The use of small- and medium-class telescopes for spot modeling through multiband photometry

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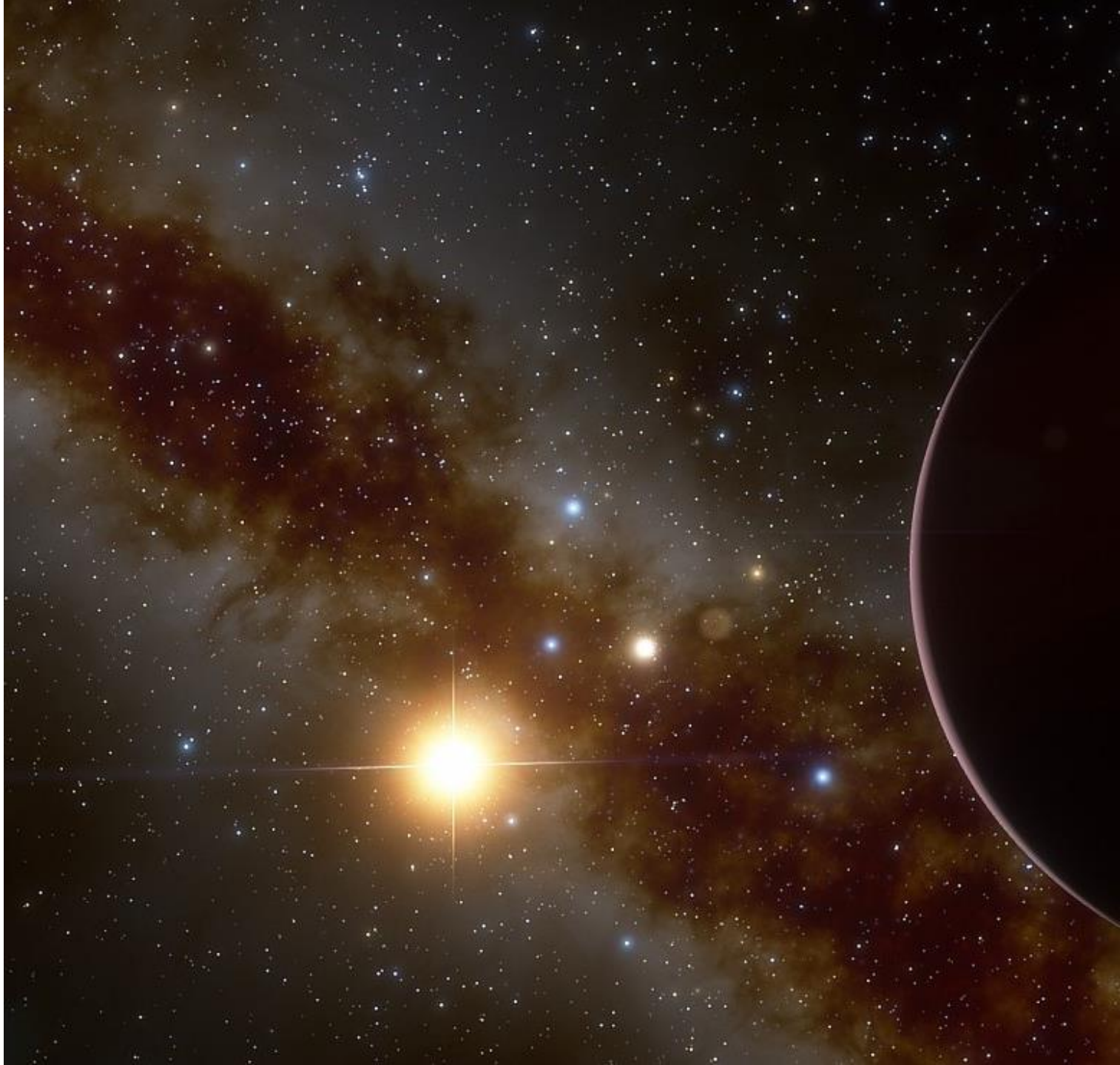
Università degli Studi di Palermo

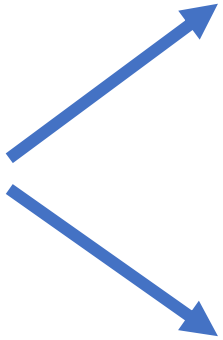
CHIANTI TOPICS
26/02/2024



Young Stellar Objects (YSO)

YSO: stars few tens of millions years old

Observations of YSO planets required to understand **planetary systems formation**



PHOTOMETRY

SPECTROSCOPY

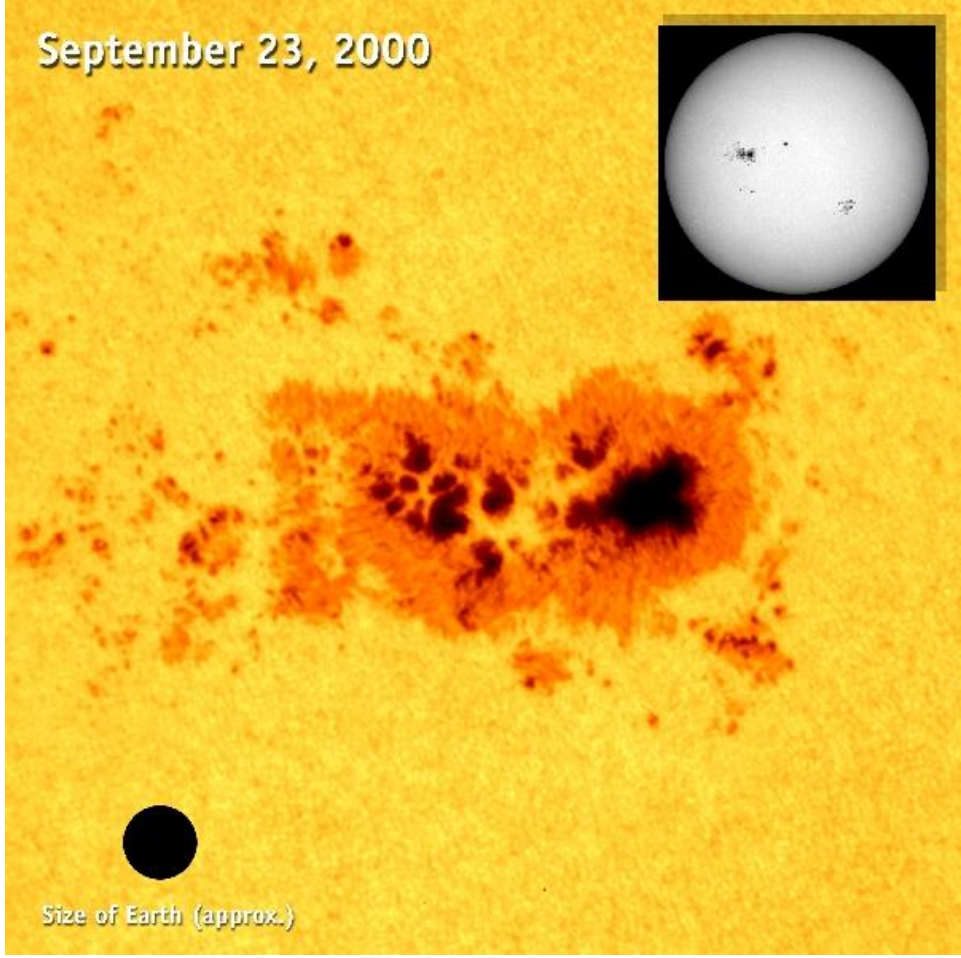
Difficult observations because of high stellar activity

Only few young planetary systems known

STELLAR ACTIVITY

Variability very common for stars with $M \leq 1\ M_\odot$

- **SPOTS**
- **FACULAE**
- **FLARES**



SOHO image (NASA) of a sunspost with respect to Earth dimensions

RELATED PROBLEMS:

- spectral lines distortion
- chromatic signals
- lightcurve alterations during transit observations
- fake transits

→ **EXOPLANETS AND EXO-ATMOSPHERES OBSERVATIONS AFFECTED** → **VARIABILITY MODEL REQUIRED**

V1298 TAU

This is a young star with the following properties (T. J. David, L. A. Hillenbrand et al., 2019) :

Mass ($M_\odot$)	Radius ($R_\odot$)	Age (Myr)	Rotational period (d)	Temperature (k)
1.101±0.005	**1.34±0.06**	**23±4**	**2.87±0.02**	**4970±120**

- a young star a with a mass ~ 1
- 3 (b,c,d) confirmed transiting planets (KEPLER) and one to be confirmed (e)

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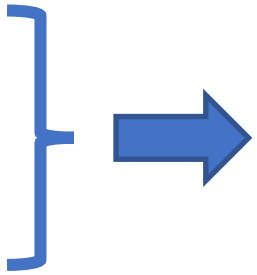
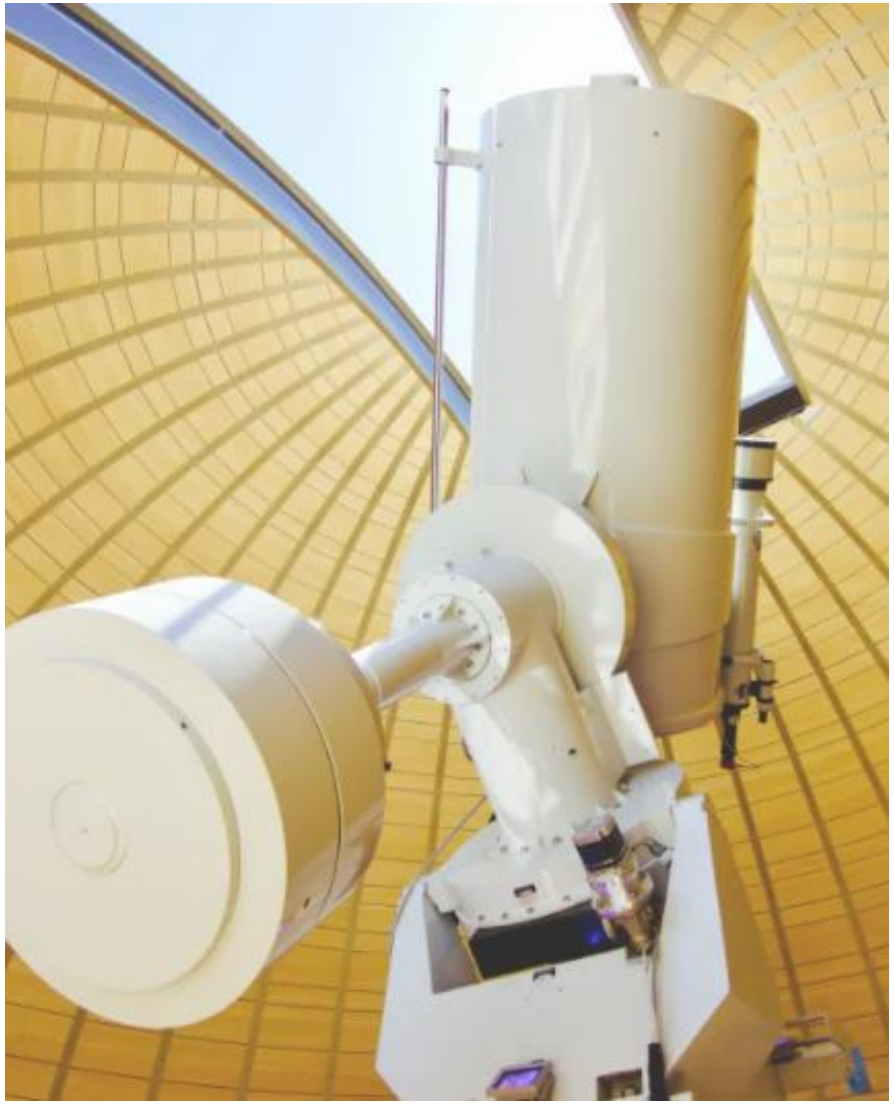


Possible clues about the Solar System formation

INSTRUMENTS

Osservatorio Polifunzionale del Chianti (OPC):

- Ritchey-Chretien
- Diameter: 80 cm
- f/8
- 20’x20’
- Johnson filters U-B-V-R-I



INSTRUMENTS

Gal-Hassin Observatory:

- Ritchey-Chretien
- Diameter: 40 cm
- f/3,8
- 83’x83’
- Sloan filters u’, g’, r’, zs_2 and H alpha filter

INSTRUMENTS

Observatory of Palermo:

- Ritchey-Chretien
- Diameter: 40 cm
- 40’x40’
- Sloan filters g’, r’, i’

INSTRUMENTS

REM Telescope (La Silla):

- Ritchey-Chretien
- Diameter: 60 cm
- f/8
- Ross2: g’, r’, i’, z’
- REMIR: z’, J, H, K

V1298 TAU OBSERVATIONS

- **February 2021:**
  - **Osservatorio Polifunzionale del Chianti (OPC)** observed with B, V and R filters
  - **Gal-Hassin** using r' and H alpha filters.

