An Update on the Hubble Cycle 22 Campaign to Investigate Europa Water Vapor Plumes

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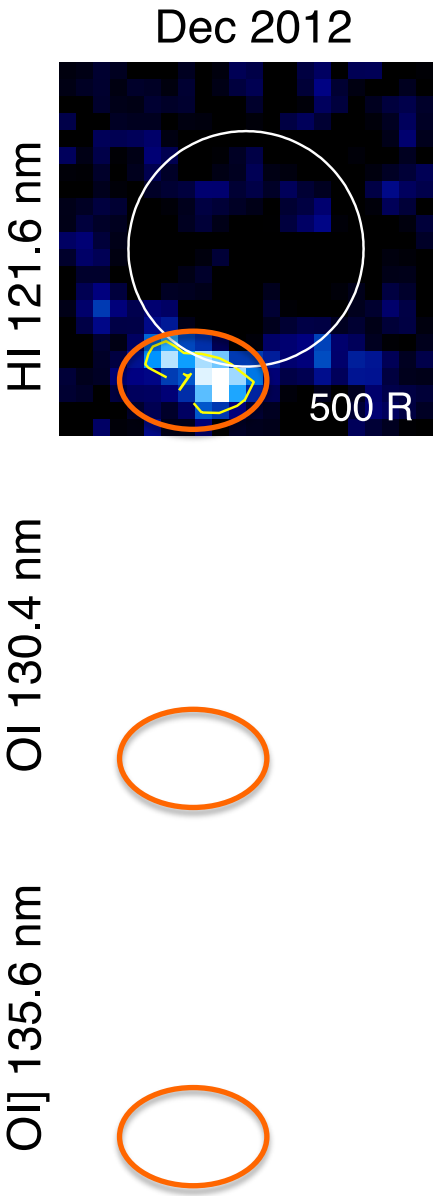
Coincident Lyman-α and OI 1304 Å surpluses near the south pole

- Roth et al, Science, 2014 (*and Supplement*)
- Lyman-α surplus at south pole of ~600 R (4.0 σ)
- Coincident OI 1304 Å surplus of ~30 R (2.4 σ)

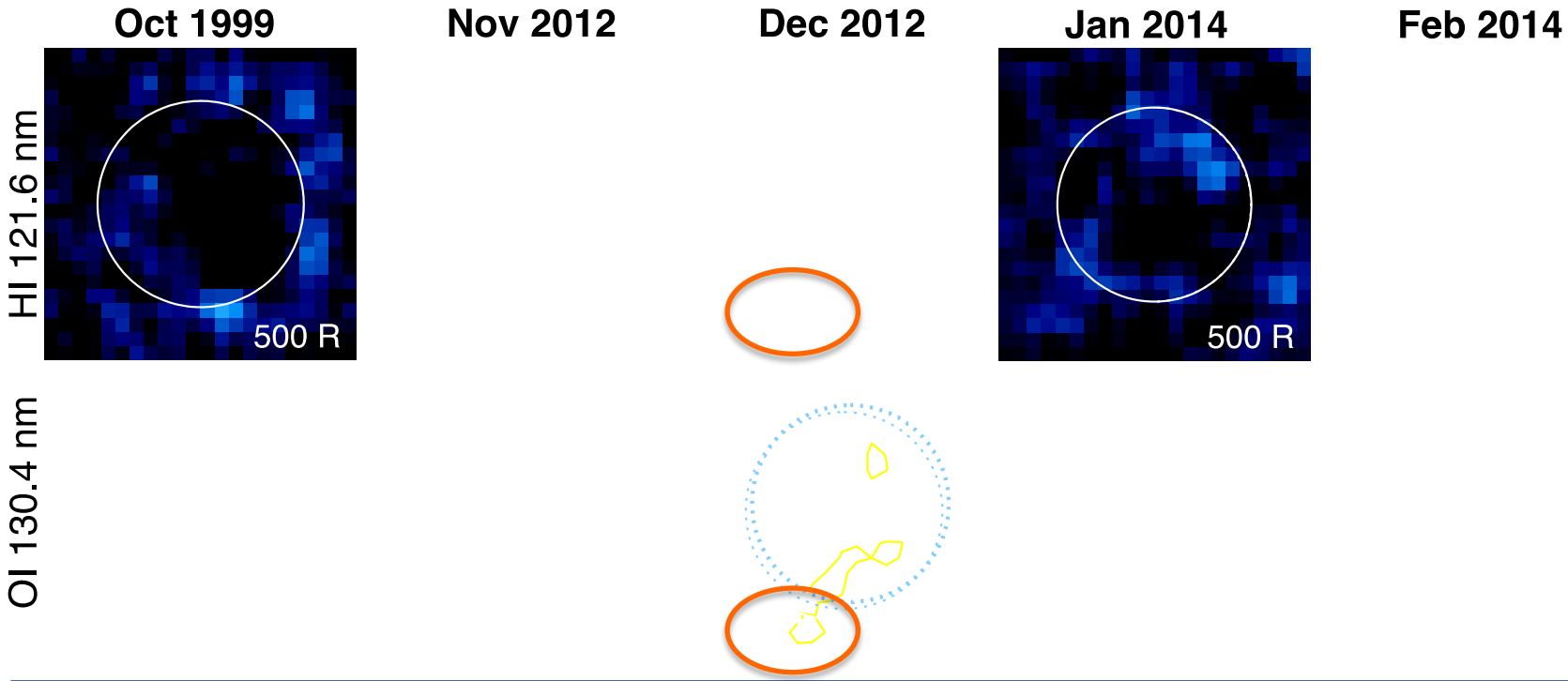
- $e^- + H_2O \rightarrow H^* / O^* \rightarrow h\nu_H / h\nu_O$

  HI 1216 Å : OI 1304 Å : OI 1356 Å
  20 : 1 : 0.3 (Makarov et al. 2004)

- Similar diagnostic H_2O line ratio for atomic emissions detected by Rosetta Alice at Comet 67P/ CG (Feldman et al., AGU, 2014)



As reported last year: 5 Visits - one detection



- Coincident hydrogen and oxygen ~200 km-high emission surpluses in Dec 2012 ➤ H_2O aurora from plumes remains only viable explanation
- Roth et al., "**Orbital apocenter is not a sufficient condition for HST/STIS detection of Europa's water vapor aurora**", PNAS, Vol. 111 no. 48, 2014

Potential variability of source activity / detectability

Roth et al. GO program 13679 investigates whether:

1. Plume activity varies with **tidal stresses?**
2. Plume activity for an individual vent source is **episodic?**
3. Plume aurora signals are detectable only when the variable **electron density and energy** environment is suitable?
4. Plumes near Europa's south pole are detectable only when the **line-of-sight geometry / time of day** is suitable?

Ongoing STIS campaign 2014/2015:
58 orbits in ~20 HST visits - including new eclipse & transit observations

[redacted]S Obtained to Date

- [redacted]nter
- [redacted]
- [redacted]
- [redacted] Coverage
- [redacted]
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- [redacted]
- 2014 Dec 30 Transit (quality issues, to be redone)
- 2015 Jan 18 Orbital Coverage
- 2015 Jan 26 Orbital Elongation 90
- 2015 Jan 27 Transit

No striking / evident plume signal detections

50% of observations taken – analysis in progress.

