Outer Planets Assessment Group (OPAG) Report
24 – 26 August 2015

NASA's Outer Planets Assessment Group (OPAG) met 24-26 August 2015 at the Johns Hopkins University / Applied Physics Lab in Laurel, MD. OPAG assembles twice per year, engaging the widest community possible. OPAG's role is to assess the current state of outer solar system exploration, discuss goals for future exploration, and identify technology development needed to achieve those goals.

The community is very pleased that there is a new start for a Europa mission and thanks NASA for its continued efforts in this regard. The *Europa Mission* new start will fill what had been an open-ended gap in US-led missions to the outer solar system after the end of the *Cassini*, *Juno,* and *New Horizons* missions in 2017, 2018, and 2019, respectively. With this timely selection of instruments for the Europa mission payload, the community can still access the experience of many of the instrument builders and scientists that built and now operate the payloads of Cassini and Juno in their unique outer solar system environments. ***We commend NASA's selection of a comprehensive payload that will return a wealth of scientific data.***

At this moment, we are reaping the rewards of investments made in the last three decades in outer solar system exploration. We celebrated the achievements of New Horizons at Pluto, and look forward to Cassini observations in the new environments that the proximal orbits will explore. We eagerly anticipate Juno's arrival and Jupiter orbit insertion next year. The challenge that OPAG now faces is maintaining a vibrant outer solar system community during the decade between the end of the Juno mission at Jupiter in 2018 and the return of the first data from the new Europa mission perhaps as early as 2025, but possibly after 2030. At this meeting we discussed three general avenues to keep the scientific community engaged and productive during that decade of down-time: 1) early addition of participating scientists to the Europa mission and/or JUICE, 2) research and analysis (R&A) funding for outer planet research, and 3) use of Earth-and space-based telescopes for planetary science.

The danger of a generational loss of young scientists leaving the field is very real. When we reach the end of funding for current flight missions as they complete their missions, the outer planets science community will rely on R&A funding alone to continue data analysis and pursuit of new hypotheses. The health of the R&A program is an ongoing concern, and we discussed our own responsibilities to help it thrive. With this motivation, we held a "science nuggets" workshop to teach everyone how to craft a science nugget on their own research, and thereby promote outer solar system research among the national stakeholders. The workshop was followed by presentations of new nuggets. The current flight projects do a great job of producing nuggets, but once the project infrastructure is gone we as individual

scientists will need to step up. Writing nuggets will enhance communication of NASA Planetary Science Division (PSD) R&A results in the future.

We continued our discussions of how to power spacecraft far from the Sun, i.e. when solar power can be used and when only radioisotope power systems are adequate. Solar power technologies are becoming more attractive for select outer planet missions, but the far reaches of the solar system will require continuation of the nascent domestic Pu238 production. The Nuclear Power Assessment Study represents a major step in evaluating future technology development needs and we are pleased that it has been released.

The remainder of the meeting was focused on the new OPAG science goals document, its over-arching themes, and the possibility of an *Ocean Worlds program*. We are anticipating the work ahead to define the next decadal survey as well as the studies, discussion and prioritization of goals that must precede this endeavor.

OPAG FINDINGS

1. Europa Mission.

1.a. OPAG lauds the progress being made on the new Europa Mission, in particular the selection of a comprehensive suite of very capable science instruments for the payload. OPAG continues to offer its firm support for the *Europa Multiple Flyby* mission. This mission is the ultimate result of more than a decade of ever more detailed study and down-selects, and offers paradigm-shifting, flagship-level science at Jupiter's ocean moon. We are pleased that the mission has passed KDPA and entered Phase A and that the selected instrument teams have begun work on designing their scientific instrumentation.

OPAG finding: OPAG is pleased with the selection of a capable comprehensive payload and strongly encourages NASA to continue to move forward with the Europa Multiple Flyby Mission as quickly as possible.

1.b. On-ramps for Europa Scientists. We are very pleased with the selection of capable instrument teams. However, many talented scientists were not selected due to a variety of factors (e.g., pressure to keep teams small, or to join only a single team). Adding these scientists during phase A would allow the Project to tap a broader depth of experience in the design and integration of the instruments as well as mission design and science operations. Emphasis on the addition of early career scientists will also lead to a stronger and more diverse team of scientists ready for the future.

