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

- *Journées LSST France* -

MARINA MASSON
JOHAN BREGEON

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BRIEF OVERVIEW

1- Scientific context

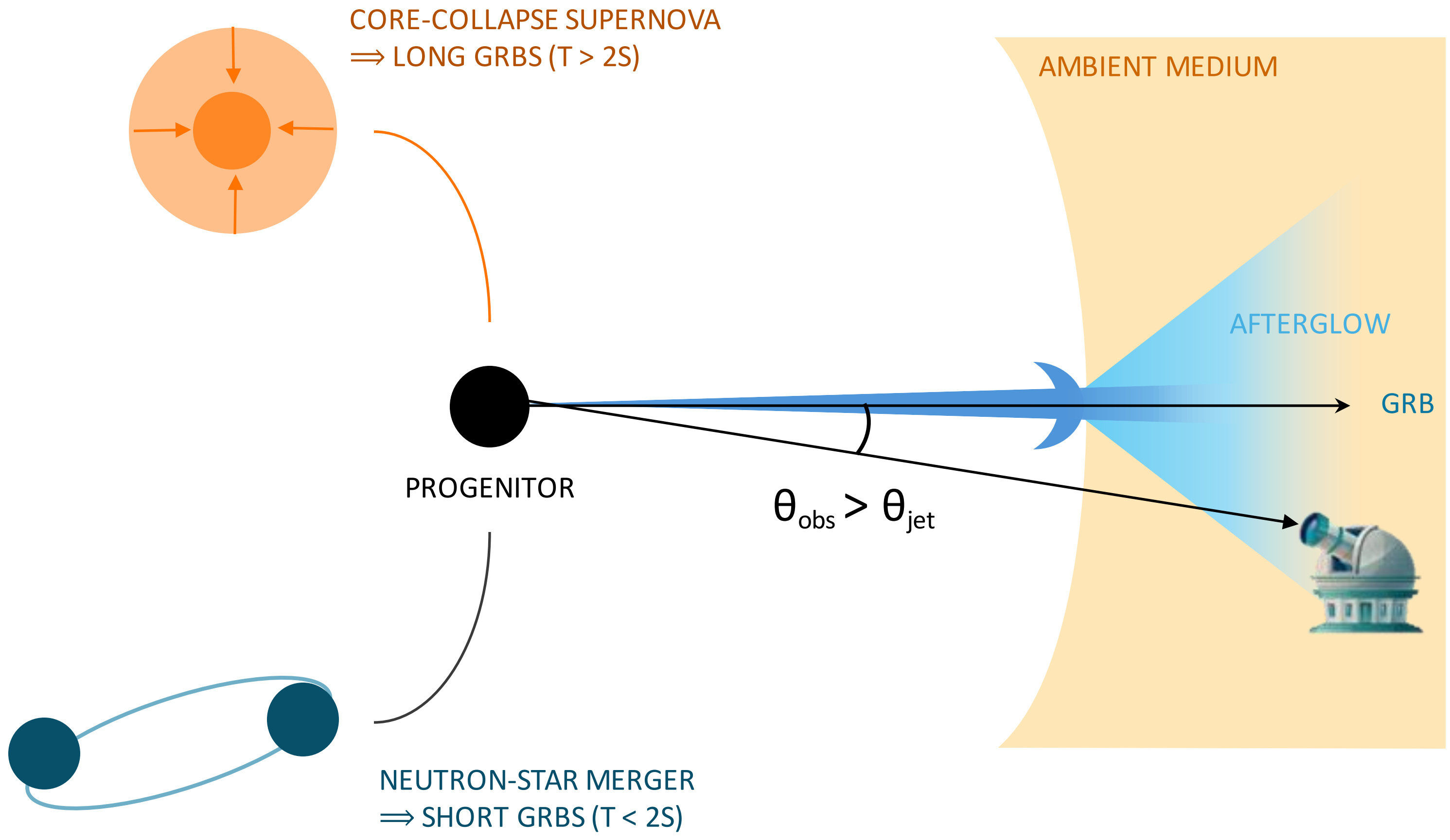
2- Simulation of a population of GRBs and their "pseudo-observations"

3- Characterising "pseudo-observed" light curves

4- Creation of a first version of a filter

5- Conclusions & perspectives

THE ORPHAN AFTERGLOW: A GRB VIEWED OFF-AXIS



GRB (prompt emission) = short and highly energetic (~ 10^{51} erg) gamma-ray flashes (observed with Fermi or Swift in keV – GeV)

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)

MOTIVATIONS

Goal = To implement a filter in FINK to identify orphan afterglows in the Rubin LSST data

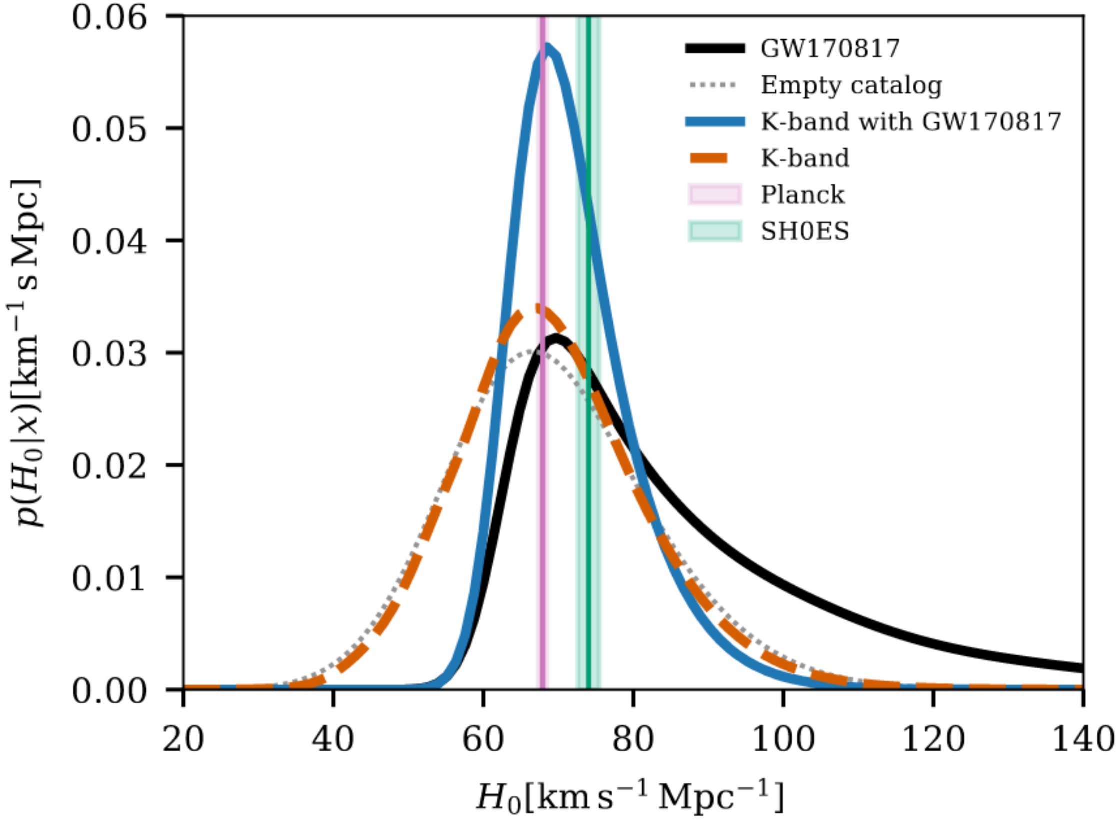
Why study orphan afterglows?

- More information on the **GRB physics and their progenitors** (acceleration of particles, jet formation and structure...)

- **Multi-messenger analysis with gravitational waves:** separate measure of the distance and the redshift to calculate the Hubble constant H0

