Noble gases in gas and solid samples from Ryugu: Preliminary results and potential research perspectives for the Ryugu Reference Project

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The scientific community has been entering a new era of sample return missions with the recent successful Hayabusa 1&2 (JAXA) and OSIRIS-REx (NASA) missions, the future missions of samples return from Mars (Mars Sample Return mission, NASA and ESA) and its moon Phobos (MMX, JAXA). Among scientific investigations conducted on returned samples, measuring the elemental and isotopic composition of volatile elements contained in these samples is a high priority scientific target as they can be used to understand the origin of planetary atmospheres and of water in terrestrial planets (*e.g.*, [1]). More broadly, such measurements could provide answers to the question: Why is the Earth habitable? Such investigations rely on the ability to conduct a proper curation of the samples containing volatile elements. A recent study highlighted the need for developing advanced curation techniques for volatile-rich samples [2] and a recent experiment developed by US-based scientists opened lunar core containers returned to Earth by the Apollo astronauts to sample volatile elements (see ref. 3). Developing new curation techniques is also one of the goals of the future curation center CNME (a Center National for Extraterrestrial Materials) which will be built at the French Musée National d'Histoire Naturelle (MNHN, Paris, France) in collaboration with the Institut de physique du globe de Paris (IPGP, France). This is also one goal of the project MARCUS led by CNES (PI. C. Mustin, G. Navarro) and which is part of the new French initiative PEPR Origins: from planets to life.

In 2019, the Hayabusa2 mission successfully sampled over 5 grams of solid samples from the surface and subsurface of the asteroid Ryugu. The preliminary scientific investigations revealed that Ryugu samples are similar to primitive carbonaceous material similar to Ivuna-type meteorites but with less alteration than identified in these meteorites [4]. Having pristine samples from carbon-rich asteroids also allows to put new constraints on the role of these bodies in the delivery of volatile elements to Earth [5]. Recent measurements of the D/H ratio of hydrogen contained in Ryugu samples revealed that carbonaceous-type material could have delivered up to 3% of Earth's water [6]. Importantly, the sealing technique adopted for closing the sample capsule consisted in an aluminum metal seal [7], maximizing the chances to retain extraterrestrial volatile-rich elements such as noble gases. A quick recovery of the sample capsule followed by careful onsite curation protocols [8] allowed to recover the gas originally contained in the sample capsule. Results obtained by a preliminary study reveal that, despite a certain degree of contamination by the Earth's atmosphere, the gas sampled during the mission is extraterrestrial with a clear contribution from solar-wind derived gases [9]. Investigations also revealed that the Al-seal partially re-opened during Earth's entry due to the strong deceleration when the parachute deployed.

The technical developments and sample handling protocols used before, during and after the return of samples by the Hayabusa2 mission are the best and most recent examples of advanced curation techniques for volatile-rich elements collected during space missions [8,9]. Therefore, they represent a reference starting point for improving the current curation protocols and developing new solutions. Ryugu samples are thus providing perfect opportunity to assess the quality of the current techniques of curation of volatile-rich extraterrestrial samples. Gas samples from Ryugu allocated by the JAXA curation center have been delivered to IPGP in fall 2023. Noble gases (Ne, Ar, Kr and Xe) elemental and isotopic composition have been immediately measured in one sample from NT1 bottle to compare with published data (*e.g.*, [9]) and evaluate if the composition of the gas has evolved since the preliminary investigations. Unfortunately, a major failure on the IPGP pipetting system (leak) has compromised this sample. Recently, samples from the NT2 bottle have been measured with success. In this presentation we will show how preliminary results showing that the composition of the Hayabusa 2 gas samples is still showing contribution from extraterrestrial gases after several years of storage in the JAXA curation facility. Sealed samples are now stored in different vacuum conditions (air pressure, moderate vacuum, ultra-high vacuum) and their composition will be reassessed in about 6 to 9 months to estimate if significant changes have occurred.

