Europa's Atmosphere and Plumes Through Ultraviolet Observations

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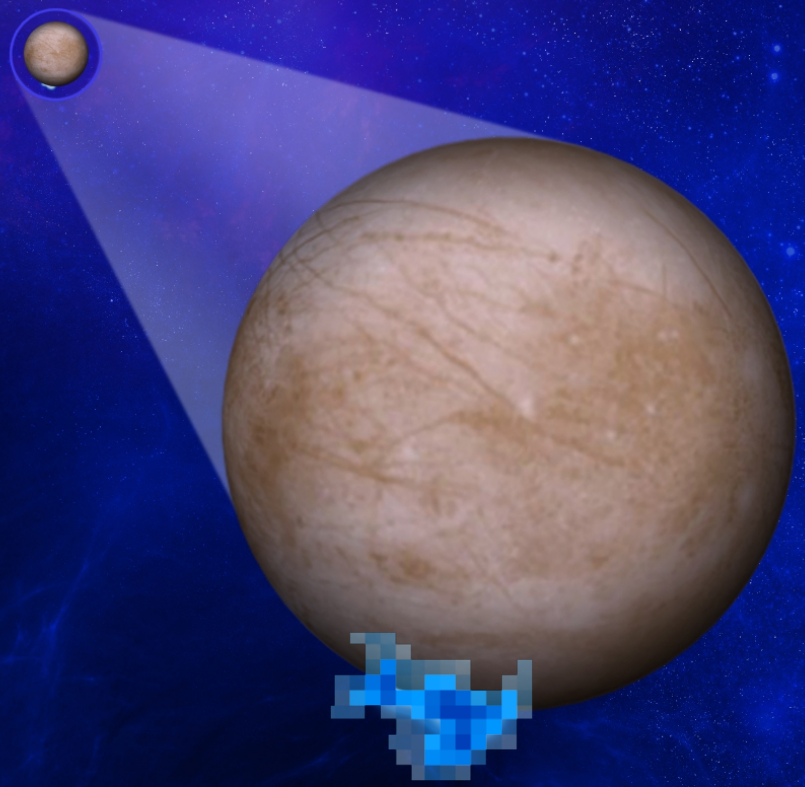
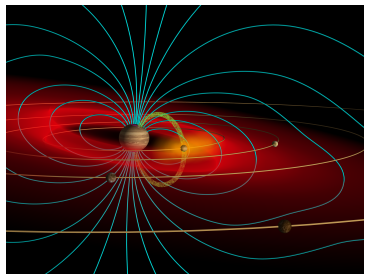


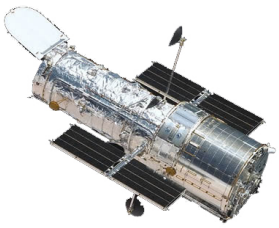
Joachim Saur, Kurt Retherford, Darrell Strobel,
Paul Feldman,Melissa McGrath, Francis Nimmo,
John Spencer, Nickolay Ivchenko

Outline

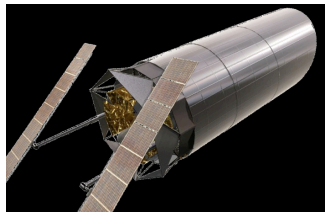
1. Jupiter's moon Europa
   & Upcoming missions

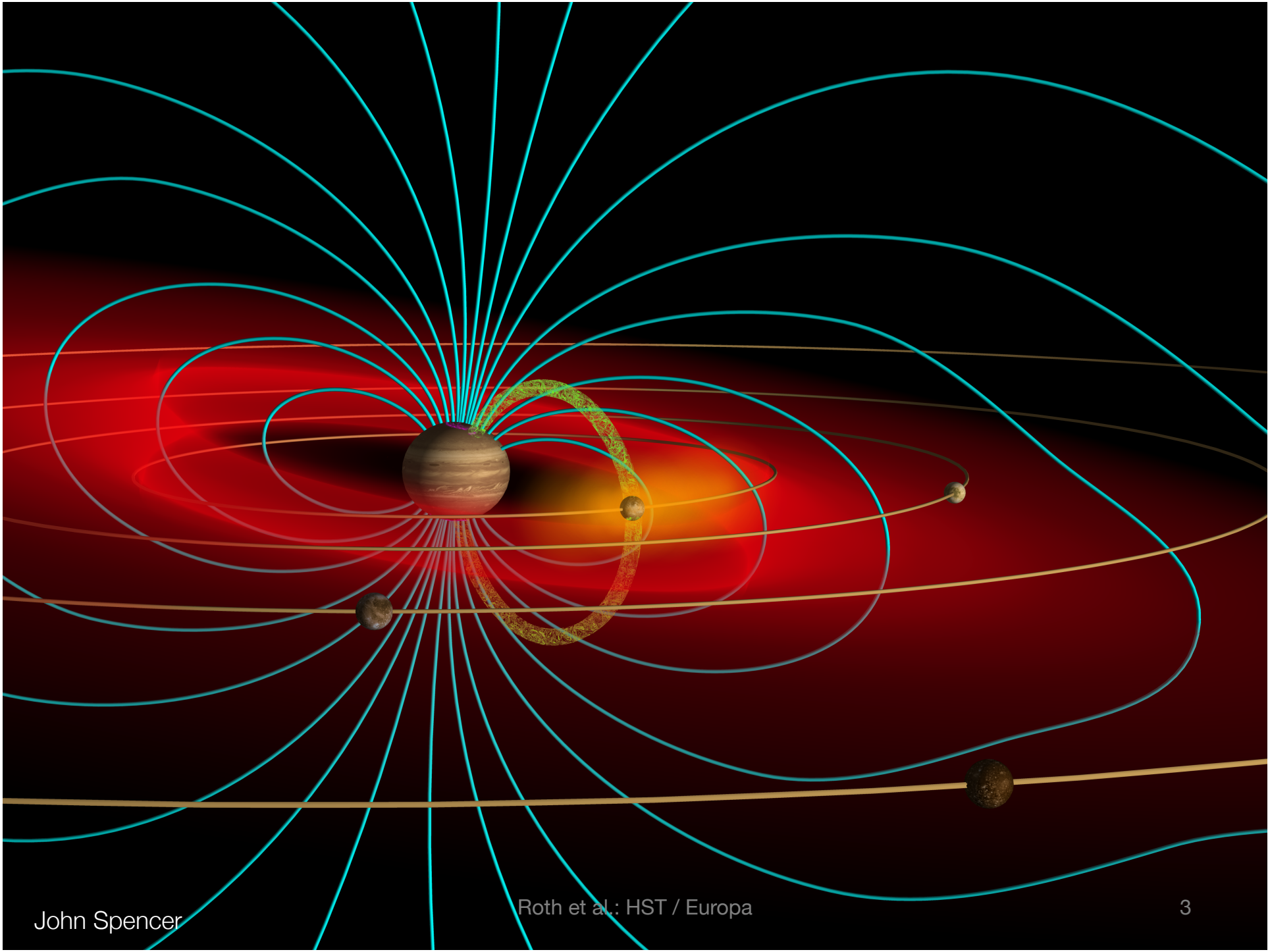


2. HST ultraviolet observations:
   Discovery of Europa's O_2 atmosphere
   and H_2O plume detection



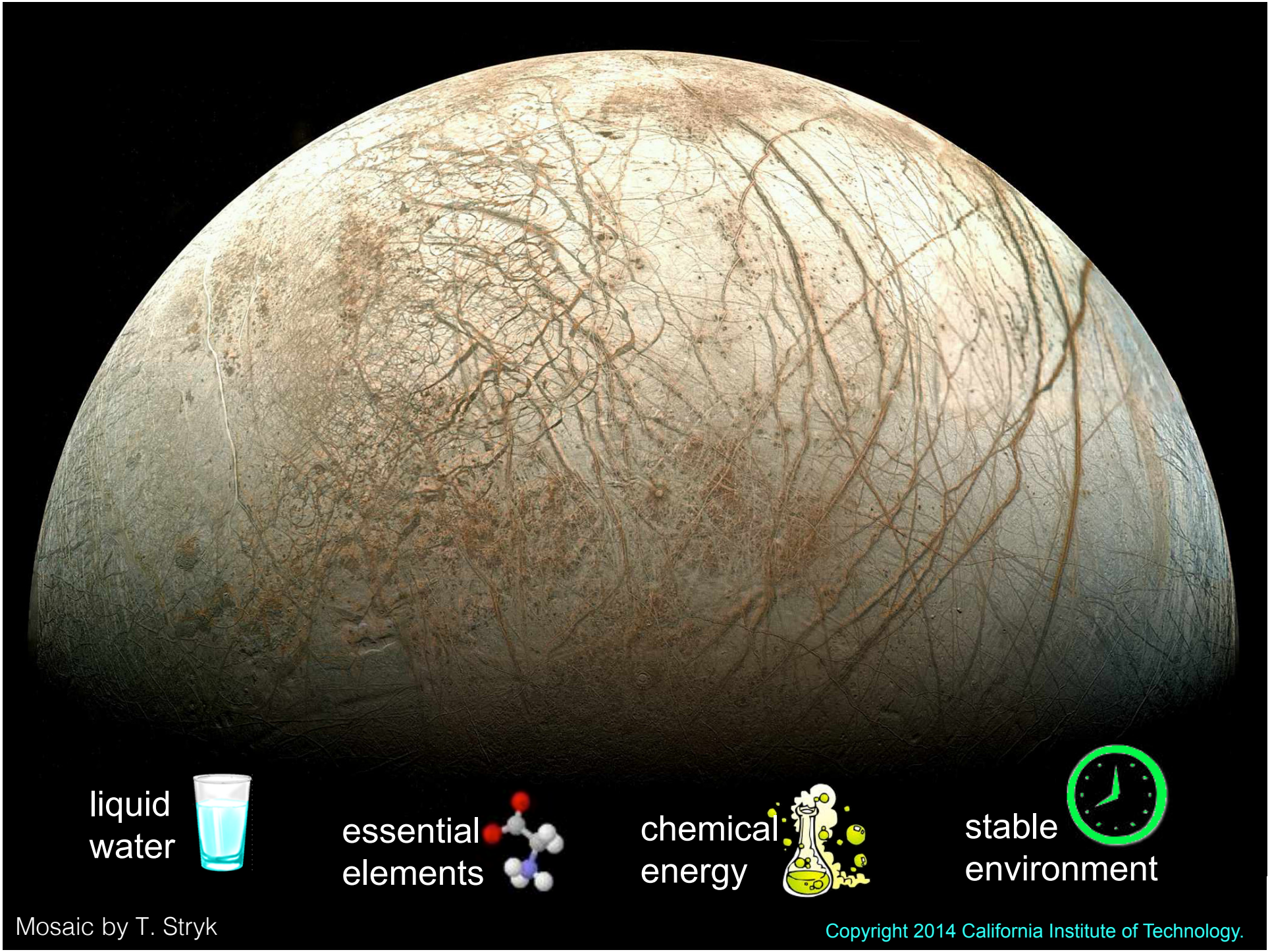
3. Results from the 2014/2015 HST
   campaign and future prospects





