SEARCH FOR ORPHAN GAMMA-RAY BURST AFTERGLOWS IN OPTICAL WITH THE VERA C. RUBIN OBSERVATORY

TRANSIENT UNIVERSE 2023

LPSC GRENOBLE | MODANE

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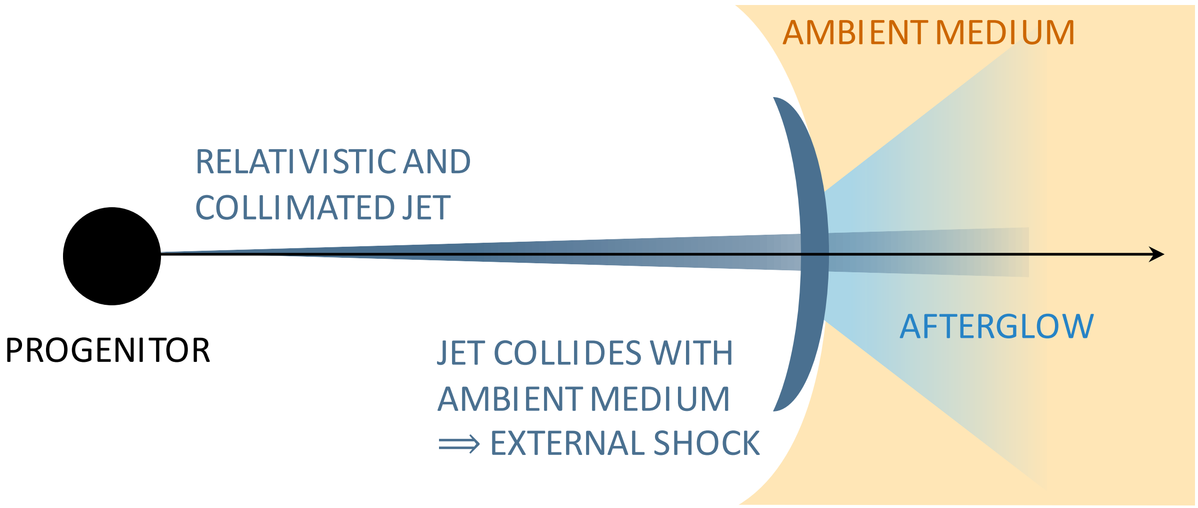
JOHAN BREGEON

THE ORPHAN AFTERGLOW: A GRB VIEWED OFF-AXIS



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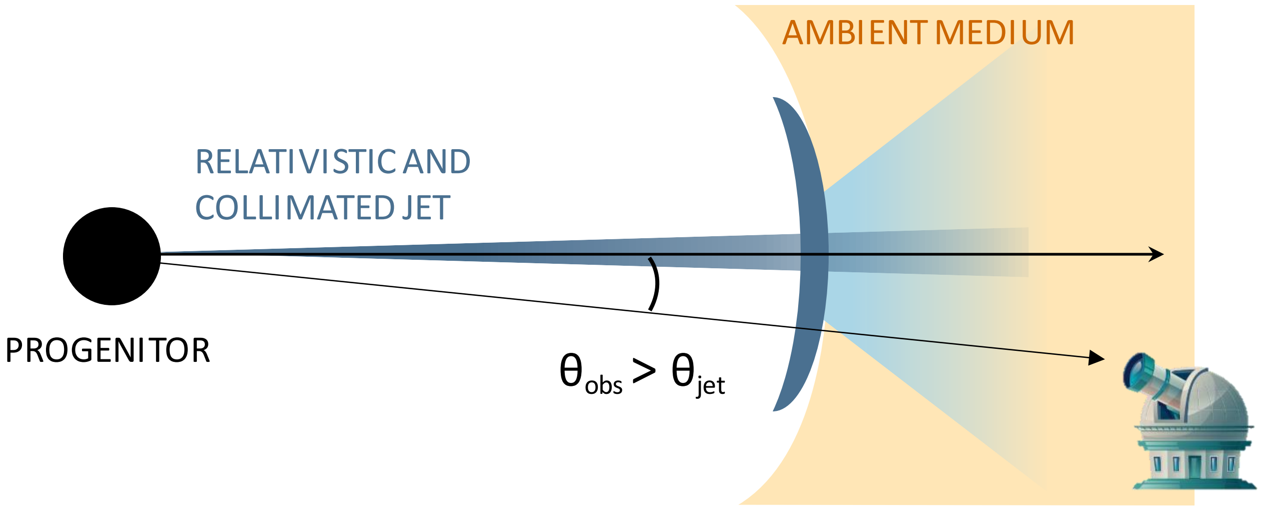

Orphan GRB afterglow = afterglow observed off-axis (without gamma-ray emission)

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

(Some candidates but none confirmed)

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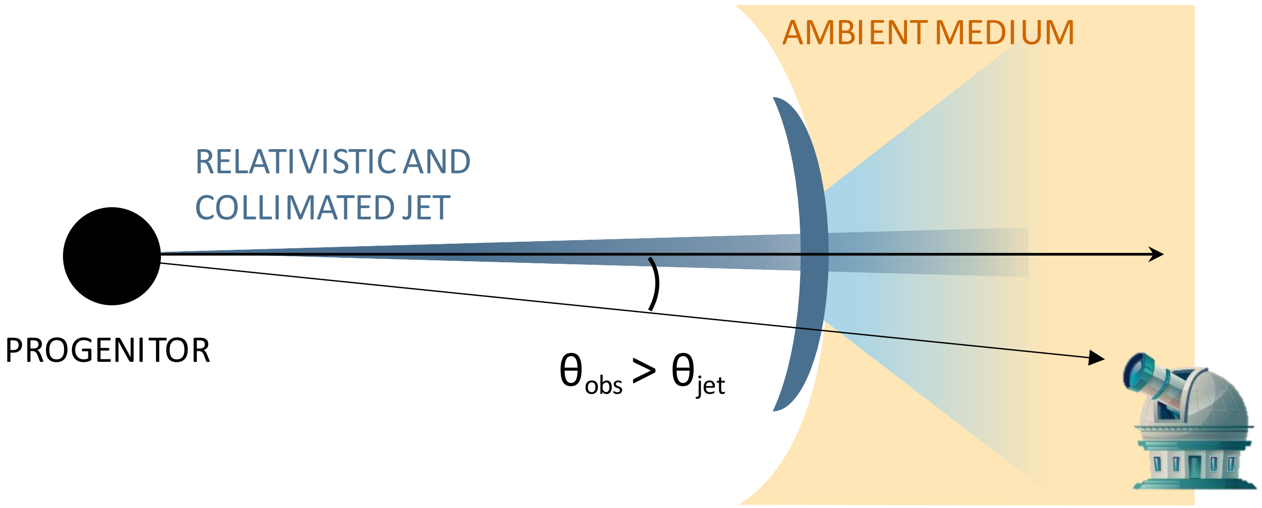


Orphan GRB afterglow = afterglow observed off-axis (without gamma-ray emission)

⟹ **No orphan afterglow detected so far!**
(Some candidates but none confirmed)

Why?

- They are faint events
- We don't have the gamma prompt emission to identify them

⟹ **Let's use the Vera C. Rubin Observatory!**

Objective > Implement a filter in FINK to identify orphans in the Rubin LSST data

THE VERA C. RUBIN OBSERVATORY

- Under construction in Cerro Pachón ridge, north-central Chile
- 10-year **Legacy Survey of Space and Time (LSST)**
- One objective: **exploring the transient optical sky** (first data expected for 2024)

SURVEY

VERA C. RUBIN OBSERVATORY

20 TB of data each night →

ALERT BROKER

FINK

Filters →

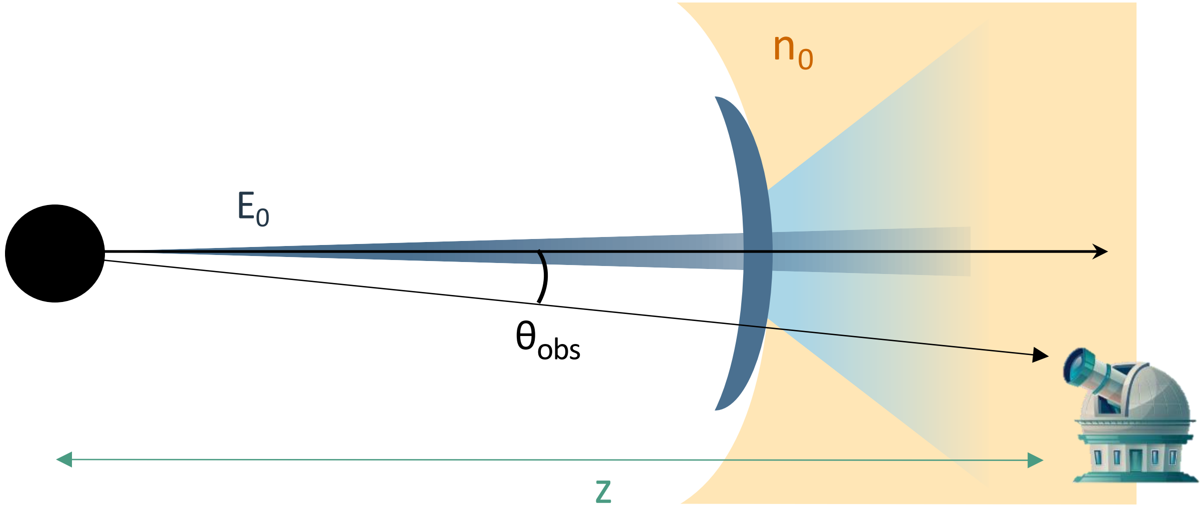
Identification of the alerts

https://github.com/geoffryan/afterglowpy

MODEL OF GRB AFTERGLOW EMISSION

Identification of orphans based on their 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}

