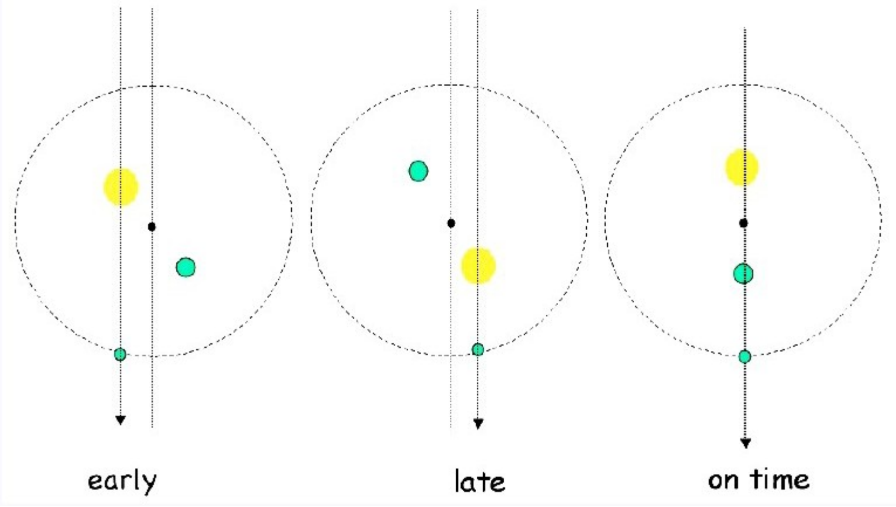
Expanding the CHEOPS discovery parameter space through TTVs

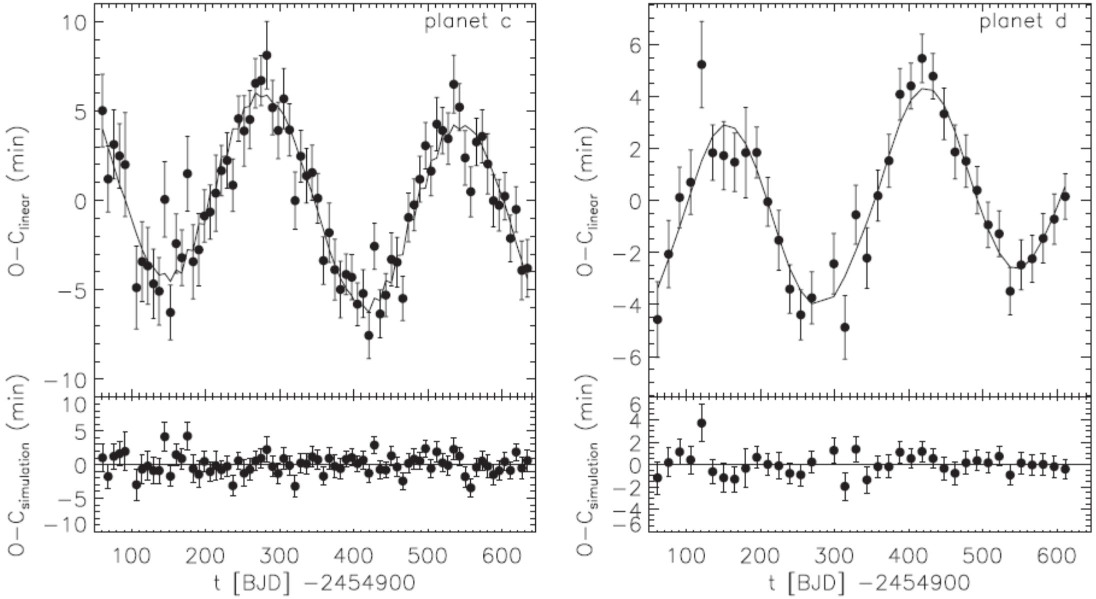
L. Borsato, V. Nascimbeni, G. Piotto
luca.borsato@unipd.it

Introduction: TTV technique

Transit Time Variations (TTV) is a powerful technique for discovering additional companions by monitoring a transiting planet (Holman & Murray 2005, Agol+ 2005).

A single planet around its host star (a simple 2-body system) should have a perfectly constant period P → if **P changes**, it can be due to a **perturber**, and we can try to derive its parameters.





The fundamental tool of TTV analysis is the O-C diagram (Observed – Calculated), which plots the residual of each observed transit center (T_0) against a reference linear ephemeris.

Flat O-C → constant period P

Why TTVs with CHEOPS?

Why we should exploit CHEOPS for TTVs:

1) TTVs allows us to detect even non-transiting planets (or to put upper limits on them), **unveiling the architecture of the system without the *i* bias**

2) TTVs give access to a region of the **parameter space** which would be otherwise **impossible/difficult to probe** (high-*i* planets, mutual-*i*, very low-M planets on resonant orbits, pulsating or fast-rotator hosts, etc)

