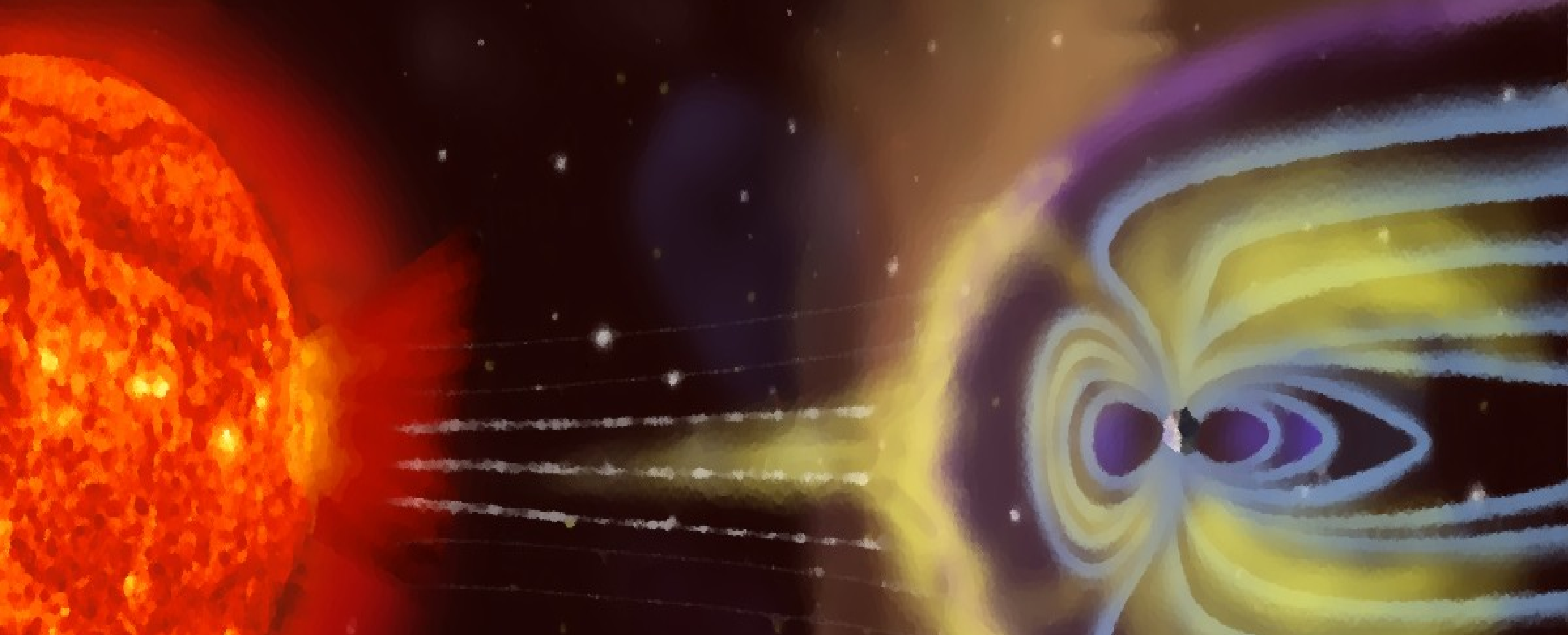


Mack Pesquisa

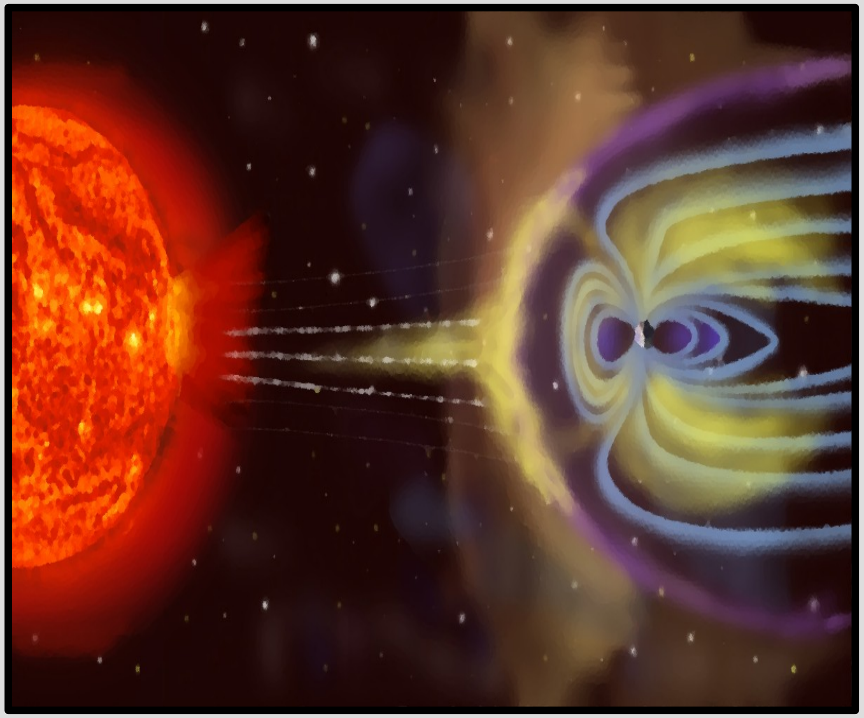
Characterization and Interaction of the magnetic field in solar-type stars and their planets

Raissa Estrela & Adriana Valio
CRAAM / Mackenzie - Brazil

- **Introduction**

Methods and results:
1) Spots on Planetary Transit
2) Residuals transit lightcurves

Conclusions & Perspectives



Magnetic Activity

- Spots are cooler than the surrounding photosphere and they are dark regions appearing and disappearing
  - days(linked to star's rotation)
  - months(spot's lifetime)
  - years(stellar cycles)

- **Flares, CMEs and Coronal loops** form in the same active regions as sunspots, they are connected to these events (follow the cycle).
- Magnetic field triggered by dynamo process

Who's active?

Main sequence-stars, those that are still burning hydrogen in their cores, have been found to exhibit signs of magnetic activity.

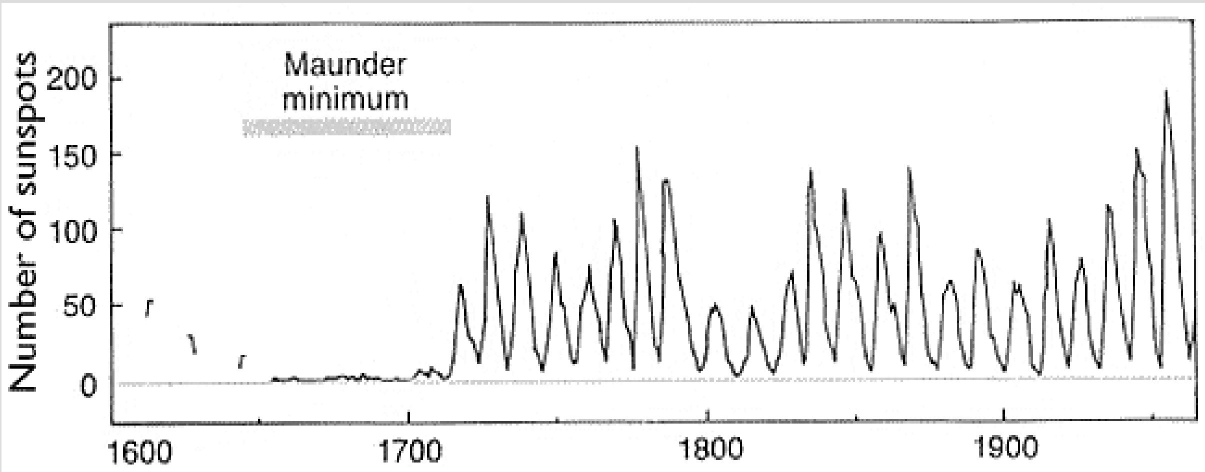
- **M dwarfs**
  Magnetic activity decline much slower in time than in solar-type stars

- **Solar-type stars**
  All cool, low-mass solar-type stars show magnetic fields comparable to that of our Sun (Berdyugina 2005).

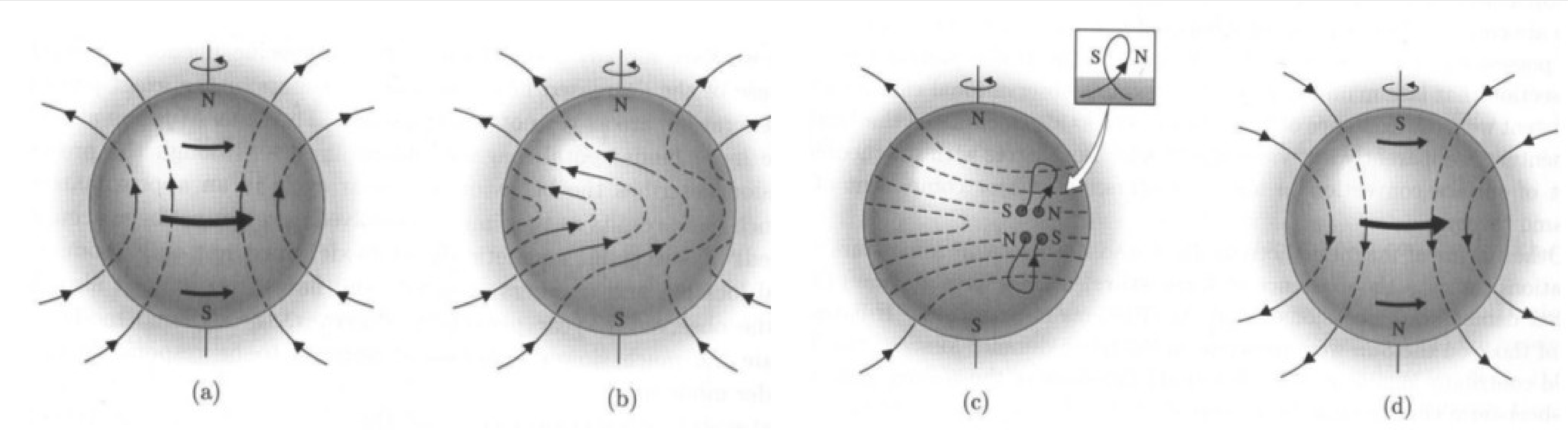
- **Increasing spectral type** → dynamo type magnetic field and the related stellar magnetic activity are expected to decrease (early F- and A-type stars)

Rotation and activity

- **Young stars with a rapid rate of rotation**
  - exhibit strong activity.
- **Middle-aged, Sun-like stars with a slow rate of rotation**
  - slow levels of activity that varies in cycles.
- **Some older stars**
  - almost no activity, compared to Sun's Maunder Minimum



