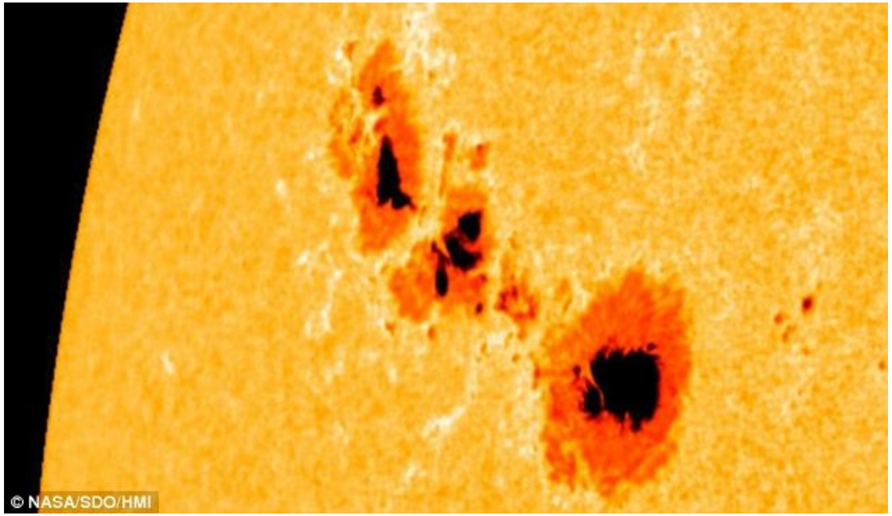
Stellar activity through different observing modes



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DI ASTROFISICA

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Rationale

- Ariel
  - Multiband approach: (3) photometry + infrared low resolution spectroscopy;
  - Timescales of observation related to the transit time (hrs);

- To approach Ariel data analysis we need to correct for the stellar activity… but first we should describe it:

  --> Need for accurate activity models (very important in a broader context);

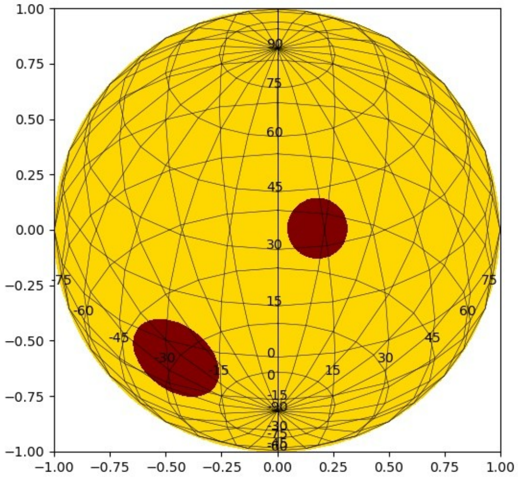
  --> Accurate timescales description;

  --> Need to build a multiband methodology;

The geometry of the model

- Spots based model;
- Circular spots built on a (R=1) sphere, then projected on a disk;
- No geometrical approximation (distortion due to projection);
- Effect of the inclination;
- Spot parameters:
  - Latitude;
  - Longitude;
  - Radius;
  - Temperature
- No temporal evolution;

Stellar disk



Same model, different applications

- High resolution spectroscopy:
  - Cross Correlation Function (CCF) --> Claudia di Maio (PhD student, claudia.dimaio@inaf.it)

- Light curves modelling:
  - Accurate high cadence light curves (Tess-like) --> Gianluca Cracchiolo (PhD student, gianluca.cracchiolo@inaf.it)
  - Simultaneous multiband photometry (R,J,I,REM etc..) --> Alfredo Biagini (see next talk)
  - (PhD student, alfredo.biagini@inaf.it)

The fitting procedure

- A bayesian framework to account for the parameter errors through a Markov Chain Monte Carlo (in python);
  - Result tested with different samplers;

- Likelihood: $$\ln p(y_n, t_n, \sigma_n^2, \theta) = -\frac{1}{2}\boldsymbol{r}^T K^{-1}\boldsymbol{r} - \frac{1}{2}\ln\det K - \frac{N}{2}\ln 2\pi$$

- We test same date with different number of spots;

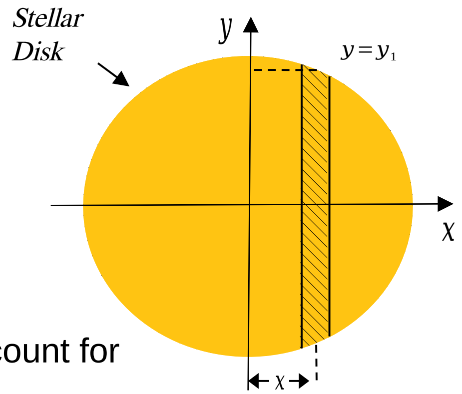
- Bayesian Information Criterion (BIC) comparison selects the preferred model:

  $BIC = k\ln(N) - 2\ln(\mathscr{L})$

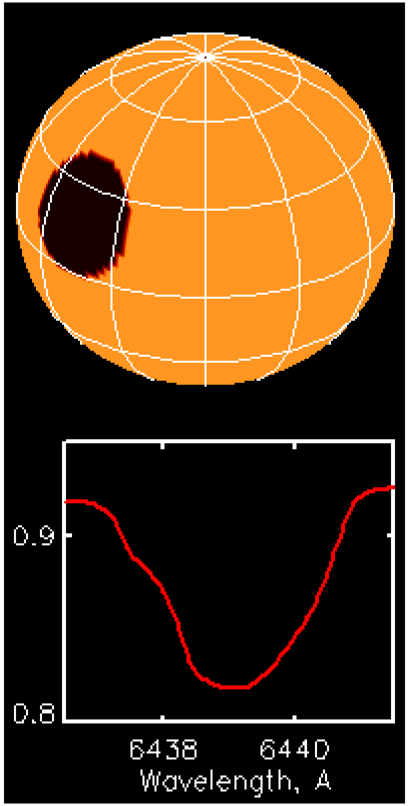
(python packages: george, emcee, pymultinest)

