RUBIN/LSST-FRANCE MEETING
16-18 MAY 2022

GRENOBLE | MODANE

IDENTIFICATION OF ORPHAN GAMMA-RAY BURST AFTERGLOWS IN RUBIN/LSST DATA

WITH THE AFTERGLOWPY PACKAGE

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With:
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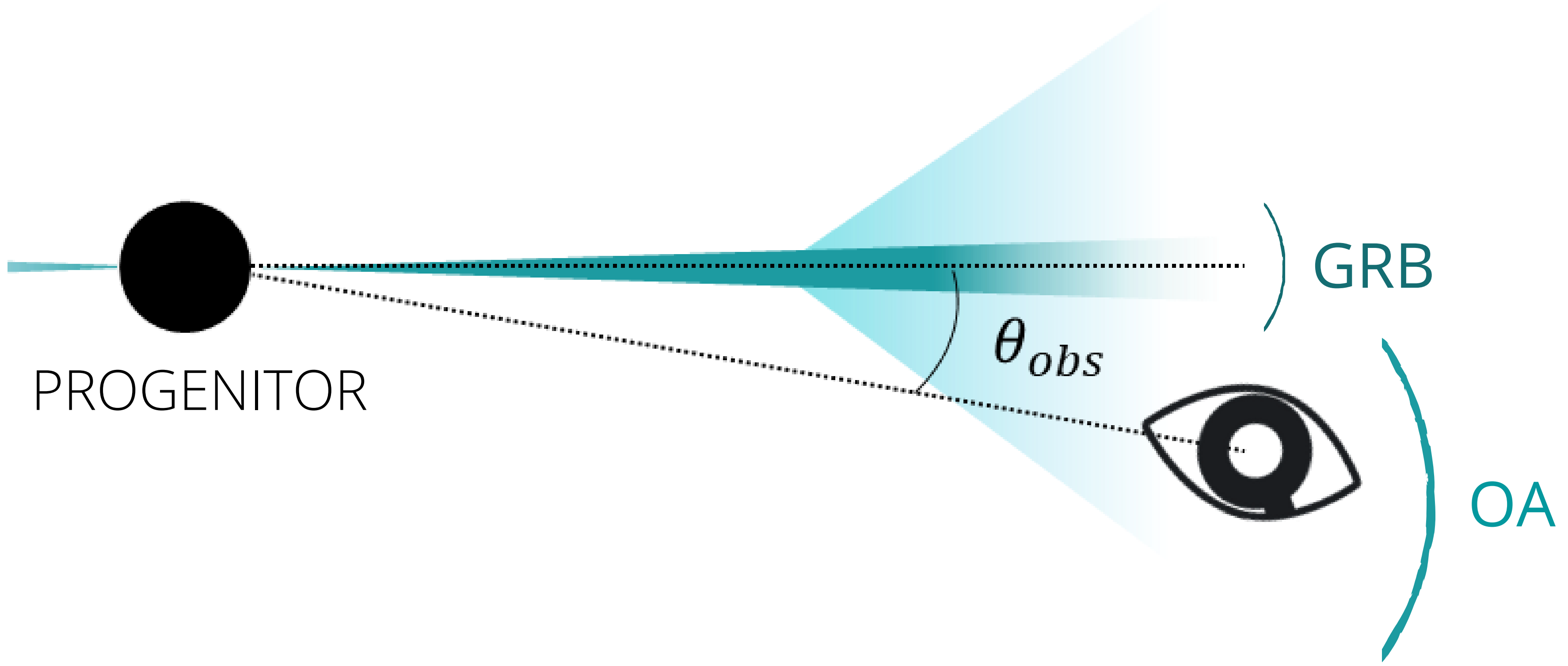
MASTER 2 INTERNSHIP

CONTENTS OF THE PRESENTATION

1. What is an orphan gamma-ray burst afterglow?
2. Simulation of light curves of orphan gamma-ray burst afterglows
3. Impact of each parameter
4. Simulation of a population of gamma-ray bursts

WHAT IS AN ORPHAN GAMMA-RAY BURST AFTERGLOW?



Objective of my internship > To identify potential orphan gamma-ray burst afterglows in Rubin/LSST data by implementing a filter in the alert broker FINK

- **Gamma-Ray Burst (GRB) =** highly energetic explosions (~ 10^51 erg) involving compact objects
- **Orphan GRB afterglow (OA) =** optical afterglow without gamma-ray emission
  ⟹ **No orphan afterglow detected so far!** (some candidates but none confirmed)
- **OAs important for**
  - GRB physics and progenitors
  - Multi-messengers analyses (gravitational waves)

THE AFTERGLOWPY PACKAGE
(Ryan et al. 2020, Van Eerten et al. 2010)

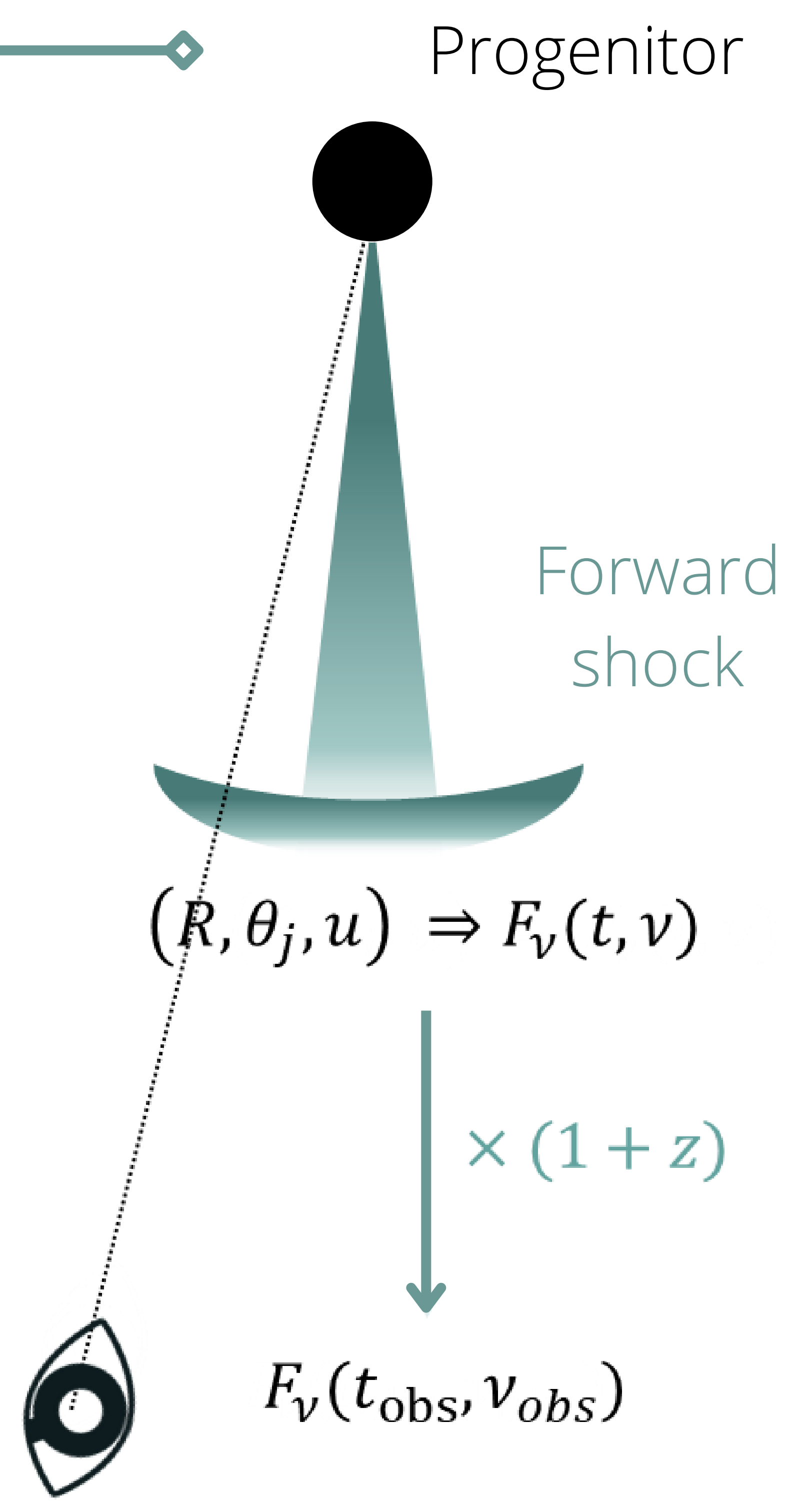
Calibrated to the **BoxFit** code (Van Eerten et al. 2012) $\Longrightarrow$ MHD simulations

- Synchrotron emission (Sari, Piran & Narayan 1997)
- Trans-relativistic equation of state + shock jump conditions
- Solves forward shock evolution equations using the single-shell approximation
- Gives the observed flux in the observer's frame:

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

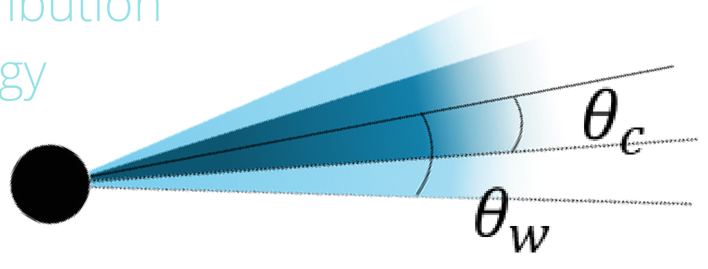
$\Longrightarrow$ **Fnu = afterglowpy.fluxDensity(t, nu, **Z)**

$\epsilon'_{\nu'}$ = rest-frame synchrotron emissivity
R = radial position of the forward shock
θj = opening angle of the jet
u = dimensionless 4-velocity of the fluid behind the shock
δ = doppler factor of the emitting fluid with respect to the observer



