RUBIN/LSST - FRANCE MEETING
28-30 NOVEMBER 2022

GRENOBLE | MODANE

IDENTIFICATION OF ORPHAN GAMMA-RAY BURST AFTERGLOWS IN RUBIN/LSST DATA WITH THE FINK ALERT BROKER

MARINA MASSON, JOHAN BREGEON

PHD THESIS

CONTENTS OF THE PRESENTATION

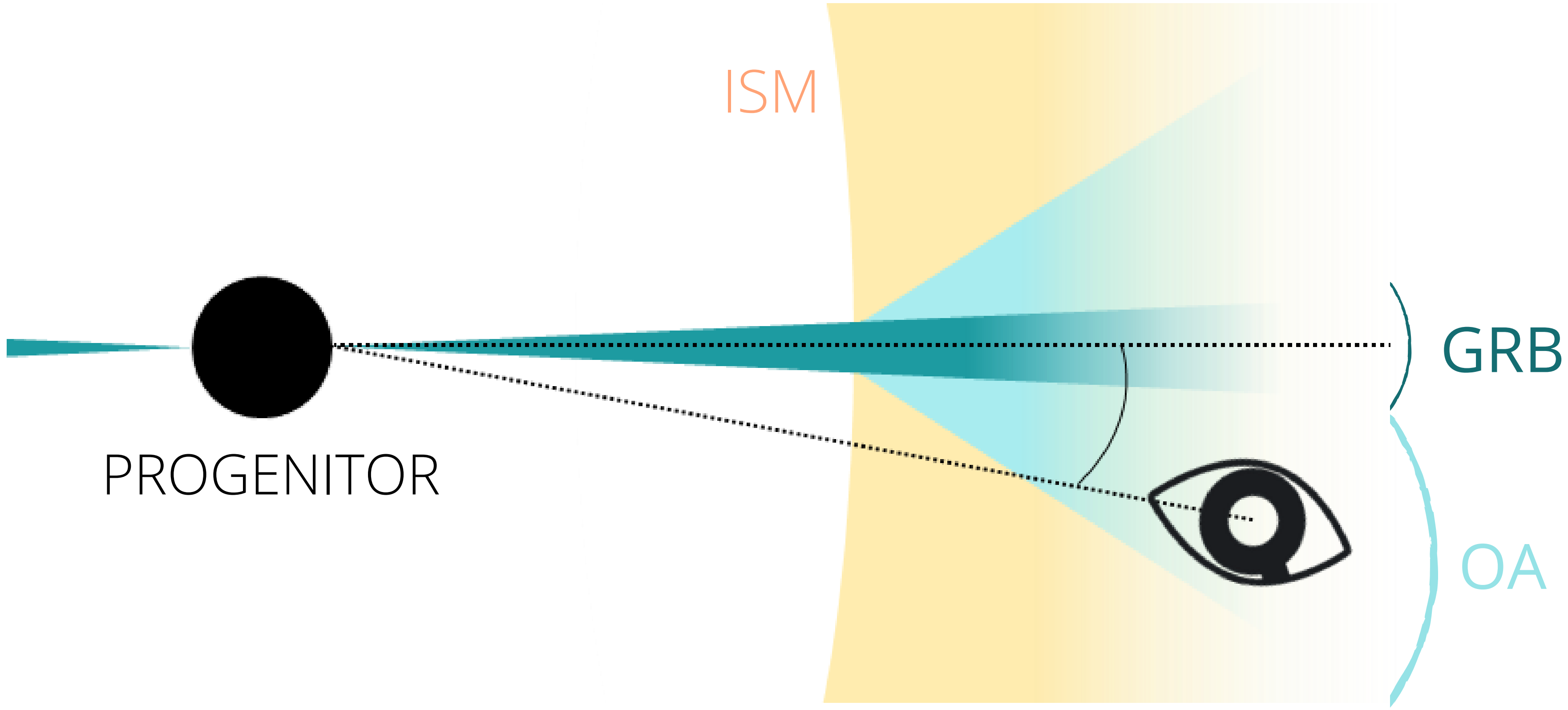
1. **General context**
   1.1 What is an orphan gamma-ray burst afterglow ?
   1.2 Gamma-ray burst emission models

2. **Simulation of a population of short gamma-ray bursts**

3. **Analyses of the pseudo-observed light curves**

4. **Conclusion & Perspectives**

WHAT IS AN ORPHAN GAMMA-RAY BURST AFTERGLOW?

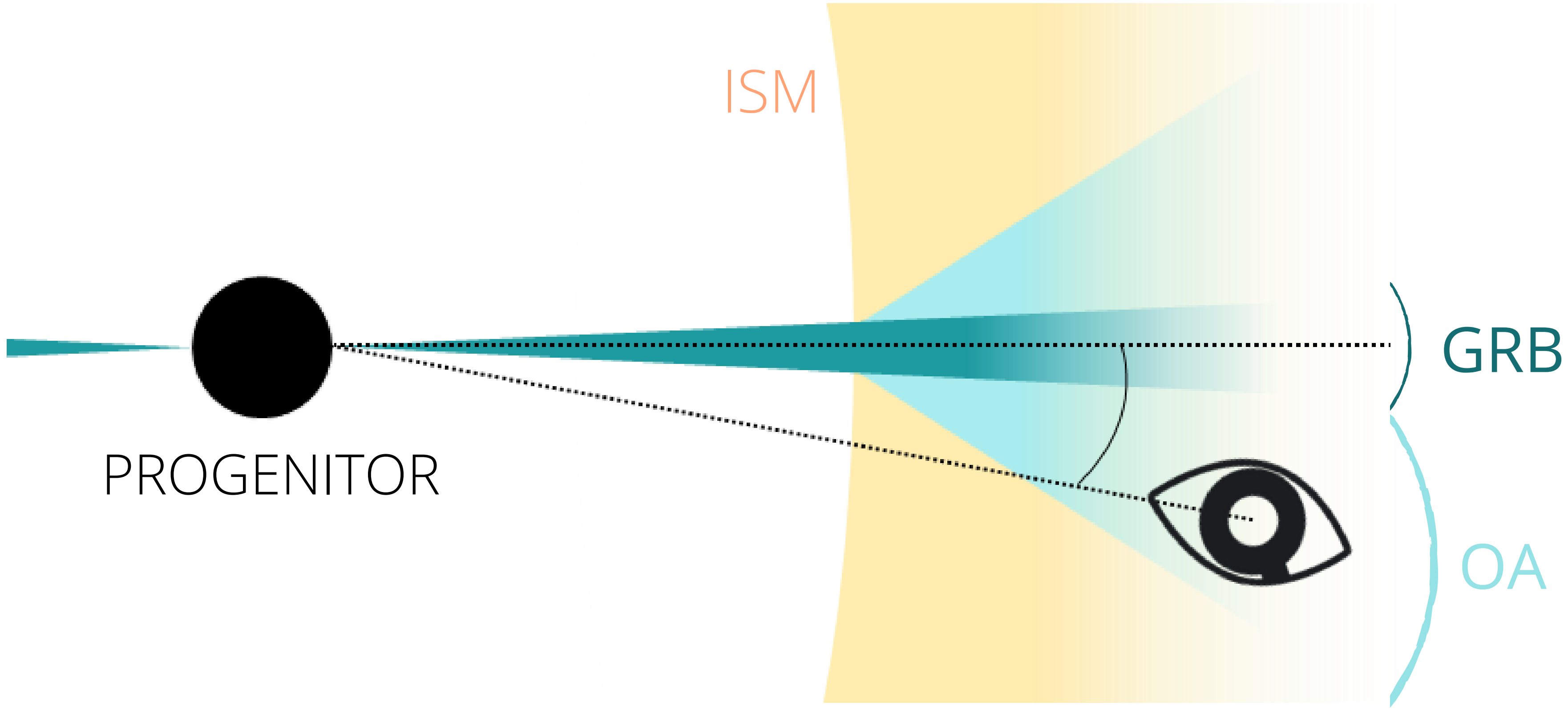


- **Gamma-Ray Burst (GRB) =** short and highly energetic gamma-ray flash (~ 10^{51} erg) involving compact objects

- **Orphan GRB afterglow (OA) =** optical afterglow without gamma-ray emission
  $\Longrightarrow$ **No orphan afterglow detected so far!**
  (some candidates but none confirmed)

- **OAs important for**
  - GRB physics and progenitors
  - Multi-messengers analyses (cosmology to measure H0 with gravitational waves)

WHAT IS AN ORPHAN GAMMA-RAY BURST AFTERGLOW?



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  - GRB physics and progenitors
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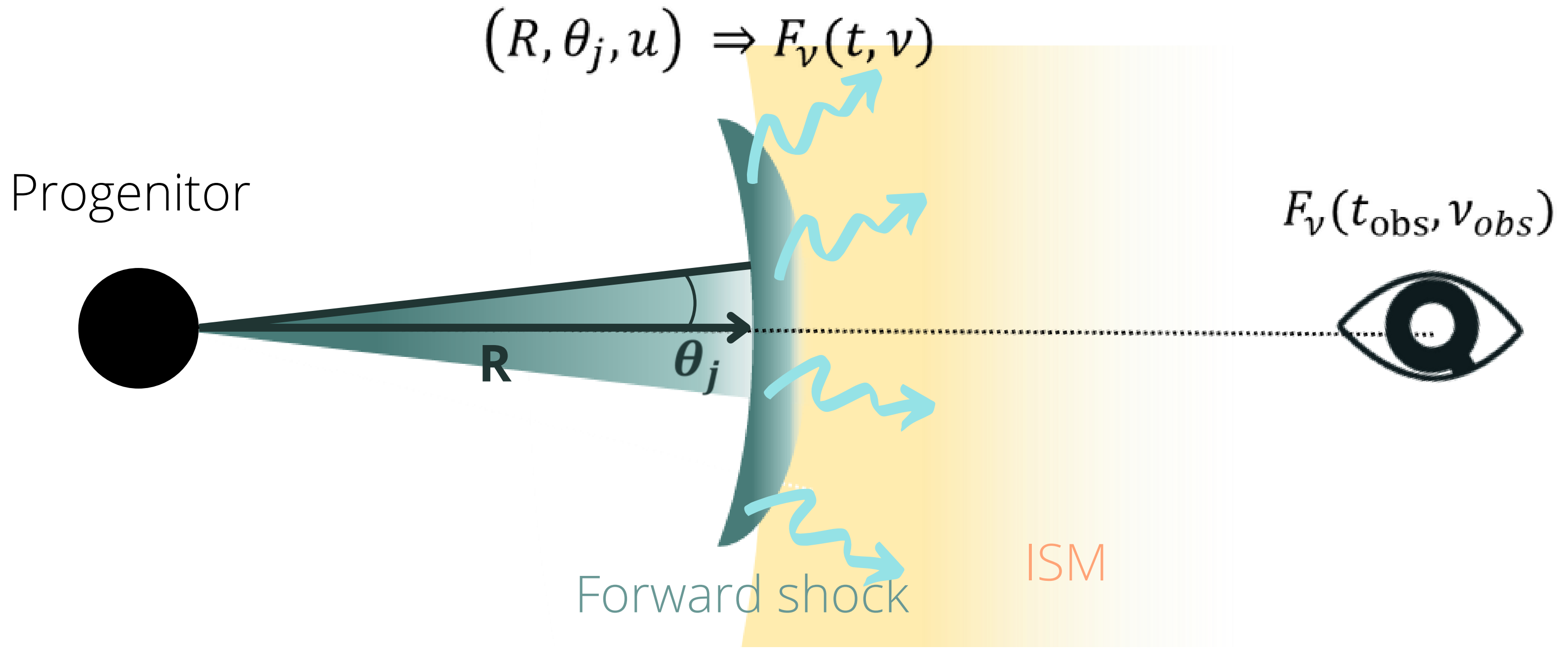
Objective > To identify potential orphan gamma-ray burst afterglows in Rubin/LSST data by implementing a filter in the alert broker FINK

GRB BURST EMISSION MODELS

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

$$F_\nu(t_{obs}, \nu_{obs}) = \frac{1+z}{4\pi d_L^2} \int d\Omega R^2 \Delta R \delta^2 \epsilon'_{\nu'}$$



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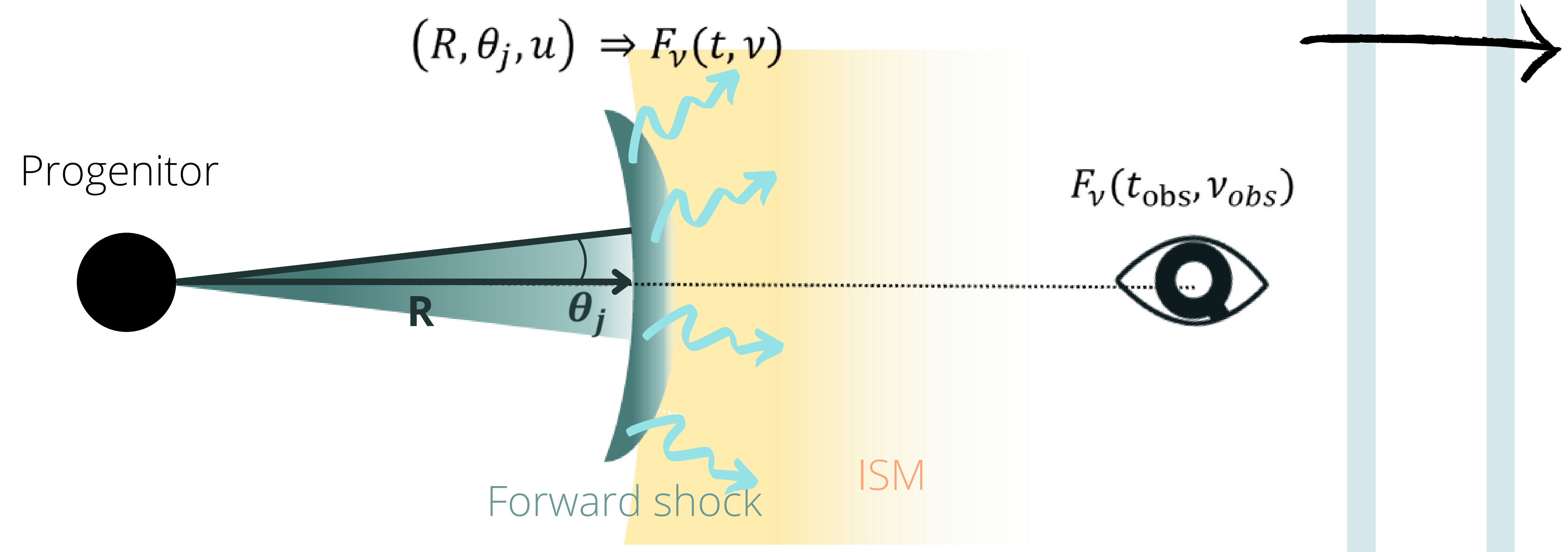
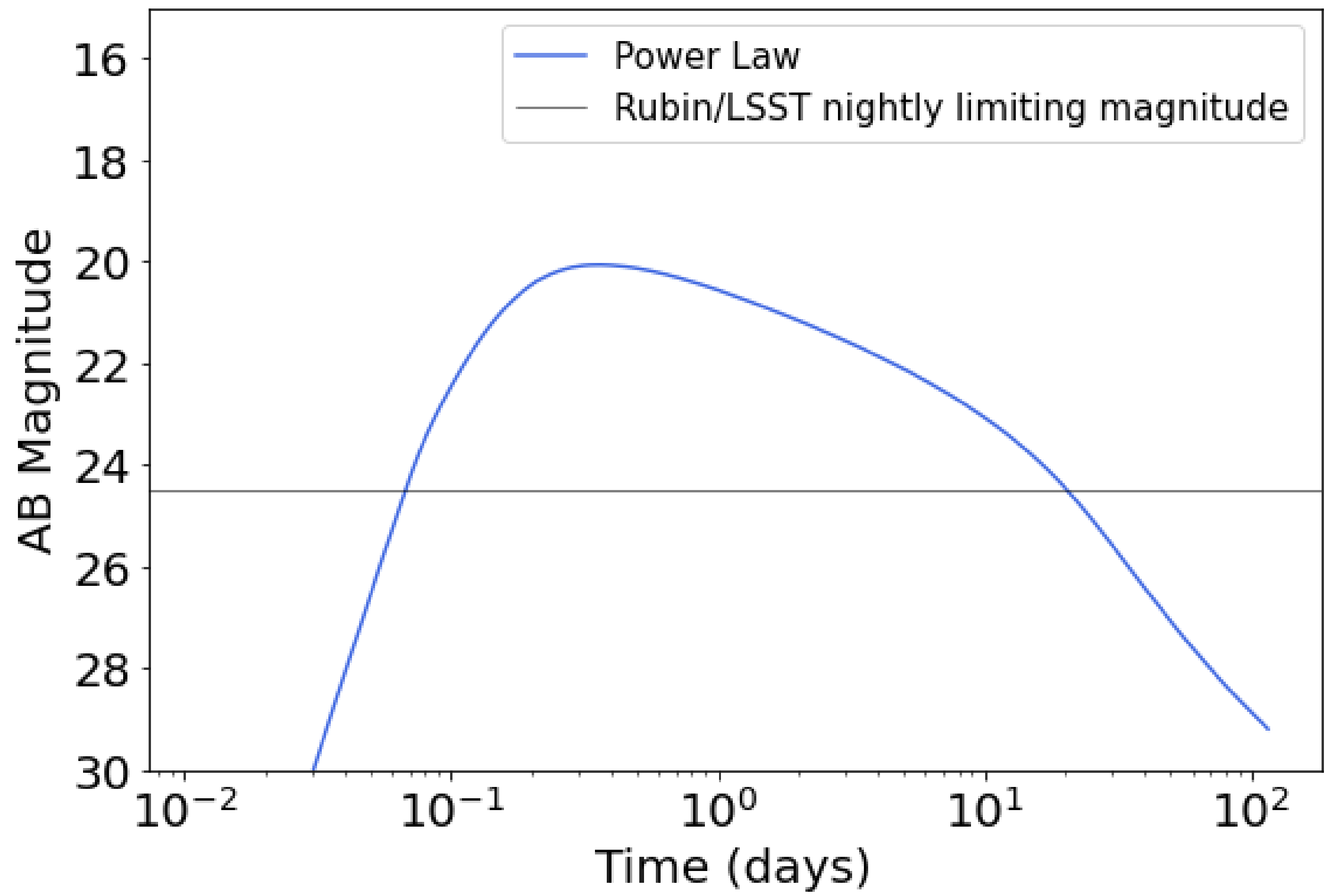


afterglowpy package
(Ryan et al. 2021)

Fnu = afterglowpy.fluxDensity(t, nu, **Z)