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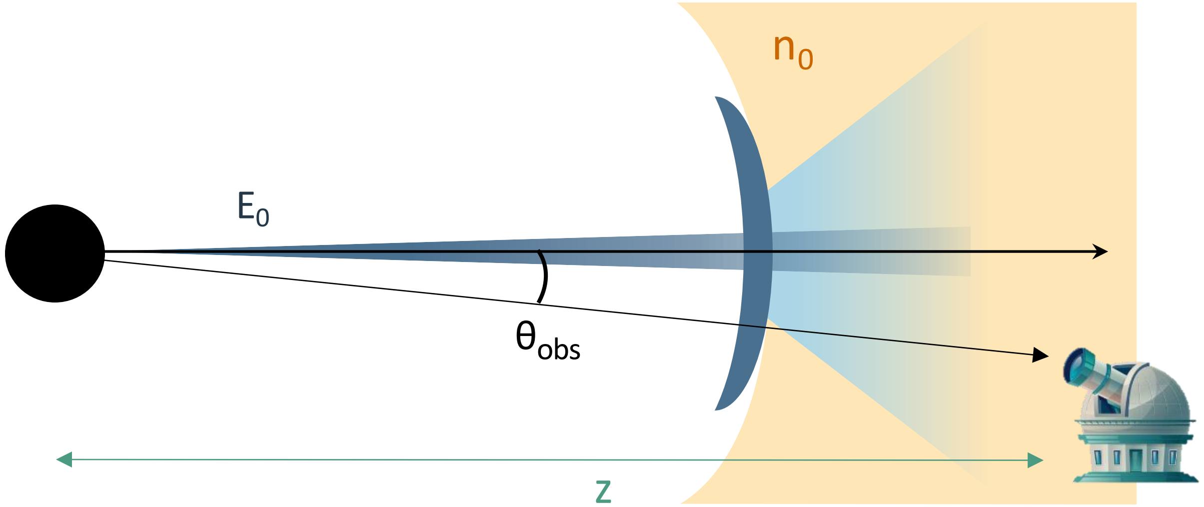
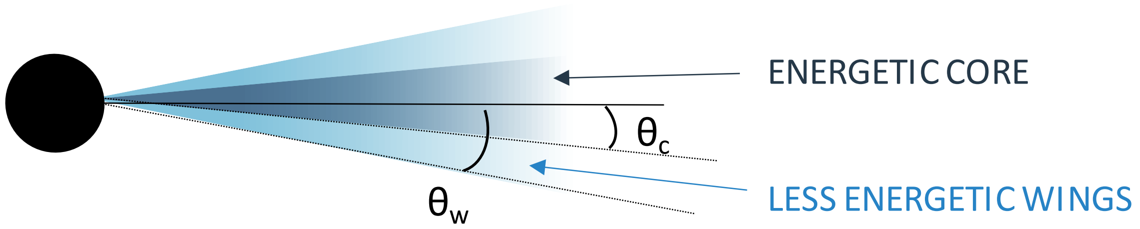
Studied parameters:

- 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

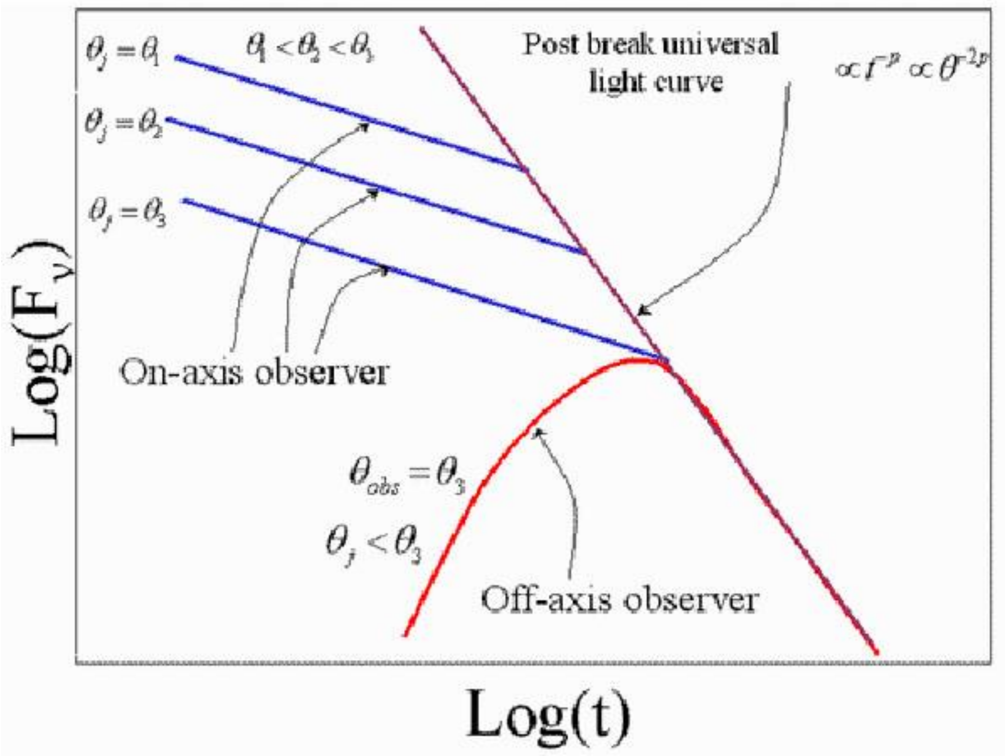




https://github.com/geoffryan/afterglowpy
(Ryan et al. 2020)

A SPECIFIC LIGHT CURVE

SCHEMATIC AFTERGLOW LIGHT CURVE



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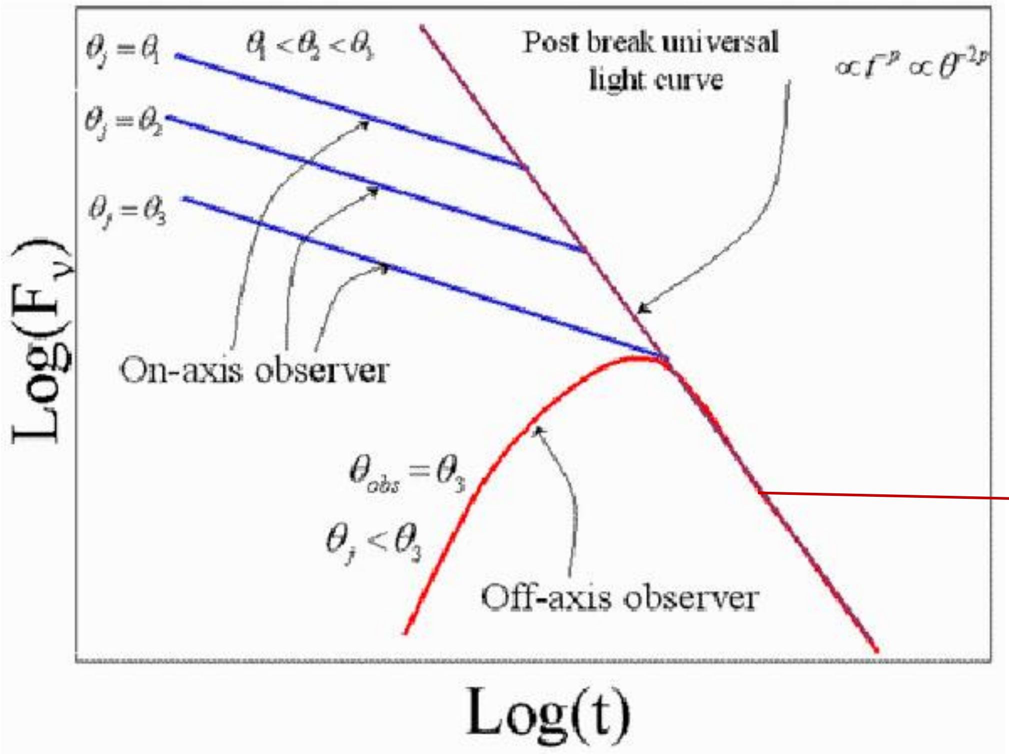
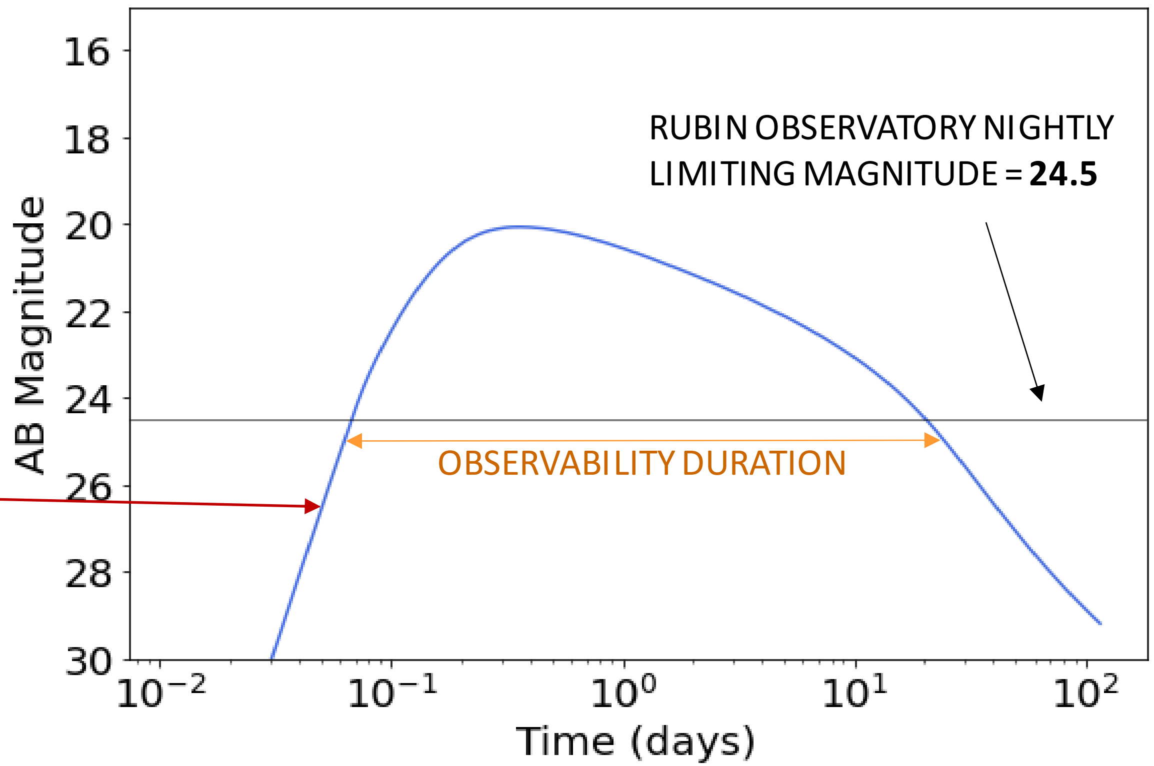