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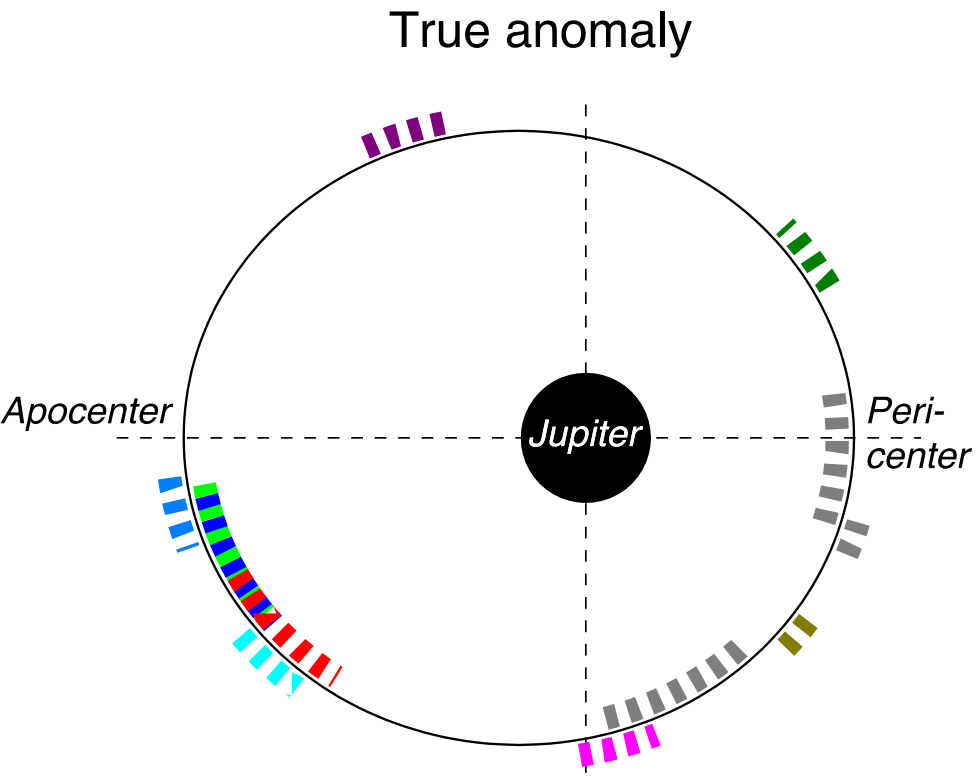
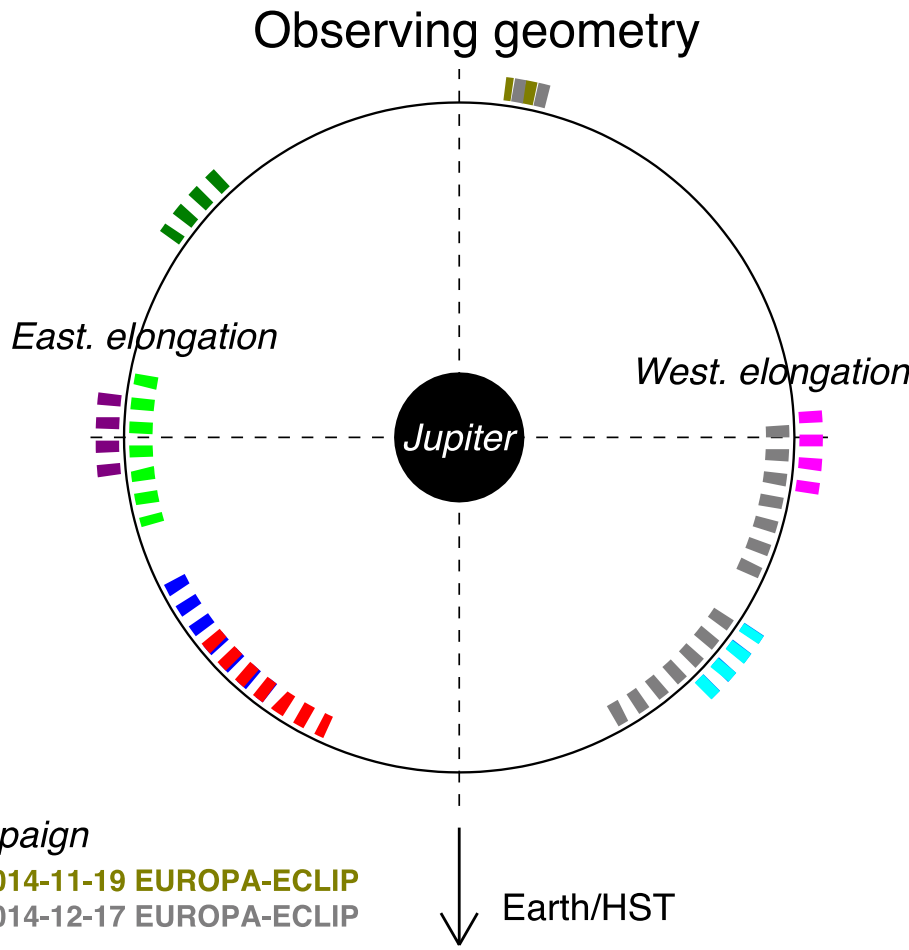
- [redacted] **Coverage**
- [redacted]
- [redacted]**nter**
- [redacted]
- 2014 Dec 30 Transit (quality issues, to be redone)
- **2015 Jan 18 Orbital Coverage**
- **2015 Jan 26 Orbital Elongation 90**
- 2015 Jan 27 Transit

Europa STIS Geometries Obtained to Date





1999 / 2012 / early 2014

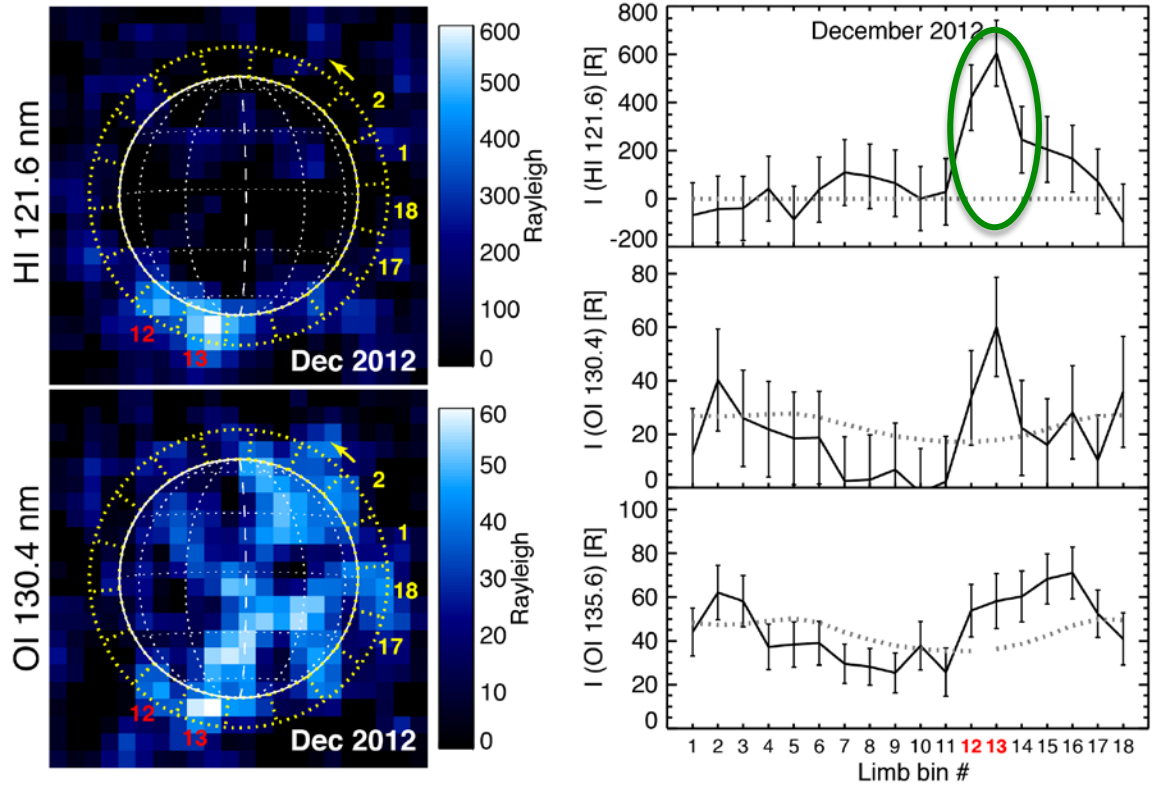
1999-10-05 EUROPA
2012-11-08 EUROPA-WEST-
2012-12-30 EUROPA-EAST-
2014-01-22 EUROPA-TA200
2014-02-02 EUROPA-TA225