John Spencer

Roth et al.: HST / Europa



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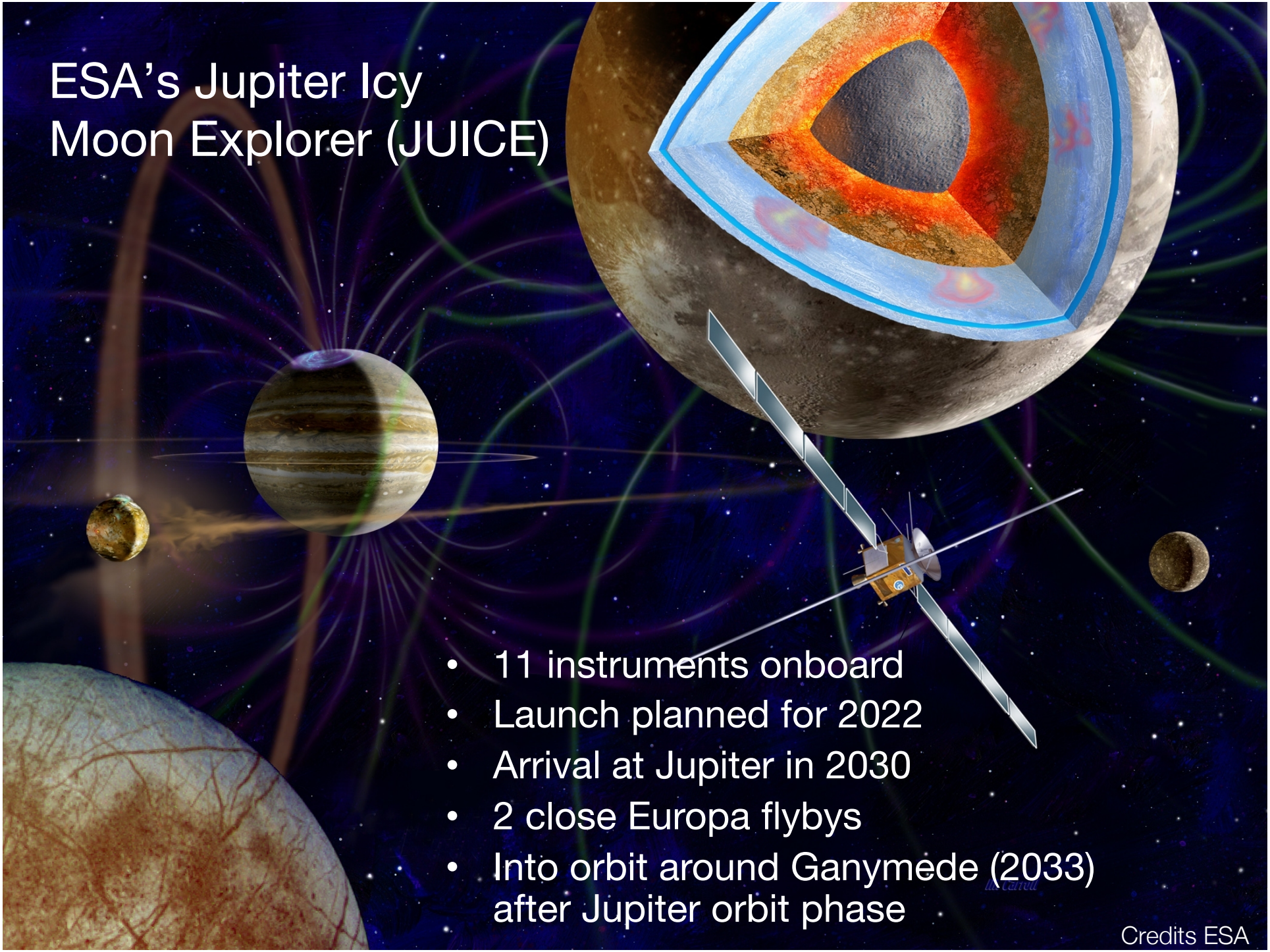
ESA's Jupiter Icy Moon Explorer (JUICE)

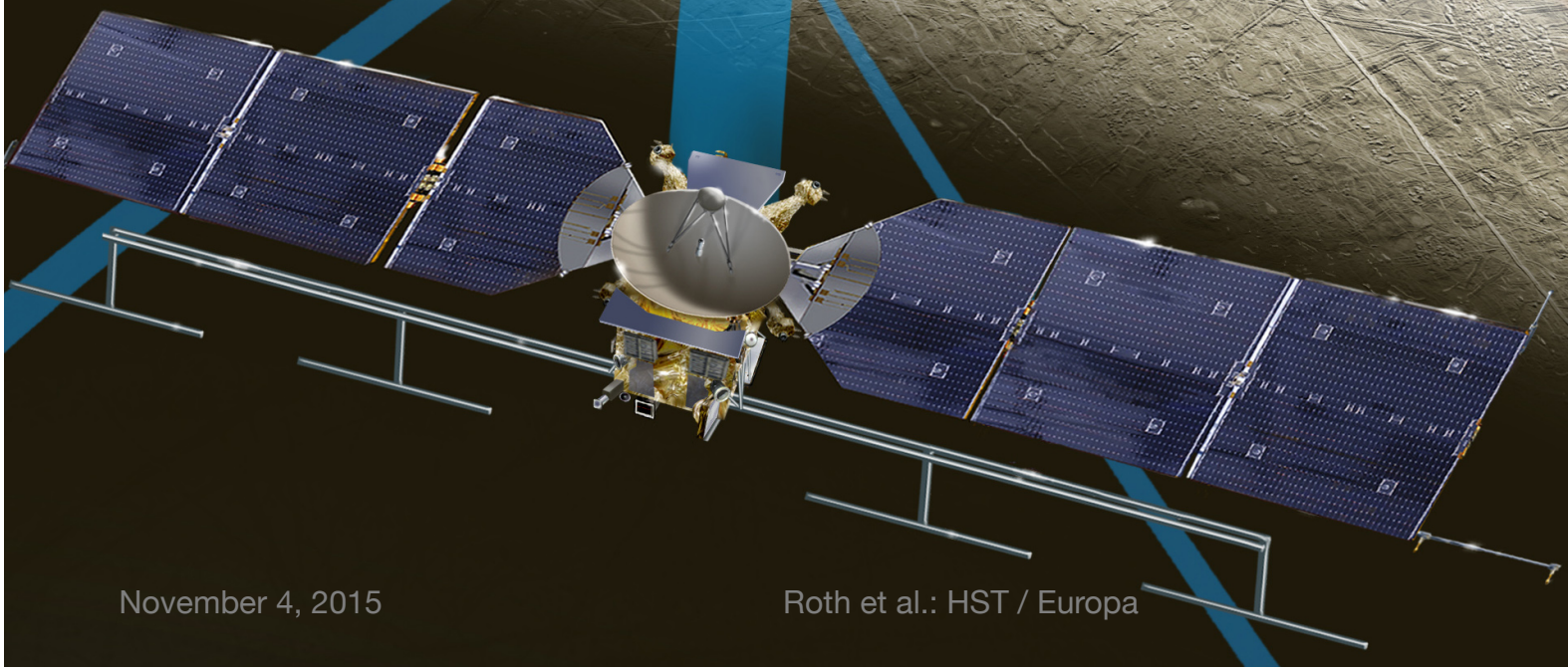


- 11 instruments onboard
- Launch planned for 2022
- Arrival at Jupiter in 2030
- 2 close Europa flybys
- Into orbit around Ganymede (2033) after Jupiter orbit phase

Credits ESA

NASA's Europa multiple-flyby mission

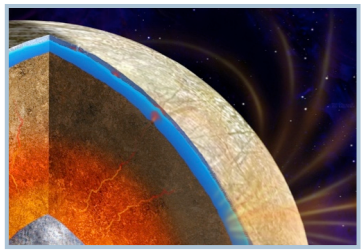
- 9 science instruments
- Possible launch date in 2022 (or 2025)
- 2-year or 7-year cruise to Jupiter



NASA / JPL

Europa Multi-Flyby Mission Science Goal & Objectives

- *Goal:* **Explore Europa to investigate its habitability**
- *Objectives:*
  - **Ice Shell & Ocean:** Characterize the ice shell and any subsurface water, including their heterogeneity, ocean properties, and the nature of surface-ice-ocean exchange
  - **Composition:** Understand the habitability of Europa's ocean through composition and chemistry
  - **Geology:** Understand the formation of surface features, including sites of recent or current activity, and characterize high science interest localities
  - **Reconnaissance:** Characterize scientifically compelling sites, and hazards, for a potential future landed mission to Europa



The Europa Mission will provide an in depth look at Europa's ice-shell-covered ocean, plumes, surface chemistry, and geophysics; identifying sites for future exploration.

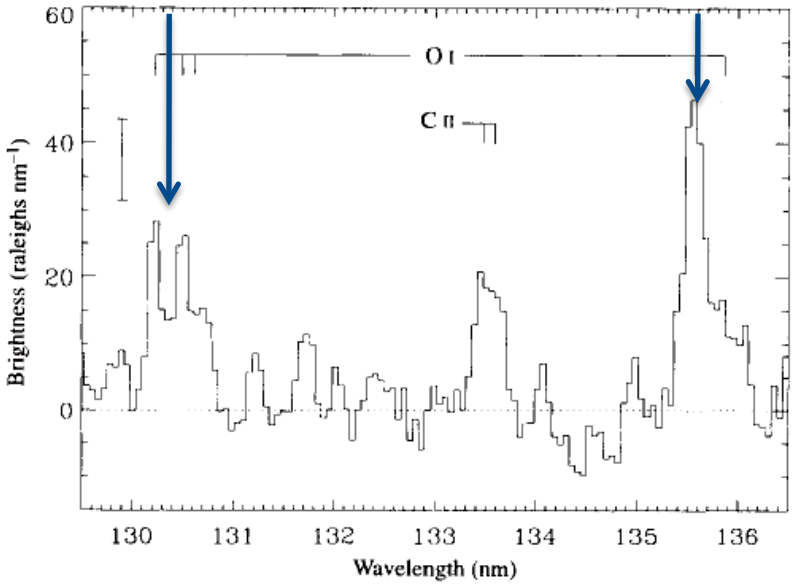
2. Hubble UV observations: O_2 Atmosphere and H_2O plumes

