The search for induced stellar flares using TESS

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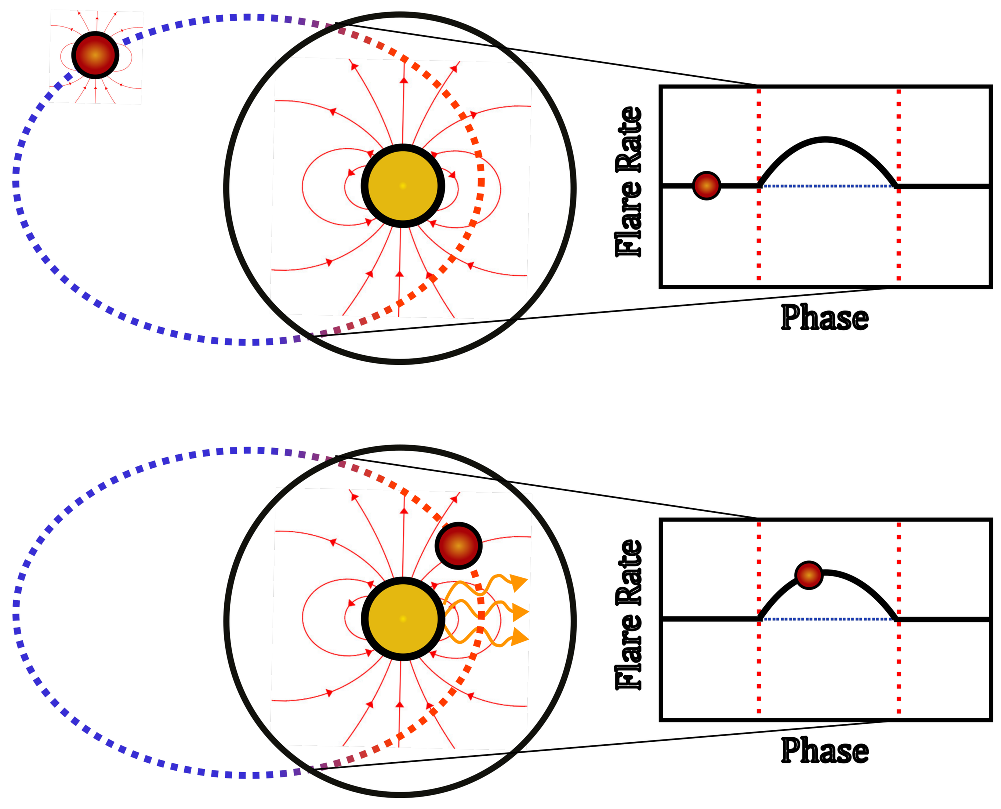
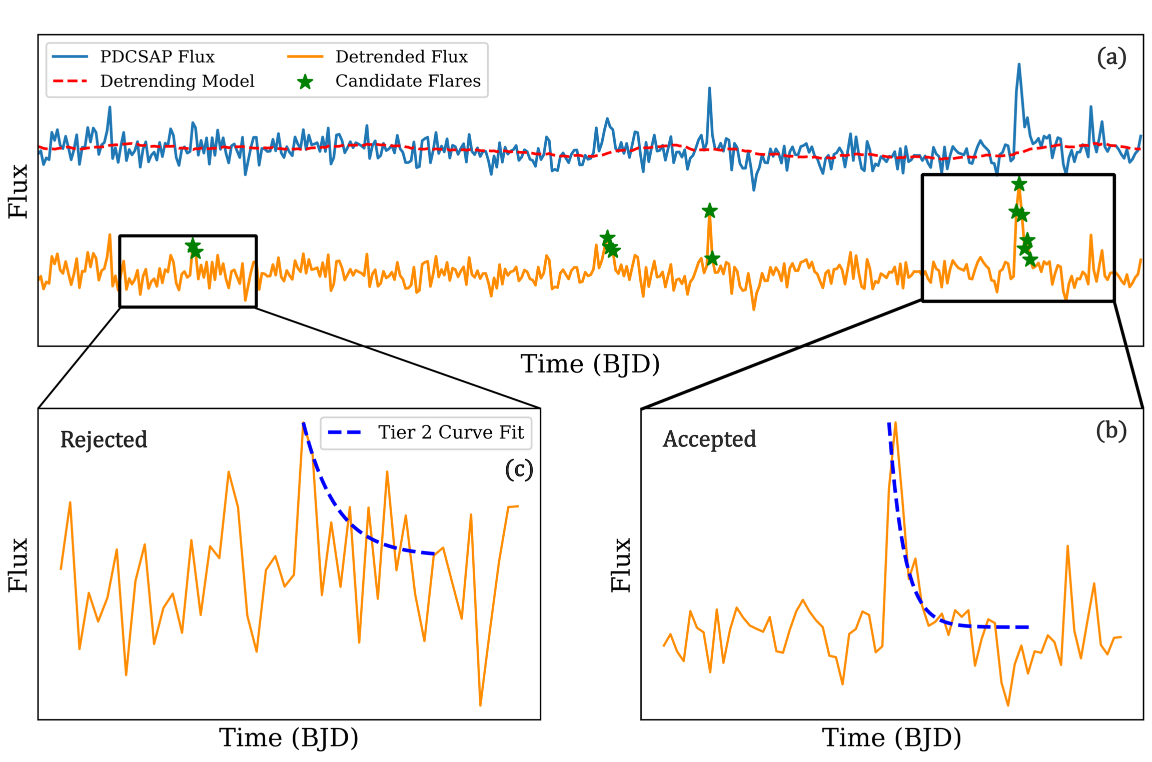
Introduction

