The effect of a star's large-scale magentic field geometry on precision radial velocities

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BACKGROUND AND AIM

Exoplanetary research aims to probe for ever-smaller, Earth-like planets, in the habitable zones of nearby stars. New dedicated radial velocity instruments such as ESPESSO at ESO's Very Large Telescope and HIRES at E-ELT will aim to detect the very small radial velocity signatures of earth-like planets in orbit around solar-like stars. The radial velocity amplitude of the Earth is however only ~10 m/s; an order of magnitude smaller than the ~1 m/s precision regularly achieved by current spectrographs.

The aim of this STSM was to investigate the role of the net field, as determined via polarimetry, on a sample of stars from the BCool project. In particular, the star ε Eri has a putative planet in a 6.9 yr orbit (Hatzes et al., 2000, ApJ, 544, 145). The large scale field evolution of ε Eri has been studied in detail by Jeffers et al. (2014, A&A, 569, 79) using polarimetric observations spanning ~7 years and Zeeman Doppler imaging. The field has been found to be highly variable on timescales of one year, while possible cyclic variability has been identified on several-year timescales.

ANALYSIS DURING THE STSM VISIT

While Reiners (2013, A&A, 552, 103) has shown that for M dwarfs, Zeeman broadening in lines can lead to radial velocity amplitudes of similar magnitude to starspots, it is currently not clear what the contribution from the large-scale magnetic field field structure might be. We have thus used the Zeeman Doppler images for BCool stars, which were obtained from Stokes V line profiles, to forward model Stokes I profiles. These line profiles thus contain the signature of only the large scale magnetic field. By cross-correlating the line profiles, generated for a complete rotation of a star, we are able to determine the contribution of the large scale net magnetic field to the radial velocity variability.

ε Eri: The results are shown in Figure 1. We simulated 20 observations using the input maps for ε Eri from the 6 yearly epochs in Jeffers et al. (2014). The simulations show the field multiplied by a factor 2 (top left) and factor 10 (top right). The input maps with fields up to 42 G (factor 1) yield radial velocities that are dominated by numerical noise (triangles in lower plots). We thus simulated radial velocities with multiplication factors up to 10 (circles in lower plots) and extrapolated the RVs back to the original field strengths by fitting a quadratic function to the results for scaling factors 2 - 10. We find that the RV amplitude is proportional to mean field $B^{2.}$ The radial velocities induced for the original, observed (x1) images at all epochs are shown in Table 1. The Pearson's correlation between r.m.s. RV and mean and max field strength shows respective moderate positive correlations of R=0.64 & 0.72. Field configuration is also an imporant consideration that will reduce the value of R.

From Table 1, we find RV r.m.s. values of 5.7 cm/s to 11.3 cm/s, (row 4) with corresponding amplitudes of 22 cm/s to 36 cm/s. For ε Eri this variability is two orders of magnitude smaller than the 3.8 year HARPS RV variability (Anglada-Escude, 2010, A&A,), which shows r.m.s. and max amplitude values 6.9 m/s 29 m/s. The global field recovered in Zeeman Doppler images at optical wavelengths contributes a very small fraction to the RV variablilty, which is nevertheless greater than the stability aims of future projects, ESPRESSO and HIRES.