  High airmass and poor time coverage per night.

- **December 2021:**

  - OPC and **REM** observations

  - Gal Hassin observatory could not observe the star due to meteorological reasons

  Low S/N ratio because of the Moon

- **February-March 2022 (analysis ongoing):**

  - OPC: B-V-R-I filters

  - PALERMO (g', r', i')

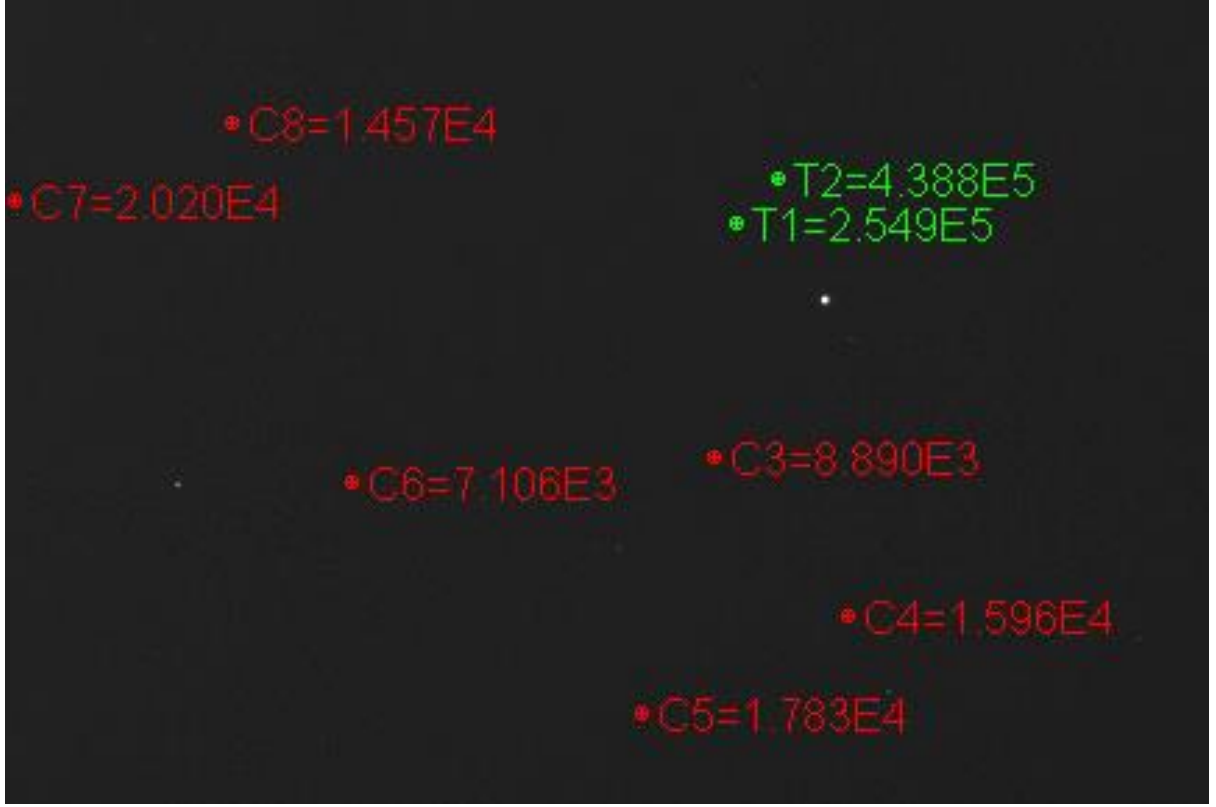
- **September 2022:**

  - REM and Gal-Hassin

- **December 2022:**

  -Palermo

DATA ANALYSIS



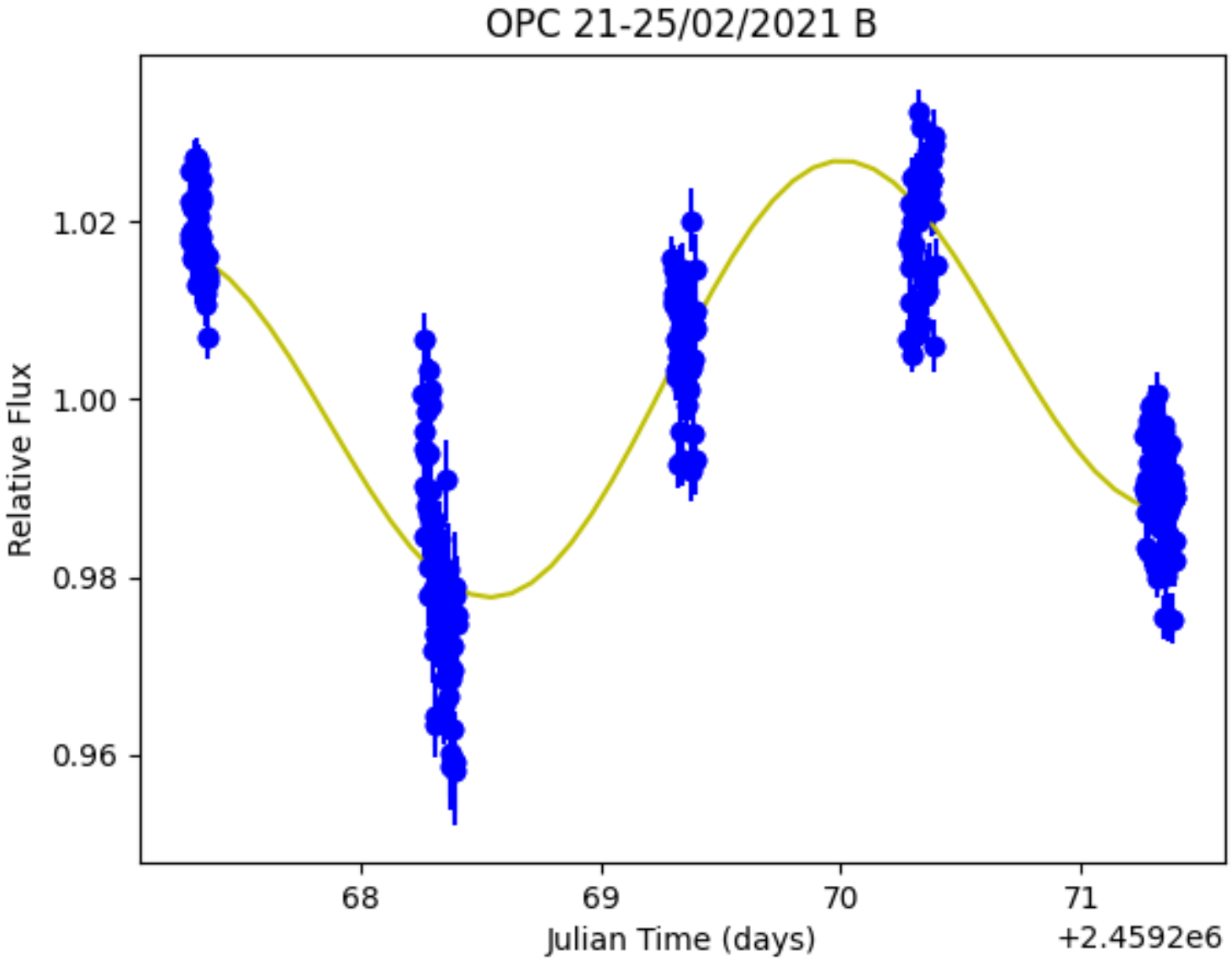
- **CALIBRATION:** dark frames, flatfield frames
- **DIFFERENTIAL PHOTOMETRY:** evaluation of the stellar flux with respect to STABLE check stars
- **EVALUATION OF CHECK STARS**, each with respect to the others

I used AstroImageJ (Karen A. Collins *et al* 2017) for the first steps of data reduction.

- **TEMPORAL BINNING**
- **SELECTION ACCORDING TO AIRMASS**

Balance between NUMBER, MAGNITUDE and STABILITY of CHECK STARS

Observed lightcurve



RESULTS.1

Gal-Hassin	$\triangle r'$	$\triangle Halpha$
02/2021	0.015 ± 0.009	0.033 ± 0.015

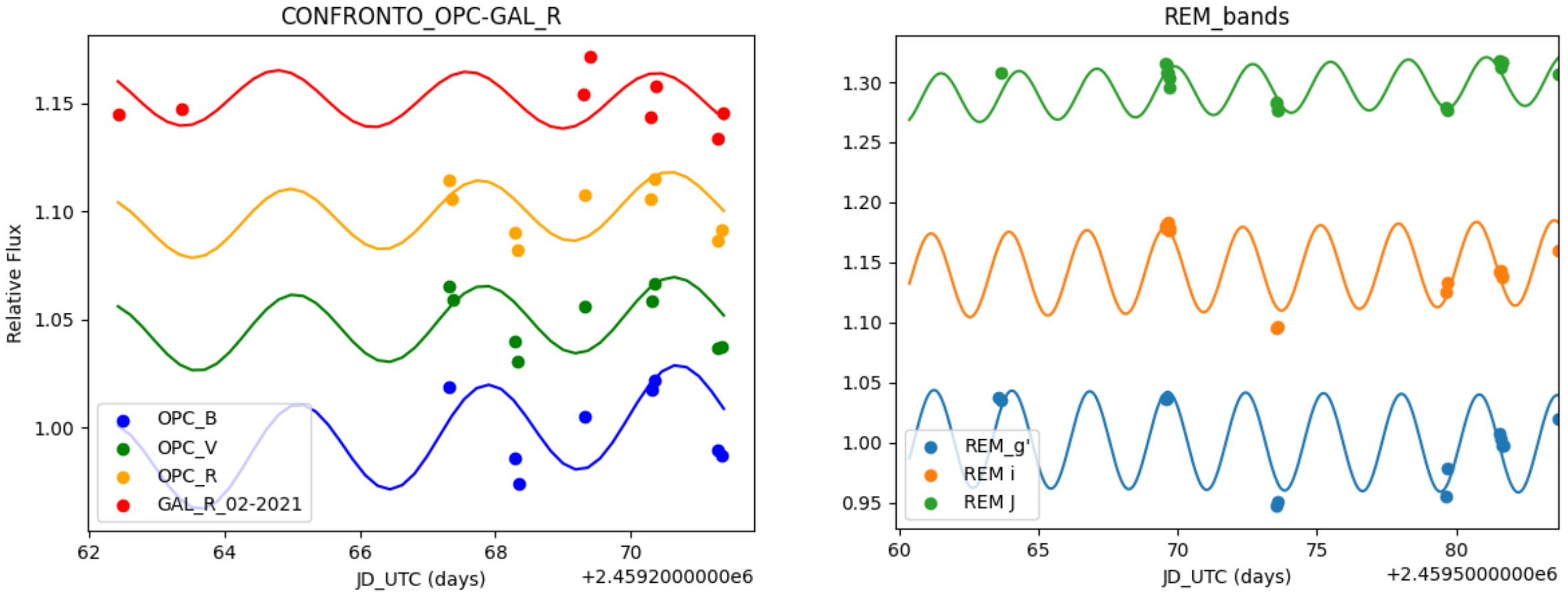
OPC	$\triangle B$	$\triangle V$	$\triangle R$	$\triangle I$
02/2021	0.0255 ± 0.0017	0.020 ± 0.002	0.017 ± 0.002	/
12/2021	/	0.028 ± 0.002	0.0206 ± 0.0018	/
02/2022	0.07 ± 0.04	0.054 ± 0.019	0.046 ± 0.005	0.026 ± 0.004

REM	$\triangle g'$	$\triangle r'$	$\triangle i'$	$\triangle z'$	$\triangle J$
12/2021	0.042 ± 0.009	0.040 ± 0.008	0.033 ± 0.006	0.017 ± 0.006	0.021 ± 0.006

Palermo	$\triangle g'$	$\triangle r'$	$\triangle Halpha$
02/2021	0.029 ± 0.009	0.04 ± 0.06	0.0161 ± 0.0016

