ICEMAG

Interior Characterization of Europa Using Magnetometry

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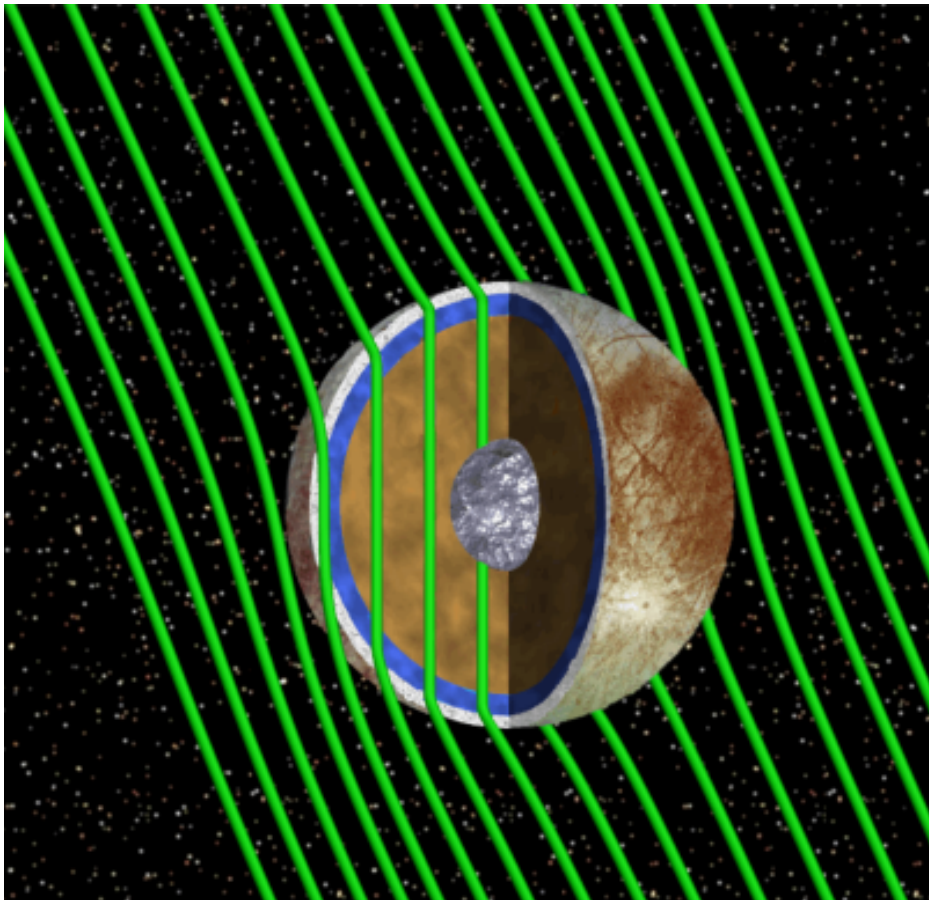

OPAG
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Science Objectives and Measurement Techniques

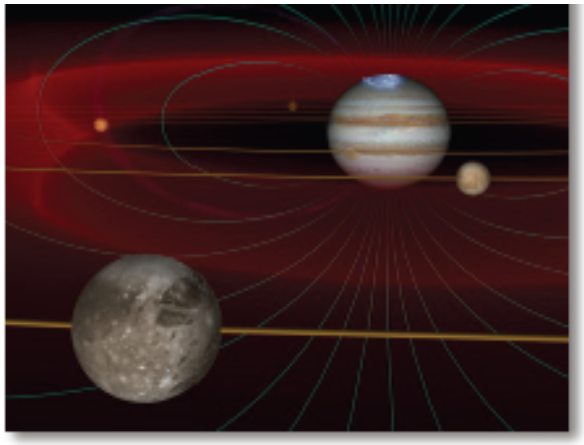
Science Goals

With the overarching goal of exploring Europa to investigate its habitability, ICEMAG will:

- Constrain Europa's thermal evolution and current interior state
- Identify the sources of the Europan atmosphere and processes by which it is lost
- Understand coupling between Europa and Jupiter's ionosphere, and coupling of plumes to the flowing plasma

Science Objectives

- Determine the location, thickness and salinity of the Europan ocean
- Constrain the locations of any active vents, plumes, and ionized plasma trails, the strength of plumes, and loss rates from the atmosphere
- Determine the strength of electric currents coupling Jupiter's corotating magnetospheric plasma to Europa's atmosphere and plumes, and coupling Europa to Jupiter's ionosphere



