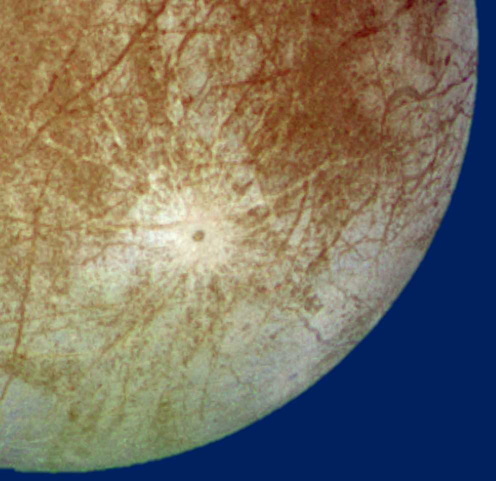
Influence of Europa's Time-Varying Electromagnetic Environment on Magnetospheric Ion Precipitation and Surface Weathering



Peter Addison (paddison6@gatech.edu), Lucas Liuzzo, Hannes Arnold, and Sven Simon

Europa's Radiation Environment

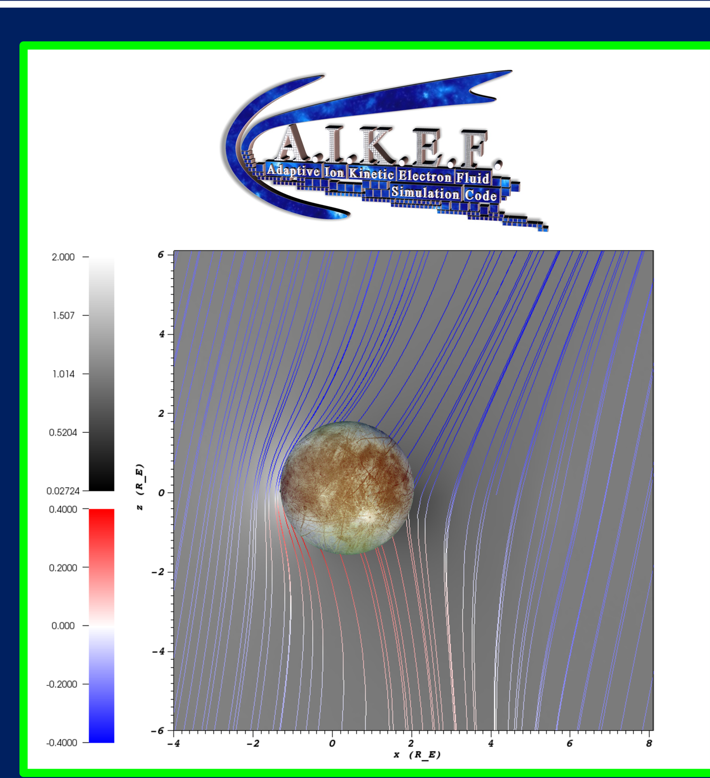
- Europa's surface continually irradiated by two plasma populations:

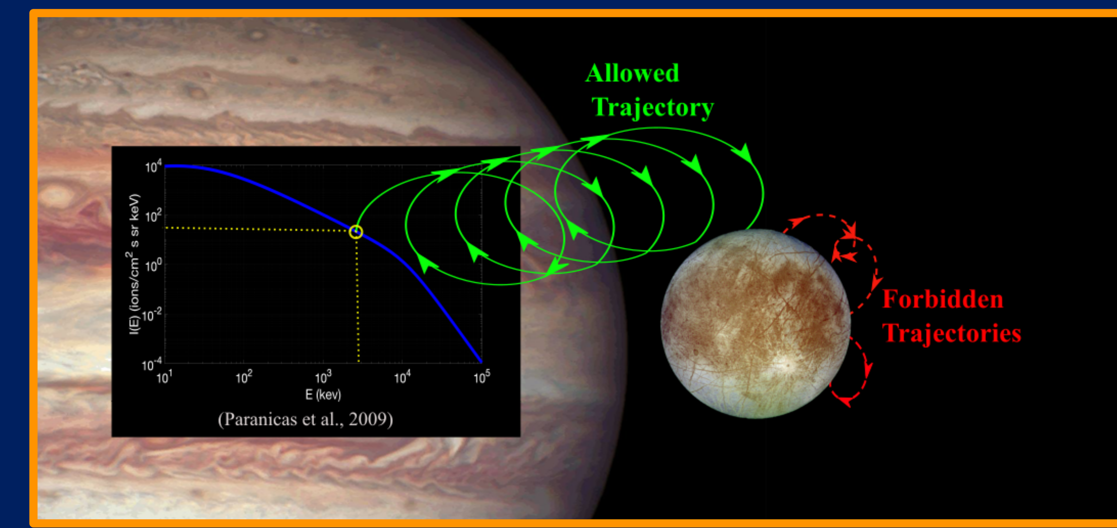
	Thermal Plasma	Energetic Plasma
Energy	~ 1 keV	5 keV – 10 MeV
Density	50-200 cm^{-3}	~0.1 cm^{-3}
Dominant Species	H^+, O^+, S^{2+}	H^+, O^{2+}, S^{3+}
Distribution	(Drifting) Maxwellian	~Kappa