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

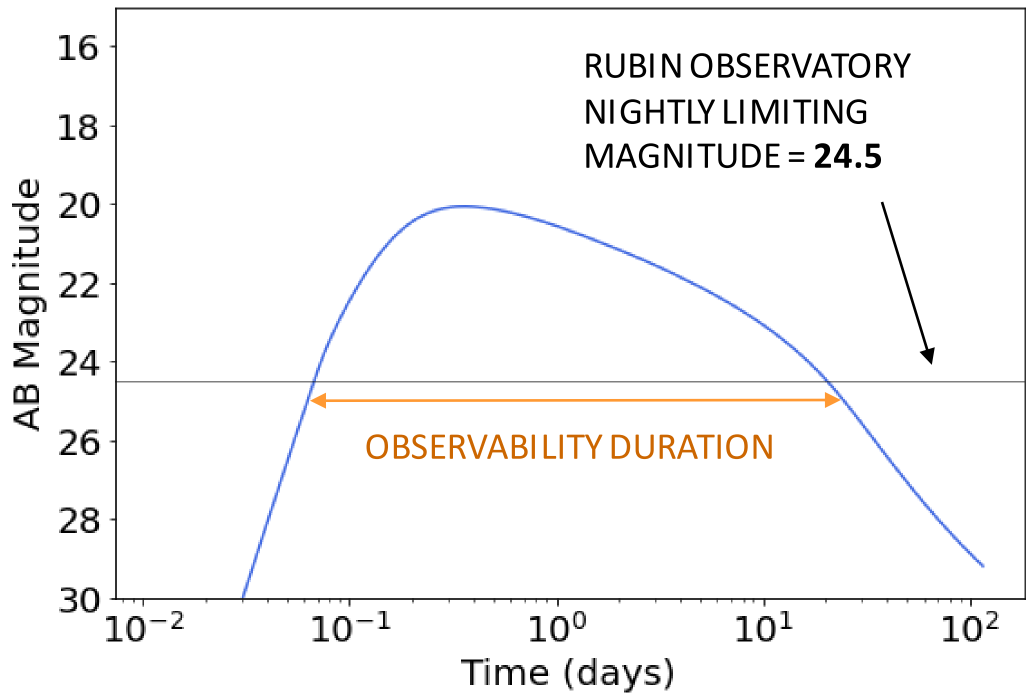
Abbott et al. 2021



https://github.com/geoffryan/afterglowpy

MODEL OF GRB AFTERGLOW EMISSION

Identification of orphans based on their light curve



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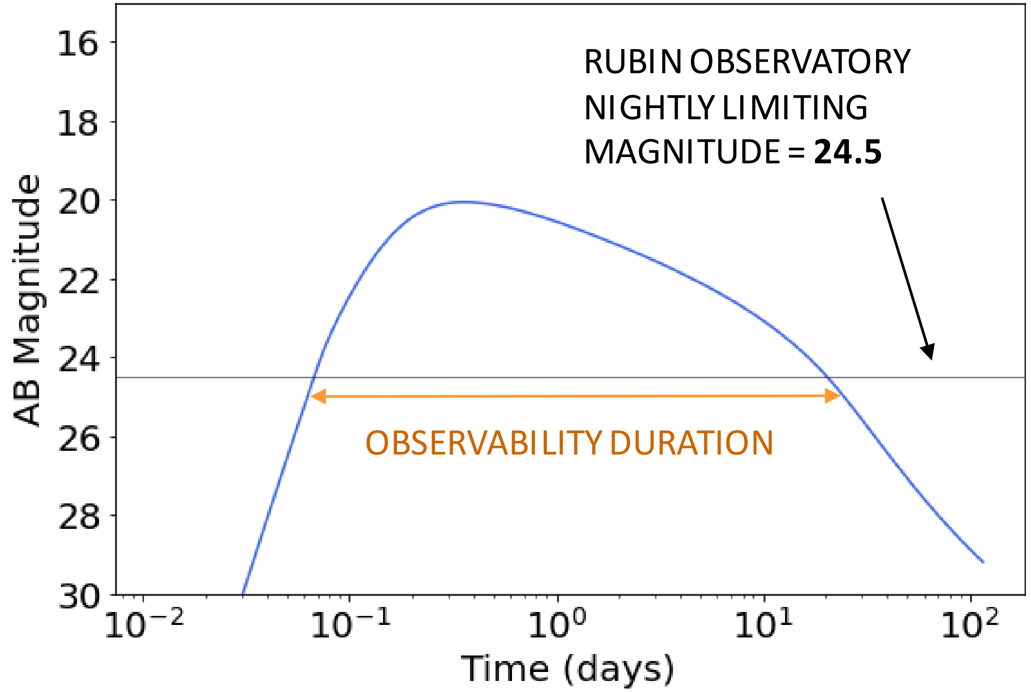
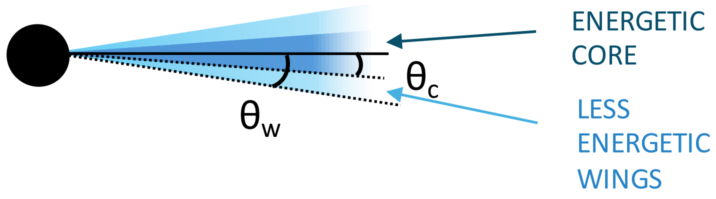


Forward shock model
+ electron synchrotron model
(Van Eerten et al. 2010)

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



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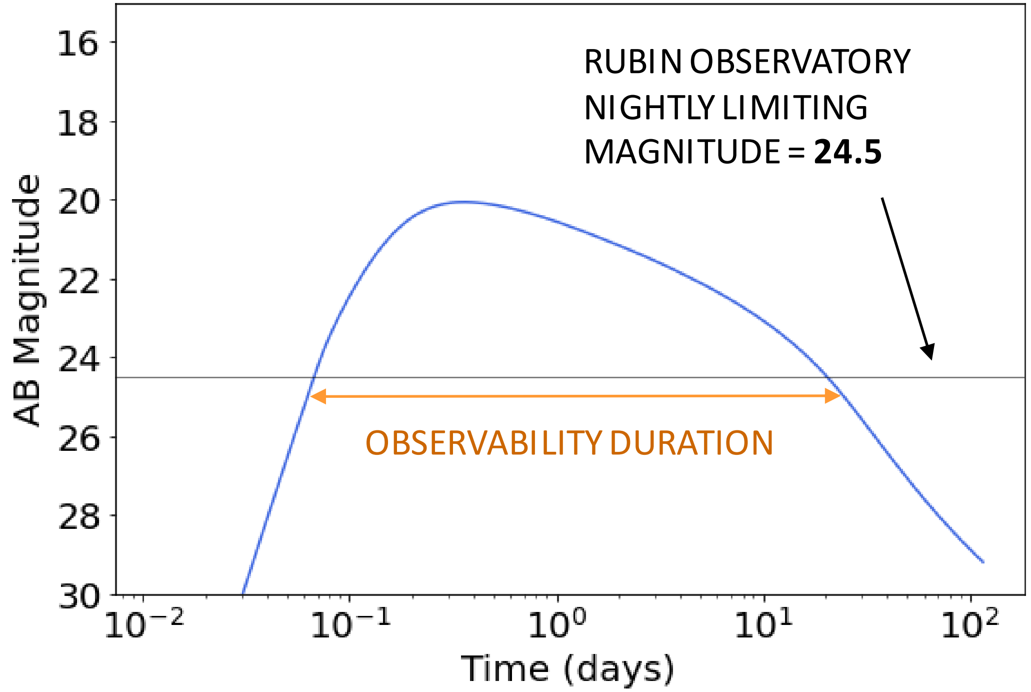

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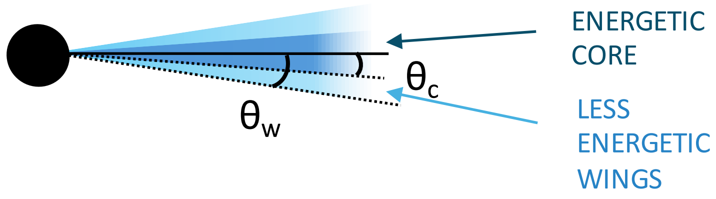
⟹ Need some parameters distributions!



POPULATION OF GRBS BASED ON SBAT4 AND BAT6 CATALOGUES

Goal: To simulate somewhat realistic distributions for GRBs

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

- Detected in the **15-150 keV energy band**
- Selection criteria: peak flux $\mathbf{PF_{64} > 3.5\ ph/s/cm^2}$

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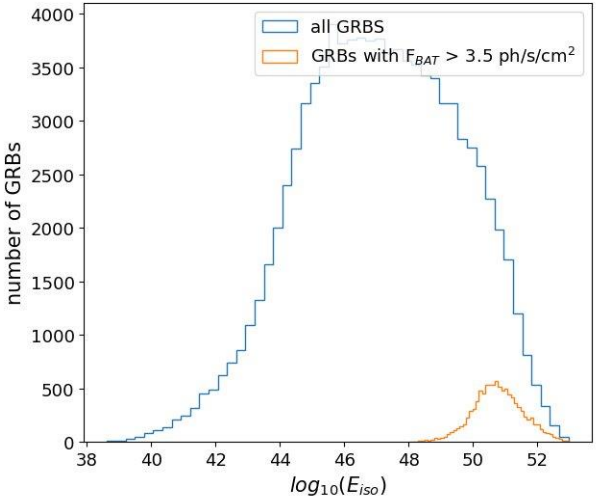
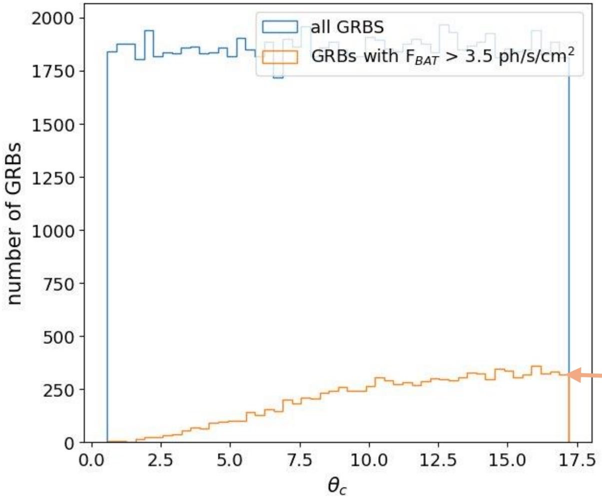
ENERGY E_{iso} (log)



CORE ANGLE θ_c



Generate configurations of parameters:
- Power-Law jet
- $log(E_c)$ uniform between 47 and 55
- θ_c uniform between 0 and 17.5°
- z ~ SFR

↓

Compute on-axis prompt emission flux

↓

GRBs with peak flux > 3.5 ph/s/cm^2

↓

~ SBAT4 GRB population

POPULATION OF GRBS BASED ON SBAT4 AND BAT6 CATALOGUES

~ SBAT4 GRB population

↓

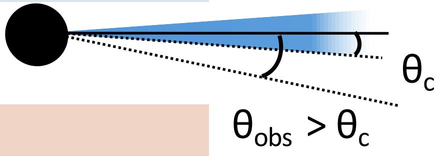
Compute afterglow flux in Fermi GBM band

