** (expected value for synchrotron emission ~ 0.3)

CORRELATIONS BETWEEN THE DEFINED FEATURES

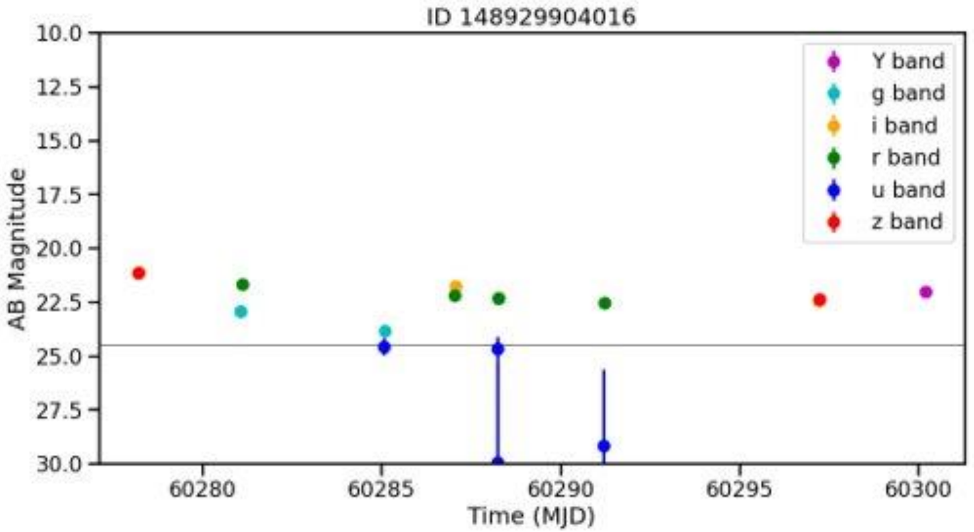


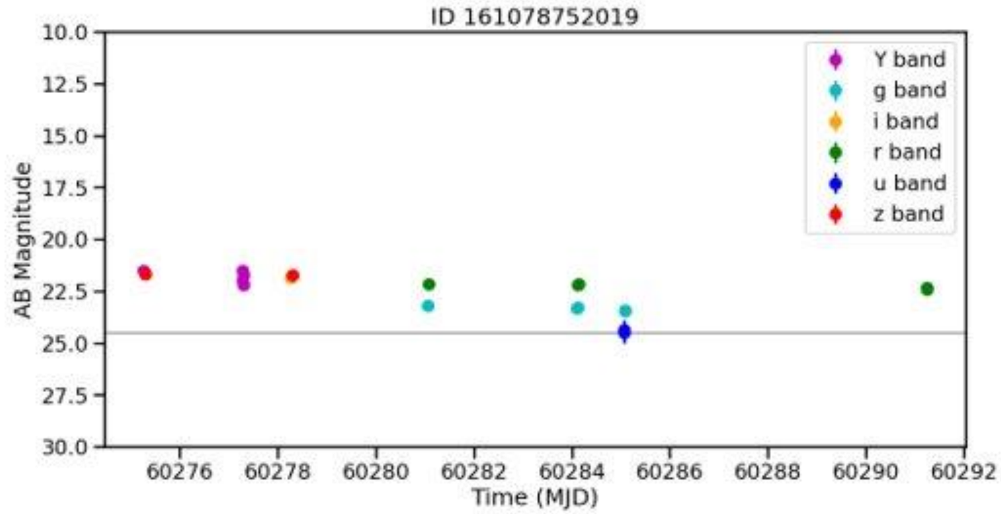


⟹ Correlations between rates and magnitude

BRIEF OVERVIEW

ELASTICC DATA CORRELATIONS





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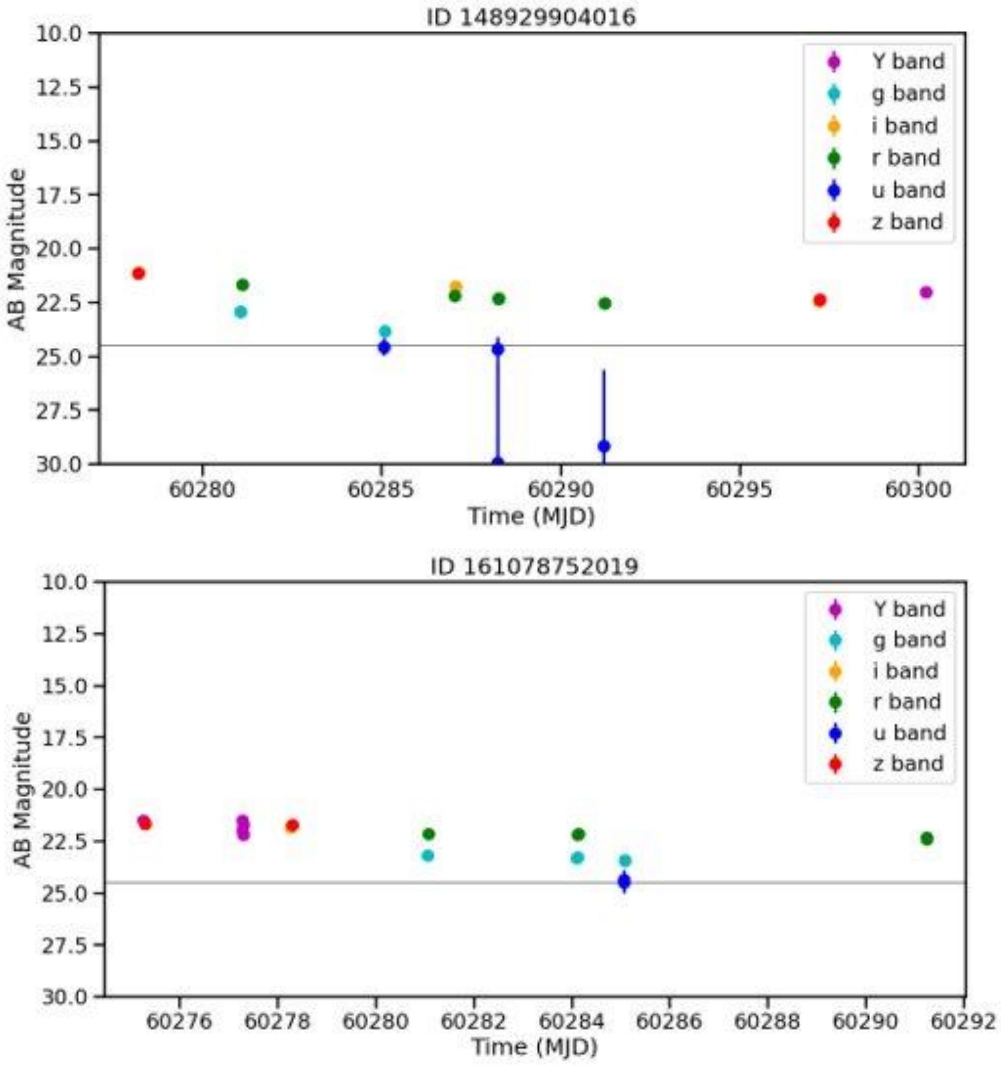
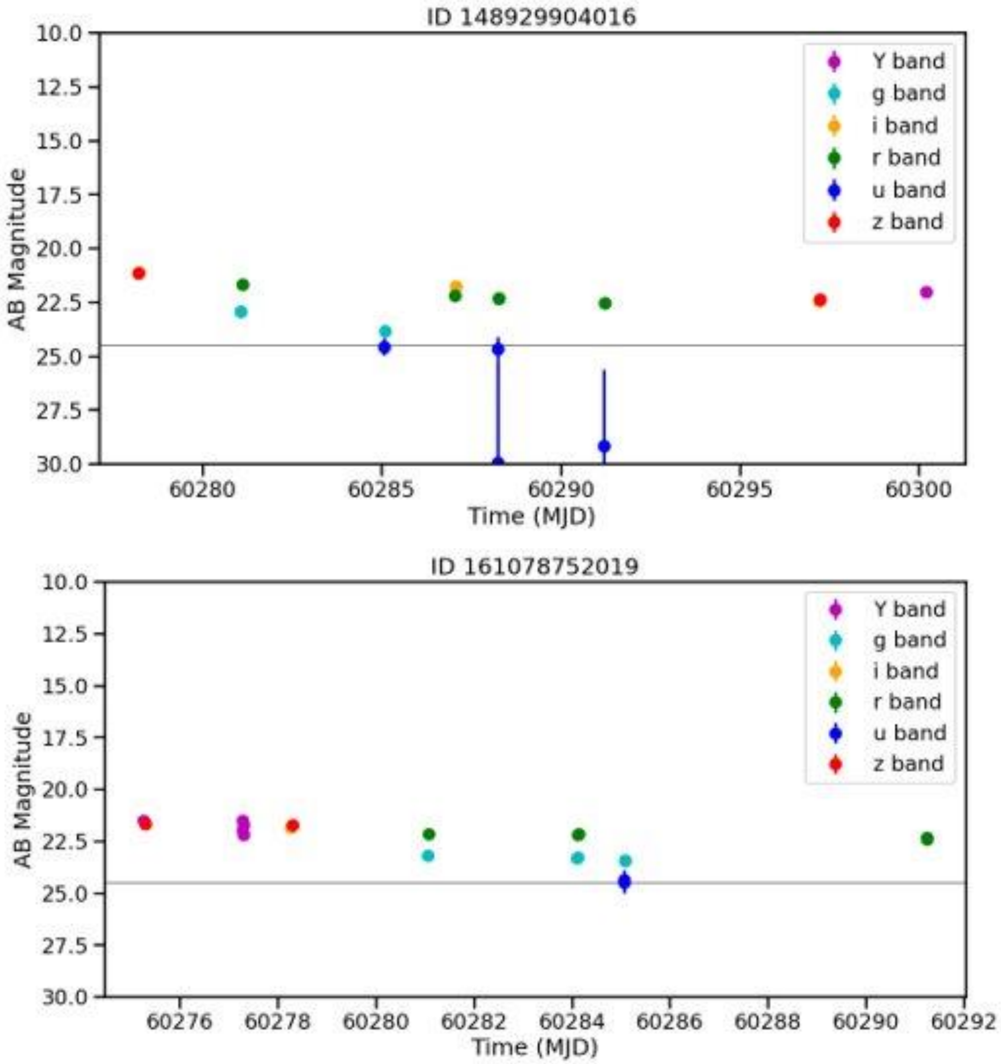


