Melt-gas interaction in the protoplanetary disk

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Primitive meteorites and their components preserve direct records of processes in the protoplanetary disk (PPD). One of the most important records are preserved in μm to mm sized, once molten silicate droplets (chondrules). Many chondrules are mineralogically zoned with olivine in the center and low-Ca pyroxene at the rim (e.g. [1-8]). Such zoning cannot be the result of chondrule melt crystallisation, as the zonation should then be reverse. Formation on the meteorite parent body (=asteroid) is impossible. Rim pyroxenes are the result of chondrule melt interaction with the surrounding PPD gas. But although chondrule zonation is a pivotal feature to understand PPD processes, no systematic study of this zoning exists.

We studied 223 chondrules in 15 different chondrites, from 6 different chondrite groups (CH, CM, CO, CR, CV, R), plus 33 chondrules from Berlin (2009), to constrain the overall systematic (appearance, abundance, etc.) of mineralogically zoned chondrules.

The fraction of zoned chondrules in 12 out of 13 carbonaceous chondrites ranges from 62 to almost 100%, with an average of ~75%. The exception is Mokoia, with 29% of zoned chondrules. Almost all zoned chondrules have porphyritic textures (99%), and are FeO poor, type I chondrules (95%). Many of the low Ca-pyroxene rims have a non-uniform thickness. In most chondrules, the pyroxenes poikilitically enclose olivine. Apparent rim thicknesses vary – an artifact of chondrule sectioning. Taking this into account, the average rim fraction of zoned chondrule is ~30 vol.%.

Mineralogically zoned chondrules must have acted as open systems and interacted with the surrounding PPD. This lead to fractional condensation, SiO enrichment in the gas phase and the reaction of chondrule olivine + SiO(g) to low-Ca pyroxene on chondrule rims. Such fractional condensation might even led to an additional silica rim around chondrules as described by [4] [5], and has been reported in the disk around the T Tauri star Hen 3-600A by [9].

[1] Scott & Taylor 1983. *JGR* **88**:B275 [2] Grossman et al. 2002. *MAPS* **37**:49 [3] Tissandier et al., 2002. *MAPS* **37**:1377 [4] Hezel et al., 2003. *MAPS* **38**:1199 [5] Krot et al., 2004. *MAPS* **39**:1931 [6] Libourel et al, 2006. *EPSL* **251**:232 [7] Chaussidon et al., 2008. *GCA* **72**:1924 [8] Jones 2012. *MAPS* **47**:1176. [9] Honda et al., 2003. *ApJ* **585**:L59