The GAPS Programme with HARPS-N@TNG: what about star-planet magnetic interaction in τ Boo?

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1. Rationale

- The **Global Architecture of Planetary Systems** (**GAPS**) project is a joint effort of italian researchers interested in exoplanets, in collaboration with a few experts abroad. The GAPS team manages a long-term observation program with the high-precision HARPS-N spectrograph (Cosentino et al. 2012) at the **Telescopio Nazionale Galileo** (TNG, La Palma, Canary Islands).
- The characterization of tidal and/or magnetic Star-Planet Interactions (SPI) is one of the tasks of the GAPS project.
- In particular, stellar magnetic fields are expected to interact with the magnetospheres of close-in Jupiter-mass planets. Magnetic stresses and reconnection events may produce heating of stellar and planetary atmospheres, and enhanced chromospheric/coronal emission.
- Detection of these effects may allow to characterize the planetary magnetospheres, and to study feedback effects, such as the evaporation of planetary atmospheres.
- We have chosen τ Bootis as a test case for studies of short-term **photospheric and chromospheric variability** with high-resolution optical spectra, as tracer of possible SPIs. We also tested the same data for assessing stellar **differential rotation** and **asteroseismological oscillations**.

2. Target and observation

Host star: **τ Bootis**, F7IV-V, $M_* = 1.3\ M_\odot$, at D = 15.6 pc. **Planet** (Butler et al. 1997): $M_p = 5.95 \pm 0.28\ M_J$, a = 0.048 AU, P_{orb}= 3.3 days, i=44.5±1.5° (Brogi et al. 2012).

P_{orb} synchronized with stellar rotation period (Donati et al. 2008). Persistent dark spots in phase with P_{orb} (Walker 2008), suggesting star-planet interaction. Switching of magnetic polarity with a 1-2 yr period (Fares et al. 2009).

Observed almost daily for 11 nights in Apr 2013. Coadding 30×1 min exposures we reached S/N ratios ≅ 2000 / in the core of the H line.

3. Analysis of CCF profiles

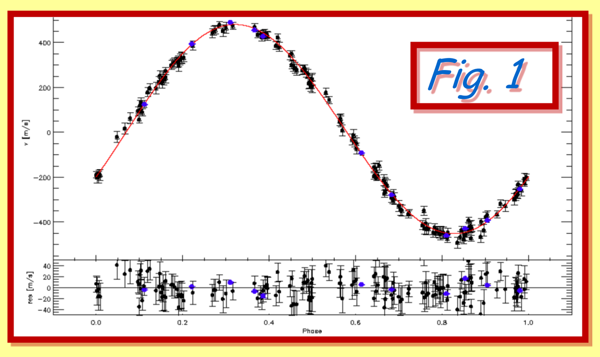

Fig. 1

The Radial Velocity (RV) is computed with the Cross-Correlation Function method (Pepe et al. 2002), using a custom mask for τ Boo. Phase-folded RVs are shown in Fig. 1 together with data taken from literature.

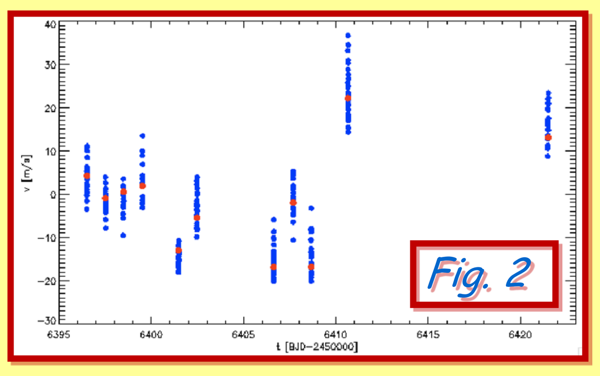

Fig. 2

The RV residuals show a trend in time (Fig. 2) which correlates with the Bisector Span (BS) of the CCF profile (Fig. 3). This result suggests variability due to stellar activity during the observing campaign.

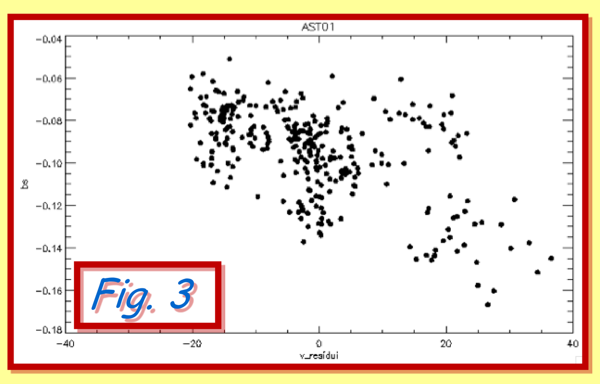

Fig. 3

4. Analysis of activity tracers

We considered the CaII H & K lines, the Na I D_{12} doublet, the He I D_3 triplet, and the Hα line (Fig. 4).

