

Can a Massive Inner Planet cause another to Migrate to Large Radii?

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Planet Formation and Migration

- Discs dissipate on a timescale of 5 – 10 Myr (Haisch, Lada & Lada 2001) and gas giants must form before this happens.
- The timescale for building a giant planet core scales with radius squared (Pollack et al. 1996) in the standard core accretion models (Safronov 1969).
- There is evidence for a large number of massive planets at great distances from their star. For example, a spiral structure seen in HD141569 could be caused by a planet of mass 0.2 – 2 M_J orbiting at 235 – 250 AU (Wyatt 2005).
- At these large distances from the star the timescale for planet formation by core accretion is too long.
- One possible explanation is that planets can form close to their star and then migrate outwards.
- Veras & Armitage (2004) examined this problem by forming planets at about 10 AU from the star in a truncated disc. They found massive planets migrate only to 20 – 50 AU.
- We need a mechanism to supply a planet with angular momentum so that it can continue to migrate outwards to larger distances.

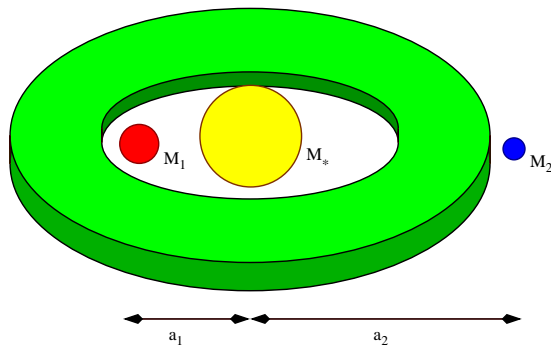


Figure 1: Diagram of a system with two planets orbiting a central star and a disc between the planets only.

Outward Migration driven by an Inner Planet

- Suppose we have two planets with masses M_1 and M_2 orbiting a star in circular orbits at distances a_1 and a_2 respectively ($a_2 > a_1$).
- If the inner planet can somehow be induced to transfer all of its angular momentum to the outer, that moves out to a final distance

$$a_f = \left(\frac{M_1}{M_2} a_1^{1/2} + a_2^{1/2} \right)^2$$

(if we assume that the outer planet remains in a circular orbit).

- For example, if $M_1 = 5 M_J$, $a_1 = 5$ AU, $M_2 = 1 M_J$ and $a_2 = 10$ AU and if the inner planet ends up at the central star with radius $R \ll a_1$ then the outer planet can migrate to a distance $a_f = 206$ AU.
- This demonstrates that mutual interaction within a two planet system can, *in principle*, drive a planet out to distances of a few hundred AU.
- We now just need a mechanism to transport angular momentum from the inner planet to the outer planet.
- We consider how the transfer of angular momentum by viscous disc interactions from a massive inner planet could cause significant outward migration of a smaller outer planet.

Disc between two Planets

We choose the planet masses and initial radii as above and put a 5 M_J disc between them (Figure 1). In Figure 2 we see that in this system the outer planet migrates a long way from its star.

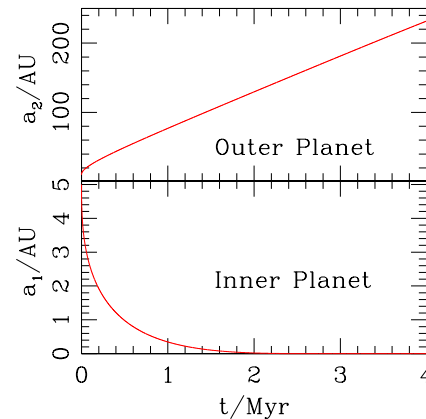


Figure 2: Migration of two planets with a 5 M_J disc between them.

Disc Outside the Outer Planet

However we assumed that there was no disc mass outside the outer planet. Mass there would provide a negative torque on the planets and so push them back towards the star. In Figure 3 we plot the distance, d , that the outer planet has reached at a time $t = 4$ Myr against the mass outside, M_{out} . In this case we also have mass between the star and the inner planet which provides a positive torque on the planets and so pushes them both outwards.

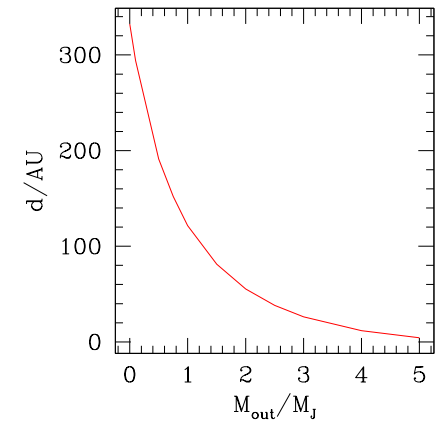


Figure 3: The position of the outer planet at a time $t = 4$ Myr against the amount of mass outside the outer planet.

We see that the more mass we have outside the outer planet the slower the migration. In all cases, migration eventually turns around and the planet heads back towards the star, pushed in by the outer disc.

Conclusions

- It is possible for a large inner planet to drive the migration of a small outer planet to large radii.
- We need a depleted disc exterior to the outer planet.

References

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