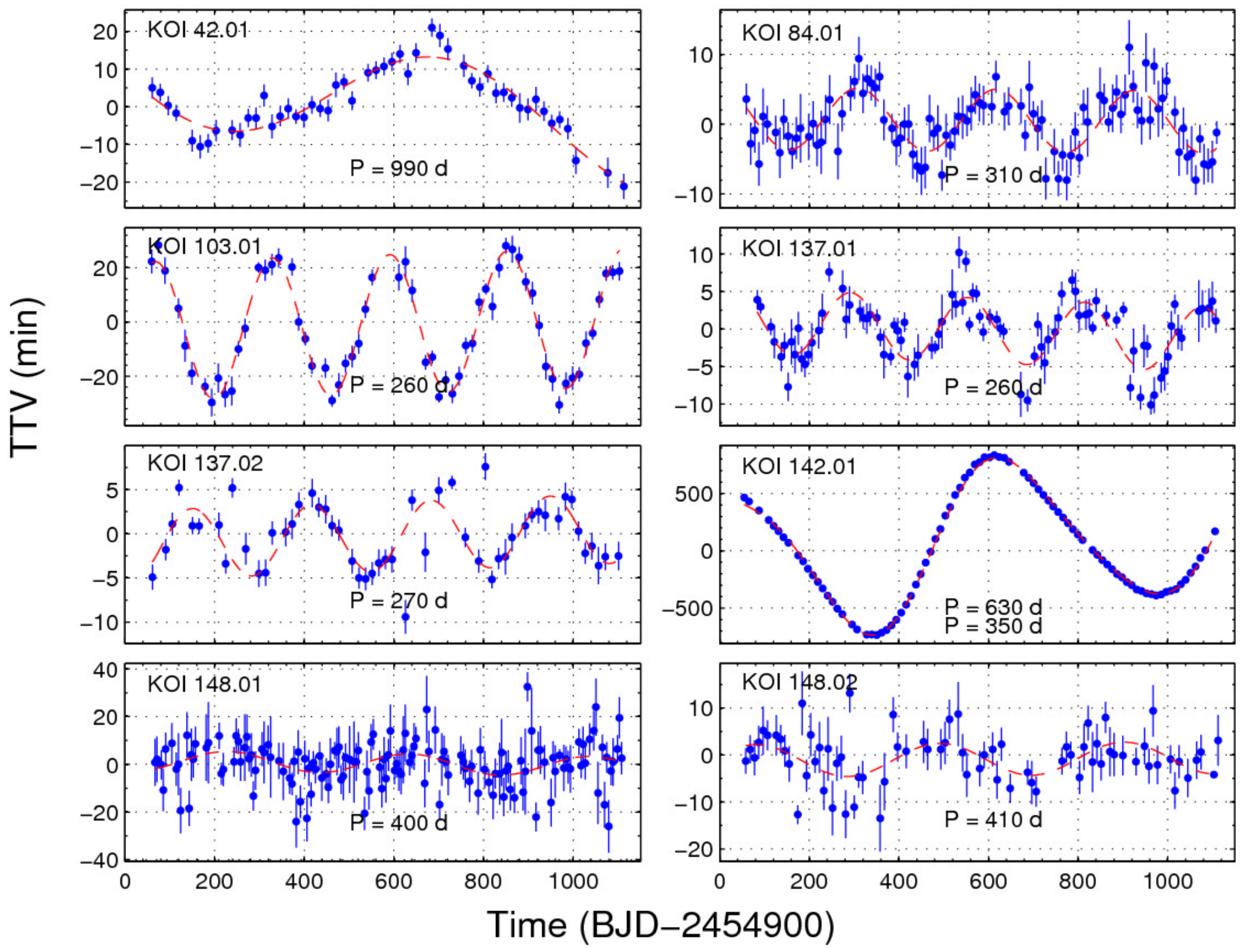
3) TTVs **+ TDVs** can be synergically exploited to **search for exomoons** (Kipping+ 2009, 2012)

Introduction: TTV application

Kepler showed us the full power of TTV analysis:

Planetary validation and mass estimates of multiple transiting systems such as ***Kepler-11*** (Lissauer+ 2011) without need of RVs.

Statistical analysis on the whole sample of planetary candidates: about 10% of them show clear signs of period modulation → **resonant multiple systems with TTVs are quite common among low-mass planets** (Ford+ 2012, Mazeh+ 2013)

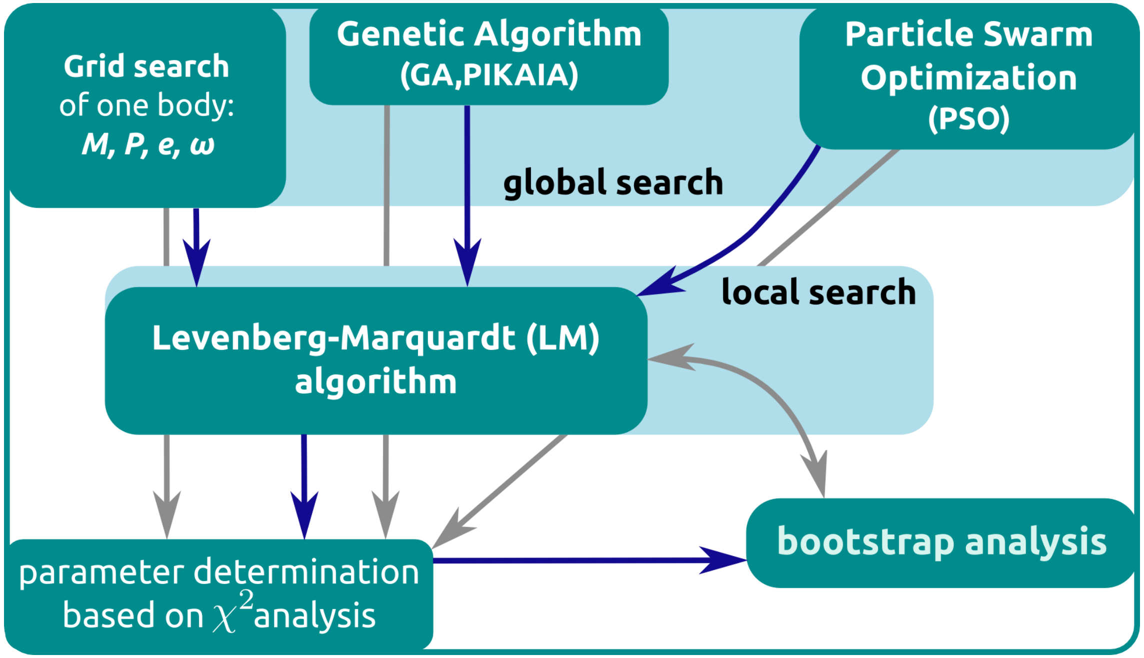


(Mazeh+ 2013)

CHEOPS/TTV inverse problem

The **inverse problem** (decipher the orbital parameters of the perturber given an observed O-C) is **computationally expensive** and prone to multiple **degeneracies**. How much will this affect CHEOPS data?