EXAMPLE OF ORPHAN LIGHT CURVE



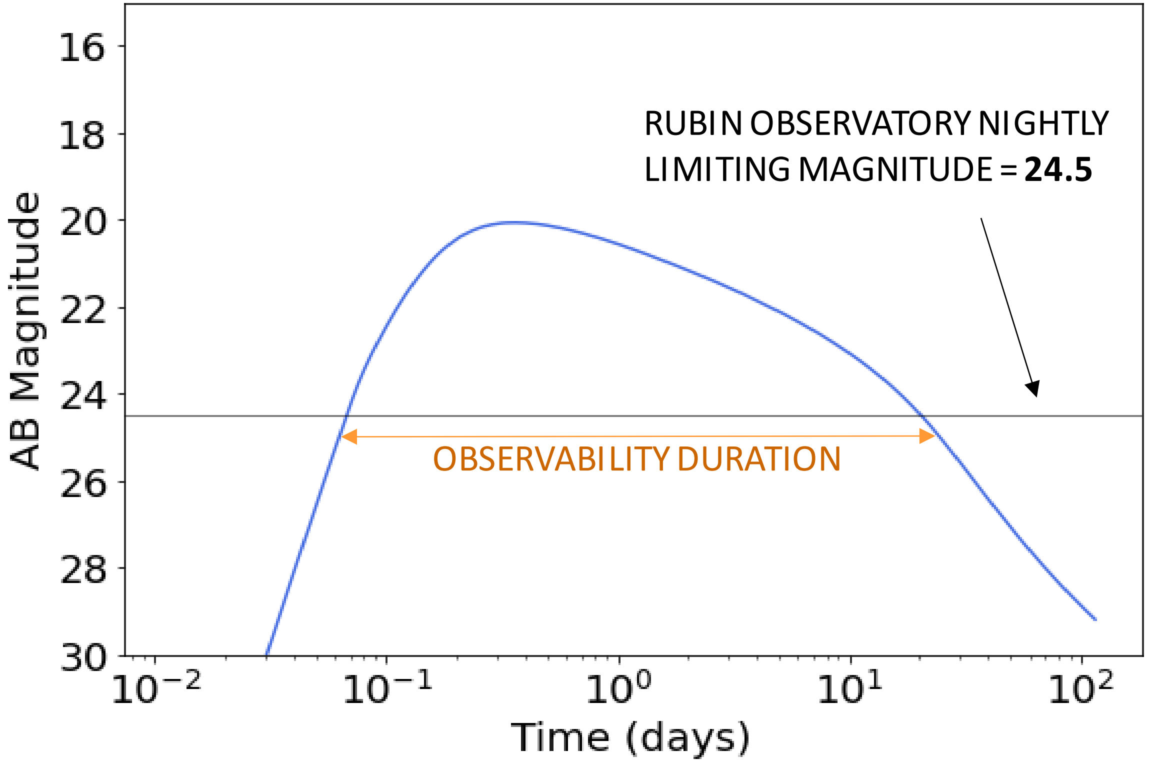
A SPECIFIC LIGHT CURVE

Orphan afterglow light curves are:

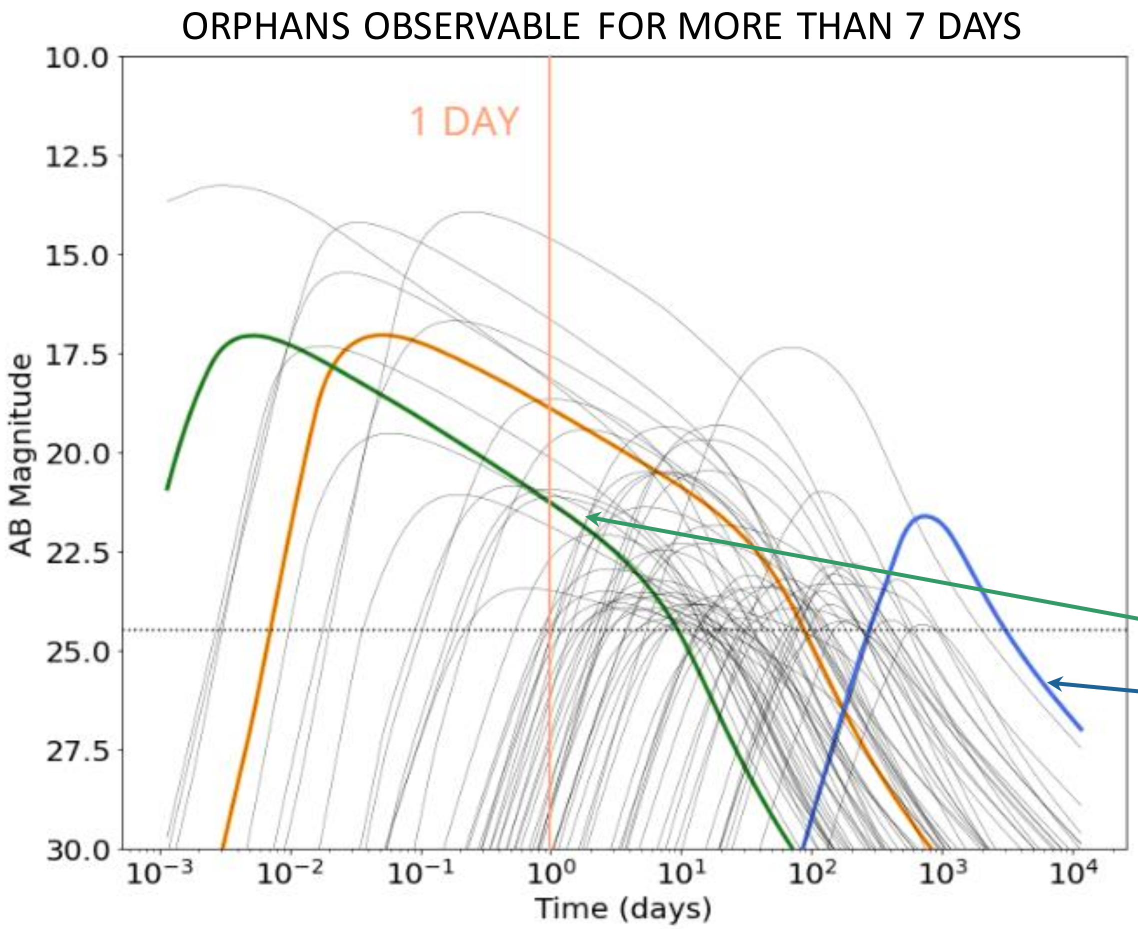
- Very long (days to months)
- Observable in multiple wavelengths (X-rays, **optical**, IR…)
- Observable at larger angle than the prompt emission
- Not choatic like those of the prompt emission

