The first direct measurement of water vapor at Europa and possible implications for the magnetospheric environment

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Overview

1. Review: HST detections of possible plume signals
   - Initial detection in emission with HST spectral imaging
   - Possible confirmation in absorption with HST transit imaging / re-analysis of the statistics and systematics

2. Keck IR survey in 2016 and 2017
   - First direction detection of gaseous H_2O at Europa

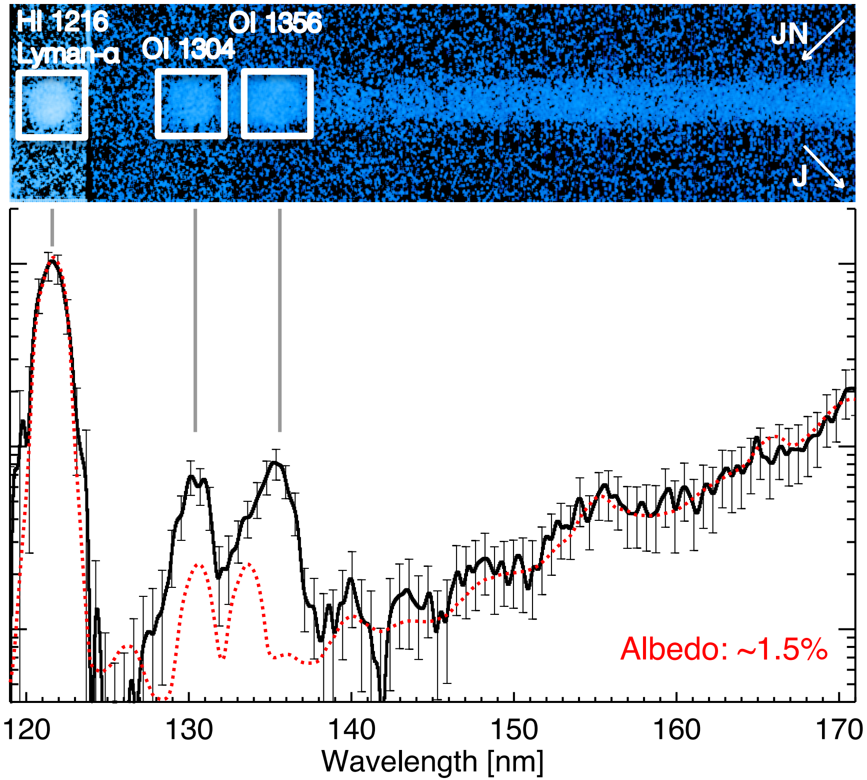
3. Possible effects on the magnetospheric environment
   - Perturbations of fields
   - Effects on particles
   - Effects on mass loading

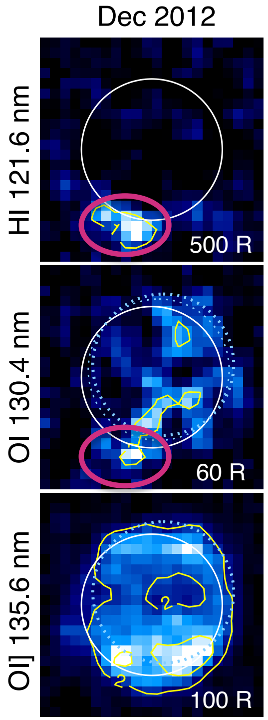
1. HST detections of possible plume signals

HST spectral imaging of atomic emissions

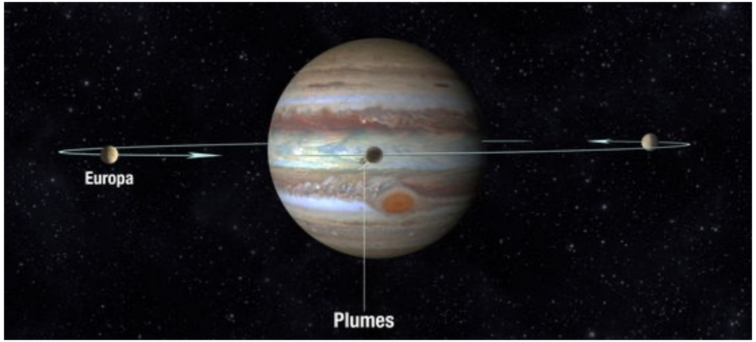
Roth et al. 2014

- Detection of localized emissions surpluses (highlighted in red on the right)
- Relative brightness of the H and O features consistent with H_2O source
- Only 1 detection in 20+ spectral images between 2012 and 2019
- Analysis ongoing