(1 month of ELAsTiCC data)

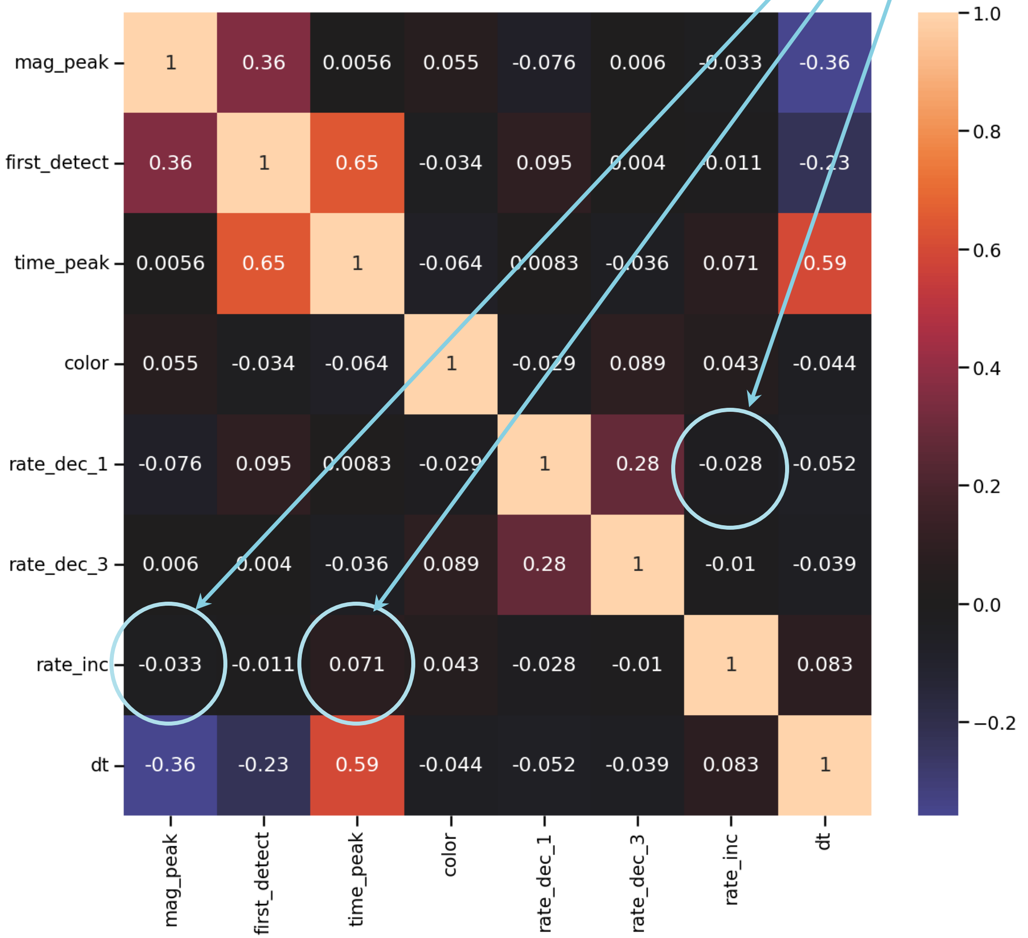
	mag_peak	first_detect	time_peak	color	rate_dec_1	rate_dec_3	rate_inc	dt
mag_peak	1	0.36	0.0056	0.055	-0.076	0.006	-0.033	-0.36
first_detect	0.36	1	0.65	-0.034	0.095	0.004	-0.011	-0.23
time_peak	0.0056	0.65	1	-0.064	0.0083	-0.036	0.071	0.59
color	0.055	-0.034	-0.064	1	-0.029	0.089	0.043	-0.044
rate_dec_1	-0.076	0.095	0.0083	-0.029	1	0.28	-0.028	-0.052
rate_dec_3	0.006	0.004	-0.036	0.089	0.28	1	-0.01	-0.039
rate_inc	-0.033	-0.011	0.071	0.043	-0.028	-0.01	1	0.083
dt	-0.36	-0.23	0.59	-0.044	-0.052	-0.039	0.083	1