CONTENTS OF THE PRESENTATION

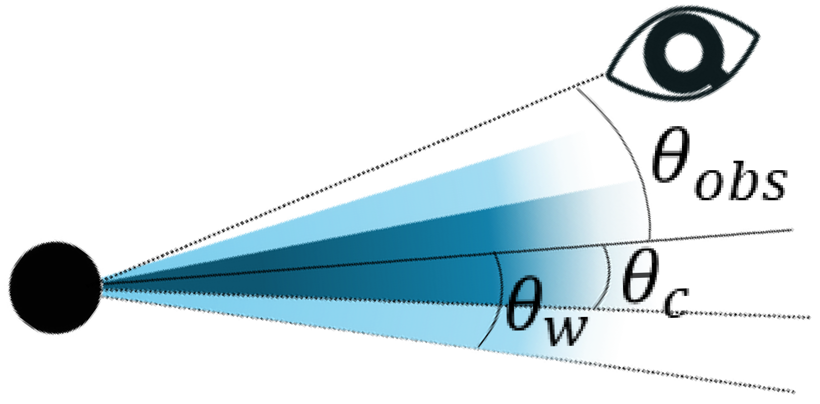
1. General context

2. **Simulation of a population of short gamma-ray bursts**
   - **2.1** Distribution of the parameters
   - **2.2** Results of the simulation
   - **2.3** Pseudo-observations with rubin_sim

3. Analyses of the pseudo-observed light curves

4. Conclusion & Perspectives

SOME SIMULATIONS FOR SHORT GRBS

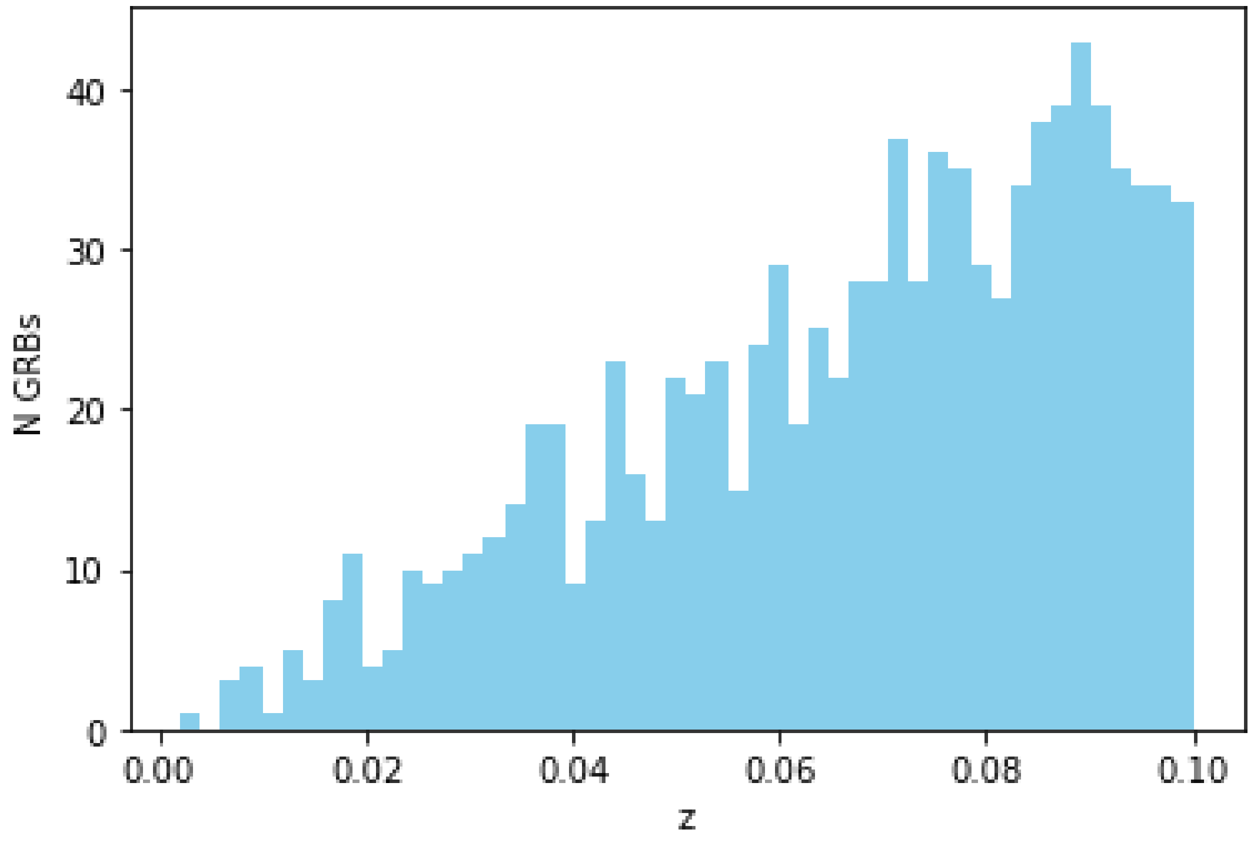


Goal: To simulate somewhat realistic distributions for short GRBs

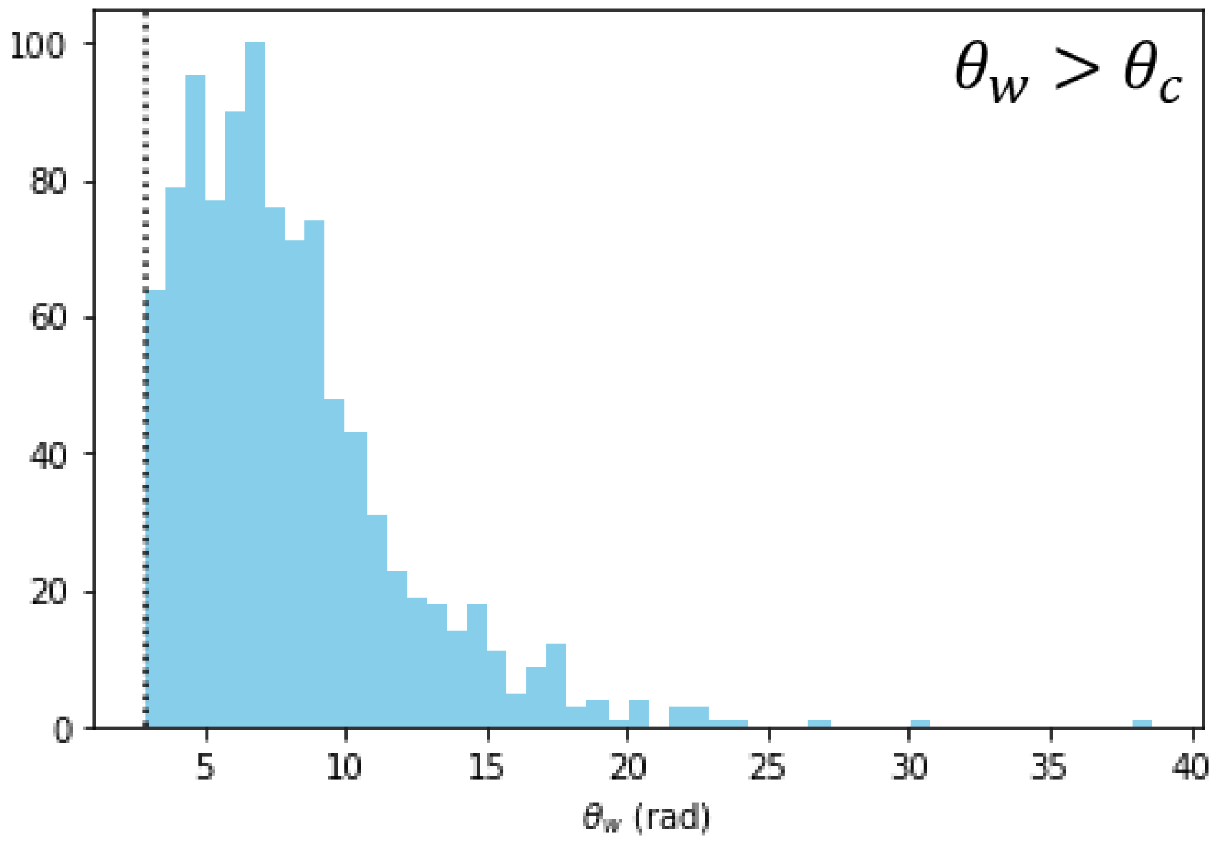
Studied parameters:

- **Core angle θ_c:** 2.86 and 8.60 degrees
- **Circumburst density n_0:** uniform distribution [0.001 ; 1.0] cm^{-3}
- **Observer angle θ_{obs}:** uniform distribution [0 ; π/2] radians

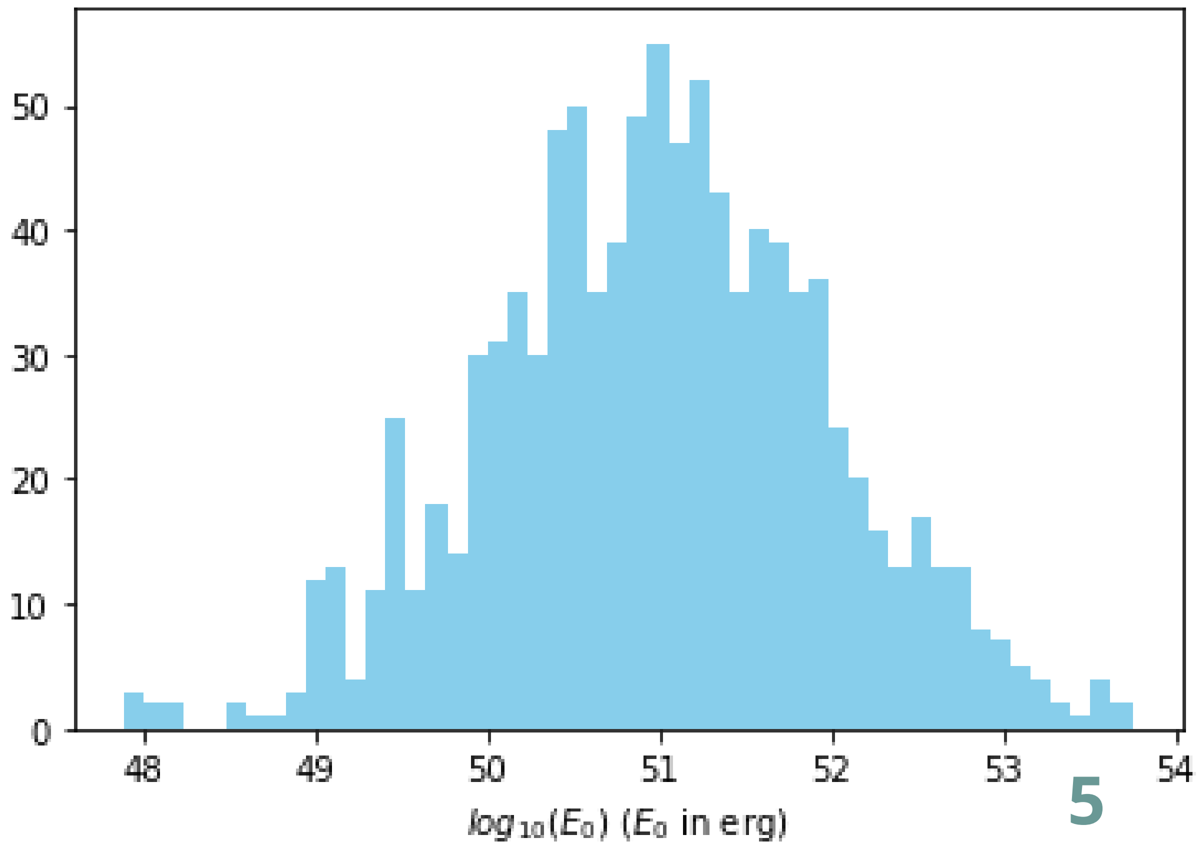
Redshift z



Truncature angle θ_w



Isotropic equivalent energy E_0



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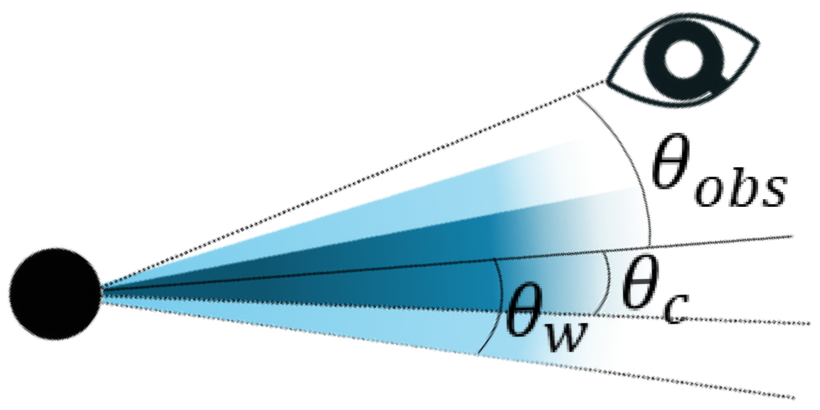

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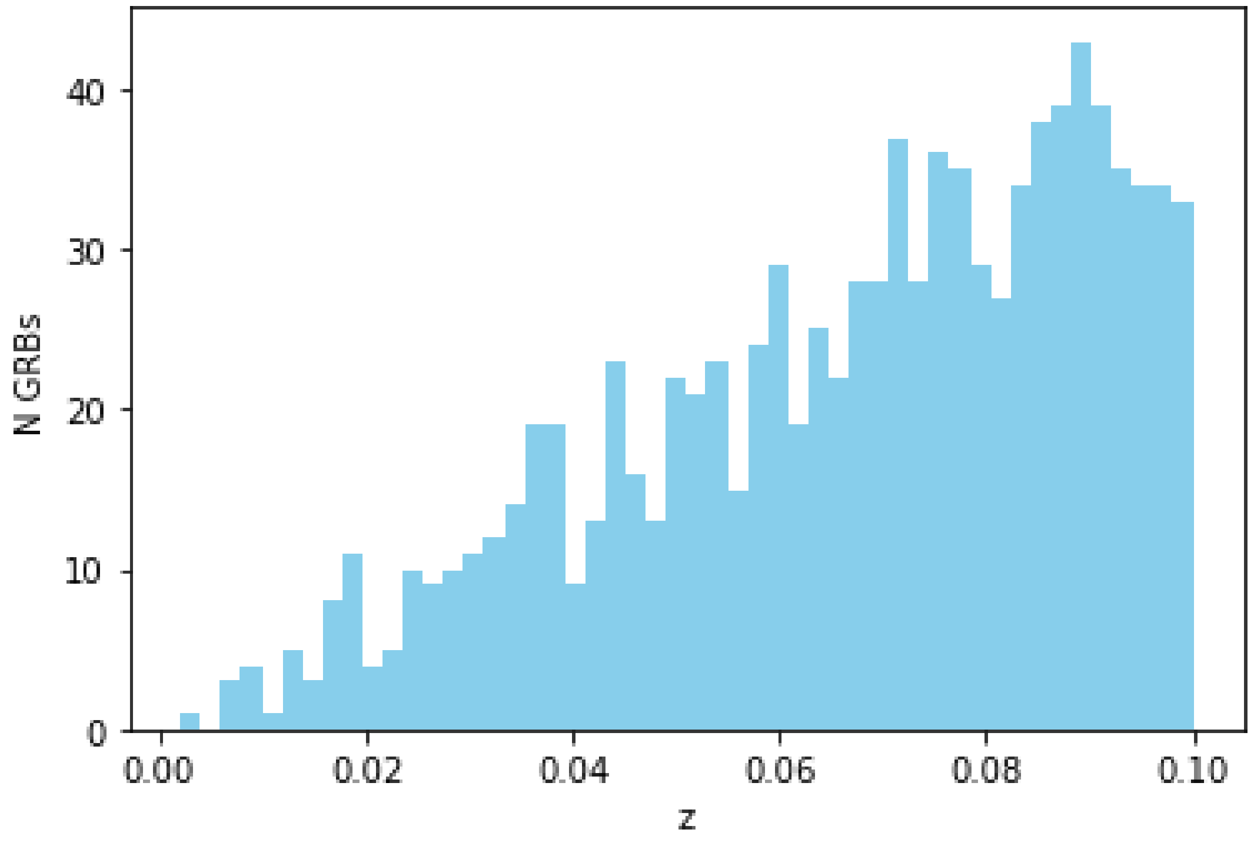
100 000 configurations saved

Redshift z



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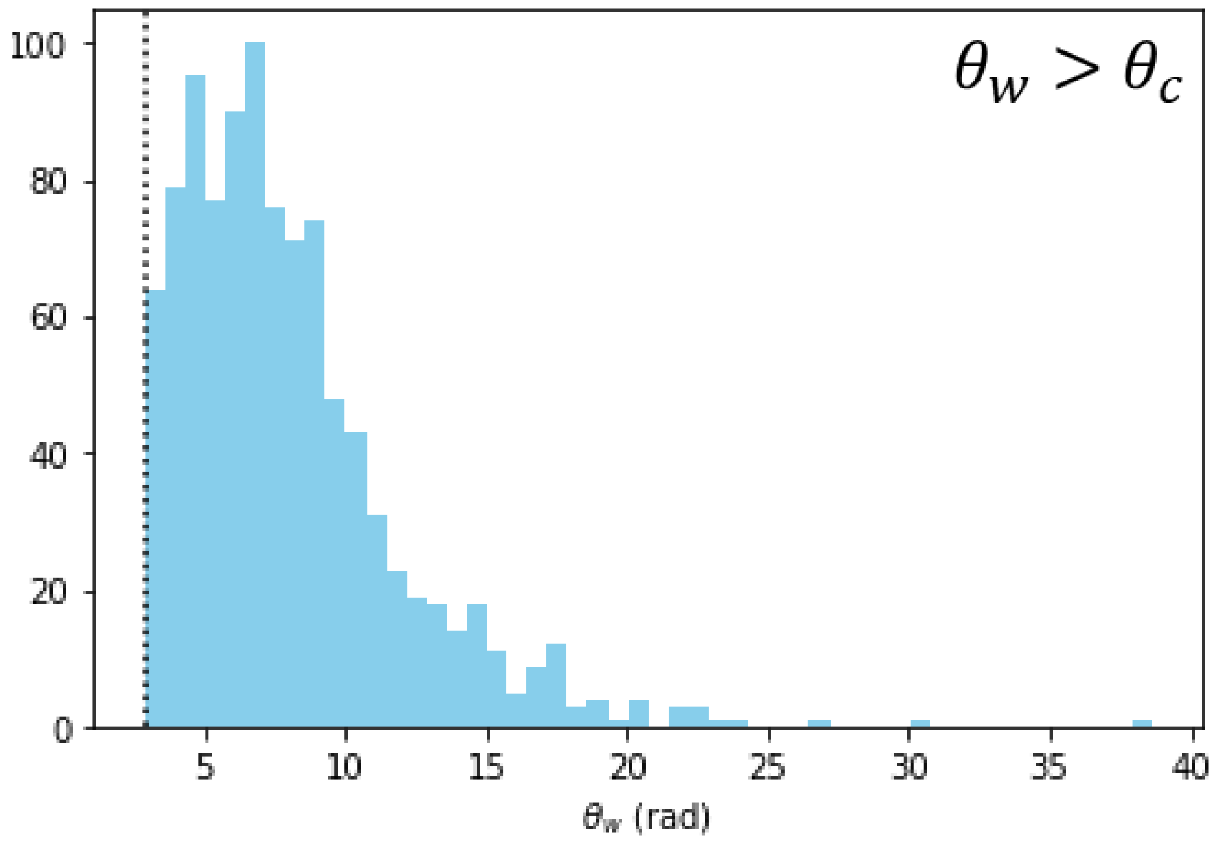