High resolution spectroscopy

- CCF is broadened by the rotation --> (2D) rotational profile built on the disk;
- Spots hide a portion of the disk;
- The integration leads to a distorted (1D) profile whose center is the radial velocity;



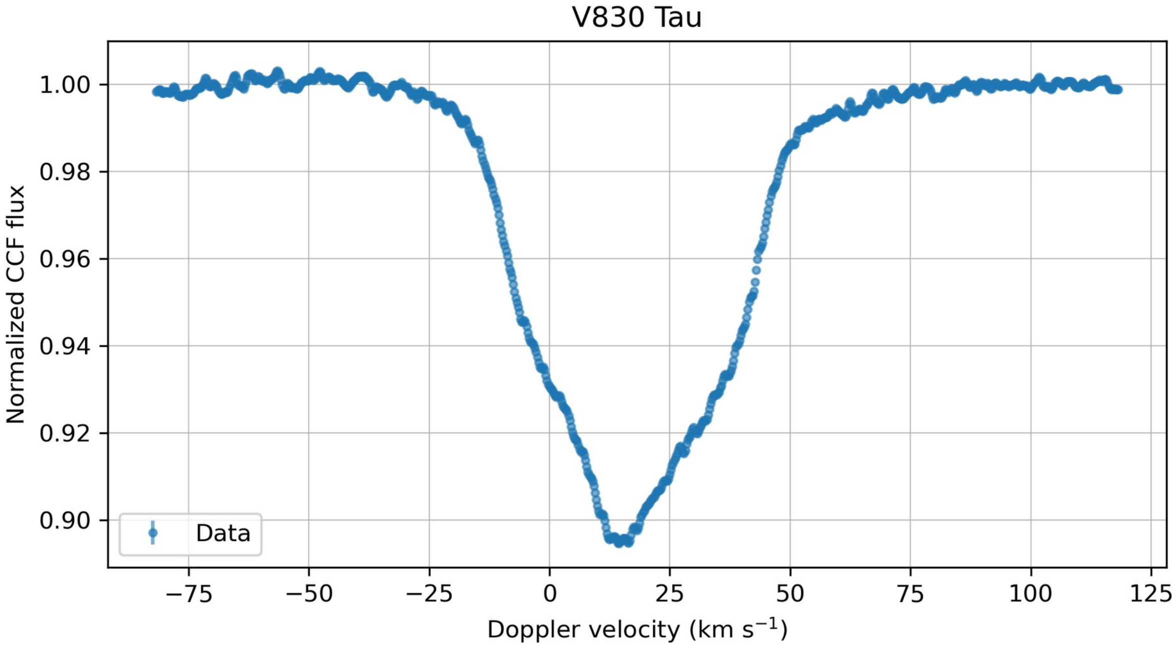
$$\frac{v_z}{v_L} = \frac{\Delta\lambda}{\Delta\lambda_L} = \frac{x}{R}$$



- The resulting profile is convoluted with a lorentz profile to account for the wings (not well described by a simple rotational profile);
- Limb darkening (linear);
- No temporal coherence is imposed in a series:
  - Each point in a series is extracted independently;

V830 tau

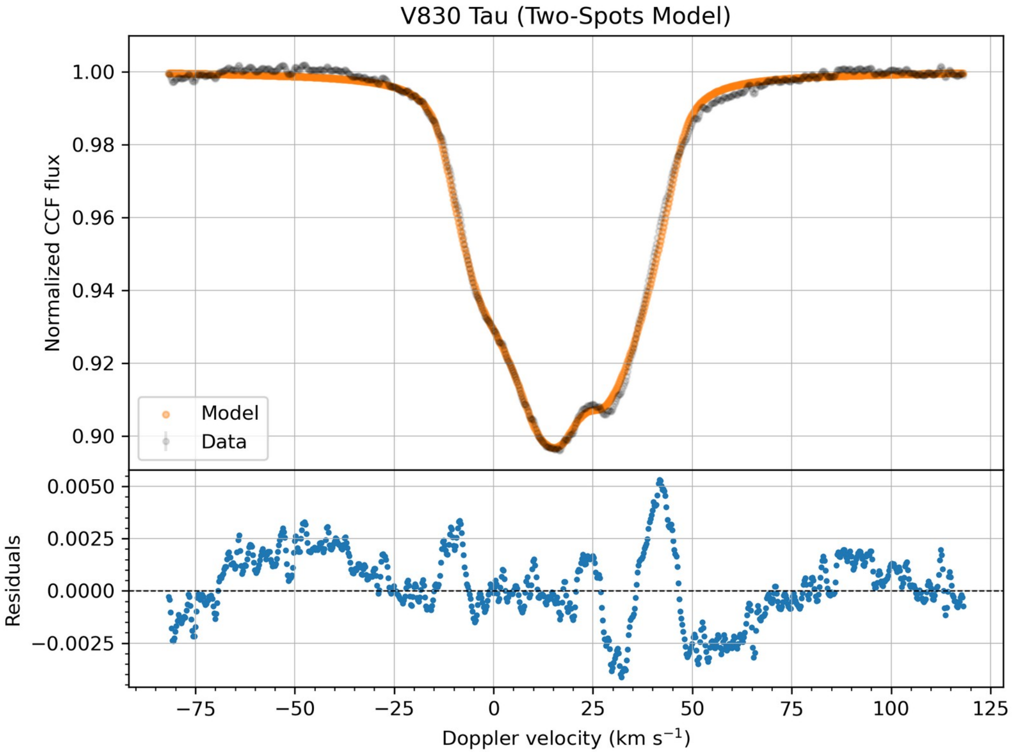
- Characteristics:
  - Stellar type: M0;
  - Mass: 1M;
  - Radius: 2R;
  - Temperature: 4050K;
  - Prot = 2.74d
  - Vsini = ~30km/s
  - i ~55deg

