Transits with Spot-Crossings in PLATO: A Data Challenge

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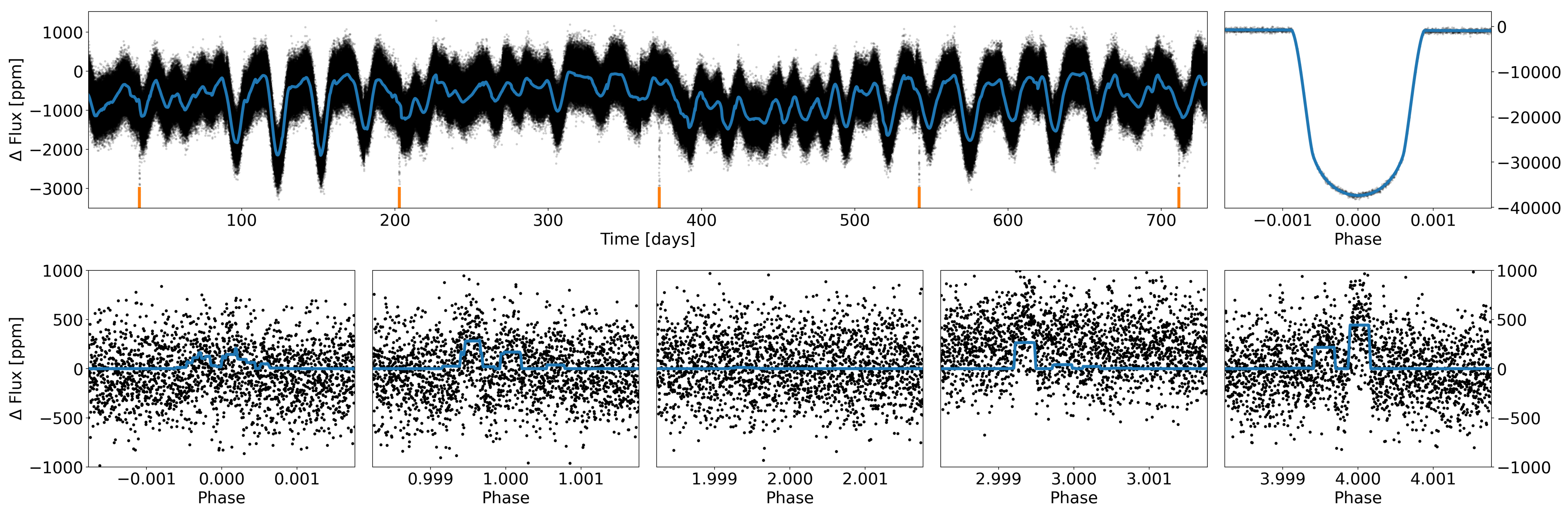
on behalf of the

PLATO Stellar Variability Working Group

Motivation

Star-spots are colder and therefore darker areas on the surfaces of stars induced by magnetic activity. Individual spots emerge and decay over time-scales of days to weeks, while to overall distribution of spots evolves with the stellar activity cycle with the number and latitude of spots changing over years or even decades, generating the well-known butterfly diagram in the sun. While the existence of spots on other stars is well known, our inability to resolve their surfaces limits our ability to constrain their properties, as we can only see the integrated effects of the spots on the total flux outside of transits, and occasional spot-crossing events where a transiting planet will cross a star-spot, thus modifying the in-transit lightcurve shape. Several codes for fitting such spot-crossing exist in the literature, but they can only be used when the amplitude of the spot-crossing is large and well-defined, coming from only a handful of distinct spots. Furthermore, the effect such spot-crossing events may have on the transit search and transit modelling is not well understood, especially in the case of small planets producing shallow transits on long orbits. We present here a set of simulated lightcurves for use in a data challenge comprising of two parts: transit detection, and transit characterisation (fitting) in the presence of star-spots.

Example Lightcurve



Simulated 2-year lightcurve of a Jupiter size planet transiting a G5 star. *Top-left*: Zoom in on the out-of-transit variability induced by the evolving spot-pattern, with the analytic spot model overlaid in blue and the planetary transits marked in orange. *Top-right*: Zoom in on the first transit, with the sum of the analytic transit and spot models overlaid in blue. *Bottom*: Zoom in on the residuals of each transit when compared to the analytic model, showing the effect of the spot-crossing on the transit shape.

Simulations

In total we generate 90 2-year simulations of Earth- to Jupiter-sized planets in the Habitable Zones of their main sequence host stars, with orbital periods ranging from 60 days to 3 years[a]. Each simulation includes an evolving star-spot distributions [1, 3] and representative noise generated using the PSLS [4] for the PLATO P1 sample. Since computational resources are limited we choose to only perform the full numerical simulation for windows centered around the transits, with the out-of-transit data calculated using an analytic spot model [2]. Spot-distributions are generated to be in the top 10% of typical activity for the chosen stellar types, and we bias the simulated time-spans toward the middle of the stellar cycle. In addition, the stellar inclination and orbital parameters are chosen semi-randomly in such a way as to ensure spot-crossings occur. Together these conditions generate a worst case scenario, ensuring we will not underestimate the potential impact of star-spots on the detection and characterisation of planets from the PLATO lightcurves alone.

[a] For those interested, 90-day lightcurves of short-period planets will also be made available.

