Ground-based observations of **T**ransit-**T**ime-**V**ariations

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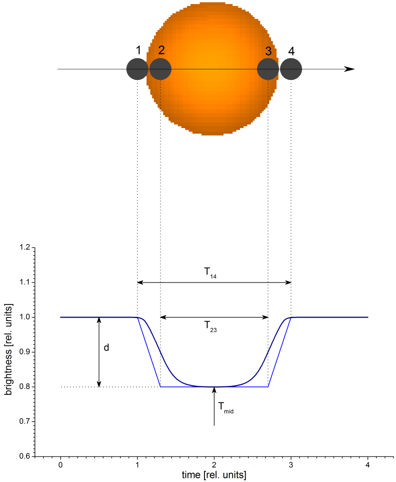
transit parameters



direct parameters of light curves:

transit-depth	d
transit-duration	T_{14} / T_{23}
transit-time	T_{mid}

connection to physical properties:

- fraction of radii R_P/R_S
- semi-major axis a/R_S
- period P
- inclination i ($\sim 90°$)
- limb-darkening

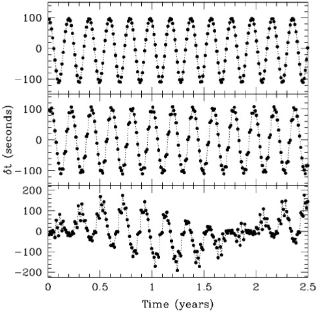
Transit-Time-Variations

- transit parameters are constant asuming undisturbed (moonless) one-planet systems
- in disturbed systems: variations of transit parameters occur due to gravitational interaction
- variation of transit mid-times
  $\rightarrow$ "Transit-Time-Variations" (TTV)
- typically: study of transit-depth- and transit-duration-variation
- state of the art tool: O–C diagrams

$\rightarrow$ plotting the difference between observed transit mid-time (O) and calculated mid-time (C) over the epoch N
$C = C_0 + N \cdot P$

- slopes $\neq 0$ point to wrong periods
- periodic distortions as results of gravitational interactions

O–C diagram – two-planet case



gas giant $M = 0.5\ M_{jup}$
$+$ trojan $M = 1\ M_{\oplus}$

gas giant $M = 0.5\ M_{jup}$
$+$ planet $M = 28\ M_{\oplus}$
out of 2:1 MMR

gas giant $M = 0.5\ M_{jup}$
$+$ planet $M = 5\ M_{\oplus}$
within 3:2 MMR

Figure: TTV amplitudes and periods from different configurations (Fig. 2, Ford & Holman 2007)

$\rightarrow$ different configurations result in similar periods / amplitudes
$\rightarrow$ necessity of many (+ consecutive) transit observations

the role of MMR

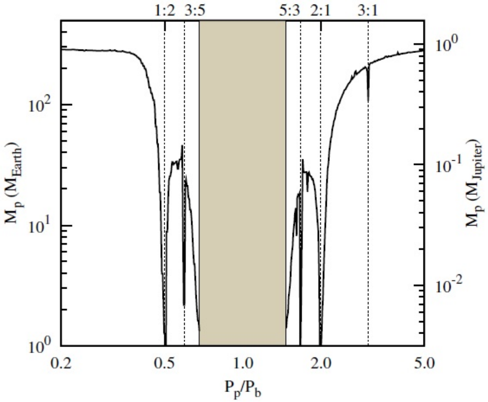


Figure: mass of a second planet with a TTV-amplitude of 73 s with respect to the period of WASP-12b (Maciejewski et al. 2011)

selection criteria

The targets for our TTV observations are selected according the following criteria:

1. target planet host stars should be bright enough for sufficient photometric and timing precision on 1-2m telescopes;
2. target location on sky visible from Jena;
3. existing indications of a perturber
   $\rightarrow$ orbital solution of known transiting planet shows non-zero eccentricity (see talk by W. Kley yesterday; Beauge & Nesvorny 2012)
   $\rightarrow$ deviant radial velocity (RV) data points
4. target has not been studied intensivelly before for TTV signals.

previous work

- observation of transits from our observing campaigns in every clear night from Jena / Großschwabhausen (GSH)
- necessity of observations of consecutive transits (i.e HAT-P-19b: $P = 4.009\,\mathrm{d}$)

$\rightarrow$ usage of the YETI network (see talk by Ronny Errmann)