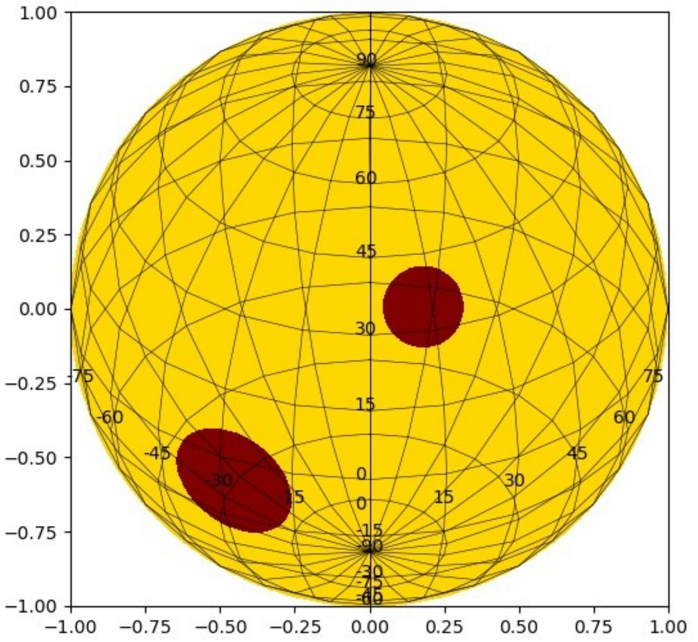


- HARPS-N Data:
  - 146 observations of V830 Tau collected between October 2017 and March 2020

(Grankin 2013, Donati et al. 2015, Damasso et al. 2020, Di Maio et al. in preparation)

