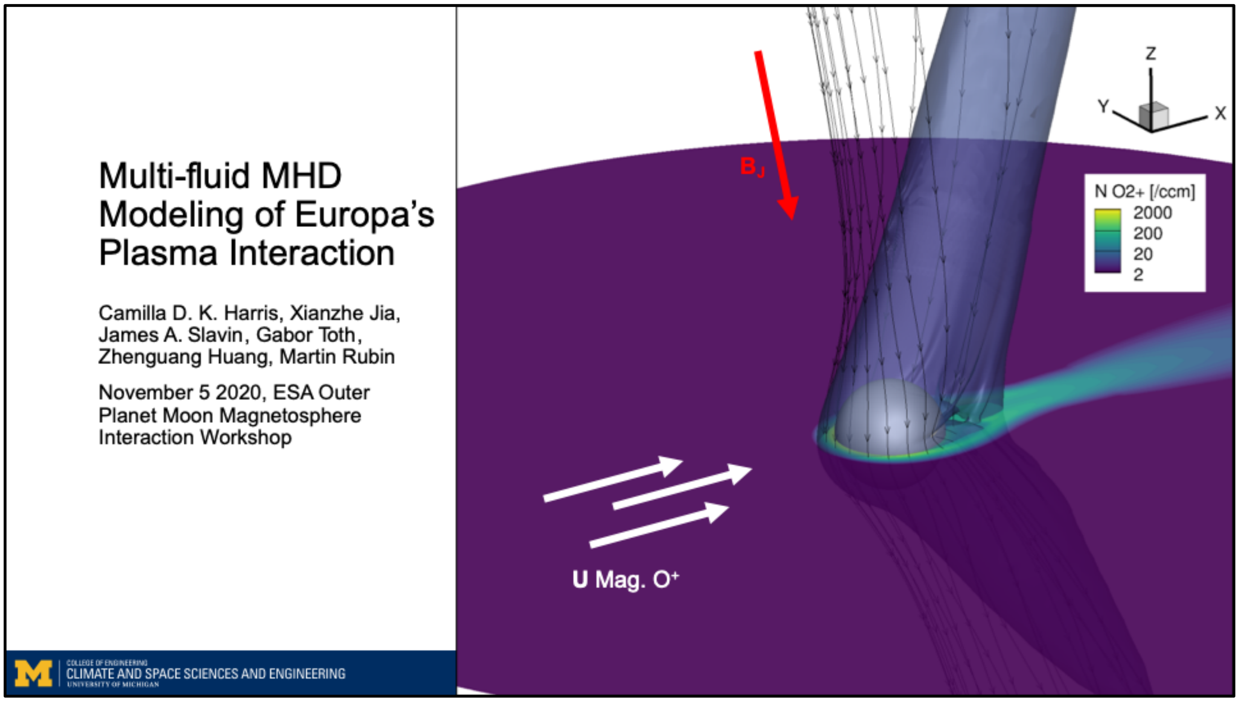
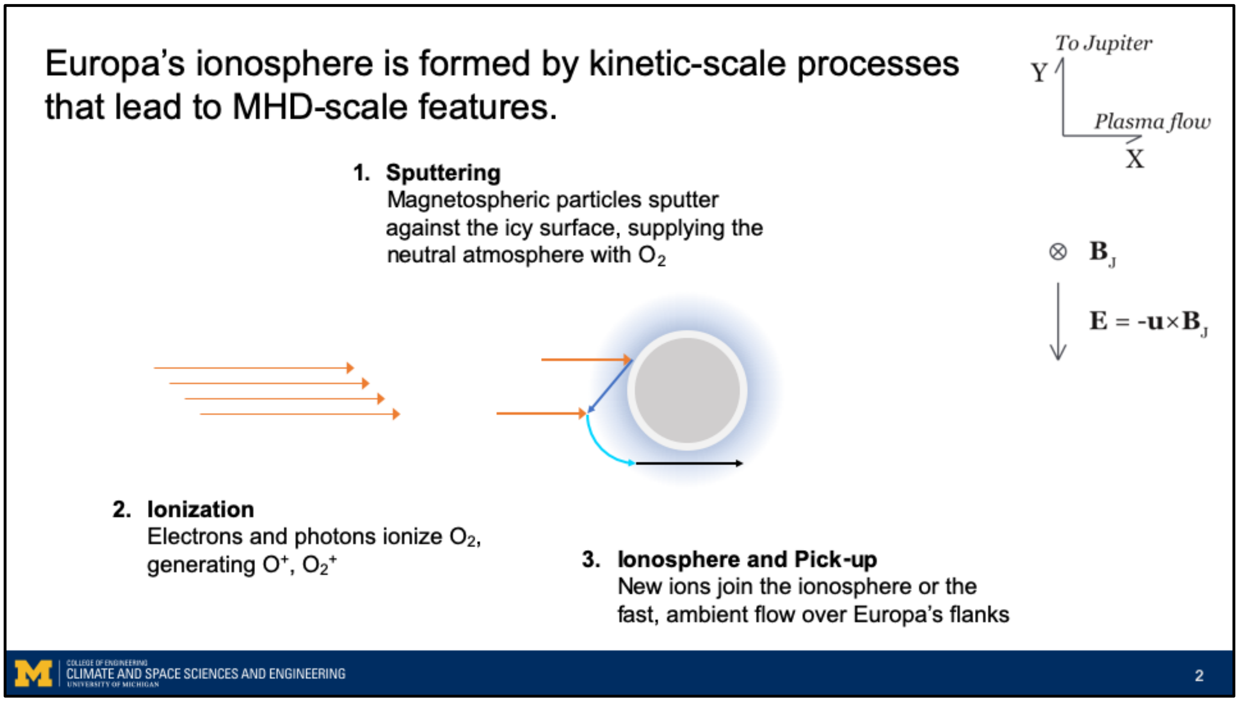
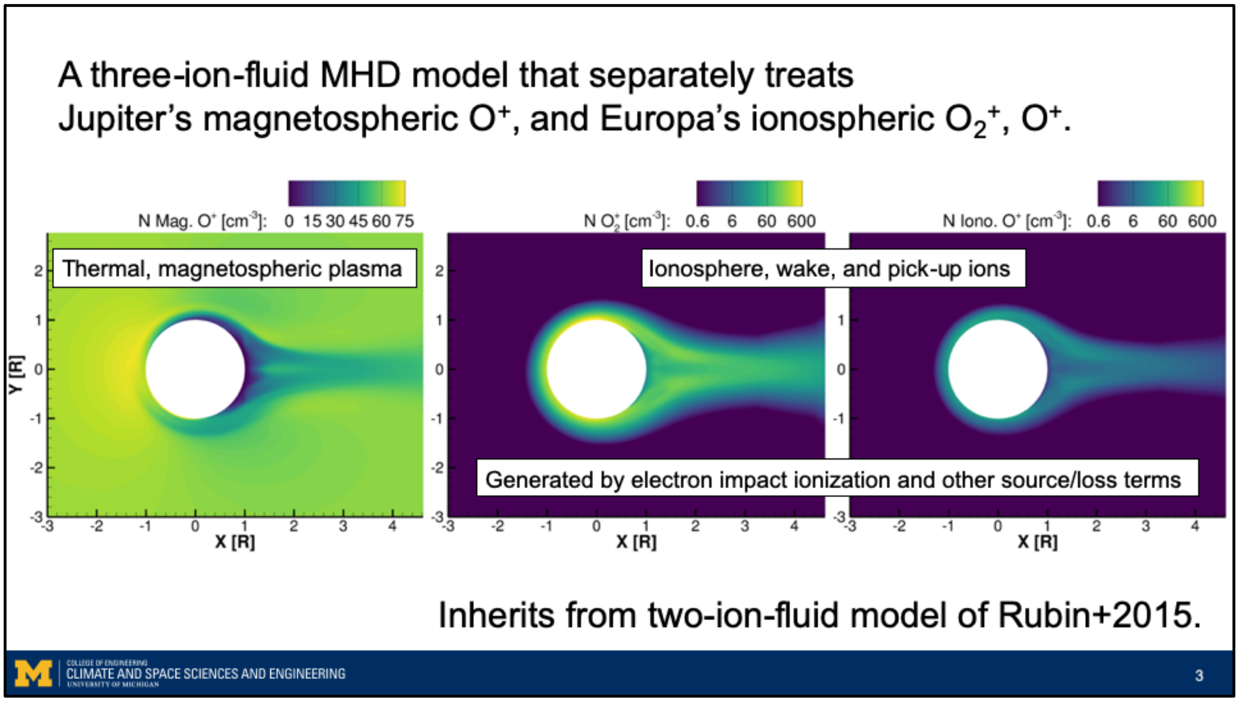


