EPSC2018

MTI6 abstracts

EPSC Abstracts
Vol. 12, EPSC2018-43-1, 2018
European Planetary Science Congress 2018

A minor mission to *Ice Giant* Neptune?

Juan R. Sanmartin and Jesús Peláez

ETSI Aeronáutica y del Espacio, Universidad Politécnica de Madrid

Abstract

Broad missions *Cassini* at *Saturn* and *Galileo*, and now *Juno*, at *Jupiter*, provided deep overall knowledge about the *Gas Giants*. For specific visits, electrodynamic tethers, which are thermodynamic in character and can provide free propulsion and power for capture by a planet, followed by free maneuvering for exploration, could make for more than 'orbiter' missions. The two *Ice Giants*, *Uranus* and *Neptune*, are being considered by NASA as *flagship* missions in the next decade. We show here how tethers could be used for a minor mission to *Neptune*, particularly effective because of its offset dipole magnetic field, while presenting the slower spin along with *Uranus*, and the highest density, among *Giants*. Preliminary estimations suggest a greater spacecraft-capture efficiency at Neptune as against Jupiter and Saturn.

1. Introduction

Missions *Cassini* at *Saturn* and Galileo, and now *Juno*, at *Jupiter*, provided overall knowledge about the *Gas Giants*. For missions involving specific visits, like exploring *Europa* at *Jupiter* [5] (or maybe *Enceladus* in the *Saturn* case [6]), electrodynamic tethers might be convenient. The two *Ice Giants*, *Uranus* and *Neptune*, are being considered by NASA as *flagship* missions in the next decade ('Ice Giants Pre-decadal Survey Mission Study', http://www.lpi.usra.edu/icegiants/mission_study/Full-Report.pdf). We discuss here whether tethers might be used for a minor mission to *Neptune*. As in the case of Saturn, tether operation could appear tough at Neptune because its magnetic field ***B*** is similarly small compared with Jupiter, the spacecraft-capture efficiency (*S/C-to-tether mass ratio*) going down as B^2 for weak fields.

It was shown, however, that efficiency for Jupiter is less than expected because of its very high *B* itself, which might result in strong tether heating and/or energetic attracted electrons crossing the tether tape and missing collection [5]. This requires design with limited tether length, to keep length-averaged current density well below its maximum, *short-circuit*, value, just proportional to *B*, thus limiting efficiency. Further, tethers were then shown as effective at Saturn as at Jupiter, weak-*B* operation avoiding the issues at [5], and allowing current-density reach near the particular short-circuit maximum [6].

2. The Neptune environment

Tether operation depends on both field *B* and electron density, data from the *Voyager* 2 1989-flyby not yielding definite models for the ambient magnetized plasma the tether would be operating in. Regarding *B* at distances of interest, *quadrupole*, even *octupole* terms of the magnetic moment might be comparable to the dipole term [3], which was dominant at Jupiter and Saturn. In this preliminary analysis of just S/C capture, we only use the dipole term, itself complex in both location and orientation. As regards plasma measurements, in-situ data from the *PLS* instrument [4] agree well with neither data from detected plasma (*whistler*) waves [1] nor *radio-occultation* data [2].

That may not be a problem, however, a reasonable range of density values leading to current-densities near the short-circuit maximum (for appropriate tether lengths), thus weakly dependent on actual electron density. The most relevant difference in planetary environment, (for which space telescopes and ground telescopes with adaptive optics made some contributions of interest), is the high *offset* of Neptune's dipole moment, shared by the other Ice Giant. That could make capture more efficient than at either Saturn or Jupiter, somehow midway between weak and strong magnetic cases.

3. Summary of Results

Tether drag in planetary S/C capture, from a slightly hyperbolic orbit to a barely elliptical one, is calculated for an equatorial orbit parabolic throughout, with periapsis very close to the planet, $r_p \approx R_N$, as for Jupiter and Saturn [5], [6]; the Lorentz drag, being quadratic in the planetary dipole field, has a limited radial reach. Because of the strong dipole offset, the S/C should best reach periapsis when crossing the meridian plane that contains the dipole center along with the Neptune rotation axis. This would result in the dipole optimally facing the S/C when at periapsis. That meridian plane has been reasonably well determined; also, when observed from away, Neptune keeps announcing its orientation with its stunning magnetic-structure rotation.

Actually, the above synchronism is not very requiring and is somewhat tempered by Neptune having the highest density and faster speed at periapsis among the *Giants* and the slowest spin along with Uranus. Preliminary estimates appear to support a higher tether-capture efficiency at Neptune as against Jupiter and Saturn.

Acknowledgements

This work was supported by the Spanish MINECO/AEI, under Project ESP2017-87271-P, and FEDER/EU.

References

[1] Gurnett, D. A. and Kurth, W. S.: Plasma Waves and Related Phenomena in the Magnetosphere of Neptune'. In *Neptune and Triton,* ed. D. P. Cruikshank (Tucson: Univ. of Arizona Press), pp. 389-423, 1995.

[2] Lindal, G. F.: The Atmosphere of Neptune. 'An Analysis of Radio Occultation Data Acquired with Voyager 2'. *Astron. J.*, Vol. 103, pp. 967-982, 1992.

[3] Ness, N. F., Acuña, M.H., and Connerney, J. E. P.: Neptune's Magnetic Field and Field-Geometric Properties'. In *Neptune and Triton*, pp. 141-168.

[4] Richardson, J. D., Belcher, J. W., and McNutt, R. L.: The Plasma Environment of Neptune. In *Neptune and Triton*, pp. 279-340.

[5] Sanmartin, J. R., Charro, M., Garrett, H. B., Sánchez-Arriaga, G., and Sánchez-Torres, A.: Analysis of tether mission concept for multiple flybys of moon Europa. *J. Prop. Power,* Vol. 33, pp. 338-342, 2017.

[6] Sanmartin, J. R., Peláez, J., and Carrera-Calvo, I.: Comparative *Saturn*-versus-*Jupiter* tether operation (submitted to *J. Geophys. Res.*: *Space Physics*).

EPSC Abstracts
Vol. 12, EPSC2018-71, 2018
European Planetary Science Congress 2018

SNAP – the Small Next-generation Atmospheric Probe Concept for Future Ice Giant Missions

D.H. Atkinson (1), K.M. Sayanagi (2), R.A. Dillman (3), A.A. Simon (4), M.H. Wong (5), T.R. Spilker (6), S. Saikia (7), J. Li (8), D. Hope (2)

(1) Jet Propulsion Laboratory, California Institute of Technology (David.H.Atkinson@jpl.nasa.gov), (2) Hampton University, (3) NASA Langley Research Center, (4) NASA Goddard Space Flight Center, (5) University of California, Berkeley, (6) Independent Consultant, (7) Purdue University, (8) NASA Ames Research Center.