2014/2015 campaign

2014-11-07 EUROPA-TA205
2014-12-07 EUROPA-ORBCO
2014-12-16 EUROPA-TA205
2015-01-18 EUROPA-ORBCO
2015-01-26 EUROPA-OLG90

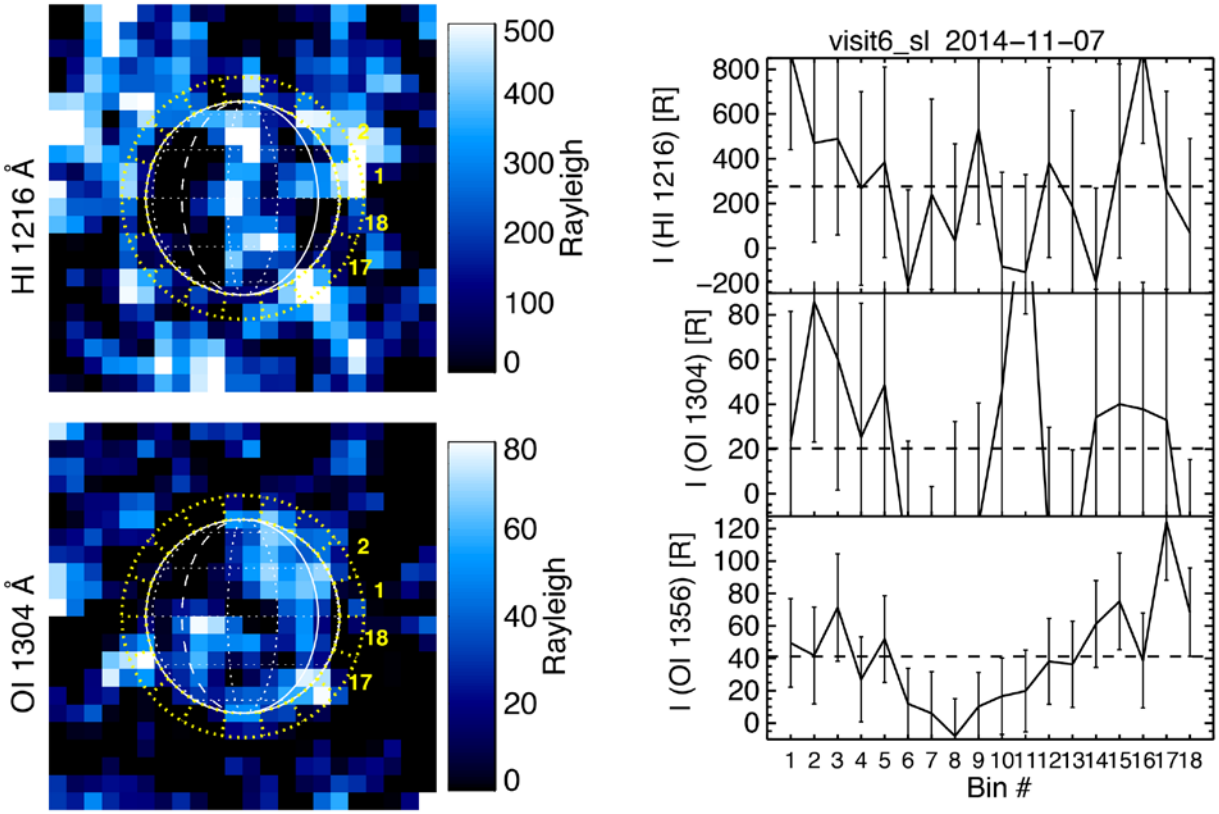
2014-11-19 EUROPA-ECLIP
2014-12-17 EUROPA-ECLIP

Limb analysis of Dec 2012 detection



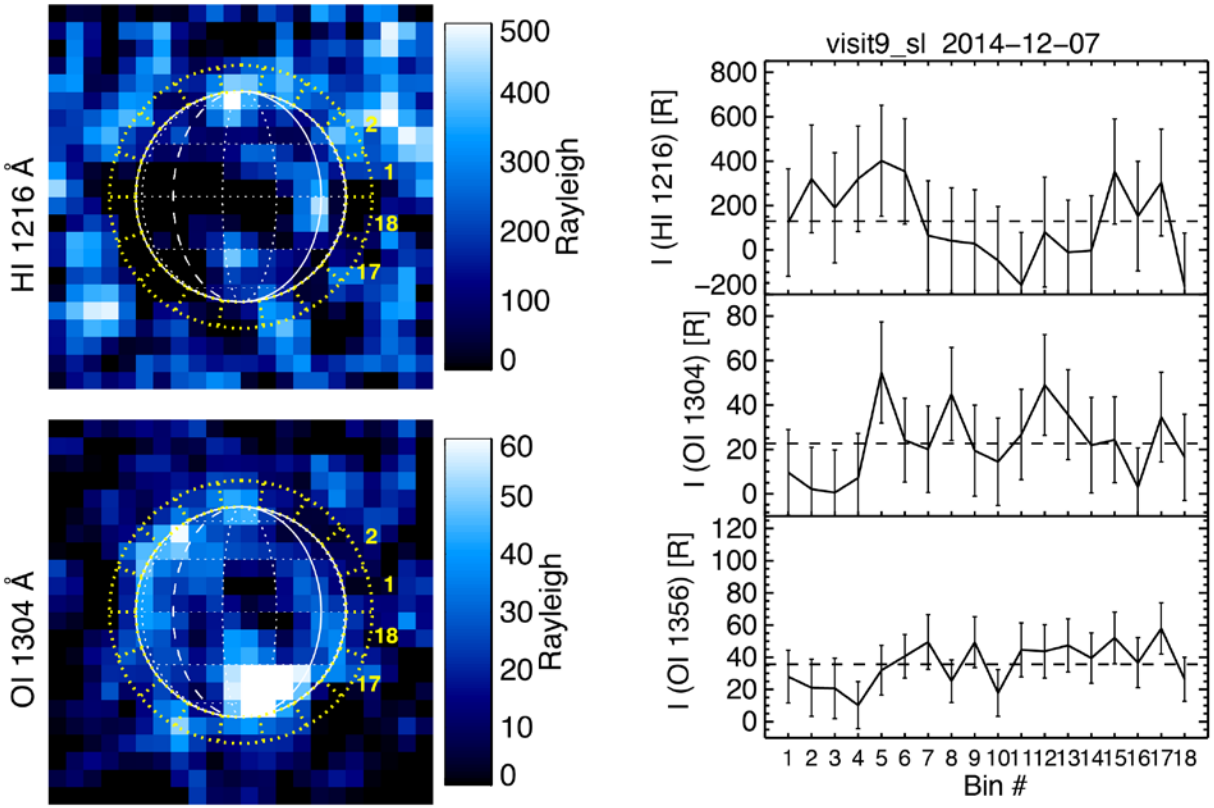
- Analysis of brightness in 20˚-wide bins around the limb
- Emission surpluses of **600 R** Lyman-alpha in limb bin consistent with 200 (±100) km high water vapor with column of **~1.5 x 10^{16} cm^{-2}**

Visit 6 – Nov 7 – Apocenter



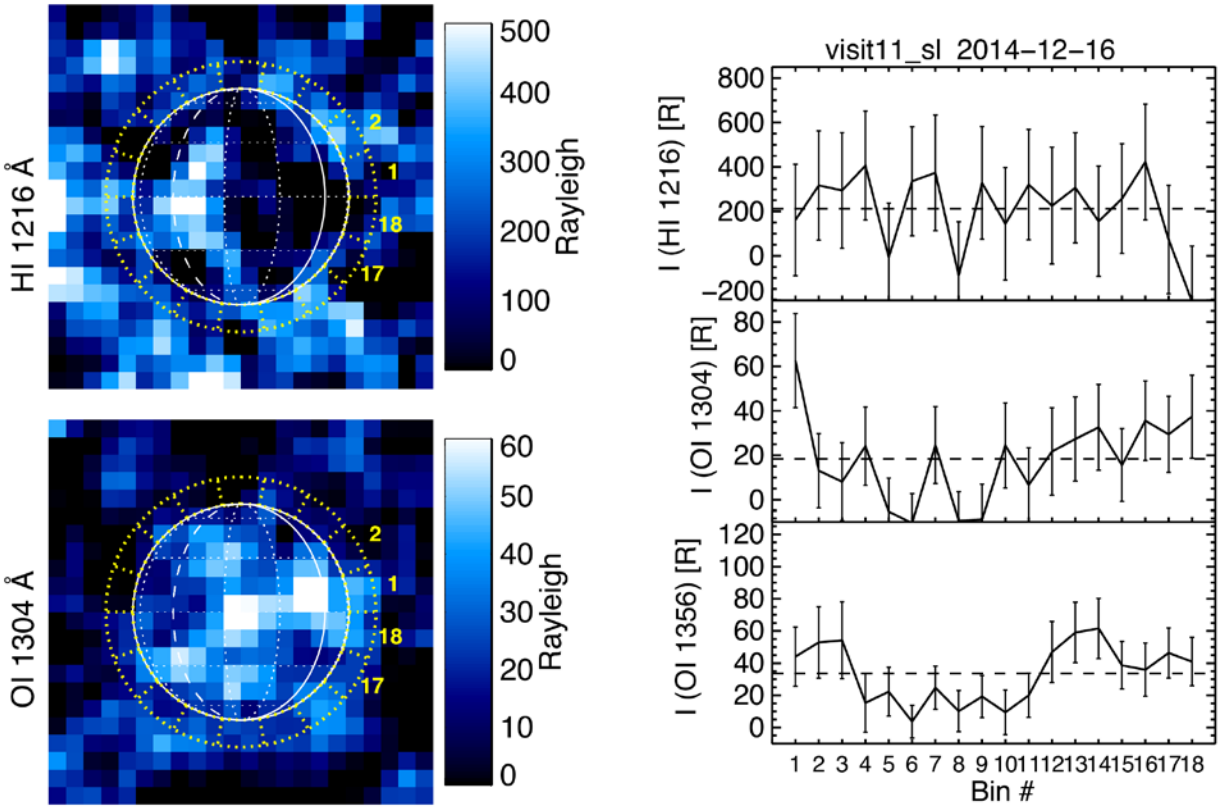
- Geocoronal background extremely high
- Constraints on H2O abundance: **$N_{H2O} < 3 \times 10^{16}$ cm^{-2}**
- Dec 2012: 600 R Lyman-alpha / N_{H2O} ~1.5 x 10^{16} cm^{-2}