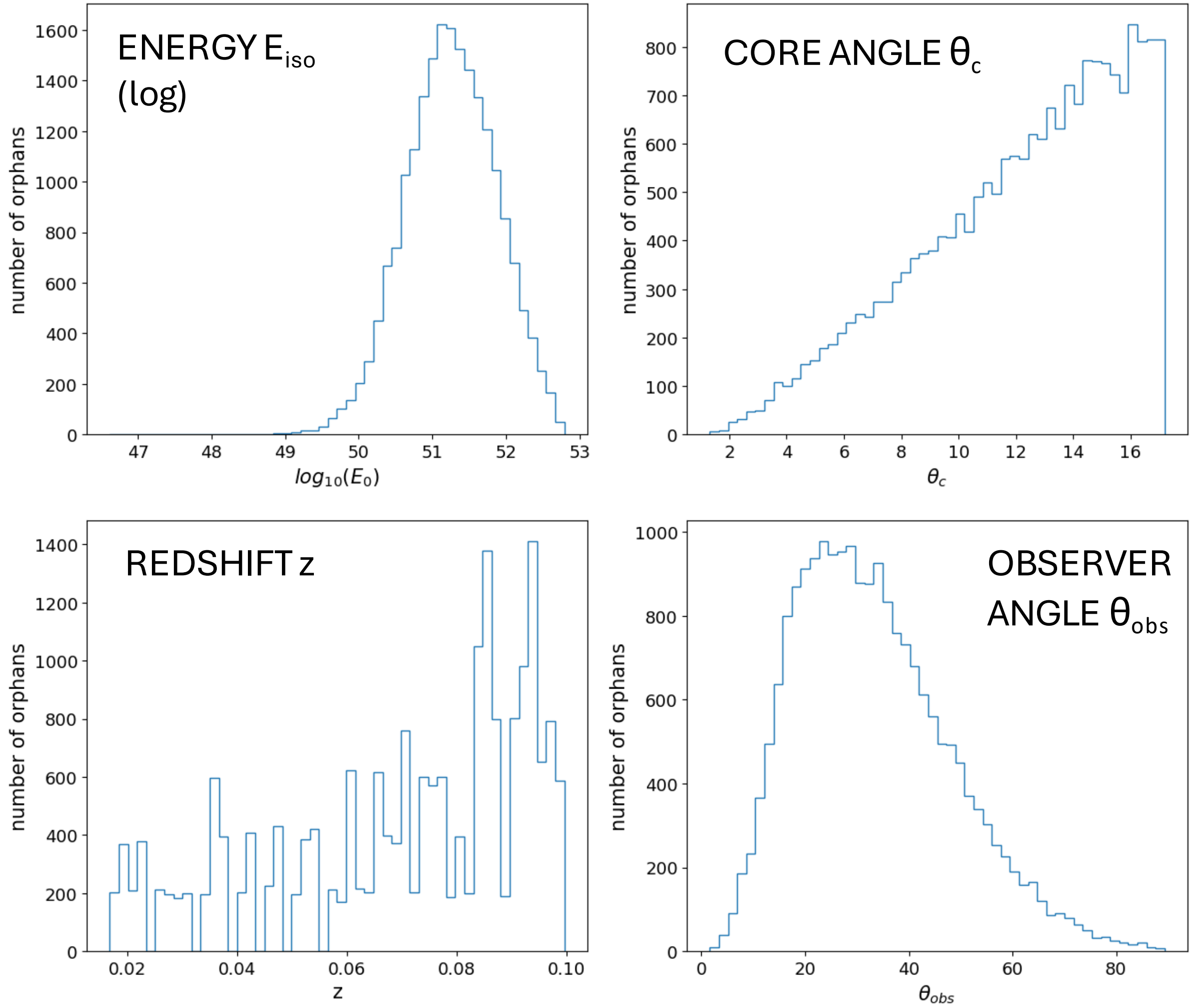
↓

Afterglows with flux < 0.5 ph/s/cm²* and $\theta_c < \theta_{obs}$ and $z < 0.1$

↓

~ SBAT4 orphan GRB population





* Fermi GBM minimal detection flux

POPULATION OF GRBS BASED ON THE SBAT4 AND BAT6 CATALOGUES

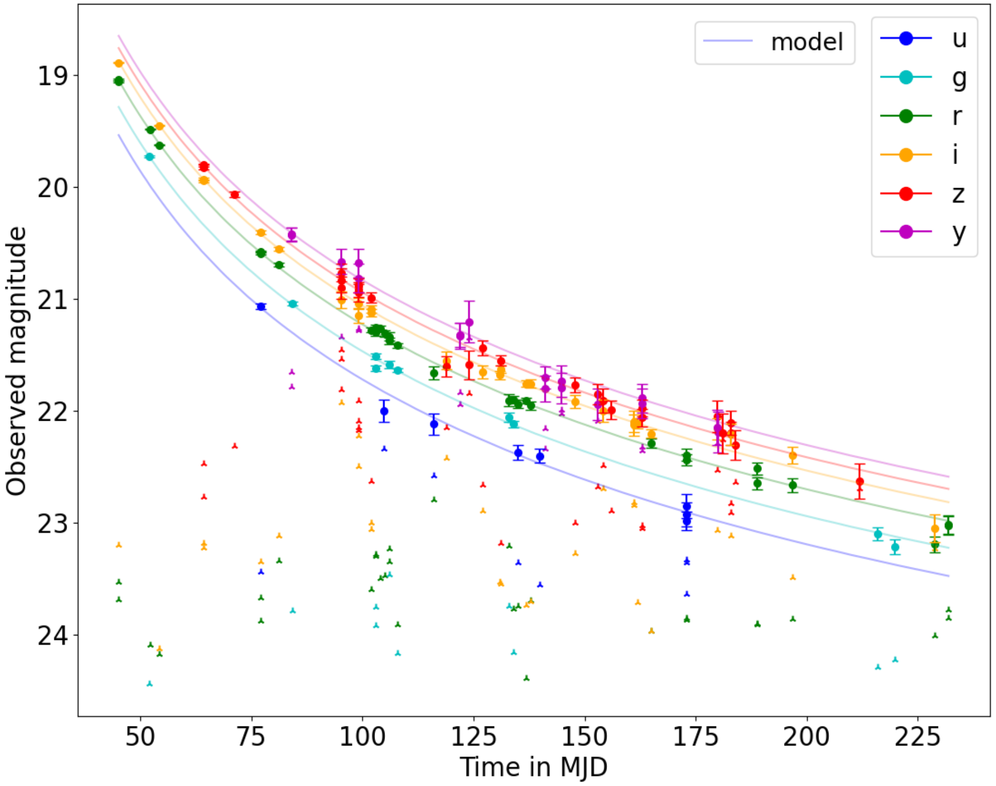
rubin_sim package ⟹ Realisation of the scheduler simulation for the 10 years of LSST (https://github.com/lsst/rubin_sim)

GRB date: 12 March, 2030

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

Parameters:

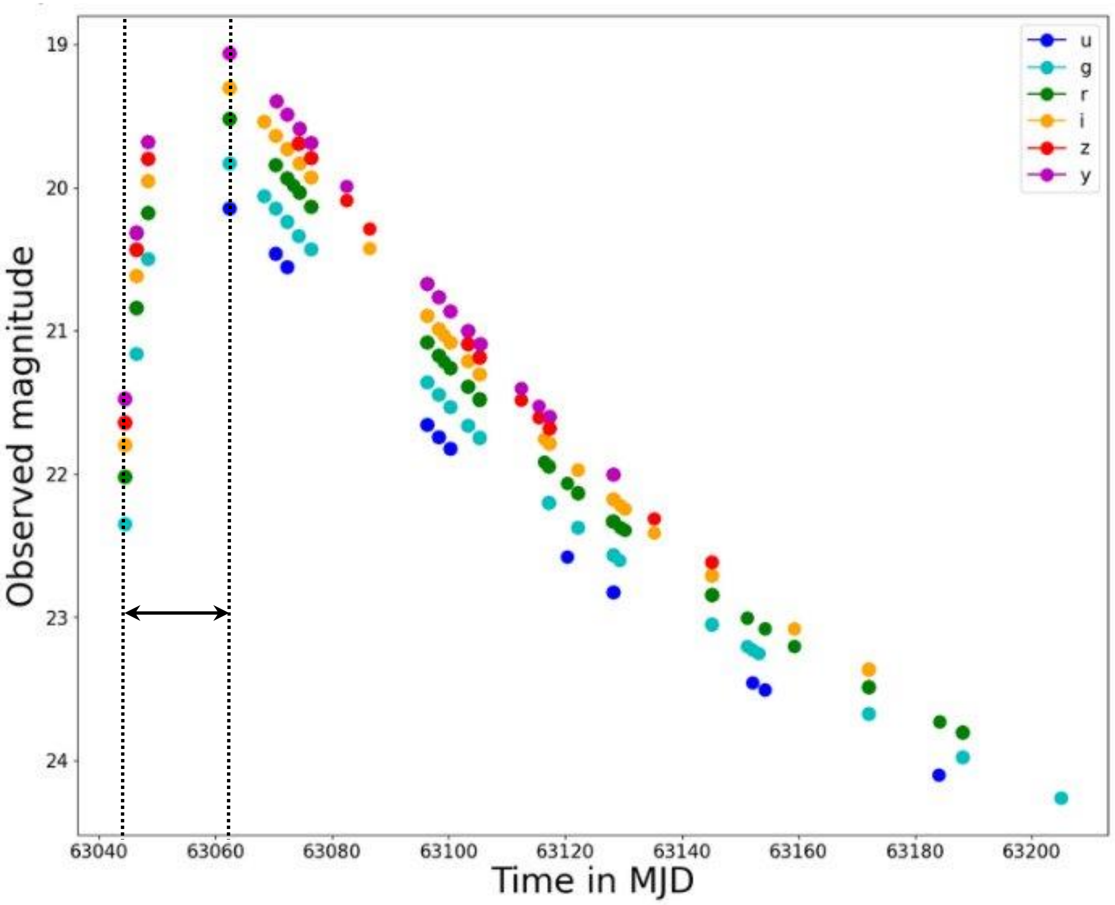
- Power-Law jet
- E_{iso} = 1.3 x 10^{52} erg
- θ_{obs} = 21.2 °
- θ_c = 2.9°
- θ_w = 8.6°
- n_0 = 0.45 cm^{-3}
- z = 0.001



⟹ Fraction of "pseudo-observable" orphans by the Rubin Observatory: ~4 %

PSEUDO-OBSERVATION ANALYSIS

CHARACTERISATION OF LIGHT CURVES



Defined features:

- **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 colour (expected value for synchrotron emission ~ 0.3)