Abstract

A concept is presented for a small atmospheric *in situ* probe designed as a secondary payload to future giant planet missions. SNAP, the Small Next-Generation Atmospheric Probe, is a 30-kg entry probe designed to enable future outer planet multi-probe missions. Specifically, the advantages and impact of adding SNAP to a future flagship Orbiter and Probe mission to Uranus are considered. SNAP would perform atmospheric *in situ* measurements in combination with a primary entry probe, at a location spatially (and possibly temporally) separated from the primary probe to enable measurement of the spatial variability of atmospheric structure and dynamics as recommended by the 2013-2012 Planetary Science Decadal Survey and the 2014 NASA Science Plan.

The primary atmospheric scientific objective of a second *in situ* entry probe is to measure the spatial variability of thermal structure and atmospheric dynamics that cannot be retrieved by a single probe. The SNAP measurement objectives are to determine (1) the vertical distribution of cloud-forming molecules including CH_4, H_2S, and NH_3; (2) the thermal stratification of the atmosphere; and (3) zonal wind speed as a function of depth at a location separated from the primary probe entry location. To the extent reasonable and possible from a mission design point of view, the SNAP entry location would be selected to examine different climatic zones (different latitudes), hemispheric seasonal differences, diurnal variations, or specific localized meteorological features or temporally transient phenomena. As a second *in situ* probe, SNAP would provide additional ground-truth for a separate region to further validate and calibrate remote sensing observations. The scientific objectives of SNAP do not include measurements of noble gas abundance and elemental isotopic ratios because these quantities are expected to show little or no spatial variation and would be measured by the primary probe equipped with a mass spectrometer.

The primary goal of the SNAP concept development is to achieve the science objectives at pressures of 5-10 bars with a 30-kg entry probe that is less than half the radius of the Galileo probe. Science data would be returned by way of a telecommunications link to a carrier relay spacecraft prior to Earth downlink. The baseline instrument payload would comprise an Atmospheric Structure Instrument (ASI) to measure the altitude profile of temperature and pressure as well as entry and descent accelerations and an atmospheric composition sensor based on carbon nanotube technologies (NanoChem), and ultrastable oscillators (USO) on both the probe and the carrier relay spacecraft to enable retrieval of atmospheric dynamics using Doppler Wind techniques. The miniaturization of SNAP is enabled primarily through the development of the low-mass NanoChem atmospheric composition sensor.

Numerous Uranus arrival trajectory options were examined to evaluate the feasibility of delivering two probes at two significantly different locations (e.g., autumn and spring hemispheres), and send data to the carrier relay spacecraft. Challenges inherent to multi-probe missions were identified and considered.

Although the current SNAP concept is developed as a possible element for a future Uranus Orbiter and Probe flagship mission, the probe conceptual design and mission architecture would maintain flexibility so as to be easily adopted as a secondary *in situ* probe for future giant planet mission.

Acknowledgements

Predecisional information for planning and discussion only.

EPSC Abstracts
Vol. 12, EPSC2018-191, 2018
European Planetary Science Congress 2018

Concept of nano-probes exploration in small-body mission

Jiangchuan Huang, Fan Guo, Huixi Liao, Jinan Ma, Linzhi Meng, Tong Wang and Xiaoyu Jia
China Academy of Space Technology, Beijing, China (gf3527@126.com)

Abstract

During the past decade, China Academy of Space Technology (CAST) has been continuing to advance researches on small-body exploration, and has achieved some success, such as asteroid Toutatis fly-by in Chang'e-2 mission on Dec. 13th, 2012. Recent one new mission is proposed and being designed through some self-funded projects. This presentation will start with the mission overview, several scientific problems of small-body are elaborated, science objectives of the mission are concluded, and configuration of scientific payload is presented. Next the profile and flight procedure of the spacecraft are introduced briefly. Because nano-probes have many benefits such as low cost, low risk, short development duration, providing complementary information of exploration and etc., the concept of multi-stage and multi-function nano-probes is proposed, including nano-landers and nano-orbiters, is an excellent way of cooperation in the mission. Different kinds of exploration form such as close range orbiting, surface in-situ and subsurface penetration are discussed, and scientific values and preliminary configuration of payloads are concluded. Finally, the top requirements of the Nano–probes are summarized, expected for cooperation with other institutes in various ways in the mission.

1. Introduction

During the past decade, China Academy of Space Technology (CAST) has been promoting researches on small-body exploration through some self-funded projects and has achieved some success, such as Toutatis asteroid fly-by in Chang'e-2 mission on Dec. 13th, 2012.

Recently leaded by the Principle designer of the Chang'e-2, a new mission design has been proposed. The principles of mission are:

- Innovative Science
- Multi-phase, preceding phase: quick outcome; latter phase: high value
- Multi-functional space probe that can accommodate multi-task and multi-target
- International cooperation

2. Mission overview

2.1 Science Objectives and instruments

In order to solve several hot issues in the science of small bodies, the total science objectives are proposed. And then the configuration of scientific payloads is proposed in detail, including name, function and corresponding scientific problems intended to be solved.

2.2 Spacecraft overview

The whole spacecraft is consisting of two parts, the main-probe and several sub-probes. The main-probe can land repeatedly. Total function and flight procedure of the main-probe is introduced briefly.

3. The concept of nano-probes

3.1 Benefits of using nano-probes

Thanks to the rapid development of microelectronics technology, nano-probes such as CubeSats with relatively low function and low R&D costs begin to play more and more important role in space technology. Benefits using nano-probes in our mission are described as following:

- Low cost, low risk and short development duration
- Provide complementary information of exploration
- Extend the duration of exploration (orbiting or in-situ)
- Excellent platform of cooperation in mission

3.2 Concept overview

Nano-probes can be divided into two categories, nano-lander and nano-orbiter. They are attached to the main-probe. Figure 1 is the profile of the nano-probes concept. After releasing the orbiter for landing observation, the main-probe will begin to decent and finally anchor itself on the surface of the asteroid. The main-probe has the ability to stay long on the surface, so the nano-lander can be separated from the main-probe with a very small relative velocity to the asteroid.

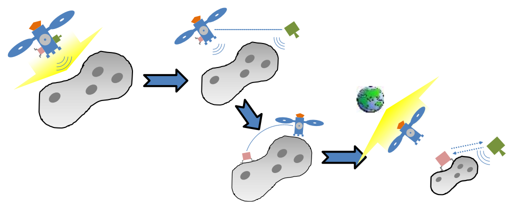

Figure 1: Nano-lander and nano-orbiter attached to the main-probe.

