# Identification of Orphan GRB Afterglows in Rubin LSST data

## WITH THE `afterglowpy` PACKAGE

Johan BREGEON
Marina MASSON

Master 2 Internship
5 April 2022

# Objectives of this work

- To use the **`afterglowpy`** package to simulate light curves of orphan gamma-ray burst afterglows,

- To understand how the different parameters (angles, energy, redshift…) impact the light curve in order to caracterise the parameters space where they evolve,

- **Final objective >** To implement a filter in the alert broker **FINK** which will allow us to identify potential orphan gamma-ray burst afterglows.

# The **afterglowpy** package (Ryan et al. 2020, Van Eerten et al. 2010)

- Has been calibrated to the **BoxFit** code (Van Eerten et al. 2012),
- Uses a trans-relativistic equation of state + shock jump conditions,
- Solves the forward shock evolution equations using the Single-shell approximation:

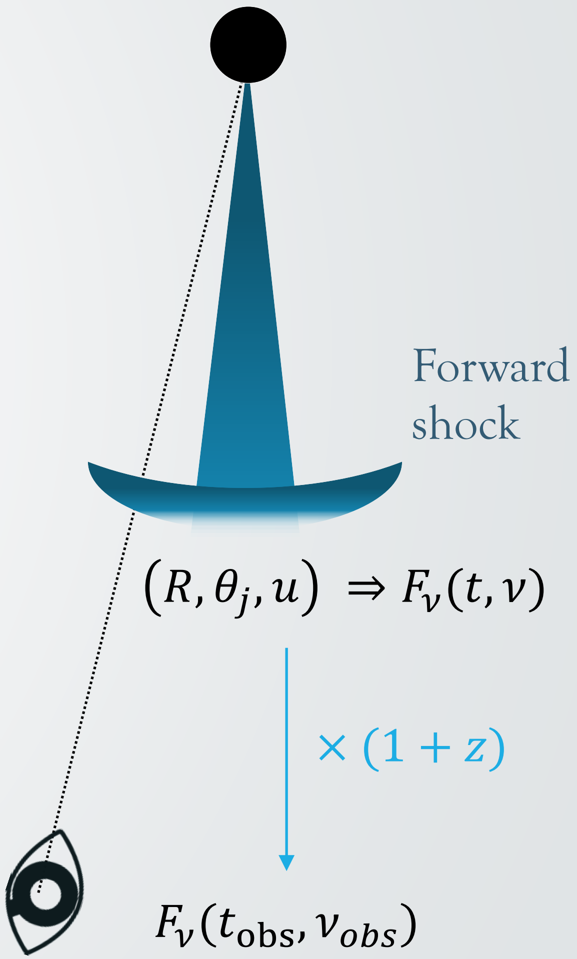
$$\left(\dot{R}, \dot{\theta}_j, \dot{u}\right) \Longrightarrow \left(R(t), \theta_j(t), u(t)\right)$$

- Gives the observed flux in the observer's frame:

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

Where $\epsilon'_\nu$, is the rest-frame synchrotron emissivity (Sari, Piran and Narayan 1997).

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




https://github.com/geoffryan/afterglowpy

# Parameters used in **`afterglowpy`**

**Studied parameters**

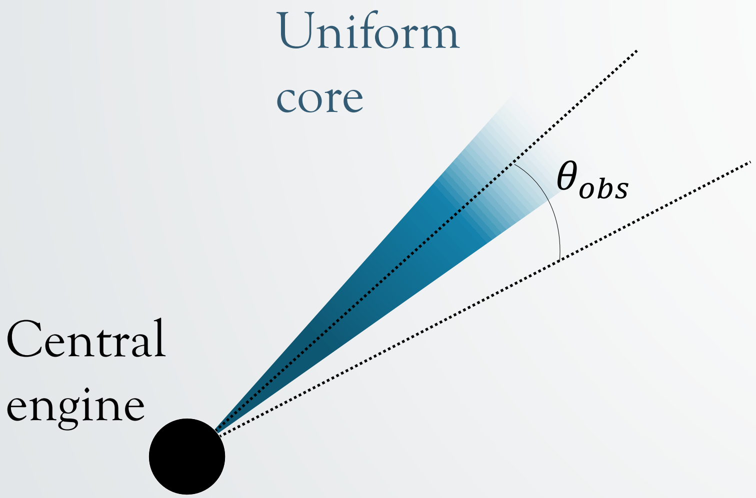
- Jet Type
- $E_0 \in [10^{50}; 10^{55}]$ erg
- $\theta_c \in [3; 26]°$
- $\theta_w \in [3; 52]°$
- $\theta_{obs} \in [\theta_w; 90]°$
- $z \in [0.01; 3.5]$

```python
Z = {'jetType':      grb.jet.TopHat,      # Jet Type
     'specType':     0,                   # Emission Spectrum
     'b':            4,       # Power Law index
     'thetaObs':     0.2,     # Viewing angle in radians
     'E0':           1.0e53,  # Isotropic-equivalent energy in erg
     'thetaWing':    0.15,    # Truncation angle in radians
     'thetaCore':    0.1,     # Half-opening angle in radians
     'n0':           1.0,     # Circumburst density in cm^{-3}
     'p':            2.2,     # Electron energy distribution index
     'epsilon_e':    0.1,     # epsilon_e
     'epsilon_B':    0.01,    # epsilon_B
     'xi_N':         1.0,     # Fraction of electrons accelerated
     'd_L':          1.0e28,  # Luminosity distance in cm
     'z':            0.55}    # Redshift
```

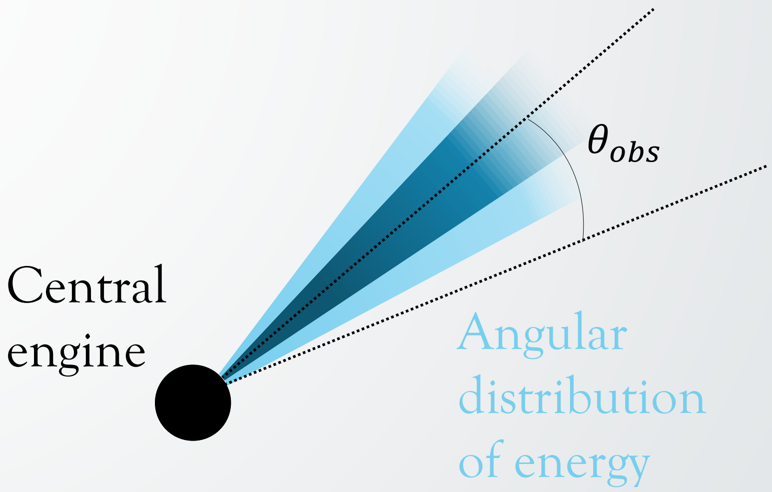
# What is a structured jet ?

**Structured jet >** Collimated blast with a non trivial angular energy distribution $E_{iso} = E(\theta) = 4\pi \frac{dE}{d\Omega}$.