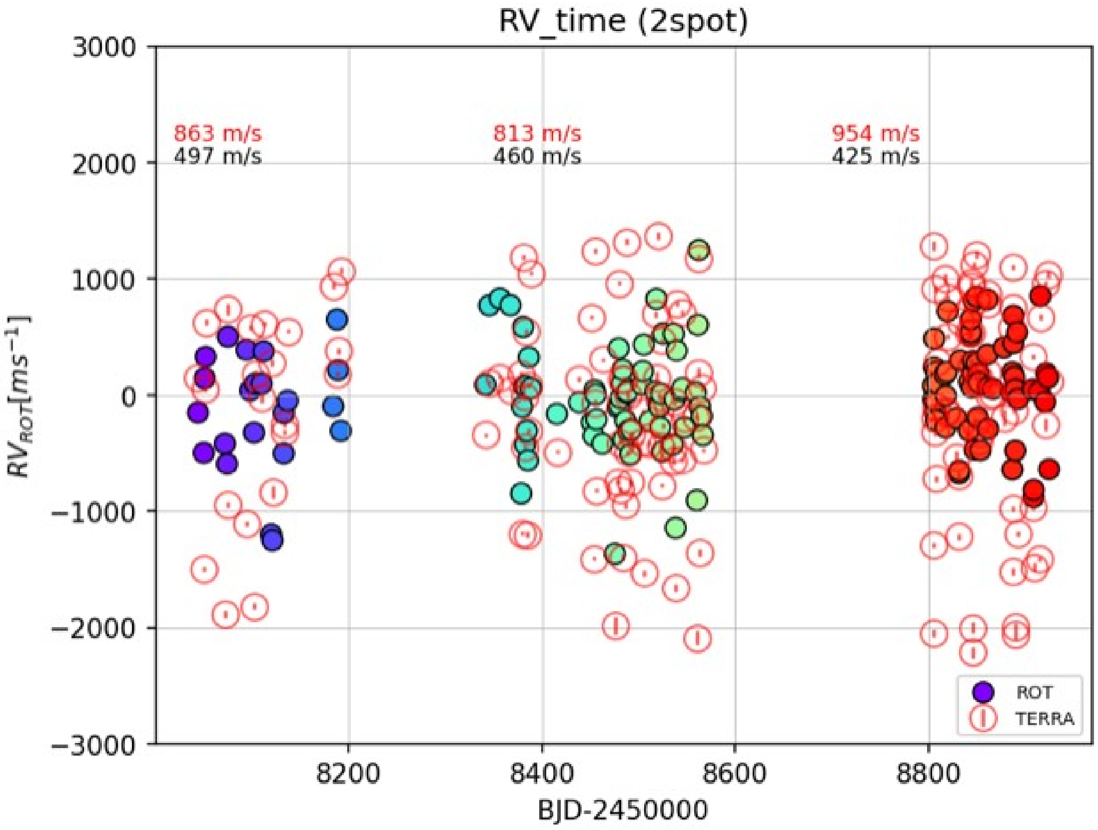
V830 Tau @ HARPS-N.2018-01-03T00-22-01





Di Maio et al. in preparation

V830 Tau – Full HARPSN series



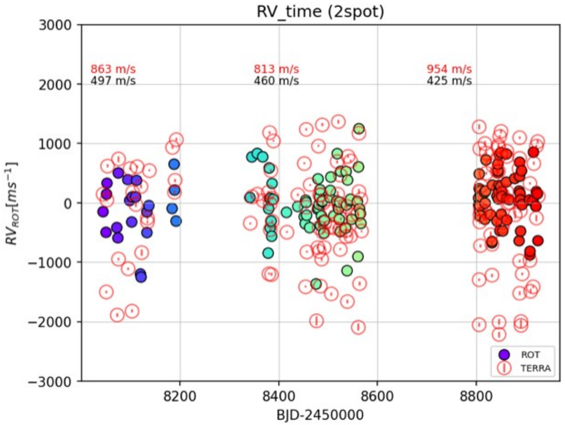
- 146 observations

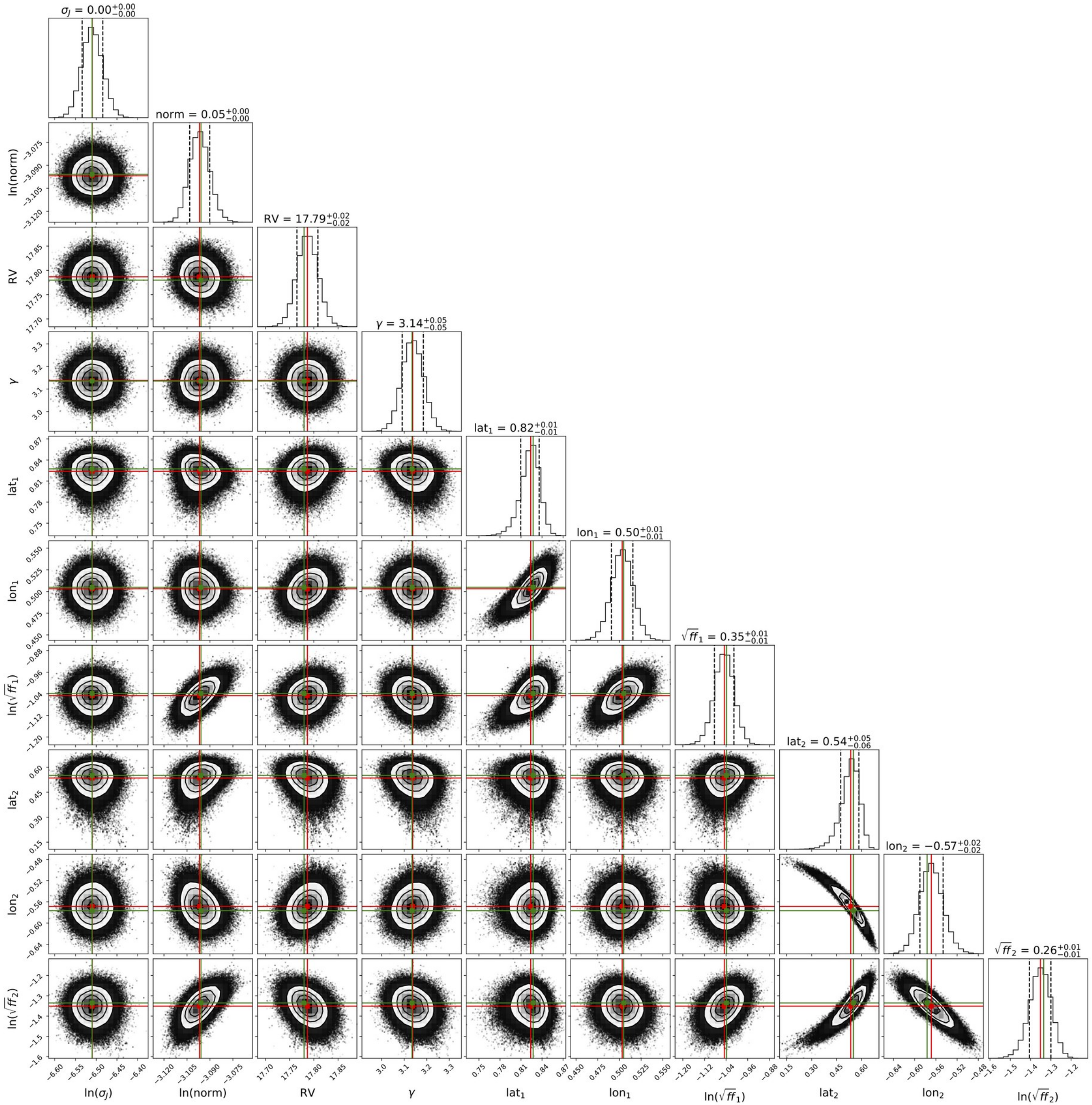
--> strong reduction of the dispersion;

Di Maio et al. in preparation

Model outcomes

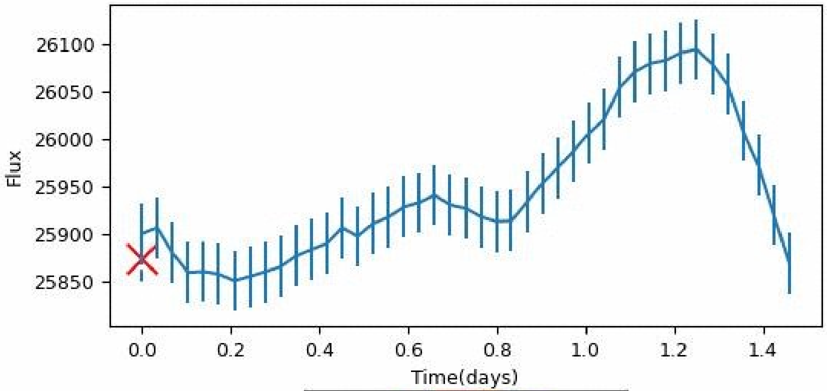
- Number of spot;
- Spot distribution and dimension (filling factor);
- (lorentzian) wings properties;
- Radial velocity;
  - The reduced dispersion could help planet detection/characterization

