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Across the Universe. The first Italian temporary exhibition of two Ryugu asteroid returned samples

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ABSTRACT
Sample return missions are specifically designed to bring back to Earth samples (e.g., gases, dust, and rocks) collected from celestial bodies. The analysis of these pristine materials in terrestrial laboratories significantly enhances our understanding of the origin and evolution of the Solar System. Moreover, these missions offer unparalleled opportunities to promote education and public engagement in space and planetary sciences as well as research on the origin of life. This work describes the first Italian temporary exhibition of asteroidal (Ryugu) returned samples held at the Natural History Museum "La Specola" of the Firenze University Museum System in March 2024.

Key words:
sample return missions, Ryugu, temporary exhibition, La Specola.

RIASSUNTO
Attraverso l'Universo. La prima mostra temporanea italiana dei campioni prelevati sull'asteroide Ryugu

Le missioni spaziali sample return sono specificamente progettate per riportare sulla Terra campioni (ad esempio, gas, polvere e rocce) raccolti da corpi celesti. L'analisi di questi materiali incontaminati nei laboratori terrestri consente l'avanzamento della nostra comprensione circa l'origine e l'evoluzione del Sistema Solare. Inoltre, queste missioni offrono opportunità senza precedenti per promuovere l'educazione e il coinvolgimento del pubblico nelle scienze spaziali e planetarie così come nelle ricerche sull'origine della vita. Questo lavoro descrive la prima mostra temporanea italiana di campioni prelevati da un asteroide (Ryugu) tenutasi al Museo di Storia Naturale "La Specola" del Sistema Museale di Ateneo dell'Università degli Studi di Firenze nel marzo 2024.

Parole chiave:
missioni sample return, Ryugu, mostre temporanee, La Specola.

INTRODUCTION

A considerable amount of literature has been published on sample return (hereafter SR) missions (as reported in Lin et al., 2020), i.e., spacecraft missions aiming at collecting from extraterrestrial bodies such as satellites, planets, comets, and asteroids different kinds of samples (e.g., gases, dust, particles, and rocks) to return them on Earth. The scientific and technological challenges to be addressed by SR missions are discussed in Longobardo (2021), which represents one of the most recent literature reviews on this topic. Overall, these studies outline the unprecedented opportunities SR missions offer to analyze pristine materials in terrestrial laboratories to acquire unique data about the evolution of the Solar System

and the origin of life. As highlighted by Sandford (2011), returned samples can be reinvestigated over time depending on the progress of scientific understanding and the advances in analytical techniques.
By drawing on this concept, a large and growing body of literature has been investigating the advanced curation of astromaterials, defined by McCubbin et al. (2019) as a cross-disciplinary research field aiming to improve curation practices (e.g., sample receiving, handling, characterization, cataloging, distribution, and storage), and to identify the criteria for the creation of curation facilities and infrastructures devoted to receive and preserve the returned samples. It has to be noted that AD is also concerned with the curation practices of Earth-based astromaterial collections (i.e., cosmic dust and meteorite collections) since their acquisition is less expensive than returned samples, and their study enables new scientific discoveries.
However, space sciences are much more than science. In this regard, Kaminski (2021) defined space sciences as the most esoteric of the sciences since it deals with an arcane quest for knowledge, apparently irrelevant to daily life, by a highly specialized scholar community. Nonetheless, the author stated that no other scientific discipline captures people's imagination as space sciences. So, it is unsurprising that space missions comprise programs concerning embedded education and public outreach (EPO). As underlined by Rosendhal et al. (2004), EPO is essential to inspire and motivate students to pursue STEM (science, technology, engineering, and mathematics) careers, promote general equality and empowerment in the space sector, and engage diverse audiences with the latest progresses in human space exploration through targeted projects and citizen science activities. EPO is also a key element in SR missions, whether completed successfully, in progress, or planned (e.g., Joyce et al., 2009; Bertrand et al., 2017), and in the engagement activities promoted by the curation facilities for returned samples, either already established (i.e., the Extraterrestrial Sample Curation Center (ESCuC) at the Japan Aerospace Exploration Agency (JAXA), and the NASA's Johnson Space Center Astromaterials facilities) or in the project planning stage (e.g., Abe, 2021; Longobardo & Hutzler, 2021; Smith et al., 2021). As remarked by Kaminski (2021), the involvement of various segments of society at diverse levels (e.g., the potential next generations of scientists, nonprofessionals, or financiers) is no less essential for space science's advancement than instrumentation, computers, and spacecraft.
This paper provides an overview of Italy's first temporary display of asteroidal (Ryugu) returned samples from a SR mission. The exhibition was held at the Natural History Museum "La Specola", part of the Firenze Museum System, from 8 to 10 March 2024. In the following pages, the Hayabusa2 mission will be briefly reported to detail its goals, along with a short survey on the cultural and scientific background of space science public engagement. Subsequently, the Ryugu returned samples will be described along with the exhibition design. Finally, the reactions to the exhibition will be analyzed in light of the EPO activities organized for the Hayabusa2 and other SR missions.