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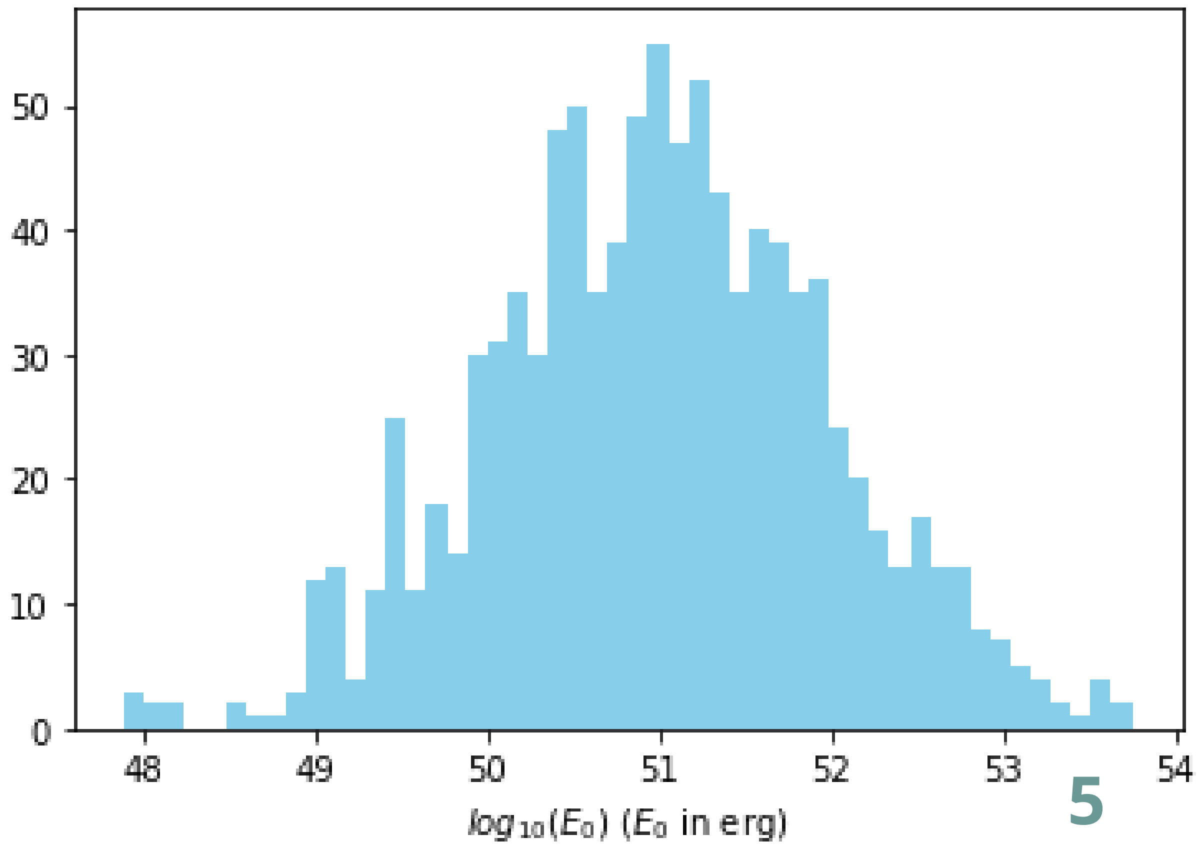
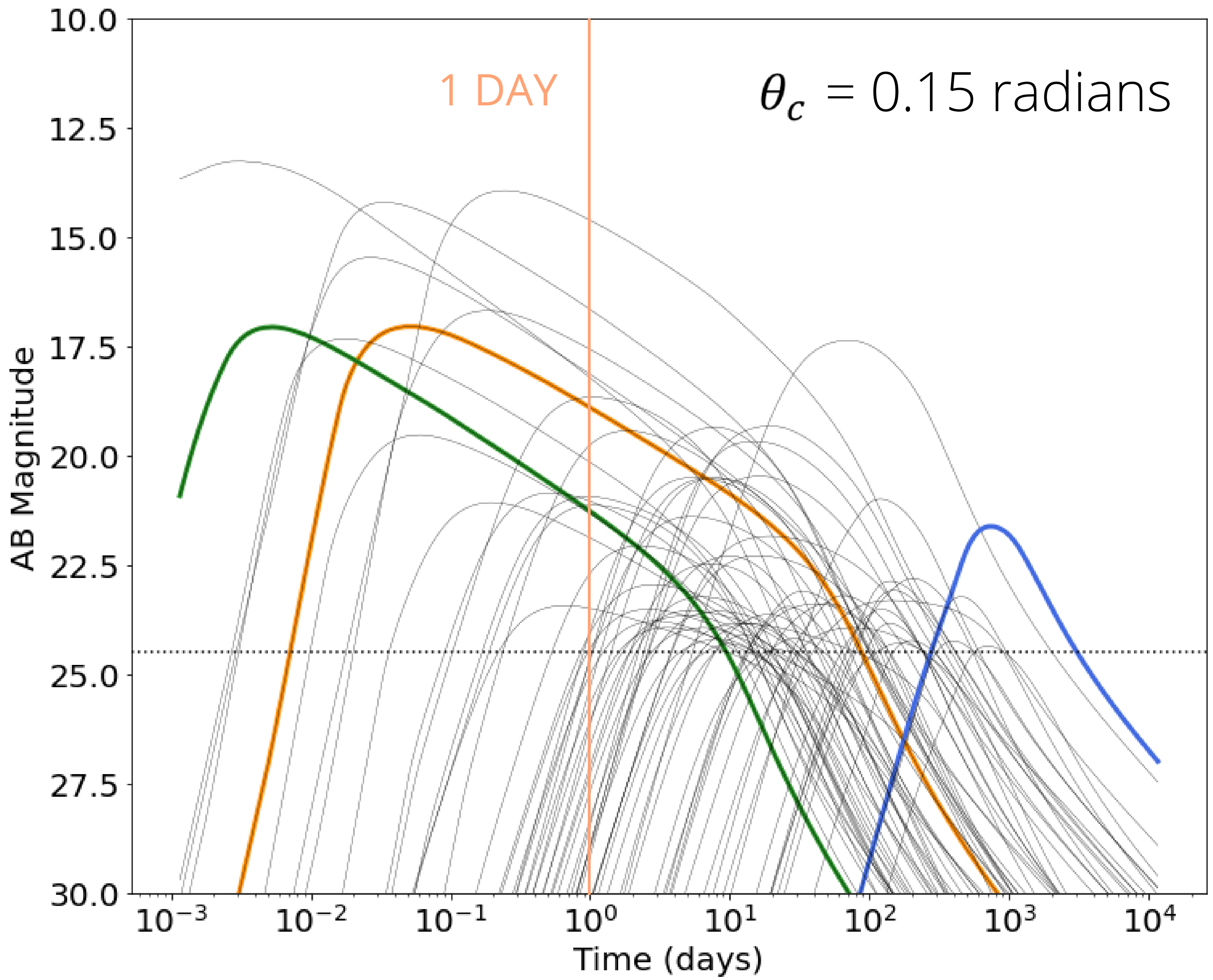


SIMULATED LIGHT CURVES FOR OFF-AXIS AFTERGLOWS

OFF-AXIS OBSERVABLE MORE THAN 7 DAYS FOR A POWER-LAW JET



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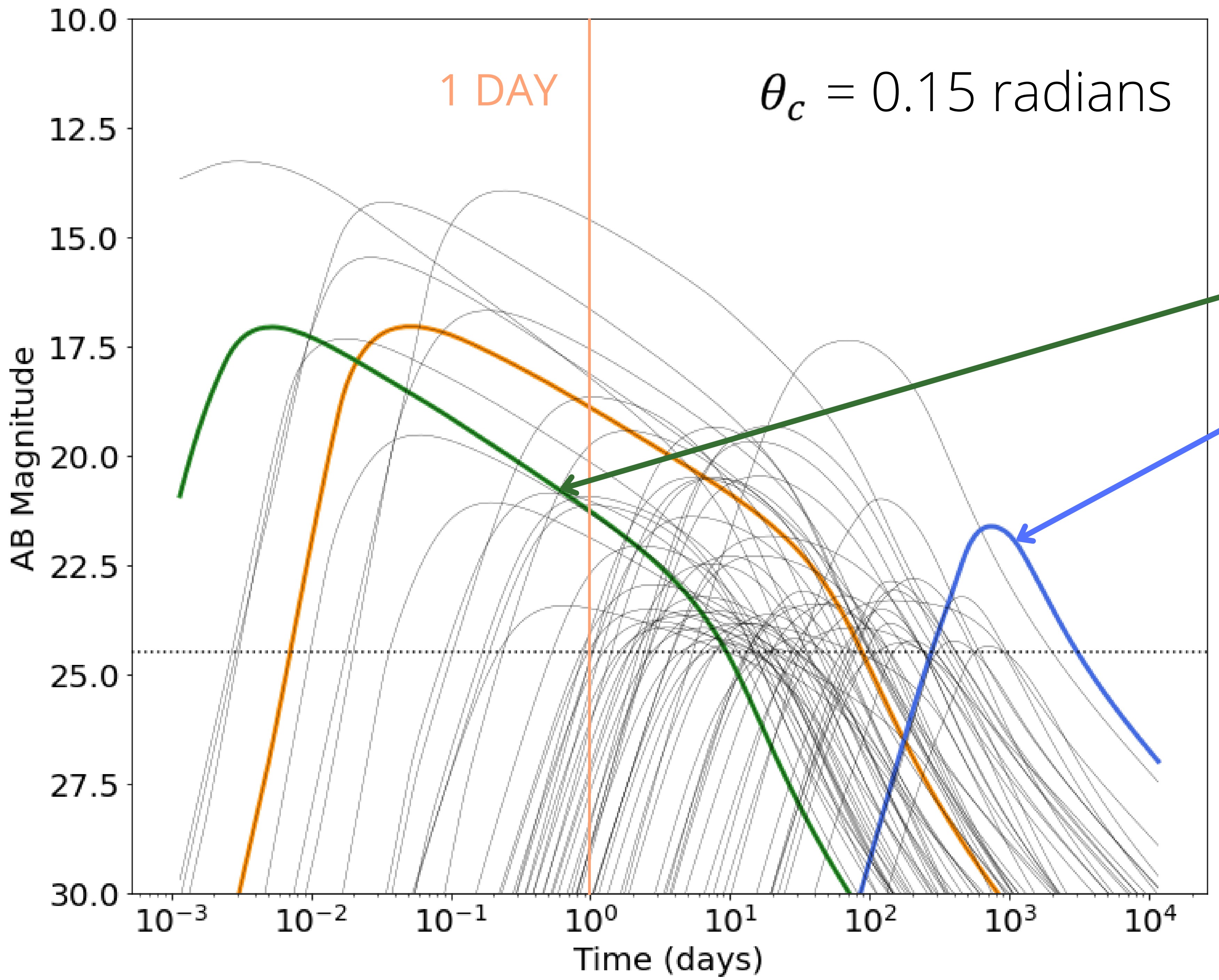

Large diversity of light curves:

- bright and short OAs
- faint and long OAs

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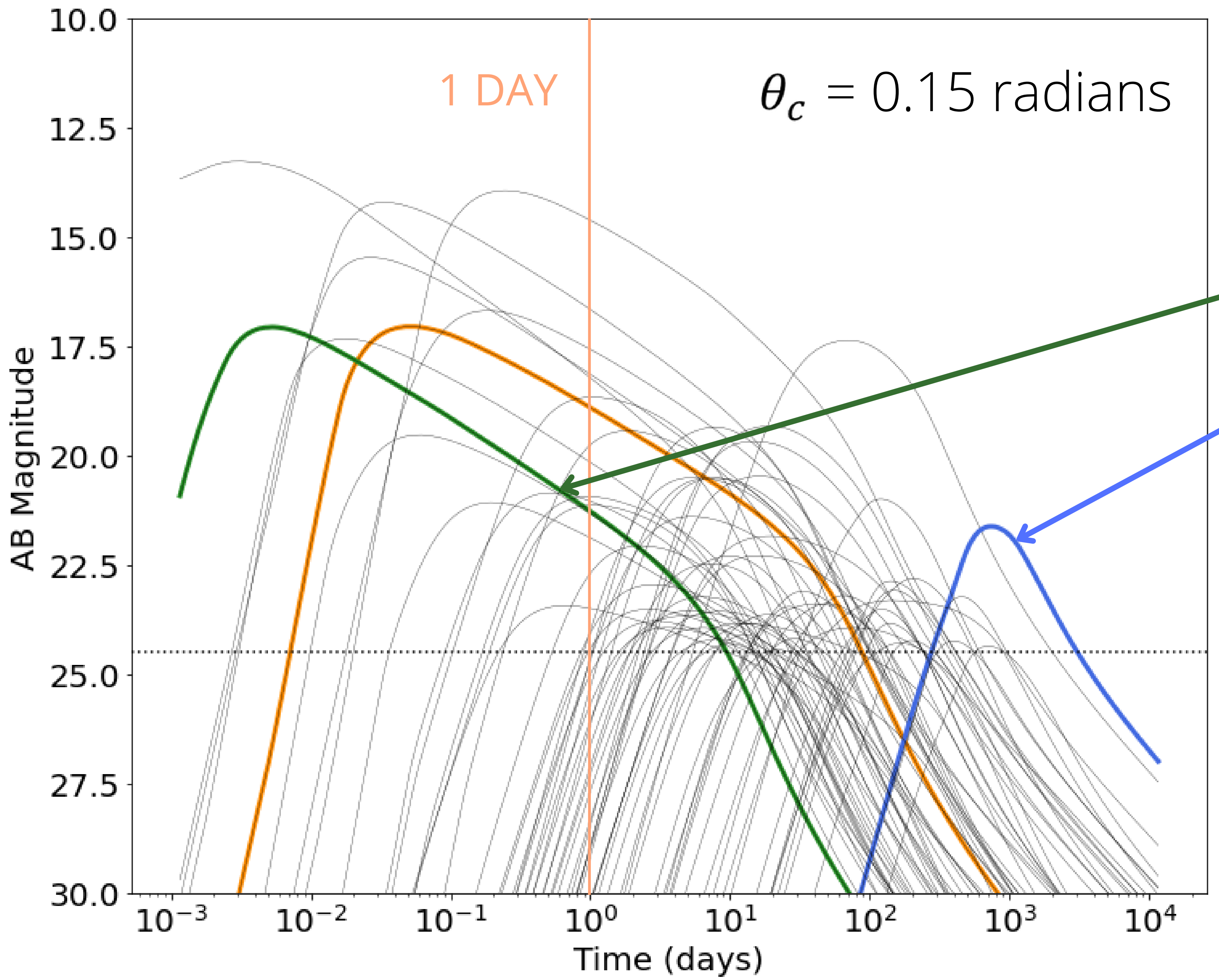


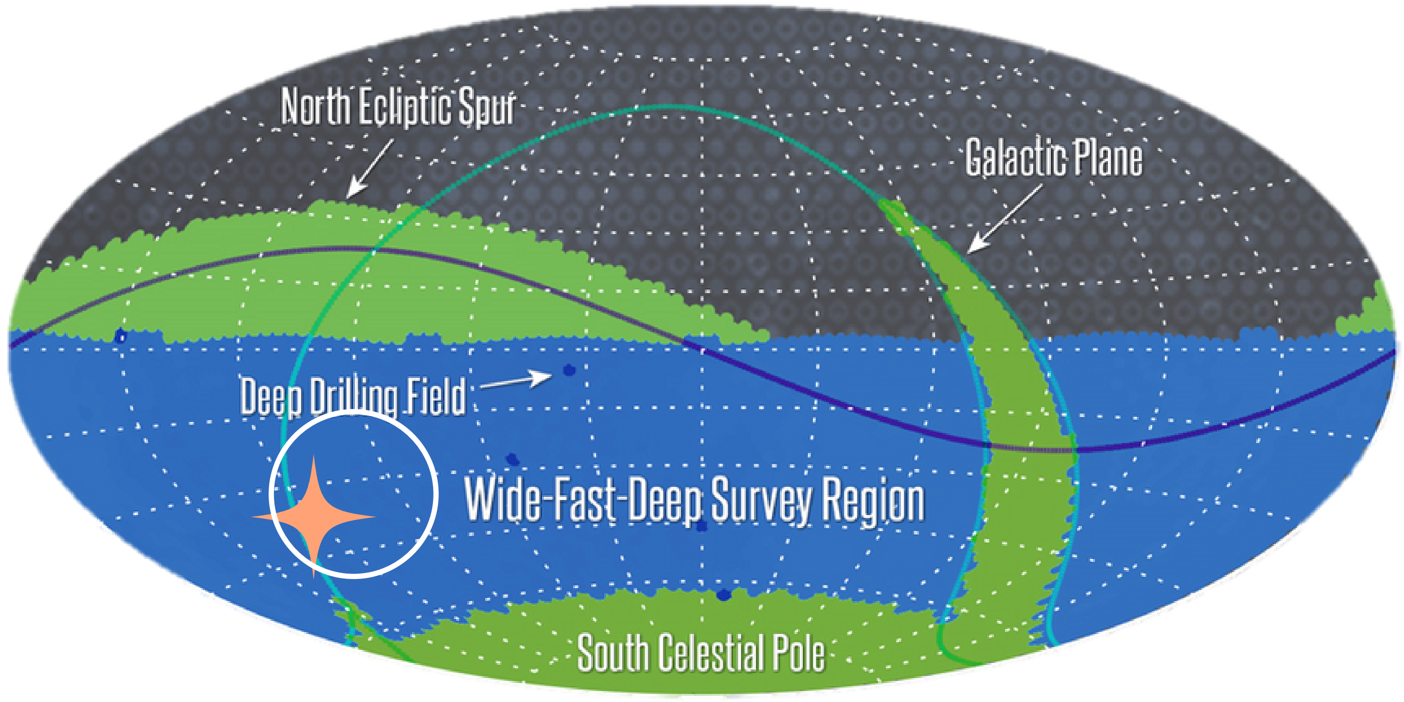
Large diversity of light curves:

- bright and short OAs
- faint and long OAs

⟹ Final fraction of theoretically observable OAs: ~ 7%

PSEUDO OBSERVATIONS WITH THE RUBIN_SIM PACKAGE

https://www.lsst.org



rubin_sim package ⟹ Realisation of the scheduler simulation for the 10 years of LSST

1- Take time and coordinates of a short GRB
2- Keep only observations inside the Rubin/LSST field of view

https://github.com/lsst/rubin_sim

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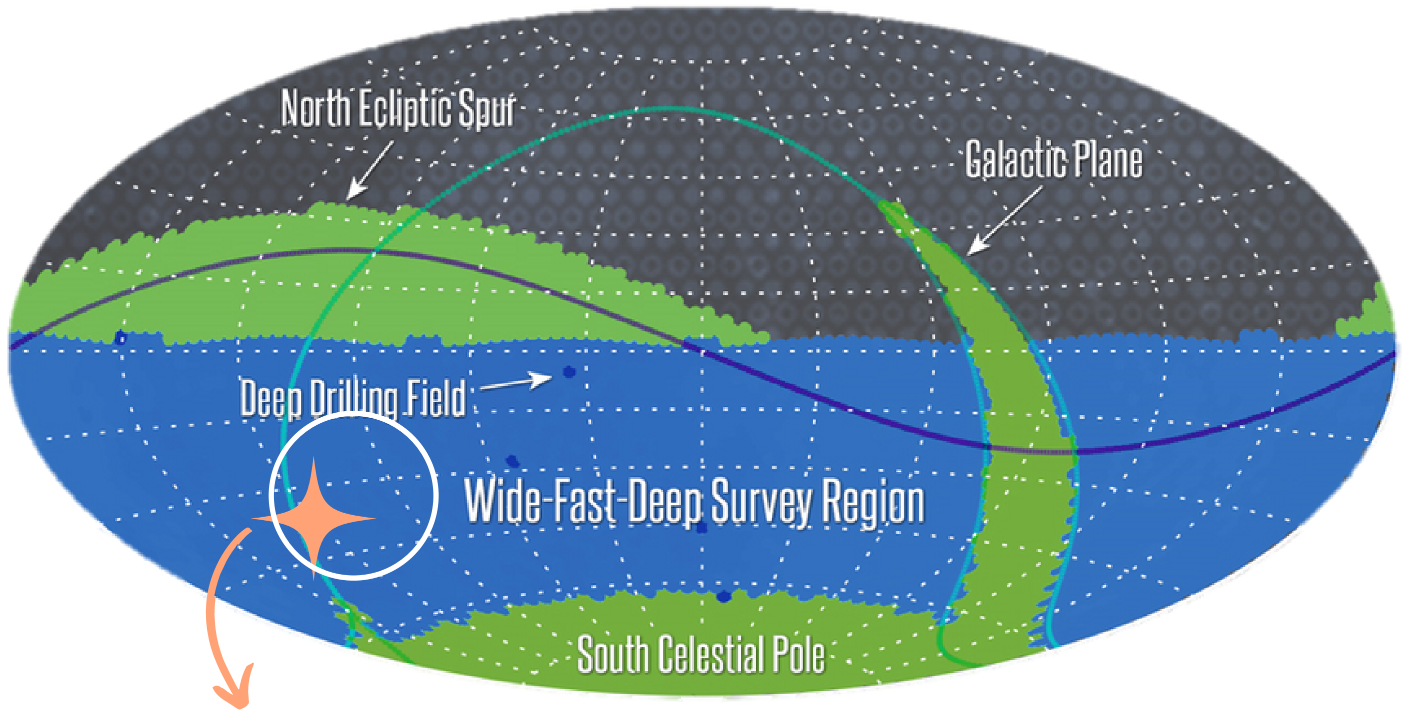
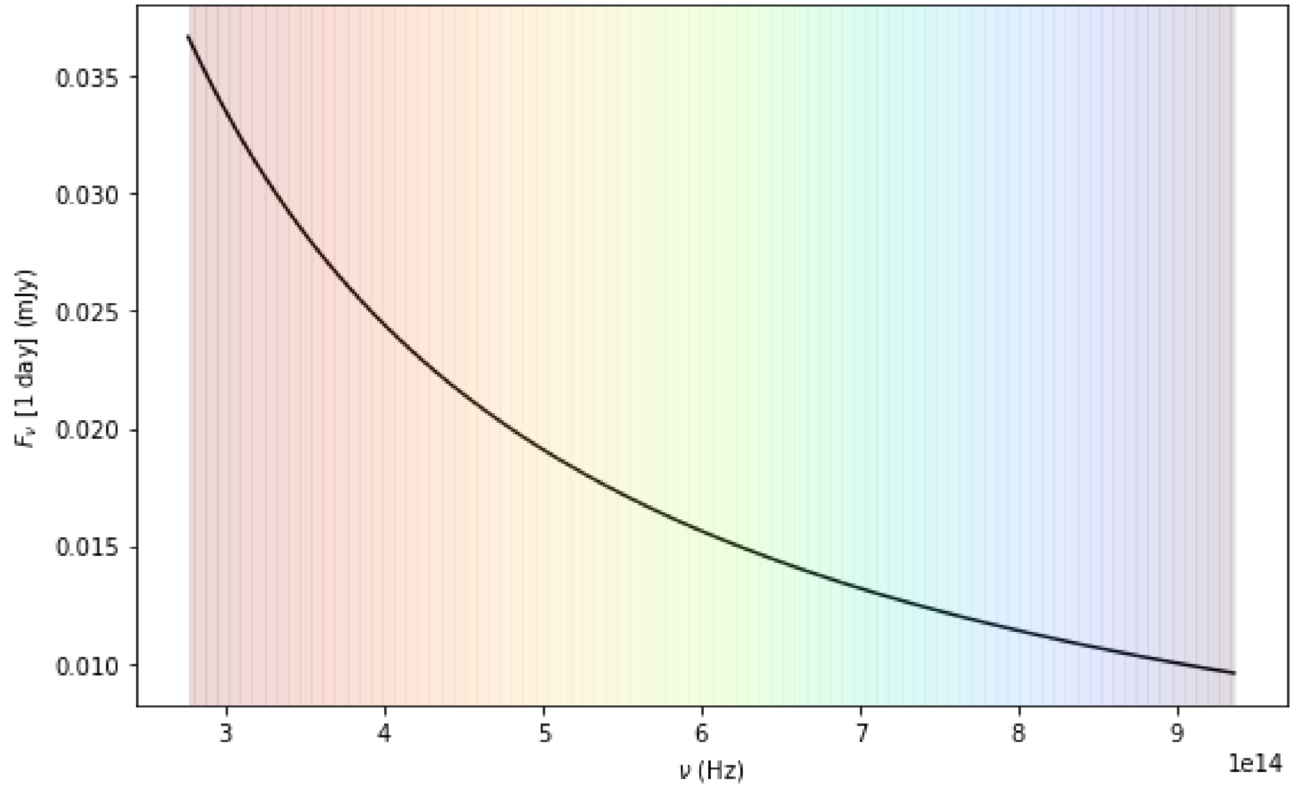


1- Take time and coordinates of a short GRB

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

3- Compute spectra at observation time bins in magnitude



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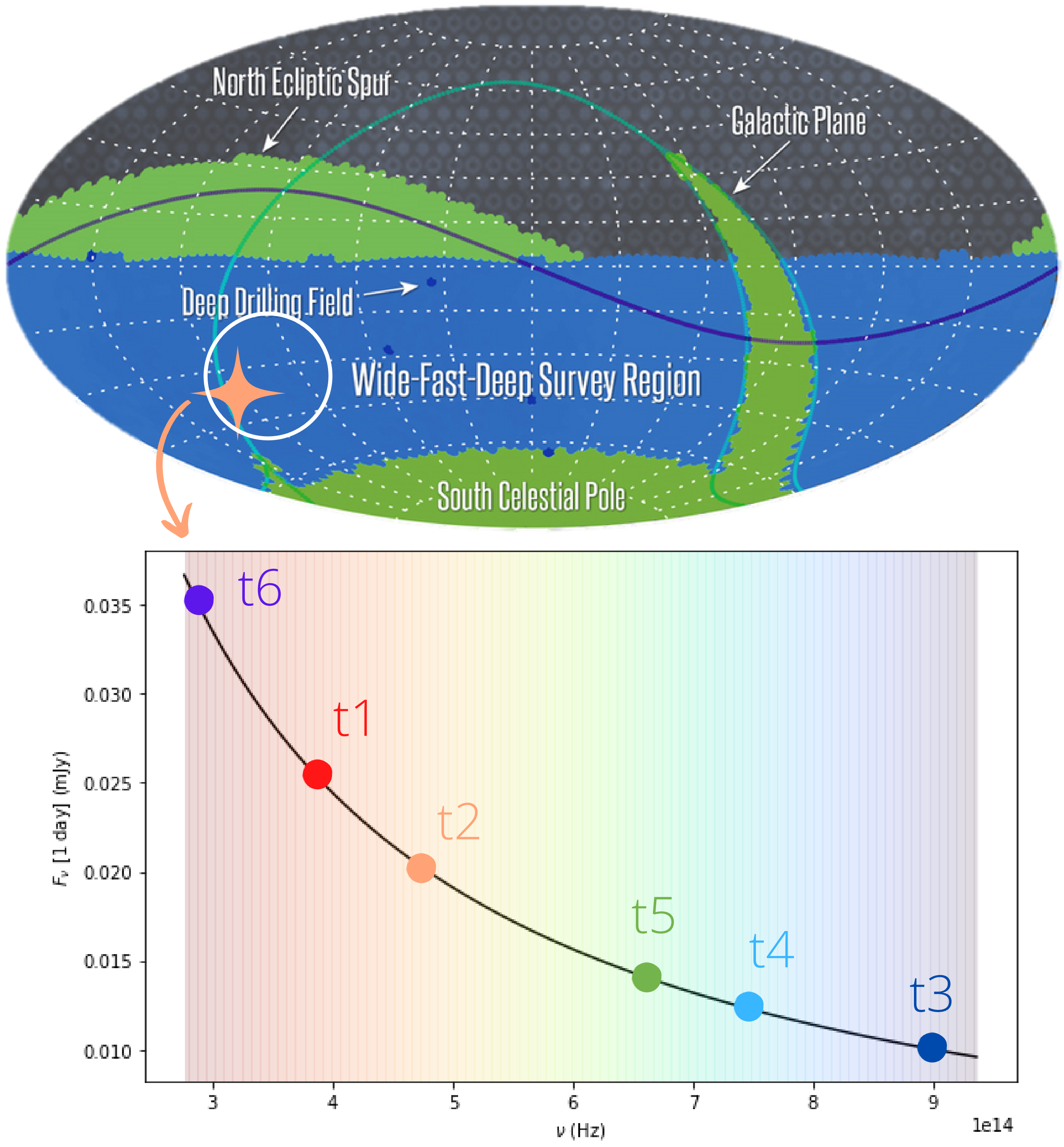


1- Take time and coordinates of a short GRB
2- Keep only observations inside the Rubin/LSST field of view
3- Compute spectra at observation time bins in magnitude
4- Keep only "real" observation for the right filter
5- Plot pseudo observed light curve

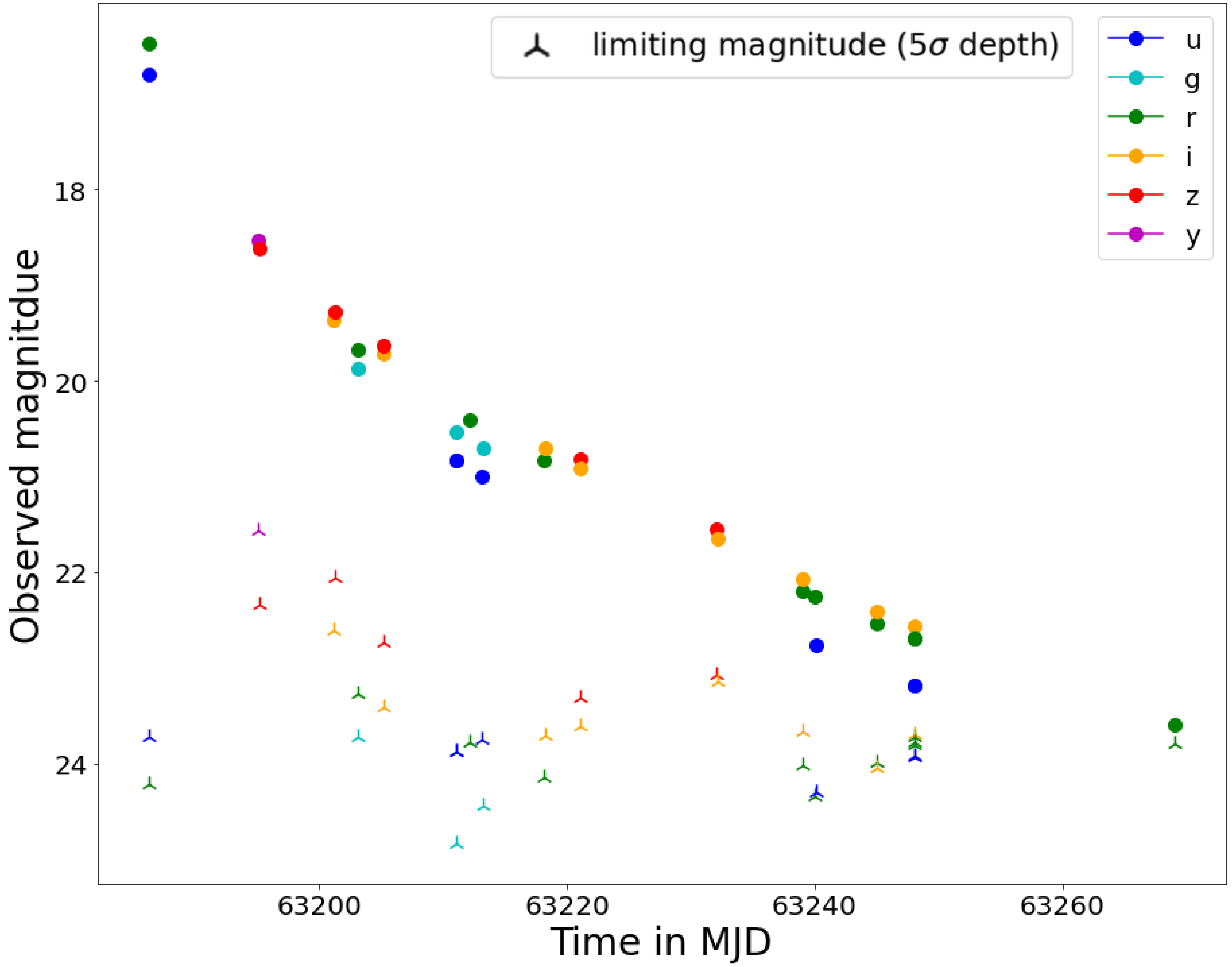
https://github.com/lsst/rubin_sim

PSEUDO OBSERVATIONS WITH THE RUBIN_SIM PACKAGE

https://github.com/lsst/rubin_sim

GRB date: 15 November 2031
GRB (RA, Dec) coordinates:
(03h40m31.6s, -13d44m34.2s)

```
Z = {'jetType':     4,
     'specType':    0,
     'b':           4,
     'thetaObs':    0.1694977553300254,
     'E0':          7.791161758307381e+52,
     'thetaWing':   0.1547857512918l205,
     'thetaCore':   0.15,
     'n0':          0.09182964074183593,
     'p':           2.2,
     'epsilon_e':   0.1,
     'epsilon_B':   0.01,
     'xi_N':        1.0,
     'd_L':         1.372113563407664 8e+27,
     'z':           0.094}
```



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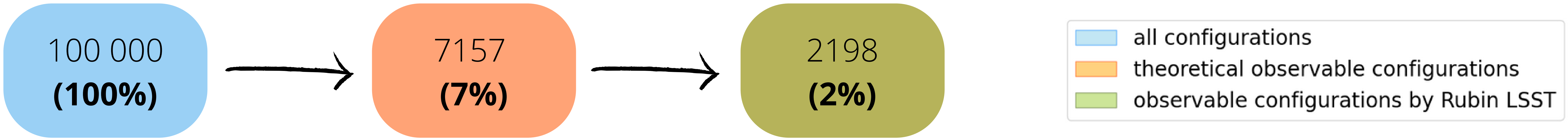
1. General context

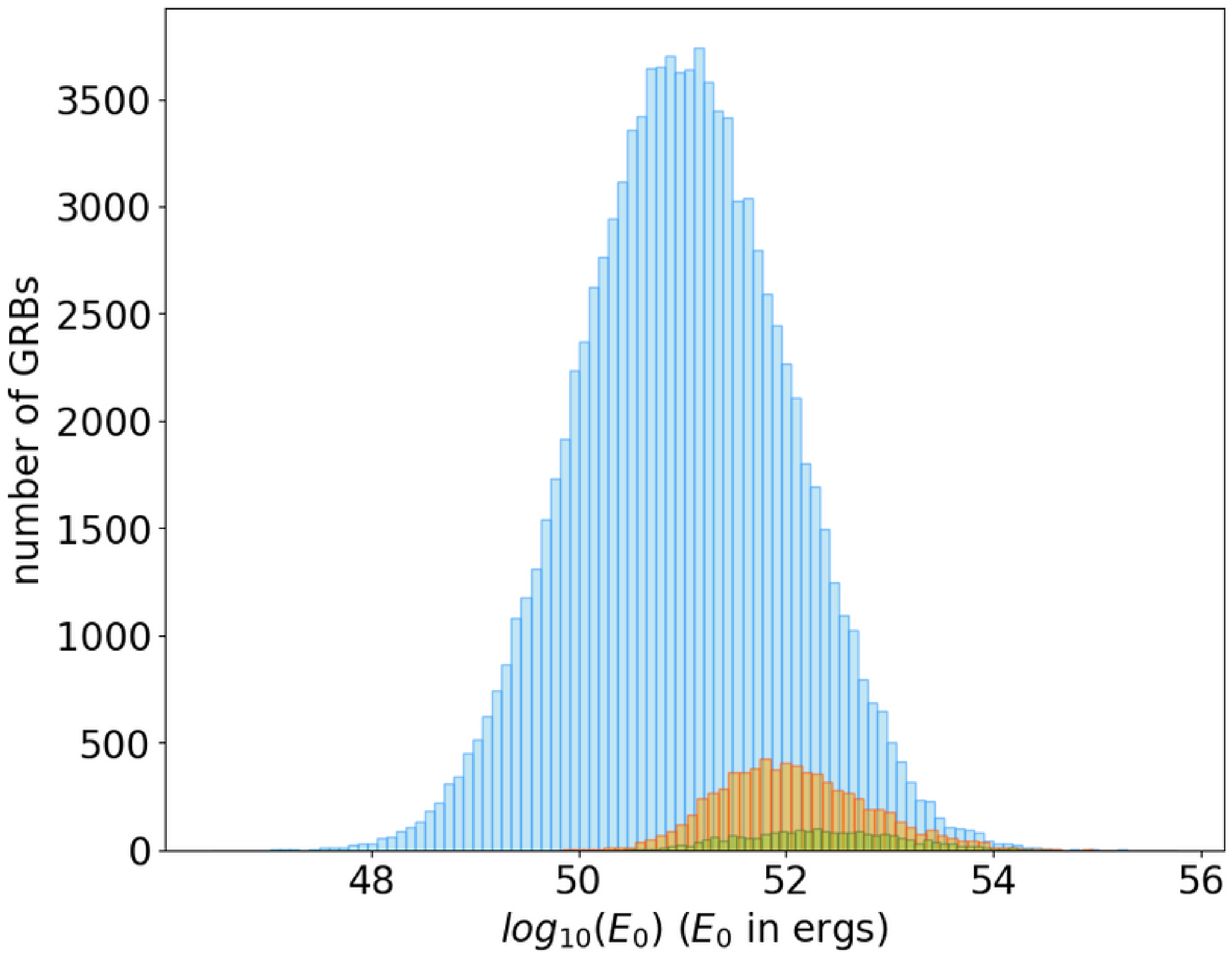
2. Simulation of a population of short gamma-ray bursts