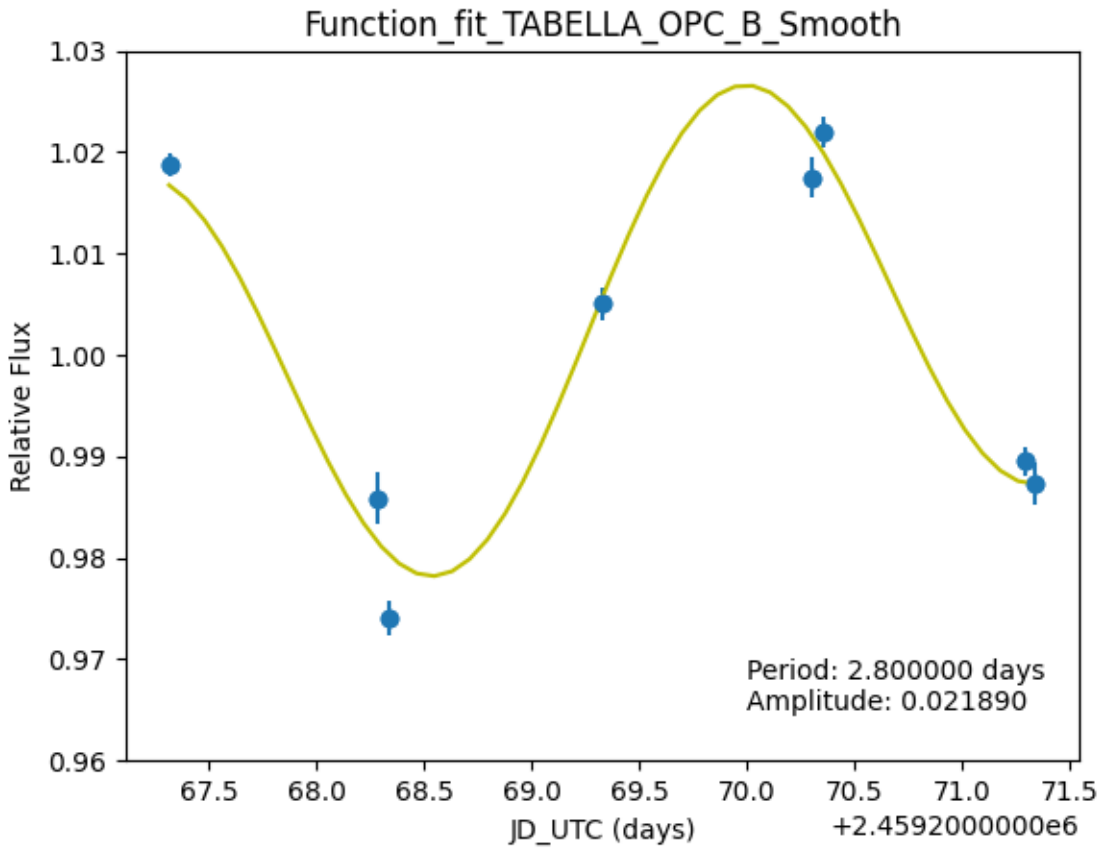
Amplitude increases at shorter wavelengths
(in B is 30% higher than in R band)

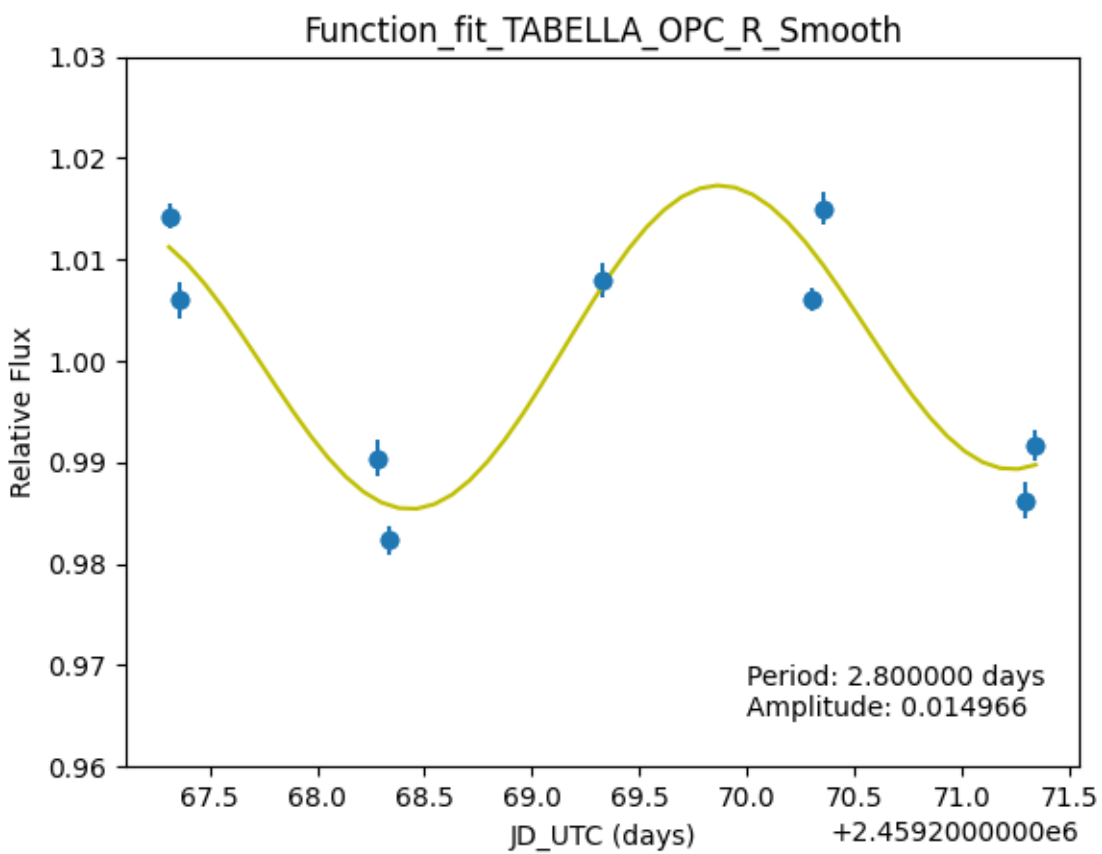
RESULTS.2



Data and fitted lightcurve of V1298 Tau observed in February 2021 by Gal-Hassin and OPC (left) and REM in December (2021). Lightcurves are shifted for clarity purpose.

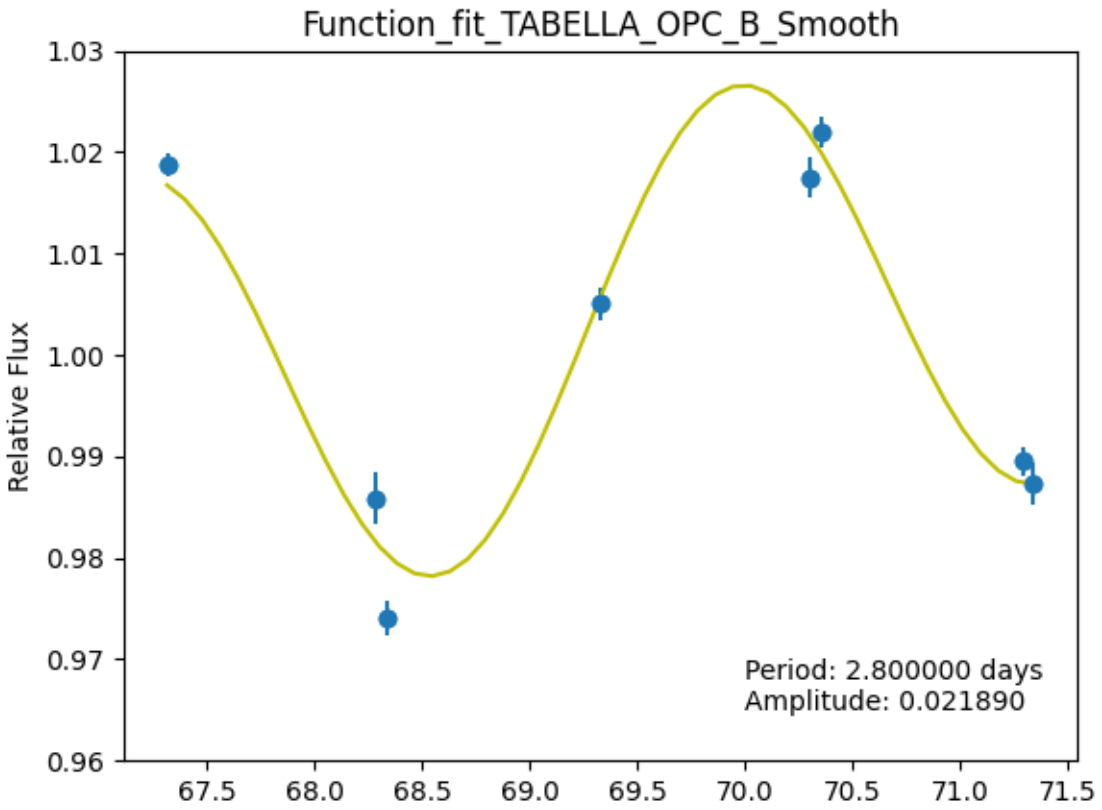
RESULTS.3

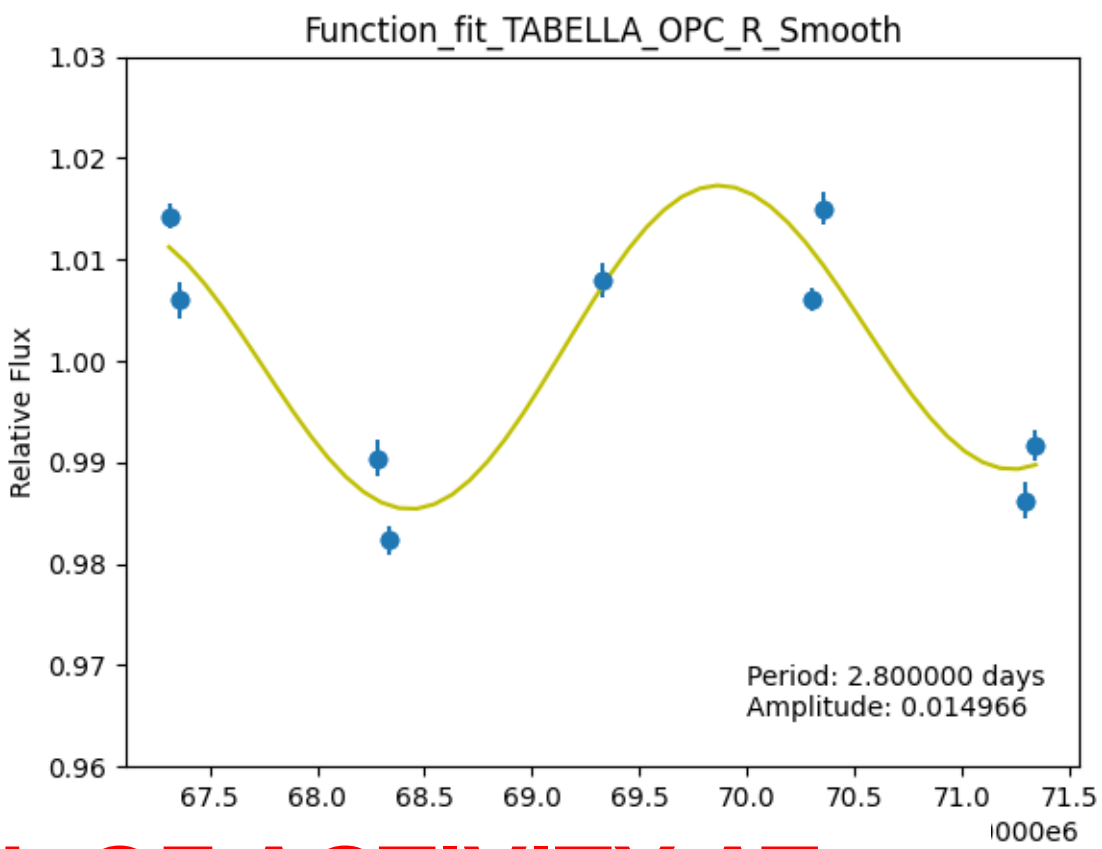




Data and fitted lightcurve of V1298 Tau observed in February 2021 by OPC in both B and R band

RESULTS.3





DECREASING LEVEL OF ACTIVITY AT LONGER WAVELENGTHS

SPOT_MODEL

Initial hyphotesis:

- Corotating spots
- Not evolving spots during an observational run

(≈ 2 rotational periods of the star): REJECTED

Then we chose a **3 days RUN** because of spot evolution

Lightcurve simulation:

- Estimation of visible stellar surface fraction occupied by spots at a given time
- Spots and surface emissions at different temperatures (estimated through Phoenyx models)
- Rotation of the star
- Fitting the data using the simulated lightcurves
- Search for common solutions for all bands

MULTINEST

Bayesian evidence based selection

GEOMETRY AND TEMPERATURE CONSTRAINS

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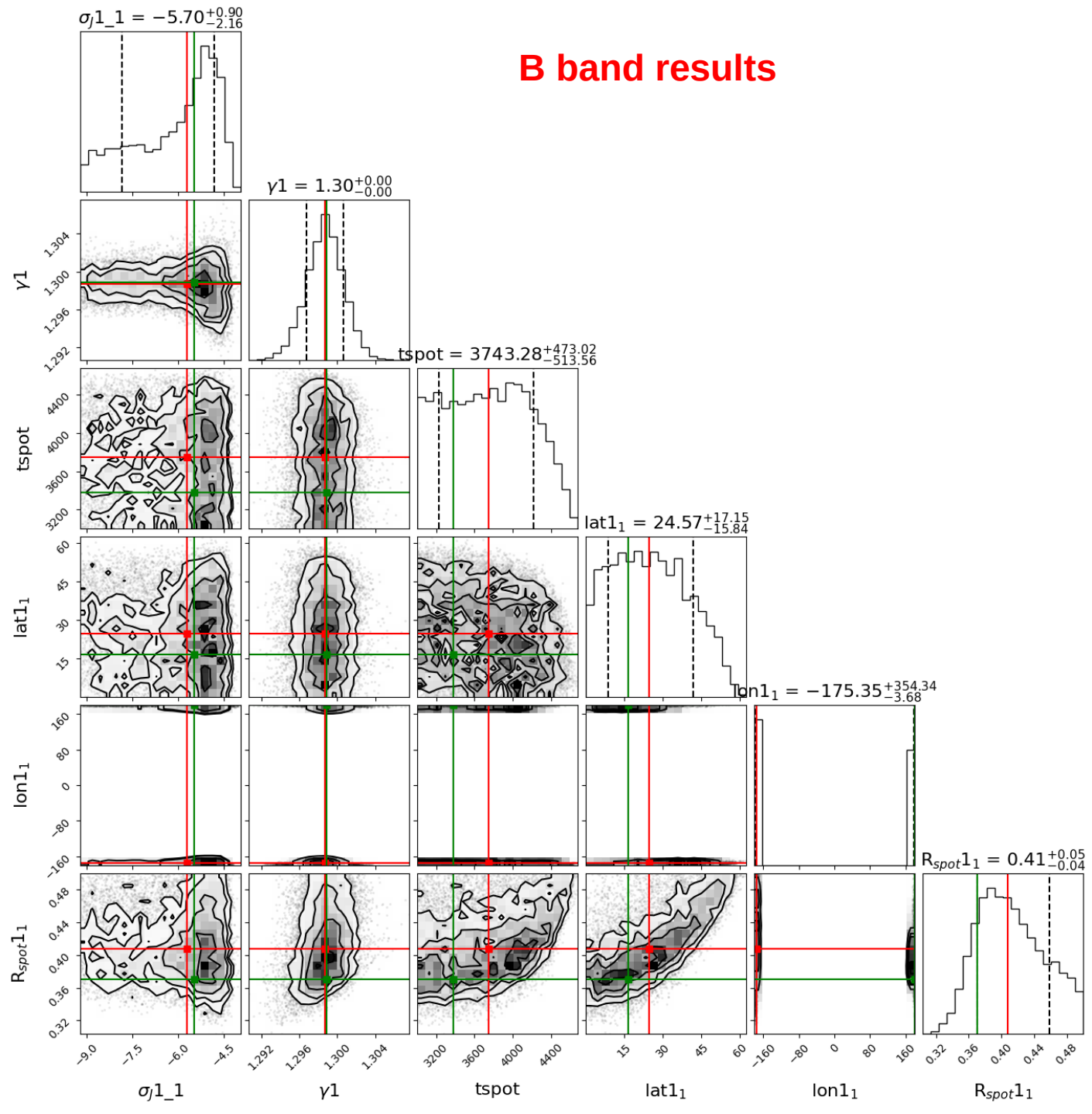
MULTINEST

Bayesian evidence based selection

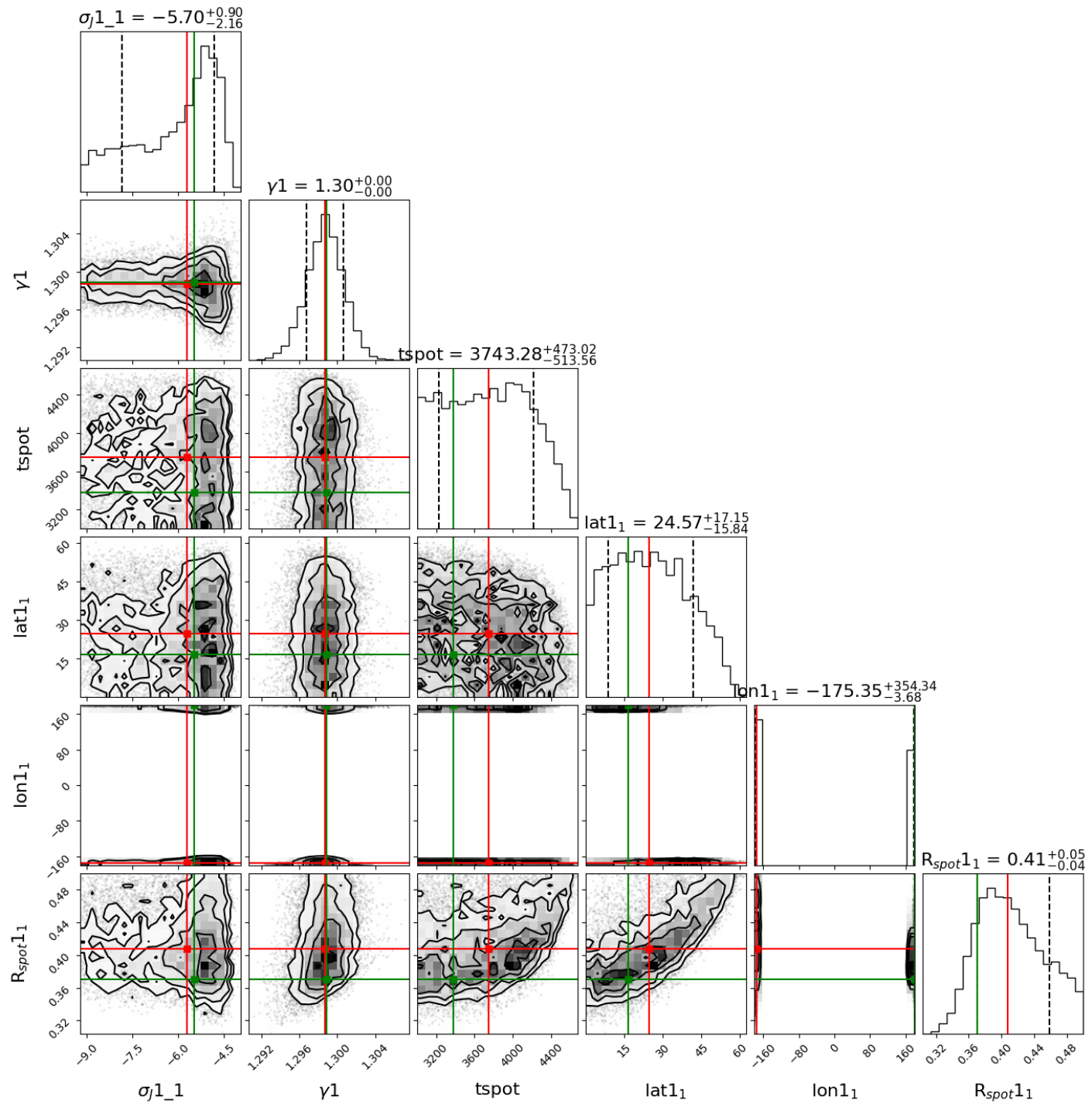
Only OPC data had SNR high enough for the retrieval procedure

GEOMETRY AND TEMPERATURE CONSTRAINS



HIGH ERROR WITH ONE BAND

(±500-600 K)



HIGH ERROR WITH ONE BAND

STRONG DEGENERACY BETWEEN **RADIUS**, **LATITUDE** AND **TEMPERATURE** OF SPOTS

MULTIBAND PHOTOMETRY

We combine data of different photometric bands to break the degeneracy, retrieving the **TEMPERATURE DIFFERENCE** between **SPOTS** and **QUIET STELLAR TEMPERATURE**

SPOTS AND FACOLAE?

We chose to verify also the presence of faculae.

We modeled the faculae as «hot rings» around the spots.

EXTREME CASES ARE INCLUDED

ONLY SPOTS = THIN FACULA RING AND BIG SPOT

ONLY FACULAE = THICK FACULA RING AND LITTLE SPOT

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ONLY SPOTS MODEL SELECTED WITH logEV criterion

RESULTS TABLE

DATES	Bands	Temperature (K)
21-22-23/02/2021	B-R-V	4327^{+184}_{-221}
22-23-24/02/2021	B-R-V	4415^{+122}_{-165}
23-24-25/02/2021	B-R-V	4132^{+188}_{-291}
11 – 12 – 13/12/2021*	R-V	3559^{+419}_{-378}
12-13-14/12/2021	B-R-V	3720^{+274}_{-421}
13-14-15/12/2021	B-R-V	3761^{+296}_{-453}
21 – 22 – 23/02/2022**	R-V-I	3761^{+276}_{-383}

