Clipper Reconnaissance Data: ICEMAG / PIMS / RadMon

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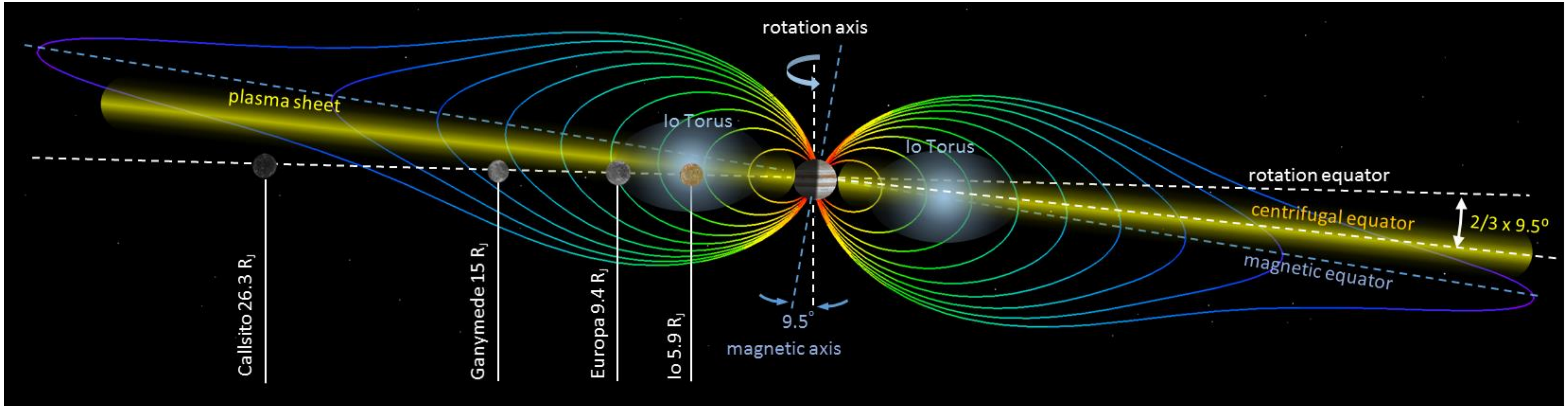