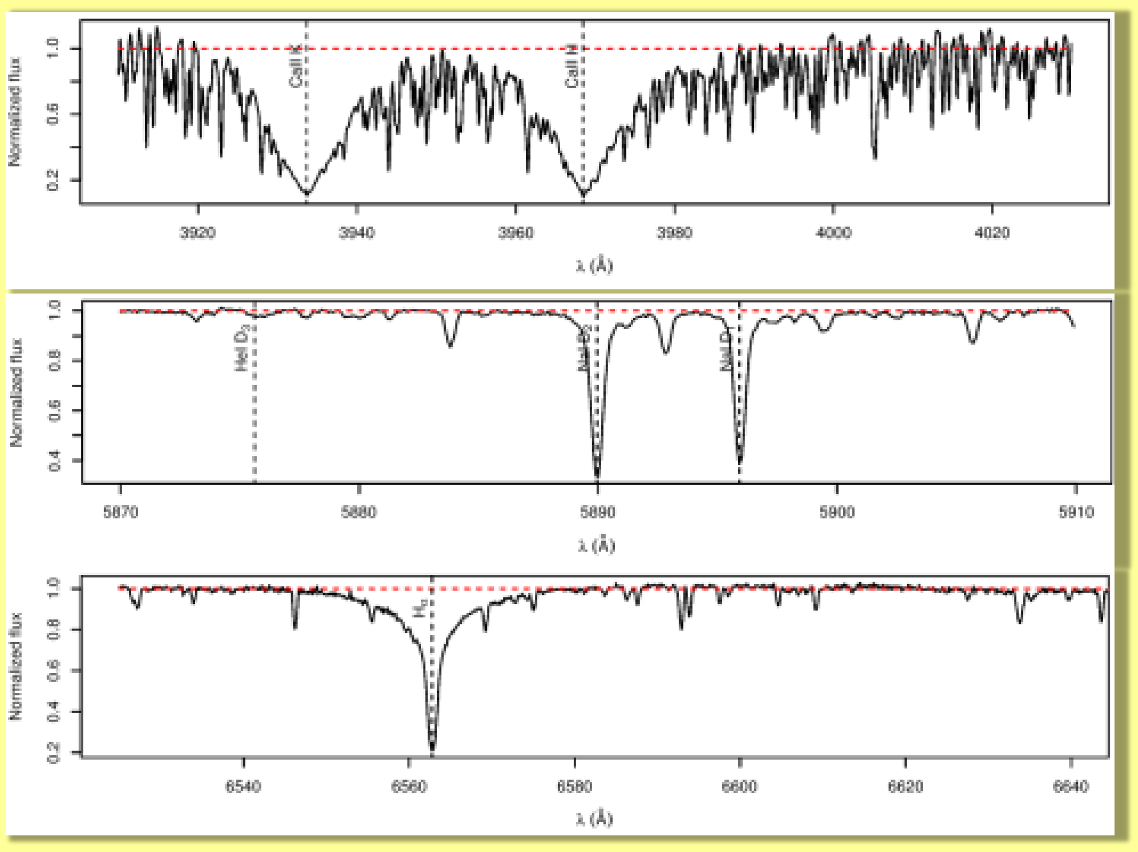

Fig. 4: Activity diagnostics in HARPS-N spectra

After a careful correction for contamination due to telluric lines, we computed residuals of each spectrum with respect to the median of all spectra (Fig. 5), and then we integrated the residuals over a ~ 1Å window around the line center so to obtain Integrated Deviations (IDs in Fig. 6).

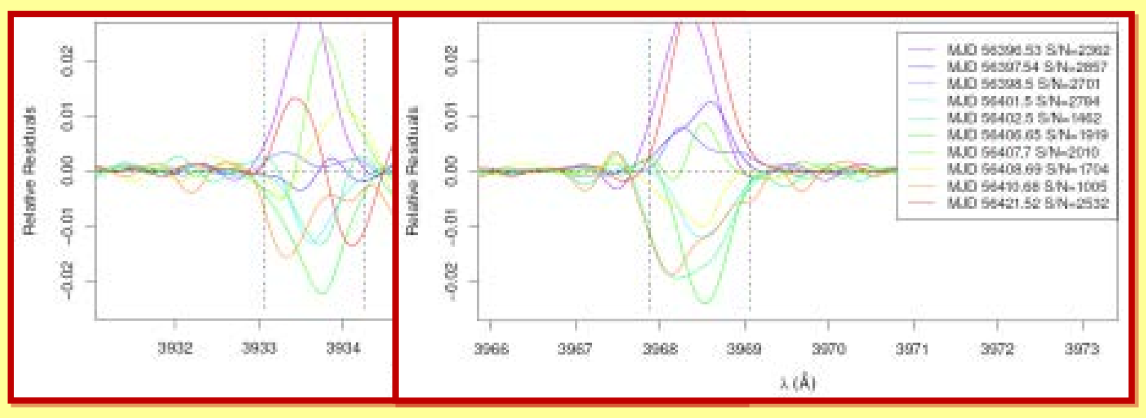

Fig. 5: Variability in H & K line cores with respect to the median (reference) spectrum of τ Boo