## Top-Hat Jet




## Structured Jet

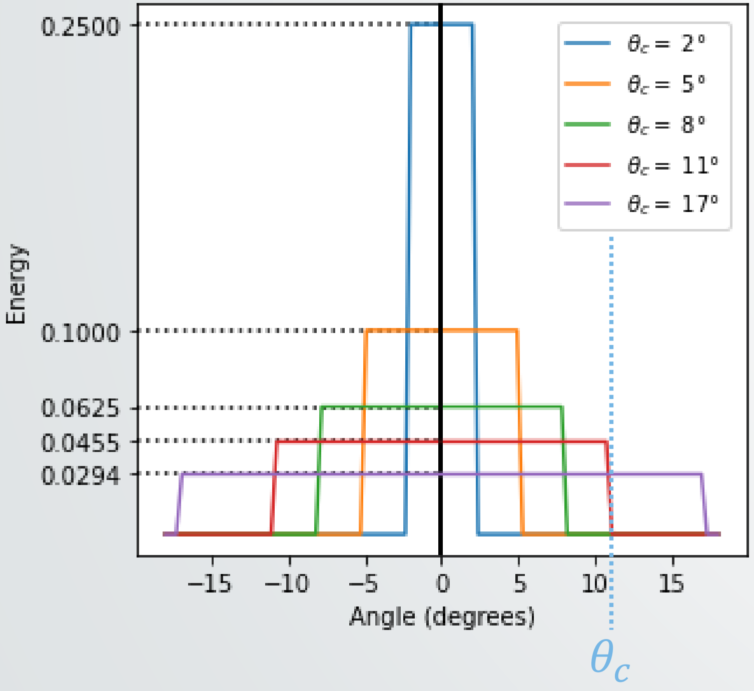


# Types of structured jet

- $E_0$ : normalization
- $\theta_c$ : core width/opening angle
- $\theta_w$ : truncation angle
- $b$ : power-law index ($\in [2;6]$)