About solid samples and the Ryugu Reference Project (RRP): Measurements of the abundance and isotopic composition of noble gases contained in various geological samples (mantle-derived gases, Martian meteorites, Venus' atmosphere, etc.) are typically compared to reference values for cosmochemical endmembers such as Solar gas (estimated from NASA/Genesis measurements), comets (measured by the ESA/Rosetta mission) and meteorites including carbonaceous chondrites. For the latter, the reference used by the community is AVCC (Average Carbonaceous Chondrites). However, AVCC has been defined using measurements conducted only a limited number of meteorites (N=6) and with results having quite a large variability (Fig. 1a). For Ryugu samples, a recent study reported the presence of a new noble gas component in one Ryugu particle (C0209) (ref. 11, Figure 1b). This component presents unique features such as a very low Ar/Xe elemental ratio and extreme isotopic fractionation of Xe isotopes, almost three times higher than for the ubiquitous Q component usually found in carbonaceous chondrite [12] and already reported for other Ryugu particles (*e.g.*, [13]). Finally, a potential exotic nucleosynthetic signature has also been measured in Ryugu samples. Excesses in ^{134}Xe and ^{136}Xe attributed to the contribution from presolar xenon contained in nanodiamonds are note accompanied by the traditional excesses of ^{124}Xe and ^{126}Xe [13]. This imbalance recalls the one measured for cometary xenon although they have opposite signs [14,15]. As pointed in ref. 13, measurements of noble gases on bigger samples need to be conducted to settle this issue.

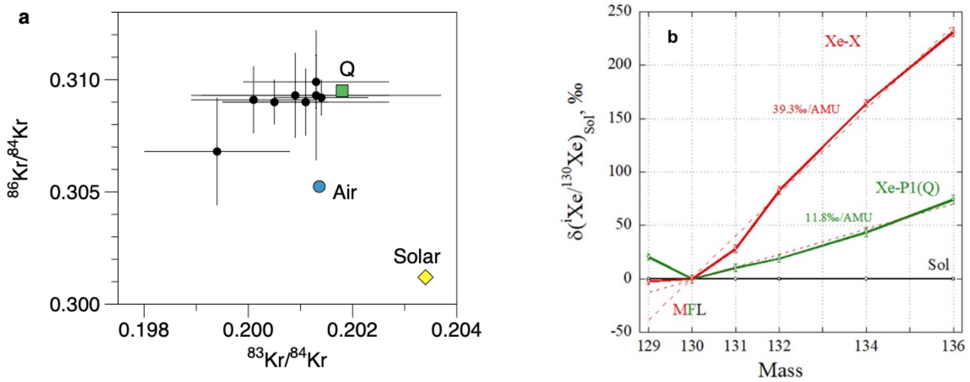

Figure 1: Examples of results relevant to the Ryugu Reference Project. *(a) Isotopic composition of krypton in meteorites (8 measurements on 6 meteorites, black dots) considered to represent the Average Carbonaceous Chondrites (AVCC). Existing values are too imprecise to understand the differences compared to Solar Kr, Q-Kr and the implications for atmospheric Kr. References in ref. 16. (b) Discovery of a new xenon component (Xe-X) in the C0209 Ryugu particle [10]. This new component presents a high degree of mass-dependent isotopic fractionation of xenon relative to the Q component [12].*

The studies mentioned above have several major implications for the RRP which we will discuss during the presentation: i) Ryugu samples are probably the best reference of unaltered CI-like material; ii) Ryugu samples are certainly heterogenous in terms of noble gas abundance and isotopic composition. All these observations above pose a serious challenge given the fact that volatile-rich carbonaceous chondritic bodies probably delivered a significant portion of volatile elements to terrestrial planets such as Earth [17] and Mars [18]. This means that a new reference value for volatile elements contained in carbonaceous asteroids must be defined.

References

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