

Surface spot coverage of solar-type and M stars

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Abstract. The correlation between starspot area coverage and stellar properties such as age, effective temperature, and rotation period is investigated for FGK and M-type stars. Photometric data from the *Kepler* and *CoRoT* satellites were analyzed for a sample of 11 stars using the starspot transit mapping method. The average spot coverage ranges from 4% to 29%. A strong anticorrelation with stellar age is identified (Spearman coefficient $\rho = -0.80$), indicating a systematic decline in magnetic activity over time, along with a moderate positive correlation with effective temperature ($\rho = 0.40$). The results suggest that incorporating spot coverage into isochrone models can substantially improve stellar age determinations and contribute to more accurate stellar dynamo modeling.

Resumo. Este trabalho investiga a correlação entre a cobertura de área por manchas estelares e propriedades estelares como idade, temperatura efetiva e período de rotação em estrelas dos tipos FGK e M. Dados fotométricos dos satélites *Kepler* e *CoRoT* foram analisados para uma amostra de 11 estrelas utilizando o método de mapeamento de trânsito por manchas estelares. A cobertura média de manchas varia de 4% a 29%. Uma forte anticorrelação com a idade estelar é identificada (Spearman $\rho = -0.80$), indicando um declínio sistemático da atividade magnética ao longo do tempo, além de uma correlação positiva moderada com a temperatura efetiva ($\rho = 0,40$). Os resultados indicam que a inclusão da cobertura de manchas em modelos de isócronas pode aprimorar significativamente as estimativas de idade estelar e contribuir para modelos de dínamo estelar mais precisos.

Keywords. Starspot — Stars — Activity Stars

1. Introduction

Magnetic activity plays a central role in the evolution of late-type stars, driving chromospheric variability, wind properties, and rotational spin-down. Among the surface manifestations of stellar magnetic fields, starspots are of particular importance as long-lived tracers of magnetic flux emergence (Berdyugina 2005). Their distribution, size, and evolution encode information on the underlying stellar dynamo, and their presence affects radius, and luminosity directly impacting stellar parameter determination.

High-precision photometry from *Kepler* (Borucki et al. 2010) and *CoRoT* (Auvergne et al. 2009) enabled the systematic identification of spot occultations during planetary transits, allowing the recovery of spot physical parameters through modeling. Transit-based spot mapping (Silva 2003) provides a geometrically constrained measurement of the spotted fraction along the transit chord, avoiding degeneracies common in rotational modulation analyses.

Despite the growing availability of spot models for individual stars, a systematic determination of *starspot area coverage* (or filling factor) derived exclusively from transit mapping had not been undertaken. This proceeding reports such an analysis, aiming to quantify correlations between starspot coverage and stellar age, mass, effective temperature, and rotation.

2. Data and Modeling

2.1. Observations

We selected 11 stars with high signal-to-noise transits, each hosting at least one exoplanet capable of producing well-defined spot occultations. The sample covers the FGK and M spectral sequence and spans ages between 0.35 and 2.7 Gyr.

Light curves were downloaded from the *CoRoT* pipeline and the *Kepler* PDCSAP dataset. Preprocessing included detrending,

outlier clipping, and local polynomial normalization around each transit.

2.2. Starspot Transit Mapping

The *ECLIPSE*¹ code (Silva 2003) was used to model spot occultation signatures. For each transit, we:

1. Fit a spotless transit model using known planetary parameters.
2. Subtract the spotless model and identify positive flux anomalies.
3. For each anomaly, retrieve spot longitude, radius, and contrast.
4. Synthesize a 2D stellar surface map and compute pixel-level spot area.

Because the transit latitude is set by the impact parameter, each transit probes a fixed latitude band on the stellar surface (see Figure 1).

2.3. Deriving Area Coverage

Starspot area coverage is defined as the fraction of pixels within the transit latitude strip whose brightness deviates from an unspotted model above a threshold. This yields a fractional area per transit, from which we compute a temporal mean and standard deviation.

Simulations indicate that the transit-chord coverage reproduces the global coverage to within 50% depending on spot latitude distribution (see Figure 2). Systems with multiple transiting planets allow independent sampling at several latitudes, improving the reliability of coverage estimates.

¹ Available as a Python code in <https://github.com/Transit-Model-CRAAM/pipelineMCMC>

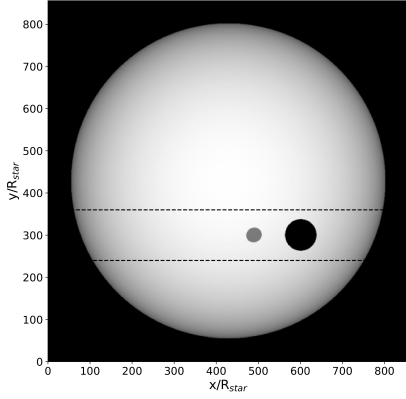


FIGURE 1. Synthesized 2D image of the star with a gray spot, while the black circle depicts the transiting planet.

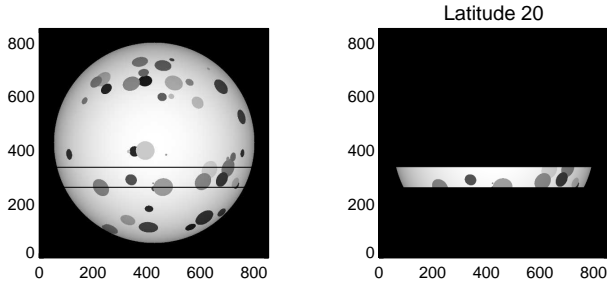


FIGURE 2. Left: One simulation of a star with 50 randomly distributed spots. Right: Area of the star occulted by the planet with a transit at latitude of 20° .