Visit 9 – Dec 7 – Sub-Jovian/leading hemisphere



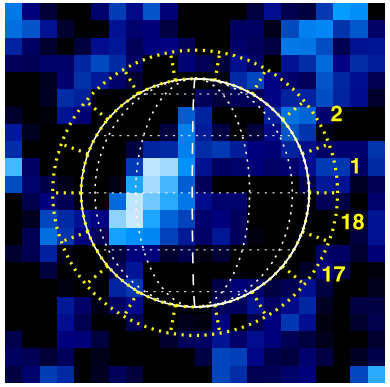
- Geocoronal background moderate
- Constraints on H2O abundance: **$N_{H2O} < 1 \times 10^{16}$ cm^{-2}**
- Dec 2012: 600 R Lyman-alpha / N_{H2O} ~1.5 x 10^{16} cm^{-2}

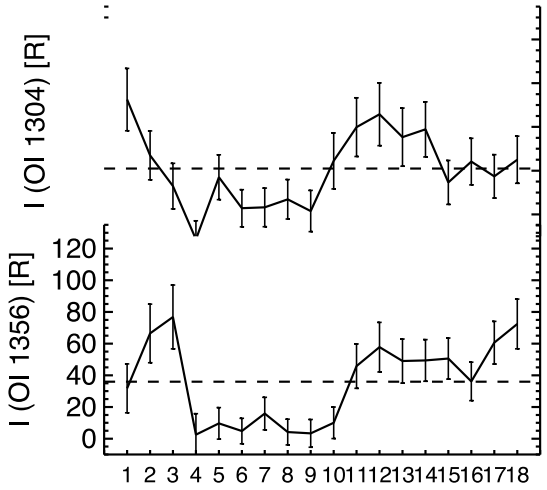
Visit 11 – Dec 16 – Apocenter



- Geocoronal background moderate
- Constraints on H2O abundance: **$N_{H2O} < 1 \times 10^{16}$ cm^{-2}**
- Dec 2012: 600 R Lyman-alpha / N_{H2O} ~1.5 x 10^{16} cm^{-2}

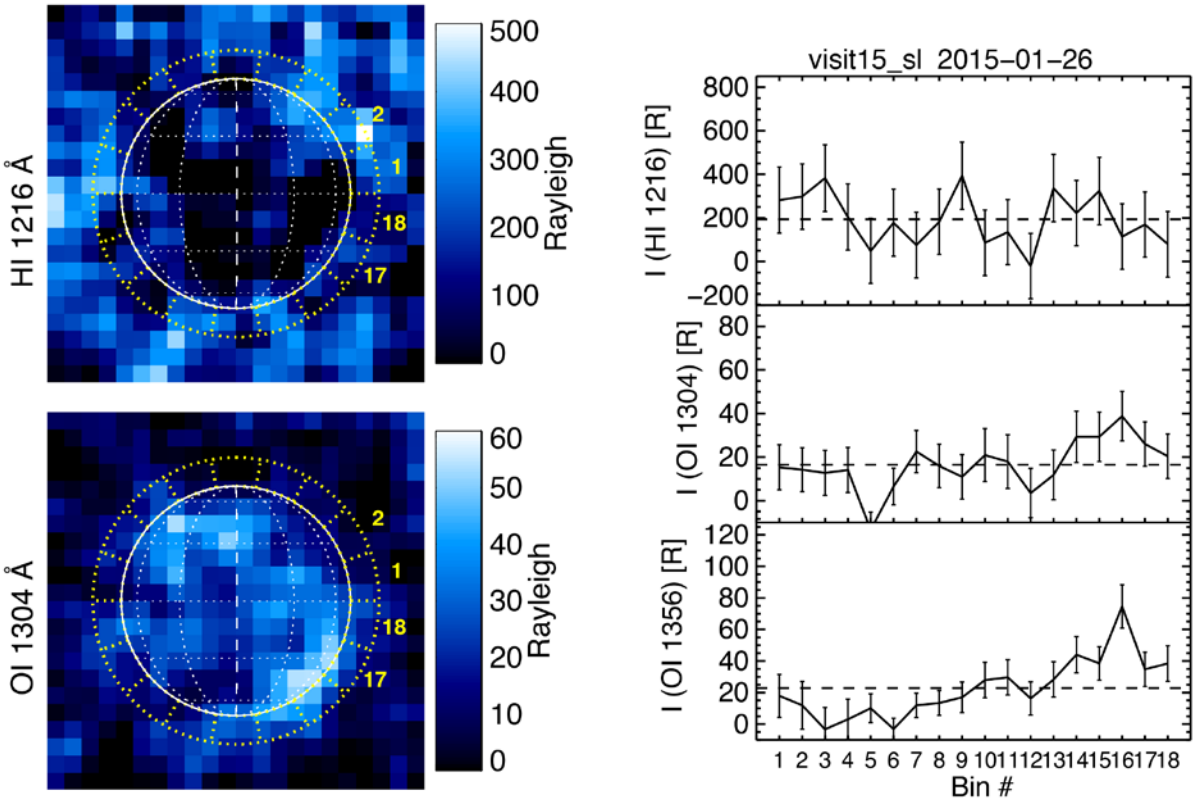
Visit 14 – Dec 16 – Max Western Elongation