Jet Propulsion Laboratory, California Institute of Technology

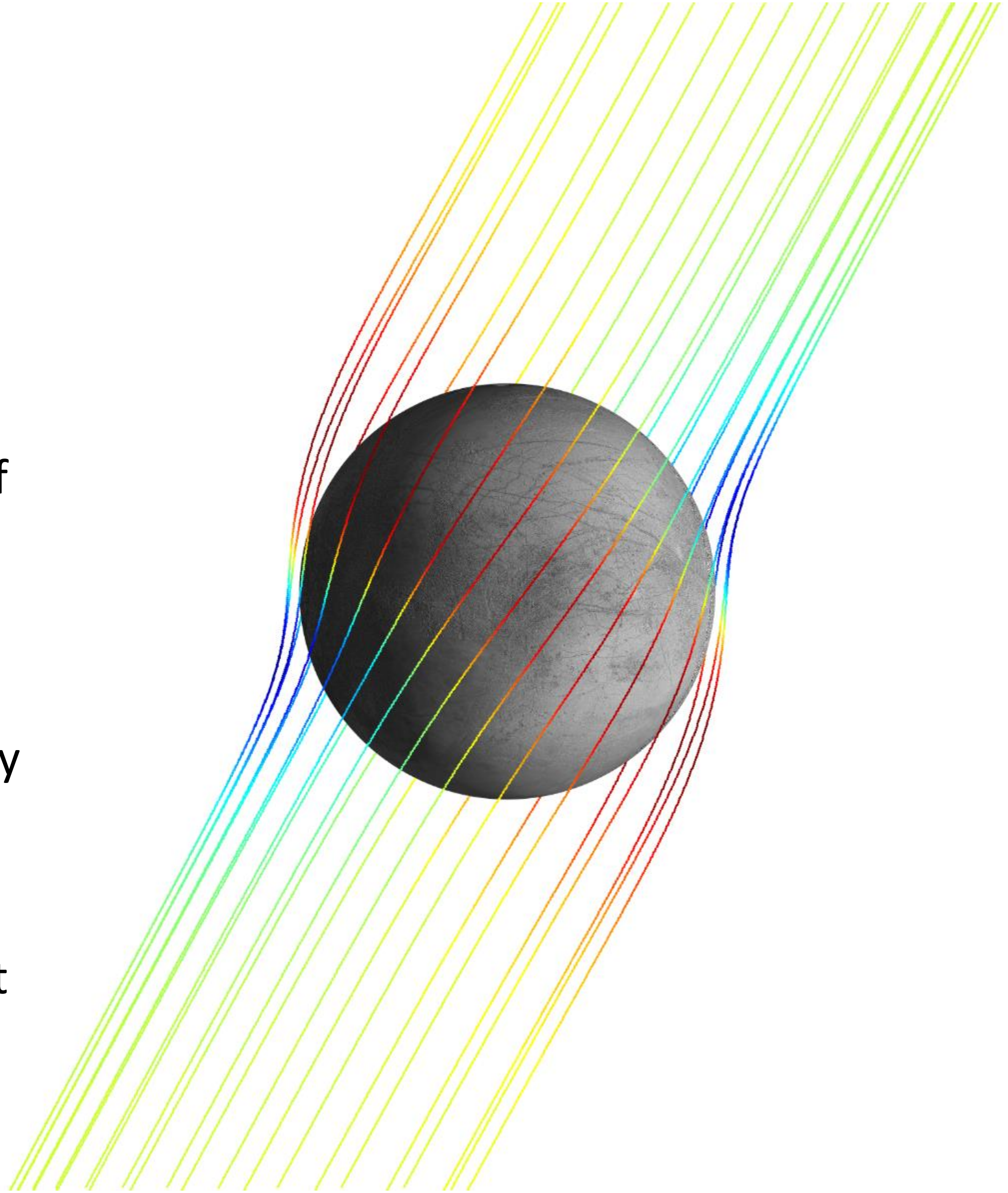
ICEMAG Overview

A subsurface conductive ocean was discovered in magnetic field data from three flybys of the *Galileo* mission (*Khurana et al.,1998*) at a single 11.2-hr induction period

ICEMAG will measure Europa's magnetic field components *in situ,* comprising the background field of Jupiter, the field induced within Europa, and fields created by the interaction of Europa and the flowing plasma

ICEMAG employs two UCLA fluxgate sensors and two JPL scalar/vector helium sensors in an array along a 5-m boom to remove spacecraft magnetic fields and achieve higher accuracy than previous magnetometers

40+ Clipper flybys combine with direct measurements of the plasma environment to derive high-fidelity induction signals at two or more frequencies



ICEMAG Sensor Suite

4 sensors allows the spacecraft field to be measured continuously and removed to within our required accuracy and precision, at a cadence of ≤5 minutes

Allows a shorter (5-m) boom and a less stringent magnetic cleanliness requirement than typical for similar missions (i.e. Cassini: ~10 nT residual field at end of 10 m boom)

Results in graceful degradation of the investigation in case of sensor failures

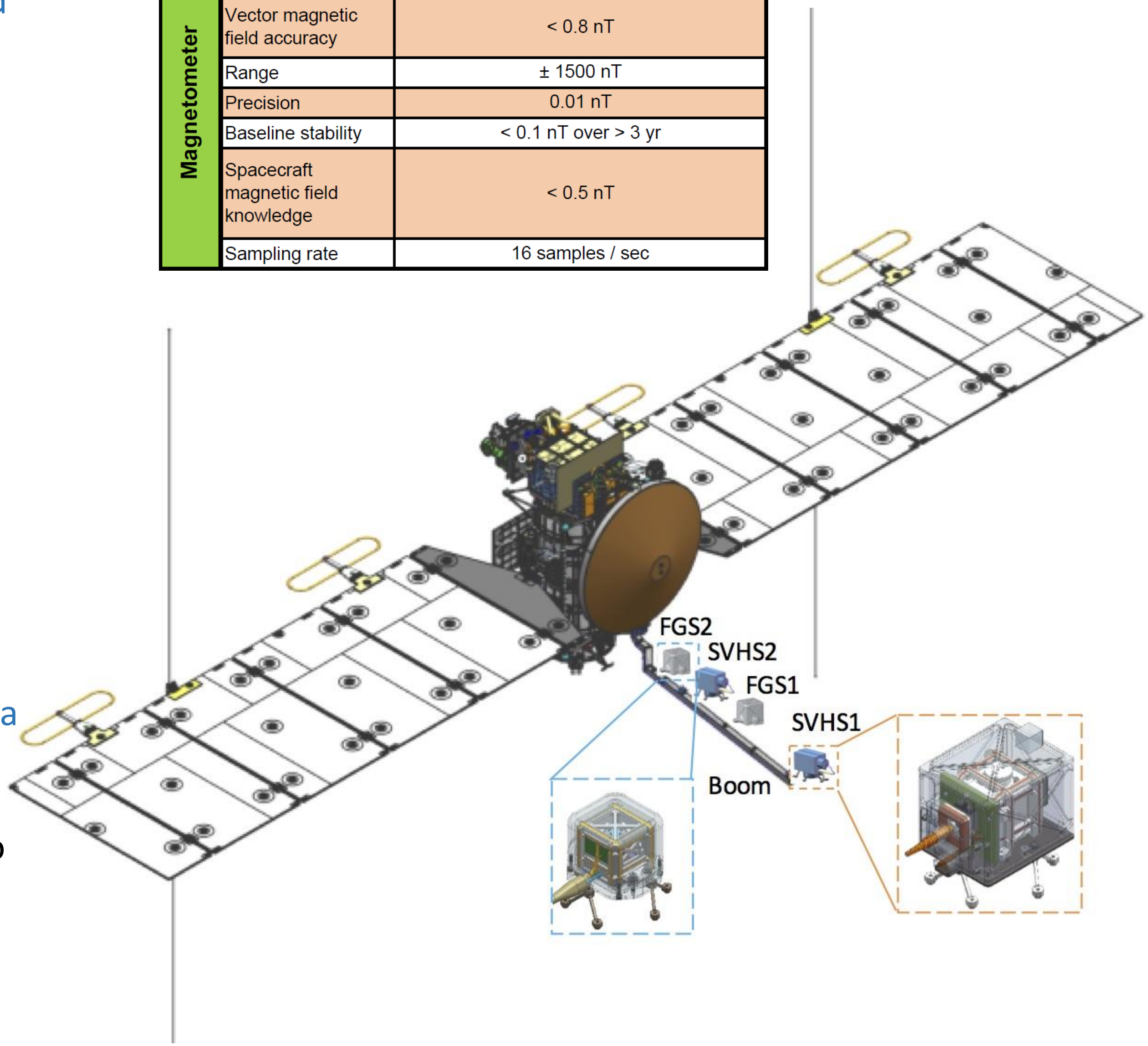
Scalar measurements allow continuous calibration of offsets