ELASTICC DATA CORRELATIONS

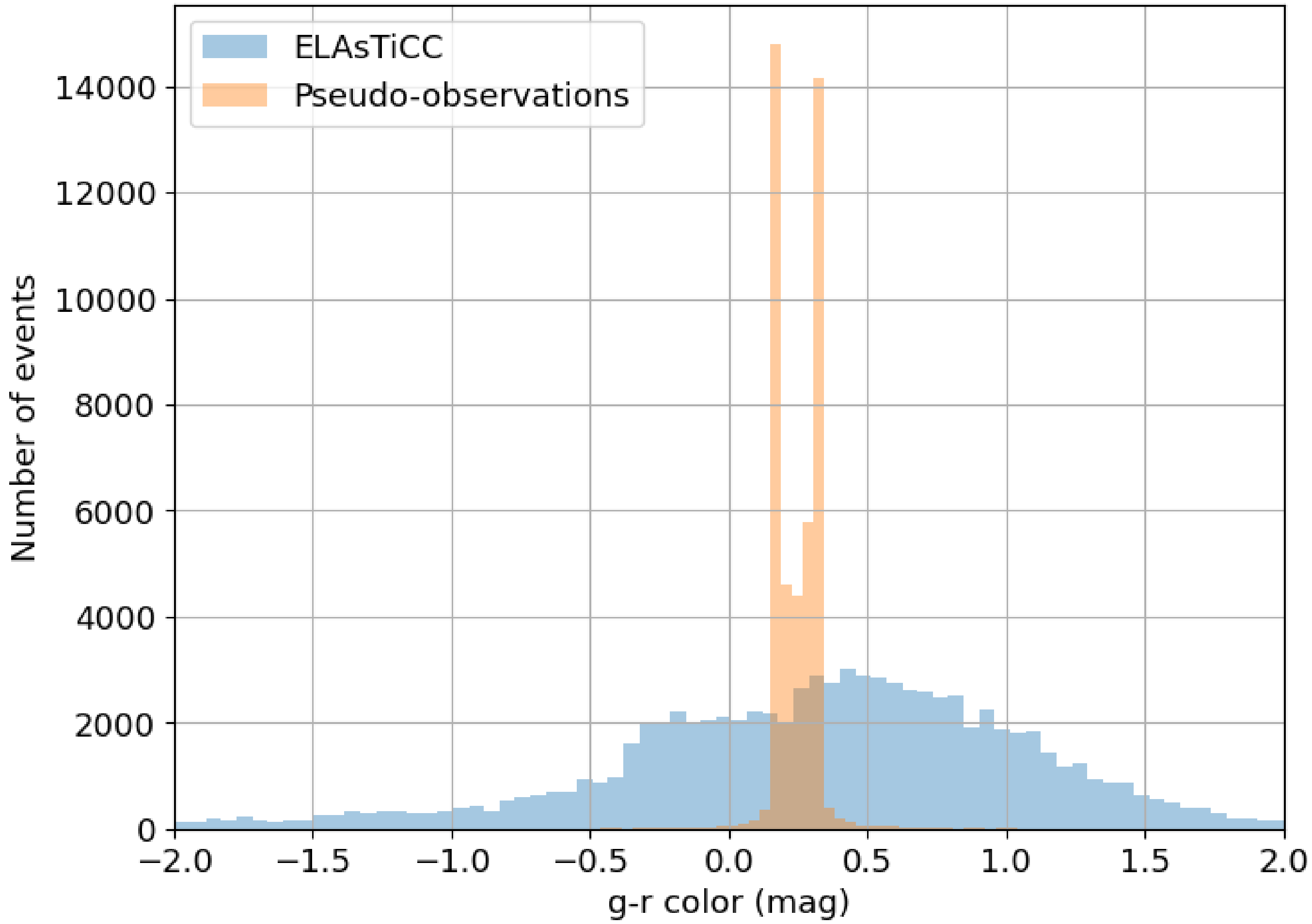


Different correlations than for orphans

(1 month of ELAsTiCC data)



EXAMPLE OF A CUT ON THE COLOR



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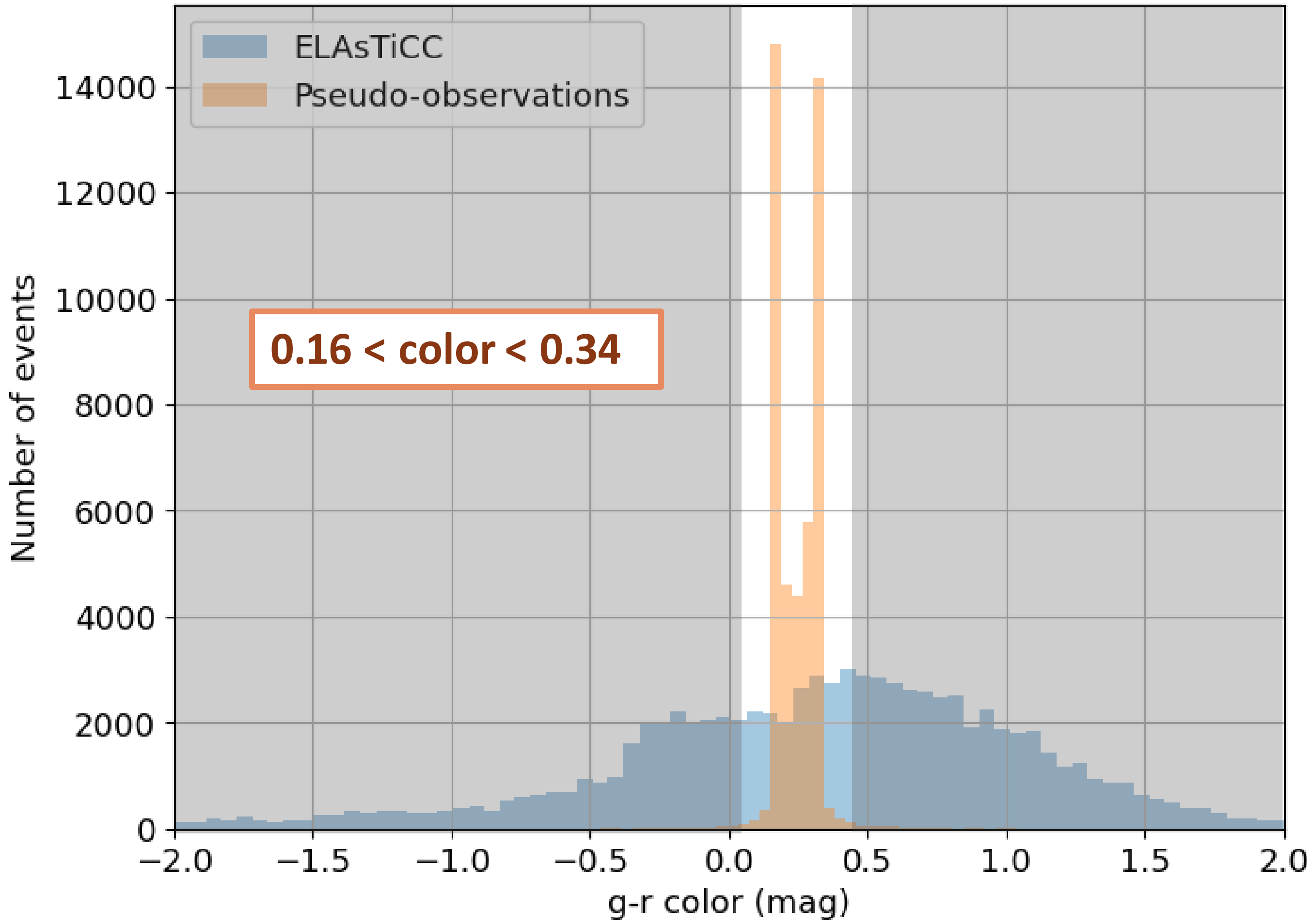
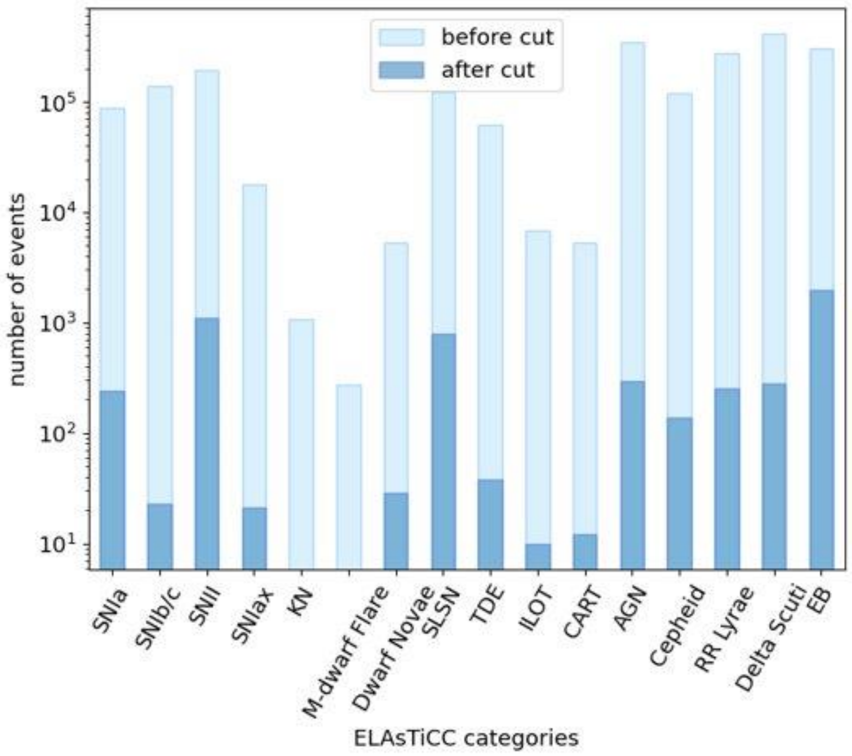


