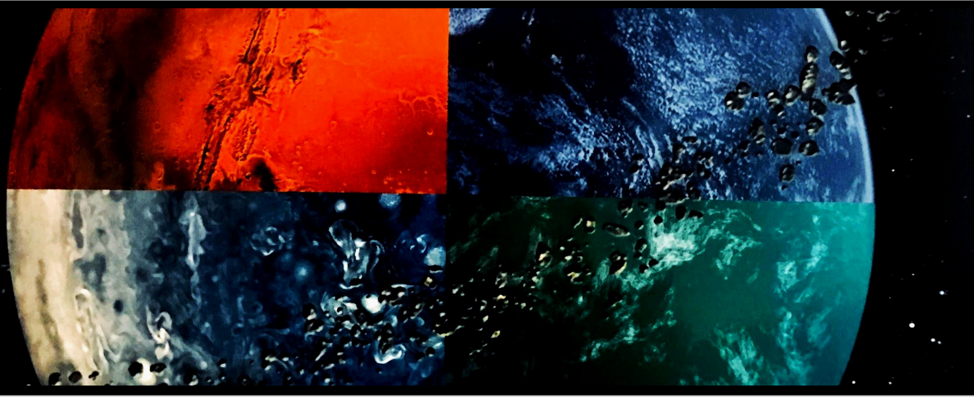

Diversis Mundi (OPS-III)

Constraints for exomoon detectability via tidal migration

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Abstract

The wealth and variety of exoplanets discovered over the last decades have inspired many efforts to detect extrasolar moons, but none has been confirmed up to now. The reason of this lack of positive results could be related to observational biases associated to the current methods of detecting exoplanets, as well as the strong dynamical effects that an exomoon orbiting a close-in giant exoplanet undergoes. According to recent models for tidal-induced migration of exomoons considering the evolution of the planet by means of parameters such as its size, Love's number and tidal quality factor, the interplay of torques triggers the orbital evolution of the satellite until a stationary semimajor axis, hereafter nicknamed as the *tidal migration's braking point* (TMBP) of the system, which depends mainly on a set of initial parameters as the moon and planet masses, distances and rotational rates. On the other hand, the detection of exomoons is linked directly to the moon's size, mass and moon-planet separation, which might be constrained by the satellital tidal biography described previously. In this work we explored the set of initial orbital and physical parameters for a planet-moon system, to numerically asses the TMBP in order to obtain some constraints in exomoon detectability when using distinct methods such as transits, radial velocity, TTV and TDV, with current available instrumentation.

Survival time-scales and distances

Tides play a very important role in the evolution and stability of exomoons orbiting close-in planets. This evolution is due to the exchange of torques between the star, the planet and the moon.

The exchange of angular momentum associated with torques affects both the planet's rotation and the satellite's semimajor-axis [1] and might define the fate of a moon in relatively short time scales. These possible fates are:

(a) Collide with the planet or form a system of planetary rings
(b) Reach areas of instability (a_s>0.48 R_{Hill}) and be ejected
(c) Remain stable below this limit for long time scales

In the classic models of satellite migration [1] the physical evolution of the planet is not included and all the above scenarios are possible.

However, if we take into account the changes in the planet's size (which shrinks [2]) and the tidal dissipation reservoir (k_2/Q, which decays [3]), only the last two scenarios become possible. Thus, the moon will always be forced to migrate away from the planet into outermost and unstable orbits [4] (See Fig. 1) .

The destination of the satellite will depend on initial parameters such as the planet and satellite masses), their orbital positions and others. Therefore 1600 semianalytical integrations were performed, ranging the space of mass and distance parameters, to evaluate the stability of the moons and determine the tidal migration's braking point of the survivors (not ejected ones). See Fig. 2.

Constraints to detectability

The surviving satellites will generate Transit Timing Variation (TTV) and Transit Duration Variation (TDV) signals according to their physical and orbital properties. These effects are the most plausible in the detection of exomoons.

The first effect is a small deviation in the periodicity of the planetary transits associated with changes in its position due to the presence of the satellite. $TTV \propto M_s a_s$ [5].
The second effect corresponds to deviations in the transits' duration due to changes in the planet's orbital speed induced by the satellite. $TDV \propto M_s a_s^{-1/2}$ [5].

Finally, the previous results have been compared with Kepler's temporal sensitivity. It was found that all surviving systems (~40% of initial sampling) can be detected by at least TTV, and that ~ 30% can be detected by both methods simultaneously (See Fig. 3).

It has been found in this work that most moons of giant planets are ejected on very short time-scales if the planets are very close to their star. However, if these are not so massive, their moons could survive and generate TTV and TDV signals detectable by Kepler. However, exomoons are still hidden in Kepler's photometry. Why?

