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Subject: Sputnik Plus Option for Jupiter Europa Orbiter Descope

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The outcome of the Planetary Science Decadal Survey (Squyres et al., 2011) makes it clear at a projected cost of \$4.7B that the current design of the Jupiter Europa Orbiter (JEO), the highest priority outer planets mission from the present and past surveys, cannot be accommodated into the NASA budget. If the mission is to fall in cost (no JEO descope cost cap is defined) below the recommended \$2.5B target for the first-priority large-class mission, Mars Astrobiology Explorer-Cacher (Max-C), in line with out-year projections from NASA's FY10 budget, the budgetary basis for the decadal survey recommendation, there must clearly be a *radical* descope on the science objectives and associated cost of the mission. Even more sobering for we enthusiasts of the mission and the science is that the FY11 budget request, as now to be modified at a reduced total U.S. government level by expected agreement of the White House and Congress, does not even support the recommended \$2.5B level for a planetary flagship. This last development leaves us with little option other than to pursue the flagship science at the level of competitive Discovery and New Frontiers mission opportunities within NASA. Supporting remote sensing observations from Jupiter and Ganymede orbits and/or near-flyby measurements of Europa could be provided by the European Space Agency's Jupiter Ganymede Orbiter (JGO), still in competition with two other large-class missions for their Cosmic Visions program.

The past and present decadal surveys have consistently maintained that the oceanic science of Europa has the highest priority among all proposed outer planets missions and their ranked science objectives. Europa apparently lacks the obvious active volcanism of Io, Enceladus, and Triton, and the rich organic surface and atmospheric environments of Titan, but the putative presence of a European water ocean within tens of kilometers or less of the surface powerfully beckons for near-term attention at the level of a flagship-class mission. The 2011 decadal survey report states that "Europa's ocean {is} the highest priority in the outer solar system to explore as a potential habitat for life. Characterization of its internal ocean and ice shell, searching for plumes and evidence of organics are key goals for this decade."

The Joint Science Definition Team study (Greeley et al., 2010) for the two-spacecraft (JEO, JGO) NASA-ESA Europa Jupiter System Mission (EJSM) defines for JEO the Ocean, Ice Shell, Composition, Geology, and Local Environment objectives collectively as a comprehensive approach to exploration of Europa's potential habitability, but the Ocean objective clearly outweighs in importance the others. The Ice Shell objective is clearly important to the issue of whether and where the ocean exists, since relative thicknesses of the ocean and overlying ice shells are the most important questions, but if there is no ocean layer, the ice shell of Europa then becomes of no greater priority for investigation as compared to that of other icy moons with geologically evolved surfaces such as Ganymede, Enceladus, Titan, and Triton. The Composition, Geology, and Local Environment objectives would similarly be of comparative

interest with respect to origins and evolution of other moons but no longer elevated in importance by the possibility of subsurface ocean existence.

The earlier Facts and Suggestions white paper (Cooper et al., 2006) suggested an alternative approach to the flagship-class oceanic science of Europa. That is, the oceanic science is what is most important as expressed by the priorities of the decadal survey, not necessarily the mission implementation by a single flagship-class spacecraft. If the most important science on the ocean can be achieved with alternative mission approaches, investment in the full flagship may not be required. This may, however, require additional investments in technology, e.g. larger telescopes on JGO, radiation tolerant systems on a stripped-down version of JEO, and so forth, to fulfill the Europa science requirements sufficient to confirm presence and extent of the ocean.

In a previous decadal survey white paper on Europa Exploration (Cooper et al., 2002), various options for Europa orbital and surface missions were suggested. Then as now, the primary science objective was habitability confirmation through detection and survey of the putative ocean, not detection of prebiotic chemistry or of active biology, succinctly stated as “find the water now, look for bugs later”. The most wildly ambitious suggestion was for a moon ocean explorer that would use probes to sense ocean presence on all the icy Galilean moons, and surprisingly this approach was actually studied in the form of the Jupiter Icy Moons Orbiter (JIMO) which would have itself orbited Callisto, Ganymede, and finally Europa. The Europa Pathfinder concept, then under study at JPL, was suggested as a potential implementation for landed mission science.

