MarcoPolo-R Integrated Sampling Mechanism (MPRISM)

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BACKGROUND: Jim Green, NASA's Director of the Planetary Science Division, proposed NASA's support for a US contribution to ESA's MarcoPolo-R mission, specifically a sampling mechanism based on the OSIRIS-REx Touch-And-Go Sample Acquisition Mechanism (TAGSAM), up to $50M as formally expressed to ESA. Tasked by NASA, the JHU Applied Physics Laboratory (APL) has teamed with Lockheed Martin (LM) to develop the MarcoPolo-R Integrated Sampling Mechanism (MPRISM) that combines APL's rock chippers with LM's TAGSAM. MPRISM will allow for the unique science requirements of the MarcoPolo-R (MP-R) to be met through additional capabilities while retaining heritage from TAGSAM. For this study phase, NASA has funded $600K for verification and validation that MPRISM will meet MP-R's requirements. Alternatively, if ESA were not to pursue the US MPRISM, NASA remains interested in discussing potential alternative contributions in the range of a total of about $50 million.

A complete, more detailed report of the MPRISM development will be delivered to NASA in calendar year 2014. This report will be available to the MP-R team and ESA. Further details on NASA's contribution study to the MarcoPolo-R mission, including US science support, can be found at http://us-marcopolor.jhuapl.edu.

SAMPLING REQUIREMENTS: MPRISM (see Figure 1) will acquire and return a sample from a primitive near-Earth asteroid, and achieves or exceeds the following performance requirements[1]:

- Perform multiple (up to 3) sampling attempts
- Acquire a minimum mass of the order of a hundred grams and return them to Earth
- Acquire a selection of cm-sized fragments plus several grams of small particles (μm-sized to mm-sized)
- Maintain sample free of organic and particulate contamination
- Collected sample shall not be contaminated by dust or liquid particles larger than 1 μm
- Until the sample arrives at curation facility, keep moisture level below 0.1 ppm in the sample

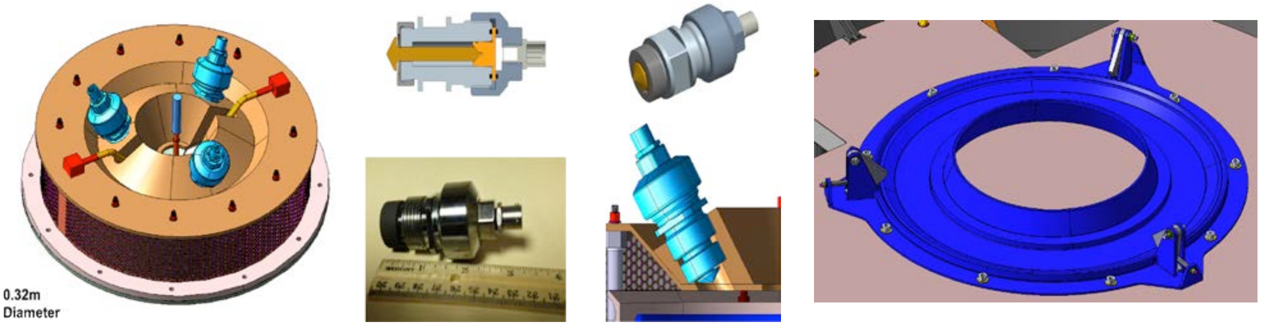


Figure 1*: TAGSAM sampler integrated with 3 rock chippers (left); rock chipper (4 views, center); sample head capture ring (right), the mechanical interface to the Earth Re-entry Capsule for MPRISM. These are simple and reliable mechanisms.*

An additional requirement states the sample shall not be exposed to a shock load >800 g. This requirement is typically shared between the Earth re-entry capsule (ERC), and the sample containment system., The ERC typically employs descent management techniques such as parachutes or impact attenuation (crushable materials, etc.) to control the loads within the vehicle; the OSIRIS-REX ERC ensures g-loads <125 g. The TAGSAM elements (head, capture ring, clamps) are capable of withstanding 800 g compressive loads. Future interaction with the re-entry capsule design will ensure the combined system meets all requirements.

MPRISM CONCEPT: MPRISM is a modified OSIRIS-REx TAGSAM, integrated with three pyro-initiated rock chippers. The OSIRIS-REx configuration is scheduled to fly in 2016.

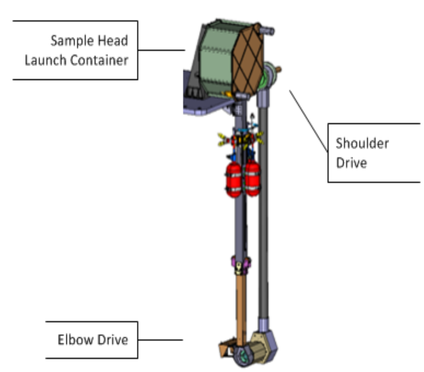


Figure 2: *Sample acquisition assembly, identical to OSIRIS-Rex design.*

The sample acquisition assembly (see Figure 2) acquires asteroid surface sample and transfers the sample to the return capsule. This assembly includes a robotic arm, sampler head launch container, and a sample head capture ring mounted in the Earth re-entry capsule to be compliant with misalignments (see Figure 1).

