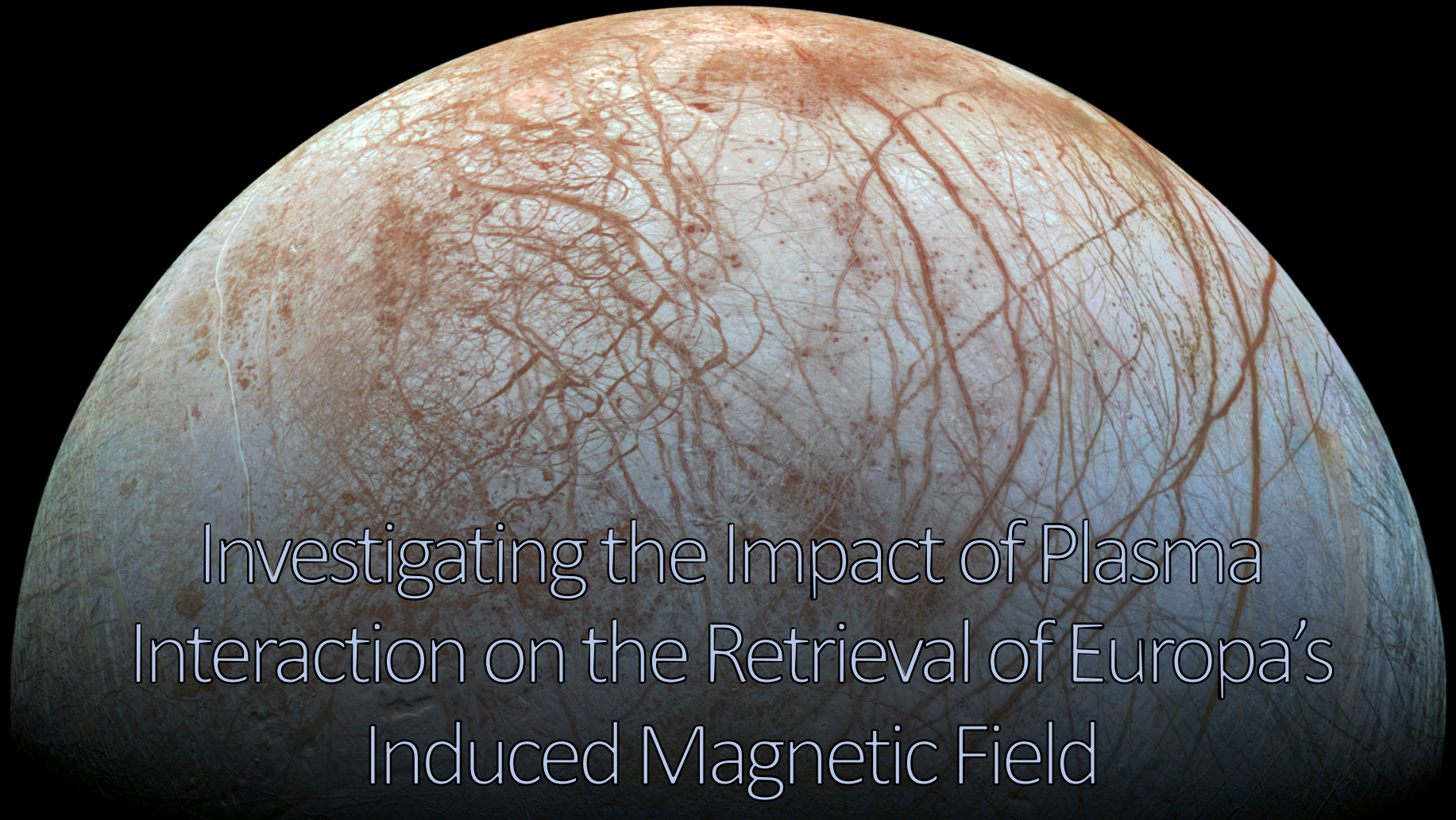

Investigating the Impact of Plasma Interaction on the Retrieval of Europa's Induced Magnetic Field

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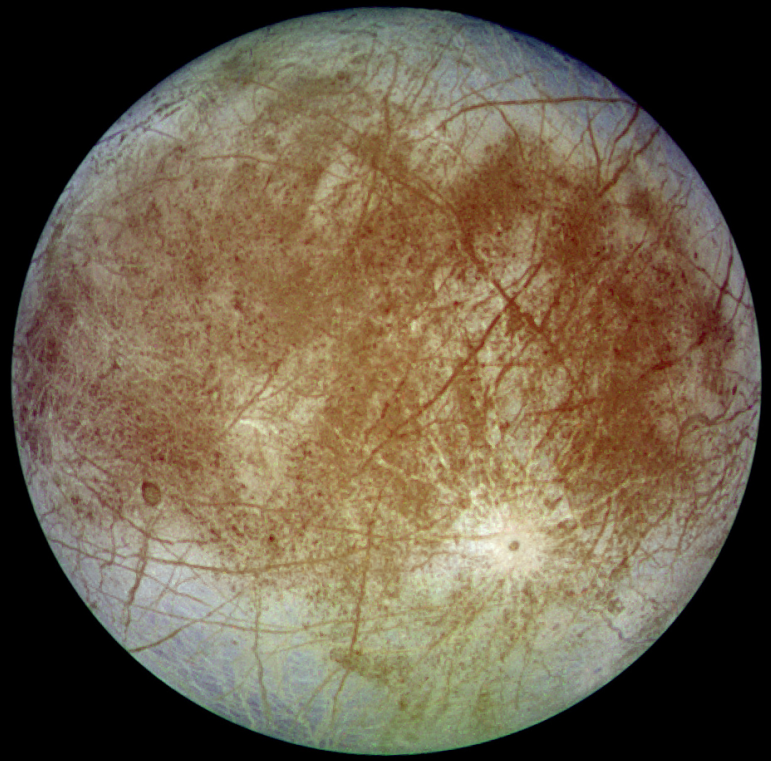
Background

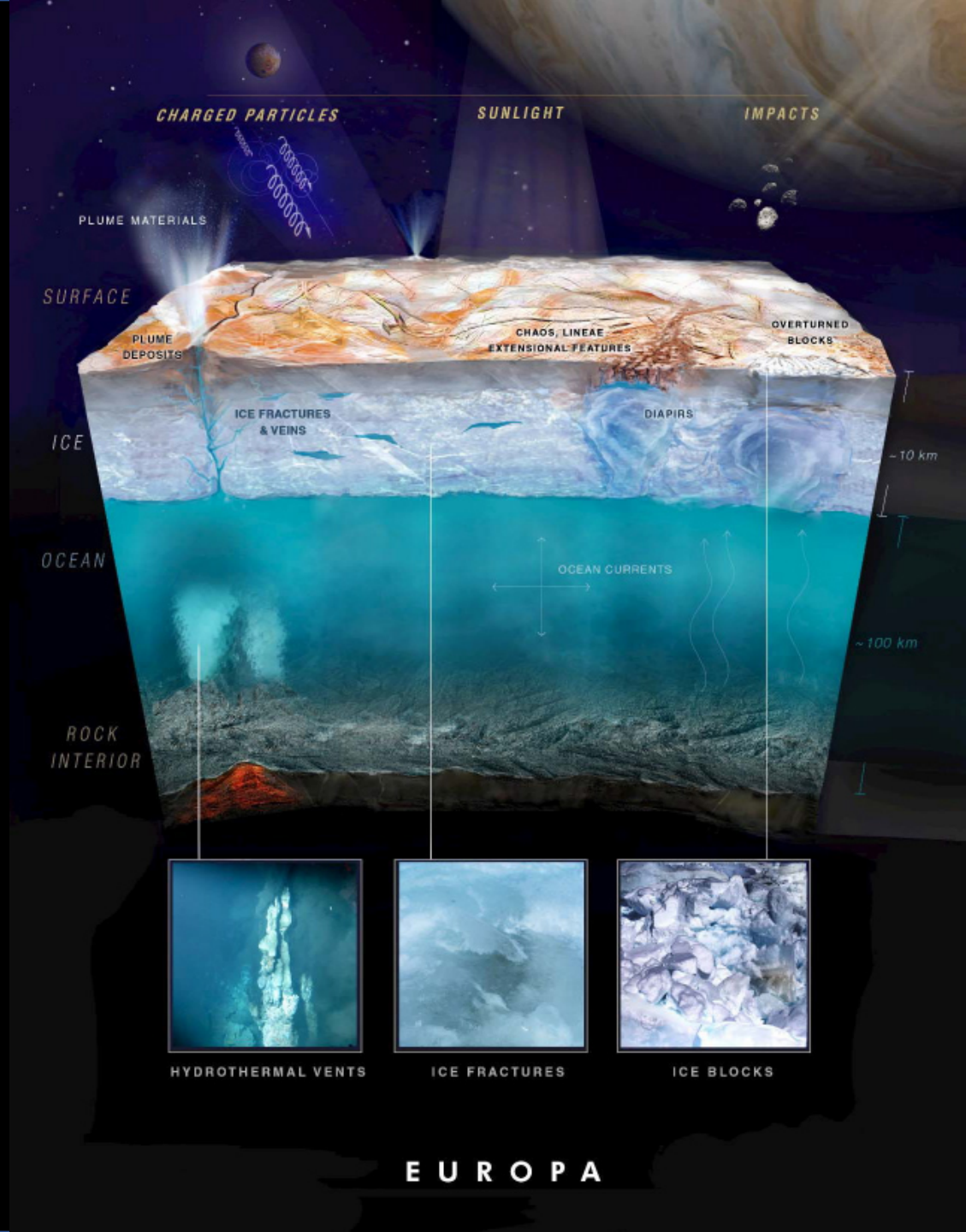
- Europa is a moon of Jupiter which resides at an orbit ~9.4 R_J
- It the smallest of the Galilean moons with a mean radius 1560 km
- Flybys during the Galileo mission showed evidence for an induced dipole, which could be explained by a global ocean



