NOBLE GASES IN A SINGLE GRAIN FROM RYUGU: INVESTIGATING THE ORIGIN OF GAS-RICH ASTEROIDAL MATERIAL

Bernard Marty[1], Laurent Zimmermann[1], Evelyn Füri[1], David V. Bekaert[1]
[1] *Université de Lorraine, CNRS, CRPG, 54000 Nancy, France*

The JAXA Hayabusa2 mission successfully returned material from the surface of the Cb-type asteroid (162173) Ryugu [1,2], which is similar in composition to Ivuna-type carbonaceous chondrites (CI) [3]. As the bulk chemical composition of CI chondrites approximates the composition of the solar photosphere, primitive CI chondrite-like materials are invaluable samples for studying the chemical composition of the nascent solar system. In addition, carbonaceous chondrites may have played a crucial role in delivering volatiles and organic material to Earth and the other terrestrial planets [4-6]. Hayabusa2 samples present a unique opportunity to analyze material that originated from a carbonaceous asteroid without the potential obfuscation arising from terrestrial contamination. Due to their inertness, noble gases serve as unique tracers of planetary volatile evolution. Primordial noble gases in carbonaceous chondrites are primarily contained within poorly defined phase(s) associated with insoluble organic matter and a variety of presolar grains, each of which has a unique elemental and isotopic signature [7,8]. As such they can provide a wealth of information on the different sources that contributed to the accretion of different planetary bodies. Previous noble gas analyses have shown that the concentration of trapped noble gases in the Ryugu samples is greater than the average composition of CI chondrites and are primarily derived from phase Q, with significant contribution of presolar nanodiamond Xe-HL [9-11]. The large noble gas concentrations coupled with a significant contribution of presolar nanodiamonds suggests that the Ryugu samples may represent some of the most primitive, unprocessed material from the early solar system, with the potential to provide unique insight into how planetary components formed in the early Solar System from a solar-like composition [11]. Here we report further noble gas results for a “large” particle in order to investigate the occurrence of noble gas sub-components in CI material (e.g., [12] and refs therein).

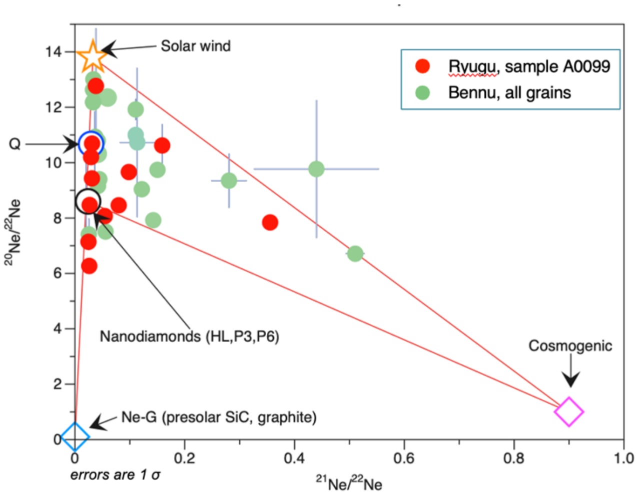

Figure 1: Neon isotope data for 12 step-heating releases from Ryugu sample A0099 (red dots) and from 8 Bennu samples (green dots [13]).

Sample A0099 (1.98±0.02 mg) was collected at the surface of Ryugu during the first touchdown. It had an intermediate spectral slope and dark reflection, suggesting it is rich in organic matter (OM; noble gases in CCs tend to concentrate in phases associated with OM). The sample was briefly exposed to air in a cleanroom (ISO6) at CRPG for weighing, using a XPR2U microbalance (Mettler Toledo@), before being loaded into a laser cell. Five other particles returned by the OSIRIS-REx mission were placed together into different pits of the laser chamber [14], which was gently baked at 100°C and pumped down to 10^{-9} mbar overnight. Each particle was sequentially heated using a CO_2 laser working at 10.6 µm by increasing its power. After each incremental laser power increase, released gases were purified, cryogenically separated, and analyzed with an Helix MC@ mass spectrometer. Twelve temperature steps were applied to sample A0099 and analyzed for all noble gas (He to Xe) abundances and isotopic ratios. Note that the exact temperature of each step could not be determined, and the rationale was to deconvolve different noble gas components according to their relative thermal retentivities. The bulk ^{20}Ne/^{22}Ne ratio of 8.34±0.02 is comparable to that of Ne trapped in nanodiamonds (^{20}Ne/^{22}Ne = 8.58±0.04 for Orgueil nanodiamonds [7]. Assuming that neon is mainly hosted in nanodiamonds [12], their concentration would be about 3,800 ppm, comparable to those of CIs. In detail **(Figure 1)**, the ^{20}Ne/^{22}Ne ratio shows large variations between 6.27±0.03 and 12.77±1.02, pointing to the contribution of two components: one rich in presolar Ne-G (SiC, graphite) and one hosting solar wind Ne. Using the ^{21}Ne production rate of [9], we compute a bulk

Cosmic Ray Exposure (CRE) age of 4.5±1.7 Ma, which is consistent within uncertainties with those of other CIs (Orgueil: 3.0±1.0 Ma; Ivuna: 2.8±0.9 [14].