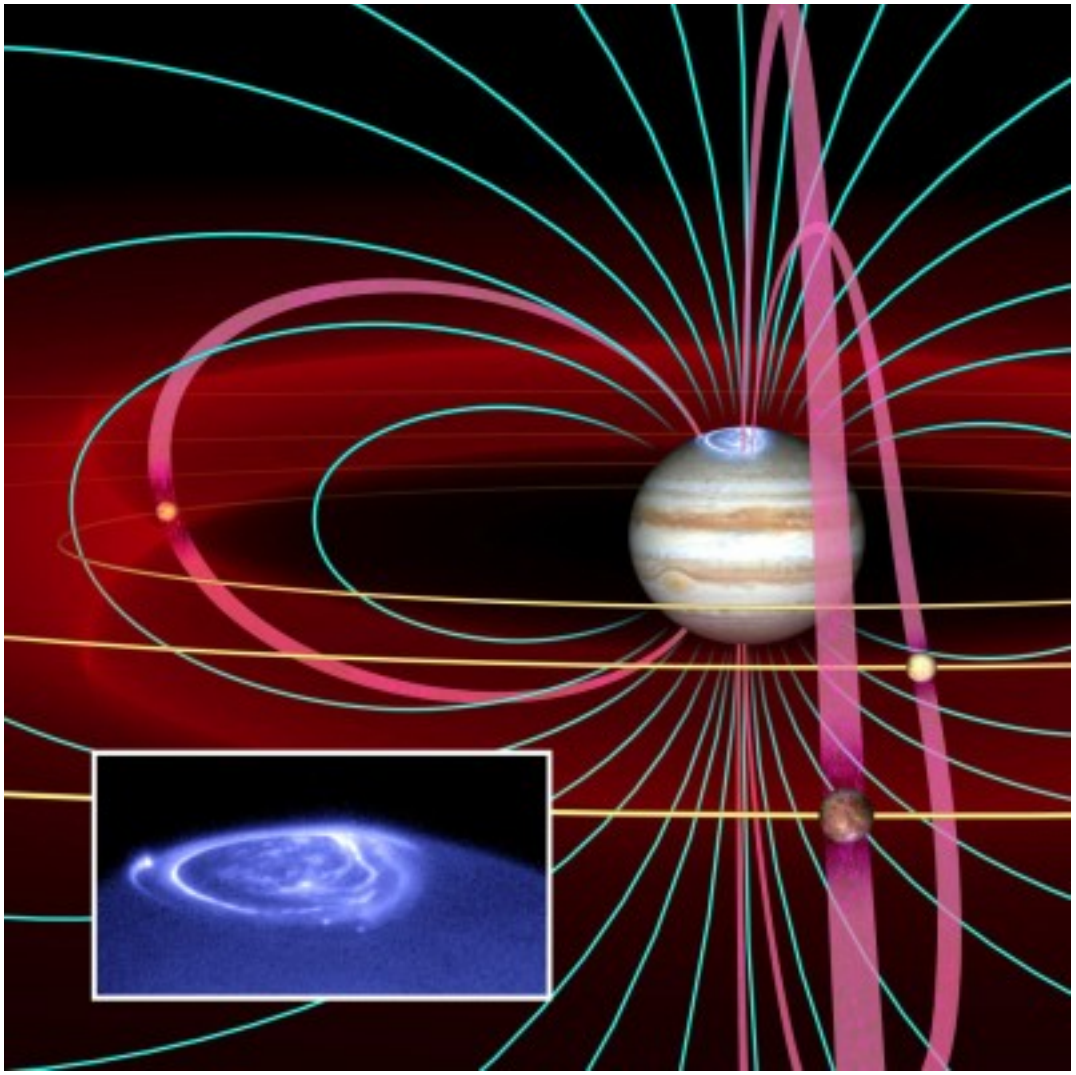
ICEMAG measurements reveal critical phenomena

- Magnetic field induced in Europa over multiple frequencies reveals ocean and ice shell thicknesses to < ±2km, and ocean conductivity to < ±0.5 S/m
- Electromagnetic waves at discrete frequencies from 10^{-2} to 1 Hz reveal localized mass flux of ions arising from plumes and the atmosphere
- Transient currents flowing near plumes and through Jupiter's magnetosphere reveal momentum transfer between plumes and plasma and between Europa and the jovian ionosphere

Induction at Europa

Jupiter's tilted dipole magnetic field and Europa's slightly eccentric orbit result in a strong time-varying (inducing) magnetic field at Europa that probes the depth, thickness and conductivity of its ocean.