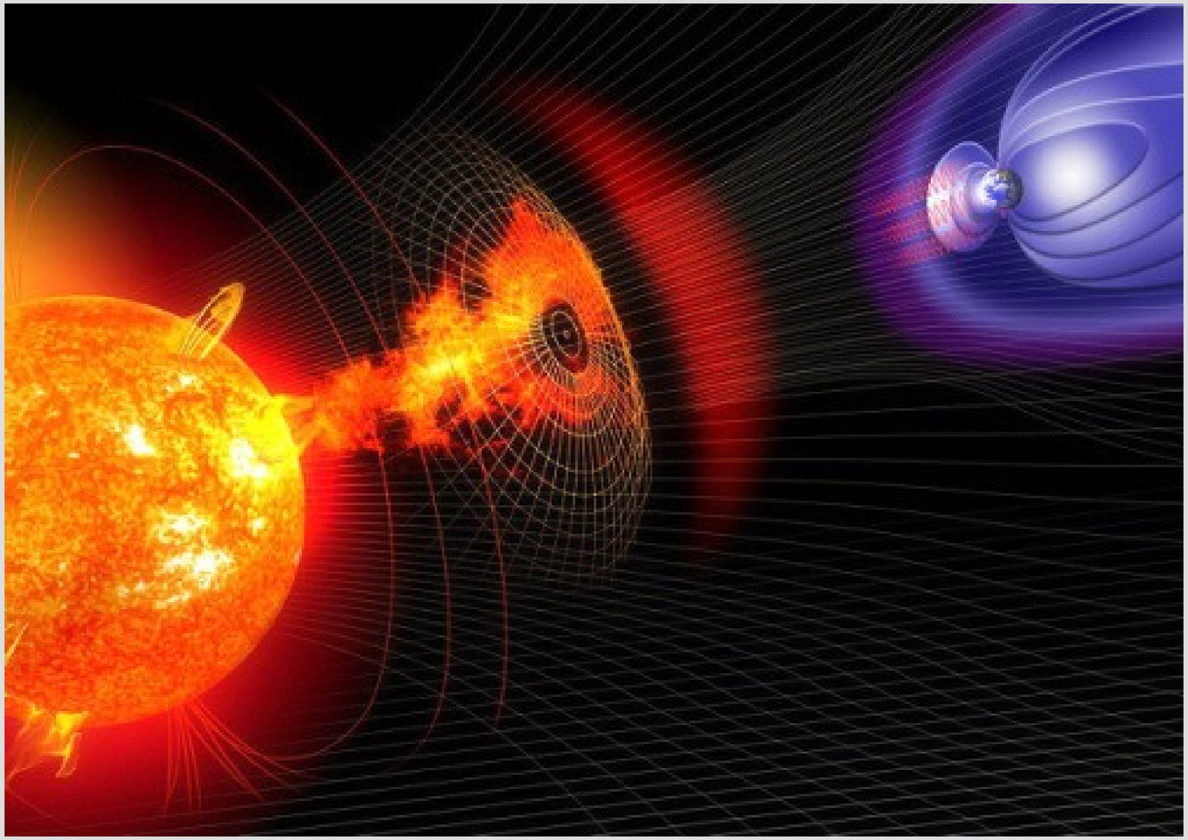
Sun's activity cycle



Carroll and Ostlie, 2007

11 year cycle of the Sun

Star magnetic activity and habitability of the exoplanet



Star magnetic activity and habitability of the exoplanet

Stellar activity can trigger

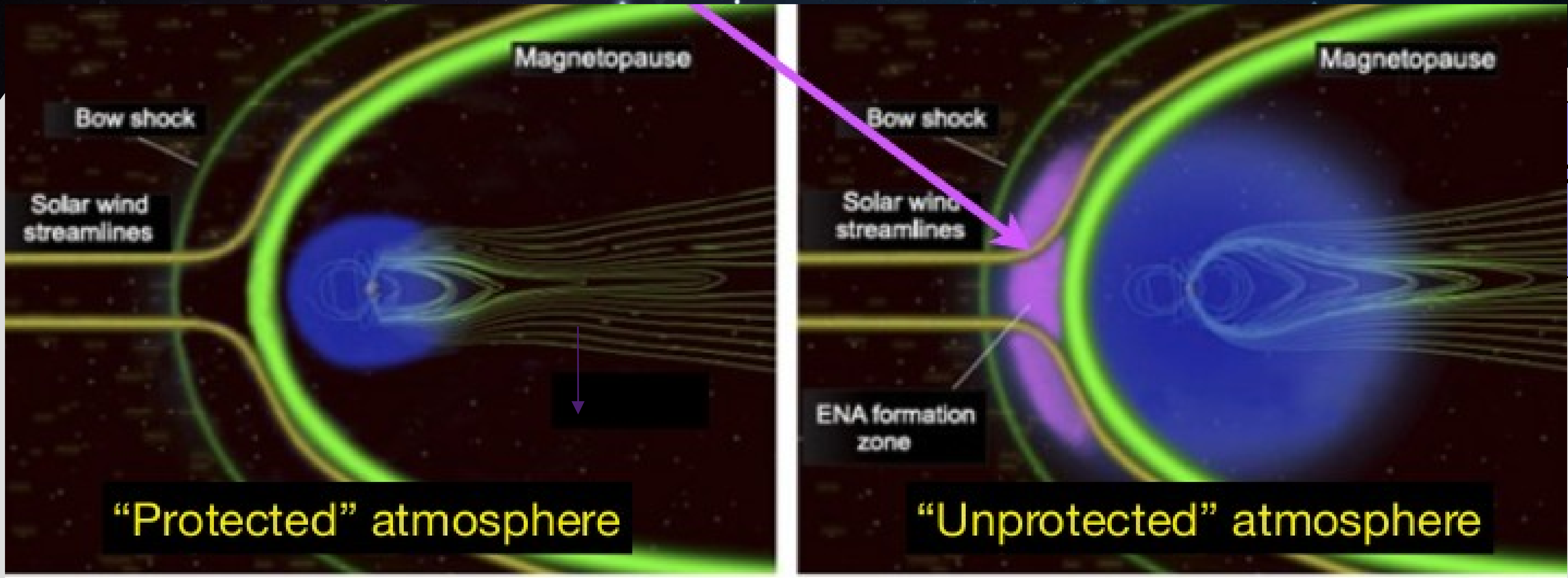
- Energetic flares
- Hot coronal plasma in magnetic loops
  - Generate a significant amount of UV, FUV, EUV, and X-rays

↓

Stellar winds

Key factor to:
Formation and atmospheric evolution
Planet's climate

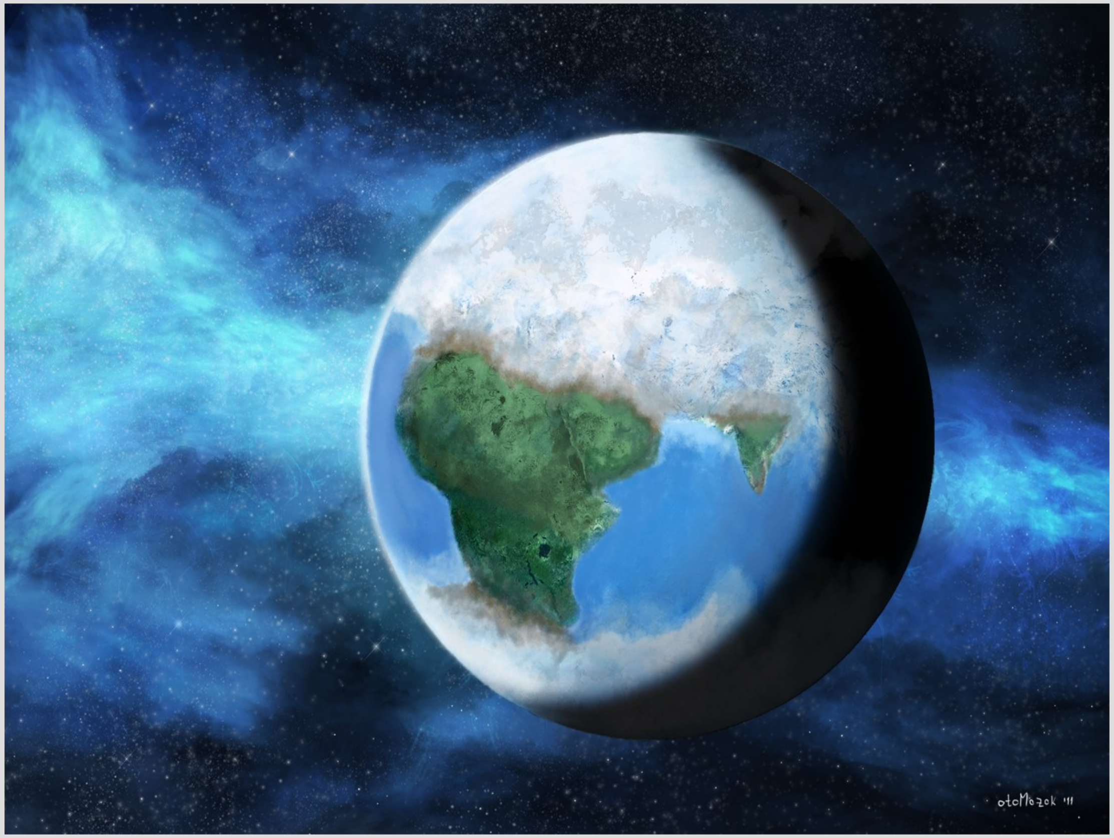
Star magnetic activity and habitability of the exoplanet



Lammer et al. 2011

→ Loss of the atmosphere mass → affects the composition and chemical evolution of upper atmospheres and habitability (Luftinger et al. , 2015)

Influence of stellar magnetic cycles on Earth

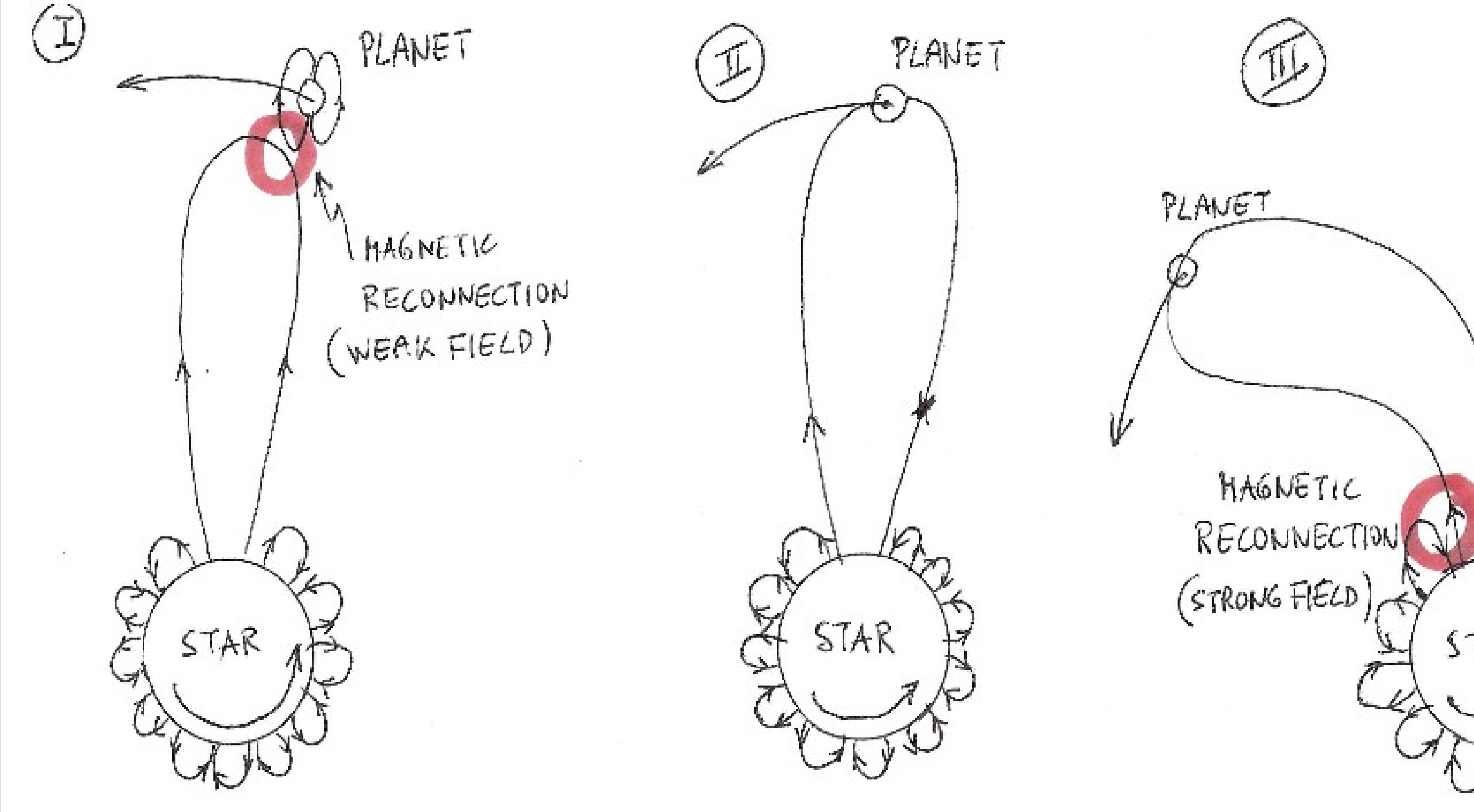


Influence of stellar magnetic cycles on Earth

- High solar activity → warmer climate on Earth
- Prolonged low activity → lower global temperature

Maunder minimum (1645-1715), during this interval few sunspots were seen and coincided with the coldest part of the Little Ice Age

Star-Planet Magnetic Interaction

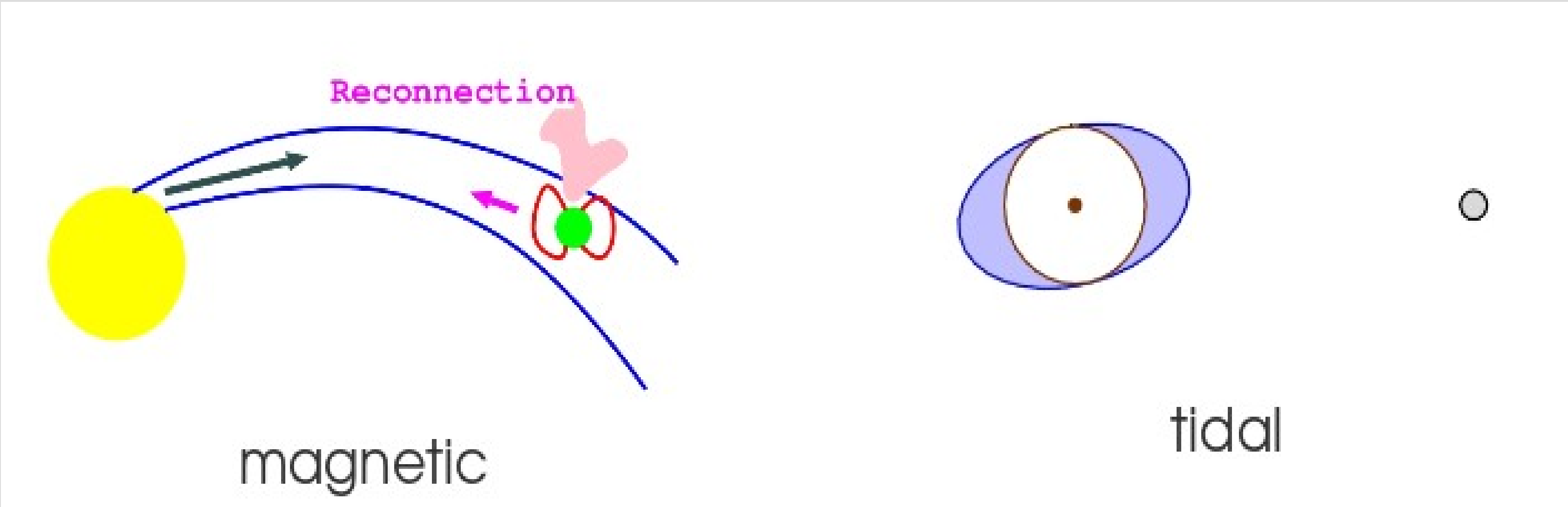


Lanza (2011)

Star-Planet magnetic interaction

- Tidal and magnetic interactions (Cuntz et. al, 2000)

Hot Jupiters (a < 0.15 AU) around late-type stars are expected to interact with both mechanisms



(Shokolnik et al., 2003)

Planet can influence stellar activity

- **Observations of Hot Jupiters:**

Repeated stellar flares where reported after the eclipse of the planet (Pilliteri et al, 2010).