- Magnitude and Spatial Distribution of Surface flux determined by local electromagnetic field structure

Methodology

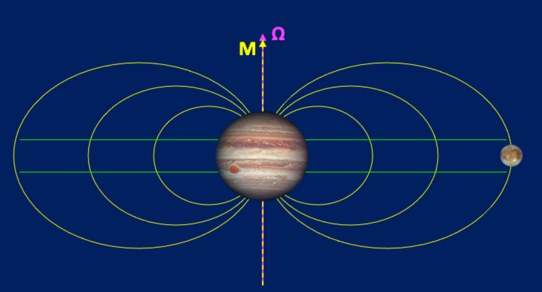
1. Use the AIKEF hybrid code to model Europa's perturbed electromagnetic field environment at three locations, evenly spaced across a synodic rotation of Jupiter: 1) Europa in the center of the plasma sheet 2) Europa north of the center of the plasma sheet. 3) Europa south of the center of the plasma sheet
2. Use the GENTOo particle-tracing code to calculate the surface flux of all ion species at discrete energies over the entire energy range observed by Galileo
3. Integrate over species and energy to obtain total surface flux
4. Average over a rotation and search for correlation with observed surface features.

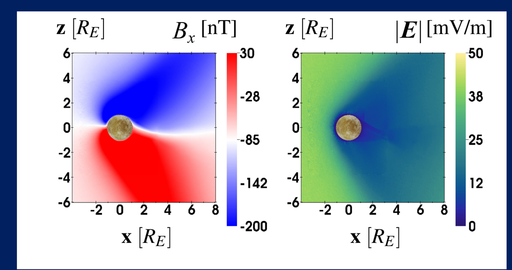




AIKEF fields combined with measured upstream distributions (Galileo, Juno) to calculate realistic surface fluxes of magnetospheric ions!

Case 1: Europa at the Center of the Plasma Sheet

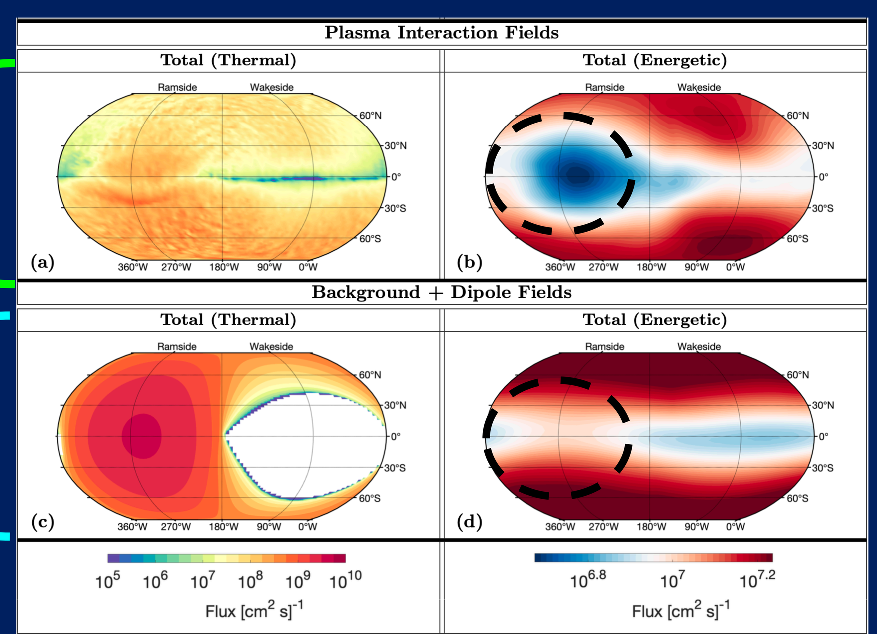




- Upstream density maximized
- Weak induction!
- Strong field line draping

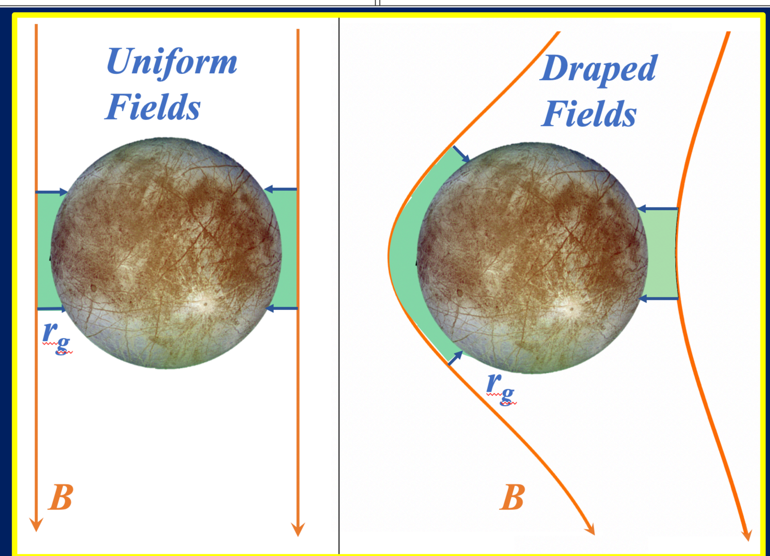
Perturbed fields (Jovian field + plasma interaction + induction)