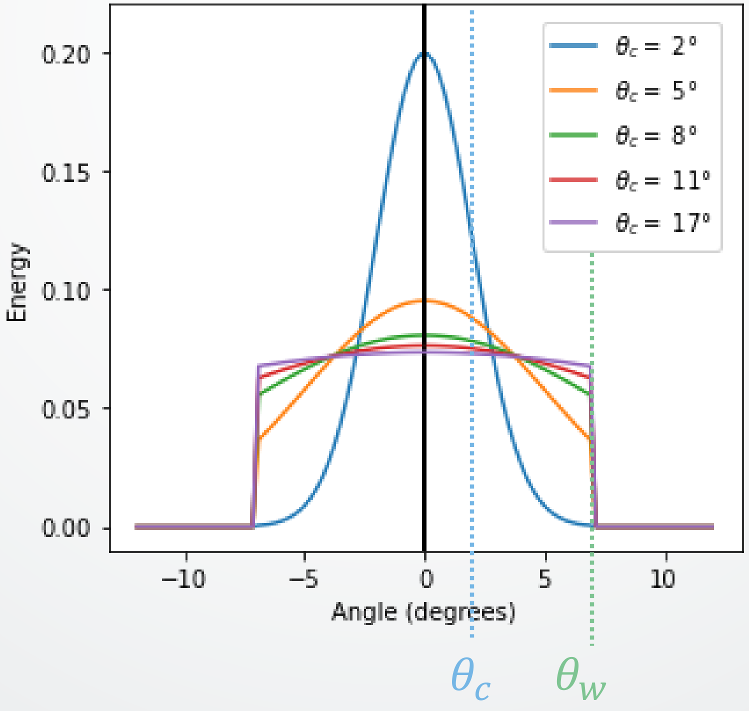
## Top-Hat Jet

$$E(\theta) = E_0$$



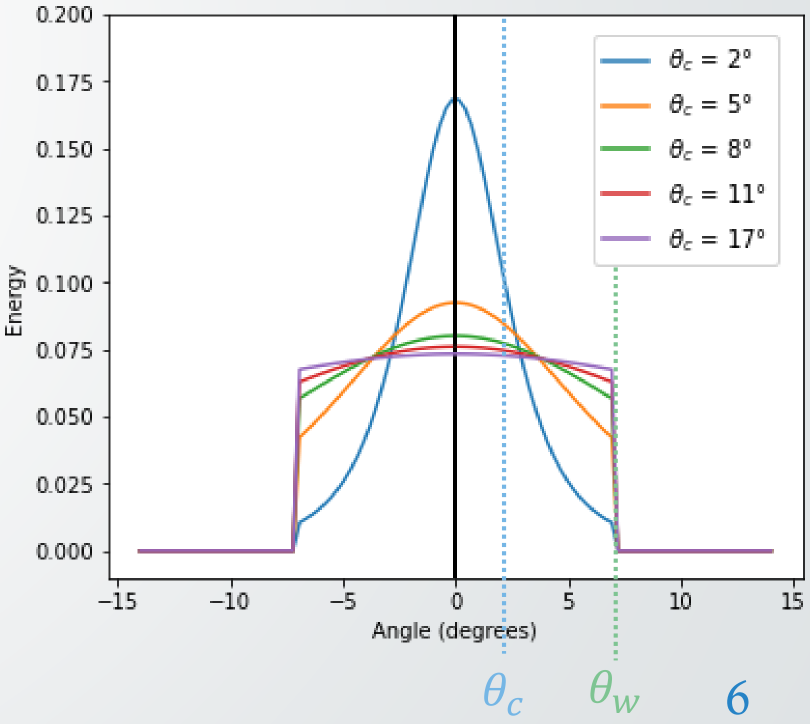

## Gaussian Jet

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



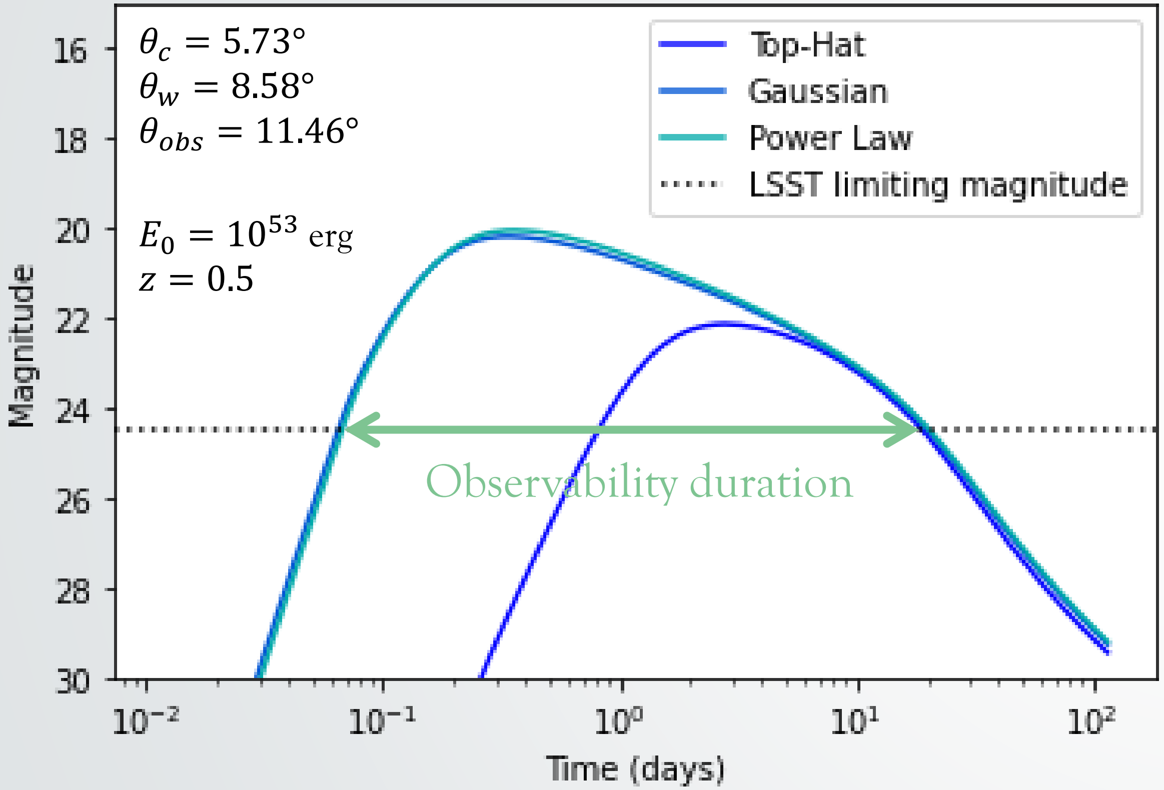

## Power-Law Jet

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



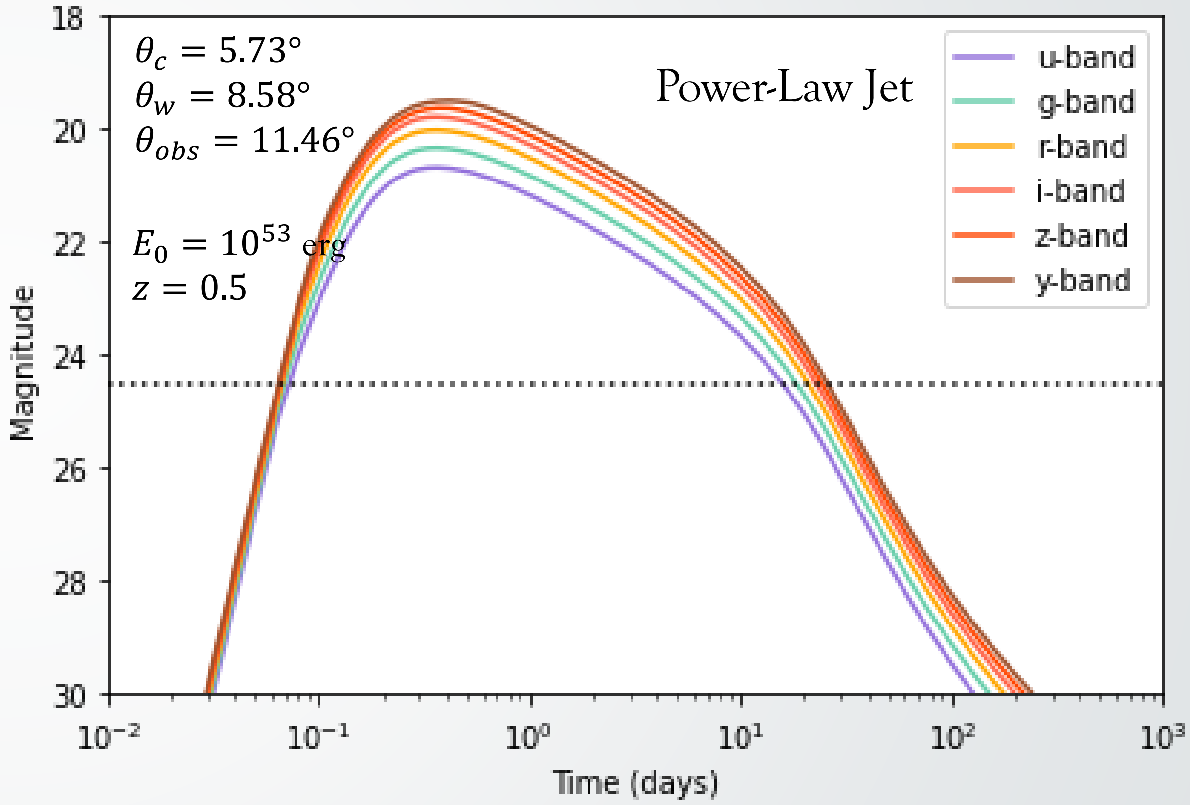
# Light curves

- Rubin Observatory limiting magnitude = 24.5
- Frequency $\nu = 5.0 \times 10^{14}$ Hz ($\lambda$ = 600 nm → r-band)




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

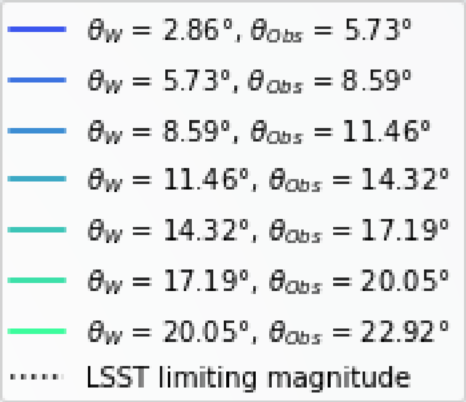
$\Longrightarrow$ Importance of $\boldsymbol{\theta_w}$.

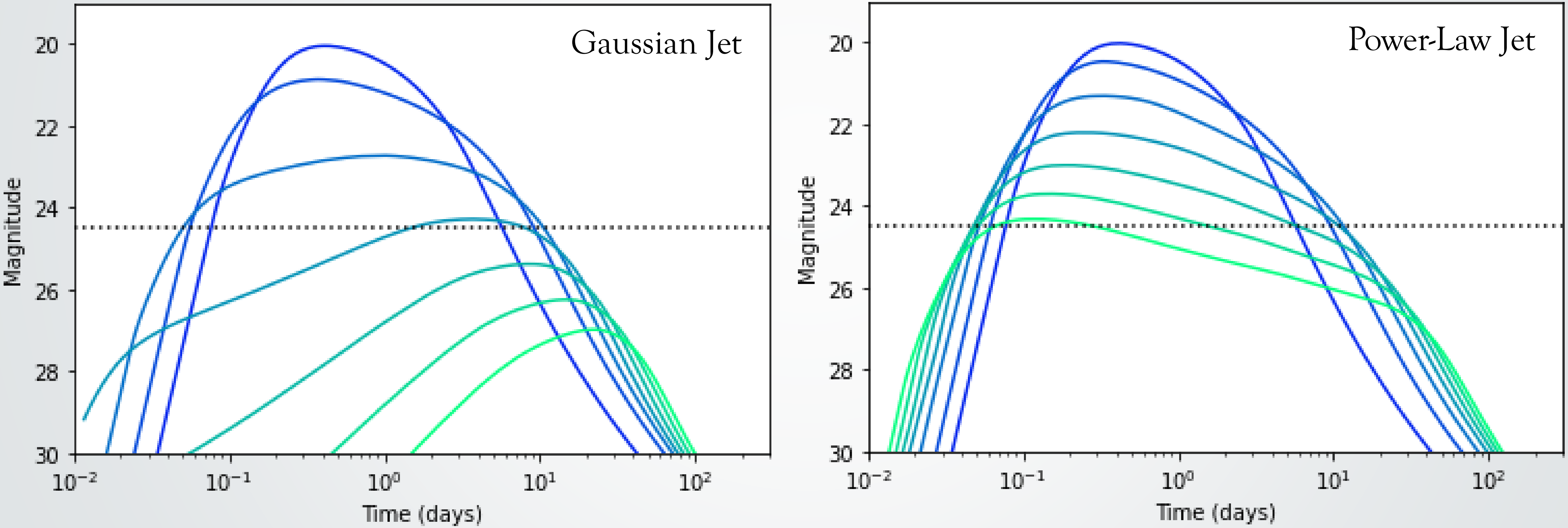



$\Longrightarrow$ Color $\boldsymbol{g - r = 0.28 \pm 0.07}$

(expected : $\boldsymbol{g - r \sim 0.3}$).