3.3 Discussion of different kinds of nano-probes

a. Close range orbiting

Close range orbiting can scan the entire surface rapidly with high spatial resolution. It also can relay the nano-lander's signal to earth for a long time, even after the departure of main-probe.

b. Surface in-situ

Surface in-situ can make nano-lander become a site, can continuously provide in-situ measurements such as temperature, magnetic field and so on. The possible scientific payloads are thermal IR radiometer, magnetometer and thermometer.

Combing the nano-orbiter or nano-lander with the main-probe, it is proposed to use the nano-probes to accommodate the bi-static radar instrument. This system provide us a way not only to estimate the inner 3D construct of the small bodies, such as "onion shell" model and the loose "rubble piles" model, but also to estimate the mean permittivity of each component. The radar is one of the main instruments capable of sounding asteroids to characterize internal structure from sub-meter to global scale.

c. Subsurface penetration

Subsurface penetration can make a chance to explore the inner micro-structure of small bodies with high resolution. For example it can obtain the particle morphology, mineral composition or physical parameters of the regolith corresponding to depth. The possible scientific payloads are X or gamma ray spectrometer, accelerometer, thermocouple and mass spectrometer.

3.4 Requirements of the nano-probes

It's expected that survival time of the orbiter and the lander should be long enough for extended operations following departure of the main-probe. The lander can continuously provide in-situ measurements. The orbiter acts as the relay satellite, relaying the signal back to earth. More mass will be distributed to the orbiter for it will directly communicate with earth. As the main-probe anchors itself on the surface and then release the nano-landers, it's expected to reduce the design difficulties for the landers as well as their mass. The requirements of the nano-lander and nano-orbiter are summarized.

4. Summary and Conclusions

Over the past the few years, CAST has been working on mission design of small-body exploration. One new mission is proposed and being designed through some self-funded projects, may solve several hot issues in small-body science. The exploration concept of multi-stage and multi-function nano-probes is presented, is an excellent way of cooperation in the mission. Different kinds of exploration form such as close range orbiting, surface in-situ and subsurface penetration are discussed. Due to the technology complexity, vast investment and high risk, we're willing to cooperate with other institutes in various ways, and jointly develop the international deep space exploration, to benefit for human being, including mission design, science issue research and development of science payloads, etc.

EPSC Abstracts
Vol. 12, EPSC2018-320, 2018
European Planetary Science Congress 2018

Lunar Meteoroid Impact Observer (LUMIO): A CubeSat at Earth-Moon L2

F. Topputo(1), M. Massari(1), J. Biggs(1), P. Di Lizia(1), D. Dei Tos(1), K. Mani(1), S. Ceccherini(1), V. Franzese(1), A. Cervone(2), P. Sundaramoorthy(2), S. Speretta(2), S. Mestry(2), R. Noomen(2), A. Ivanov(3), D. Labate(4), A. Jochemsen(5), R. Furfaro(6), V. Reddy(6), K. Jacquinot(6), A. Cipriano(7), J. Vennekens(7), R. Walker(7), **C. Avdellidou**(7), D. Koschny (7)
(1) Politecnico di Milano, Milano, Italy, (2) TU Delft, Delft, The Netherlands, (3) École Polytechnique Fédérale de Lausanne, Lausanne, Switzerland, (4) Leonardo, Airborne & Space System Division, Florence, Italy, (5) S[&]T Norway, Oslo, Norway, (6) University of Arizona, Tucson, AZ, United States, (7) ESA/ESTEC, Noordwijk, The Netherlands
(francesco.topputo@polimi.it)

Abstract

The Lunar Meteoroid Impact Observer (LUMIO) is a CubeSat mission to observe, quantify, and characterise the meteoroid impacts by detecting their flashes on the lunar farside. This complements the knowledge gathered by Earth-based observations of the lunar nearside, thus synthesising a global information on the lunar meteoroid environment. LUMIO is one of the two winner of ESA's LUCE (Lunar CubeSat for Exploration) SysNova competition, and as such it is being considered by ESA for implementation in the near future.

1. Scientific framework

Meteoroids are small Sun orbiting fragments of asteroids and comets, whose sizes range from micrometres to meters and masses from 10^{-15} to 10^{4} kg [1]. Their formation is a consequence of asteroids colliding with each other or with other bodies, comets releasing dust particles when close to the Sun and minor bodies shattering into individual fragments. Therefore, understanding meteoroids and associated phenomena can be valuable for the study of asteroids and comets themselves. Since the Earth and Moon are impacted by the same meteoroid streams and swarms, studying the meteoroid flux at the Moon can be useful, not only to understand the meteoroid flux impacting Earth, but also to improve the meteoroid models of the Solar System. Furthermore, understanding the meteoroid flux distribution at the Moon is also critical for future Moon surface missions, as it could help understand, for example, future lunar living areas.

In a lunar meteoroid impact, the kinetic energy of the impactor is partitioned into (i) the generation of a seismic wave, (ii) the excavation of a crater, (iii) the ejection of particles, and (iv) the emission of radiation. Any of these phenomena can be observed to detect impacts. The detection of lunar impact flashes is the most advantageous method as it yields an independent detection of meteoroid impacts, provides the most information about the impactor, and allows for the monitoring of a large Moon surface area.

The first unambiguous lunar meteoroid impact flashes were detected during 1999's Leonid meteoroid showers [2, 3], while the first redundant detection of sporadic impacts was only reported six years later [4]. Since then there have been several attempts for ground-based lunar observations with three programs to provide the majority of the detections (Spanish survey [5], NASA survey [6] and NELIOTA project [7]).

However, observing the lunar impacts with space-based assets, and especially on the lunar farside, yields a number of benefits over ground-based telescopes, namely: the absence of atmosphere, weather and earthshine, the increase of the observing hours, no restrictions on lunar longitudes and latitudes.

2. Description of the mission

The LUMIO mission utilises a CubeSat that carries the LUMIO-Cam, an optical instrument capable of detecting light flashes in the visible spectrum. On-board data processing is implemented to minimise data downlink, while still retaining relevant scientific data: only those images containing flashes are stored. The mission implements a sophisticated orbit design: LUMIO is placed on a halo orbit about Earth–Moon L2 where permanent full-disk observation of the lunar farside is made. This prevents having background noise due to Earthshine, and thus permits obtaining high-quality scientific products. Repetitive operations are foreseen, the orbit being in near 2:1 resonance with the Moon orbit. Innovative full-disk optical autonomous navigation is proposed, and its performances are assessed and quantified. The spacecraft is a 12U form-factor CubeSat, with <22 kg mass. Novel on-board micro-propulsion system for orbital control, de-tumbling, and RW desaturation is used. Steady solar power generation is achieved with solar array drive assembly and eclipse-free orbit. Accurate pointing is performed by using reaction wheels, IMU, start trackers, and fine sun sensors. Communication with the Lunar Orbiter is done in UHF band. Advanced thermal coating and resistance heater for thermal control, as well as lightweight structure with radiation shielding are considered.