- 11-h periodic variation resulting from the rotation of Jupiter in the Europan frame (synodic period)
- 85-h period resulting from Europa's orbit around Jupiter (orbital period)
- Shorter periods (half and third of synodic period) also contribute



INDUCTION AT EUROPA

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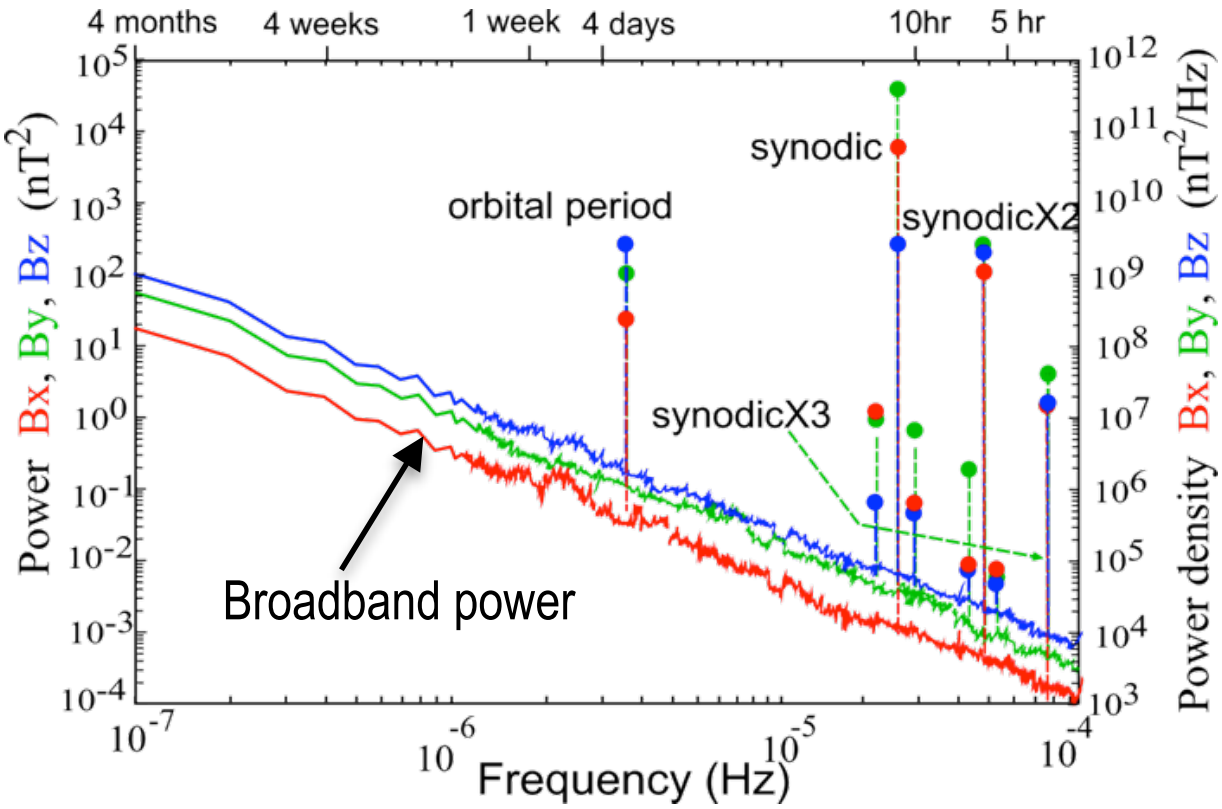
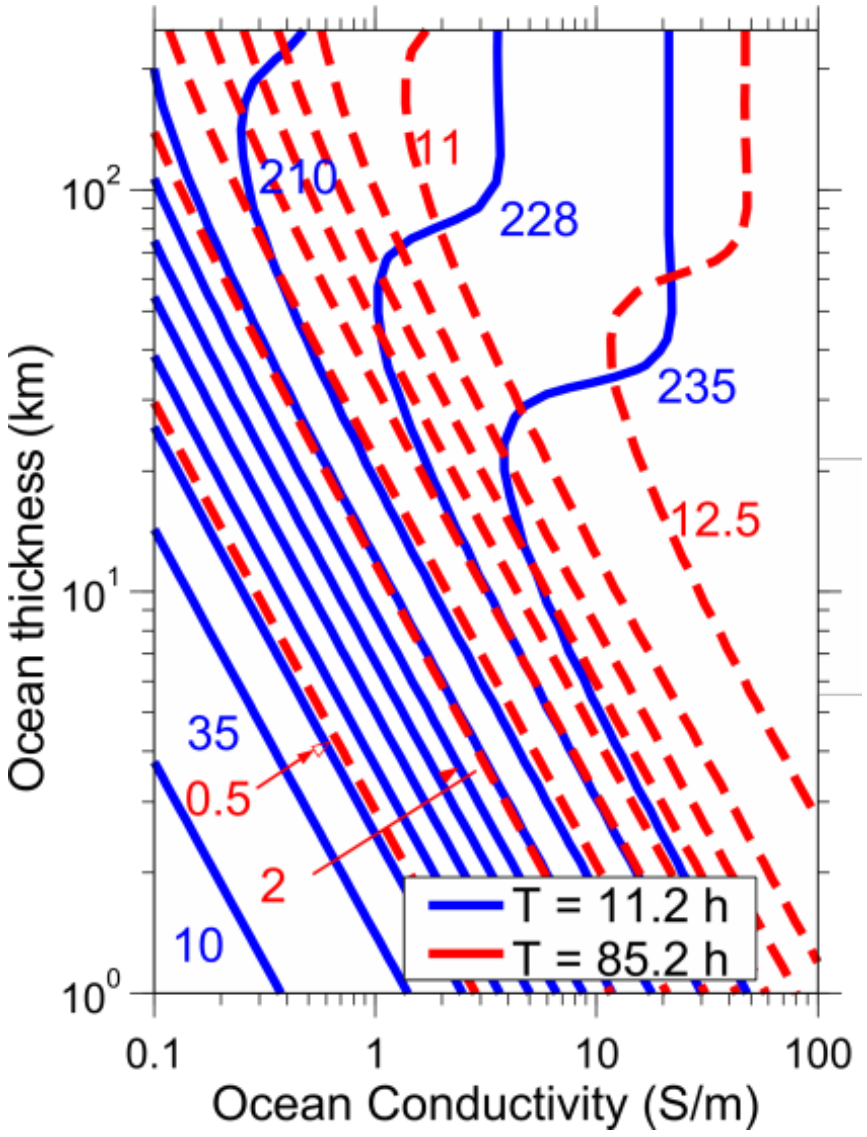
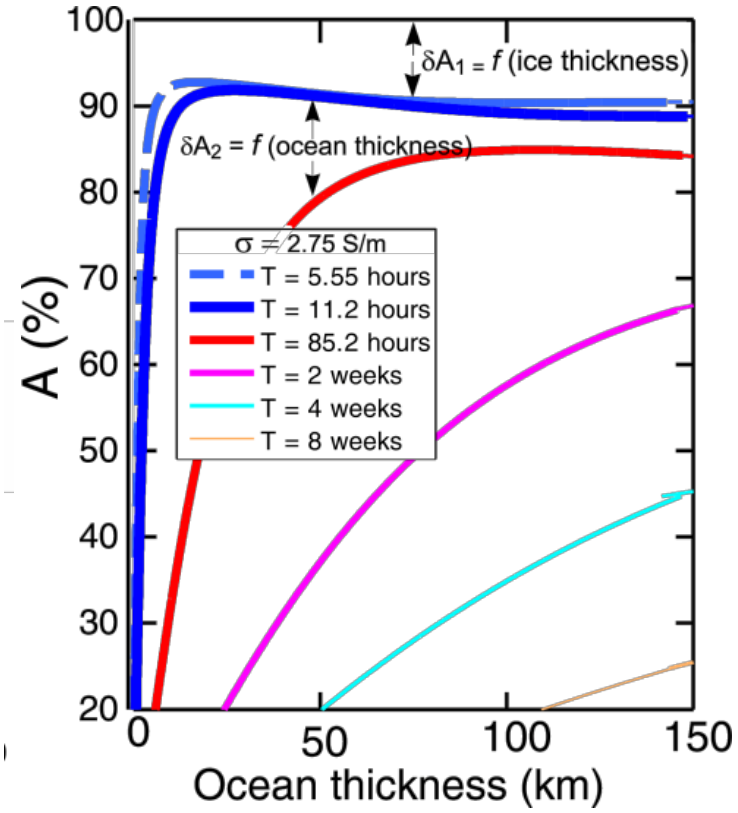


