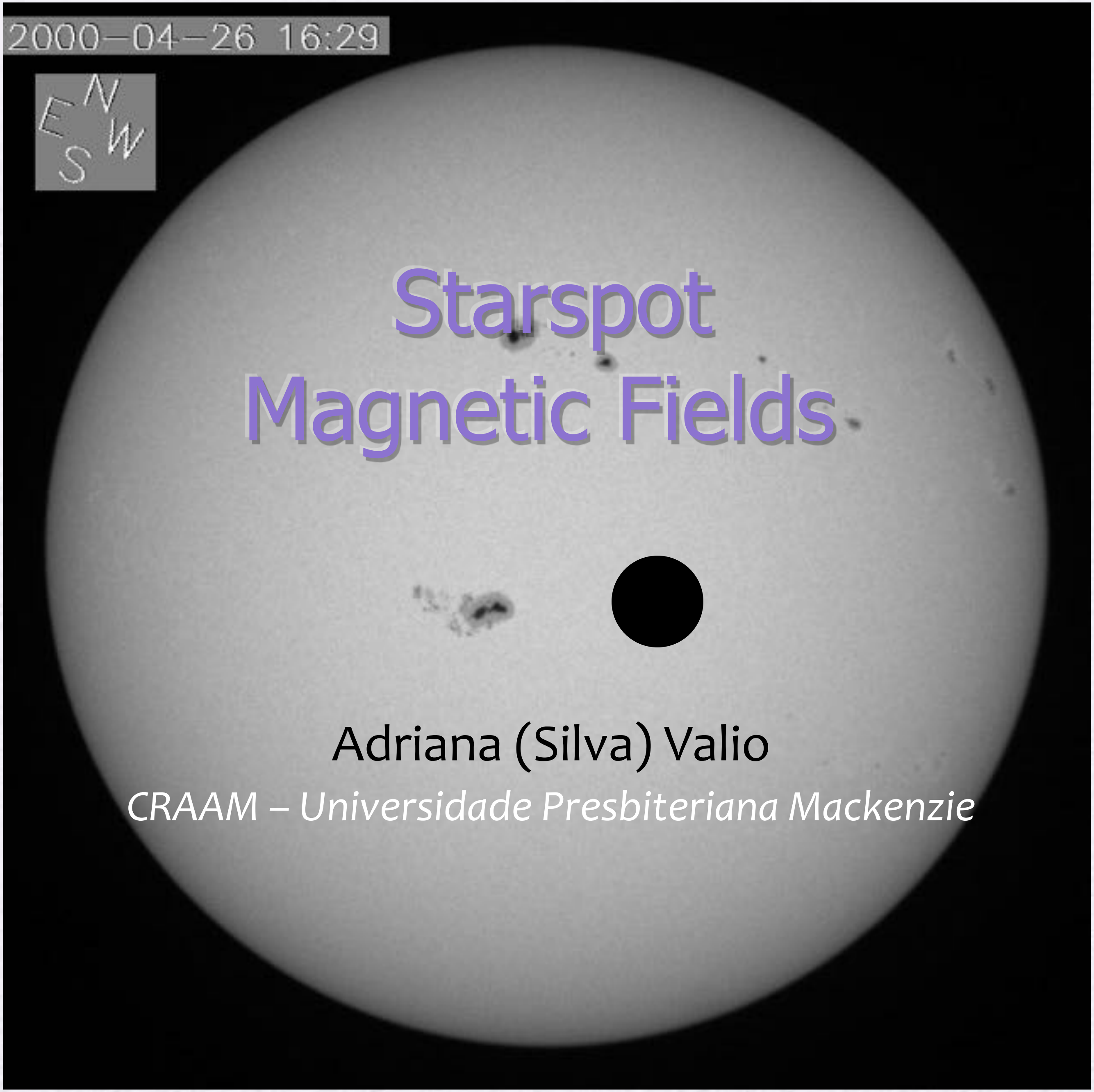
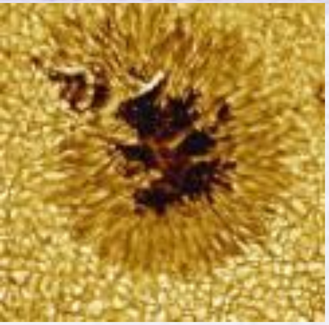