Chromospheric activity peaks phased with the orbital period of the planet. (Shkonilk et al., 2005; 2008)

Star-Planet magnetic interaction

- **Magnetic reconnection**

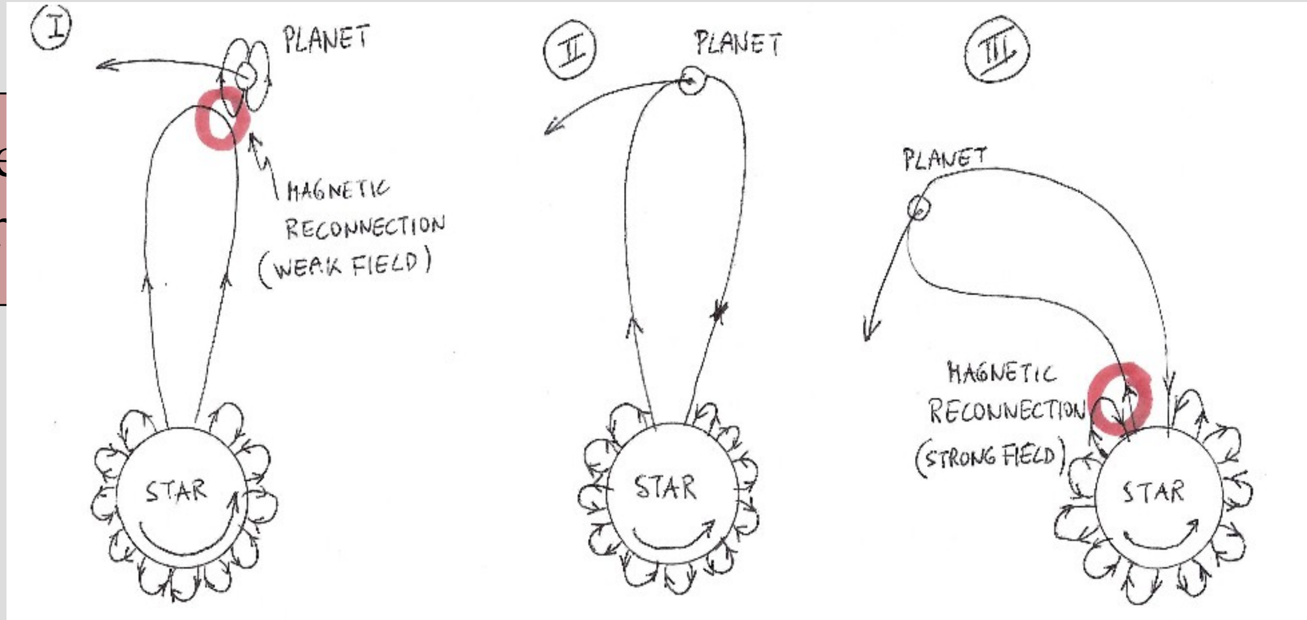
The stellar coronal field or its magnetized wind interact with planetary magnetosphere (Lanza, 2011).

- Mass loss are found for atmospheres heated by electrons acelerated by magnetic reconnection (Lanza, 2013)

Star-Planet magnetic interaction

► Magnetic reconnection

The ste … with
plan …

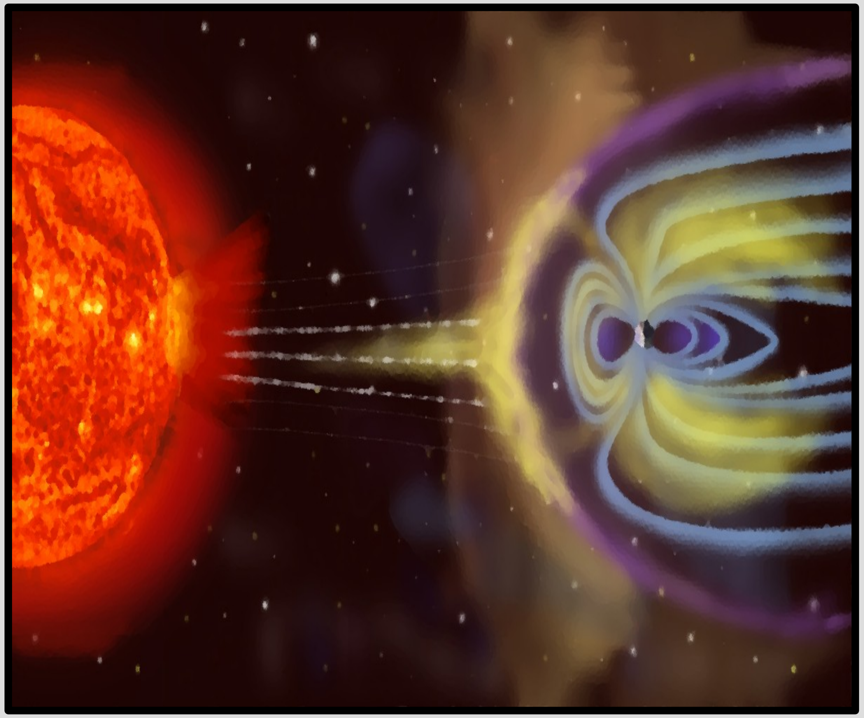


- Mass loss are found for atmospheres heated by electrons acelerated by magnetic reconnection (Lanza, 2013)

Introduction

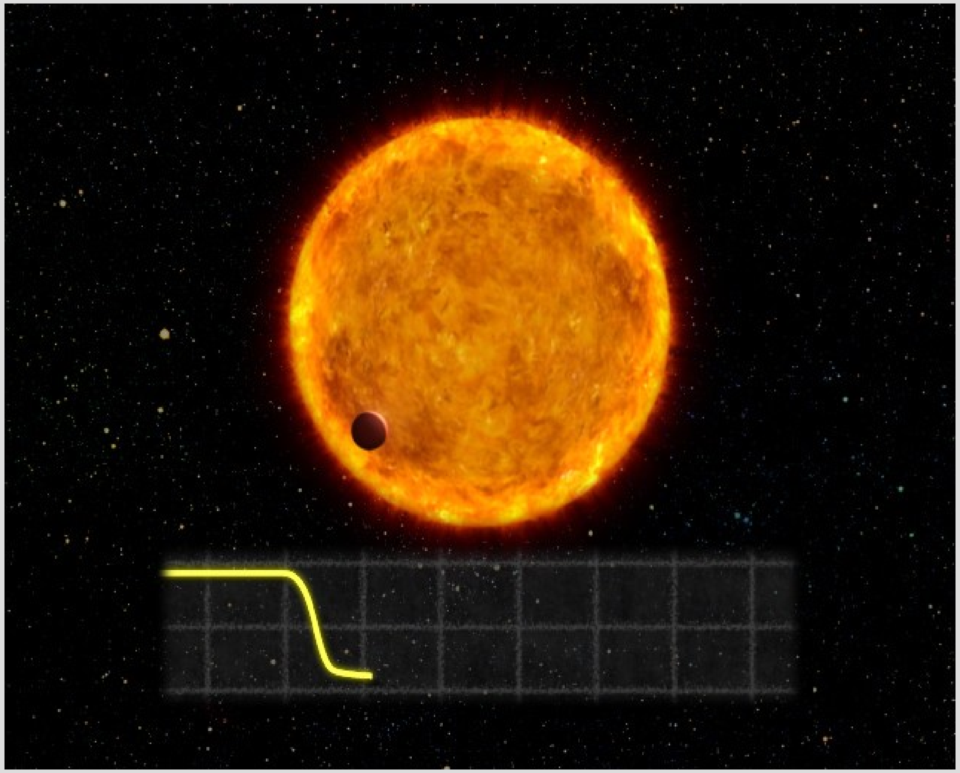
- **Methods and results:**
  1) Planetary Transit Model
  2) Residuals transit lightcurves

Conclusions & Perspectives



Method 1

Planetary Transit Model

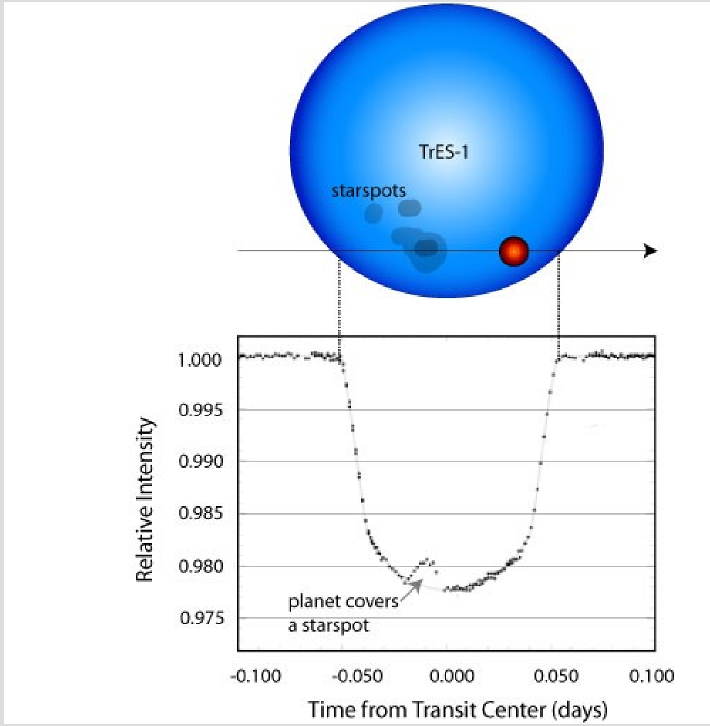


Detecting spots

Spots detection during Planetary Transit

- Total of 1225 planets discovered. And 692 of them in planetary systems (Oct.-2015, Exoplanet.eu)

- During one of these transits, the planet may pass in front of a spot group and cause a detectable signal in the light curve of the star.

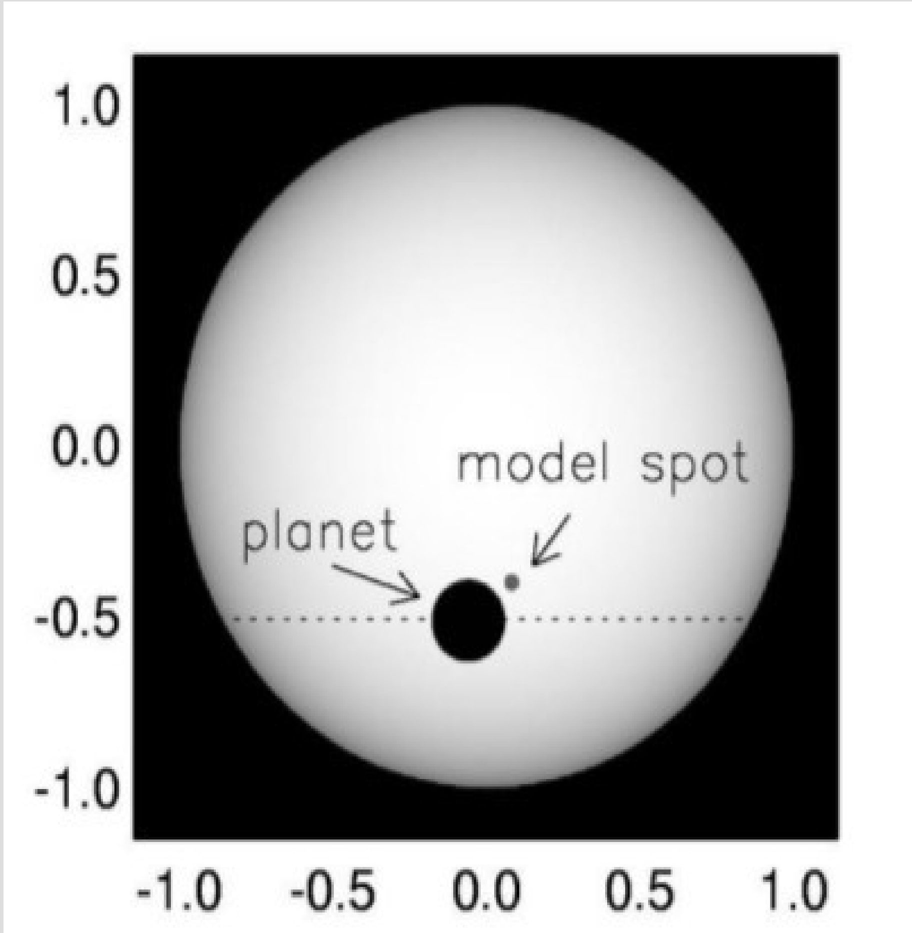


The model

Model that simulates planetary transits: use the planet as a probe to study starspots (Silva, ApJ Letters , 585, L147-L150, 2003).

Spots → Characterized by 3 parameters:

- ▶**Intensity**: measured with respect to stellar maximum intensity (center);
- ▶**Size**: measured in units of planetary radius
- ▶**Position**: Latitude(restrited to the transit band) and Longitude(constrained to +- 70°).



