Europa Plume Advisory Meeting Report

Organizers:

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Purpose of the Europa SDT Plume Advisory Meeting

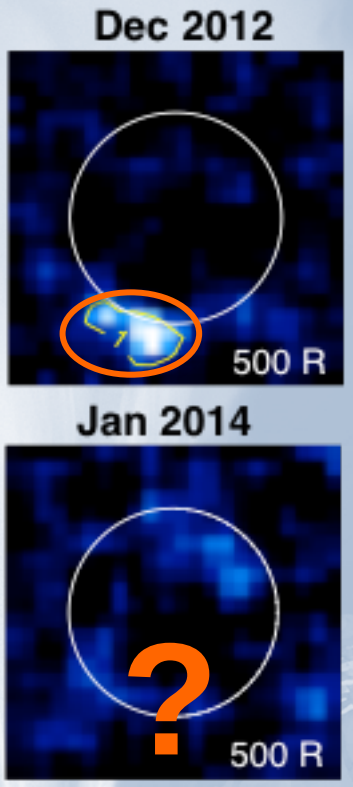
- ***How can Clipper explore Europa plumes?***
- The potential existence of large plumes of water emitted from Europa's surface has exciting implications for what the Europa Clipper mission might encounter and investigate with regard to the habitability of this icy world.
- While the evidence from Hubble Space Telescope observations presently awaits confirmation, the analogy to active plumes at Enceladus has motivated discussion of how the Clipper would be able to detect and characterize plumes if they were found.

Purpose of the Europa SDT Plume Advisory Meeting

- To better inform the Europa Science Definition Team (SDT) and the Europa Clipper study team, attendees were asked to identify the highest priority constituents and species potentially entrained within such plumes.
- Advice regarding plume density modeling for engineering and scientific analyses is also sought.
- A discussion of the measurement techniques needed to characterize plume materials will help guide the science and reconnaissance measurements for the Clipper.

UPDATE: Europa Plume HST Campaign 2014/2015
PI Lorenz Roth (Southwest Research Institute)

- Previous observations:
  - Plume detection in Dec. 2012 when Europa was near orbital apocenter in HST/STIS UV images of H and O emissions
  - Plume activity potentially connected to orbital phases
  - But: No confirmation in subsequent HST/STIS observations in January and February 2014 at similar orbital positions
- New Cycle 22 Campaign with 58 observing orbits during 23 HST visits to Europa
- Comprehensive approach to systematically scan potential variability of plume activity and detectability
- Primary goal: Constrain plume frequency & locations
- Utilizing successful UV aurora technique and new UV absorption mode

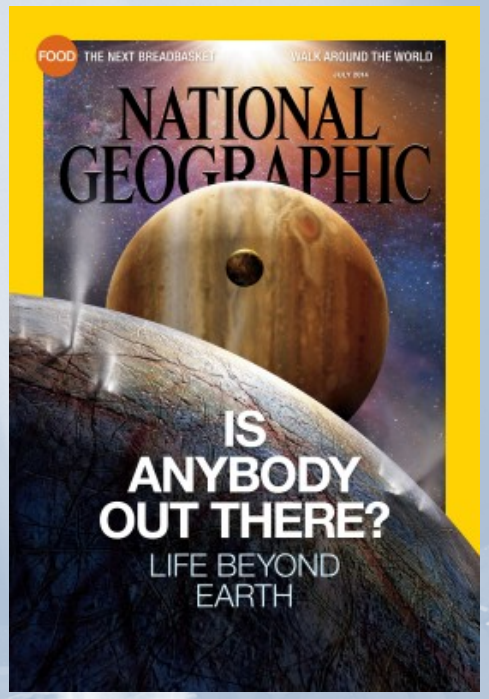


UPDATE: Europa Plume HST Campaign 2014/2015 Comprehensive Approach

- We have identified 5 potential variability sources:
  1) Plume activity varies with tidal stresses
  2) Plume activity for an individual vent source is episodic with an as yet unconstrained frequency
  3) Plumes arise at numerous global locations with long periods of dormancy for any given site
  4) Plume signals in Europa's aurora are most detectable when the plasma environment is suitable
  5) Plumes are detectable only when several vents are aligned with the line-of-sight

- With 23 visits around Jupiter opposition (Feb. 2015) between Nov. 2014 and May 2015 we will cover:
  a) Various orbital stress periods
  b) Various viewing geometries and surface locations
  c) Long time span (episodic activity)

Europa plumes on NGM cover July 2014



Meeting Scope (1/3)

- 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 currently conceived Europa Clipper mission would detect and characterize plumes.
- On June 2-3, 2014, NASA's Europa Science Definition Team (SDT) held its final meeting at JHU/APL, and the implications of potential eruptive plumes at Europa was a key agenda topic.

