Findings from the Europa Science Definition Team Plume Advisory Meeting

The potential existence of large plumes of water vapor emitted from Europa's surface has exciting implications for future spacecraft exploration of this icy world. Although the evidence from Hubble Space Telescope observations presently awaits confirmation, the analogy to active plumes at Enceladus has motivated discussion of how the Europa Clipper mission concept would detect and characterize plumes.

On June 2-3, 2014, NASA's Europa Science Definition Team (SDT) held its final meeting at the Johns Hopkins University Applied Physics Laboratory (JHU/APL), and the implications of potential eruptive plumes at Europa was a key agenda topic. The attendees included members of the SDT, Pre-Project personnel from the Jet Propulsion Laboratory (JPL) and JHU/APL, and a diverse group of 37 invited experts from across the planetary science community. The group was tasked with: identifying the highest priority constituents and species potentially entrained within such plumes; providing guidance regarding plume density modeling for engineering and scientific analyses; and identifying measurement techniques needed to characterize plumes and their materials. The format used "seed" presentations to spur extended discussion of these topics. Presentations and discussion were divided into four topical areas: 1) review of Europa datasets illustrating potential evidence for eruptive plumes; 2) lessons learned at Enceladus for application at Europa; 3) plume density and dynamics models (working toward a plume reference model); and 4) plume composition and astrobiology (what constituents from ice or liquid reservoirs?). The group concluded with general discussion of how Europa plumes could best be explored using the Europa Clipper mission concept. The day of short presentations and discussion on June 2 led to summary presentations by the discussion leads for each of these topical areas, that were provided to the SDT on the morning of June 3 (Appendix 1).

Based on this input, the SDT then reached consensus on 6 key findings:

1. ***Evidence for Europa eruptive plumes is intriguing but not definitive. Plumes have exciting science potential in exposing subsurface material but today remain unconfirmed; moreover their source is unconstrained.***

   Since the exciting Dec 2012 report of a region of concentrated H and O emissions in Hubble Space Telescope (HST) data from one set of observations, follow-on space and ground-based telescope observations have yet to confirm the potential plume observation. Plumes are a definite possibility at Europa, based on the recent HST findings as well as indications from previous spacecraft missions, but alternative hypotheses are viable.

2. ***Plumes are currently unpredictable and, if they exist, could have spatial or temporal variability that is plausibly cyclical, episodic, or sporadic on***

uncertain time scales and with uncertain location; this range of possibilities should be considered when developing potential observation strategies, using the payload ultimately selected by NASA.

Plumes at Enceladus originate from a unique geological province that is exceptionally geologically active, and have been linked to the Enceladus tidal cycle. Europa, more than 400 times the mass of Enceladus, shows signs of recent geologic activity across its entire surface. Anomalies detected in Europa's tenuous atmosphere in prior decades could plausibly be linked to plume activity, but they also suggest that plumes might not persist as they have at Enceladus. Future observations could plausibly reveal plumes erupting from anywhere on Europa on time scales that are not currently predictable, creating both opportunities and, less likely, potential hazards. A mission to Europa should be capable of observing Europa globally and targeting regions of interest as they are identified. Such a mission must have a suite of scientific instruments capable of discerning and understanding the signatures of plumes.

3. ***The mission objectives recommended for Europa by the Planetary Science Decadal Survey[*] remain fully applicable and valid, and based on the available evidence, plume investigations should not drive Europa mission concepts.***

   Eruptive plumes could provide a window into the ocean of Europa, so a future Europa mission should be able to capitalize on the science potential of plumes if they occur. At the same time, it remains critical to confirm the presence of an interior ocean, characterize the satellite's ice shell, and enable understanding of its geologic history. These goals, specified by the Decadal Survey, provide required context for assessing Europa's potential habitability.

4. ***The Cassini experience at Enceladus shows the great scientific value of a broad and capable suite of instruments in addressing plume science.***

   The Cassini science team discovered and characterized the Enceladus plume through a combination of field and particle measurements (magnetometry, gravity, plasma, ions and neutrals, and dust) combined with imaging over a broad wavelength range (ultraviolet, visible, infrared, and thermal). The plume source, composition, and dynamics could not have been so well understood without the combination and synergy provided by these combined instrumental techniques.

5. ***The Europa Clipper tour design and operations concept should remain adaptable to possible future plume discoveries.***

[*] Vision and Voyages for Planetary Science in the Decade 2013-2022. National Academies Press.

The multiple-flyby approach to investigating Europa's habitability from orbit around Jupiter provides consistent opportunities to observe eruptive plumes with appropriate viewing geometries during Europa's entire cycles of tidal and magnetic field interactions. The trajectory design should remain adaptable to plume findings in order to take advantage of discoveries.

6. ***Further searches for, and research into, possible plumes will help to guide decisions on how to optimize investigations of plumes with Europa Clipper; moreover, the plausible characteristics of Europa plumes should be analyzed and modeled for consideration of spacecraft low-altitude safety.***

   Future observations, along with mining of existing data, may help to constrain the presence, frequency, and characteristics of possible plumes. Such improved understanding may allow for pre-encounter optimization of trajectory and search techniques with the Europa Clipper payload selected by NASA. Modeling of the physics and chemistry of potential eruptive plumes will aide in bounding the environment that a spacecraft flying low through plumes (within 10s of kilometers of Europa's surface) would need to safely manage.