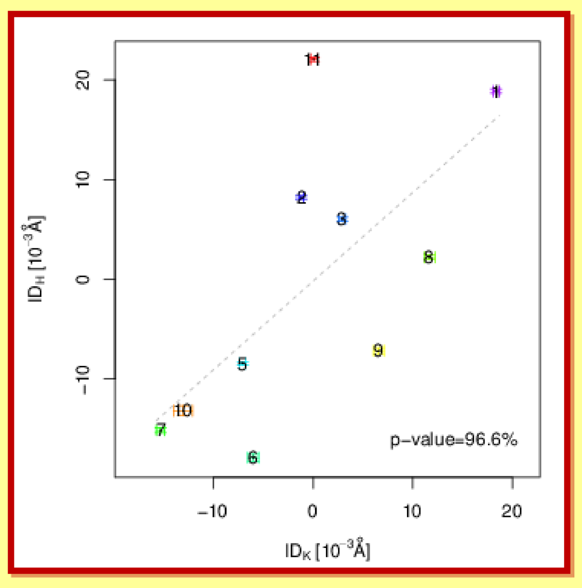

Fig. 6: Correlation of the Ca II H vs. K signals (Integrated Deviations in the line cores with respect to the median spectrum). Error bars are comparable to the size of the symbols .

The correlation shown in Fig. 6 indicates that the variations are coherent and hence likely related to chromospheric activity. This is confirmed by the correlation of the combined H+K Integrated Deviations with those derived from a similar analysis of the Hα line (Fig. 7).

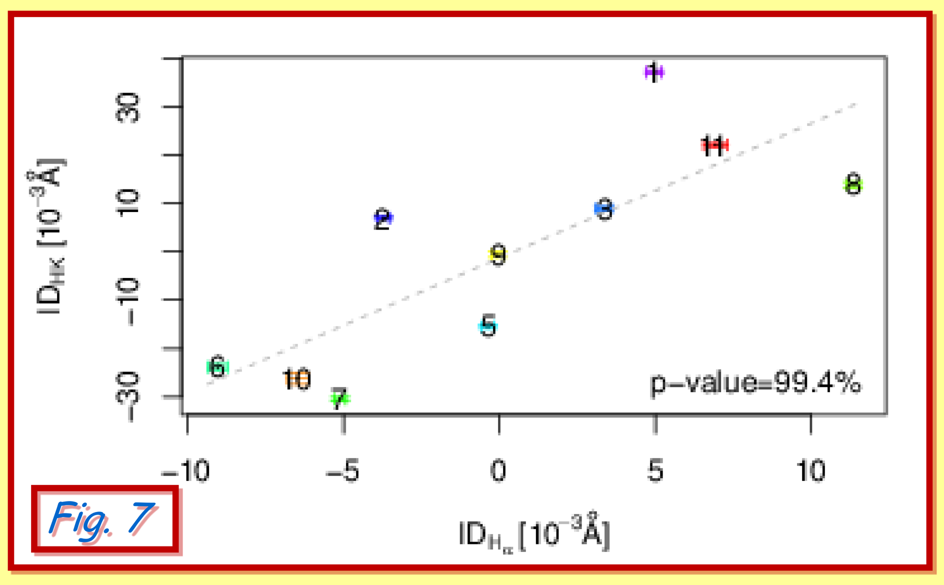

Fig. 7

5. Rotation and oscillations

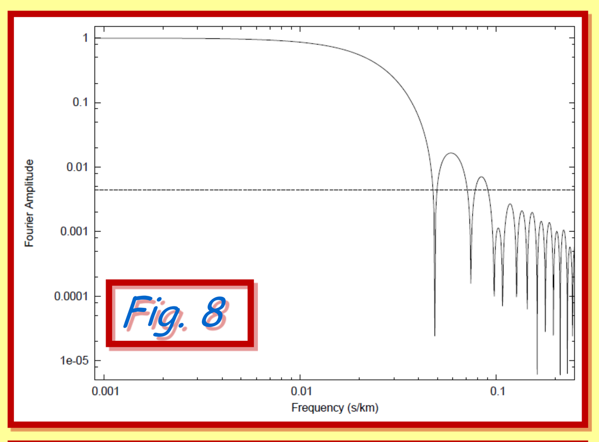

Fig. 8

We computed mean line profiles from the co-added spectra; the ratio of the first two zeros of the Fourier Transform (Fig. 8) yields an estimate of the differential rotation (Reiners & Schmitt 2003).

