Student questions: SESE Students Colloquium

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Isotopic investigations of meteorites: using forensic tracers to unravel the mysteries of our early Solar System

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Could you explain further what events/elements you think caused or catalyzed the mixing of the depleted supernova derived nuclides in the late infall?
Based on models of the protoplanetary disk dynamics, it is thought that after infall stopped mass continued to be accreted by the Sun through inward transport of material in the disk. This inward transport would lead to mixing between materials from the inner and outer regions of the disk.

What do the different colors of CAI's indicate?
The different colored symbols for CAIs are indicative of their rare-earth element (REE) patterns. Briefly, the different REE patterns indicate different condensation histories of the CAIs.

What makes Cr have larger CAIs than Ti??
Both Cr and Ti were measured in all of these CAIs.

I've seen geochemists, spacial geologists, and other majors showing their studies and talking about the space using their majors as point of views. What made you choose Isotope Geochemistry and what was something that you would say that when you studied you said to yourself "That's why I focus on studying the isotopes?"
I was a geology major in undergrad, and I became involved in planetary science through an internship at NASA. I chose isotope geochemistry and meteorites because I enjoy the process of using these samples and techniques to learn about our Solar System. As far as a "that's why" moment, probably being able to hold pieces of the Moon and Mars at the same time in our meteorite vault!

Is the CAI referenced referring to this solar system, galaxy, or universe?
These CAIs are from our Solar System. We don't have samples from elsewhere, but if we ever get some I would love to study them!

What differences would you expect to see between other Solar System measurements and our own?
I would expect compositional differences depending on the type of Solar System, but I also suspect that there could also be many compositional similarities and analogous processes occurring.

Would the divison of enriched versus non-enriched material due to Jupiter contribute to the reason why inner planets are rocky, and the Jovian planets are gasceous?
These materials were distinct isotopically, but it is thought that they were likely similar elementally and therefore likely did not affect the types of planets that formed. We think the

primary factor explaining the presence of rocky planets closer to the Sun is the higher temperature in this region compared to the outer Solar System.

Are there any isotopes that are more preferred than others in your research?
The focus of my research is on the neutron-rich isotopes of Cr and Ti because these elements are abundant enough to measure and these isotopes have proven useful for this type of work. Many isotopes of different elements are useful for similar types of analysis.

Is there any undergraduate opportunities at ASU to get involved in research on this topic?
Yes, I know that several undergraduates in SESE do this type of research (inlcluding in my lab group). I believe there are opportunites to do undergraduate theses and also do work through the NASA Space Grant program. I would suggest contacting professors you would be interested in working with. I am also happy to talk to you in more detail about this if you send me an email.

If CAIs are snapshots of the early solar system makeup, how much change can/has occurred since then and how do you distinguish that to look at the true early composition?
We carefully study these CAIs to check for signs of reprocessing (such as remelting) and alteration, and this is always something that we take into account while interpreting data.

Could you explain how we know that the two elements that you were looking for data on are two elements that are planet creators?
We know this from measuring the abundances of the elements in samples from Earth and other rocky bodies.

Will you work with the Bennu sample when it arrives at the Earth?
I hope so!

How do you plan to extend you research after you've graduated, what are your future plans for your research?
After defending my PhD, I will be starting a postdoc position doing similar work and expanding on some of the topics I showed in my presentation.

If we can conduct experiments on asteroids soon, what would shed the most light on the questions we still currently have?
I think studying samples for which we know the parent body and geological context would prove to be the most helpful. This is why sample return missions (such as OSIRIS-REx and Hayabusa2) are so important.

If Jupiter cuts off the ability for CAI's to return to the inner solar system, how did we come into possession of one?
The separation of materials by Jupiter is only an early part of the story! Later in time, we think that Jupiter and Saturn migrated first inward and then outward, which scattered material in the Solar System and brought objects that were originally outside of Jupiter's orbit (such as the CAI-bearing carbonaceous asteroids) inside of Jupiter's orbit into the asteroid belt. From there, CAIs fell to Earth aboard meteorites.

As Jupiter formed between the NC and CC areas, can the titanium and chromium isotopes that Jupiter consumed when it formed be found?
Hopefully one day we have a sample of Jupiter to measure and conclusively answer this question.

What is CC and NC?
The "carbonaceous" and "non-carbonaceous" isotopic reservoirs.

What is the most interesting facet (in your opinion) of your research?
The ability to handle a sample in our laboratory and use its composition to map out what was happening billions of years ago!

What is the age of the oldest meteorite you have worked with in the lab?
The oldest CAI is ~4.567 billion years old, and the meteorite holding it probably formed a few million years later.

What is the most common meteorite composition that you have come across in your career thus far?
I work on carbonaceous chondrites, so those are the types of samples I primarily handle.

Really great talk, thanks! Is there other robust evidence besides Cr and Ti isotopes to inform us about Jupiter's roll in separating CAIs?
Yes, we also see evidence for this in Mo, Ru, Ni, Ca, Sr, Zr, Ba, Nd, Hf, W, Sm, and Os isotopes as well as the measured ages of meteorites from these two reservoirs (see Kruijer et al., 2017 or Kruijer et al., 2020 for more details).

Is there will be a way to analyze these tracers in extrasolar objects like 'Oumuamua and possibly determine their origins?
Yes, if we can get a sample of it!

What are CG and FG ACIs?
Coarse-grained and fine-grained CAIs.

Do you believe the supernovae derived enrichment was from a nearby supernova that fell onto our disk or was it the debris of a supernova in our parent molecular cloud?
This is still an open question. Either is plausible, but it is difficult to conclusively prove one or the other.

Can these CAI rich meteorites be able to tell us about possible habitability factors if they came from other star systems?
If we ever get a sample from another Solar System, we will likely be able to study it to learn about that Solar System. CAIs themselves may not tell us about habitability, but if we see compositions analogous to our own Solar System this could hint that similarly habitable planets might be present there.

Can these isotopic measurements give a timeline of the separation of carbonaceous and non-carbonaceous chondrites?
Yes, the measurement of isotopic anomalies combined with age determinations of meteorites using isotopes has told us that the separation started less than 1 million years after Solar System formation and continued until ~3-4 million years after Solar System formation (see Kruijer et al., 2017).

Through what processes does infall from clouds form CAIs?
CAIs are refractory solids that condense from the gas near the young Sun at very high temperatures.