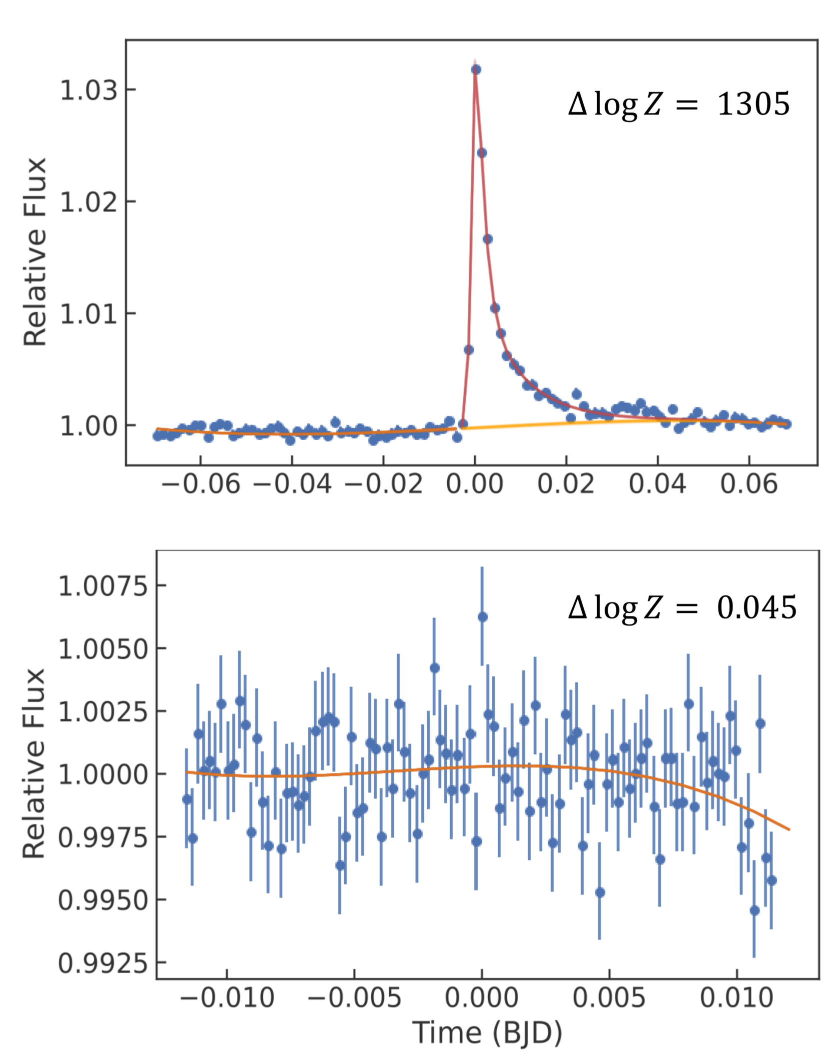
The relatively low occurrence rate of small, close-in exoplanets across the radius-period plane suggests several pathways of atmospheric escape. Stellar flares induced due to magnetic star-planet interactions (SPIs) can potentially erode the atmospheres of planets that orbit within or regularly cross the Alfvén surface of the host star.