Removes

~ 98% of ELAsTiCC data

~ 28% of orphans



FIRST STAB AT BASIC CUTS

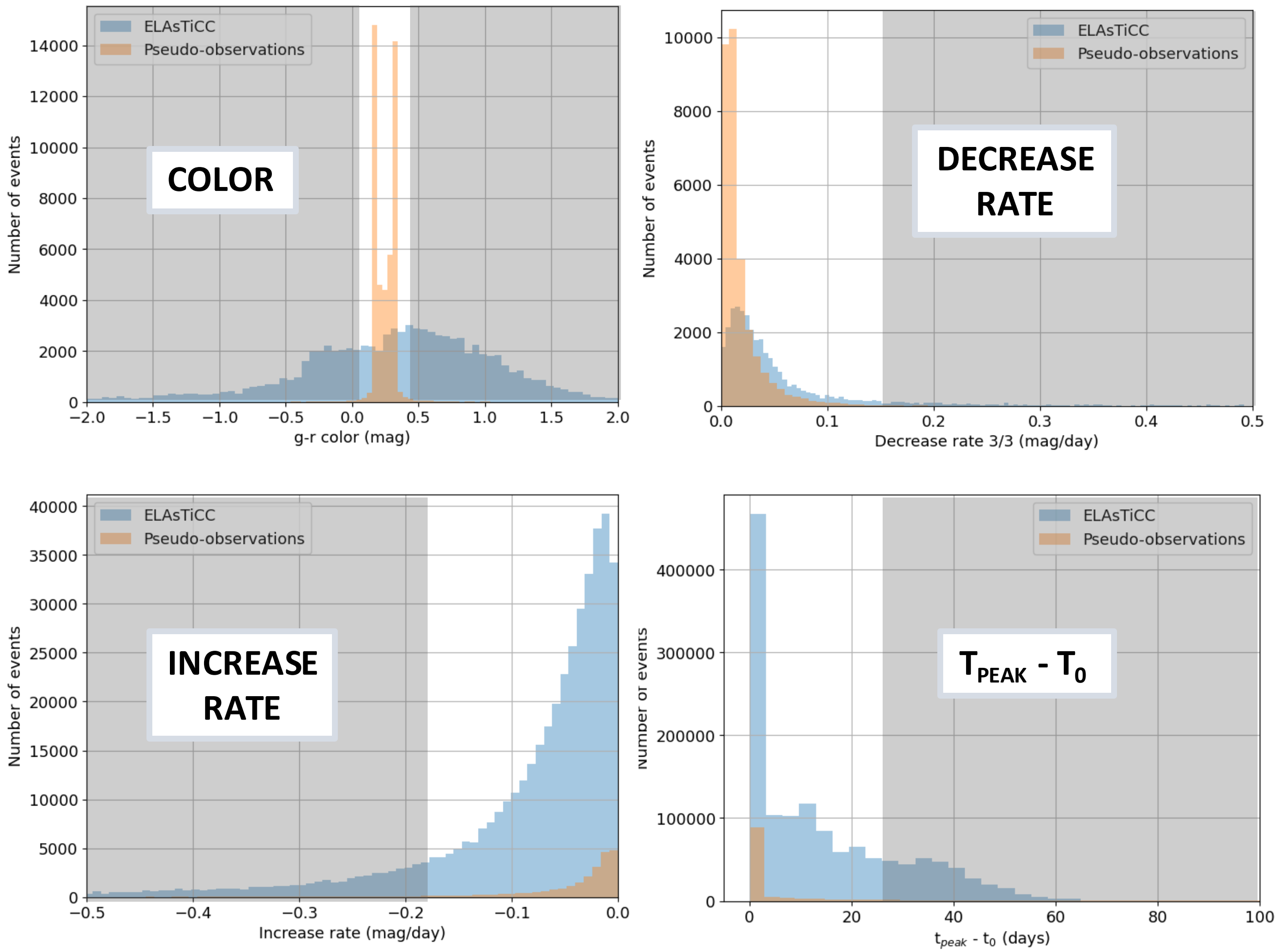
CUTS

Color:
0.16 < color < 0.34 mag

Decrease rate:
rate < 0.15 mag/day

Increase rate:
rate > -0.18 mag/day

Duration between the first detection and the peak:
dt < 25 days



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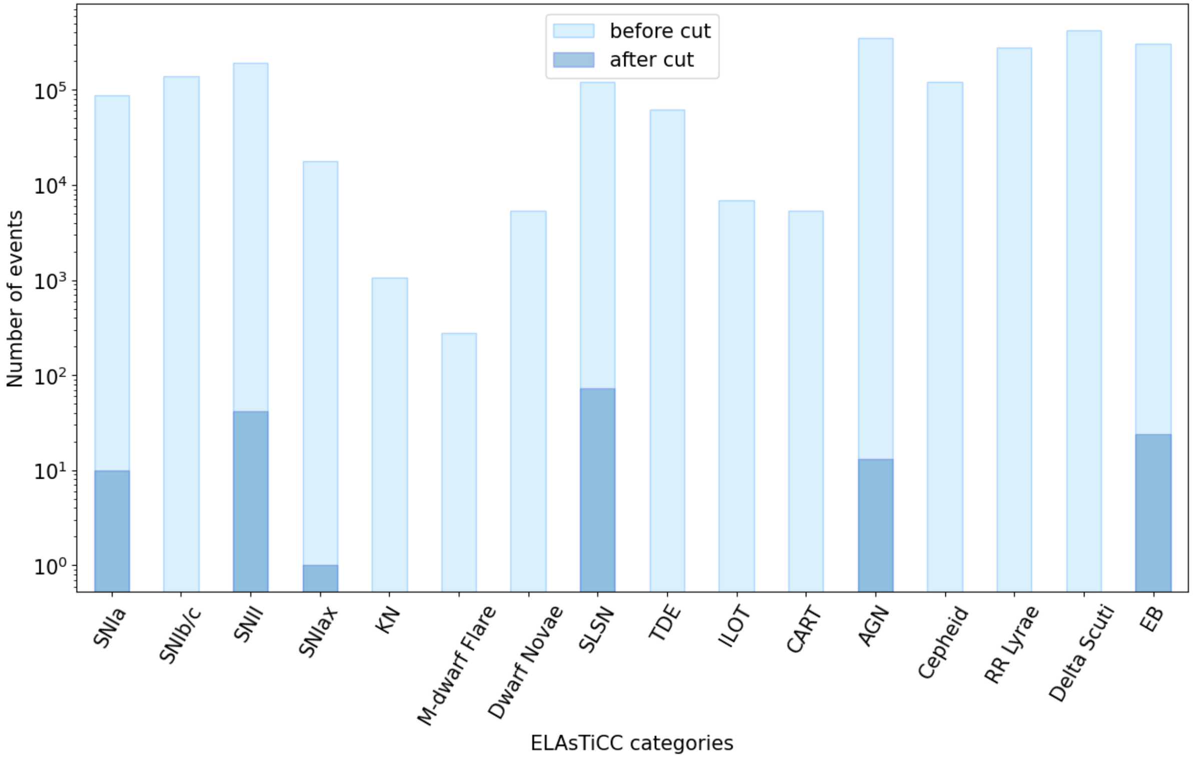
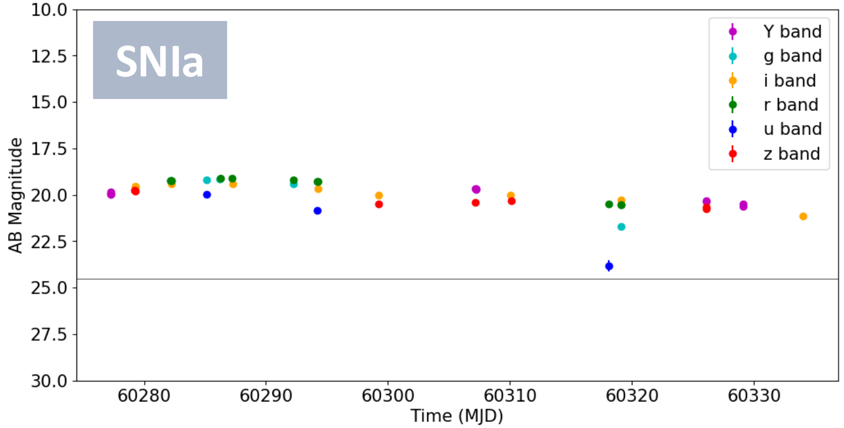