- Features of the thermal plasma interaction:
  - Europa at the inner boundary
  - Flow of magnetospheric plasma
  - Ionosphere (green/blue)
  - Southward-directed magnetic field lines
- Interesting things to note:
  - Twists and kinks in B due to interaction, Alfvén wing
  - Alfvén wing highlighted by isosurface of velocity; everything inside the boomerang-shaped region is slowed down by interaction with Europa's ionosphere



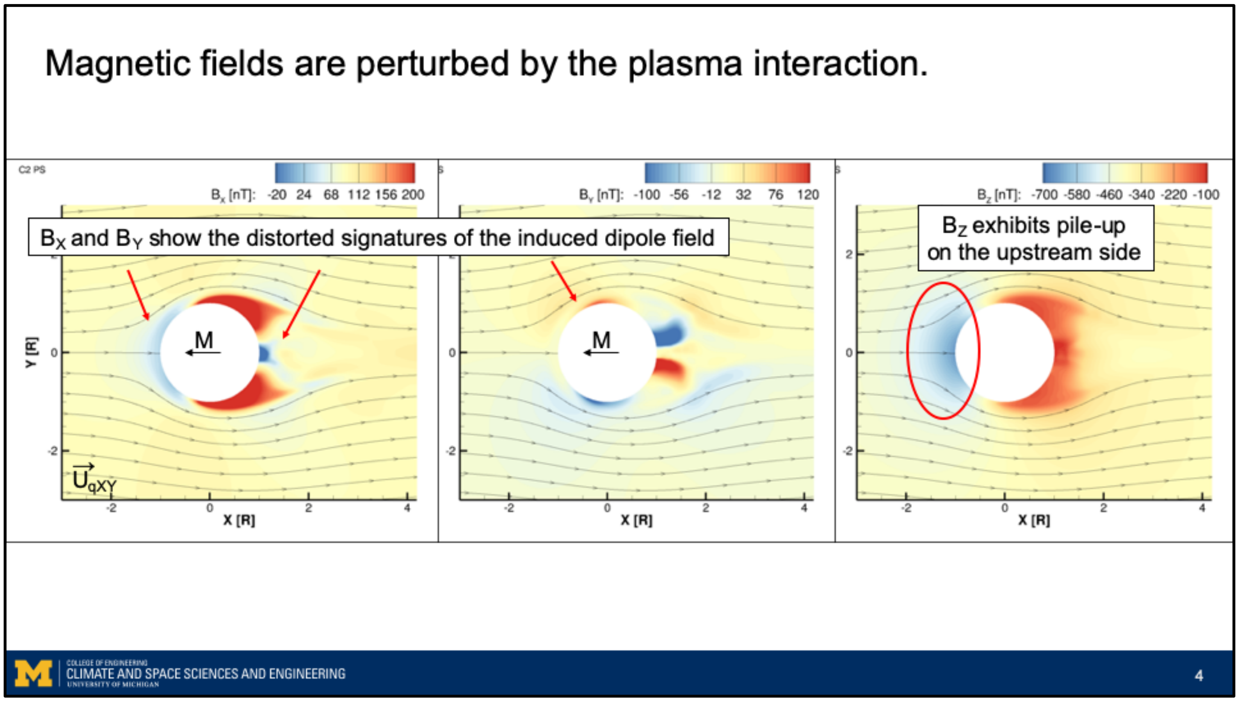
Small/kinetic scale features:

1. Sputtering: Magnetospheric particles sputter against the icy surface, setting off the chain of processes that generates O2 for the neutral atmosphere
2. Ionization: Neutral atmosphere is ionized through electron impact ionization and, to a lesser extent, photoionization
3. Ionosphere and pick-up: New, cold ions either join the ionosphere or are picked up by the ambient flow of plasma



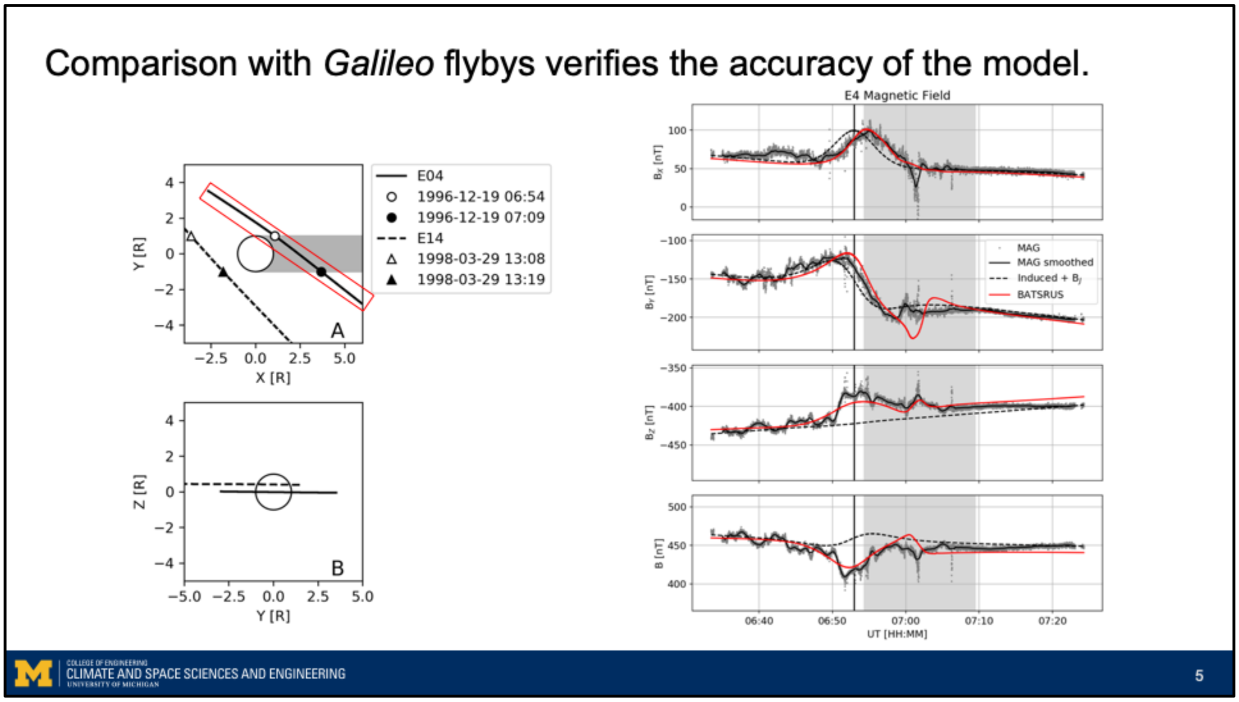
Three-ion-fluid model:

1. Magnetospheric O^+: represents thermal, magnetospheric plasma. Enters from the upstream boundary and flows over Europa. Absorbed and diverted through the interaction, leaving behind an empty wake downstream.
2. O_2^+: primary fluid of the ionosphere, generated mainly by electron impact ionization of the static neutral atmosphere. Relatively cool, transported downstream to fill Europa's wake.
3. Ionospheric O^+: secondary fluid of the ionosphere, behaves similarly to O_2^+ because the sources are similar. This is the main difference between the work I've been doing and the previous model; separation of O^+ into two fluids. We did this because the magnetospheric and ionospheric O^+ have such different sources and bulk properties.



