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HOW TO BRING TWO NEPTUNE MASS PLANETS ON THE SAME ORBIT

Crida, A. [1,2]

Abstract. We perform numerical simulations of Uranus and Neptune migrating in a dense protoplanetary disk, in the presence of a non migrating Saturn. Due to the high density of the gaseous disk, the two 15 Earth mass planets are caught in the same resonance by Saturn. Different kinds of configuration are observed: planets in opposition, at 30 degree from each other, or satellite of each other. This would lead to horseshoe, tadpole, or satellite orbits after dissipation of the gas disk. This appears to be a new way of making double planets or pairs of planets on the same orbit (Crida, 2009).

1 Introduction

Planets form in protoplanetary gaseous disks, in which they also migrate. If several planets migrate together in a same disk, the ratio of their semi-major-axes (and of their orbital periods) varies. It is then possible that they enter in a Mean Motion Resonance (MMR). If the disk torques are stronger than the MMR, the planets cross the MMR and go on migrating at different speeds. If the MMR is stronger than the torques from the disk, the planets stay locked in resonance and migrate together.

In this work, we consider the migration of the giant planets of the Solar system in a disk about ten times denser as the standard Minimum Mass Solar Nebula. In this case, resonances between two Neptune mass planet are not strong enough to hold them away from each other against migration, which leads Uranus and Neptune to end on the same orbit.

2 Results

We present the results of three simulations performed using the code FARGO-2D1D (code publicly available at `http://fargo.in2p3.fr/`). The initial density profile of the disk is: $\Sigma_0 = 3430(r/10\text{AU})^{-2.168}$ kg.m^{-2}. Jupiter, Saturn, Neptune and Uranus start on circular orbits at 5.45, 8.18, 11.5 and 14.2 AU respectively, and are released after 1250 years. Jupiter's fast inwards migration stops when Jupiter encounters the inner edge of the 2D grid. Then, Jupiter catches Saturn in MMR, which stops Saturn's migration. Then, Neptune is caught in MMR by Saturn. Because the disk is too massive for Neptune to hold Uranus, Uranus ends in the same MMR with Saturn as Neptune, as can be seen in Figs. 1 and 2.

Opposition In the first case, the equation of state of the gas is radiative, and the grid resolution is $\delta r/r = \delta\theta = 0.01$. After 12000 years, Uranus and Neptune have close encounters, and after 15000 years, the distance between them stays equal to two times their common semi-major-axis (see red crosses in the left panel of Fig. 1): they are in opposition. One can expect that once the disk disappears, the two planets should have mutual horseshoe orbits.

30° **angle** In the second case, the equation of state is locally isothermal, and the resolution is $10^{-2.5}$. After Uranus and Neptune end on the same orbit, the angle between them as seen from the Sun stays constant to $\sim 30^\circ$. This is not a stable configuration in the 3-bodies problem (Sun, Uranus, Neptune). Once the disk disappears, these two planets should librate around their mutual L_4 L_5 points, in tadpole orbits.

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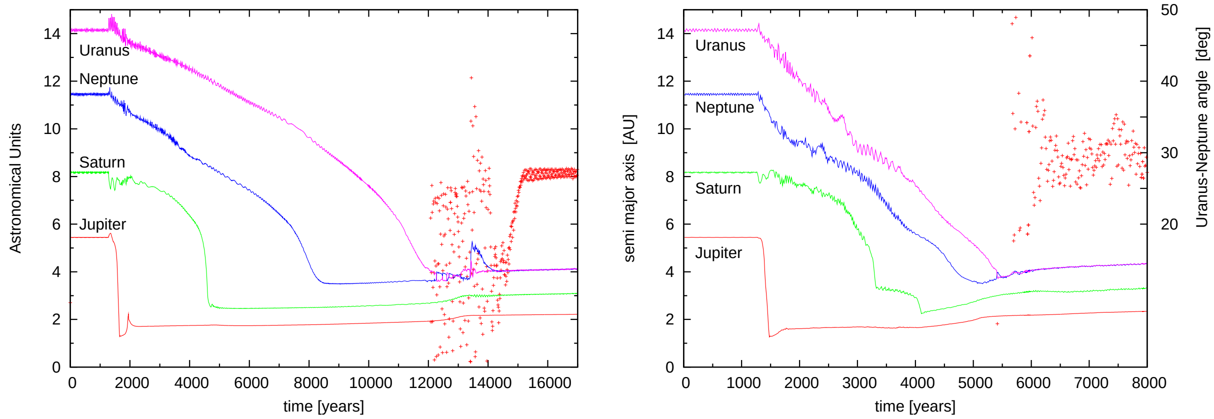