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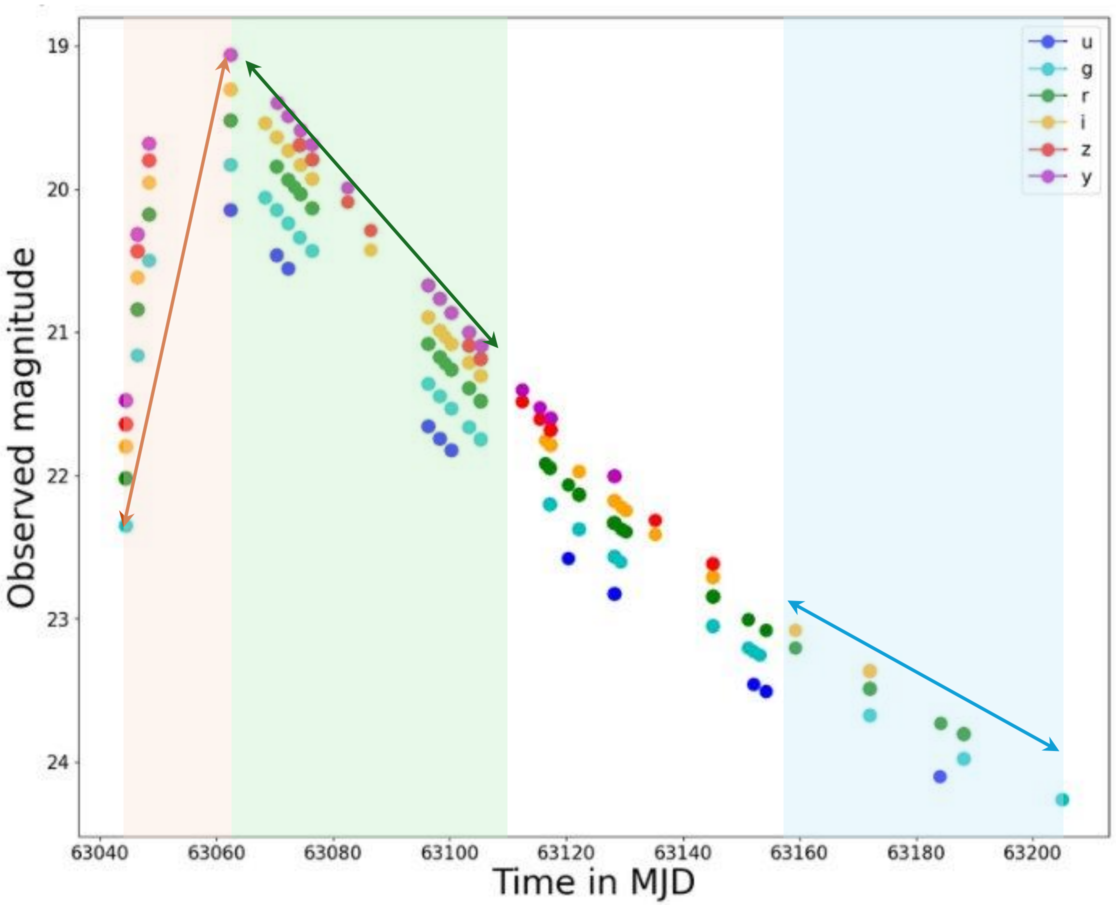

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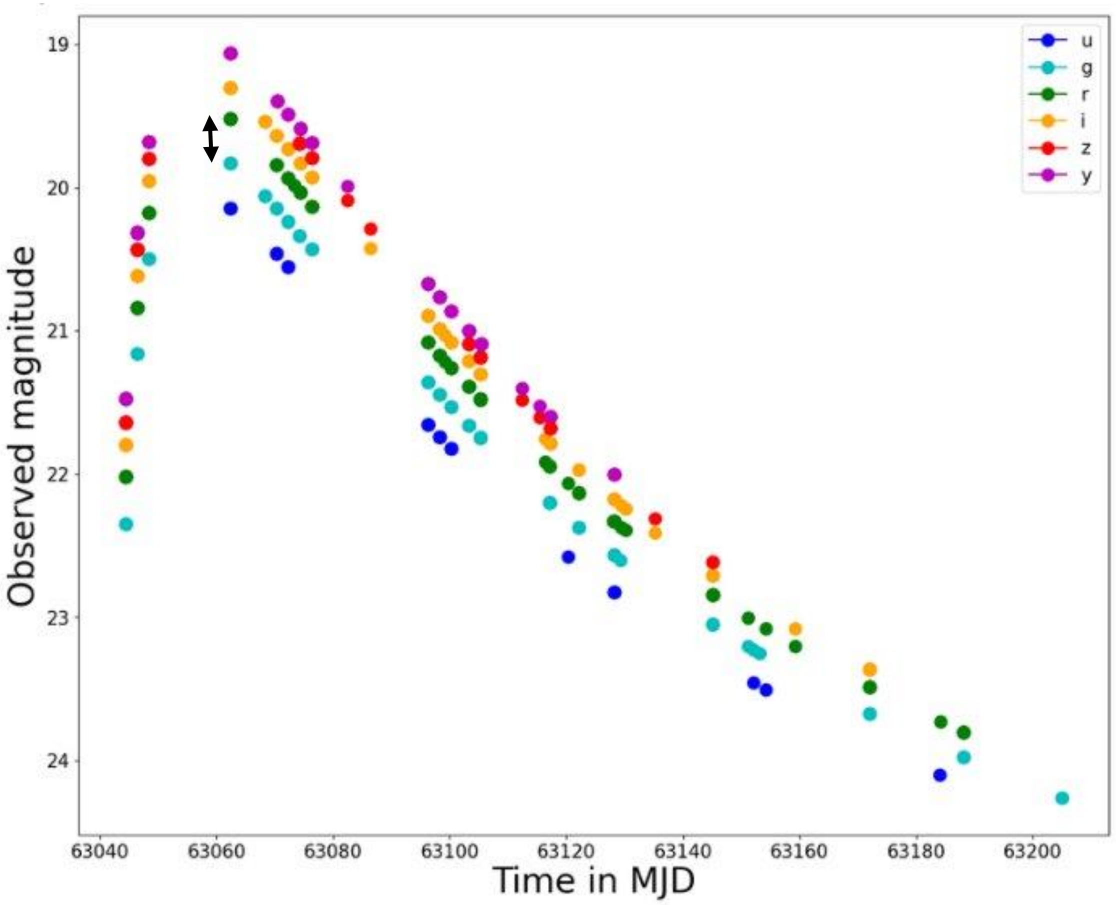

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RESCALING DATA TO THE R-BAND

Fit data with a function with free parameters (Russeil et al. (arXiv:2402.04298)):

$$mag(t) = A \times t + B + C \times \exp(-D \times t)$$

Points are rescaled to be on the r-band

RESCALING DATA TO THE R-BAND

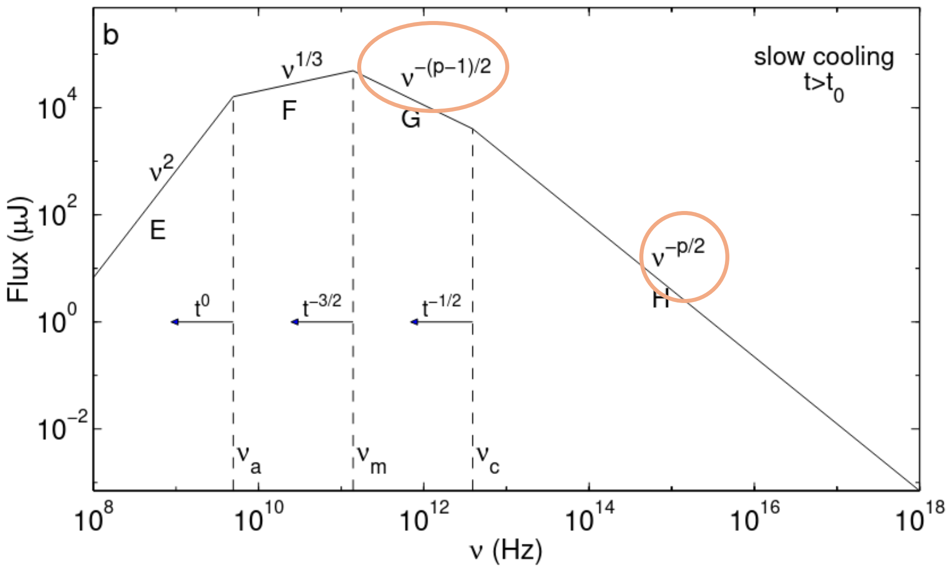
$F_\nu \propto \nu^{-\beta}$

β spectral index

- β = -(p-1)/2 when $\nu_m < \nu < \nu_c$
- β = -p/2 when $\nu_c < \nu$

ν_c decreases with time $\Longrightarrow$ we don't know which value of β we have to use

Sari & Piran 1998



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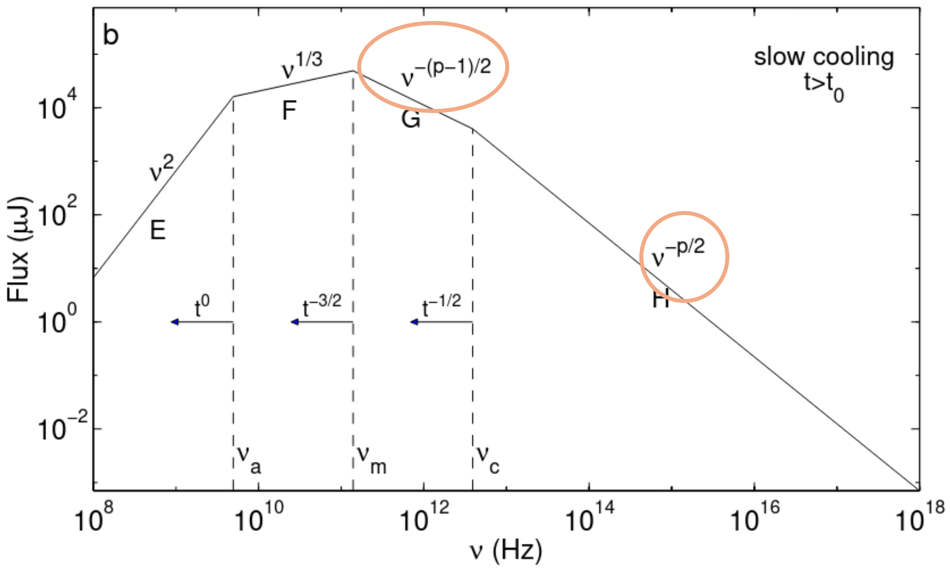

