Transit Timing in the *Kepler* Field with *PLATO*: The case for 24 cameras on the *Kepler* Field

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Intro: *How can PLATO maximize the impact of transit timing data in characterizing low-mass planets?*

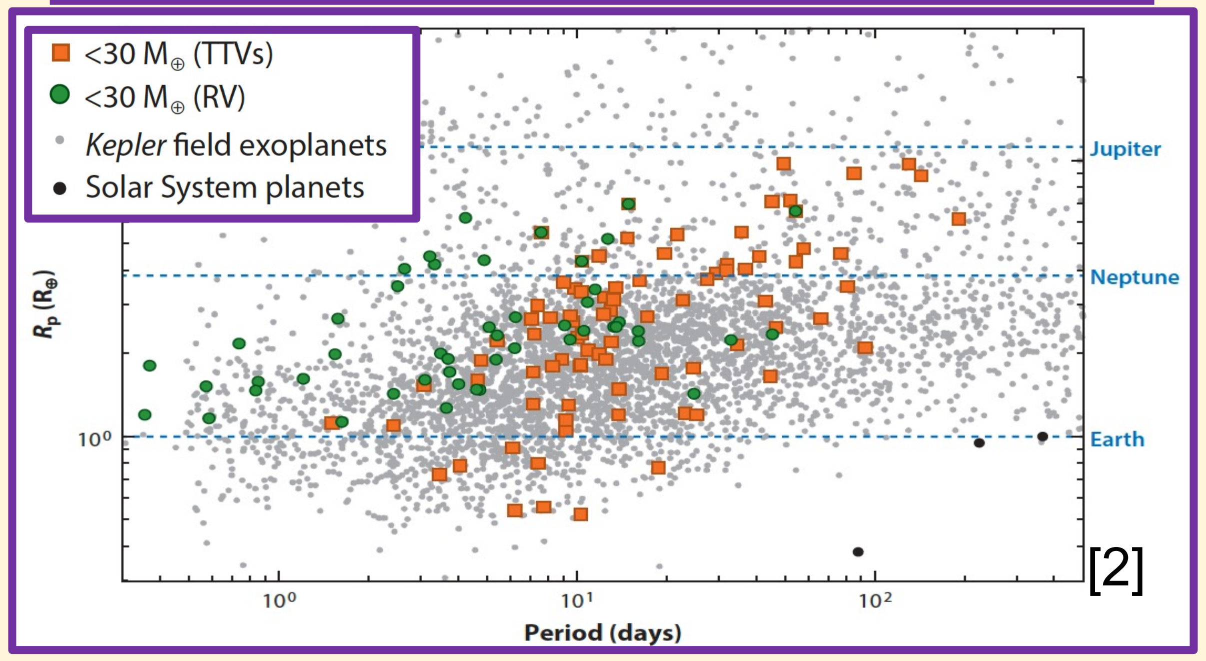
TTV signals *increase* with the observational baseline. Hence, *PLATO*'s Long-duration Observation Phase (LOP) in the *Kepler* field alongside *Kepler* data will provide TTV masses at longer period planets than *Kepler* or *PLATO* alone.

We argue that *PLATO*'s impact will be maximized with 24 cameras on the *Kepler* field with a split interval LOP as necessary [1], and summarize some anticipated highlights.

At what orbital periods are known characterized planets?