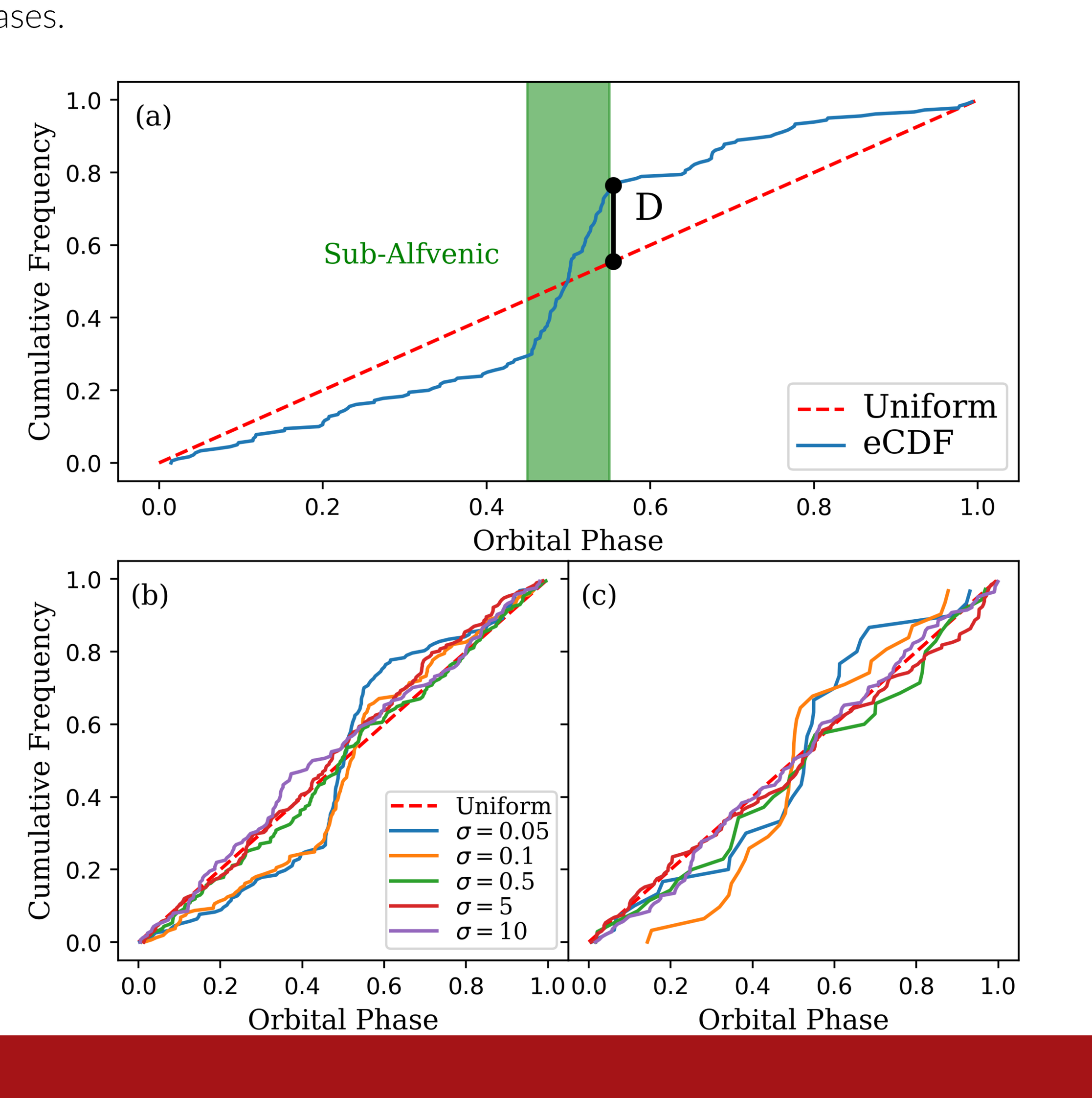
We developed a stellar flare detection and simulation pipeline, `ardor` (https://github.com/astromusers/ardor), to search for stellar flares phased with orbiting planets using time-series photometry, particularly from the Transiting Exoplanet Survey Satellite (TESS) [1].