# Difference between Gaussian and Power-Law Jets



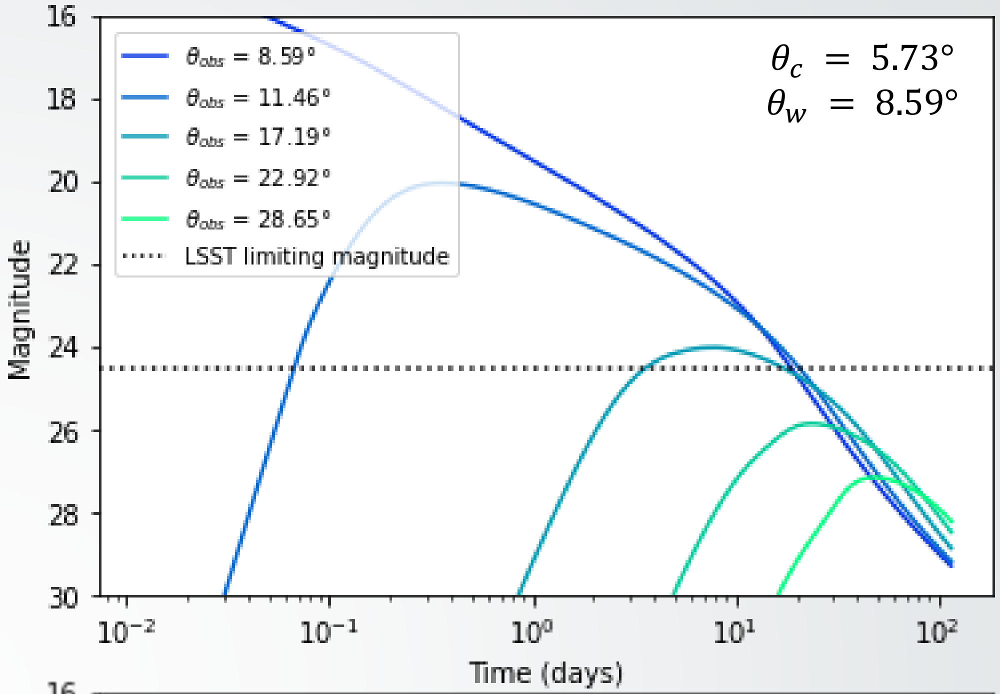



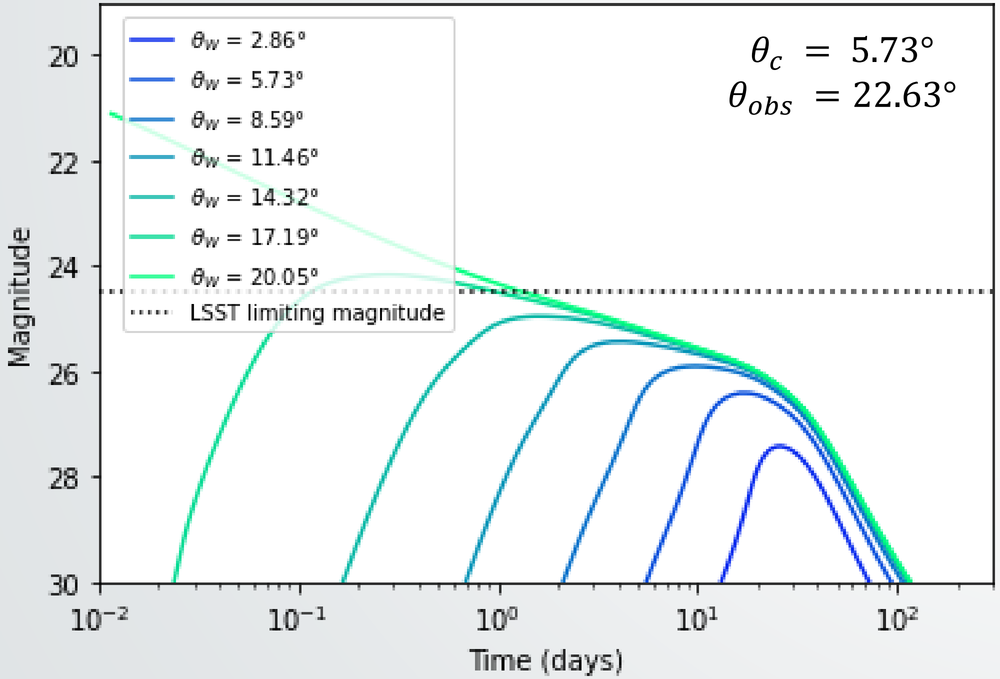

$\Longrightarrow$ For high values of $\boldsymbol{\theta_w}$, Power-Law jet is observable while Gaussian jet is not.

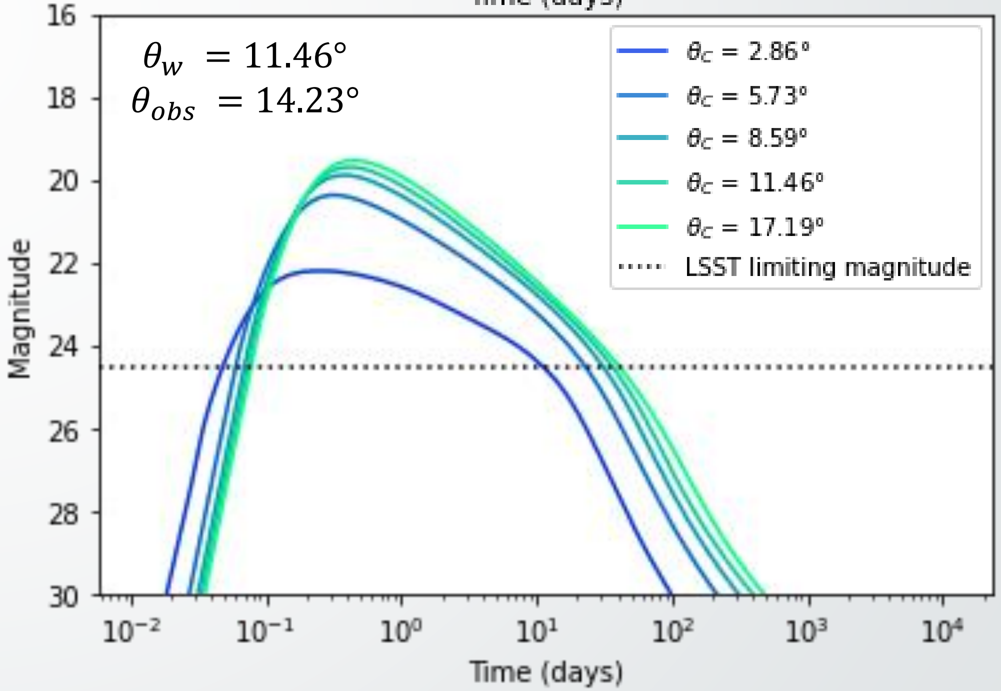
# Impact of $\theta_c$, $\theta_w$ and $\theta_{obs}$ on the light curves