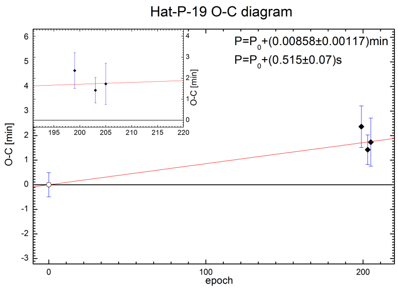
- WASP-3b: Maciejewski et al. 2010 (MNRAS)
- WASP-10b: Maciejewski et al. 2011 (MNRAS), 2011 (A&A)
- WASP-12b: Maciejewski et al. 2011 (A&A)

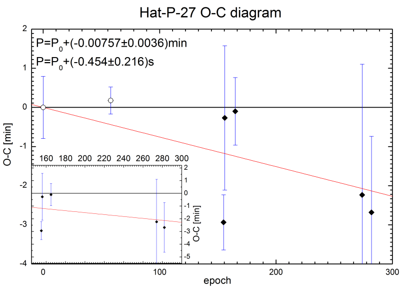
$\rightarrow$ see poster 55

- TrES-2, WASP-14b: Raetz PhD thesis $\rightarrow$ no variations found including Kepler data on TrES-2

$\rightarrow$ see poster 61

present work – HAT-P-19b & HAT-P-27b





- HAT-P-19b: 3 (+3) observations – Jena, Trebur, Calar Alto
- HAT-P-27b: 5 (+5 / 2) observations – Lulin, Trebur, Tenagra, Xinglong, Stara Lesna, Cerro Armazones

present work – HAT-P-32b

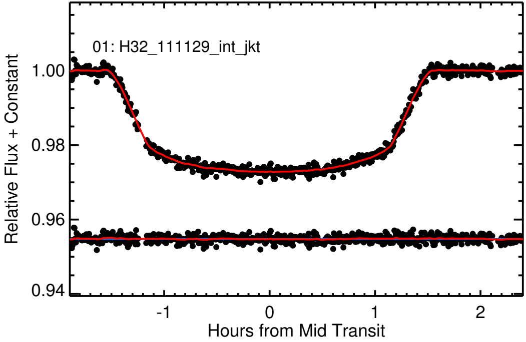
- Hartman et al. 2011: $M_P = 0.860\, M_{\rm jup}$; $R_P = 1.79\, R_{\rm jup}$; P∼2.15 d
- F-G-type host star; $V = 11.3$ mag
- deviant RV points and jitter

→ additional body proposed by Hartman et al. 2011

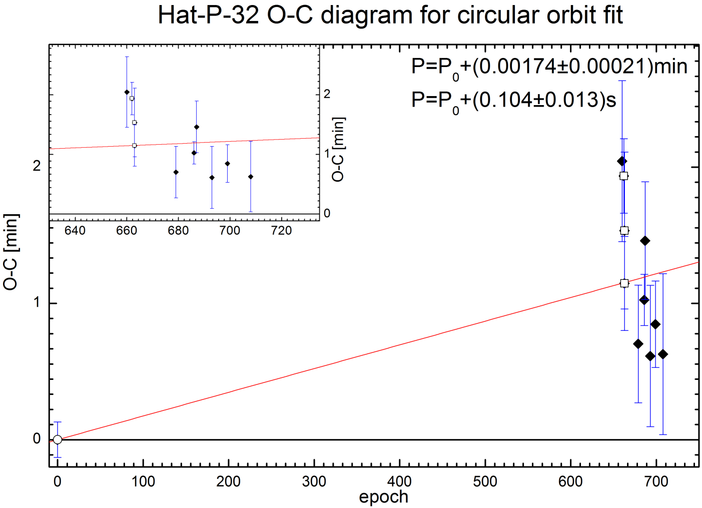
- 7 (+5 / 1) observations: Jena, Torun, Ankara, Swarthmore, Gettysburg, Rozhen, Teneriffa
- best transit light curve obtained @ 3m telescope in Rozhen with timing precision ∼11 sec

present work – HAT-P-32b

- best transit light curve obtained @ 3m telescope in Rozhen with timing precision ∼11 sec



present work – HAT-P-32b



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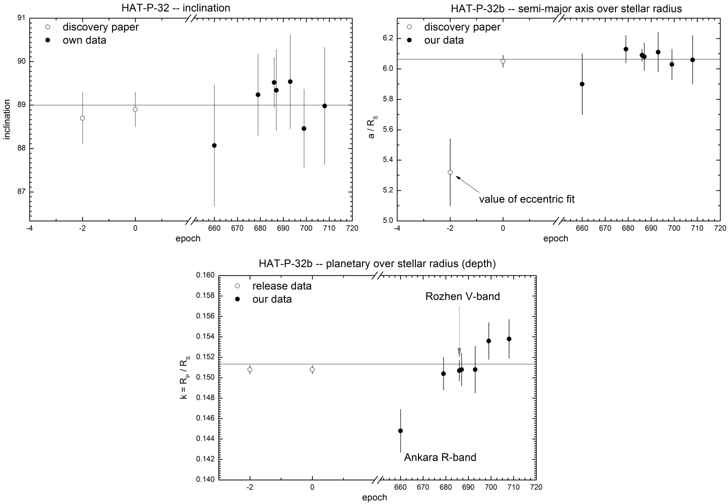