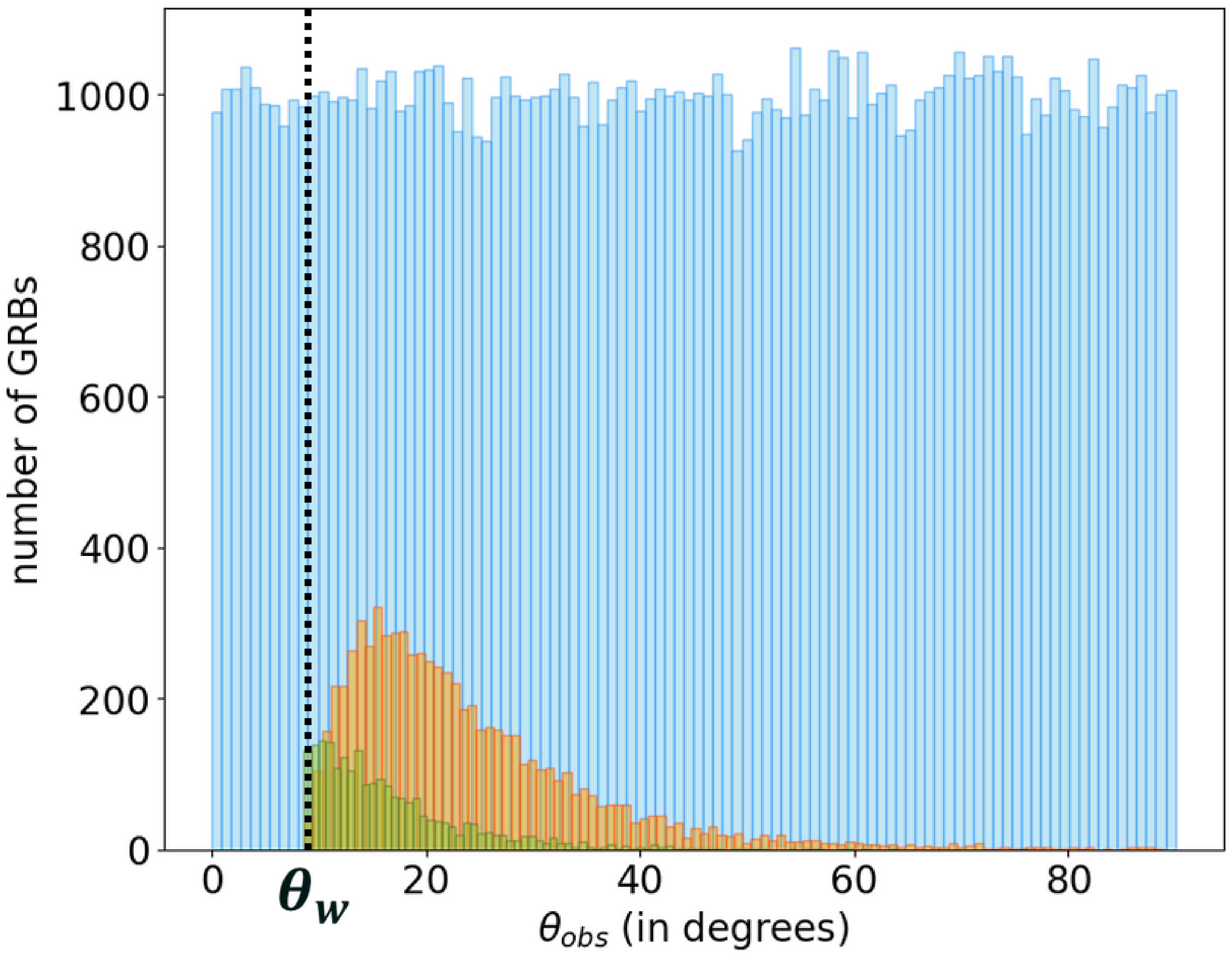
3. **Analyses of the pseudo-observed light curves**
   - **3.1** Parameters distributions of the observable orphan afterglows
   - **3.2** Defined features of a pseudo-observed light curves
   - **3.3** Correlations between the features and the initial parameters

4. Conclusion & Perspectives

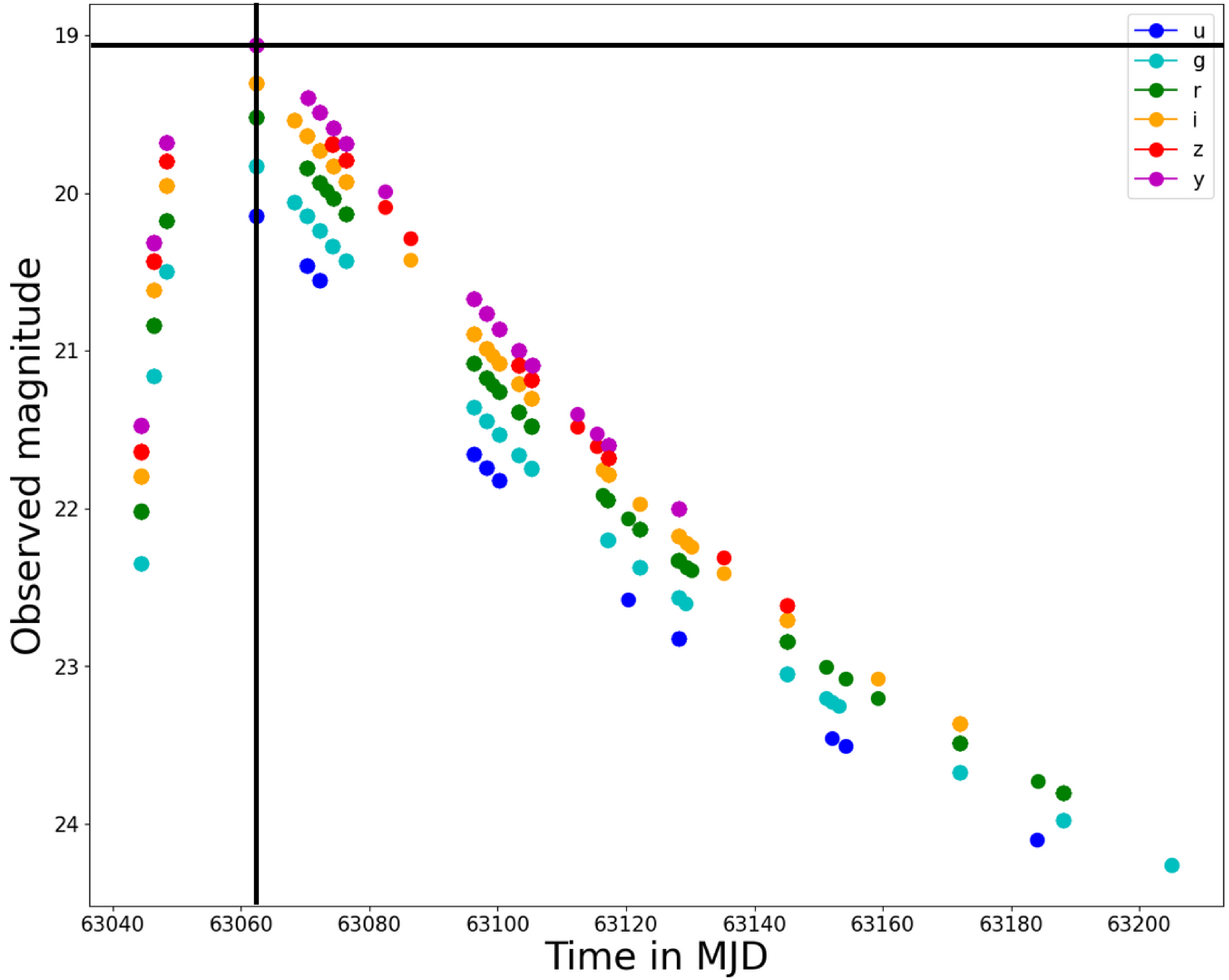
PARAMETERS DISTRIBUTIONS OF THE OBSERVABLE OAs







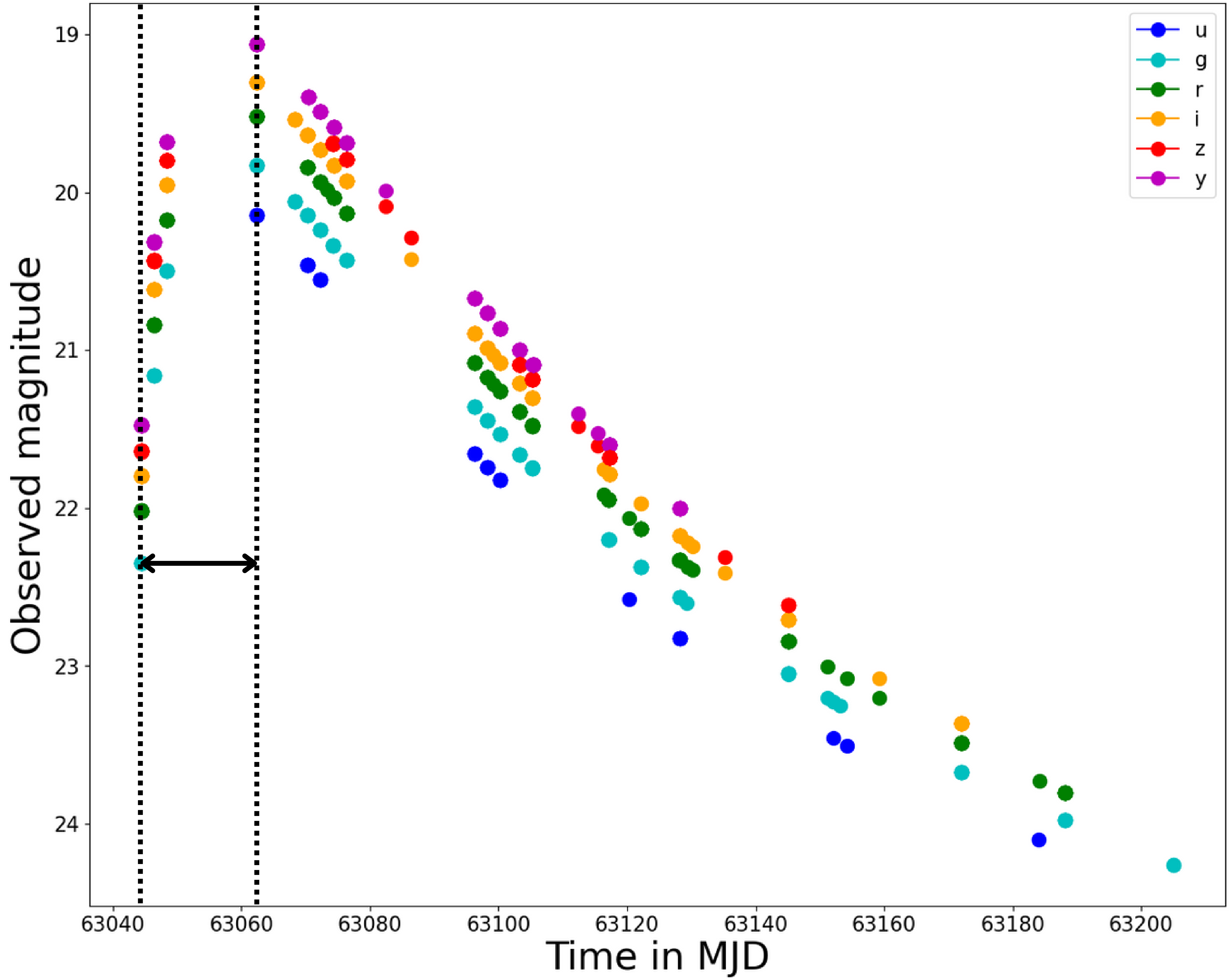
CHARACTERIZATION OF PSEUDO-OBSERVED LIGHT CURVES



Defined features:

- **Minimal magnitude (= peak)**
- **Time of the peak**

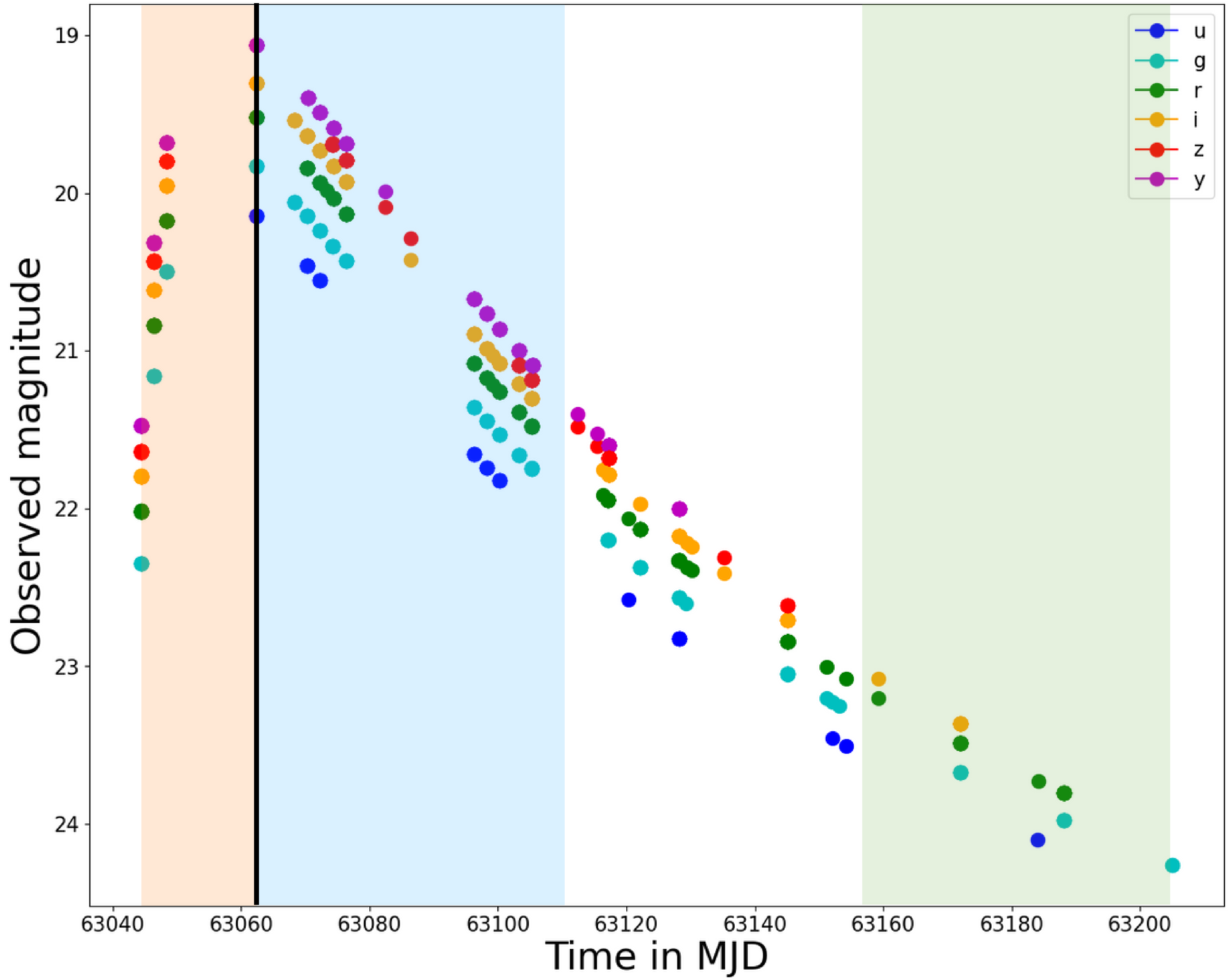
CHARACTERIZATION OF PSEUDO-OBSERVED LIGHT CURVES



Defined features:

- Minimal magnitude (= peak)
- Time of the peak
- **Duration between the first detection and the peak**