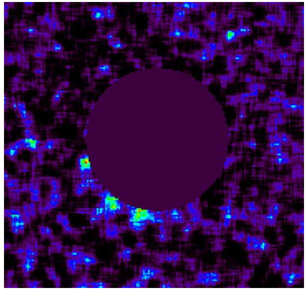




HST imaging in transit of Jupiter

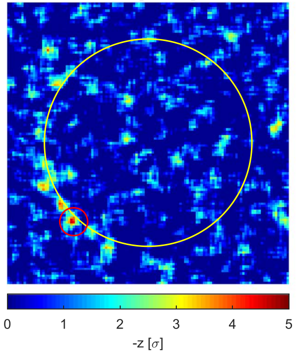


Limb “anomalies” in HST images



Sparks et al. 2016

Statistical outliers in synthetic data

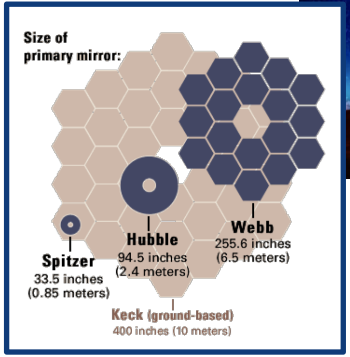


Giono et al. 2020

- Sparks et al. (2016, 2017):
  - Detection of anomalies (negative outliers) above the limb in 4 images
  - Interpreted as local absorption by plumes in Europa’s atmosphere
- Giono et al. (2020):
  - The limb features from Sparks et al. (2016) are consistent with statistical fluctuations
  - The HST transit images *do not provide evidence* for plumes

2. Keck detection of IR emission from H_2O

Keck Infrared observations (2016/2017)

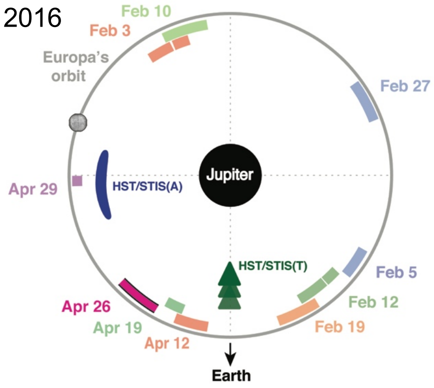


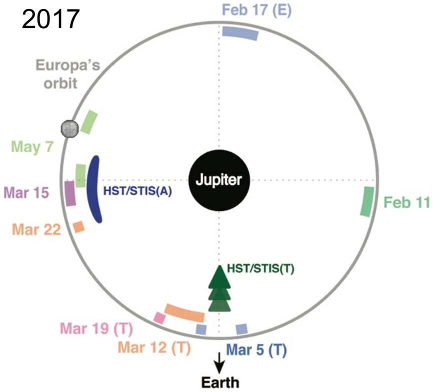
Advantages of infrared observations

- Infrared spectroscopy allows direct observations of water
- Large collecting area
- Key Science Mission Support program through NASA/Keck TAC:
  20 nights in 2016 and 2017