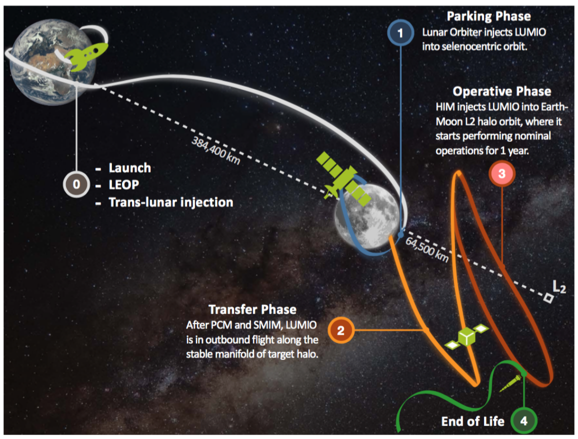

Figure 1: Outline of LUMIO mission.

References

[1] Ceplecha, Z., Borovicka, J., Elford, W. G., ReVelle, D. O., Hawkes, R. L., Porubcan, V. , and Simek, M.: Meteor Phenomena and Bodies, Space Science Review 84.3, pp. 327-471, 1998.

[2] Ortiz, J. L., Aceituno, F. J., Aceituno, J.: A search for meteoritic flashes on the Moon, A&A, 343, L57, 1999

[3] Ortiz, J. L., Sada, P. V., Bellot Rubio, L. R., Aceituno, F. J., Aceituno, J., Gutierrez, P. J., Thiele, U.: Optical detection of meteoroidal impacts on the Moon, Nature, 405, 921, 2000

[4] Ortiz, J. L., Aceituno, F. J., Quesada, J. A., Aceituno, J., Fernandez, M., Santos-Sanz, P., Trigo-Rodriguez, J. M., Llorca, J., Martin-Torres, F. J., Montanẽs-Rodriguez, P., and Palle, E.: Detection of sporadic impact flashes on the Moon: Implications for the luminous efficiency of hypervelocity impacts and derived terrestrial impact rates, Icarus 184.2, pp. 319–326, 2006.

[5] Madiedo, J. M. , Ortiz, J. L. , Organero, F. , Ana-Hernandez, L. , Fonsenca, F. , Morales, N., and Cabrera-Canõ, J.: Analysis of Moon impact flashes detected during the 2012 and 2013 Perseids, A&A 577, A118, 2015.

[6] Suggs, R. M., Moser, D. E., Cooke, W. J., and Suggs, R. J.: The flux of kilogram-sized meteoroids from lunar impact monitoring, Icarus 238, Supplement C, pp. 23–36, 2014.

[7] Bonanos, A. Z., Avdellidou, C., Liakos, A., Xilouris, E.M., Dapergolas, A., Koschny, D., Bellas-Velidis, I., Boumis, P., Charmandaris, V., Fytsilis, A., Maroussis, A. : NELIOTA: First Temperature Measurement of Lunar Impact Flashes, A&A, 612, 2018.

EPSC Abstracts
Vol. 12, EPSC2018-764, 2018
European Planetary Science Congress 2018

PRIME – A concept for passive radar investigation of Jupiter's moon Io

G. Steinbrügge[1,4], L. Fanara[1], D. Haack[1], M. Hamm[1], A. Heffels[1], **M. Maurice**[1], A. Nikolaou[1], Y. Rosas Ortiz[1], I. Varatharajan[1], D. Schroeder[2], K. Zikidis[3], H. Hussmann[1], T. Spohn[1]

[1]German Aerospace Center, Institute of Planetary Research, Berlin, Germany [2]Department of Geophysics, Stanford University, Stanford, CA, USA, [3]Department of Aeronautical Sciences, Hellenic Air Force Academy, Dekelia Air Base, Greece, [4]Institute for Geophysics, University of Texas at Austin, Austin, TX, USA

The Passive Radar Io Magma Explorer (PRIME) is a concept study to investigate the most active body in our Solar System with a low budget approach. Radar sounders have been successfully used on the Moon, on Mars and will also be represented aboard NASA's upcoming Europa Clipper mission by REASON [1] and aboard ESA's Jupiter Icy Moon Explorer (JUICE) by RIME [2]. However, despite their high scientific value, active radars usually have significant power consumption and suffer from radio noise; therefore operation might be limited to anti-Jovian sounding. For sub-Jovian operation, the concept of passive radar sounding has been previously suggested in the context of Ganymede and Europa [3,4,5]. PRIME would employ this concept exploiting the intense radio noise emissions of Jupiter at frequencies below 40 MHz [6]. The large distance to Sun and Earth, as well as the harsh Jovian environment make Io an extraordinarily difficult target when considering a low mass and low power approach. PRIME is intended in the frame of a flyby mission with limited deltaV budget in a highly inclined and eccentric orbit to avoid Jupiter's main radiation belts. PRIME aims at answering questions about the physical state of Io, the presence of a global subsurface magma ocean [7] and local magma reservoirs as well as the crustal thickness and state. It might also obtain important constraints on the thermal distribution of Io's interior by studying the sulfur cycle within Io's mantle and crust as well as distinguish between different tidal heating models by getting latitude dependent profiles. Io, being part of the Laplace resonance but not covered by the current mission concepts of Clipper and JUICE focusing on the icy moons, is a crucial target to obtain a comprehensive view on the Jovian system and its evolution. PRIME aims at filling this gap. The major science goals could be accomplished with a sequence of few flybys at high inclination and high velocity. We investigate the instrument concept in terms of signal to noise ratio and potential penetration depth as a function of various crustal parameters.

References

[1] Blankenship, D. et al. 2009, Europa, The University of Arizona Press [2] Bruzzone L. et al. 2013, *IEEE* International Geoscience and Remote Sensing Symposium - IGARSS, Melbourne, VIC [3] Hartogh P., and Ilyushin Y.A., 2015, Planet. and Space Sci. 130 [4] Romero-Wolf A., 2015, Icarus 248 [5] Schroeder D. et al., 2016, Planet and Space Sci. 134, [6] Cecconi B. et al. 2012, Planet. Space Sci., 61 [7] Khurana, K. et al. 2011, Science 332

EPSC Abstracts
Vol. 12, EPSC2018-839, 2018
European Planetary Science Congress 2018

ASPECT hyperspectral imager for small interplanetary spacecrafts

Tomas Kohout (1), Antti Näsilä (2)

(1) Faculty of Science, University of Helsinki, Finland (tomas.kohout@helsinki.fi)
(2) VTT Technical Research Centre of Finland Ltd, Espoo, Finland

Abstract

ASPECT hyperspectral imager is a scalable instrument for small spacecrafts to study composition of planetary surfaces.

