TTV@YETI: Transit Timing Analysis using ground-based observations

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seit 1558

Motivation

The progress in the field of exo-planet science has become tremendous since the first extra solar planets have been found in the late 80s. Many projects were set out to find planets around other stars in order to find an analogon to our own solar system as a whole and the Earth in particular, and to find the answer if multi-planetary systems are common in the universe. While the first exoplanets have been detected using the radial velocity method, the transit method has become more and more successful. Apart from ground-based missions like HATnet or WASP, satelites dedicated to transiting planets have been launched. Having much longer continuous observations and no disturbing atmosphere, CoRoT and Kepler found lots of planetary transit candidates. New techniques are used to find even smaller planets, rapidly getting close to finding the first Earth-like extra solar planet, which is, due to its properties, still most challenging.

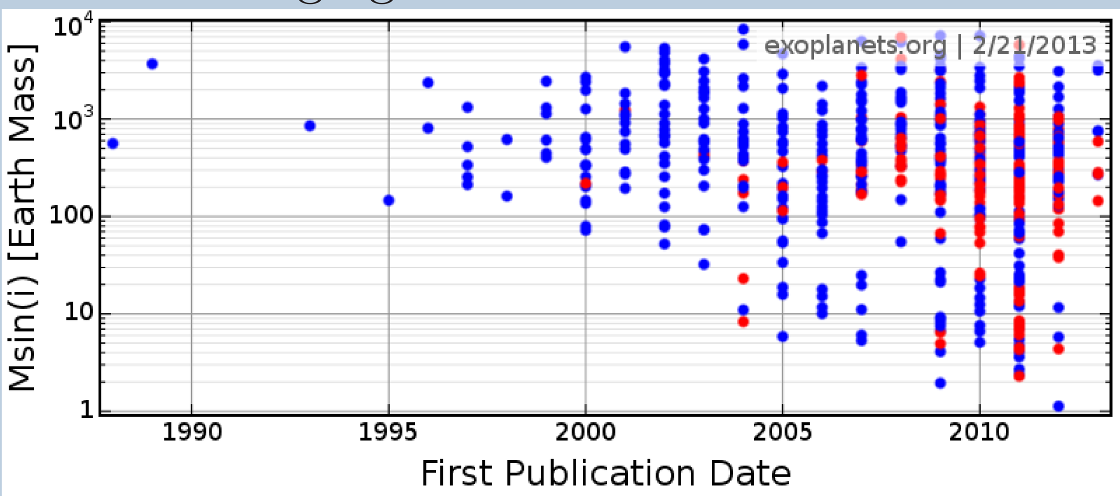

Fig.1: The lower mass limit of planet candidates detected since the late 80s is steadily falling towards the Earth-mass regime (transit method marked in red).

Basics

While common photometric surveys look for transit events itself, the **T**ransit **T**iming **V**ariation method takes a secondary effect to look for unseen companions. If a planet revolves its host star on a keplerian orbit (at an inclination of $\sim 90°$), transits occur at equal time intervals. If a second, not necessarily transiting body is present, it gravitationally interacts with the first one, resulting in variations of transit midpoints (TTVs). If the two bodies are in a mean motion resonance (MMR), these perturbations and resulting TTVs are maximised, even for small (even Earth-mass) perturbers. Thus, even though one can not see the perturber, one can detect it.

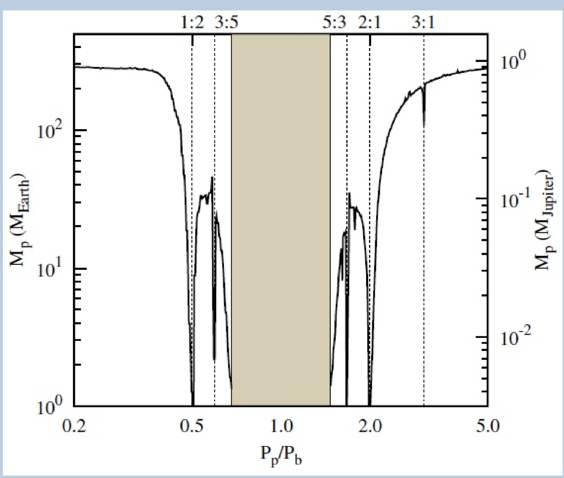

Fig.2: The perturber mass needed to result in a 73s TTV signal reaches the Earth-mass limit within MMRs (an example calculation for WASP-12b, [5]).