We follow a four-tier approach to detrend the light curve, identify flare candidates as outliers with respect to a local estimate of standard deviation, maximize the likelihood of a flare model, and eventually use allesfitter [2] to estimate the Bayesian evidence for flare models to vet the flare candidates.

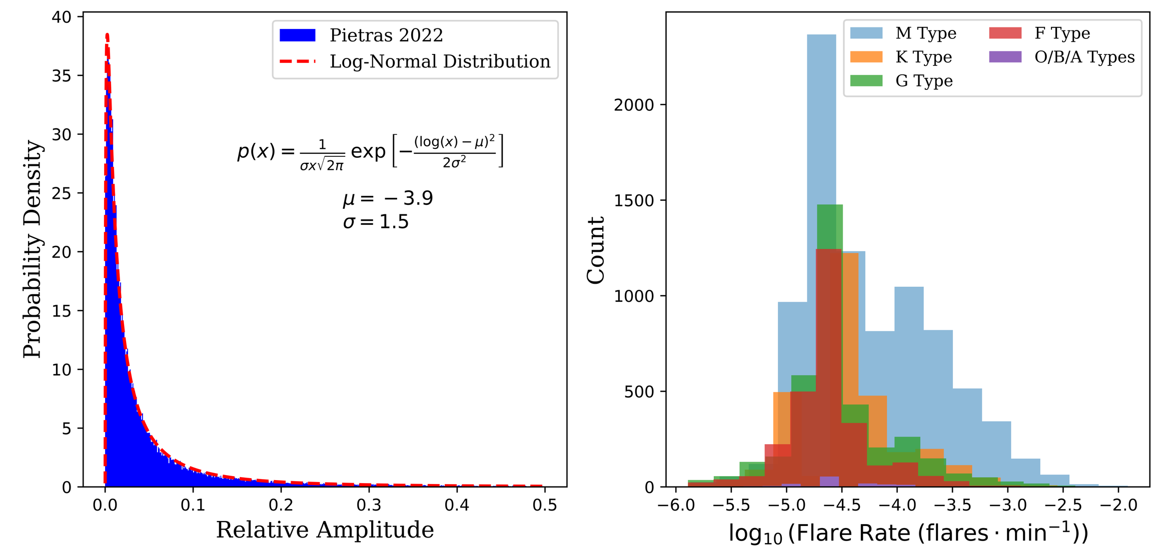


After finding flares from planet-hosting stars, we use both the Kolmogorov-Smirnov (KS) and Anderson–Darling (AD) tests to search for clustering of flare phases.