Modeling observations Kepler-17 and Kepler-63

Young solar analogues

Kepler-17

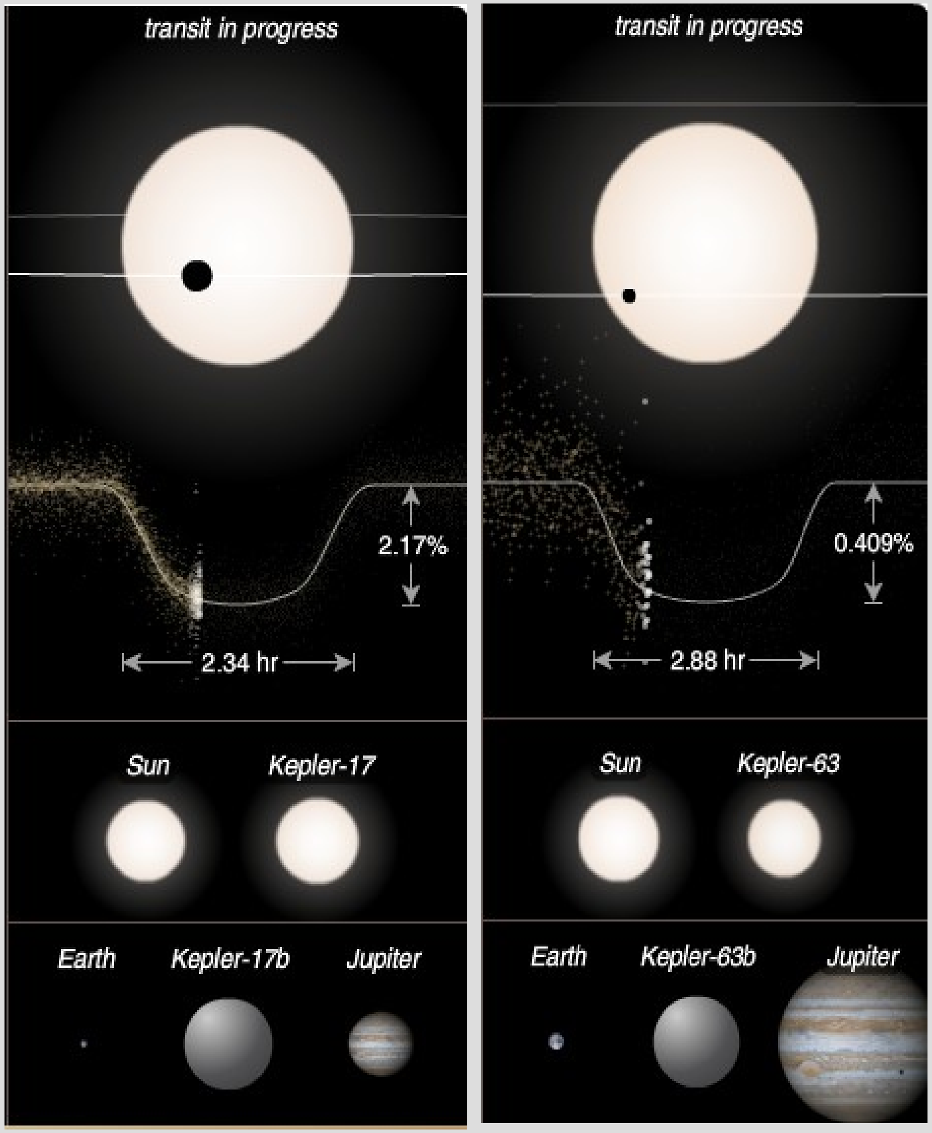
Spectral type: G2V

- $Mass = 2.45(\pm 0.014) M_J$
- $T_{eff} = 5781 K$
- Hot Jupiter: Kepler-17b
- Semi-major: 0.025 ± 0.0003 AU

Kepler-63

Spectral type: G-type

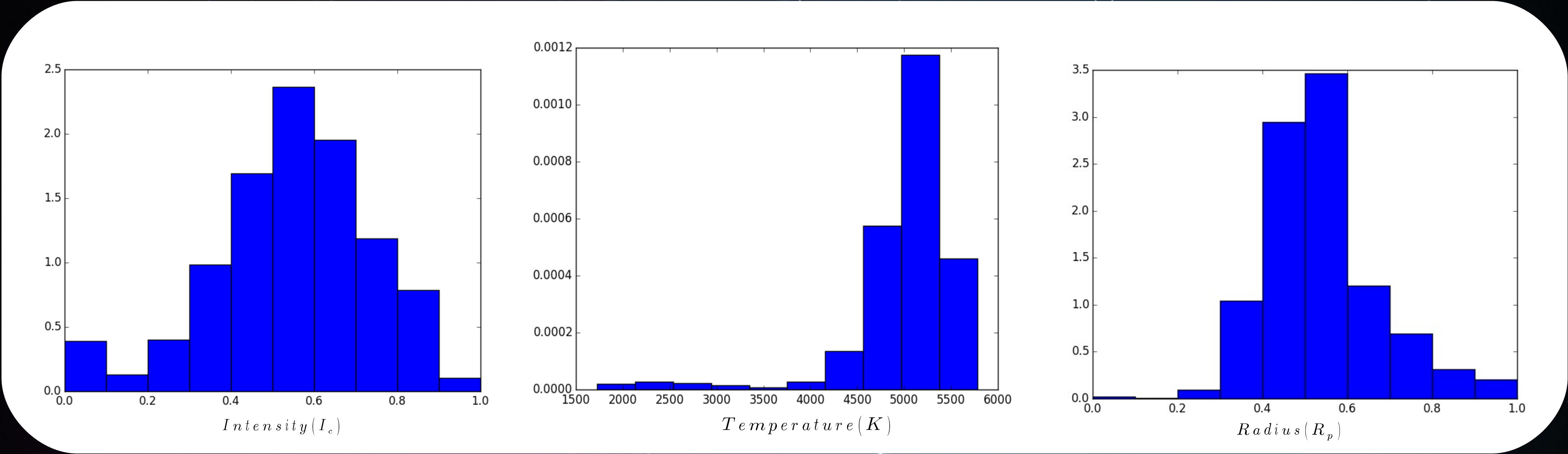
- $Mass = --$
- $T_{eff} = 5576 K$
- Hot Jupiter: Kepler-63-b
- Semi-major: 0.080±0.002 AU



Nasa

Spots Characteristics

Kepler-17



Total of 1059 spots.

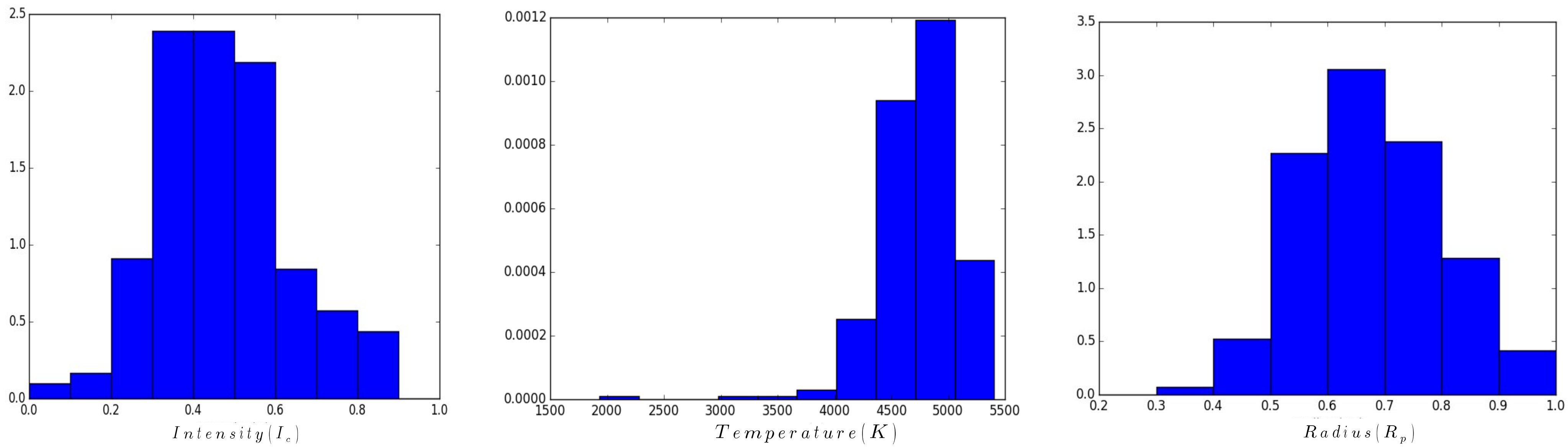
- $Intensity = 0.54 \pm 0.19 I_c$
- $Radius = 0.53 \pm 0.13 R_p$
- $Temperature = 5000 \pm 600 K$

$$\frac{I_{spot}}{I_{star}} = \frac{e^{h\nu/K_B T_{ef}} - 1}{e^{h\nu/K_B T_0} - 1}$$

$$T_0 = \frac{K}{h\nu \, \ln\left(\frac{I_e}{I_m}\left(e^{\frac{h\nu}{KT_e}} - 1\right) + 1\right)}$$

Spots Characteristics

Kepler-63

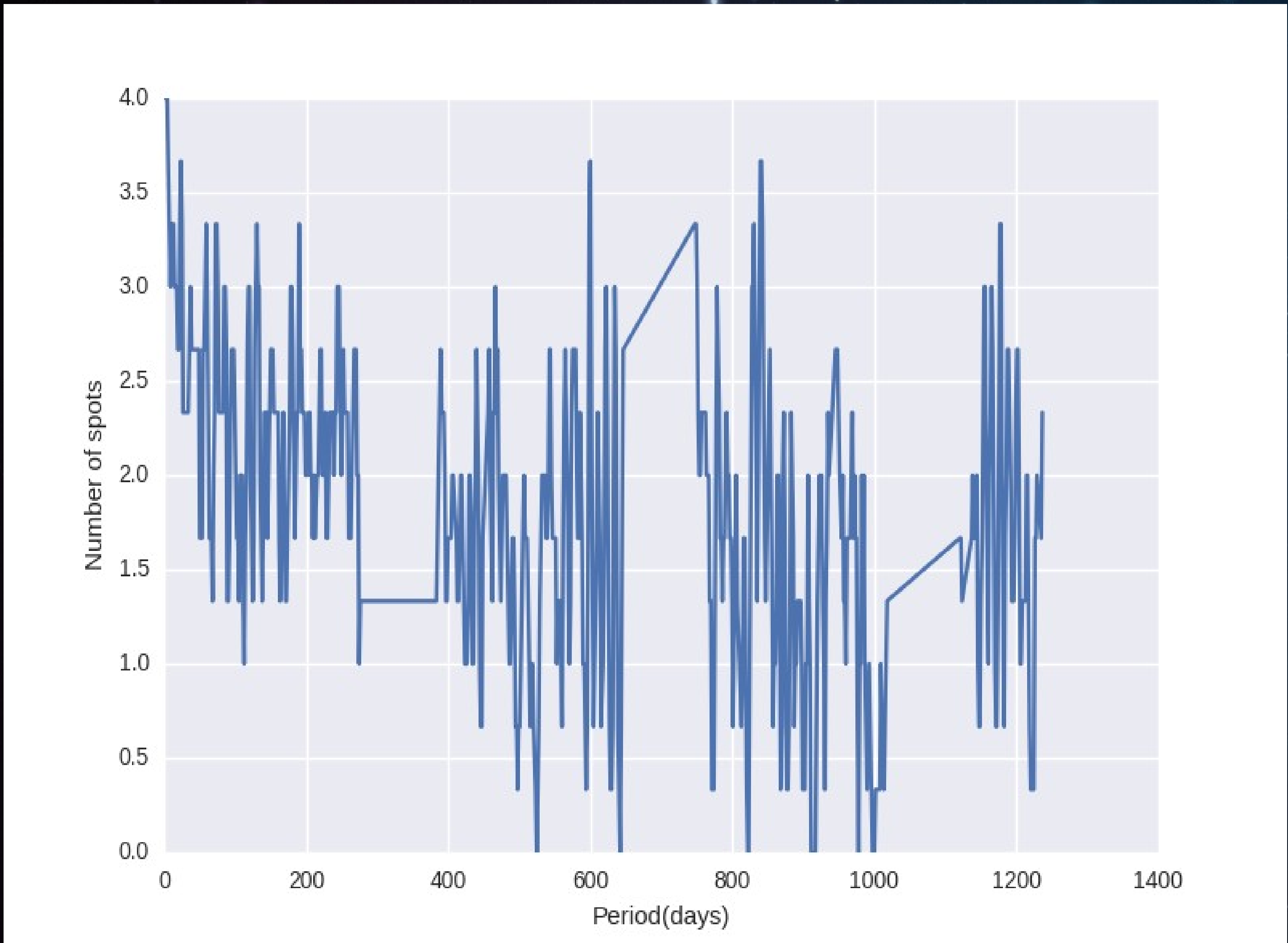


Total of 297 spots.

- $Intensity = 0.47 \pm 0.16 I_c$
- $Radius = 0.68 \pm 0.12 R_p$
- $Temperature = 4800 \pm 400 K$

Kepler-17

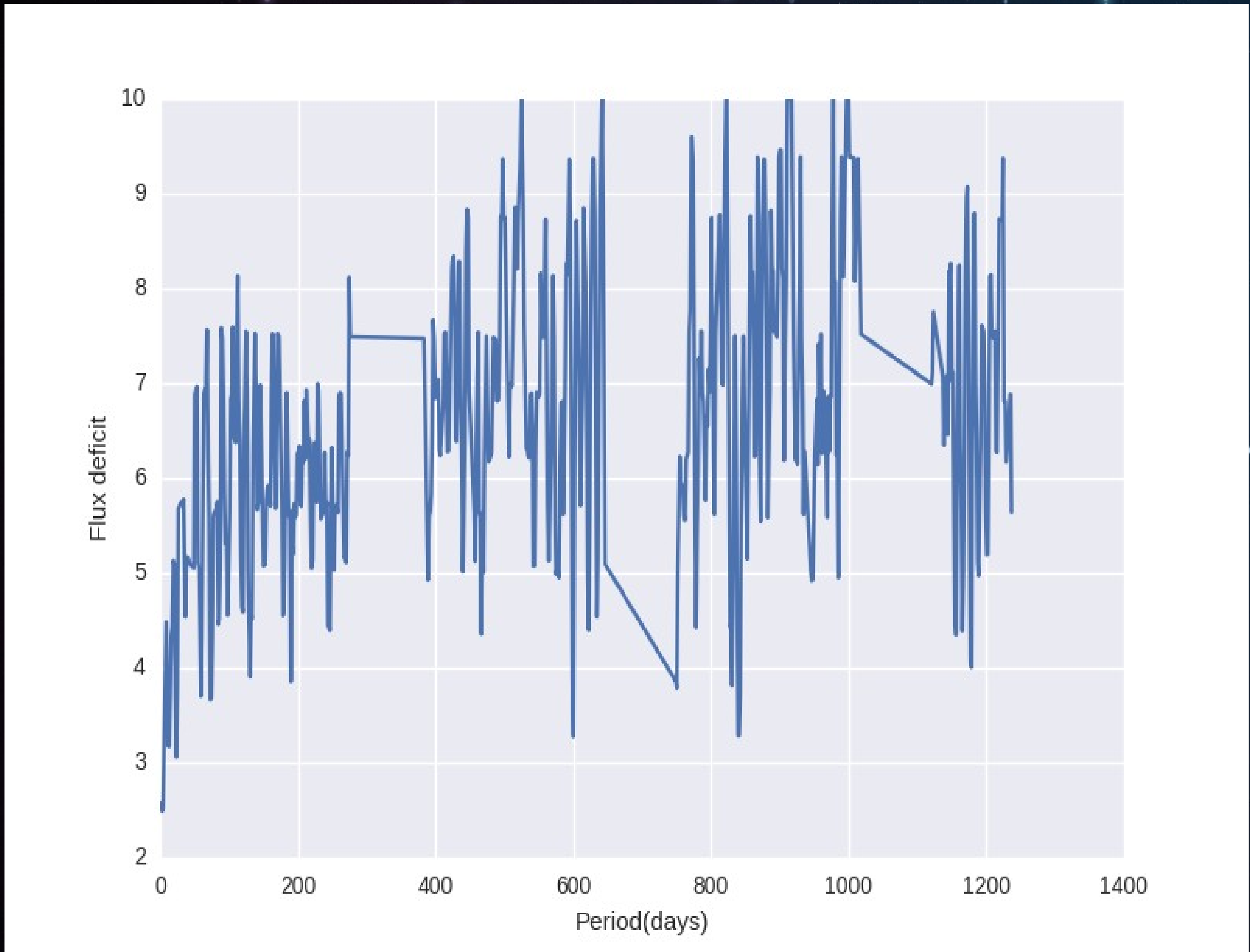
▸ Number of spots



Total of **589 transits observed.**

Number of spots per transits during ~ 4 years observation.