Meeting Scope (2/3)

- A diverse group of 37 invited experts from across the planetary science community joined the SDT and pre-project team members to provide their advisory input.
- 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.

Meeting Scope (3/3)

- 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)**
  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.

On-line Materials

Find Presentations online here:

- http://solarsystem.nasa.gov/europa/docs/PlumeAdvisoryMeetingPresentations.zip

Main page for SDT related materials:

- http://solarsystem.nasa.gov/europa/sdt2013.cfm

SDT Findings Regarding Plumes at Europa

- http://solarsystem.nasa.gov/europa/docs/SDTFinding_v7.1_6-27-14.pdf

Plume Forum Key Findings by SDT

A. 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.

B. Plumes are currently unpredictable and, if they exist, could have spatial and/or temporal variability that could plausibly be cyclical, episodic, or sporadic, on uncertain time scales and with uncertain location; this range of possibilities should be considered in developing potential observation strategies, using the payload ultimately selected by NASA.

C. 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.

Plume Forum Key Findings by SDT

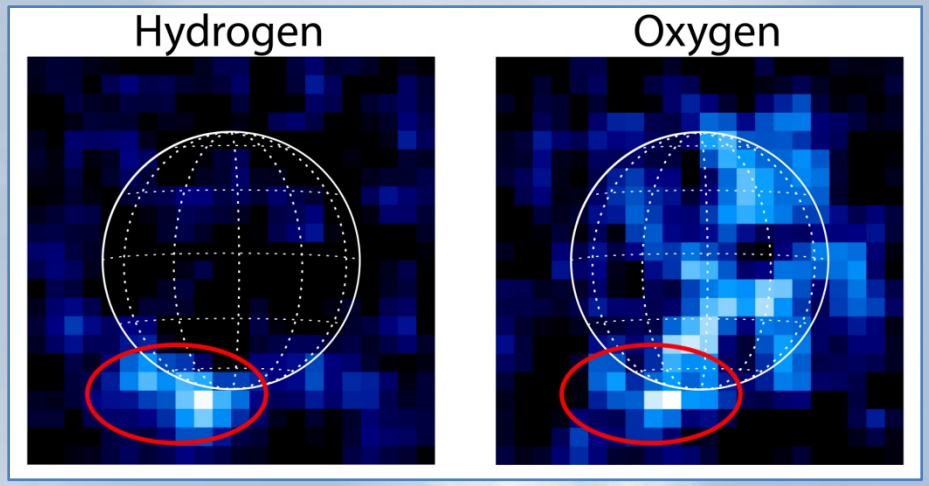
D. The Cassini experience at Enceladus shows the great scientific value of a broad and capable suite of instruments in addressing plume science.

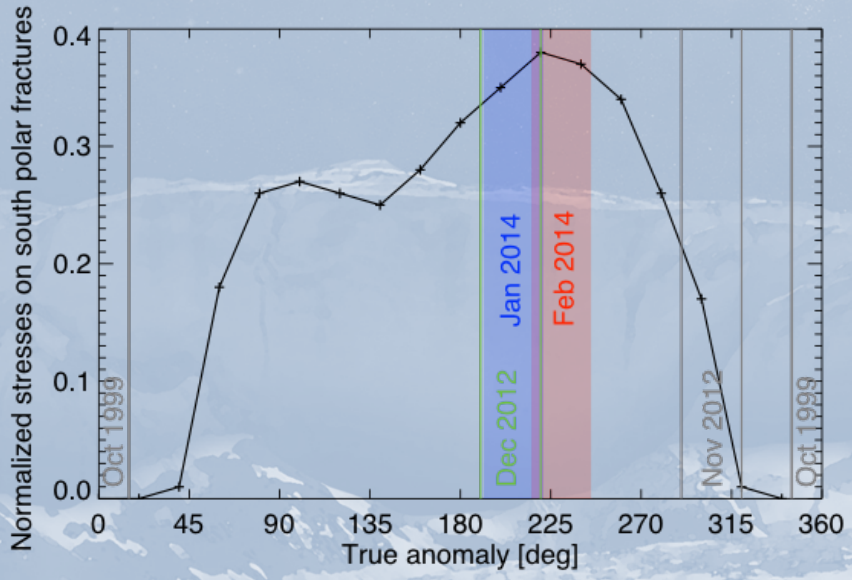
E. The Europa Clipper tour design and operations concept should remain adaptable to possible future plume discoveries.