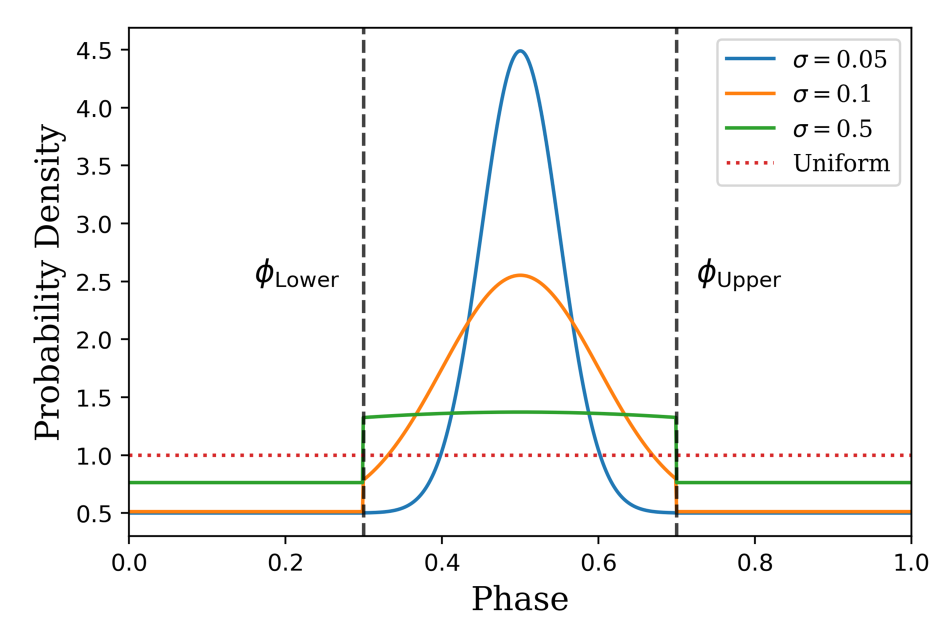


Injection recovery tests

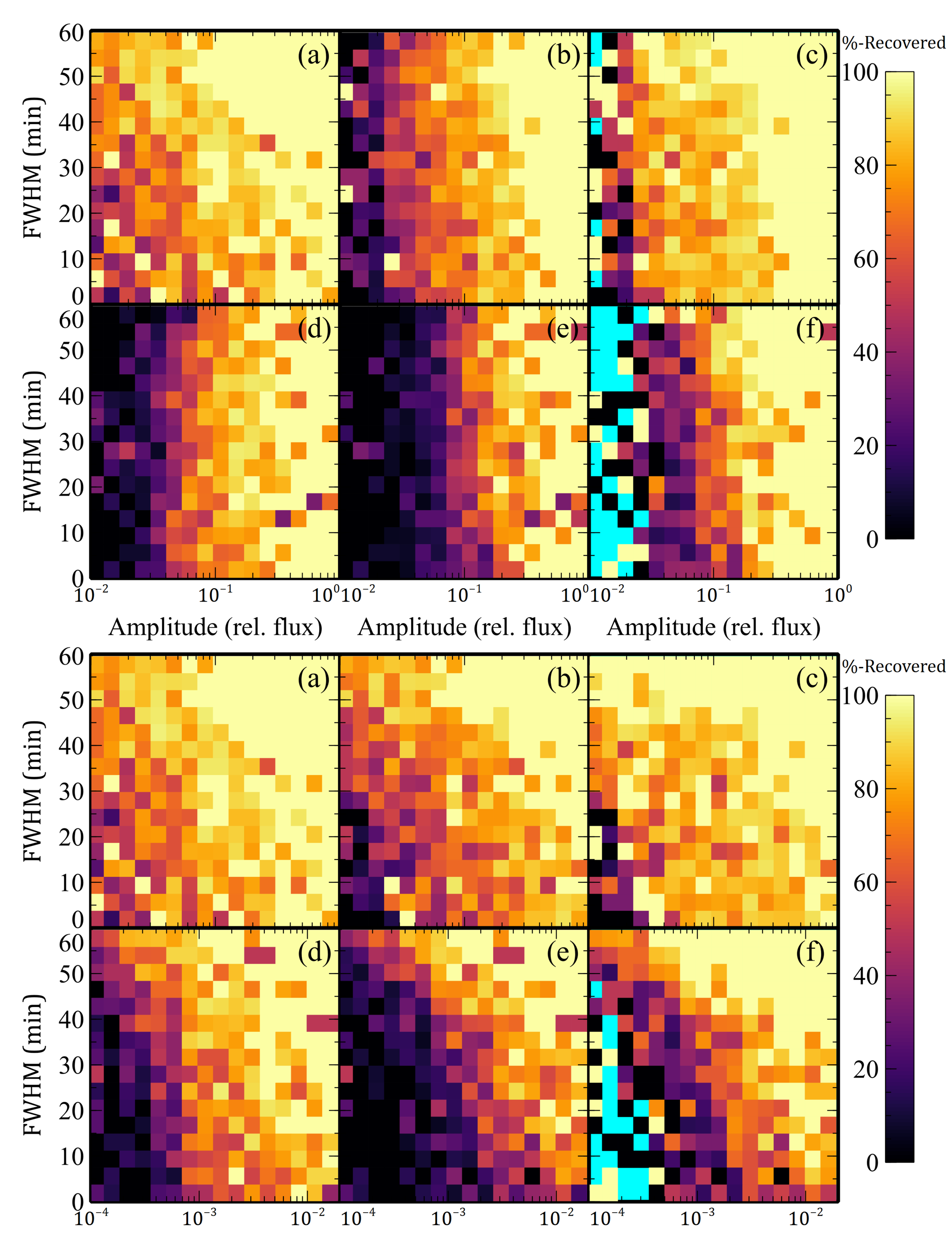
To assess the performance of the pipeline, we simulate TESS light curves with flare amplitudes drawn from a log-normal amplitude distribution consistent with Pietras et al. 2022 [3]. We use only short cadence (i.e., 20-second and 2-minute) data when available.