Enables long-term stability needed to connect the flybys into a single measurement set

Two types of vector sensors (FG and VHM) deliver performance over a wide frequency range

Improves measurement of induction fields, and waves related to plumes

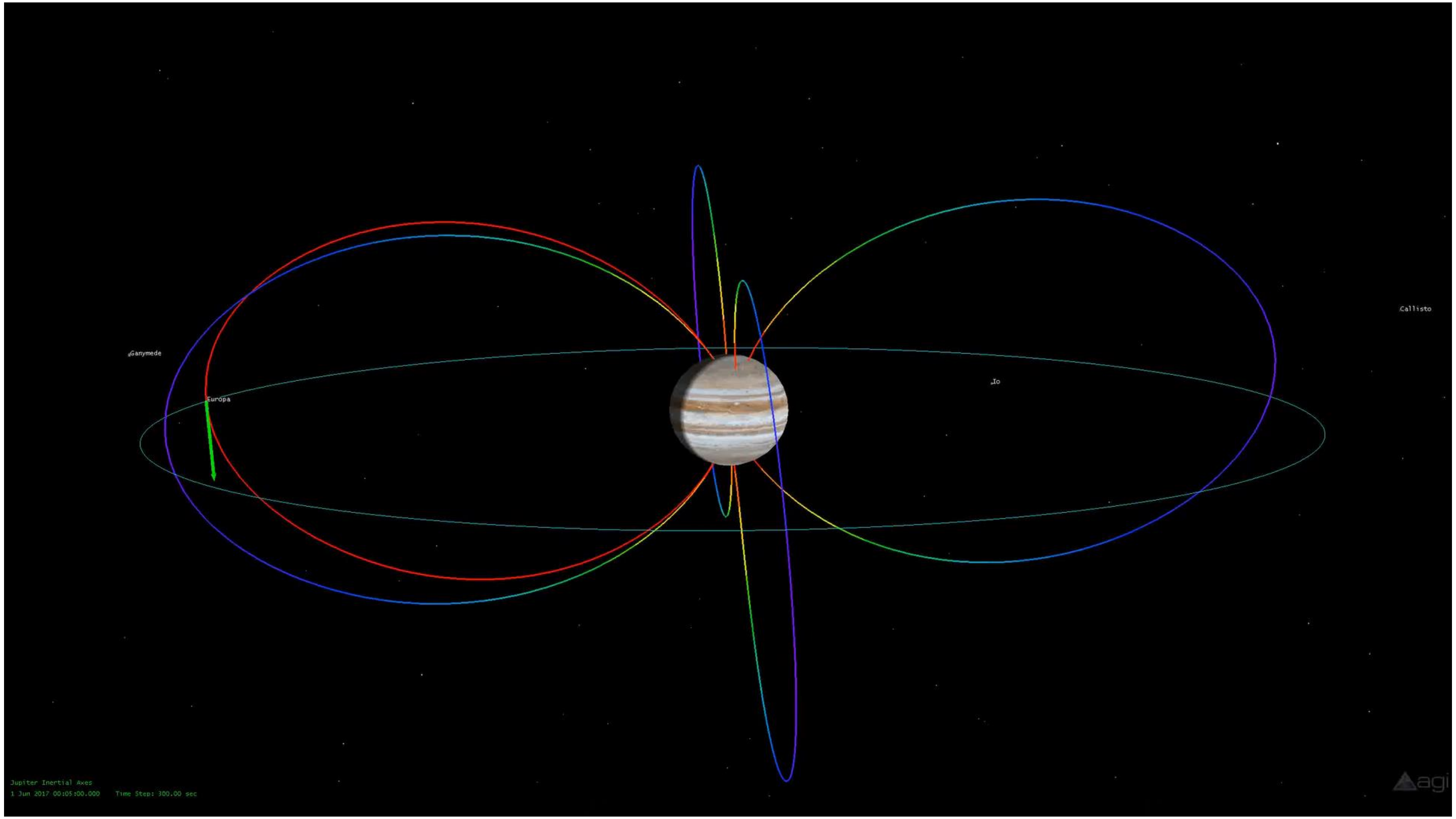
Magnetometer	ICEMAG: Key Instrument Parameters	
	Vector magnetic field accuracy	< 0.8 nT
	Range	± 1500 nT
	Precision	0.01 nT
	Baseline stability	< 0.1 nT over > 3 yr
	Spacecraft magnetic field knowledge	< 0.5 nT
	Sampling rate	16 samples / sec



