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Towards a Carbon Nanotube Ionization Source for Planetary Atmosphere Exploration

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Technology Objective

A carbon nanotube electron gun (CNTEG) is constructed for the highly sensitive exploration of exospheres, i.e. extremely tenuous atmospheres \((n < 10^8 \text{ cm}^{-3})\). The CNTEG is based on the quantum principle of field emission1, seeking to efficiently impact and therefore ionize diffuse neutrals known to be present around planetary bodies.

![Fig. 1 CNTEG](image)

- Electron field effect emission generates current due to solid-state quantum tunneling. 
- Moderate E field. 
- Power-efficient. \((P < 0.1 \text{ Watts})\). 
- Sufficiently powerful current. \((I \approx 200 \mu A/0.1 \mu A)\). 
- Very stable. \((dI/dt < 0.1 \mu A/s)\). 
- Light-weight and robust.

Carbon Nanotubes as Cold Cathodes

![Fig. 2 SIMION simulation of CNTEG electrodes' equipotentials and \(e\) trajectories. *Overlaying grid *source.](image)

- Field emission from \(d_{\text{CNT}}=90 \text{ nanometer} \text{ CNT} \text{ at } 95 \text{ V/cm}\).
- CNT emission measured at each electrode labeled above.
- CNTEGs are emitting consistently at ~ 60%. 
- Axole emission is at 76%.
- Emission \(I_{\text{CNT}}=100 \mu A\) at a cathode gate distance of \(d_{\text{cath}}=250 \mu m\).

Exosphere Ionization

![Fig. 3 SIMION simulation of CNTEG electrodes’ equipotentials and \(e\) trajectories. *Overlaying grid. *Source.](image)

- Overall water exosphere is uniform in 1 yr. HST detection of excess \(H I/\beta\) may be an anomaly.
- Sub-Jovian water is more than 10x dense at high altitudes.
- Sub-Jovian \(O_i\) is \(\approx 1000 x\) more dense than the anti-Jovian observations.
- Jupiter is a unique source of \(upper\) atmosphere \(O_2\) \(Atomic\) \(O\) more likely.

Europa’s Hydro-Exosphere

![Fig. 4 CNTEG electron field emission measured at each electrode labeled above.](image)

- Upper exospheric oxygen behavior is identical to other water-products: \(H_2, OH, H_2O\).

![Fig. 5: Selected SIMION simulation of ionization volume demonstrating ion production via \(e\) impact.](image)

- EUROM simulations of Europa’s Hydro-Exosphere show stark atmospheric structures dominated principally by Jupiter’s gravitation.

Exospheric Global Model (EGM) is a 3D parallelized Monte Carlo code developed for the characterization of exospheres. Here, we model Europa. Test particles are ejected from Europa’s surface up to \(15 R_E\), following known energy distributions. The test particles are on ballistic trajectories and can escape, stick, and bounce on the surface. Furthermore the particles can be dissociated/ionized by physicochemical processes.

![Fig. 6: EGM domain modeling physical processes in spherical coordinates.](image)

- Extended Exosphere Clouds are simulated, due to: 
  - Jovian gravitational drag is evident. 
  - Similar to sodium clouds at Io^5. 
- Escape rates could indicate an Enceladus-like hydrotorus.

Perspectives from Surface-Exosphere inhomogeneities:

1. Sputtering may not be global^8. 
2. \(O_+\) ions may not dominate^7. 
3. Water-product escape rates match previous studies \(^6\).
4. \(O_2\) is thermalized to \(T_{\text{Surf}}\), speeds are not sufficient to populate upper exosphere.

Results

![Fig. 7: Top view of simulated atomic oxygen exosphere.](image)

- Europa’s hill sphere extends to about \(5 R_E\) beyond which Jovian gravity dominates.
- Day-night asymmetry is apparent. Effect is less for leading hemisphere as anti-jovian is close to anti-pole.

References