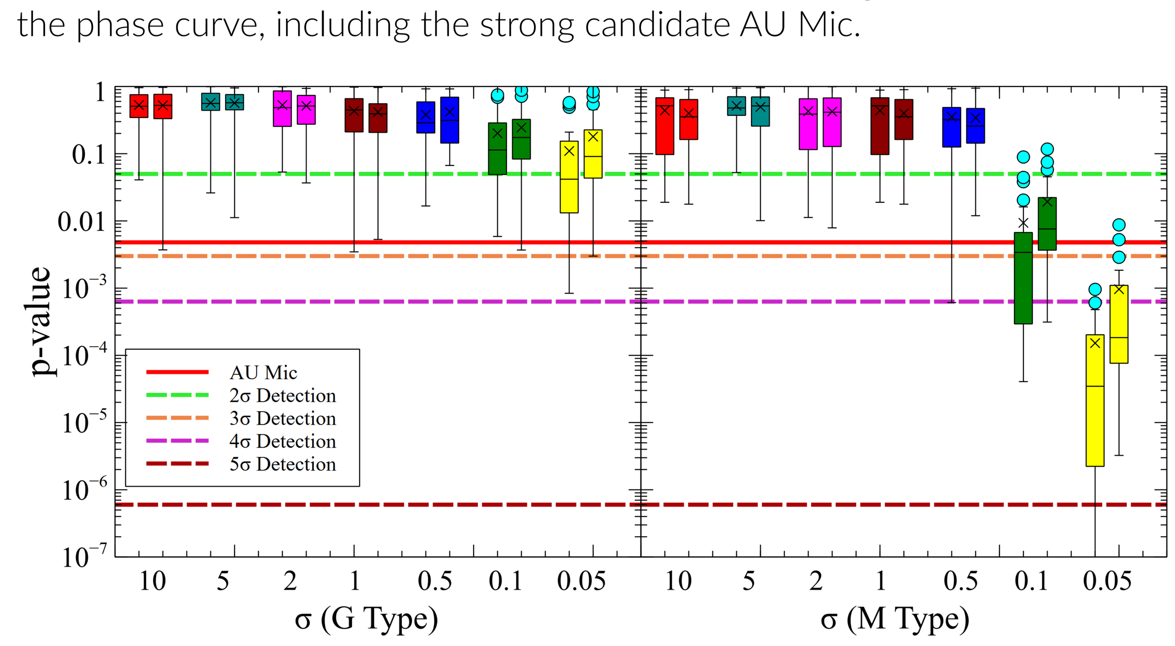
We assume that in the presence of magnetic SPIs, the flare rate is enhanced over a duration determined by the orbital period, size of the magnetopause, and eccentricity. Therefore, for a random fraction of targets in our simulations, we add a phase correlation into the timing of flares based on a parameter σ that tunes the level of clustering of flare phases.