Induction at Europa

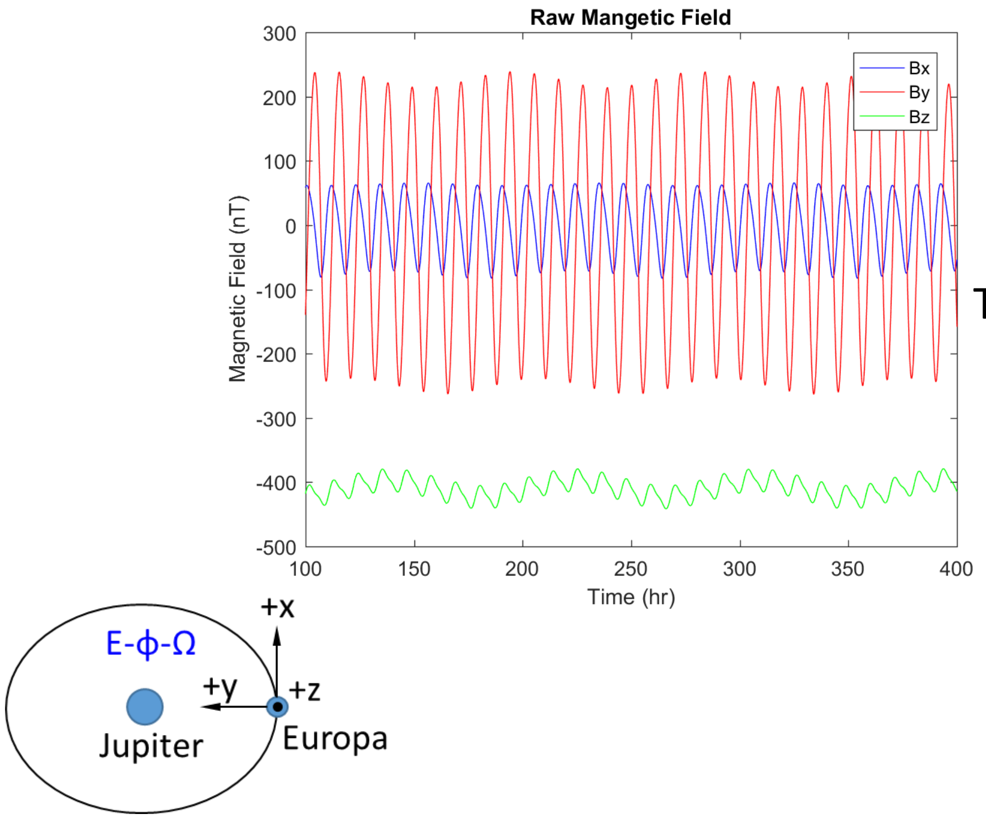
Jupiter's tilted dipole magnetic field and Europa's slightly eccentric orbit result in a strong time-varying (inducing) magnetic field at Europa