BANDS with SNR <20 discarded

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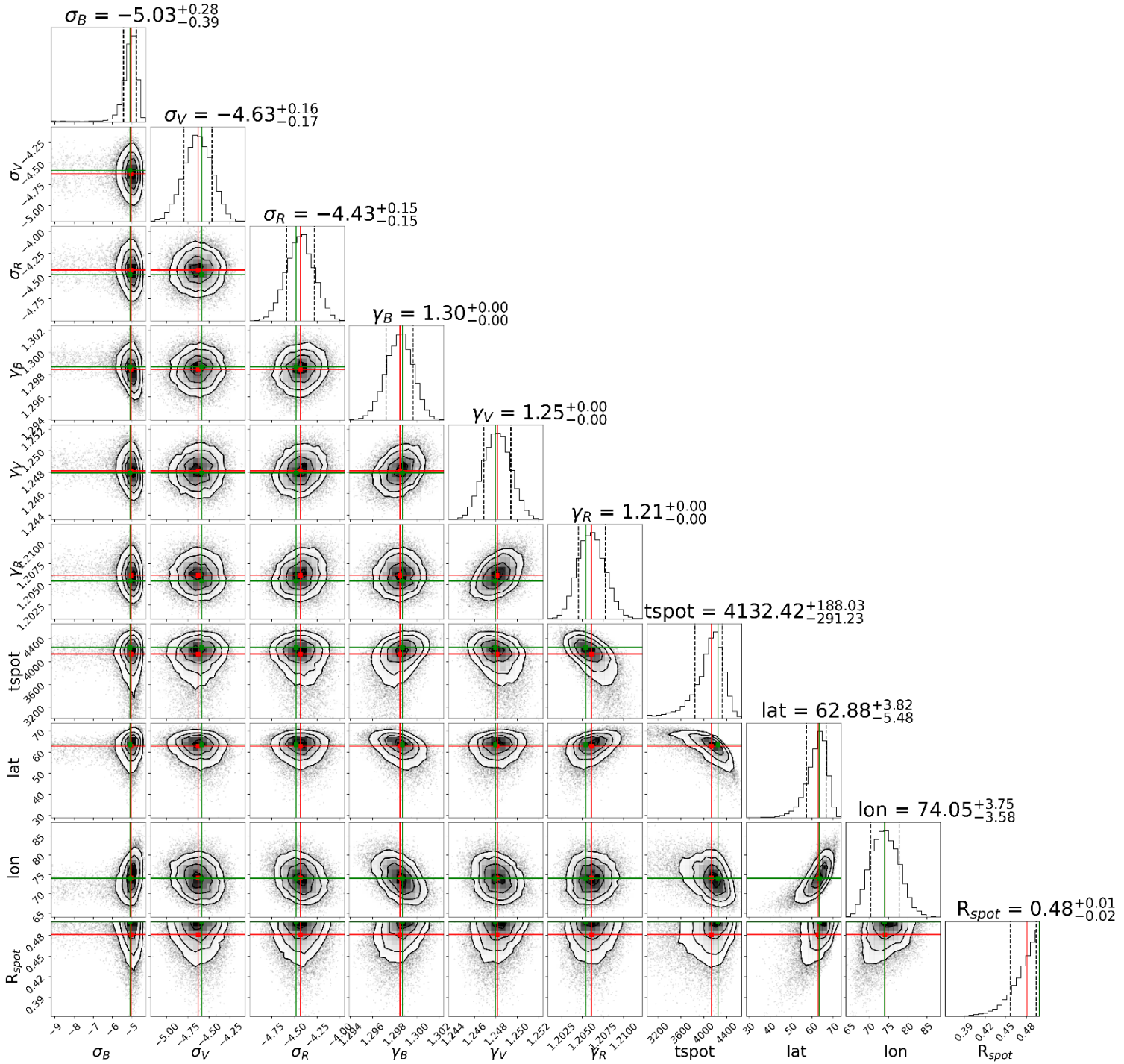
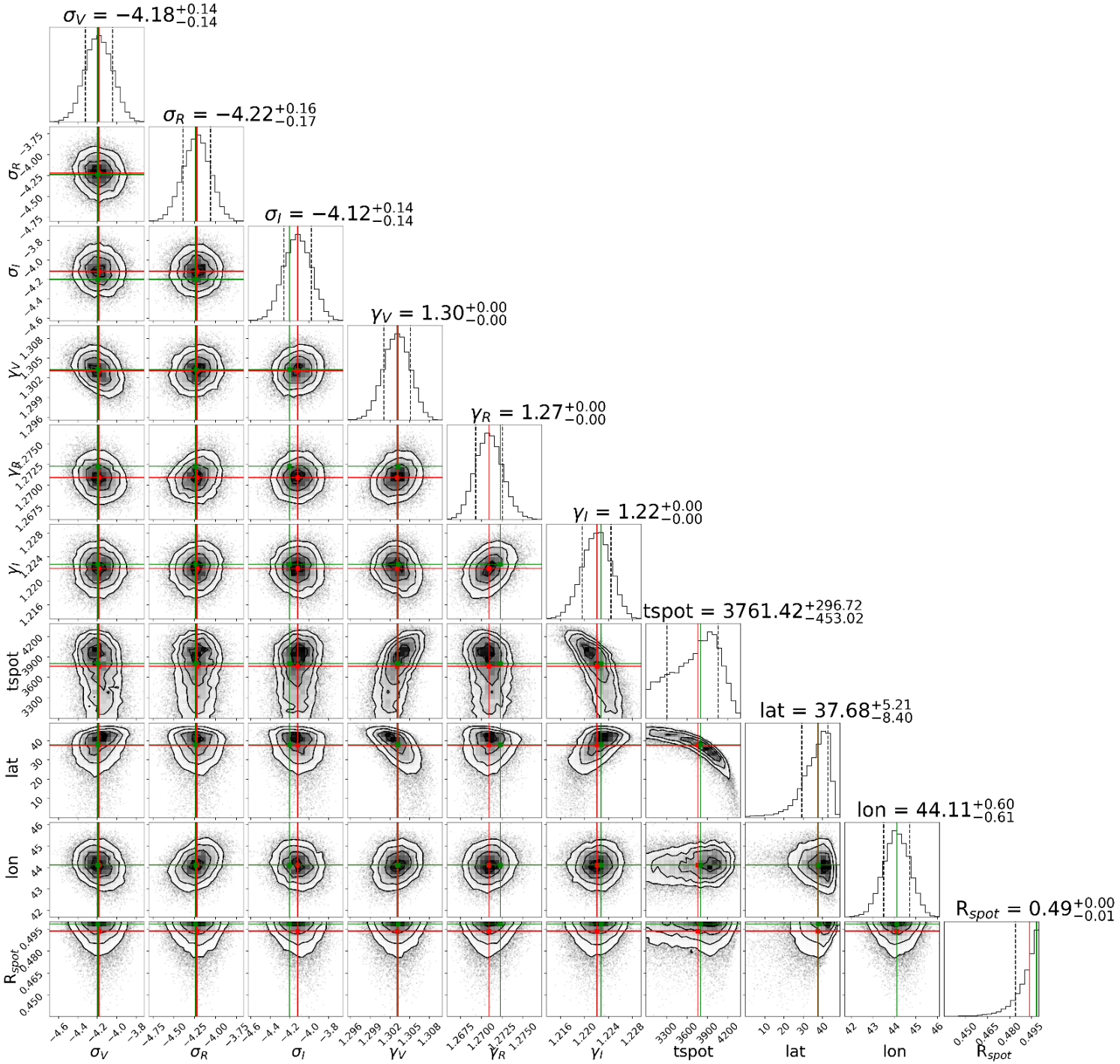
BANDS with SNR <20 discarded

BANDS at SHORTER WAVELENGTHS are MORE EFFICIENT in constraining spots temperature

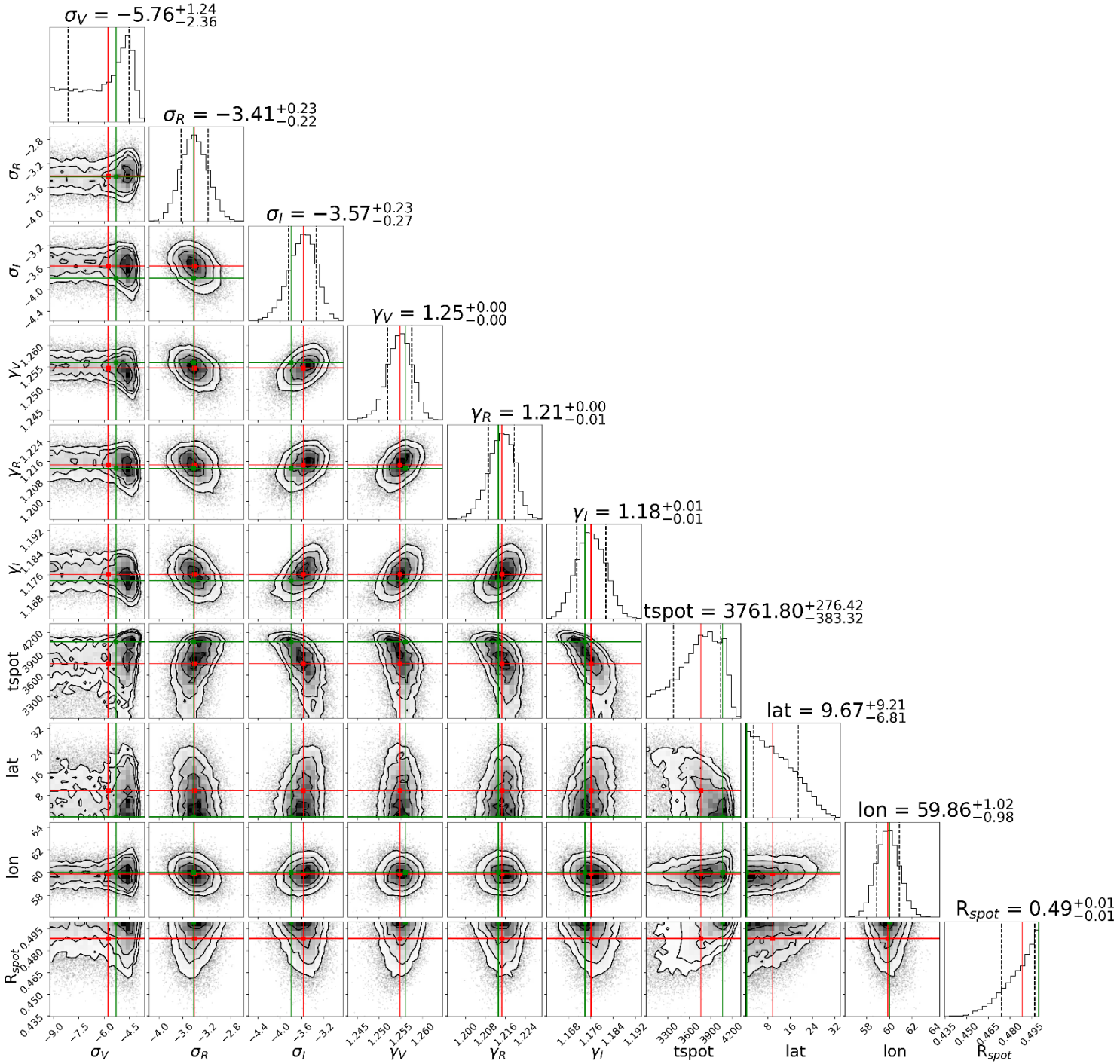

$\sigma_B = -5.03^{+0.28}_{-0.39}$
$\sigma_V = -4.63^{+0.16}_{-0.17}$
$\sigma_R = -4.43^{+0.15}_{-0.15}$
$\gamma_B = 1.30^{+0.00}_{-0.00}$
$\gamma_V = 1.25^{+0.00}_{-0.00}$
$\gamma_R = 1.21^{+0.00}_{-0.00}$
tspot $= 4132.42^{+188.03}_{-291.23}$
lat $= 62.88^{+3.82}_{-5.48}$
lon $= 74.05^{+3.75}_{-3.58}$
$R_{spot} = 0.48^{+0.01}_{-0.02}$
σ_B
σ_V
σ_R
γ_B
γ_V
γ_R
tspot
lat
lon
R_{spot}

FIRST RUN


$\sigma_V = -4.18^{+0.14}_{-0.14}$
$\sigma_R = -4.22^{+0.16}_{-0.17}$
$\sigma_I = -4.12^{+0.14}_{-0.14}$
$\gamma_V = 1.30^{+0.00}_{-0.00}$
$\gamma_R = 1.27^{+0.00}_{-0.00}$
$\gamma_I = 1.22^{+0.00}_{-0.00}$
tspot = $3761.42^{+296.72}_{-453.02}$
lat = $37.68^{+5.21}_{-8.40}$
lon = $44.11^{+0.60}_{-0.61}$
$R_{spot} = 0.49^{+0.00}_{-0.01}$
σ_V
σ_R
σ_I
γ_V
γ_R
γ_I
tspot
lat
lon
R_{spot}