Our signal injection and recovery tests ensure the completeness of resulting flare catalogs down to the cadence and photometric sensitivity of the underlying TESS light curves.



We demonstrate sensitivity to phase correlations in M-dwarfs at a p-value of less than 10^{-3} when the FWHM of the phase clustering subtends ∼12% of the phase curve, including the strong candidate AU Mic.



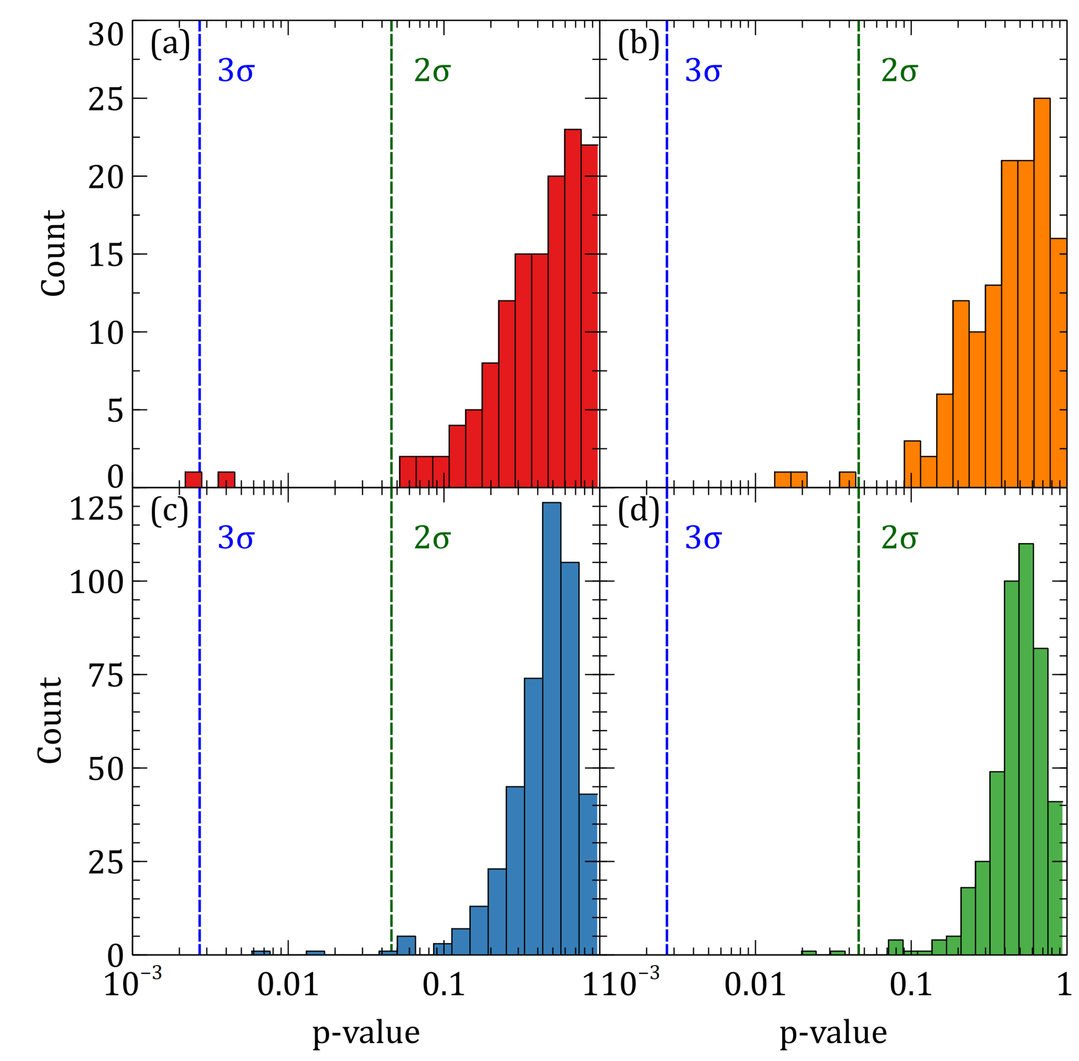
In contrast, the lack of frequent flaring activity on more massive stars typically results in flare-starved analyses. The growing temporal baseline of multi-sector TESS observations will soon make the analysis sensitive to more massive stars with rarer flares.