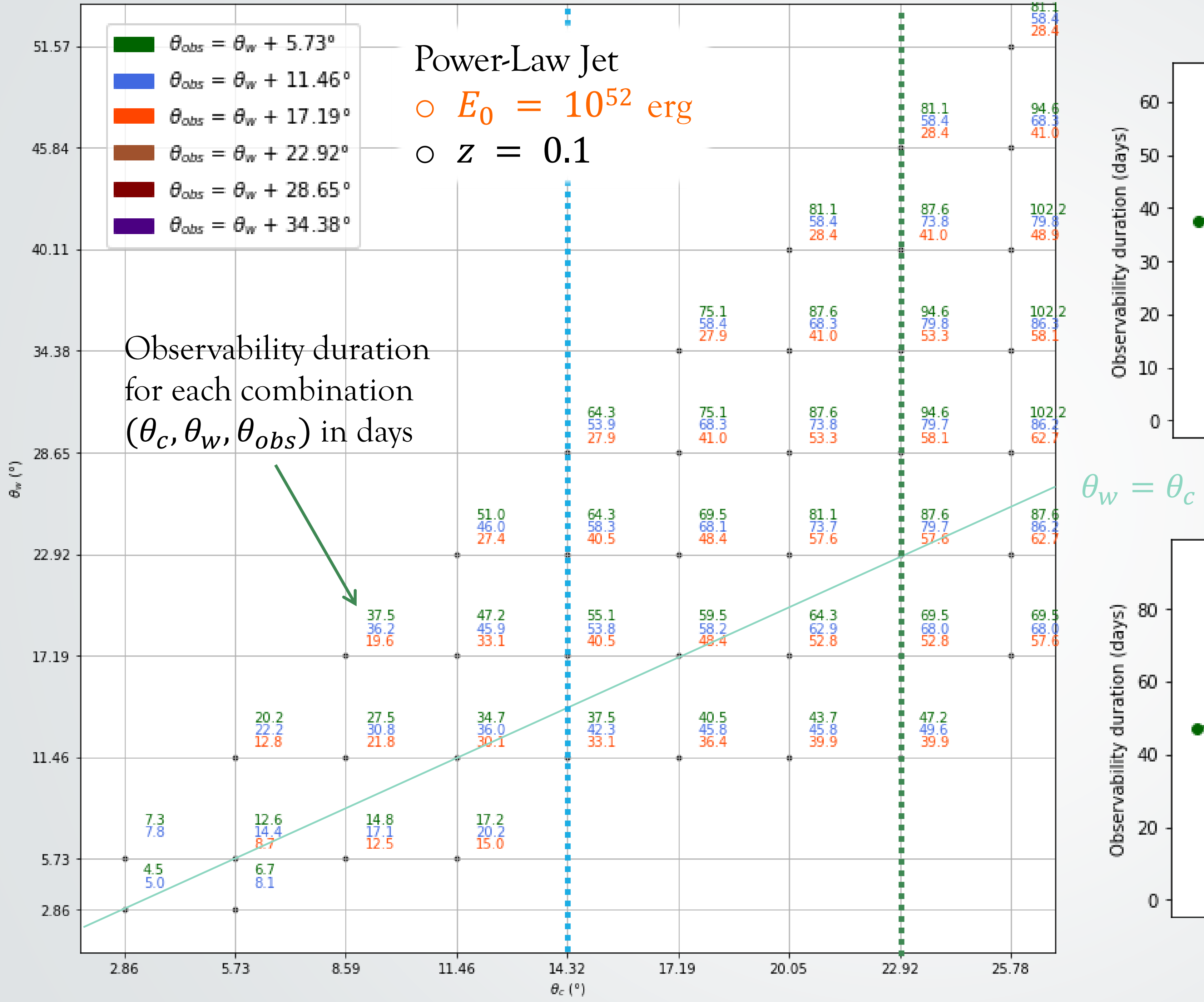
(Example of the Power-Law jet)

$\Longrightarrow$ For how much time is an afterglow observable for each combination of $(\theta_c, \theta_w, \theta_{obs})$ ?