OPAG Finding: OPAG strongly encourages NASA to consider judiciously adding participating and interdisciplinary scientists to the Europa Mission. Adding

these scientists during phase A would improve the overall scientific return of the Mission and help train a generation of young scientists.

1.c. JUICE coordination. We note that with two missions in operation at Jupiter at the same time, overall scientific return will be enhanced by the foundation of a standing Europa mission - JUICE coordination working group.

OPAG Finding: Science return of both JUICE and the Europa Mission will be enhanced by a standing science coordination working group, which we encourage NASA to form.

2. Ocean Worlds Exploration Program. Exploration of the outer Solar System reveals a vast array of amazing worlds. Among the most astonishing discoveries are those of liquid water present at Europa, Titan, and Enceladus, in probable "oceans" beneath their icy surfaces.

The 2016 budget proposal from the U.S. House Appropriations Committee calls for the creation of an "Ocean Worlds Exploration Program" which would fund new missions to explore ocean worlds. From the proposal: "Many of NASA's most exciting discoveries in recent years have been made during the robotic exploration of the outer planets. The Cassini mission has discovered vast oceans of liquid hydrocarbons on Saturn's moon Titan and a submerged saltwater sea on Saturn's moon Enceladus. The Committee directs NASA to create an Ocean World Exploration Program whose primary goal is to discover extant life on another world using a mix of Discovery, New Frontiers and flagship class missions consistent with the recommendations of current and future Planetary Decadal surveys."

OPAG supports an Ocean Worlds Exploration Program, reflecting the recognition by Congress that the discovery of potentially habitable environments in the outer solar system has the capacity to grip the public's imagination, increase programmatic attention and funding on outer solar system science, focus our best efforts for advanced exploration technologies (which can be tested in Earth's cryosphere and oceans), and generate historic astrobiology discoveries in our time.

OPAG Finding: OPAG strongly endorses the creation of an Ocean Worlds Exploration Program. The OPAG community looks forward to being deeply engaged in the definition of the science goals of this program to maximize science return.

3. The Legacy of Cassini. Cassini's data return from the Saturn system continues to inspire, enchant and challenge us. During its final year, the Cassini Grand Finale Mission will produce many hundreds of gigabits of fundamentally new data, including unique near-field gravity measurements, novel in-situ sampling of

atmospheric constituents and magnetic fields and plasmas. OPAG is very pleased that NASA plans to continue the Cassini Data Analysis Program (CDAP) after the conclusion of the Cassini/Huygens Mission. We are concerned that to accommodate the need to analyze Cassini's wealth of unique new data at the end of the mission the normal level of support for the CDAP program may be inadequate. We encourage PSD to monitor the selection levels and be prepared to augment CDAP funding if needed in the future.

OPAG finding: The CDAP program has been incredibly successful in funding analysis and modeling of the wealth of data collected by Cassini. Continuation of CDAP will help to bridge the large gap before the next outer solar system mission and ensure that a knowledgeable cadre of outer planet scientists will be ready to analyze data from the Europa mission, as well as other future outer planet missions. The wealth of new data collected at the end of the Cassini mission may require more time and resources than has typically been available to analyze adequately.

4. Power Systems. There are many potential planetary missions that require use of Radio-isotope Power Systems (RPS), including nearly all that would venture beyond Jupiter. These missions range from Discovery class to flagships. Ideally RPS would be offered GFE for Discovery missions in a continuing effort to "level the playing field" for outer solar system missions in the Discovery program. RPS is currently the only viable option for ice giant missions and long-duration missions to Titan's surface and lower atmosphere. OPAG supports continued investment in RPS production and efficiency-enhancing technologies, but is concerned that the planned 400 g/year production rate falls far short of the 1.5 Kg/year need identified previously. We also acknowledge the improved capability of solar power solutions, and support a smaller but significant investment in new solar and energy storage technology.

OPAG finding: The re-start of domestic production of Pu238 is a significant achievement without which continued exploration of the outer solar system is severely curtailed. It is important to continue investments in future technologies that offer end-of-life improvement over the current MMRTGs. A small, but significant, investment in solar power and energy storage technologies is also warranted.