BACKGROUND

In their literature reviews, Tachibana (2021) and Watanabe et al. (2017) pointed out that Hayabusa2 was the second JAXA asteroid SR mission following Hayabusa (2003-2010), which collected surface particles from the near-Earth asteroid (NEA) (25143) Itokawa. Among the other relevant outcomes, the most striking finding was that Itokawa returned samples resulted to be similar to equilibrated ordinary chondrite meteorites (OC), thus indicating S-type asteroids as the most probable OC parent bodies.
Hayabusa2 was launched on 3 December 2014 from Tanegashima Space Center (TNSC), which is in the south of Kagoshima Prefecture and represents the largest Japanese rocket-launch complex (ca. 9.7 km^2) (Sogame, 2005). This SR mission targeted the NEA C-type (162173) 1999 JU_3, which was named Ryūgū after the undersea palace belonging to Ryūjin, the tutelary deity of sea in the Japanese mythology. The Hayabusa2 landing operations were made on 22 February and 11 July 2019, and surface samples and impact ejecta were respectively collected. In the latter case, a projectile-shooting sampling device was used, and the firing was performed in a closed chamber to avoid contamination (e.g., Sawada et al., 2017). Hayabusa2 returned to Earth on 6 December 2020 and collected 5.4 g of surface asteroidal materials. The mission science goals are reviewed in Tachibana et al. (2014). In this regard, it is important to highlight, quoting Tachibana (2021), that Hayabusa2 returned samples (i.e., volatile components, coarse and fine grains) provide unique insights into Ryugu's history (e.g., space weathering processes), and the origin and evolution of the Solar System from 4.56 Gyr ago to the present, mainly focusing on galactic chemical evolution and Sun's parent molecular cloud chemistry, pre-accretional chemical evolution and planetesimal formation in the protosolar disk, planetesimal evolution, NEAs orbital evolution, and surface geological processes. One of the most relevant results, as illustrated by Yokoyama et al. (2022), is that the returned samples' mineralogical assemblage and petrographic texture resemble those of the Ivuna-type carbonaceous meteorites (CI). Still, the returned samples are more chemically pristine since meteorites are all affected by terrestrial alteration although to different degrees (e.g., Stephant et al.,

2018). Therefore, the composition of Ryugu's sample represents the closest match to the Sun's photosphere compared to any other natural samples available on Earth. Furthermore, as stated by Yamaguchi et al. (2023), C-type asteroids can be considered as the source of carbonaceous chondrites, thus representing the remnants of primitive planetesimals that formed in the early outer Solar System.

The outstanding results obtained by Hayabusa2 are marking a breakthrough in the investigation of asteroids and the Solar System, thus highlighting the paramount importance of SR missions for advancing knowledge in planetary sciences. SR missions provide scientists and scholars with samples complementary to meteorite collections, opening an invaluable window into understanding the Solar System's origins while answering critical questions in Earth and planetary sciences (Editorial, 2023).