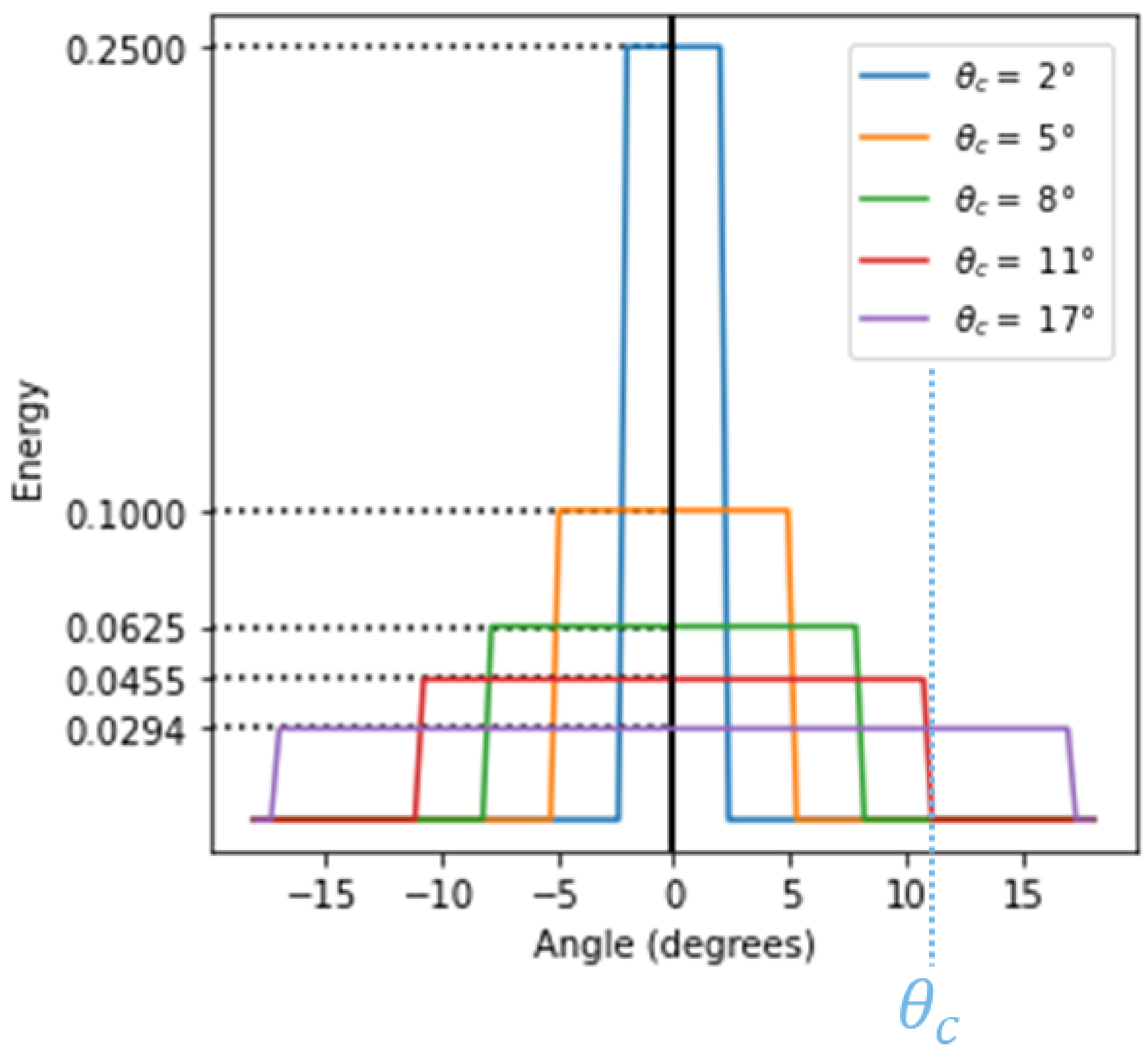
TYPES OF STRUCTURED JETS

Angular distribution of energy



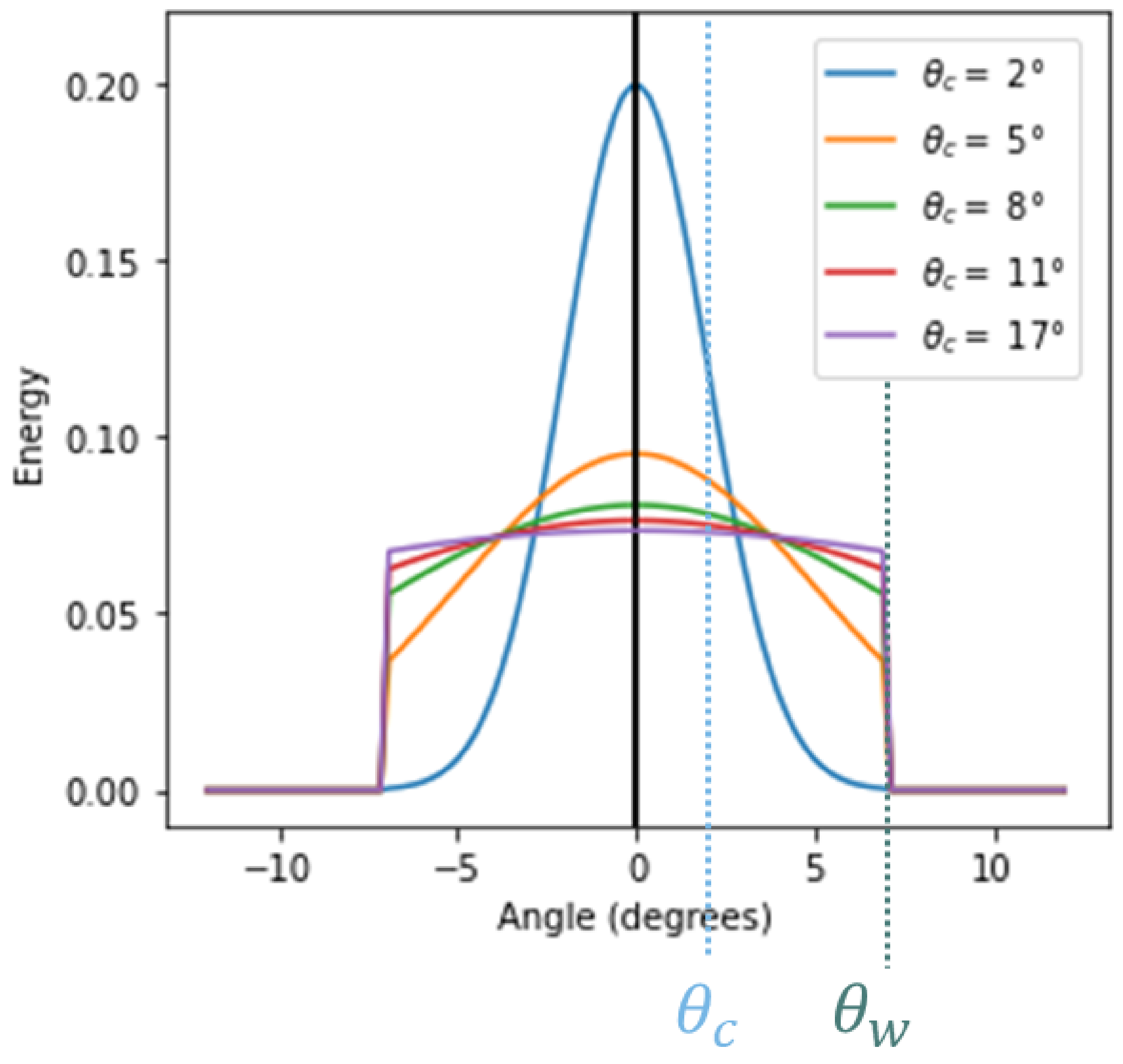
TOP-HAT

$$E(\theta) = E_0$$



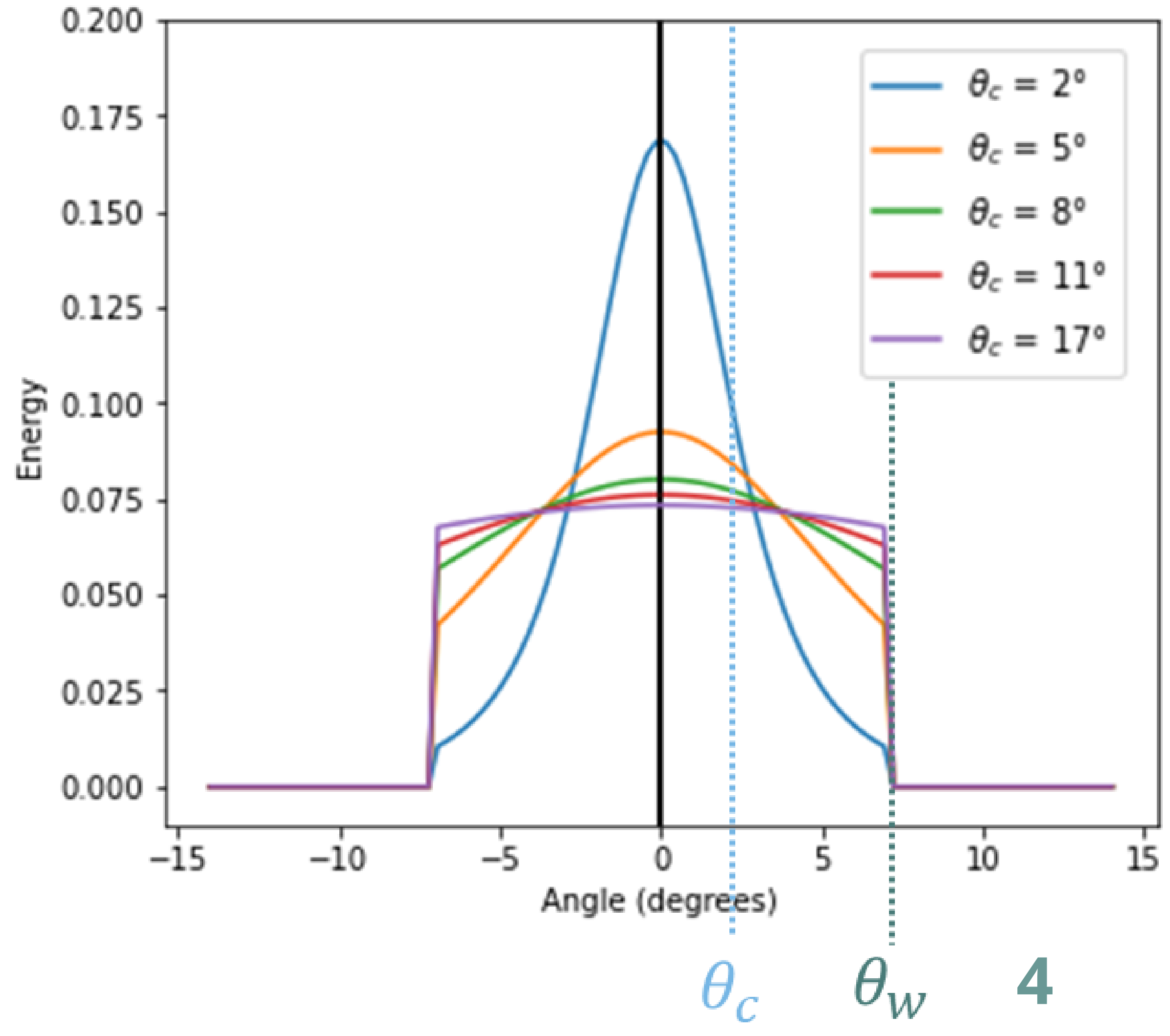
GAUSSIAN

$$E(\theta) = E_0 \exp\left(-\frac{\theta^2}{2\theta_c^2}\right)$$

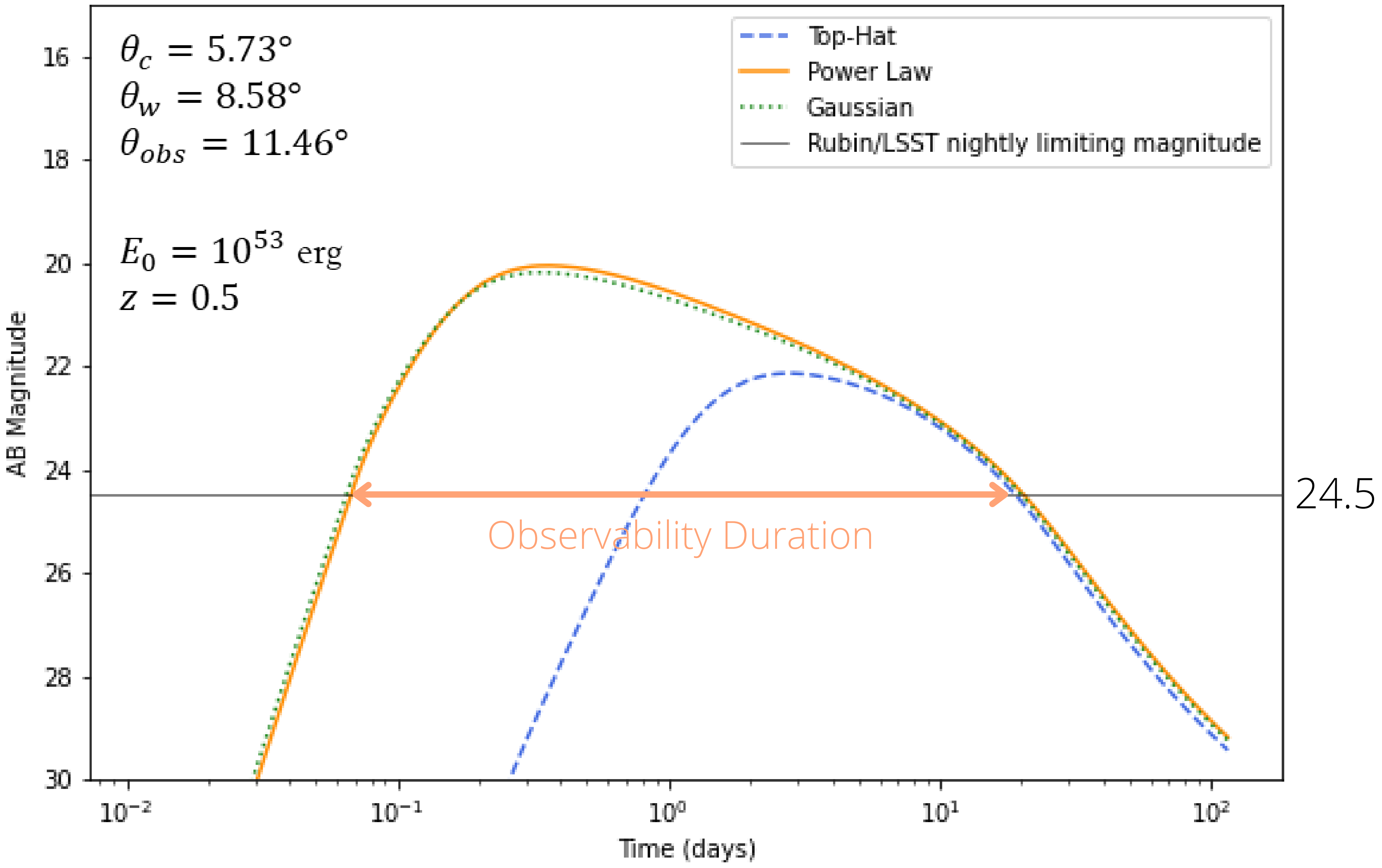


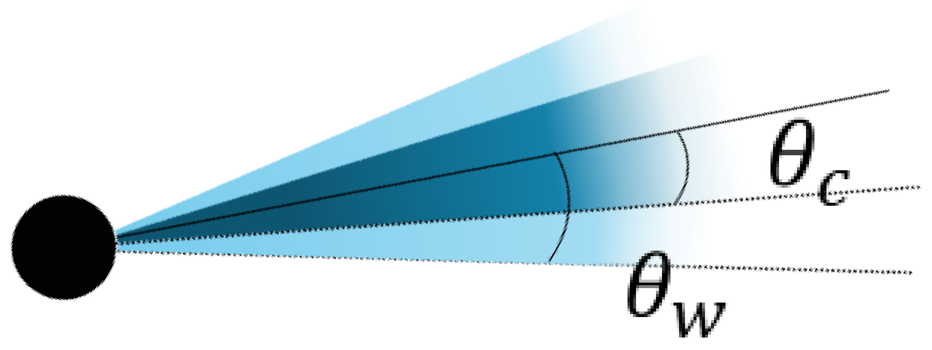
POWER-LAW

$$E(\theta) = E_0 \left(1 + \frac{\theta^2}{b\theta_c^2}\right)^{-b/2}$$



LIGHT CURVES