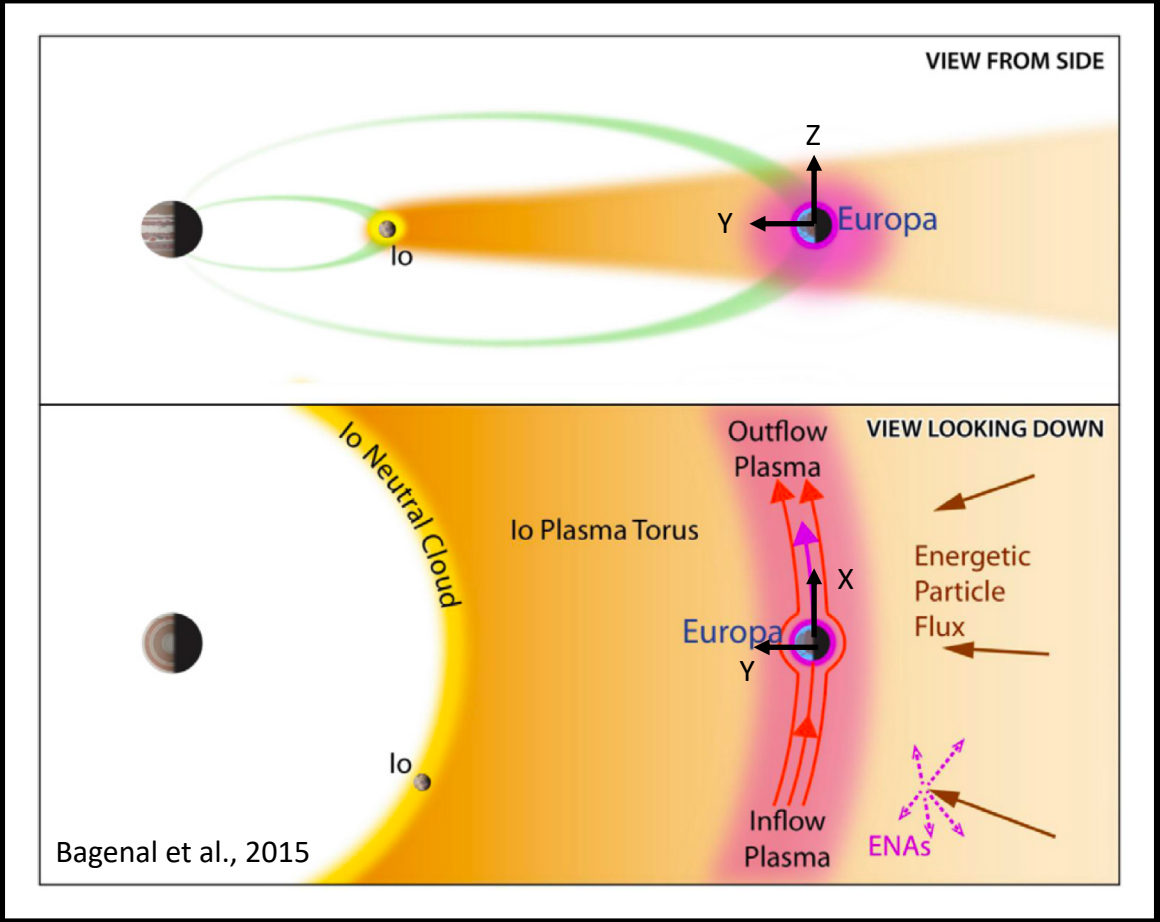
Background

- Europa is extensively geology interesting
  - Geologically young surface (few craters)
  - Chaos terrain
  - Fractures
  - Ridges
  - Plumes (remotely detected)
  - Exosphere created by sputtering of the surface
  - Astrobiological interest

ICE SHELL THICKNESS, OCEAN THICKNESS, and CONDUCTIVITY (SALINITY) STILL NOT WELL CONSTRAINED



Coordinate System



EphiO Frame

- Centered on Europa

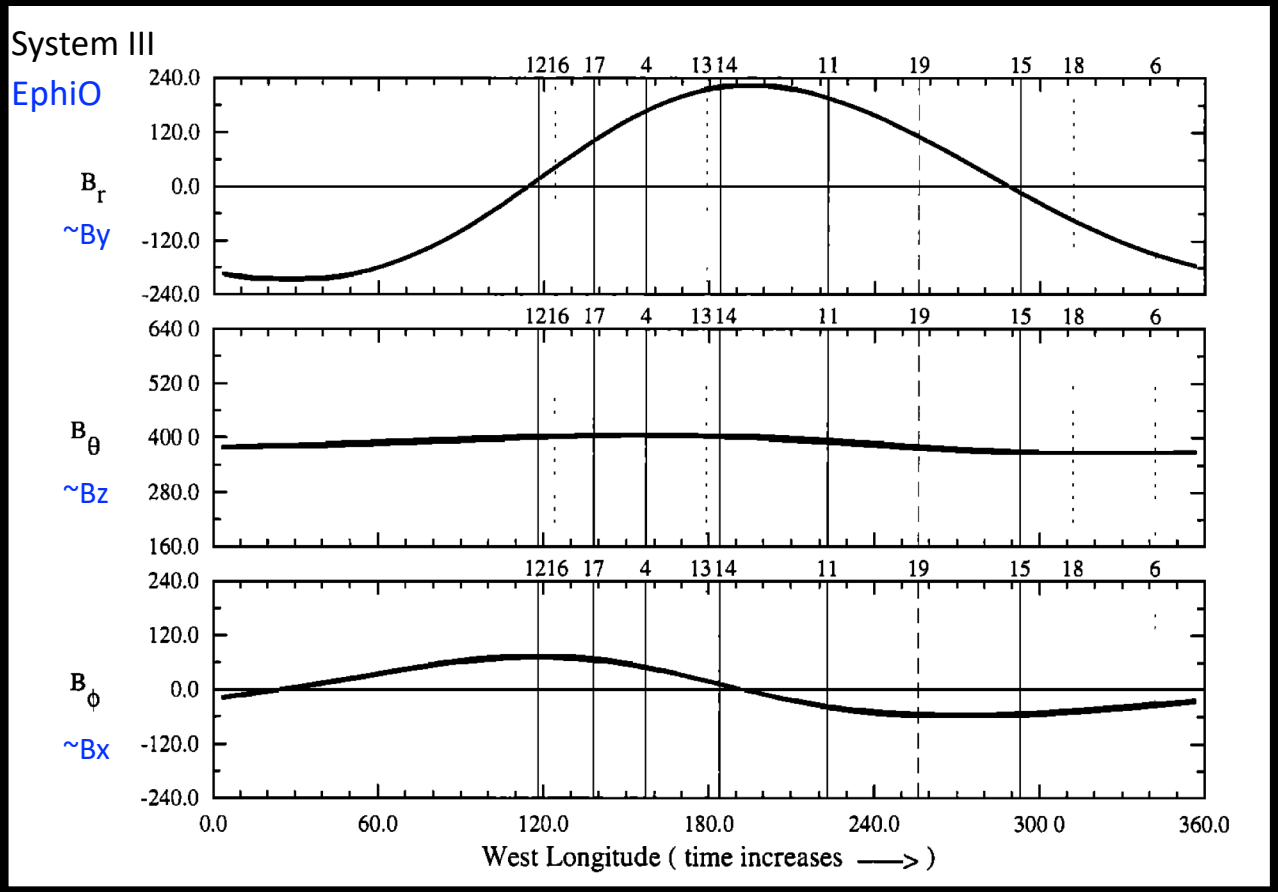
X=direction of the magnetospheric plasma flow

