Stellar magnetic activity, Exercise VI

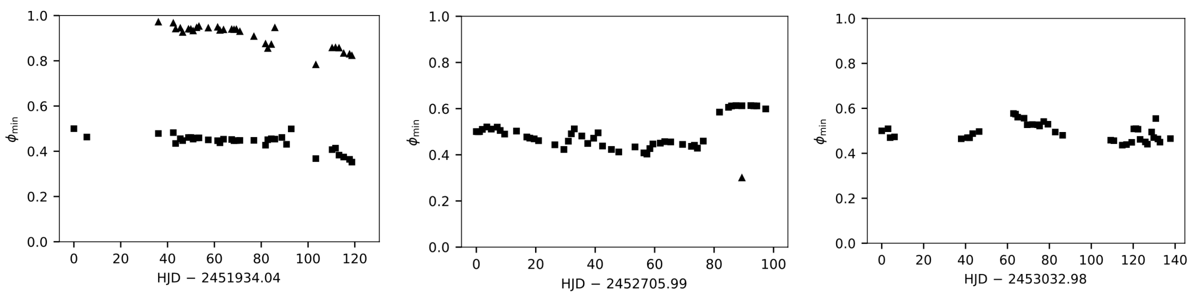
April 26, 2024

Model solutions

1. (a) The continuous period search (Lehtinen et al., 2011) is applied to HD 116956 (NQ UMa), which is a young solar anologue of G9V spectral class with an estimated rotation period of $P \approx 7.85$ d. The window width was the deafult $\Delta t = 20$d.

   There are clear signs of persistent active longitudes in the minimum phase $\phi_{\rm min}$ plots in segments 3, 5, 6, 7, 8, 9, 10, 11, 12, 15, 18, 21. In segment 4, the primary photometric minimum is reasonably constant in phase, but the secondary signal showed much greater variations. In the segments not reported above, data was usually too sparse for persistent active longitudes to be clearly visible.

   Example plots of the phases of signals in different segments are shown in Fig. 1.



(a) (b) (c)

Figure 1: The minimum phase $\phi_{\rm min}$ evolution of light curves in different segments (a: 3, b: 6, c: 7) of the observations HD 116956, where clear signs of persistent active longitudes are visible.

   (b) After running the script `plotres.py`, the weighted rotation period of $P_{\rm w} = 7.8094 \pm 0.0194$ d, and a weighted differential rotation of $\Delta P_{\rm w} = 0.2771$ d where obtained.

   The rotation period against the amplitude is plotted on Fig. 2. Compared to the DR-model of V889 Her, this star seems to have a simpler, monotonic differential rotation. Unlike in the DR-model of V889 Her, where the points are distributed along two lines, resembling a “>”-mark in shape, the points on the plot of HD 116956 are distributed along one line, nearly horizontally, showing a slight increase in amplitude towards longer rotational periods.

2. Vedantham et al. (2020) analysed the observations of LOFAR Two-Metre Sky Survey, by matching the radio sources from LOFAR with nearby stars ($d < 20$ pc) from the

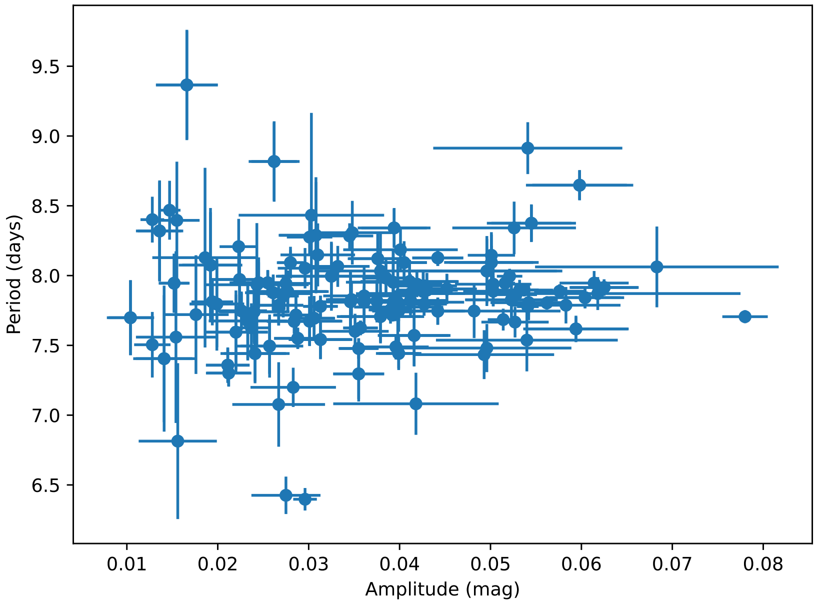


Figure 2: Rotation period and light-curve amplitudes for independent parameter estimates of spots on HD 116956.

Gaia DR2 database. They found an object coinciding with radio emissions of high significance, GJ 1151, an M4.5V star, with a rotation period of 125 ± 33 d. This radio emission was detected in mid June 2014, but not two weeks earlier.

The authors argue that the source of the radio signal is the interaction of the star's magnetospheric plasma with a short-period ($P_{\rm orb} = 1 - 5$ d) planet. Vedantham et al. (2020) base this claim on the following considerations:

- The star has a quiescent chromosphere. Stellar GHz-frequency radio emission is powered by chromospheric magnetic activity. Stars that were observed in this frequency range were known either as flare stars, rapid rotators, or close binaries – GJ 1151 is none of those.
- Properties of observed radio emissions fall into two phenomenological categories: i) incoherent gyrosynchrotron emission, similar to solar noise storms, ii) coherent emission (plasma or cyclotron emission), similar to solar radio bursts. The observed radio emission is clearly distinct from these categories.
- Based on the brightness temperature and the high polarisation fraction of the signal, the emission originates from a coherent emission mechanism. Two known classes of coherent emission mechanism are known in non-relativistic plasma: plasma and cyclotron emission. Plasma emission models predict a cut-off of brightness temperatures ($< 10^{11}$ K, which is lower than the brightness temperature of the signal). Cyclotron maser emission from a coronal loop could only occur if the coronal loop itself was larger than the star. Auroral cyclotron maser emission, on the other hand, can explain the signal, given that the corona is of low enough density.
- For sub-stellar objects with largely neutral atmospheres the currents are attributed to two processes: i) breakdown of rigid co-rotation of magnetospheric plasma, ii) sub-Alfvénic interaction of the objects magnetosphere with an orbit-

ing body. The breakdown of co-rotation produces a significant signal for a fast rotating body. GJ 1151 has a rather long, ~ 3000 hour rotation period, which would yield a much weaker signal than the one observed. This implies that the source of the emission is the sub-Alfvénic interaction of the stellar magnetosphere with a close-in orbiting body, a putative planet.

References

J. Lehtinen, L. Jetsu, T. Hackman, P. Kajatkari, and G. W. Henry. The continuous period search method and its application to the young solar analogue HD 116956. *Astronomy & Astrophysics*, 527:A136, Mar. 2011. doi: 10.1051/0004-6361/201015454.

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