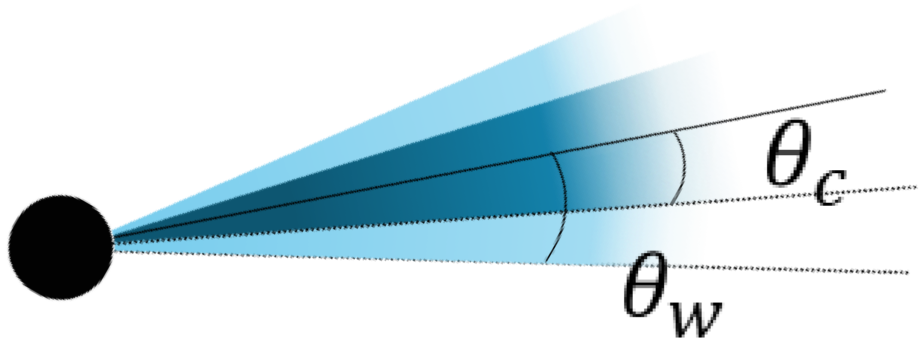


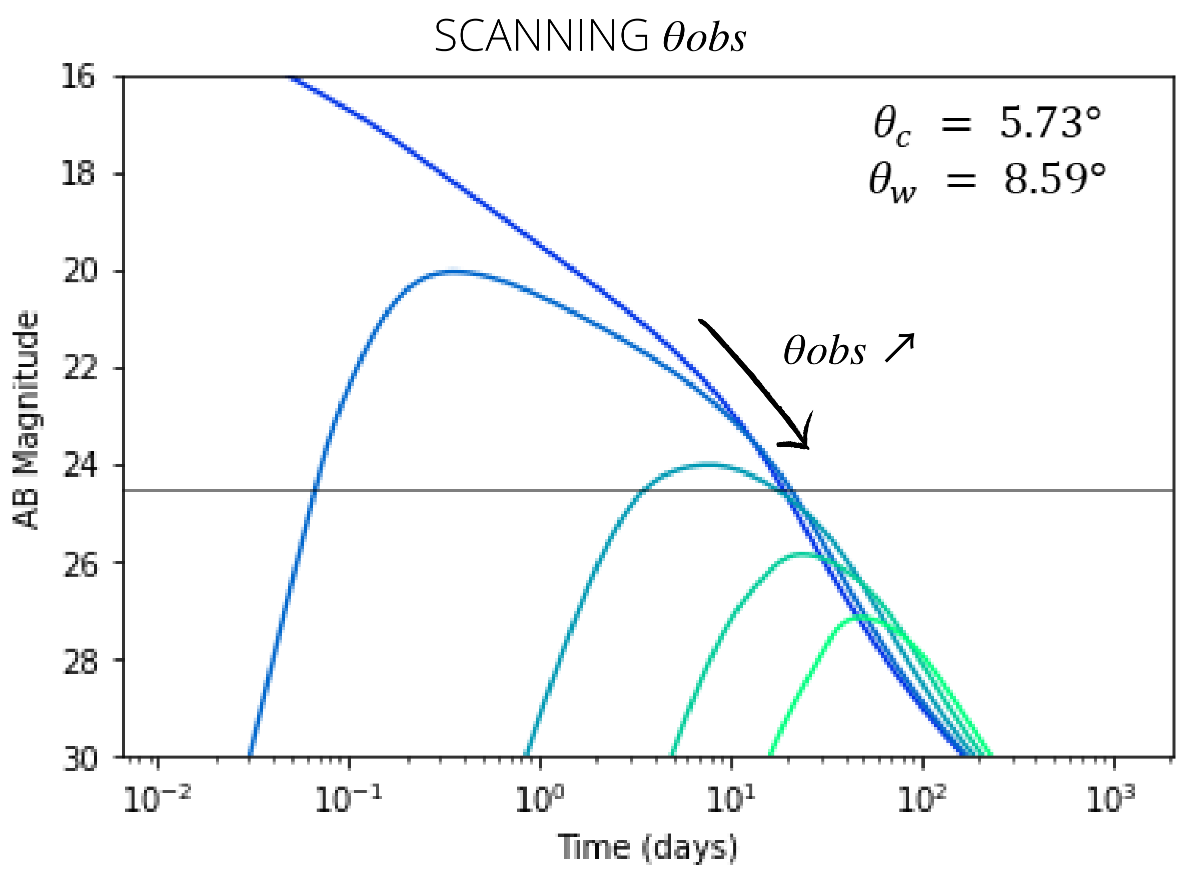
r-band → 600 nm:
Frequency $\nu = 5.0 \times 10^{14}$ Hz

If $\theta w > \theta c$, Power-Law and Gaussian jets are observable earlier than Top-Hat jet

$\Longrightarrow$ **Importance of the jet structure**

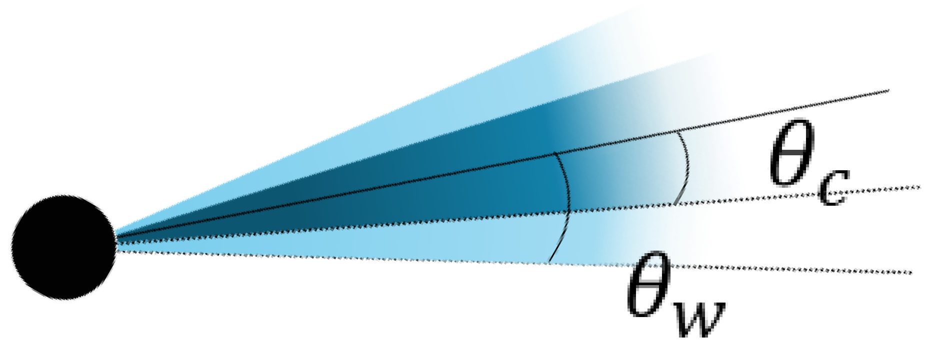
IMPACT OF θc, θw AND θobs ON THE LIGHT CURVES

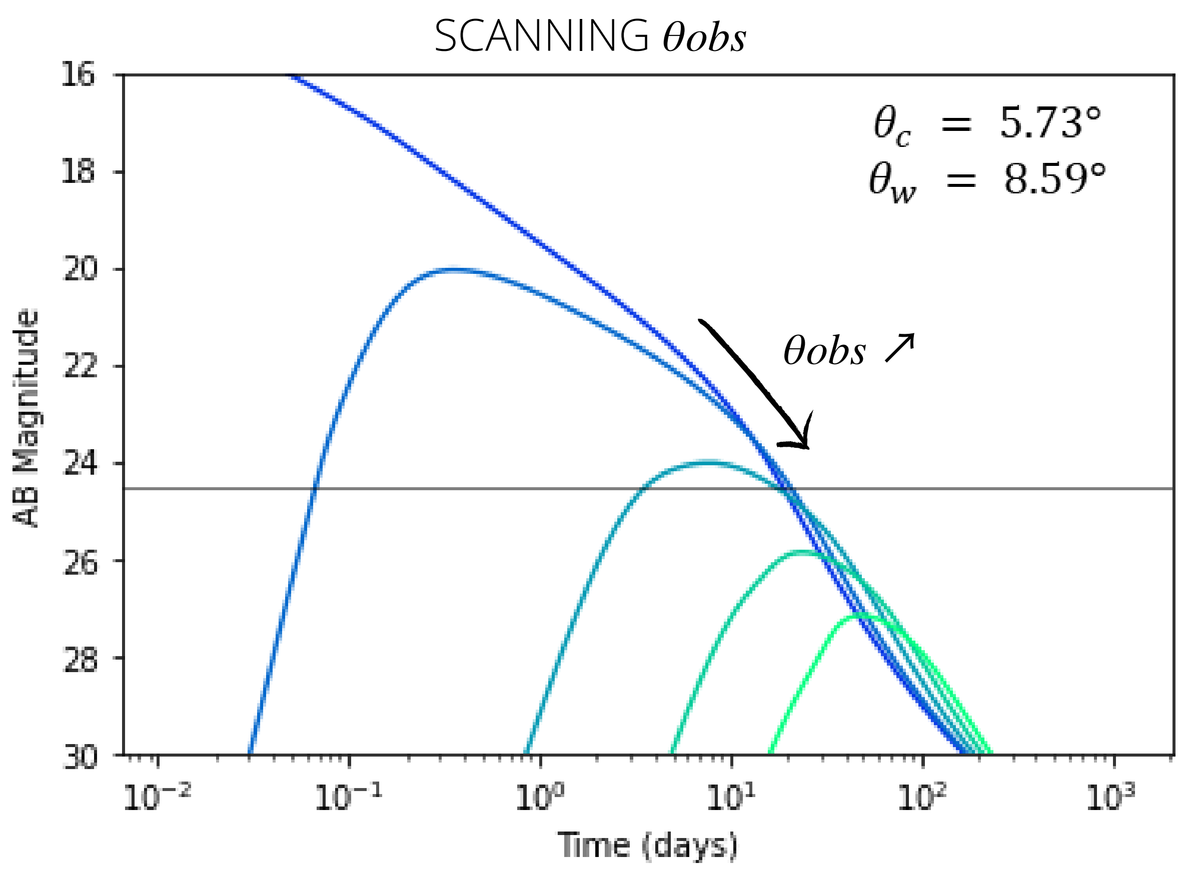




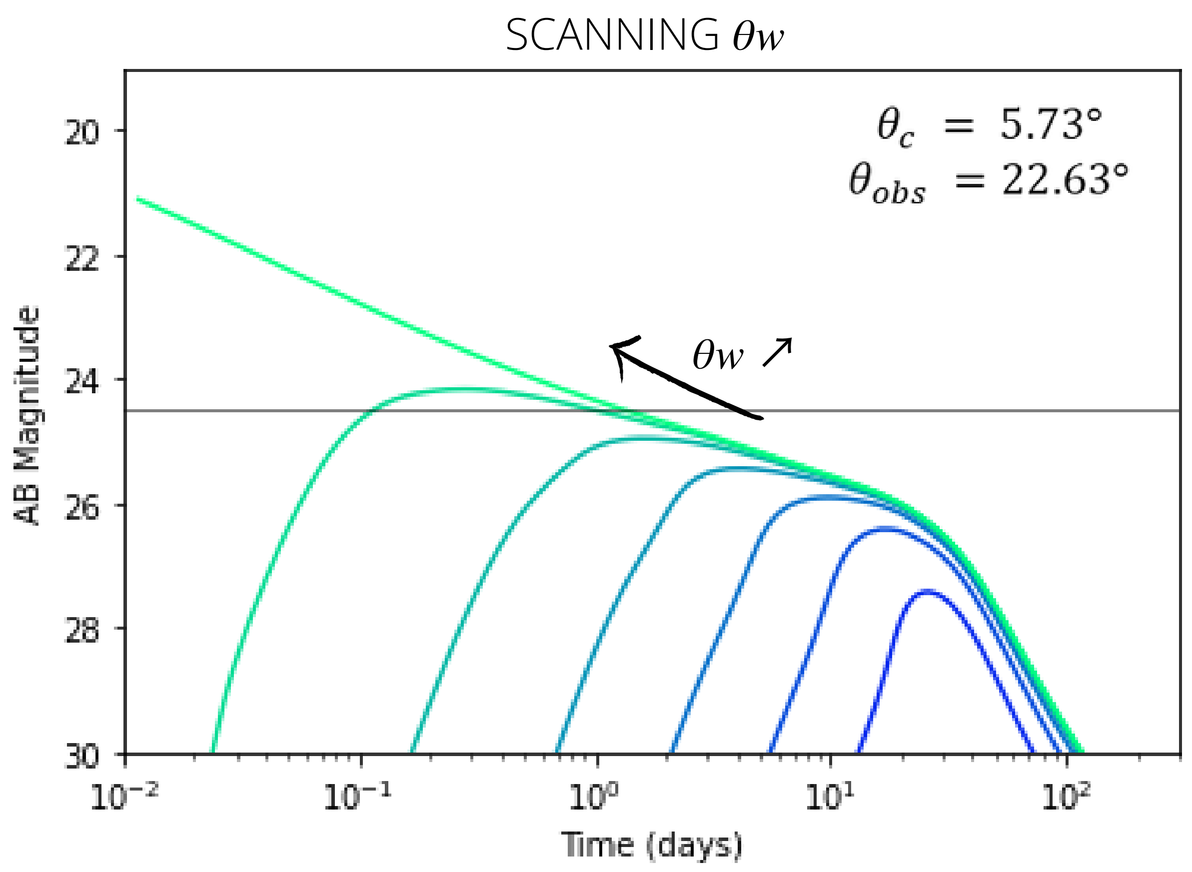
θobs increases $\Longrightarrow$
OA less observable