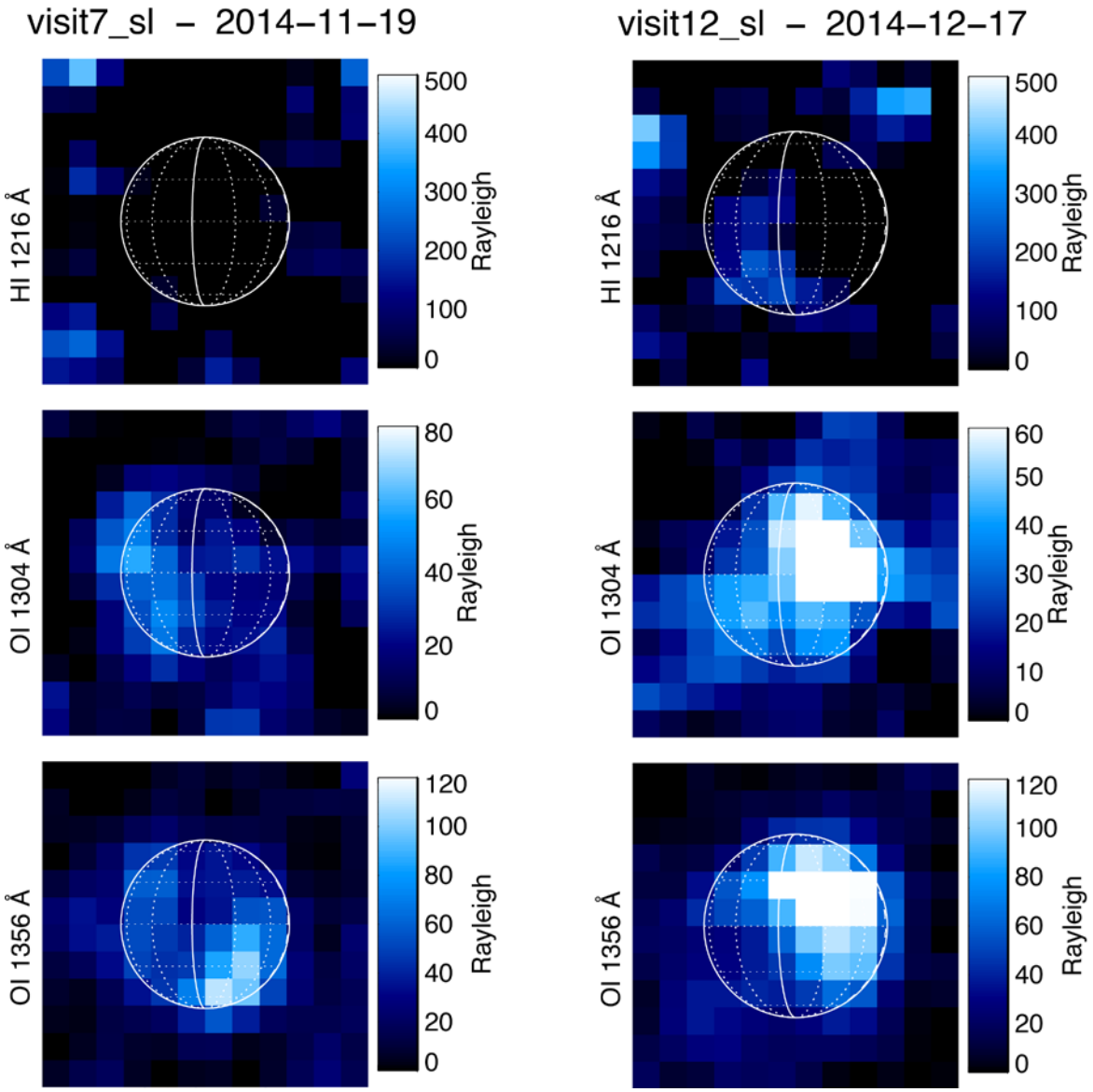
- Geocoronal background low
- Constraints on H2O abundance: **$N_{H2O} < 0.5 \times 10^{16}$ cm^{-2}**
- Dec 2012: 600 R Lyman-alpha / N_{H2O} ~1.5 x 10^{16} cm^{-2}

Visit 11 – Dec 16 – Apocenter



- Geocoronal background low/moderate
- Constraints on H2O abundance: **$N_{H2O} < 1 \times 10^{16}$ cm^{-2}**
- Dec 2012: 600 R Lyman-alpha / N_{H2O} ~1.5 x 10^{16} cm^{-2}

Eclipse visits



Summary

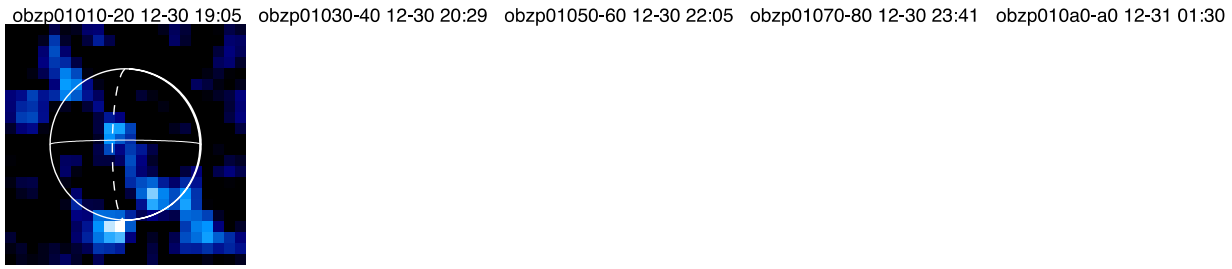
- Hubble observations do not allow strong constraints on H_2O abundance
- Detection potentially a combination of ideal conditions for plasma environment AND plume activity
- Still need a repeated detection with Hubble and/or other observatories to confirm the plume existence
  - No apparent reason to discount the initial plume assessment in the meantime
  - Other ideas for testable hypotheses are welcome
  - We'll follow the scientific method where it takes us

➢ "Orbital apocenter is not a sufficient condition for HST/STIS detection of Europa's water vapor aurora" (Roth et al., PNAS, 2014)

Impact generated plume?

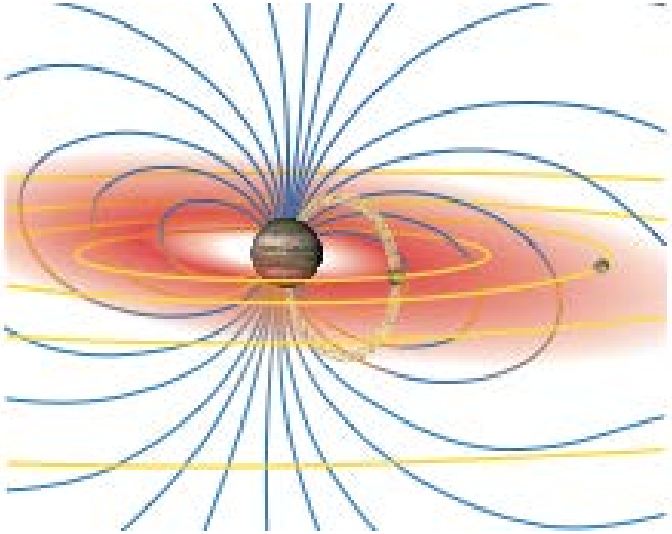
Highly-unlikely Hubble coincidently viewed such an event, but not entirely impossible

- The total H_2O mass: ~3 × 10^6 kg
- Lifetime in plume: ~20 min
- STIS images: ~ 7 hours
- Impact diameter: ~7 m
- Impact probability: ~ 10^{-2} y^{-1} (Zahnle+ 2003)
- Similar 1 per >80 yr timescale for impact melts