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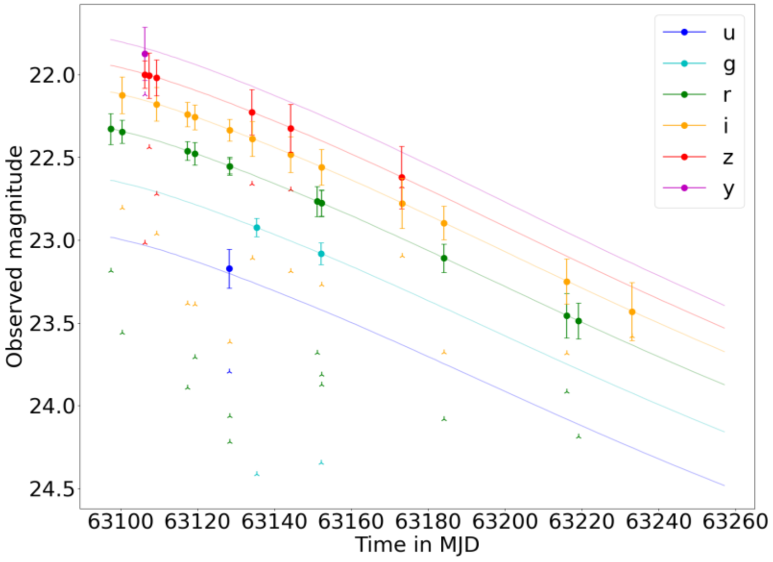
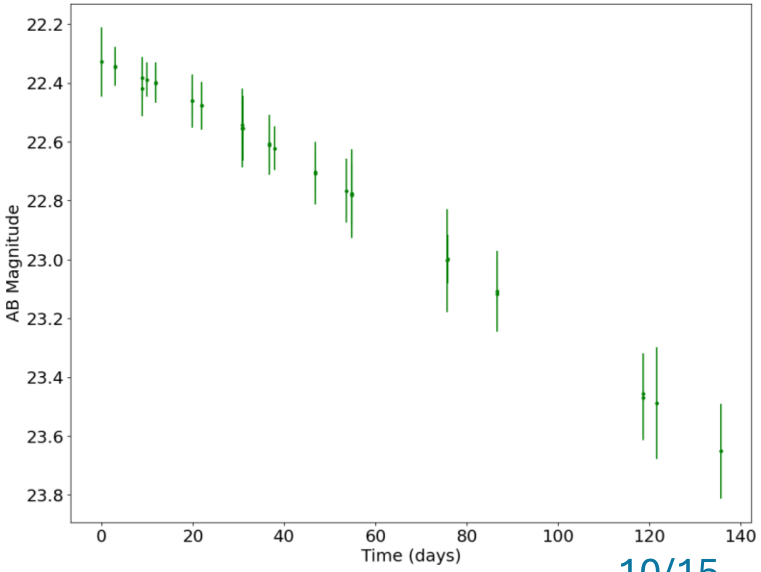
What we do:

1. Test several values of β between -(p-1)/2 and -p/2

2. Keep the one that minimize the distance between the re-scaled points and the true r-band points





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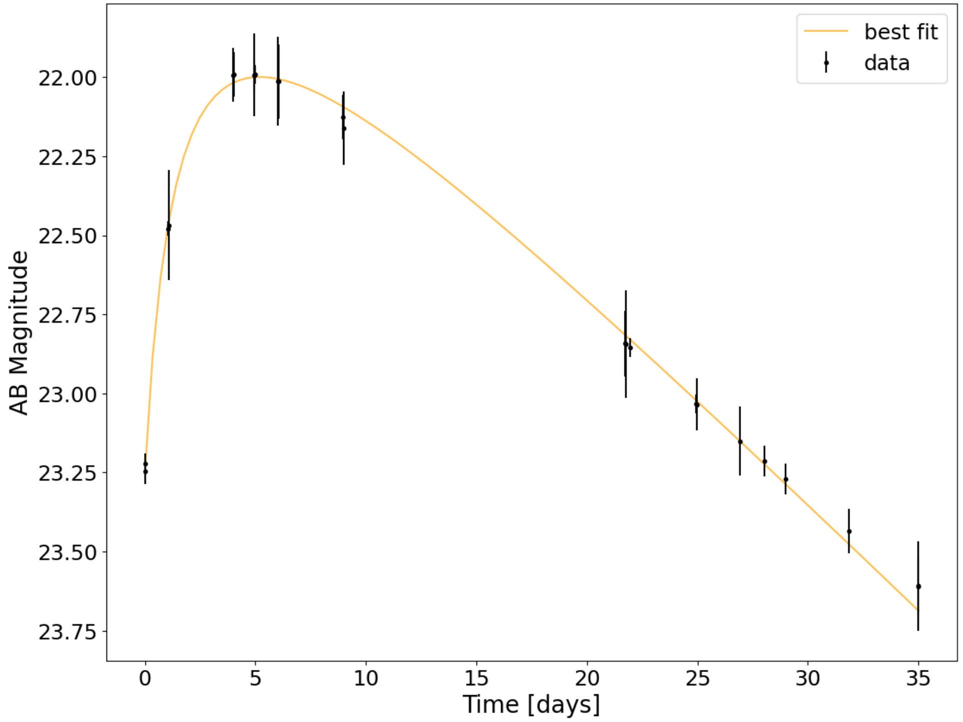


All features used to characterize one event:

$(t_{peak}-t_0)$	Increase rate	Decrease rate (1/3)	Decrease rate (3/3)	Colour	A	B	C	D	χ^2

FIRST VERSION OF A FILTER

USING ELASTICC DATA AS A BACKGROUND

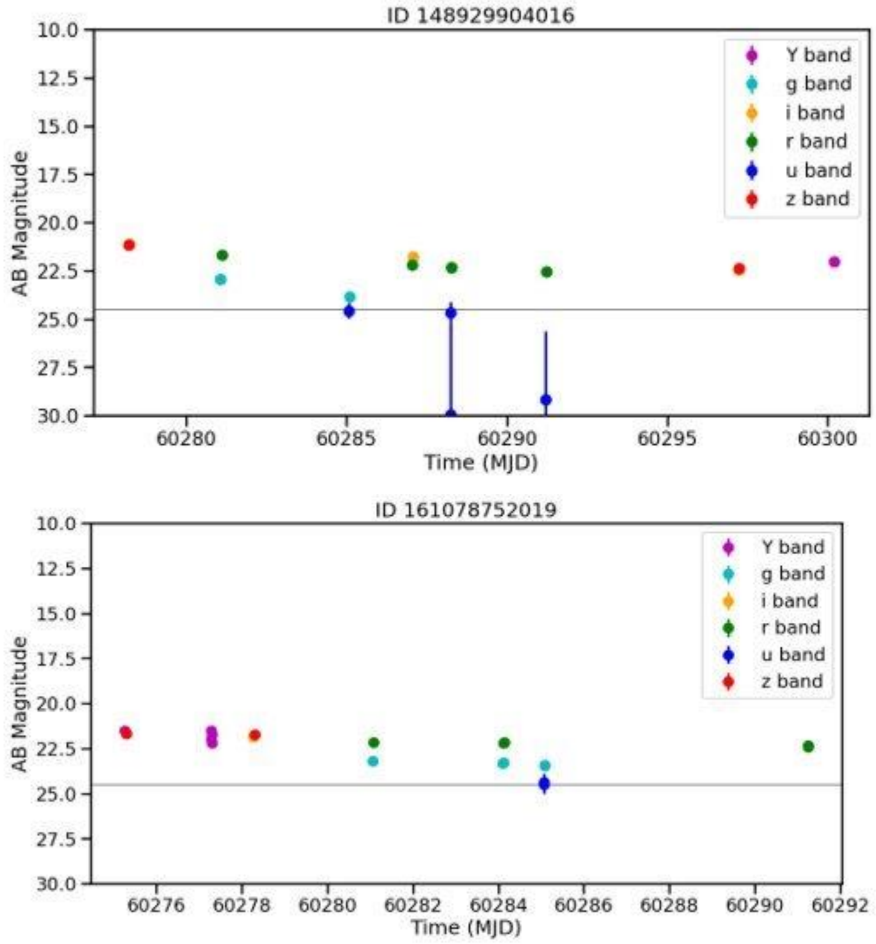
https://portal.nersc.gov/cfs/lsst/DESC_TD_PUBLIC/ELASTICC/

ELAsTiCC = DESC simulation of LSST alerts (**E**xtended **L**SST **A**stronomical **T**ime-**S**eries **C**lassification **C**hallenge)

Synthetic transient light curves and host galaxies for:

- Supernovae
- Active galactic nuclei
- Tidal disruption events
- Kilonovae
- M-dwarf flares
- Cepheid variables
- ...
- **But no orphans!**

⟹ Create a realistic data stream to test broker alert systems and classifiers



EXAMPLES OF ELASTICC LIGHT CURVES

FIRST TEST OF A MACHINE LEARNING ALGORITHM

TRAINING

500 orphans
5000 ELAsTiCC events

(only non-periodic events)

→ **features** →

ML CLASSIFIER
`scikit.learn` Gradient Boosting Classifier

→

TESTING

2026 orphans
442348 ELAsTiCC events

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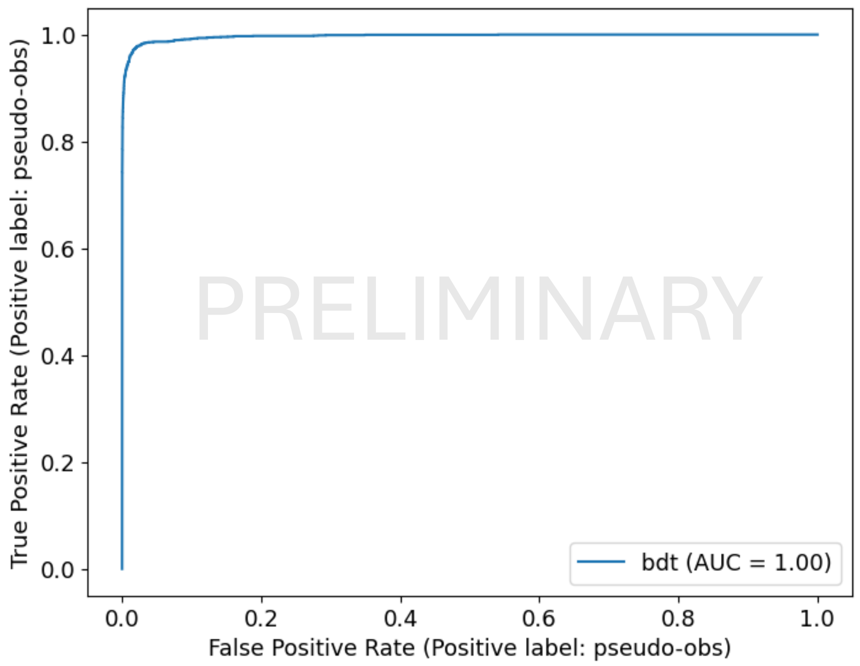
2026 orphans
442348 ELAsTiCC events

