PSI #3 : Characterize the exchange processes at the interface between the surface/subsurface and the exosphere-ionosphere

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From the magnetosphere to the exosphere
Europa in the Jovian magnetosphere

Magnetic Field Lines

Jupiter

Europa's Orbit

Jovian B Field

keV S⁺, O⁺

e⁻

O₂

H₂O

Na

H₂

O₂

O₂

O₂

O₂

O₂
Radiation-induced surface chemistry

Hydrated sulfates on Europa (NIMS, Carlson et al. 2002)

⇒ Magnetospheric irradiation effects

Differential flux upstream of Europa (Cooper et al. 2005)
Europa's atmosphere and Torus

Species observed in atmosphere:
\( \text{O}_2 (\sim 10^{15} \text{ cm}^{-2}), \text{Na} (10^{10} \text{ cm}^{-2}) \), \( \text{K} (10^9 \text{ cm}^{-2}) \)

Species observed in Torus:
\( \text{H}_2 (4.2 \times 10^{33}), \text{O} (4.0 \times 10^{32}) \)
\[ = 3 \times (\text{Io torus O + S}) = 200-1000 \text{ Europa atmosphere} \]

Additional Volatiles Observed in the Surface:
\( \text{O}_2, \text{SO}_2, \text{CO}_2 \) (Will sputter with ice like Na)

Non-volatiles:
\( \text{H}_2\text{O}, \text{H}_2\text{O}_2 \)
Sulfur, Sulfate, Carbon, Carbonate, CN,
Organics, Minerals?

Atmospheric loss rates predicted from models:
\[ \sim 5 \times 10^{26} \, \text{O+O}/s \quad + \quad \sim 2 \times 10^{26} \, \text{O}/s \quad + \]
\[ \sim 1 \times 10^{26} \, \text{H}/s \quad + \quad \sim 1 \times 10^{26} \, \text{H}_2\text{O}/s \quad + \quad \sim 1 \times 10^{25} \, \text{OH}/s \] (Smyh & Marconi 2006)
\[ \sim 1.2 \times 10^7 \, \text{Na}/\text{cm}^2/s \] (Leblanc et al. 2005)
Ion Density

Neutral Densities

Entry/Exit asymmetry: Photo-ionization or latitude dependency effects?

Solid 1D: Shematovich et al. (2005)
Dashed 2D: Wong et al. (2006)
Europa
Oxygen
Spatially
Non-uniform

McGrath et al.
(2004)

September 07-09-2016
Europa initiative team meeting
"...significant coincident surpluses of hydrogen Lyman-α and oxygen OI 103.4 nm emissions above the Southern hemisphere in December 2012."

"Nondetection in November and in previous HST images from 1999 suggests varying plume activity..."
“Both brightness and aurora morphology undergo systematic variations correlated to the periodically changing plasma environment.”
"The dusk side is consistently brighter than the dawnside with only few exceptions, which cannot be readily explained by obvious plasma physical or known atmospheric effects."

"Europa’s bound atmosphere is dominated by O$_2$."

"…a more extended atomic O corona, but O$_2$ prevails at least up to altitudes of $\sim$900 km. "

Roth et al. (2015)
A 3D model of Europa’s exosphere: EGM

- Parallelized Monte Carlo approach for H₂O, H₂, O₂, H, O, OH
- Sublimation + Sputtering
- Surface reservoir
- Europa’s rotation and Jupiter gravity
- Collisions can be included but are neglected for most of the runs

Turc et al. (2014), Oza et al.; (2016)

The EGM predicts a dawn/dusk asymmetry as observed, due to:
- \( \text{O}_2 \) transport with time scale of the order of Europa rotation,
- rotation of main sources of \( \text{O}_2 \).

The absorption controls the size of the dawn/dusk asymmetry.

\( \Rightarrow \) The spatial distribution of \( \text{O}_2 \) depends on Europa phase angle.
O$_2$ migrates slowly from day to night. Its spatial distribution is highly related to its ~half rotational period previous history.

O is essentially produced from O$_2$. O density is larger than O$_2$ density above few hundreds km (collisions populate higher altitudes in O$_2$).
$\text{H}_2$ shows nominal day/night asymmetry. No dawn/dusk due to rapid migration and no absorption.

$\text{H}_2\text{O}$ leading/trailing asymmetry due to change in albedo, sputtering, and lack of migration due to efficient absorption.
Orbital evolution of $O_2$ emission
The spatial distribution and composition of Europa’s exosphere should change along its orbit around Jupiter.

Orbital evolution of O₂ emission
From the exosphere to the surface
Implantation/Sputtering
(Na⁺, K⁺) O⁺, S⁺

(O₂, H₂, H₂O)

(Meteoroids)

(O₂, H₂, H₂O)

(Na, K, SO₂, H₂S, CO₂)

(Radiolysis)
e, H⁺

(H₂O₂)

Surface

Optical Layer

Organics? Metals? Salts?

Mixing

H₂SO₄ X H₂O

H₂CO₃ X H₂O

SO₂, H₂S

Sₓ

CO₂

Cₓ

Na₂SO₄ X H₂O ?

Mg SO₄ X H₂O ?

Sₓ, Other Na, S ?

From Johnson et al. (2004)

September 07-09-2016 Europa initiative team meeting
What measurements?
Objective
What are the origins of Europa’s exosphere?

Approach
How is Europa’s exosphere today?
- **Composition** *(major and trace species)*
- **Spatial distribution** *(relations with magnetosphere, phase angle and surface)*
- **Evolution** *(Jupiter and Europa periods time scale)*

What are the main drivers of its formation?
- **Role of the magnetosphere/Sun/dust**
- **Role of the Surface/subsurface**
How is Europa’s exosphere today?

- **Composition (major and trace species)**
  Density of the neutral exospheric species
  From few cc to $10^8$ cm$^{-3}$ up to 100 amu
  Density of the ion exospheric species (eV range)
  From few $10^{-2}$ to $10^4$ cm$^{-3}$ up to 50 amu

- **Spatial distribution (relations with magnetosphere, phase angle and surface)**
  Spatial resolution of few tens of km horizontally and few km in altitude (depending on species).
  Full coverage at few phase angles

- **Evolution (Jupiter and Europa periods time scale)**
  From one hour to few 10s of hours for major species
What are the main drivers of its formation?

- Role of the magnetosphere/Sun/dust
  Ion and electron densities (keV range) with spatial resolution and on hour time scale
  Dust density and composition with spatial resolution and on few hour time scale
  Coverage of Europa’s exosphere during eclipse

- Role of the Surface/subsurface
  Latitudinal and longitudinal coverage at different phase angles for major and trace species
  Spatial resolution of few tens of km horizontally and few km in altitude for trace species; of hundred km horizontally and ten km in altitude for major species