TRADES: Transits and Dynamics of Exoplanetary Systems (Borsato+ 2014, A&A)



Simultaneous fit of T_0 and RV data

CHEOPS/TTV test case

Test case: ***Kepler*-9**

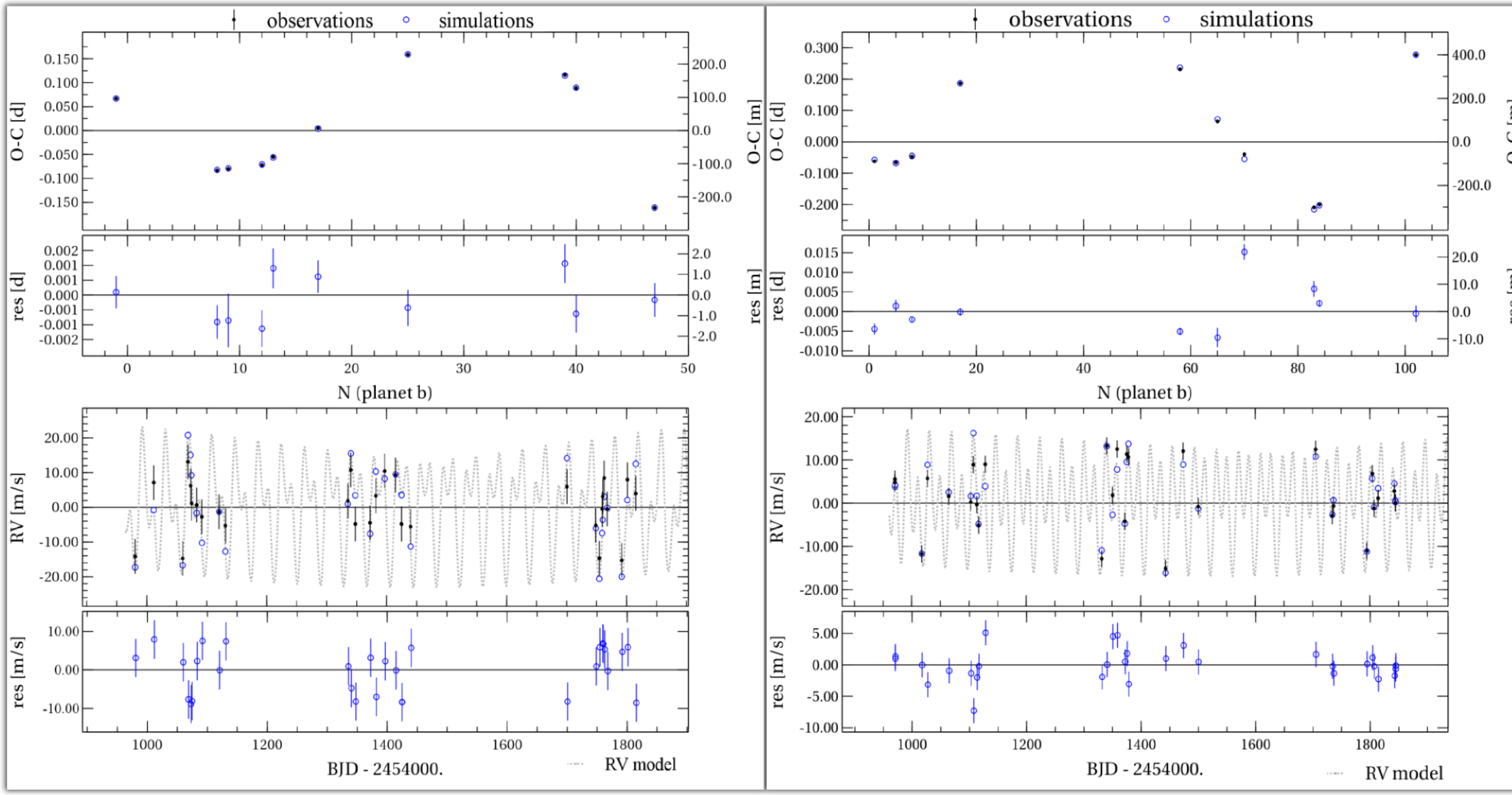
a **pair of transiting “Saturns”** locked close to a **2:1 MMR** (P_b=19.24 and P_c=38.99 d).