O_2 atmosphere detected with UV aurora spectra

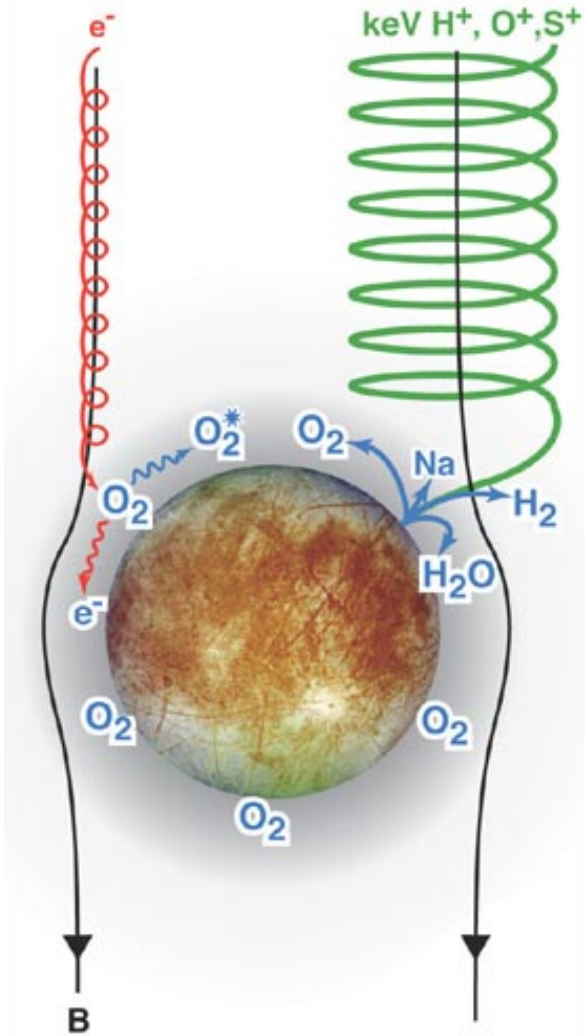
- HST/GHRS FUV spectrum revealed oxygen emissions from the atmosphere
- OI1356 Å / OI1304 Å ratio of ~2 is diagnostic for:

$$e^- + O_2 \rightarrow O^* \rightarrow O + h\nu \text{ (OI)}$$

➤ O_2 atmosphere / exosphere



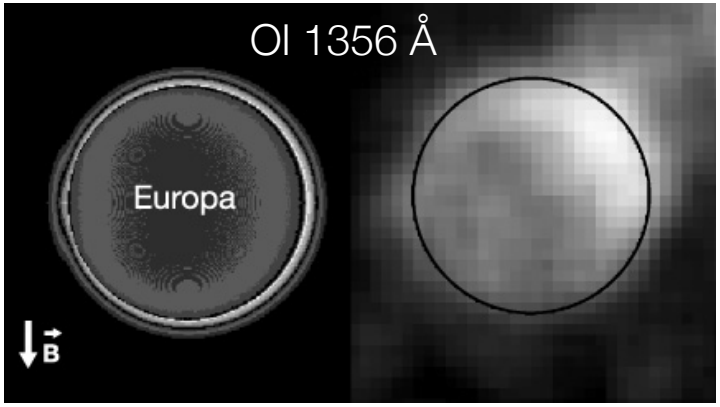
Hall et al. 1995



Johnson et al. 2004

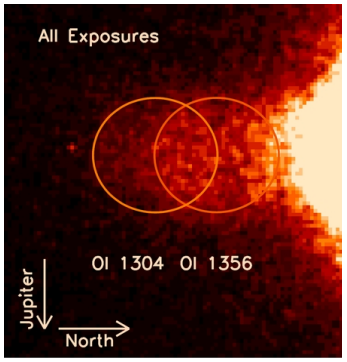
Irregular aurora morphology – hint for plumes?

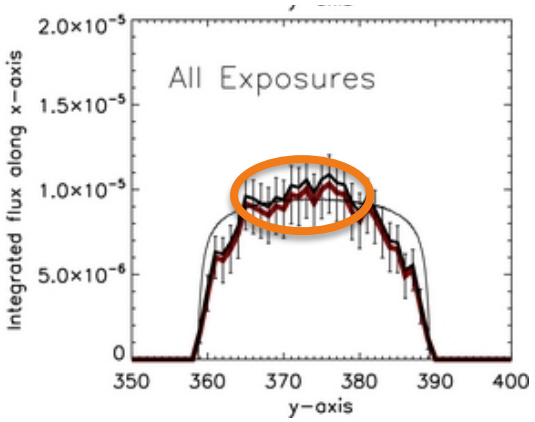
- 1999: First aurora images taken by Hubble's Space Telescope Imaging Spectrograph (STIS)
- Possible causes for irregular aurora morphology:
  ➤ Inhomogeneous electron environment
  ➤ Atmospheric inhomogeneity
- HST/ACS images 2008:
  - High noise – low signal
  - Hints of plumes?



McGrath et al. 2004 / Saur et al. 1999

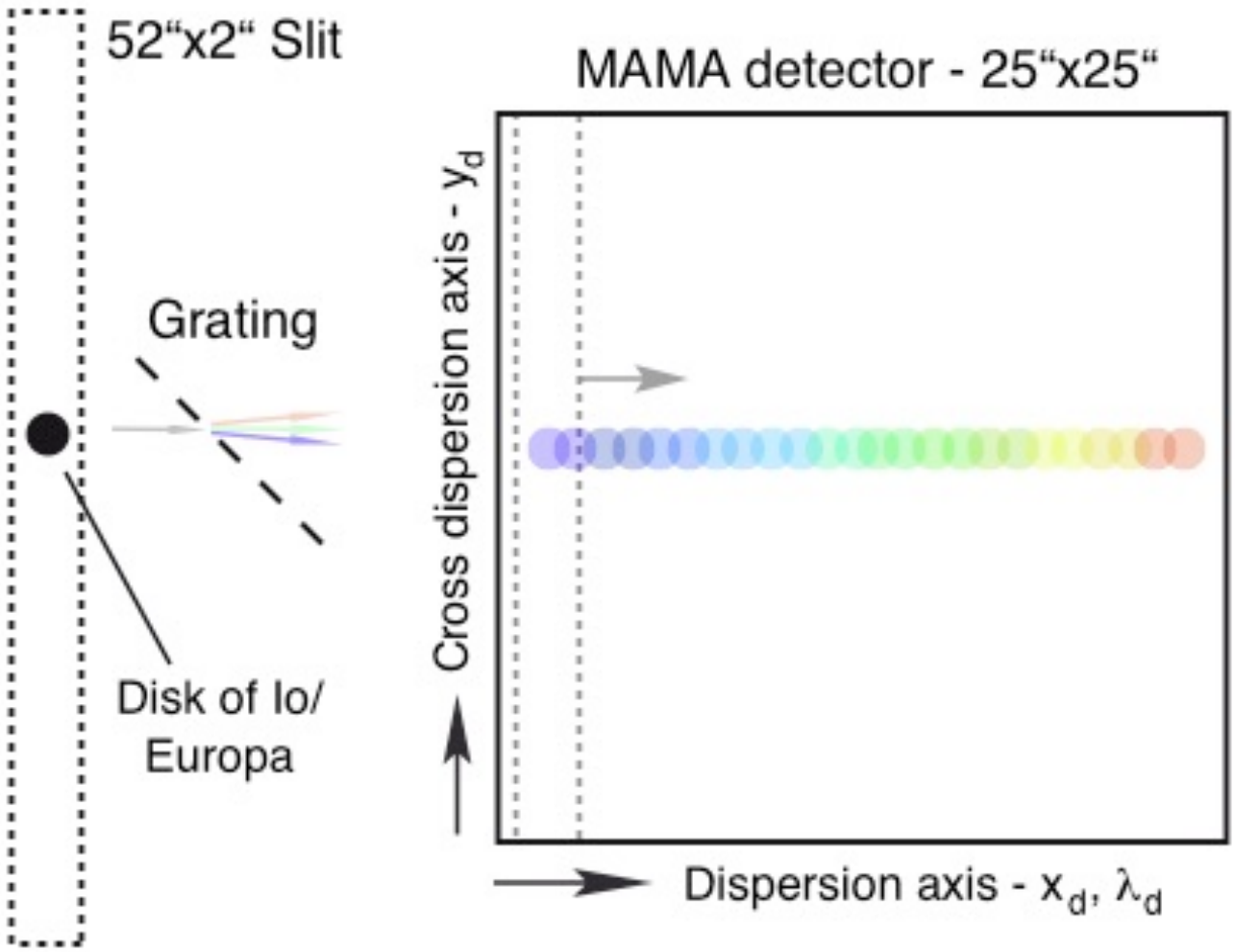
$$e^- + O_2 \rightarrow O^* \rightarrow O + h\nu\ (OI)$$