In each simulation we can see how the plasma interaction affects the magnetic fields in many different ways.

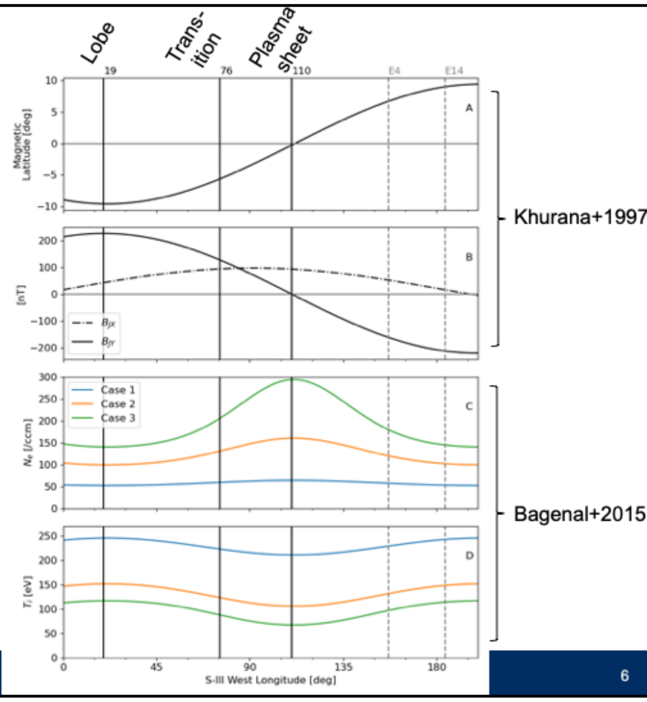
- In the B_{XY} components, we see the signatures of the prescribed induced dipole field distorted by the ambient flow
- In B_Y we can see that farther away the field lines bulge out, bending around the high-density wake
- In B_Z we see the pile-up of the magnetic field on the upstream side of the interaction



The first thing we can do with this model is verify it against data from the Galileo flybys to ensure that it’s giving an accurate representation of the plasma interaction.
The E4 flyby passed through Europa’s wake and very nearly in the equatorial plane.
The B_X and B_Y components are dominated by the induced field.
The B_Z component shows that our model is accurately capturing the depletion in magnetic field strength that Galileo observed through the wake.

How does the magnetosphere control thermal plasma precipitation?

We conducted a parameter study covering the range of magnetospheric conditions for the plasma interaction.

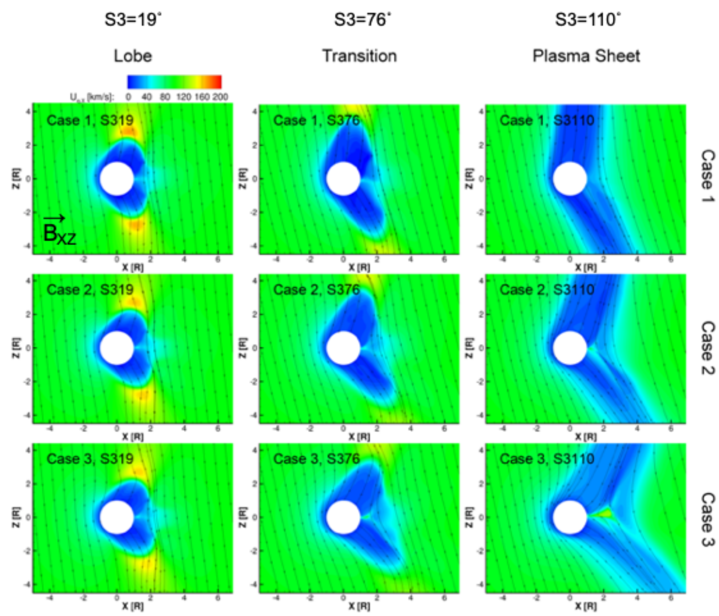


To understand how Jupiter's magnetosphere drives the plasma interaction we conducted a parameter study covering the range of conditions we expect Europa to experience.

- 3 different excursions from the plasma sheet
- 3 different cases for the general state of the magnetosphere (Cases, increasing in density)

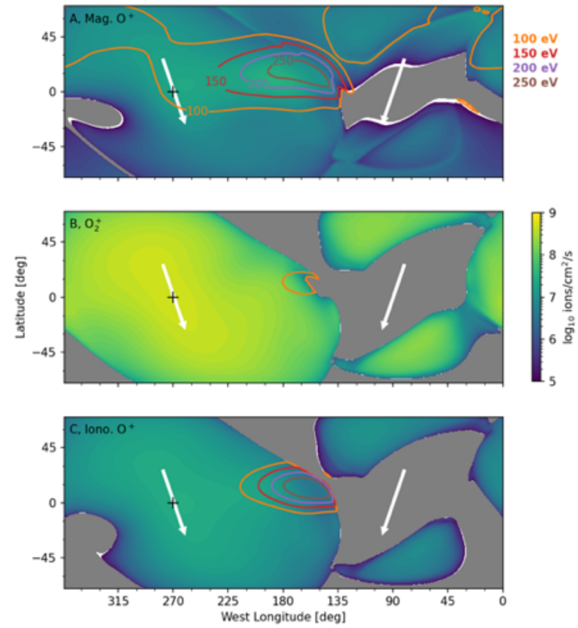
Comprising 9 different simulations total.