Flux deficit



Total of **589 transits** observed.

Total **flux deficit** subtracted from a star by the presence of spots:

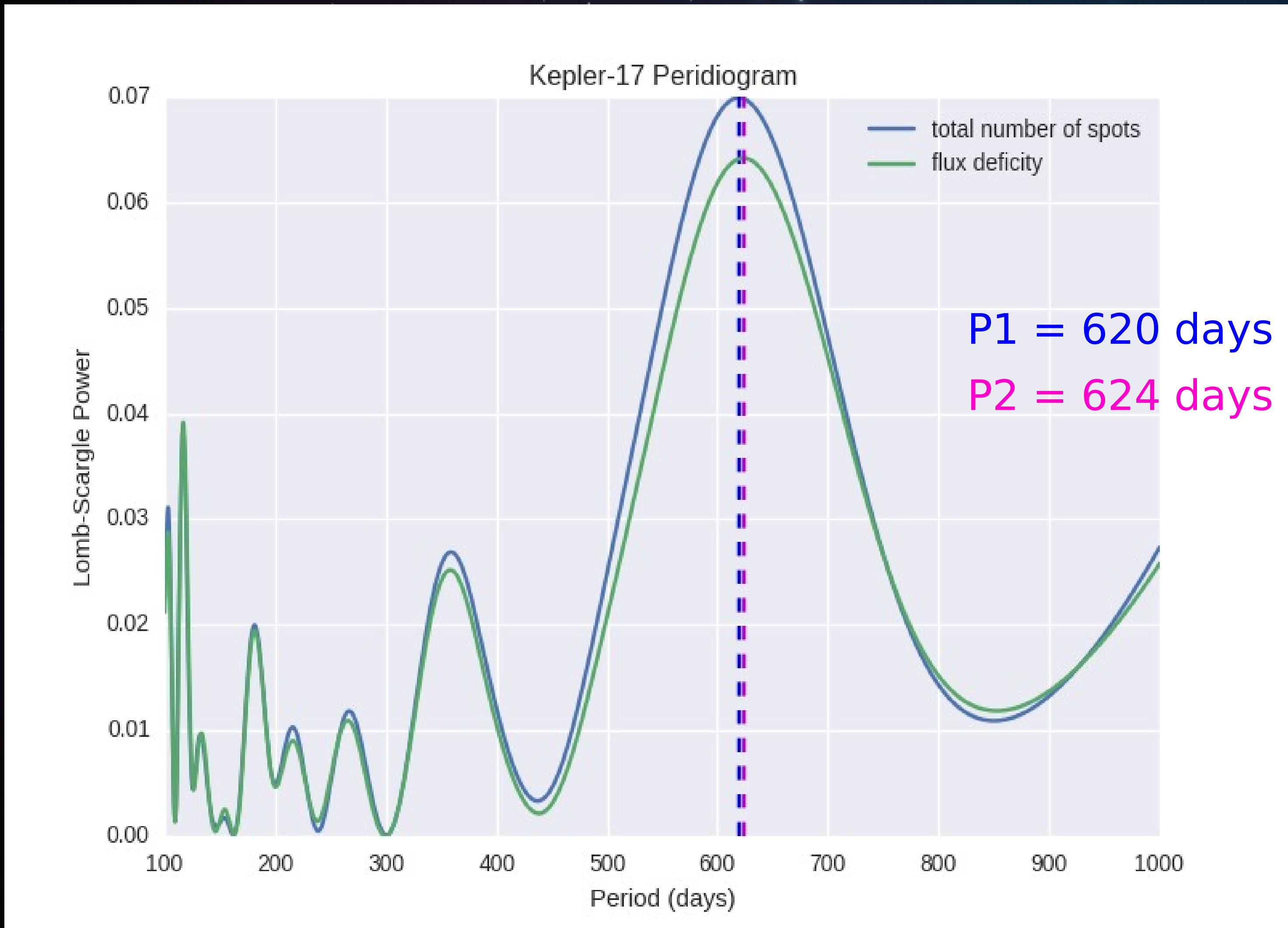
$$F \propto (1 - f_i)(R_{spot})^2$$

Stellar magnetic cycles

- Number of spots
- Total flux deficit

Stellar magnetic cycles

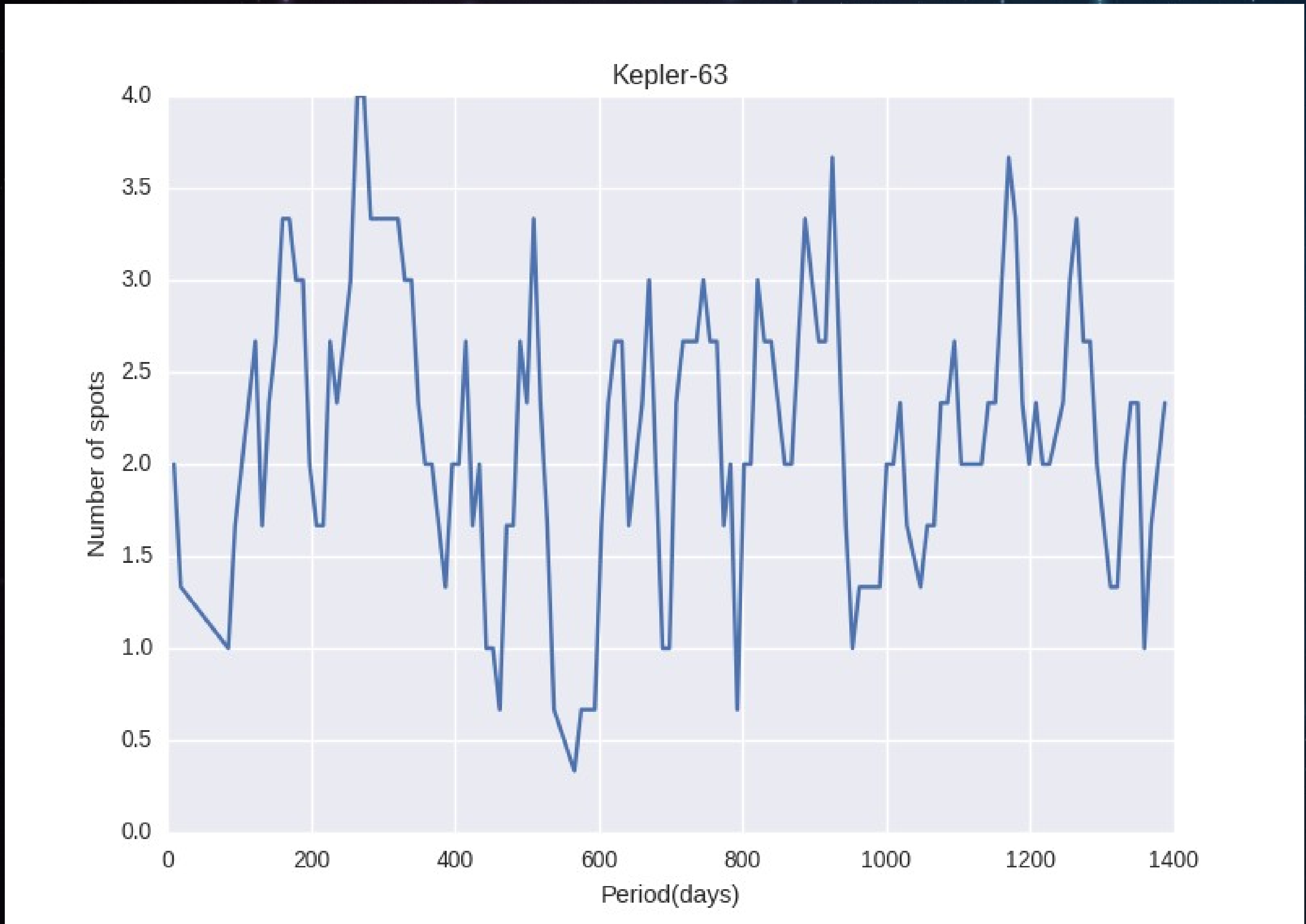
Lomb Scargle method: Number of spots and Flux deficit



Magnetic cycle of 1.7 years.

Kepler-63

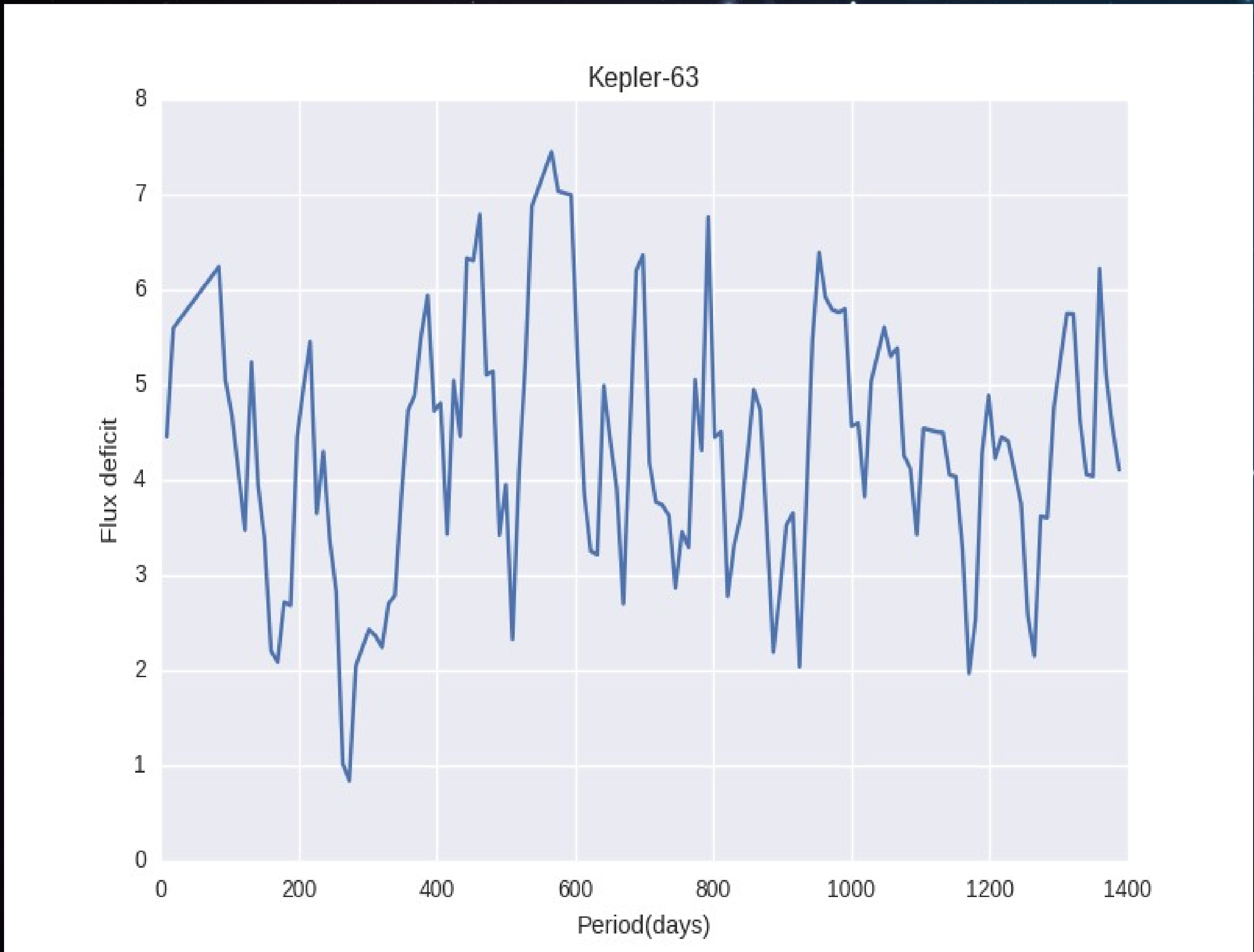
Number of spots



Total of **135 transits observed.**

Number of spots per transits during ~ 4 yrs observation.

Flux deficit



Total of **135 transits** observed.