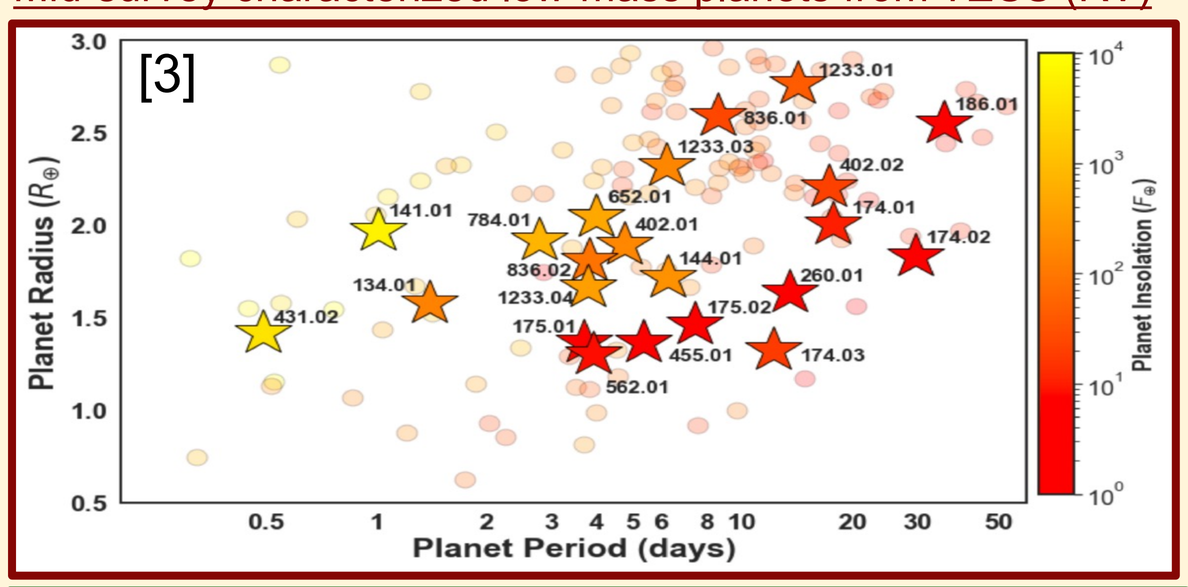
The majority of low-mass planet characterizations among transiting planets have occurred in the *Kepler* field, among planets with periods ~7-200 days.

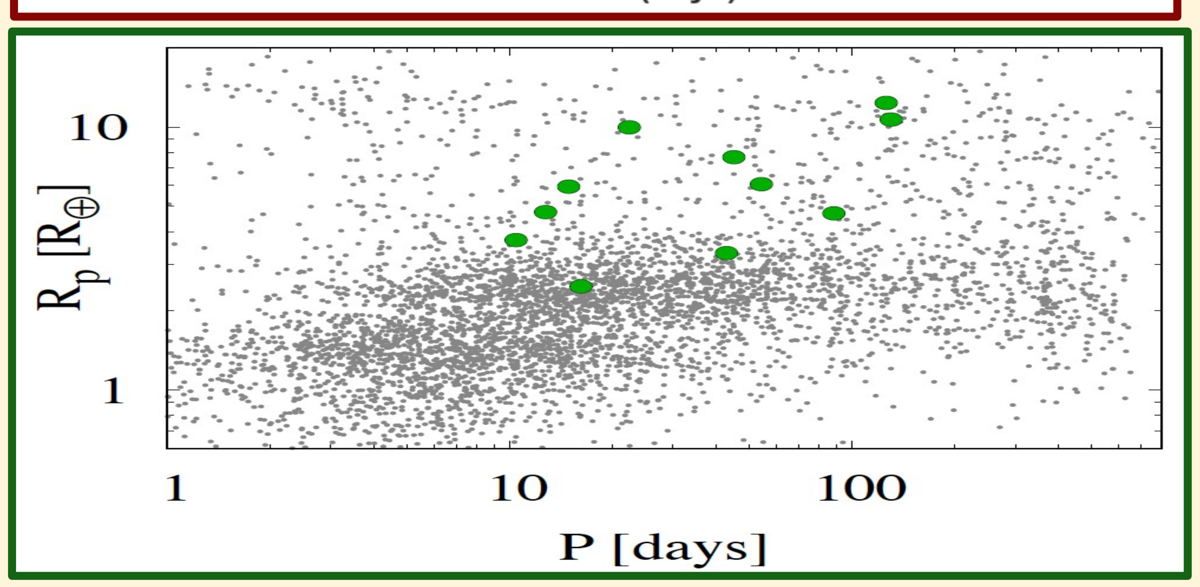
Characterized Low-Mass Transiting Planets Pre-*TESS*:



Where will TESS have the most impact?