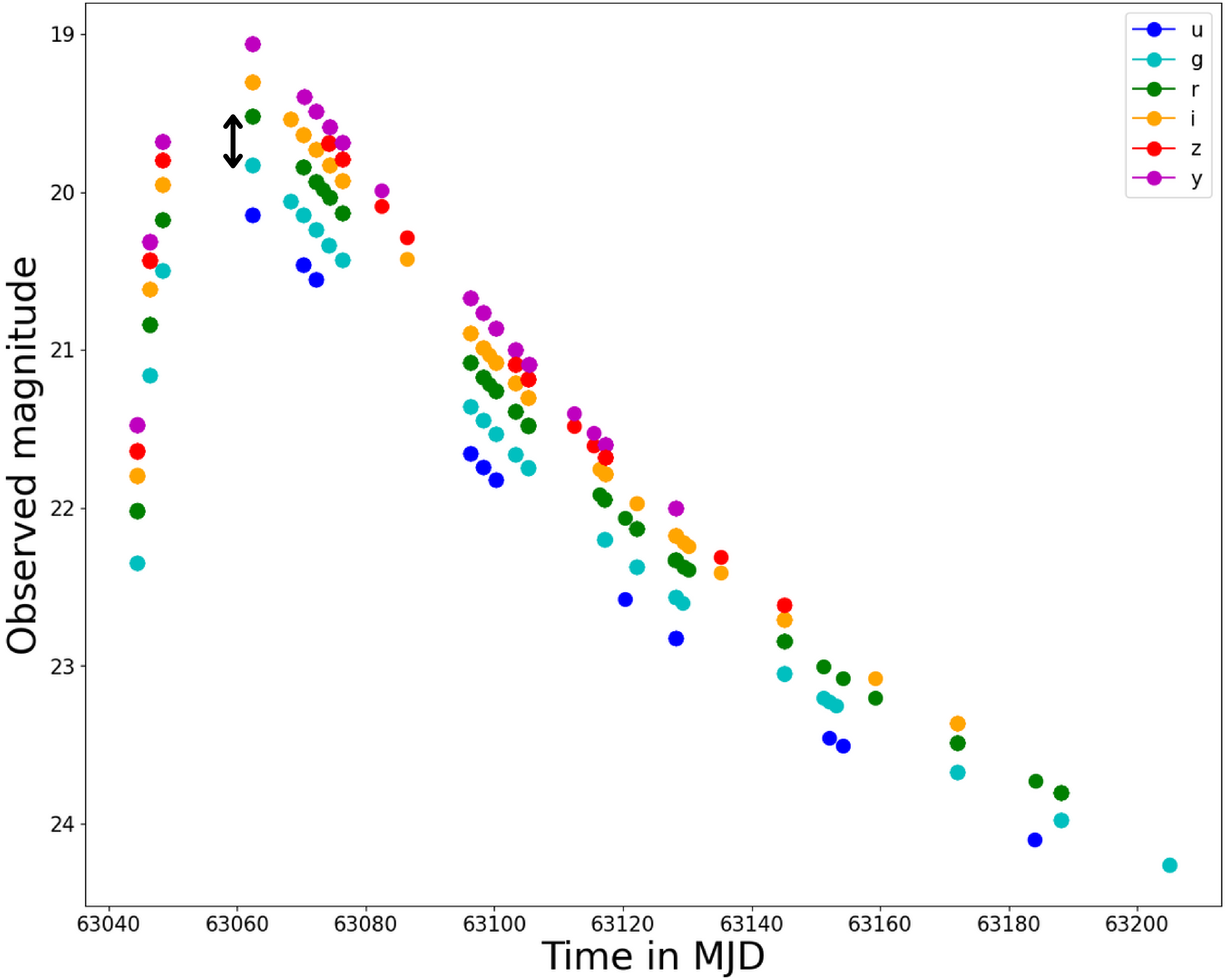
CHARACTERIZATION OF PSEUDO-OBSERVED LIGHT CURVES



Defined features:

- Minimal magnitude (= peak)
- Time of the peak
- Duration between the first detection and the peak
- **Increasing rate of the magnitude**
- **Decreasing rates of the magnitude in the 1st third and the last third of the light curve**

CHARACTERIZATION OF PSEUDO-OBSERVED LIGHT CURVES

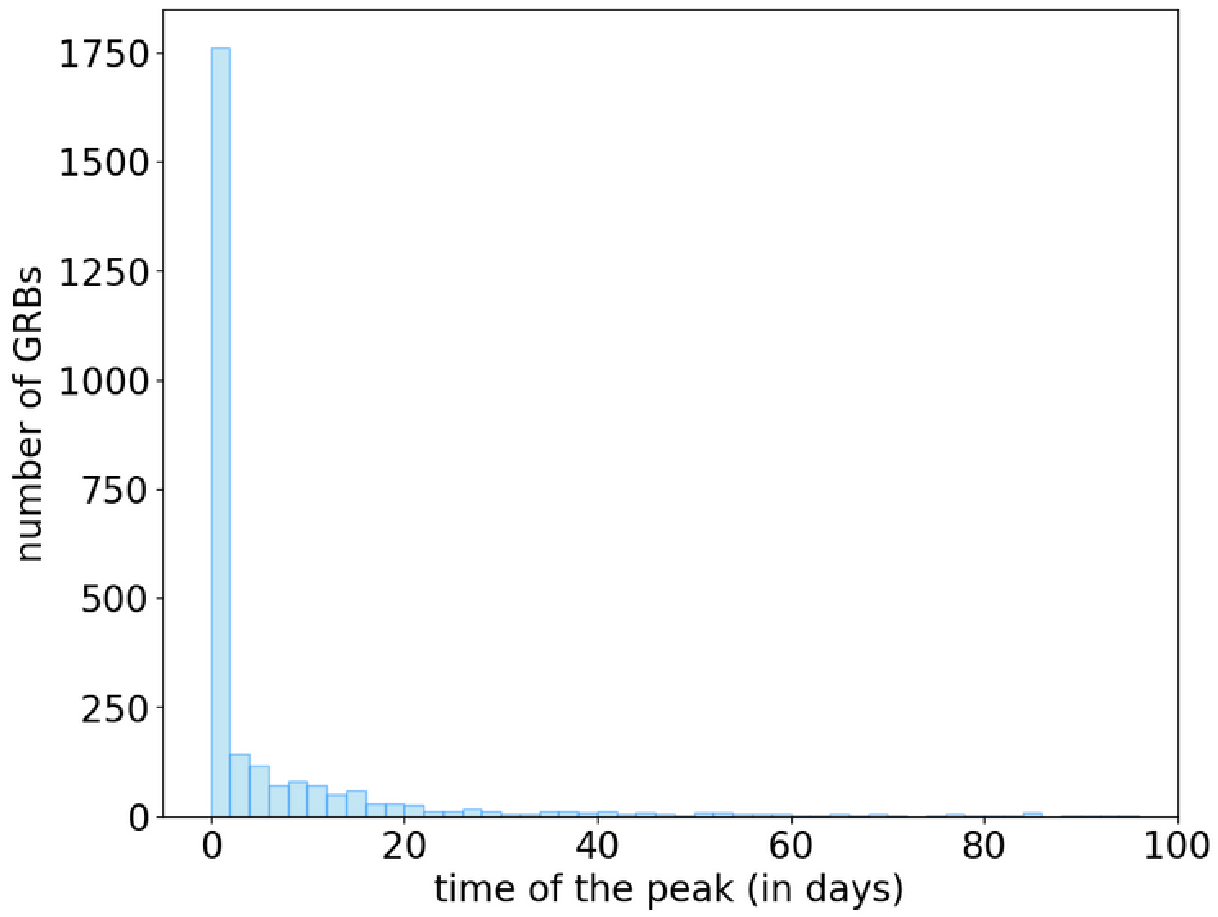


Defined features:

- Minimal magnitude (= peak)
- Time of the peak
- Duration between the first detection and the peak
- Increasing rate of the magnitude
- Decreasing 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)

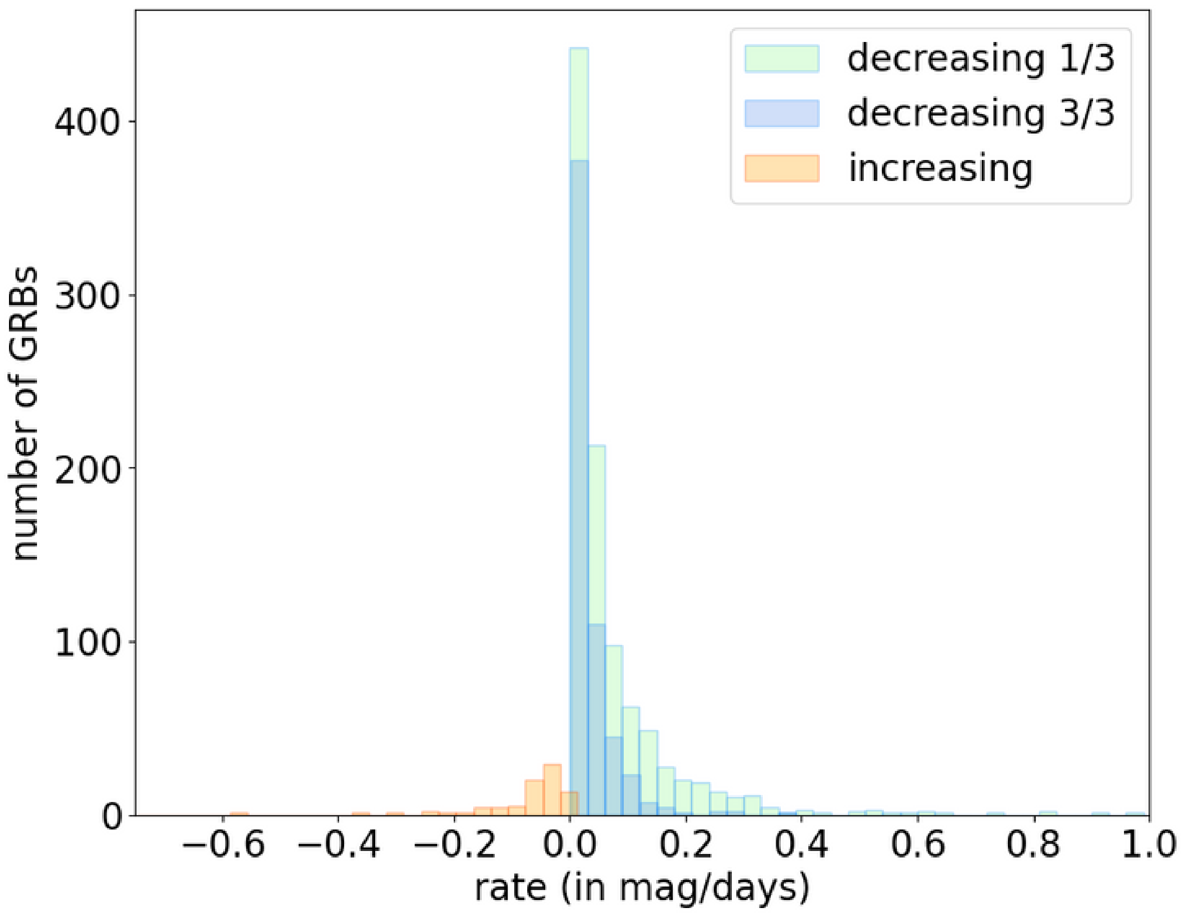
CHARACTERIZATION OF PSEUDO-OBSERVED LIGHT CURVES

Time of the peak



⟹ Generally, the first point detected corresponds to the peak

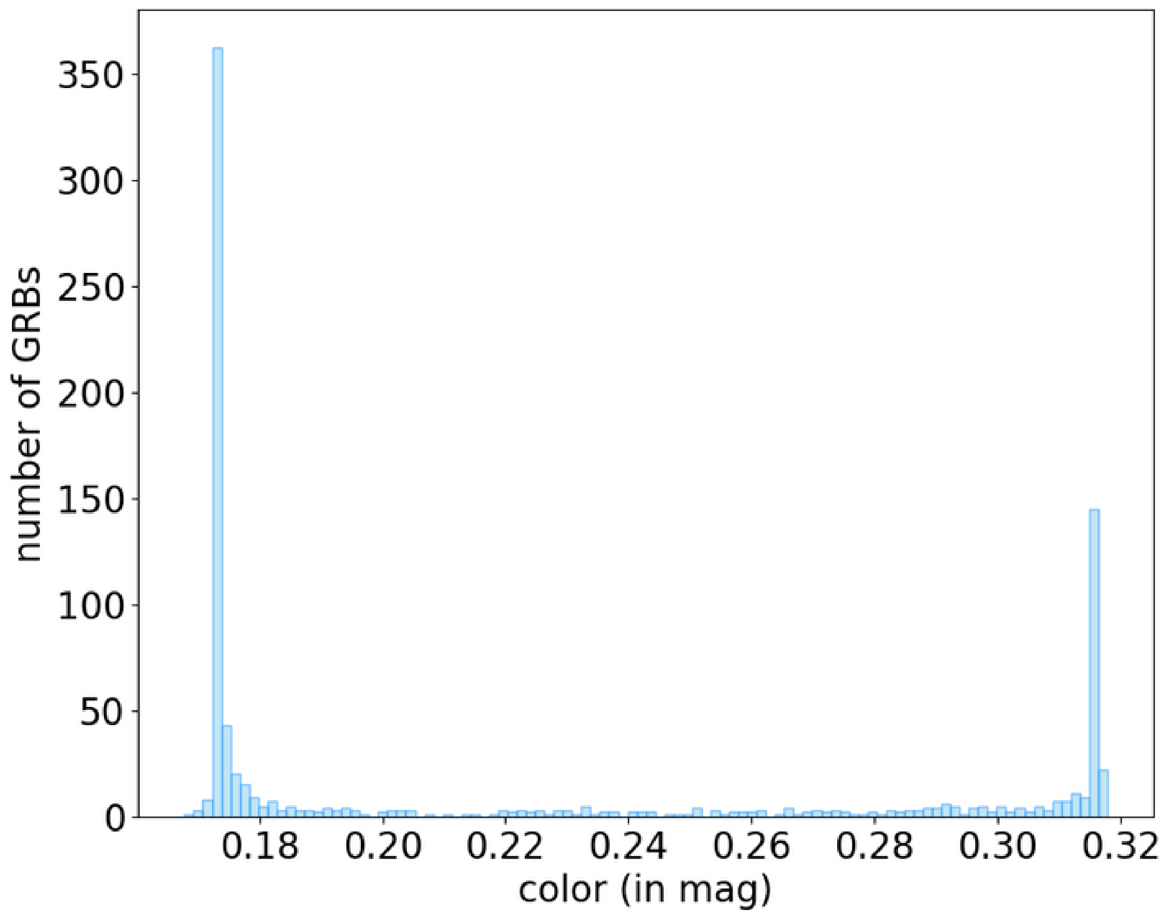
Mean decreasing and increasing rates



⟹ More data in the 1st third

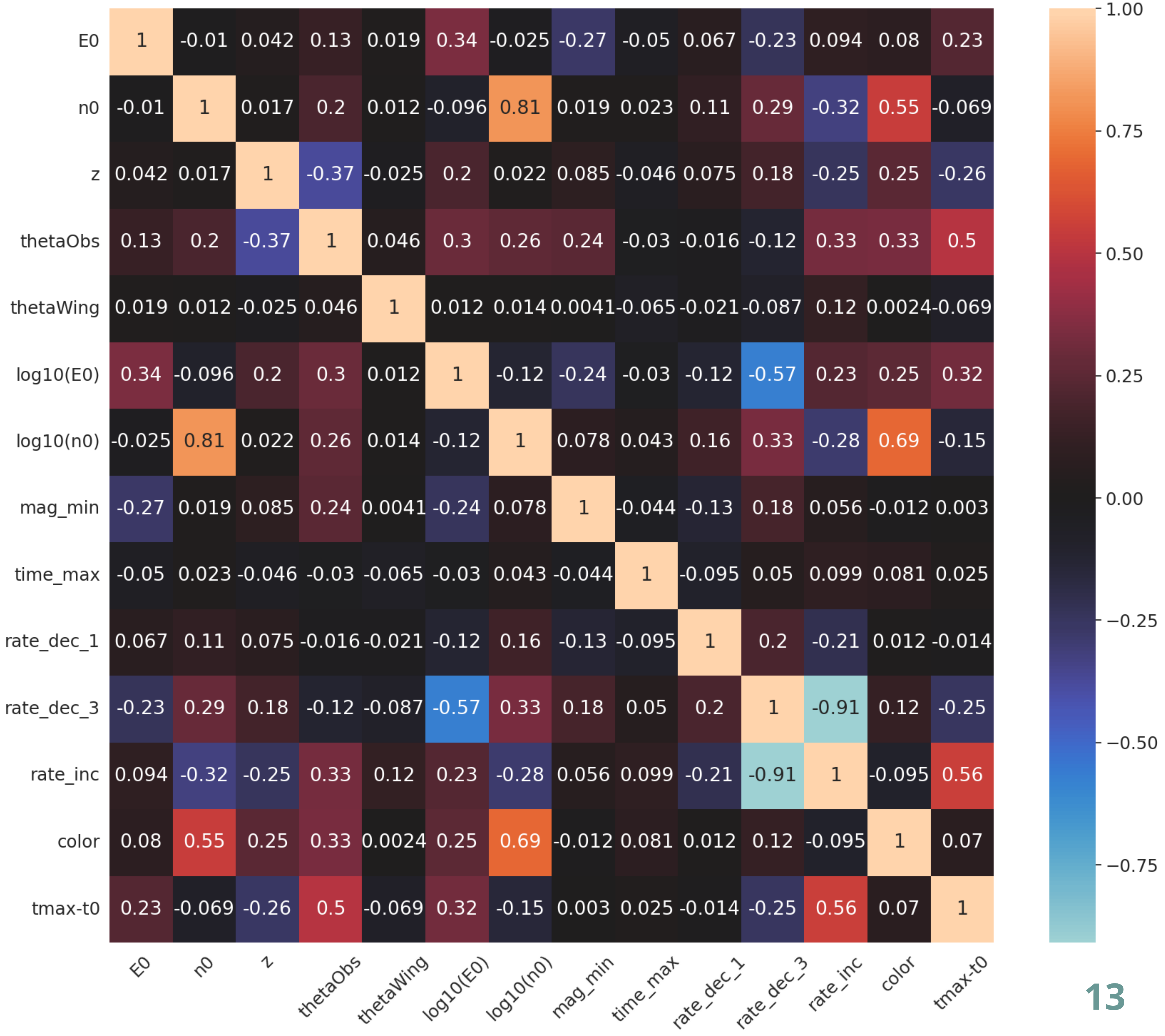
⟹ 1/3 and 3/3 rates can be very different