What remains

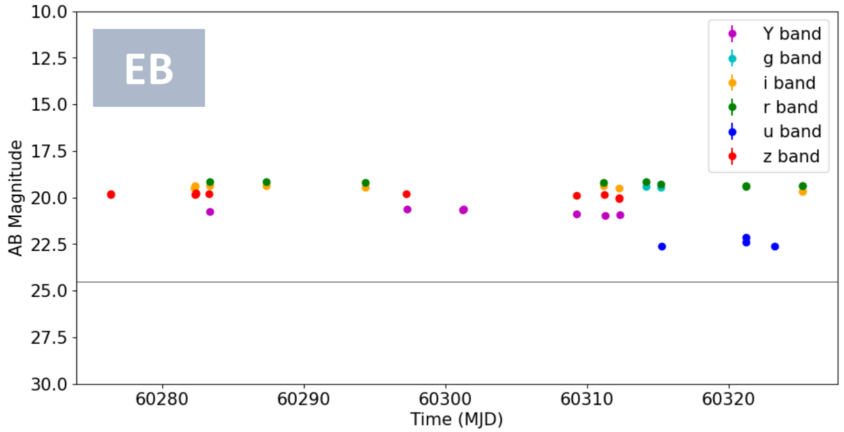
- ELAsTiCC data: 163 / ~2 millions events (but for 1 month...)
- Orphans: 1884 / ~200,000 events (~ 30 years...)



EVENTS THAT PASS AND DON'T PASS THE CUTS

ELAsTiCC data that pass the cuts





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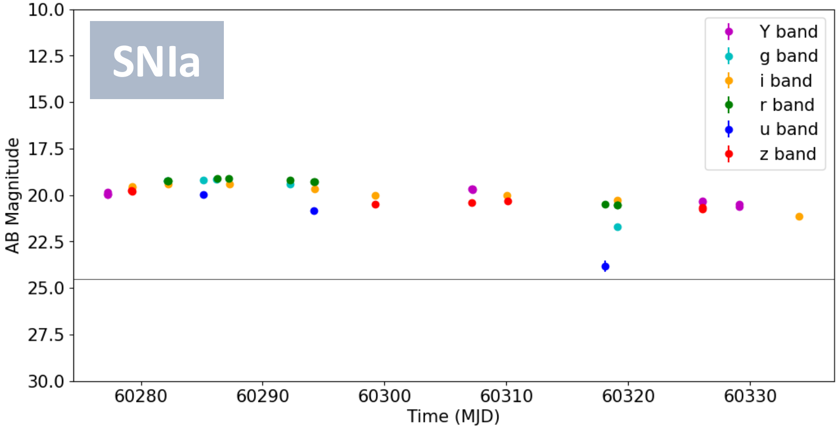
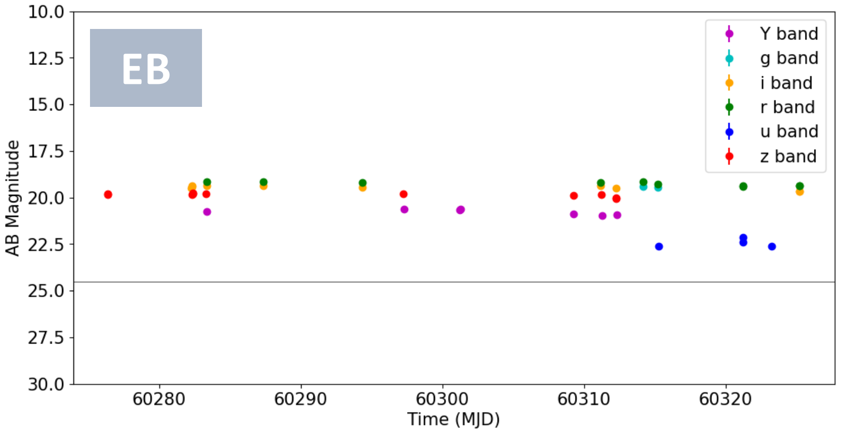
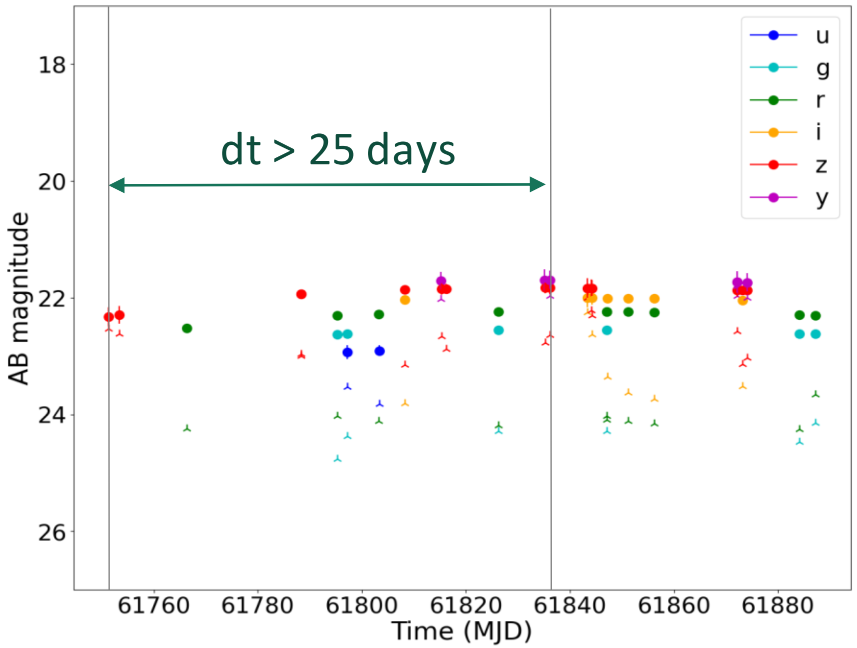