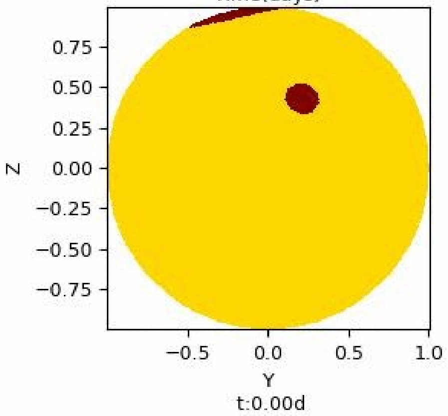




Light curves modelling

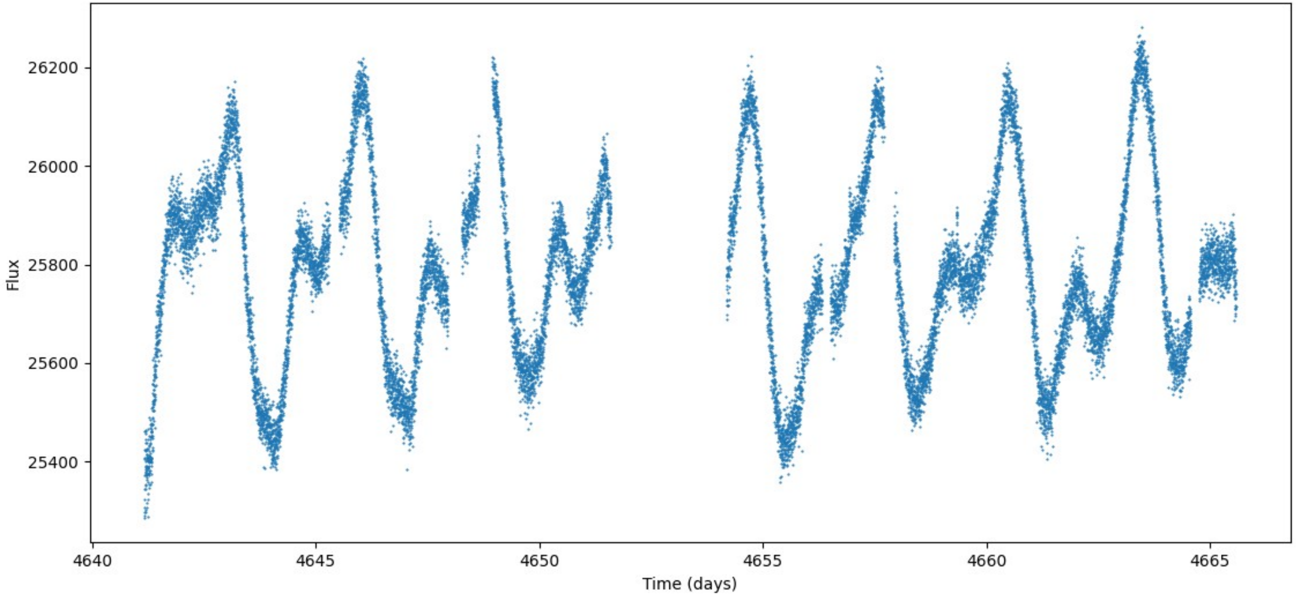
- Phoenix spectra to derive fluxes in the desired spectral band (when possible, a black body otherwise);
- Limb darkening (linear);
- Spot Temperature;
- Spots hide a portion of the disk;
- Integration of the disk leads to a point in the time series;
- Temporal coherence is imposed:
  - Spots are built for the first time point and then rotate with the star;
  - The fit provides the initial spot configuration;
- Spot do not evolve;





V1298 tau

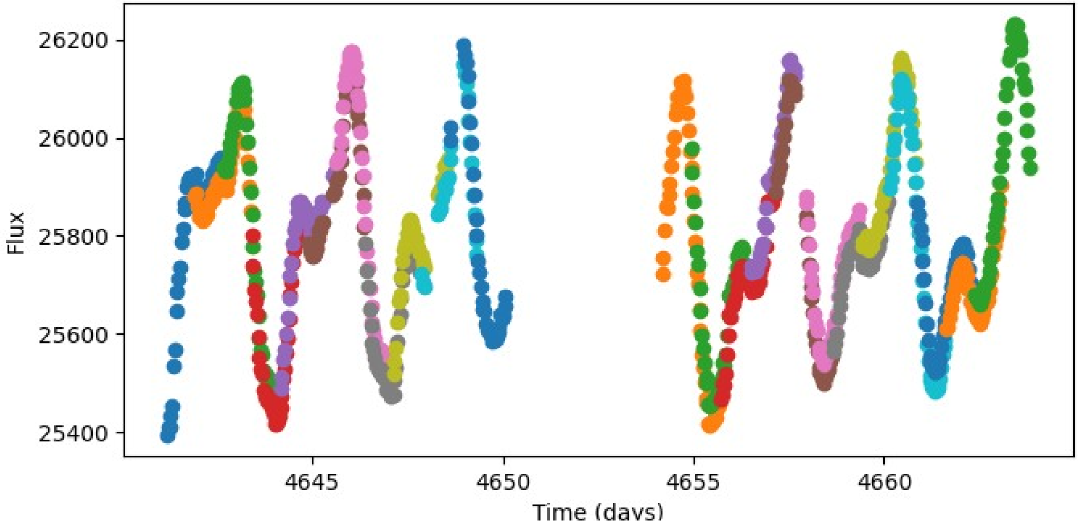
- Characteristics (Suárez Mascareño et al. 2022):
  - Stellar type: K1;
  - Mass: 1.17M;
  - Radius: 1.278R;
  - Temperature: 5050K;
  - Prot = 2.91d
  - 4 confirmed planets;
  - i = ~90 (equatorial-on);