Example System

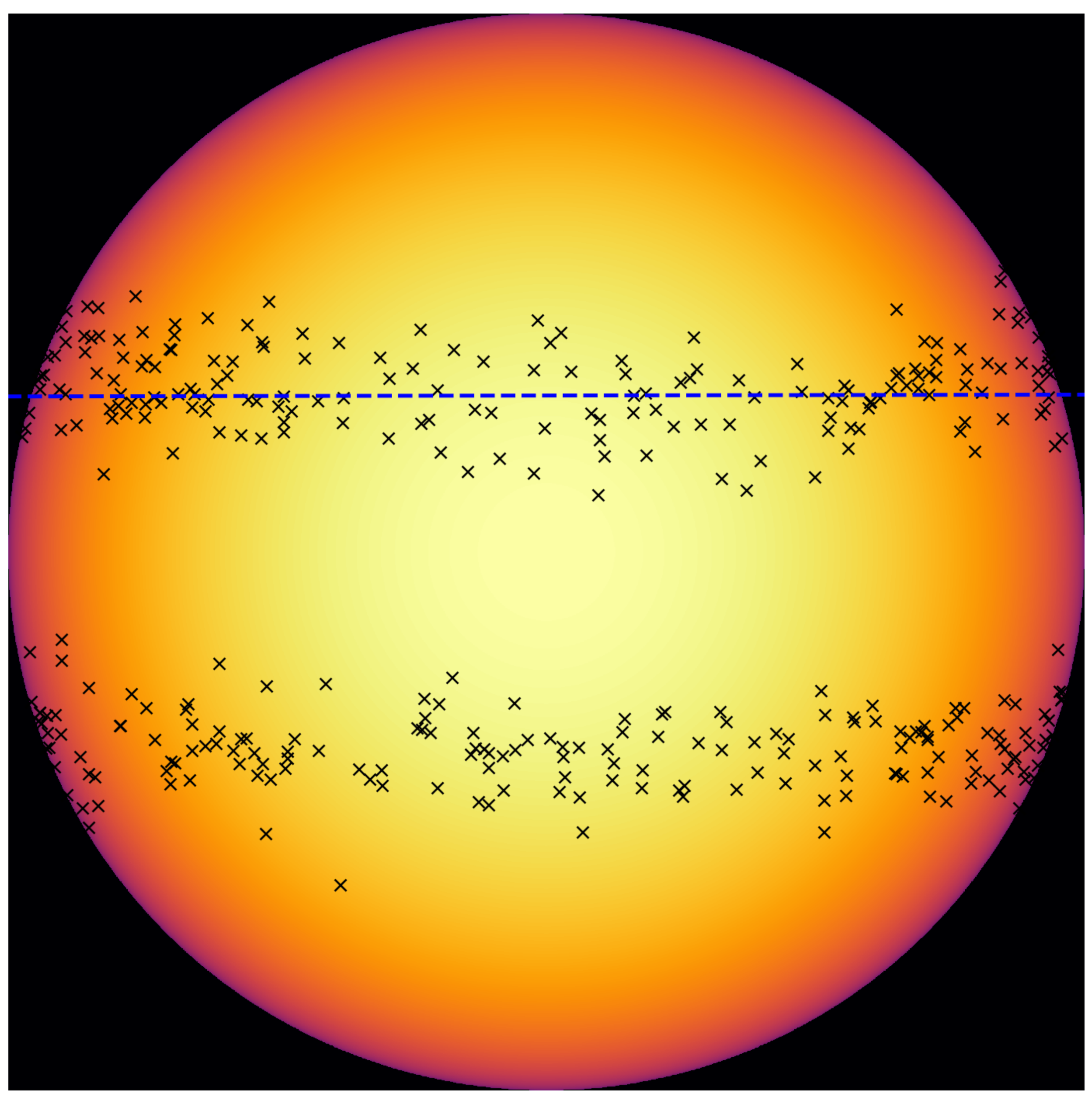


Illustration of the planetary system shown in the figure above. Black crosses mark the locations on the star where spots are at maximum size across the 2-year span of the simulations. The blue line marks the transit chord of the planet.

Joining

If you are interested in joining the data challenge - either to test transit detection, transit fitting or both - please follow the QR code or go to the link below.

Timeline:

- Distribution of data - Early June.
- Closed to new participants - End of June.
- Submission of results - End of August.
- Discussion - September

https://forms.gle/Y3SVWPpueThy1k8c9

Citations

[1] Aigrain, S., Llama, J., Ceillier, T., et al. 2015, MNRAS, 450, 3211. doi:10.1093/mnras/stv853

[2] Kipping, D. M. 2012, MNRAS, 427, 2487. doi:10.1111/j.1365-2966.2012.22124.x

[3] Meunier, N., Lagrange, A.-M., Boulet, T., et al. 2019, A&A, 627, A56. doi:10.1051/0004-6361/201834796

[4] Samadi, R., Deru, A., Reese, D., et al. 2019, A&A, 624, A117. doi:10.1051/0004-6361/201834822

Want to join the PSVWG?

- **Visit our confluence webpage.**
- Contact the WG leaders(*) to join **the mailing list** and **the Mattermost** channel.
- **Join regular Zoom meetings**: next one is May 21, 2024 at 10:30 am CET

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