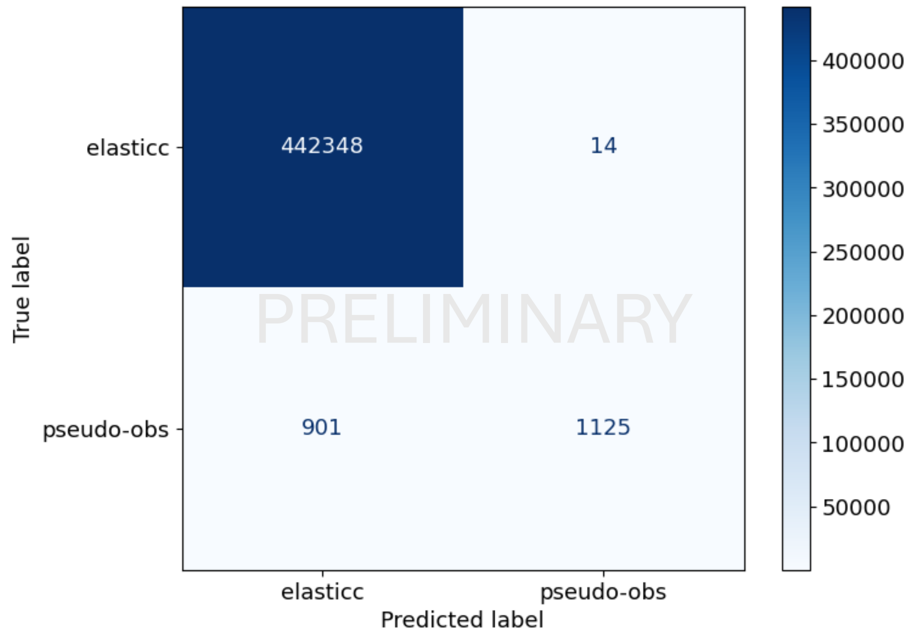
proba > 0.999

PRELIMINARY

1125/2026 orphans
14/442348 ELAsTiCC

(only non-periodic events)





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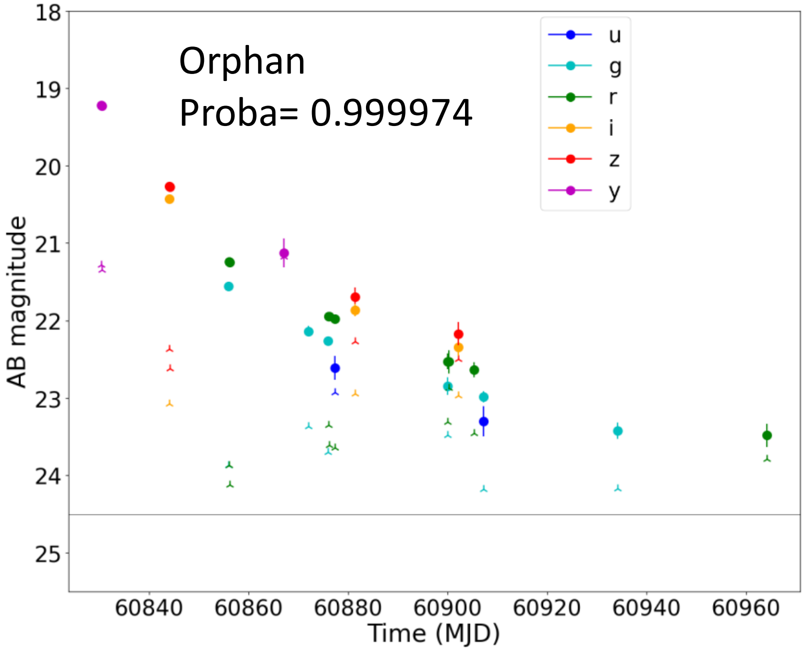

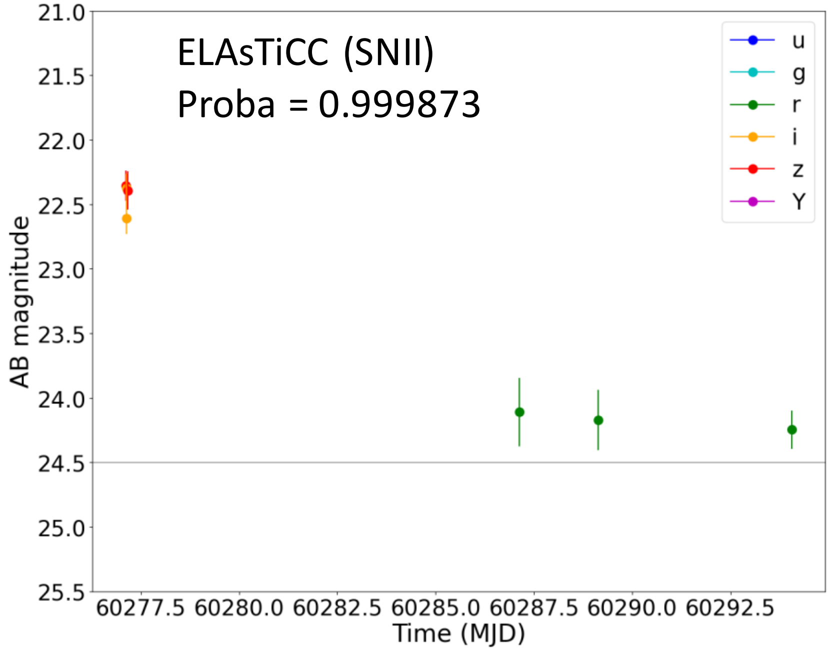

CONCLUSION & PERSPECTIVES

GOAL Implement a filter in FINK to identify orphan GRBs among Rubin LSST data

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Simulation of a population of GRBs based on Swift BAT catalogues

Characterise "pseudo-observed" light curve of orphan GRBs

Create ML filter to discriminate orphan among LSST data

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NEXT STEPS

- Adapt our filter and test it on ZTF data
- Discussion with IJCLab on GW-orphan joint detection

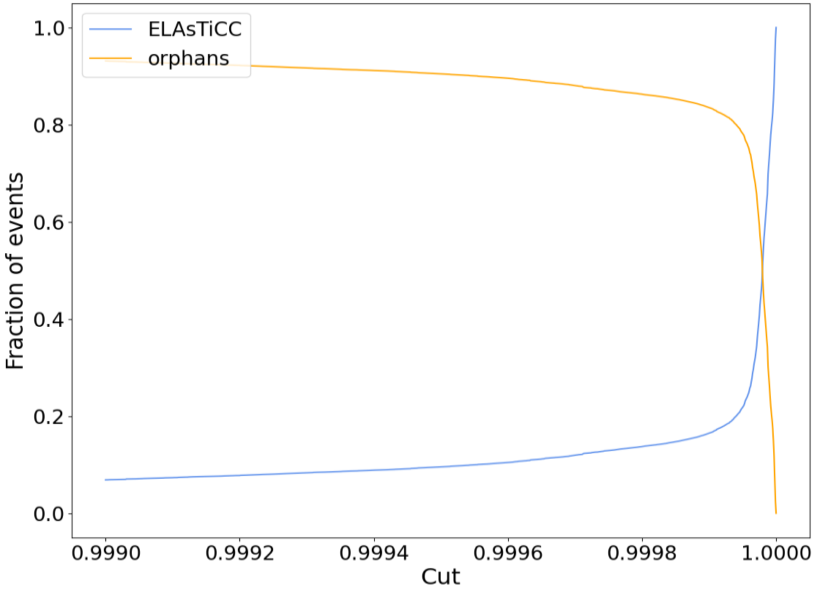
THANK YOU FOR YOUR ATTENTION!