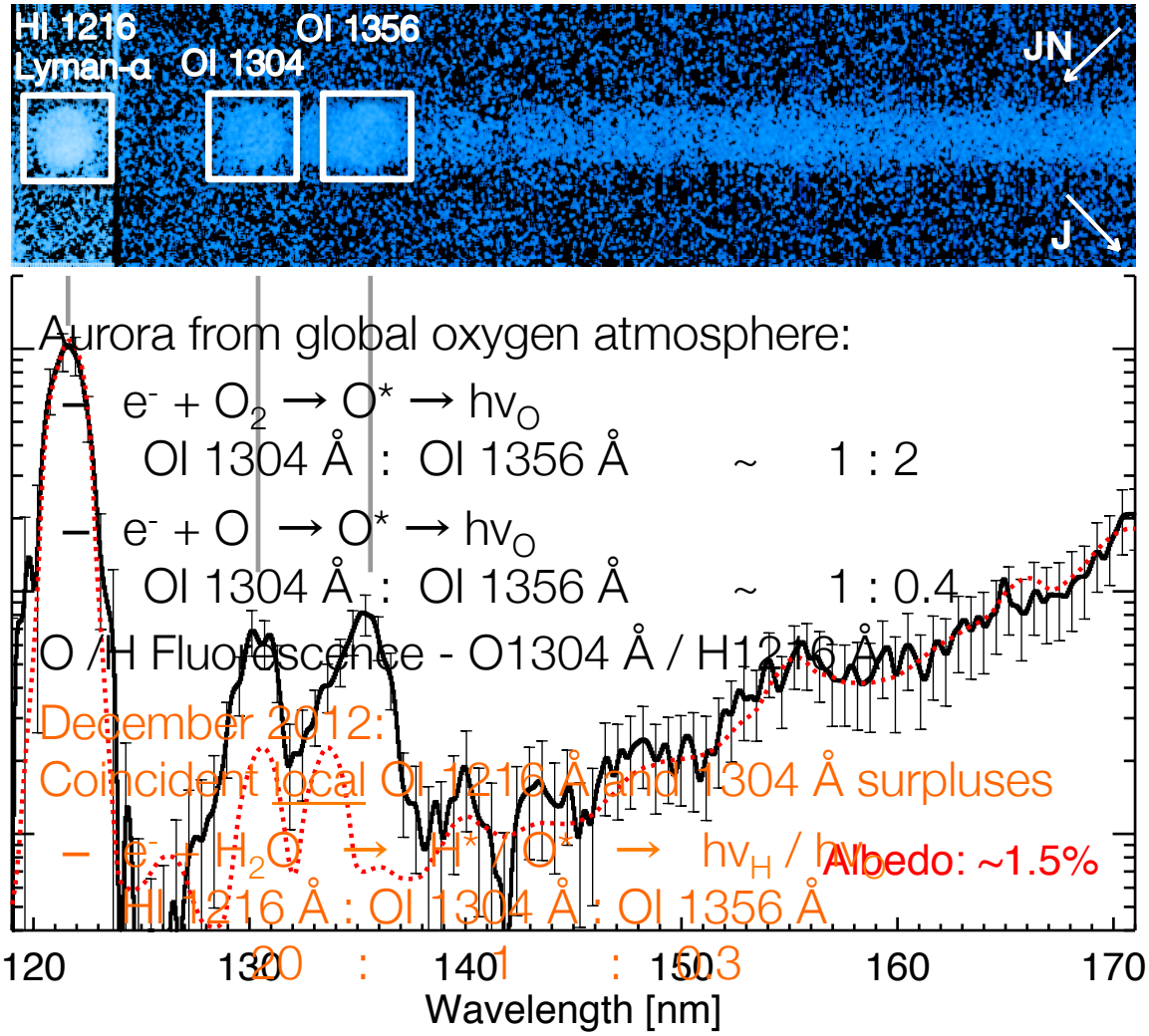


Saur et al. 2011

FUV imaging spectroscopy with HST / STIS



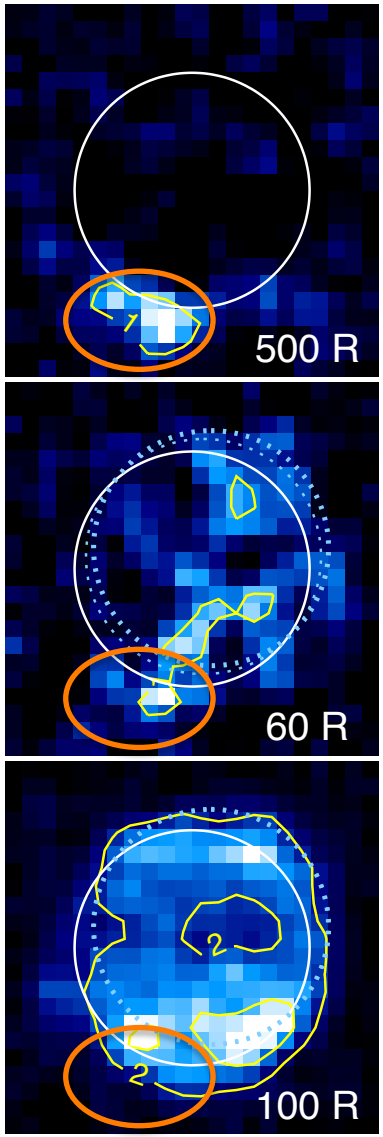
FUV imaging spectroscopy with STIS



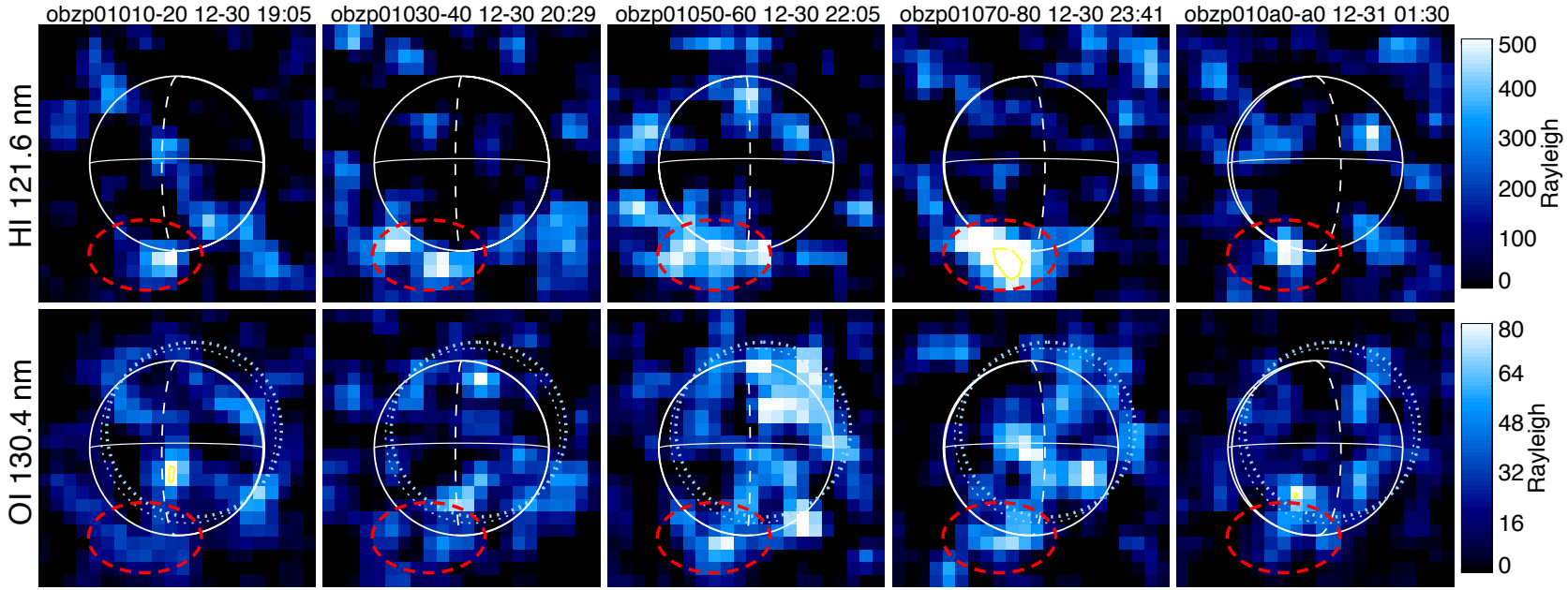
- Aurora from global oxygen atmosphere:
  - $e^- + O_2 \rightarrow O^* \rightarrow h\nu_O$
    OI 1304 Å : OI 1356 Å ~ 1 : 2
  - $e^- + O \rightarrow O^* \rightarrow h\nu_O$
    OI 1304 Å : OI 1356 Å ~ 1 : 0.4
- O / H Fluorescence - O1304 Å / H1216 Å
- December 2012:
  Coincident local OI 1216 Å and 1304 Å surpluses
  - $e^- + H_2O \rightarrow H^* / O^* \rightarrow h\nu_H / h\nu_O$
    HI 1216 Å : OI 1304 Å : OI 1356 Å
    20 : 1 : 3