[1] MarcoPolo-R Science Requirements Document, MPR-RSSD-RS-001, 08/10/2011, Rev 1

The single mounting panel enables a simple, one-time alignment plan and maintains sampler acquisition assembly positioning. The fully integrated MPRISM enables full system testing (TAGSAM plus chippers) prior to delivery, and maintains a strict contamination control environment consistent with OSIRIS-REx requirements and plans.

MPRISM CONCEPT OF OPERATIONS: The arm maneuvers the sampler head to the asteroid surface. Upon contact with the asteroid surface, the rock chipper is fired if desired and high-pressure gas flow is initiated (nitrogen gas flows from storage containers on arm, around head, and down to surface). The chipper breaks apart and dislodges cobbles within the regolith, the gas fluidizes dislodged and/or fragmented regolith particles and carries them into the collection tray within the sampler head. The sampler head, with sample, is then transported by the arm to the capture ring (Figure 1), where it is latched and secured in the ERC.

MPRISM TEST RESULTS: MPRISM consists of actual hardware that has been developed/fabricated over several years, with multiple design and test iterations using a variety of target materials, under different environmental conditions. Testing of the rock chipper alone, performed in May 2013 before integration with TAGSAM, used a target much stronger than required for MP-R. This test demonstrated projectile velocity of ~122 m/sec and resulted in sample mass extracted of ~10 g from a 100 MPa compressive strength simulant (much stronger than the 30 MPa maximum strength requirement 26-09-2012 applicable to single pebbles up to 3 cm or to solid surface) in 1-g, 1-atm conditions.

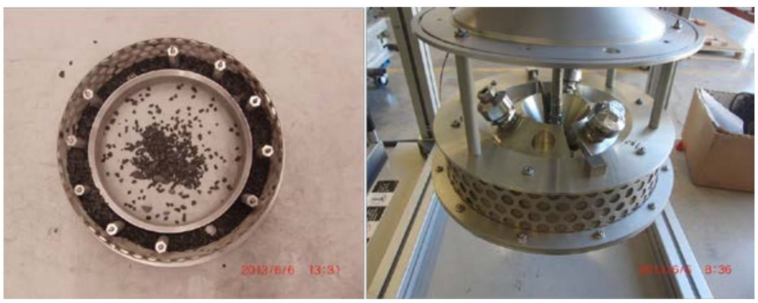
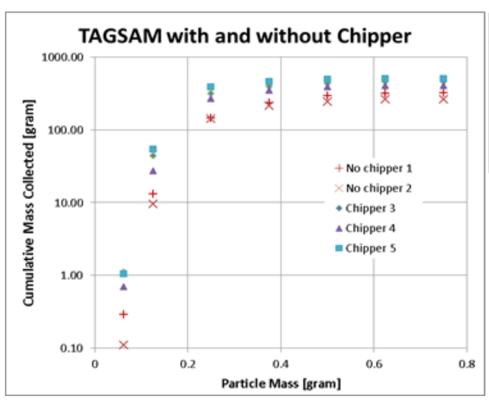


Figure 3. *MPRISM sample collection test results with Mix 7C Basalt (left); integrated MPRISM sampler test fixture (right). MPRISM increases sample collection from regolith simulant and enables sampling of hard targets without loose regolith.*

The integrated MPRISM system was tested in June, 2013 with Mix 7C Basalt, which is the standard asteroid regolith simulant used to qualify TAGSAM for OSIRIS-REx. This test operated TAGSAM without any chipper and with one chipper firing, in 1-g, 1-atm conditions. The TAGSAM collection tray with collected sample is shown in the left panel of Figure 3, and the integrated MPRISM test fixture is shown on the right.

Results of the MPRISM tests with the OSIRIS-REx basalt simulant are shown in Figure 4. Use of one chipper with TAGSAM significantly increases the total sample mass collected with only minor alteration of the collected size distribution. The chipper increases the collected mass in every size fraction with a slightly greater increase in the collection of small particles. Actual performance at the asteroid in vacuum and in microgravity is expected to yield even greater sample mass.

Further testing of MPRISM was performed in October, 2013 with three sets of simulant targets, in order to demonstrate MPRISM sample collection for a wider range of target properties than is represented with the OSIRIS-Rex simulant. All three simulant sets specifically included high porosity particles and large particle sizes >3 cm. These simulant sets combined a porous, cohesive material (pumice) and a carbonaceous chondrite meteorite (Allende), as well as quartz sand, in order to test MPRISM over a full range of target properties that may plausibly be encountered at the asteroid. The Allende meteorite is believed to originate from a primitive asteroid.