Uniform fields (Jovian field + induction)

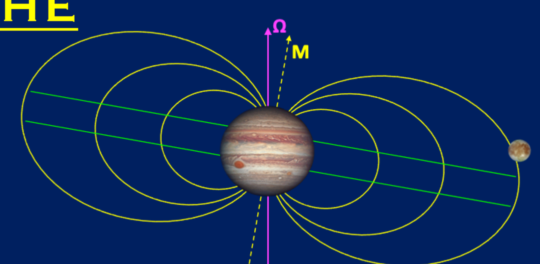


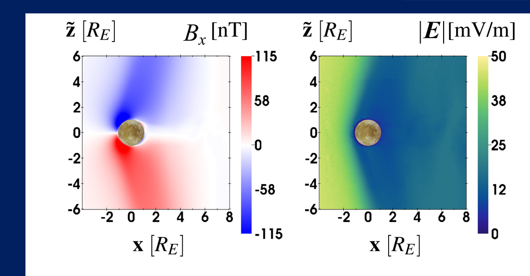
"Valley of Death"

- Magnetic field draping increases the distance where ions with large field-aligned velocities are within one gyroradius of the moon's surface!
- Ion population depleted at high latitudes: upstream apex protected!



Case 2: Europa North of the Plasma Sheet





- Upstream density minimzed!
- Strongest induction from subsurface ocean!
- Weaker draping, "quenching" of Alfvén wings by induced field

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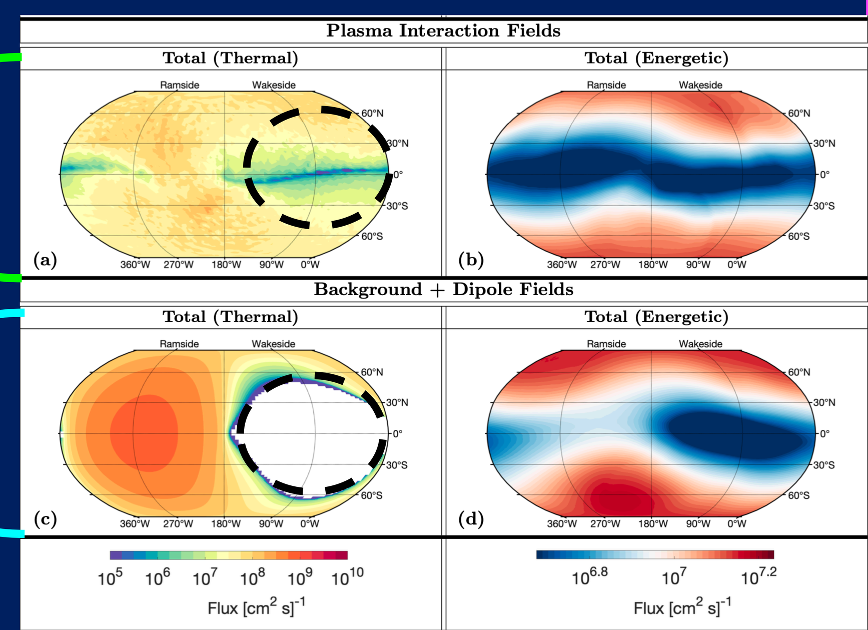
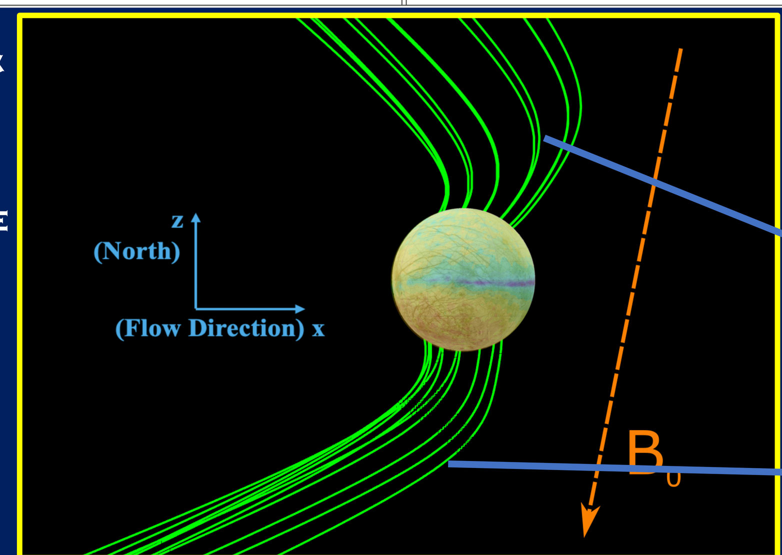
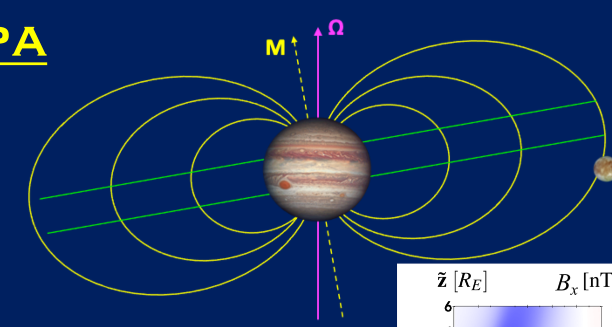


