# CHONDRULE FORMATION IN SHOCKS GENERATED BY JUPITER TRAVELLING IN THE PROTOPLANETARY DISK.

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**Introduction:** Over the last decades, chondrules studies yielded a wealth of elemental and isotopic data leading to relatively well constrained thermal histories. They showed that chondrule formation likely included the heating of precursor dust to high temperatures (1800-2200 K) and relatively slow cooling within hours to days in a gas/dust-rich environment in the protoplanetary disk [e.g. 1]. Moreover, the combination of petrologic characteristics with isotope systematics (e.g. O and Ti) also showed that chondrules sampled distinct reservoirs within the protoplanetary disk e.g. [1,2]. However, the processes by which chondrules formed are still debated. Recent imaging of protoplanetary disks by ALMA revealed gaps in the imaged dust disks, which could have been generated by planets of e.g. Jupiter-size e.g. [3]. Moreover, it is well known that a Jupiter-sized planets traveling in a gas-rich disk will induce shocks. It has been shown that shocks around smaller eccentric planetary embryos can provide local regions in which the conditions for chondrules formation are met [4]. Here, we assess if shocks induced by the presence of a massive planet in the disk can create areas of higher pressure and temperature, in which the chondrule precursor material can melt and cool under the right conditions to produce chondrules. This is the first time that global disk hydrodynamical simulations are applied to a model in which chondrule formation is triggered by Jupiter.

**Methods:** The hydrodynamical code ROSSBI [5] was used to perform 2D simulations of the protoplanetary disk and explore the parameter space for shocks that originate from the presence of a massive planet (30 Earth masses ($M_\oplus$) up to Jupiter-size (318 $M_\oplus$)). Some simulations included gas and dust, but most were run using gas only because for small grain sizes relevant to chondrule precursors (µm-sized), the effect of gas drag is negligible over the duration of the runs. To study the influence of the shocks on the pressure and temperature regime of the disk, several parameters were tested, such as, the distance of the planet from the Sun ($r_0$), its mass, and the planet's orbit eccentricity (e).

**Discussion:** One of the most ubiquitous effects of the presence of a planet is the rapid formation of a gap in the wake of the planet, even for low mass planets (30 $M_\oplus$). In this gap, the density and pressure of gas and/or dust is strongly reduced, hindering the transfer of dust and thus forming a barrier between the populations on both sides of the gap. Such gaps could explain why chondrules from different meteorite classes were formed in distinct regions of the disk [1,2] and were accreted onto their parent bodies without significant later mixing [6]. This is in agreement with the observed dichotomy in isotopic systems (e.g., 50Ti) between carbonaceous chondrites, forming in the outer parts of the disk, and a group (including ordinary and enstatite chondrites) that formed closer to the Sun e.g. [6,7]. Another widespread feature across most simulations is the formation of a large vortex (and several smaller ones) on the outer edge of the gap. In these vortices, density and pressure are enhanced. In simulations including dust (mm sized), the dust concentrates in these locations and can reach enrichment factors up to $10^2$ relative to the rest of the disk, while gas density increases ~10x. When the shock front induced by the planet encounter these vortices, the temperature at the front strongly increases due to their higher density, and often reaches the temperatures required to melt and form chondrules. The actual achieved temperatures strongly depend on (i) $r_0$ and (ii) the planet mass. (i) $r_0$ - The peak temperatures required for chondrule formation could only be obtained with a planet relatively close to the sun ($r_0 < 5$ AU). Such close distances are proposed e.g., by Grand Tack model [8], which involves Jupiter migrating inwards early during disk evolution before migrating outwards to its current position at ~5 AU. (ii) *Planet mass* - In simulations using 30 $M_\oplus$, (e.g. an early core of Jupiter), temperatures sufficient to form chondrules cannot be reached. With a half-mass Jupiter, such temperatures are only achieved close to the Sun (~1.5 AU). This implies that chondrule formation can only take place once Jupiter has accreted enough mass to cause stronger shocks.

**Conclusions:** Simulations indicate that nebular shocks caused by the presence of a big planet such as Jupiter can induce chondrule formation, in particular if Jupiter migrated inwards in the early times of the disk. However, detailed analysis to assess cooling rates after the particles have encountered the high peak temperatures remains to be conducted.

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