

Spectroscopic Starspot Filling Factor Measurements with APOGEE

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We present a large sample ($\sim 135,000$) of two-temperature star spot filling factor measurements for the intersection of APOGEE DR17 and Gaia DR3 on the lower main sequence. These infrared spectroscopic starspot detections are tied to the intrinsic activity of the star and its dynamo. We show the existence of a Rossby scaling comparable to that for other activity diagnostics, and that large star spot filling factors are the norm and not the exception for active stars. We demonstrate that including star spots at the level seen in the data leads to more accurate stellar parameters in the era of precision stellar astrophysics, with strong shifts in derived effective temperature, radius, and age. This work has broad applications as it makes starspot measurements accessible for a large fraction of the sky, with immediate applications in stellar parameter estimation and exoplanet characterization/habitability.

Starspot filling fractions are modelled in our **LEOPARD** starspot estimation pipeline as a two-temperature spectroscopic fit, using APOGEE empirical linelists and PHOENIX model atmospheres on APOGEE DR17 spectra with the *FERRE* least-squares solver.

We use the Pleiades and M67 as testbeds. Once binaries are removed (right panel Fig. 1), we see clear starspot detection patterns across each cluster sequence.

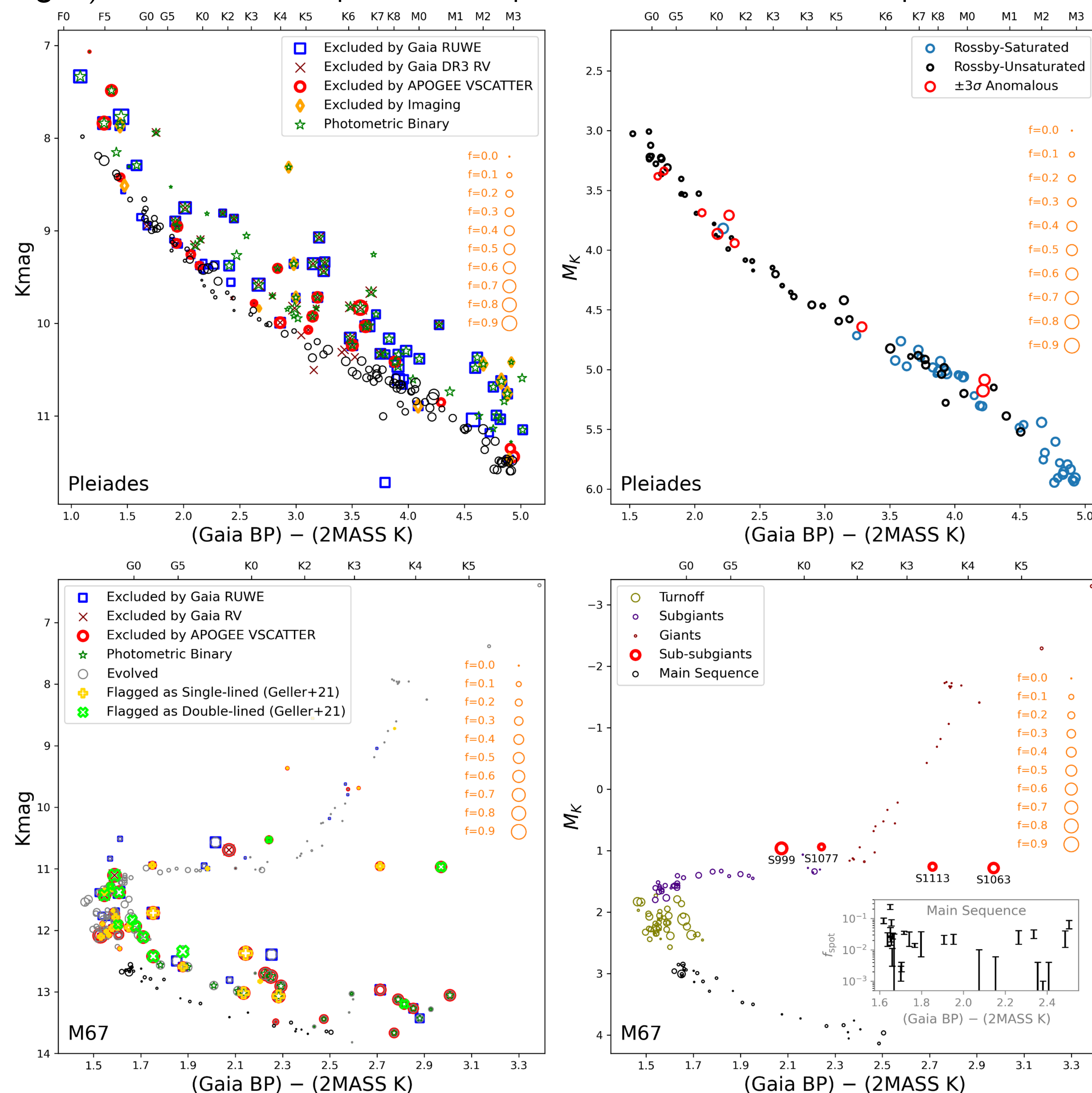
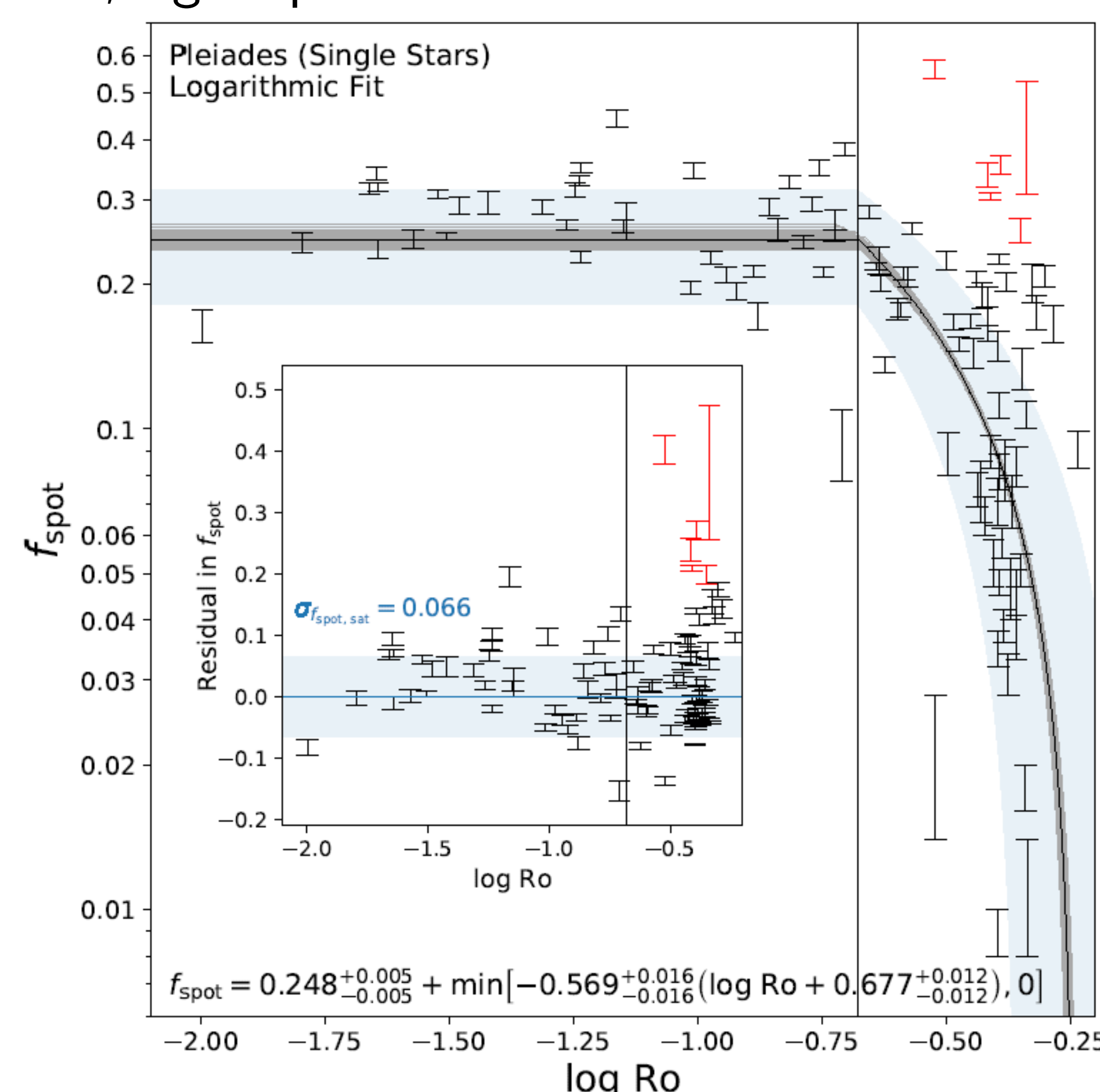


Fig. 1: Open cluster CMD's. Left: all stars; right: photometric binaries removed.