Y=from Europa toward Jupiter

Z=parallel to Jupiter's spin axis

- Europa orbits near the equatorial plane of Jupiter, so Jupiter's magnetic equator oscillates above and below it over an 11.2 hr period

Coordinate Systems

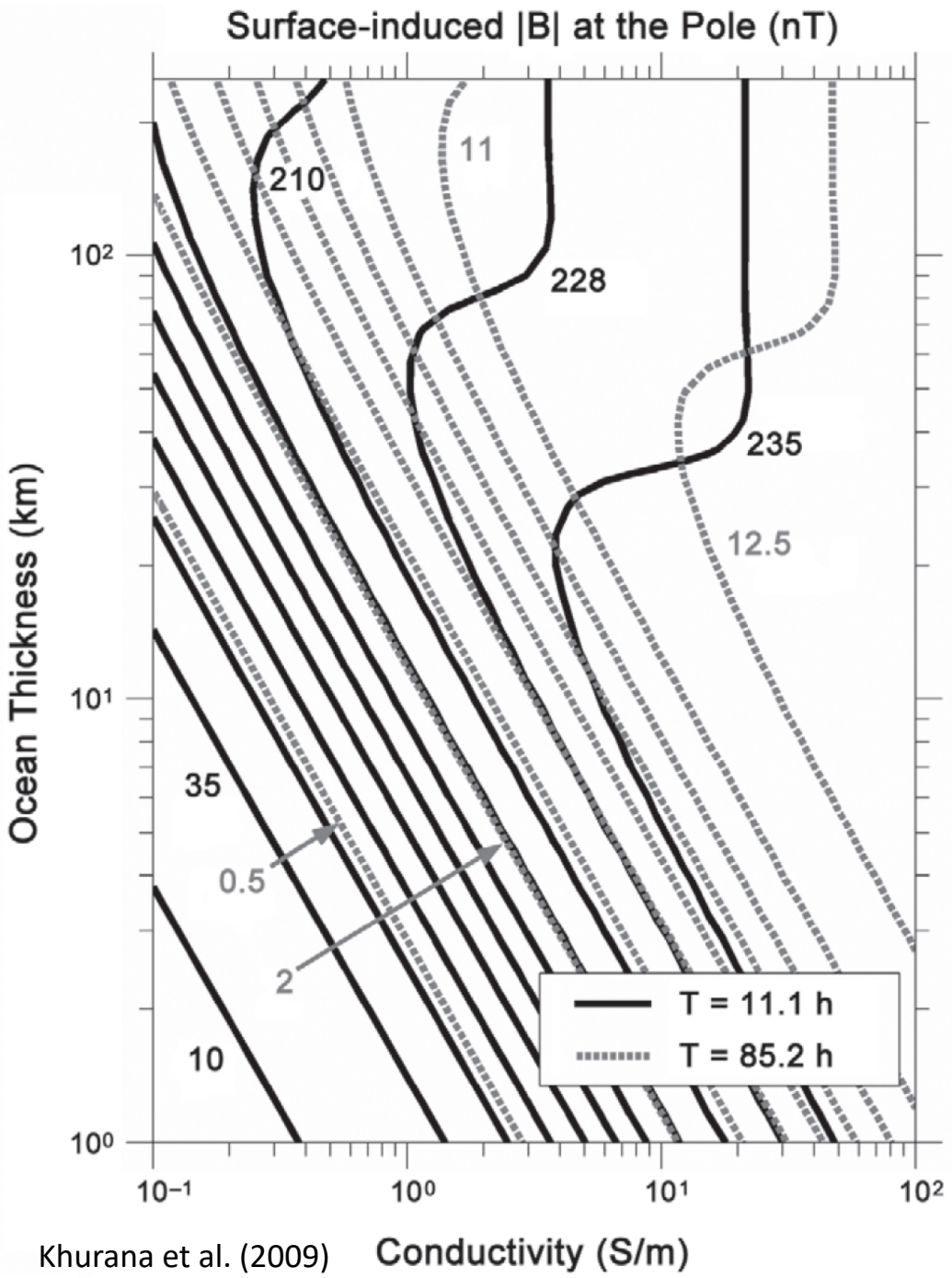


Kivelson et al. (1999)

- Europa experiences a time-varying field of ~250 nT associated with Jupiter's rotation period
- Europa experiences an additional ~20 nT time-varying field due to the eccentricity of its orbit

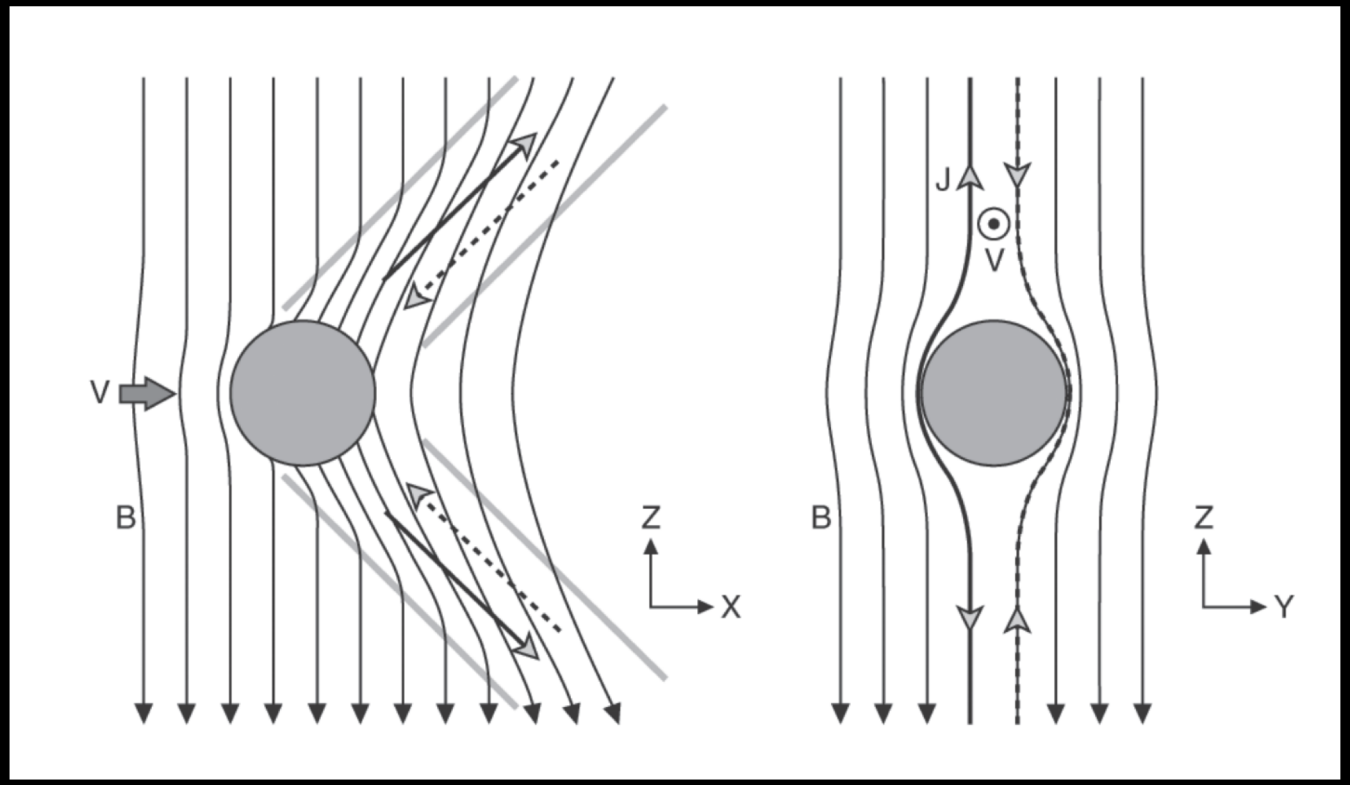
Induced Dipole

- The magnetic field as seen by Europa varies dominantly in its Bx and By components
- There are two principal frequencies at which Europa responds:
  1) 11. 2 hrs due to Jupiter's rotation
  2) 85.2 hrs due to the ellipticity of Europa's orbit
- Obtaining the response at both frequencies are needed to obtain a unique solution for the ocean thickness and conductivity



Khurana et al. (2009)

