The Chemical Evolution of Chondrite Components: Implications for Mixing in the Solar Nebula

Overview
A crucial period during the history of any solar system is the first ~5 Myr following the ignition of the host star. Within this short time, the solar system transitions from a protoplanetary disk of dust and gas into a organised collection of orbiting planetary bodies. Within our solar system, a large number of meteorites formed during this early time and, as such, can act as a unique window into the processes that occurred during this transitional period. One class of meteorite - called chondrites - are aggregates of millions of millimetre-sized solids that formed directly from our protoplanetary disk. As such, these meteorites can provide insight into the formation mechanisms and histories of the earliest solids in the solar system, and the processes by which these objects accumulated to form the first asteroid-sized bodies.

The isotopic compositions of individual chondrite components (chondrules, refractory inclusions and matrix) suggest that some of these solids are composed of mixtures of material that originates from different locations within the protoplanetary disk. For example, the titanium isotopic compositions of individual chondrules from carbonaceous chondrites argue that these objects contain remnants of refractory solids that are believed to have formed very close to Sun immediately following its ignition (Gerber et al., 2017). Moreover, the oxygen isotopic composition of the matrix of these meteorites has been used to argue that this component contains material that originates from the far reaches of the solar system (Bryson et al., 2019; under review). Together, these observations support the migration of primitive solids throughout the protoplanetary disk and suggest that the chemical composition of chondrites evolved through the incorporation of these different objects. Because large planetary bodies formed through the agglomeration of numerous asteroid-sized bodies, this migration and mixing could ultimately have played a significant role in generating the chemical composition of the different planetary bodies in our solar system. For instance, the inward flux of distal material has been proposed to be the source of water in hydrated asteroids and possibly the terrestrial planets (Gomes et al., 2005).

Light microscope image of chondrules in the WIS 91600 chondrite. The compositions of objects similar to these will be measured in this project.

Such mixing events in the early solar system will have imparted specific chemical signatures onto the individual components of chondrites. Importantly, these signatures will still exist in components that could be mixtures of materials with relatively similar isotopic compositions. As such, detailed measurements of the chemical compositions of individual chondrite components could be used to both explore previously proposed mixing trends as well as potentially identify new mixtures. The aim of
this project is to conduct these measurements and use these compositions to constrain the mixing of different reservoirs within the early solar system. The results of these measurements will be used to investigate the extent to which the compositions of different planetary bodies evolved through the addition of material that originates from different regions of the solar system. As such, this project could uncover novel insight into the dynamics of solids throughout the solar system, the addition of dust and gas to the early solar nebula, and the origin and evolution of the chemical composition of a range of planetary bodies.

Methodology
The student conducting this project will use a range of techniques to measure to compositions of individual components of chondritic meteorites, including ion microprobe, electron microprobe and synchrotron X-ray fluorescence. The student will also measure the compositions of a variety of individual minerals within these components to gain a thorough understanding of the chemical evolution of chondrites. Together, all of these measurements will be used to constrain the compositional pathway along which these solids evolved within the first ~2 - 5 Myr of the solar system. The student will also ideally conduct relatively straight forward modelling of the compositional evolution of this solids to assist in the interpretation of their data.

Timeline
Year 1: Familiarisation with the literature on solid formation and possible mixing hypotheses in the early solar system. Identification and acquisition of ideal samples. Applications for time at the synchrotron and ion probe. Preliminary electron probe measurements.

Years 2 and 3: Electron probe, ion probe and synchrotron measurements of the compositions of a range of different components in a number of different meteorites. Data processing and interpretation. Presentation of results at national and international conferences. Writing and publishing papers presenting the measured compositions and possible implications regarding mixing and the origin of the compositions of different planetary bodies. Modelling of the compositional evolution of chondrite components to reinforce data interpretation.

Year 4: Continued modelling, collection of supporting data, thesis completion and defence, paper publishing.

Training & Skills
The student conducting this project will gain a broad range of analytical and numerical skills through the collection, treatment and interpretation of a large amount of quantitative data. They will also gain key skills in writing and presenting scientific ideas and data. Also, through leading independent research on a variety of instruments at a number of facilities, the student will gain a range of management and organisational skills. The student will be taught how to use the different instruments during this project as well as how to handle and treat data. Finally, the student will have the opportunity to learn how to write code that complements their data interpretation.

References & Further Reading

J Bryson, B Weiss, J Biersteker, A King & S Russell (under review), Constraints on the distances and timescales of solid migration in the early solar system from meteorite magnetism, The Astrophysical Journal


Further Information
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