Objective 1: Probing the Europan Ocean

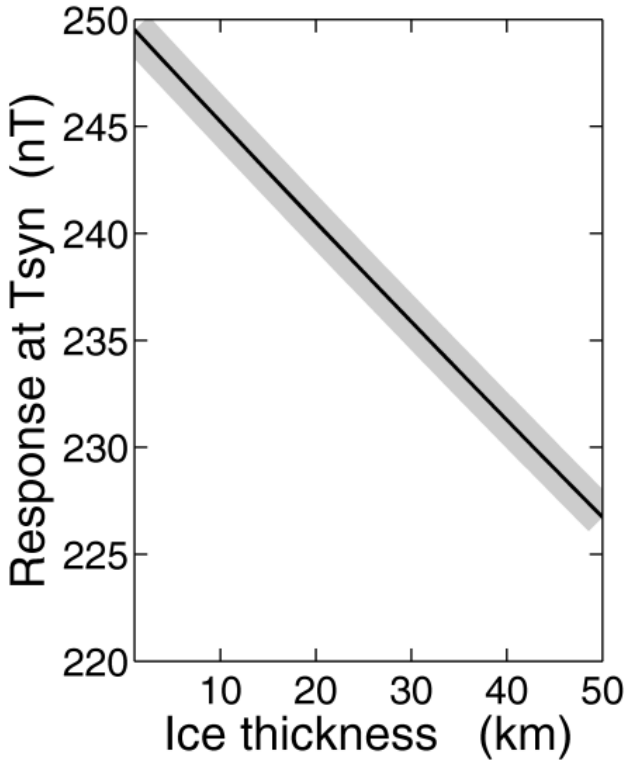


Induced field (in nT) at the surface of Europa in response to the 11.2–hr (blue, solid lines) and 85.2–hr waves (red, dashed lines) show that response at multiple frequencies can uniquely determine ocean parameters.

Objective 1: Probing the Europan Ocean

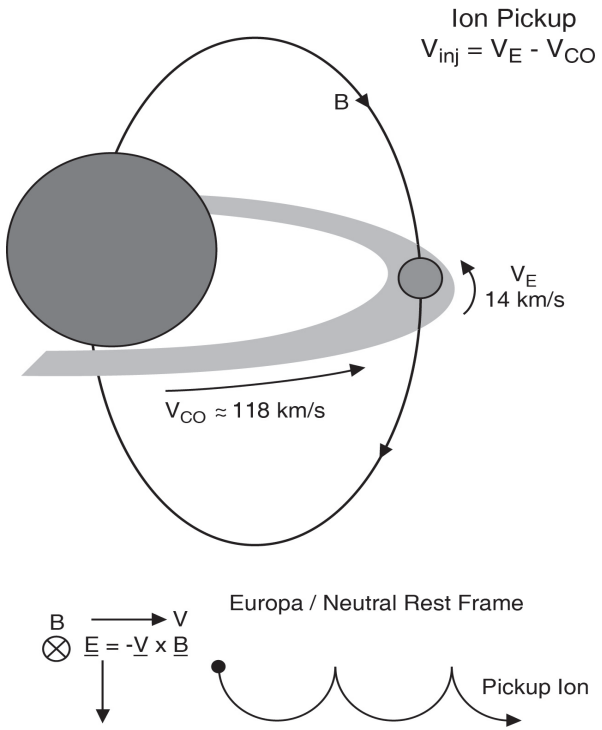


Induction response (efficiency), *A*, at multiple frequencies allows a unique determination of the thickness of the ice shell, and further constrains the ocean depth.