IMPACT OF θc, θw AND θobs ON THE LIGHT CURVES



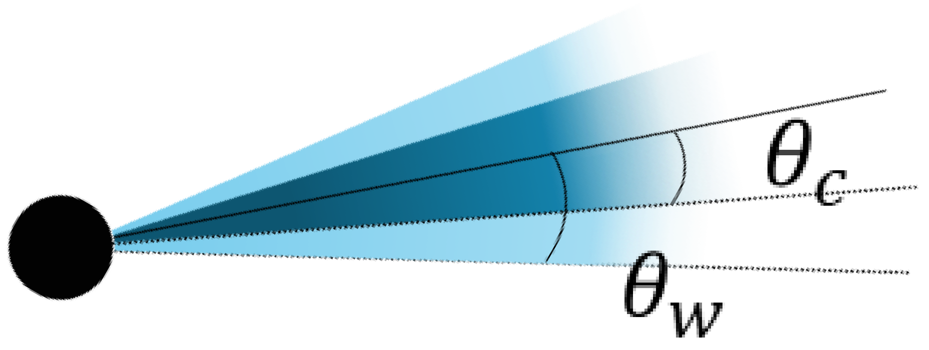


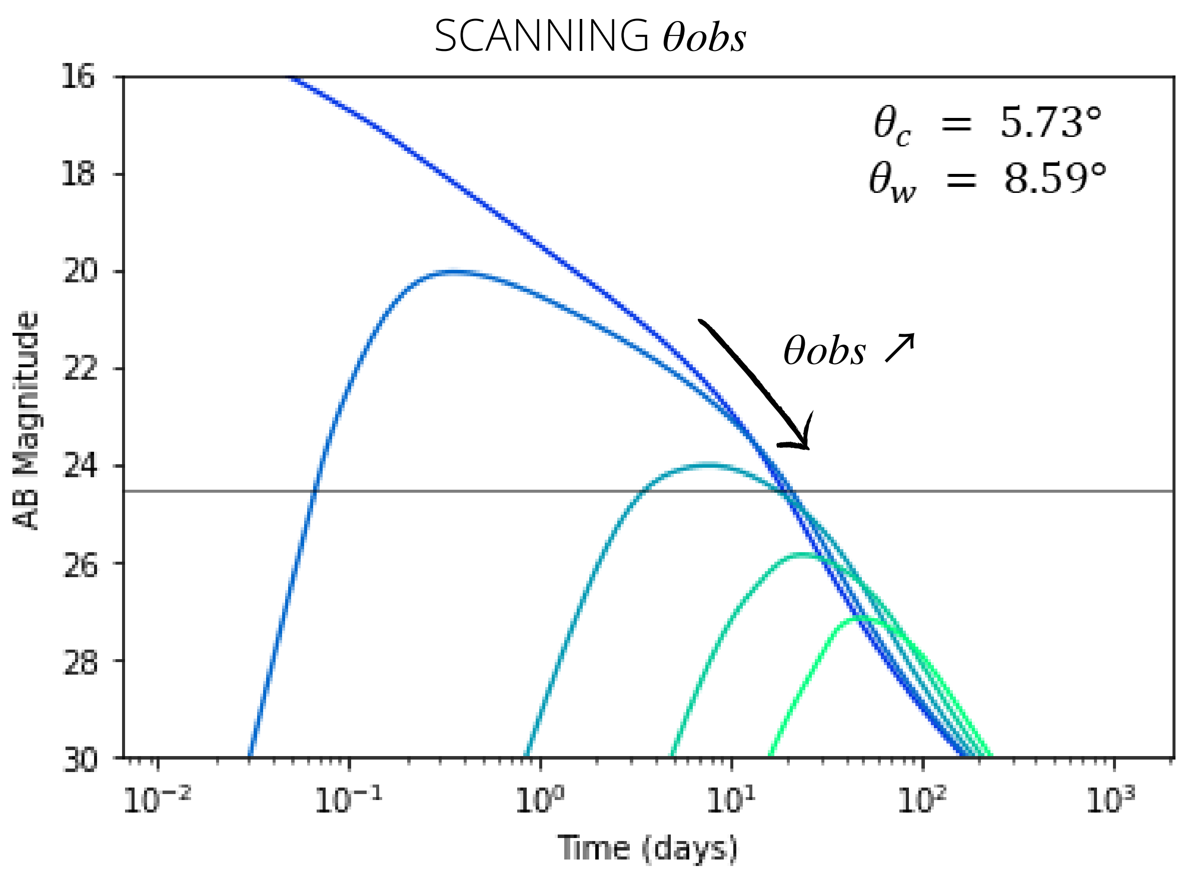
θobs **increases** ⟹
OA less observable



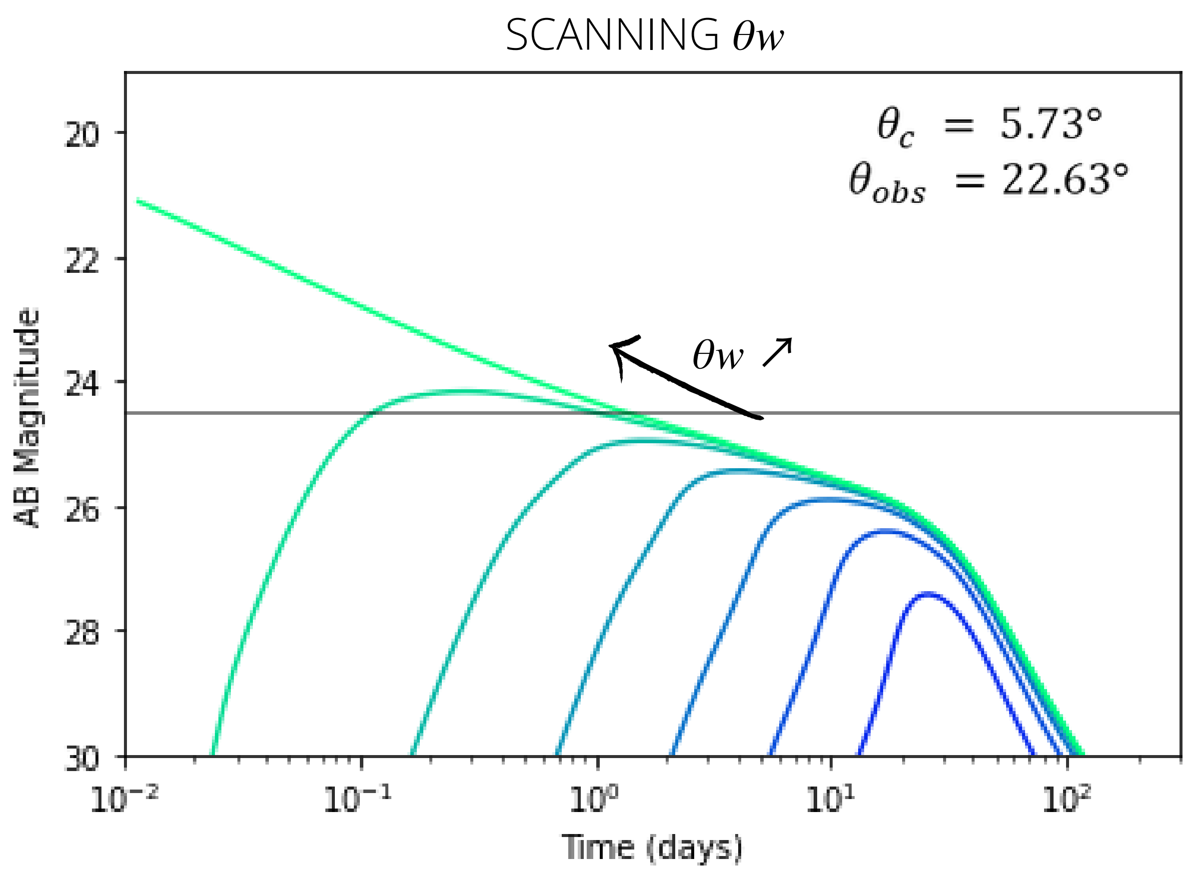
θw **increases** ⟹
OA more observable

IMPACT OF θc, θw AND θobs ON THE LIGHT CURVES

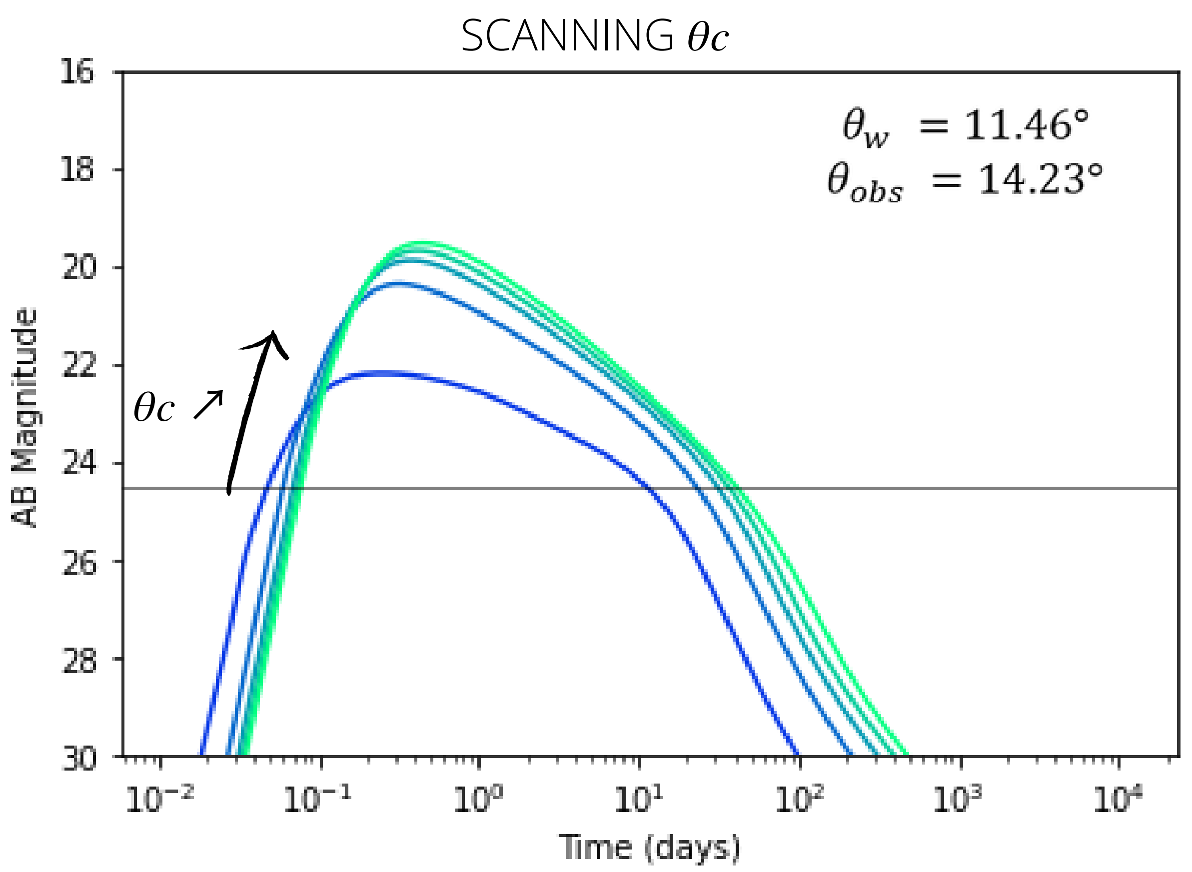




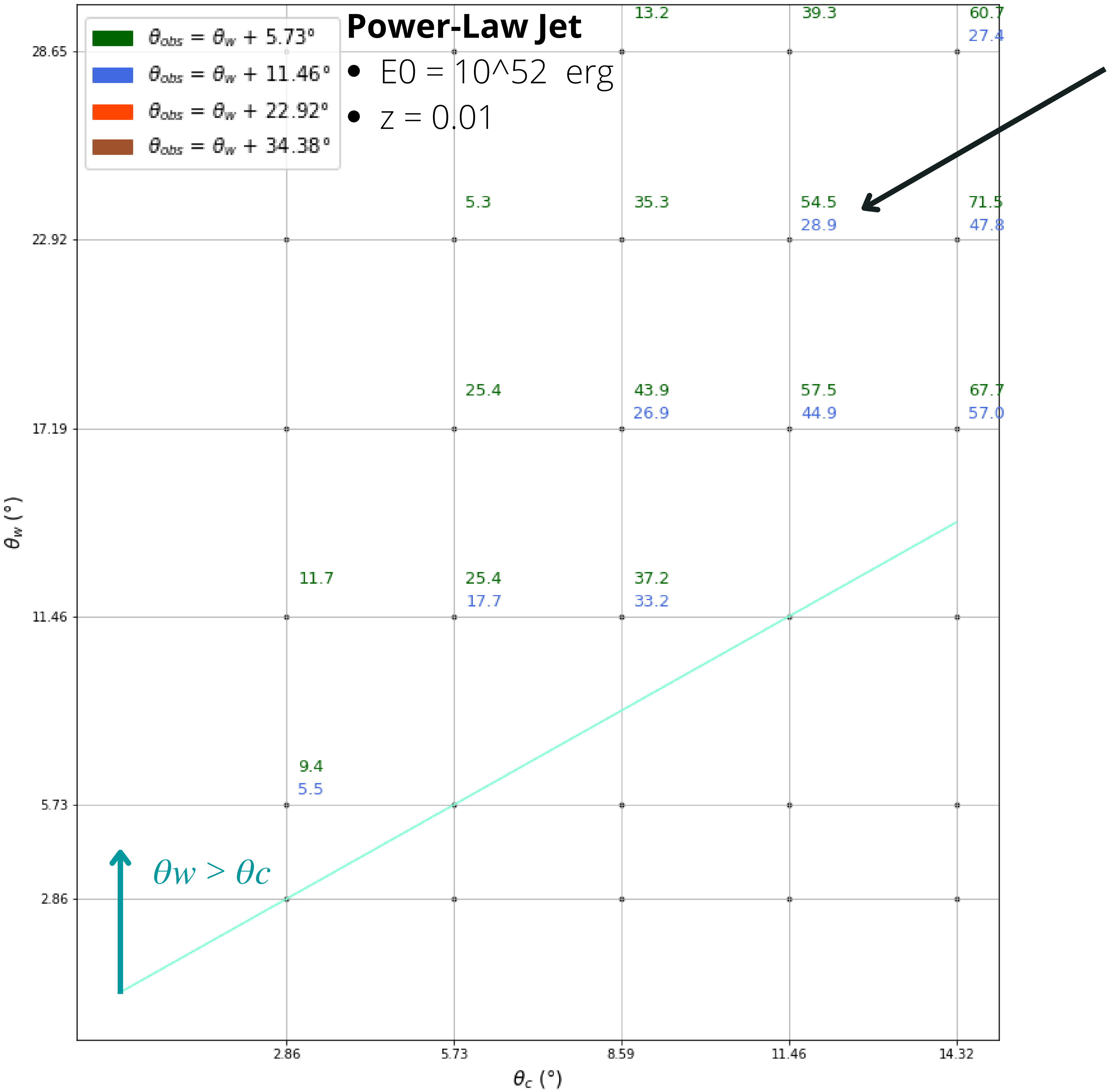
θobs **increases** ⟹
OA less observable



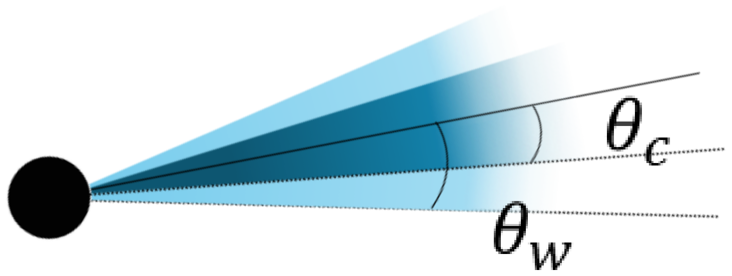
θw **increases** ⟹
OA more observable

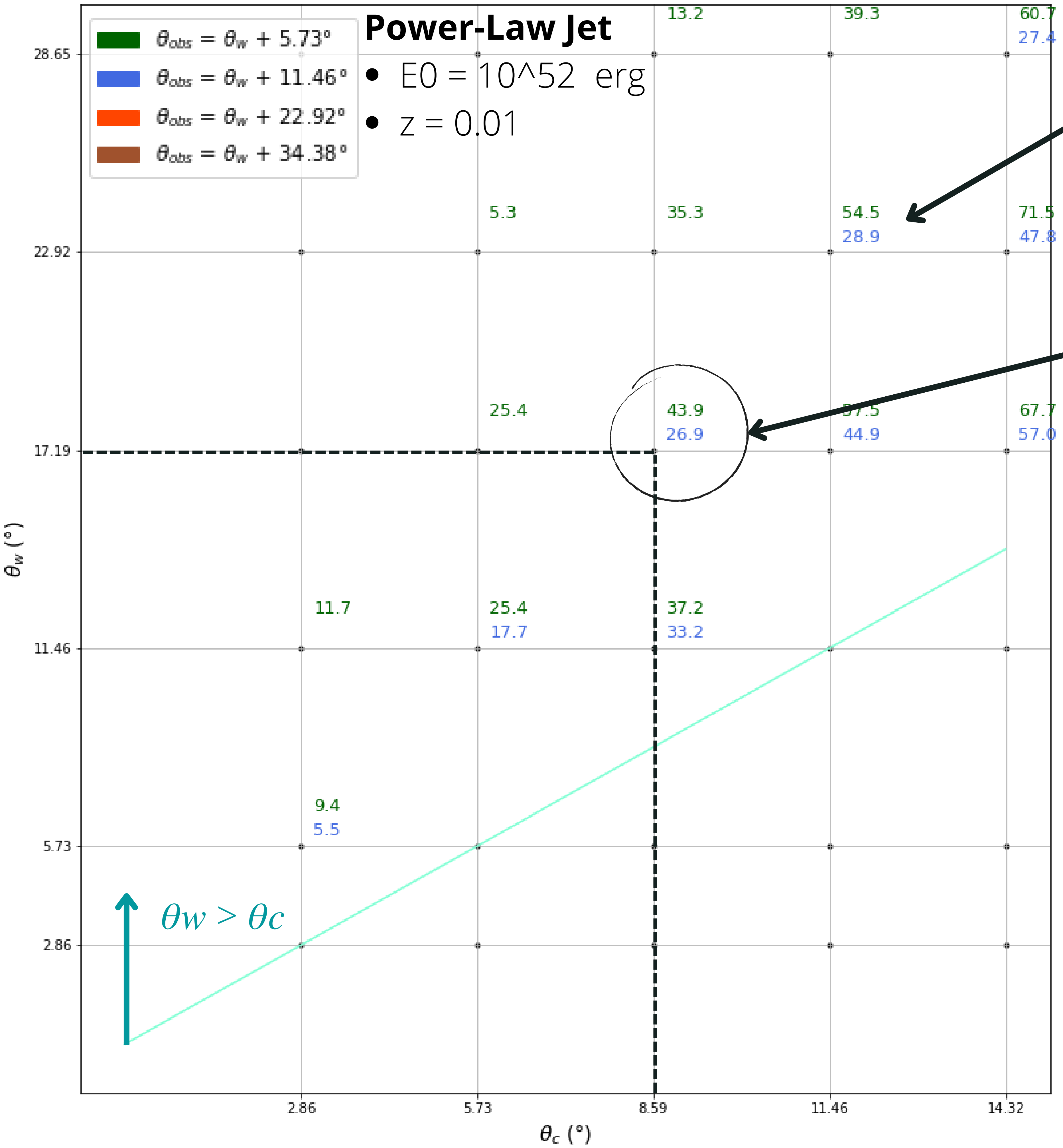


θc **increases** ⟹
OA more observable

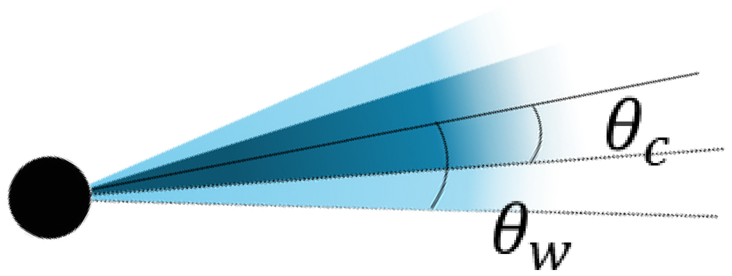


Observability duration for each combination (θc, θw, θobs) in days





Observability duration for each combination (θc, θw, θobs) in days



