Preservation of previously unsampled primordial isotopic components in Ryugu and Bennu samples

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Abstract: Ivuna-type (CI) carbonaceous chondrites are primitive meteorites whose relative elemental abundances closely match the solar photosphere[1], making them critical benchmarks for the bulk chemical and isotopic composition of the planet-forming disk. Recent sample-return missions to Ryugu[2] and Bennu[3] have enabled direct laboratory analysis of these rubble-pile CI-like asteroids[4], formed from the reaccumulated fragments of once-larger parent bodies. As such, they may retain a broader spectrum of primordial nucleosynthetic components than is preserved in known meteorites. Here, we report the nucleosynthetic compositions of silicon (μ^{30}Si), magnesium (μ^{26}Mg*), and iron (μ^{54}Fe), three of the four most abundant planet-building elements, in samples from Ryugu and Bennu, along with the newly discovered Oued Chebeika 002 CI chondrite[5]. In contrast to the isotopic homogeneity of CI chondrites, Ryugu and Bennu preserve resolvable μ^{26}Mg* and μ^{30}Si heterogeneity, revealing μ^{26}Mg*- and μ^{30}Si-rich nucleosynthetic components not sampled in meteorites. These components may reflect the preservation of previously unsampled primordial isotopic signals, prior to thermal processing[6,7] and late infall of primordial molecular cloud material to the outer disk[8,9]. Additionally, Ryugu particle C0002 exhibits a μ^{26}Mg*-poor and μ^{54}Cr-rich signature, consistent with incorporation of presolar material from massive supernovae[10,11]. Ryugu and Bennu samples define one end

of a μ^{54}Fe–μ^{30}Si array among carbonaceous asteroid materials[9], suggesting that the isotopic compositions of these asteroidal materials reflect mixing between early disk isotopic components identified in this study and material derived from the outermost disk[9]. This observation demonstrates that materials with solar chemical abundances can nonetheless exhibit markedly distinct nucleosynthetic signatures. Thus, Ryugu and Bennu samples are critical records of nucleosynthetic diversity among carbonaceous asteroids and underscore the value of sample-return missions in accessing primitive isotopic signatures absent from meteorite collections.

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