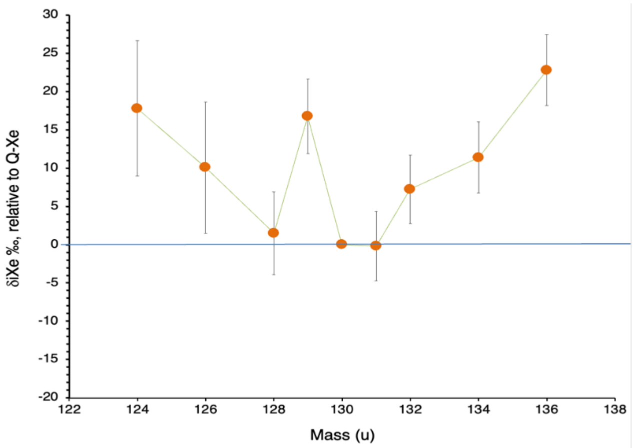

Figure 2: Bulk Xe isotope composition normalized to Q-Xe.

The bulk Xe isotope composition shows relative excesses in both the light isotopes (^{124}Xe, ^{126}Xe) and the heavy ones ($^{132-136}$Xe) compared to Q-Xe **(Figure 2)**, evidencing clear contribution of HL-Xe hosted by nanodiamonds. The pattern also shows excess of ^{129}Xe* presumably from the in-situ decay of ^{129}I ($T_{1/2}$ = 15.6 Ma). With an I content of 57±7 ppb, as measured in Orgueil [16], we obtain a I-Xe closure age of ~4.5±0.3 Ma after CAI, which could correspond to the end of hydrothermal alteration.

The different extraction steps permit to identify the main noble gas components trapped in the Ryugu sample **(Figure 3)**. Atmospheric contamination (likely arising from sample exposure to air for weighing) is mainly seen in the first two heating steps which corresponds to < 6 % of total released Xe. Data from other extraction steps define a mixing trend between Xe-Q and Xe-HL and exclude SW irradiation as a major component. The proportion of HL-Xe, estimated from the bulk Xe composition, is ~2.3±0.5 %, comparable to the one observed in Orgueil [12]. We did not identify the newly discovered P7 component in our sample, which is not surprising taking into account its rarity [11].

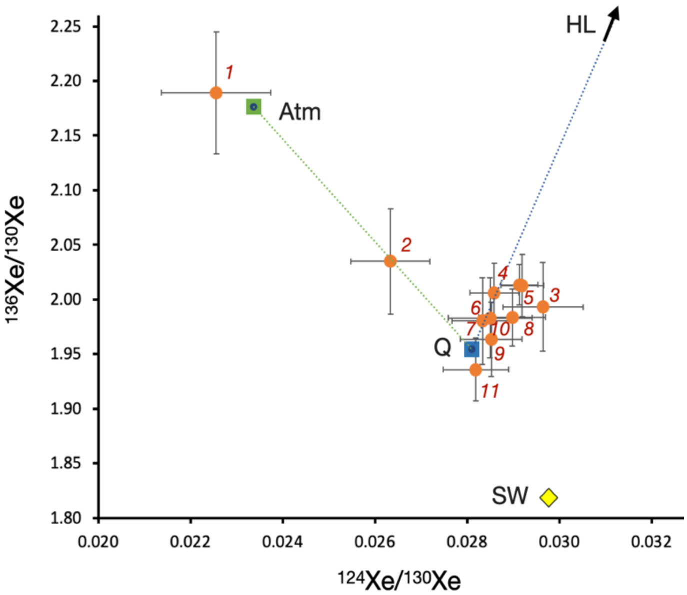

Figure 3: Evolution of Xe isotopic ratios upon step-heating extraction. Numbers close to the dots refer to the order of incremental heating. The first two steps reveal evolving mixing between atmospheric Xe and Q-Xe. Starting from the 3rd step, all gases are dominated by the Q component with variable contribution of HL-Xe from nanodiamonds. SW: solar wind

In summary, noble gases trapped in Ryugu material ([9,10], this study) appear very similar to those observed in CIs [12, 15]. They consist in a mixture of Q-noble gases with presolar components hosted in nanodiamonds and in presumably other phases (e.g., graphite, SiC rich in ^{22}Ne). In the present surface sample, solar wind irradiation appears to have been limited and only seen in few step releases of the light noble gases. One important difference with CI meteorites is that the Ar and Xe concentrations, including those measured in this study, are greater by a factor of ~2 than those of the other CIs and in the CMs, in probable relation with the fact that Ryugu material had very limited, if any, contact with the terrestrial environment.

We thank JAXA and the curation team for excellent handling of Ryugu samples and for confidence in allocating us this precious sample. This study was supported by the Centre National d'Etudes Spatiales (CNES).

[1] Yada T. et al. 2014 Meteoritics Planet. Sci. 49, 135. [2] Tachibana S. et al. 2022 Science 375, 1011. [3] T. Yokoyama T. et al. 2023 Science 379, eabn7850. [4] Marty B. 2012 Earth Planet. Sci. Lett. 313–314, 56. [5] Pizzarello S. & Shock E. 2017 Orig Life Evol Biosph 47, 249. [6] Broadley M. W. et al. 2022 Nature 611, 245. [7] Huss G.R. & Lewis R.S. 1994 Meteoritics 29, 811. [8] Busemann H. et al. 2000 Meteoritics Planet. Sci. 35, 949. [9] Okazaki R. et al. 2023 Science 379 eabo0431. [10] Broadley M. W. et al. 2023 Geochim. Cosmochim. Acta 345, 62. [11] Verchovsky A. B. et al. 2024 *Nature Commun* **15**, 8075. [12] Ott U. 2014 Chemie der Erde – Geochem. 1–26. [13] Marty B. et al. 2024 55th LPSC 2129. [14] Gamblin J. et al. 2024 Geochem. Persp. Lett. 31, 44. [15] King A. J. et al. 2019 Geochemistry 79, 125531. [16] Clay P. L. et al. 2017 Nature 551, 614.