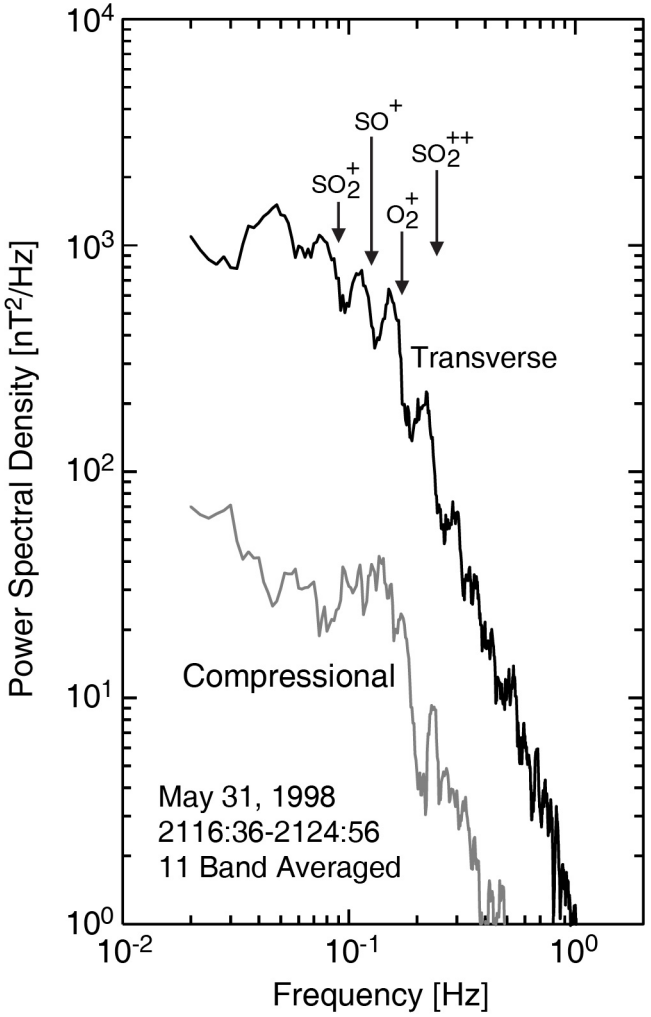
The induction response to the expected 250 nT (Bz) field at 11.2-hr period is linearly related to the ice shell thickness when d << R_E. The shaded region shows the expected ICEMAG accuracy of ±1.5 nT.

Objective 2: Probing the Europan Exosphere



Molecular species from Europa are ionized by charge exchange and photon impacts by Jupiter's plasma torus.

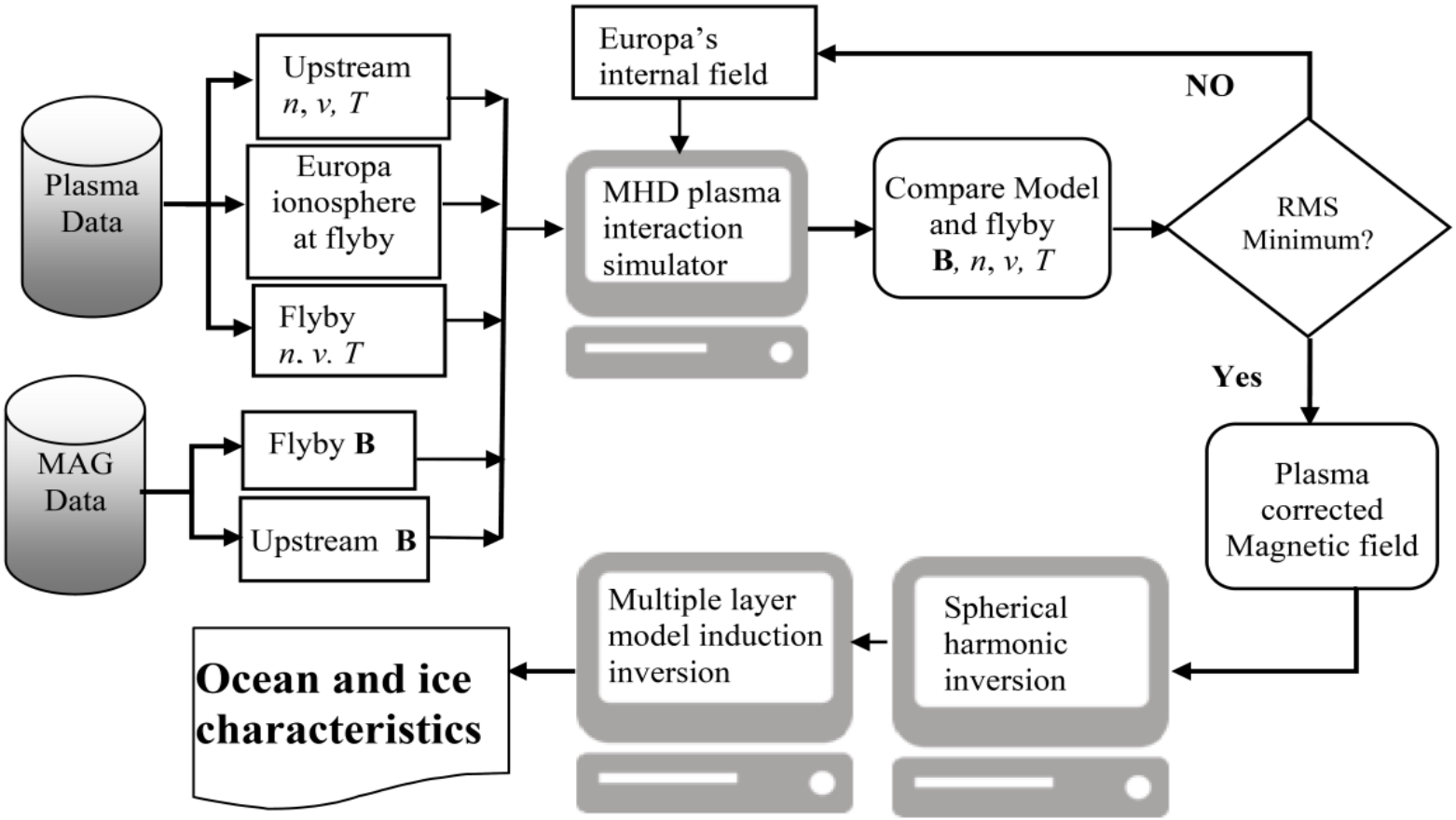
The ions orbit the magnetic field emitting ion cyclotron waves at characteristic frequencies.