Alfvén Wings

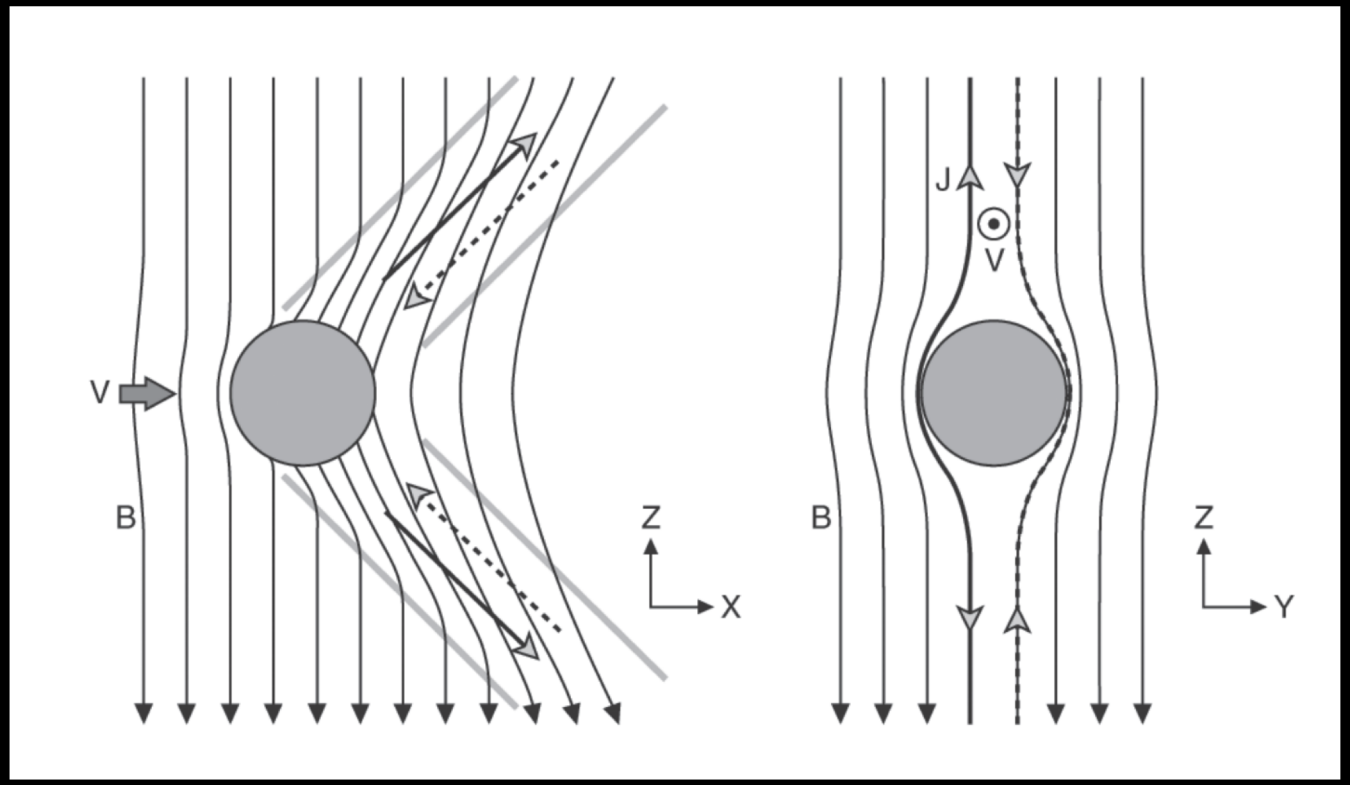


Kivelson et al. (2009)

- Pick-up ions create a current in the direction of the convection electric field
- This current closes through field-aligned currents which produce magnetic perturbations that bend the field
- The kink is propagated by an Alfvén wave
- If the flow is perpendicular to the magnetic field, the angle at which the wings bend can be described by

$$\theta_A = tan^{-1} M_A$$

Alfvén Wings



Kivelson et al. (2009)

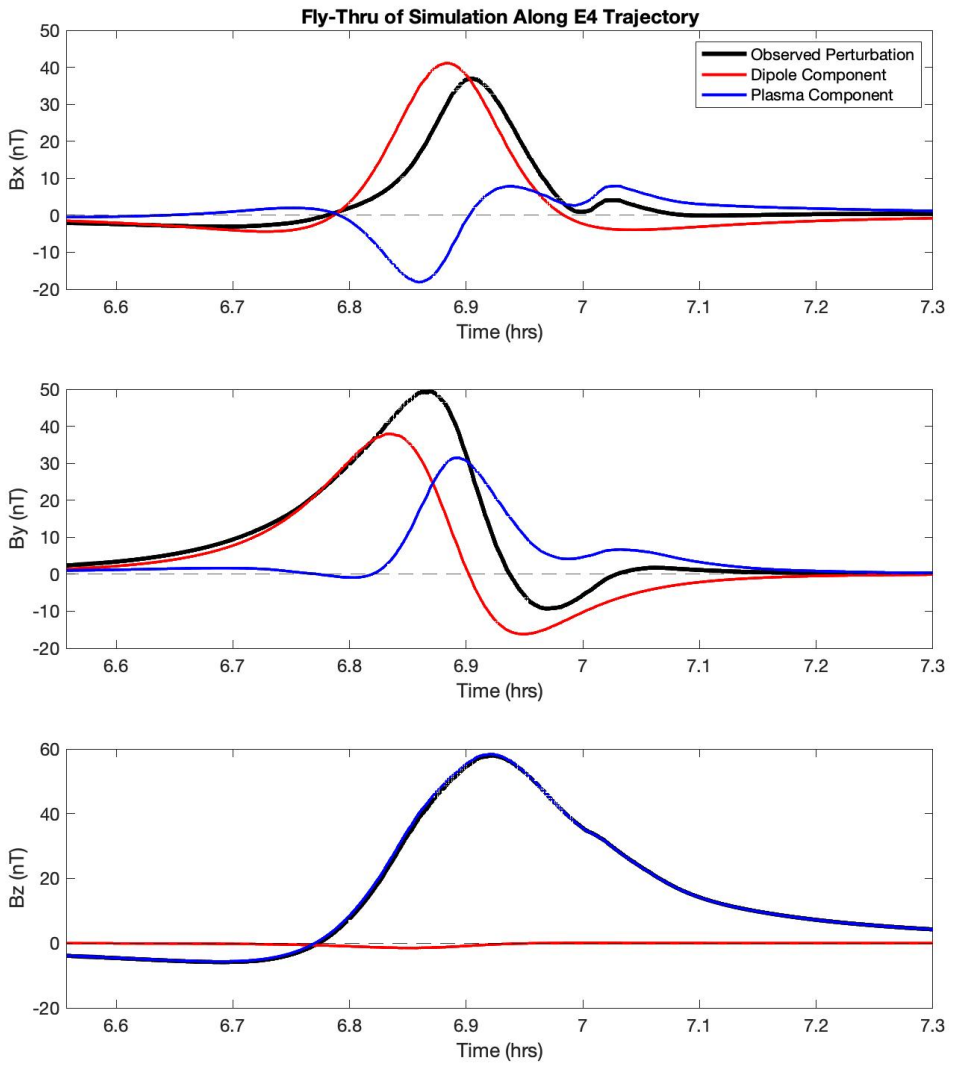
Will need to account for this second perturbation when trying to retrieve dipole parameters for Europa's ocean

The Europa BATS-R-US Code

- Multi-fluid MHD model (Harris et al.,2019) that tracks 3 ion fluids plus one electron fluid (O+ magnetospheric ions, O_2+ pick-up ions, O+ pick-up ions, and electrons)
- Sources for the production of ions include electron impact ionization, charge exchange, and photoionization.
- Losses are due to the impact onto the moon's surface and ion-electron recombination.
- Simulations are centered on Europa in the EphiO coordinate system.
- For each simulation, the magnetospheric plasma bulk velocity, ion and electron temperatures, Jupiter's magnetic field, and an induced dipole moment at Europa are specified for Europa's location in its orbit.
- Using these parameters, the model is iterated until a steady state is reached.

