Long-Term Datasets for the Understanding
of Solar and Stellar Magnetic Cycles
Proceedings IAU Symposium No. 340, 2018
D. Banerjee, J. Jiang, K. Kusano & S. Solanki, eds.

doi:10.1017/S1743921318000959

The long-term variation of the effective magnetic field of the active star ϵ Eridani

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Abstract. Long-term periodicities of magnetic fields in cool stars are usually studied from activity indicators, which are only indirectly related to the presence of the field. Direct detections are complicated issues since even a complex magnetic structure, as the solar one, has a very low disk integrated magnetic signal, which is usually hidden in the noise level. We introduce a method for the direct measurement of small integrated longitudinal stellar magnetic fields (effective magnetic fields), called multi-line slope method, based on the regression of the Stokes V signal with respect to the first derivative of Stokes I. We present the results of the application of this technique to a dataset of 9 yr of observations of the active star epsilon Eridani, obtained with the spectropolarimeters Narval, HARPSpol and CAOS, showing that the long-term variation of the effective magnetic field corresponds to the period of the cycle retrieved by the activity indicators.

Keywords. stars: late-type, stars: magnetic fields, stars: activity, techniques: polarimetric, techniques: spectroscopic, methods: data analysis

1. Introduction

Magnetic fields of late type stars can be studied extending the results of solar physics, assuming that the physical processes are the same as the Sun, but they runs with a different set of parameters, such as temperature, gravity and stellar rotation (Reiners 2012).

The presence of the field can be indirectly inferred by activity indicators, such as the S-index, which is related to emission chromospheric lines of Ca H & K that are connected to the presence of magnetic active regions. A big effort for the measurement of S-index was made by the Mt. Wilson survey, which revealed for the first time periodical activity in stars other than the Sun (Baliunas *et al.* 1995).

This work represents a link between indirect and direct measurements of magnetic fields of cool stars. We analysed a long-term dataset of spectropolarimetric observations in order to infer the periodicity of the star ϵ Eri.

2. The multi-line slope method

In the case of weak field approximation and assuming low rotational velocity, Landstreet (1982) showed that the stellar integrated Stokes V signal can be related to the first

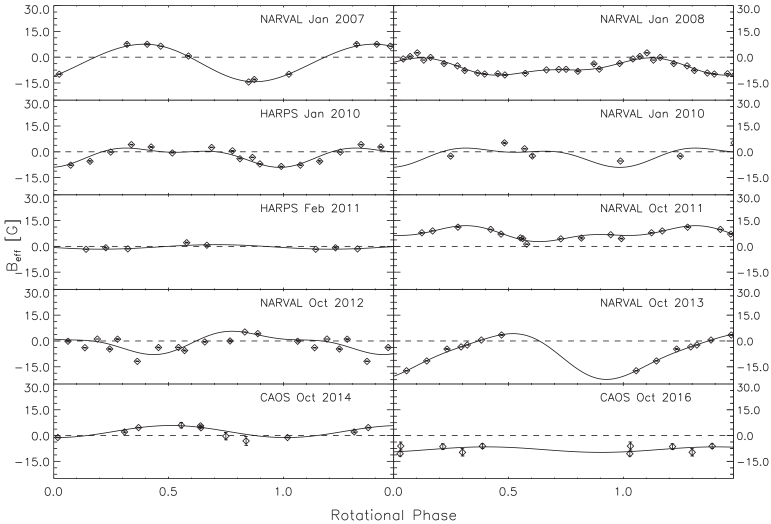

Figure 1. Effective magnetic field variability curves of ϵ Eri folded with the period of rotation $P_{rot} = 11.35$ d (Fröhlich 2007).

spectral derivative of Stokes I:

$$\frac{V}{I} = -4.67\,10^{-13}\, g_{eff}\, \lambda^2 B_{eff} \frac{dI}{d\lambda}\frac{1}{I} \tag{2.1}$$

where B_{eff} is the *longitudinal* or *effective magnetic field* (expressed in Gauss) and g_{eff} is the effective Landé factor.