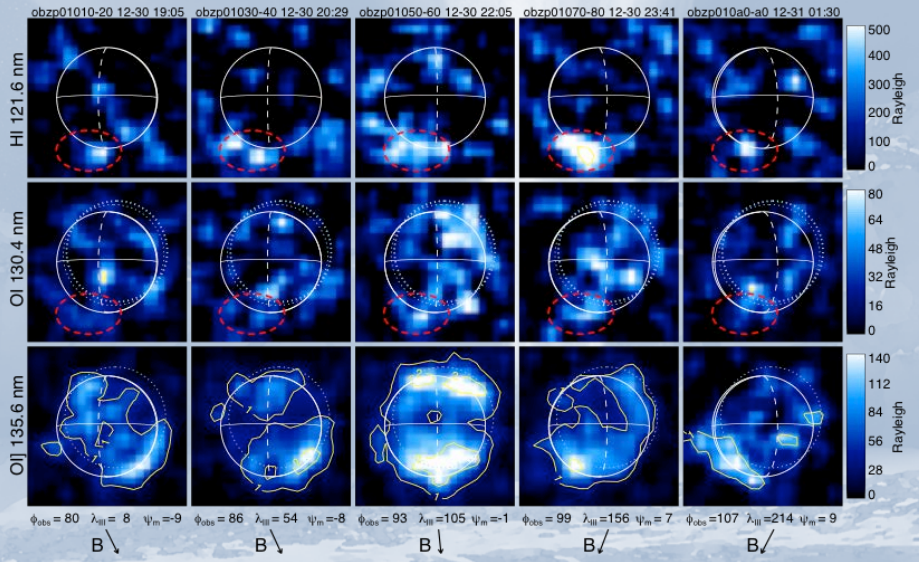
F. Further searches for, and research into, possible plumes will help to guide decisions on how to optimize investigations of plumes with Europa Clipper; moreover the plausible characteristics of Europa plumes should be analyzed and modeled for consideration of spacecraft low-altitude safety.

Hubble Datasets: STIS Far-UV Spectra & Images

- Roth et al. 2014 detections with STIS far-UV spectral images are still best explained by plumes, even if variability not as simple as first thought
- Sparks et al. transit and other far-UV imaging in 2014 have hints of interesting off-limb features (*images not shown here upon request*)