Galileo E4 Flyby Example: Edge of Plasma sheet

E4 MHD Simulation



The dipole moment in BATS-R-US is specified by the user and is therefore known. The model uses values from Kivelson et al. (2000) for the expected induced dipole moment:

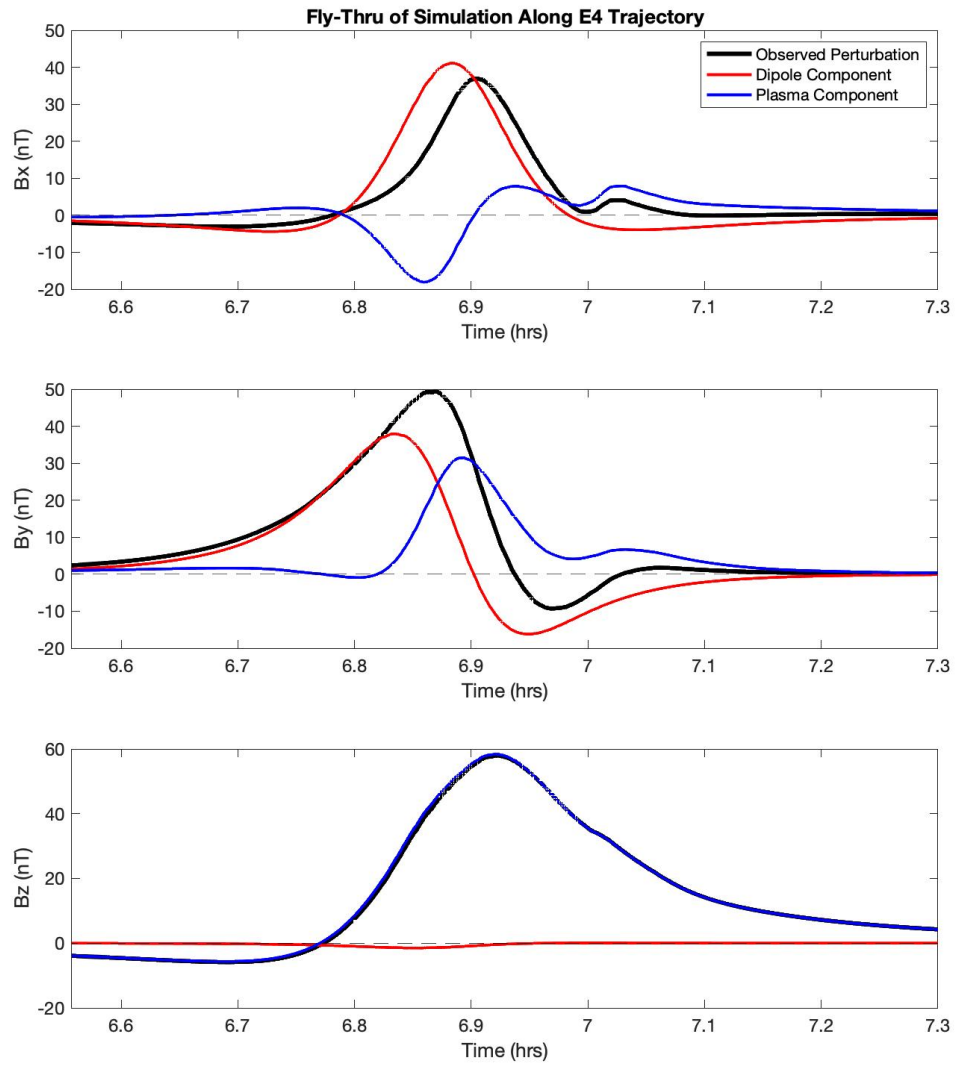
Mx=-27 nT

My=88 nT

Mz=0 nT

(Induced Magnetic Moment, $\mathbf{M}$=-1/2(B_X(t), B_Y(t), 0)

E4 MHD Simulation



Red: Fly-thru of model with time-stationary Jovian magnetic field and dipole field with no plasma (Jovian field and dipole field used are the same as that inputted for the E4 MHD model)

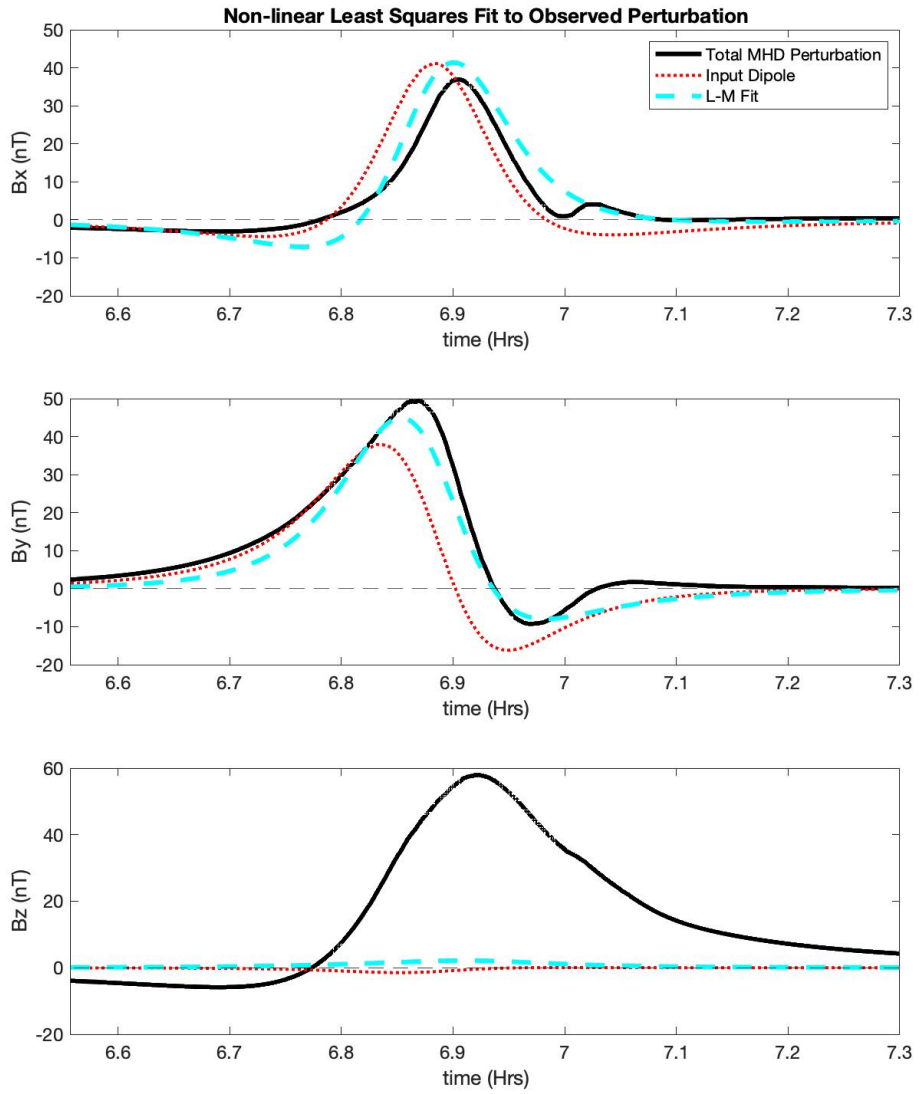
Blue: Plasma response outputted by Harris et al.'s E4 MHD simulation

Black: Total magnetic perturbation modeled along Galileo

Apparent shifts in peak locations between the expected dipole and the BATS-R-US full-interaction fly-thru for Bx and By

Plasma interaction dominates the Bz component

E4 MHD Simulation



Dipole moment inputted into simulation:

Mx=-27 nT

My=88 nT

Mz=0 nT

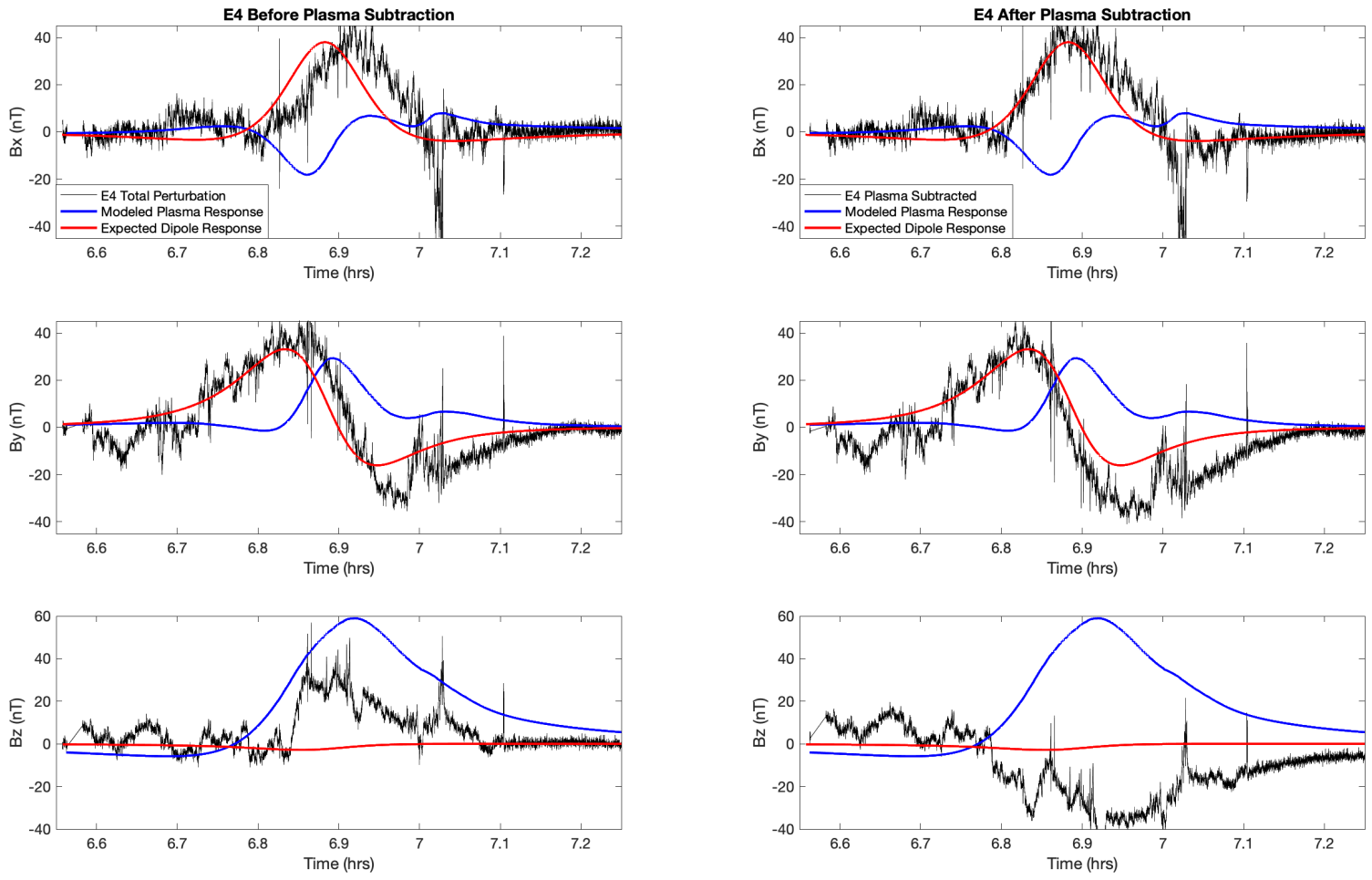
Dipole moment retrieved (no plasma subtraction):