"Good" orphan (> 10 points) that does not pass the cuts



⟹ Work needed on feature design and selection cuts!

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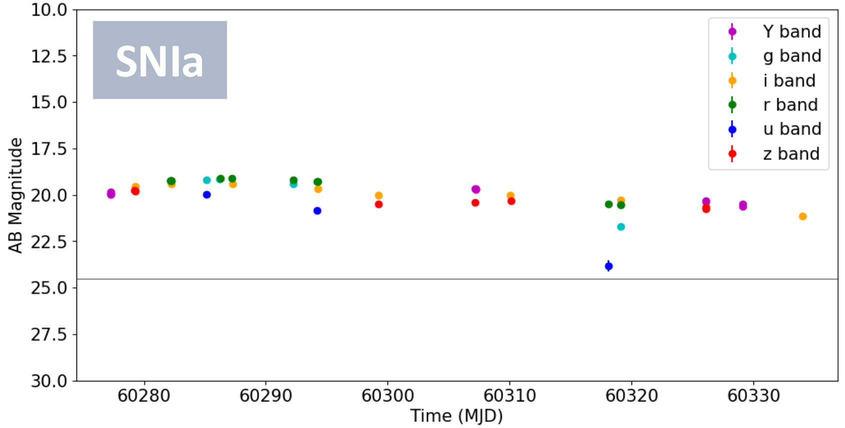

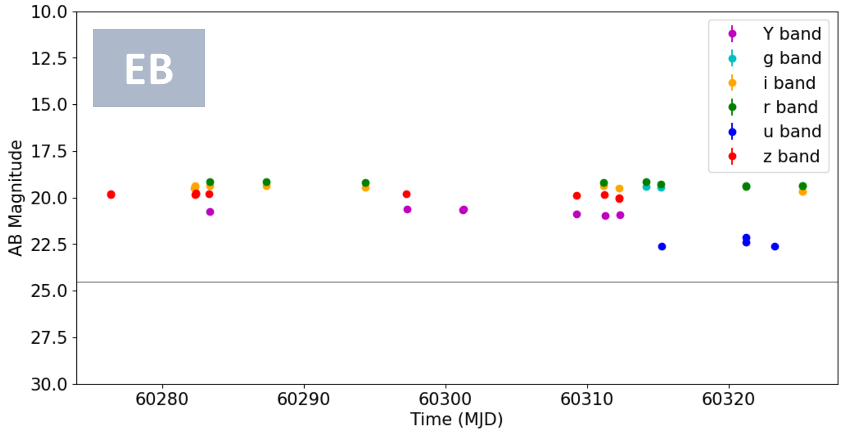

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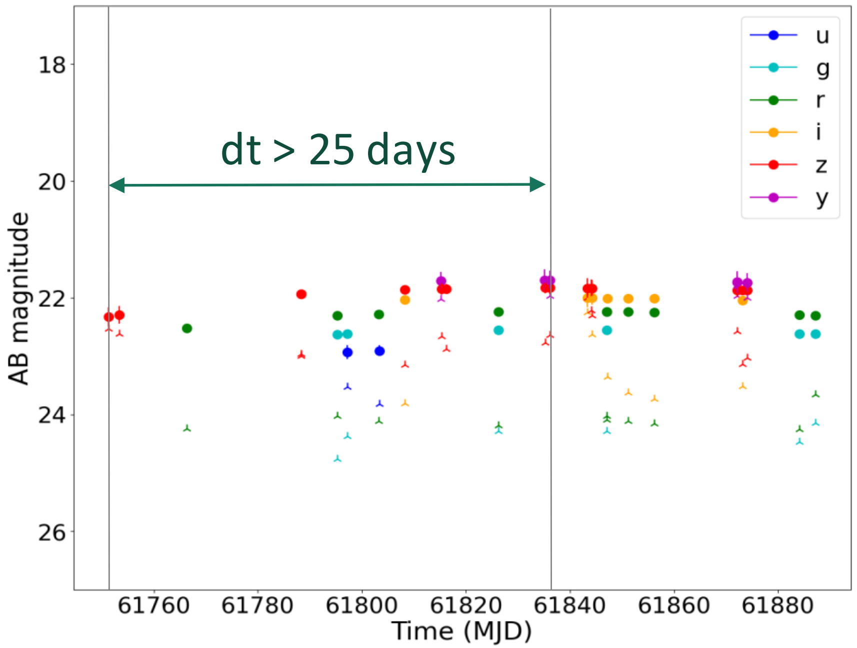

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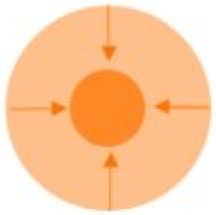
BRIEF OVERVIEW

KILONOVA (KN) AND SUPERNOVA (SN) OVERLAP

STILL IN PROGRESS



CORE-COLLAPSE SUPERNOVA
⟹ long GRBs + supernova
(GRB980425 + SN1998bw)

NEUTRON STAR MERGER
⟹ short GRBs + kilonova
(GRB 170817 + AT 2017gfo)

KILONOVA (KN) AND SUPERNOVA (SN) OVERLAP

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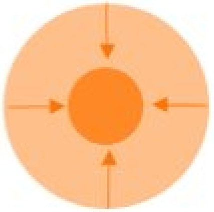