- Tess Data:
  - Sector 43;
  - (data binned to 50 mins in the analysis)

Temporal evolution

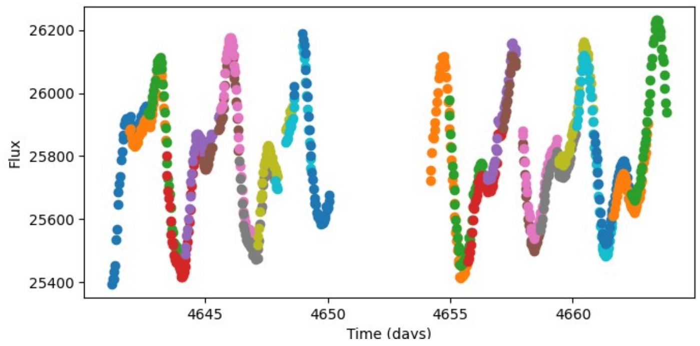
- The model does not consider spot evolution (yet..);
- To study how spots evolves?
  - → The fit is performed for time-scales shorter than the period (Prot/2);
  - → we divide the light curve in several temporal windows (shifted by Prot/4) and we fit them separately;

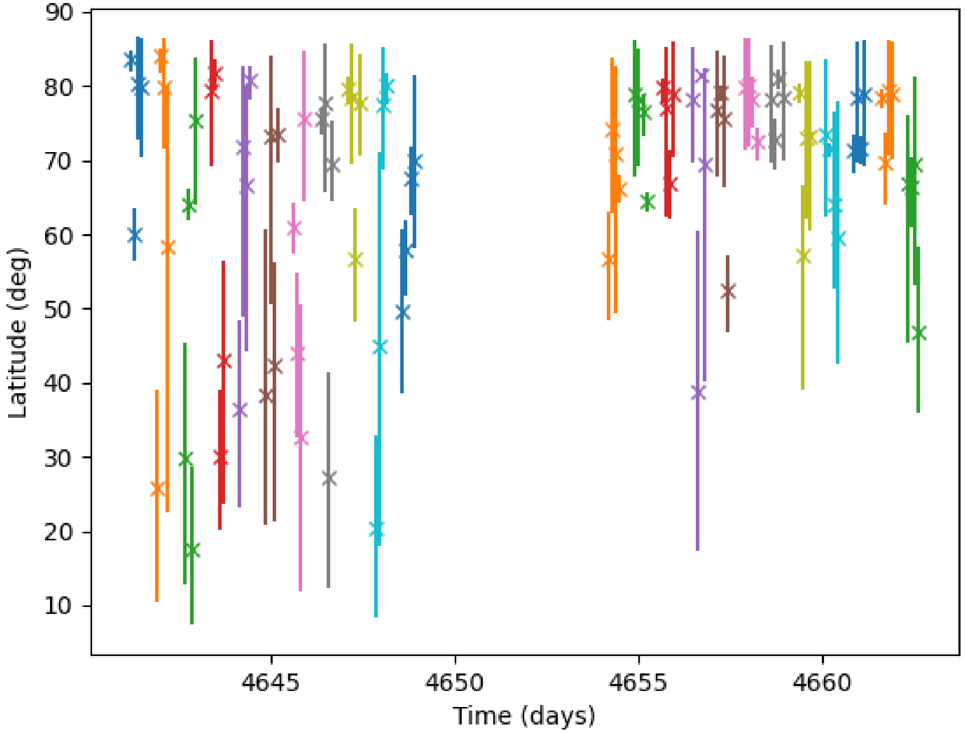


(data binned to 50 mins)

Spot latitudes

(4 spot model - preliminary results)





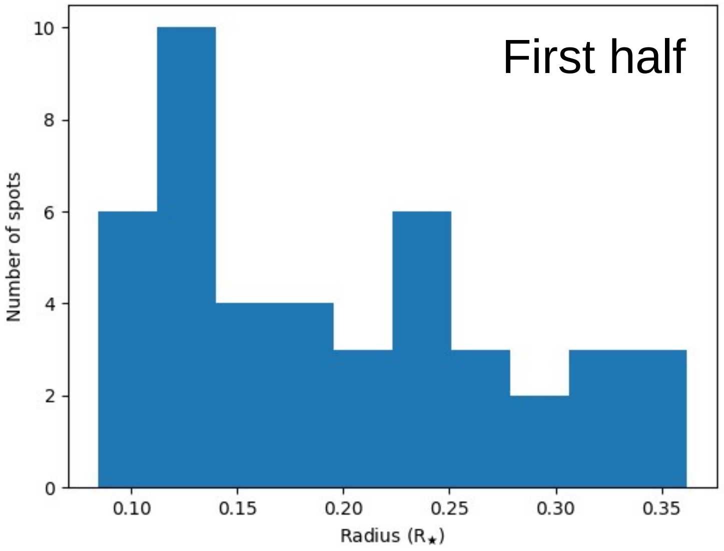
Issues:

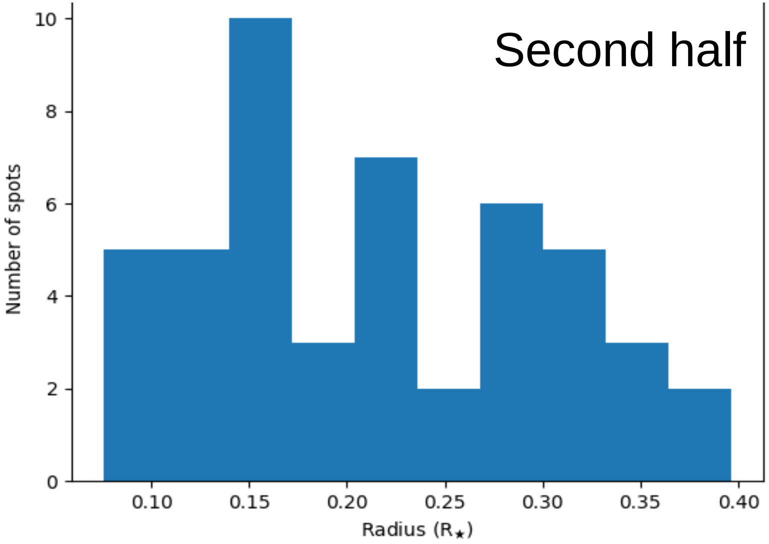
- Not randomly distributed, high latitudes seems to be preferred;
- In the second half, low latitudes spots disappear;

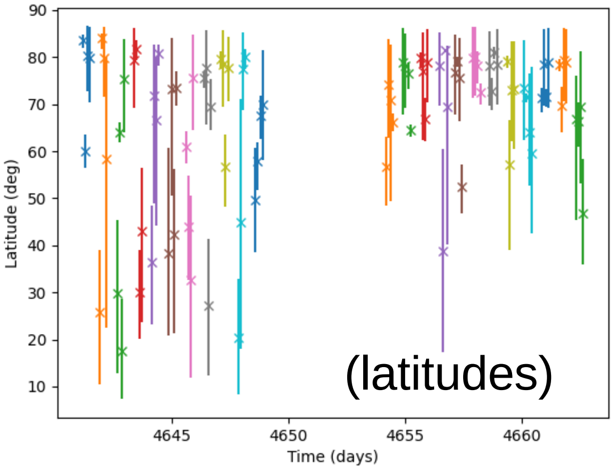
Spot radius distribution
(preliminary results)

Issues:

- Three main distributions;
- Small changes in radii;



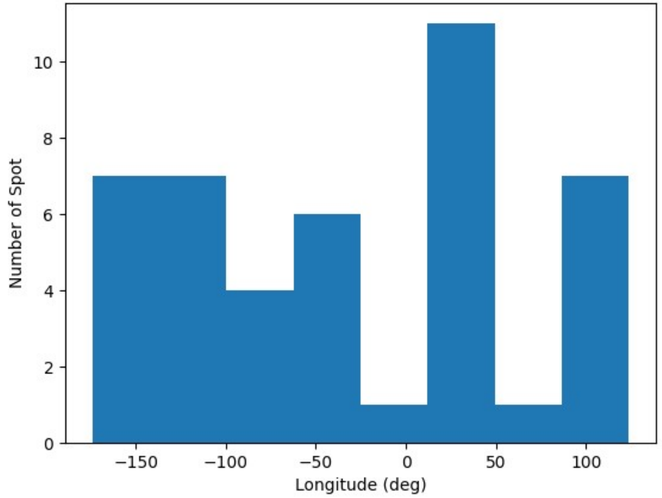




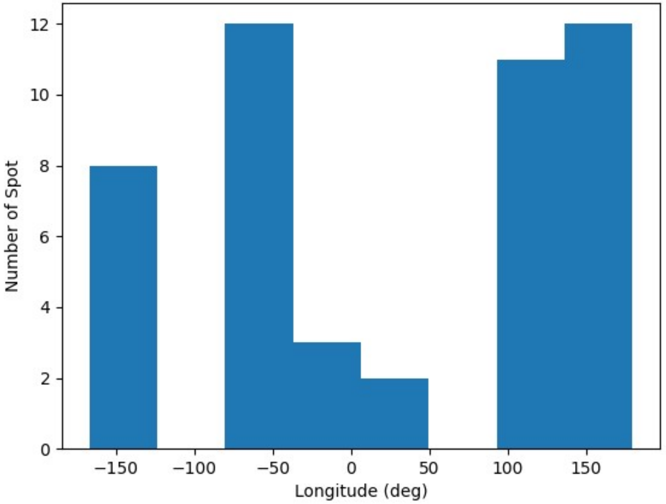
Spot longitudes
(preliminary results)

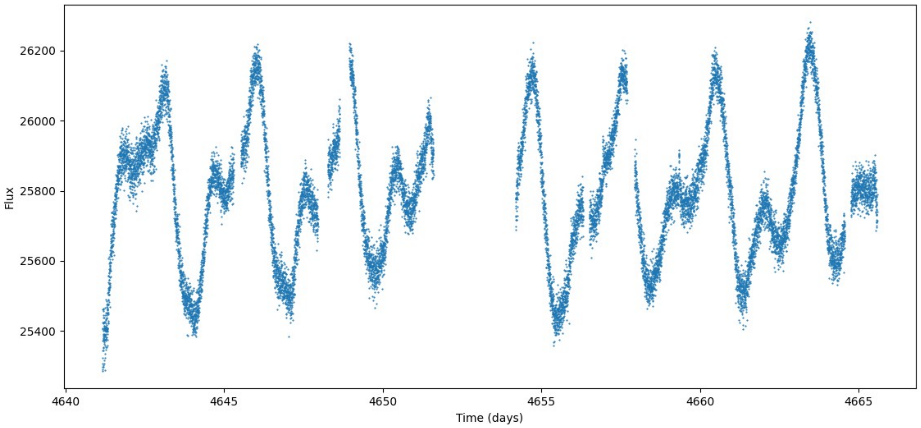
- Phased longitudes at t=0;
- Different distributions in the two halves --> spot evolution