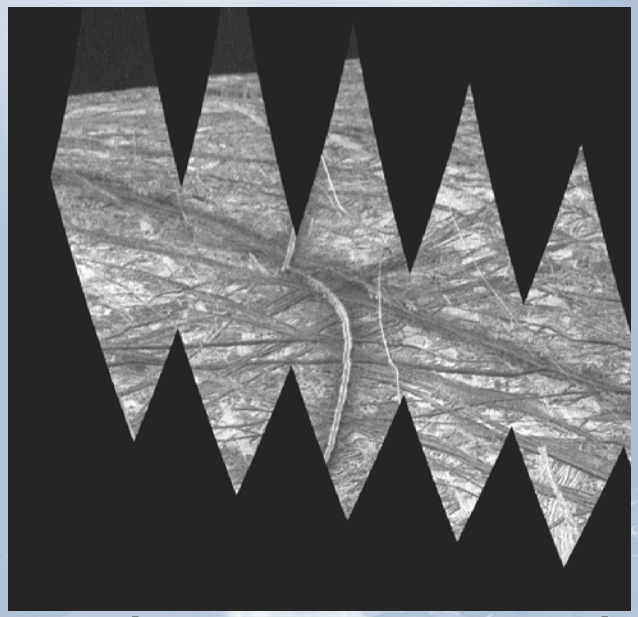






Review of Europa Datasets with Potential Plume Evidence

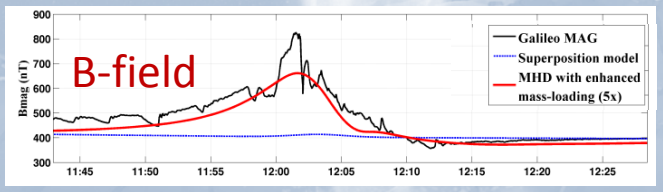
- **Chair - *Retherford***
- Sparks (HST transits),
- Khurana (magnetic environment),
- Kurth (plasma environment),
- Hansen (neutral cloud),
- Westlake (torus),
- Phillips (geological plume search),
- Schenk (surface colors),
- Kempf (Jovian dust),
- Gudipati (irradiated ice chemistry)

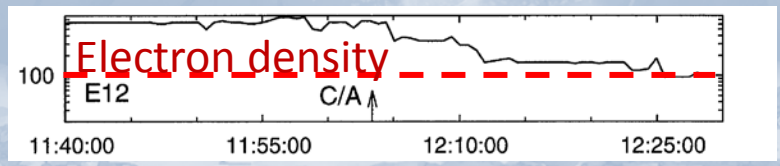


Galileo E19 Plume search mosaic (Phillips et al. 2000)

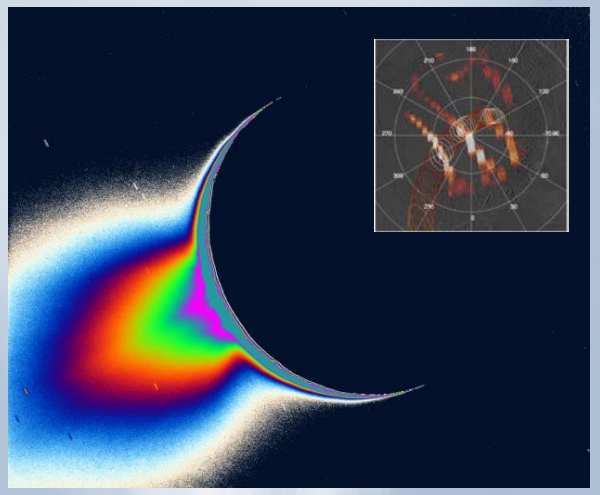
Europa Dataset Findings

- No showstoppers in current datasets that would refute plumes
- New observations are needed
  - Earth-based observations, while difficult to resolve plumes from such a distance, will continue to guide mission decisions all the way through JOI
  - Hubble observations proposed for next cycle would start ±4 months from Jupiter opposition in early Feb. 2015, potentially influencing Phase A studies and Step-2 decisions
- New models are needed to interpret current datasets
  - Plume models – recent RFP from JPL will get these going
  - Europa torus, neutral clouds, and plasma-interaction models would greatly help interpretations of current datasets





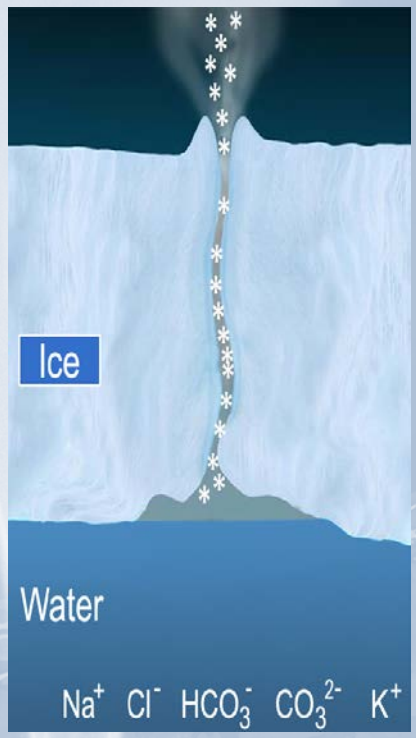
Lessons Learned at Enceladus for Application at Europa



- **Chair – *Hendrix***
- Postberg (plume particles),
- Waite (plume gas),
- Spencer (thermal indicators),
- Nimmo (geophysics),
- Esposito (structure and composition),
- Rhoden+Hurford (Europa plume modeling)

