Transit-timing Variations by an Earth-like planet 1/3

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Introduction & background:

Currently 87 transiting planets have bee detected. As seen from an observer on Earth, these planets occult their host star causing a decrease of its brightness. This results in a photometrically recorded light curve. The size and mass of known transiting planets are comparable to Jupiter. The ratio of the planet radius to star radius is reflected in the depth of the light curve. The larger the transiting planet the more light is blocked at a given wavelength. Ideally, in a two-body system (star+planet) the mid-transit time is repeated exactly. However, this might not be the norm. In case of additional perturbations (3^{rd} body perturbations, oblateness effects, general relativistic effects, etc.) the orbit of the transiting planet is affected (showing possible apsidal motion) and changes in time. Timings of the mid-transit time can therefore change significantly and introduce transit-timing variations (TTVs) of the transiting planet. Searching for a TTV signal of known transiting giant planets can reveal the existence of additional planets including Earth-like planets.

Motivation & details about this work:

The work presented here focuses on the calculation of a TTV signal caused by an Earth-like planet in a given stable three-body orbit. The motivation of this work is the recent observations of 'exotic' orbits of extrasolar planets (high-eccentric orbits and/or inclined orbits, retrograde orbits). Furthermore, the TTV technique provides a promising alternative method to detect Earth-like planets. The underlying system is the three-body problem, possibly (or, most certainly) exhibiting chaotic (unstable) motion. Both the orbit size (semi-major axis) and shape (eccentricity) of the Earth-like planet is systematically changed to map the location of stable orbits of the Earth-like planet for various orbital configurations. The chaotic nature is quantified by the MEGNO (Mean Exponential Growth of Nearby Orbits) indicator. Stable orbits are confirmed by long-term numerical integrations and a corresponding 5-year TTV signal calculated.

Results & conclusions:

Combining chaos detection and long-term numerical orbit integrations provides a method to find stable orbits. This approach is applied to locate stable Earth-like planetary orbits in a 'hot Jupiter' transiting system and calculate the resulting TTV signal. If such 'exotic' Earth's exists elsewhere, we should be able to detect them.

Background Image credit: NASA/JPL-Caltech

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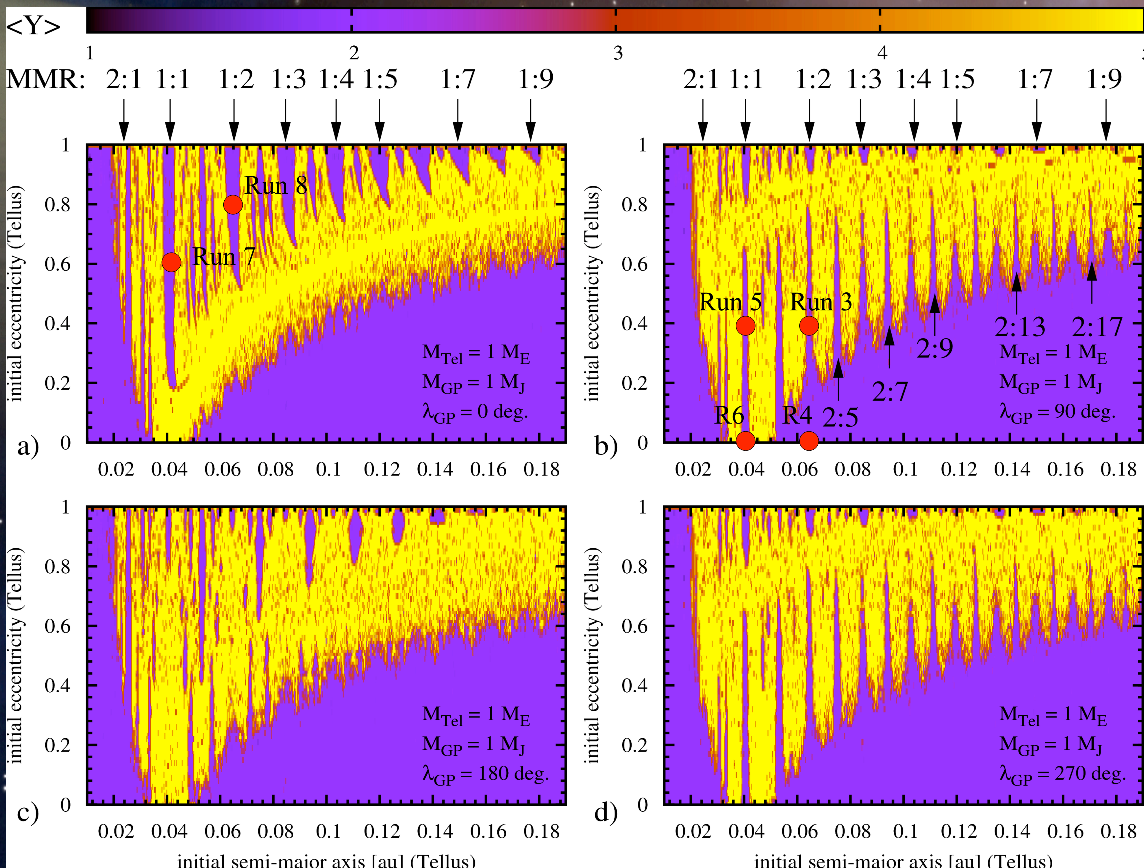