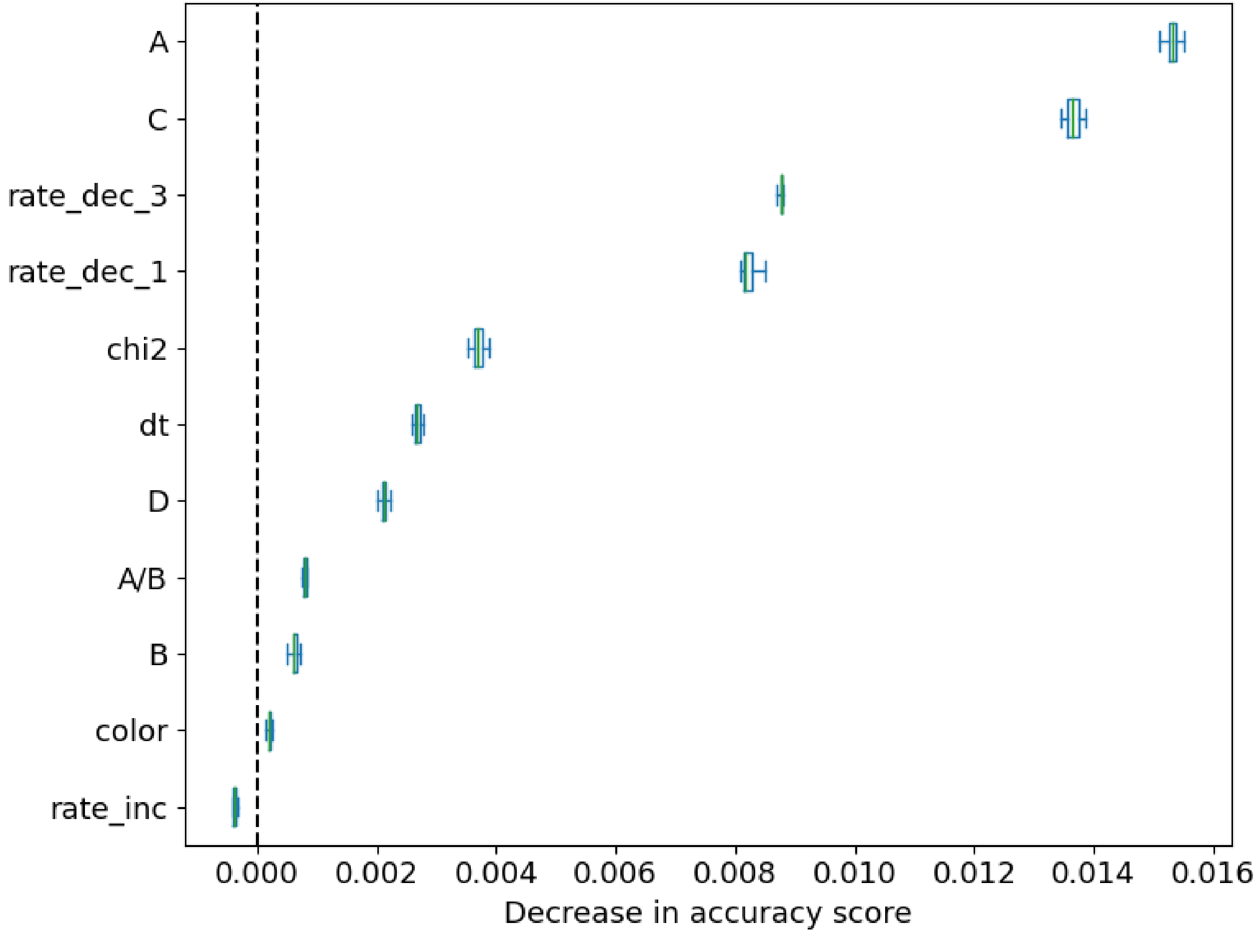
BACKUP SLIDES

MORE DETAILS ON THE CLASSIFIER

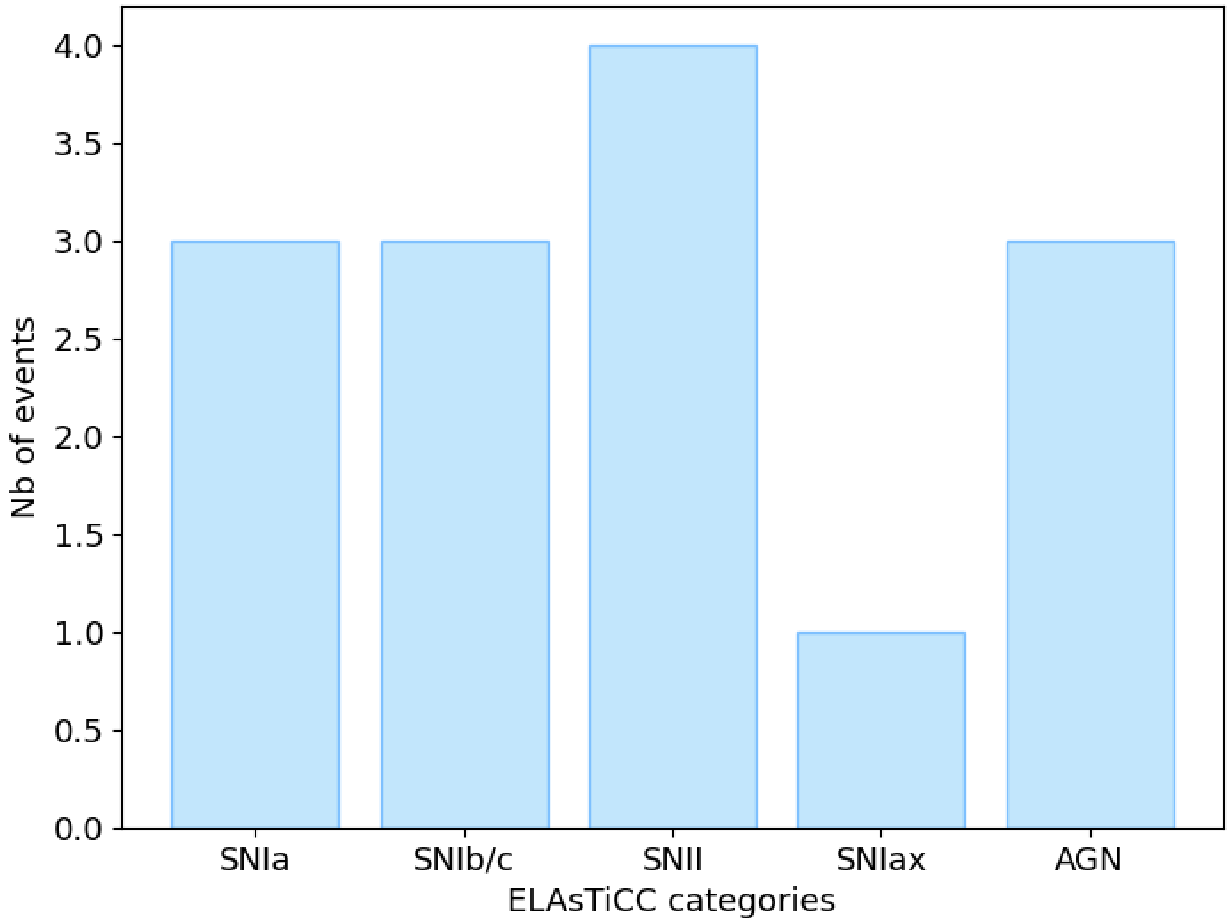
HYPER PARAMETERS

150 decision trees
learning_rate = 0.1
max_depth = 5





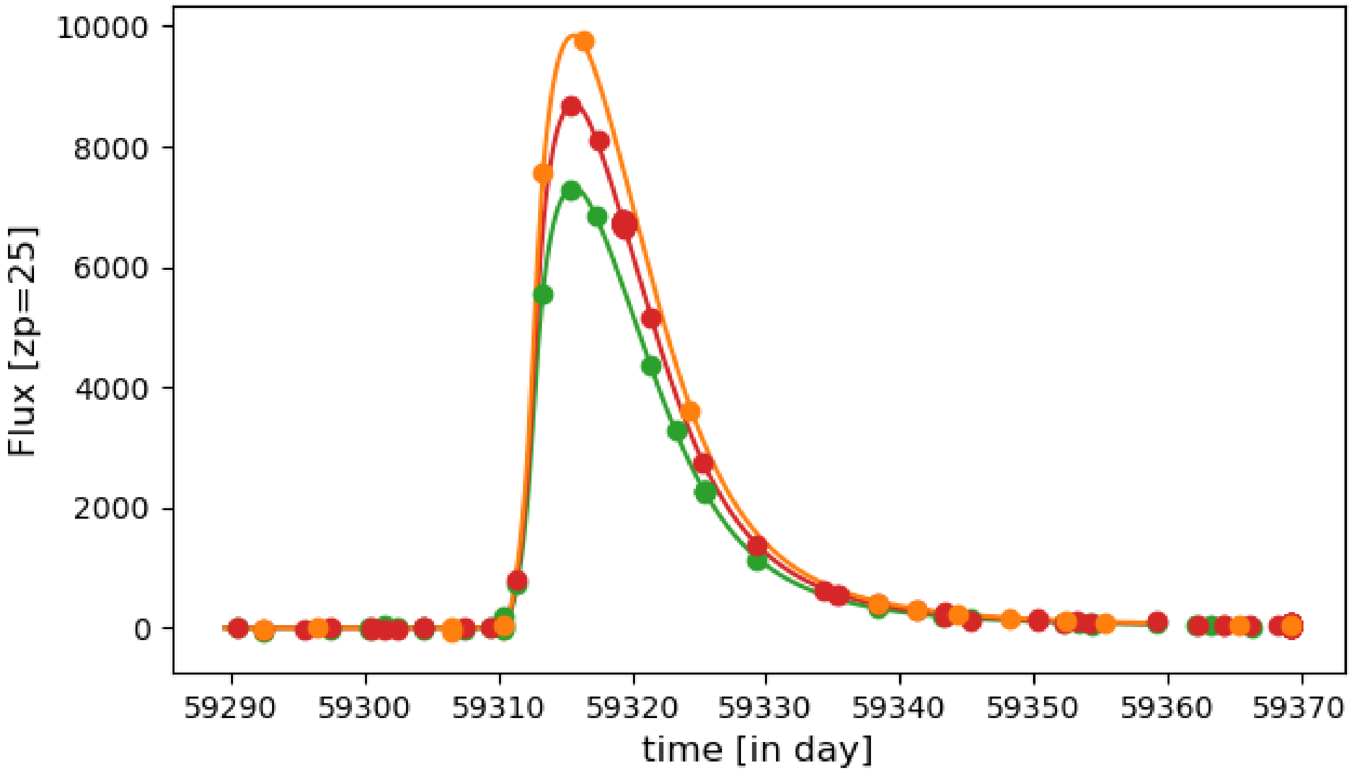
CLASSIFICATION OF THE ELASTICC EVENTS



LOOKING INTO ZTF DATA

skysurvey package ⟹ Simulate astronomical targets as they would be observed by a survey (https://github.com/MickaelRigault/skysurvey)

Survey	Nightly limiting magnitude (r-band)	Filters	FOV (deg^2)	Cadence
LSST	24.5	u, g, r, i, z, y	9.6	3-night
ZTF	**20.5**	**g, r, i**	**47**	**2-night**