Bagnulo *et al.* (2002) used Eq. 2.1 to measure the effective magnetic field of magnetic early type stars from the ”slope” of the distribution of Stokes V with respect to the spectral first derivative of Stokes I. The multi-line slope method (Scalia *et al.* 2017) is an extension of this technique to the measurement of weak magnetic fields from the simultaneous application of the slope method to selected unblended spectral lines, in order to retrieve a most sensitive measure. The field is computed through minimisation of χ^2:

$$\chi^2 = \sum_{ij} \frac{(y_{ij} - B_{eff}\; x_{ij})^2}{\sigma_{ij}^2} \tag{2.2}$$

where for each j lines we computed:

$$x_{ij} = -4.67\,10^{-13}\, \lambda_{0j}^2\, g_{eff_j} \frac{1}{I_{ij}(\lambda)} \frac{dI_{ij}(\lambda)}{d\lambda_{ij}} \tag{2.3}$$

The quantity $y_{ij} = \frac{V_{ij}}{I_{ij}}$ is used for the measurement of the field and $y_{ij} = \frac{N_{ij}}{I_{ij}}$ is used for the estimation of systematic errors.

3. ϵ Eri

ϵ Eri is one of the most studied solar analogue. A huge data set of activity measurements, spanning more than 45 yr, was analysed by Metcalfe *et al.* (2013), who found a short cycle period of 2.95 yr (1077.49 d) modulated by a long cycle of 12.7 yr (4638.68 d).

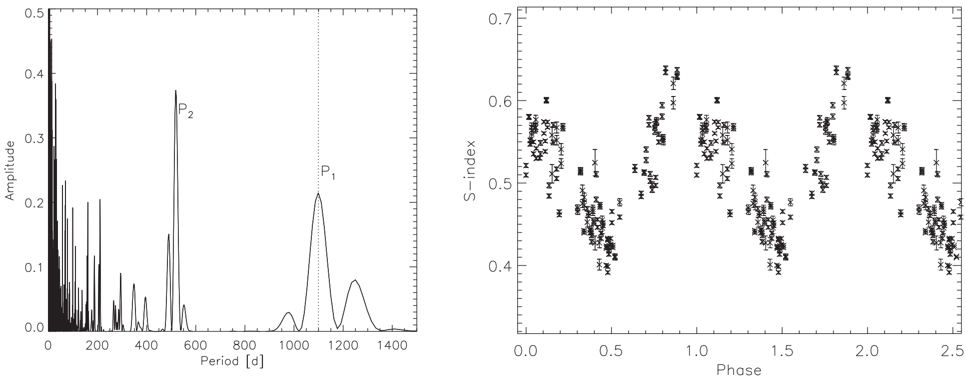

Figure 2. (Left): Cleaned Fourier transform of A_0 (black); (Right): S-index measures of Metcalfe *et al.* (2013) folded with the period P_1.

We analysed all the available spectropolarimetric data of the star, collecting a sample spanning 9 yr of observations performed by the spectropolarimeters HARPSpol (Piskunov *et al.* 2011), NARVAL (Aurière 2003) and CAOS (Leone *et al.* 2016). Effective magnetic field measurements are reported in Fig. 1.

4. Results and conclusions

Each magnetic curve was fitted with the function (Scalia *et al.* 2017):

$$f(t) = A_0 + A_1 \sin\left(2\pi \frac{t - t_0}{P} + A_2\right) + A_3 \sin\left(4\pi \frac{t - t_0}{P} + A_4\right) \tag{4.1}$$

where t is the time in days, t_0 is a reference time, P is the rotational period, A_1 and A_3 are amplitudes (expressed in Gauss), A_2 and A_4 are phase shifts and A_0 represents the level of the variation of the curves (in Gauss) and it allows to separate the short-time sinusoidal variations, ascribed to stellar rotation, from long-term changes.

In order to find the long-term periodicities we performed the Fourier transform of A_0 (Fig. 2 left) where it is possible to note a peak $P_1 = 1099 \pm 71$ d, which corresponds to the short cycle period in the S-index measurements found by Metcalfe *et al.* (2013).

It is possible to conclude that long-term monitoring of effective magnetic field can be used to infer periods of the cycles of active cool stars and that this measurement agrees with the results obtained by indirect indicators.

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https://doi.org/10.1017/S1743921318000959 Published online by Cambridge University Press