1. Introduction

The ASPECT Hyperspectral Imager was originally developed as a payload for ASPECT CubeSat (Asteroid Spectral Imaging Mission) [1] within the ESA-NASA AIDA (Asteroid Impact & Deflection Assessment) project. It is a miniaturized, CubeSat-sized, hyperspectral imager with primary scientific task of high resolution compositional mapping of target surface. Thanks to its modular design, ASPECT hyperspectral imager range and resolution can be easily modified to match specific mission objectives.

2. Scientific and prospecting capabilities

The scientific and prospecting objectives of the instrument are are supported by its VIS-NIR (visual – near-infrared) spectral range. The ASPECT Hyperspectral Imager allows for global compositional mapping and imaging of the target asteroid with sub-meter resolution.

The spectral range of 500-2500 nm covers most common silicate mineral (olivine, pyroxene, and plagioclase) absorption bands related to Fe^{2+} ions in their structure. Additionally, hydrated minerals as serpentine can be detected using ~700 nm Fe^{3+} absorption features. Direct presence of -OH an H_2O can be detected at 1400 and 1900 nm respectively. Observations at various phase angle allows for estimation of surface roughness. An extension of the spectral range into MIR (mid-infrared) region is being currently investigated. This spectral range allows for direct detection of hydrated materials and water/ice in 2700-3000 nm region as well as organic materials at 3200-3600 nm (Fig. 1).

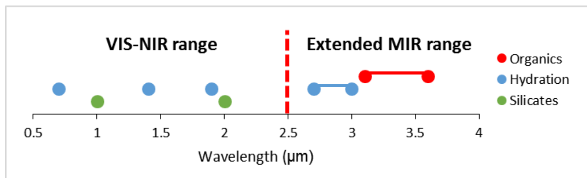

Figure 1: Spectral features detectable with ASPECT hyperspectral imager.

3. Design

The ASPECT Hyperspectral Imager is a miniaturized instrument with range extending from the visible (VIS) up to near-infrared (NIR) wavelengths. In contrast to more traditional spatial scanning imaging spectrometers, the Asteroid Spectral Imager takes 2D snapshots at a given wavelength. When multiple snapshots are combined, a spectral datacube is formed, where the wavelength bands are separated in the time domain. The spectral separation is done by a tunable Fabry-Perot Interferometer (FPI).

The ASPECT asteroid hyperspectral imager is split into three measurement channels, one in the visible (VIS), and two in the infrared (NIR1 and NIR2). The parameters of each channel as well as possible extensions are summarized in Table 1. Sub-meter imager resolution can be achieved at orbital distances of 3 km or lower. All three channels have dedicated FPIs optimized for the desired wavelength range and are independent on each other. The imaged wavelengths are freely selectable within these ranges, and the targeted spectral resolution is 10-50 nm. Recently, a feasibility study of additional MIR channel with spectral range of 2500-4000 nm was launched. An extension in other direction towards UV (ultraviolet) is also currently under development for ESA ALTIUS and can be potentially integrated into the ASPECT Hyperspectral Imager.

4. Customization

The number of ASPECT imager channels, spectral range and resolution can be customized to meet specific mission objectives. Spectral resolution can be increased using FPI's higher orders of interference. However, this will result in smaller spectral range of the single channel and subsequent need to increase number of the imager channels. For example, improving the spectral resolution from 20 to 10 nm in NIR1 channel, the range will decrease from 900-1400 nm to approx.900-1100 nm. Cascading the FPI will also result in better spectral resolution, however, the throughput and sensitivity will be decreased. Thus, there is a possibility for customization of ASPECT hyperspectral imager configuration satisfy mission requirements.

References

[1] Kohout T. et al.: Feasibility of asteroid exploration using CubeSats – ASPECT case study, Advances in Space Research, http://dx.doi.org/10.1016/j.asr.2017.07.036, in press, 2017.

Table 1: ASPECT Hyperspectral Imager configuration with optional extensions.

Range	VIS	NIR1	NIR2	UV (optional)	VIS (optional)	MIR (optional)	VNIR mini
Size	0.5U	0.5U	0.25-0.5U	0.5-1U	0.5U	0.25U	1 cubic inch
FoV [deg]	10 × 10	5.3 × 5.3 10 × 10	5.3 × 5.3	TBD	2.5 × 2.5	TBD	10 × 10
Spectral range [nm]	500-900	900-1600	1600-2500	250 - 400	430-800	2500-4000	500-800 or 700-1000
Image size [px]	1024 × 1024	512 × 512	256 × 256	Single point	2048 × 2048	Single point	512 x 512
Spectral resolution [nm]	10-15 nm	20-40 nm	20-30 nm	< 2.5 nm	< 2.5 nm	30-50	20 nm
TRL	9	7	5	5	8	3	3-4
Flight heritage	Aalto 1 (in orbit, 2017)	Reaktor Hello World (FM delivered, launch 2018)	Under development, prototype in 2018	ESA ALTIUS (under development)	VISION (FM delivered, launch 2019)	Concept	Under development with ESA
Note			2 FPI cascade. With a single FPI the range is 1600 - 2100	4 FPI cascade. Can also be used with imaging detector		2 FPI cascade. With a single FPI the range is 2500 - 3500	Based on MEMS technology

EPSC Abstracts
Vol. 12, EPSC2018-1074, 2018
European Planetary Science Congress 2018

NASA SMALL INNOVATIVE MISSIONS FOR PLANETARY EXPLORATION (SIMPLEx)

Doris Daou
NASA Heaquarters, Washington DC, USA (Doris.Daou@nasa.gov)

Abstract

In the planetary decadal report, Visions and Voyages, "The committee unequivocally recommends that a substantial program of planetary exploration technology development should be reconstituted and carefully protected against all incursions that would deplete its resources. This program should be consistently funded at approximately 6 to 8 percent of the total NASA Planetary Science Division budget." In addition, the reports states, "The committee recommends that the Planetary Science Division's technology program should accept the responsibility, and assign the required funds, to continue the development of **the most important technology items** through TRL 6."

In 2016, a National Academies Report concluded that CubeSats have proven their ability to produce high-value science. In particular, CubeSats are useful as targeted investigations to augment the capabilities of larger missions or to make a highly-specific measurement.

The Planetary Science Division has released a revolving Announcement of Opportunity as a Program Element Appendix J (PEA-J) to the Third Stand Alone Missions of Opportunity Notice (SALMON-3) for the purpose of soliciting proposals for Small Innovative Missions for Planetary Exploration (SIMPLEx) as small complete mission of opportunity (SCM) science investigations.