Test scaled to a V=10 target; we **assumed**:

- the outer planet is not seen transiting and its parameters are unknown
- 10 transits are randomly sampled over the 3.5yr baseline of the CHEOPS mission
- 30 RV points randomly sample over 3 seasons (5m/s and 2m/s rms)

$\sigma_{T0} \sim 3$ min $\sigma_{RV} \sim 5$ m/s $\chi^2_r \sim 1.5$

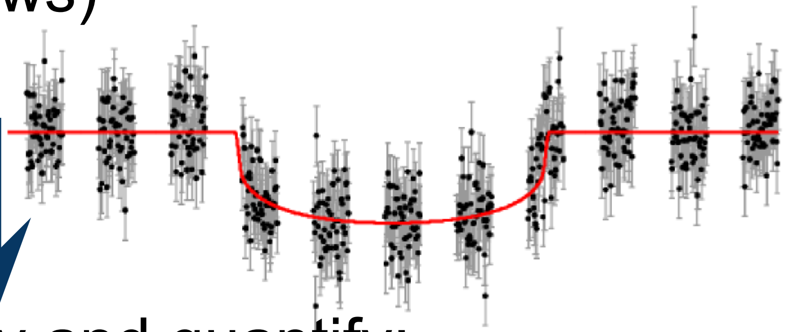
$\sigma_{T0} \sim 3$ min $\sigma_{RV} \sim 2$ m/s $\chi^2_r \sim 5.3$



Impact of the transit time precision

CHEOPS orbit will influence the observations

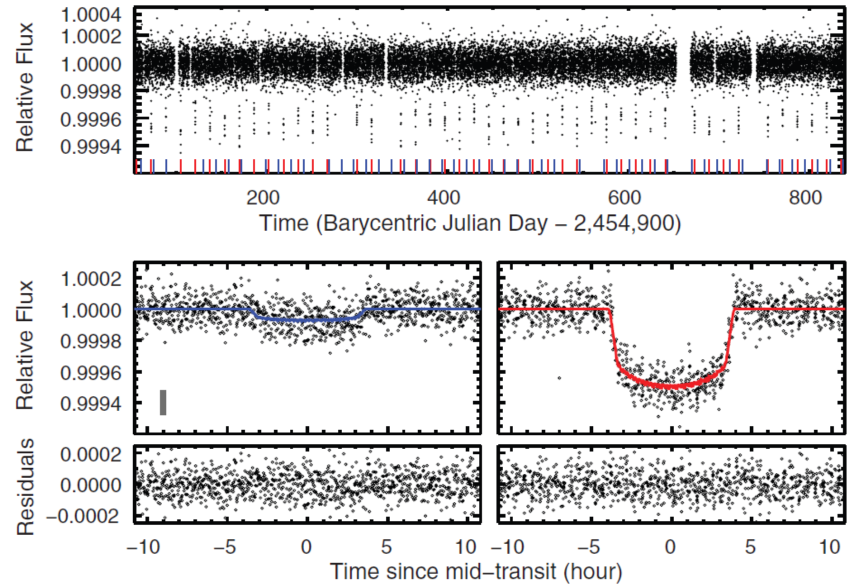
non-continuous light curves
(observational windows)



we need to study and quantify:

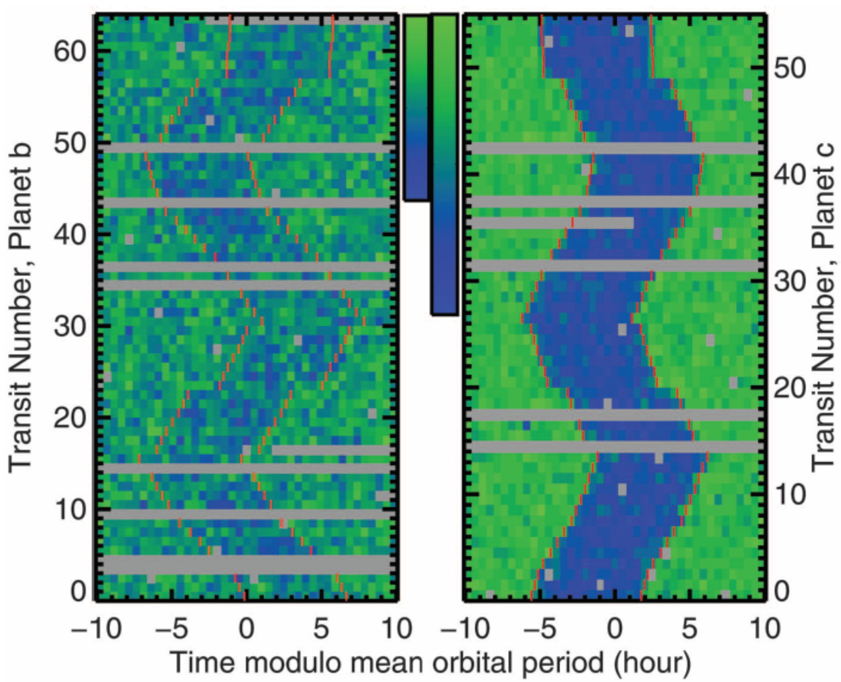
1) how this can **impact the measurement errors of T_0s**
2) how it can **influence the TTV signal**

The Kepler-36-like TTV case



<u>Test case</u>: ***Kepler*-36** (Carter+ 2012), a **super-Earth** and a **mini-Neptune** locked in a **6:7 MMR** around a G subgiant.

P_b = 13.839 d, 1.5 R_e, 4.4 M_e
P_c = 16.238 d, 3.7 R_e, 8.0 M_e



<u>ideal target for CHEOPS:</u>
RV confirmation unfeasible
(1+2 m/s, pulsations)
&
large TTV signals (~2-4 h)

Libration period: ~475 d, typical of resonant pairs of low-mass planets (100-1000 d from Kepler, Xie+ 2014)