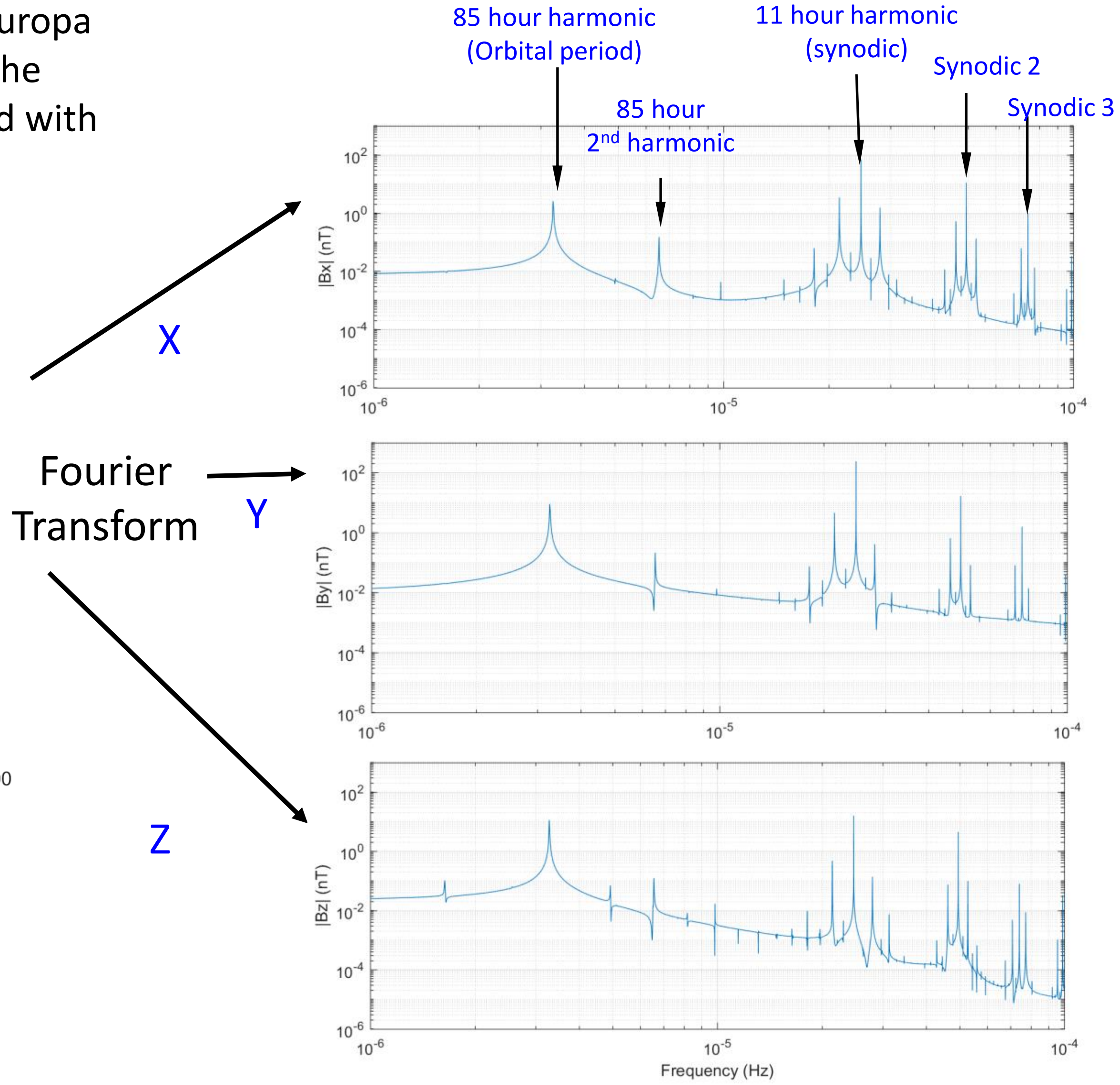
- 11-h periodic variation resulting from the rotation of Jupiter in the Europan frame (synodic period)
- 85-h period resulting from Europa's orbit around Jupiter (orbital period)
- Modulated frequencies also contribute



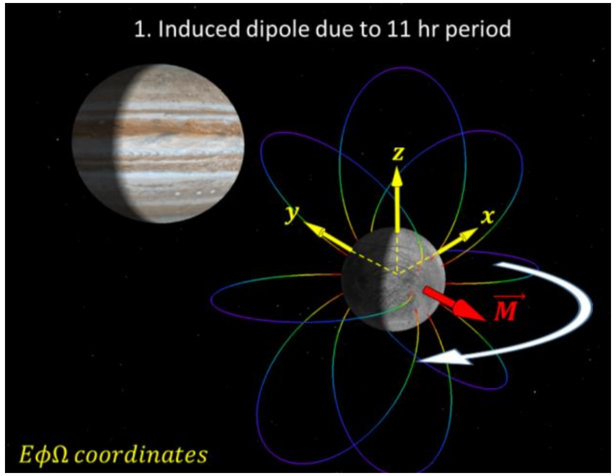
Frequency Content of Time Varying Magnetic Field

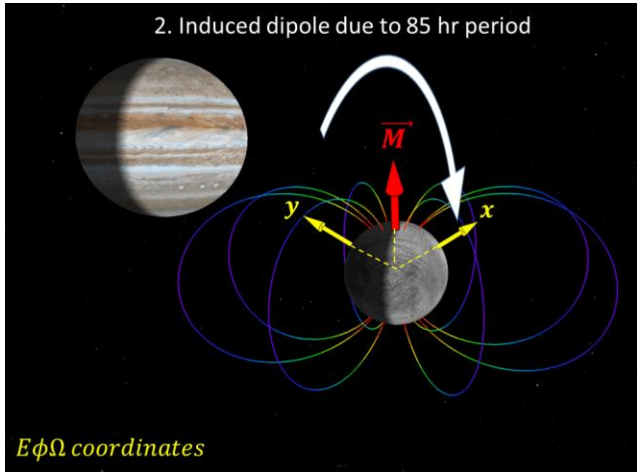
Taking the Fourier transform of the magnetic field at Europa reveals not only the 11 hr and 85 hr periods, but also the higher order harmonic and beat frequencies associated with the time varying magnetic field of Jupiter.