Interdependencies and Synergies

- Isolation of the induced magnetic field depends on the combined analysis of plasma and magnetometer data
  - Plasma field can be estimated in magnetometer data analysis but results will be of lower fidelity
- Combined constraints from radar and mag data will better define the ice shell thickness
  - Mag will be key to detect at thick shell
- Combined constraints from gravity and mag will better define the ocean shell thickness
- Ocean salinity will add a constraint on the surface processes
- Ion cyclotron waves contribute to understanding exospheric composition
- Localized transient currents indicate plume activity

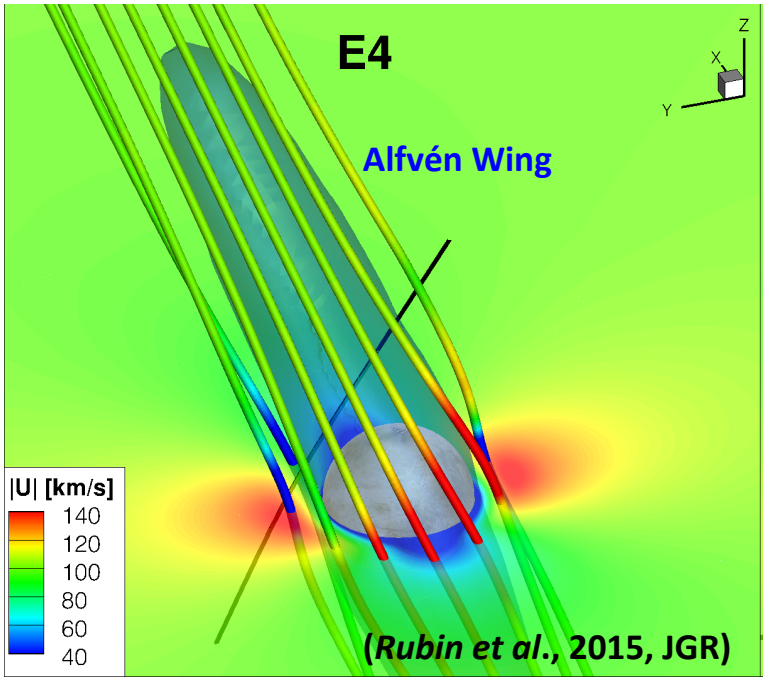
DATA ANALYSIS: COMBINED ICEMAG AND PIMS FLOW



The MHD plasma interaction simulator, fed by the mag and plasma data, is key for isolating the induced magnetic field. The aggregated plasma-corrected Europa mag data set is decomposed into the primary external field and seven wave frequencies from which ocean and ice characteristics are derived.