SALMON-3 PEA-J describes the requirements for Small Complete Mission of Opportunity proposal opportunities and documents specific requirements for SIMPLEx. Through this PEA, NASA Science Mission Directorate, Planetary Science Division (SMD/PSD) solicits investigations in which a secondary payload small spacecraft is built and deployed from a primary spacecraft mission, followed by production of high quality and highly useful science data from that SmallSat, analysis of the data and publication of scientific results, and delivery of the data to an appropriate NASA archive.

Participation in this opportunity is open to all categories of organizations (U.S. and non-U.S.), including educational institutions, industry, not-for-profit organizations, Federally Funded Research and Development Centers, NASA Centers, the Jet Propulsion Laboratory, and other Government agencies. This paper will introduce this program and present the specifics for proposals specially in the case of non-U.S. institutions.

1. Introduction

The Third Stand Alone Missions of Opportunity Notice (SALMON-3) AO is an omnibus Announcement of Opportunity that provides the overall structure, guidelines and requirements for several types of Mission of Opportunity (MO) solicitations. Each new opportunity is announced through a Program Element Appendix (PEA) that details the solicitation and may include additional guidelines and requirements.

The NASA Science Mission Directorate, Planetary Science Division (SMD/PSD) has solicited SmallSat investigations in response to the technology findings described in *Visions and Voyages,* the PSD decadal report, as well as the *2016 National Academies'* Report. The solicitation is in the form of a PEA to the SALMON-3 for the purpose of inviting proposals for Small Innovative Missions for Planetary Exploration (SIMPLEx) as small complete mission of opportunity (SCM) science investigations. Proposed investigations may target any planetary science scientific investigation that advances the objectives outlined in NASA's strategic objective in planetary science. Investigations that address NASA goals in other areas, such as astrophysics, Earth science, or heliophysics, are not solicited. Investigations of extrasolar planets are not solicited in this PEA.

Selected missions will launch as a secondary payload on one of the specific flight opportunities described in the PEA. The PEA will be amended as new launch opportunities become available. Proposals will be accepted at any time, but there is a cut-off date for each specified launch opportunity nominally four years before its expected launch readiness date (LRD).

1.1 SmallSats

SmallSats are defined as ESPA-Class or smaller, including CubeSats built from a set of standardized subunits that each measure 10x10x10 cm with a mass of 1.33 kg (designated '1U'). Allowable configurations in this SIMPLEx PEA include 1U, 2U, 3U (nominally 4kg), 6U (2Ux3U - up to nominally 12 kg) and 12U (2Ux6U, 3Ux4U, or 1x12U - up to nominally 24 kg) satellites. ESPA-Class SmallSats are defined as spacecraft that can be launched from a standard evolved expendable launch vehicle (EELV) secondary payload adaptor (ESPA). The dimensions of an ESPA-Class SmallSat must be no larger than 61x71x97 cm. For launch opportunities that allow an ESPA Grande or Propulsive ESPA ring (See Table A-1), the volume constraints are 106x116x96 cm. For all three ESPA cases, the total wet mass of the proposed SmallSat must not exceed 180 kg.

2. SIMPLEx Goals and Objectives

The goal of SIMPLEx is to increase the science return of future missions by launching secondary payloads to conduct planetary science that would otherwise not be possible, for instance, either because of cost constraints or by providing the opportunity to make simultaneous measurements at multiple locations. SIMPLEx secondary payloads are limited to SmallSats and will be cost capped. SIMPLEx missions will be science focused, not technology demonstrations, however SIMPLEx missions will accept technical risks that might not be acceptable on larger, higher cost primary missions.

3. SIMPLEx proposals

This PEA solicits planetary science investigations that require a spaceflight mission that can be accomplished using small spacecraft as secondary payloads on future launch opportunities, listed in Appendix A of this PEA. The launch readiness date and initial release trajectory will be individually determined for each primary mission. Proposal due dates for each launch opportunity are listed in Appendix A of this PEA. Proposals for investigations to be launched from Low Earth Orbit (LEO) or Geostationary Transfer Orbit (GTO) will also be considered with no specific deadline imposed.

Proposals submitted in response to this PEA will be selected for flight through a two-step competitive process. Proposals submitted in response to this PEA will be evaluated based on the entire proposed flight project lifecycle (formulation through implementation, Phases A through F). As the outcome of the first step evaluation, NASA intends to fund one or more SCM investigations to proceed to a twelve-month Phase A/B study concluding with a preliminary design review (PDR). In the second step, NASA will conduct an evaluation of the Phase A/B PDR results (KDP-C). From this evaluation, NASA expects to select one or more of the funded SCMs to proceed into implementation. In addition, this program requires a Notice of Intent (NOI). Proposals that are not preceded by the mandatory NOI will be returned without review. No feedback will be provided in response to the NOI.

Proposals in response to this PEA will be accepted at any time. PSD will conduct nominally one review per year. Cut-off dates for specific launch opportunities are given in Appendix A of this PEA. A typical mission development lifetime is described below:

- Launch minus four years (L-4): Cut-off consideration for a specific mission
  - Select and award ~1 year Phase A/B design studies; expected product is PDR-level design
  - Launch Vehicle is unknown
- L-3 years: Down-select secondary mission(s) for specific primary mission
  - May be possible to select multiple secondaries for a given primary mission
  - Selections coordinated with launch vehicle selection
  - Provided for Phase C design/build:

- More detailed launch vehicle trajectory, environments and interfaces
- L-2 years: Build/test secondary payload
- L-1 years: Build/test/integrate secondary payload
- L-3 months: Integrate secondary payload into the launch vehicle (nominal date)
- L: launch

4. SIMPLEx Evaluations

Evaluation and selection of proposals in response to this PEA will be done using a two-step process. This is different from the traditional two-step approach, where NASA funds only Phase A before down-selection. In the SIMPLEx case, NASA funded Phase A/B activities will be conducted by the investigation team(s) selected as a result of the first step of this solicitation.

NASA expects to conduct proposals evaluations nominally once per calendar year. Proposers are encouraged to factor specific launch information into their proposals; however, this solicitation will remain open and proposals that are not selected for one launch opportunity may be considered for subsequent launch opportunities if appropriate, through the next proposal evaluation cycle. In addition, launch opportunities to low Earth and geostationary transfer orbits are frequently available and proposers may target such launches at any time. As part of NASA's Lunar Discovery and Exploration Program, proposals are also sought for CubeSat missions to be launched with expected missions to Earth’s moon. These secondary payloads launched with expected lunar missions will be evaluated and funded separately from other proposed missions and must address either lunar science or human exploration objectives.