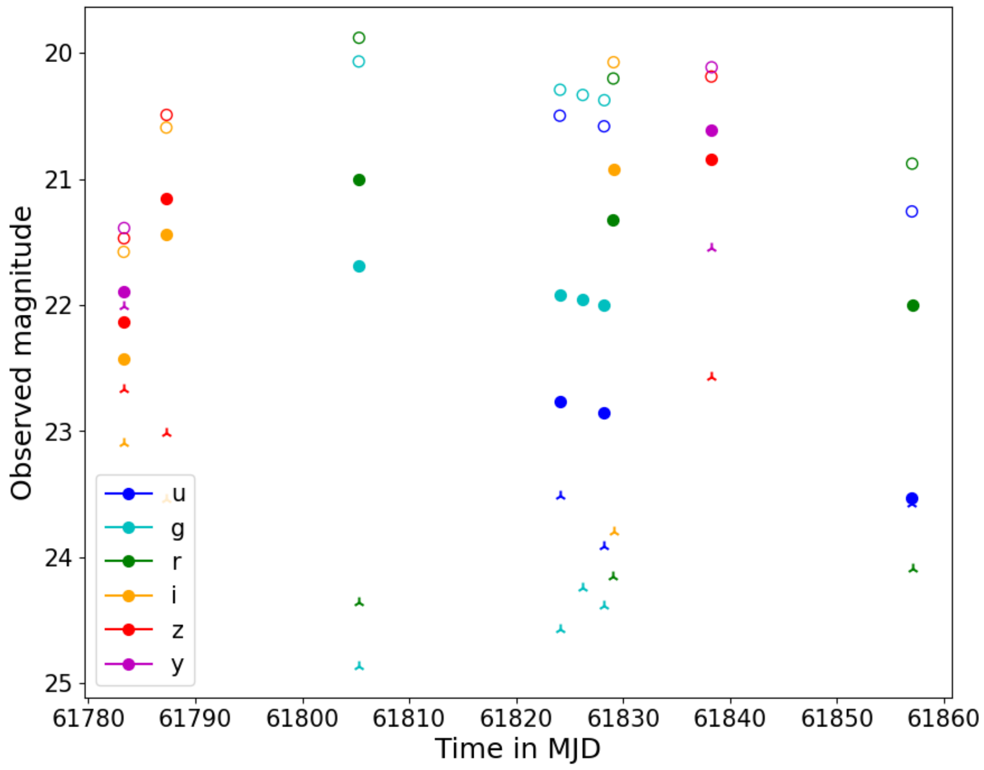
GRAVITATIONAL WAVE COUNTERPART

- Specific analysis needed because we have a precise position but large uncertainties on T_0 for orphans
- GWTC-3 catalogue all-sky triggers: given a position, look for synchronised GW signals
- How the size of the time window for the PyCBC coherent analysis impacts the number of detected events?

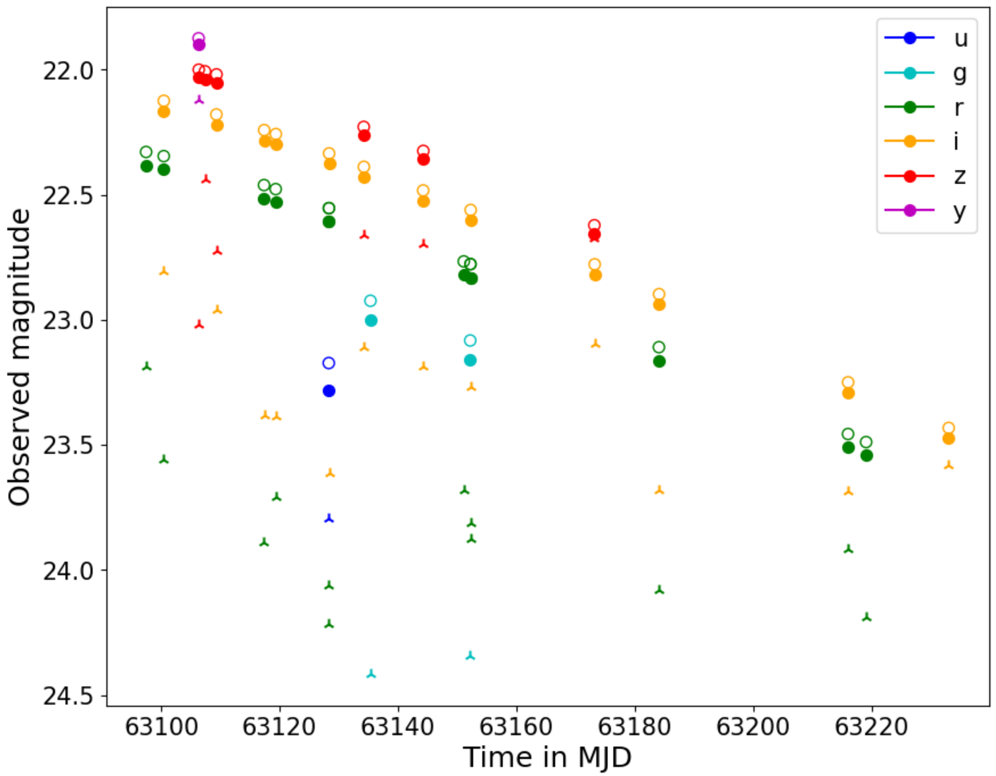
HOST EXTINCTION

○ Without extinction
● With extinction

Host extinction more important for long GRBs than for short GRBs

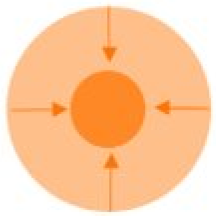


LONG



SHORT

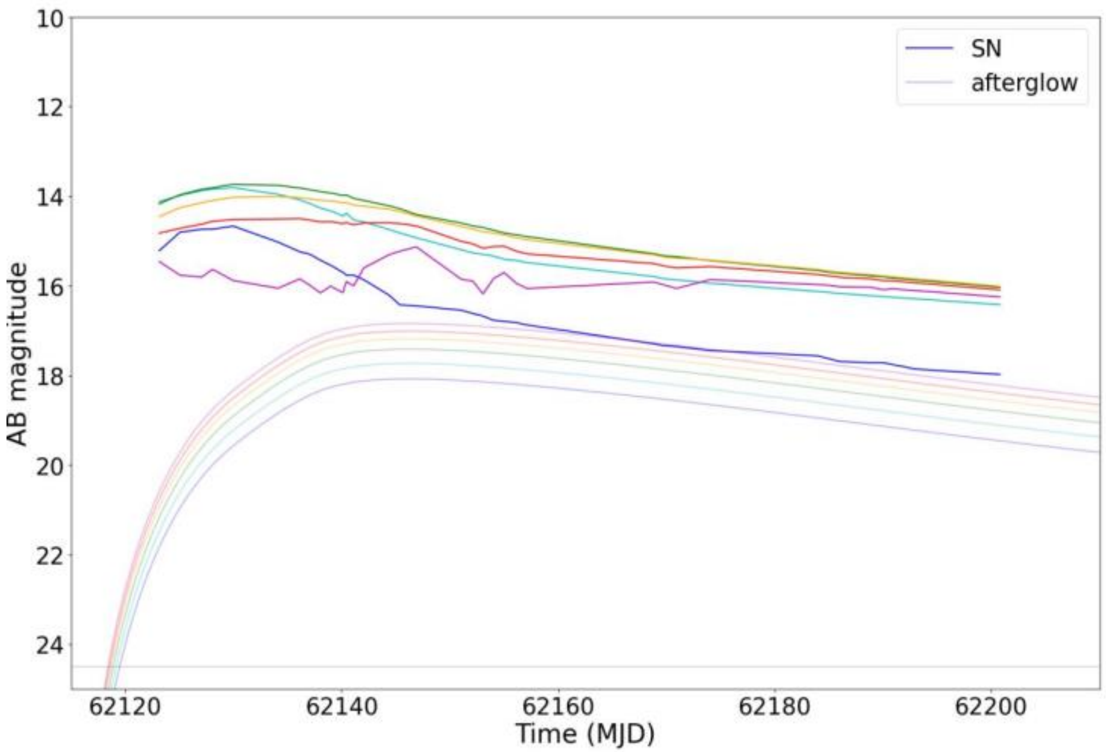
SUPERNOVA OVERLAP



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

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

Collaboration with the Osservatorio Astronomico di Brera, Italy



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

KILONOVA OVERLAP

Collaboration with the Osservatorio Astronomico di Brera, Italy

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

NEUTRON STAR MERGER
⟹ short GRBs + kilonova
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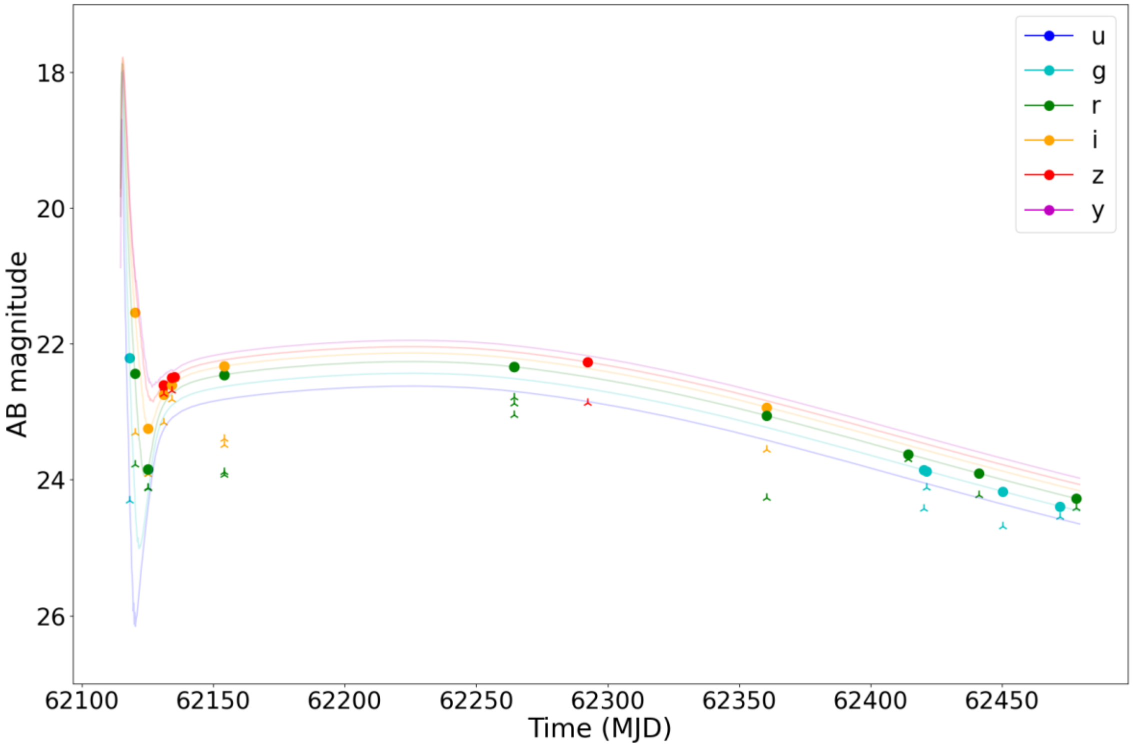

⟹ KN light curve may appear at early times
⟹ Quantify impact of KN on light curve features