Mid-survey characterized low-mass planets from *TESS* (RV)

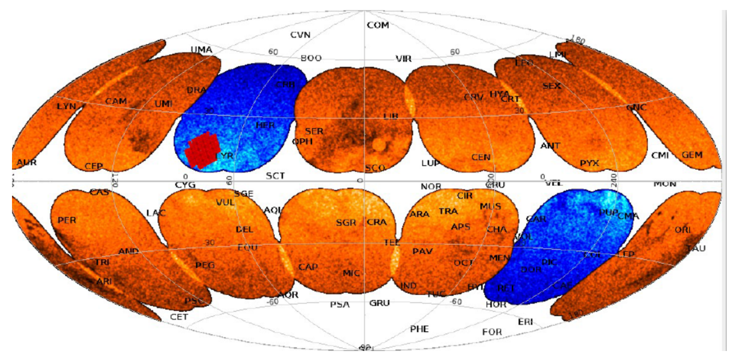


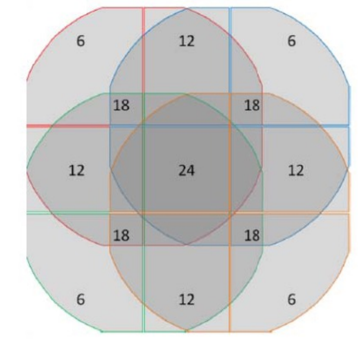


Preliminary results of transits detected by *TESS* in S14,15, and 26 among *Kepler* multis with TTVs [4]. Only ~11 planets have high enough SNR in *TESS* to provide TTV constraints beyond *Kepler* alone.

While TOIs are substantially increasing the the number of characterizations of low-mass planets within 50 days, longer periods are still primarily *Kepler*'s domain.

How can PLATO enable planet characterization at orbital periods sparsely sampled by Kepler and TESS alone?