EXAMPLE: θc = 8.59°

θw = 17.19°

$\theta obs = \theta w$ + 5.73° = 22.92°

$\Longrightarrow$ OA observable during 43.9 days

$\theta obs = \theta w$ + 11.46° = 28.65°

$\Longrightarrow$ OA observable during 26.9 days

When E0 increases: 10^52 ⟶ 10^53 erg

$\Longrightarrow$ Observability duration × ~5

For (θc, θw, θobs): parameters space is large

$\Longrightarrow$ Observability of OA is not trivial !

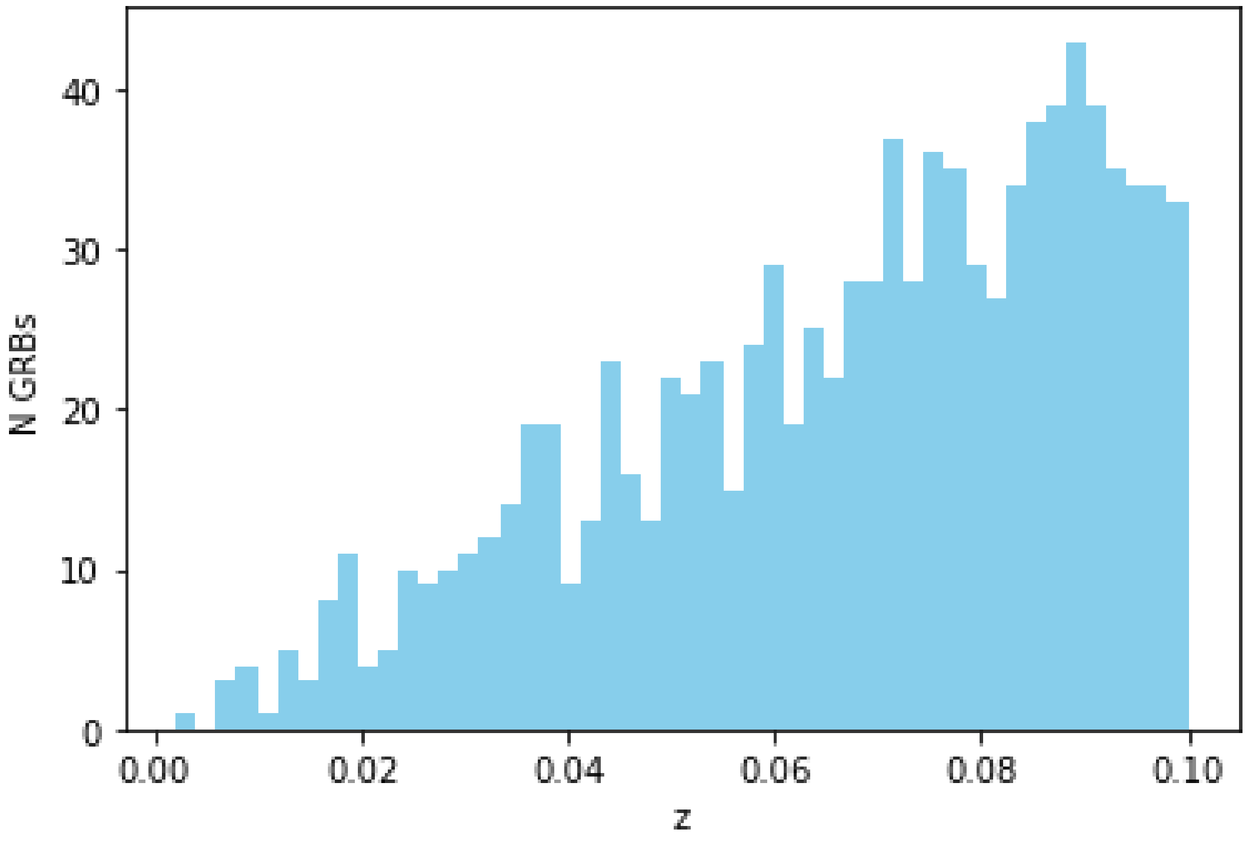
SOME SIMULATIONS FOR SHORT GRBS

Goal: To simulate somewhat realistic distributions for short GRBs

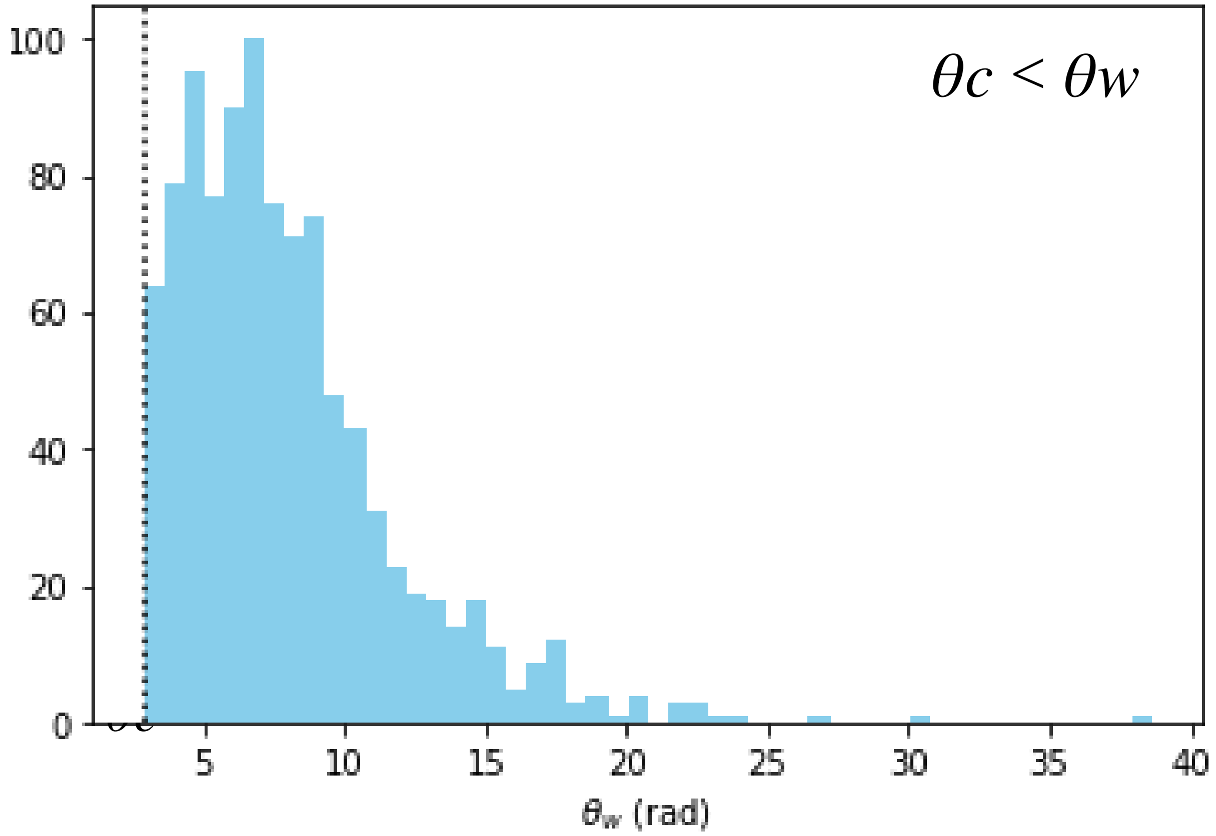
Studied parameters:

- **Core angle θc:** 2.86 and 8.60 degrees
- **Circumburst density n0:** uniform distribution [0.001 ; 1.0] cm^-3
- **Observer angle θobs:** uniform distribution [0 ; π/2] radians