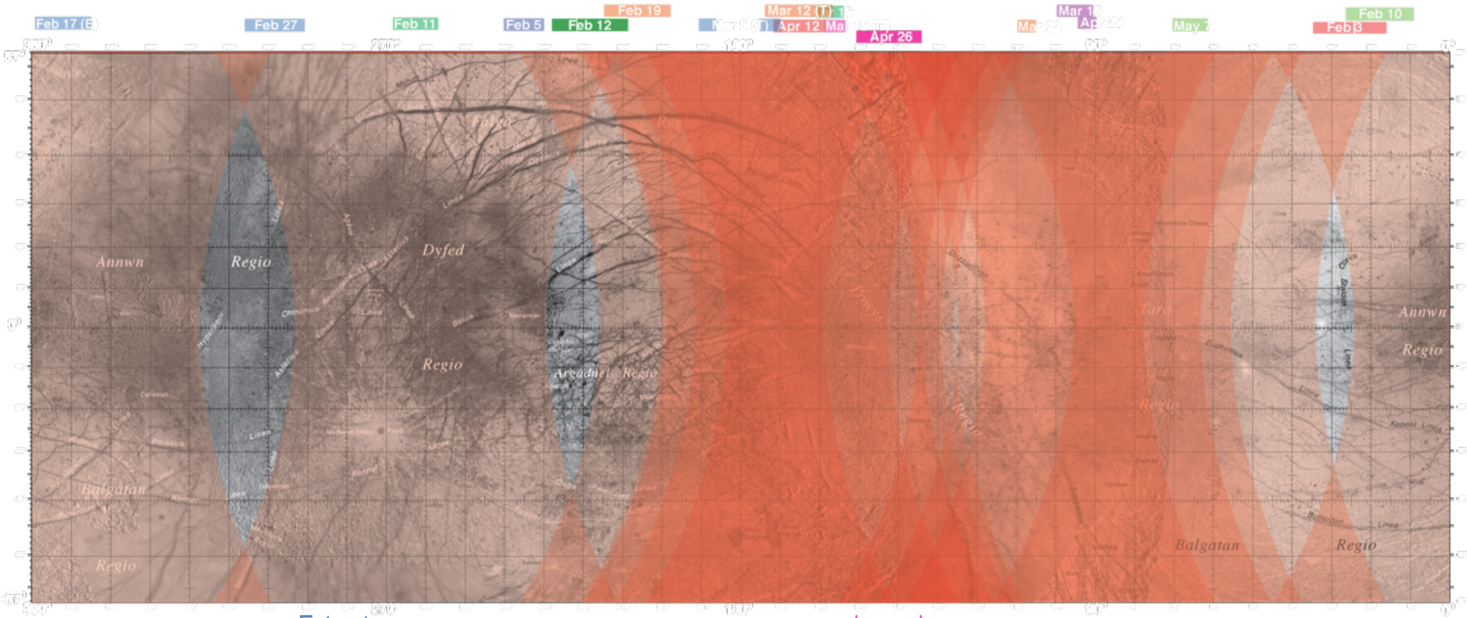
Program strategy and goals

- Search for key species: **water vapor** but also C_2H_6, CH_3OH, CO, HCN, and NH_3
- Longitude-dependent observations / Cadence



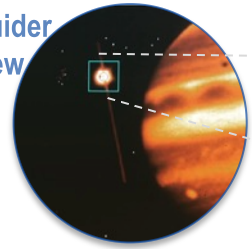


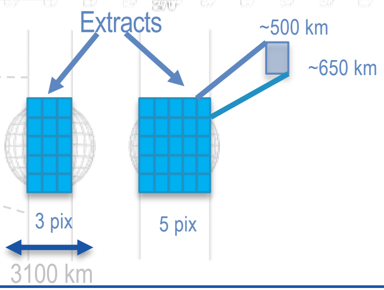
Cadence and coverage



~4 hr clock
(2.5 hr on source)

