Fe Isotopic Dichotomy in Iron Meteorites and the Stellar Origin of Nucleosynthetic Fe Isotope Anomalies

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Introduction: Nucleosynthetic isotope anomalies in meteorites can be used to identify stellar sources that contributed material to the solar system's parental molecular cloud core, and to investigate mixing and physicochemical processes in the circumsolar accretion disk. For example, isotopic anomalies in elements like Ti, Cr, Mo, and Ni revealed the existence of a fundamental isotopic dichotomy among bulk meteorites, the so-called *non-carbonaceous* (NC) and *carbonaceous* (CC) dichotomy, which indicates that the meteorite parent bodies must have formed in co-existing, spatially distinct reservoirs in the disk [*e.g.*, 1-3].

Iron isotopic anomalies in bulk meteorites do not seem to exhibit a clear dichotomy between NC and CC meteorites. While several iron meteorites hint towards a possible difference between samples from the NC and CC reservoirs, this difference is not observed for chondrites [4]. The determination of nucleosynthetic Fe isotope anomalies in iron meteorites may be complicated by mass-independent Fe isotope variations induced by prolonged exposure to galactic cosmic rays (GCR) [5]. Thus, it is currently unclear whether a Fe isotope dichotomy between NC and CC iron meteorites exists and holds for all major iron meteorite groups. Additionally, the origin of nucleosynthetic Fe isotope anomalies in bulk meteorites remains unknown because this would require ^{58}Fe data, which were not reported in [4]. Here we present a systematic study of Fe isotope anomalies in iron meteorites to test the existence of an isotopic dichotomy in the early solar system and constrain the possible stellar origins of nucleosynthetic Fe isotope anomalies in bulk meteorites.

Samples and Methods: We investigated 23 iron meteorites belonging to five NC (IAB, IC, IIAB, IIIAB, IVA) and four CC (IIC, IID, IIIF, IVB) groups. For 18 of these samples, the Fe isotopic composition was analyzed on solution aliquots previously analyzed for their Pt isotopic composition to monitor GCR-effects [3,6,7]. Iron was purified from digestion aliquots using anion exchange chromatography. High-precision Fe isotope measurements were performed at the University of Chicago using a *Thermo Scientific Neptune* multicollector inductively coupled plasma mass spectrometer. Mass-independent Fe isotope anomalies are reported in μ-notation defined as parts-per-million deviation of a sample ratio relative to the mean value of two bracketing standards where all isotope ratios are internally normalized to a fixed ^{57}Fe/^{56}Fe ratio.

Results: The Fe isotopic data of iron meteorites display resolvable mass-independent variations in $\mu^{54}Fe_{(7/6)}$ but no resolvable variations in $\mu^{58}Fe_{(7/6)}$ within ±15 ppm. Samples from the four CC groups have $\mu^{54}Fe_{(7/6)}$ ranging from +24 to +42 whereas NC groups have values ranging from -5 to +30. Most samples from the same group have indistinguishable $\mu^{54}Fe_{(7/6)}$. However, IC and IIAB iron meteorites display within group variations that correlate with GCR-effects monitored by their Pt isotopic compositions.

Discussion: The correlations of the measured $\mu^{54}Fe_{(7/6)}$ and Pt isotopic compositions in IC and IIAB iron meteorites agree with model calculations of GCR effects on Fe isotopic compositions in IAB iron meteorites [5]. After correction of these effects the average pre-exposure Fe isotopic compositions of the iron meteorite groups display a NC-CC dichotomy with consistently larger $\mu^{54}Fe_{(7/6)}$ values in CC groups. Thus, the NC and CC reservoirs must have been well separated in the early solar system at least for the accretion timescales of iron meteorite parent bodies. The absence of any resolvable variations in $\mu^{58}Fe_{(7/6)}$ suggests that ^{56}Fe, ^{57}Fe, and ^{58}Fe are present in proportions that correspond to the terrestrial compositions. Thus, the dichotomy in $\mu^{54}Fe_{(7/6)}$ is predominantly caused by excesses in the neutron-poor ^{54}Fe in CC relative to NC iron meteorites. Similarly, Ni isotope anomalies in bulk meteorites are assumed to be produced by variation of neutron-poor ^{58}Ni [8]. ^{54}Fe and ^{58}Ni are predominantly produced by *nuclear statistical equilibrium* in *(i)* type Ia supernovae (SNIa) and *(ii)* the inner regions of core-collapse supernovae (cc-SN). Following [8] we evaluated different scenarios of bulk admixture of SN material to solar composition and find that none of the considered models can explain the ^{54}Fe and ^{58}Ni variations in bulk meteorites simultaneously. In contrast, admixture of material from the inner Si/S zone of cc-SNe [8,9] can reproduce the observed slopes of Fe and Ni isotope anomalies in bulk meteorites.

Conclusion: Iron meteorites display a NC-CC Fe isotopic dichotomy. The Fe isotope anomalies predominantly reflect variations of ^{54}Fe and are caused by heterogeneous distribution of material in the protoplanetary disk that was produced by *nuclear statistical equilibrium* in supernovae.

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