# Helium isotopic ratios in carbonaceous chondrites: Significant for the early solar nebula and circumstellar diamonds?

Conference or Workshop Item

**HELIUM ISOTOPIC RATIOS IN CARBONACEOUS CHONDRITES: SIGNIFICANT FOR THE EARLY SOLAR NEBULA AND CIRCUMSTELLAR DIAMONDS?**

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**Introduction:** A confusingly large number of noble gas components has been found in meteorites, based on distinct compositions, origins, carrier phases, or release characteristics [1]. The discovery that the carriers of the primordial noble gases survive acid treatment [2] led to the identification of several circumstellar grain types [3]. The oxidisable carbonaceous carrier "phase Q", however, which contains most of the isotopically "normal" Ar-Xe in acid-resistant residues has not been identified yet [see 4 for references].

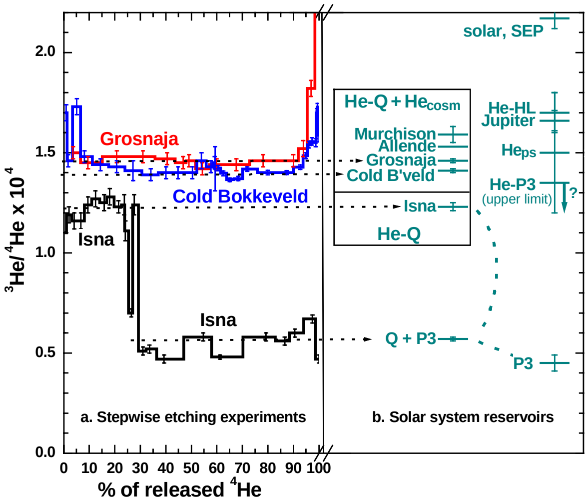


**Fig. 1.** $^3He/^4He$ release patterns during CSSE and $^3He/^4He$ ratios from different solar system reservoirs.

The He composition is difficult to measure. Ratios for He-Q have been given only for the Q-gas-rich Allende and Murchison [5,6], because He-Q is strongly depleted relative to other He components and easily overwhelmed by cosmogenic He ($He_{cosm}$). Circumstellar He has been measured in diamonds and SiC-rich separates. Helium in the latter is accompanied by Ne-E and appears to be a mixture of pure $^4He$, originating in the He shell of AGB stars, and "normal" He with $^3He/^4He$ ~2.6 x $10^{-4}$ [7]. Huss et al. found $^3He/^4He$ = (1.7 ± 0.1) x $10^{-4}$ for He-HL which is probably related to circumstellar diamonds [8] and can amount to ~80 % of the primordial He in meteorites. The $^3He/^4He$ ratio for P3, another, probably superficially bounded component in diamonds, is ≤1.35 x $10^{-4}$ [8]. The published data yield numerous $^3He/^4He$ ratios in the range (0.95-1.50) x $10^{-4}$ for mineral and density separates, stepwise heating experiments, diamond-rich separates, and acid-resistant residues of carbonaceous chondrites [e. g. 9-12]. This indicates at least one important primordial He component with a correspondingly low isotopic ratio. Here, we present new estimates for Q and P3 and discuss possible implications.

**Experiment:** HF/HCl-resistant silicate-poor residues from unequilibrated chondrites have been analysed with our on line closed system stepped etching technique (CSSE) [4-6]. This allows to clearly recognize the release of different He components from residues of the chondrites CV3 Grosnaja, CM2 Cold Bokkeveld, and CO3.7 Isna.

**Tab. 1.** $^3He/^4He$ ratios in phase Q, Jupiter, circumstellar diamonds, and local interstellar cloud (LIC).

| | $^3He/^4He$ x $10^4$ | |
|---|---|---|
| **Isna** | **1.23 ± 0.02** | **He-Q** |
| Cold Bokkeveld | 1.41 ± 0.01 | He-Q (+ $He_{cosm}$) |
| Grosnaja | 1.46 ± 0.01 | He-Q (+ $He_{cosm}$) |
| Allende | 1.59 ± 0.04 | [5] |
| Murchison | ≤ 1.33* | [6] |
| Jupiter | 1.66 ± 0.05 | [15] |
| LIC | 2.48 ± 0.68 | [23] |
| LIC | 1.30 ± 0.76 | [24] |

*We adopted the lowest ratio measured instead of the more conservative limit given in [6].

**Results:** Fig. 1 shows the extraordinarily constant plateaux of the He isotopic ratios released during the etch runs, indicating well-defined components. The adopted ratios (Tab. 1) lie below that of Allende [5]. The differences can be attributed to $^3He_{cosm}$ which increases the originally trapped $^3He/^4He$ ratios. Indeed, Fig. 2 shows a positive correlation of $(^3He/^4He)_Q$ with exposure age. Isna has an almost negligible exposure age. We thus adopt its very low $^3He/^4He$ = (1.23 ± 0.02) x $10^{-4}$ as the true ratio for He-Q. Conservatively correcting for $^3He_{cosm}$, assuming 1 % silicates in the residue, would lower this ratio by 0.1 %.