This inference technique results in starspot filling fractions which are both accurate and precise in Fig. 2; detecting a strong magnetic field saturation at rapid rotation with a predictable decline at higher Rossby number (P_{rot}/τ_{CZ}) and correlating with other activity proxies (X-ray, H α , Ca IRT, amplitude, B-field).

A small number of over-spotted stars (shown in red in Fig. 2 and in red in the top right panel in Fig. 1) are selected from a 3σ cut; these *single* stars are also over-active in other non-simultaneous activity diagnostics, suggesting this is not due to cycle variability or binarity.

Fig. 2: Starspot—Rossby fit in the Pleiades single stars. Left: logarithmic fit between $\log Ro$ and f_{spot} ; right: power law fit between Ro and f_{spot} .



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We have applied this method to the full APOGEE DR17 dwarf catalog. This includes the unevolved lower main sequence ($\log g > 4$, $3500 \text{ K} < T_{eff} < 6000 \text{ K}$) for which we provide $\sim 135,000$ cool dwarf starspot measurements and equipartition magnetic field strengths.

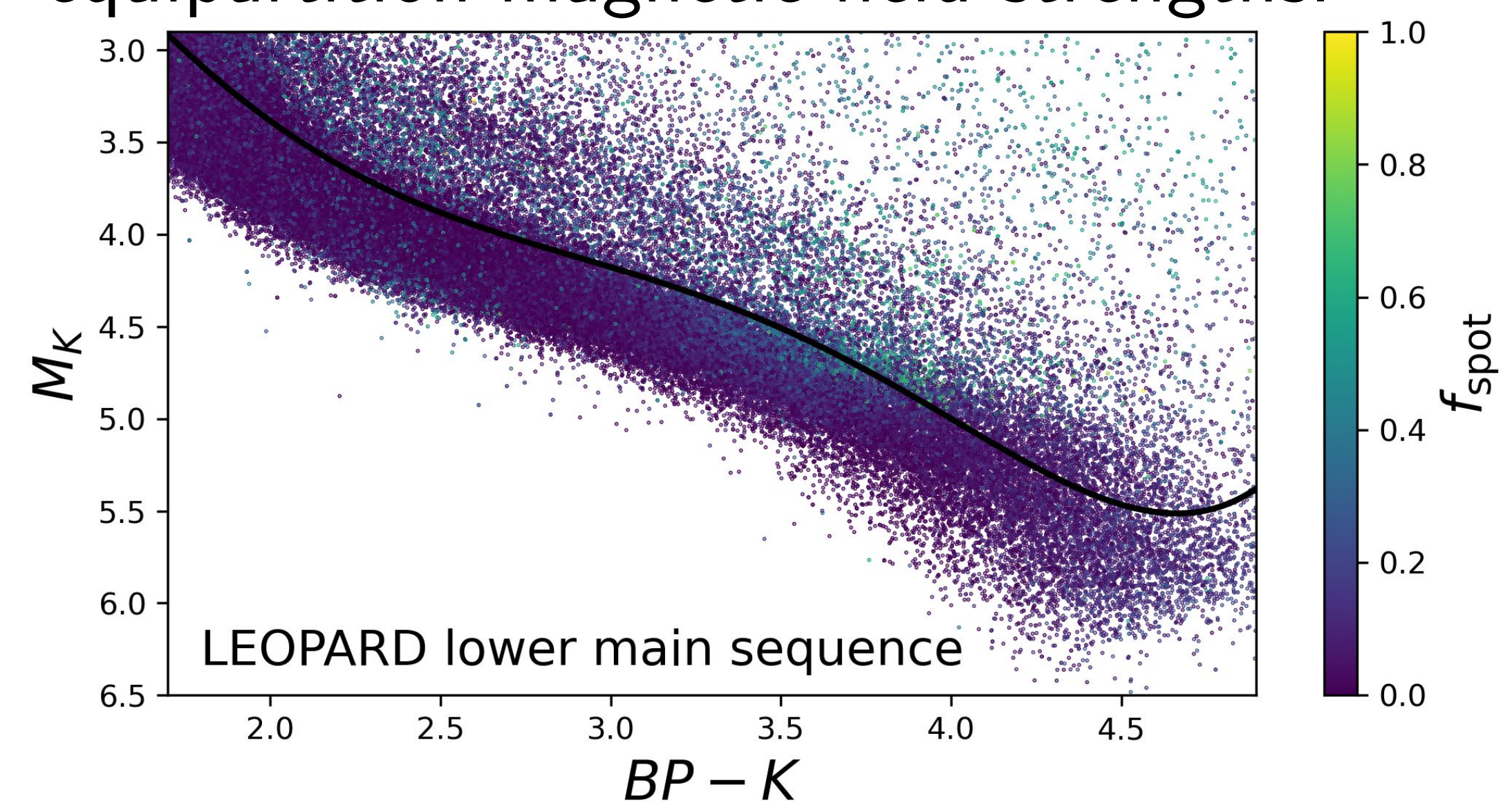


Fig. 3: Unevolved lower MS CMD; black line indicates a photometric binary cut 0.3 mag above the 75th percentile empirical isochrone.