Test#	Chipper Used	Sample Mass (g)
1	No	320.0
2	No	259.9
3	Yes	452.0
4	Yes	402.2
5	Yes	498.4

With OSIRIS-Rex simulant, the rock chipper increases TAGSAM-collected mass in every size fraction

Figure 4. *TAGSAM sample collected with and without rock chipper, using OSIRIS-REx simulant: (left) cumulative mass distribution; (right) total mass collected.*

The pumice pieces used in the October test series were of variable density ranging from 0.56 g/cc to 0.76 g/cc. The measured unconfined compressive strength ranged from 2 to 3 MPa. As is well known, pumice efficiently dissipates energy by crushing pore spaces. In compression testing, the pumice did not unload completely after failing, but continued to sustain loads of half or more of its initial strength for displacements of several times the strain at initial failure. The sand bulk density was 1.57 g/cc. The density[2] of CV meteorites (like Allende) is 3 g/cc and strengths of

[2] Britt D and Consolmagno G. 2003. *Meteoritics & Planetary Science* 38:1161-1180.

carbonaceous chondrites[3] are in the range 0.3-30 MPa. The Mix 7C basalt in OSIRIS-REx simulant is much stronger and less porous than pumice or meteorite, and it is a less dissipative target material.

The three simulant test sets are shown in Figure 5. Test Set 1 was a layered target with a top layer of >3cm pumice pieces, averaging two particles thick, covering a layer of sand; for this target, the top layer of the target consisted only of particles >3cm without any fines within >6cm of the surface. The test objective was to determine if MPRISM could sample large pumice pieces at the surface as well as sand at depth. Test Set 2 was a mixed regolith target of sand and pumice pieces with sizes ranging from sub-cm to >3 cm. Test Set 3 used Allende meteorite pieces (> 3 cm size) on a bed of sand, with the chipper aimed at the meteorite. The contribution of the chipper to MPRISM sample collection was demonstrated, by performing three collections for each of Test Sets 1 and 2, where two collections used TAGSAM with one chipper firing and one collection used TAGSAM only, no chipper firing.

Figure 5 *MPRISM October test series. (a) Test set 1 with coarse pumice pieces on top of sand layer; (b) Test set 2 with mixed coarse pumice pieces and sand; (c) Test set 3 with >3 cm piece of Allende resting on sand layer, above before sampling, below after sampling with meteorite piece completely shattered; (d) Large pumice pieces collected in Test Set 2 (inch ruler for scale).*

Table 1 summarizes the test results. The October tests demonstrated that MPRISM with the chipper can sample a carbonaceous chondrite meteorite, collecting several grams of meteorite within TAGSAM together with several hundred grams of surrounding regolith (the largest single piece of meteorite collected was 2.1 g). All six collections with a chipper firing resulted in collection of cm-sized samples from the individual particle hit by the chipper (meteorite or pumice; the latter was marked by food coloring). The tests with a layered target (Test Set 1) demonstrated sample collection of material at depth > 6 cm. The largest particle collected witin the TAGSAM had, in 4 of 8 collections, a largest linear dimension >2.6 cm; the longest particle in any of the 8 collections was 5.2 cm.

CONCLUSION: MPRISM integrates three rock chippers with the OSIRIS-REx TAGSAM sampler. If the chippers are not fired, MPRISM retains the full performance of TAGSAM. With a chipper firing, MPRISM collects a larger sample from the OSIRIS-REx simulant than does TAGSAM alone. With the chipper, MPRISM is able to sample Allende meteorite collecting cm-size fragments inside TAGSAM. MPRISM is demonstrated to repeatably meet the MP-R sampling requirements over a wide variey of targets, including very coarse regolith with high porosity particles. MPRISM with rock chippers helps to increase the range of potential sampling sites.

Table 1. October Test Results: total collected sample and largest collected piece

Test	Target Set-Up	Result
TAGSAM only	Mixed regolith target of sand and pumice pieces with size distribution from sub-cm to >3 cm	Total sample 462g, including 67.8g pumice, largest piece 5.2 cm
TAGSAM and one chipper		Total sample 386g, including 32.7g pumice, largest piece 4.4 cm
TAGSAM and one chipper		Total sample 265g, including 25.5g pumice, largest piece 4.3 cm
TAGSAM and one chipper*	Allende meteorite piece (> 3 cm size) on a bed of sand, with the chipper aimed at the meteorite	Meteorite originally 75.8g completely shattered; 4.59g recovered in sample (0.3g largest piece); total sample 1093g including sand
TAGSAM and one chipper*		Meteorite originally 50.8g completely shattered; 7.65g recovered in sample (2.1g largest piece); total sample 891g including sand
TAGSAM only	A layered target with a top layer of >3cm pumice pieces, two particles (>6cm) thick, covering a layer of sand	Total sample 29.7g, including 0.29g pumice, largest piece 1.3 cm
TAGSAM and one chipper		Total sample 25.4g, including 1.22g pumice, largest piece 1.8 cm
TAGSAM and one chipper		Total sample 10.9g, including 1.14g pumice, largest piece 2.6 cm

***Collection with TAGSAM only not performed as no meteorite sample was expected, only sand.**

3 Tsuchiyama A et al. 2009. *72^{nd} Annual Meteoritical Society Meeting*, 2009.7.17, 5189.pdf