5. Non-U.S. Participation

Non-U.S. organizations are not eligible to submit proposals to this PEA. In fact, only U.S. organizations are eligible to propose as the sole or lead organization. However, Non-U.S. organizations may participate as non-lead organizations collaborating with U.S. leads. Contributions from sources other than NASA, whether U.S. or non-U.S., are accepted. The sum of non-U.S. contributions of any kind to the entirety of the investigation is not to exceed one-half (1/2) of the proposed Total Mission Cost. Such contributions will not be counted against the PI-Managed Mission Cost, but they must be included in the calculation and discussion of the Total Mission Cost.

Should a proposal with non-U.S. participation be selected, NASA's Office of International and Interagency Relations will arrange with the non-U.S. sponsoring agency for the proposed participation on a no-exchange-of-funds basis, in which NASA and the non-U.S. sponsoring agency will each bear the cost of discharging their respective responsibilities. These arrangements will be documented and affirmed in a legally binding agreement between NASA and the non-U.S. sponsoring agency.

6. Summary and Conclusions

The Small Innovative Missions for Planetary Exploration (SIMPLEx) is a Small Complete Mission of opportunity (SCM) science investigations. It is in the form of a Third Stand Alone Missions of Opportunity Notice (SALMON-3) Program Element Appendix (PEA) that invites proposals for a secondary payload small spacecraft deployed from a primary spacecraft mission. Contributions from sources other than NASA, whether U.S. or non-U.S., are accepted. This paper, describes the SIMPLEx program, its requirements and evaluation process.

EPSC Abstracts
Vol. 12, EPSC2018-1181, 2018
European Planetary Science Congress 2018

ArgoMoon, a multipurpose CubeSat platform for missions in Moon vicinity and orbit

Mr. Valerio Di Tana (1), Carlo Fiori (2), Simone Simonetti (3), S. Pirrotta (4).

(1) Argotec Srl, Italy (valerio.ditana@argotec.it)
(2) Argotec Srl, Italy (carlo.fiori@argotec.it)
(3) Argotec Srl, Italy (simone.simonetti@argotec.it)
(4) Italian Space Agency, ASI, Italy

Abstract

ArgoMoon is an Italian 6U CubeSat, to be launched at the end of 2019 during the maiden flight of the NASA Space Launch System (SLS), and injected in a high elliptic – high apogee orbit, so that in the following months several Moon fly-bys and imaging of the surface will be performed. Together with its own scientific objectives, the ArgoMoon mission will allow the in orbit and deep space environment validation of specific technologies for nanosats.

1. Introduction

The Moon has recently consolidated and enhanced its importance in the main international Exploration Roadmaps, both as intermediate step on the mid-long term way to the human presence on Mars surface, both as celestial target for scientific investigation and technologies validation. In particular, the lunar vicinity is considered as the most promising environment for a human-tended facility, based on principles of sustainability, affordability, accessibility, that will allow and support human and robotic exploration of the Moon surface both from orbit and in situ. The so-called Deep Space Gateway will be the next key element, following the ISS, to enable human space exploration, allowing for scientific observations and contributing to test of readiness for Mars missions [1]. Then, Lunar surface will host lander, rovers and permanent outposts, based on key enabling technologies like in-situ resources utilization, communication device and power generation systems. In this scenario, small satellites in the class of CubeSats can be considered as very suitable and promising tools for a flexible and sustainable approach to modular validation of specific functionalities and to support the main elements of the architectures. Several of the next challenging missions will include CubeSats that are demonstrating their suitability to operate in Deep Space. In this sense, the Moon vicinity environment offers a new operational framework that fits all the characteristic of this small satellites.

2. ArgoMoon mission

ArgoMoon is a new generation 6U CubeSat, developed for the Italian Space Agency by Argotec, that will be launched on the maiden flight of the NASA Space Launch System (SLS), named Exploration Mission 1 (EM-1). The primary goal of the mission is to take detailed photographs of the SLS secondary propulsion stage during its travel towards the Moon. The pictures will be collected by ArgoMoon during a proximity maneuvering phase, which will also allow to validate the tracking algorithm developed by Argotec. After that, orbital maneuvers will move the satellite in a geocentric highly elliptic orbit, whose apogee is so high to allow flybys and imaging of the Moon and surrounding environment. The highly demanding mission environment required tailored design strategies, while COTS components have been implemented in the design, some key systems have been developed or customized by Argotec to increase their performance and reliability qualifying the satellite for the operation from lunar orbit.

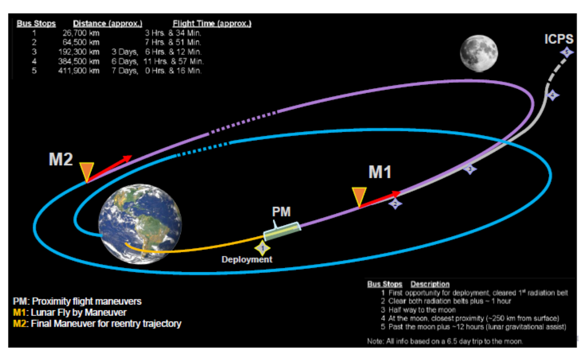

Fig. 1: ArgoMoon mission profile.

3. Design status description

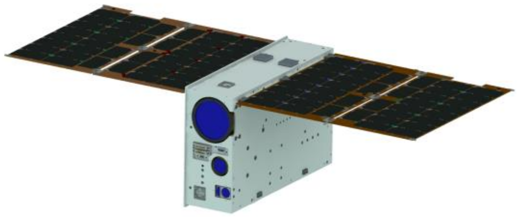

Fig. 2: ArgoMoon external configuration.

4. Summary and Conclusions

This paper provides an overview on ArgoMoon mission profile and satellite design in support of SLS EM1 mission and, later, with own scientific objectives. Moreover, it drafts possible future applications in Moon orbit of the ArgoMoon platform, considered as a multipurpose Space-Drone. In fact, its modular and flexible architecture can be easily adapted to accommodate different scientific instruments without strong impacts and thus significantly reducing the development costs.

Acknowledgements

We thank the Italian Space Agency (ASI) for funding and fully supporting ArgoMoon mission (ASI/Argotec grant n. 2016-10-I.0 and n. 2017-14-I.0).

References

[1]International Space Exploration Coordination Group ISECG "The Global Exploration Roadmap" January 2018.