Phase-correlated flares from the TESS mission

We run our pipeline on three sets of targets with available TESS light curves:

1. all confirmed exoplanets with measured arguments and epochs of periapsis that provide strong priors on where the clustering should emerge,
2. other confirmed exoplanets lacking characterization of periapsis and
3. all TOIs, which extend the target list at the expense of lower detection probability due to potential false positives.

We find several systems exhibiting potential-phased flares with 2-3σ detection significance. Some of these orbiting planets could be inducing flares on their hosts through reconnection of the stellar magnetic field and the magnetopause as the planets move into and out of the Alfvén surfaces of their host stars.



The table below lists the KS- and AD-test p values and the number of flares associated with each candidate, where the target names and planetary orbital periods have been redacted.

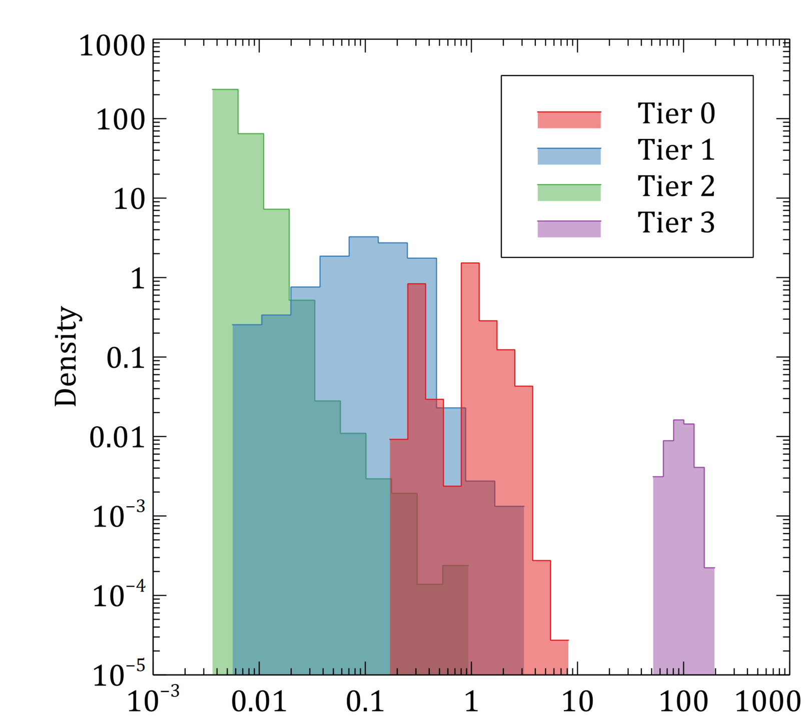
Host	KS p-value	AD p-value	N	Period (Days)
	0.0098	0.030	7	
	0.010	0.048	4	
	0.017	0.043	5	
	0.017	0.044	5	
	0.020	0.053	8	
Redacted	0.026	0.049	6	Redacted
	0.031	0.069	4	
	0.032	0.075	5	
	0.037	0.083	5	
	0.038	0.034	14	
	0.053	0.113	3	

The KS and AD tests complement each other as they are relatively more sensitive to the center and tails of the distribution, respectively.

These candidates offer opportune targets for searches of planetary radio emission, which can constrain the strength and extent of the planetary magnetic fields. The targets can be further characterized by future surveys in ultraviolet and soft X-rays, such as the upcoming ULTRASAT mission [4] that is expected to launch at the end of 2027 and AXIS [5], which was recently submitted as a probe concept to NASA APEX solicitation.

Speed-testing the pipeline

To ensure the scalability of the pipeline to large numbers of targets (i.e., all TOIs), we optimize the time performance of the pipeline to ensure no single tier dominates the time budget.



References

1. Ricker, G. R. et al. 2015, JATIS, 1, 014003, doi: 10.1117/1.jatis.1.1.014003
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