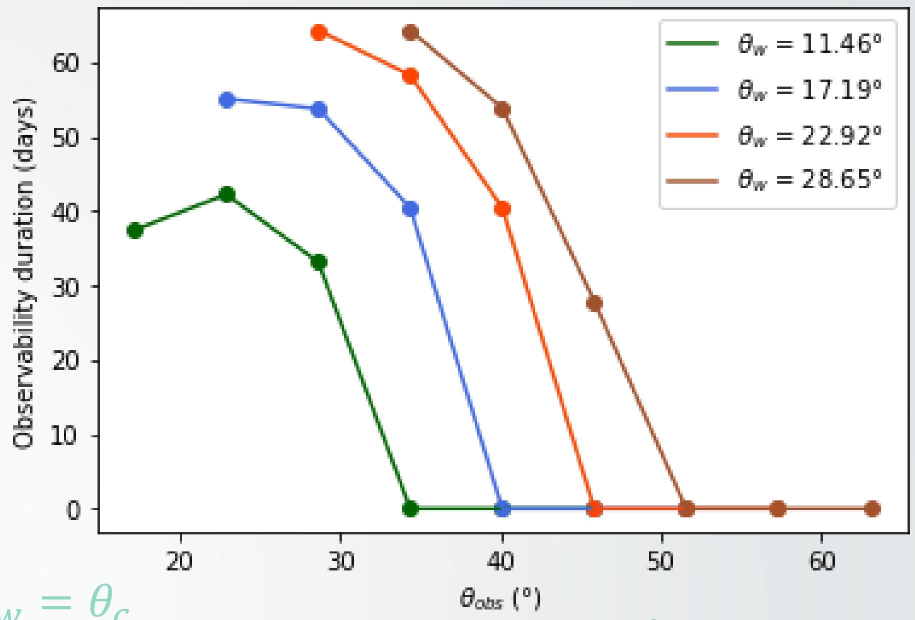


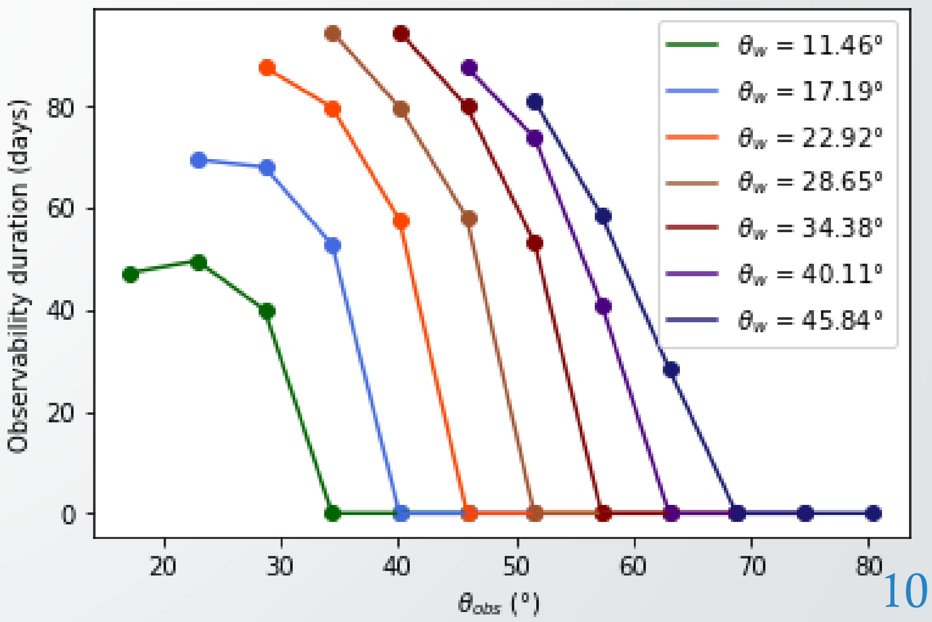



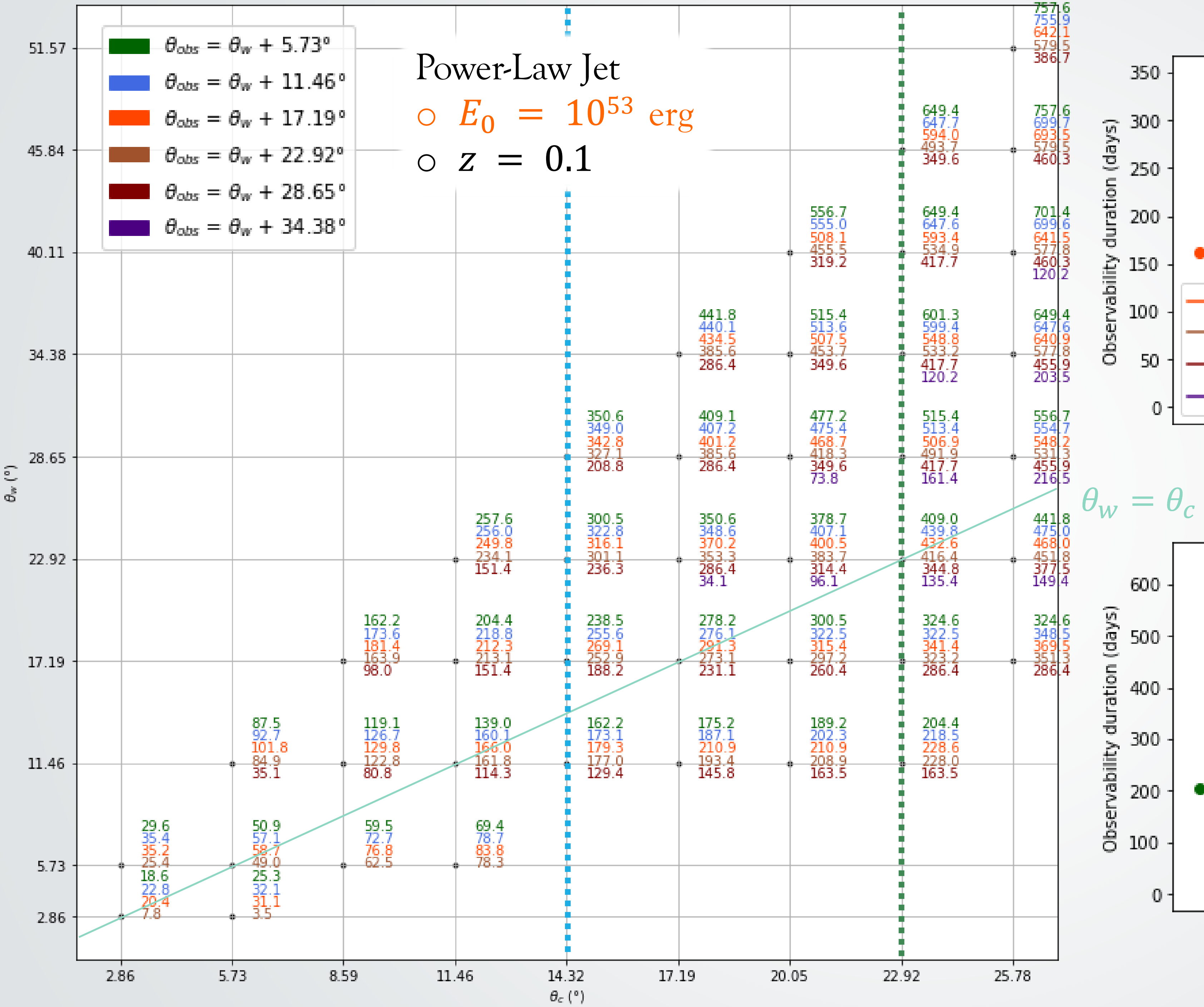



$\theta_c = 14.32°$

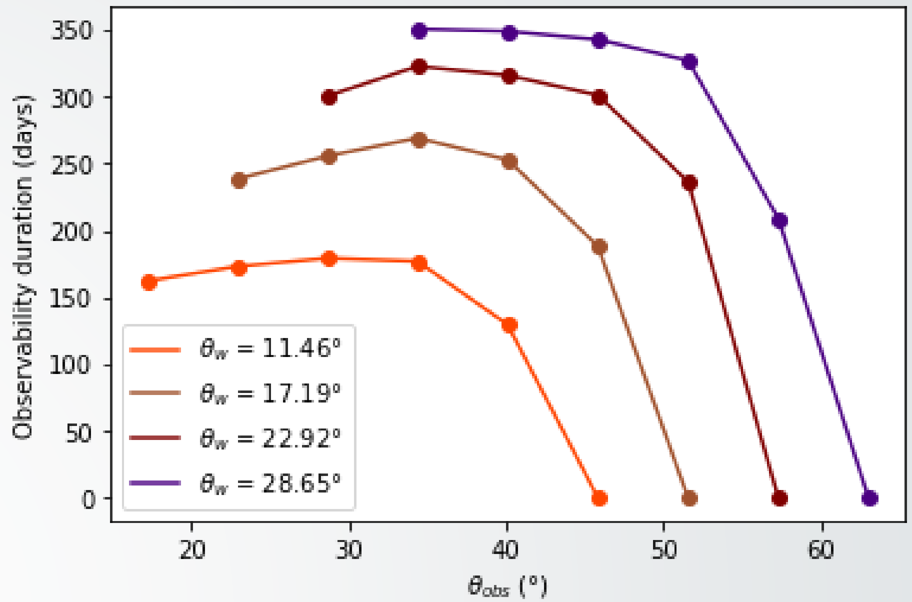



$\theta_c = 22.92°$

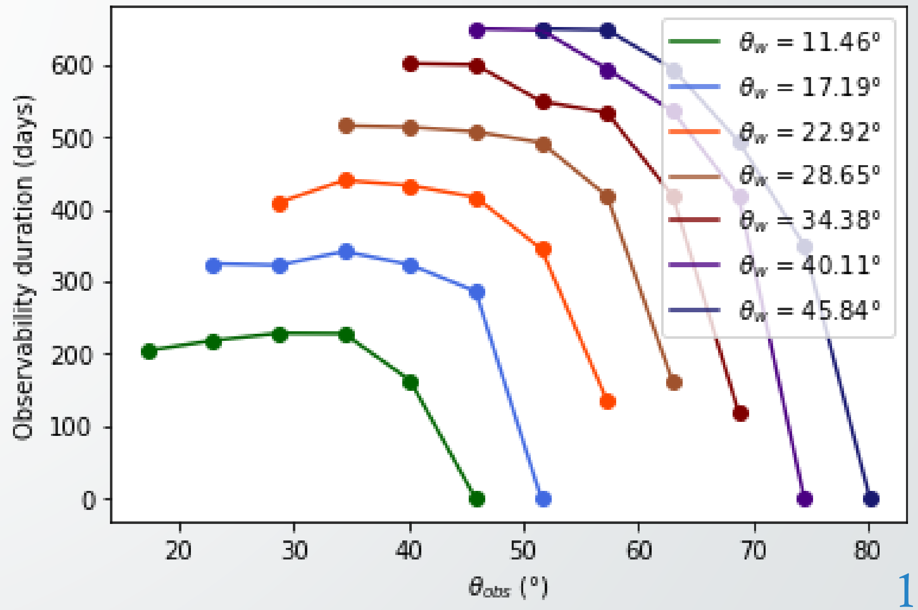


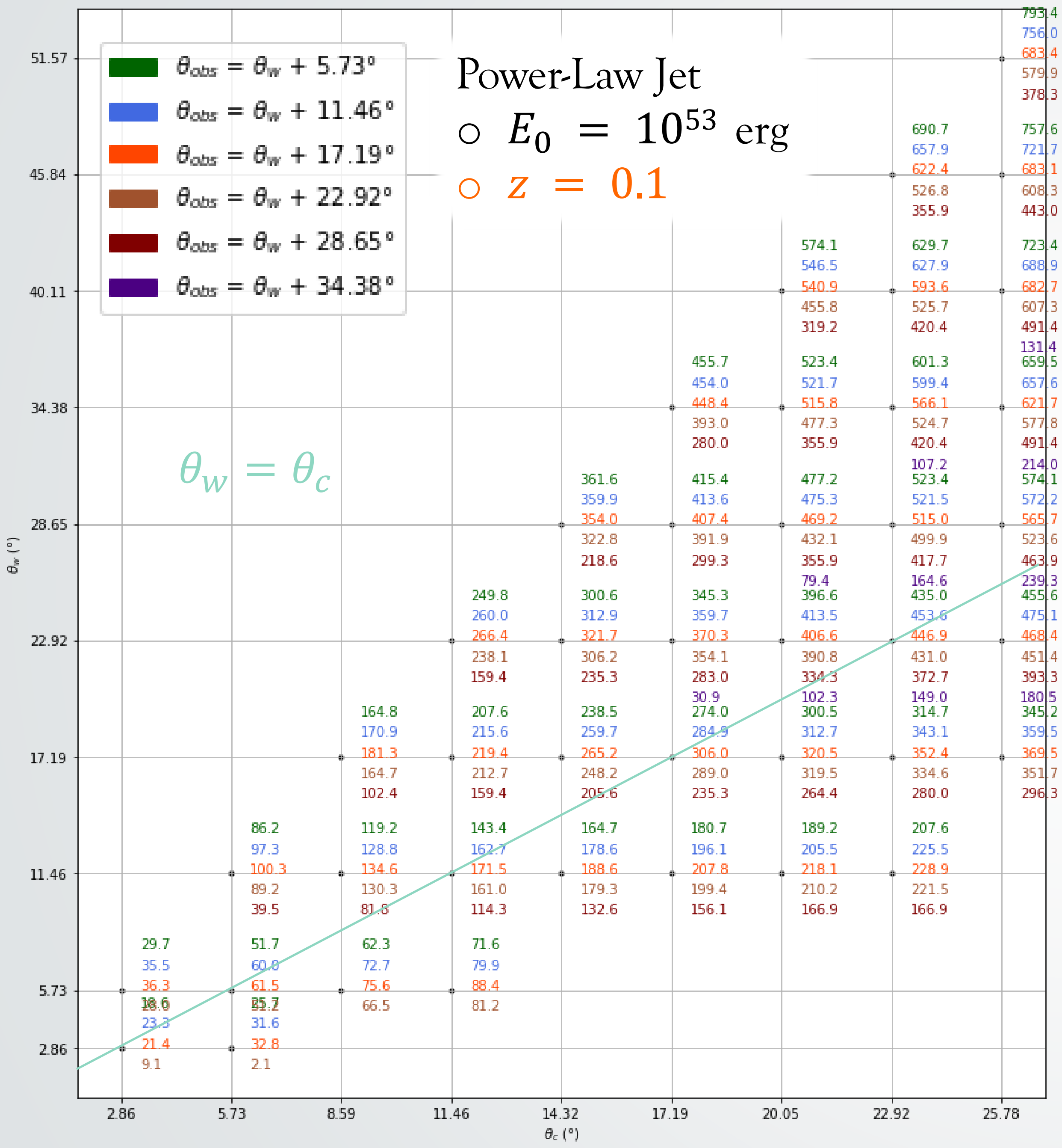


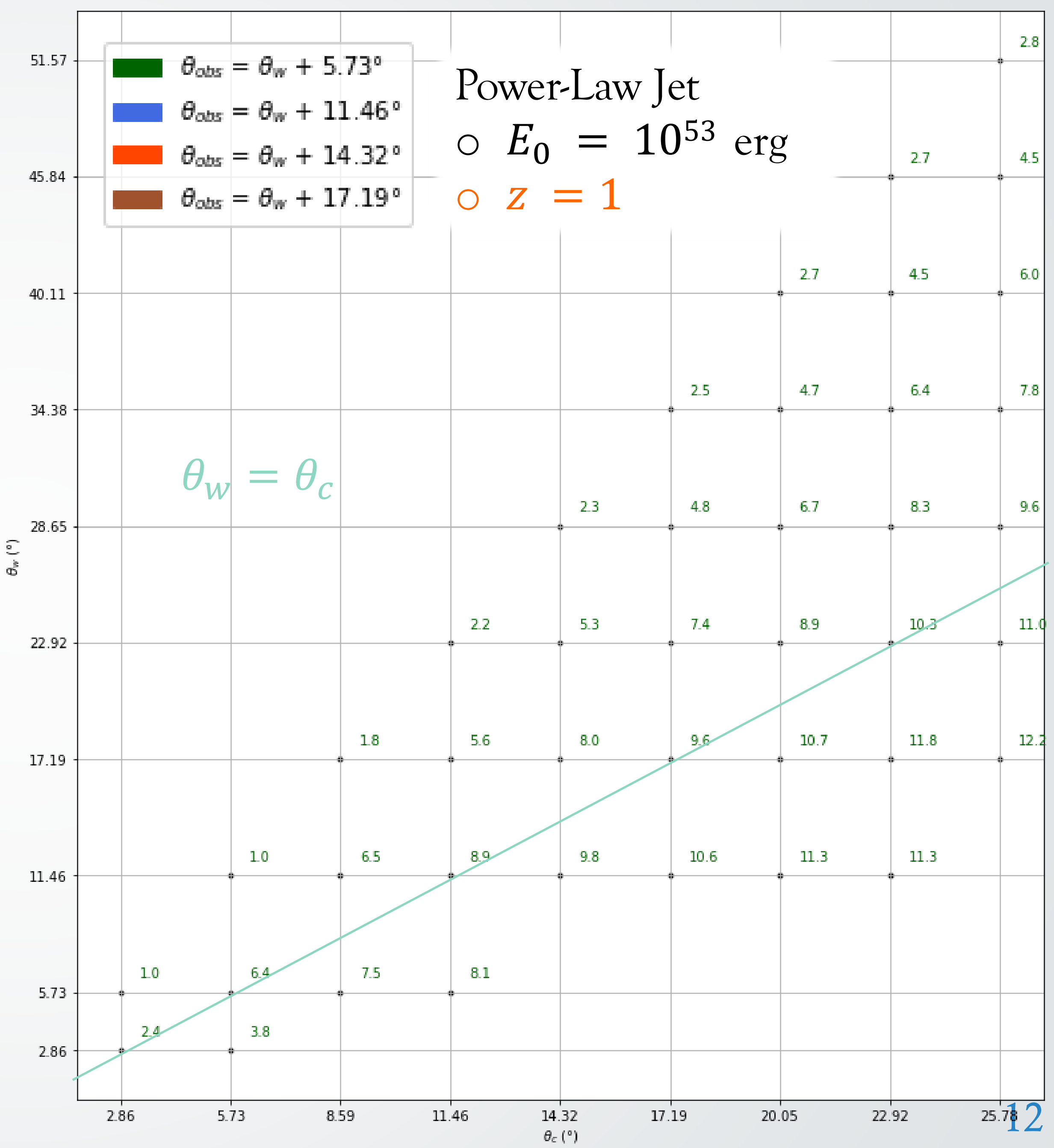

$\theta_c = 14.32°$




$\theta_c = 22.92°$

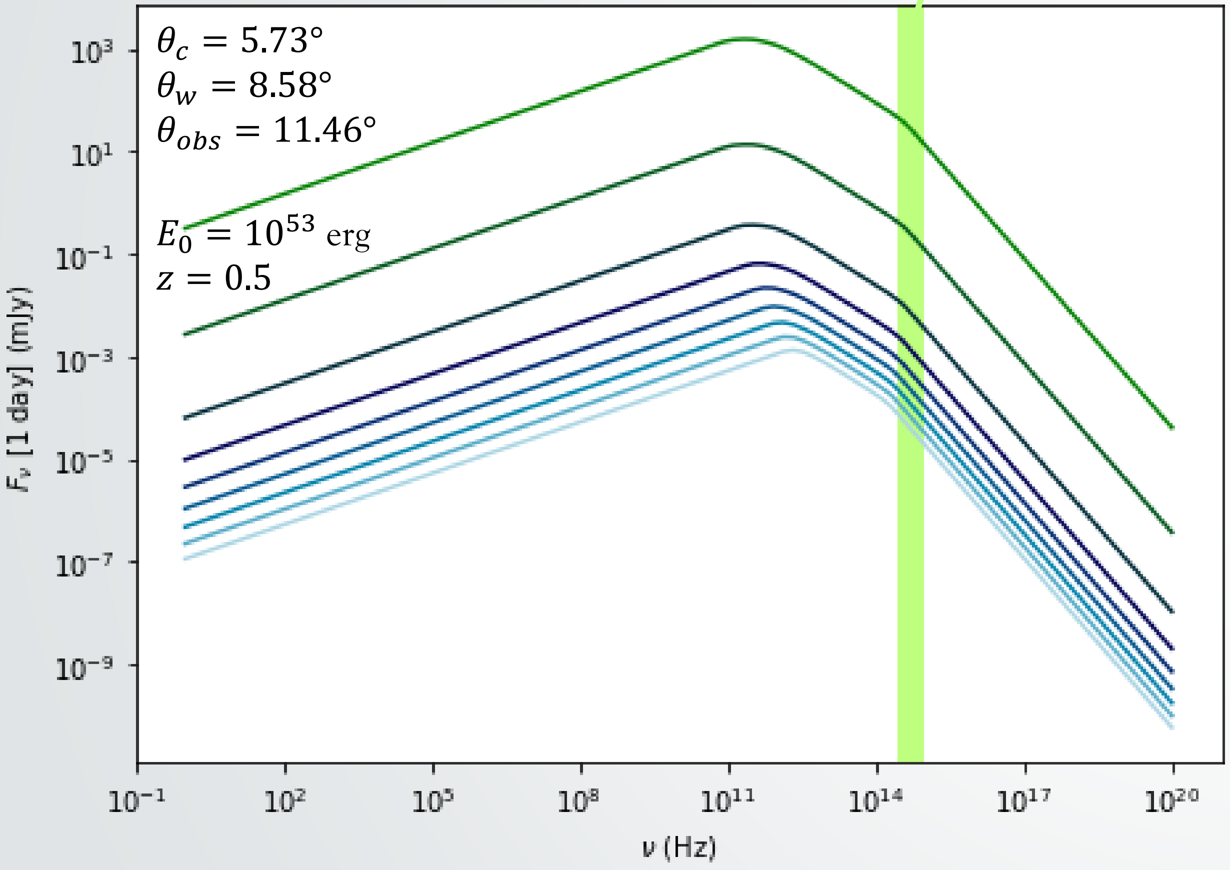


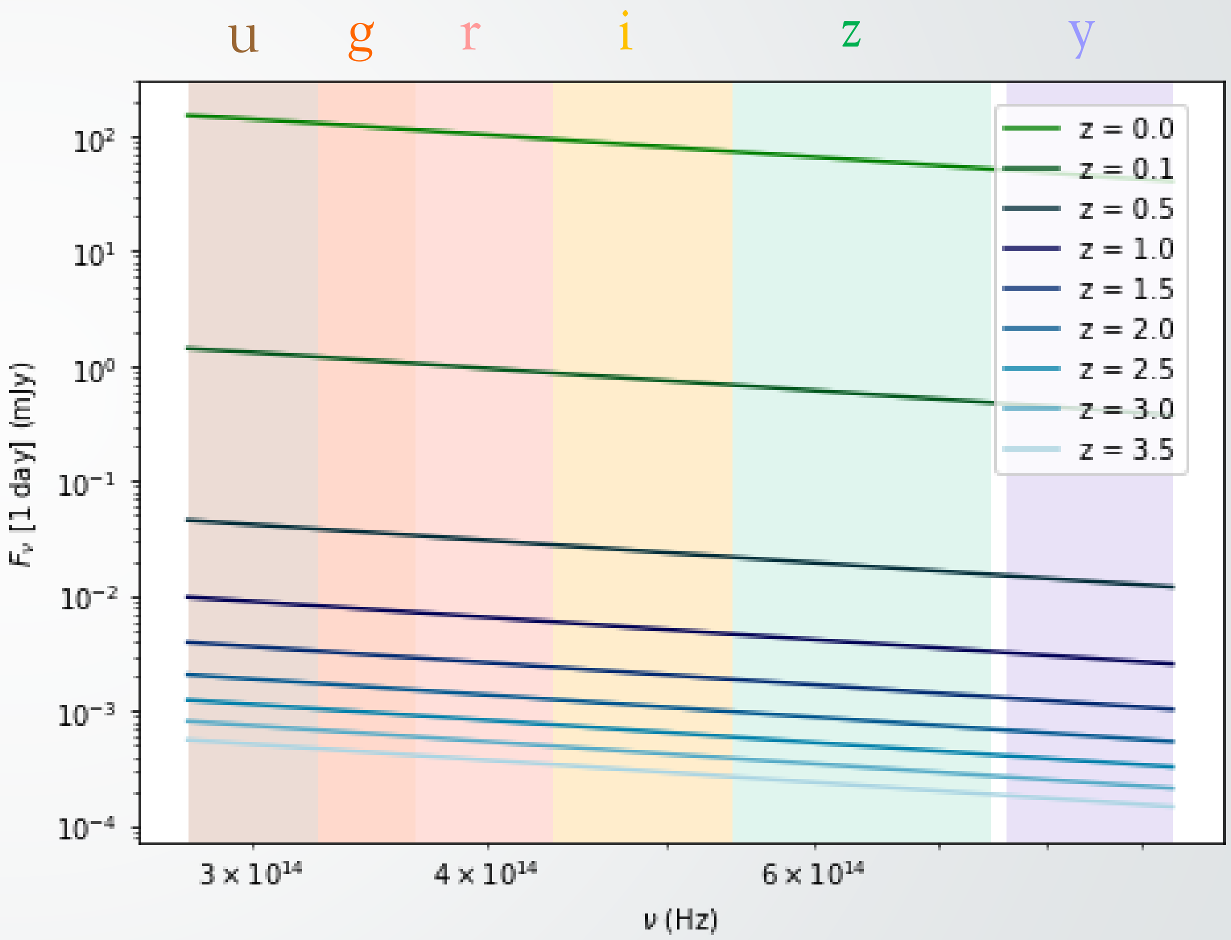

θobs = θw + 5.73°
θobs = θw + 11.46°
θobs = θw + 17.19°
θobs = θw + 22.92°
θobs = θw + 28.65°
θobs = θw + 34.38°
Power-Law Jet
○ E0 = 10^53 erg
○ z = 0.1
θw = θc
θw (°)
θc (°)


θobs = θw + 5.73°
θobs = θw + 11.46°
θobs = θw + 14.32°
θobs = θw + 17.19°
Power-Law Jet
○ E0 = 10^53 erg
○ z = 1
θw = θc
θw (°)
θc (°)

# Spectra

Rubin Observatory filters



# Conclusion and perspectives

The **afterglowpy** package allows us to calculate light curves and spectra of orphan GRB afterglows and the parameters space is large $\Longrightarrow$ we have to agree on the same parameters space to compare differents works.

## Perspectives

- To use **rubin_sim** package to simulate "true" pseudo-observations in order to generate pseudo-alerts for the alert broker FINK,
- To generate a population of gamma-ray bursts and study them to know whether or not they can be observed thanks to the pseudo-observations.

All the codes can be accessible at https://gitlab.in2p3.fr/johan-bregeon/orphans.