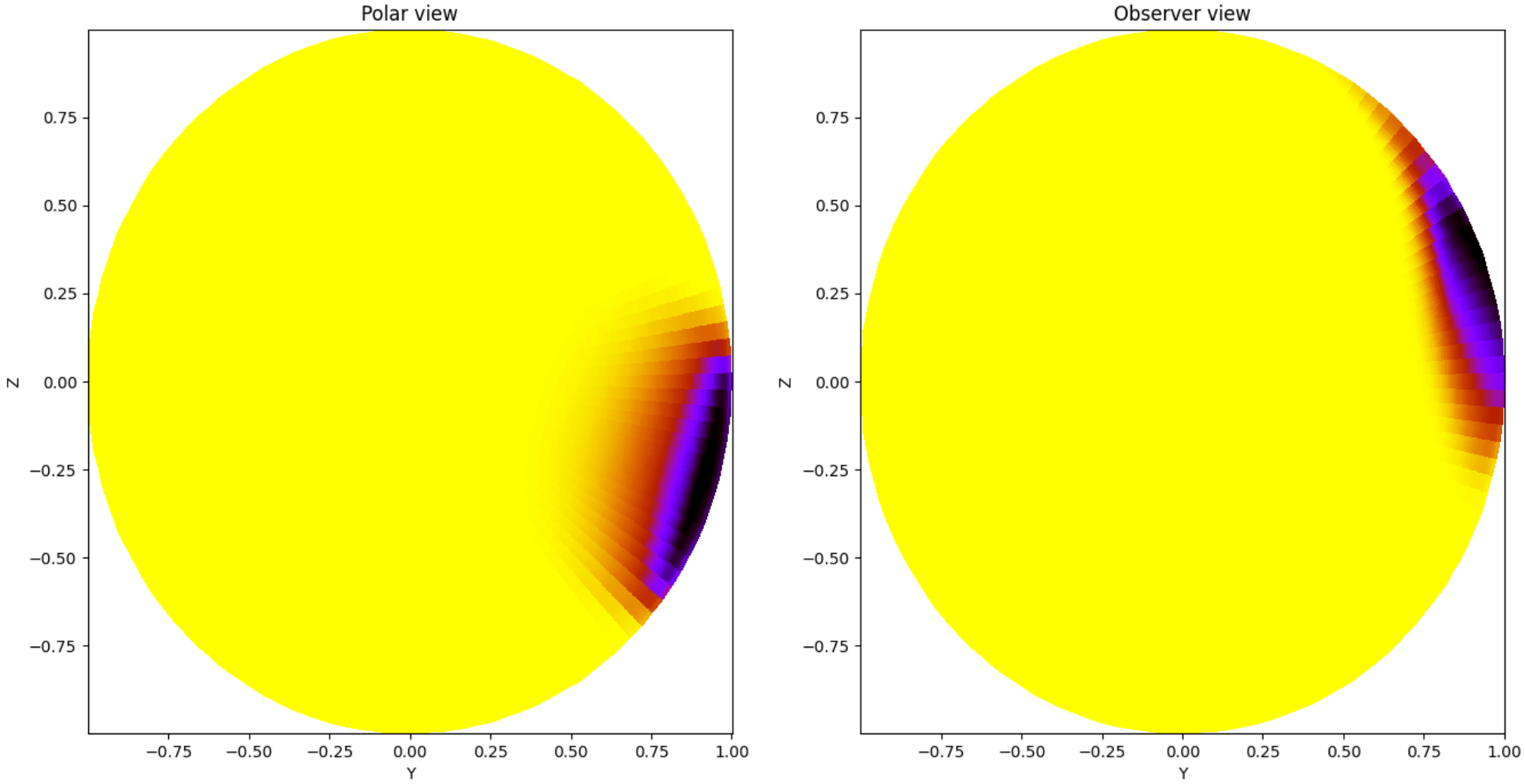
SECOND RUN

THIRD RUN

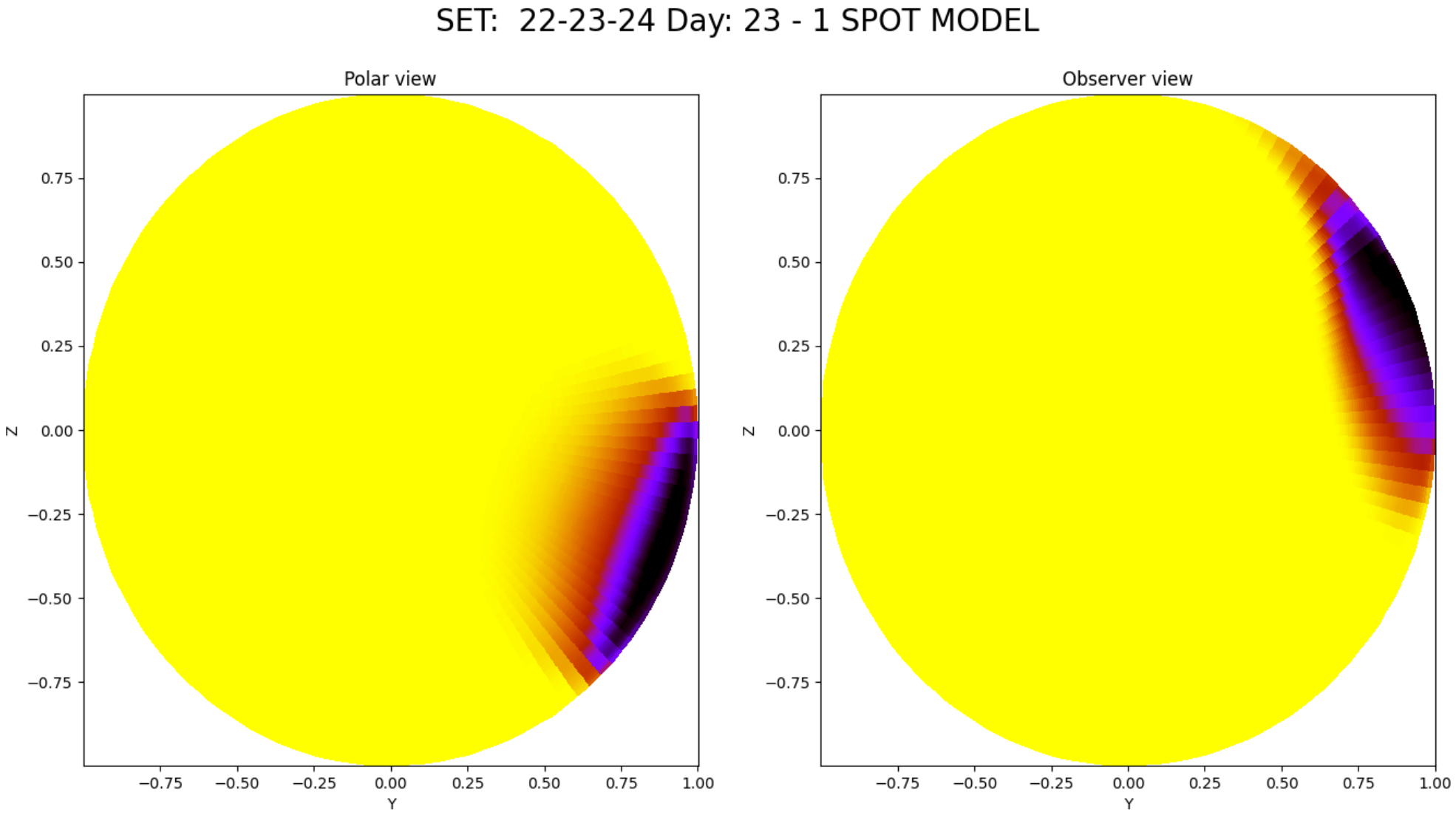

$\sigma_V = -5.76^{+1.24}_{-2.36}$
$\sigma_R = -3.41^{+0.23}_{-0.22}$
$\sigma_I = -3.57^{+0.23}_{-0.27}$
$\gamma_V = 1.25^{+0.00}_{-0.00}$
$\gamma_R = 1.21^{+0.00}_{-0.01}$
$\gamma_I = 1.18^{+0.01}_{-0.01}$
tspot = $3761.80^{+276.42}_{-383.32}$
lat = $9.67^{+9.21}_{-6.81}$
lon = $59.86^{+1.02}_{-0.98}$
$R_{spot} = 0.49^{+0.01}_{-0.01}$
σ_V
σ_R
σ_I
γ_V
γ_R
γ_I
tspot
lat
lon
R_{spot}