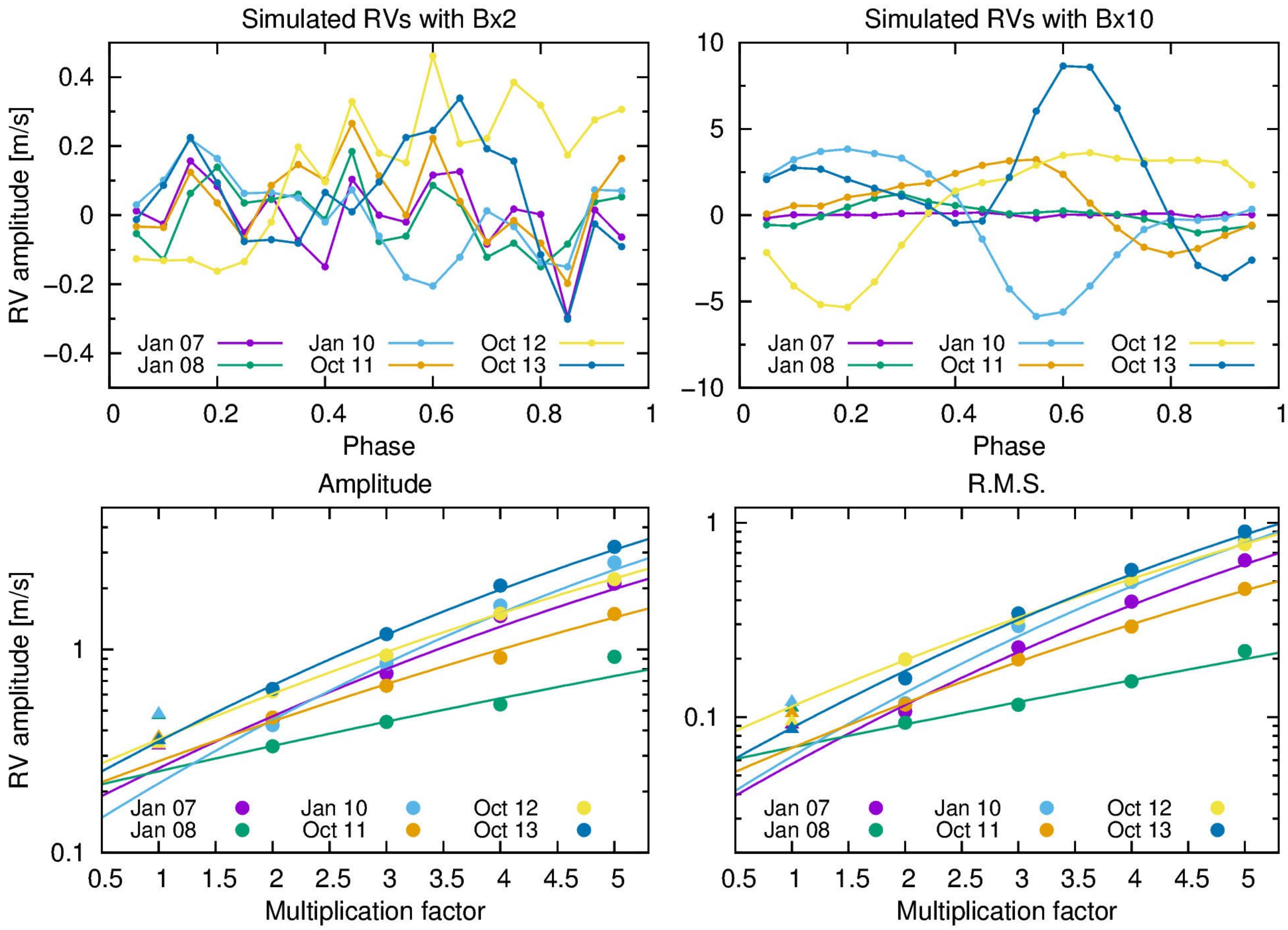

Figure 1: Radial velocity simulations for ε Eri. Radial velocities are in m/s. Simulations with magnetic maps x2 and x10 are shown (top panels). The amplitude of variability and r.m.s variability is shown in the bottom panel for results (triangles and circles) and fitted functions. See text for details.

	Jan 07	Jan 08	Jan 10	Oct 11	Oct 12	Oct 13
Mean field (G)	12 ± 1	10 ± 1	16 ± 4	10 ± 1	18 ± 3	20 ± 1
Max field (G)	28 ± 3	29 ± 6	39 ± 9	32 ± 1	42 ± 7	42 ± 2
Amplitude-observed x1 (m/s)	0.26	0.25	0.22	0.28	0.36	0.35
Amplitude (m/s) x3 (m/s)	0.80	0.44	0.86	0.68	0.97	1.18
r.m.s. x1 (m/s)	0.057	0.070	0.063	0.069	0.113	0.088
r.m.s. x3 (m/s)	0.22	0.12	0.26	0.19	0.32	0.32

Table 1: Radial velocities on ε Eri. induced by global / large scale magnetic field.