The 9 parameter study simulations span the full range of variability we expect for Europa's plasma interaction.



- Charge-averaged velocity U_{qX} in color, B_{XZ} field lines
- Columns: Different positions relative to Jupiter's plasma sheet
- Rows: Different global conditions of the magnetosphere (cases)
- Lobe and Transition configurations include background B_Y
- Plasma sheet simulations are more symmetric about the XZ plane
- Plasma slows in the Alfvén wings
- Plasma speeds up as it flows around the wings
- Field lines bend more strongly in Case 3 due to high density

We extracted the properties of the model fluids near the inner boundary of the model, which represents Europa's surface.



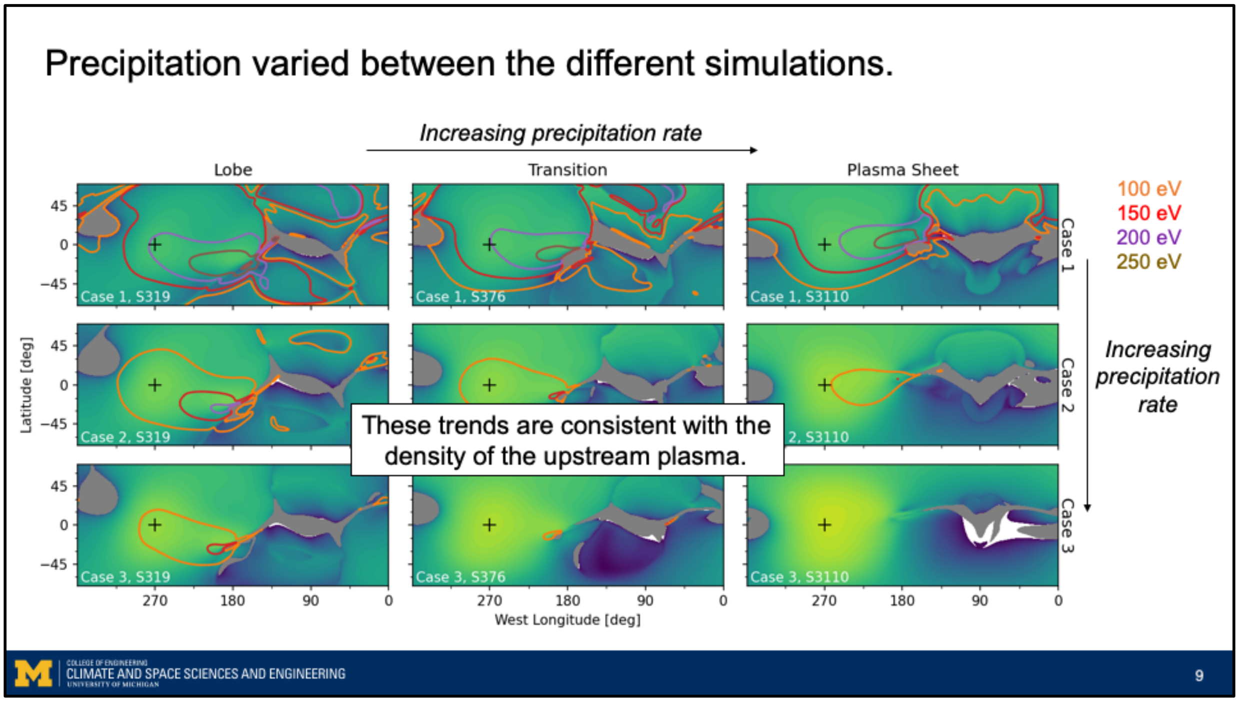
To study the precipitation of the thermal plasma, we extracted the bulk parameters of the model fluids on a spherical surface at the inner boundary of the 3D model results. On the right we have an example from the E4 flyby simulation.

- Top panel: Magnetospheric O^+. Thermal magnetospheric plasma.
- Middle panel: O_2^+, the main fluid of the ionosphere
- Bottom panel: ionospheric O^+, the secondary fluid of the ionosphere

By looking at the maps we can see that the precipitation is guided by the background magnetic field (white arrows)

We also see that the downward flux of the ionospheric fluids is generally higher than the magnetospheric fluid

- This makes sense because their densities near the surface are much higher
- However their temperatures are a lot lower, and that's important for sputtering
- We found that very little of the ionospheric precipitation exceeded 100 eV
- While as we can see from the color contours in the top panel that some of the magnetospheric precipitation gets very hot indeed, and an appreciable amount exceeds 100 eV

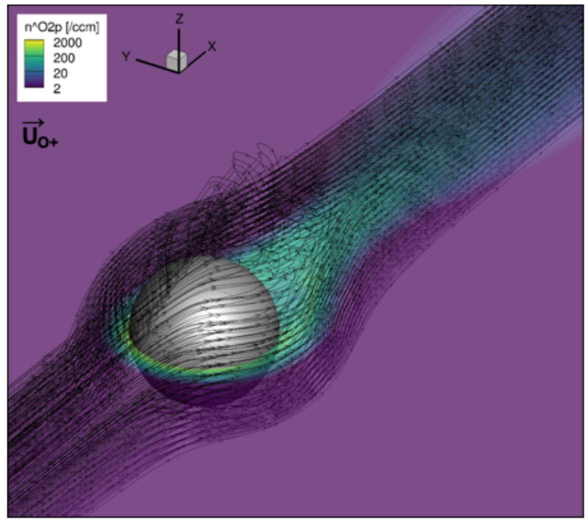


So we looked at the precipitation of the thermal plasma in each of the 9 parameter study simulations.
The precipitation and the temperature of that precipitation varied across all the different simulations.
We found that in general the precipitation rate was higher in simulations where the upstream plasma density had been set high, so we sought to understand that.