Tidal biography

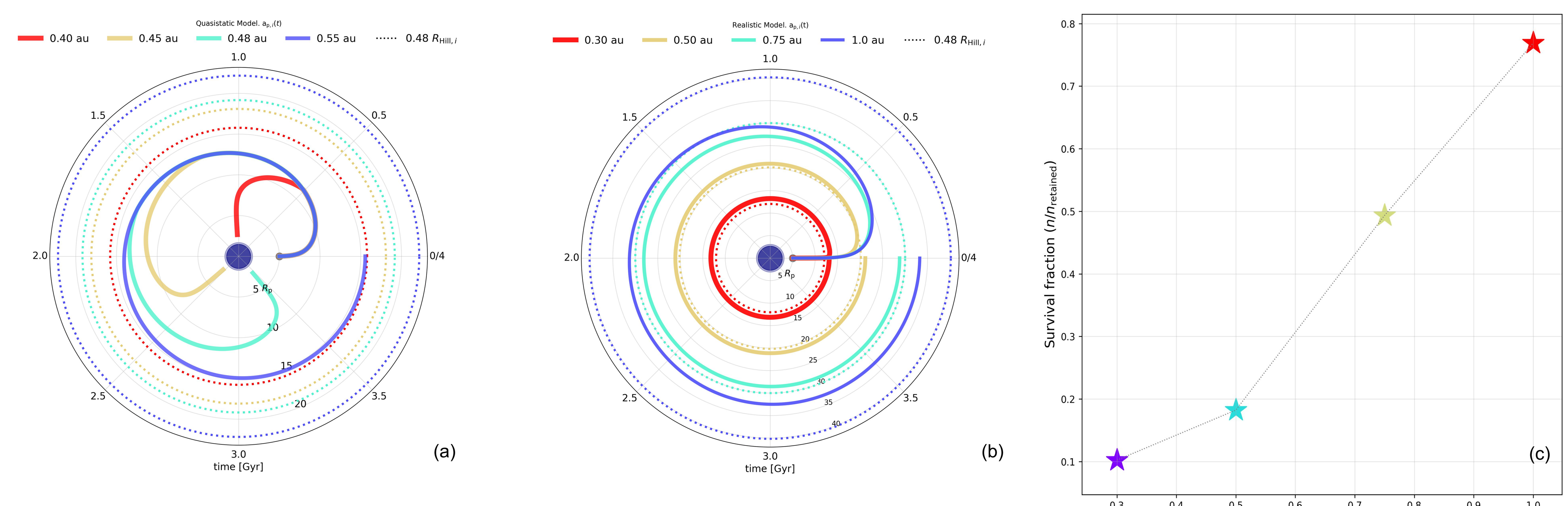

Fig. 1. *(a) The semimajor axis' evolution according to the classic models [1], for a moon (gray dot) orbiting a planet (dark blue dot) located at 0.40, 0.45, 0.48 and 0.55 au from the star. Note that the three innermost orbits moves outward and then inward until to collide with the planet. The outermost orbit evolves outward, but the round-trip timescale is greater than the integration time (4 Gyr). None of these orbits reach the planetary Hill's limit (dotted circles) where a orbit becomes unstable. (b) The semi-major axis evolution of a moon according to the "realistic" model [2], around a planet located at 0.3, 0.5, 0.75 and 1.0 au. Note that the two outerrmost orbits end inside the secondary Hill's limit, while the innermost do not, thus becoming unstable. (c) Number of surviving moons in stable orbits as a function of the planet's semi-major axis, for a set of 1600 numerical experiments.*