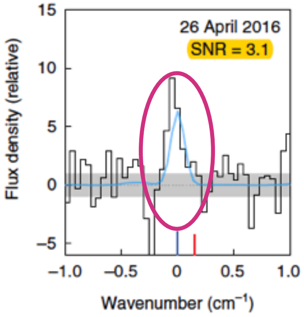
Guider view



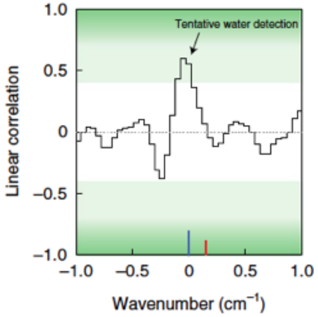


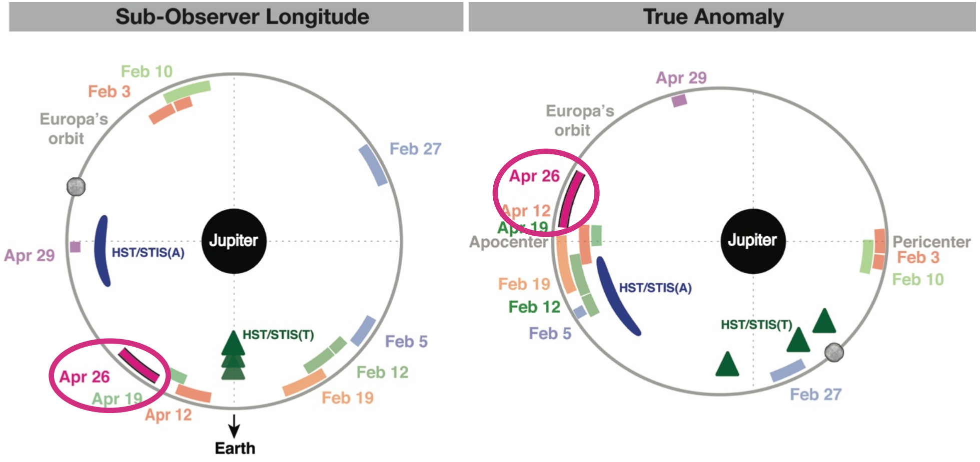
First detection of gaseous H_2O! - 1 marginal detection of 17 observing nights

Co-added residuals (and model) of the seven most significant water lines



Cross correlation

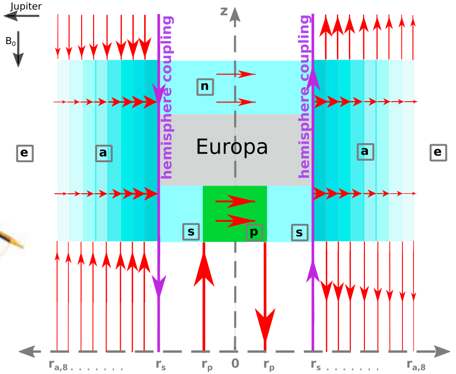


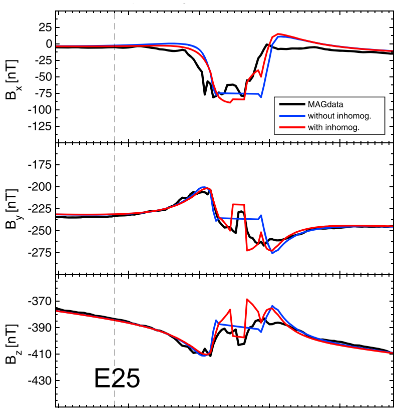


Measurement occurred at sub-observer longitude of ~140° ± 40° (leading hemisphere), near apocenter (true anomaly ~159–176°)

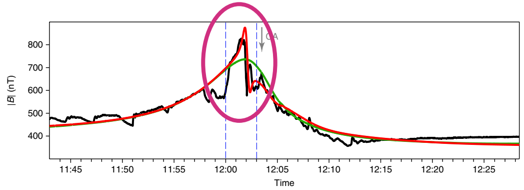
3. Effects on the magnetospheric environment

