An Astromaterial Curation Facility at MNHN-Paris, the National Center for Extraterrestrial Material

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The study of extraterrestrial samples requires developments in curation facilities to preserve, and allocate pristine samples to international scientific teams. During the last decades, the return to Earth of samples from the Stardust NASA mission [1], Hayabusa1 and Hayabusa2 JAXA missions (e.g. [2, 3]), allowed the first analysis of samples from an identified comet (81P/Wild2) and from two asteroids (Itokawa and Ryugu). Within the coming years, samples from asteroid Bennu will return to Earth thanks to the OSIRIS-REx NASA-led mission [4] and, on a longer term, samples from the Martian moon Phobos will be returned by the MMX JAXA-led mission [5]. After 2030, material currently sampled at the Martian surface is expected to be returned to Earth by the NASA/ESA Mars Sample Return (MSR) campaign [6]. Major curation facilities already exist at both NASA and JAXA [7-9] to receive, curate and handle samples directly returned from space missions. Advanced curation studies are on-going [9, 10] while others facilities are currently into construction [11]. Beside space missions, extraterrestrial materials (meteorites and cosmic dust) have been collected for centuries in many environments, including hot and cold deserts, deep sea sediments, sediments, polar ice caps, and stratospheric collections [12-14]. As recently illustrated by the striking similarity between Ryugu samples and the CI1 meteorites [15, 16], the comparison between returned samples (i.e. with known parent body) and meteorites or micrometeorites from terrestrial collections is an essential step in our understanding of these complex objects.

Together with the French spatial and scientific research agencies (CNES and CNRS), the Institut de physique du globe de Paris (IPGP) and Sorbonne University, the National Museum of Natural History (MNHN) launched a project to build a national curation facility, the CENAME (National Center for Extraterrestrial Materials) located at MNHN in the center of Paris. The CENAME will include instruments and advanced storage facilities developed by several French laboratories, including IAS and IJCLab at University Paris-Saclay. The CENAME will be designed to ensure long term curation of different major collections of extra-terrestrial samples including: the national meteorite collection from MNHN, large micrometeorites collections from Greenland and Antarctica, terrestrial analogues and samples from past and future space missions. The MNHN hosts an historical meteorite collection with more than 1500 different meteorites, including 521 falls, and a rich panel of Martian samples (Shergottites, Chassignites, Nakhlites) [17]. It contains the largest sample of the Orgueil CI-chondrite, a reference for cosmochemistry studies. The MNHN meteorite collection is actively used for cosmochemistry research projects and is constantly growing with new additions every year. Thanks to the pioneering work of M. Maurette in the 80s, large numbers of micrometeorites (interplanetary dust reaching Earth surface) with diameters ranging from a few tens up to a few hundred µm have been recovered from both Greenland and Antarctica [18, 19]. Since 2000, this program was pursued, in the central regions of Antarctica, where collections have been performed with the support of the French polar institute (IPEV) [20, 21]. The Concordia micrometeorites collection contains thousands of particles. A part of this collection is now fully characterized and contains micrometeorites with minimal terrestrial weathering, including particles of cometary origin that are exceptionally rich in organic matter (Ultra-Carbonaceous micrometeorites [22, 23]). The Concordia Collection is currently stored in a dedicated cleanroom at IJCLab in Orsay and will be transferred to the CENAME when the facility will be completed. The CENAME will also host a suite of terrestrial natural and synthetic analogues that are essential for analysis of complex extraterrestrial matter, calibration and interpretation of remote sensing analyses (e.g. on Mars). The CENAME will benefit from the MNHN Geological collection of rocks and minerals located in the same building. It contains about a billion scientific samples accumulated over 2 centuries of worldwide scientific exploration. The collection has been recently enriched with samples recording early Earth surface environments and the earliest traces of life on Earth (more than 1200 specimens spanning 3.5 billion years of Earth History). Beside these natural samples, several laboratories involved in the CENAME project have developed dedicated experimental protocols to synthetize analogues of asteroidal and cometary organic matter.

Beyond these historical and on-going collections, the objective of the CENAME will be to allow sample handling, pre-characterization and long-term preservation for the next generations of samples for current and future space missions. As a result of on-going agreements between JAXA and the French space agency CNES, a fraction of Phobos (MMX) samples are expected to be transferred to the CENAME at MNHN after the period of initial description at JAXA-ISAS sample receiving laboratory and after the first scientific analysis by the MMX Science Sub-Teams (i.e. after 2030). The design of the CENAME will be modular to allow flexible configuration of different environments for the curation of pristine samples from other space missions. The CENAME will consist in a clean-room infrastructure of about 180 m^2, divided in separated modules with ISO7 to ISO5 [24] environments, together with a laboratory for sample preparations and experiments that do not require a cleanroom environment. The cleanroom area will contain secured cabinets and glove boxes under controlled atmospheres (dry and purified N_2, Ar, vacuum, …). In the long-term perspective of MSR, an ambitious program was recently launched, under the supervision of CNES, to study an apparatus for small sample (solid and gas) handling in clean and bio-contained (BSL4-like) environment. The CENAME will include a dedicated space to allow rehearsal on such type of apparatus (before their operation in BSL4-like laboratories).

Instrumentation in the CENAME will focus on acquisition of the basic properties on samples with sizes going from µm to cm scales. It will include optical 2D and 3D microscopy and imaging, weighting, magnetic susceptibilities, scanning electron microscopy, Raman and infrared (IR) microspectroscopy with a dedicated suite of instruments, to achieve initial characterization and cataloging of samples before allocations. The magnetic environment of the samples and the magnetic properties of the handling tools will be monitored to ensure preservation of the genuine magnetic properties of the samples. A strict control of terrestrial contamination within CENAME cleanrooms will be achieved by real-time monitoring of inorganic, organic and biological contamination. The CENAME will develop research programs to improve existing curation techniques and new technological solutions for the mid to long-term curation of volatile elements (*e.g.*, H_2O, N, noble gases) contained in samples collected by future space missions (e.g. ice and gas from cometary objects or planetary atmospheres). Specific tasks will include the characterization of materials outgassing properties. A specific setup will be developed at IAS in order to allow a multi-scale (from mm down to µm) IR reflectance micro-imaging characterization on the CENAME samples. The analysis will be fully non-destructive and non-invasive, and it will be performed within a dedicated bench in a controlled atmosphere (e.g., N_2), with no need for specific sample preparation. In the case of returned samples, the setup will allow measurements complementary to the IR characterization performed at other curation facilities hosting the main sample collection (e.g., JAXA [25]).

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