This rich magnetic dataset may test tensions in stellar evolution (e.g., radius inflation, isochrone skew, and lithium spread), probe galactic archaeology, and calibrate gyrochronological relations.

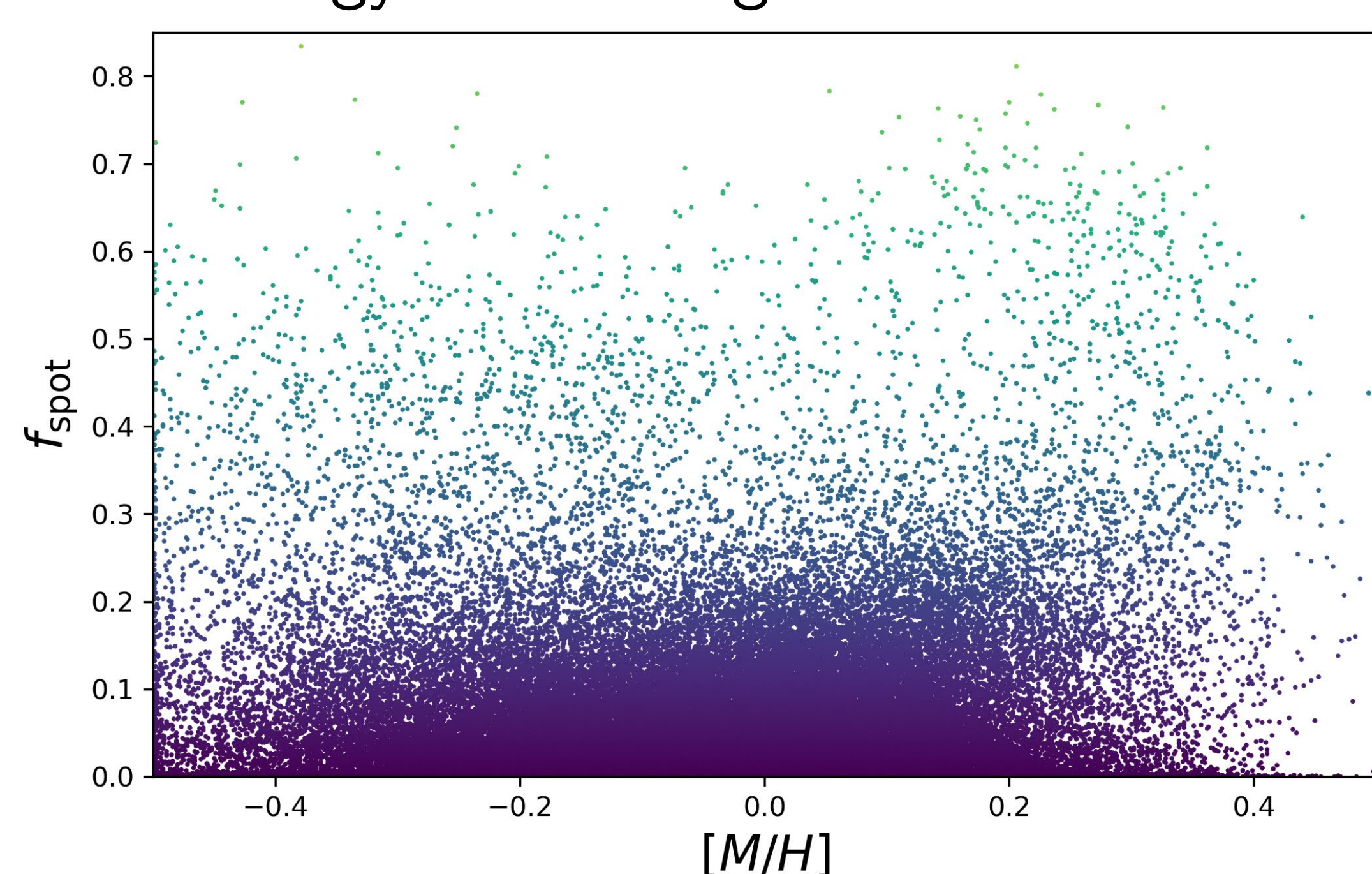


Fig. 4: Metallicity— f_{spot} relation in single stars.