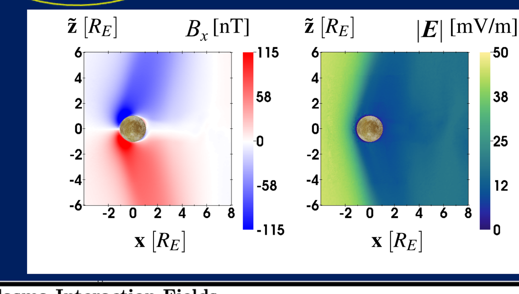
Downstream hemisphere irradiation

- Draping of the magnetic field diverts upstream particles with inclined trajectories against the corotation direction into the moon's downstream hemisphere!
- High irradiation near poles in all three cases



Case 3: Europa South of the Plasma Sheet

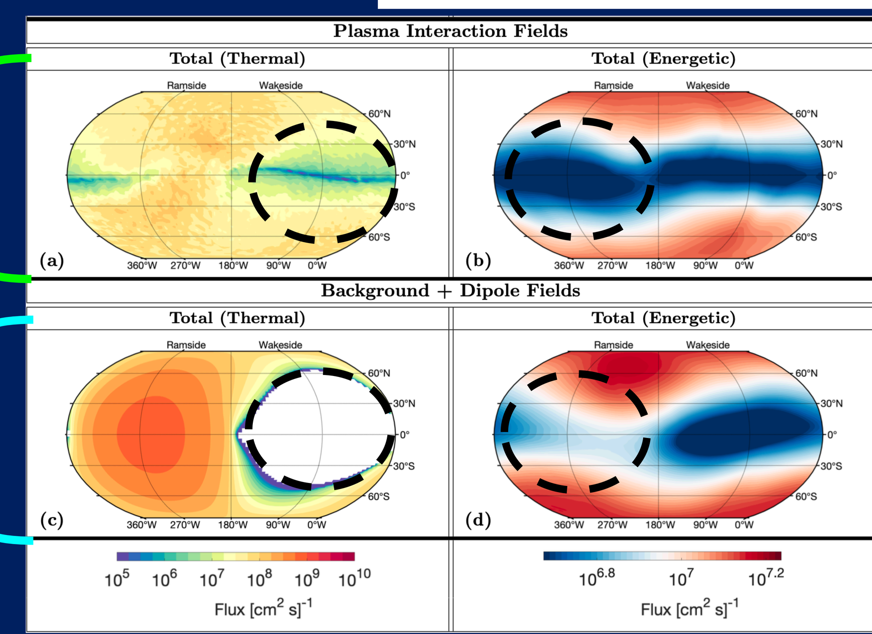




- Upstream density minimized!
- Direction of inducing and induced fields reversed from case 2

Perturbed fields (Jovian field + plasma interaction + induction)

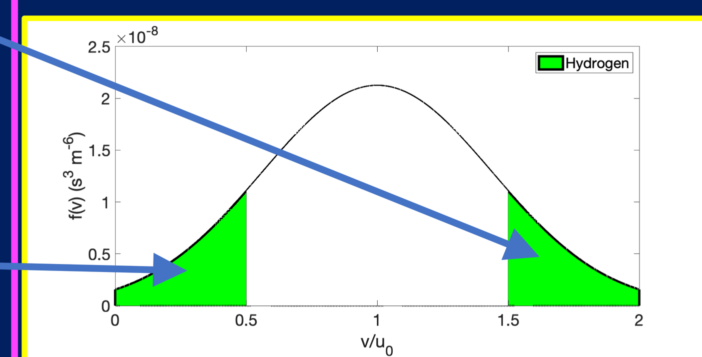
Uniform fields (Jovian field + induction)



- Cases 1,2 & 3 cover an entire synodic rotation!

Irradiation pattern symmetric between northern and southern elongation relative to the plasma sheet, pattern only flips around Europa's equator

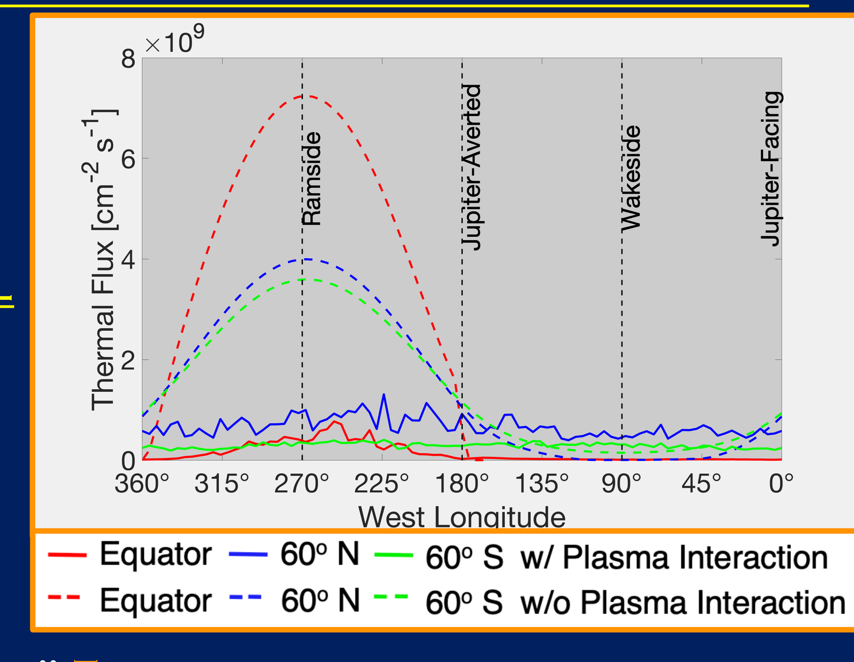
- Valley of death and downstream irradiation present at all points along a synodic rotation!