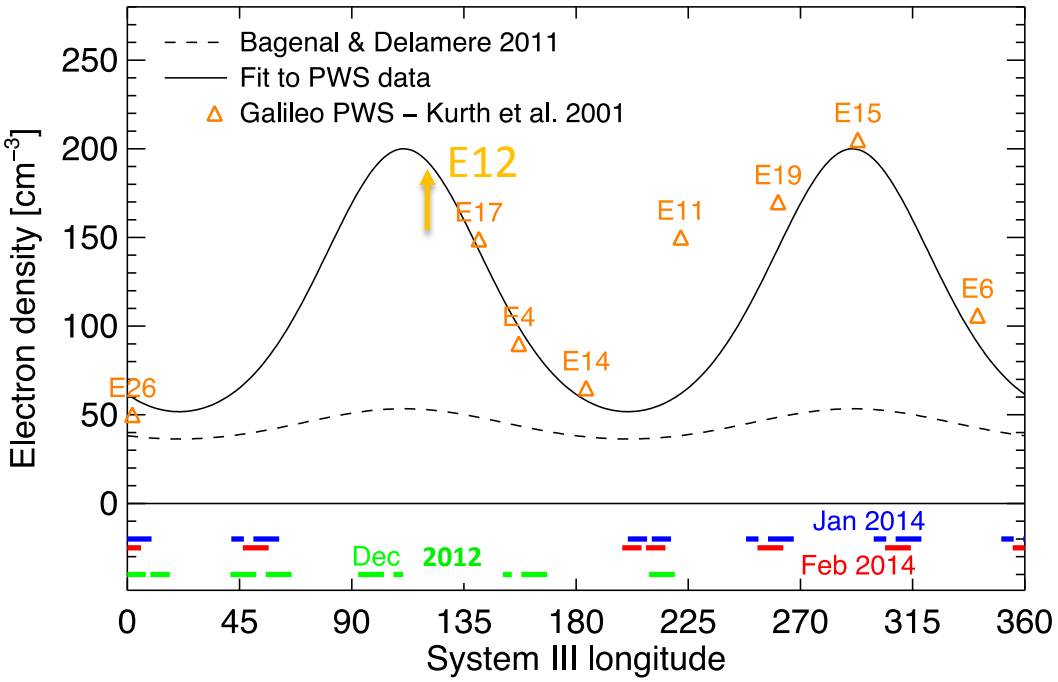


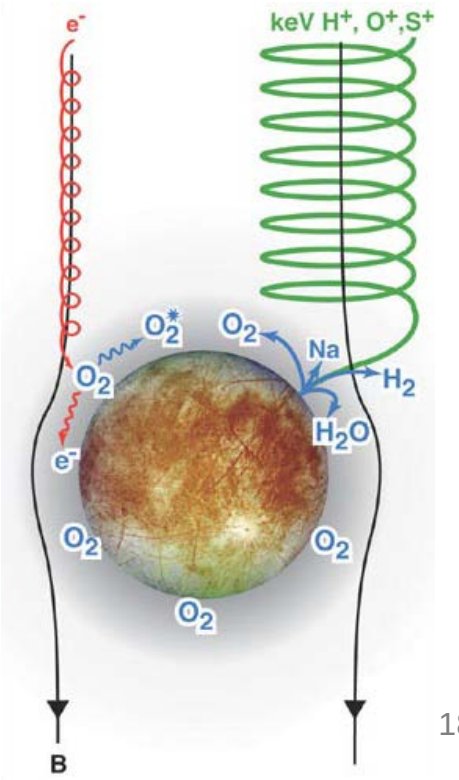
Variability of plasma environment

- Observations over ~7 hours (5 HST orbits)
- Similar coverage of periodic variations of plasma environment in 2012 and 2014
- Aperiodic variations of plasma environment? Flyby E12 density ~650/cc is off the chart!



~11.5 hour period

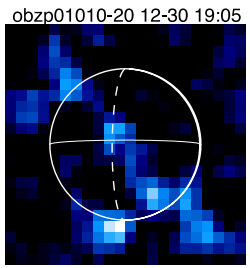




Simply a Noise Signal Misinterpreted?

- Detectable signals persist for 5 orbits (~7 hours)
  - With multiple detected occurrences in a row this noise explanation is unsatisfactory
- Roth et al., Science, 2014 Supplement details three rigorous statistical approaches

- Unlike the O_2 aurora, the H_2O aurora features do not rock with Jupiter's magnetic field orientation
  - Several dozen similar Io and Ganymede STIS G140L datasets show no signs of a ~600 R Lyα feature above the limb
  - Likely not proton aurora
  - Brightens in plasma sheet



Upcoming STIS Europa Visits

- 2015 Feb 22 Orbital Coverage
- 2015 Feb 24 Orbital Elongation 90
- 2015 Feb 25 Transit
- 2015 Mar 9 Orbital Coverage
- 2015 Mar 21 Apocenter
- 2015 Mar 28 Apocenter
- 2015 Mar 30 Transit
- 2015 April 3/14 Eclipse
- 2015 May 2 Eclipse
- 2015 TBD Transit (a redo of Dec 30)

Backup

Recent / upcoming HST Europa observations

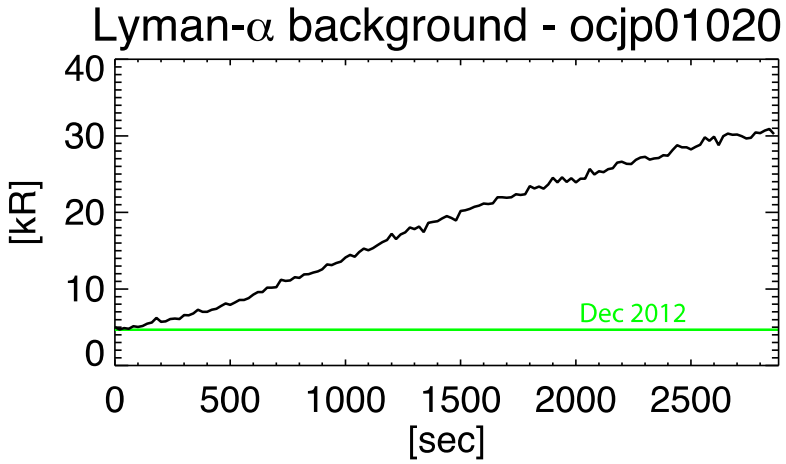
- GO 13679: Roth et al.
  STIS G140L FUV spectral imaging of:
  - Hydrogen and oxygen aurora in sunlight
  - Hydrogen and oxygen aurora in eclipse of Jupiter
  - H Lyman-a Jupiter dayglow absorption in transit

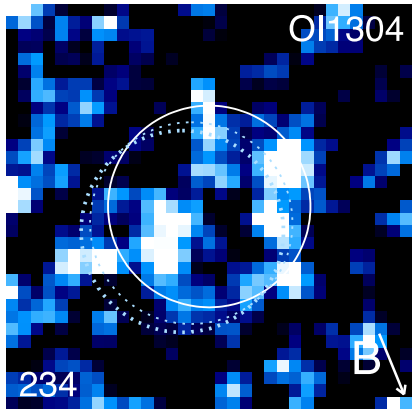
- GO 13829: Sparks et al.
  STIS FUV imaging of absorption in Jupiter transit

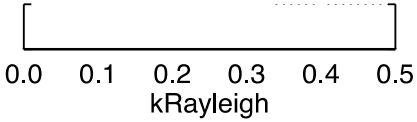
- GO 13803: McGrath et al.
  High resolution spectra of Europa's atmospheric composition – spectra not suitable to look for localized H/O emissions

First visit of new campaign - at apocenter - 7 Nov 2014

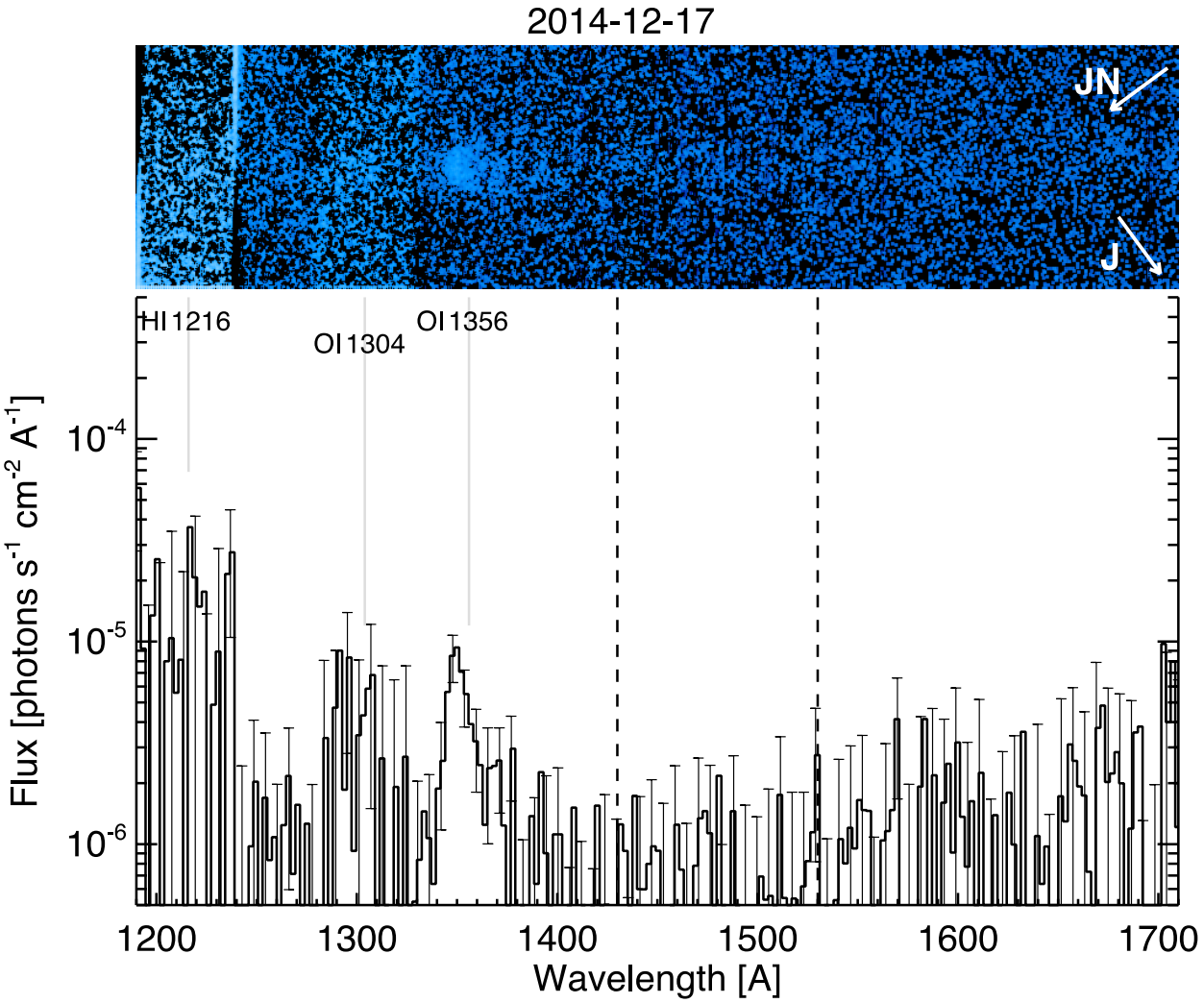
- Very high geocoronal noise: ~15 kR Ly-a on average (Dec 2012: < 5 kR)
- No reasonable constraints on H_2O abundance
- Geocoronal noise will go down closer to opposition (Feb 6, 2015)