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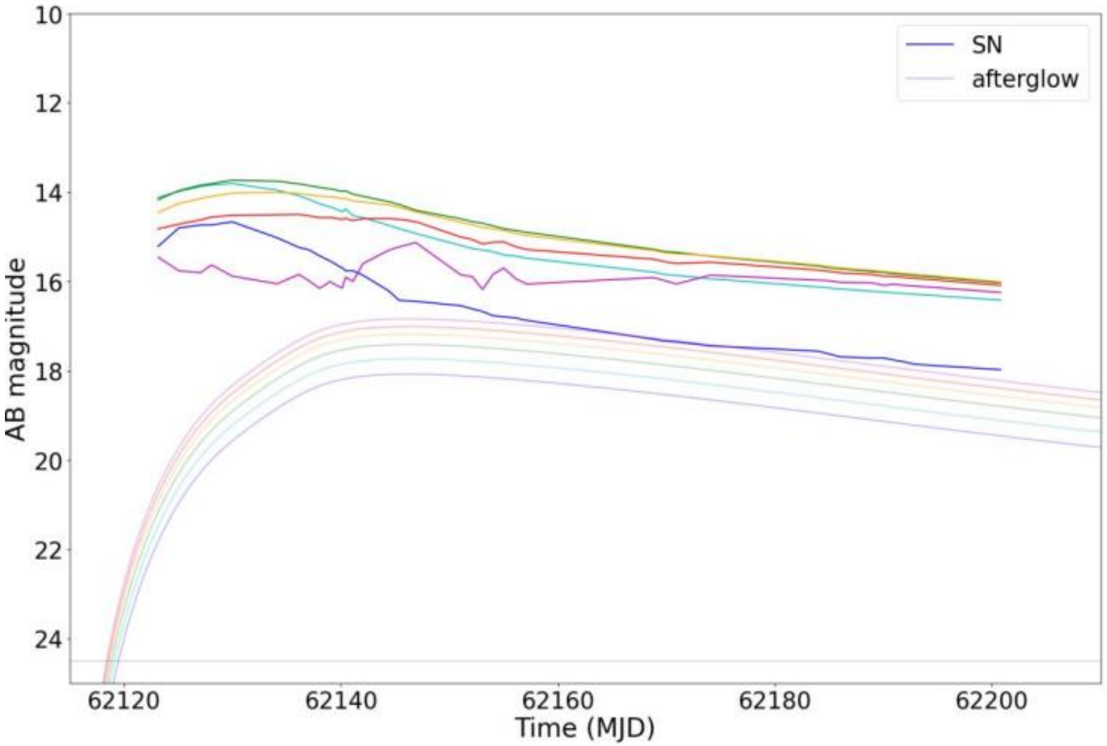

⟹ Orphan light curve "hidden" by the SN light curve
⟹ Impact of the orphan on the SN light curve seen at later times

OVERLAP WITH SUPERNOVA AND KILONOVA LIGHT CURVES

KILONOVA (KN) AND SUPERNOVA (SN) OVERLAP

STILL IN PROGRESS

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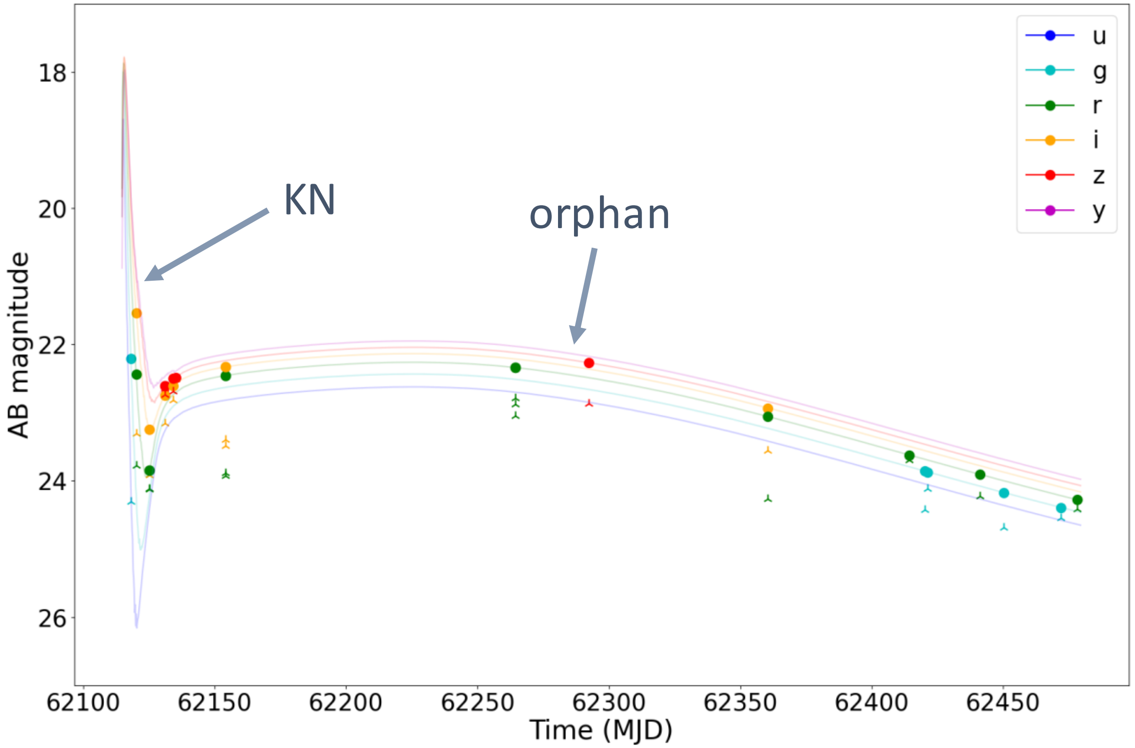


⟹ KN light curve may appear at early times

⟹ Quantify impact of KN on light curve features

CONCLUSION & PERSPECTIVES

All the codes can be accessible on GitLab

CONCLUSION

Simulation of a population of GRBs

- Choose parameter distributions
- Work on a short GRB population based on SBAT4 catalogue STILL IN PROGRESS

Simulation of "pseudo-observations"

- Just a few % of "pseudo-observations" will be observable by the Rubin Observatory
- Expected number of observed orphans by the Rubin LSST **~ 10 orphan/yr** (compatible with Ghirlanda et al. 2015)

Characterize "pseudo-observed" light curve of orphan GRBs

- Compute some features to describe the shape of the light curve and their correlations
- Compare to ELAsTiCC data and define some cuts to discriminate orphans
- Study of the impact of a SN or KN light curve STILL IN PROGRESS

PERSPECTIVES

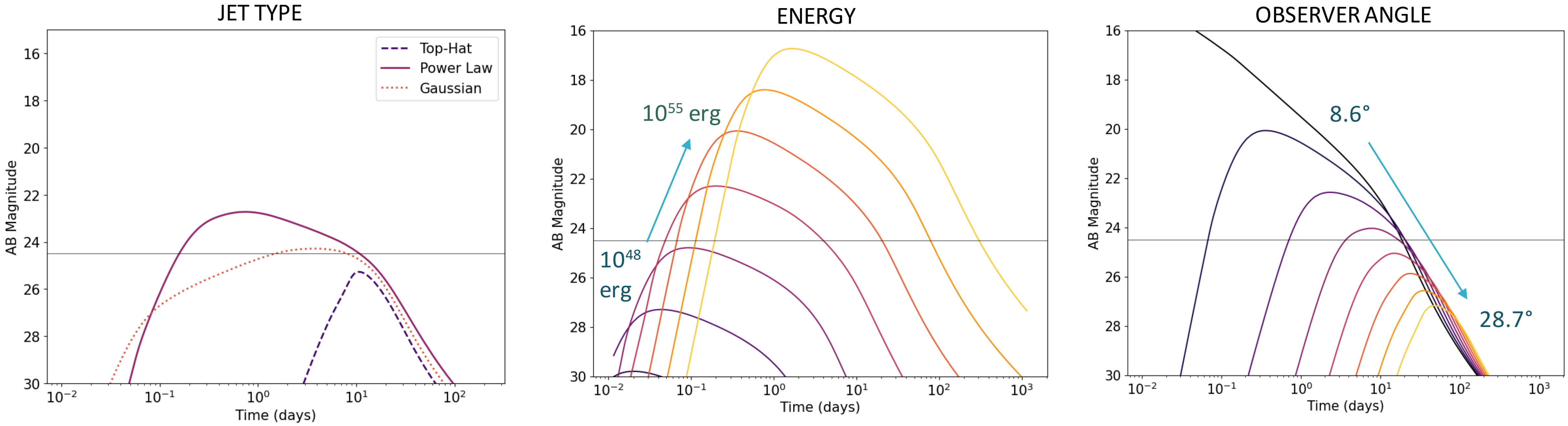
- **Develop a first version of a filter for FINK to identify OAs**