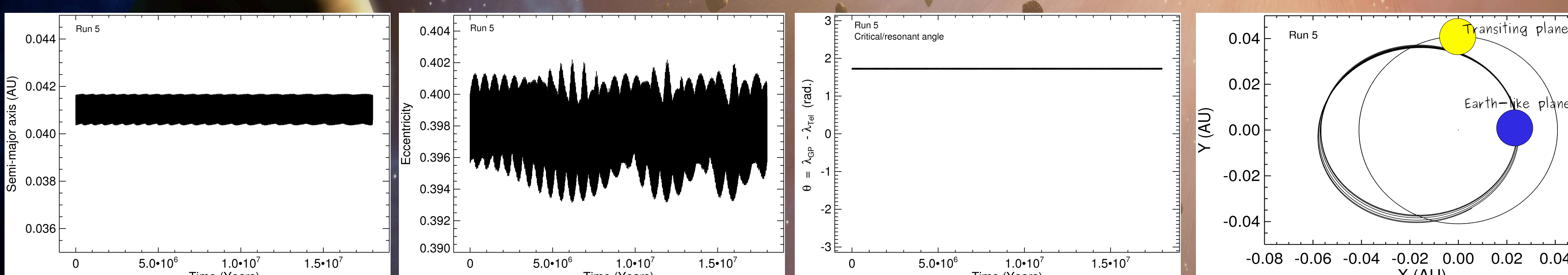
Stability maps of the Earth-like planet:

- <Y> denotes the MEGNO indicator.
- $\langle Y \rangle = 2.0$ indicates quasi-periodic orbits.
- $\langle Y \rangle \neq 2.0$ indicates chaotic orbits.
- Location of mean-motion resonances (MMRs$=n_{Tel}/n_{GP}$) are shown by arrows. Recall, that $P_{GP}/P_{Tel} = n_{Tel}/n_{GP}$.
- We study several orbits (Run1-8) and present results for some of them.

Long-term integrations:

- Stable orbits from num. Integrations.
- We present results for Run 5, where the Earth-like planet is in a 1:1 MMR with the giant transiting planet.

Upper panel: MEGNO maps for various initial conditions.
Lower panel: Long-term integrations of the orbit in Run 5.



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Calculations of TTV signals:

* We show preliminary results of TTV signal calculations (work in progress).
* In each figure we show a +/− 10 seconds uncertainty error bar.
* We consider low and high eccentric orbits for the Earth-like planet.
* TTVs were calculated by num. integ. using Runge-Kutta with a very small time step.
* The TTV in Run 4 (1:2 MMR) has a peak-to-peak variation of around 6 minutes.
* Most orbital configurations are detectable by ground-based, 1m-2m sized telescopes.
* Photometric follow-up of transiting planets is done using the Danish 1.54m ESO/La Silla telescope as part of the MiNDSTEp collaboration (www.mindstep-science.org).