However, as Haltigin et al. (2022) outlined in their review of the rationale for the Mars Sample Return (MSR) Science Program, SR missions encompass not only scientific and technological challenges, but also diverse activities linked, for instance, to sample curation, management procedures, and public engagement. Concerning the latter topic, SR missions have to provide an EPO plan, including activities aiming to communicate the results in a friendly manner to enhance people's engagement in these unique initiatives. In this regard, Shaby et al. (2017) stated that exhibiting science in informal learning settings as museums, science centers, and planetariums (e.g., Schweingruber & Fenichel, 2010) fosters scientific education, improving visitors' engagement through physical and emotional interactions with the exhibits and the scientific issues they are bearers. On this topic, Viotti (2021) highlighted how the Mars Museum Visualization Alliance, part of the Mars Exploration Program (MEP) Public Engagement, enabled informal scientific learning environments to share landings and discoveries from Mars rovers, thus providing visitors not only an immersive experience, but also a real-time front-row-seat on the Martian exploration. The involvement of museums, science centers, and planetariums, as Viotti (2021) suggested, transformed Mars from a planetary body to investigate into a place to discover through cognitive, psychological, and cultural interactions. These actions also apply to EPO plans regarding SR missions. A firsthand experience and close knowledge of the returned samples improve public engagement, providing new opportunities for a more comprehensive understanding of the importance of SR missions as scientific and sociocultural initiatives.

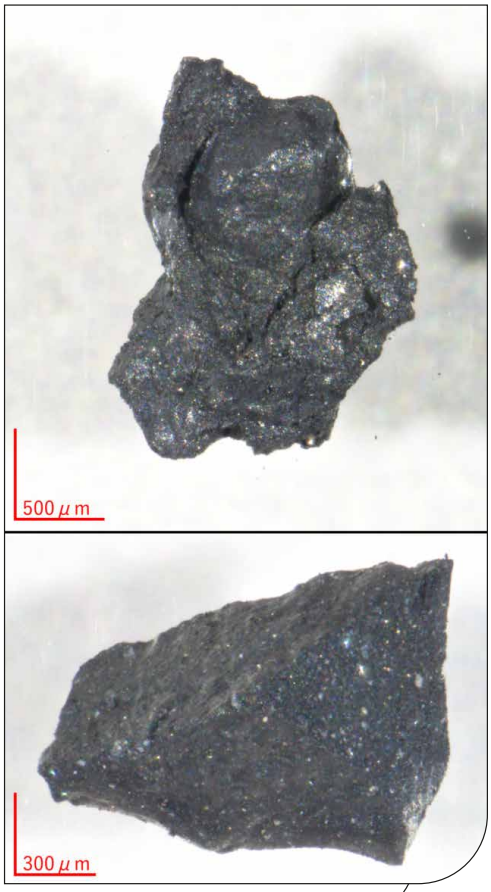

Fig. 1. The Ryugu returned samples exhibited at the Natural History Museum "La Specola". From the top: grain A0226 (Totoro) and grain C0242 (Kiki) (photo credits: Jaxa, Media INAF).

THE RYUGU RETURNED SAMPLES

As stated by Palomba et al. (2024), the Japanese Astromaterials Science Research Group of the Institute of Space and Astronautical Science (ASRG-ISAS) at JAXA opened two worldwide yearly calls to request part of the Ryugu returned samples for scientific investigations. On the second call, the team formed by diverse researchers from the National Institute of Astrophysics (INAF) located in Rome, Naples, and Catania and from the Department of Earth Sciences, Department of Industrial Engineering, and the Department of Chemistry of the University of Firenze received two Ryugu returned samples (see websites 1 and 2) to investigate the space weathering processes that affect the asteroid surface using the following analytical techniques: Micro-Fourier Transform Infrared Spectroscopy (Micro-FTIR), X-ray Photoelectron Spectroscopy (XPS), Scanning Electron Microscope-Energy dispersive spectroscopy (SEM-EDS), and Micro-RAMAN spectroscopy.