Thermal ions from the "edges" of the distribution contribute significantly to surface flux!

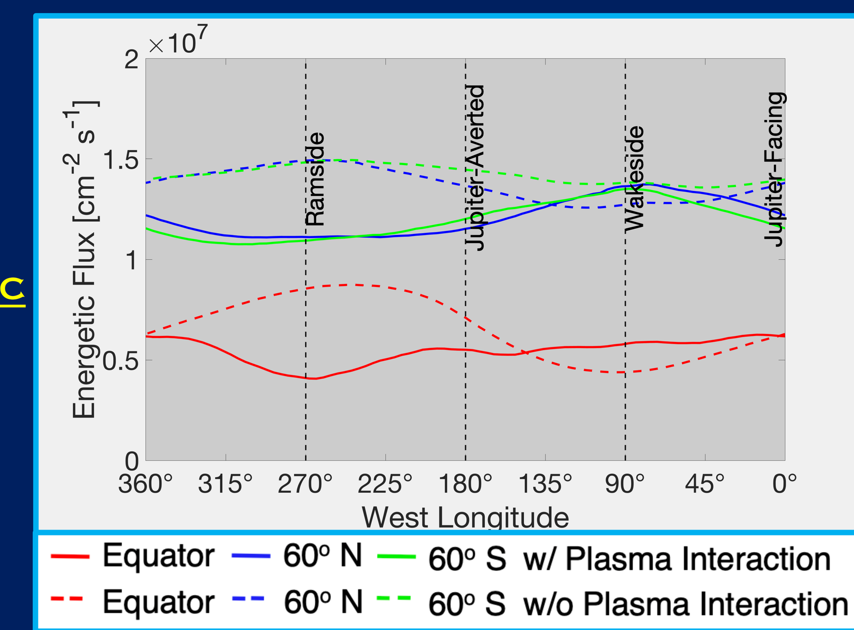
Average Surface Flux Across an Entire Synodic Rotation

Thermal ions



- "Bullseye" thermal ion flux pattern of uniform fields smeared out by plasma interaction downstream hemisphere highly irradiated!

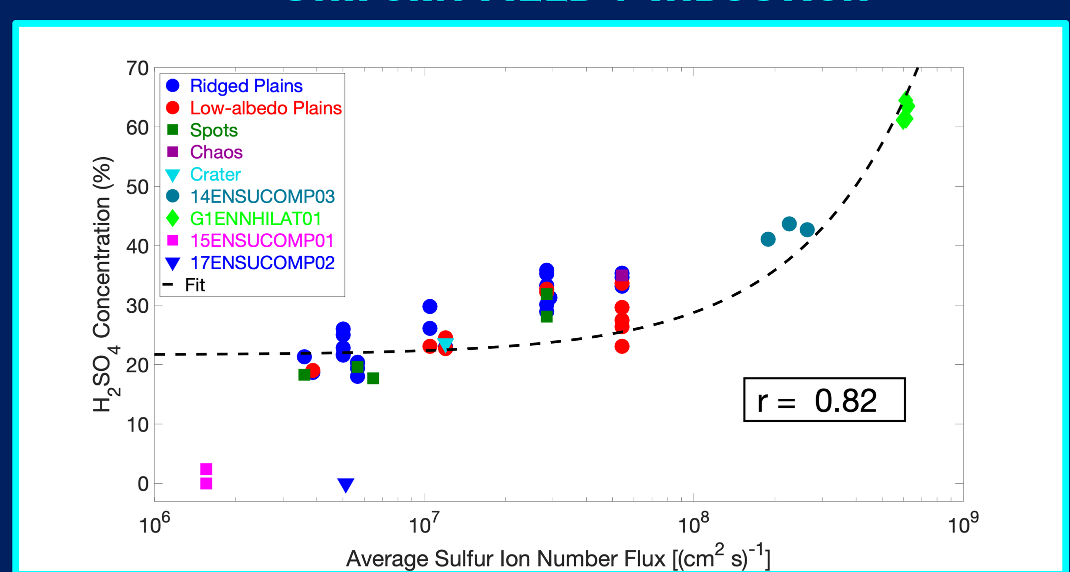
Energetic ions



- Valley of death mechanism reverses flux pattern of energetic ions: upstream hemisphere most protected!