Fig. 1. Migration paths of Jupiter, Saturn, Neptune and Uranus (from bottom to top) in a dense disk. Left: radiative equation of state and grid resolution 0.01. Right: locally isothermal equation of state, $\delta r/r = \delta\theta = 10^{-2.5}$.

Satellite motion In the last case, the equation of state is still locally isothermal and the grid resolution is 0.01. When Neptune joins Uranus, their distance shrinks below the Hill radius of the latter (see crosses in right panel of Fig. 2), betraying a satellite motion. This capture is enabled by the high density of the gas that provides dissipation. To our knowledge, this is the first time that a satellite capture is observed in numerical simulations between two bodies of the mass of Neptune in the frame of planetary migration. This satellite configuration is stable over the disk dissipation.

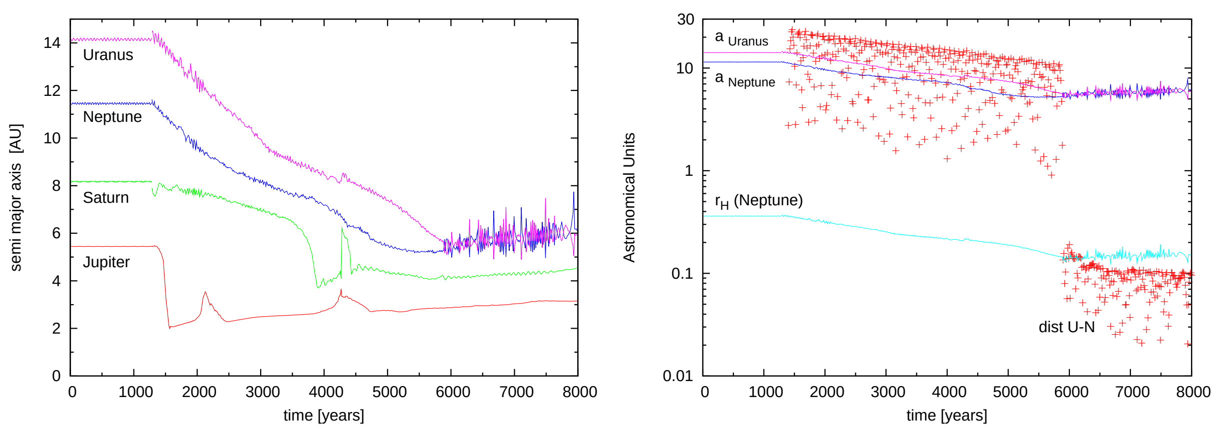

Fig. 2. Right: Migration paths of Jupiter, Saturn, Neptune and Uranus (from bottom to top). Left: Uranus and Neptune semi-major-axes (top curves), distance (crosses), and Hill radius (bottom curve).

3 Conclusion

Migration in dense disks can be a way of forming pairs of Neptune-mass planets on the same orbits. If for some reason their migration is halted at some point in the disk (like a resonance with an other, more massive planet), they will both end on the same orbit. This can lead to configurations like tadpole orbits, mutual horseshoe orbits, or double planets, one being satellite of the other. More detail on this work can be found in section 5.2 of Crida (2009).

References

Crida, A. 2009, ApJ, 698, 606