Other Bcool stars: The BCool sample includes stars with 120 G field strengths. With similar field configurations and vsini, we find r.m.s. and maximum amplitude variability of 32 cm/s and 1.18 m/s, by scaling the field by a factor of 3 from our ε Eri results (see Table 1). We have so far also applied the above procedure to two other stars :-

HN Peg: A 200 My solar analogue with vsini = 10.6 km/s. Over 6 epochs, spanning a similar period to the ε Eri observations, the mean filed strength similarly varies between 11 G and 26 G (Saikia et al. 2015, A&A, 573, 17). We find r.m.s. variability in the 8 cm/s to 24 cm/s range and maximum amplitude variability of 29 cm/s to 1.17 m/s.

61 Cyg A: A ~2-3 Gyr K5 dwarf (0.6 solar mass) with vsini = 4.72 km/s. The magnetic field on 61 Cyg A is much lower than for the other two stars above. Only one epoch enabled reliable measurement of the RV variability from which we find only 2 cm/s r.m.s. and 5 cm/s maximum amplitude.

Other stars in the BCool sample are under analysis.

Removal of activity induced jitter: Techniques for removing the effects of all jitter are important when searching for planets that might induce similar amplitude. Active stars are often avoided in surveys, but since activity scales with rotation and decreases with age, planets detected with the radial velocity technique cannot be considered unbiased since they target only older stars.

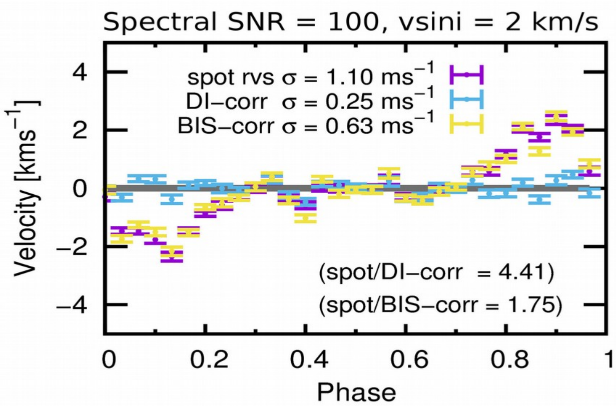

Figure 2: Correction of RV variations due to magnetic activity. DI-corr represents our Doppler imaging technique. BIS-corr shows results for more traditional bisector approach. Our technique is more than twice as efficient.

We have developed a method using Doppler imaging techniques that apllies to the line distortions from both starspots and the polarmietric Stokes V observations when the Stokes I observations are re-created as outlined above. The method involves summing the weighted velocities (according to magnetic filling or spot filling) in the 3D images recovered during Doppler imaging. During the STSM, we carried out simulations that are applicable to any kind of activity that distorts line profiles. For a solar-maximum model with a pair of typical sunspots, we found that for typical spectral S/N ratios of ~100, we are able to reduce the RV variability by a factor of 4.4, which is 2.5x more effective the more traditional techniques using line bisector analysis (see Figure 2).

ONGOING WORK

A number of additional lines of enquiry are being followed up as a result of the STSM visit. These include:

- Complete analysis for other stars in the BCool sample
- Wavelength dependence polarmetric observations - the Zeeman effect is dependent both on the Lande factor (which can be large, particularly in molecules) and wavelength.
- Related to the above is the Zeeman broadening on un-polarised lines, which can effect the radial velocity stability when poorly resolved lines are broadened by magnetic fields. The magnitude of this effect is being investigated for ε Eri and the BCool sample.

The results from this analysis are being collated with thesis work and are expected to be included in forthcoming publications.