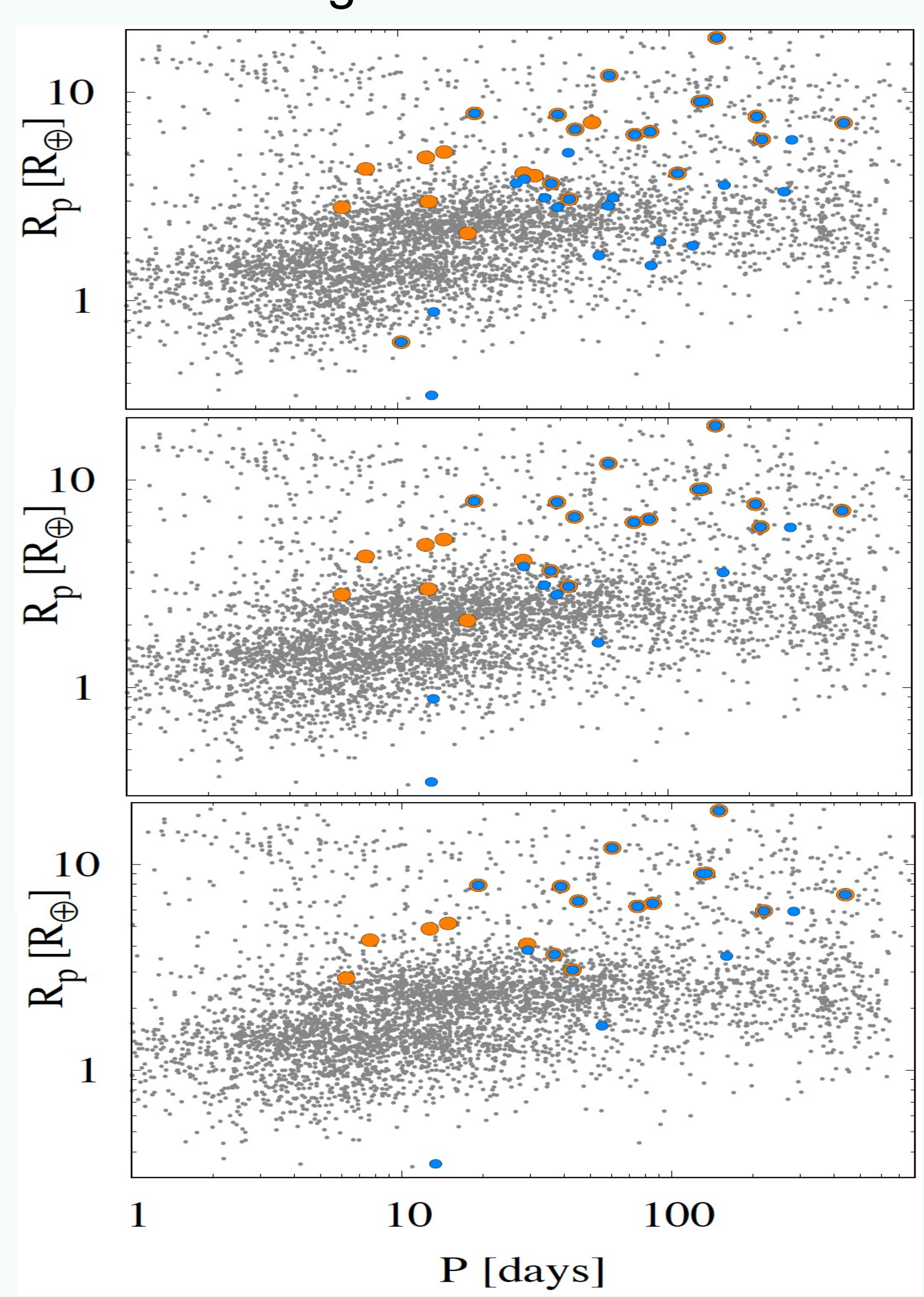


PLATO's preliminary strategy includes a two-year LOP with the *Kepler* field in its periphery [5] with 6-12 cameras on the *Kepler* field. Below, we show that centering the LOP on the *Kepler* field (with 24 cameras) will significantly enhance the return for planet characterization via TTVs. We advocate splitting the LOP over different intervals as necessary to optimize the TTV return from the LOP. This will not adversely affect the yield from TTV by time domain, given the long baseline that includes both *PLATO* and *Kepler*. For the analysis below, we assume that with 24 cameras, the *PLATO transit SNR* will be ~0.62 that of *Kepler*, and that it scales as sqrt(num_cameras).

Sample A: We identified targets with an expected TTV signal in the *Kepler* field that could characterize transiting planets [6], given an assumed minimum mass from the planet radius (in Earth-units $M_p = \min(4, R_p^3)$), the orbital periods of adjacent pairs and pairs with an intermediate planet, the solution of [7] for TTVs caused by near first-order orbital resonances, and the median transit timing uncertainty, σ_{tt}, from [8]. Targets where the expected minimum TTV amplitude > 5 σ_{tt} are in orange below.

Sample B: We identified targets in the *Kepler* field with TTV periods from first and second order resonances > 1000 days. These targets are in blue below.

TTV targets with *PLATO transit SNR* > 5 (per transit)

