Accretion of terrestrial planets: Dynamical and cosmochemical constraints

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The assembly of the terrestrial planets is classically simulated from the accretion of Moon to Mars-mass planetary embryos orbiting between 0.5 and 4 AU. This scenario has been proven successful in producing a variety of constraints of the inner solar system as for example: Earth and Venus analogues, accounting for the origin of Earth's water and its accretion within the timescale consistent with radioactive chronometers. However, classical simulations also suffer from some important drawbacks [1]. One of the most important ones is that the planet formed around 1.5 AU is about 5-10 time more massive than Mars [2].

One solution to the so-called "Mars problem" is to invoke that the terrestrial planets formed from a narrow annulus [3]. The Grand Tack scenario invokes a specific migration history of Jupiter and Saturn to remove most of the mass initially beyond 1AU and to leave the asteroid belt on an excited dynamical state [4]. However, one could also invoke that a akin steep mass density gradient was achieved by the inward migration and pile-up of a large amount of small particles induced by gas-drag. This process is appealing in a broad context of planet formation since it has been proposed to explain the formation of extrasolar close in super Earths [5].

Using a series of N-body numerical simulations in disks with steep surface density profiles we show that the asteroid belt orbital excitation provides a crucial constraint against this scenario for the Solar System. We find the small mass of Mars and the dynamical excitation of the asteroid belt have diametrically opposite scalings; Mars' small mass requires a mass deficit but producing asteroids with inclinations above ~ 10 deg requires a significant amount of mass in embryos. Therefore, we conclude that no disk profile can explain at the same time the structure of the terrestrial planet system and of the asteroid belt. Thus, the asteroid belt has to have been depleted and dynamically excited by an external agent as, for instance, in the Grand Tack scenario.

[1] Izidoro et al. 2014, *ApJ*, **782**, 31; [2] Raymond et al. 2009, *Icarus*., **203**, 644 ; [3] Hansen, 2009, *ApJ*, **703**, 1131; [4] Walsh et al. 2011, *Nat*., **475**, 206; [5] Chatterjee & Tan 2015, *ApJL*, **798**, LL32