Total **flux deficit** subtracted from a star by the presence of spots:

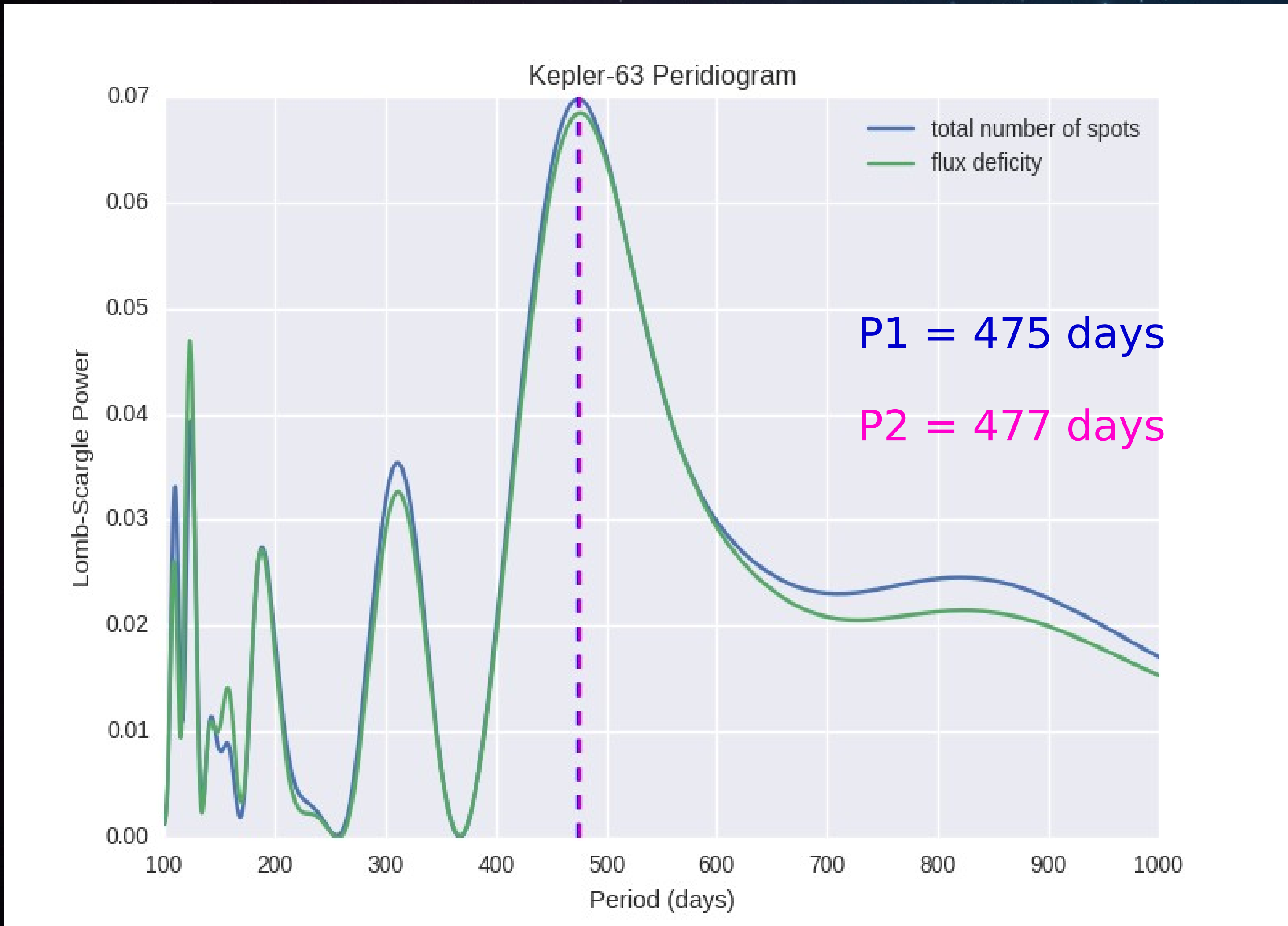
$$F \propto (1 - f_i)(R_{spot})^2$$

Stellar magnetic cycles

- Number of spots
- Total flux deficit

Stellar magnetic cycles

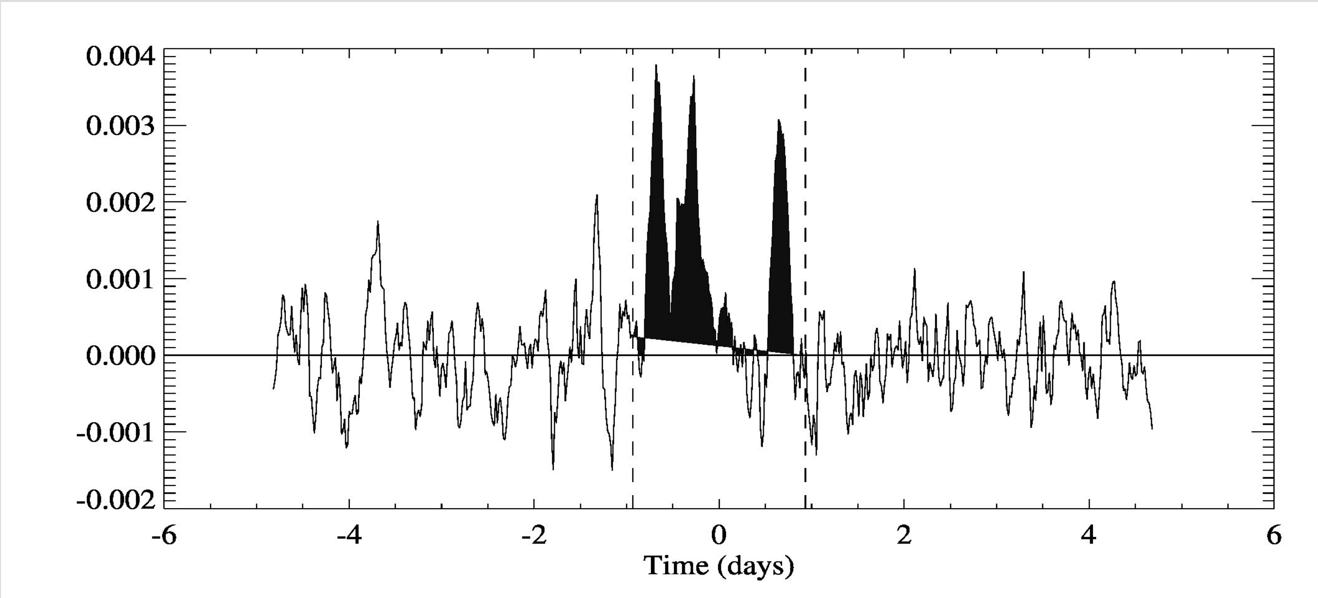
Lomb Scargle method: Number of spots and Flux deficit



Magnetic cycle of 1.3 yr.