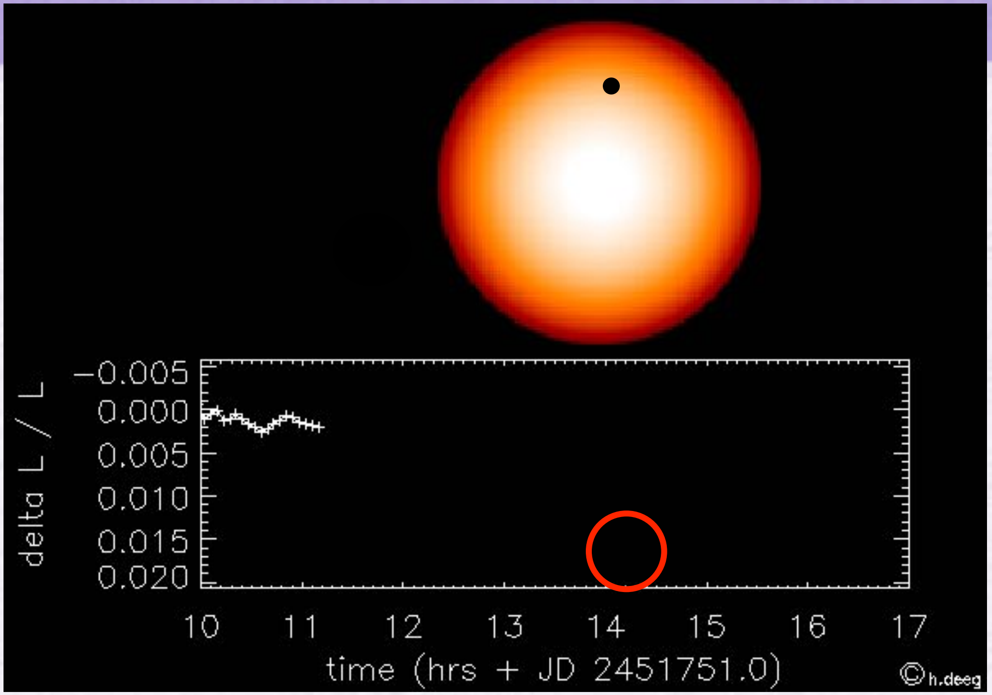
Starspot Magnetic Fields

Adriana (Silva) Valio

CRAAM – Universidade Presbiteriana Mackenzie

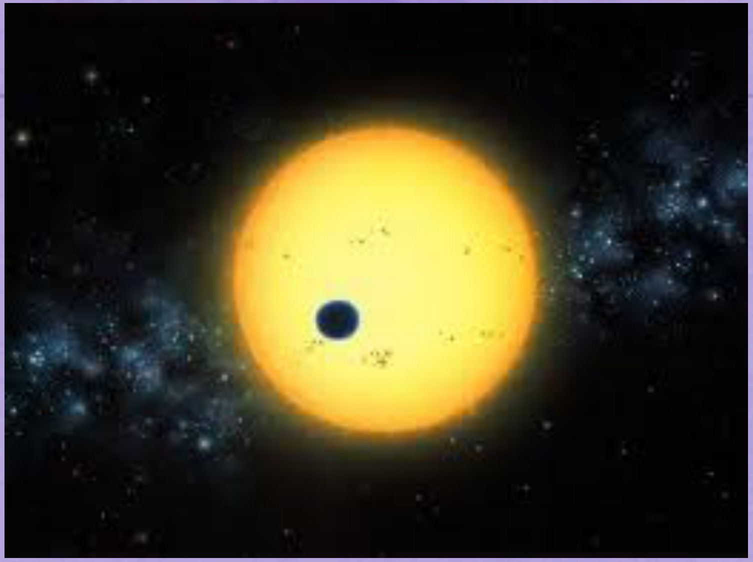
Spot detection during transit





- Very likely, all cool stars with a convective envelope like the Sun will have spots on their surfaces
- 2731 (74%) of them transit their host star (31/07/2017);
- 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;

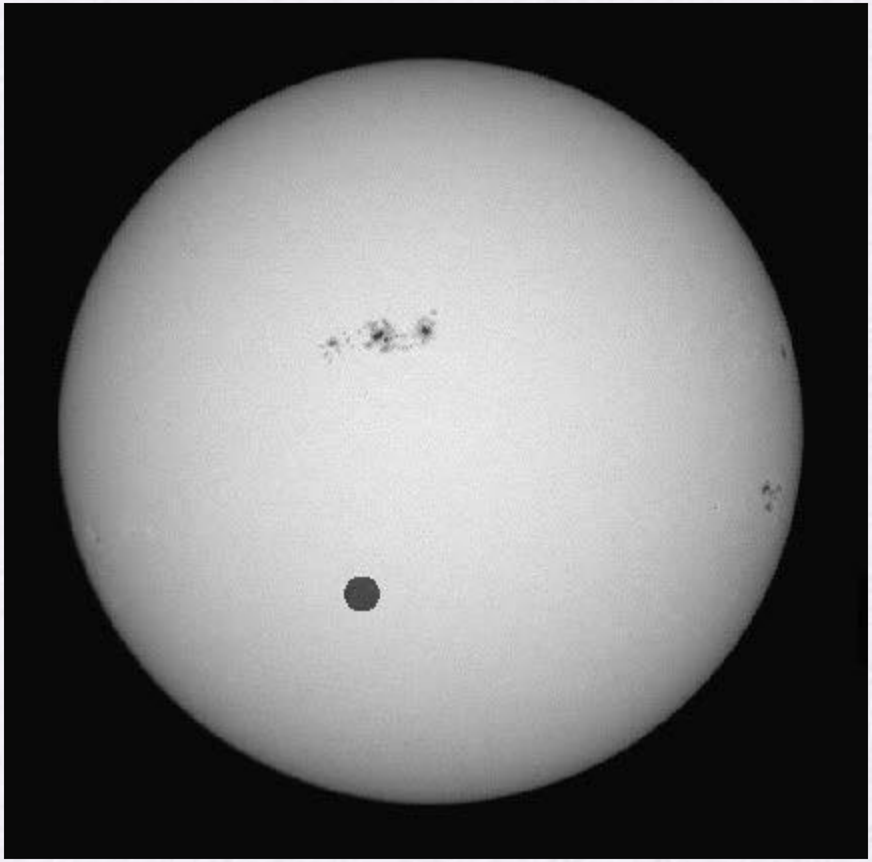
Planetary Transit Model



Starspots

- Method that simulates planetary transits: uses the planet as a probe to study starspots (Silva, ApJ Letters, 585, L147-L150, 2003)
- Stellar activity - infer spots physical characteristics:
    - Size (area coverage)
    - Intensity – temperature – magnetic fields
    - Location (long & lat)
- Stellar properties:
    - Rotation period
    - Differential rotation
    - Activity cycle

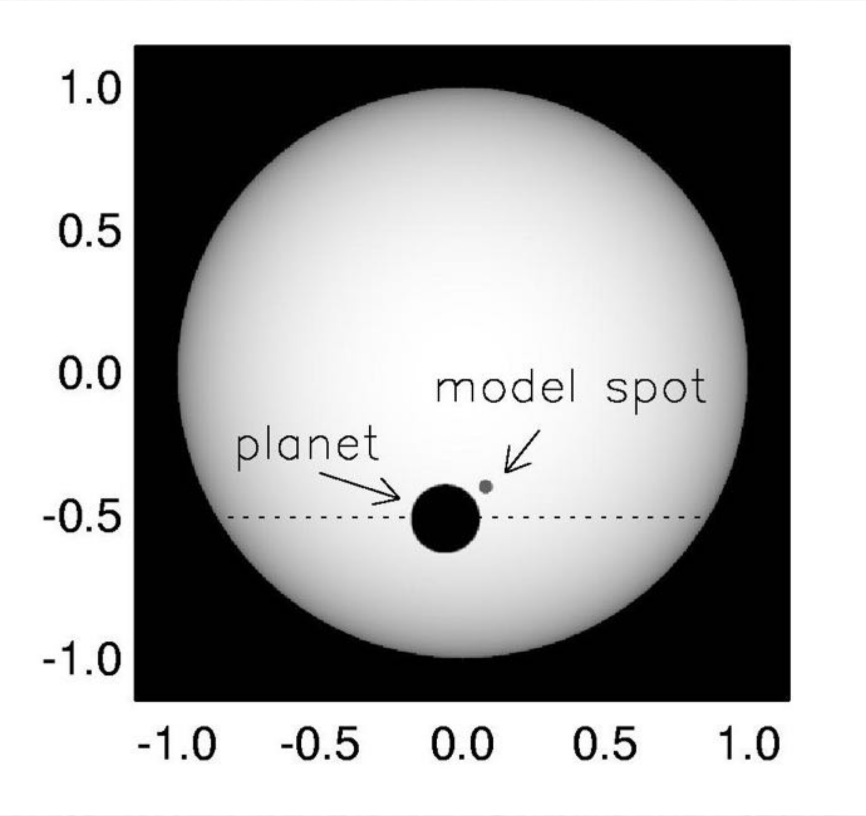
Transit Model



- Star: image of the Sun or a synthesized image of a star with limb darkening;
- Planet: opaque disk of radius r/R_s
- Transit: every 2 min, the planet is centred at its calculated position in a circular orbit (a_{orb}/R_s and i) with zero obliquity.
- Light curve flux is the sum of all pixels in the image.
- Input parameters: P_{orb}, r/R_s, a_{orb}/R_s, and i

Spot model

- Spot: 3 parameters:
  - Intensity: measured with respect to stellar maximum intensity (center);
  - Size: measured in units of planetary radius;
  - Position: Longitude and Latitude (restricted to the transit band).
- Foreshortenning taken into account