The returned samples are represented by two grains named C0242 (weight 0.7 mg, size 1.712 mm) and A0226 (weight 1.9 mg, size 2.288 mm) (fig. 1), which

were respectively renamed Kiki and Totoro after Hayao Miyazaki's Kiki's Delivery Service (1989) animation movie (see website 3). A brand-new sample holder and container, along with specific mounting procedures, were designed to preserve the grains from terrestrial contamination during the analytical investigations and transportation among the different facilities (Shehaj et al., 2024).
After the analyses at the Materials Characterisation Laboratory (MATCHLAB) and Service Center of Electron Microscopy and Microanalysis (MEMA) of the University of Firenze concluded in early March 2024, the Ryugu returned samples were displayed in a temporary exhibition entitled "From the deep space to La Specola: exhibiting the smallest fragments of the Ryugu Asteroid" held at the Natural History Museum "La Specola", part of the Firenze University Museum System from 8 to 10 March 2024.

EXHIBITION DESIGN

The Ryugu returned samples, settled in their custom-made container, were displayed within a repurposed showcase at the entry into the Meteorite Gallery of the Mineralogy and Gems Hall, next to the display case showing a sample of meteorite fallen in Siena in 1794 (e.g., Baldanza et al., 1969; Marvin, 1995). The container was exhibited in the lower part of the showcase, with the chamber displaying the grains on the front to be visible to children and people with disabilities (fig. 2).
No educational panels were arranged since one member of the research team (Dr. Xhonatan Shehaj) was present during the opening hours to describe the exhibited samples, their holder and container, the scientific goals of the Hayabusa2 mission, and the preliminary findings of the analytical investigations performed in the laboratories of the University of Firenze.
The Firenze University Museum System carried out the social media campaign, publishing an informative press release about the scientific project, the sampling of Ryugu's grains, and their curation practices on its website and social media profiles (see website 4).

EXPERIENCING THE EXHIBITION

The number of visitors (1498) who visited the temporary exhibition of Ryugu's grains at the Natural History Museum "La Specola" suggests it was well received. Visitors were surprised to see, for the first time live in Italy, two asteroidal returned samples in their original custom-made container and intrigued to learn more about the Hayabusa2 spacecraft mission and its scientific outcomes. The presence of a member of the research team illustrating the exhibition and answering visitors' questions was strongly appreciated.

DISCUSSION

As mentioned in the literature review, EPO programs, outreach activities, and public engagement initiatives are pivotal in communicating space sciences to the general public. In this framework, the present study aimed to assess the importance of exhibiting returned samples in informal learning environments such as natural history museums, to inform and educate the public on the advancements in space exploration, while creating connections between scientists, amateurs, and a broader society. Concerning the research question, this study reported on the first Italian temporary exhibition of the Ryugu returned samples held at the Florentine Natural History Museum "La Specola" from 8 to 10 March 2024. The exhibition was arranged soon after the reopening of La Specola after four years of renovation (see website 5). The exhibition opening was scheduled on 8 March to celebrate International Women's Day and foster the increasing involvement of women in astronautics and space exploration (Duggirala et al., 2022). The Ryugu's returned samples temporary exhibition was advertised mainly through press releases posted on the University of Firenze Museum System's website and related social media profiles. The press releases

Fig. 2. The Ryugu returned samples within their custom-made container displayed at the Natural History Museum "La Specola".

were written using metapragmatic features such as pseudo-quotations (also known as constructed direct speech) released by the PI of the University of Firenze research team (Prof. Giovanni Pratesi) to be retold by journalists as accurately as possible and with minimal effort in their news reporting (e.g., Sleurs et al., 2003).