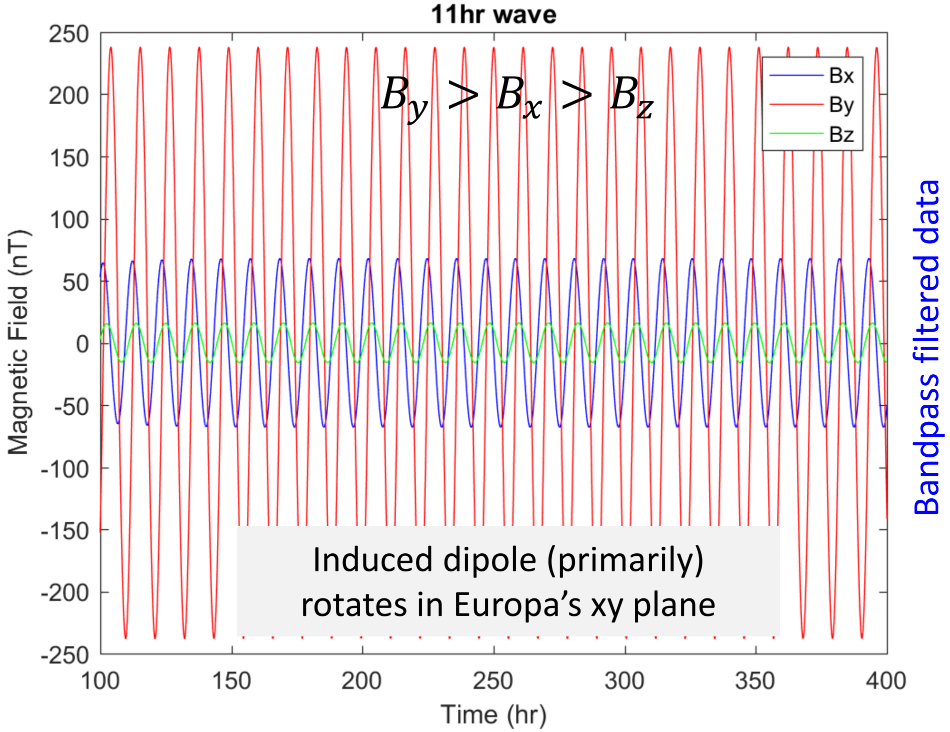


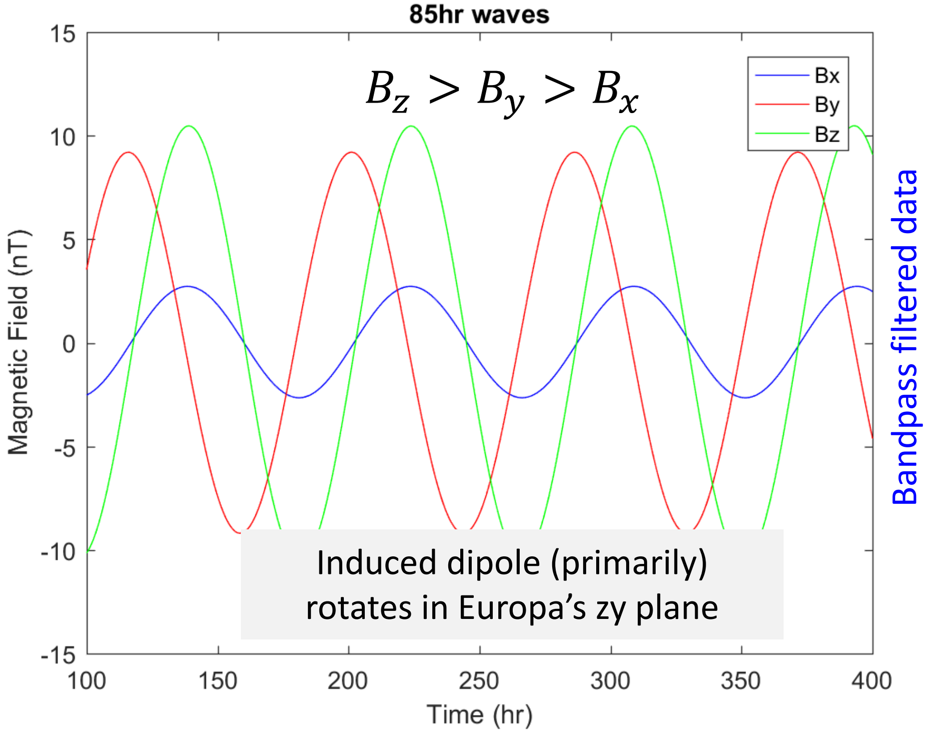


Orientation of Induced Magnetic Dipoles

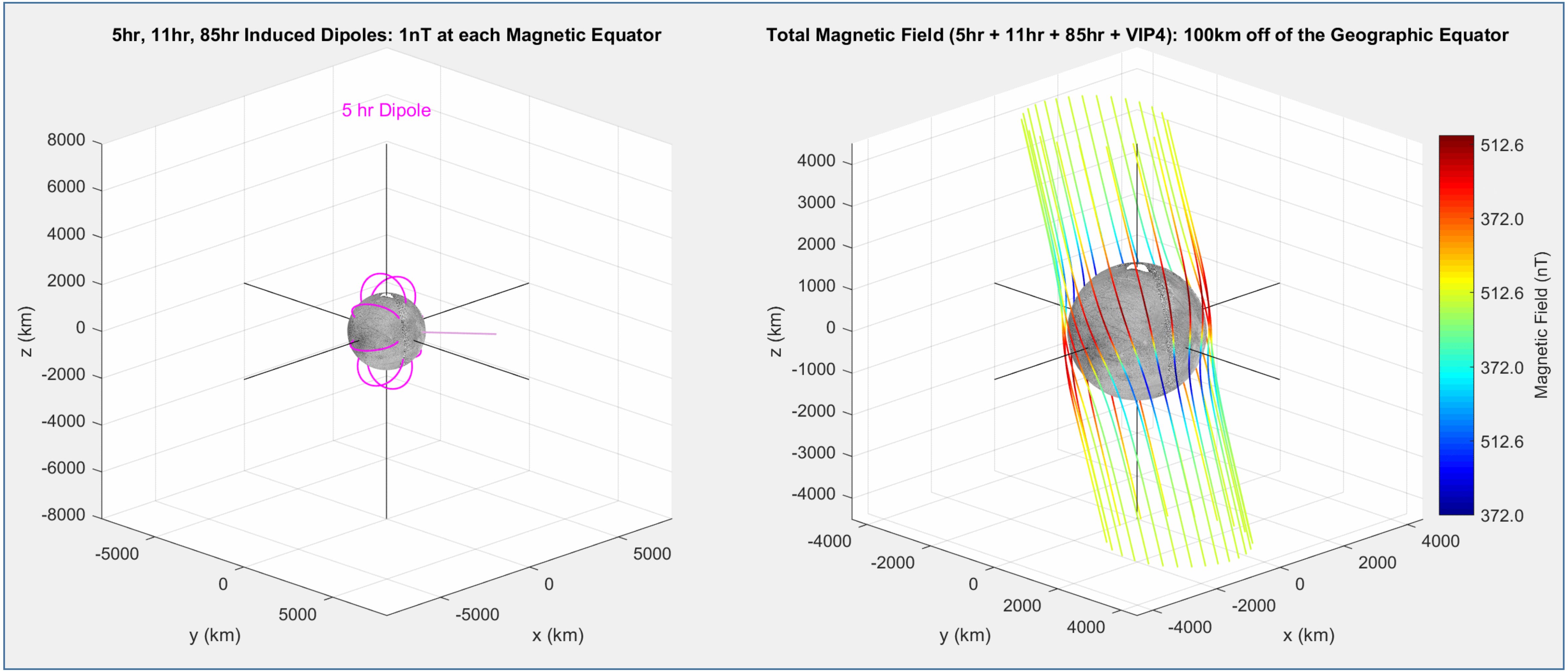








Simulated Induced Field at 5hr, 11hr, and 85 hr



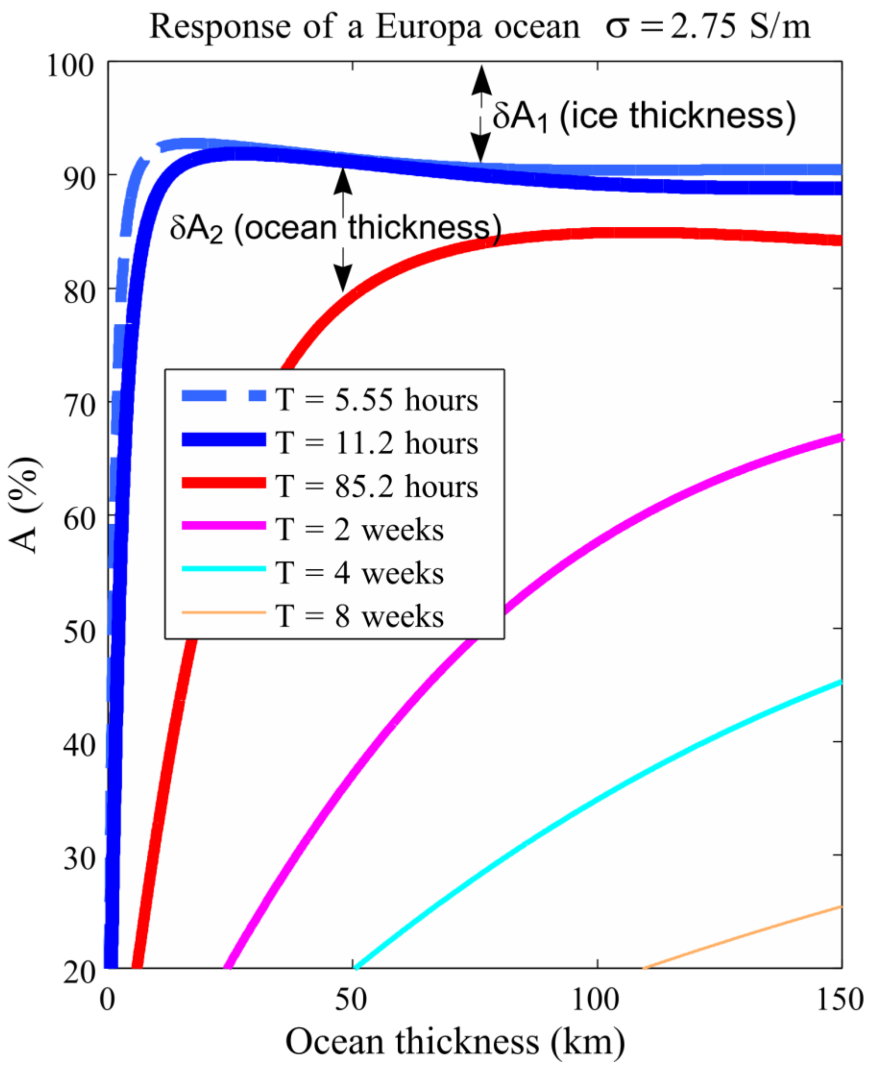