Tidal migration's braking point

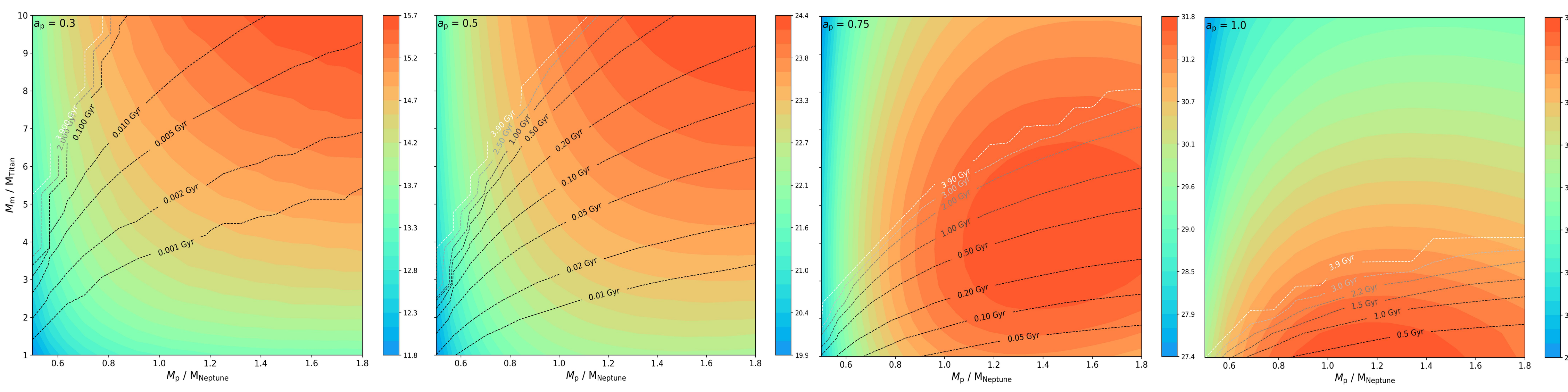

Fig. 2. *The color-maps show the asymptotic value of the semimajor axis for a tidally-migrated exomoon in the scenario of the "realistic" model [2]. Dashed lines contours represents the time expensed by a combination of planetary and moon mass to reache the unstable limit. Hence survival moons are those such their migration times are greater than ~4 Gyr (above the white contour-line). Each plot corresponds to diverse planetary semi-major axis: 0.3, 0.5, 0.75 and 1.0 au.*

Detectability

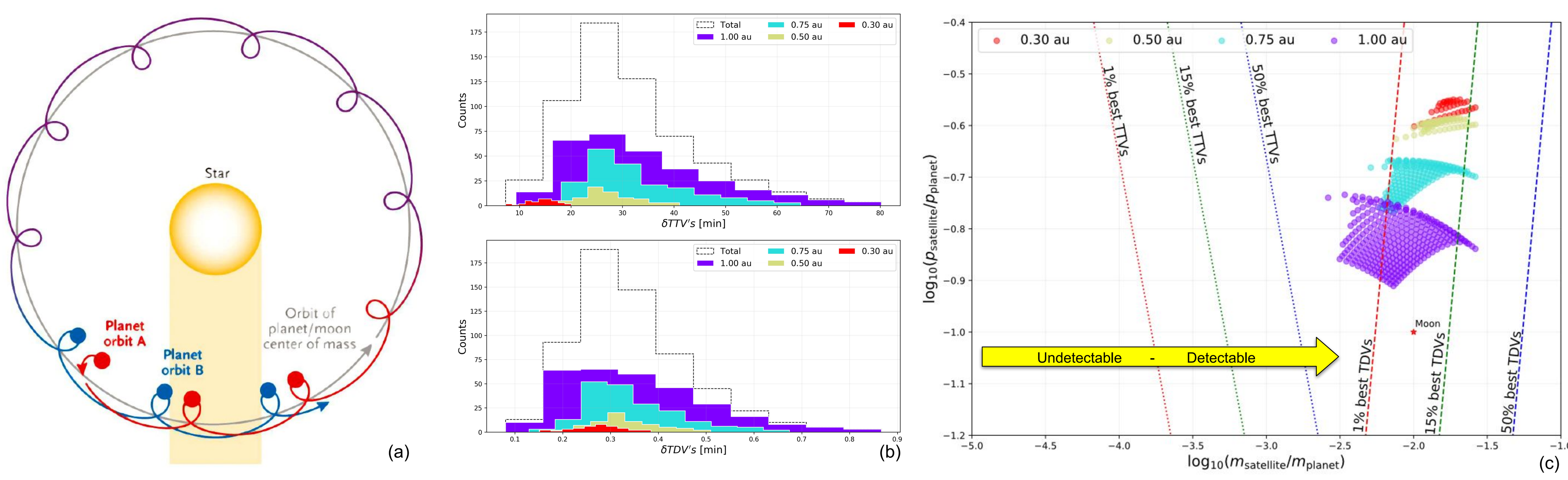

Fig. 3. *(a) Schematic (and exaggerated) representation of the movement of a planet around its star in response to the presence of a massive satellite (not shown). The planet's position and velocity is altered, compared to that expected from an undisturbed Keplerian orbit (gray line), producing variations in the times and durations of the transits, respectively. Credits: D. Kipping 2014 [5]. (b) TTVs and TDVs produced in the planetary transits due to the moons that survived the process of tidal migration. (c) Detectability of the systems with moons that survived, based on the temporal sensitivity of the Kepler spacecraft. The Earth - Moon system (red star) is also shown in the case where the earth had an orbital period of 100 d.*

Main References

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Acknowledgments and sponsors

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