Salient Enceladus Lessons

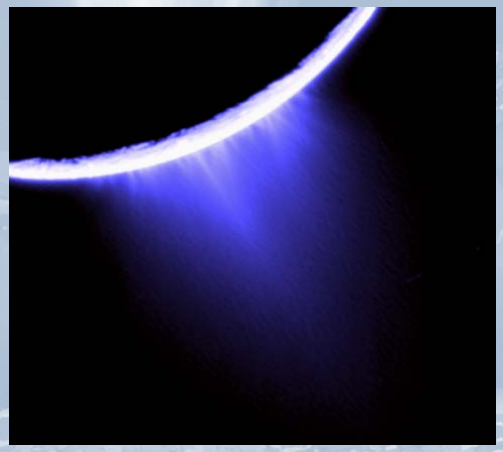
- **Structure and Composition:** Thermal imaging, UV imaging and monitoring, in situ INMS measurements have been critical techniques for studying Enceladus with Cassini
  - These techniques work whether plumes are dust+gas or stealth (gas-only)
  - INMS results have been dependent on flyby velocity
- **Dust in the plume:** Dust measurements have provided critical compositional information that relate plume grains to interior
  - Visible, NIR imaging at high phase allow for grain size distribution measurements and also orbital variability studies
- **Enceladus plume and geophysical models:** Provide information on history and evolution. Perhaps it is more appropriate to compare Europa with Io in terms of activity, rather than Enceladus?
  - Sporadic activity on both? Europa may be a young Io?
- **Flexible & Comprehensive Cassini Enceladus Observations:** Combine monitoring, remote sensing and in-situ measurements
  - Provide multiple approaches to determine habitability, good estimates of plume risk, and identify possible future exploration locations



Plume density and dynamics models

Working toward a plume reference model

- **Chair - *McKinnon***
- Fagents (cryovolcanism),
- Goldstein (eruptions and atmosphere),
- Hedman (plume model),
- Mitchell (plume model in development),
- Teolis (gas dynamics),
- Postberg (dust in situ),
- Ingersoll (dust remote),
- Bolton (microwave technique)
- McEwen (Lyman-alpha imaging)

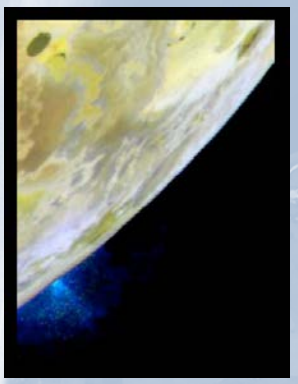


Plume Models: Take Home Points

- Review of cryovolcanism: higher gravity may lead to intermittent eruptions, evolution of gas compositions
- Detailed DSMC models of volcanic plumes and impacts: Io-like patterns expected; transient events from small impacts are similarly rarefied gases
- Gas dynamics models: volatiles don't just erupt but freeze out, hop, migrate. Search for Europa cold traps and evidence of prior venting.
- Plume vent model in development: "follow the fluid" to contribute to understanding ocean, shallow subsurface, subsurface-surface interface
- Application of Enceladus plume dust/ice formation models to Europa
- Enceladus plume model of particle velocities from ISS analyses: Particle size distribution depends on balance of homogeneous and heterogenous nucleation with vent geometry
- Remote sensing techniques: microwave emissions provide another compositional technique (e.g., Rosetta, JUICE); Lyman-alpha imaging for plume identification and structure

Some Higher Order Questions for Plume Models

- How can dynamics models best work together to address the big questions? Can discrepancies be resolved?
- What measurements can we make from "Europa Clipper" in order to understand the dynamics of the (putative) plumes? What do we really need?
- What can mission data contribute to engineering constraints relating to flybys through plumes?
- Can broader science questions be addressed with plume data through modeling (e.g. interior processes)?



Plume Composition and Astrobiology:
What constituents from ice or liquid reservoirs?