Albedo: ~1.5%

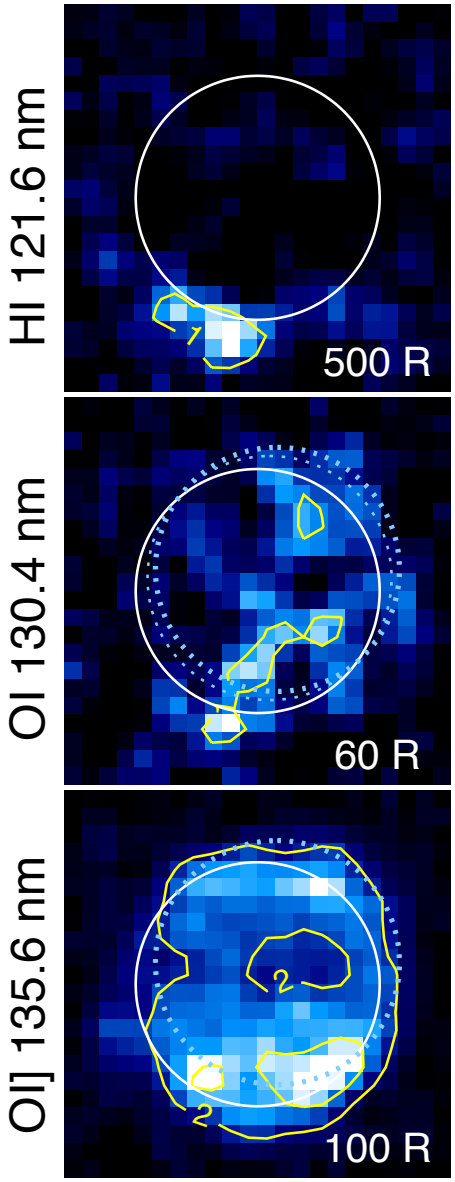
Dec 2012

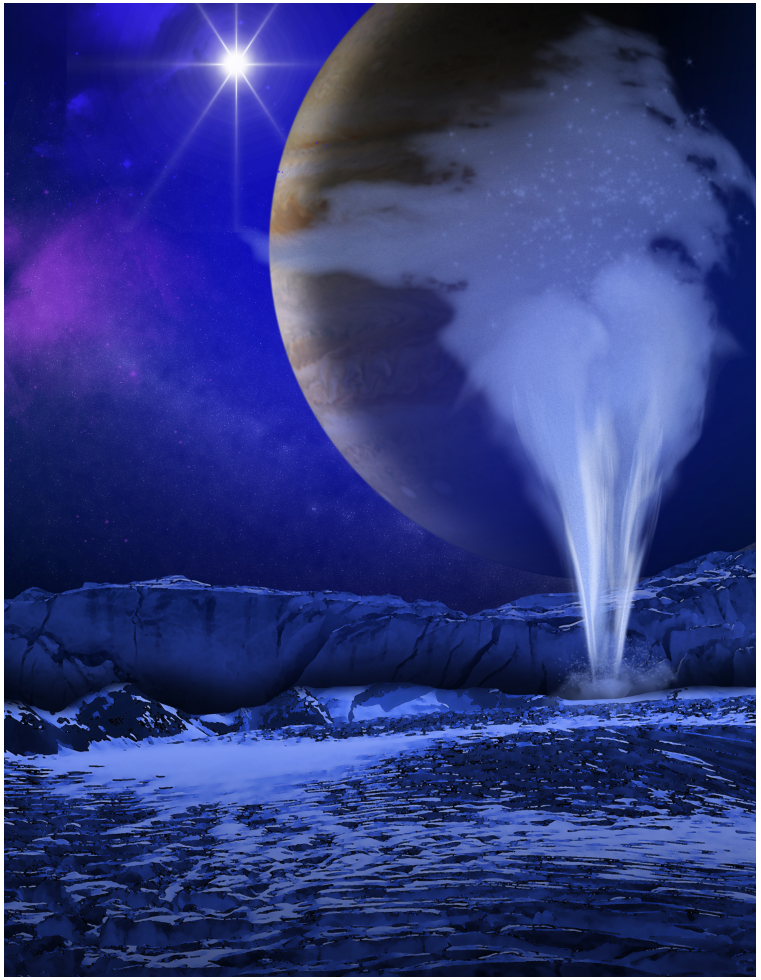


5-orbit images series

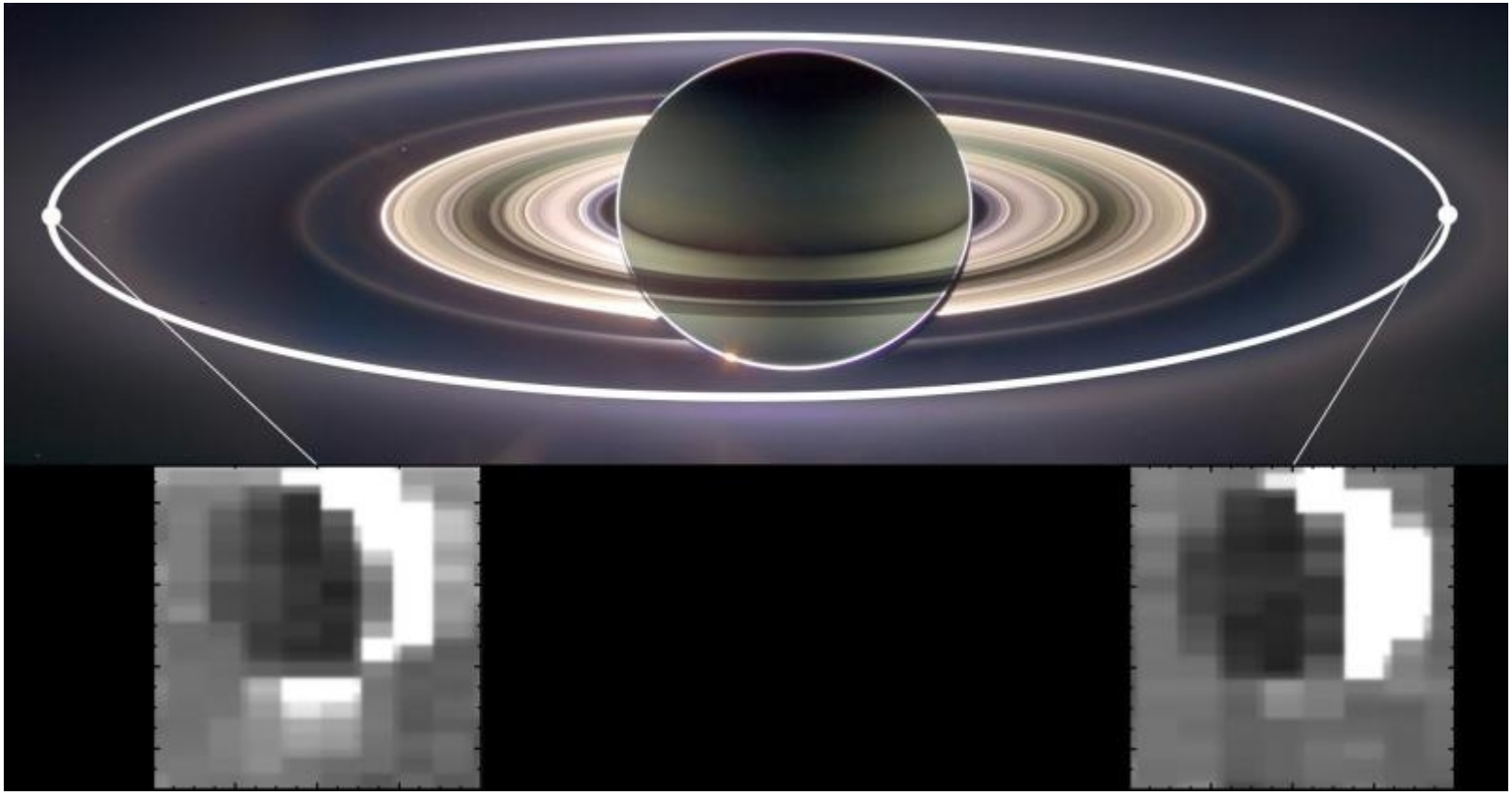


- Local H Lyman-α and O 1304 Å emission surplus time-stationary
- Persistency indicates atmospheric inhomogeneity
- Surpluses consistent with two ~200 km high water vapor plumes with column densities of N ~ 10^{20} H_2O/m^{-2}


HI 121.6 nm
500 R
OI 130.4 nm
60 R
OIJ 135.6 nm
100 R

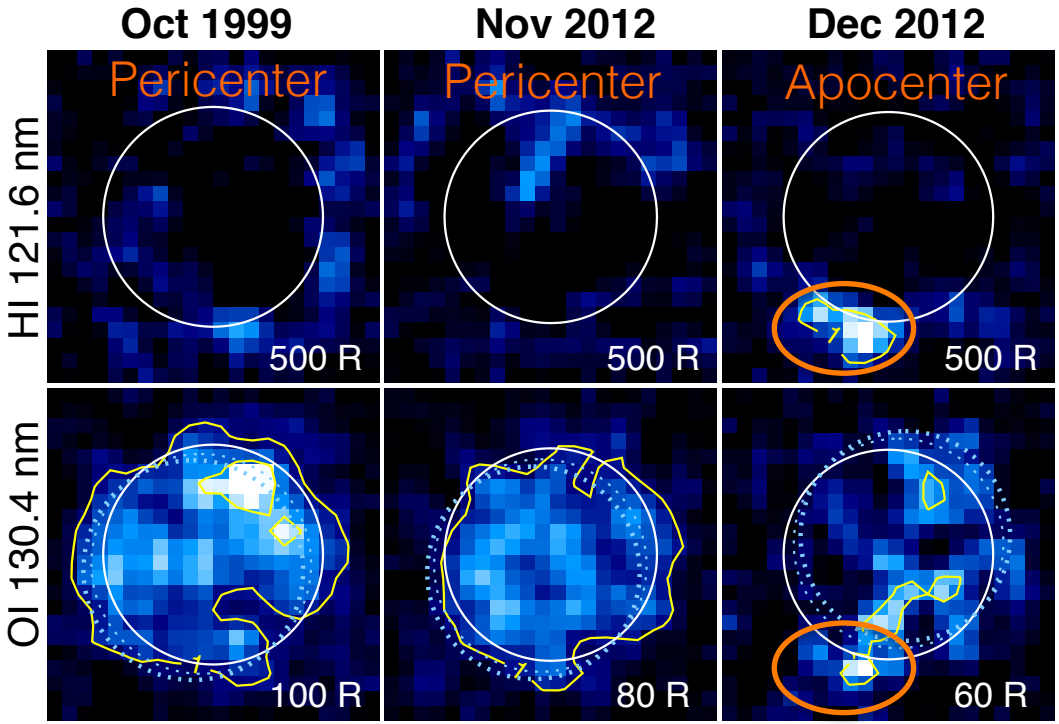


Tidal Forces Controlling Enceladus' Jets



ASA/JPL-Caltech/University of Arizona/Cornell/SSI

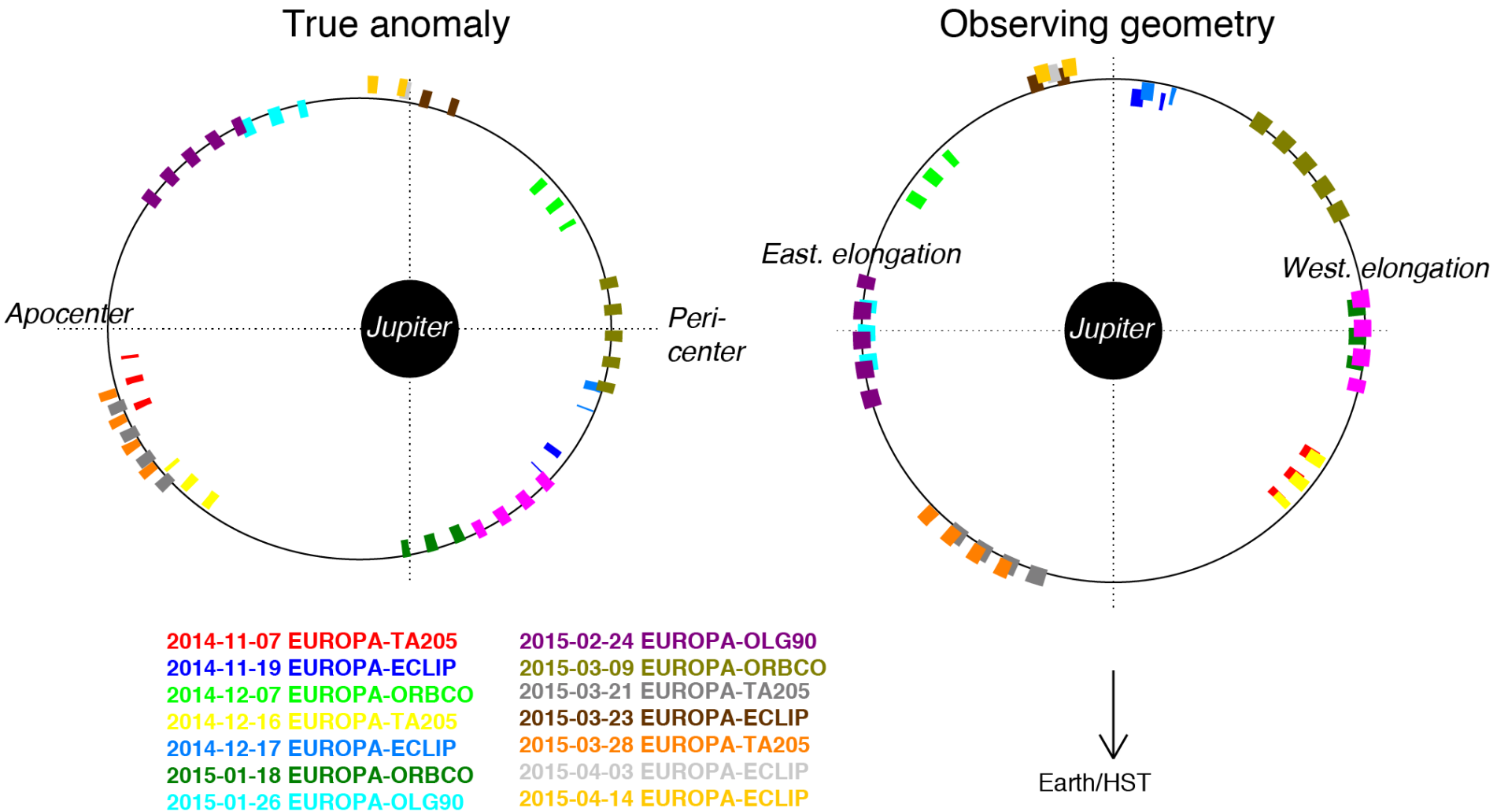
As reported last year: 5 Visits - one detection

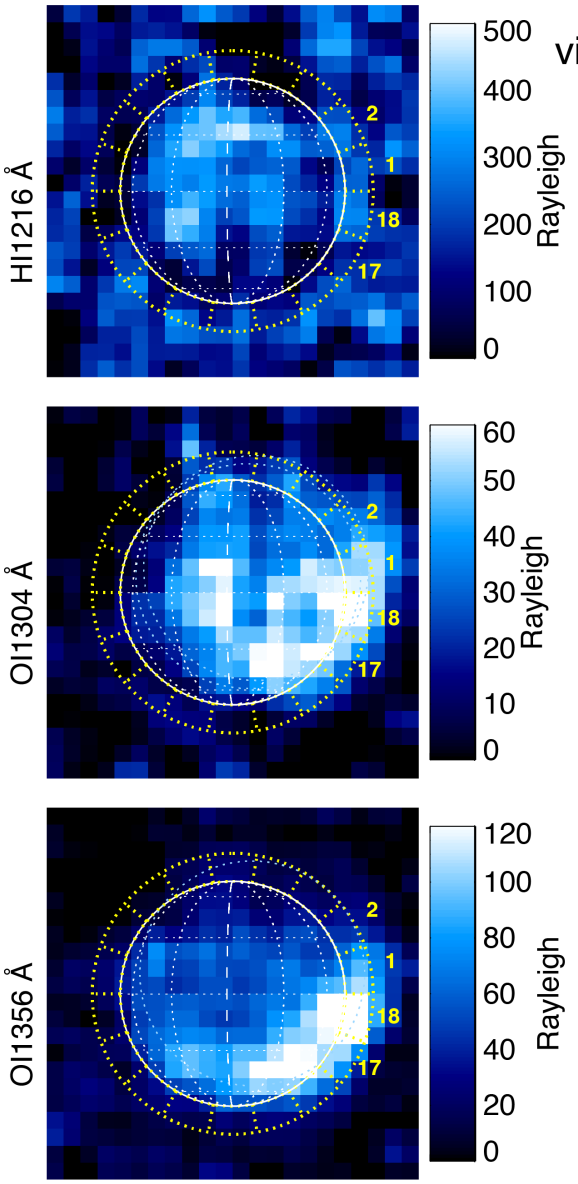


- Plume activity connected to tidal stresses on surface fractures?
- Roth et al., "Orbital apocenter is not a sufficient condition for HST/STIS detection of Europa's water vapor aurora", PNAS, 2014