We measured how plasma was diverted in each simulation.

88 ± 2% of streamtraces were diverted.

If the upstream conditions were so different, why was the diversion so similar?



COLLEGE OF ENGINEERING
CLIMATE AND SPACE SCIENCES AND ENGINEERING
UNIVERSITY OF MICHIGAN

10

We started by measuring the diversion of magnetospheric O^+ streamtraces in each simulation.

We seeded many streamtraces on a disc far upstream.

Without the plasma interaction, all of these streamtraces would have flowed unimpeded into Europa's surface.

But across all the various simulations in the study we found that they were pretty consistent in how many streamtraces they diverted.

But if the upstream conditions were so different, why are we seeing the same number of streamtraces diverted?

Why wouldn't "stronger" upstream plasma be able to push more streamtraces into the surface?

We found that ionosphere density also increased with the upstream density.

Upstream plasma density increased

↓

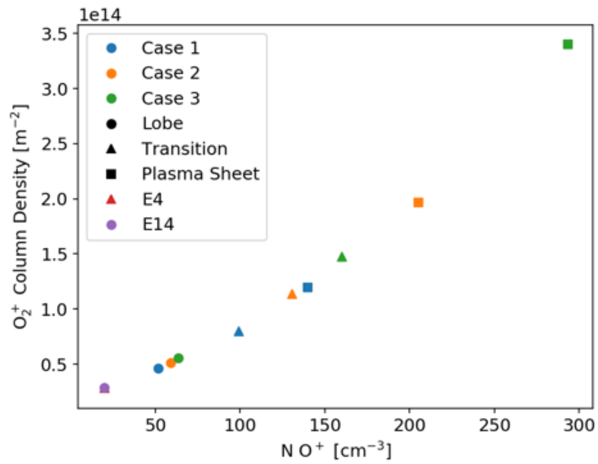
Electron density increased

↓

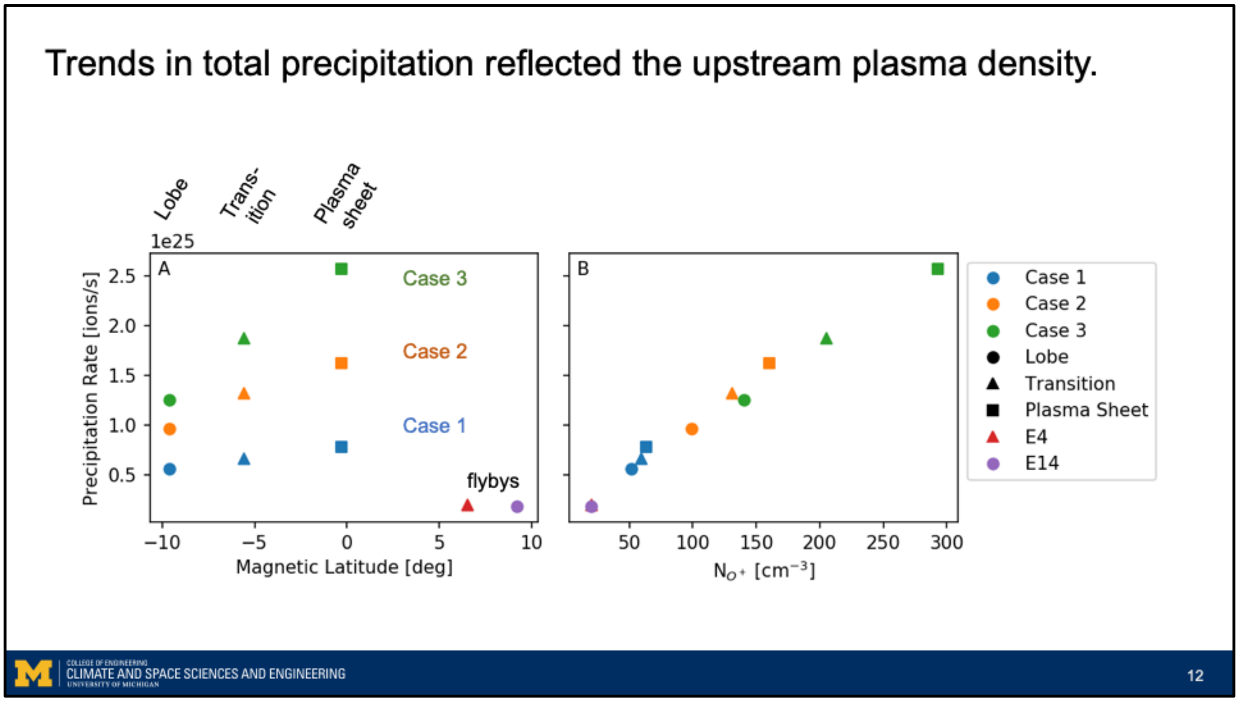