next steps

- observation of transits from our observing campaigns

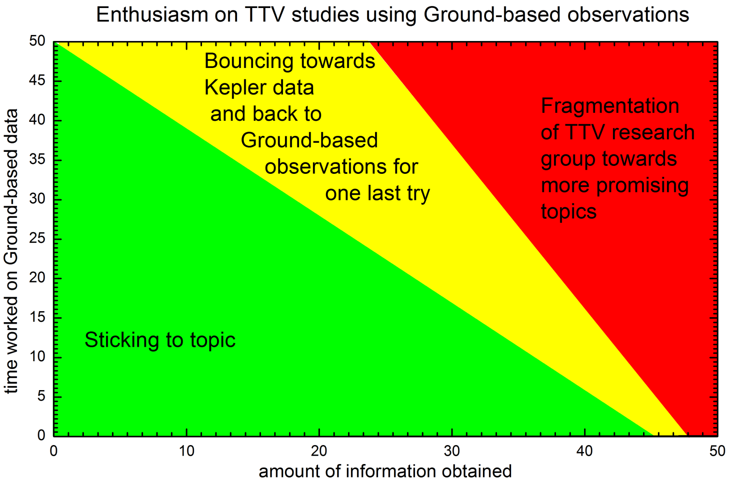
→ from Jena / Großschwabhausen

→ using the YETI network

→ using your telescope; for contribution information see: `web.astri.umk.pl/ttv`

→ more proposals for additional observations at larger telescopes for chosen epochs

- analysis of other possible variations (i.e. depth, duration, shape)
- simulation of TTV signals using n-body integrators (Mercury6), perturbation theory calculators (PTmet, Nesvorny & Morbidelli 2008), or systemic console (Meschiari et al. 2009)


Enthusiasm on TTV studies using Ground-based observations
time worked on Ground-based data
amount of information obtained
0
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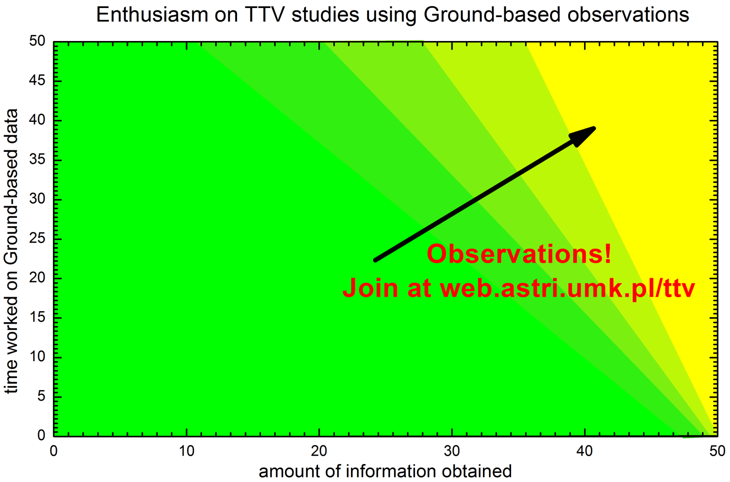
Sticking to topic
Bouncing towards Kepler data and back to Ground-based observations for one last try
Fragmentation of TTV research group towards more promising topics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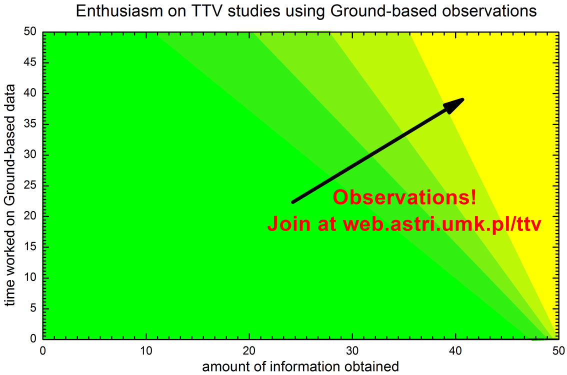
Observations!
Join at web.astri.umk.pl/ttv



Thanks for your attention!