But the more realistic Europa mission concept in the present budget-limited climate of NASA would be the Sputnik (what we now call “Sputnik Plus”) concept discussed in Section 3.3 of the 2002 white paper with respect to minimum science requirements for the ocean. The approach of this concept is to build up through the highest priority ocean science using simultaneous radio science laser altimetry measurements of internal gravity fields and surface tidal deformation to magnetic field & supporting plasma current measurements for orbital sensing of the oceanic induced magnetic field. A small VIS imaging telescope (D. Smith, private communication, 2011), comparable to JunoCam on Juno (Dodge et al., 2007), would be needed for surface geologic context determination in support of the altimetry measurements. The altimetry resolution need not be as high as for JEO, since the main objective would be global tidal deformation and not correlations to geologic imaging. If the applicable budget cap TBD is still not broken, the science payload could then be further enhanced to address Ice Shell science with a radio sounder, and the Composition science, mainly that potentially connected to surface detection of oceanic materials, would be achieved with plasma and energetic ion composition measurements. Energetic neutral atom and molecular measurements would also be useful for the hot exospheric environment and could be integrated with the plasma instrumentation. Needless to say with respect to spacecraft and instrument operations in the extreme radiation environment of Europa, simple dosimeter arrays would be needed at minimum to monitor the changing radiation dosage rates. What falls to lowest priority, and may not be feasibly included within the descope JEO cost cap, would be the full suite of multi-spectral imaging instruments originally planned for JEO. Overall, the Sputnik Plus strategy is alternatively to build up in stages, progressively budgeted to each new stage, from the absolute minimum requirements rather than to attempt major descope to “JEO Minus” from the full flagship configuration.

The suggested Sputnik Plus science payload in floor to baseline configurations, whatever falls within the mission cost cap as determined by NASA Headquarters, is composed of those instruments that must be in low-altitude (100-200 km) polar orbit at Europa to achieve the top priority ocean and related science. Other instruments such as imagers with larger optical elements could be on another platform such as JGO in Ganymede orbit, or a Juno-class spacecraft doing many high-inclination flybys of Europa, for which the cumulative radiation environment would be less severe and imagers of higher performance could be developed.

This minimal mission will still address many of the EJSM science objectives with the following science returns in addition to Ocean science: 1) Laser Altimeter (LA) surface coverage for geologic studies with ~ 50-100 m {assumes same angular resolution as LOLA on LRO} spatial resolution along each ground track plus JunoCam-type context imaging at comparable surface resolution, 2) several km or better (JGO mission might be changed to do Europa flybys) resolution over most of the surface from cameras on JGO or flyby missions, 3) measurements of Europa's ionosphere and its composition using the Radio Science (RS) Instrument and the Particle Plasma Instrument (PPI) suite of instruments, 4) measurements of the Jovian magnetosphere's interaction with Europa's exosphere and ionosphere using data from the magnetometer (MAG) and PPI, 5) measurements of the surface composition of Europa's surface with spatial resolution ~ 100 km by the PPI Ion Mass Spectrometer's (IMS) measurement of pickup ions with origin near Europa's surface and surrounding exosphere, 6) the plasma-magnetic properties, ion composition of the plasma and radiation belt particles of Jupiter's magnetosphere by PPI and MAG instruments (plasma density, plasma flow velocities, plasma pressure, pickup ions, magnetic field, MHD waves and ion cyclotron waves), 7) flyby measurements for radio science determination of gravity fields and ionospheric environments, and other in-situ measurements, at other Galilean moons, 8) flyby or remote sensing measurements of magnetospheric interactions with the atmospheres and surfaces of these other moons, and 9) other remote sensing measurements of Jupiter's atmosphere and rings. Measurements 1) to 5) would drive the instrument configuration to be accommodated within a given cost cap, while 6) to 9) capabilities, e.g. telescopic resolution, would be mainly limited to the instrument specifications already defined for 1) to 5).

The suggested floor Oceanic Payload for Sputnik Plus is:

Instrument	Mass (kg) <sup>1</sup>	Power (W) <sup>1</sup>	Telemetry Rate (kbps)
Radio Science	Part of comm. System with ultra-stable oscillator (Ka-band)		
Laser Altimeter (LA) <sup>2</sup>	17	24	3
Magnetometer (MAG)	5.6	4.8	4
Particle Plasma Inst (PPI)	24	15.6	4
Total + 30%	61	58	14

1. We've assumed mass growth of 40% and power growth ~ 20% from that in SDT Report as consistent with the JEO cost growth to \$4.7B.
2. Shielded JunoCam-type context imager (3 kg/6 W/1 kbps) included in the LA allocations.

As discussed in the many EJSM documents Radio Science will provide the needed gravity field measurements, Laser Altimetry will provide Europa's shape in response to tidal forces, the Magnetometer will provide direct measurements of the ocean's presence from its induced magnetic field and the Particle Plasma Instrument will provide correction currents for the MAG ocean measurements from Jupiter's magnetospheric interaction with Europa and its ionosphere-exosphere. All these instruments must get close to achieve ocean science objectives with 90-day 100-200 km high inclination orbit around Europa. Payload mass and power would be ~ four times smaller than present payload and telemetry requirements would be ten times smaller.

The descope science on multi-spectral imaging could be recovered by NASA contributions to advanced imaging instrumentation on JGO to take km resolution images of Europa's surface from the Jovian system tour phase and from Ganymede orbit, including spectral data for surface composition information. Combining these remote images with overlapping altimetry ground tracks from the LA context imager would increase spatial resolution and surface height information. As for JunoCam, multiple color filters on the context imager could return some information on surface composition for correlation to compositional maps at higher spectral precision from the remote imagery. This approach minimizes any re-design to the JGO mission with NASA absorbing any additional cost to the JGO mission which already is near its cost cap of 700 M Euros.