⟹ **How to recognize orphan light curves among all the Rubin LSST data?**

EXAMPLE OF ORPHAN LIGHT CURVE



SIMULATION OF A POPULATION OF SHORT GRB AFTERGLOWS



Goal: To simulate a somewhat realistic population of short GRBs (parameters distributions are not the same for long and short GRBs)

10^5 simulated short GRBs

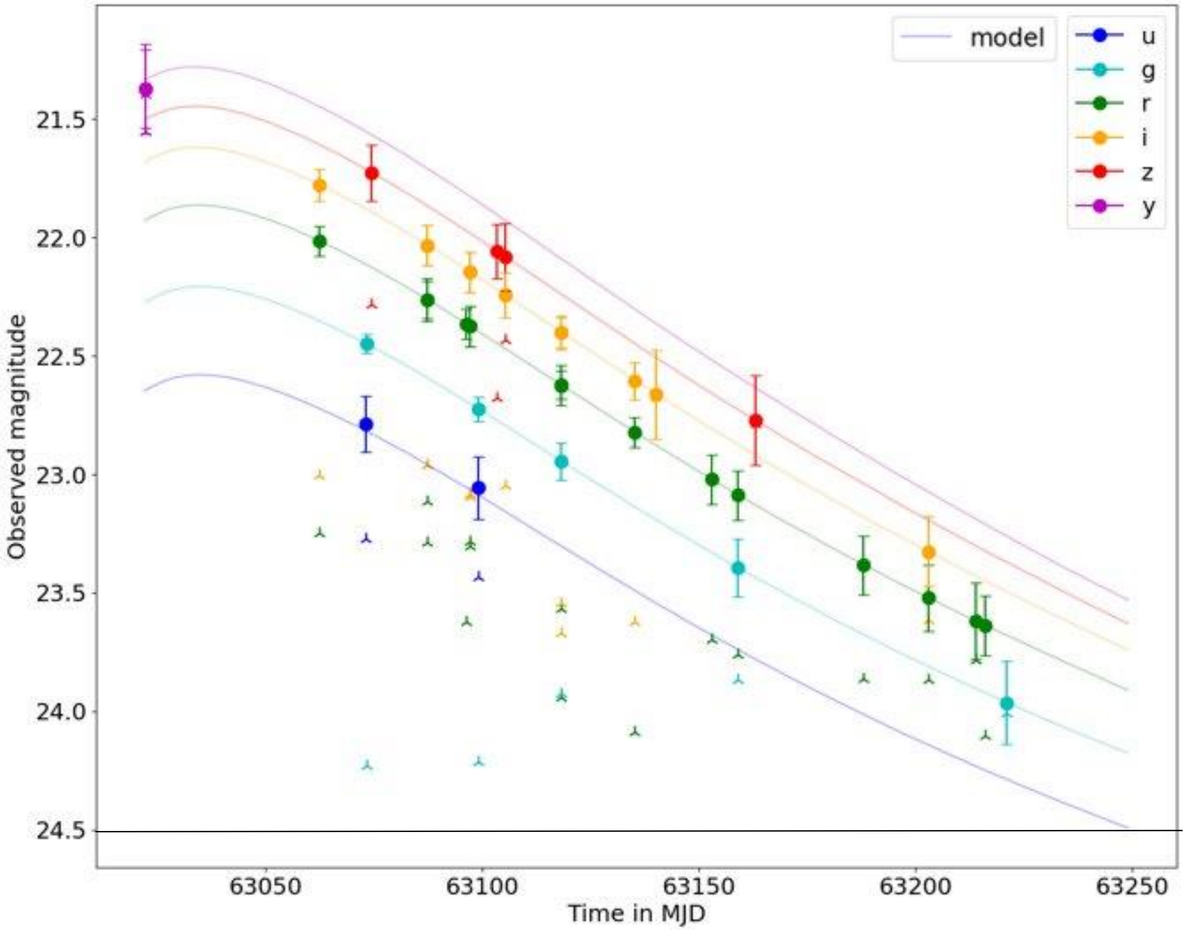
Large diversity of light curves:

- Bright and short orphans
- Faint and long orphans

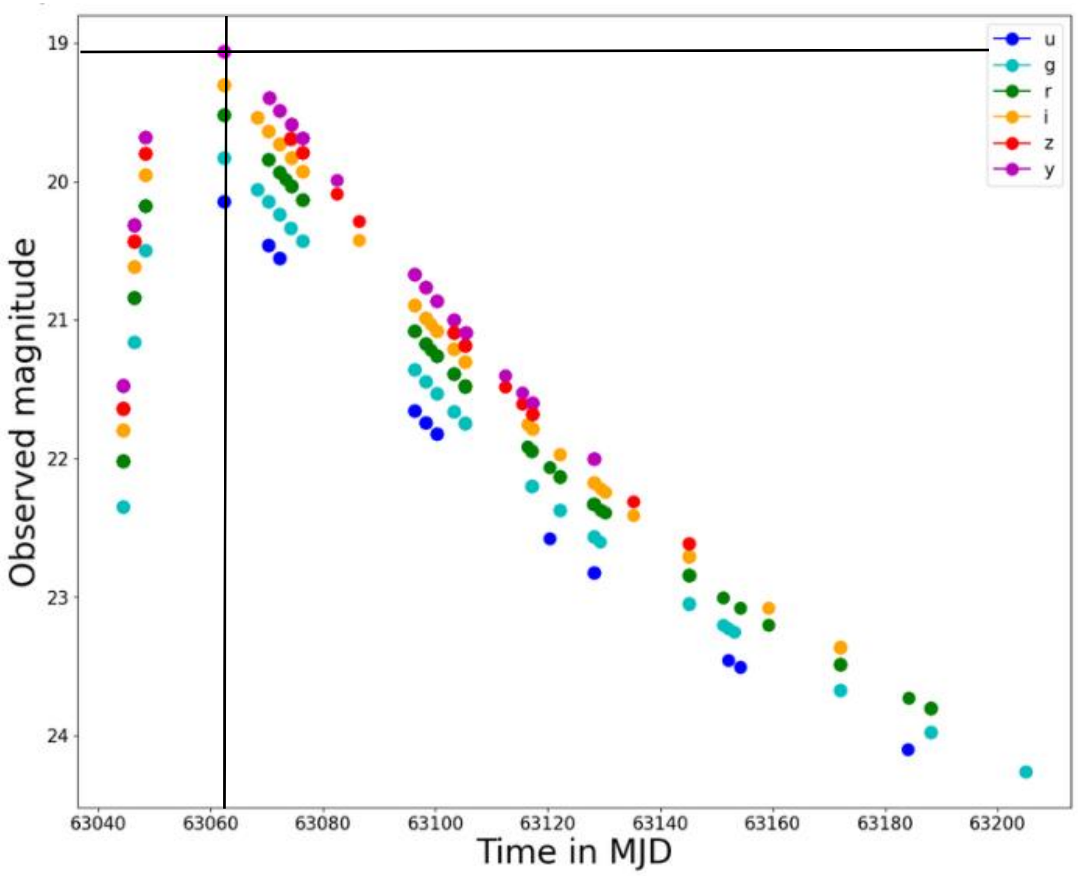
SIMULATION OF AN OBSERVATION: A "PSEUDO-OBSERVATION"

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

⟹ Fraction of "pseudo-observable" orphans by the Rubin Observatory: ~ 2%



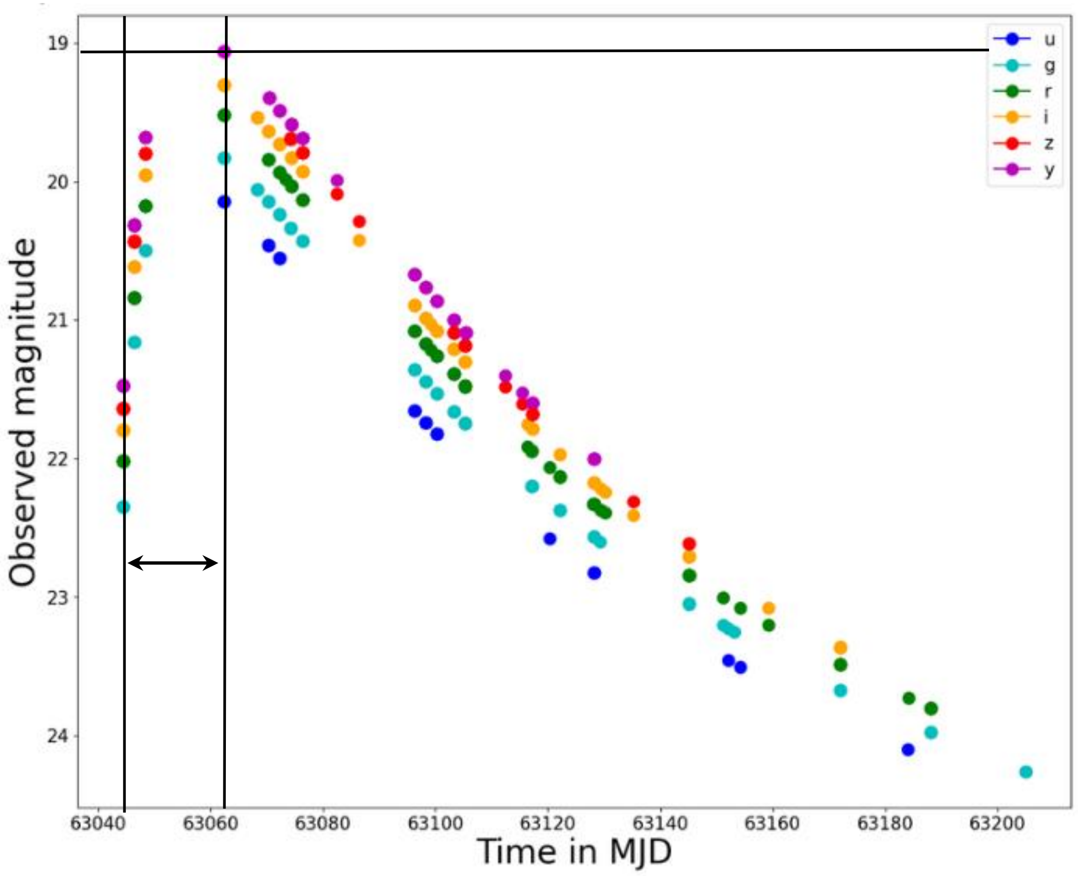
CHARACTERIZATION OF ORPHAN PSEUDO-OBERVED LIGHT CURVES



Defined features:

- **Minimal magnitude**
- **Time of the minimum**

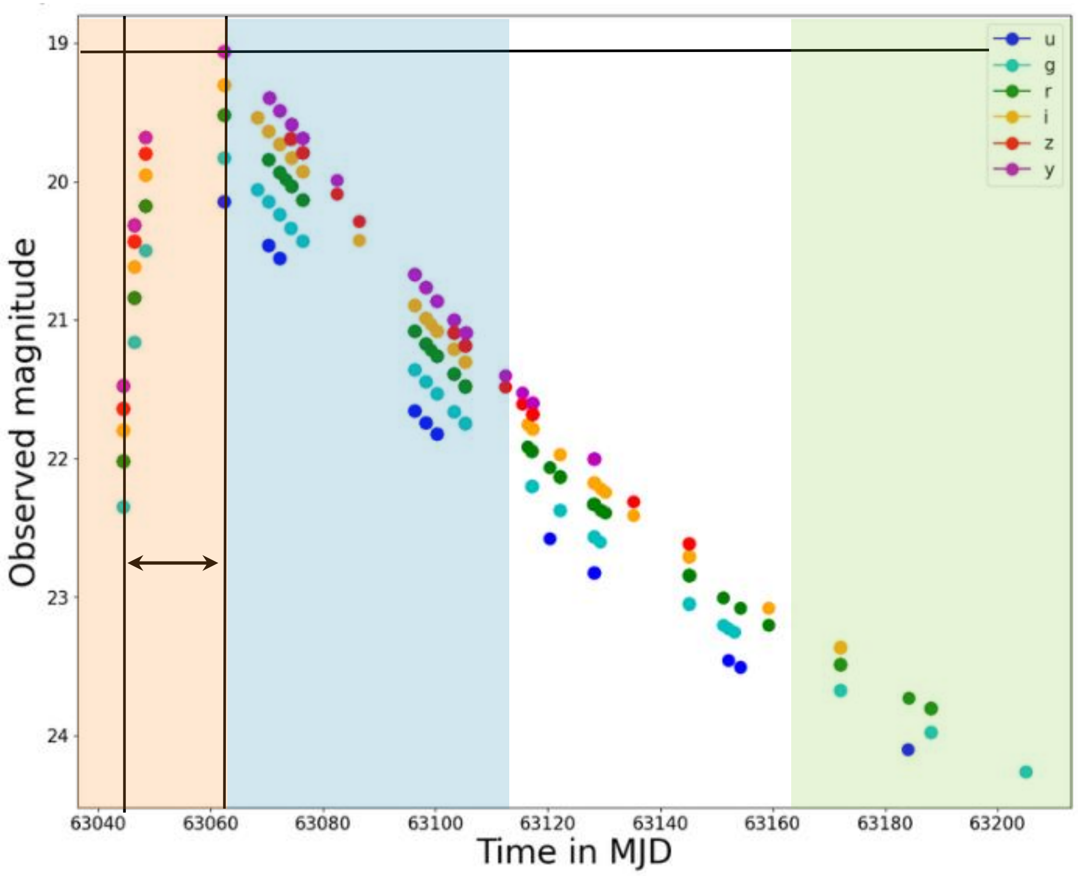
CHARACTERIZATION OF ORPHAN LIGHT CURVES



Defined features:

- Minimal magnitude
- Time of the minimum
- **Duration between the first detection and the peak**

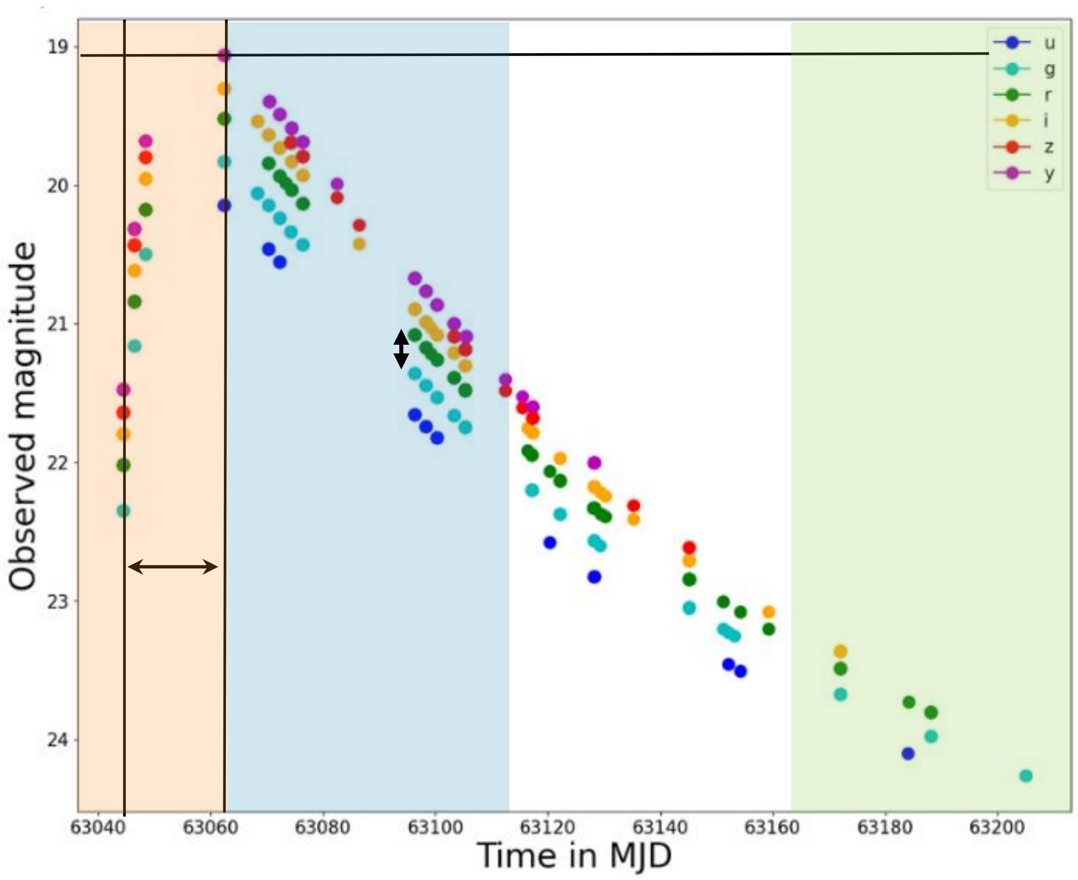
CHARACTERIZATION OF ORPHAN LIGHT CURVES



Defined features:

- Minimal magnitude
- Time of the minimum
- Duration between the first detection and the peak
- **Increase and decrease rate of the magnitude**