Method 2

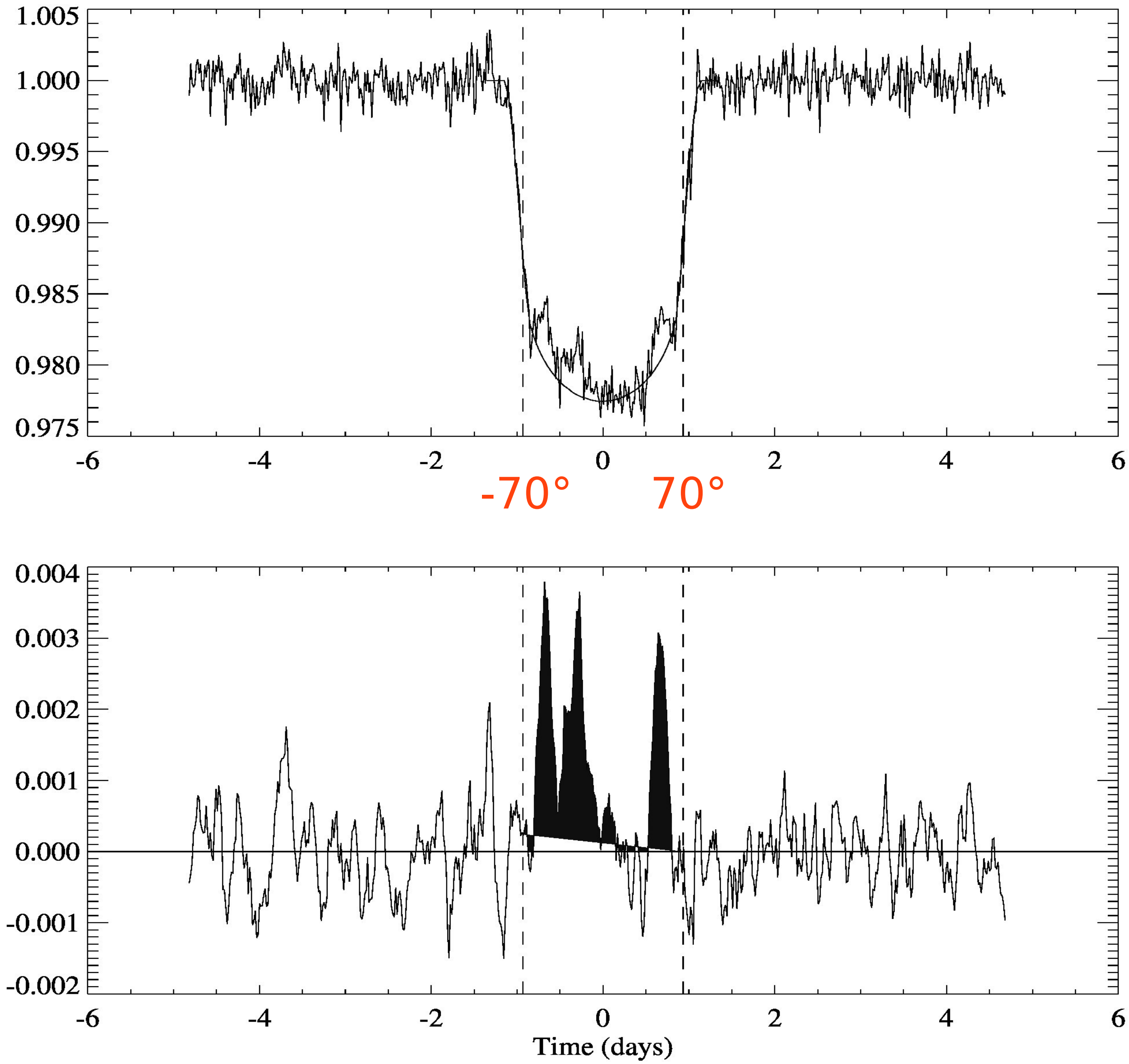
Residuals transits lightcurves



Kepler-17

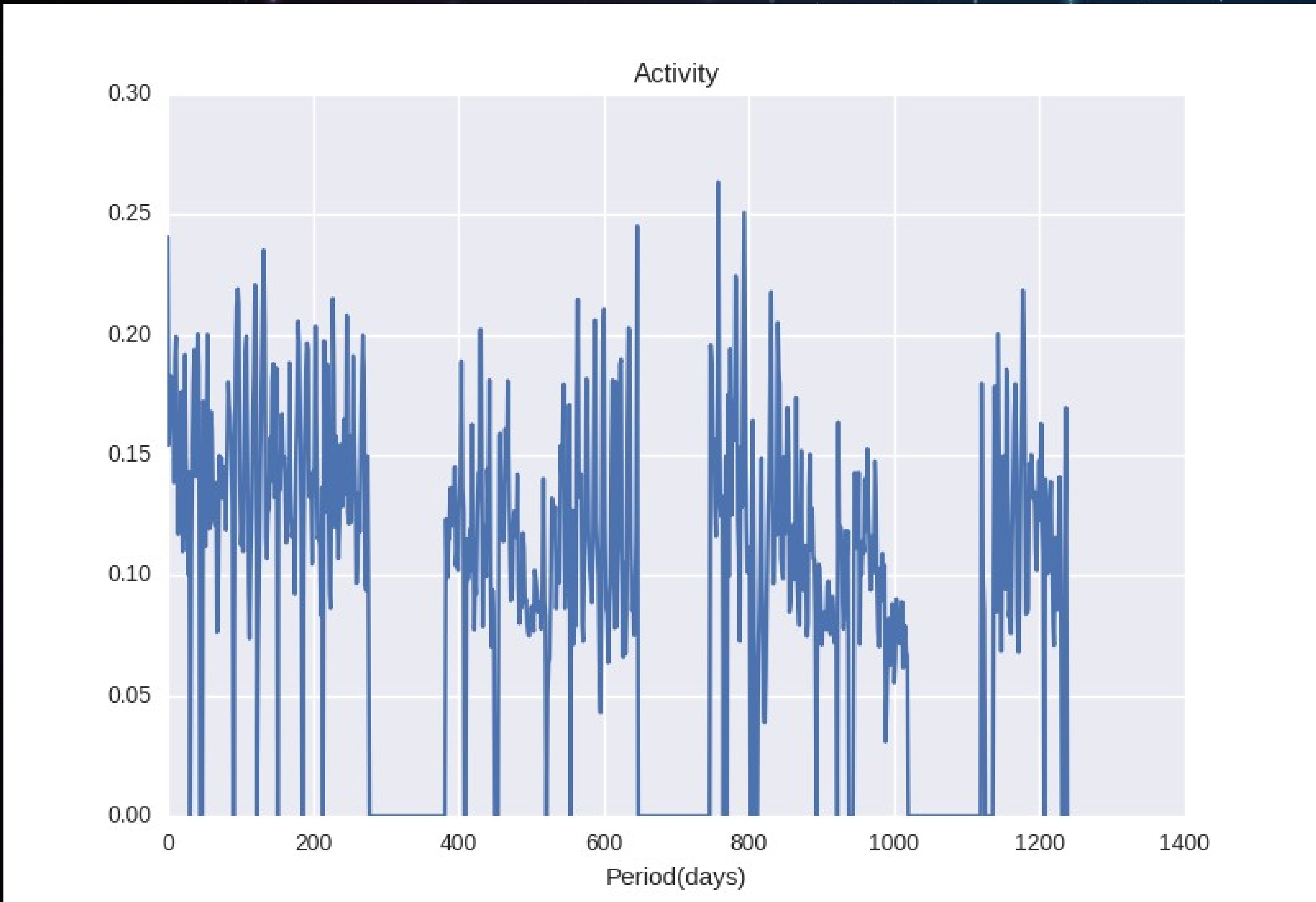
Magnetic Activity

100th transit – Kepler-17



592 transits analyzed

Magnetic Activity

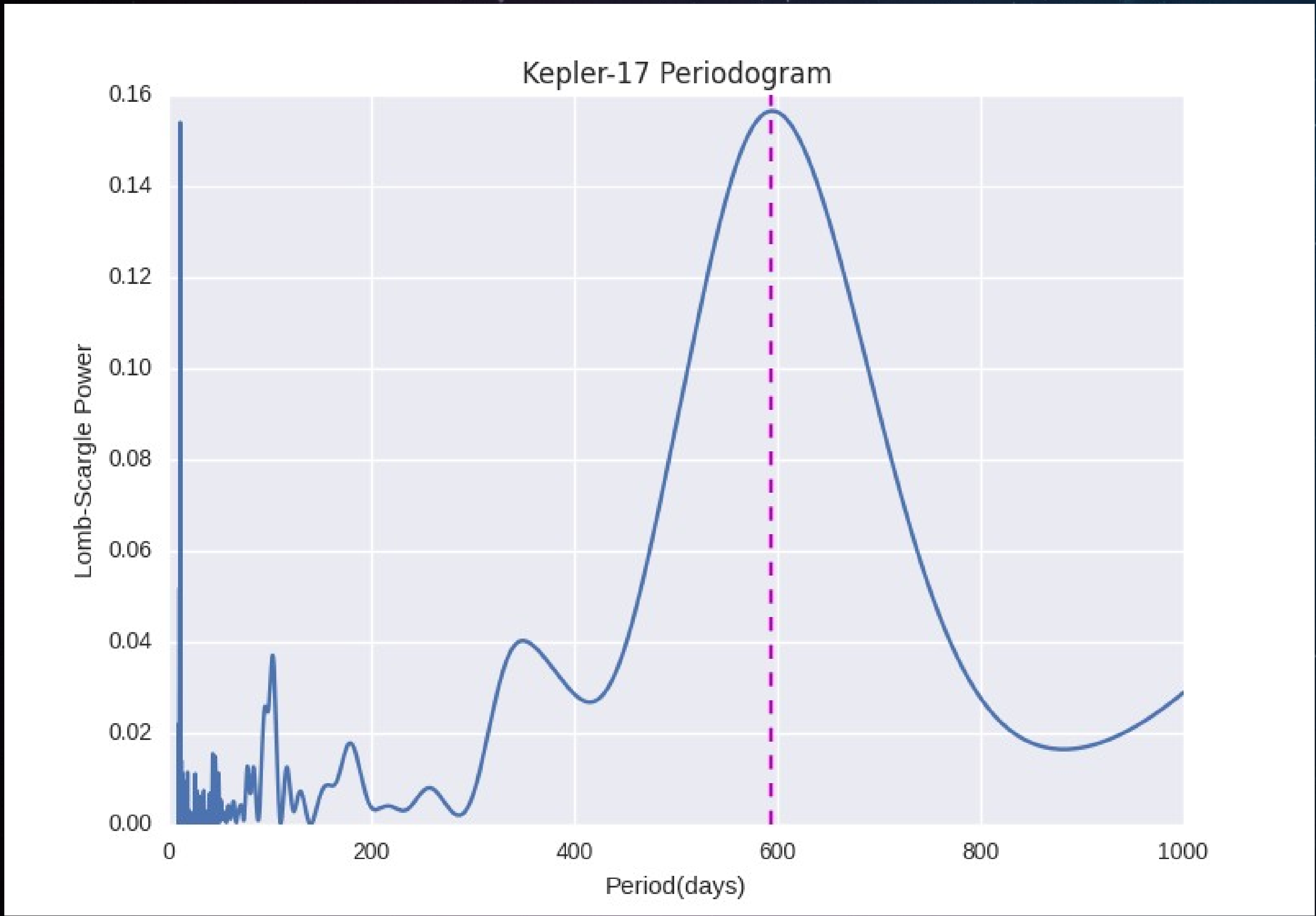


592 transits analyzed.

Levels of activity during ~ 4 years of observation.

Kepler-17 activity cycle

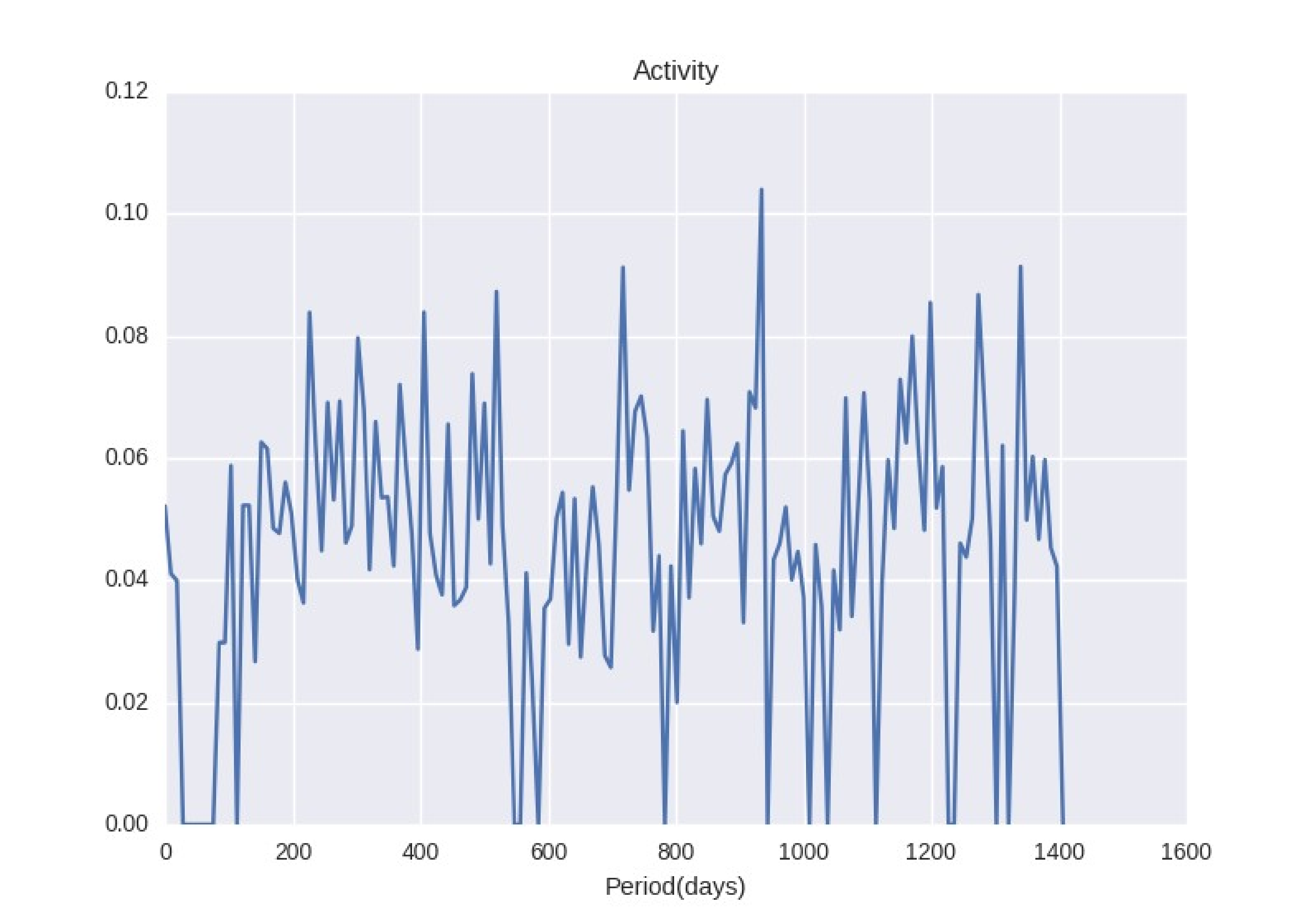
Lomb Scargle method



Magnetic cycle of 594 days or 1.62 yr.
Rotational period of 12 days.

Kepler-63

Magnetic activity

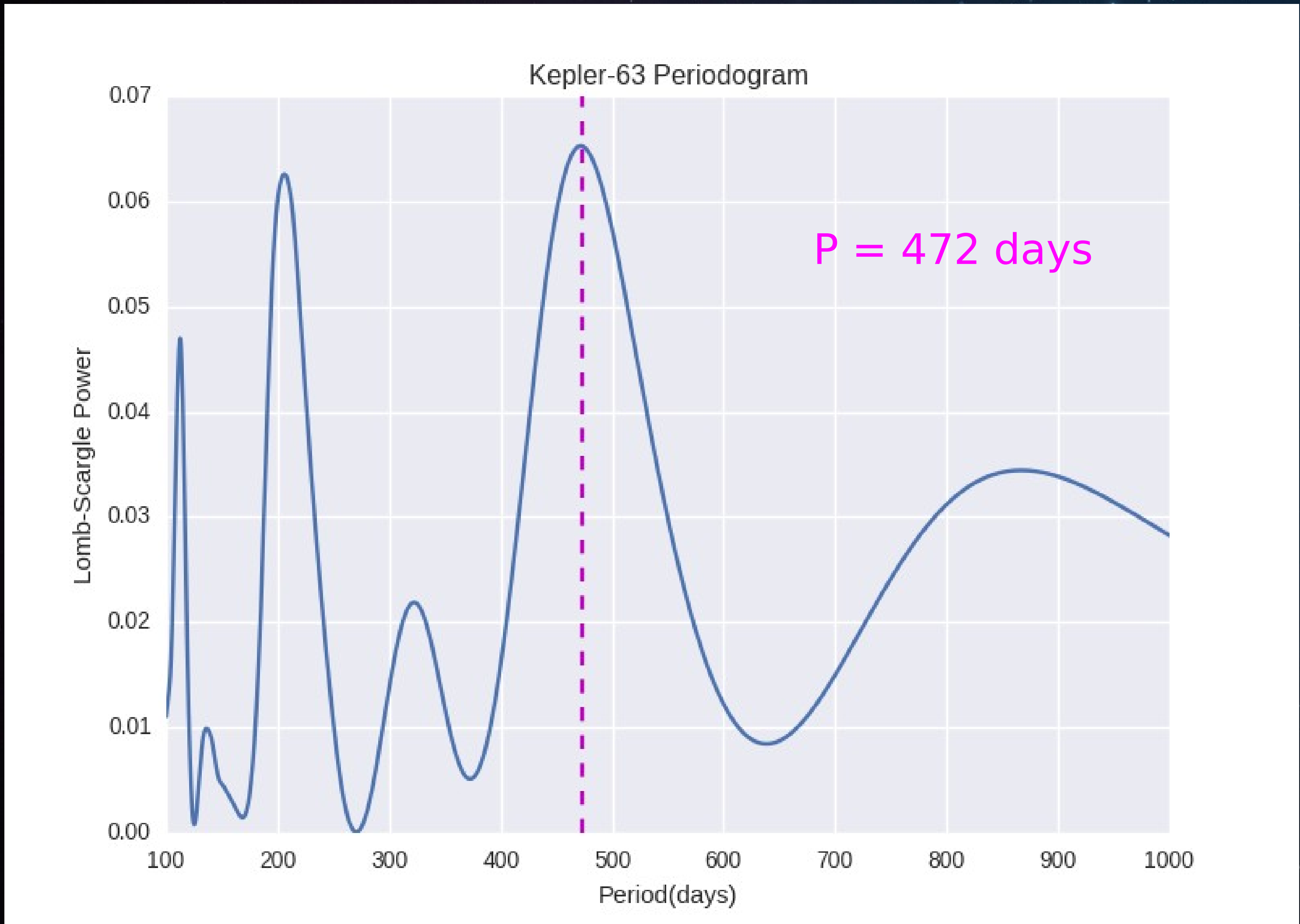


120 transits analyzed.

Levels of activity during ~ 4 years of observation.

Kepler-63 activity cycle

Lomb Scargle method



Magnetic cycle of 472 days or 1.29 yr.

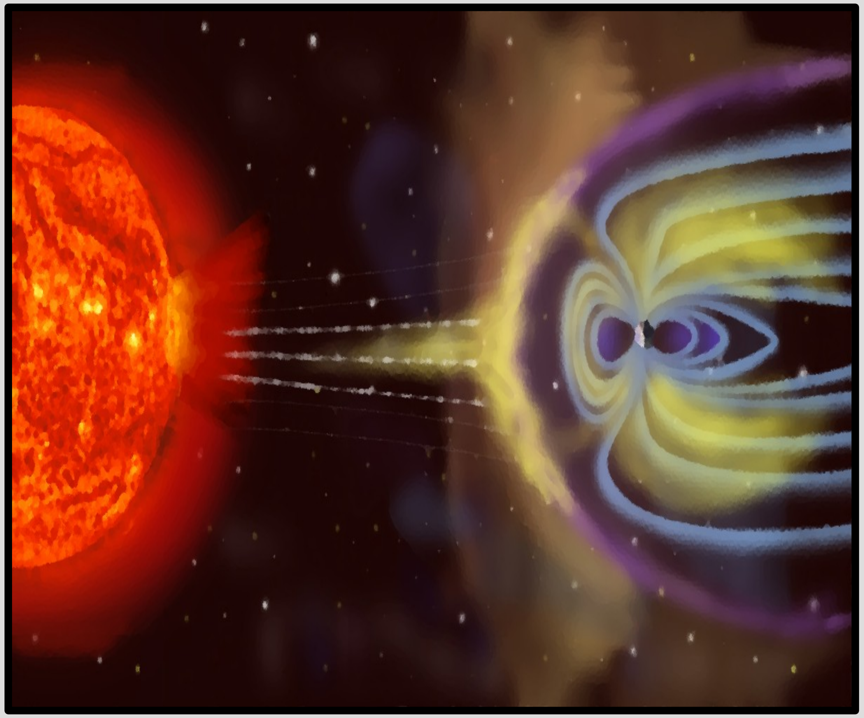
Activity cycles: summary

	Activity (residuals transits)	Number of spots	Flux deficit
Kepler-17	1.62yr	1.69yr	1.70yr
Kepler-63	1.29yr	1.30yr	1.30yr

Introduction

Methods and results:
1) Planetary Transit Model
2) Residuals transit lightcurves

► **Conclusions & Perspectives**



Conclusions

- By modelling small variations observed in transit light curves, we infered spots characteristics (size, intensity, temperature).

