WHERE DID THE CHONDRITES FORM?

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Introduction: Two recent models propose that the parent bodies of the carbonaceous chondrites formed in the outer Solar System and were implanted into the asteroid belt during periods of dramatic giant planet migration [1, 2]. To test these models, the challenge for meteoriticists has been to find indicators of formation distance from the Sun. Water/rock ratios are one possibility as outer Solar System bodies tend to be ice-rich [3]. Hydrogen isotopes in H_2O are another potential indicator as they should vary dramatically with distance as a result of radial mixing between interstellar ice and H_2O that equilibrated with H_2 in the hot (>300 K) inner disk [4-6]. Based on a comparison of estimates of water D/H ratios in chondrites with those of comets and Saturn's moon Enceladus [7] concluded that chondrites formed <3-7 AU. This estimate was based largely on the D-rich composition of Enceladus's water. However, there is some debate about whether Enceladus formed from fragments of a catured object rather than in Saturn's subdisk. Also, methane in the atmosphere of Saturn's largest moon, Titan, are Earth-like [8]. If Titan's atmospheric methane reflects the D/H of the bulk moon, this could simply mean that Saturn's subdisk was warmer than the surrounding nebula when Titan formed. Nevertheless, the questions about Enceladus's origins and the significance of Titan's methane D/H require finding a new distance indicator.

Discussion: Nitrogen isotopes are one possibility because, as in the H system, there could have been large isotopic fractionations between the major N reservoir, N_2, and more minor species, such as HCN and NH_3. Relative to bulk solar, comets have been shown to contain almost uniformly ^{15}N enriched HCN [9] and NH_3 [10, 11], and Titan's atmospheric NH_3 is also ^{15}N enriched [12]. The bulk N isotopic compositions of chondrites are similar to or slightly enriched compared to Earth, which in turn is modestly enriched compared to bulk solar. However, bulk chondrites are dominated by IOM, and the origin of its N may be unrelated to those of HCN and NH_3. On the other hand, the N in amino acids in CCs may well have come from HCN and NH_3 and they exhibit a similar range of N isotopes to the bulk/IOM.

Conclusions: As with H isotopes, there seems to have been a gradient in the N isotopes of condensed species. As with H, Saturns moons provide the best constraint on chondrite formation distances. Saturn's current orbit is ~10 AU, but in the Grand Tack model it finished growing between 3 and 7 AU. Saturn's moons would have formed at the end of its growth phase. The fact that chondritic N is not as ^{15}N-rich as Titan (or comets), indicates that the chondrites must have formed <3-7 AU from the Sun. This is a very similar estimate to that obtained from H isotopes. More stringent limits will require detailed modeling of how and when Saturn's moons formed.

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