Beyond the floor Oceanic Payload above, the next recommended instrument would be a radio sounder system to characterize the structure of the Ice Shell and hopefully locate the ice-ocean boundary. The Ice Penetrating Radar (IPR) for JEO would have operated at 5 and 50 MHz with a total mass of 31 kg, including 5 kg for shielding. Power and data rate would respectively be 45 W and 150-300 kbps. In mass, power, and data rate, addition of IPR would therefore substantially increase the spacecraft resource requirements but would valuably extend the mission capabilities into the Ice Shell objectives of the original JEO design. We suggest modification of the JEO IPR to allow variation of the lower frequency for sounding of the ionosphere with a nominal cutoff at about 1 MHz, dependent on variable ionospheric electron density, so that corrections for ionospheric noise could be applied to analysis of the ice sounding data. The IPR design should be carefully reevaluated to extract maximum science return for the additional investment, if it can be accommodated at all within the new TBD mission cost cap.

#### JEO Descope Implications:

1. Smaller spacecraft
2. Reduced bandwidth requirements of comm. System
  - a. Reduce size of HGA (i.e., 3 m to 2 m or less)
  - b. Reduce onboard memory requirements
  - c. Reduce power requirement?
3. Reduce attitude control requirements

- a. Reduce precision to mrad and mrad/s
- b. PPI needs  $1/3^\circ$  knowledge, comparable for MAG
- c. LA needs 0.5 mrad (50 m) pointing and context imaging resolution at 100-km altitude, comparable to JunoCam.
4. Reduce number of RTGs since now payload power requirements x4 smaller
5. Recommend common electronics and power systems box collocated with instrument cluster on payload pallet to save in harness shielding mass requirements.
6. Smaller payload should allow more  $\Delta v$ , so could that be used to reduce time of tour?
7. If tour is shorter then accumulated dose will be lower and thus less shielding mass required.
8. Reduce length of cruise period and avoid need for Venus gravity assist?
  - a. Simplify thermal design of spacecraft and instruments and reduce heater power requirements. If one has further reductions in power can another RTG be dropped?
  - b. With smaller spacecraft and science payload it might take less time to assemble payload for launch and with reduced trip time, even though starting later, would arrive at Jupiter at the original JEO arrival time.
9. Simplify operations. Except for Radio Science, a simple on-state and maintaining nadir alignment for orbiter is all that is required. This could be a significant cost savings.
10. Add other instrumentation as allowed within the TBD NASA-defined cost cap.

In conclusion, we suggest that the Sputnik Plus approach may be preferable to radical descope of JEO for maximally cost-effective achievement of the primary Ocean science objective, confirmation of existence and extent of the Europa ocean. It would at least be useful to approach the descoped mission design from the two directions of Sputnik Plus and JEO Minus to find the optimum interaction that meets both the floor science and the cost cap requirements.

## References

Belton, M. J. S., et al., *New Frontiers in the Solar System: An Integrated Exploration Strategy*, National Research Council, The National Academies Press, Washington DC, 2003.

Cooper, J. F., C. B. Phillips, J. R. Green, X. Wu, R. W. Carlson, L. K. Tamppari, R. J. Terrile, R. E. Johnson, J. H. Eraker, and N. C. Makris, *Europa exploration: Science and mission priorities, in The Future of Solar System Exploration, 2003 - 2013, Community Contributions to the NRC Solar System Exploration Decadal Survey*, ASP Conf. Ser. 272, M. Sykes (ed.), p. 217-252, Astronomical Society of the Pacific, San Francisco, CA, 2002.

Cooper, J. F., R. W. Carlson, R. Dissly, J. H. Eraker, K. K. Khurana, J. T. Pitman, E. C. Sittler, Jr., S. J. Sturmer, and M. C. Wong, *Facts and Suggestions on New Approaches to More Complete Fulfillment of Outer Planets Science Objectives from the 2003 Solar System Decadal Survey*,

Outer Planets Assessment Group (OPAG) Discussion Documents, <http://www.lpi.usra.edu/opag/cooper.pdf>, 2006.

Dodge, R., et al., Key and driving requirements for the Juno payload suite of instruments, conference paper, AIAA Space Conference & Exposition, Long Beach, California, September 18-20, 2007.

Greeley, R., et al., *Europa Jupiter System Mission (EJSM) Exploring the Emergence of Habitable Worlds Around Gas Giants*, JPL D-67959, Task Order NMO711062, NASA Jet Propulsion Laboratory, November 15, 2010.

Squyres, S., et al., *Vision and Voyages for Planetary Science in the Decade 2013-2022*, National Research Council, The National Academies Press, Washington DC, Draft Version, March 2011.