Mx=20.3 nT

My=79.7 nT

Mz=-11.2 nT

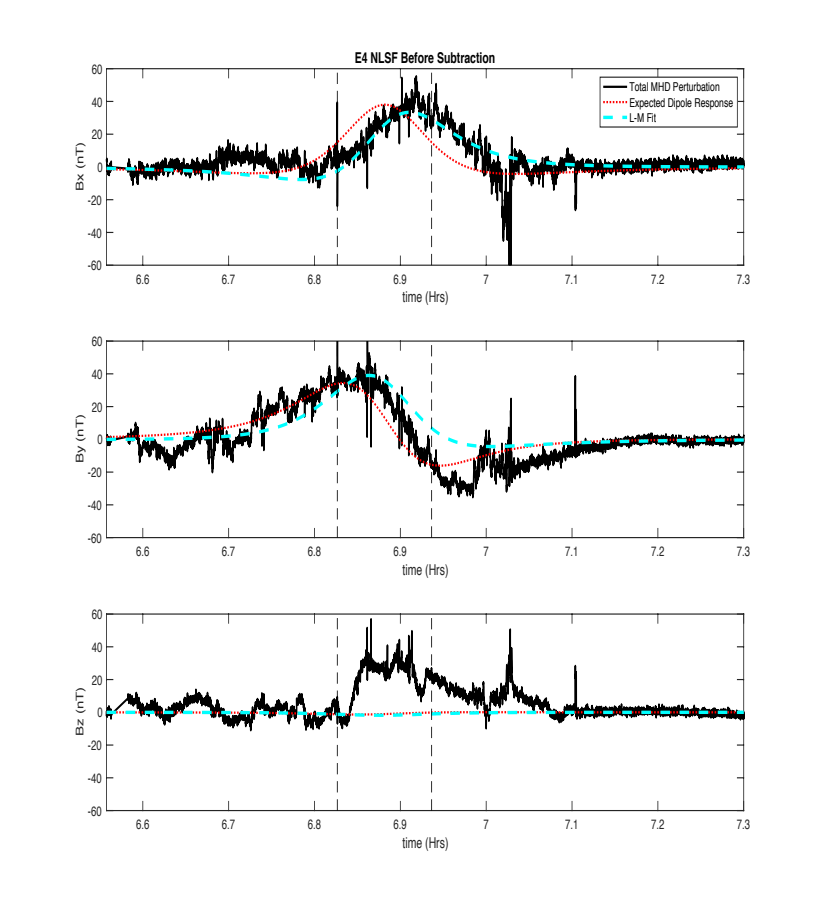
Application to Galileo E4 Flyby



We subtract the plasma perturbation as modeled by the E4 MHD simulation

After subtraction, the peaks in the Galileo data are now better aligned with those of the dipole response expected for a perfect conductor

Application to Galileo E4 Flyby



Dipole moment for perfect conductor:

Mx=- 27 nT

My=88 nT

Mz=0 nT

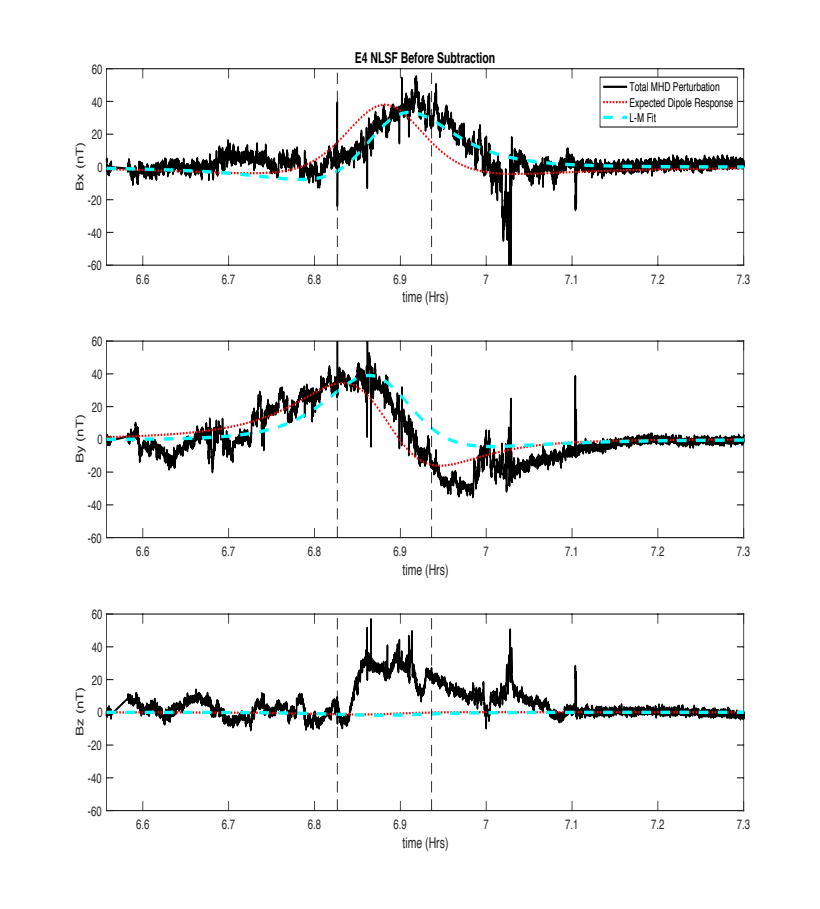
Dipole moment retrieved (no plasma subtraction):

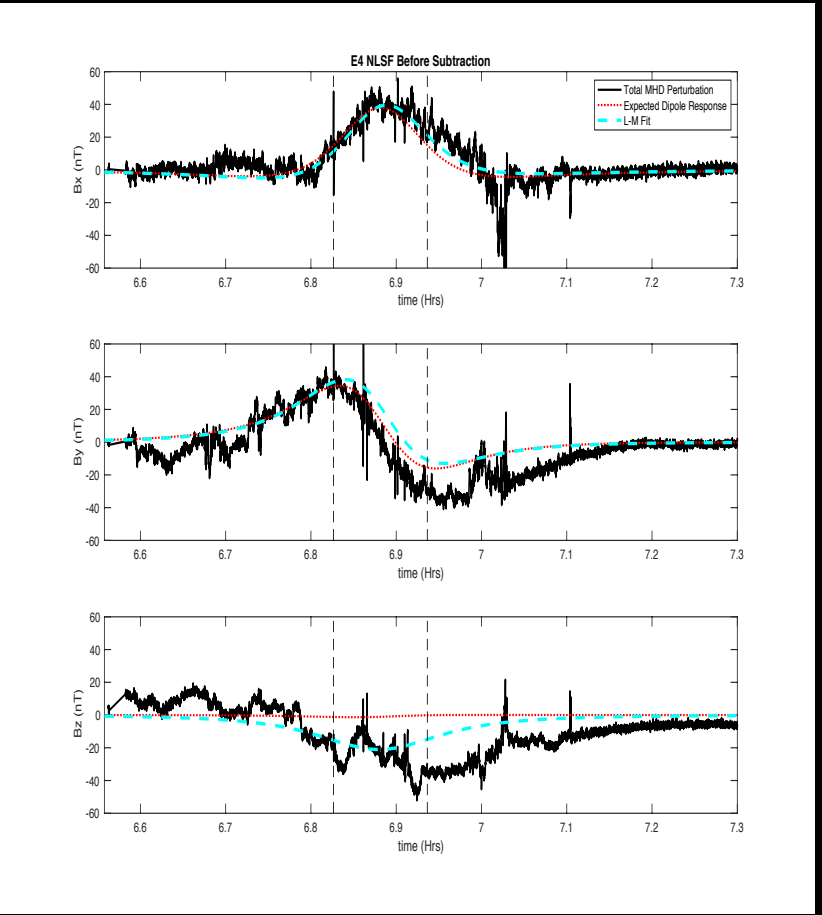
Mx=37.4 nT

My=55.6 nT

Mz=1.06 nT

Application to Galileo E4 Flyby





Dipole moment for perfect conductor:

Mx=-29.6 nT

My=81.4 nT

Mz=0 nT

Dipole moment retrieved (no plasma subtraction):

Mx=37.4 nT

My=55.6 nT

Mz=1.06 nT

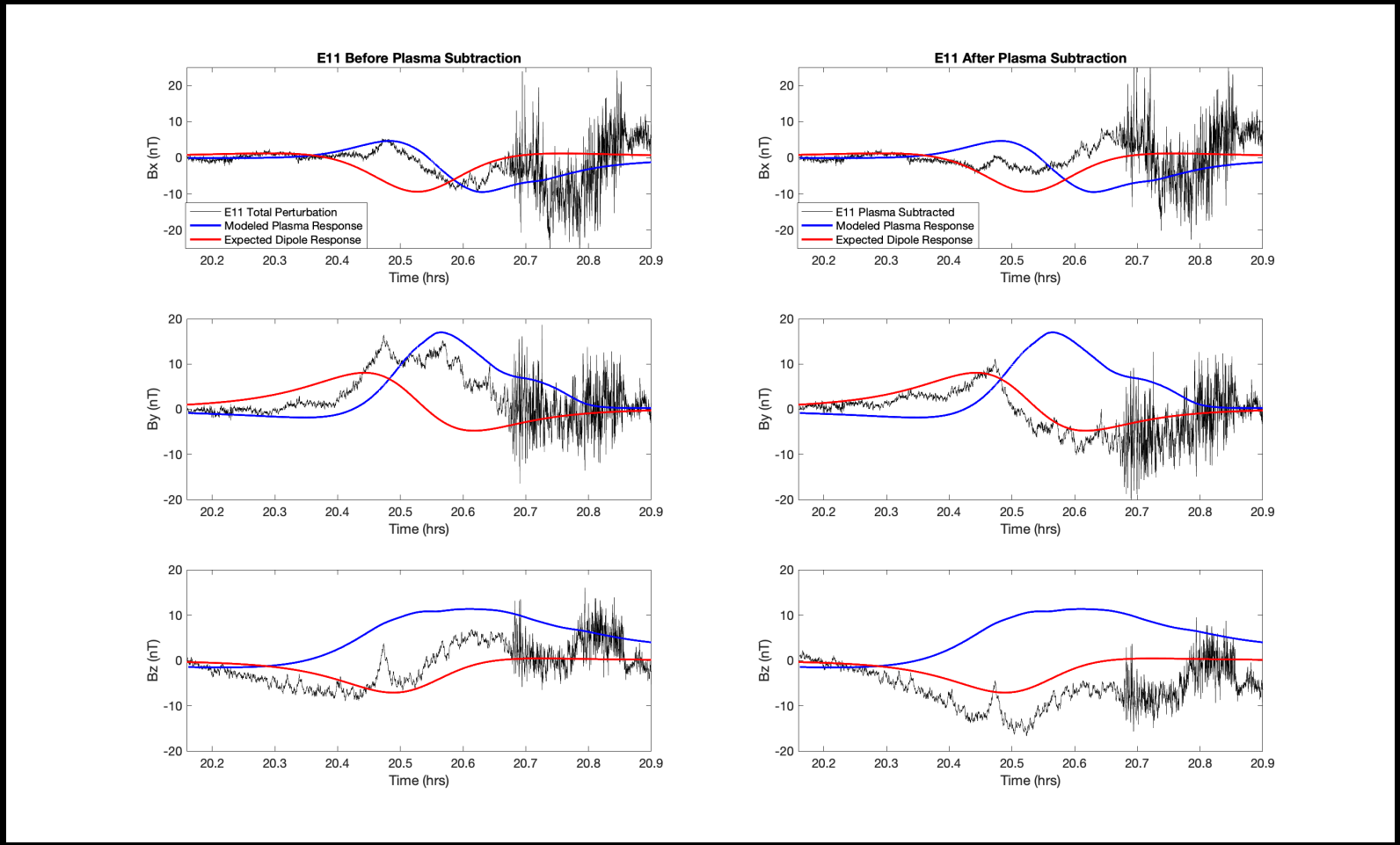
Dipole moment retrieved (w/ plasma subtraction):

Mx=-11.9 nT

My=85.2 nT

Mz=59.7 nT

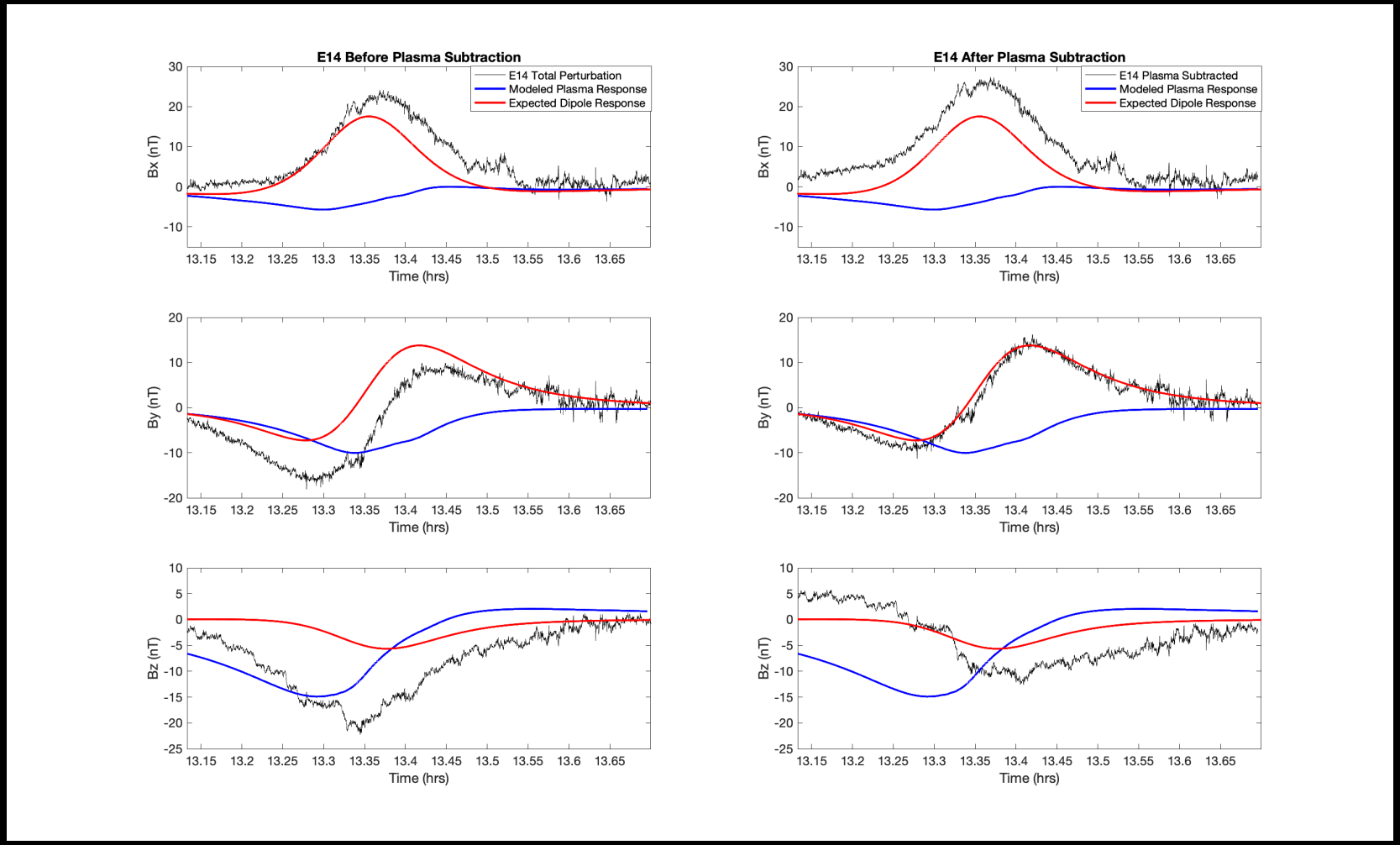
Application to E11 and E14 Flybys



CA=2039 km

Though the MHD simulation was not modeled for the specific conditions in E11 and E14, the E4 simulation appears to bring out the features of the dipole in By when the modeled plasma is subtracted