CHEOPS The Kepler-36-like TTV case

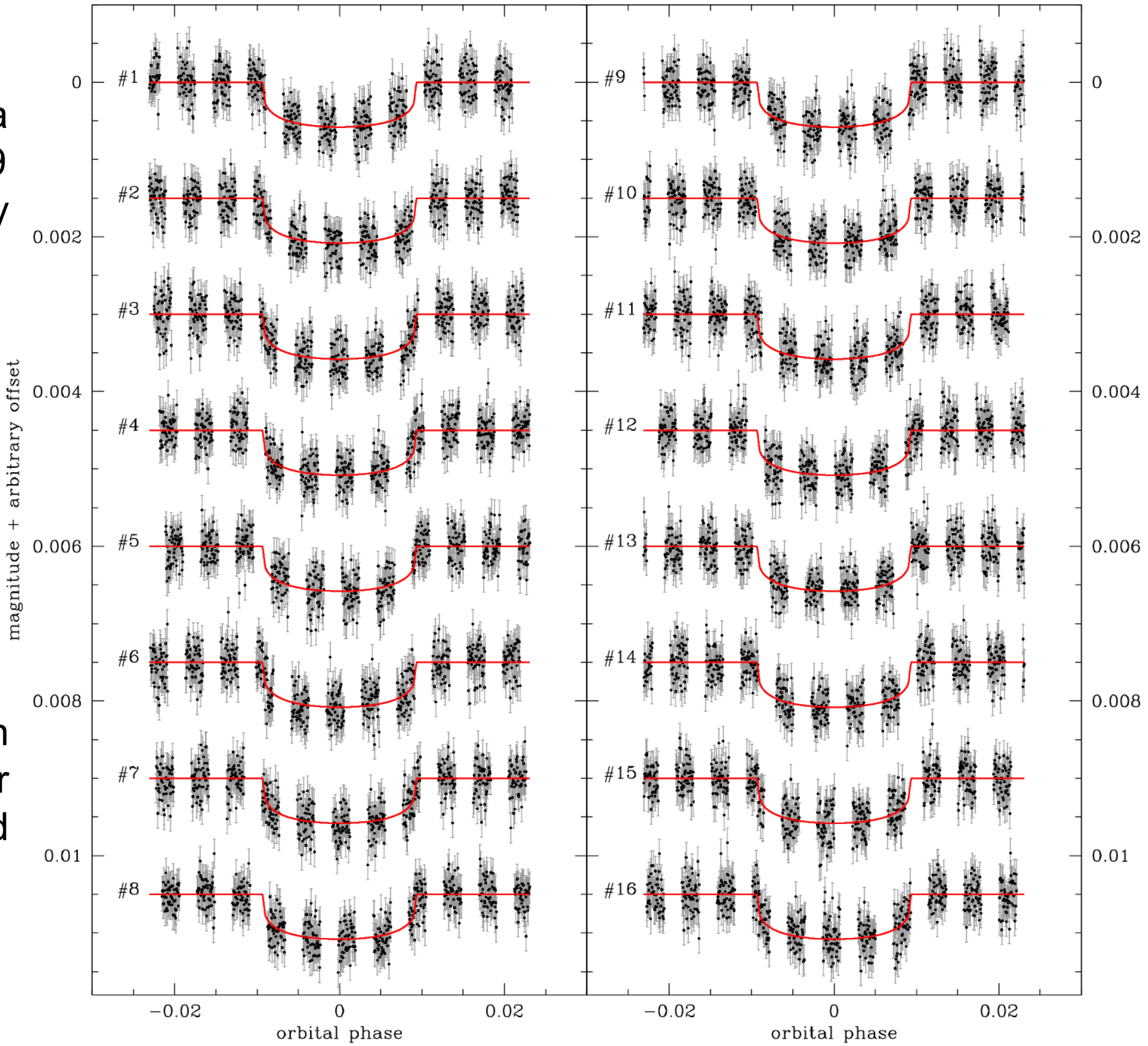
We simulated light curves of a **Kepler-36-like** system at V=9 as should be realistically observable with CHEOPS:

1) 20 ppm/6 h noise
(SciReq 1.1)

2) observing window
90 d/yr and 50 min/orbit
(SciReq 2.1 + CHEOPS-UBE-INST-TN-033)

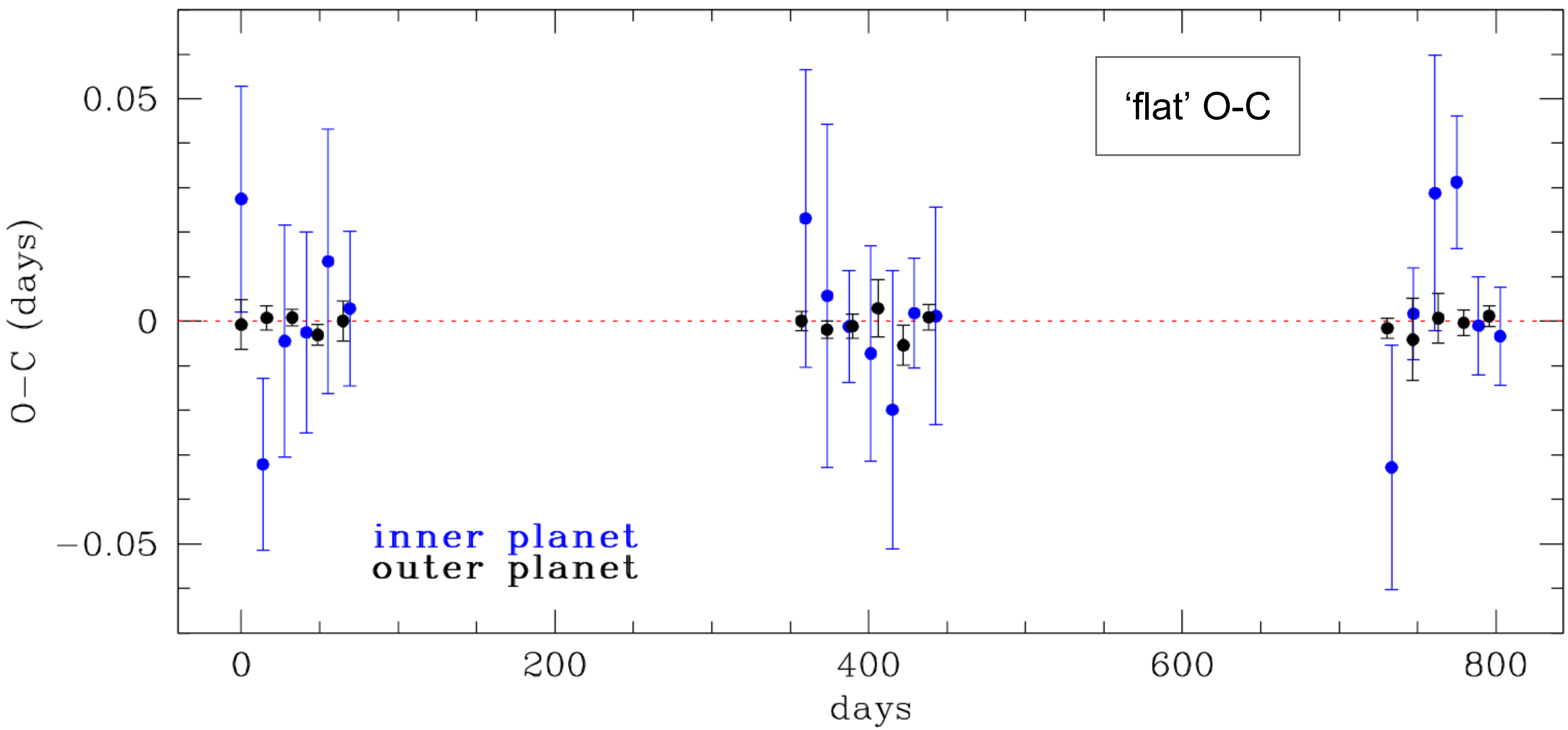
3) 60 s cadence
(SciReq 5.1)