Another component with a lower ratio was released from Isna in the second part of the run (Fig. 1). The $^4He$ *and* $^3He$ abundances relative to Ar-Xe strongly increased in these steps, suggesting that this He was more likely released from circumstellar grains rather than phase Q. Solar or terrestrial gases can be excluded according to the isotopic composition of Ne-Xe in these steps. Correcting for He-Q released in the later steps as well with the ratio given above, we obtain $^3He/^4He$ = (0.45 ± 0.04) x $10^{-4}$ for this component, which might represent P3, because this is the least bound component in diamonds, and Ne-E indicating SiC or graphite has not been observed.

**Discussion:** Protosolar (ps) $^3He/H$ and D/H ratios are important to test predictions of the Big Bang nucleosynthesis theory and set constraints on cosmic parameters [13]. These ratios can be obtained from solar wind and meteoritic He isotopic ratios or direct measurements in Jupiter's atmosphere [14,15]. A $^3He/^4He$ ratio of (1.5 ± 0.3) x $10^{-4}$ from carbonaceous chondrites has widely been used [14]. However, as discussed above, this He is largely related to circumstellar diamonds. We thus propose that He-Q better represents the gaseous protosolar cloud He. Arguments that support this view are: The depletion of the light Q-gases relative to the heavier ones and solar ratios can result from trapping on ice-coated circumstellar grains in the molecular cloud [16]. Q-gases and circumstellar grains must have been homogeneously mixed in the nebula prior to formation of the first planetesimals [17]. Experiments simulating conditions in the molecular cloud yield residues that contain heavy noble gases in concentrations similar to phase Q [18].

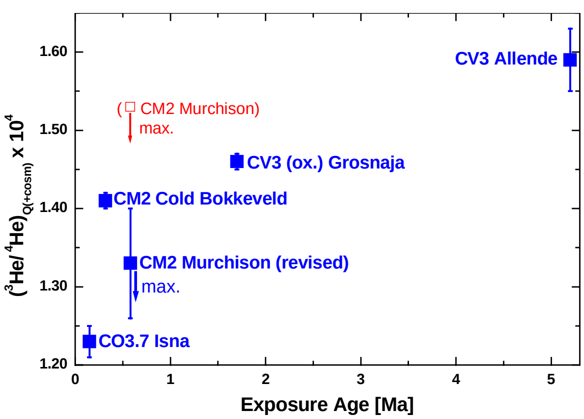


**Fig. 2.** $(^3He/^4He)_{Q(+cosm)}$ vs. exposure age [26,27].

Multiplying $(^3He/^4He)_{Q/ps}$ as determined above with $(^4He/H)_{ps}$ = 0.095 ± 0.010 [19] yields $(^3He/H)_{ps}$ = (1.16 ± 0.12) x $10^{-5}$. The present solar $^3He$ is the sum of protosolar $^3He$ and D, because of pre-main-sequence D-burning in the Sun [14]. Subtracting $(^3He/^4He)_{ps}$ from the present $^3He/^4He$ in the solar outer convection zone [20], we obtain $(D/H)_{ps}$ = (2.4 ± 0.7) x $10^{-5}$ which is in agreement with earlier determinations [14] and the ratio in Jupiter's atmosphere [15]. Thus, the latter might contain unfractionated protosolar hydrogen and Jupiter's precursor planetesimals experienced only minor fractionations by physicochemical processes.

The new $(^3He/^4He)_{ps}$ ratio is 35 % lower than the ratio measured in Jupiter's atmosphere [15]. This points to fractionation either in the solar nebula prior to incorporation into phase Q, within the carrier itself, during accretion of Jupiter, or within its atmosphere. Helium is indeed elementally fractionated in Jupiter because of rainout in metallic H [21], but the He depletion is 10 % only. The icy precursor planetesimals that formed the Jovian core might also contain fractionated He. These ices must have formed at temperatures below 30 K and thus beyond the Pluto region of the solar system [22]. However, it is argued that these ices do not trap large amounts of He.

Our $(^3He/^4He)_{ps}$ is lower than the $^3He/^4He$ in the present local interstellar cloud (LIC) as given in [23]. However, a preliminary ratio from foils directly exposed to the LIC [24] suggests no significant difference. A ratio in the LIC higher than $(^3He/^4He)_{ps}$ would reflect the $^3He$ production within stars and subsequent mixing into the interstellar medium during the last 4.6 Ga. The agreement of our protosolar and the new LIC ratio (Tab. 1) might support the idea that no major net $^3He$ production or loss has occurred in the galaxy [25].

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