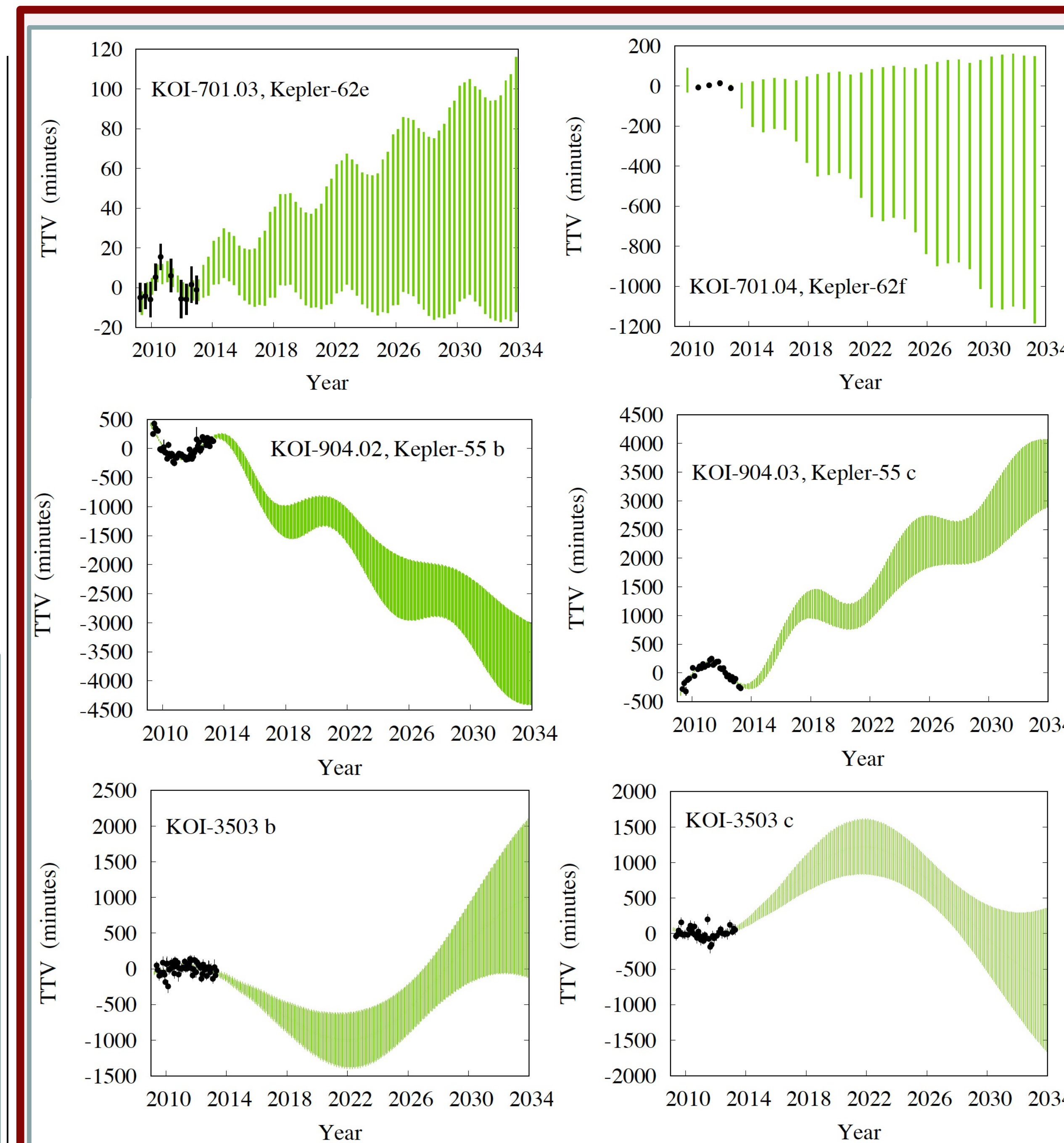


24 cameras
Just A: 9 targets
Just B: 16 targets
A and B: 16 targets
Total: **41 targets**

12 cameras
Just A: 7 targets
Just B: 8 targets
A and B: 14 targets
Total: **29 targets**

6 cameras
Just A: 5 targets
Just B: 5 targets
A and B: 13 targets
Total: **23 targets**

Just three planets beyond ~100 days have been characterized from TTV with *Kepler* data alone. A combined *Kepler*/*PLATO* dataset will increase the mass characterizations at longer periods significantly. Note that transit timing uncertainty scales as ~1/SNR [9]. Hence, having just 6 (or 12) cameras on the *Kepler* field instead of 24 would increase transit timing uncertainties by ~2 (or sqrt(2)). Centering on the *Kepler* field would provide ~60% more targets for mass characterizations with *Kepler*/*PLATO* data, compared to the the current LOP plan. *Further, a higher SNR on those targets will give better mass characterizations.*



Diverging future transit times at illustrative systems:

The *Kepler* data (black points) show a TTV signal with a periodicity longer than the 4 year *Kepler* dataset. The diverging 1σ confidence intervals on projected transit times (in green) follow posterior sampling of the planetary parameters that cause the TTVs.

Discussion: The baseline of combined *Kepler*/*PLATO* datasets longer than 20 years will enable *PLATO* to substantially improve TTV characterizations of long period planets in the *Kepler* field.

The most impactful *PLATO* transit times will be among planets with longer orbital periods than those characterized from *Kepler* data alone (including nearer the HZ), or with TTV periodicities longer than the *Kepler* dataset alone that cannot be accessed by *TESS* or from the ground.

Optimizing the return by centering on the *Kepler* field with *PLATO* with a split LOP as necessary is the best opportunity to explore long period transiting planets in the coming decades.

References:
[1] see talk by Jack Lissauer and poster by Jason Rowe.
[2] Jontof-Hutter, D (2019) AREPS, 47, 141
[3] Teske, J. et al. (2020) arXiv 2011.11560
[4] Jontof-Hutter, D. et al. (2021) in prep.
[5] https://platomission.com/2018/05/19/the-plato-sky/ https://platomission.com/payload-module/
[6] Jontof-Hutter, D. et al. (2021) AJ, 161, 246
[7] Lithwick, Y. et al. (2012), ApJ, 761, 122
[8] Rowe, J. & Thompson, S (2015), arXiv 1504.00707
[9] Holczer, T. et al. (2016) ApJS, 225, 9