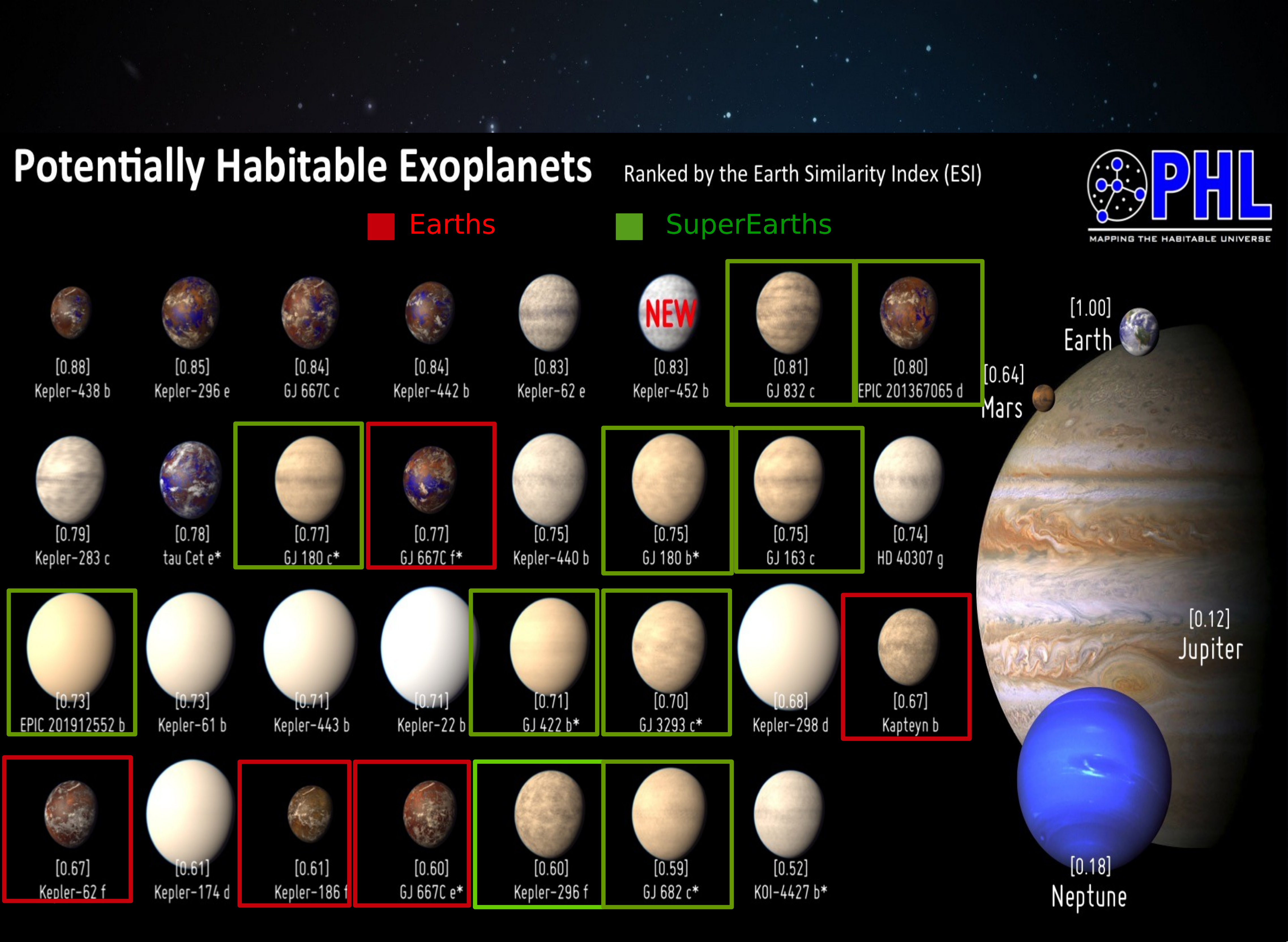
- From the analysis of both methods (Planetary Transit Model and Residuals transit lightcurves), we found **evidence of a magnetic cycle** with about 1.7 yr for Kepler-17 and 1.3 yr for Kepler-63.

- Despite the constraint of the 4 years period of observation of Kepler telescope, we could observe short cycles of activity in both stars.

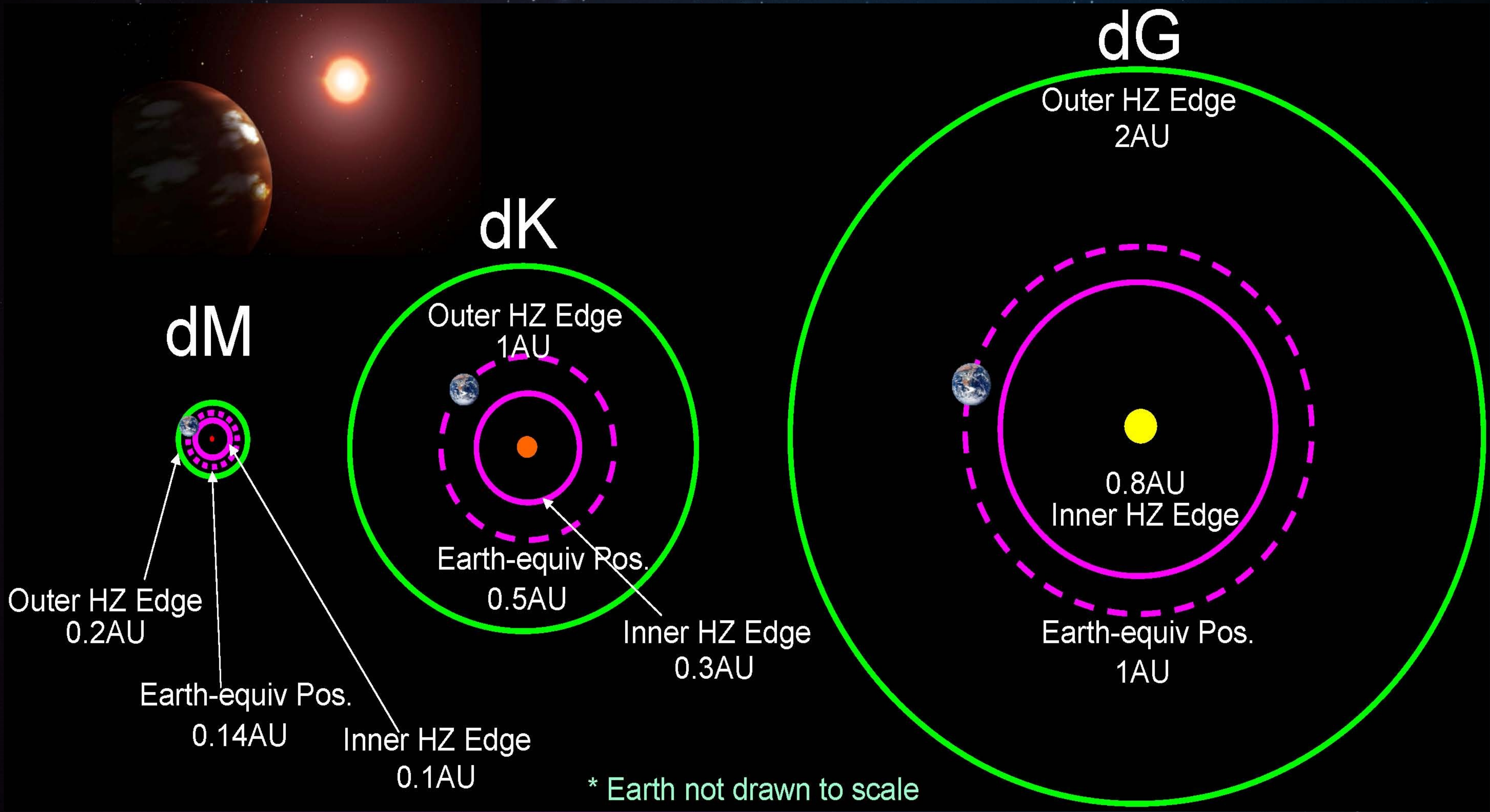
Perspectives

- Study the star-magnetic interaction in these stars.

- Analyze **M stars** and apply a model of star-planet magnetic interaction to planets in the habitable zone of these stars, for example:

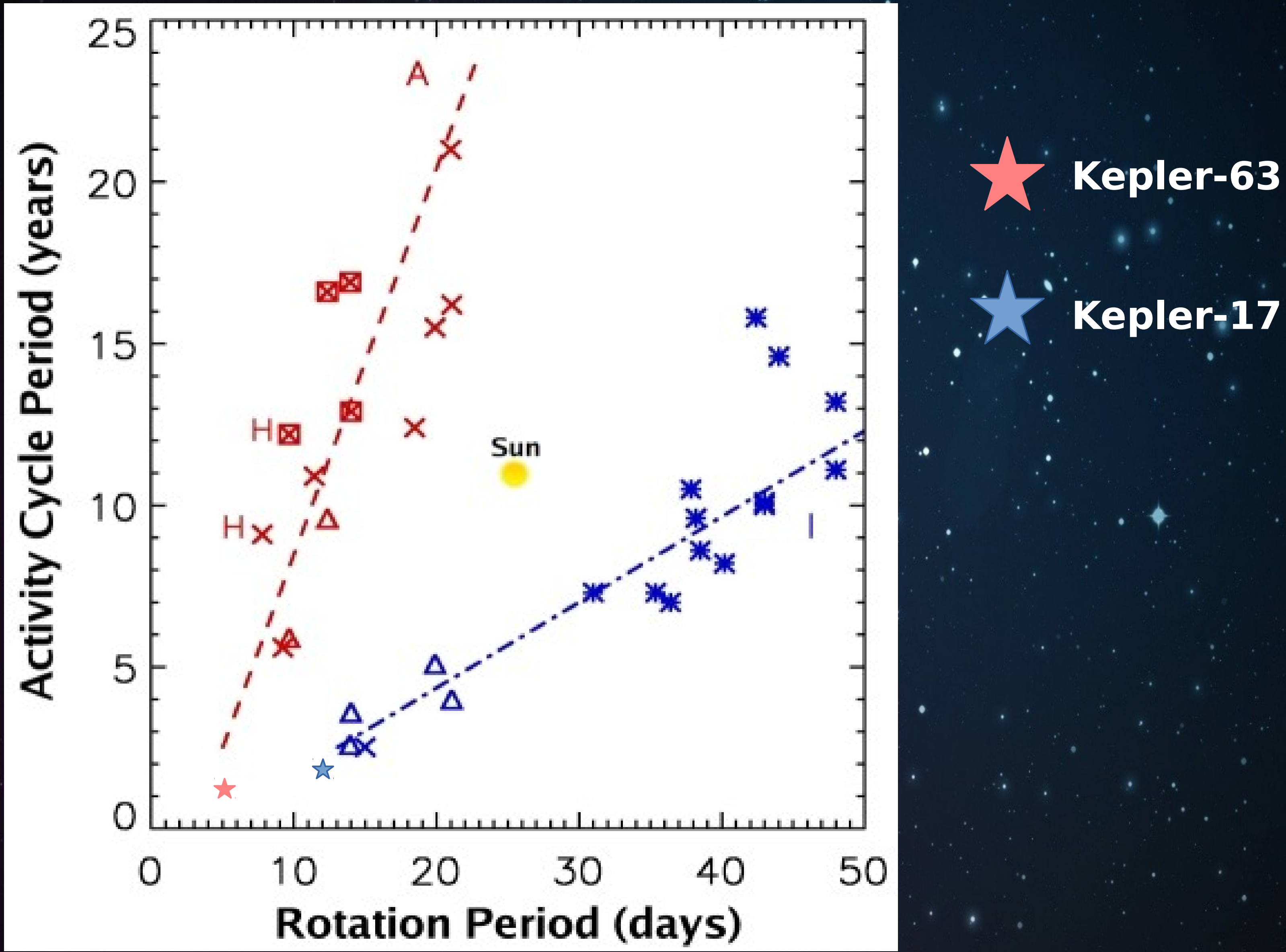


Potentially Habitable Exoplanets
Ranked by the Earth Similarity Index (ESI)
PHL
MAPPING THE HABITABLE UNIVERSE
Earths
SuperEarths
[0.88] Kepler-438 b
[0.85] Kepler-296 e
[0.84] GJ 667C c
[0.84] Kepler-442 b
[0.83] Kepler-62 e
NEW
[0.83] Kepler-452 b
[0.81] GJ 832 c
[0.80] EPIC 201367065 d
[0.79] Kepler-283 c
[0.78] tau Cet e*
[0.77] GJ 180 c*
[0.77] GJ 667C f*
[0.75] Kepler-440 b
[0.75] GJ 180 b*
[0.75] GJ 163 c
[0.74] HD 40307 g
[0.73] EPIC 201912552 b
[0.73] Kepler-61 b
[0.71] Kepler-443 b
[0.71] Kepler-22 b
[0.71] GJ 422 b*
[0.70] GJ 3293 c*
[0.68] Kepler-298 d
[0.67] Kapteyn b
[0.67] Kepler-62 f
[0.61] Kepler-174 d
[0.61] Kepler-186 f
[0.60] GJ 667C e*
[0.60] Kepler-296 f
[0.59] GJ 682 c*
[0.52] KOI-4427 b*
[1.00] Earth
[0.64] Mars
[0.12] Jupiter
[0.18] Neptune


dG
Outer HZ Edge
2AU
0.8AU
Inner HZ Edge
Earth-equiv Pos.
1AU
dK
Outer HZ Edge
1AU
Earth-equiv Pos.
0.5AU
Inner HZ Edge
0.3AU
dM
Outer HZ Edge
0.2AU
Earth-equiv Pos.
0.14AU
Inner HZ Edge
0.1AU
* Earth not drawn to scale

THANKS!

Exoplanetary Atmospheres and Habitability
12-16 Oct 2015, Observatoire de la Côte d'Azur, Nice (France)
http://exoatmo.sciencesconf.org/



Activity Cycle Period (years)
Rotation Period (days)
Sun
A
H
H
I
0
5
10
15
20
25
0
10
20
30
40
50
Kepler-63
Kepler-17