5. New Frontiers. We celebrate the success of NASA's first New Frontiers mission, the New Horizons revelations at Pluto. OPAG welcomes and strongly supports NASA's continuing efforts to put the New Frontiers program on a healthy mission cadence with the news of an Announcement of Opportunity in 2016 for a New Frontiers mission. These medium-class PI-led missions allow the NASA planetary

science community to target regions of great importance in the solar system with capable missions of moderate breadth.

OPAG lauds NASA's efforts to produce a reliable supply of Radioisotope Power Systems (RPS) for use across all mission categories and we encourage NASA to allow RPS's in the upcoming New Frontiers #4 (NF4) Announcement of Opportunity (AO). The seven missions called for in the 2013 Decadal Survey for NF4 + NF5 each have their own challenges, and allowing flexibility in how they are powered ensures that NASA and the community can field the most capable and scientifically compelling mission possible.

OPAG Finding: We are pleased that an AO for New Frontiers will come out in 2016. OPAG encourages NASA to make Radioisotope Power Systems an allowed option for the New Frontiers #4 mission.

6. "Vision and Voyages" Decadal Survey. OPAG continues to support the Decadal Survey. The 2013 Planetary Science Decadal Survey document, Vision and Voyages, describes a compelling program for planetary exploration in the 2013 to 2023 time span. We support those recommendations for New Frontiers missions and we think that maximizing the choices available for the upcoming NF4 opportunity by combining the Vision and Voyages recommended lists for NF4 and NF5 will allow selection of the most compelling technology-ready science mission.

OPAG finding. We suggest, from a scientific and technological perspective, that the lists of possible missions from Vision and Voyages for New Frontiers 4 and 5 be combined for the 2016 NF4 Announcement of Opportunity.

7. Preparation for the next Decadal Survey. Two areas of preparation are needed in advance of the next decadal survey: a) mission studies, and b) collection of process lessons-learned with recommendations for the next survey.

7.a. Ice Giant Mission Study. OPAG was very pleased to note the announcement of studies for Ice Giant orbiter missions. OPAG thanks NASA PSD for initiating this effort, which is consistent with the recommendations of the past two decadal surveys for planetary science. OPAG is particularly pleased to hear that the science community will be engaged in this process from the outset. OPAG notes that finding a means for international collaboration for ice giant mission studies would be advantageous, given the broad interest in these bodies as evidenced by meetings and mission proposals abroad.

We believe that additional studies are also needed to inform the next Decadal Survey which will likely recommend missions to Titan, follow-on to the Europa Mission, Enceladus plume investigations, etc.

OPAG Finding: OPAG endorses PSD's direction that the next-in-line flagship priority of the 2013 Decadal (Uranus orbiter with probe) be used now to convene an ice-giant Science Definition Team (SDT) to steer a comprehensive mission concept study. OPAG urges other Decadal Survey preparatory studies and commits to supporting NASA in developing and documenting credible mission concepts to inform the next Decadal Survey.

7.b. Future Decadal Survey Structure. A number of structural/process decisions had an impact on outer solar system mission recommendations in the Decadal Survey, including (but not limited to) putting all outer solar system moons in one panel, and requiring that preliminary mission concepts be fully costed (thus limiting the innovative nature of a competitive process). Although the NRC recently completed a Survey of Surveys, these were high-level general results. OPAG feels that lessons learned at the deeper PSD level could be collected from the planetary community to feed forward to the next planetary Decadal Survey. We will pursue this at our next meeting.

OPAG Finding: We suggest that a query go out to the planetary science community to solicit feedback with regard to how the next Decadal Survey is structured.

8. Earth-based observations for mission support. Earth-based, telescopic observations of planetary objects being studied by spacecraft enable greater science return than the mission itself can provide. These assets provide context to the spacecraft observations, and assist in targeting observations to optimize science return from the mission. The Galileo, Cassini, and New Horizons missions have demonstrably benefitted from Earth-based observations that helped target their remote observations (such as the satellite flux tube footprints) and yielded contextual information on Io's volcanoes and Titan's and Jupiter's clouds, for example.

Some of the key elements for such support are Earth-orbiting spacecraft that are Astrophysics division assets, such as HST, Spitzer, Kepler, and JWST. Recent observations by HST have enabled detection of several dozen KBOs, two of which are possible targets for the New Horizons extended mission. The giant planet atmospheres are dynamic places, and our understanding of them requires frequent monitoring. We are pleased that HST and Kepler support such monitoring programs.

