Highlights of the year – DNRF Chair Anders Johansen

I describe here two highlights from my research as DNRF Chair in 2022.

Unravelling the history of the Solar System
Liu, B.; **Johansen, A,**; Lambrechts, M.; Bizzarro, M.; Haugbølle, T., "Natural separation of two primordial planetary reservoirs in an expanding solar protoplanetary disk", 2022, Science Advances, 8, eabm3045

The origin of Earth's building blocks can be inferred by comparing the isotopic composition of major elements in the Earth's mantle to various classes of meteorites. Such meteorites are fragments of asteroids and they come in two flavors: from inner Solar System objects that are depleted in neutron-rich isotopes and from outer Solar System objects that are enhanced in neutron-rich isotopes. Earth, despite its formation in the inner Solar System, appears to be a mixture of 60-80% inner Solar System material and 20-40% outer Solar System material. We demonstrate in this paper how the inner Solar System bodies became depleted in neutron-rich isotopes due to loss of tiny presolar grains that were produced in supernova explosions before the birth of the Sun. This depletion happened when the young Sun underwent powerful energy outbursts that heated the grains out to 30 AU (AU=Earth-Sun distance) from the star. The material depleted in supernova grains then drifted in gradually over the next 3-4 million years, and the inner Solar System eventually transitioned back to a composition characteristic of outer Solar System bodies. This explains why our planet accreted from a mixture of material from the inner and outer Solar System. We also used our model to place the formation region and formation time of various classes of meteorites, inferred by comparing their isotopic compositions to the model. This way we provide a full history of the formation of both asteroids and planets in the Solar System.

Understanding the mysterious composition of Mercury
Johansen, A.; Dorn, C., "Nucleation and growth of iron pebbles explains the formation of iron-rich planets akin to Mercury", 2022, Astronomy & Astrophysics, 662, 19

Mercury is the strangest of the terrestrial planets in the Solar System. The planet is 20 times less massive than Earth and Venus, but has a similar density despite the much lower interior pressure. This implies that Mercury has a metal core of approximately 70% of its mass, more than twice the core mass fraction of Earth. The high core mass fraction is traditionally ascribed to evaporation of the rocky mantle following an impact with another planet. However, the high abundance of volatile elements in the mantle of Mercury observed by NASA's Messenger probe is inconsistent with reaching temperatures above 1000 K during its formation. We explored here the idea that Mercury formed from accumulation of metal-rich asteroids. But how would such planetesimals form? We investigated the cooling of gas close to the young Sun, where all solids had been sublimated after an energetic stellar outburst. We found that two distinct types of particles condense out from the gas: small silicate particles and large iron particles. Those large iron particles easily come together to form iron-rich planetesimals, leaving behind the small silicates. Our results imply that the iron-rich planets known to orbit the Sun and other stars are not required to have experienced mantle-stripping impacts. Instead, their formation could be a direct consequence of energetic outbursts of young stars and chemical separation of distinct minerals.