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Supplementary information

A super-massive Neptune-sized planet

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Supplementary Informations

Description of the dynamical simulations from Sect. 2.12.

The first simulation considers 2 planets of 40 Earth masses around a solar-mass star. Their initial orbital elements are:

a_1=0.02000 au, e_1=0.006, i_1=1.27 deg., Ω_1=54.8 deg., ω_1=297.5 deg, M_1=76.3 deg.

a_2=0.02121 au, e_2=0.002, i_2=1.02 deg., Ω_2=112.6 deg., ω_2=227.2deg, M_2=110.9 deg.

The two planets merged into a single one with orbital elements:

a=0.02065 au, e=0.007, i_2=0.76 deg.

The second simulation considers 4 planets of 20 Earth masses. Their initial orbital elements are:

a_1=0.02000 au, e_1=0.006, i_1=1.27 deg., Ω_1=54.8 deg., ω_1=297.5 deg, M_1=76.3 deg.

a_2=0.02096 au, e_2=0.002, i_2=1.02 deg., Ω_2=112.6 deg., ω_2=227.2deg, M_2=110.9 deg.

a_3=0.02185 au, e_3=0.044, i_3=0.31 deg., Ω_3= 4.9 deg., ω_3=18.3 deg, M_3=307.8 deg.

a_4=0.02258 au, e_4=0.004, i_4=1.07 deg., Ω_4=51.5 deg., ω_4=322.0 deg, M_4=253.0 deg.

The planets merged into a single one with orbital elements:

a=0.02121 au, e=0.012, i_2=0.81 deg.

In the third simulation we considered 8 planets of 10 Earth masses. Their initial orbital elements are:

a_1=0.02000 au, e_1=0.006, i_1=1.27 deg., Ω_1=54.8 deg., ω_1=297.5 deg, M_1=76.3 deg.

a_2=0.02076 au, e_2=0.002, i_2=1.02 deg., Ω_2=112.6 deg., ω_2=227.2deg, M_2=110.9 deg.

a_3=0.02146 au, e_3=0.044, i_3=0.31 deg., Ω_3= 4.9 deg., ω_3=18.3 deg, M_3=307.8 deg.

a_4=0.02203 au, e_4=0.004, i_4=1.07 deg., Ω_4=51.5 deg., ω_4=322.0 deg, M_4=253.0 deg.

a_5=0.02283 au, e_5=0.037, i_5=0.13 deg., Ω_5=247.6 deg., ω_5=271.0 deg, M_5=216.5 deg.

a_6=0.02344 au, e_6=0.042, i_6=0.84 deg., Ω_6=245.6 deg., ω_6=121.8 deg, M_6=203.5 deg.

a_7=0.02431 au, e_7=0.044, i_7=0.67 deg., Ω_7=183.5 deg., ω_7= 99.4 deg, M_7=259.5 deg.

a_8=0.02521 au, e_8=0.031, i_8=0.28 deg., Ω_8=9.3 deg., ω_8=268.3 deg, M_8= 37.9 deg.

This system results into two planets of 50 and 30 Earth masses with, respectively, orbital elements:

a_1=0.02026 au, e_1=0.043, i_1=0.46 deg.

a_2=0.02642 au, e_2=0.081, i_2=0.63 deg.

The second simulation depicts a Jupiter-mass planet on an orbit with a 1 au, e=0.98 (so that its perihelion distance is 0.02 au) and i=10 deg.