More O_2^+ generated by EII

↓

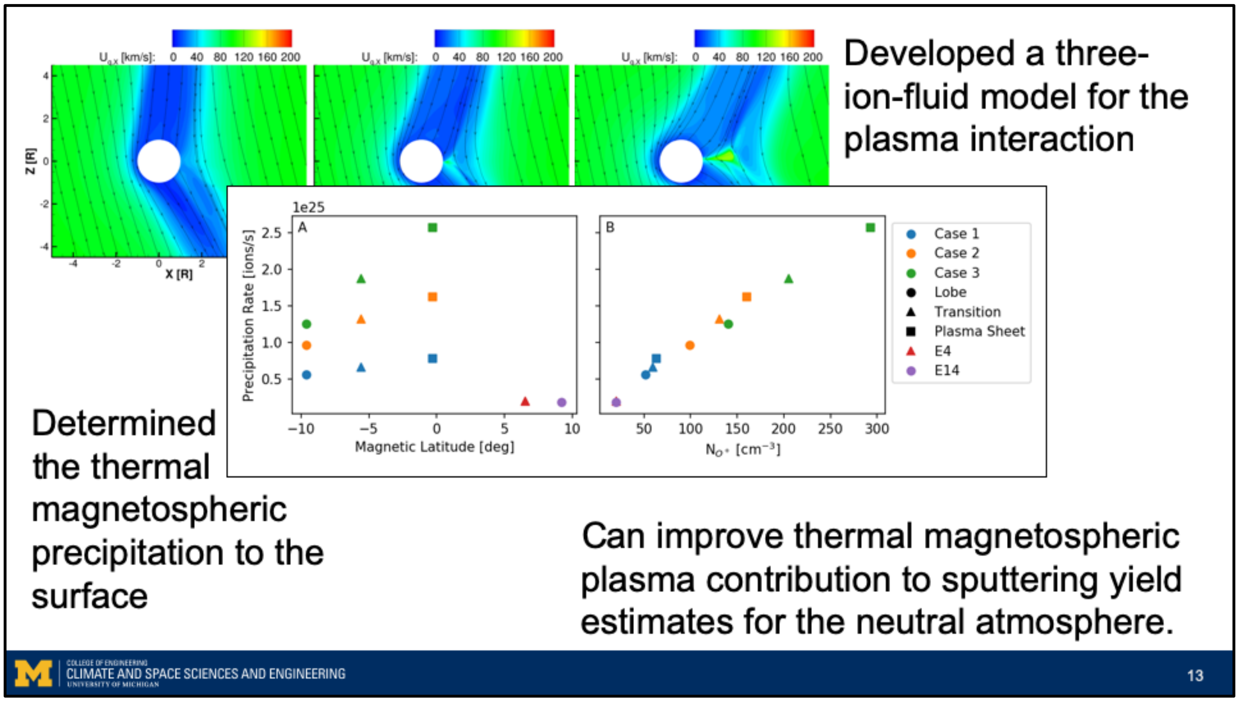
Ionosphere shields more effectively



Ultimately it’s the ionosphere that’s responsible for shielding the surface from impinging plasma.
We then measured the column density of the ionosphere on the upstream most point, to understand how the ionosphere differed across all the simulations.
We found out that the ionosphere was more dense in simulations with higher upstream plasma density.
Given how we had implemented the electron impact ionization that generates the ionosphere, this made sense.



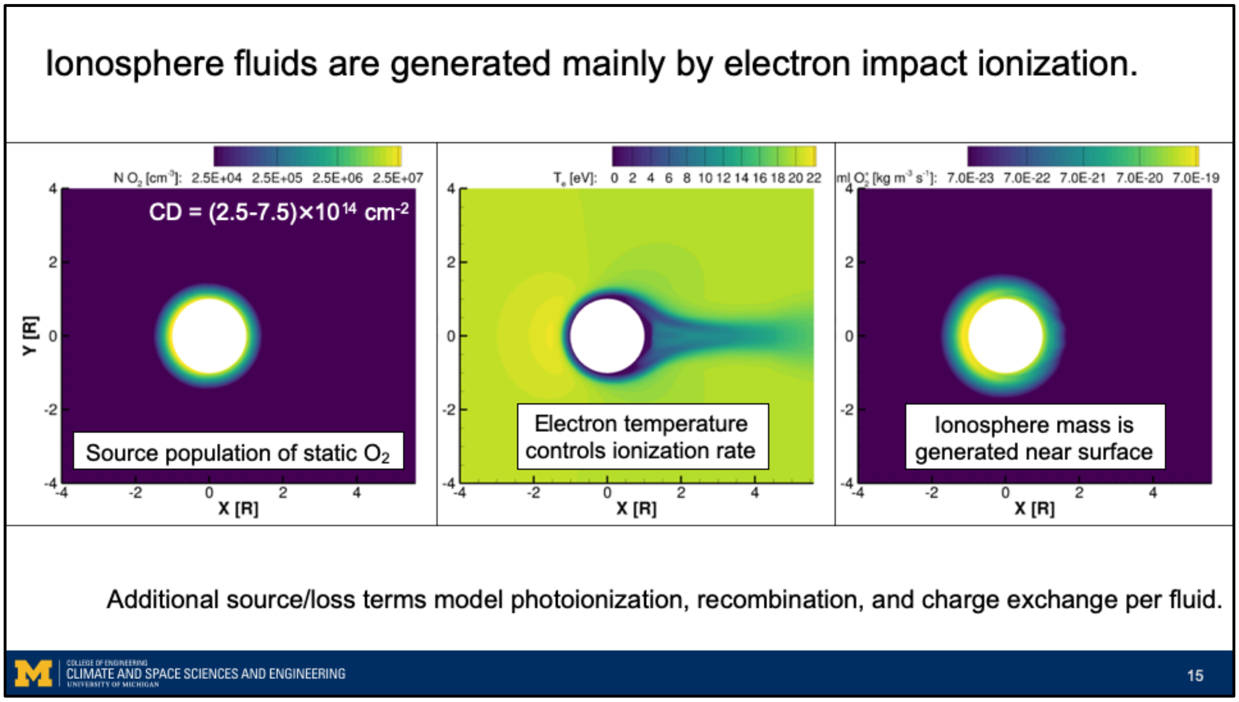
So what this all is telling us is that even though the impinging plasma from the magnetosphere can increase in density, the ionosphere should be able to compensate for that.
In the model what this looks like is that the percent of diverted streamtraces is approximately constant.
And so if the same number of streamtraces are carrying the plasma that ultimately precipitates to Europa's surface, then the factor controlling the precipitation rate is the density of the upstream plasma.