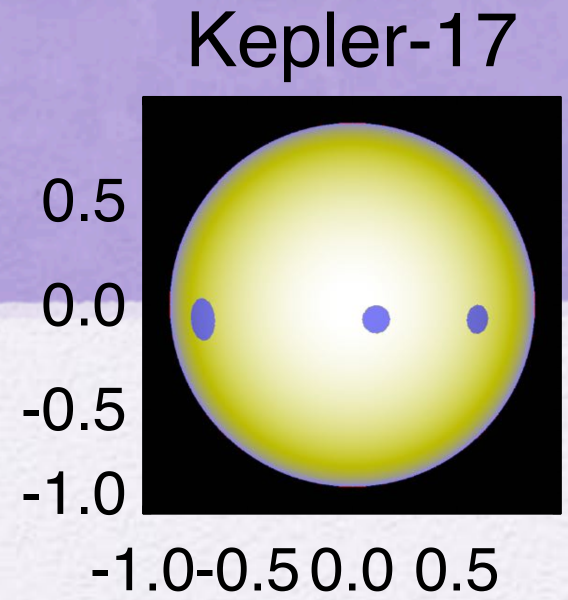
Modeling of observations:

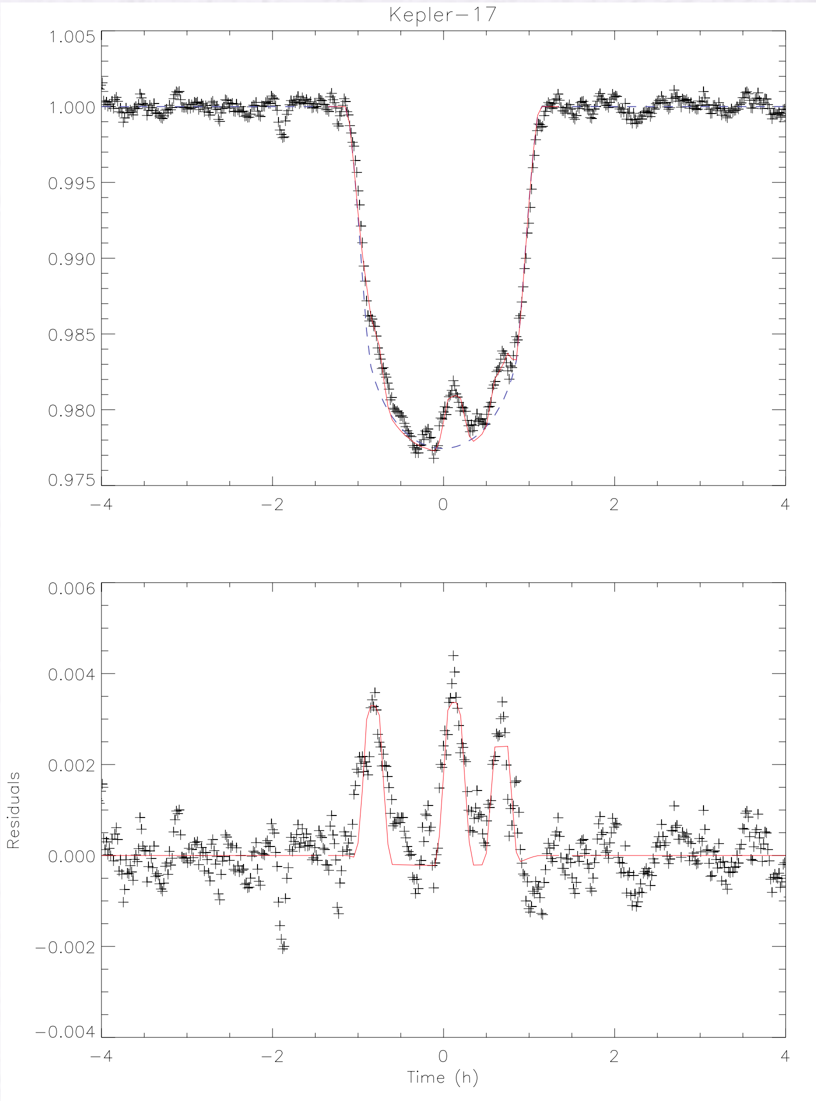
CoRoT and Kepler stars

Stellar and Planetary parameters

Star	CoRoT-2	CoRoT-4	CoRoT-5	CoRoT-6	CoRoT-8	CoRoT-18	Kepler-17
Spectral type	G7V	F8V	F9V	F9V	K1V	G9V	G2V
Mass (M_{sun})	0.97	1.10	1.0	1.055	0.88	0.95	1.16
Radius (R_{sun})	0.902	1.17	1.19	1.025	0.77	1.0	1.05
Prot (d)	4.54	8.87	26.6	6.35	21.7	5.4	12.28
Teff (K)	5625	6190	6100	6090	5080	5440	5781
Age (Gyr)	0.13-0.5	0.7-2.0	5.5-8.3	1.0-3.3	2.0-3.0	?	>1.78
Planet							
Mass (M_{jup})	3.31	0.72	0.467	2.96	0.22	3.47	2.45
Radius (M_{star})	0.172	0.107	0.120	0.117	0.090	1.31	1.312
Porb (d)	1.743	9.203	4.038	8.886	6.212	1.90	1.49
a (R_{star})	6.7	17.47	9.877	17.95	17.61	6.35	5.31
Latitude (°)	-14.6	0	-47.2	-16.4	-29.4	-22.8	-4.6