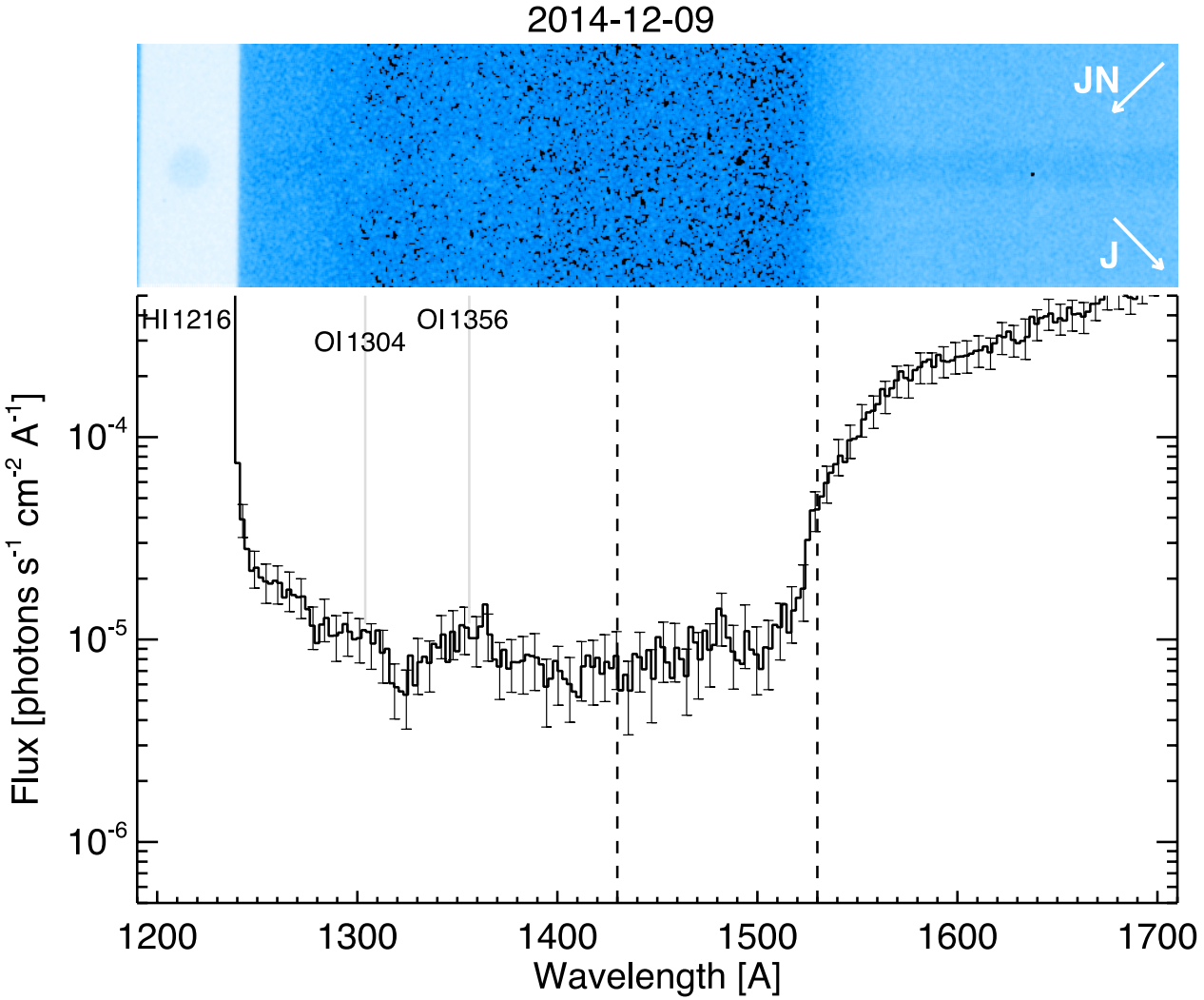




Eclipse spectrum

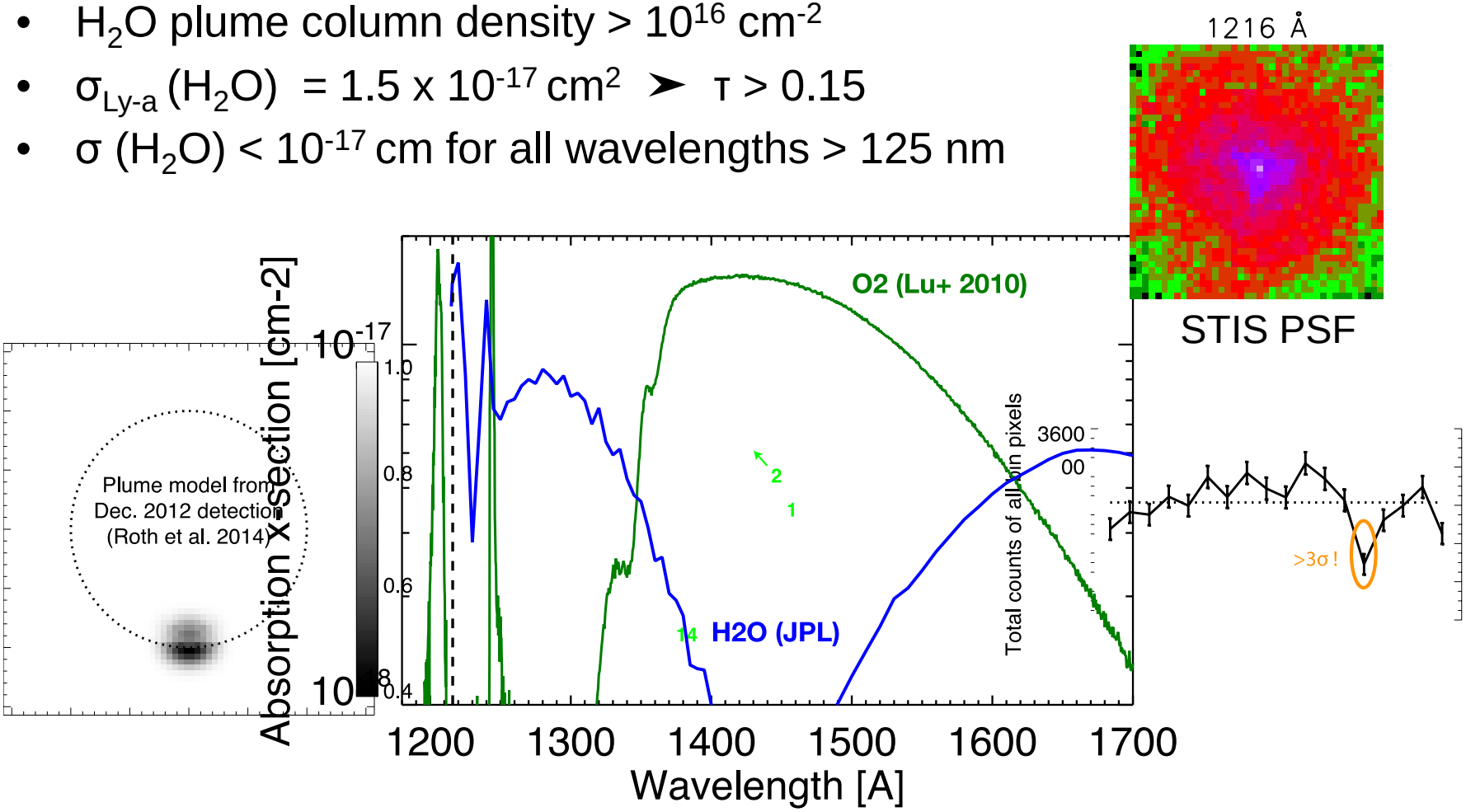


First transit FUV spectrum



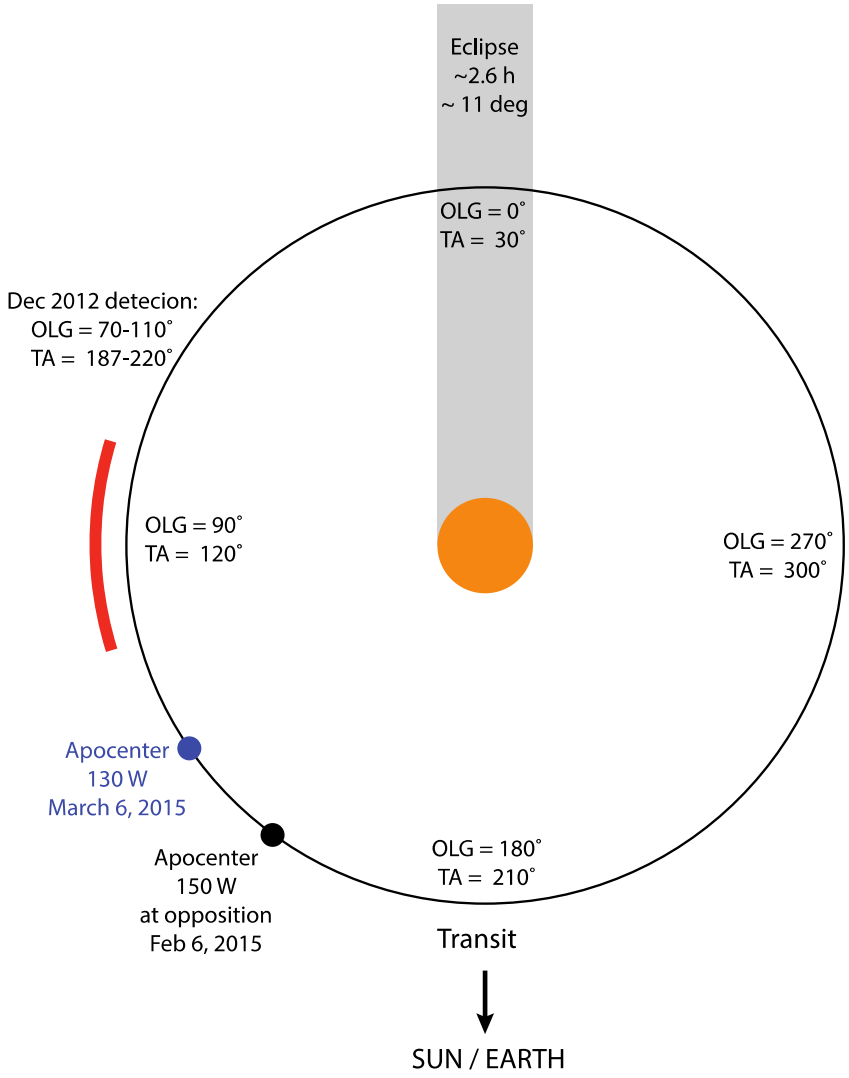
Transit Observations

- H_2O plume column density > 10^{16} cm^{-2}
- $\sigma_{Ly\text{-}a}(H_2O) = 1.5 \times 10^{-17}\ cm^2$ ➤ $\tau > 0.15$
- $\sigma(H_2O) < 10^{-17}$ cm for all wavelengths > 125 nm



Geometrical parameters / observing conditions

- Jupiter opposition: 6 Feb 2015
- True anomaly TA: Tidal stresses are function of TA (Dec2012: TA=200º)
- Orbital longitude /viewing geometry:
  Line-of-sight effects might favor plume detection
  (Dec 2012: OLG=90º)
- Next OLG=90º & TA=200º occasion: May 2015
- Europa in transit at TA=200º

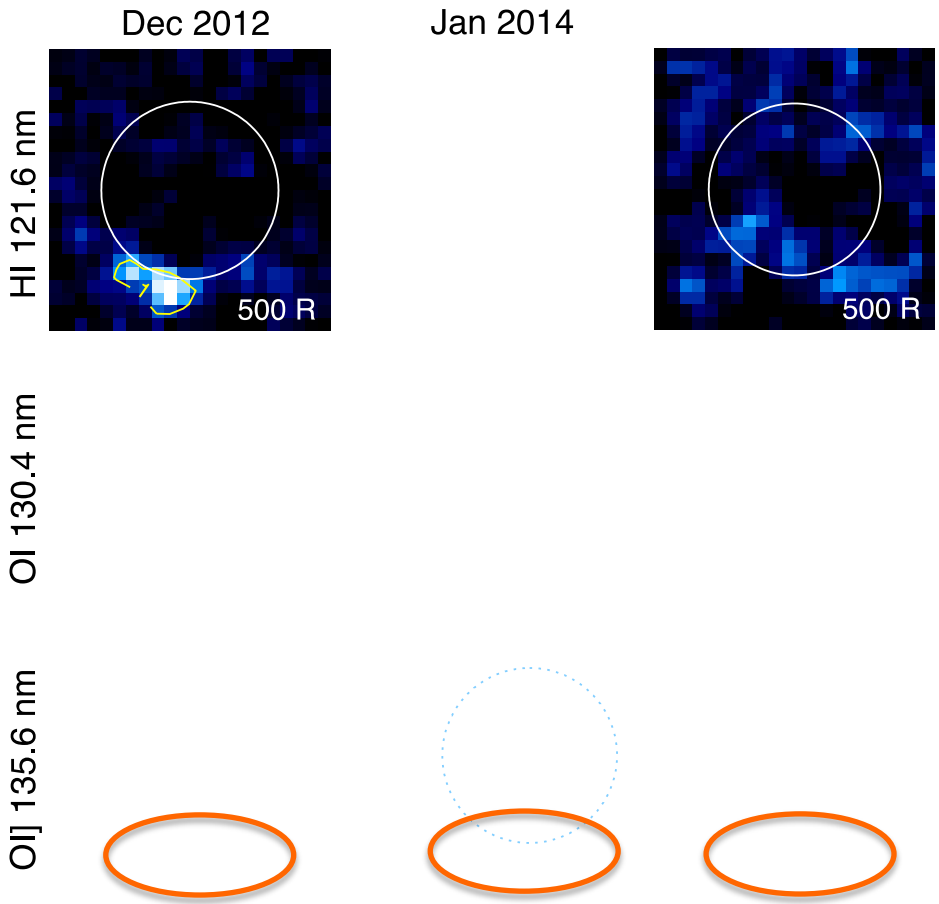


Variability of plasma environment

- Comparing O_2 and H_2O aurora:
  $e^- + O_2 \rightarrow \ldots \rightarrow h\nu_O$
  (OI 1304 Å + OI 1356 Å)
  $e^- + H_2O \rightarrow \ldots \rightarrow h\nu_H / h\nu_O$
  (HI 1216 Å + OI 1304 Å)

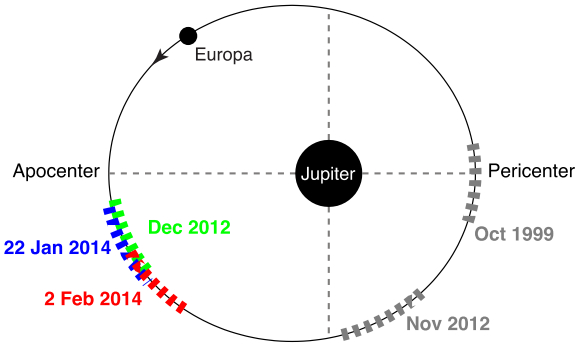
- O_2 aurora near south pole 2x lower in 2014 than in Dec 2012
- Due to changing abundance of energetic electrons above southern hemisphere?

- 2x lower H_2O abundance still required to explain 4x lower Ly-α



No pronounced H and O emissions detected at the southern limb in early 2014

- Upper limit on southern Lyman-α flux: **<u>~4 times lower than in Dec 2012</u>**
- **Lower H_2O abundance or lower electron excitation, or both?**
- Constraints on H_2O limb abundance: $N_{H2O} = (0 – 5) \times 10^{15}$ cm^{-2} (Dec 2012: 1.5×10^{16} cm^{-2})
- Timed to coincide with maximum tensile stresses on south polar region



2014