During the nominal mission (3.5 yr), 19+16 transits (inner + outer planet) are gathered spanning three seasons



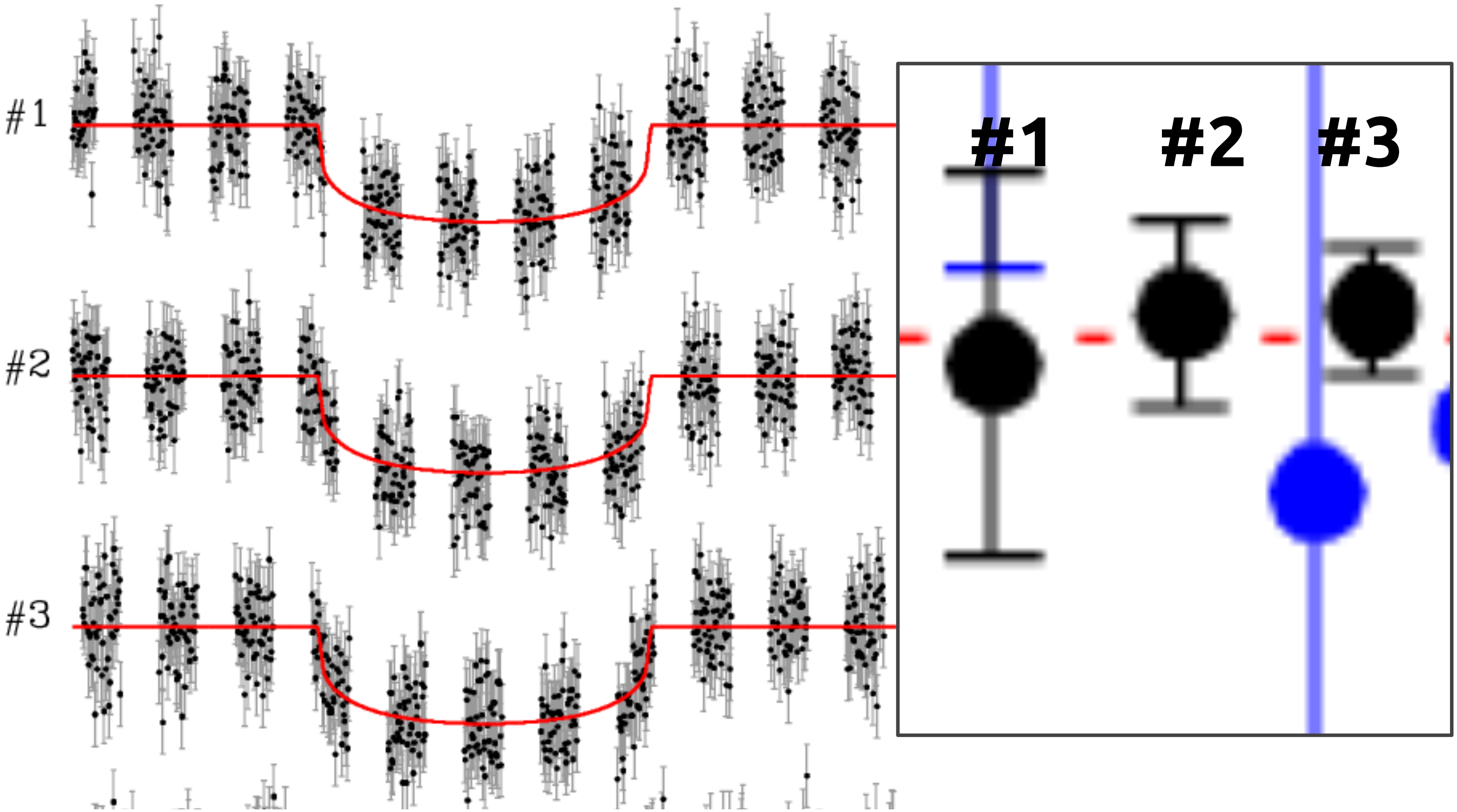
The Kepler-36-like TTV case

Each synthetic light curve was fitted with a JKTEBOP transit model (Southworth+ 2008) and the errors on T_0 estimated through a residual-shift algorithm.
Typical errors range from 15-45 min (inner) to 3-12 min (outer).



