Stars and their variability observed from space
C. Neiner, W. W. Weiss, D. Baade, R. E. Griffin, C. C. Lovekin, A. F. J. Moffat (eds)

STARSPOTS AND ROTATION VELOCITIES OF NORMAL A- AND AM- STARS

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Abstract. Using the "hump and spike" features, we computed the rotation frequencies and amplitudes. The corresponding equatorial rotational velocity (V_{rot}) and spot size were estimated. On fitting the auto-correlation functions of the light-curves with the appropriate model, we obtained the starspot decay-time scale. The V_{rot} agrees well with the projected rotational velocity ($\nu \sin i$) in the literature. Considering a single circular and black spot, we estimate its radius from the amplitude of the "spike". No evidence for a significant difference in the average "spike" amplitude and spot radius was found for Am/Fm and normal A stars. Indeed, we derived an average value of $\sim 21 \pm 2$ and $\sim 19 \pm 2$ ppm for the photometric amplitude and of 1.01 ± 0.13 and $1.16 \pm 0.12\,R_E$ for the spot radius (where R_E is the Earth radius), respectively. We do find a significant difference for the average spot decay-time scale, which amounts to 3.6 ± 0.2 and 1.5 ± 0.2 days for Am/Fm and normal A stars, respectively. In general, spots on normal A stars are similar in size to those on Am/Fm stars, and both are weaker than previously estimated. The existence of the "spikes" in the frequency spectra may not be strongly dependent on the appearance of starspots on the stellar surface. In comparison with G, K and M stars, spots in normal A and Am/Fm stars are weak which may indicate the presence of a weak magnetic field.

Keywords: stars: photometry, stars: chemically peculiar, stars: rotation, stars: starspots

1 Introduction

Rotation is one of the most important phenomena in stellar physics. Thanks to the availability of high-precision and almost continuous photometric data from space missions like *Kepler*/K2 and *TESS*, precise rotation periods can be obtained. Balona (2013) derived rotation periods of a large number of A-type stars from the original *Kepler* field based on spot induced rotational modulation. The spot based rotational modulation in these stars was unexpected, since they possess a thin sub-surface convective envelope. Balona (2013) observed in the frequency spectra of 135 stars of the 875 normal A-stars a sharp peak ("spike") on the high frequency side of a broad hump of very close frequencies ("hump"). Balona et al. (2015) observed the same scenario in some Am/Fm stars. Balona (2014) suspected the sharp peak corresponds to the rotational frequency and its amplitude to be related to the starspot size, but the hump remained unexplained. Recently, Saio et al. (2018) named these stars "hump and spike" stars. Saio et al. (2018) reported that the broad humps as observed for these stars are induced by Rossby modes (*r* modes) and the spike structures are the rotation frequencies induced by one or more spots. This has improved estimates of rotational velocities and spot sizes of such stars.

2 Methods and Results

We studied a total of 170 "hump and spike" stars of which 131 are part of the normal A stars reported by Balona (2013), 3 are within the sample studied by Balona et al. (2015), and 36 are from Gray et al. (2016). We used all the available quarters (Q_0 upto Q_{17}) of the long-cadence *Kepler* data processed by the pre-search data conditioning (PDC) pipeline. We calculated the frequency spectra using the discrete Fourier fitting technique.

We derived the luminosity from GAIA parallaxes, reddening from a 3D model and adopted the effective temperature from the revised catalog of *Kepler* targets for Q_{1-17} by Mathur et al. (2017) which were used to calculate the stellar radius. Using the rotation frequencies (spike frequency) and stellar radius, we computed the rotational velocities from the standard relation. The average rotational velocity of Am/Fm and normal A stars is 105 ± 3 km s^{-1} and 161 ± 3 km s^{-1}, respectively.

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From the frequency spectra, we obtained and considered the amplitudes of the spikes to be the photometric amplitudes (A_{rot}) associated with rotation. The average A_{rot} of Am/Fm and normal A stars was found to be $\sim 21 \pm 2$ ppm and $\sim 19 \pm 2$ ppm, respectively. For simplicity, we assume that the stars are spherical and that a single, circular and black spot reproduces the amplitude of the spike. This is identical to determining the size of an exoplanet from a transit. We computed the radius of the spot (R_{spot}) from the standard relation, $R_{spot} = \sqrt{A_{rot}} R$. The average spot radius is 1.01 ± 0.13 and $1.16 \pm 0.12\, R_E$ for Am/Fm and normal A stars, respectively.

We computed autocorrelation function (ACFs) for the combined *Kepler* light-curves. To estimate the decay-time scale of the active regions, we fitted the ACFs with a model for an under-damped simple harmonic oscillator, as shown in Fig. 1. About 40% of the ACFs do not show any significant peaks. This points towards a short decay-time and low amplitudes, so it suggests very weak or the absence of starspots and co-rotating structures. However, the "hump and spike" features exist in their frequency spectra. The majority of the stars have decay-time scales of a few days or less. The average decay-time in Am and normal A stars is 3.6 ± 0.2 and 1.5 ± 0.2 days, respectively.

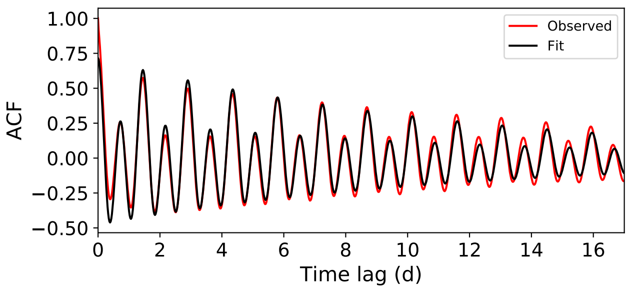

Fig. 1. An ACF for KIC 5121064. The second local maximum corresponds to the rotation period (P_{ACF}) while a lower local maximum is observed at almost half the rotation period. This indicates that there is(are) weak starspot(s) opposite to the stellar face with the dominant starspot(s).

3 Conclusions

Am/Fm stars rotate slowly relative to normal A stars. This confirms the conclusion from several studies (e.g, Abt & Morrell 1995). The starspot size in normal A and Am/Fm stars is smaller than previously estimated by Balona (2013) and Balona et al. (2015) by about 38 %. This implies that the activity in Am/Fm and normal A stars is weaker than previously suggested by these studies. Finally, significantly large starspots may not be required to produce the existing spikes in the frequency spectra.

The International Science Program (ISP) of Uppsala University financed the study. The part of work presented here is supported by the Belgo-Indian Network for Astronomy & Astrophysics (BINA), approved by the International Division, Department of Science and Technology (DST, Govt. of India; DST/INT/Belg/P-02) and the Belgian Federal Science Policy Office (BELSPO, Govt. of Belgium; BL/33/IN12).

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