On the metallicity—starspot plane, there is a trend in f_{spot} with a drop-off at low and high $[M/H]$, which may be evidence for radial migration in these dwarfs.

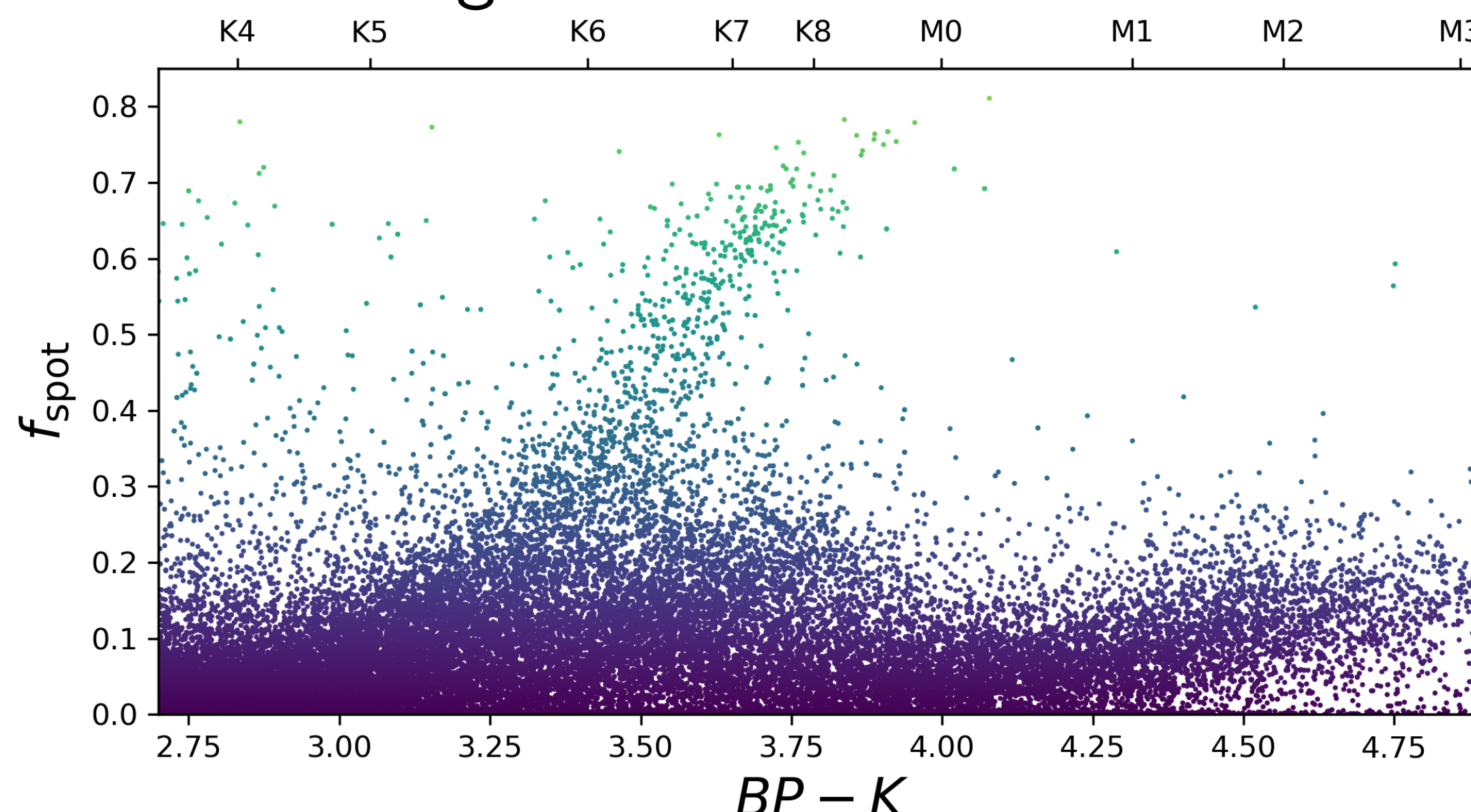


Fig. 5: Color— f_{spot} relation in single stars.

f_{spot} measurements above 0.4 may be unresolved binaries from incomplete binary rejection. We see strong activity trends with mass in main sequence K&M dwarfs.