The Kepler-36-like TTV case

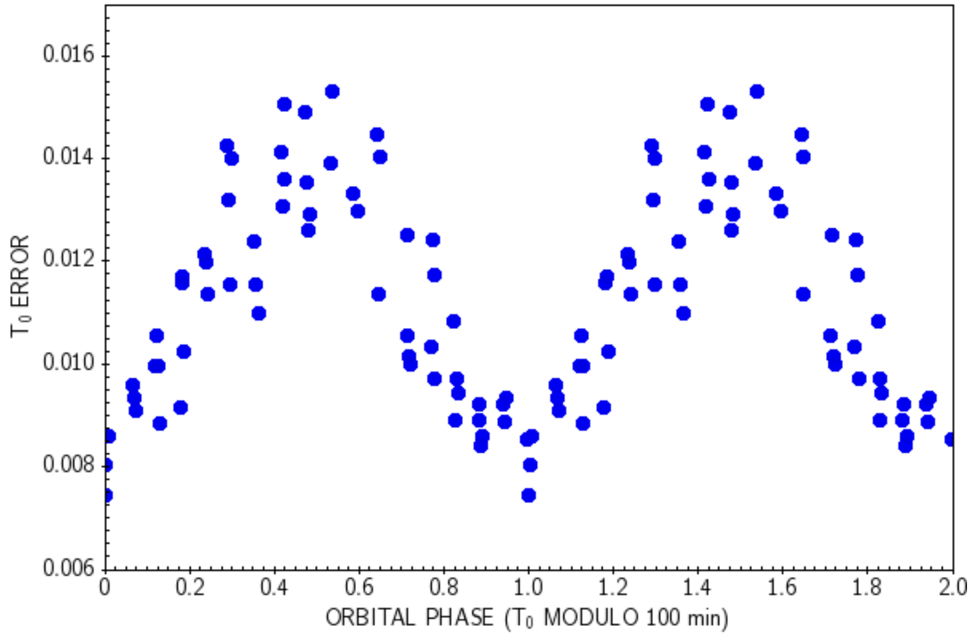
Sampling the right phases makes the difference!



The Kepler-36-like TTV case

Sampling the right phases makes the difference!

Given the orbital constraints of CHEOPS, the ingress and/or egress (i.e., the light curve parts with the largest time derivative = the highest information content on T_0) can be missed. **The precision on the T_0 measurement is therefore dependent on the right phasing.**



In principle, we could exploit this fact to **schedule follow-up observations at the most suitable transit phases**. However, as we will trigger a follow-up on targets showing TTV, **predicting the phase in an effective way may be impossible**, with the exception of some small-amplitude TTV signals (O-C << 30 min)

CHEOPS

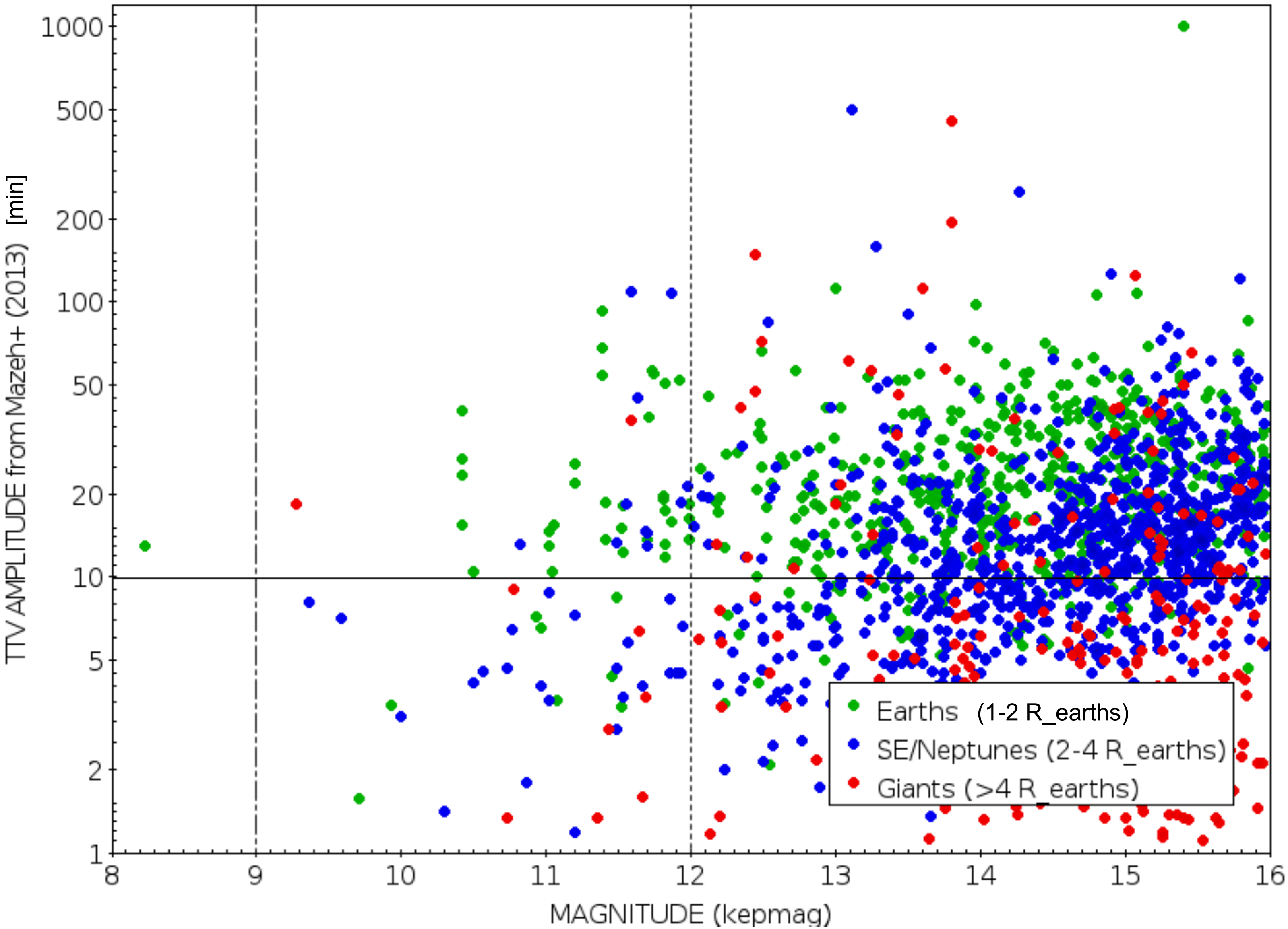
Work in progress...