Data fit

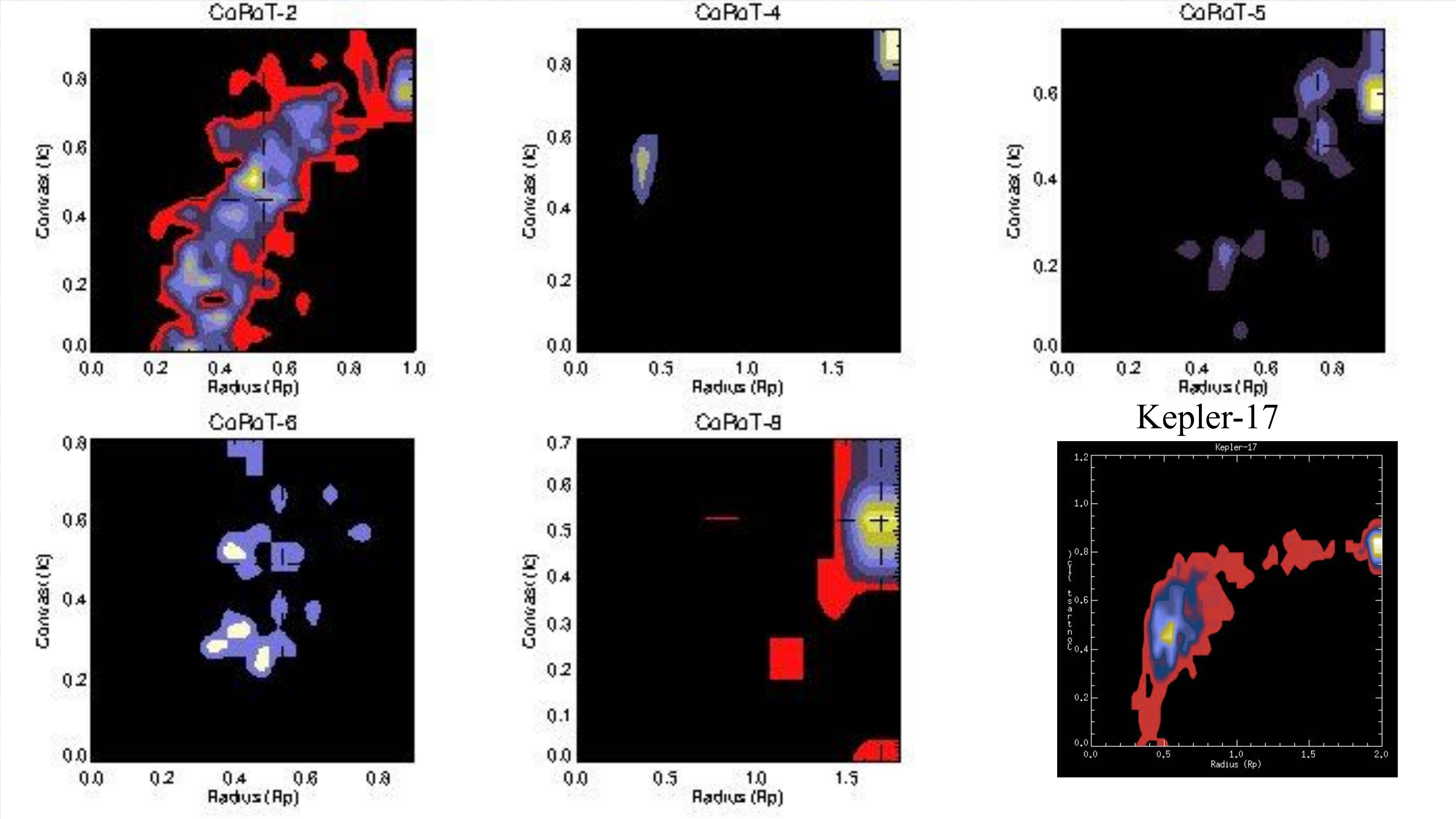




- N spots per transit, at fixed Latitude
- Fit parameters:
  - Longitude: between -70º and +70º
  - Intensity: 0 – 1 I_c
  - Radius: f_a R_p

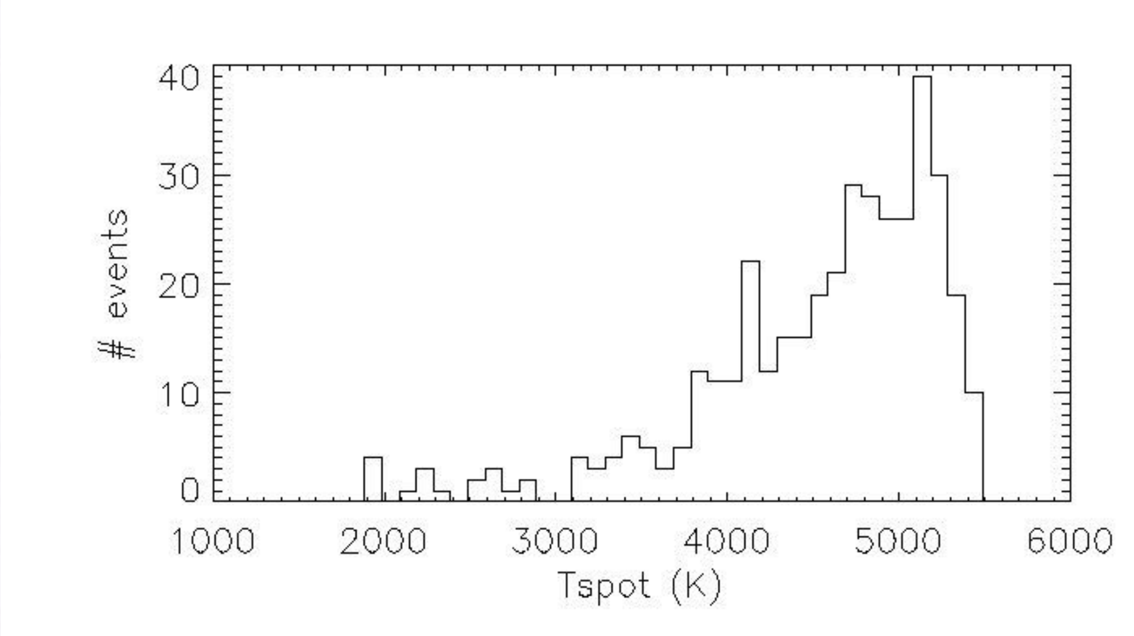
Spots characteristics

Results: spots size x intensity



Intensity to temperature

- Black body emission for stellar photosphere and spots

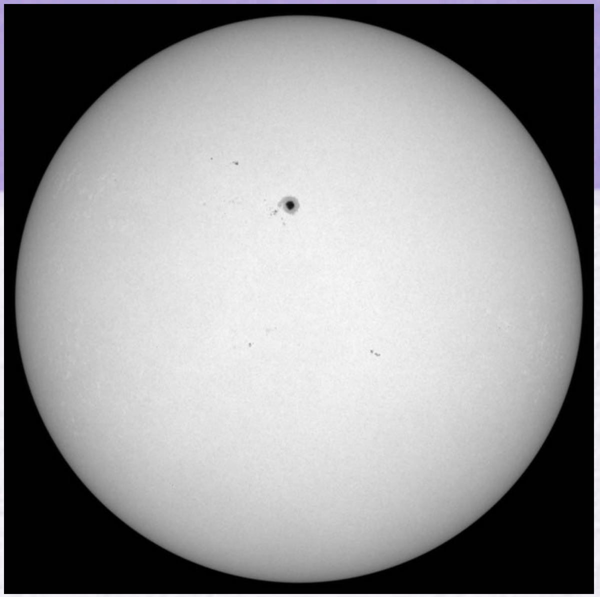


$$\frac{I_o}{I_e} = \frac{\exp\left(\frac{h\upsilon}{KT_e}\right) - 1}{\exp\left(\frac{h\upsilon}{KT_o}\right) - 1}$$