Application to E11 and E14 Flybys

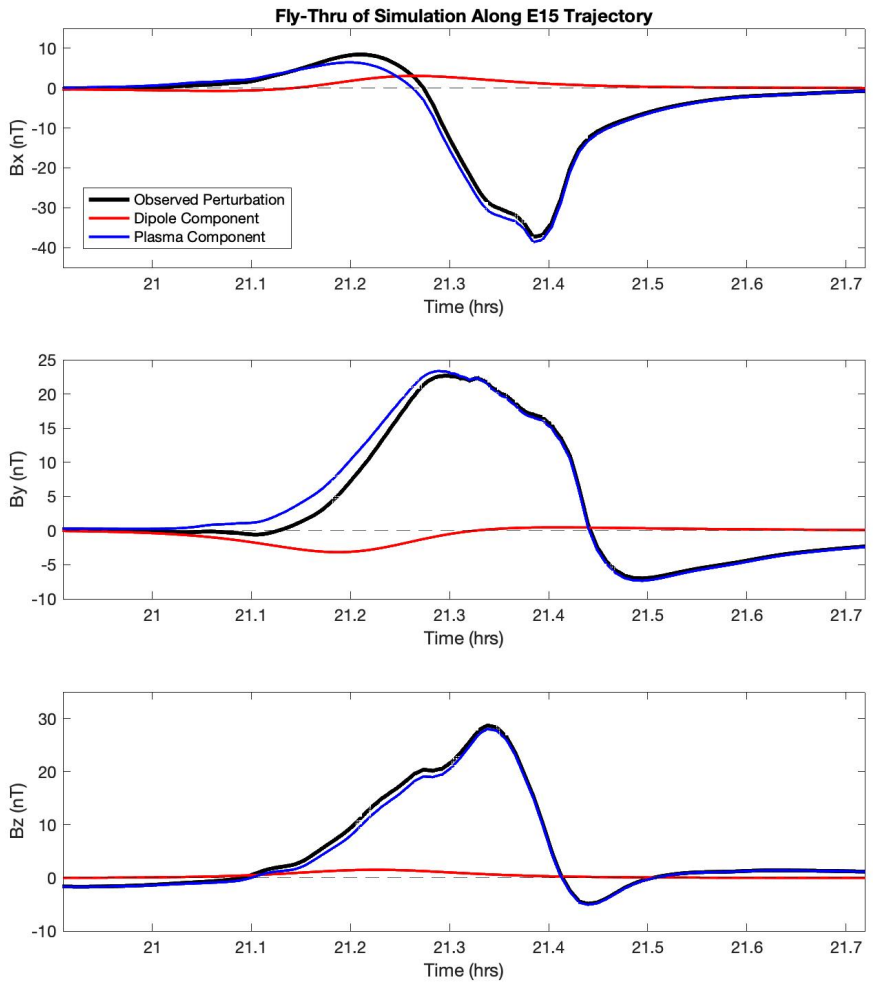


CA=1649 km

Though the MHD simulation was not modeled for the specific conditions in E11 and E14, the E4 simulation appears to bring out the features of the dipole in By when the modeled plasma is subtracted

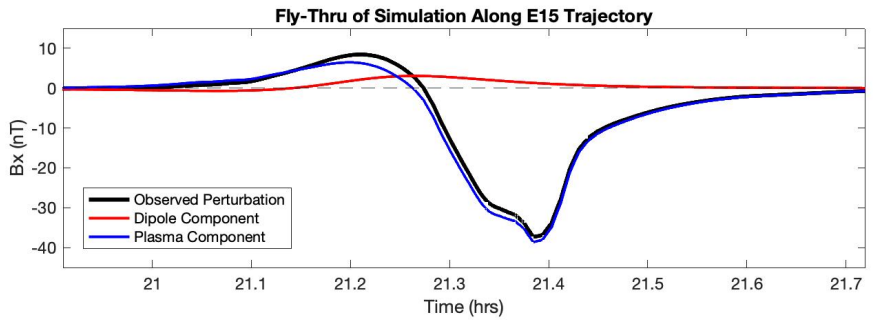
Galileo E15 Flyby Example: Center of Plasma sheet

E15 MHD Simulation



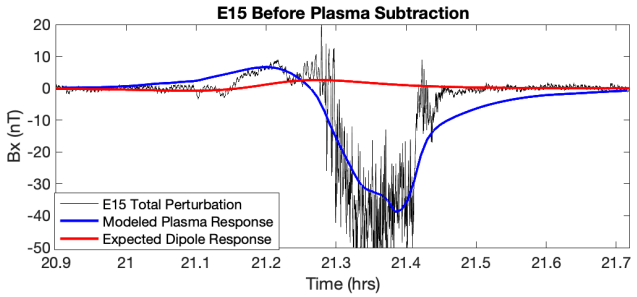
Comparisons of the dipole component (blue) and the plasma-perturbation component (red) for the E15 MHD model (jovian field has been subtracted) along the E15 trajectory

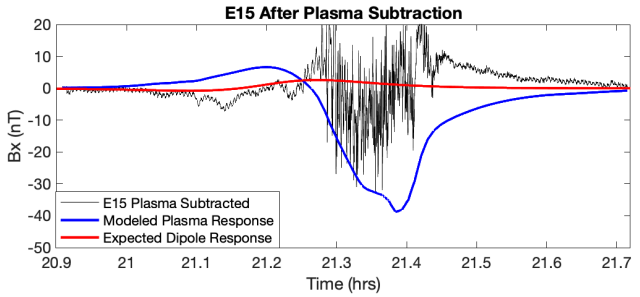
E15 MHD Simulation

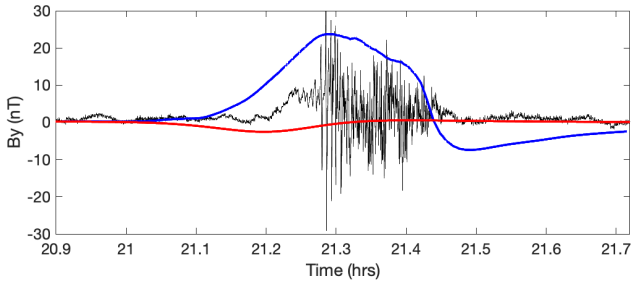


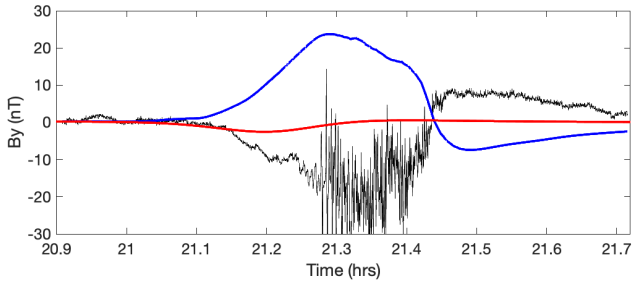
Total observed perturbation is dominated by the plasma interaction

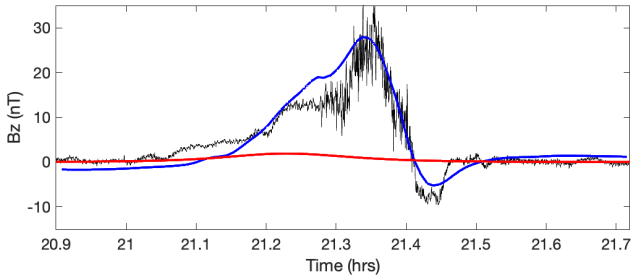
Application to Galileo E15 Flyby

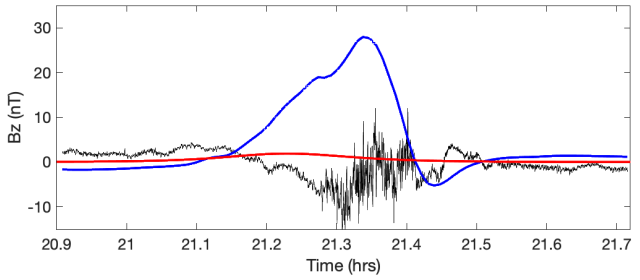












For this flyby, we were unable to isolate the dipole response

Summary

- The plasma perturbation shows a distinct signature relative to the dipole response which can be modeled through MHD simulations to help isolate the induced dipole response
- Early results show an improvement in bringing out the features of Europa's induced dipole when plasma is accounted for using a MHD model for the low plasma (E4) case.
- Noise in the wake region for the high plasma (E15) case did not allow for isolation of the dipole response
- Currently performing similar analysis for Europa Clipper trajectories to understand what the impact of the plasma component will be on retrieving dipole parameters for each flyby