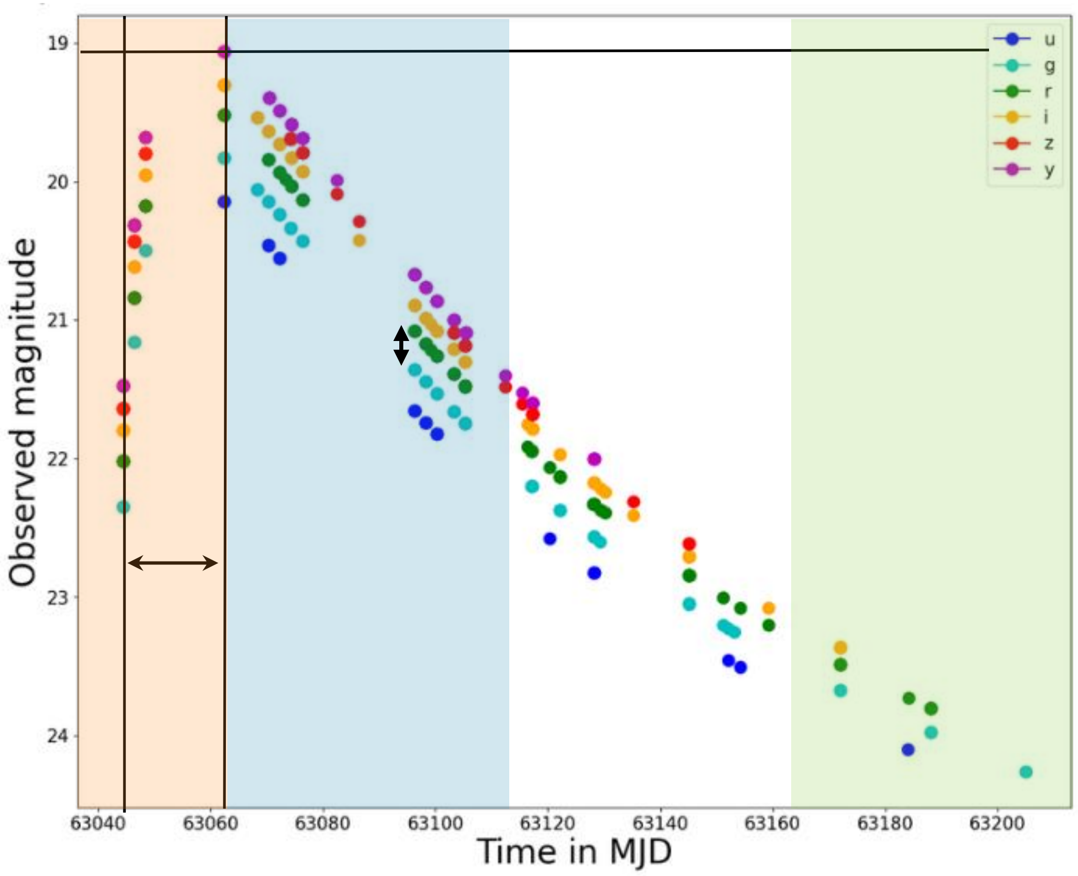
CHARACTERIZATION OF ORPHAN LIGHT CURVES



Defined features:

- Minimal magnitude
- Time of the minimum
- Duration between the first detection and the peak
- Increase and decrease rate of the magnitude
- **g-r color** (expected value for synchrotron emission ~ 0.3)

CHARACTERIZATION OF ORPHAN LIGHT CURVES



Defined features:

- Minimal magnitude
- Time of the minimum
- Duration between the first detection and the peak
- Increase and decrease rate of the magnitude
- **g-r color** (expected value for synchrotron emission ~ 0.3)

⟹ Correlations between the model parameters (E_0, θ_{obs}, ...) and these features

CONCLUSION & NEXT STEPS

Next steps:

CORRELATIONS BETWEEN THE PARAMETERS AND THE OBSERVED LIGHT CURVE FEATURES → CREATE A FIRST VERSION OF A FILTER IN FINK → TEST THIS FILTER WITH SIMULATED ALERTS (ELASTICC DATA)

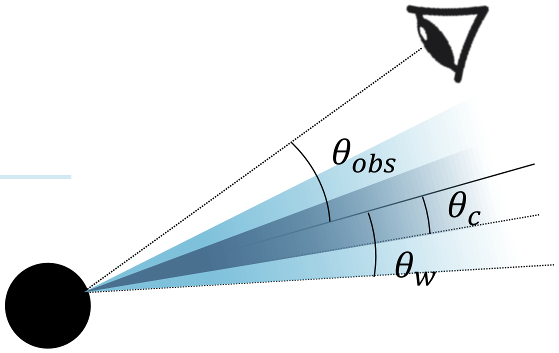
(actually, this step is done...)

No orphan afterglow detected so far but the Vera C. Rubin Observatory shall change that! Expected number of observed orphans by the Rubin LSST ~ 50 orphan/yr (Ghirlanda et al. 2015).

Can we detect them? Yes, but their identification will be more complicated...

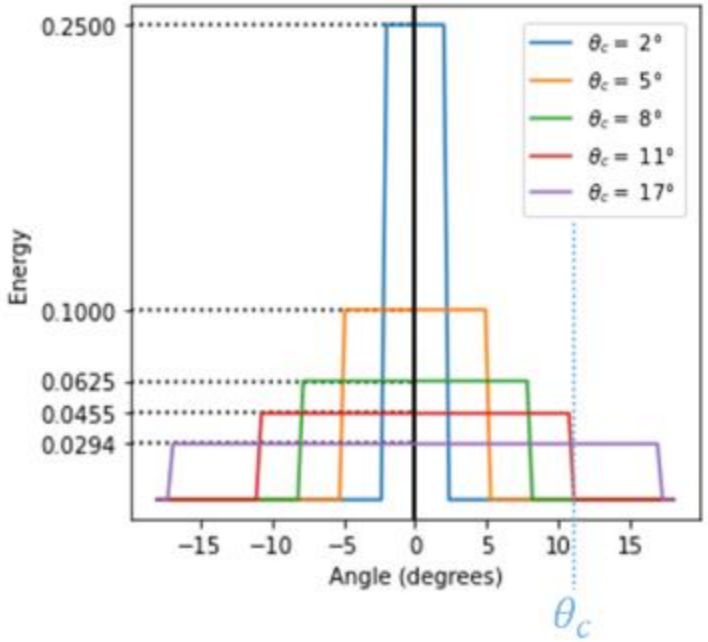
THANK YOU FOR YOUR ATTENTION!