Mean g-r color

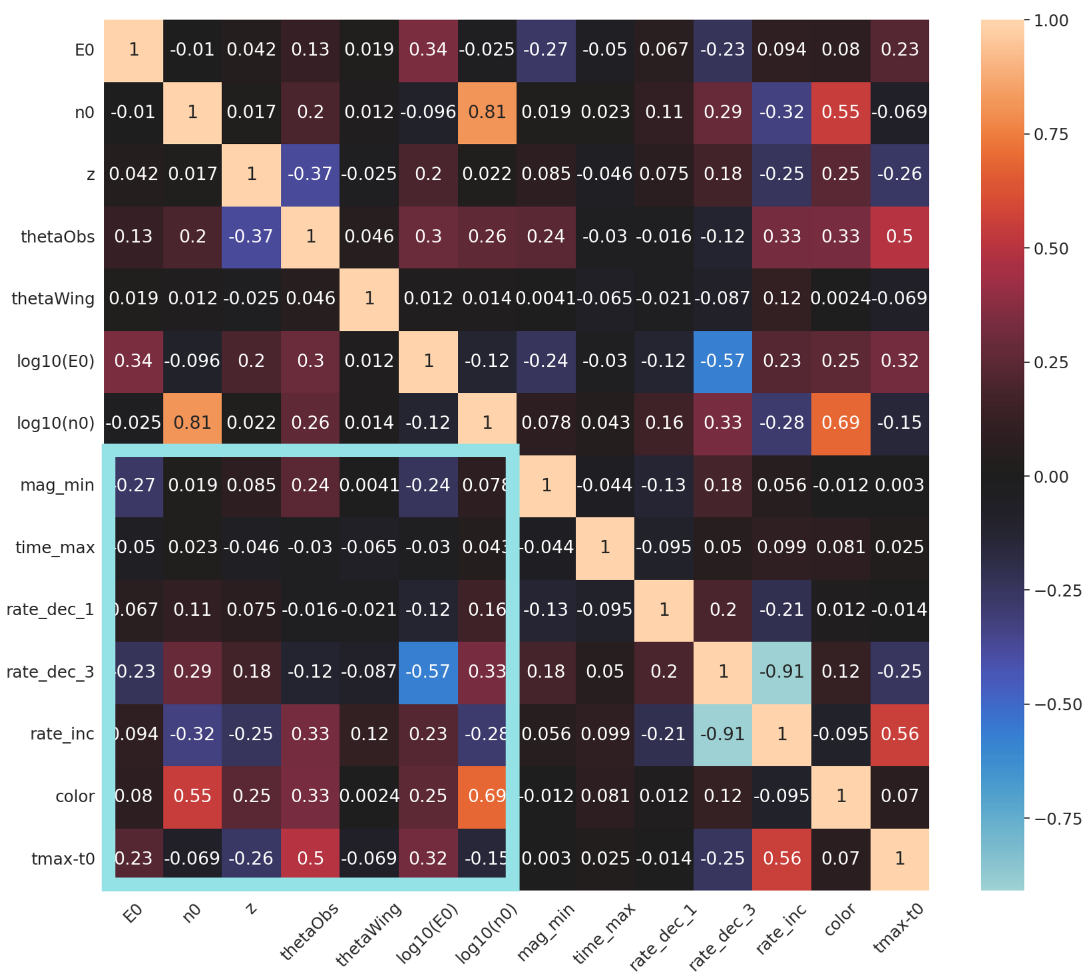


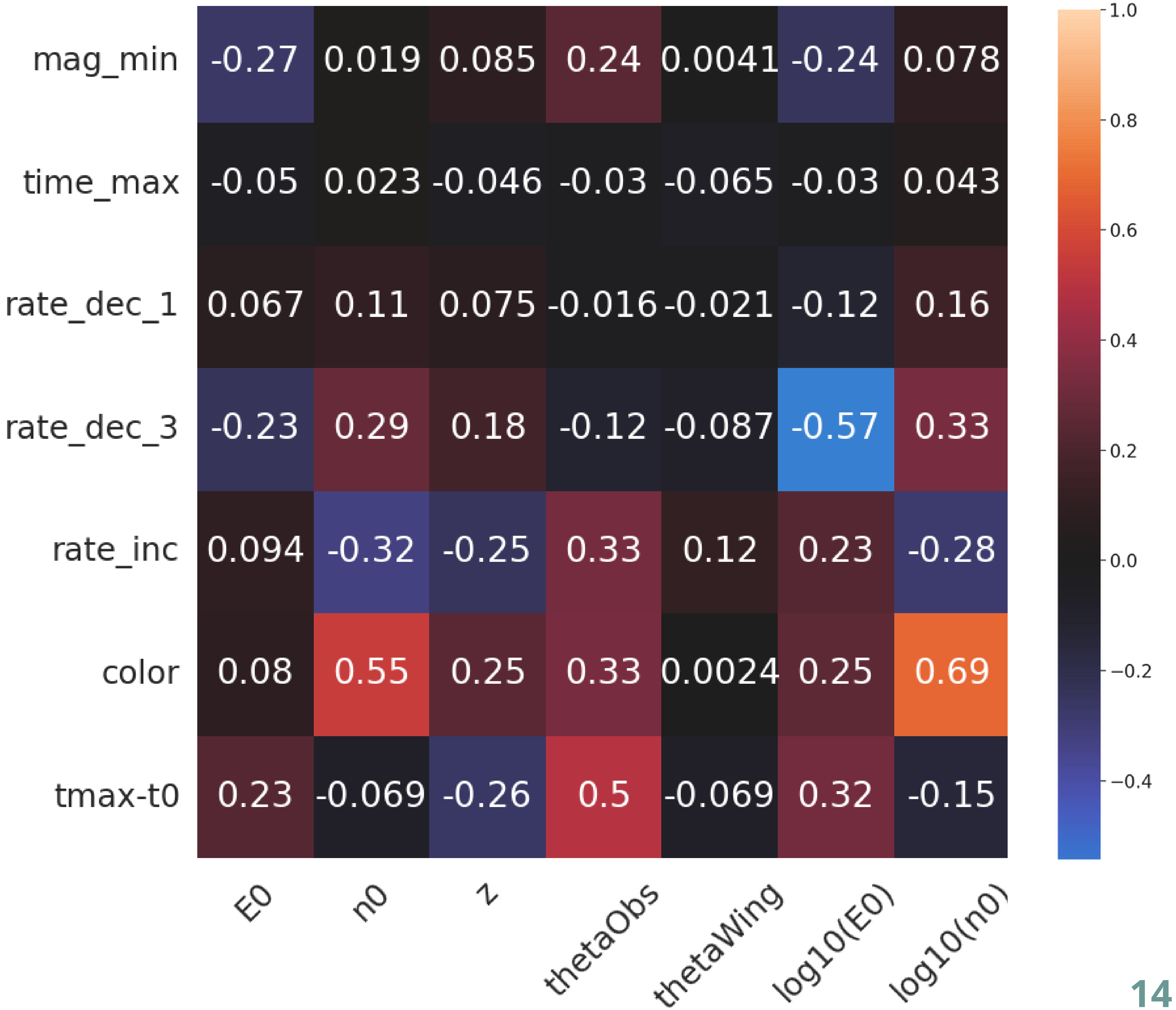
⟹ Bimodal distribution not understood

CORRELATIONS



CORRELATIONS





$\Longrightarrow$ Importance of θ_{obs}

$\Longrightarrow$ Correlations between color and n_0

$\Longrightarrow$ Correlations between decreasing rate and E_0

CONCLUSION AND PERSPECTIVES

"Rough" simulations of a "rough" population of GRBs:

$\Longrightarrow$ Estimation of the number of theoretically observable OAs: **~ 7%**

Pseudo-observations of a "rough" population of GRBs:

$\Longrightarrow$ Estimation of the number of observable OAs: **~ 2%**

Perspectives

- Take into account the galactic extinction for the pseudo-observations
- Improve the population of short GRBs
- Explore other afterglow models
- Use Elasticc data as a background sample
- Develop a first version of a filter for FINK to identify OAs

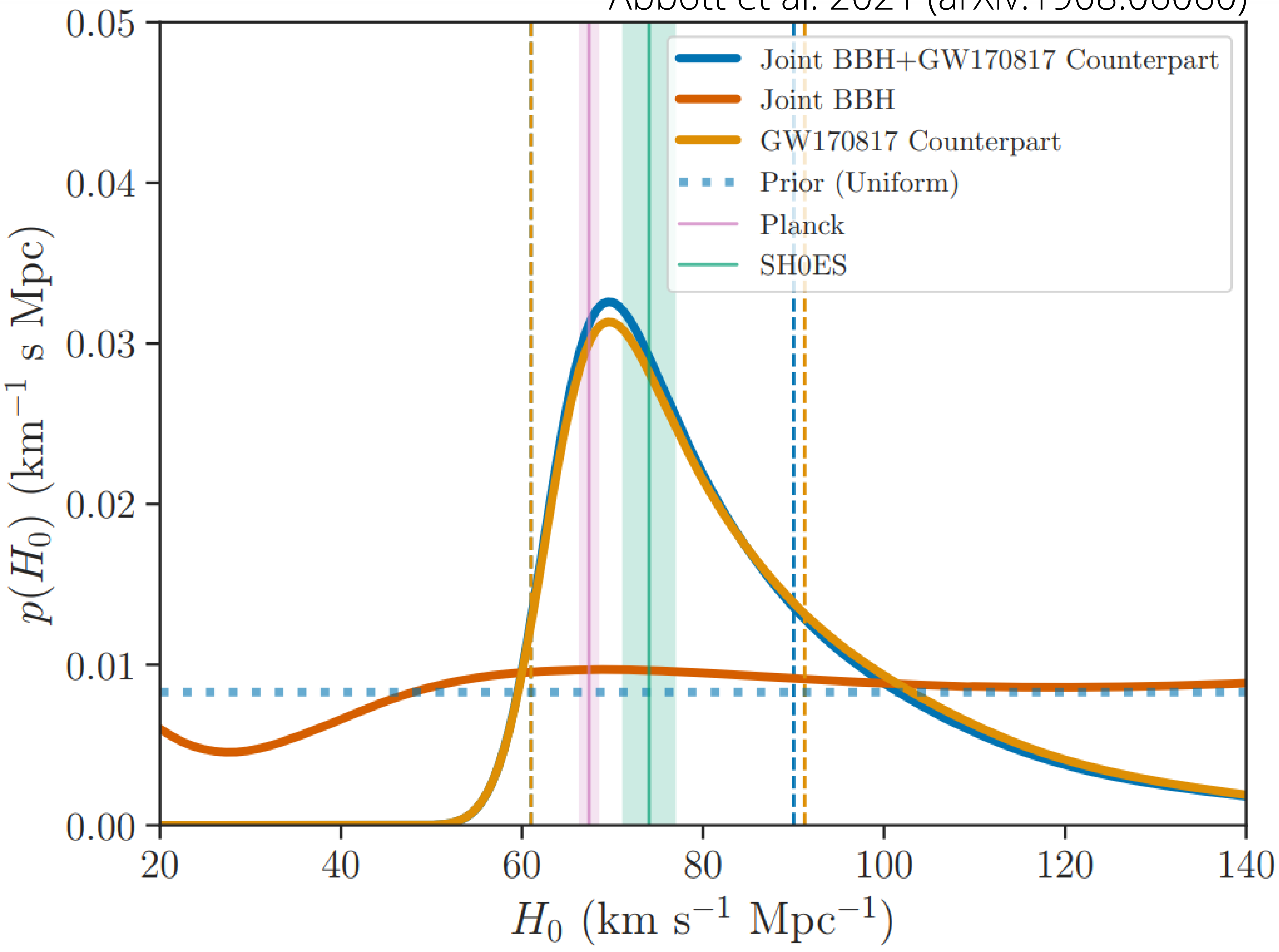
All the codes can be accessible at:

https://gitlab.in2p3.fr/johan-bregeon/orphans/-/tree/main/notebooks

THANK YOU FOR YOUR ATTENTION!

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:

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

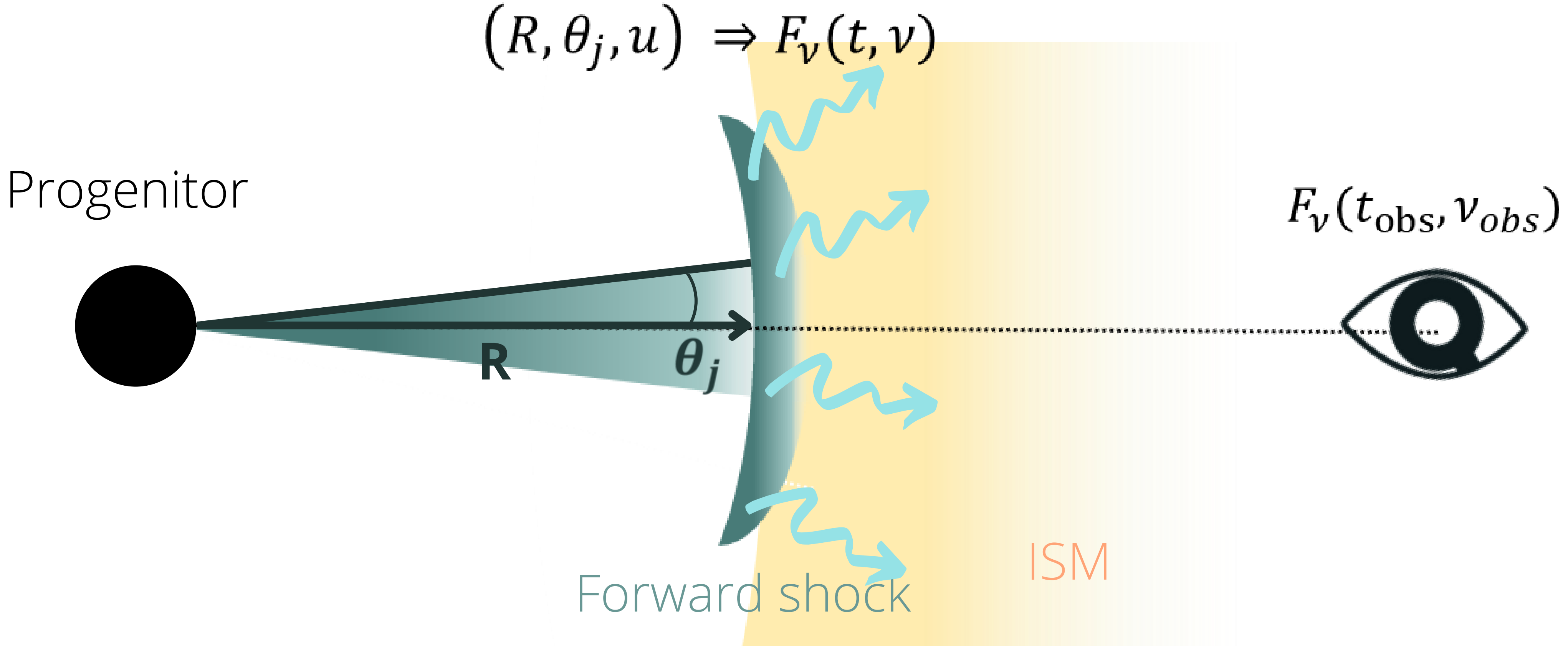
ANNEXE 1

GRB BURST EMISSION MODEL

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

$\Longrightarrow$ Trans-relativistic equation of state + shock jump conditions + single-shell approximation

$$F_\nu(t_{obs}, \nu_{obs}) = \frac{1+z}{4\pi d_L^2} \int d\Omega R^2 \Delta R \delta^2 \epsilon'_{\nu'}$$



$\epsilon'_{\nu'}$ = rest-frame synchrotron emissivity

R = radial position of the forward shock
δ = doppler factor of the emitting fluid with respect to the observer
Ω = solid angle
θj = opening angle of the jet
u = dimensionless 4-velocity of the fluid behind the shock

dL = luminosity distance
z = redshift

ANNEXE 2

WHAT IS SIMULATED BY THE rubin_sim PACKAGE?

Scheduling

- Field RA
- Field Dec
- Observation start in MJD
- Visit exposure time
- Filter
- Number of exposition
- ...

Sky conditions

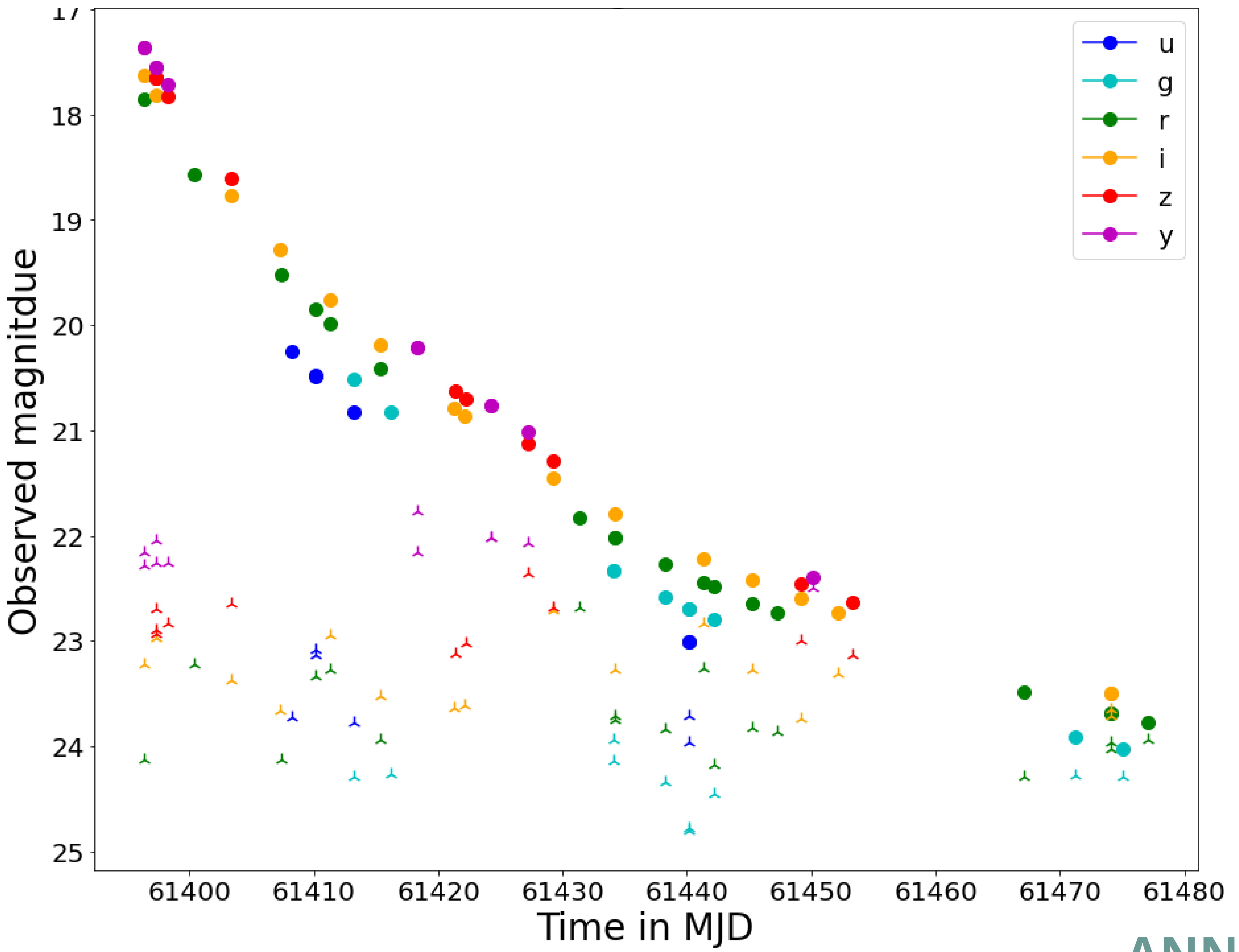
- Airmass
- Seeing
- Sky brightness
- Five sigma depth
- Cloud
- Moon position
- Sun position
- ...