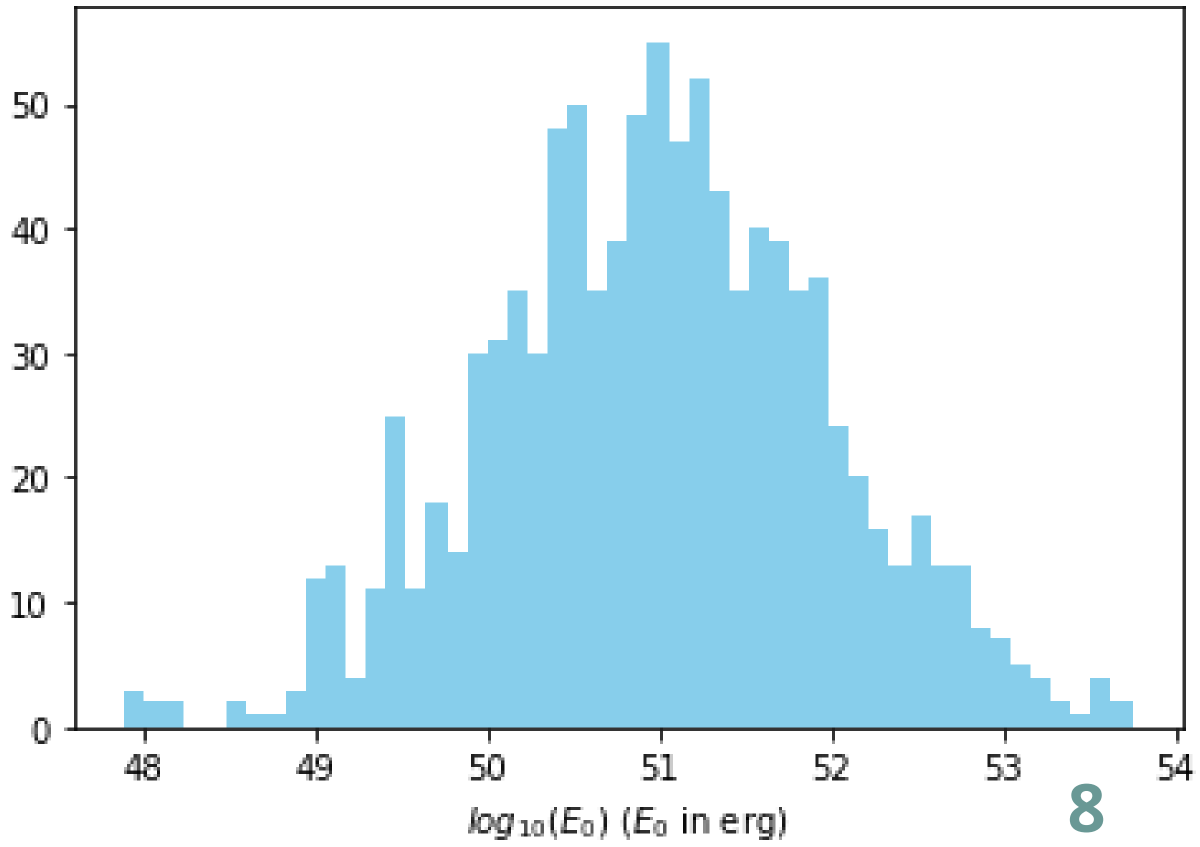
Redshift z



Truncature angle θw



Isotropic equivalent energy E0

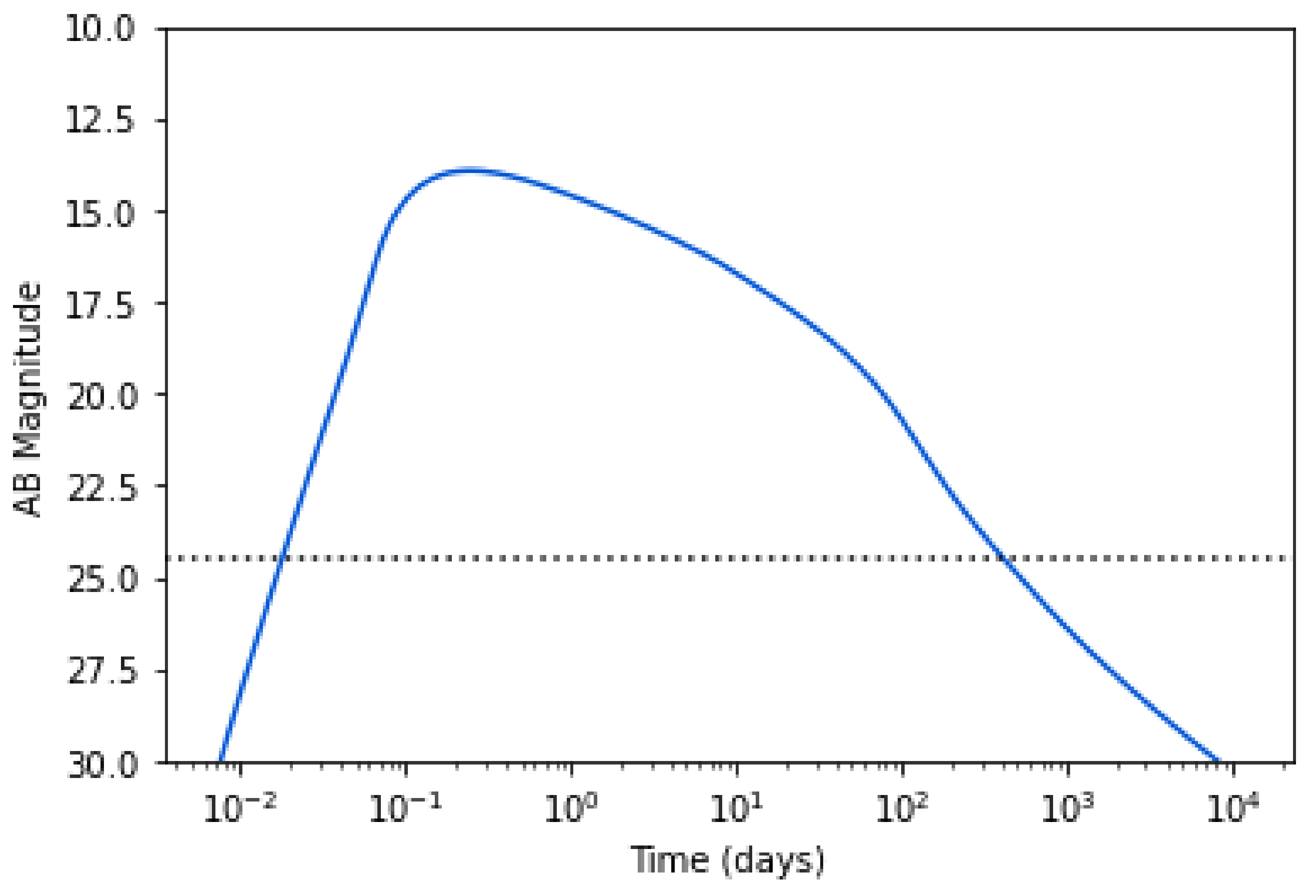


RESULTS OF THESE SIMULATIONS

1000 configurations saved

Example of one configuration

```
Z = {'jetType':    4,
     'specType':   0,
     'b':          4,
     'thetaObs':   0.1838941891510758,
     'E0':         5.492301861314063e+53,
     'thetaWing':  0.15865635331999467,
     'thetaCore':  0.15,
     'n0':         0.06598782216867752,
     'p':          2.2,
     'epsilon_e':  0.1,
     'epsilon_B':  0.01,
     'xi_N':       1.0,
     'd_L':        1.4655325839375382e+27,
     'z':          0.1}
```

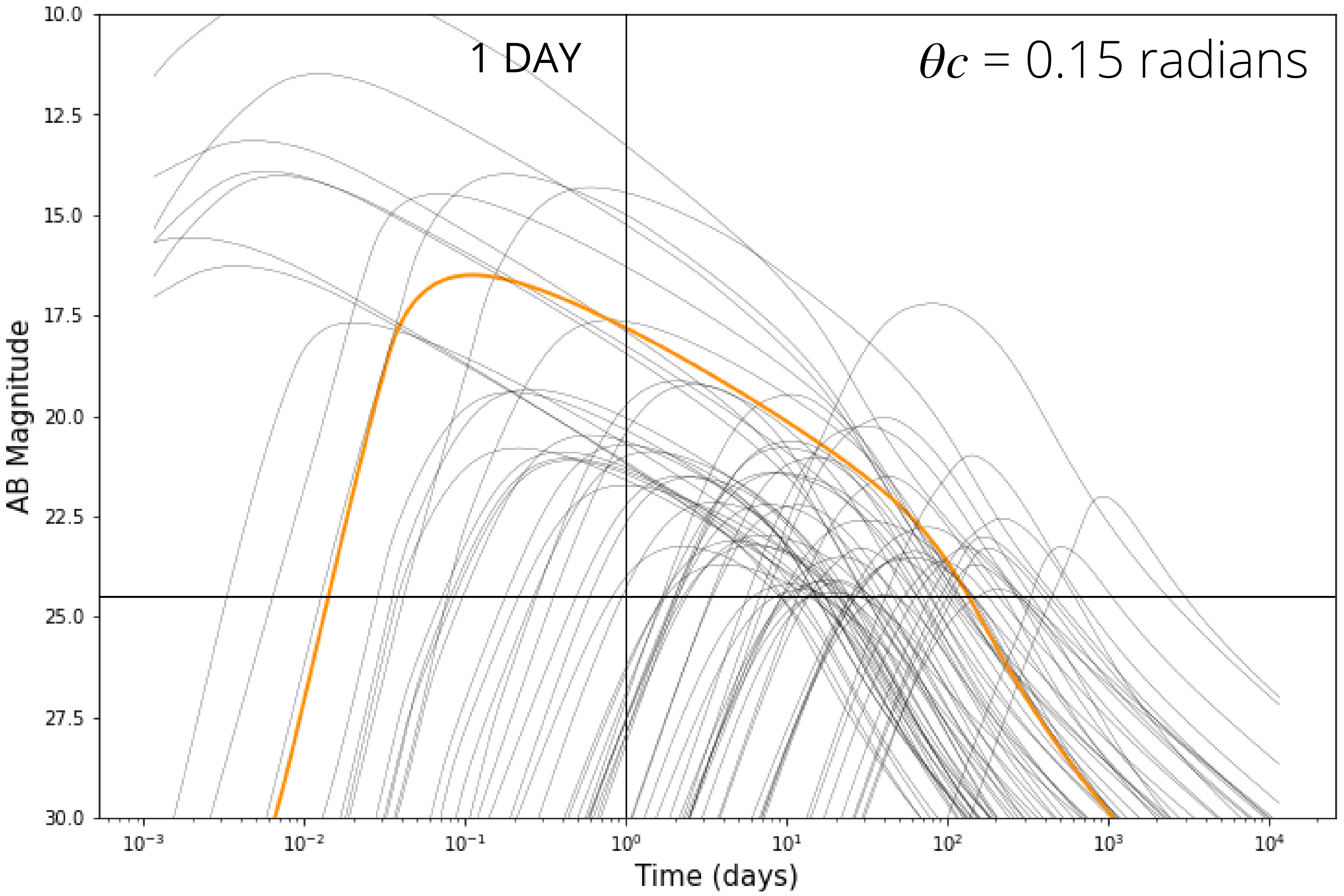


t_obs (days)	mag_min	axis	observable	...
409.2	13.9	off	> 7 days	...
...	...	...	...	...

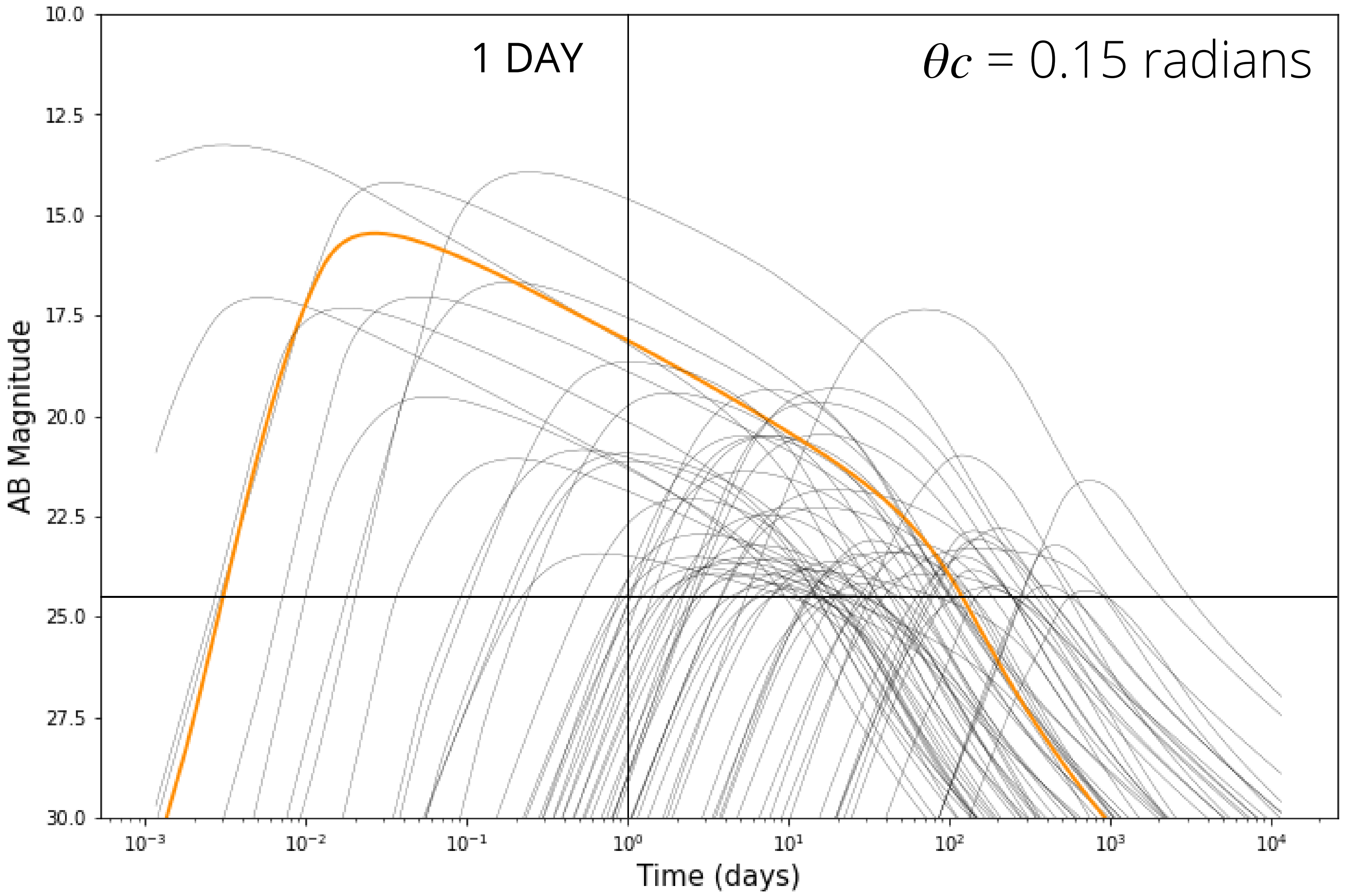
SIMULATED LIGHT CURVES FOR OFF-AXIS AFTERGLOWS

(OFF-AXIS OBSERVABLE MORE THAN 7 DAYS)

TOP-HAT JET



POWER-LAW JET



⟹ **Large diversity of light curves:** faint and long OAs + bright and short OAs

⟹ **Not obvious impact of the jet structure on observability**

FINALLY, HOW MANY OBSERVABLE AFTERGLOWS?

