Temporal variability of the wind from the star τ Boötis

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5th BCool Meeting, February 2016

Understanding winds is important...

- Stellar evolution: Mass loss, angular momentum loss and spin-down.

Image Credit: NASA
Understanding winds is important...

- Planet habitability: planetary atmosphere stripping
But observing them is hard...

- Can only be observed directly in the most extreme cases:
But observing them is hard…

- Can be observed indirectly:

So we model them instead!

Wood et al. (2004)
Study Aim:

To model the wind of the planet-hosting star $\tau$ Boötis (Tau Boo) based on magnetic field information obtained from 8 sets of spectropolarimetric observations taken from May 2009 to January 2015, and estimate the wind properties and its impact on the planet.
Stellar Wind Modelling with BATSRUS

- Block-Adaptive Tree Solar-wind Roe Upwind Scheme (BATSRUS) is a 3D MHD code created to simulate the solar wind.

- Grid structure that can be refined in areas of interest to save computational resources.

- A modular code that can be adapted to model the wind of other stars.
Stellar Wind Modelling with BATSRUS

Input:
- Stellar parameters
- Radial magnetic field maps, reconstructed using Zeeman Doppler Imaging

Output at each point of the 3D grid:
- Plasma velocity
- Plasma density
- Plasma pressure
- Magnetic field
- Current
τ Boötis (Tau Boo)

An F7V star with a 1:1 tidally-locked, close-in Hot Jupiter with mass 5.6 $M_{\text{Jupiter}}$

Parameters for the simulation:

- Mass = 1.341 $M_{\text{Sun}}$
- Radius = 1.46 $R_{\text{Sun}}$
- $v \sin i = 14.98$ km/s
- Equatorial Rotation Period = 3.0 days
- Coronal Base Temperature = $2 \times 10^6$ K
- Coronal Base Density = $8.36 \times 10^{-16}$ g cm$^{-3}$

It has been previously shown to have a magnetic cycle of ~740 days
Stellar Wind Modelling with BATSRUS

**Input:**
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- Plasma velocity
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Radial Magnetic Field of Tau Boo

Longitude (deg)

Latitude (deg)
Simulation Results:
Extended Global Magnetic Field

Jan 2015
Simulation Results:
Extended Global Magnetic Field
Simulation Results: Global Wind Parameters

- Surface magnetic flux ($\times 21.8 \times 10^{22}$ Mx)
- Angular momentum loss rate ($\times 1.78 \times 10^{32}$ ergs)
- Mass loss rate ($\times 2.31 \times 10^{-12} M_\odot \text{ yr}^{-1}$)

Time (HJD +2450000)
Simulation Results:Wind Around the Planet

Stellar magnetic field strength at \( \tau \) Boo b \( \times 2.7 \times 10^{-2} \) G
Total wind pressure \( \times 1.19 \times 10^{-3} \) dyn cm\(^{-2}\)
Ratio of planetary magnetospheric radius to planetary radius \( \times 3.6\)

Time (HJD +2450000)
Simulation Results:
Pressure on the Planet

- Total Pressure
- Ram Pressure
- Thermal Pressure
- Magnetic Pressure

Time (HJD +2450000)
Pressure (x10^{-4} Dyn cm^{-3})
Simulation Results: Wind Around the Planet

Stellar magnetic field strength at τ Boo b (× 2.7 ×10^{-2} G)
Total wind pressure (× 1.19 ×10^{-3} dyn cm^{-2})
Ratio of planetary magnetospheric radius to planetary radius (× 3.6)

Time (HJD +2450000)
Summary: The Wind of Tau Boo

- Mass loss rates vary only slightly over the cycle.
- Angular momentum loss rates vary with the changing magnetic field of the star.
- Whilst the wind environment of the planet is varying greatly, the planet’s magnetosphere (assuming it is similar to that of Jupiter) is expected to remain relatively stable.