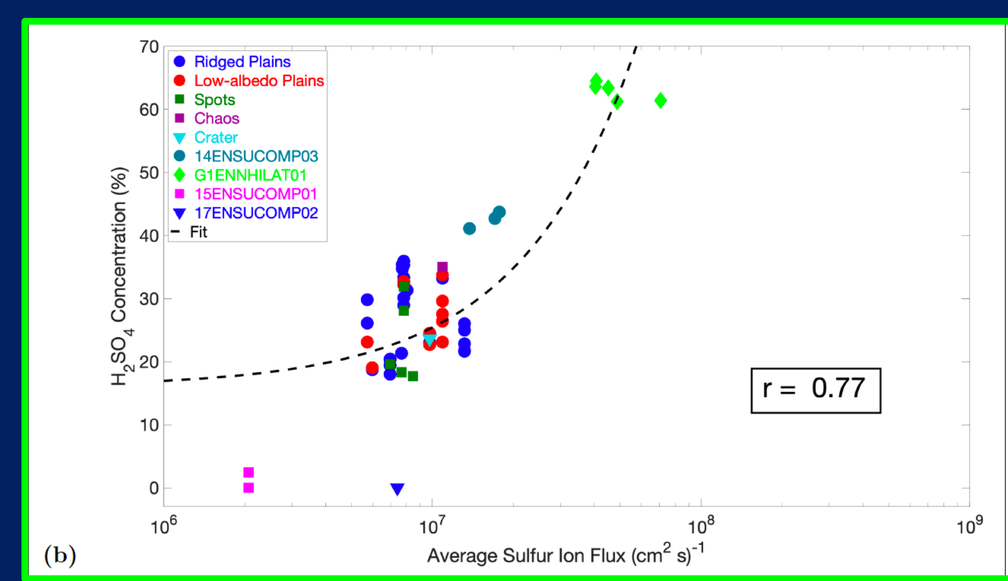
Correlation between Distribution of Modeled Sulfur Ion Flux onto the Surface and Measured Sulfuric Acid Surface Concentration

Uniform Field + Induction



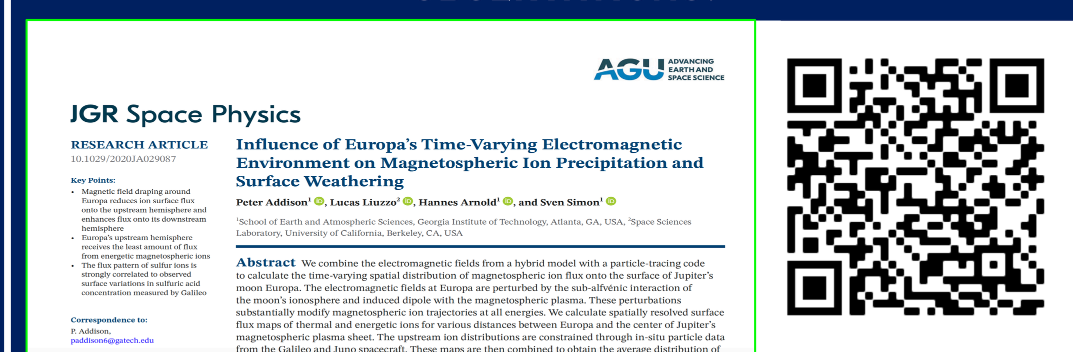
- Strong correlation found with uniform field model (left) only slightly weakened with perturbed field model (right)
- Modeled sulfur ion influx onto surface & observed sulfuric acid surface concentrations *(Dalton et al., 2013)*: strong correlation!
- Supports notion of exogenic sulfur implantation chemically altering Europa's surface!

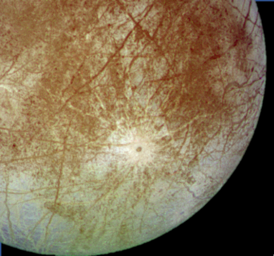
Perturbed Fields



Conclusions:

- Perturbations drastically alter surface fluxes!, and cannot be ignored!
- Fluxes calculated with perturbations correlate strongly with surface observations!





Effect of the Magnetospheric Plasma Interaction and Solar Illumination on Ion Sputtering of Europa's Surface Ice

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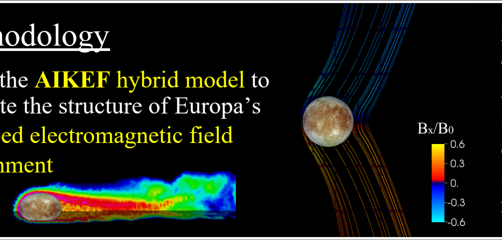
Europa's Sputtered Exosphere

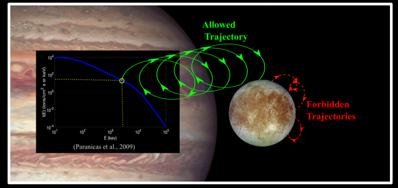
- Surface constantly irradiated by magnetospheric charged particles with energies ~100 eV—10MeV
- Ion impacts (mainly H^+, O^{n+}, S^{n+}) "kick up" surface material (sputtering), generating Europa's dilute exosphere
- Main exospheric constituents: O_2, O, H_2, H_2O
- O_2 dominates near-surface layer (height ~ 300 km)