TEMPORAL COHERENCE

SET: 21-22-23 Day: 23 - 1 SPOT MODEL

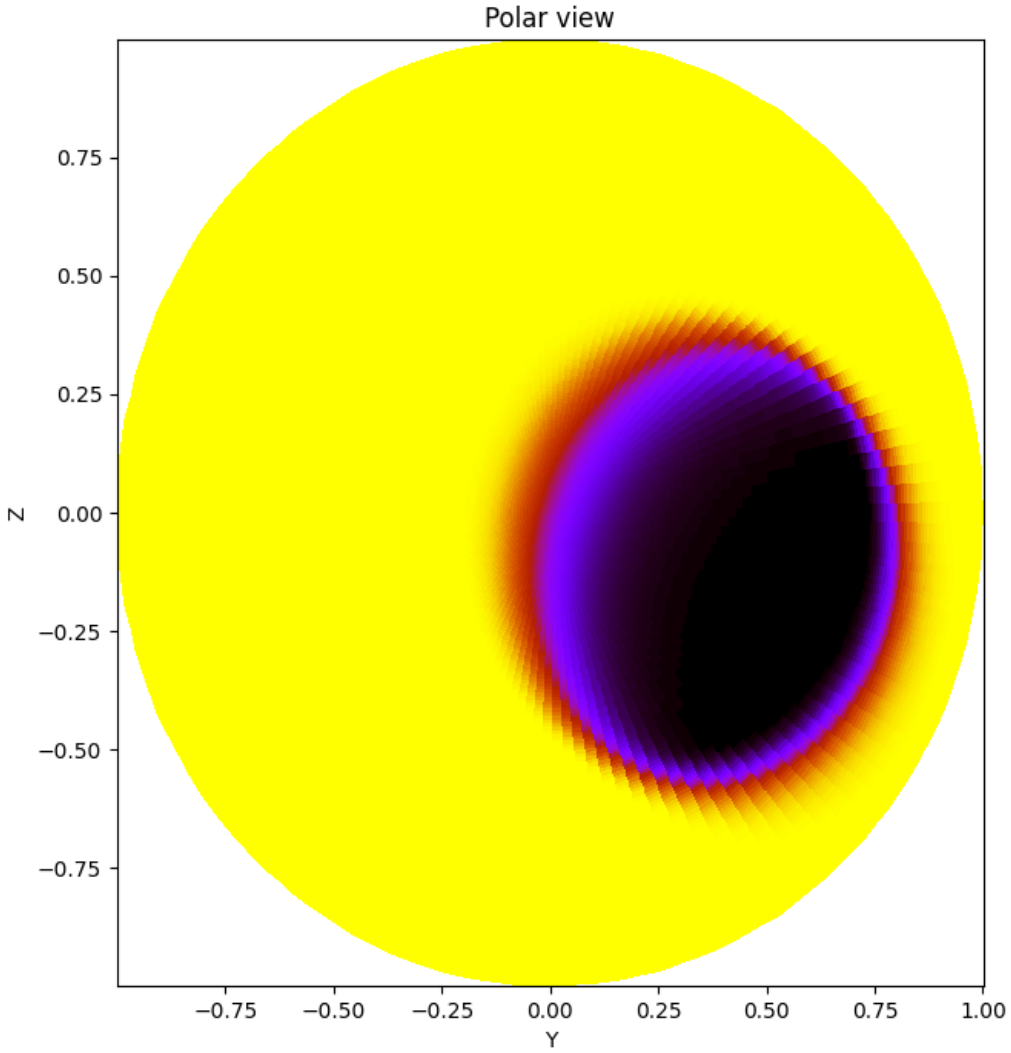


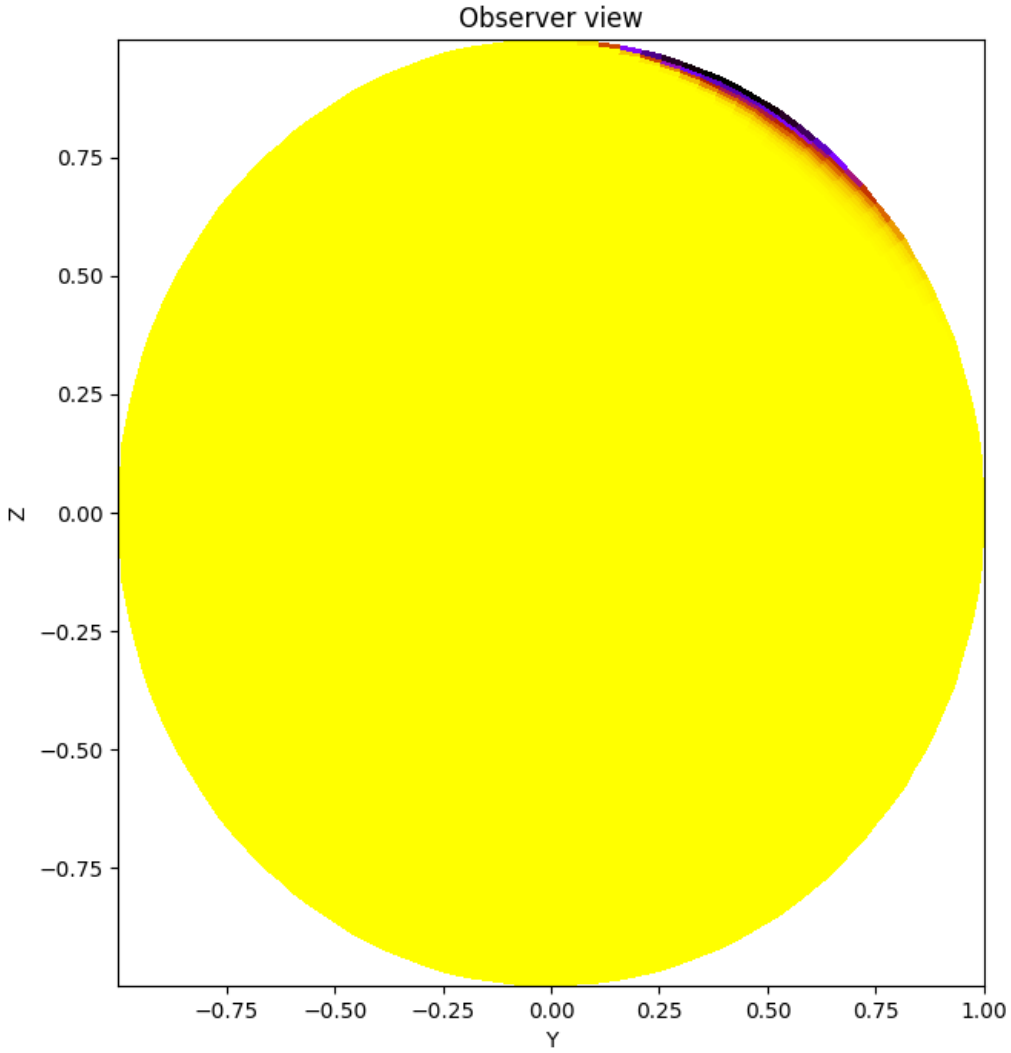
TEMPORAL COHERENCE



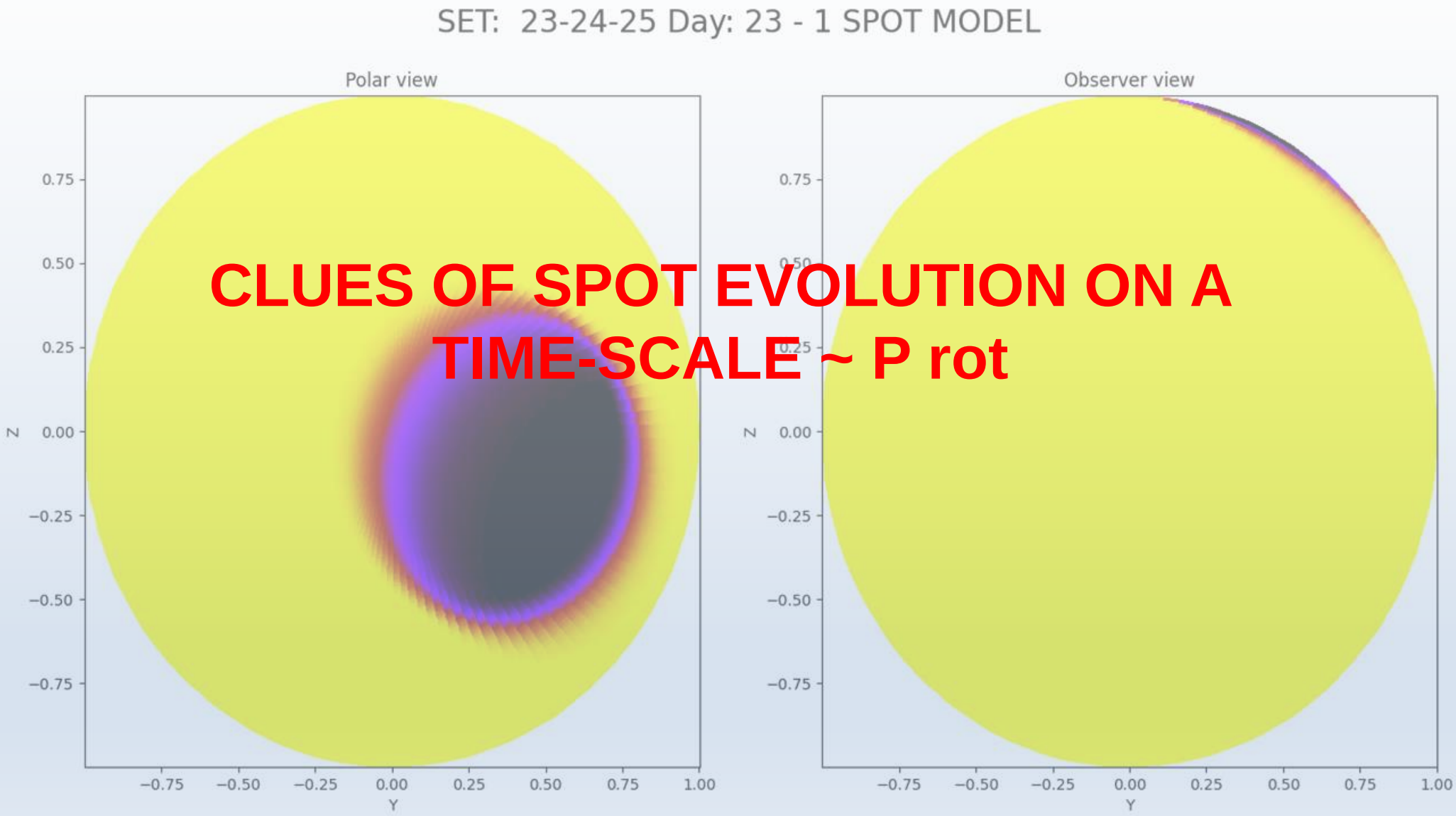
TEMPORAL COHERENCE

SET: 23-24-25 Day: 23 - 1 SPOT MODEL



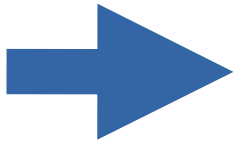


TEMPORAL COHERENCE



ONLY SPOTS

- **Transition in activity pattern?**
- **Only effective spot-facola temperature measured?**
- **We need more observations with also UV band if possible**



PERIODS	Spot Temperature (K)
02/2021	$4250 - 4320K$
12/2021	$3308 - 3978K$
02/2022	$3377 - 4507K$

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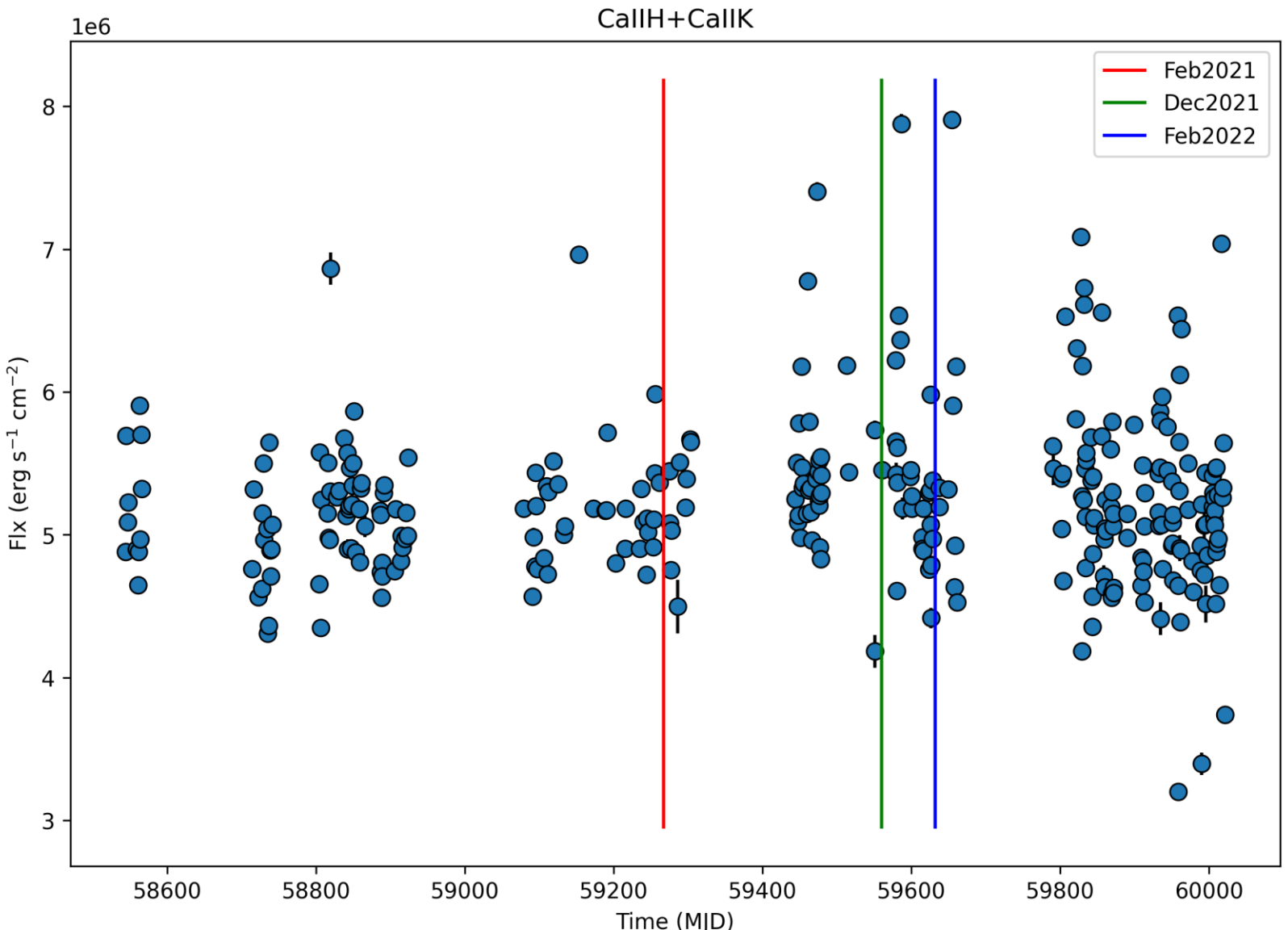
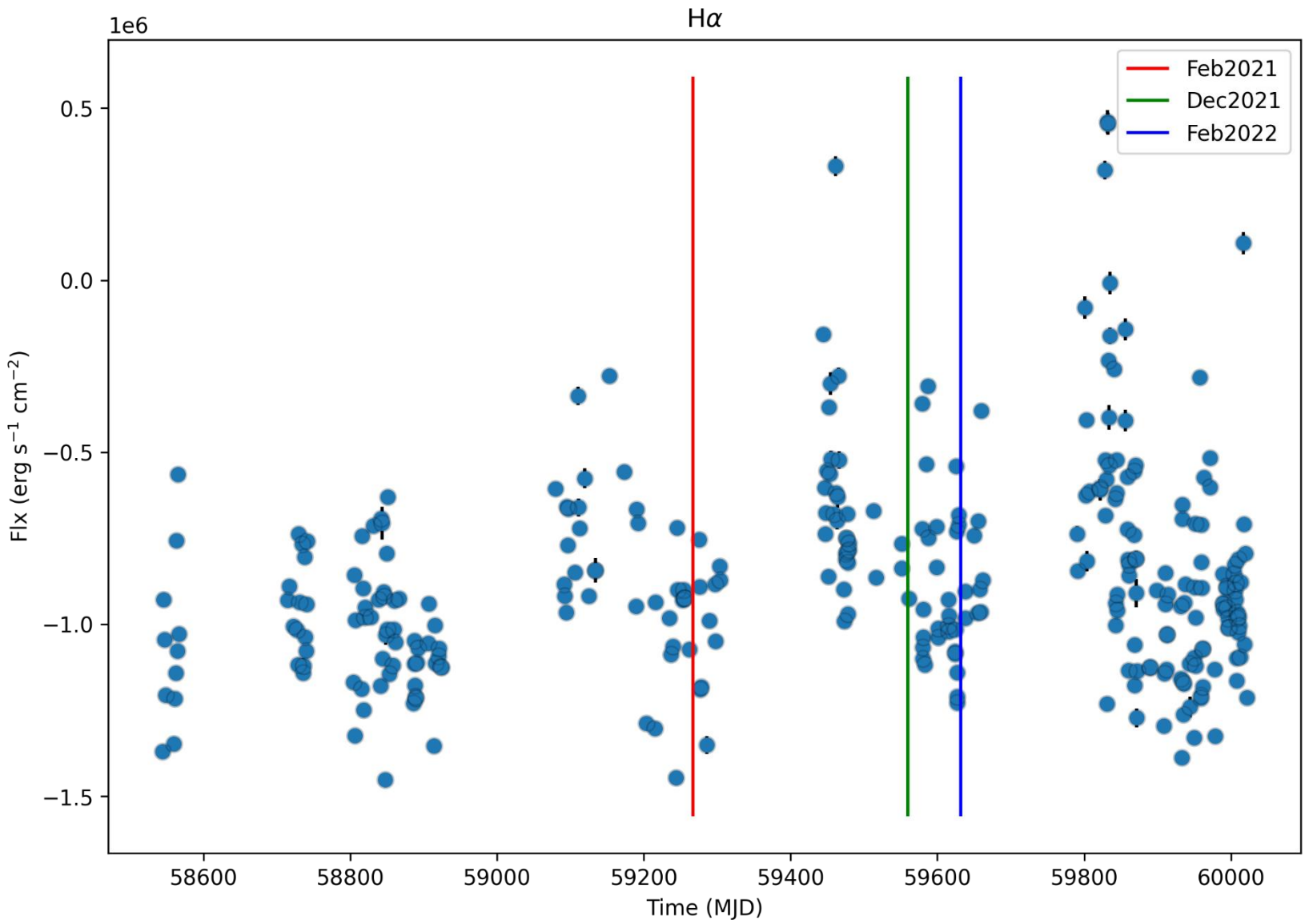
A CHANGE IN ACTIVITY?