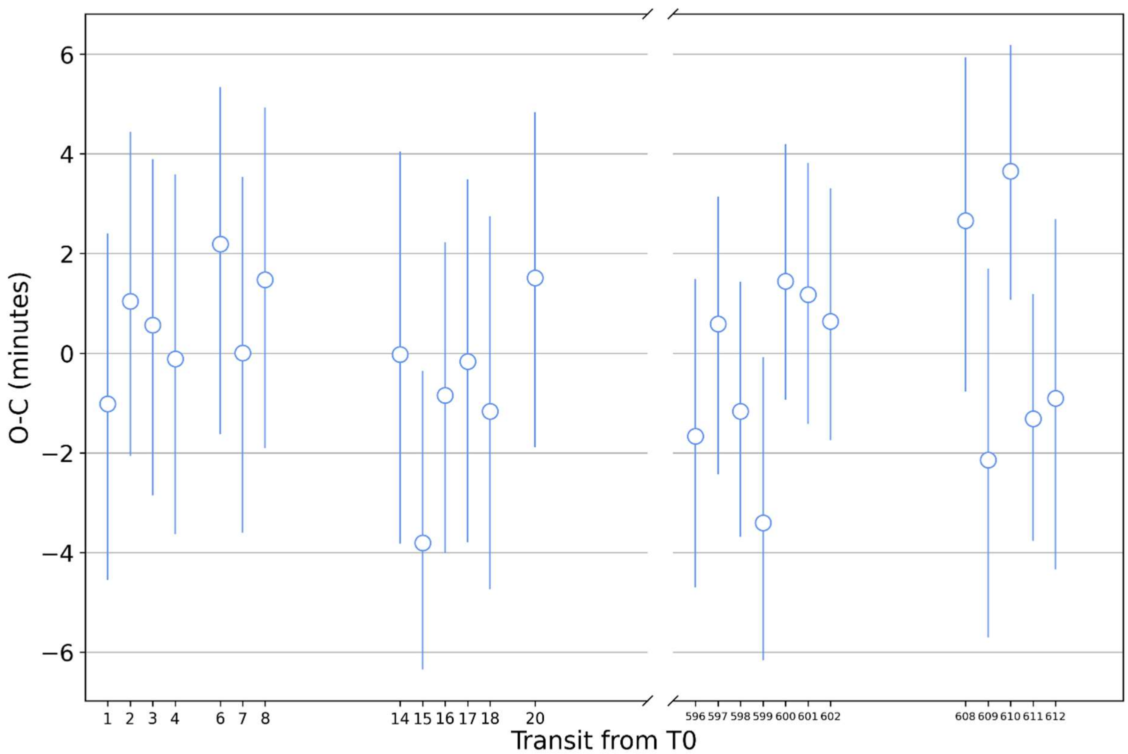
We simulated the effect of this planet on a disk of 1000 test particles (representing planetesimals or planets of smaller mass with respect ot the giant planet) with 0.02 au < a < 0.06 au, e<0.1 and i<2.5

degrees. We simulated the system for 150'000 years, at the end of which only 2 particles survive. 309 (31%) have been accreted by the giant planet.

We then repeated the simulation with a disk of 1000 test particles with 0.1 au < a < 0.3 au and then with 0.5 au < a < 1.5 au, both still with e<0.1 and i< 2.5 deg.. Only 65 and 20 particles from disk disks have been accreted by the giant planet, namely 6.5 and 2% of the total. This shows that the efficiency of accretion of particles by the eccentric giant planets falls rapidly with the distance of the particles from the star.

All these simulations have been performed using the simplectic swift_symba5 integrator (properly referenced in the main text), with a timestep of $5x10^{-5}$ years.

Observed-Calculated (O-C) time of transits figure.



The « observed » transit times of TOI-1853b were evaluated by fitting its light curves with the orbital period fixed at its best-fitting value and leaving each time of transit as free to vary. Then the observed times were compared with the « calculated » (expected) times from the orbital period. We found no evidence of Transit Time Variations (TTV) as all the observed transit times are compatible with their expected value within ≈1-sigma. The periodogram of O-C does not result in any relevant peaks either.

Indeed, considering the mass and orbital period of TOI-1853b, the shallow transit depth, and also the lack of clear massive planets nearby (see Sect. 2.9), we didn't expect to detect TTVs unless the planet was being rapidly engulfed by the host star (which is unlikely according to Sect. 2.10).