Methodology

1. Use the **AIKEF** hybrid model to calculate the structure of Europa's perturbed electromagnetic field environment

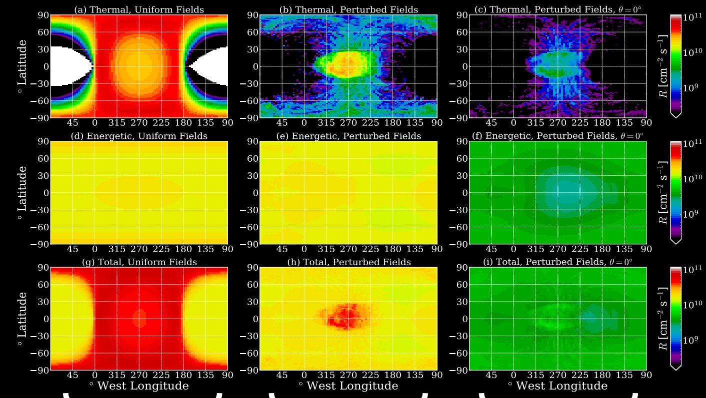


2. Apply the GENTOo code to calculate ion trajectories the AIKEF output. Combine with sputtering yield models to calculate maps of ion surface sputtering rates. Examine how rates change over an orbital period



NO STUDY TO DATE HAS CALCULATED SPATIALLY-RESOLVED MAPS OF ION SPUTTERING AT EUROPA WHILE CONSIDERING THE FIELD PERTURBATIONS AND ORBITAL POSITION

H_2O Sputtering Rates



Uniform Fields, Modeled Incidence Angles

- Corotating thermal ions impinge directly onto upstream hemisphere: no deflection
- Inverse cosine dependence creates "inverted bullseye" sputtering pattern
- Downstream face inaccessible to thermal ions: filled in by uniform energetic ion sputtering

Perturbed Fields, Modeled Incidence

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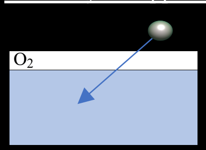
- Europa's surface topography not constrained at small scales: incidence angles uncertain
- Assuming normal incidence for all ions minimizes sputtering yields, resultant rates
- Normal incidence does not substantially alter the sputtering pattern, quantitative reduction only

O_2 Sputtering Rates at Different Orbital Positions

Two conceptual models of O_2 Sputtering

"Thin-layer" Approach

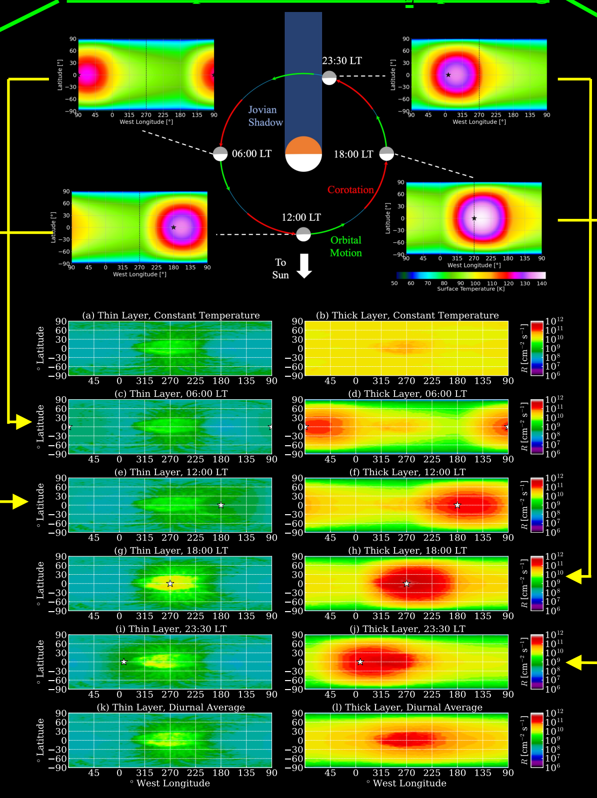


-O_2 concentrated in a thin layer (~280 nm) at the very top of the surface ice. Formulated by *Teolis et al., (2017)*

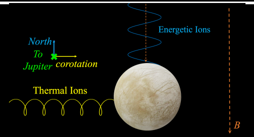
-With a thin O_2-bearing layer, extra penetration depth of energetic ions is wasted: thermal ions dominate

- Upstream-downstream dichotomy in thermal ion flux dominates the sputtering pattern

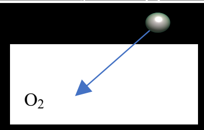
- In this case, O_2 sputtering is always maximized at the upstream hemisphere, regardless of solar orientation!



O_2 sputtering is temperature-dependent!



"Thick-layer" Approach



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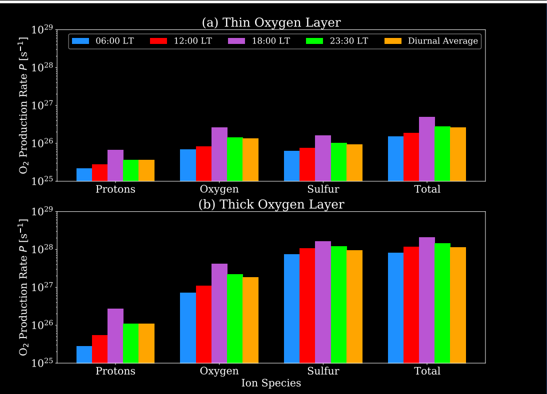
-Surface composition affects exosphere production!