SUMMARY TABLE

Jet Type	θc	Axis	tobs	Number of observable afterglows (/1000)
TOP-HAT	**0.15 radians** (~ 8.60 degrees)	**ON**	> 7 days	32
		OFF	> 7 days	69
POWER LAW	**0.05 radians** (~ 2.86 degrees)	**ON**	> 7 days	14
		OFF	> 7 days	29
	0.15 radians (~ 8.60 degrees)	**ON**	> 7 days	49
		OFF	> 7 days	66

⟹ Final fraction of observable OAs: ~ 5%
⟹ Influence of the jet structure not trivial
⟹ Slightly more off-axis afterglows than on-axis afterglows

CONCLUSION AND PERSPECTIVES

afterglowpy package easily calculates light curves and spectra of OAs:

$\Longrightarrow$ Large parameters space (E0, n0, θc, θw, θobs, z)

$\Longrightarrow$ Observability of an OA not trivial!

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

$\Longrightarrow$ Estimation of the number of observable OAs: **~ 5%**

Perspectives

- To simulate "true" pseudo-observations with the **rubin_sim** package: scheduler, filters, air mass, night sky conditions...
- To generate pseudo-alerts for the alert broker **FINK**
- To develop a filter for FINK to identify OAs

All the codes can be accessible at:

https://gitlab.in2p3.fr/johan-bregeon/orphans

THANK YOU FOR YOUR ATTENTION !

COMPARISON WITH DETECTED ON-AXIS AFTERGLOWS

(Kann 2008)

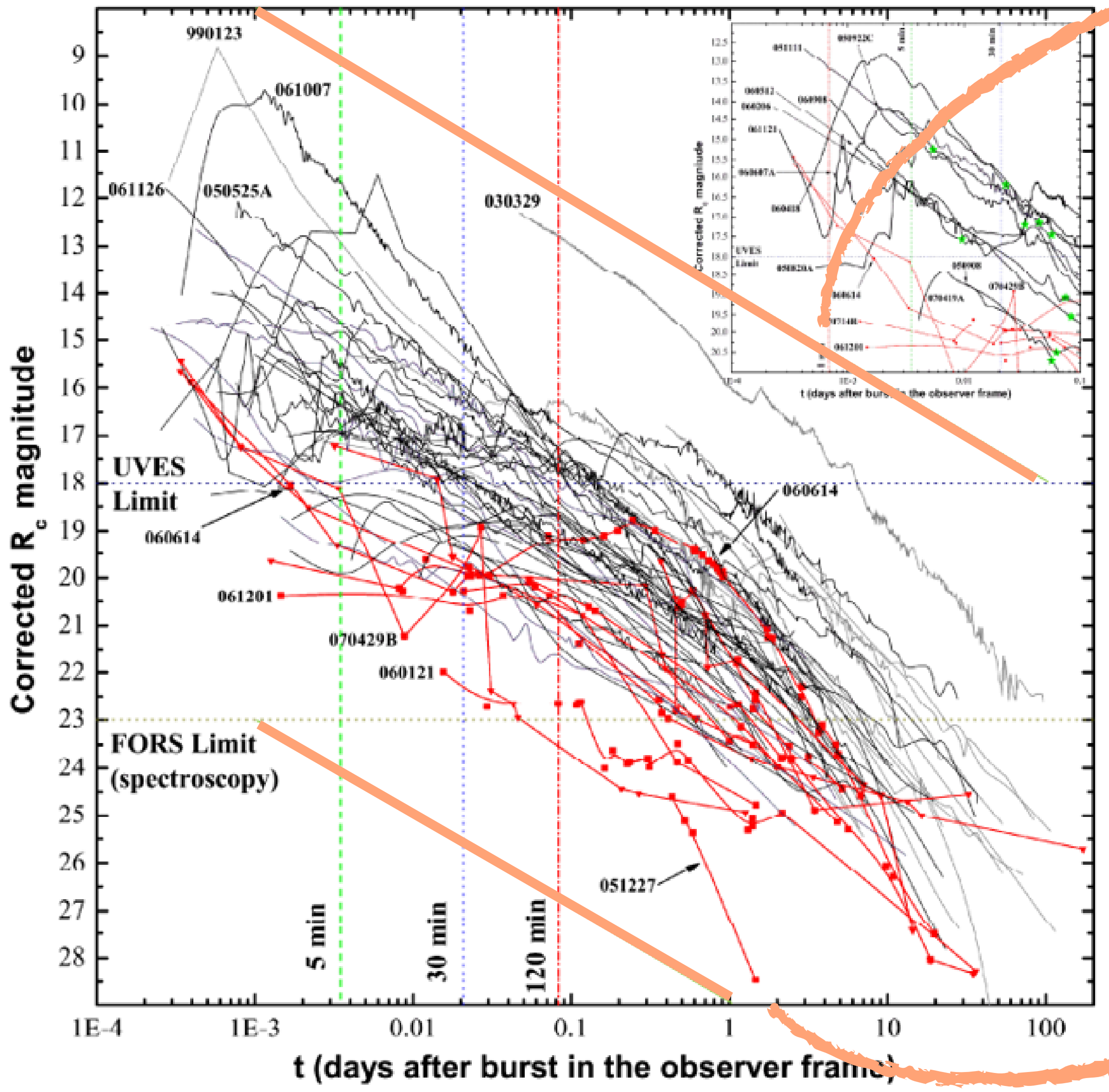
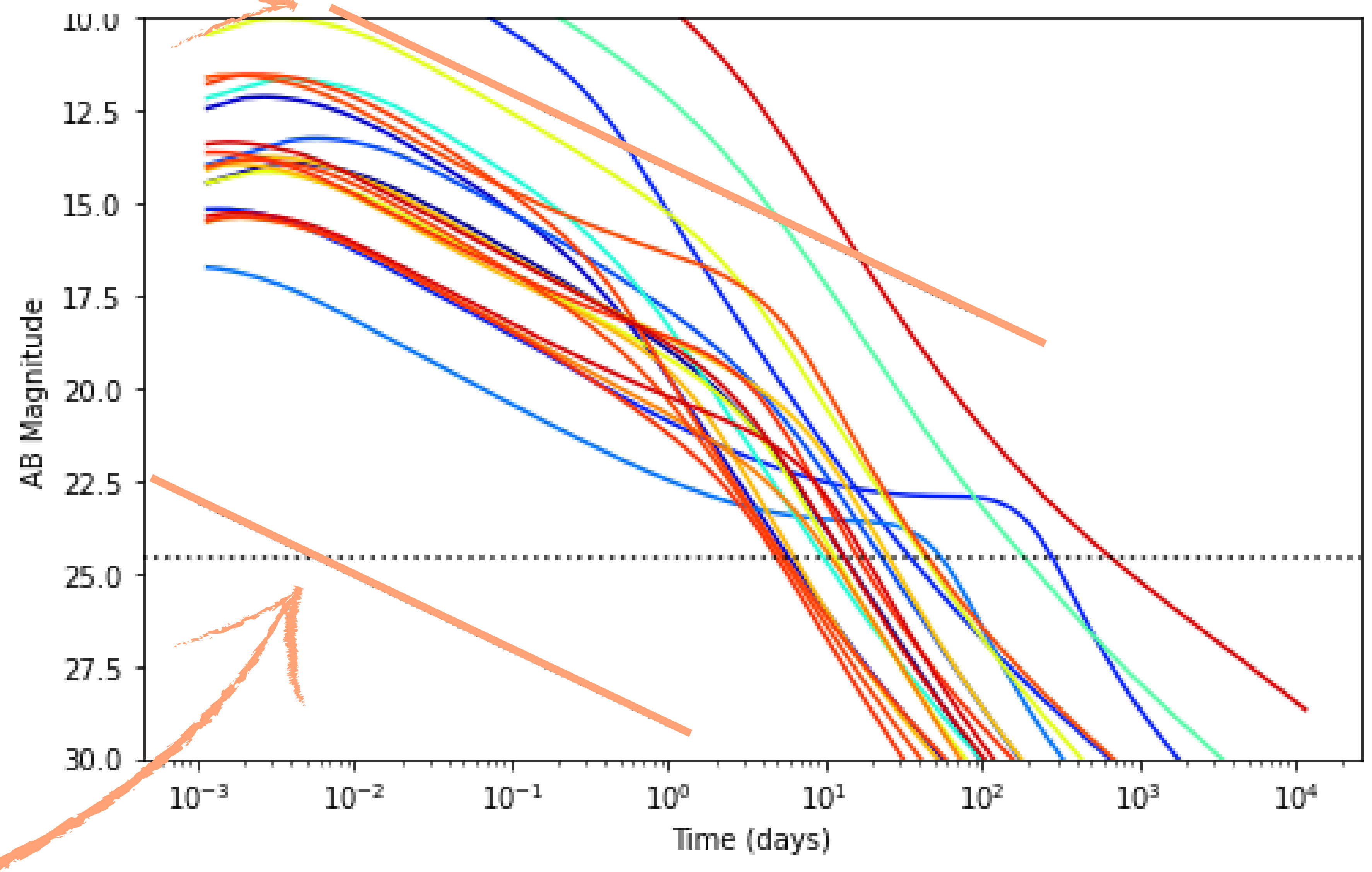


Fig. 1. GRB optical afterglow light curves with well-sampled data up to the end of August 2007. Pre-Swift long GRB afterglows are grey, Swift era ones are black. Short GRB afterglows are red, with detections marked by squares, and additional upper limits by triangles.The inset shows early light curves of long GRBs with rapid spectroscopic follow-up.

