Imaging of Ganymede through Energetic Neutral Atoms sputtered/backscattered from the surface

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The **JUICE** spacecraft will investigate **Jupiter and its icy moons** in the 2030s, with a focus on Ganymede.

Onboard JUICE, the **Jovian Neutrals Analyzer (JNA)** will measure low energy Energetic Neutral Atoms (ENAs).

<table>
<thead>
<tr>
<th>JNA specifications</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Energy range</strong></td>
</tr>
<tr>
<td>10 eV – 3.3 keV</td>
</tr>
</tbody>
</table>
MOTIVATION

- **Energetic ions** hit the surface of Ganymede (water ice) and **sputter** (or are backscattered as) **Energetic Neutral Atoms**

- By measuring **ENAs** at Ganymede, JNA can **map ion precipitation** at the surface

- To optimize operations planning at Ganymede, estimates of emitted neutral fluxes at Ganymede are needed
**METHOD**

- Input: ion velocity distribution for energetic H+, O++, S++ (1 keV - 10 MeV) and thermal H+, O+ (10 eV – 10 keV)
- Obtained through a three dimensional **hybrid simulation** *(Fatemi et al. 2016, Poppe et al. 2018)*

**Velocity distribution of impinging ions**

- H2O, H2 and O2 yield
- Sputtered velocity distribution

**Neutral flux map**

*Poppe et al., 2018*
Velocity distribution of impinging ions

- H2O, H2 and O2 yield
- Sputtered velocity distribution

Neutral flux map

- Yield = number of particles sputtered (assumed neutral) by one particle impinging on water ice
- Sputtering yield formulas derived in Fama et al., 2008 for $E_i < 100$ keV and in Johnson et al., 2004 for $E_i > 100$ keV

\[ E_i < 100 \text{ keV} \Rightarrow \text{Fama et al., 2008} \]

\[ E_i > 100 \text{ keV} \Rightarrow \text{Johnson et al., 2004} \]
**METHOD**

Velocity distribution of impinging ions

- H2O, H2 and O2 yield
- Sputtered velocity distribution

Neutral flux map

- Yield = number of particles sputtered by one particle impinging on water ice
- Sputtering yield formula derived in *Teolis et al., 2017* for particles of all energies

*Poppe et al., 2018*

*Teolis et al., 2017*
Velocity distribution of impinging ions

- H2O, H2 and O2 yield
- Sputtered velocity distribution

We use a Thompson-Sigmund law (Sigmund, 1969) to estimate the energy distribution of emitted ENAs.

Neutral flux map
Velocity distribution of impinging ions

- H2O, H2 and O2 yield
- Sputtered velocity distribution

Neutral flux map

Previous Work

- Results shown in Poppe et al., 2018, replotted here for better comparison with our results (next slide)

- Poppe et al., presented the first estimate of emitted neutrals at Ganymede, using Johnson’s formula for yield

- However, Fama’s formula for sputtering yield is more accurate than Johnson’s for $E_i < 100$ keV (see Cassidy et al., 2013)
FIRST RESULTS

Velocity distribution of impinging ions
- H2O, H2 and O2 yield
- Sputtered velocity distribution

Neutral flux map

- Using Johnson’s formula for \( E_i > 100 \text{ keV} \) and Fama’s for \( E_i < 100 \text{ keV} \), we calculated the estimated neutral H2O flux at Ganymede (shown above).
- Results show higher fluxes than previously calculated (up to x2 higher).
- The difference is largest where the ion flux is dominated by thermal ions, for which Johnson’s formula underestimates the sputtering yield (e.g. at the poles on the trailing side (left-hand side)).
We identified a method to estimate the sputtered neutral fluxes that JNA will observe at Ganymede in the 2030s using:

1. Results from hybrid simulations of ion precipitation at Ganymede
2. Experimentally derived expressions to calculate the sputtering yield of water ice and the energy distribution of sputtered products

Our calculation of sputtered neutral H$_2$O at the surface of Ganymede showed higher fluxes than previously estimated in Poppe et al., 2018

Future steps include investigating the energy distribution of emitted neutrals, calculating H$_2$ and O$_2$ fluxes, accounting for the angular distribution of emitted neutrals, accounting for backscattering of impinging ions, and converting fluxes to JNA counts