3. Results

Table 1 summarizes the spot coverage measurements for all stars. Fractional coverage spans a large interval, from 4% (Kepler-411) to 29% (CoRoT-18), reflecting a wide range of magnetic activity states. The number of detected spots per system varies by over an order of magnitude, driven by the number of available transits and the spot evolution timescale.

A pronounced anticorrelation is observed between the fractional starspot coverage and stellar age (Spearman $\rho = -0.80$) (see the left panel of Figure 3), demonstrating that younger stars exhibit substantially larger spotted fractions. This trend aligns with canonical magnetic-activity decay laws, often approximated by $L_{\text{activity}} \propto t^{-1/2}$, and indicates that the surface emergence of large-scale magnetic structures diminishes steadily as the stellar dynamo loses efficiency with time. On the other hand, a moderate positive correlation is seen between the absolute areas and effective temperatures (see the middle panel of Figure 3).

Notably, even older stars retain significant absolute spot areas ($\sim 10^{10} \text{ km}^2$), implying that the decline in fractional coverage is driven by changes in the *number* of active regions rather than their characteristic size.

Two regimes emerge:

- Fractional coverage (%) shows a weak negative trend with effective temperature.
- Absolute spot area (km^2) shows a moderate positive correlation.

TABLE 1. Summary of Starspot Area Coverage for the 11-star Sample

Star	Mean Coverage (%)	Area (km^2)	N ^o of Spots
CoRoT-2	17 ± 7	7.2×10^{10}	392
CoRoT-6	5.1 ± 1.8	2.6×10^{10}	31
CoRoT-8	10 ± 4	2.9×10^{10}	21
CoRoT-18	29 ± 8	1.4×10^{11}	21
Kepler-17	8 ± 7	4.3×10^{10}	1069
Kepler-45	6 ± 4	8.8×10^9	34
Kepler-63	8 ± 5	3.1×10^{10}	297
Kepler-71	6 ± 5	2.1×10^{10}	76
Kepler-210	16 ± 9	3.3×10^{10}	107
Kepler-411	4.0 ± 2.8	1.3×10^{10}	191
KOI-883	12 ± 6	2.8×10^{10}	78

This indicates that hotter stars exhibit similar spot sizes but a lower coverage fraction due to their larger surface area.

Rotation is only weakly correlated with spot coverage (see right panel of Figure 3). Departures from the Skumanich (Skumanich 1972) relation between age and rotation suggest angular momentum exchange in planet-hosting stars, through tidal or magnetic star–planet interactions.

4. Discussion

Starspot transit mapping accesses high-precision spot properties but remains limited by geometric constraints, sampling only a narrow latitude band. Nevertheless, simulations and multi-planet systems indicate that transit-chord coverage provides a robust tracer of global magnetic activity.

Our results emphasize:

- The need to incorporate starspots into isochrones to avoid age underestimation in spotted stars.
- The nearly constant physical spot size suggests a universal scaling law for flux tubes in cool stars.
- Systems with close-in planets may deviate from expected spin-down evolution.

These findings align with recent insights from spectroscopic, photometric, and magnetohydrodynamic analyses (Tregloan-Reed and Unda-Sanzana 2021; Yamashita et al. 2022; Lanza et al. 2009).

5. Conclusions

1. Starspot fractional coverage declines strongly with stellar age, but absolute spot sizes remain nearly constant.
2. The FGKM sequence shows only mild dependence of spot size on temperature.
3. Weak correlations with rotation indicate the influence of planetary companions on stellar angular momentum.

In summary, our results not only support previous theoretical findings but also provide an important observational basis for refining predictions on magnetic activity, the evolution of active stars, and their physical properties, making a significant contribution to the field of stellar astrophysics. More detailed results and extended discussions are presented in Araújo et al. (2025).

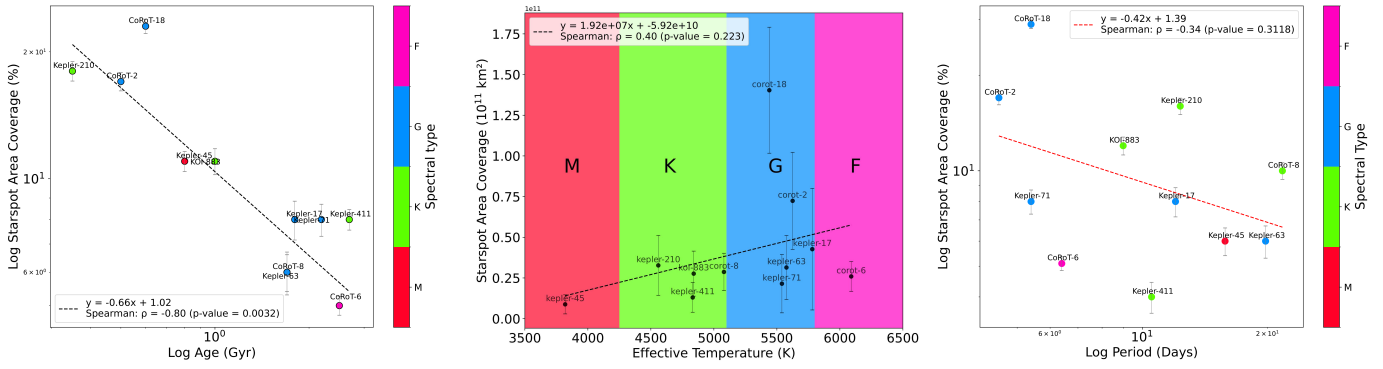


FIGURE 3. Right panel: Weak anticorrelation of the area coverage of starspots with the mean stellar rotation period. Middle panel: Moderate correlation between the absolute starspot area coverage and stellar effective temperature. Left panel: Strong anticorrelation of the percentage of starspot area coverage as a function of stellar age.

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