EPSC Abstracts
Vol. 8, EPSC2013-53, 2013
European Planetary Science Congress 2013

New steps in testing the Tidal Downsizing hypothesis for planet formation

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Abstract

Broadly speaking, there are two opposite views on how planet formation proceeds. The first of these is the Core Accretion (CA), a well established theory in which assembly of all planets occurs in the bottom-up direction.

The second one is a modified gravitational disc instability model, which originally was thought to form only giant gaseous planets at large distances from the star (e.g., Rafikov 2005). Now it emerges that migrating gaseous clumps may form not only giant planets but also terrestrial-like planets if dust sediments into the cores and the clumps' gas is removed by tidal disruption (Boley et al 2010, Nayakshin 2010; also reviewed in the upcoming PPVI by Helled et al 2013). This top-down scenario is referred to as "Tidal Downsizing" (TD) hypothesis. While TD hypothesis may potentially explain all of planet populations at any separation from the parent star (as planets migrate from 100 AU all the way to their disruption at ~ 0.1 AU; Nayakshin and Lodato 2012), this scenario is currently in the embryonic state and needs further detailed calculations. Here we present several new calculations aimed at testing the theory with observations of exoplanets and young accreting stars possibly in the process of planet formation.

(1) Nayakshin (2011) proposed that young massive "hot jupiters" may actually be tidally disrupted by the gravity of their parent stars if they migrate inward too quickly. If a significant fraction of dust grains managed to sediment into the centres of these gas clumps before they are disrupted, the solid cores are left behind as hot super-Earths and "hot neptunes". The disc-planet interaction before and during planet disruption was modelled in detail by Nayakshin and Lodato (2012), who showed that the process of tidal disruption produces FU-Ori like accretion events onto the parent star. This model thus may account for both the hot planets observed and episodic accretion of young stars (Dunham and Vorobyov 2012).

Another crucial prediction of our model is that giant young proto-planets, in addition to interrupting accretion flows by creating deep gaps, can also feed their protostars by "restarting" the accretion flows. Since dust sediments and is locked in the solid cores, the envelopes of these proto-planets are dust-poor. Therefore, in Nayakshin (2013) we proposed that the observed transition discs with large inner holes, accreting gas but not dust, may in fact be exactly the systems accreting dust-poor envelopes of giant planets being in the process of "downsizing".

We shall also discuss whether this model can acount for some of the most challenging exoplanetary systems found by Kepler, such as the densly packed multi-planet worlds Kepler 36 and Kepler 11. The obvious challenge is that bringing in a massive giant planet could destabilise the orbits of the inner lower mass planets.

(2) Whether the massive young protoplanets born by gravitational instability at 100 AU migrate rapidly inward (which is the key assumption of TD) or stay behind and accrete gas rapidly to become Brown Dwarfs is a key issue for both planet and low mass binary companion formation fields. Population synthesis models based on analytical estimates of the process (Forgan and Rice, 2013) show that only a few percent of their theoretical discs are in the TD regime; most produce BDs and low mass stars, as previously found by Stamattelos and Whitworth (2009).

Nayakshin and Cha (2013; MNRAS accepted) study the effect of radiative preheating from growing giant planets on their immediate disc environment. It is found that gas in vicinity of the protostar is significantly hotter than found in simulations and analytical estimates that neglect the preheating effect. Clumps less massive than 6 Jupiter masses are found to build massive hot radiative atmospheres around them, "protecting" them from further gas accretion. These clumps rapidly migrate in and are in the TD regime, in whereas clumps more massive than 10 Jupiter masses indeed form BDs or more massive stars. We believe

the preheating effect discussed here must be incorporated in simulations of gravitationally unstable discs to reliably predict the outcome. Most current simulations of such discs over-predict the population of BDs and low mass stellar companions.

(3) We shall also present our ongoing work to calculate chemical composition of the solid cores formed in the TD hypothesis. We show that it is vertually impossible to form water-dominated massive solid cores since the compressional heat and rapid radiative cooling of the clumps preclude sedimentation of water ice (except for a very low density, small mass gas clumps). As the result TD predicts that composition of "hot" sub-jovian exoplanets should be dominated by rock/Fe and H/He mixes.

1 Bibliography

The relevant bibliography is all very recent and can be easier found on ADS.