After removal of trends due to the orbital period and low-frequency variations, the resulting RV time series can be analyzed in frequency (Fig. 9) to detect short -scale periodicities.

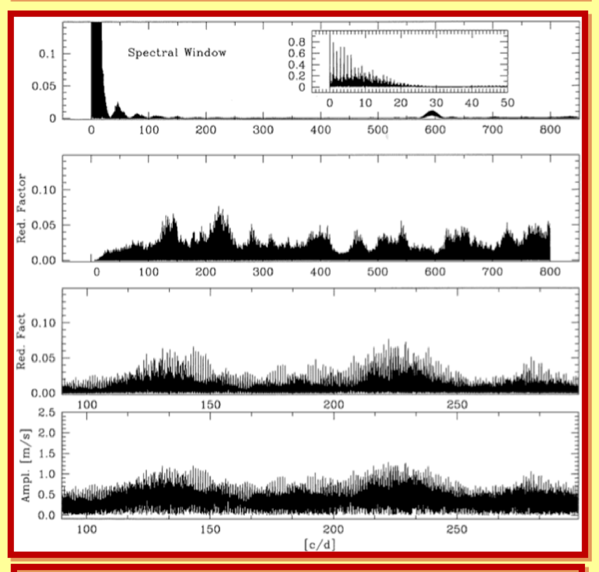

Fig. 9: Spectral window (top), frequency spectrum in reduction factor with zoom, and amplitude (bottom).

6. Results and conclusions

τ Bootis is a slightly evolved solar-type star with a non negligible activity level. In 2013 it showed a low (1–2 %) variability of chromospheric activity diagnostics. Coherent variation in Ca II H&K and Hα lines indicate a genuine activity signal, but we found no correlation with the orbital and stellar rotation phase.

In Fig. 10 we compare our 2013 measurements for τ Tau Boo with data taken in 2010 with SARG@TNG, and with measurements obtained with ESPaDOnS@CFHT for HD 179949, another F-type star hosting a hot Jupiter.

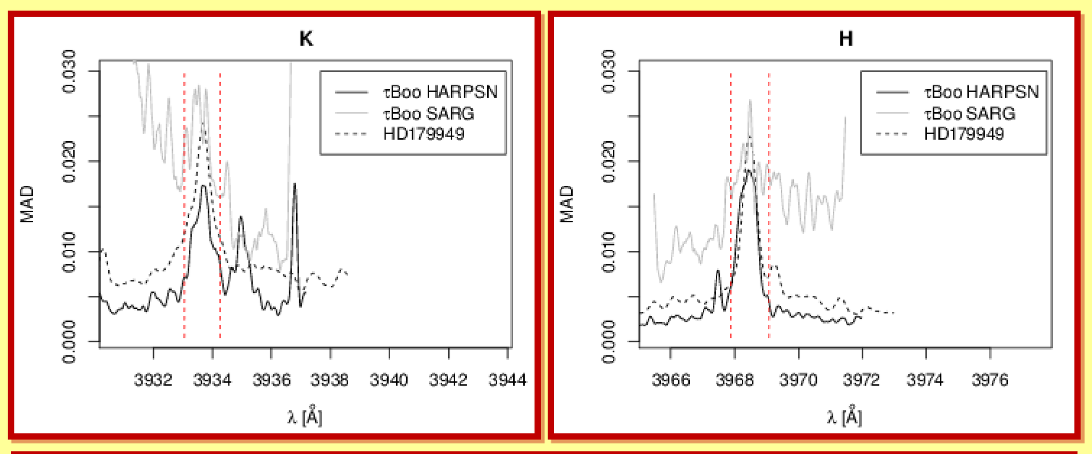

Fig. 10: Mean Absolute Deviations (proxy for activity) in Ca II H&K lines for τ Boo (2010 and 2013), compared with HD 179949.

- HARPS-N@TNG observations can reach a very high sensitivity for studies of SPI effects.
- The lack of correlation between the variability of activity diagnostics with the planetary orbital phase (≅ stellar rotation phase) confirms the low probability of magnetic SPI effects in systems with synchronous hot Jupiters.
- An high-cadence observation strategy also allows us to perform measurements of asteroseismological oscillations: for τ Boo the available data suggest a 6-7 min period, to be confirmed with further observations.
- We are able to confirm also a solar-type latitudinal differential rotation with $\Delta\Omega/\Omega_0$ = 0.24 ± 0.07.
- Finally, comparison with data taken in 2005-2009 indicate a long-term trend in the RV, possibly due to a long-period (P≅1000 d) known binary companion in eccentric orbit.

References

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