First half



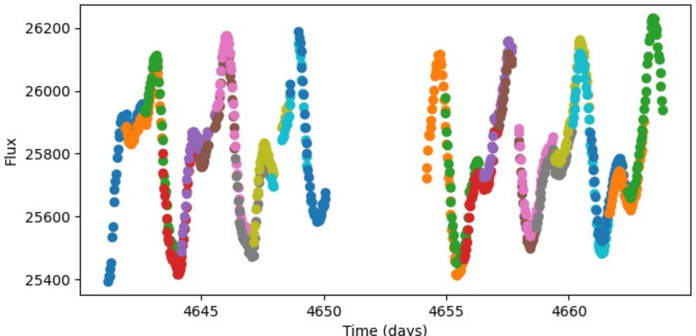
Second half

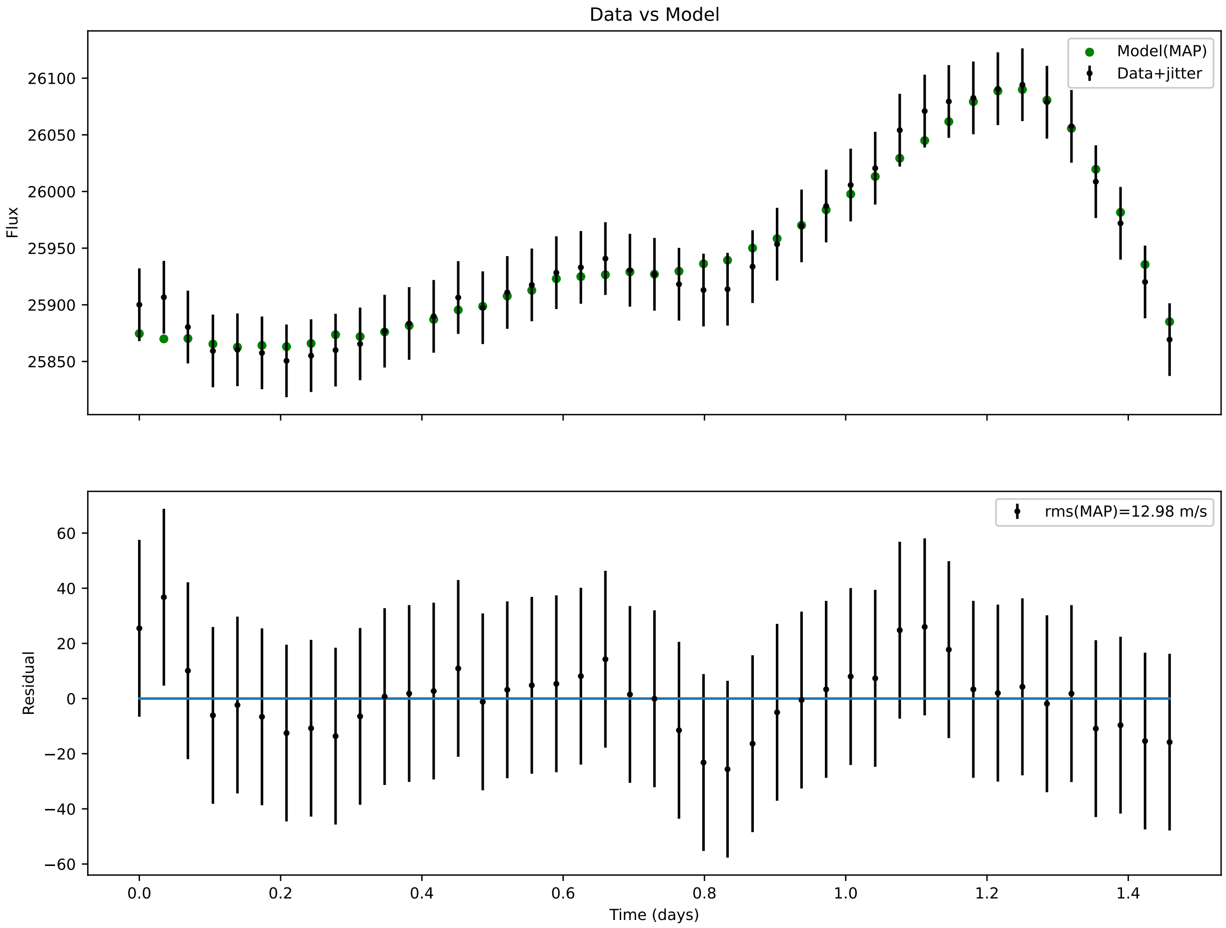




Model outcomes

- Number of spots (could be time dependent);
- Spot distribution and dimension (filling factor);
- Temperature;
- Time scale of spot evolution;





Future perspective

- **Expanding the model:**
  - Facolae (in development);
  - Spot evolution (time variation);

- **Methodology to apply the model to Ariel data:**
  - Interoperability with accurate high cadence photometers (ex. Tess):
    - Spot distribution and their evolution (in which time scales);
  - Multiband analysis (see Alfredo’s talk):
    - Temperature in different bands --> constrain spectral properties of spots;

--> Characterization of the star activity in the out of transit (of interest in a broader context than planet characterization);

--> Spot distribution and temperature to correct the in-transit spot effects;

--> Apply the method to Ariel simulator in order to help target selection;