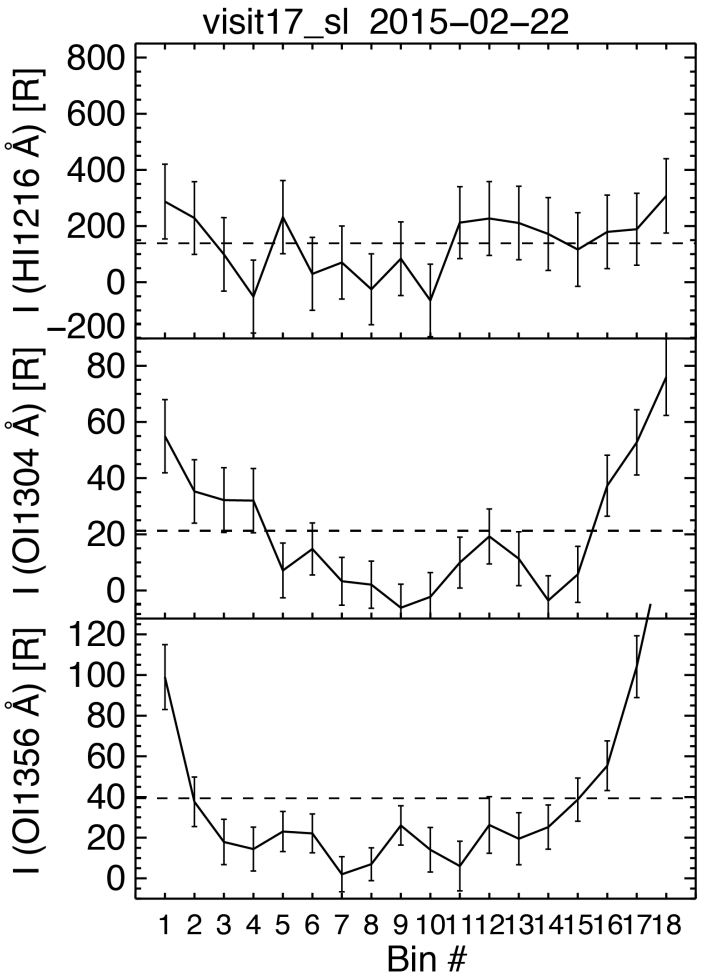
3. Results from the 2014/2015 HST Europa UV campaign and future prospects

2014/2015 Cycle 22 HST Europa campaign: 15 aurora / emission visits





visit17_sl / 2015–02–22 / EUROPA–OLG270



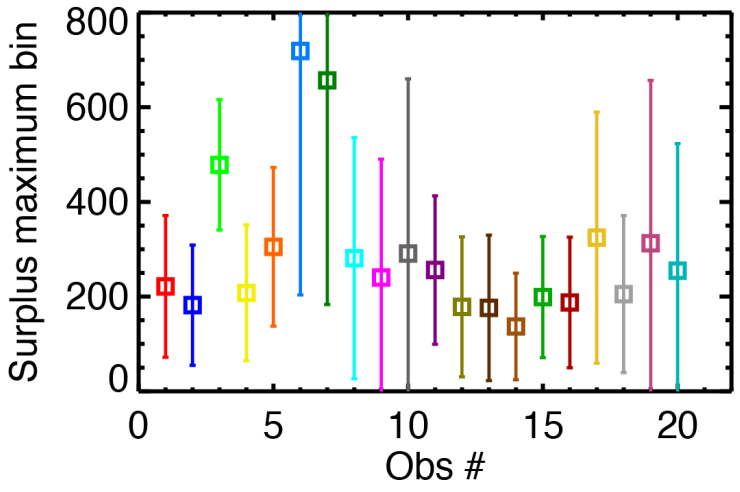
Maximum Ly-α:
300 R

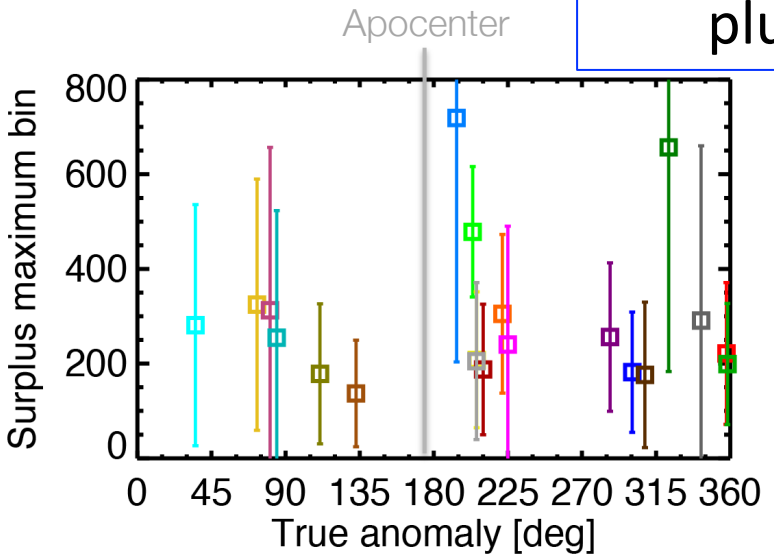
Constraint on H_2O abundance:
$N < 0.8 \times 10^{16}$ cm^{-2}

Dec 2012:
600 R Ly-α
N_{H2O} ~1.5×10^{16} cm^{-2}

Ly-α limb surpluses for all 20 visits

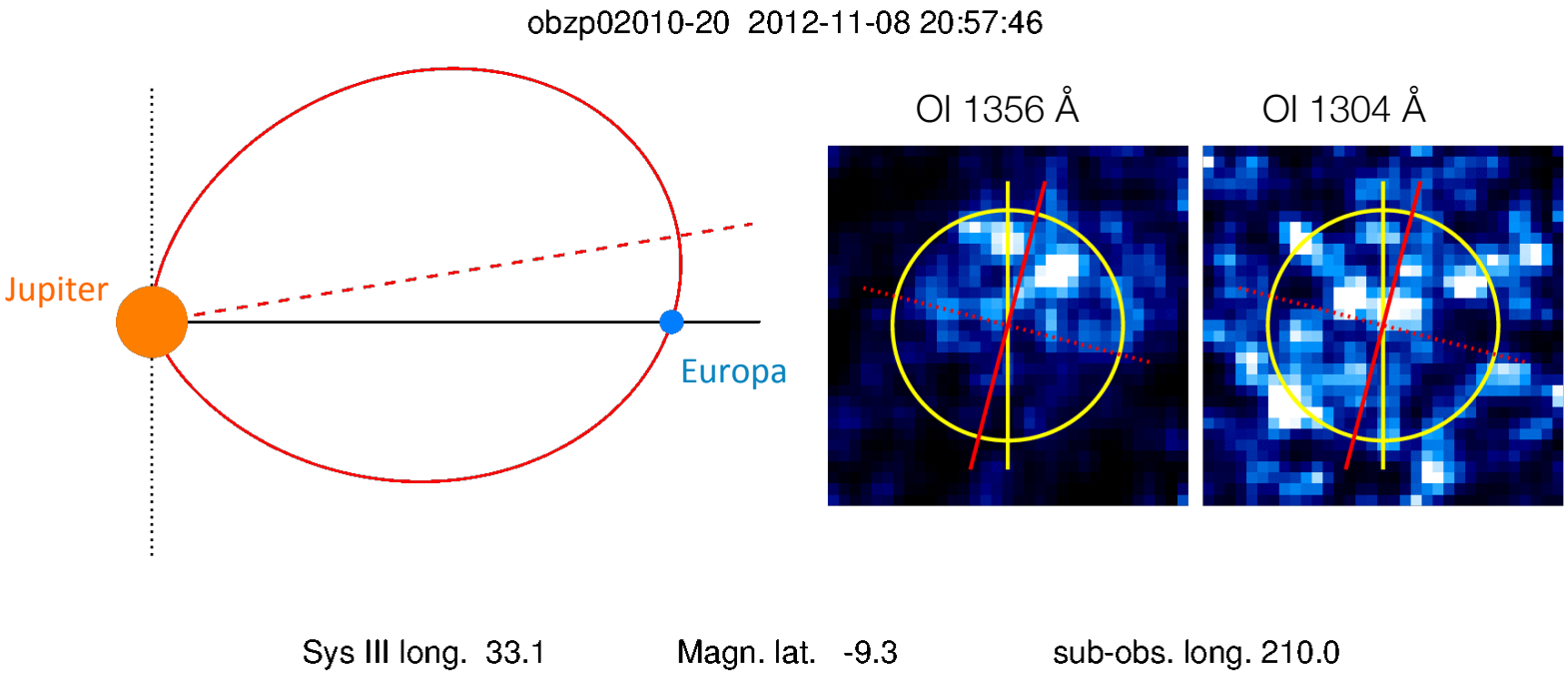
No confirmtion of water vapor plumes





1999–10–05
2012–11–08
2012–12–30
2014–01–22
2014–02–02
2014–11–07
2014–11–19
2014–12–07
2014–12–16
2014–12–17
2015–01–18
2015–01–26
2015–02–22
2015–02–24
2015–03–09
2015–03–21
2015–03–23
2015–03–28
2015–04–03
2015–04–14

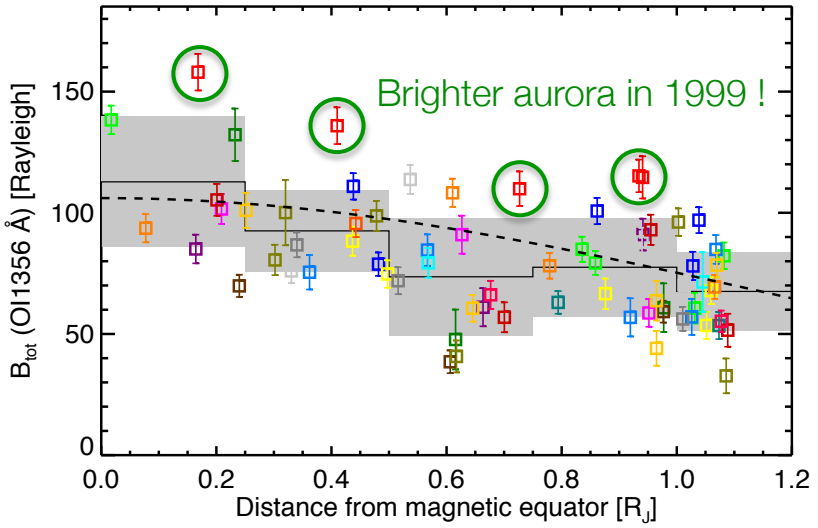
Oxygen aurora from global O_2 atmosphere correlated to magnetospheric environment

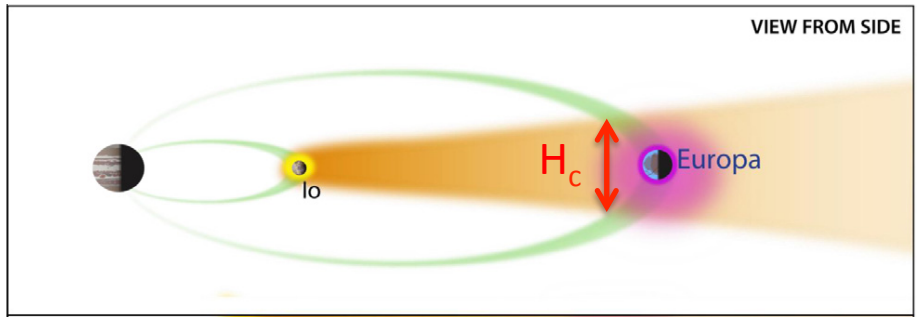


1. Brightness decreases with distance to the plasma sheet
2. Bright emission symmetric around ‘magnetic’ poles
3. Hemisphere that is facing the plasma sheet is brighter