In summary:

- We developed a three-ion-fluid model for the plasma interaction.
    - We verified it against data from the Galileo flybys
    - We then used it to model the plasma interaction under different magnetospheric conditions
- Using this survey of the state of the plasma interaction,
    - We estimated the precipitation rate of thermal magnetospheric plasma
    - We identified trends in the precipitation rate that are controlled by the external conditions of the plasma interaction
- And we hope that these results will be useful to models of the neutral atmosphere

Back-up slides



In the model we have many different source terms affecting the mass, momentum, and pressure of the different MHD fluids.

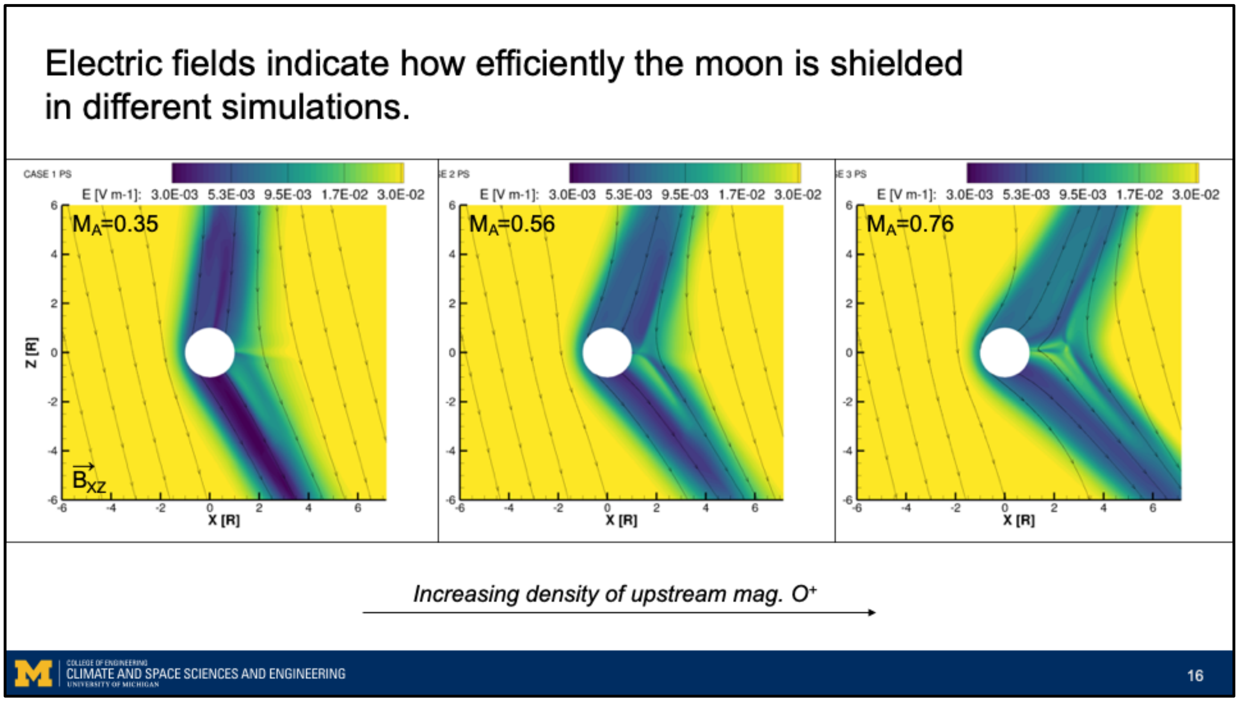
The most important is electron impact ionization; this is responsible for generating the density of the ionospheric fluids.

The static neutral O^2 atmosphere provides the source for the EII.

The EII rate is calculated in two components

- A uniform rate representing the effect of the suprathermal, hot, low-density electrons from the Io plasma torus
- A variable rate calculated from the local electron temperature, temperature augmented by field-aligned electron heat conduction

And the combination of the neutral density and the EII rate is what determines the mass loading rate of the ionospheric fluids.



We can also calculate the –uxB electric field as a measure for the strength of the interaction in different simulations.

In these three cases we see that as the density of the upstream plasma (and therefore the Alfvén Mach number) increase,

- The Alfvén wings and the magnetic fields are bent more strongly
- The electric field inside the Alfvén wings increases; where the electric field is weaker that indicates that Europa's ionosphere has more effectively shielded the surface from magnetospheric plasma.