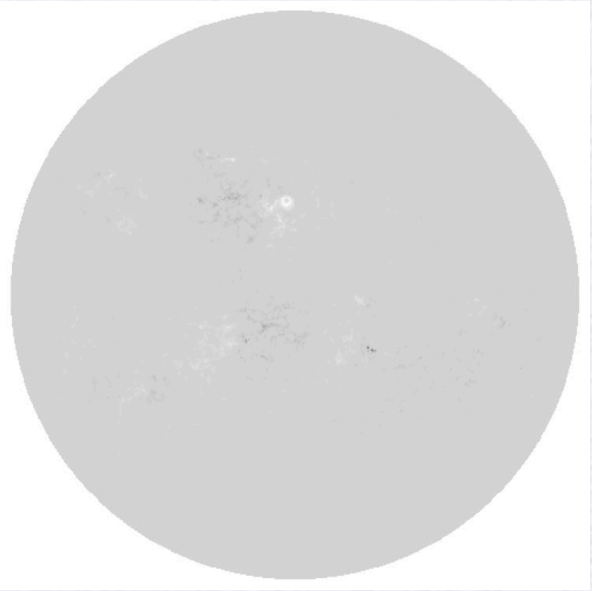
- T_{eff}= 5625 K (CoRoT-2)
- T_{spot} = 4700 $\pm$ 300 K (Sun: 3500 – 4500 K)

Eduardo Spagiari

Sunspots



- Empirical relation between the intensity of sunspots and their magnetic field.
- Solar data from the MDI instrument on board the SOHO satellite.
- A total of 2132 spots were identified within the solar images twice a month for cycle 23 (1996-2007).
- Only spots located between longitudes -40º and 40º were analysed.
- Sunspot area and average intensity with respect to the central disk intensity were determined
- The magnetic field was estimated from the corresponding magnetograms, both the maximum and minimum magnetic intensity were recorded within the same area used in the white light images.

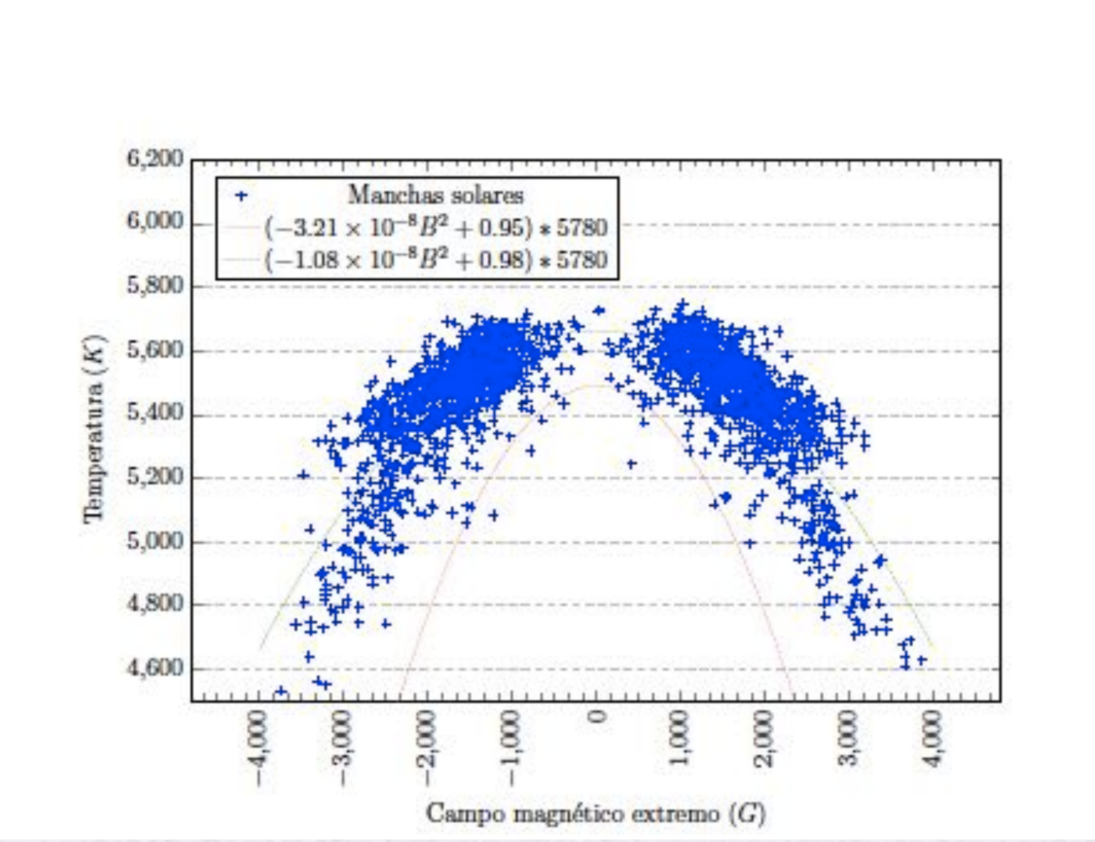


Sunspots T(B)

- Following Dicke (1970): $\boxed{\frac{T}{T_e} = -3{,}21 \cdot 10^{-8} \cdot \mathrm{B}^2 + 0.95}$