OPAG finding: To leverage greater science return from active missions, OPAG continues to encourage NASA to support Earth-based observations in general, as well as observations with Earth-orbiting facilities operated by the Astrophysics Division.

9. Research and Analysis (R&A) Program. R&A plays an essential role in maximizing science return from NASA's missions, and was recognized by the 2013 Decadal Survey as an essential part of a balanced program of planetary exploration. While almost all "Excellent" proposals are getting funding, innovative but less familiar proposals could be passed over in favor of the more conventional fare. Many "Very good" proposals would yield "Excellent" science results if given the opportunity. The looming decade-long gap in outer solar system missions means that many scientists with that expertise will have to be funded largely or even purely through R&A. We are concerned that we will lose vital skills and knowledge as many outer solar system scientists may be forced to leave the field or seek alternative subjects to study. The Cassini mission has not only been the primary source of support for Cassini data analysis, but a substantial support for the Outer Solar System science community overall, i.e. Cassini's end of mission will raise the pressure on R&A across the board. We are pleased that the National Research Council has accepted the charge to evaluate the re-structured R&A program and we urge that looking at the challenges the outer planets community will face in the coming decade be part of their task.

OPAG finding: OPAG finds that increased funding to the R&A programs would improve selection rates and allow more excellent peer-reviewed planetary science and data analysis to proceed. We note the looming pressure on R&A as science mission support for scientists comes to a close.

Meeting Outline

Presentations were heard as follows:

Monday, 24 August 2015

Welcome, meeting objectives, logistics
Candy Hansen, Planetary Science Institute

Planetary Science Nuggets
Jim Green, NASA Headquarters

How to Construct a Nugget
Scott Edgington, Jet Propulsion Laboratory

Planetary Science R&A Program Update
Michael New, NASA Headquarters

NASA Planetary Science Division Report
Jim Green, NASA Headquarters

Outer Solar System Exploration
Curt Niebur, NASA Headquarters

Outer Planets' Exploration Goals Introduction
Candy Hansen, Planetary Science Institute

Europa Mission Update
Bob Pappalardo, Jet Propulsion Laboratory

Europa Mission Instruments;
Report from each instrument PI:
UVS: Kurt Retherford, SWRI
EIS: Zibi Turtle, JHU/APL
MISE: Diana Blaney, JPL
eTHEMIS: Phil Christensen, ASU
REASON: given by Wes Patterson, JHU/APL
ICEMAG: Carol Raymond, JPL
PIMS: Joseph Westlake, JHU/APL
MASPEX: J. Hunter Waite, SWRI
SUDA: Sascha Kempf, University of CO

Tuesday, 25 August 2015

JUICE Mission Update
Olivier Witasse, European Space Agency

ESA's M-Class Missions
Favio Fabata, European Space Agency

Space and Defense Power Systems: Program Update
Rebecca Onuschak, Department of Energy

Solar Power and Energy Storage
Pat Beauchamp, Jet Propulsion Laboratory

Progress through Decay
Ralph Lorenz, JHU/ Applied Physics Laboratory

New Horizons at Pluto
Alan Stern, Southwest Research Institute

Juno Mission Status
Scott Bolton, Southwest Research Institute

Cassini Solstice Mission
Linda Spilker, Jet Propulsion Laboratory

Rings Book
Matt Tiscareno, Jet Propulsion Laboratory

Enceladus and Friends Conference
Paul Schenk, Lunar and Planetary Institute

Technology poster session overview
Pat Beauchamp, Jet Propulsion Laboratory

Technology Poster Session
The list of presenters and posters is on the OPAG website: www.lpi.usra.edu/opag/

Wednesday, 26 August 2015

Solar System Observations with Spitzer
Lisa Storie-Lombardy , California Institute of Technology

The Hubble 2020 Outer Planet Atmospheres Legacy (OPAL) Program
Amy Simon, NASA Goddard Space Flight Center

Kepler Outer Planet Observations
Amy Simon, NASA Goddard Space Flight Center

James Webb Space Telescope
Stefanie Milam, NASA Goddard Space Flight Center

ESO Workshop Report
Stefanie Milam, NASA Goddard Space Flight Center

Show your nugget (posted on OPAG website)

Outer Planets' Exploration Program Potential
Candy Hansen, Planetary Science Institute