TYPES OF STRUCTURED JETS

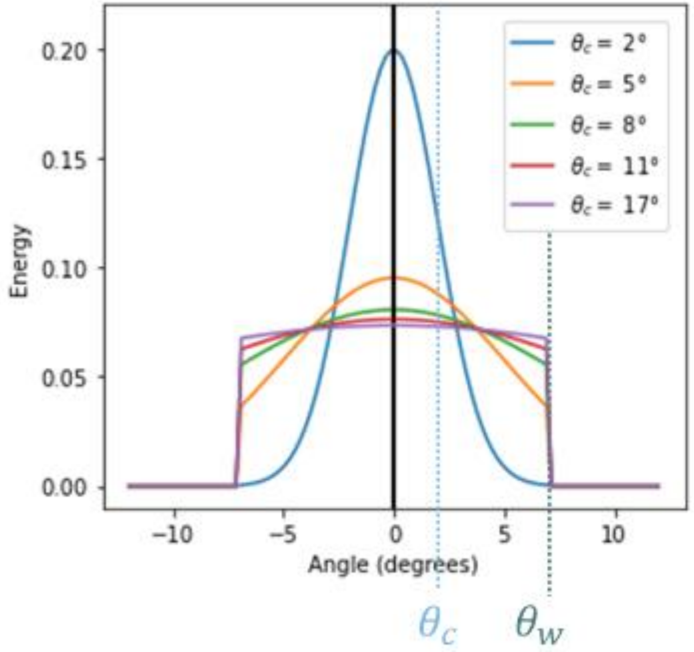


Structured jet = jet with a non-uniform angular distribution of energy

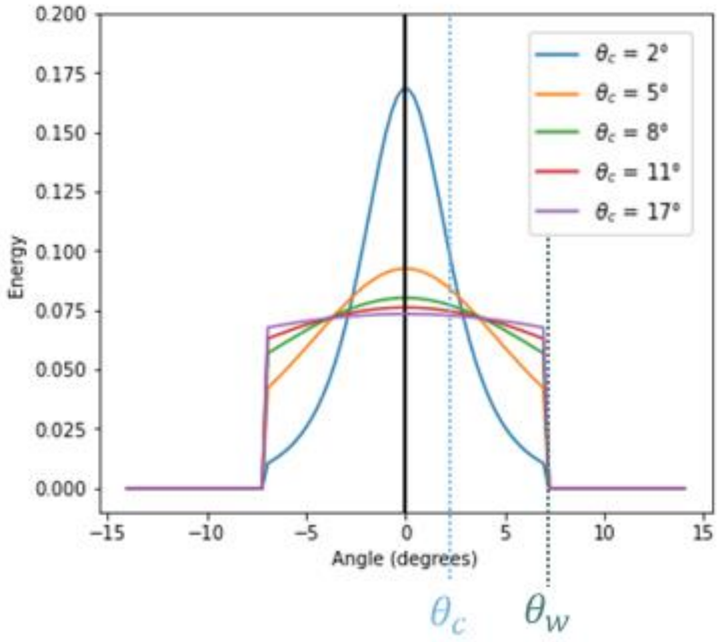
TOP-HAT



GAUSSIAN

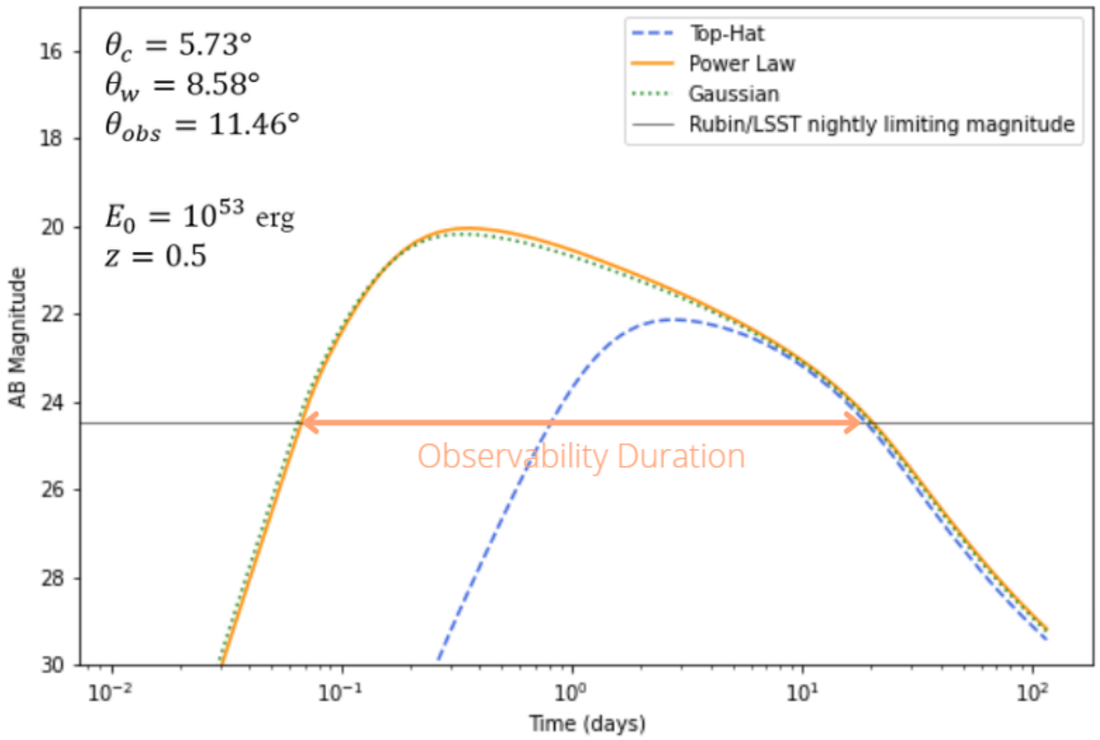


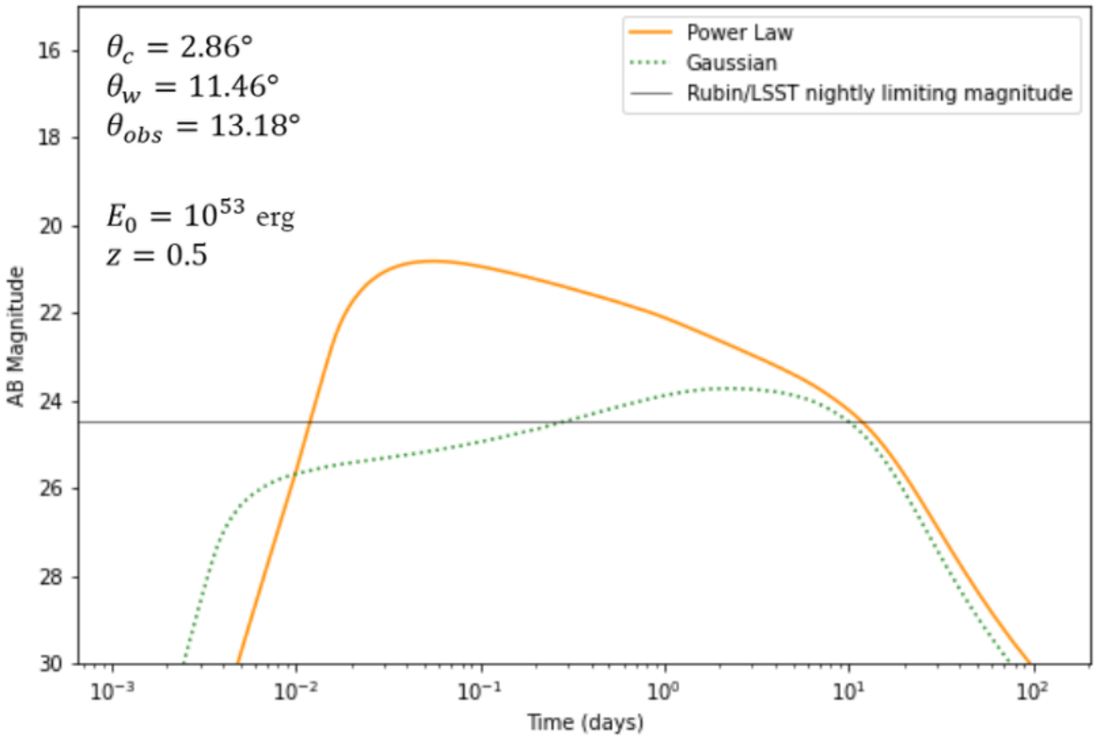
POWER-LAW



ANNEXE 1

LIGHT CURVES FOR DIFFERENT STRUCTURED JETS





If $\theta_w > \theta_c$, Power-Law and Gaussian jets are observable earlier than Top-Hat jet

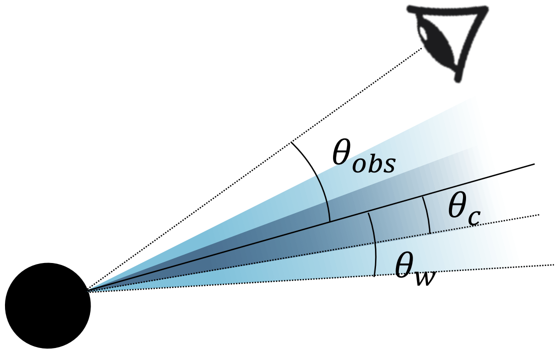
$\Longrightarrow$ Importance of the jet structure

If θ_w "large" compared to θ_c, Power-Law and Gaussian jets have a different shape of light curve

$\Longrightarrow$ Importance of the jet type

ANNEXE 2

PARAMETERS DISTRIBUTIONS



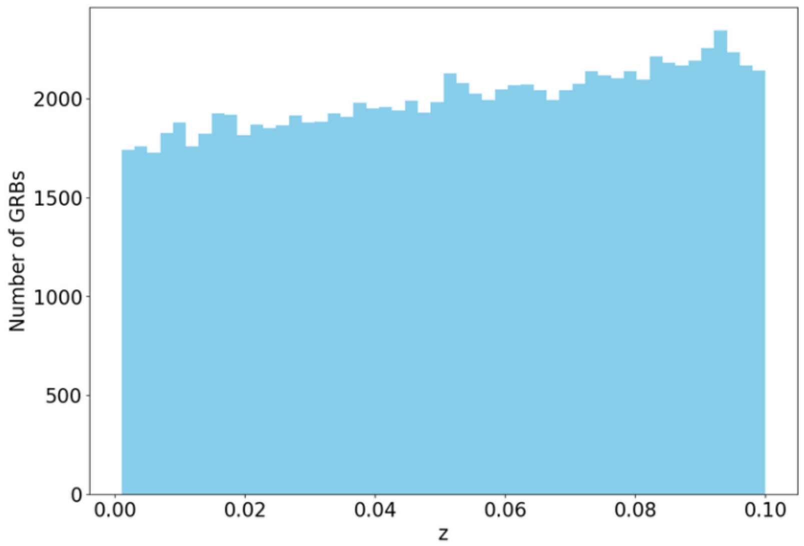
Goal: To simulate somewhat realistic distributions for short GRBs

Studied parameters:

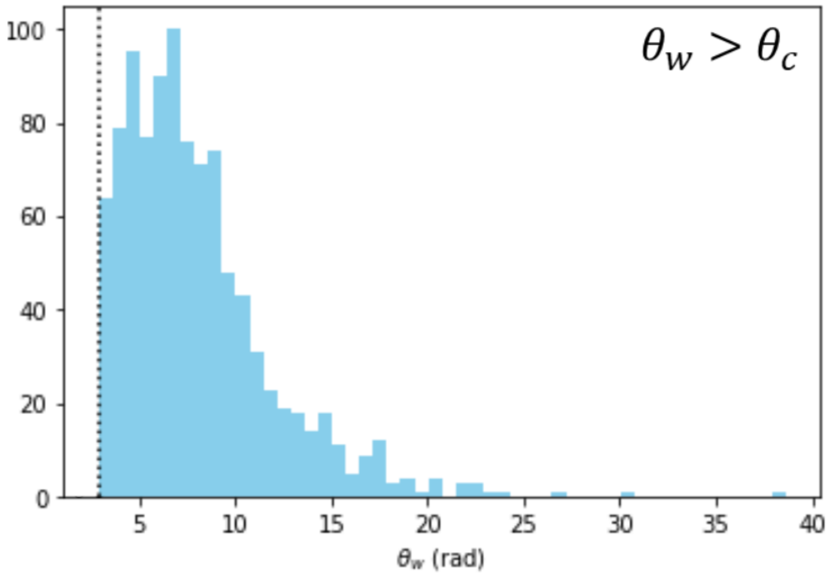
- **Core angle θ_c:** 2.86 and 8.60 degrees
- **Circumburst density n_0:** uniform distribution [0.001 ; 1.0] cm^{-3}
- **Observer angle $\cos(\theta_{obs})$:** uniform distribution [0 ; 1]