$$\boxed{\frac{T}{T_e} = \alpha \cdot \mathrm{B}^2 + \sigma}$$

	B_{max}
α	(-1.08 ± 0.04) x 10^{-8}
σ	0.98 ± 0.03

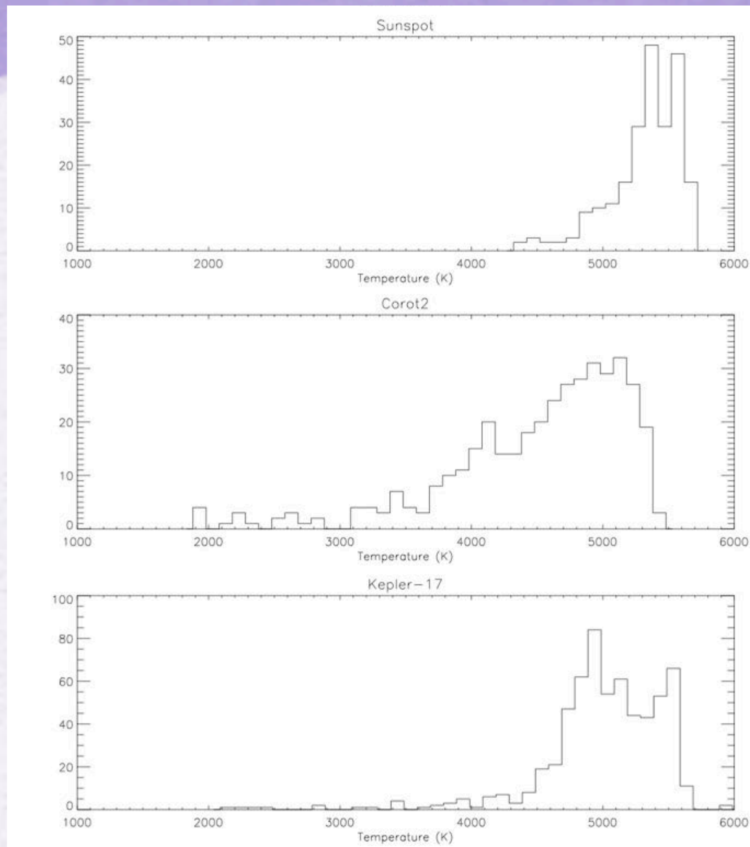


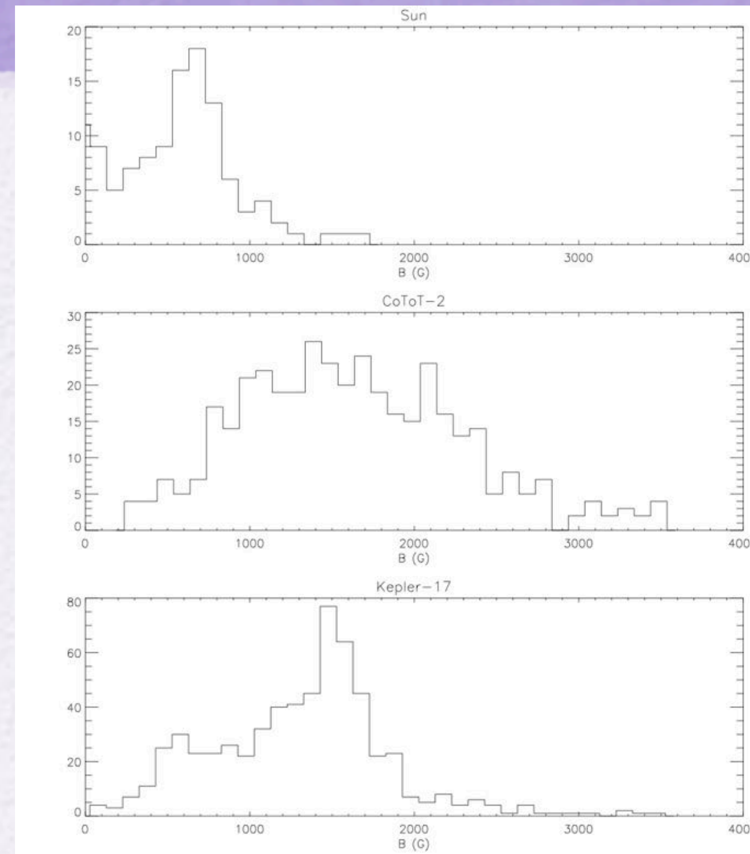
Other stars

- Two stars with transiting planets were analyzed: CoRoT-2 (T_{eff}=5575 K) and Kepler-17 (T_{eff}=5781 K).
- Small variations in the transit light curves of these stars have been fit yielding the characteristics of:
  - 392 spots - CoRoT-2
  - 615 spots - Kepler-17
- Spot intensity => Temperature => Magnetic Field

$$\boxed{\frac{T}{T_e} = -1.08 \times 10^{-8} \cdot \mathrm{B}^2 + 0.98 \Rightarrow B = 9622\sqrt{0.98 - \frac{T}{T_e}}}$$

B_{max}





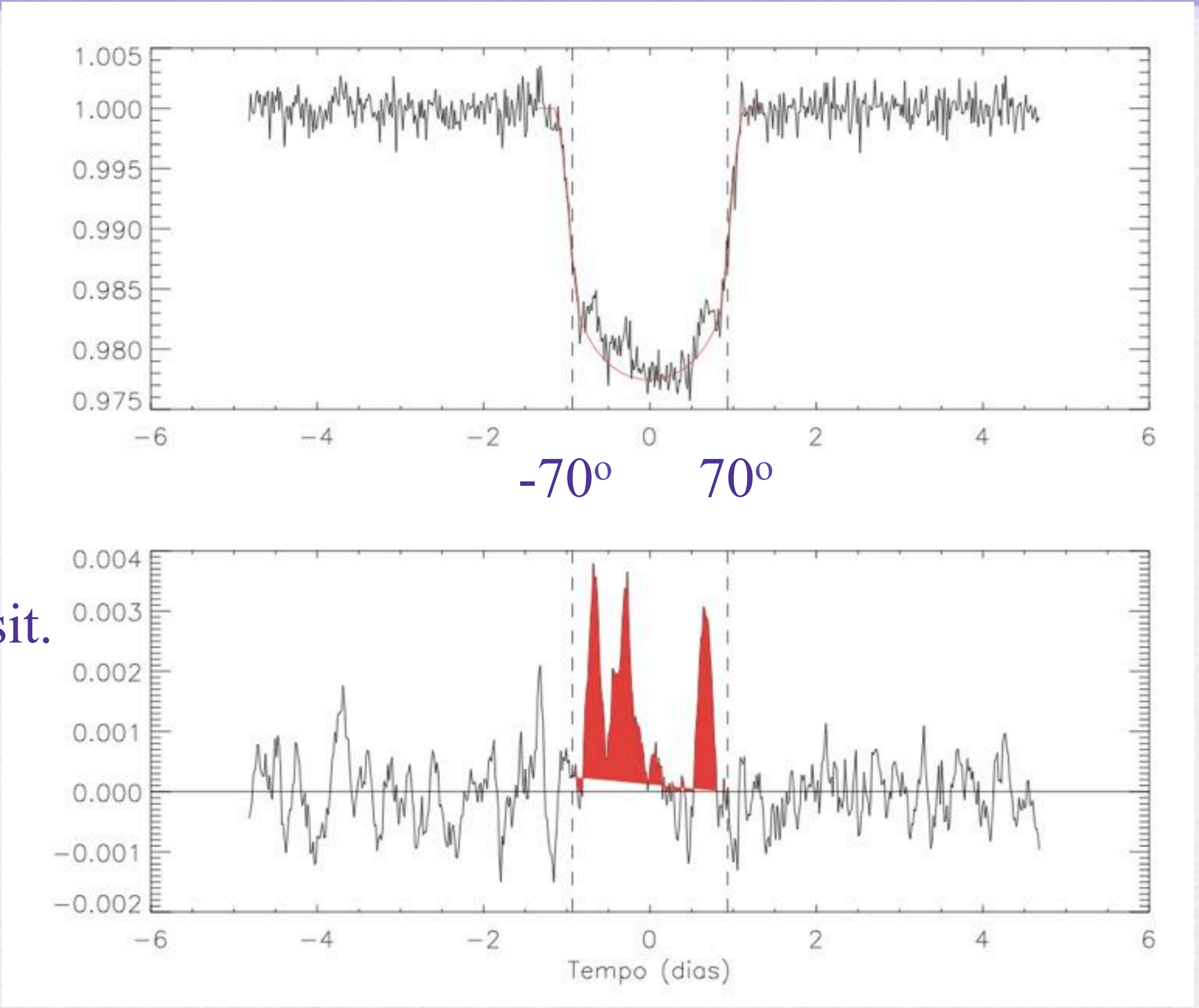
Star	B_{max} (Gauss)
Sun	700 $\pm$ 350
CoRoT-2	1700 $\pm$ 700
Kepler-17	1400 $\pm$ 500

Spots characteristics

Star	CoRoT-2	CoRoT-4	CoRoT-5	CoRoT-6	CoRoT-8	CoRoT-18	Kepler-17	Sun
Radius (Mm)	55$\pm$19	51$\pm$14	75$\pm$17	48$\pm$14	82$\pm$21	65$\pm$19	80$\pm$50	12$\pm$10
Area (%)	13	6	13	9	29	13	11	< 1
Tspot (K)	4600$\pm$700	5100$\pm$500	5100$\pm$600	4900$\pm$600	4400$\pm$600	4800$\pm$600	5100$\pm$500	4800$\pm$400
T_{eff} (K)	5625	6190	6100	6090	5080	5440	5780	5780
B_{max} (G)	1700 $\pm$ 700						1400 $\pm$ 500	700 $\pm$ 350

