CHONDRULES – UBIQUITOUS DISK SOLIDS TRACKING THE EVOLUTION OF THE SOLAR PROTOPLANETARY DISK. M. Bizzarro[1] and J. N. Connelly[1], [1]Centre for Star and Planet Formation, Natural History Museum of Denmark, University of Copenhagen, Copenhagen, Denmark.

In the Solar System, a record of the earliest evolutionary stages of the protoplanetary disk is preserved in chondrite meteorites, which are fragments of asteroids that avoided melting and differentiation. Most chondrites consist of chondrules, refractory inclusions [Ca,Al-rich inclusions (CAIs) and amoeboid olivine aggregates (AOAs)], and fine-grained matrix. CAIs represent the oldest Solar System dated solids and, thus, define it's age at 4,567.3±0.16 Myr [1]. It is commonly accepted that CAIs formed in a hot (~1300 K) disk region near the proto-Sun characterised by approximately solar oxygen isotopic composition near the proto-Sun by evaporation, condensation and aggregation processes during a brief time interval that corresponded to high stellar mass accretion rates (~$10^{-5} M_\odot$ y^{-1}) [2]. Some CAIs were subsequently melted, most in the same disk region. Most chondrules formed by melting (typically incomplete) of solid precursor material during transient heating events (peak temperature of ~2000 K) of unknown nature in different, relatively cold dust-rich regions throughout the protoplanetary disk during its entire lifetime [1]. Therefore, CAIs and chondrules provide time-sequenced samples allowing us to probe the composition of the disk material that accreted to form planetesimals and planets.

The majority of chondrules formed as melt droplets in high-density regions of the protoplanetary disk and accumulated in the disk mid-plane together with other chondritic components. Chondrules are mainly composed of olivine and pyroxene minerals, which crystallised within minutes to days between ~1800 and ~1300 K [3]. Several heat sources have been proposed for the thermal processing of chondrule precursors, including shock waves [4], current sheets [5], x-winds [6], magnetised disk wind [7], and colliding planetesimals [8]. A long standing paradigm used to constrain chondrule-formation models is the so-called chemical complementarity that apparently exists between chondrules and matrix in individual chondrite groups [9]. In this model, it is proposed that chondrules and matrix are genetically related and formed in highly-localised regions of the protoplanetary disk. The chronology of chondrule formation is typically based on the short-lived ^{26}Al to ^{26}Mg decay system (^{26}Al decays to ^{26}Mg with a half-life of 0.705 Myr). Assuming that ^{26}Al was uniformly distributed in the protoplanetary disk with the canonical ^{26}Al/^{27}Al ratio of 5×10^{-5} commonly observed in CAIs, the ^{26}Al-^{26}Mg systematics of chondrules suggest that these objects formed >1 Myr after CAIs and rapidly accreted into chondrite parent bodies together with matrix in discrete events during the lifetime of the disk [2]. In this view, chondrule formation is restricted to the inner regions of the solar protoplanetary disk.

However, a number of recent studies investigating the absolute chronology of chondrule formation as well as the isotopic systematics of individual chondrules from various chondritic meteorites requires a reassessment of current thinking with respect to the formation history of chondrules as well as the parent asteroids of chondrite meteorites. For example, the absolute isotopic dates of individual chondrules suggest that the formation of these objects started contemporaneously with the condensation and melting of CAIs and lasted ~3.5 Myr [10], which indicate the existence of multiple generations of chondrules within individual chondrites. Moreover, variability in the titanium and chromium stable isotope compositions of chondrules from individual chondrites suggest that these objects or their precursor were formed in distinct regions of the protoplanetary disk and subsequently transported to the accretion regions of their respective parent bodies [11, 12, 13]. These new data are at odds with the traditional view of a short formation history for chondrule population from individual chondrites, the basic concept of chondrule-matrix complementarity as well as the timescales and style of chondrite parent body accretion. In this contribution, we review the current state-of-the-art data with respect to the chronology and stable isotopic compositions of individual chondrules from various chondrite groups and discuss how these data can be used to provide novel insights into the thermal and chemical evolution of the solar protoplanetary disk, including mass transport processes.

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