1. Brightness variations
Consistent dependence on plasma sheet distance

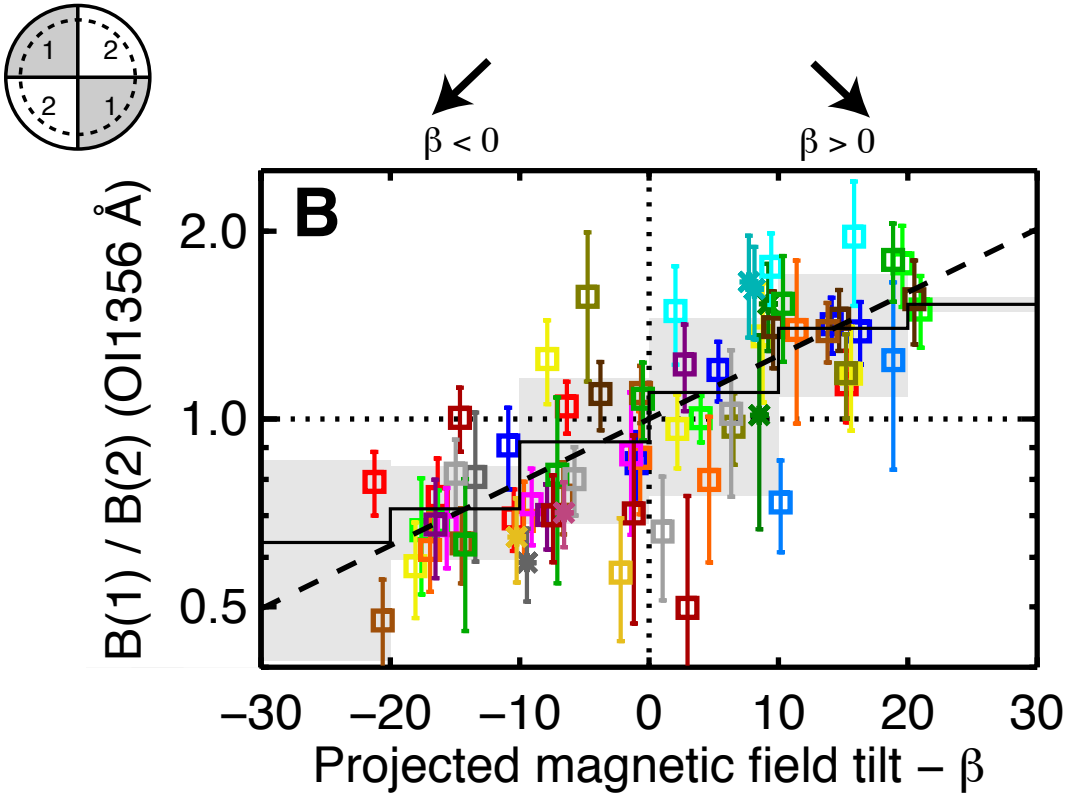
- Brightness decreases with distance
- Fit for latitudinal plasma sheet profile (dashed): Characteristic length scale of $H_C = 1.7\ R_J$
- Consistent with density profile of Bagenal & Delamere (2011)



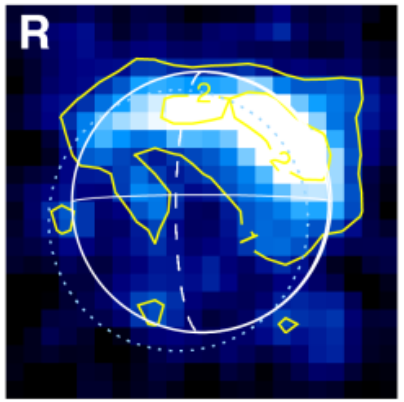


Bagenal+ 2015

2. Morphology correlated / symmetric to magnetic field orientation



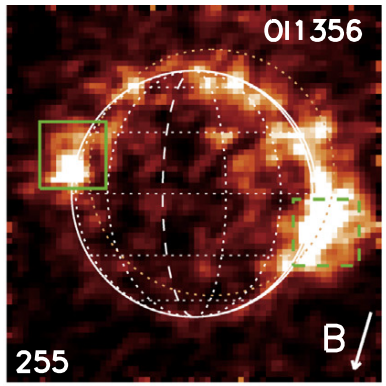
Europa



ϕ_{obs} =259 λ_{III} = 45 ψ_m =-9

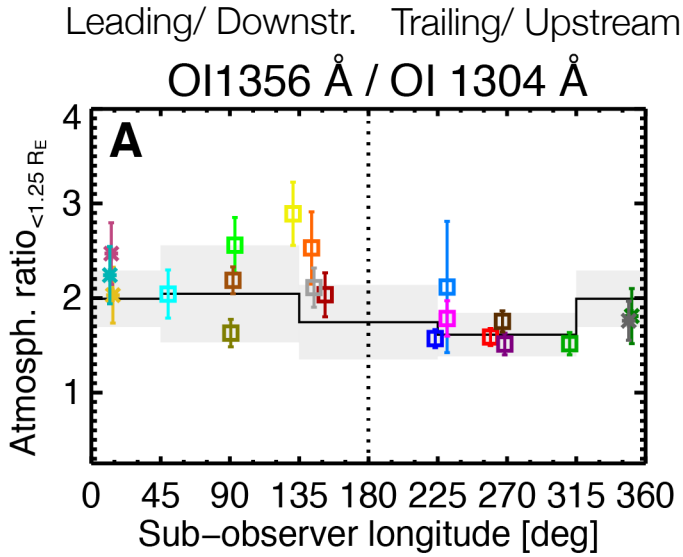
B

Io



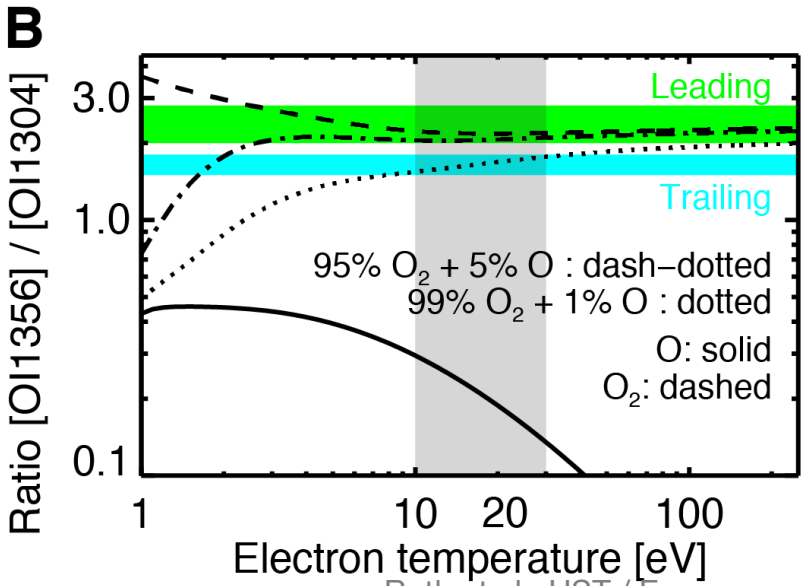
=> Polar aurora – no equatorial spots!

OI1356 Å / OI 1304 Å ratio => O / O_2 ratio



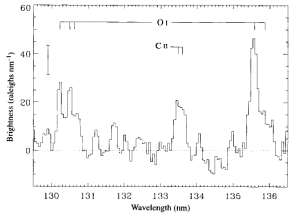
- Oxygen line ratios between 1.5 and 2.8 detected
- Upstream: < 2
- Downstream: ≥ 2

=> lower abundance of atomic oxygen in downstream region

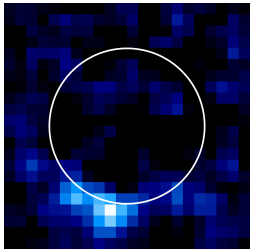


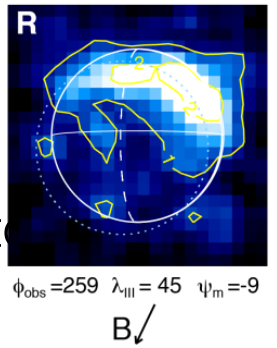
=> Roth et al., "Europa's FUV oxygen aurora", JGR, under revision

Hubble Science Summary



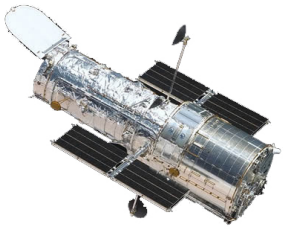
- HST observations of Europa FUV emissions a useful tool to explore the moon and its environment:
  - First detection of global O_2 atmosphere in oxygen aurora
  - Detection of coincident Lyman-α and OI 1304 Å surpluses indicative of transient H_2O plume abundance
  - Large 2014/2015 HST FUV campaign provided (only) upper limits on H_2O plume abundance
  - Detection of plumes hampered by variable plasma environment and possibly very transient plume nature
  - Brightness and morphology of oxygen aurora can be used t probe Europa's interaction with the magnetosphere

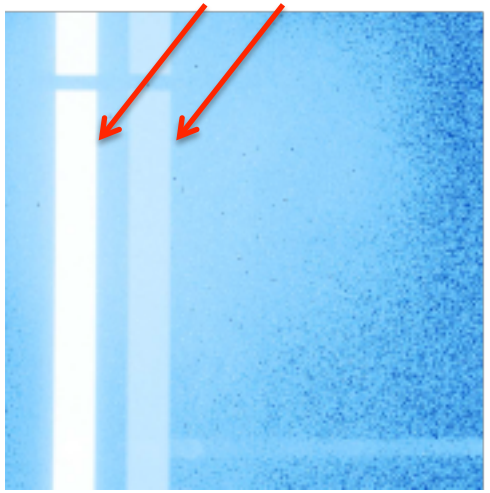




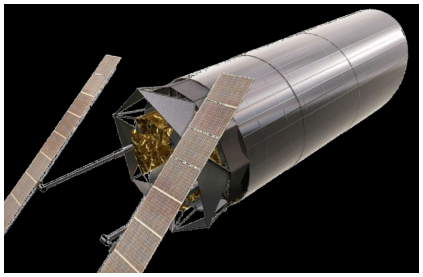
Observing issues and future UV telescope

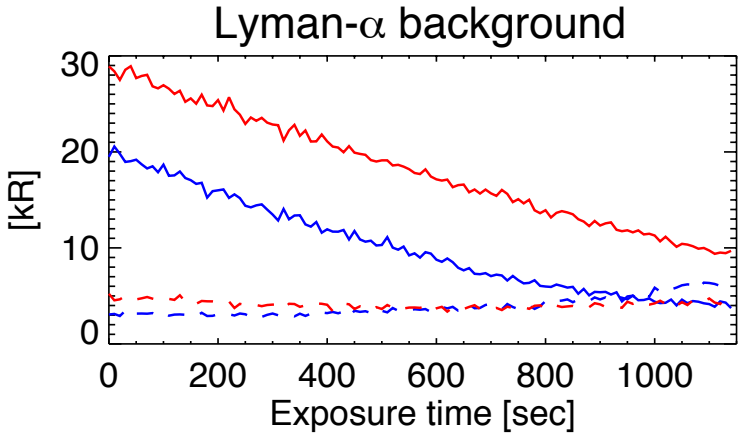
- H Lyman-α signal essential diagnostic to search for plume aurora
- But: Strong geocoronal contamination for HST