Magnetic field perturbations – local and in far-field

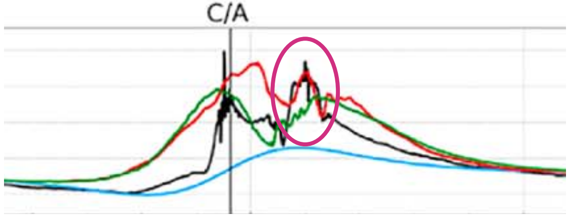




Blöcker et al. 2016 – study of distant flyby / Alfven wing crossing



Jia et al. 2018 – plume E12 flyby data

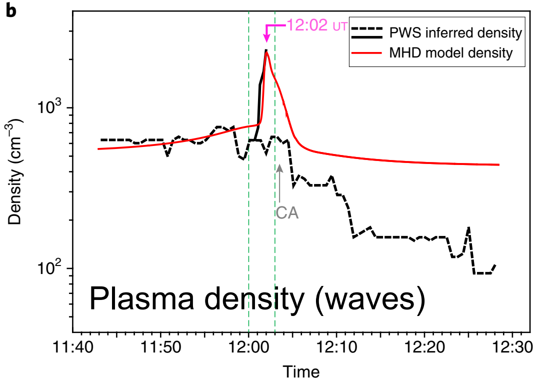


Arnold et al. 2019 – plume in E26 flyby data

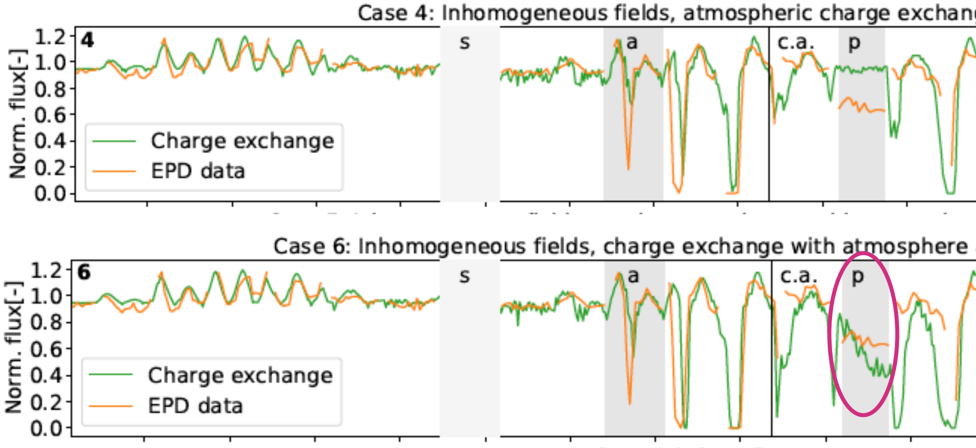
- Local neutral density inhomogeneity generates local conductivity inhomogeneity in Europa's ionosphere
  => such inhomogeneity affects the near and far magnetic field (Blöcker et al. 2016)
- Small wiggles in Galileo magnetic field data during E12 and E26 are consistent with numerical simulations of Europa's plasma interaction that included local plumes (Jia et al. 2018, Arnold et al. 2019)

Effects on thermal plasma and energetic particles

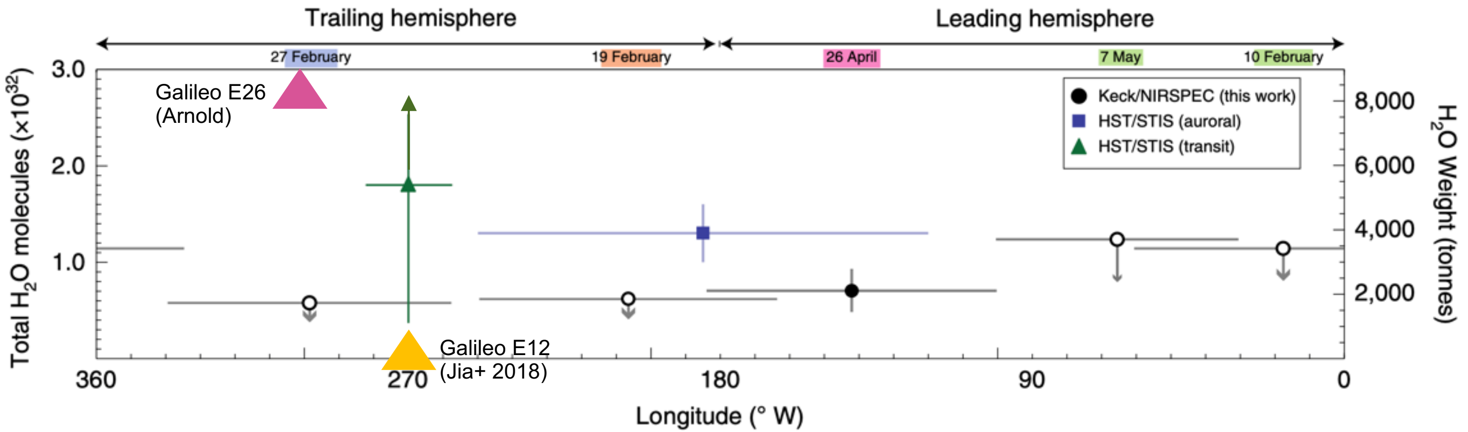
- Plume can cause local increase of bulk plasma density due to electron-impact ionization of plume material
- Jia et al. 2018: Jump in electron density derived from upper hybrid frequency / Galileo PWS
- coincident with B perturbation during E12 flyby / consistent with plume