Dynamical simulation with TRADES
of the Kepler-36-like system

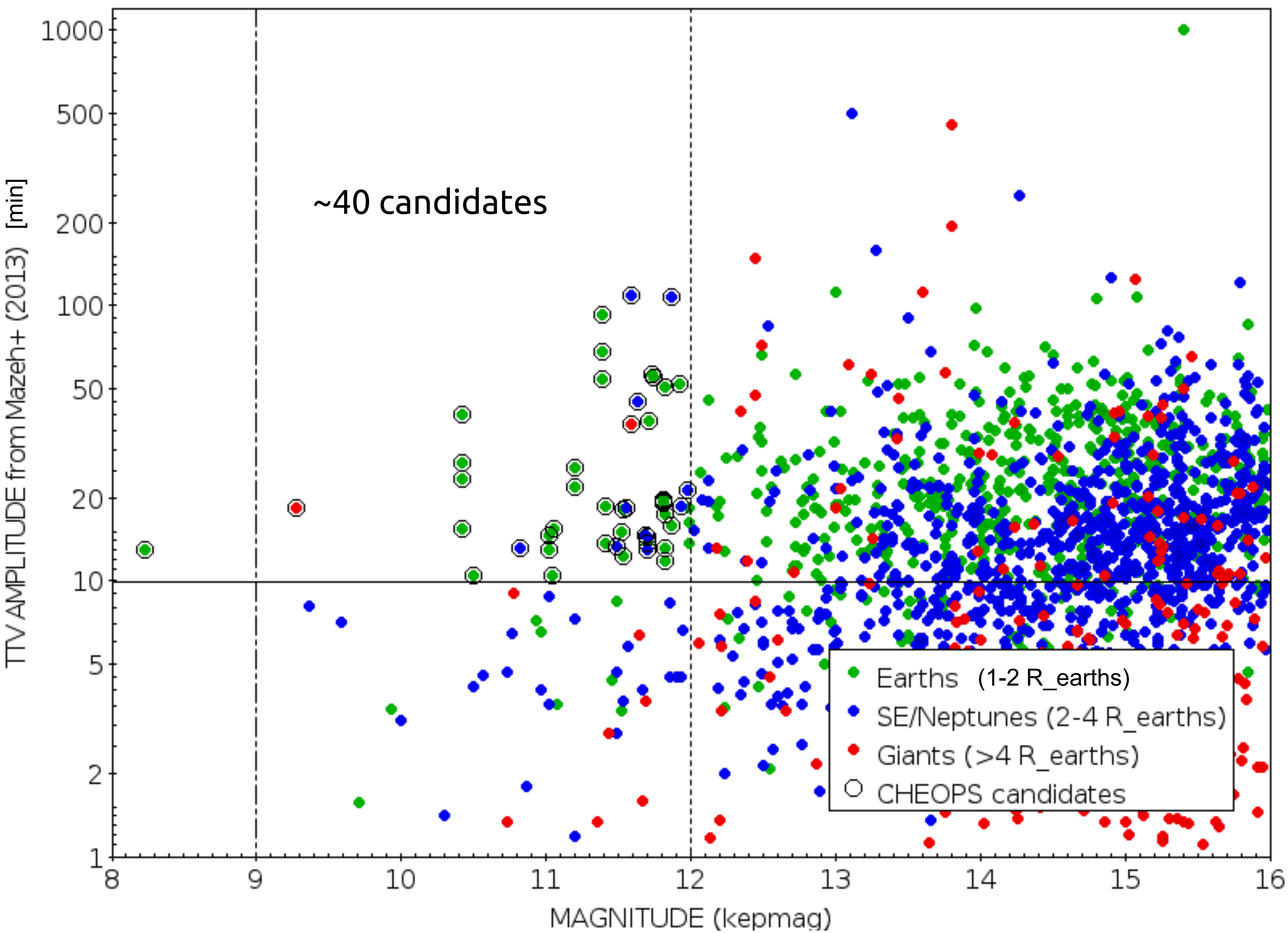
Simulating synthetic light curves with
CHEOPSim

CHEOPS

CHEOPS TTV targets extrapolated from Kepler



CHEOPS TTV targets extrapolated from Kepler



CHEOPS TTV targets extrapolated from Kepler