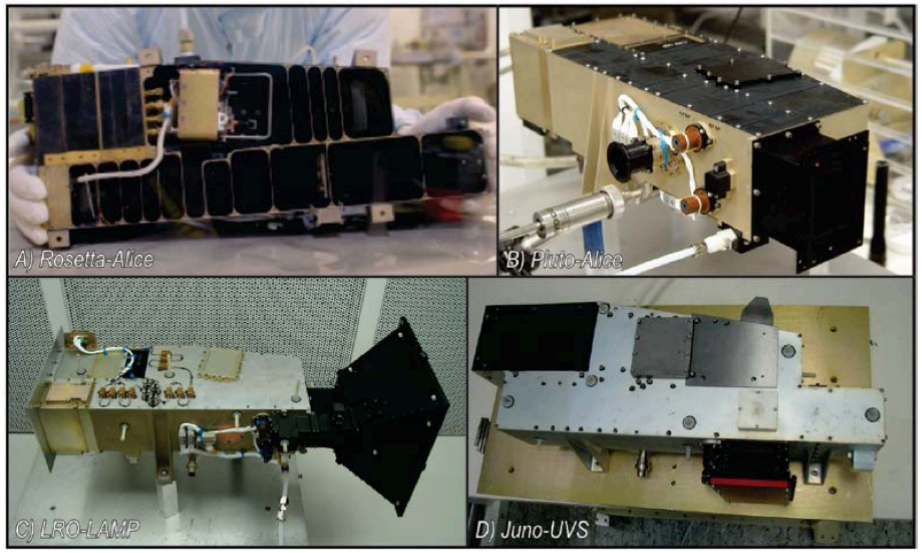


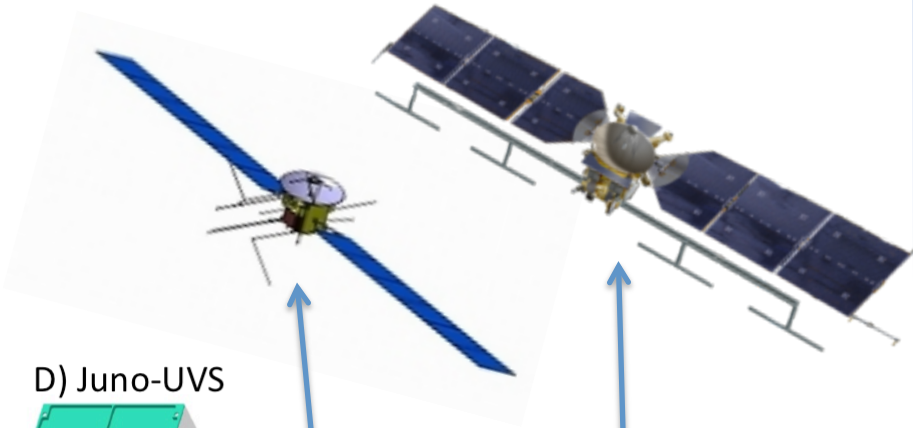
- 8 m telescope at L2:
  - ~10 times higher SNR for 500 R Lyman-α plume signal
  - Small (200 km x 200 km) plume signal detectable in 2 minutes with 3 sigma!





JUICE and Europa UVS Extend SwRI's UV Instrument Family





D) Juno-UVS

B) Pluto-Alice C) LRO-LAMP

A) Rosetta-Alice

E) JUICE-UVS

F) Europa-UVS

A near-copy of JUICE-UVS

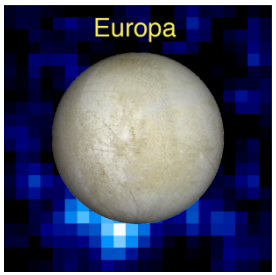
TA008973-EuropaUVS

Europa-UVS

- Selected by NASA in 2015 to serve as the Europa Multi-Flyby Mission "Plume Hunter"
- Europa-UVS Instrument PI: Kurt Retherford (Southwest Research Institute)

Mass (CBE+cont.):	6.43 kg plus 11.1 kg shielding = 17.5 kg
Power (CBE+cont.):	9.7 W
Dimensions:	34.6 cm x 38.2 cm x 14.5 cm
Spectral Range:	55-210 nm
Spectral Resolution:	<0.6 nm (point source); <1.2 nm (extended source)
Spatial Resolution:	0.16° (AP); 0.04° (HP), Nyquist sampled
Field of View:	0.1° x 7.3° + 0.2° x 0.2° (7.5° full length)
Effective Area:	0.6 cm^2 @ 125 nm
Telescope / Spectrograph:	Off-axis Primary / Rowland circle mount
Detector Type:	2D MCP (solar blind), CsI photocathode, cross-delay-line (XDL) readout, 2048 spectral x 512 spatial x 256 PHD
Radiation Mitigation:	Contiguous Tantalum / Tungsten shielding (4π sr @ detector and electronics)

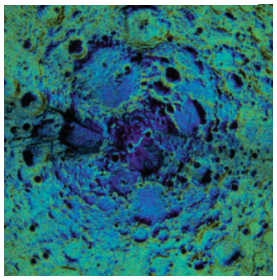
1) UV Emissions



HST-STIS observation of H aurora diagnostic of water vapor plumes

Aurora & Airglow

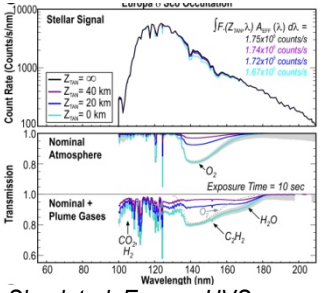
2) UV Reflections



LRO-LAMP observation of reflected solar Lyα from the Moon's north polar region

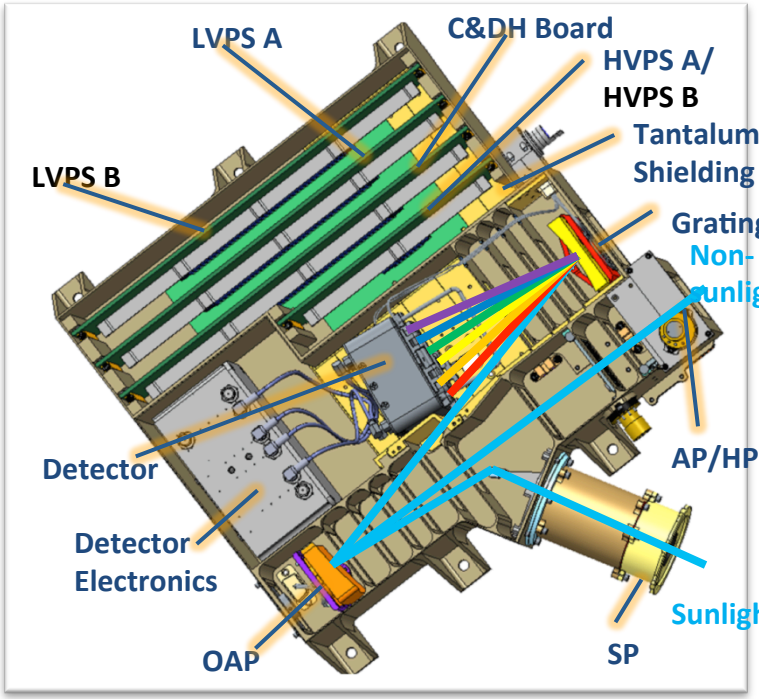
Surface Albedos

3) UV Transmissions

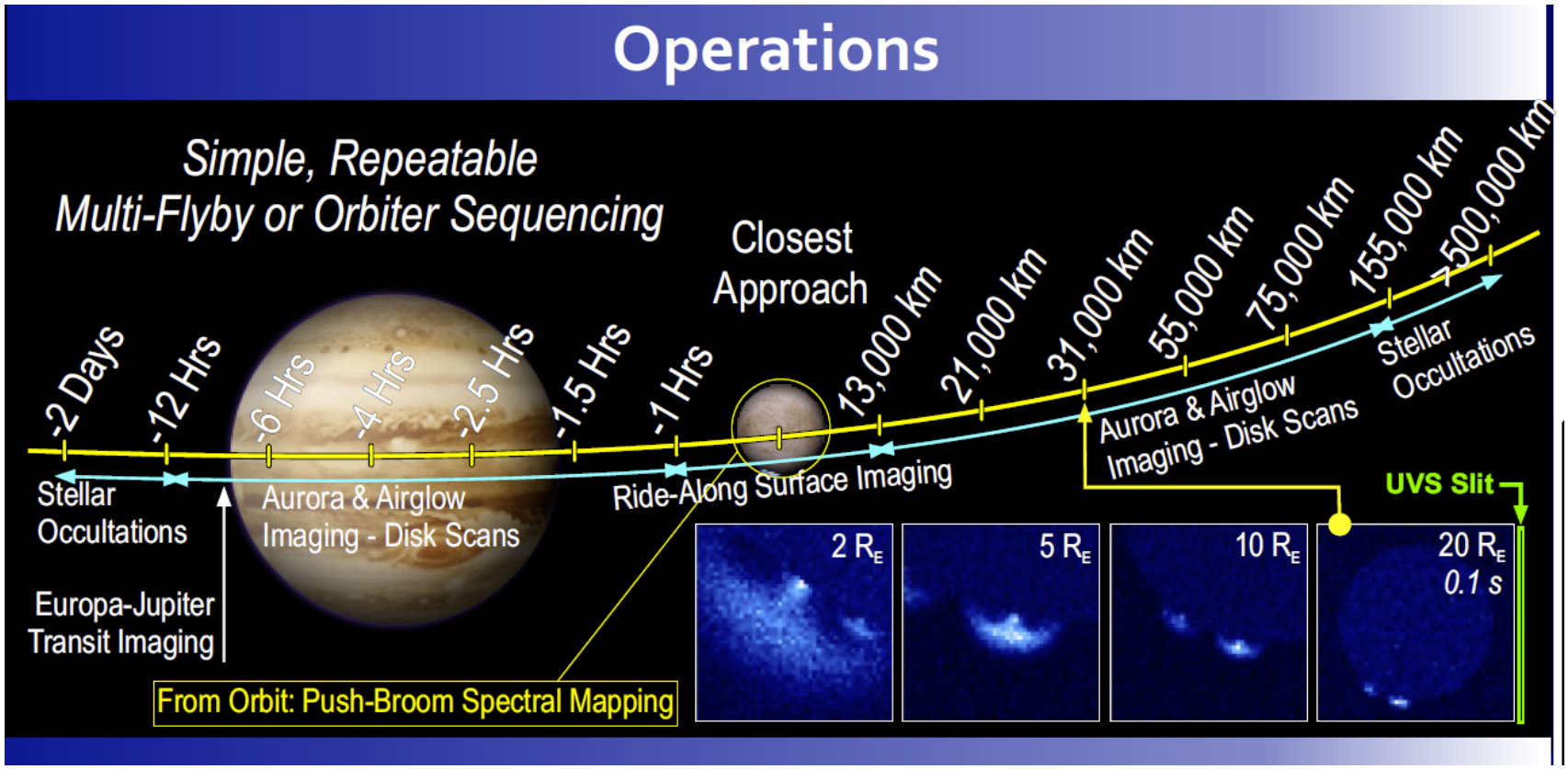


Simulated Europa-UVS observation of a stellar occultation by Europa

Stellar & Solar Occultations



Europa-UVS – Flyby Sequence



Direct observation of UV emissions from Europa aurora, airglow, surface albedo, and other Jovian system atmospheres, and atmospheric absorption measurements via stellar and attenuated solar occultation

Outlook

- NASA's Europa mission might arrive as early as 2025!
- ESA's JUICE mission to arrive in 2030 with 2 Europa flybys
- Future UV telescope above geocorona could be perfect tool to observe outer planetary water worlds!