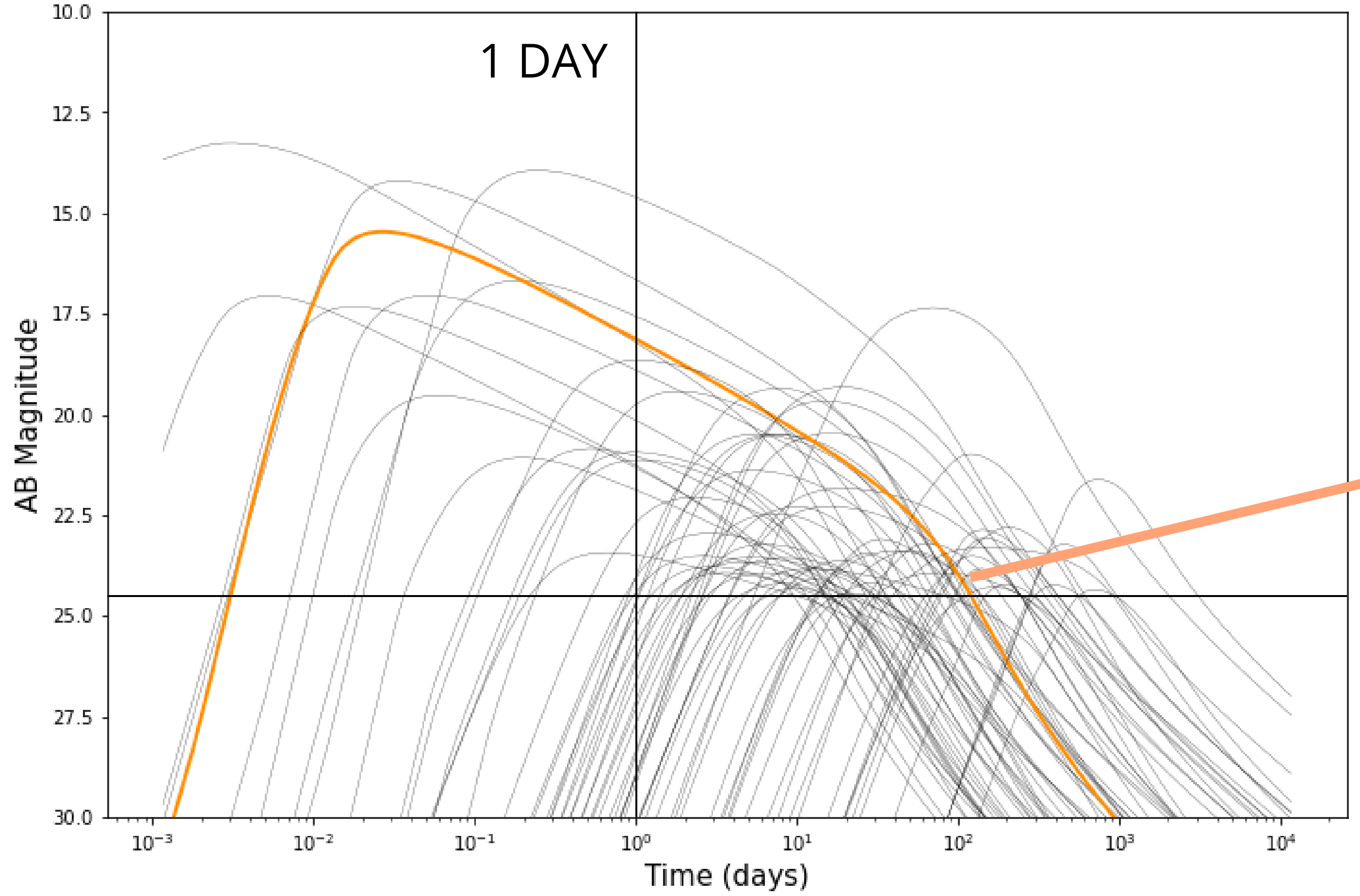


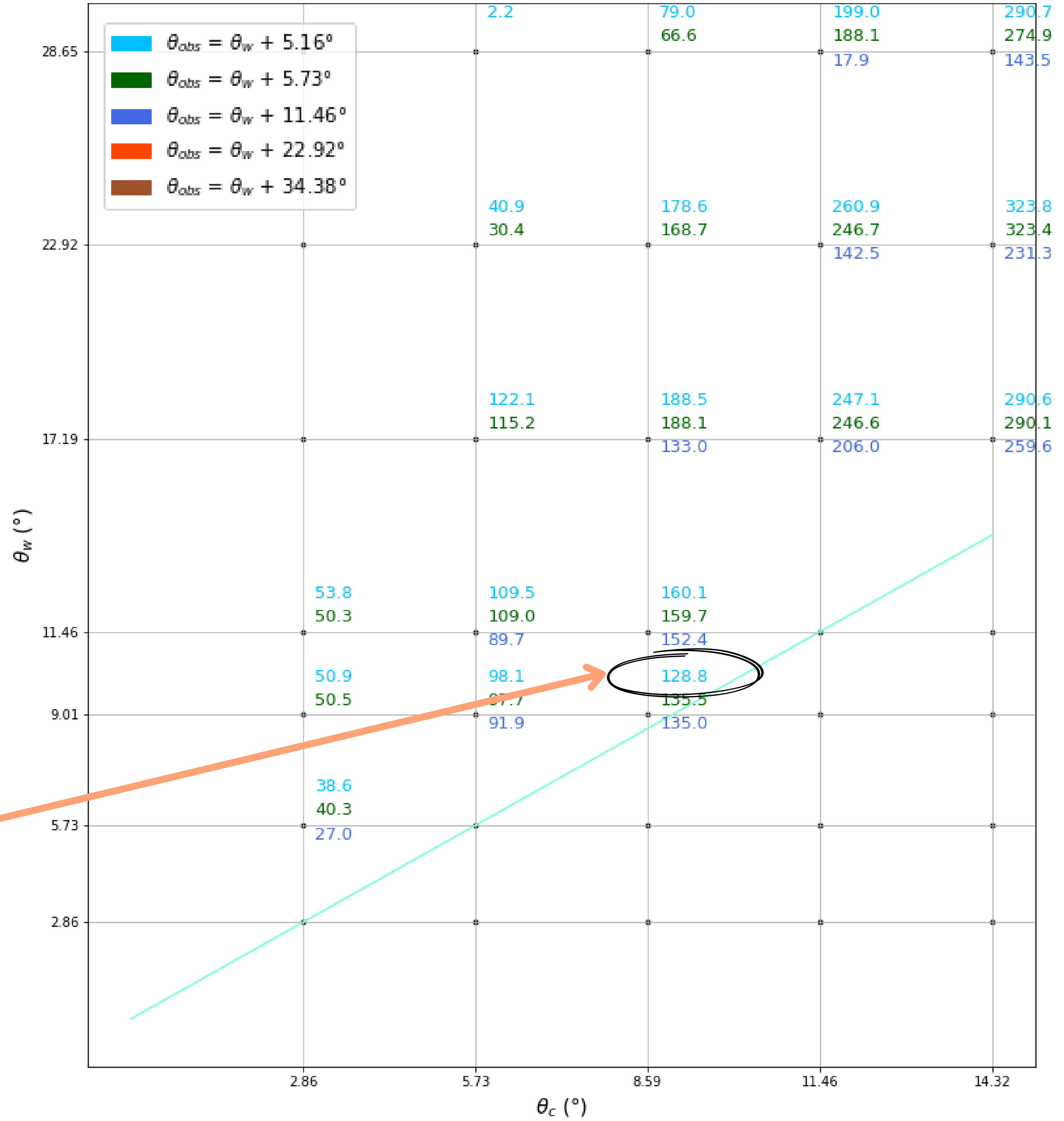
⟹ Simulated on-axis afterglows are included in the "enveloppe"

ANNEXE 1

MATRIX FOR ONE OF THE LIGHT CURVE

```
Z = {'jetType':     4,
     'specType':    0,
     'b':           4,
     'thetaObs':    0.16616312453730092,
     'E0':          6.123407761152622e+52,
     'thetaWing':   0.15719393241077656,
     'thetaCore':   0.15,
     'n0':          0.0033510057131371173,
     'p':           2.2,
     'epsilon_e':   0.1,
     'epsilon_B':   0.01,
     'xi_N':        1.0,
     'd_L':         1.0354044735824974e+27,
     'z':           0.072}
```

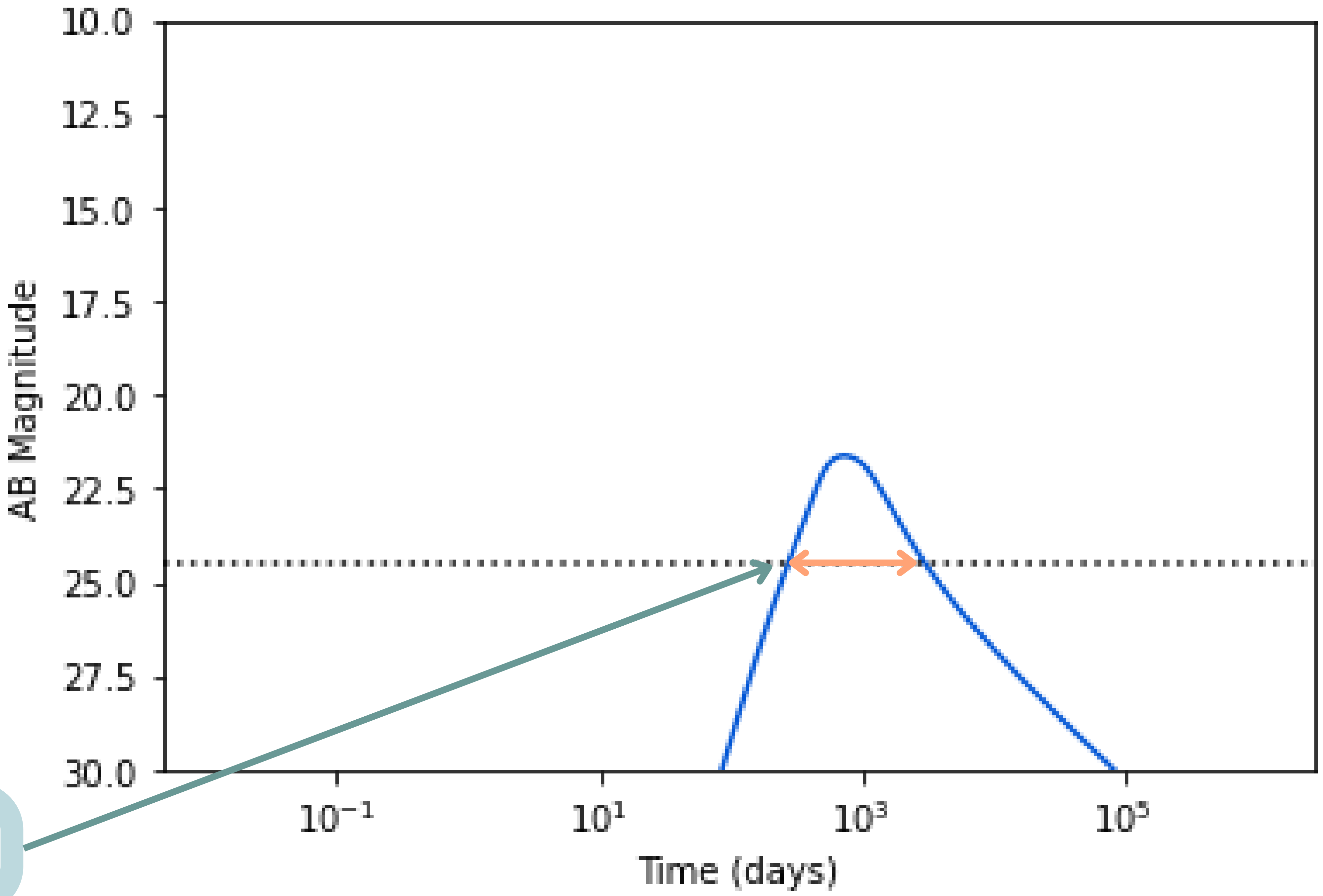




ANNEXE 2

A VERY LONG OFF-AXIS AFTERGLOW

```
Z = {'jetType':      4,
     'specType':     0,
     'b':            4,
     'thetaObs':     1.0784303637555728,
     'E0':           9.512700488776103e+52,
     'thetaWing':    0.2300527861676748,
     'thetaCore':    0.15,
     'n0':           0.037671470075268915,
     'p':            2.2,
     'epsilon_e':    0.1,
     'epsilon_B':    0.01,
     'xi_N':         1.0,
     'd_L':          8.225822969686203e+25,
     'z':            0.006}
```



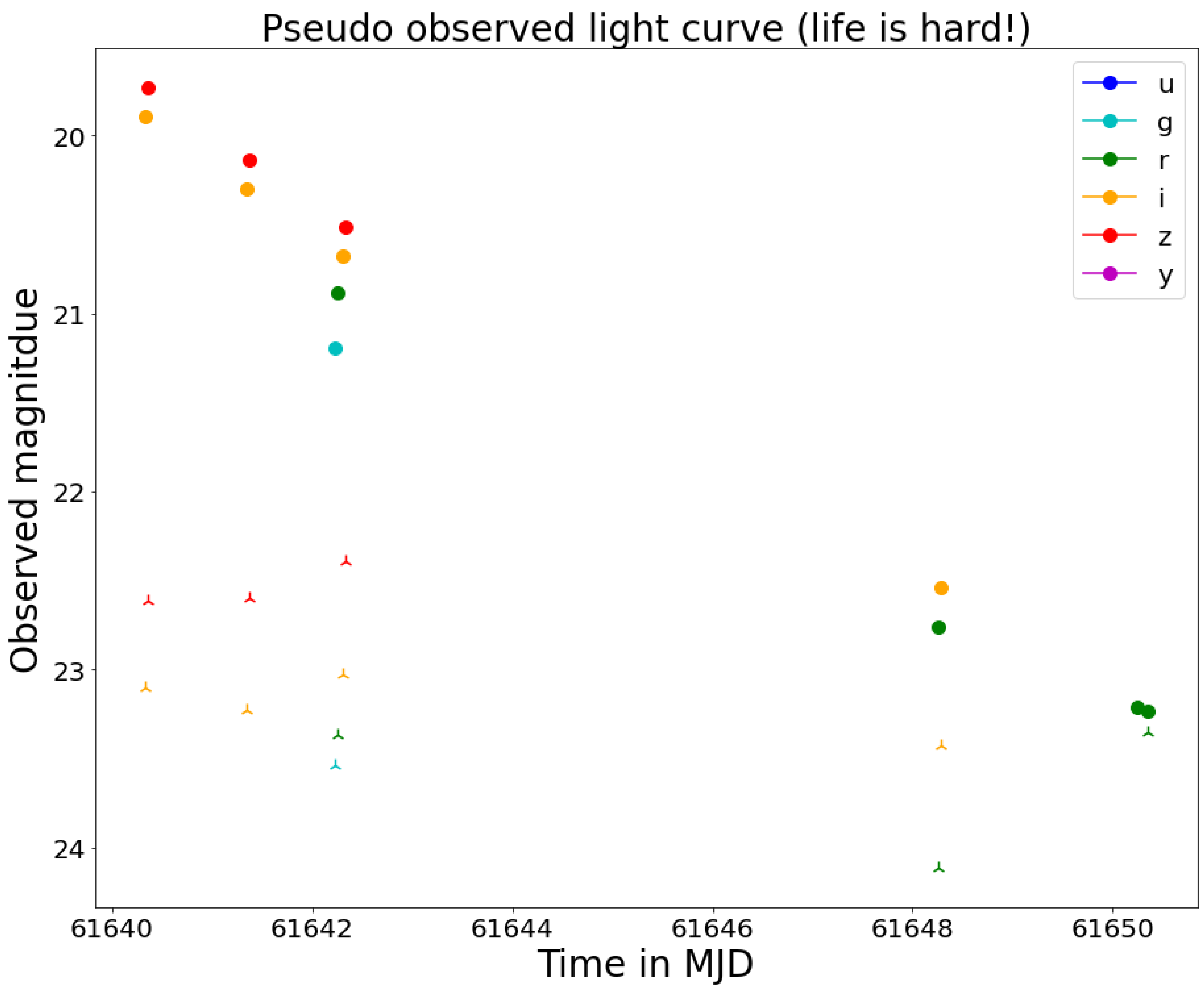
This afterglow is observable during 2727 days!

ANNEXE 3

PSEUDO OBSERVATIONS WITH THE RUBIN_SIM PACKAGE

With rubin_sim:

1- Take time and ra/dec of GRB270817 ("future" GW170817)
2- Keep only observations inside the Rubin/LSST field of view (angular separation < 1.7 degree)
3- Compute observation time in the GRB time frame
4- Compute spectra at observation time bins in magnitude
5- Keep only "real" observation for the right filter
6- Plot pseudo observed light curve



ANNEXE 4