- Huybrighs et al. 2020: Plumes affect energetic particles via modified fields and charge exchange
- Plumes possible sources of ENAs
- Galileo EPD data consistent with plume during E26 flyby



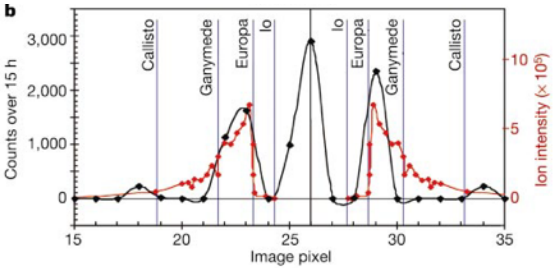
Longitudes, H_2O abundance and detection rate - plumes everywhere?



- Detections so far indicate plumes at various locations with differing amounts of water derived and differing rates of abundance (detection rates, duty cycles):
  - Plume detections reported during 2 of the 2 close (<500 km) flybys of Galileo (100%)
  - Keck IR survey detected H_2O on 1 of 17 observing nights
- So far, no consistent picture of occurrence/detection rate and locations!

Mass loading from Europa – atmosphere or plumes?

- Presence of neutral torus in Europa's orbit suggested by observations of ENA's and pitch angles anomalies (Mauk et al. 2003, Lagg et al. 2003, and later papers)
- Mass loading from sputtered atmosphere is sufficient to supply the torus (Smyth & Marconi, 2006; Smith et al. 2019)
- <u>No indications for mass loading from plumes</u>

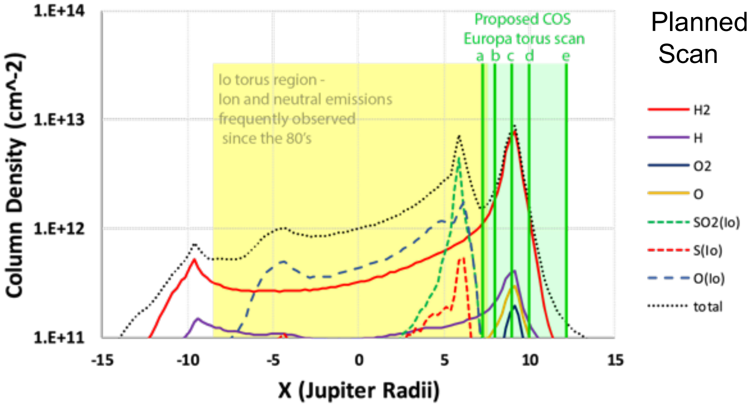


ENA detection near orbit Europa
- Mauk et al. 2003

➢ New HST/COS program: "Confirming the Europa torus" (HST #15848, PI Roth)

➢ scheduled for 4th of July 2020!

➢ possibly helps to constrain torus sources



Planned Scan

Summary

1. HST detections of possible plume signals
   - HST spectral emissions: Still only 1 detection of local surpluses
   - HST transit absorption: Re-analysis suggests that limb anomalies are statistical outliers

2. Keck IR survey in 2016 and 2017
   - First direction detection of gaseous H_2O at Europa at 3.1 sigma

3. Possible effects on the magnetospheric environment
   - Studies suggest that different plumes (different location and amount of water) were present at both low-altitude flybys of Galileo
   - Generally: Strength of effects of plumes on the environment much depends on
     1. *the duty cycle of plume activity*
     2. *the relative neutral gas abundance of an active plume vs the global sputtered atmosphere*

Some references

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