Magnetic Cycles

Magnetic activity

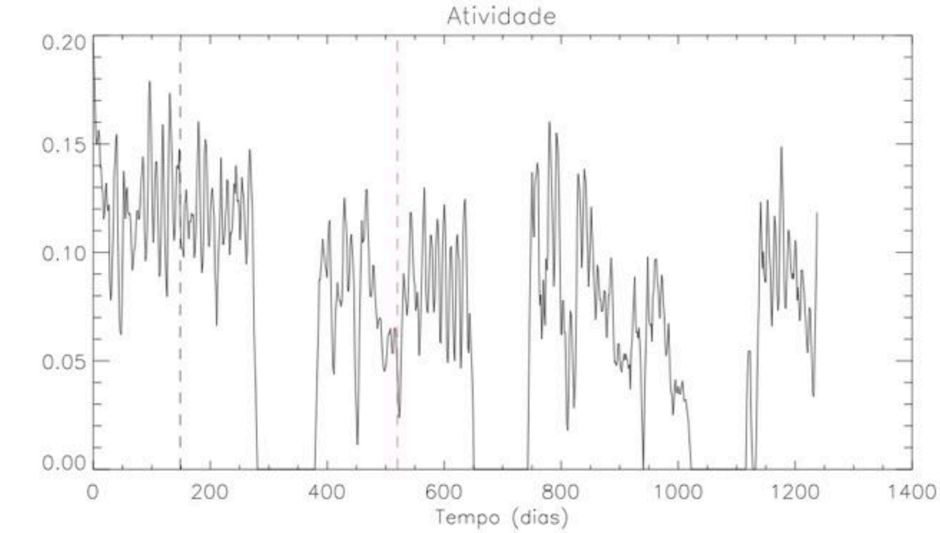


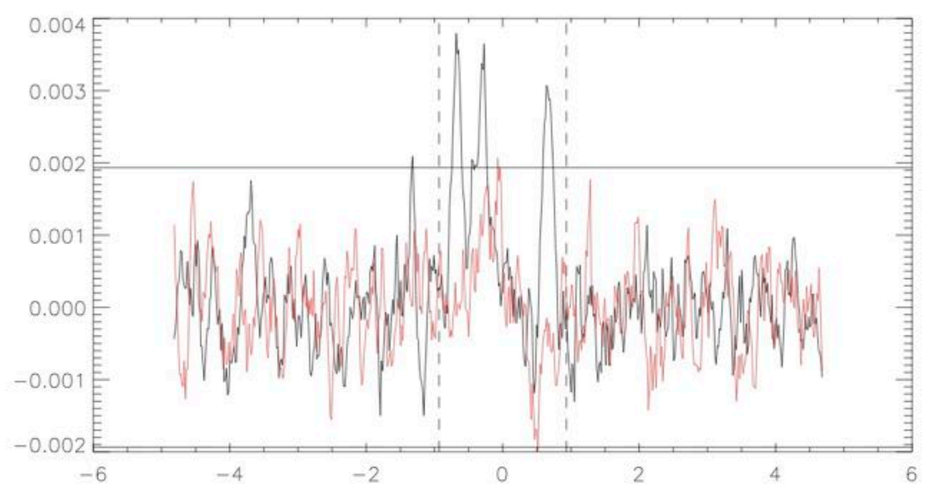
-70º 70º

Kepler-17

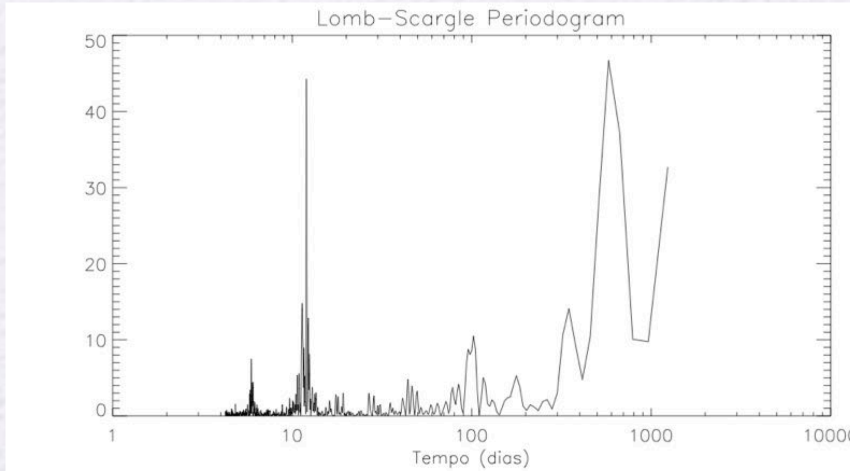
100th transit.