One interesting finding emerging from the temporary exhibition of Ryugu's returned samples was the public's appreciation for the custom-made returned sample container design, which some visitors compared to a modern-day steampunk object (e.g., Kiehlbauch, 2015). Another interesting finding was the positive reception given to the member of the Florentine research team present during the exhibition's opening hours. Visitors were encouraged to question and discuss the importance of SR missions and relative returned samples for advancing space and planetary sciences. Over the past decade, most research in museum studies has emphasized the importance of social interactions in non-formal learning environments (e.g., Packer & Ballantyne, 2005) across different audiences and ages groups (e.g., Shaby et al., 2019) to the point that, as outlined by Falk (2009), the recollection of a museum visit depended on the social interactions people built during their permanence. In this context, a pivotal role is played by that part of the museum staff (the so-called "explainers", "informal science educators", "demonstrators", "hosts") devoted to the illustration of objects, collections, and exhibitions to visitors (e.g., Rodari & Xanthoudaki, 2005). Concerning this topic, Bobbe et al. (2023) underlined the importance of inter- and trans-disciplinary communication to illustrate science and technology in an effective way to nonprofessionals in different environments. Informal science educators (even in the case of scientists working with the general public in non-formal settings) are thus crucial to explaining space sciences, technologies, and instrumentations, just as occurred in the case of the exhibition of the returned Ryugu samples and their custom-made container. The literature on inquiry-based learning in non-formal learning venues is extensive and focuses mainly on how questioning improves people's engagement from initial attraction to a deeper learning experience (e.g., Ash & Klein, 2000; Braund & Lelliott, 2017).

Furthermore, this methodology showed positive outcomes for illustrating space sciences in informal settings. In this regard, Stengler (2021) outlined how museums and science centers provide unique informal experiences, for example, within the content domain of astronomy and planetary sciences, which can improve visitors' science capital, i.e., a conceptual category elaborated by Archer et al. (2015) comprising all the science-related knowledge, attitudes, experiences, and resources acquired in a lifetime. The appreciation demonstrated by the public for the temporary exhibition of Ryugu's returned samples and for the presence of a research team member as an informal science educator, as well as the active participation through open questions about the space mission and its scientific goals, is thus consistent with the literature.

These findings match those obtained by McCoy et al. (2024) during the first exhibition of the returned samples collected from asteroid (101955) Bennu by the OSIRIS-REx space mission (e.g., Lauretta et al., 2017) at the Smithsonian National Museum of Natural History in October 2023. In their study, McCoy et al. (2024) highlighted visitors' surprise and inquiries about the exhibition of Bennu's returned samples in such a short period, and how the research team managed to select and arrange their public viewing in less than six weeks (OSIRIS-Rex returned to Earth on 24 September 2023, see website 6). As in the case study discussed in this paper, the visitors' discovery process produces learning outcomes characterized by surprise and discussions reflecting, as outlined by Leinhardt et al. (2002), the emotional, cognitive, and physical engagement with the displayed objects.

Finally, the temporary exhibition of Ryugu's returned samples at the Natural History Museum "La Specola" aligns with the previous EPO and outreach activities organized for the Hayabusa missions, reviewed in Yoshikawa et al. (2022). Concerning the strategies supporting the public engagement initiatives for Hayabusa2, Ikuta (2022) underlined that all the content provided by the outreach team to journalists and science reporters was arranged and shared under Creative Commons Attribution 4.0 and generated more than 67.000 online articles. Furthermore, Yoshikawa et al. (2017) outlined that public engagement events were conceived at diverse levels of involvement, including observation campaigns of the Ryugu asteroid and Hayabusa2 spacecraft at its Earth swing-by that were attended by much more people than expected, thus showing the positive outcomes of advanced space science outreach activities. Other public initiatives about the Hayabusa missions discussed by Yoshikawa et al. (2015), concerned the organization of exhibitions in formal and informal settings and the release of a jazz music album entitled "Lullaby of Muses", inspired by the space mission code name (MUSES-C).

CONCLUSIONS

The first Italian temporary exhibition of the returned samples collected from the Ryugu asteroid by the Hayabusa2 spacecraft, held at the Natural History Museum "La Specola" of the Firenze University System from 8 to 10 March 2024, was in line with the outreach activities conceived for the SR missions carried out so far.

This study suggest that organizing public engagement events, particularly the exhibition of returned samples in informal learning environments, improves public engagement with the advances in space sciences research, especially if the exhibitions encompass the presence of an informal science educator available to visitors to illustrate the scientific content of the samples on display and answer their questions. In conclusion, as recalled by Ikuta (2022), the organization of outreach activities, involving the direct participation of diverse audiences and age groups at different levels, contributes to popularazing hard-to-digest concepts while enhancing public awareness of the advancements in space sciences and exploration.

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