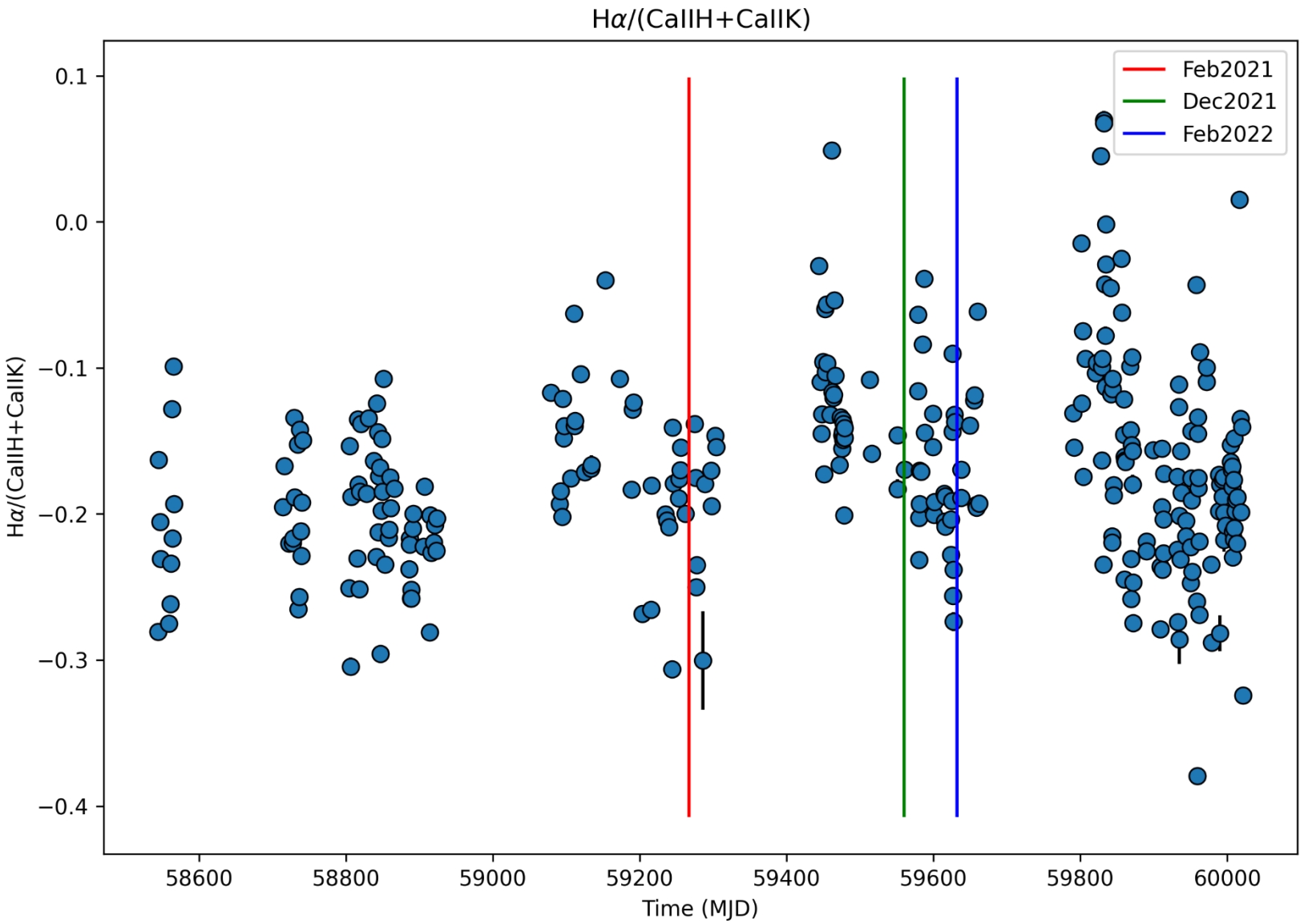
ACTIVITY CHANGE? CaII



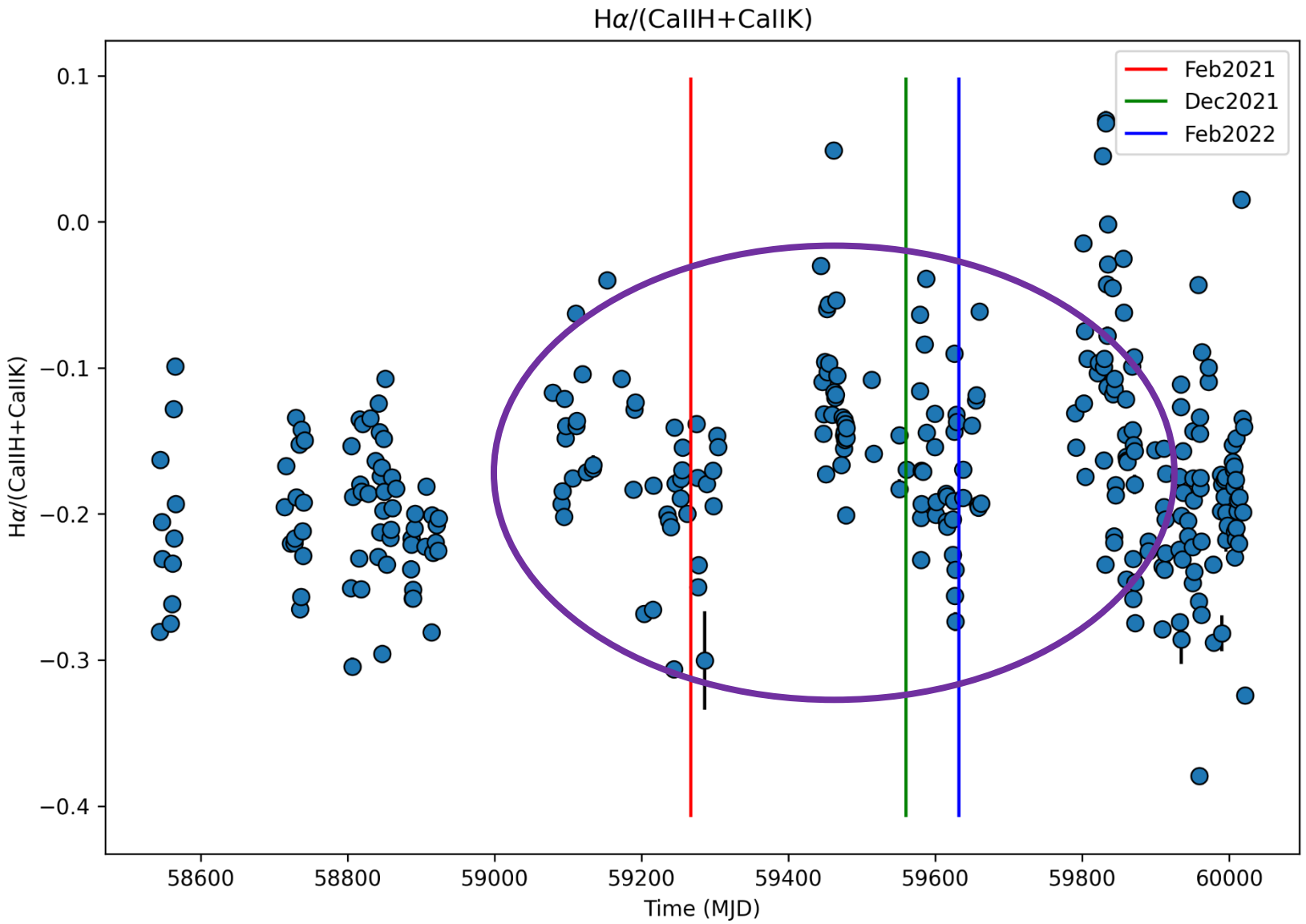
ACTIVITY CHANGE? H alpha



Halpha/CaII

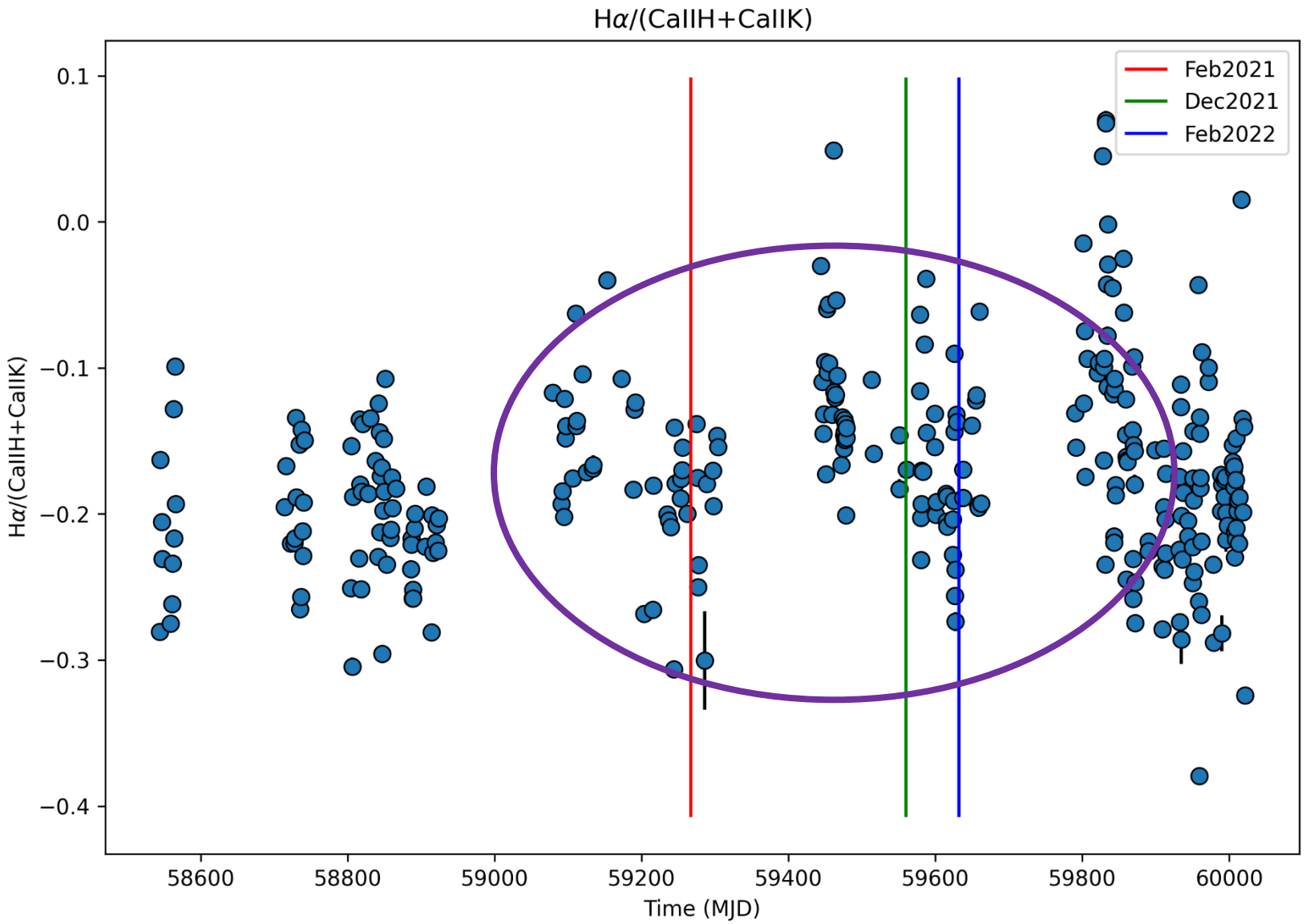

Hα/(CaIIH+CaIIK)
Feb2021
Dec2021
Feb2022
0.1
0.0
−0.1
−0.2
−0.3
−0.4
Hα/(CaIIH+CaIIK)
58600
58800
59000
59200
59400
59600
59800
60000
Time (MJD)

Halpha/CaII



Change in stellar activity between first and second run

H alpha/CaII



Change in stellar activity between first and second run

HYPHOTESIS: change in the ratio of FILLING FACTORS of FACOLAE and SPOTS

FUTURE PROJECTS

- **Model validation using solar multiband photometrical data**
- **spots model for the red dwarf stars**
- **Analysis of REM and HARPS-N data of our AOT48 proposal**
- **Observation of AOT48 proposal targets from OPC.**

THANKS

There is a lot of work to do!

Please… save me! HELP!!

THANKS!!