Magnetic cycle



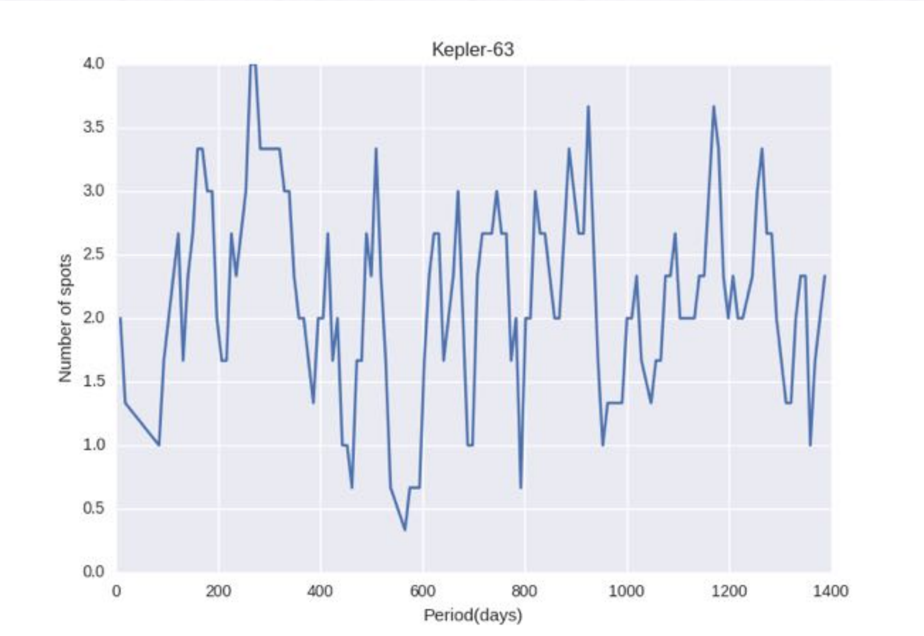


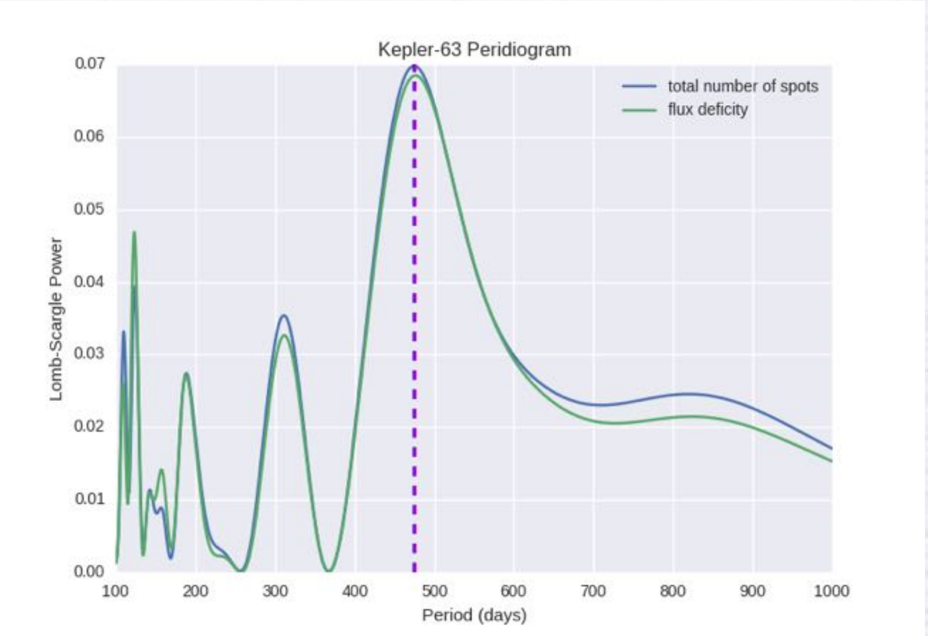
- Magnetic activity cycle of 579 days or 1.58 year
- Rotation period of 12.4 d



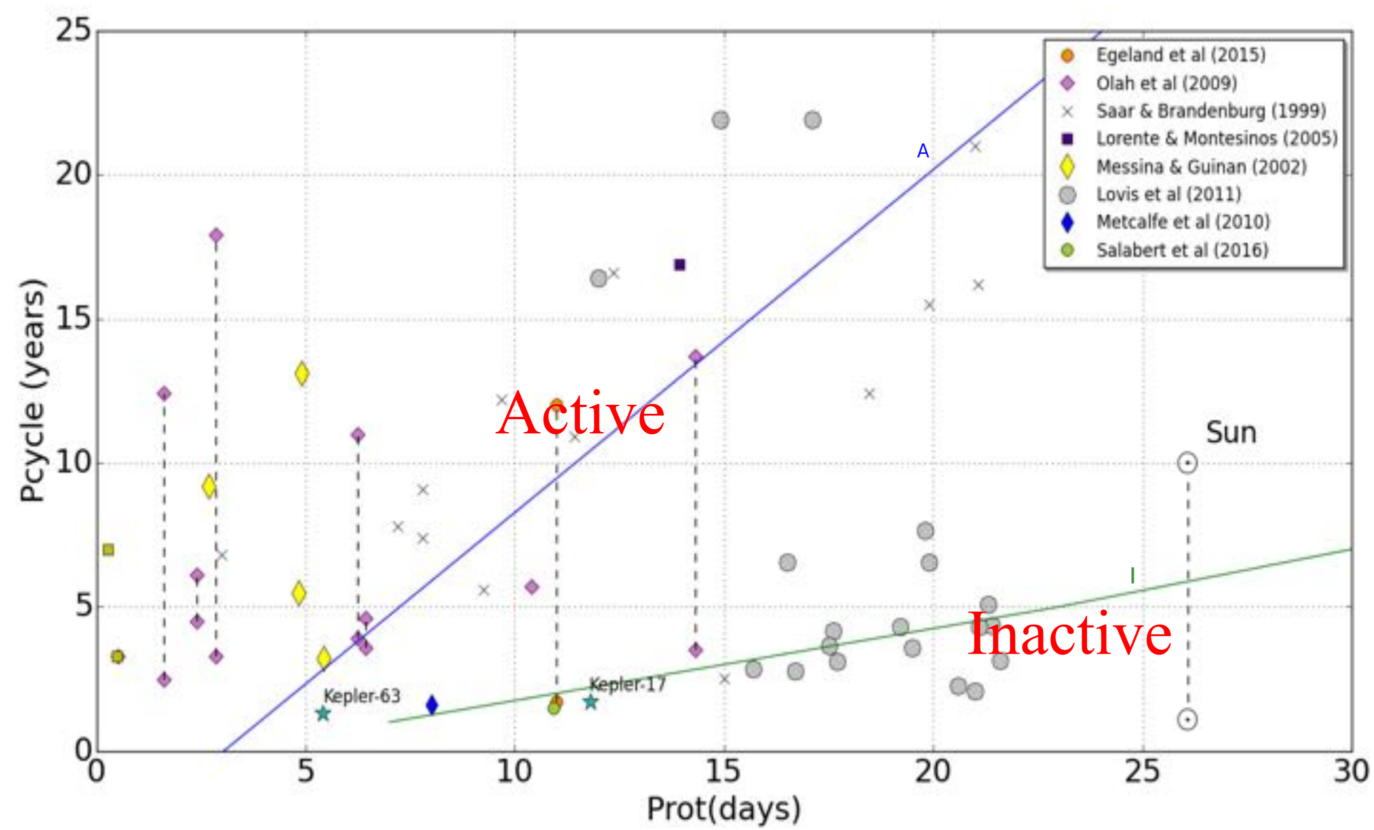
Kepler-63

P = 1.3 yr





P_{cycle} x P_{rot}



Summary

- Assuming that the decrease in intensity is caused by intense magnetic fields, and that the relation follows that of the Sun:

$$\boxed{\frac{T}{T_e} = -1.08 \times 10^{-8} \cdot \mathrm{B}^2 + 0.98 \Rightarrow B = 9622\sqrt{0.98 - \frac{T}{T_e}}}$$

- Applied to CoRoT-2 and Kepler-17 yields max magnetic fields of 1700 and 1400 G;
- Evidence of a magnetic cycle with about 1.6 yr for Kepler-17 and 1.3 yr for Kepler-63.

Conclusion

- The modelling of small variations observed in the transit light curves yields:
  - ❖ Spots physical characteristics (size, temperature, location – active longitudes, evolution/lifetime, surface area coverage, magnetic fields) - *(Silva 2003, ApJL, 585, L147)*
- Multiple transits:
  - ❖ Stellar rotation *(Silva-Valio 2008, ApJL, 683, L179)*
  - ❖ Stellar differential rotation *(Silva-Valio et al. 2010, A&A, 510, 25, Silva-Valio & Lanza 2011, A&A, 529, 36)*
- For longer observing period:
  - ❖ Stellar activity cycles

OBRIGADA!

IDL and Python code ECLIPSE available

Email: adrivalio@gmail.com