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-Thin oxygen layer better reproduces observed column densities--- modeled ~ 0.7-2x10^{14} cm^{-2}, observed ~ 2-6x10^{14} cm^{-2}, thick layer estimate two orders of magnitude too high (~0.8-2x10^{16} cm^{-2})

-Production varies by ~3x depending on position

Conclusions

-Electromagnetic field perturbations drastically alter sputtering rate patterns, must be considered.

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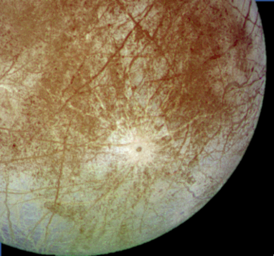

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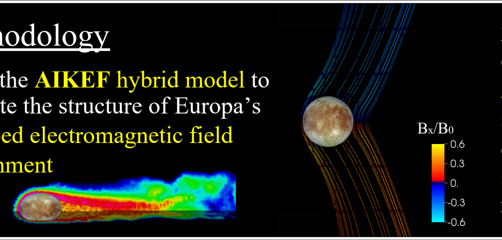

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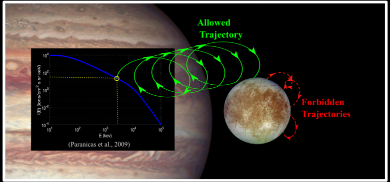

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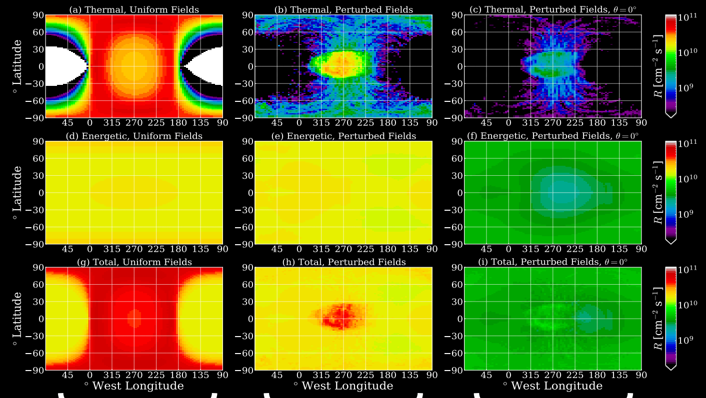

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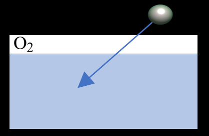

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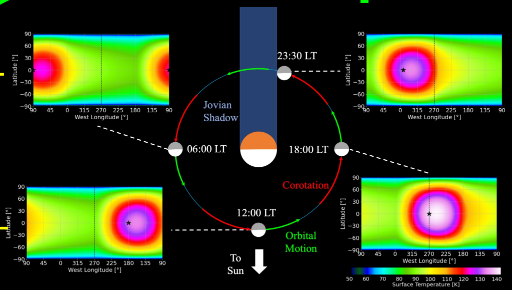

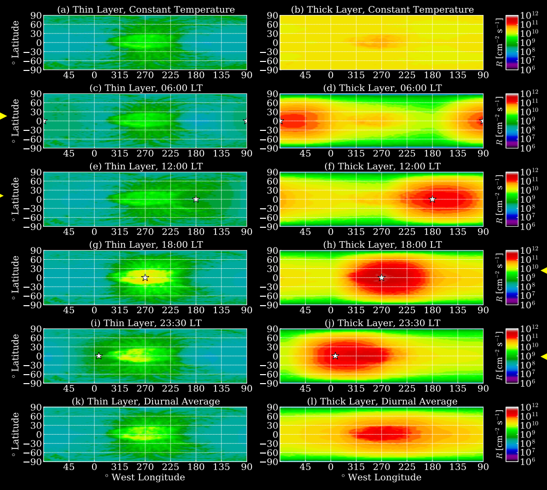

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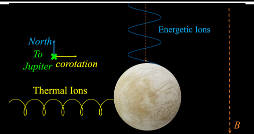

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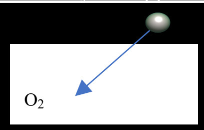

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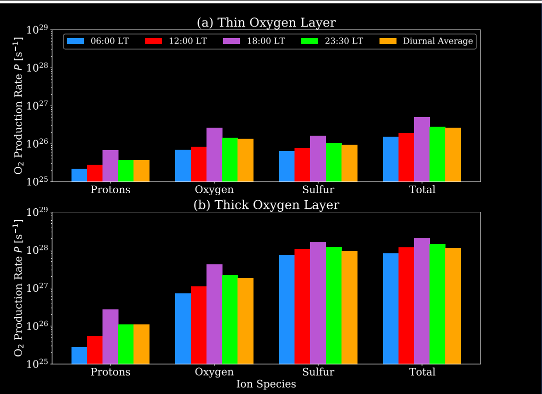

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