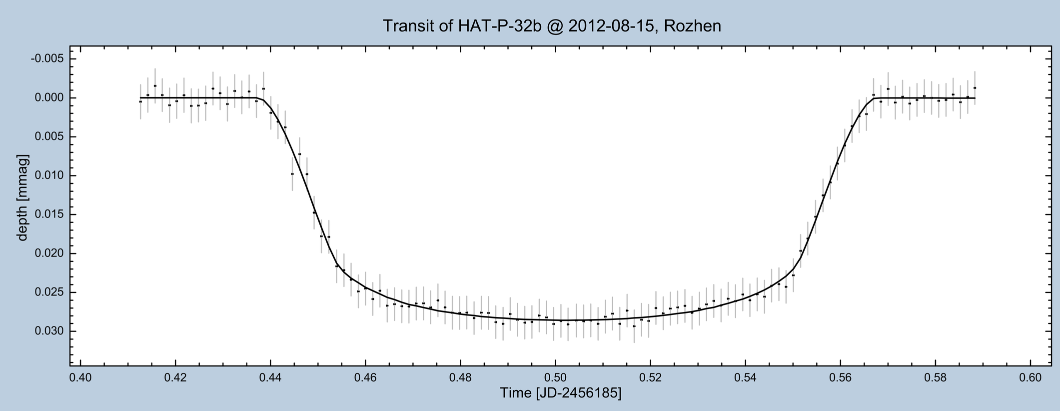

Fig.3: A transit of HAT-P-32b observed at the Rozhen 2m telescope with a photometric precision of 1.2 mmag and a timing precision as good as 21.6 s.

Previous Work

So far, we have observed transits of interesting planets in every clear night from our own observatory in Großschwabhausen near Jena. To get as many transits as possible and due to transit periods that make it difficult to get data at only one telescope, we are fortunatelly able to make use of the worldwide YETI network ([8], see poster by Ronny Errmann EP4.13).

By now, we have found no variations in the TrES-2 and WASP-14b system (Raetz PhD thesis, including Kepler data on TrES-2).

In the WASP-12b data we could find a periodic signal indicating a perturber with a period of 500 ± 20 epochs and a semi-amplitude of 0.00068 ± 0.00013 d [6].

Currently there are 6 new systems under investigation, including HAT-P-27b and HAT-P-32b.

HAT-P-27b

HAT-P-27b (discovered by [2]), is also known as WASP-40b (independently discovered by [1]). Looking at the RV-meassurements of both groups, one can see an almost perfect fit of the data of [2], but strong deviations in the data of [1]. Interestingly both groups nevertheless come to equal results leading to a 0.62 M_{jup} planet with a radius of 1.05 R_{jup}. While [1] have adopted zero eccentricity, [2] found a nonzero eccentricity of $e = 0.078 \pm 0.047$ as a best fit, thus matching our requirements of an interesting TTV target.

So far we could collect transit data of HAT-P-27b from Lulin (Taiwan), Stara Lesna (Slovakia), Tenagra (Arizona, USA), Trebur (Germany) and Xinglong (China) throughout the YETI network.

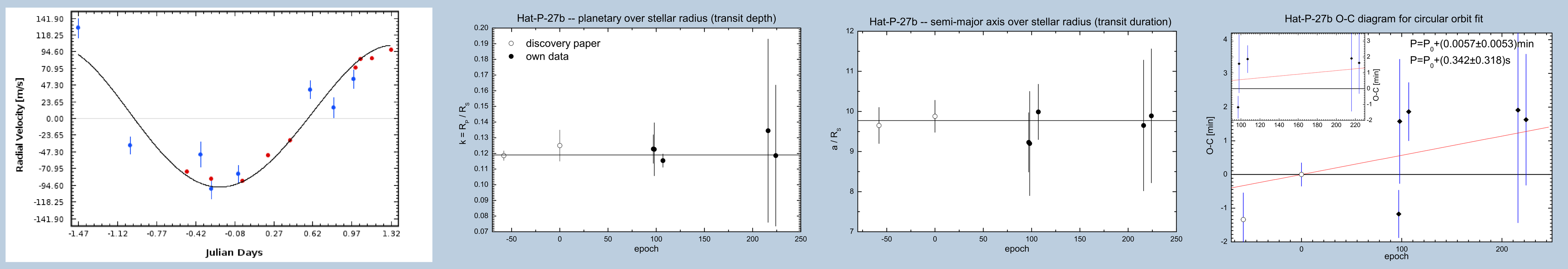

Fig.4: left: analysis of RV data from [1] (blue) and [2] (red) as mentioned in the text; right: the analysis of the tranits obtained for HAT-P-27b. There are no changes in transit depth ($k = R_P/R_S$) or transit duration ($\sim a/R_S$). The transit midpoints can be explained by redetermining the ephemeris by 0.342s. So far, no deviations from a linear trend can be seen, though five points are not enough to confirm this result.