3D Multi-fluid MHD Model for Europa

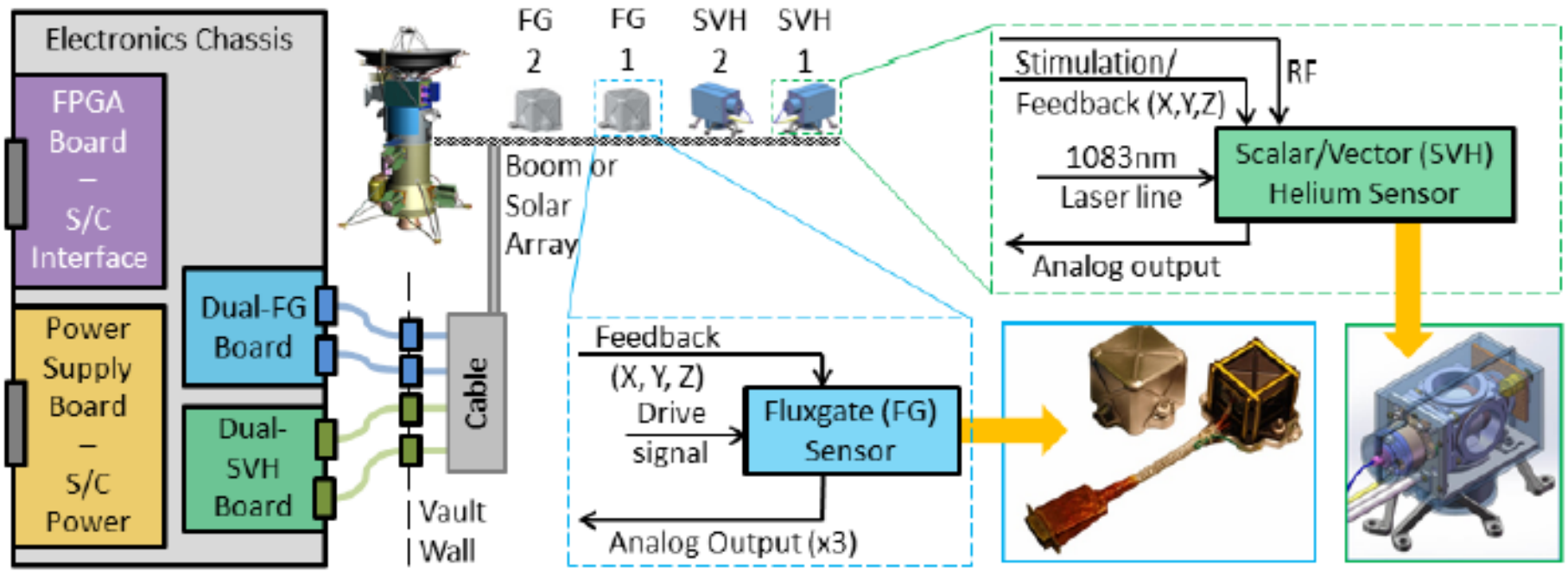
- Multi-fluid U. Mich MHD model, including:
  - ambient Jovian plasma
  - plasma originating from Europa (e.g., pickup ions and ionospheric plasma)
  - Electrons
- Also includes various source and loss processes occurring in the near-Europa environment:
  - Electron impact ionization and photoionization
  - Charge exchange
  - Elastic and inelastic collisions between ions, neutrals, and electrons
  - Ion-electron recombination
- Solves for the distribution and evolution of the electron temperature
  - Enables accurate calculation of Europa's neutral atmosphere ionization rate



- 3D perspective of Europa's plasma and field environment during the Galileo E4 flyby:
  - Magnetic field lines color coded with field strength
  - Equatorial plane with contours of mass averaged plasma bulk velocity

(*Xianzhe Jia, Univ. of Michigan*)

ICEMAG Design – CAD View & Key Subsystems



- Helium sensors alternate between vector and scalar modes. Scalar mag data used to perform calibrate the vector sensors.
- Fluxgate sensors are based on recent InSight and MMS instruments
- Four sensor array yields precise field gradient allowing spacecraft nuisance field to be measured and removed

KEY POINTS

- Magnetometer array provides precise measurements of induced fields at Europa (to <1.5 nT accuracy over length of mission)
  - Gradient measurements allow removal of spacecraft fields
  - Scalar data establishes stable offsets (zero-level) to achieve a self-calibrating instrument

- ICEMAG will:
  - determine ice shell thickness(to accuracy of +/-1.5 km) and ocean thickness
  - detect ion cyclotron waves resulting from major and minor ion species picked up from Europa's exosphere
  - detect transient electric currents generated by plume emissions

- ICEMAG is a low-resource investigation using innovative sensors built on decades of heritage in a novel implementation

- ICEMAG and PIMS are interdependent and share an analysis pipeline

- ICEMAG data combine synergistically with other data sets to improve knowledge of interior properties and exosphere activity