Tracing 3 years of magnetic activity on GJ 1243

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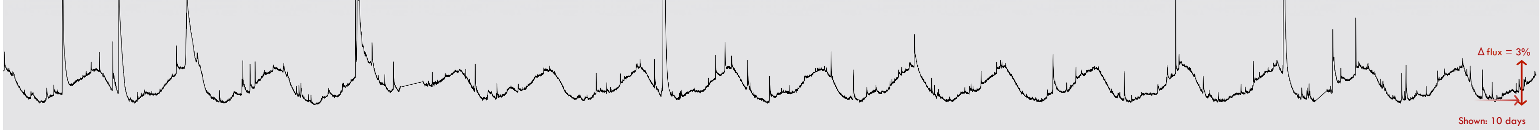

Flares and their Morphology

GJ 1243 (KIC 9726699) is a rapidly rotating (P_{rot}=0.5926d) and highly active (EWHα=4Å) M4V star (Hawley 2013 in prep). The light curve morphology of flares provides insight into the flare ignition and cooling physics at work in stellar active regions. We analyze one star to control for variations due to e.g. mass, age, rotation, temperature, log g.

We examined over 300 days (11mo) of short cadence data. Flares were found automatically by finding runs of ≥2 data points with ≥2.5σ flux above the detrended lightcurve. Each flare was examined by eye, giving a total sample of 5400 flares. The 660 flares with duration ≥ 10min and a simple shape (no secondary peaks noted by eye) is shown in Fig 1 (blue), and was used to create an empirical median model flare (red). Each flare was scaled to a peak flux=1, and by the characteristic timescale ($t_{1/2}$=FWHM). This model therefore only has 2 free parameters to describe its morphology.

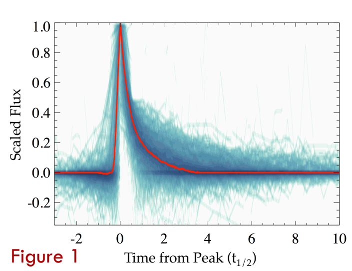

Figure 1

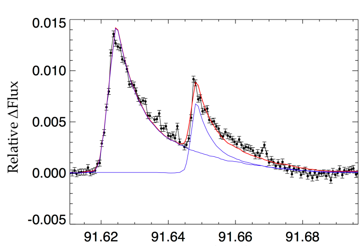

Figure 2

This median flare model can be used to identify and decompose complex flare events. We fit each flare with {1,2, … 7} median model flares, and use the Bayesian Information Criterion (BIC) to determine "best" fit. In Fig. 2 is shown a sample complex event (with starspot removed) and our chosen solution (red) with both underlying flares (blue).

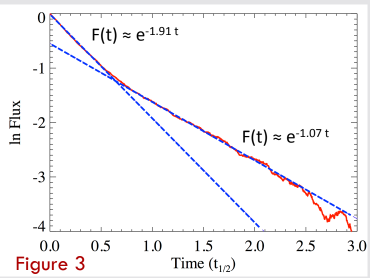

Figure 3

The decay phase of the median flare model in Fig. 3 is well fit using two exponential functions (blue) with slopes -1.91 and -1.07, indicating two distinct cooling phases. These intersect at a relative time,flux = (0.63, 0.29). The model fits most flares, spanning 3.5 dex in energy, indicating a high degree of homology among simple flares.

We then determined which were "classical" (fit with 1 median model) versus "complex" (>1 model) for the sample of 5400 flares. Fig. 4 shows the fraction of complex flares as a function of duration. Also shown is the fraction of complex flares when randomly placing flares from a power-law duration distribution (red). The excess of complex events indicates that flares are not randomly placed, and instead are physically associated.

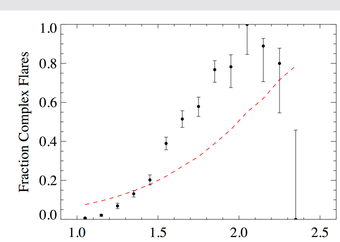

Figure 4

Evolution of Starspots

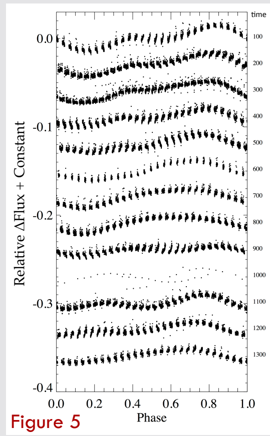

Figure 5

The lightcurve of GJ 1243 is characterized by frequent flares and persistent starspot modulations with an amplitude of 3%, first noted by Savanov & Dmitrienko (2011) in Q0 Kepler data. Echelle spectra on the ARC 3.5-m gives v sin i ≈ 25 km/s, indicating an inclination of 32°. We used 13 Quarters of long-cadence Kepler data to trace spot evolution over a +3 year timespan. In Fig. 5 100-day bins of the lightcurve are phased at the rotation period. The primary starspot, Phase≈0.1, is roughly constant throughout, consistent with an asymmetric component of a large polar spot "cap". The secondary spot, initially Phase≈0.5, changes phase and amplitude throughout, even disappearing (e.g. t=300 and 800). Such long-lived spots are consistent with a strong, highly organized, and possibly *poloidal* magnetic field.

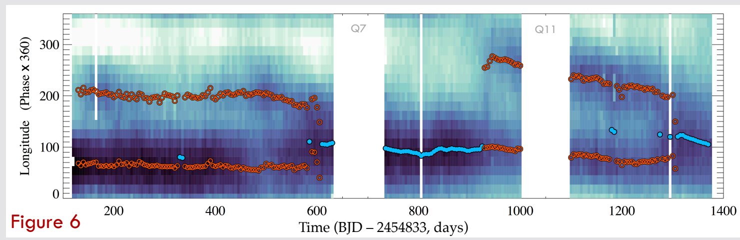

Figure 6

Fig. 6 shows the flux (dark to light) as a function of rotational phase over time. To trace the location and properties of the two starspots over time we ran our starspot fitting code on 10-day windows of the light curve. Our code (Hebb 2014 in prep) uses an affine invariant MCMC sampler, based on *emcee* (Foreman-Mackey 2012), to explore the spot radius and position (lat, long), for a given number of starspots. We computed 1, 2, 3 starspot models within each time window, and used the BIC to decide the best solution. Time steps best fit by 1-spot are shown in blue, 2-spots in red in Fig. 6. The primary spot (long ≈70°) remains constant, while the 2nd spot evolves and disappears on 100-400day timescales. As with all starspot models, our code experiences degeneracy between spot radius and latitude.

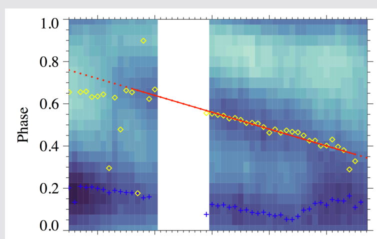

Figure 7

The secondary spot exhibited a linear change in phase with time, starting at t~940, and lasting ~400 days (Fig. 7). We interpret this as a change in spot longitude due to differential rotation. Assuming this spot is at the equator, and primary spot rotates slower near the pole (Solar-like diff. rot.) yields an Equator-Lap-Pole time of 1250 days, consistent with models of strong *multipolar* **B** fields on M dwarfs.

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