HAT-P-32b

HAT-P-32 was found to harbor a transiting exoplanet by [4]. With a host star brightness of $V = 11.3$ mag and a transit depth of 22 mmag it is a brilliant target for small telescopes, hence perfect for the YETI network. The radial velocity signal of HAT-P-32 is dominated by high jitter. [4] already claimed that "a possible cause of the jitter is the presence of one or more additional planets". Indeed, by fitting a second body the χ^2 can be reduced by a factor of 2.

We have performed follow-up observations of HAT-P-32b transits at Jena, Ankara (Turkey), Gettysburg (USA), Rozhen (Bulgaria), Sierra Nevada (Spain), Swarthmore (USA), Trebur (Germany) and Tubitak (Turkey). Furthermore, 3 literature data points are available (Kitt Peak, USA, [9]).

Alltogether we got 17 high quality data points shown in figure 5. Though we do not see any periodic variations, the linear fit does not explain all data points. There are outlyers (both own data and literature data from [9]) around epoch 660 that could indicate an eccentric perturber. Further meassurements are needed and planned to confirm or decline this hypothesis.

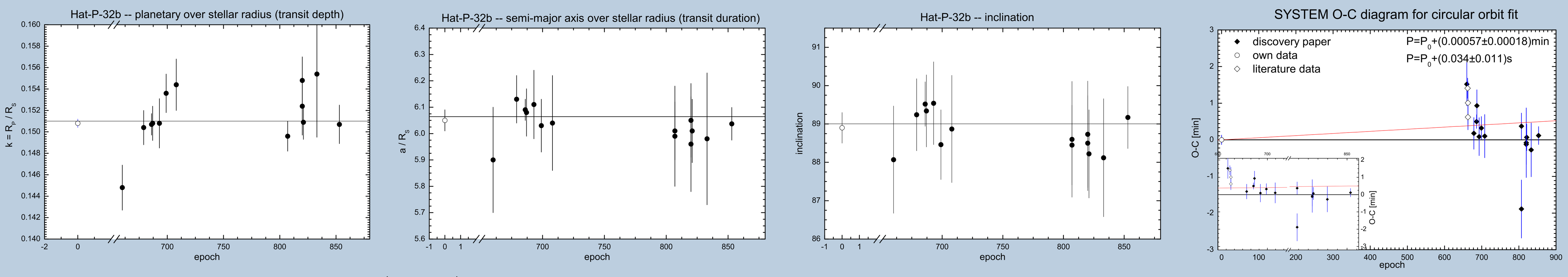

Fig.5: The same as figure 4 (right) for HAT-P-32b, including the inclination i. There are no significant changes in transit depth, transit duration or inclination. Redetermining the period by 0.034 s can explain almost all points. The outlier at epoch ~ 800 is most probably due to bad synchronisation of the telescope computer time. The systematic offset of literature and our own data points at epoch ~ 660 might indicate nonzero eccentricity of a possible perturber.

Outlook

We will continue observing transits of interesting TTV targets from our own 90cm telescope at Großschwabhausen near Jena, as well as from other YETI telescopes all over the world to cover as many epochs as possible, and to find possible variations in the O–C diagram.

If any variation is found, we will perform n-body simulations with the Mercury6 [3] and PTmet [7] codes to find out the most probable configuration that produces the given TTV amplitude and period.

References

[1] Anderson et al. 2011, **PASP 123**, 555
[2] Bèky et al. 2011, **ApJ 734**, 109
[3] Chambers 1999, **MNRAS 304**, 793
[4] Hartman et al. 2011, **ApJ 742**, 59
[5] Maciejewski et al. 2011, **A&A 528**, 65
[6] Maciejewski et al. 2013, **arXiv:1301.5976**; accepted for publication in A&A
[7] Nesvorny & Morbidelli 2008, **ApJ 688**, 636
[8] Neuhäuser et al. 2011, **AN 332**, 547
[9] Sada et al. 2012, **PASP 124**, 212