THANK YOU FOR YOUR ATTENTION!

https://github.com/geoffryan/afterglowpy

STUDY OF THE MODEL: PARAMETERS IMPACT

Scan of the model parameters ⟹ study their impact on the observability of the afterglow

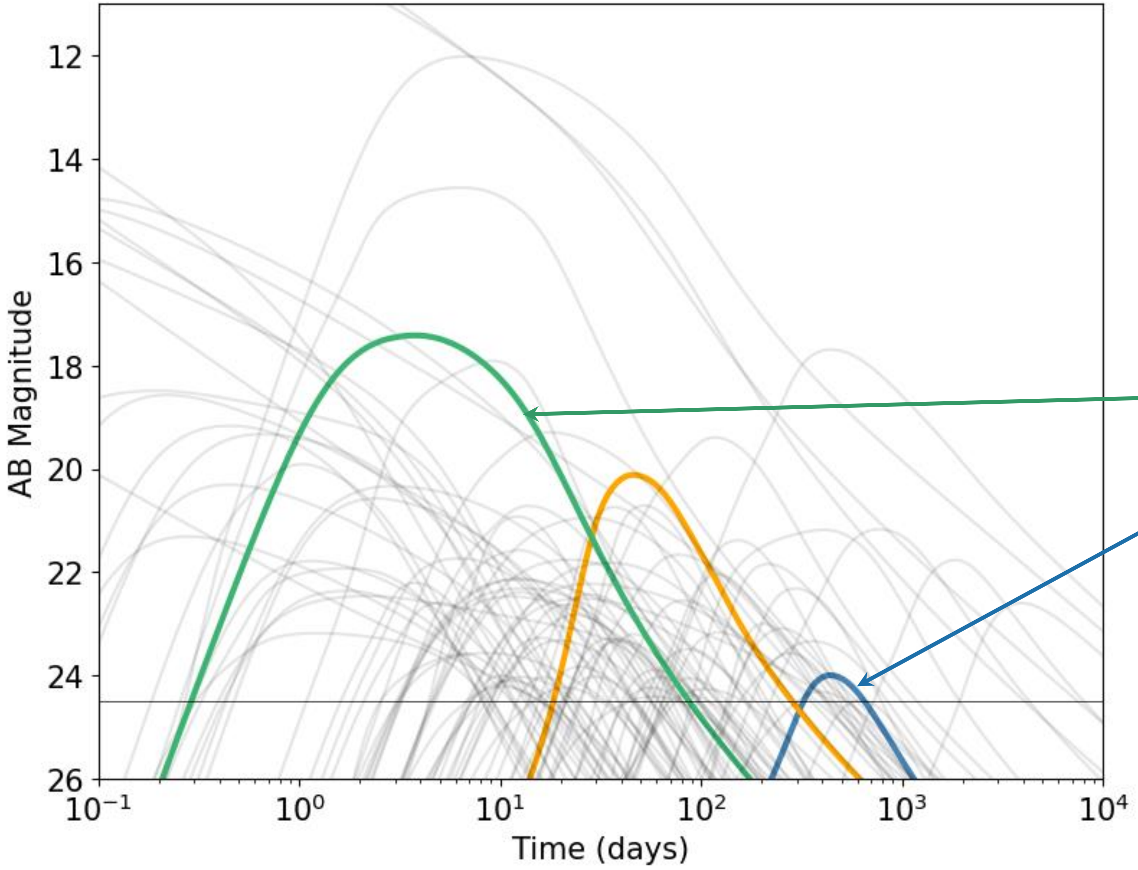


⟹ Some parameters may balance out each other
⟹ The parameters space is very large

ANNEXE 1

https://github.com/geoffryan/afterglowpy

THEORETICAL ORPHAN LIGHT CURVES



Orphans from structured (power-law) jets observable for at least 7 days

Large diversity of light curves:

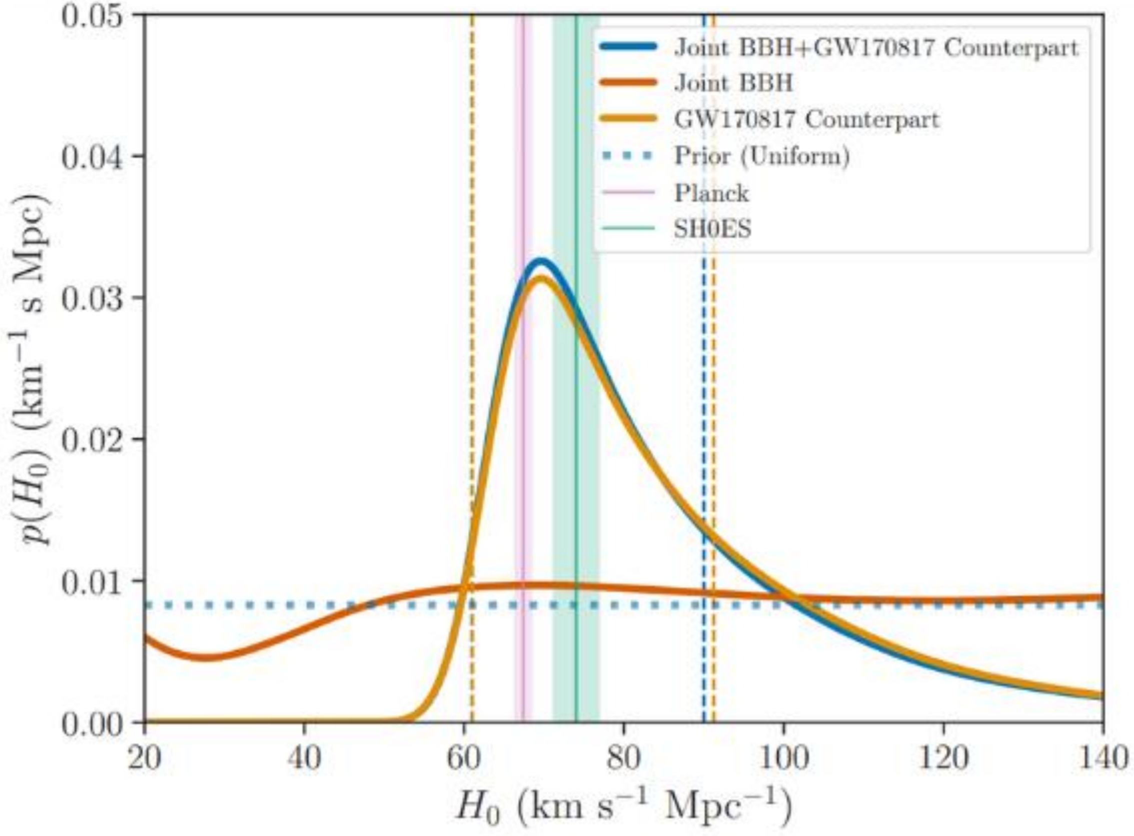
- Bright and short orphans
- Faint and long orphans
- …

⟹ Characterizing orphan light curves will be complex

ANNEXE 2

H0 MEASUREMENT

Abbott et al. 2021 (arXiv:1908.06060)



$$d_L(z) = \frac{c(1+z)}{H_0}\int_0^z \frac{dz'}{\sqrt{\Omega_m(1+z')^3 + \Omega_\Lambda(1+z')^{3(1+w(z'))}}}$$

When z << 1:

$$d_L(z) = \frac{cz}{H_0}$$

ANNEXE 3