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
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

11 year cycle of the Sun

Carroll and Ostlie, 2007
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

→ 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

I. PLANET
MAGNETIC RECONNECTION (WEAK FIELD)

II. PLANET

III. PLANET
MAGNETIC RECONNECTION (STRONG FIELD)

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

(Shkolnik et al., 2003)
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 accelerated by magnetic reconnection (Lanza, 2013)
Star-Planet magnetic interaction

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

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

Conclusions & Perspectives
Method 1

Planetary Transit Model
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.

Spots → Characterized by 3 parameters:

- **Intensity**: measured with respect to stellar maximum intensity (center);
- **Size**: measured in units of planetary radius
- **Position**: Latitude (restricted 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 (± 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
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**: $5000 \pm 600 K$

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

\[
T_0 = \frac{K}{h\nu \ln \left( \frac{I_e}{I_m} \left( e^{h\nu/K T_e} - 1 \right) + 1 \right)}
\]
Total of 297 spots.

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

P1 = 620 days
P2 = 624 days
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 \textbf{flux deficit} subtracted from a star by the presence of spots:

\[ F \propto (1 - f_i)(R_{\text{spot}})^2 \]
Stellar magnetic cycles

- Number of spots
- Total flux deficit
Stellar magnetic cycles

Lomb Scargle method: Number of spots and Flux deficit

Kepler-63 Periogram

- Total number of spots
- Flux deficit

P1 = 475 days
P2 = 477 days

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**

![Kepler-63 Periodogram](image)

- Magnetic cycle of 472 days or 1.29 yr.
- $P = 472$ days

Kepler-63 Periodogram

Lomb-Scargle Power

Period (days)

Exoatmo Workshop, Nice 12/10  Estrela, R & Valio, A.
## Activity cycles: summary

<table>
<thead>
<tr>
<th></th>
<th>Activity (residuals)</th>
<th>Number of spots</th>
<th>Flux deficit</th>
</tr>
</thead>
<tbody>
<tr>
<td>Kepler-17</td>
<td>1.62yr</td>
<td>1.69yr</td>
<td>1.70yr</td>
</tr>
<tr>
<td>Kepler-63</td>
<td>1.29yr</td>
<td>1.30yr</td>
<td>1.30yr</td>
</tr>
</tbody>
</table>
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 inferred 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)

- Earths
- SuperEarths

[Diagram showing various exoplanets and their ESI values, with Earth, Mars, Jupiter, and Neptune indicated.]
THANKS!

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