10^5 saved configurations

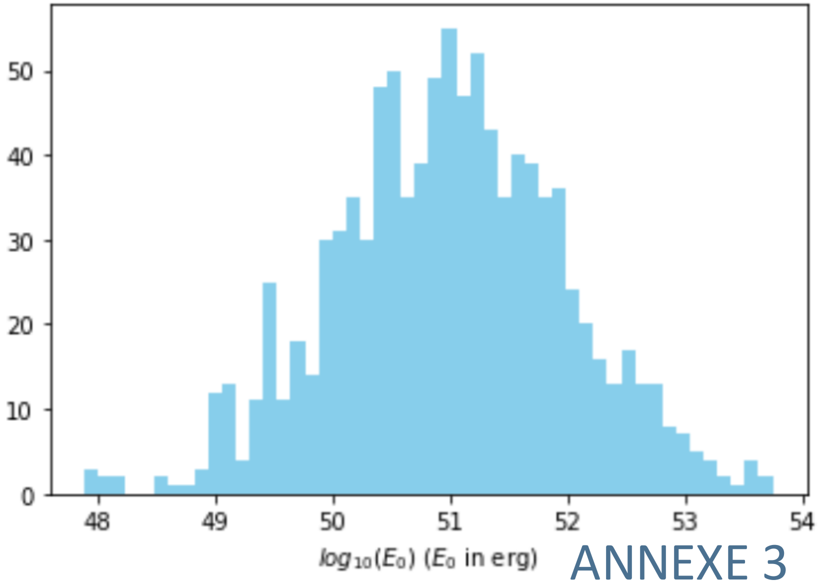
REDSHIFT z



TRUNCATURE ANGLE θ_w



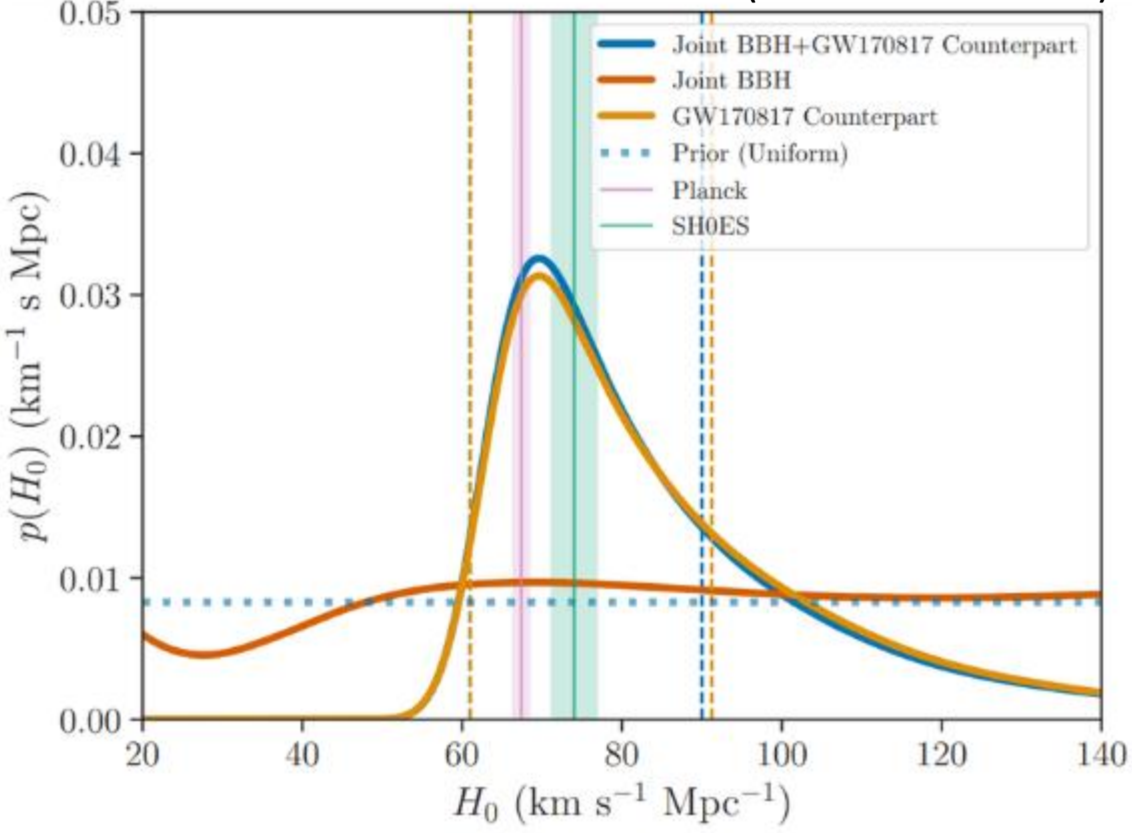
ISOTROPIC EQUIVALENT ENERGY E_0



ANNEXE 3

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 4

THE VERA C. RUBIN OBSERVATORY

- Under construction in Cerro Pachón ridge, north-central Chile
- 10-year **Legacy Survey of Space and Time (LSST)**: 20 TB of data each night
- One objective: **exploring the transient optical sky** (first data expected for 2024)

Zwicky Transient Facility
1.22-m primary mirror
Limiting nightly magnitude: 20.5
Filters: g, r and i

→

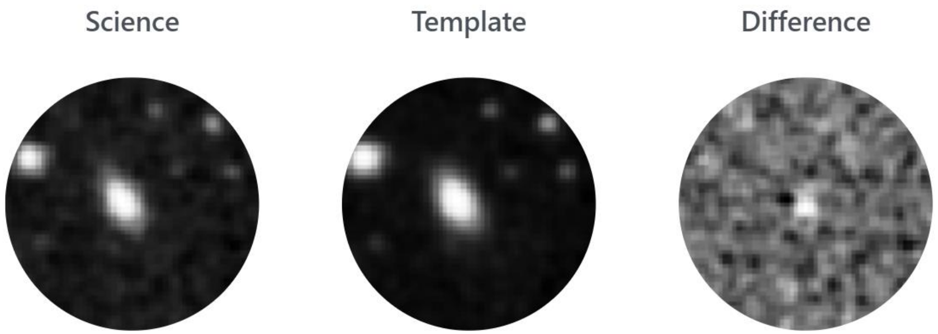
Rubin LSST
8.4-m primary mirror
Limiting nightly magnitude: 24.5
Filters: u, g, r, i, z and y

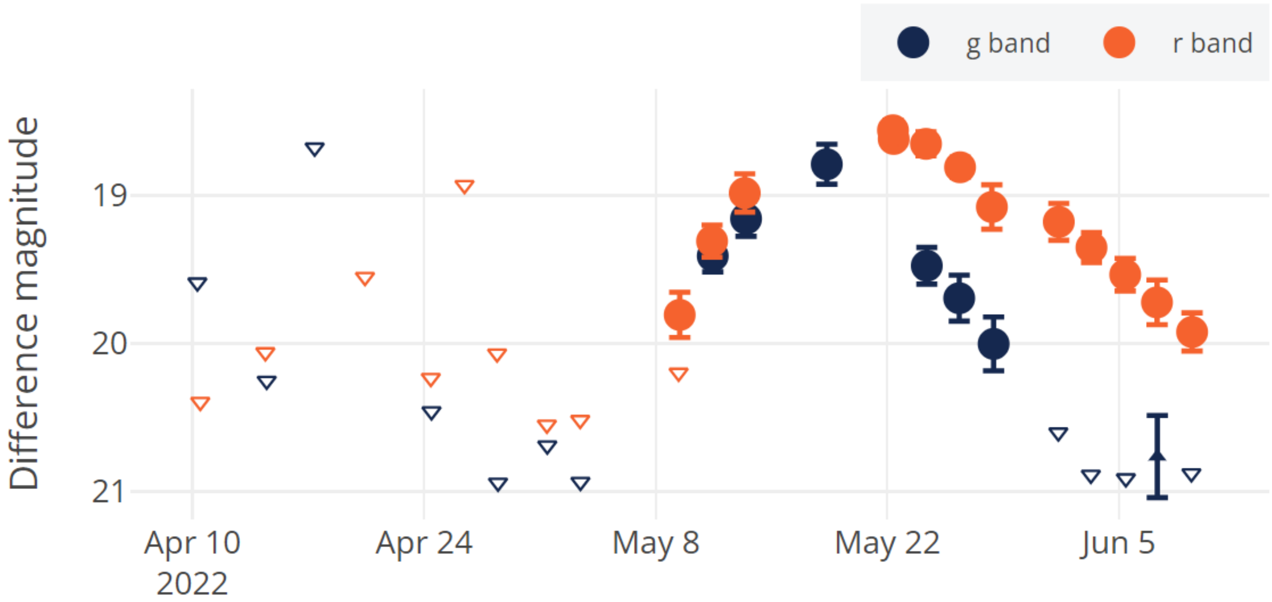
→

10x more data!

ANNEXE 5

THE ALERT BROKER FINK





Detection of a source > specified detection threshold in the difference image $\Longrightarrow$ alert

Alert broker = software that process data from a telescope:

- Cross-matches with catalogs
- Generate photometric classification based on light curve analyses

FINK = official alert broker of Rubin LSST, developed by the french community

https://fink-portal.org/

ANNEXE 6