EPSC Abstracts
Vol. 12, EPSC2018-1190, 2018
European Planetary Science Congress 2018

Nanospacecraft design and mission overview for statistical small asteroids prospecting

Iaroslav Iakubivskyi (1,2), Laurynas Mačiulis (3), Pekka Janhunen (4), Andris Slavinskis (1,2), Mihkel Pajusalu (5), Mart Noorma (1,2)

(1) University of Tartu, Institute of Physics, W. Ostwaldi 1-D601, 50411, Tartu, Estonia (iaroslav.iakubivskyi@estcube.eu)
(2) Tartu Observatory, University of Tartu, Department of Space Technology, Observatooriumi 1, 61602, Tõravere, Estonia
(3) Antanas Gustaitis' Aviation Institute, Linkmenu str. 28, 08217 Vilnius
(4) Finnish Meteorological Institute, Erik Palménin aukio 1, P.O. Box 503, FI-00101, Helsinki, Finland
(5) Massachusetts Institute of Tech- nology, Department of Earth, Atmospheric and Planetary Sciences, 77 Massachusetts Avenue, Rm 54-1728, 02139 Cambridge, MA

Abstract

This work describes the detailed design of small spacecraft for interplanetary mission. We present a selection of optimal materials and configurations for thermal and radiation environments. The main spacecraft consists of approximately three CubeSat units and includes an auxiliary unit for deployment of the electric solar wind sail (E-sail). E-sail is a primary propulsion employing 20 km aluminium charged tether. The minimum viable E-sail configuration can propel ~ 5 kg body to the main asteroid belt. The spacecraft will spin slowly (2 rpm) and maintain the tether stretched. It will be achieved by attaching a mass body or so-called remote unit on a tether's tip. Hence, the remote unit will orbit the main spacecraft in the unnatural way by means of centrifugal force. The remote unit utilizes wireless communication with the main spacecraft. The round trip will take 3-4 years. The structural and thermal requirements remain similar for both bodies. This study is performed for Multi-Asteroid Touring mission (Slavinskis, 2018[1]) but can be utilized for other similar mission.

[1] Slavinskis A. et al. (2018) *IEEE Aerospace Con- ference 2018*, 2.0209.

EPSC Abstracts
Vol. 12, EPSC2018-1228-1, 2018
European Planetary Science Congress 2018

Reliability of Small Satellites for Planetary Science Missions

Patricia Beauchamp[1] Michael Johnson[2], Harald Schone[1], Catherine Venturini[3]

[1]Jet Propulsion Laboratory, 4800 Oak Grove Dr, Pasadena, CA 91109, USA (pbeauch@jpl.nasa.gov); [2]NASA Goddard Spaceflight Center, 8800 Greenbelt Rd, Greenbelt, MD 20771, [3]The Aerospace Corporation, 2310 E El Segundo Blvd, El Segundo, CA 90245 USA,

Abstract

Planetary Science is expected to benefit greatly from the advent of CubeSats and/or SmallSats and the science community is embracing this. The two MarCo CubeSats are heading towards Mars while the Asteria mission has met all its level one requirements and is in extended mission searching for exoplanets. More planetary CubeSats or SmallSats are planned. In the future we anticipate that SmallSats will be used routinely for Planetary missions often using CubeSat components and subsystems but not necessarily using the CubeSat form factor. In general, however, CubeSat components and buses are not appropriate for planetary missions where significant risk of failure, or the inability to quantify risk or confidence is unacceptable. Both CubeSats and SmallSats could then be used where their attributes enable or enhance mission objectives or provide other meaningful benefits—e.g. lower cost, increased coverage (spatial, temporal, spectral), agility, resiliency, etc. This paper will discuss some available and upcoming technologies that will enable planetary missions. It will also discuss the genesis of and drivers for a Small Satellite Reliability Initiative, how a public-private collaboration is being executed, progress in recommendations and next steps towards broadening small satellite mission potential.

1. Introduction

Planetary Science is expected to benefit greatly from the advent of CubeSats and/or SmallSats and the science community is embracing this as evidenced by the 102 submissions to the NASA Planetary Science Division call for Deep Space SmallSat Studies and the Simplex call for SmallSats for Planetary exploration. In addition, the two MarCo spacecraft are heading towards Mars while Asteria mission has met all its level one requirements and is in extended mission looking for exoplanets. More planetary CubeSats/SmallSats are planned and in the future we anticipate that SmallSats will be used for routinely for Planetary missions often using CubeSat components and subsystems but not necessarily using the CubeSat form factor. In the past, CubeSat components and buses have not been appropriate for planetary missions where significant risk of failure, or the inability to quantify risk or confidence is unacceptable. Historically, it was understood and accepted that "high risk" and "CubeSat" were largely synonymous; expectations were set accordingly. However, commercial and various government agency ventures are improving the quality of these spacecraft and in the future we anticipate that CubeSats will be used for 1-3 years Earth science missions requiring and even longer for Planetary and Exoplanet missions. Both CubeSats and SmallSats could then be used where their attributes enable or enhance mission objectives or provide other meaningful benefits—e.g. lower cost, increased coverage (spatial, temporal, spectral), agility, resiliency, etc. Their growing potential utility is driving an interagency effort to improve and quantify CubeSat reliability, and more generally, small satellite mission risk.

2. Small Initiative Reliability (SSRI)

The Small Satellite Reliability Initiative (SSRI)—an activity with broad participation from civil, DoD, and commercial space systems providers and stakeholders—has been targeting this challenge. The collaborative team has made significant progress towards defining and documenting the full range of best practices and design/development guidelines—from those aligned with “do no harm” missions, to those whose failure would result in loss or delay of key national objectives. The approach addresses two architectural scopes—the mission/system-level, and the component/subsystem-level. The mission/system-level scope recommends strategies or best practices that increase resiliency to mission or system anomalies. The component/subsystem-level scope addresses the challenges at lower architectural levels.

SSRI is intently focused on maintaining to the extent practical, cost efficiencies associated with small satellite missions. In addition, the team is looking for thoughts on novel and innovative solutions instead of limiting recommended strategies to proven and traditional methodologies. Finally, Initiative recommendations target a range of SmallSat communities—from system developers to mission architects and persons acquiring SmallSat-based systems and missions.

3. Summary and Conclusions

This paper will update the community on how the public-private collaboration is being executed, discuss the next steps the team will implement to broaden small satellite mission potential. SSRI is intently focused on maintaining to the extent practical, cost efficiencies associated with small satellite missions. In addition, the team is looking for thoughts on novel and innovative solutions instead of limiting recommended strategies to proven and traditional methodologies. Initiative recommendations target a range of SmallSat communities—from system developers to mission architects and persons acquiring SmallSat-based systems and missions. In addition to a discussion of the Initiative, some examples will be given of potential technological advances that can enable planetary SmallSat missions.

Acknowledgements

The authors would like to acknowledgement the support from NASA, JPL-Caltech, the multiple US agencies involved in SSRI and the CubeSat/SmallSat community of suppliers and vendors.