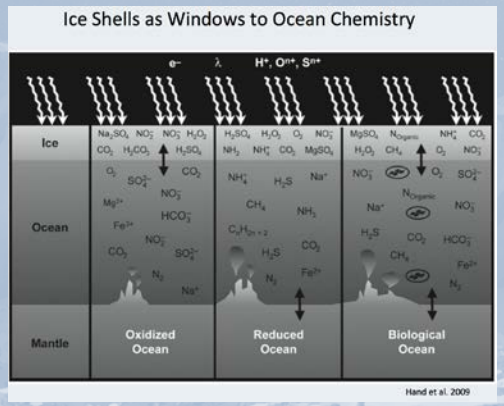
- **Chair - *Kargel***
- Cassidy (atmosphere),
- Glein (ocean composition, Enceladus, Earth),
- Hand (astrobiology),
- Lorenz (astrobiology)
- Kargel (Europa ocean composition)

Astrobiology Session Highpoints

- Tenuous global exosphere composition, tied to surface composition, is important, as it affects what we see in plumes.
- Need improved reflectance spectroscopy for trace species seen on Enceladus's surface (e.g., organics).
- Needed Ocean Measurements for Astrobiology
  - Enceladus ocean pH (acidity state) is likely to be alkaline (pH ~12)
  - Enceladus ocean Eh (oxidation state) is not well constrained but might be reducing (CH_4 and NH_3).
  - Ocean composition, temperature, ice shell thickness are interdependent.
  - Ocean circulation and thermohaline layering are important unknowns.
  - Suboceanic crustal structure may be complex and is not known, e.g., volcanic rocks vs altered serpentinite mud vs. thick salt beds.
- Flying through plume is clearly advantageous , but analogy of detecting life by a flight through imaginary plume of Earth's seawater is sobering.
- Beware of plumes not linked to an ocean - Maybe CO or CO_2 or H_2 plumes

Astrobiology Session Discussion

- We should learn from Cassini's successes (and shortcomings) with Enceladus plumes:
  1. A multi-instrument perspective of the plume is valuable.
  2. Nimble mission planning/flexibility is needed to take advantage of unexpected finds.
  3. Need to balance facilitating plume investigations, but should not re-orient to go after plumes exclusively. Avoid "fishing expeditions".
  4. Mission safety should consider the possible plumes, but over-conservatism is to be avoided (note Galileo plume fly-through at Io, Cassini plume fly-throughs at Enceladus – they survived)



Conclusions

- The Europa Plume Advisory Meeting served its purpose of providing the SDT/NASA a broad conversation on the topic of plumes to inform the Europa mission definition
- Advice was provided on:
  - the highest priority constituents and species potentially entrained within such plumes.
  - plume density modeling for engineering and scientific analyses
  - measurement techniques needed to characterize plume materials
- The Europa Instrument Investigation opportunity will follow its own path from here on

Backup

Agenda

- ***Day 1***
- **08:30 Introduction, meeting goals-McGrath**
- **08:40 Europa Program Update-Niebur**
- **08:50 Europa Clipper status, and science and reconnaissance traceability update-Vance**
- **09:00 Plume Observation Update-Roth**
- **09:10 Review of Europa Datasets with Potential Plume Evidence-*Retherford***
- Sparks (space-based), Khurana (magnetosphere), Kurth (plasma environment), Phillips (geological plume search), Kempf (Jovian dust)
- **10:45 Lessons Learned at Enceladus for Application at Europa- *Hendrix***
- Postberg (plume particles), Waite (plume gas), Spencer (thermal indicators), Nimmo (geophysics), Esposito (structure and composition), Rhoden (Europa plume modeling)
- **13:00 Plume density and dynamics models - working toward a plume reference model-*McKinnon***
- Fagents (cryovolcanism), Goldstein (eruptions and atmosphere), Hedman (plume model), Mitchell (plume model in development), Teolis (gas dynamics)
- **14:45 Plume Composition and Astrobiology: what constituents from ice or liquid reservoirs?-*Kargel***
- Cassidy (atmosphere), Glein (ocean composition, Enceladus, Earth), Hand (astrobiology), Lorenz (astrobiology) Kargel (Europa ocean composition)
- **16:15 General discussion, including measurement needs and techniques:**
- *How can Clipper explore Europa plumes?*

- ***Day 2***
- What do we know?
- What do we need to know? – lab work, new observations (e.g., Earth-based)?
- What measurements should Europa Clipper make?
- **08:30 Reports from topic chairs, 20 mins each, 10 min discussion between**
- **10:30 Wrap-up discussion**
- **10:45 Adjourn Advisory Meeting**
- **11:00 Begin Closed SDT Discussion**