https://github.com/lsst/rubin_sim
https://rubin-sim.lsst.io

ANNEXE 3

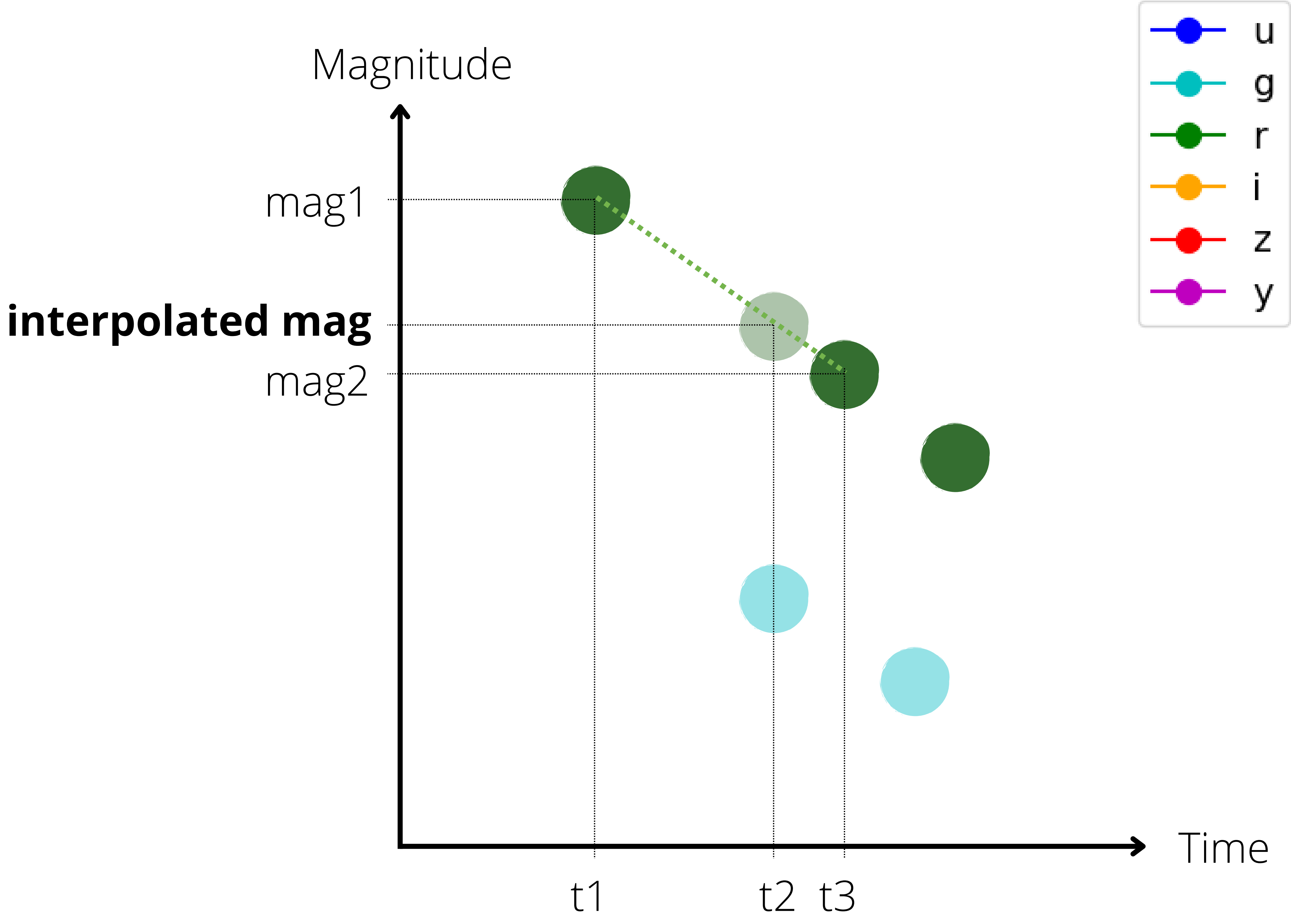
DEEP DRILLING FIELDS

Deep Drilling Field = region of the sky with a deeper coverage and a more frequent temporal sampling



ANNEXE 4

g-r COLOR FROM PSEUDO-OBSERVATIONS



Linear interpolation of a point

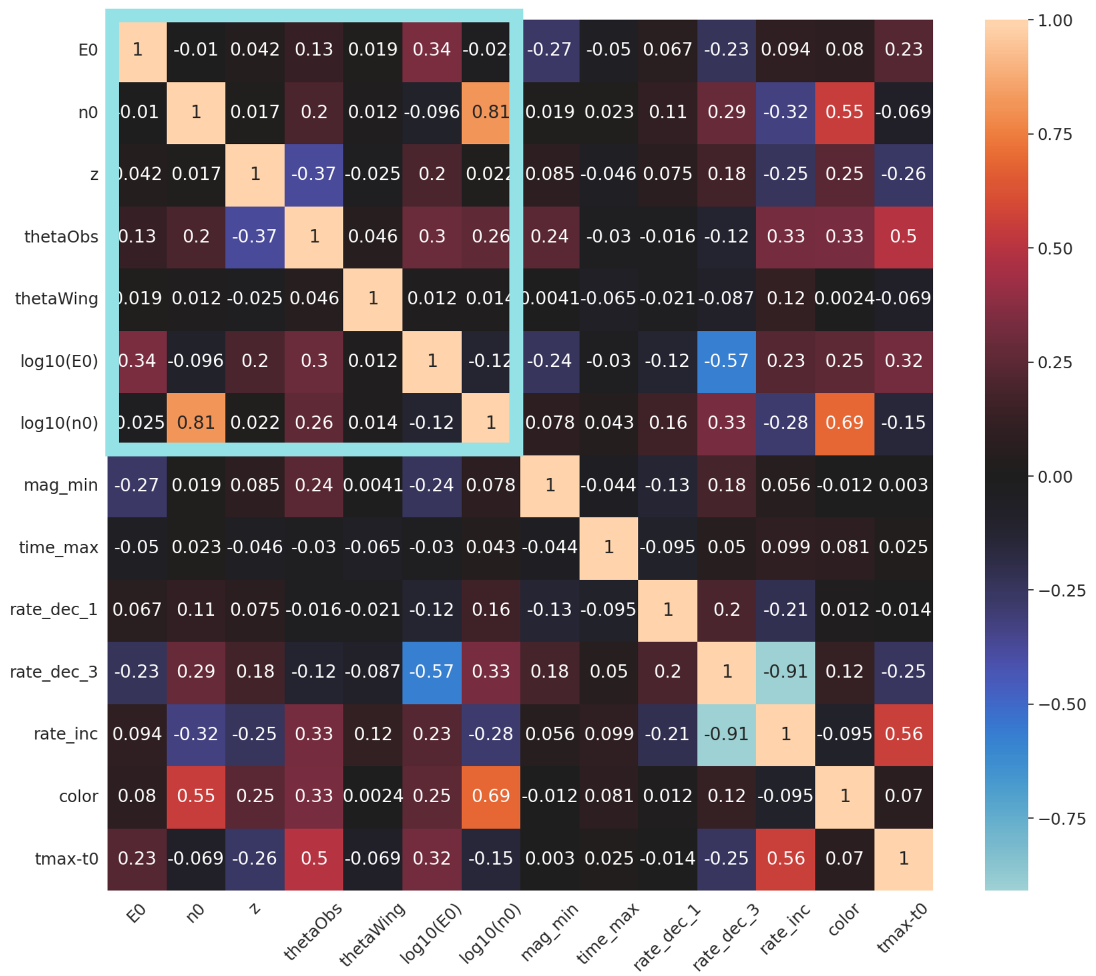
⟹ interpolated magnitude used to calculate the g-r color

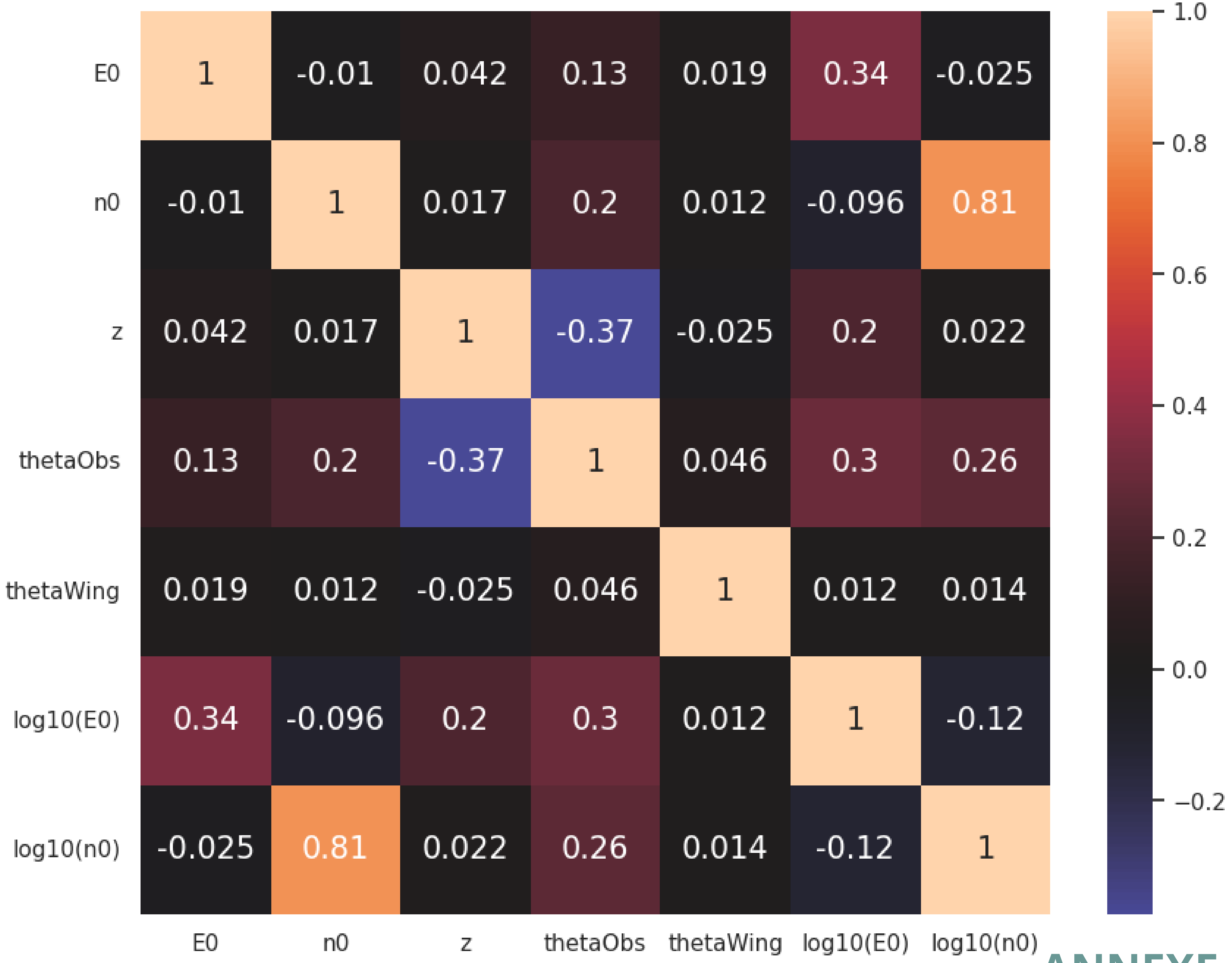
The color is approximately constant for all the time

⟹ mean g-r color for a light curve

ANNEXE 5

CORRELATIONS

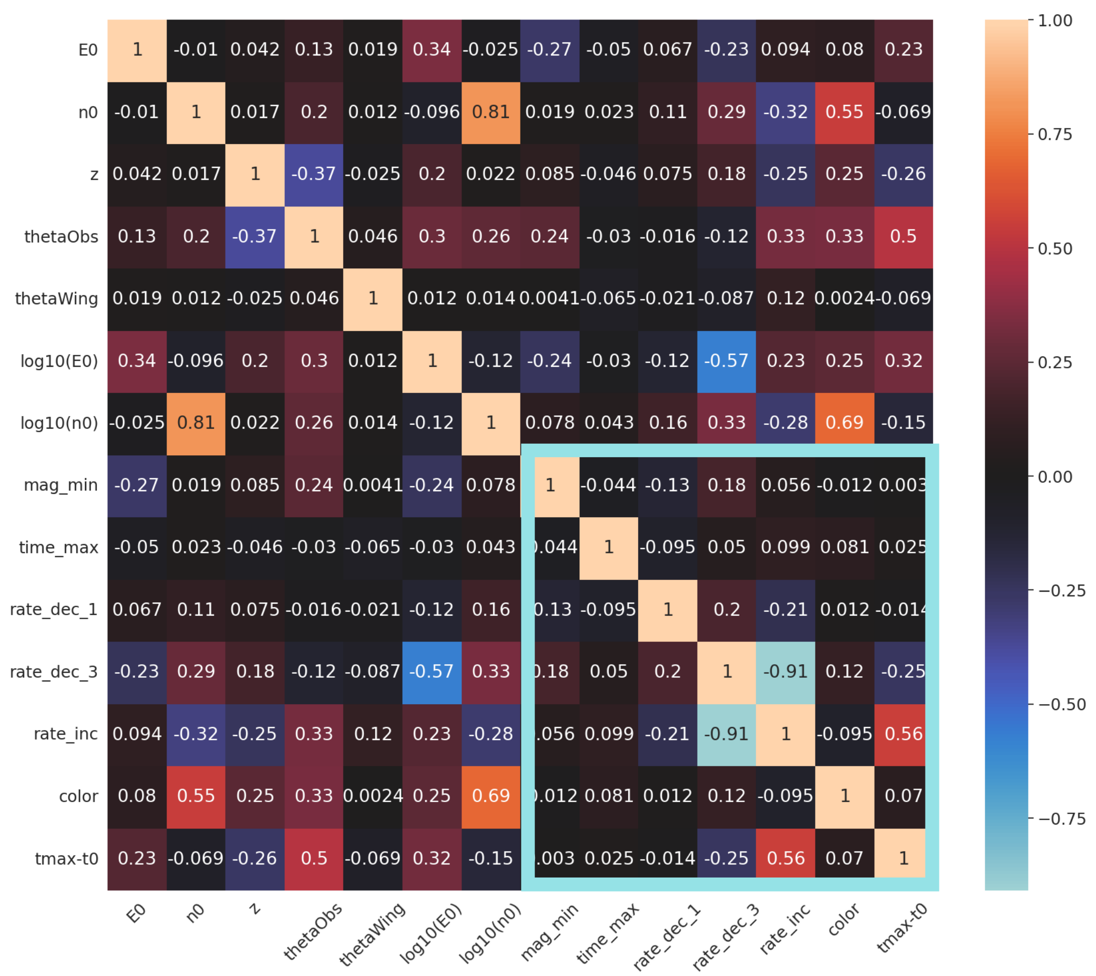


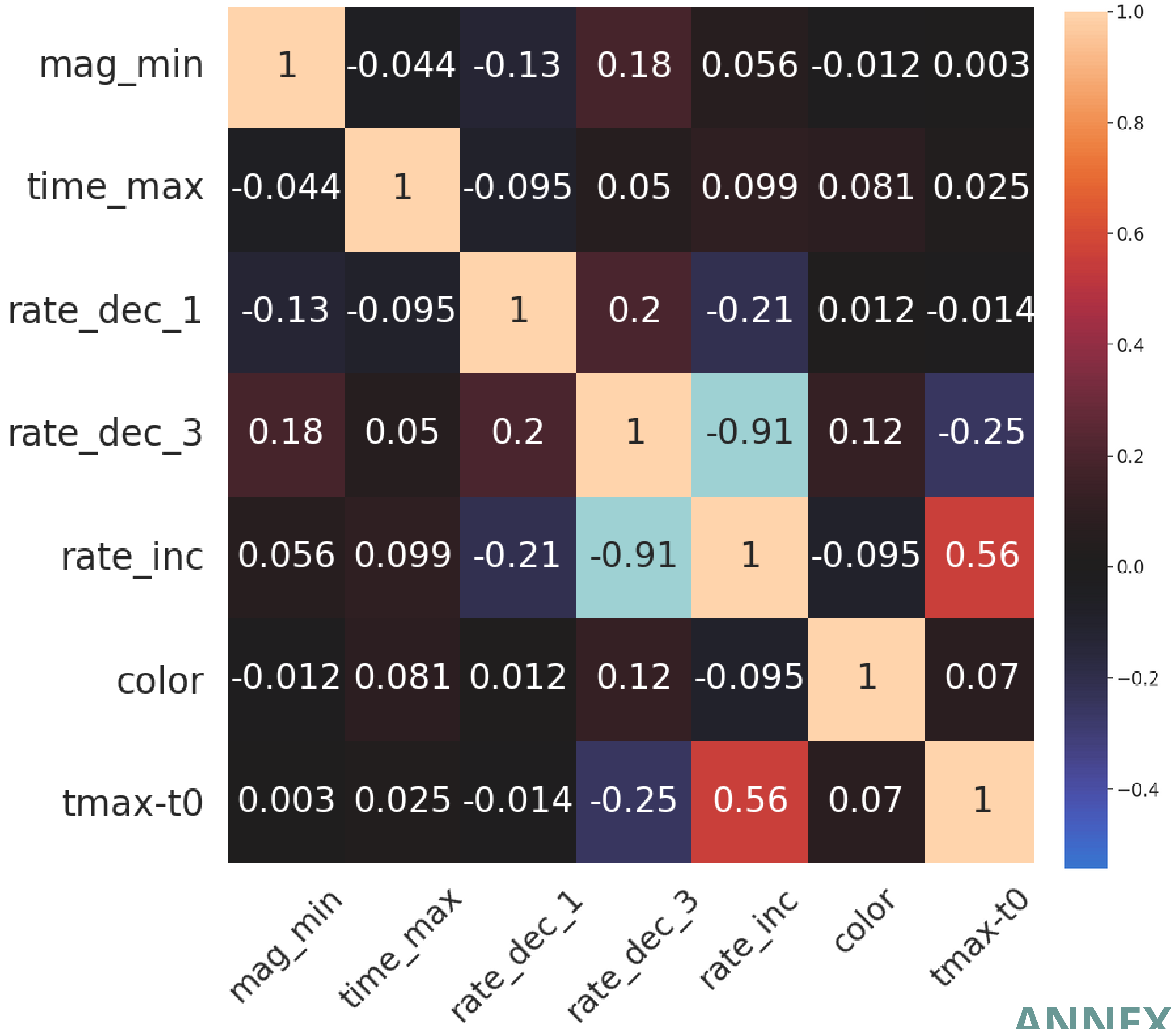


$\Longrightarrow$ Correlations between θ_{obs} and E_0, n_0 and z

ANNEXE 6

CORRELATIONS





Just a few correlated features
⟹ Will give more informations

ANNEXE 7