This material was presented by Corey Cochrane at Europa Science Series on January 12, 2018

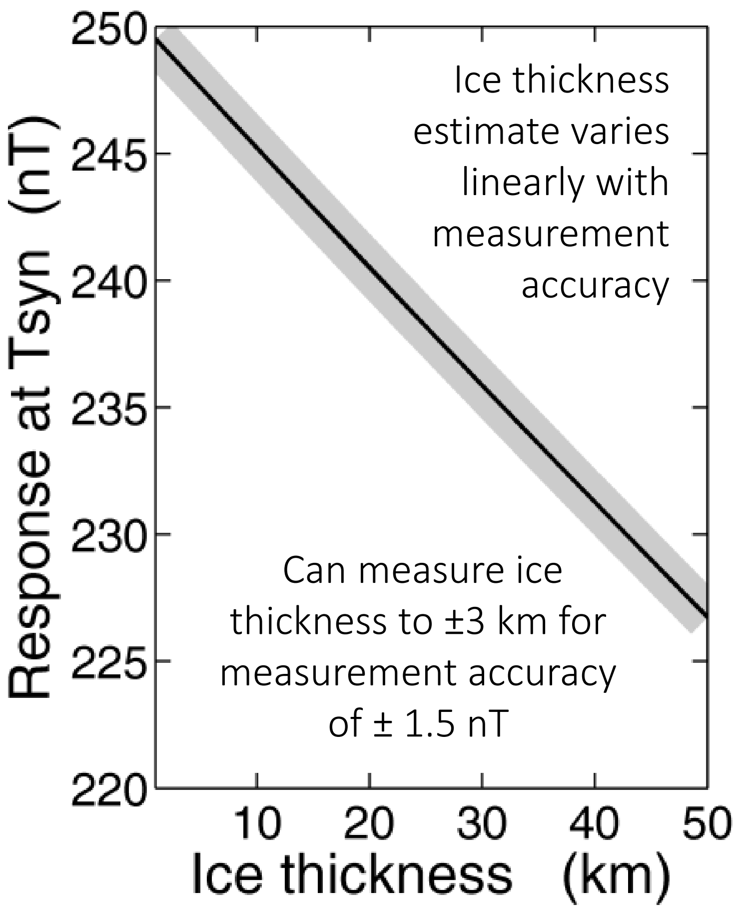
Measuring ICE Properties

Constrain the average thickness of the ice shell, and the average thickness and salinity of the ocean, each to within 50%.

- For ice shell thickness:
  - ICEMAG accuracy of **± 1.5 nT** resolves an ice shell of 6 km thickness to within ± 50%
  - Current CBE of **± 1 nT** resolves and ice shell of 4 km within ± 50%

Induction efficiency at the synodic period (11.2-hr) is a direct measure of ice thickness



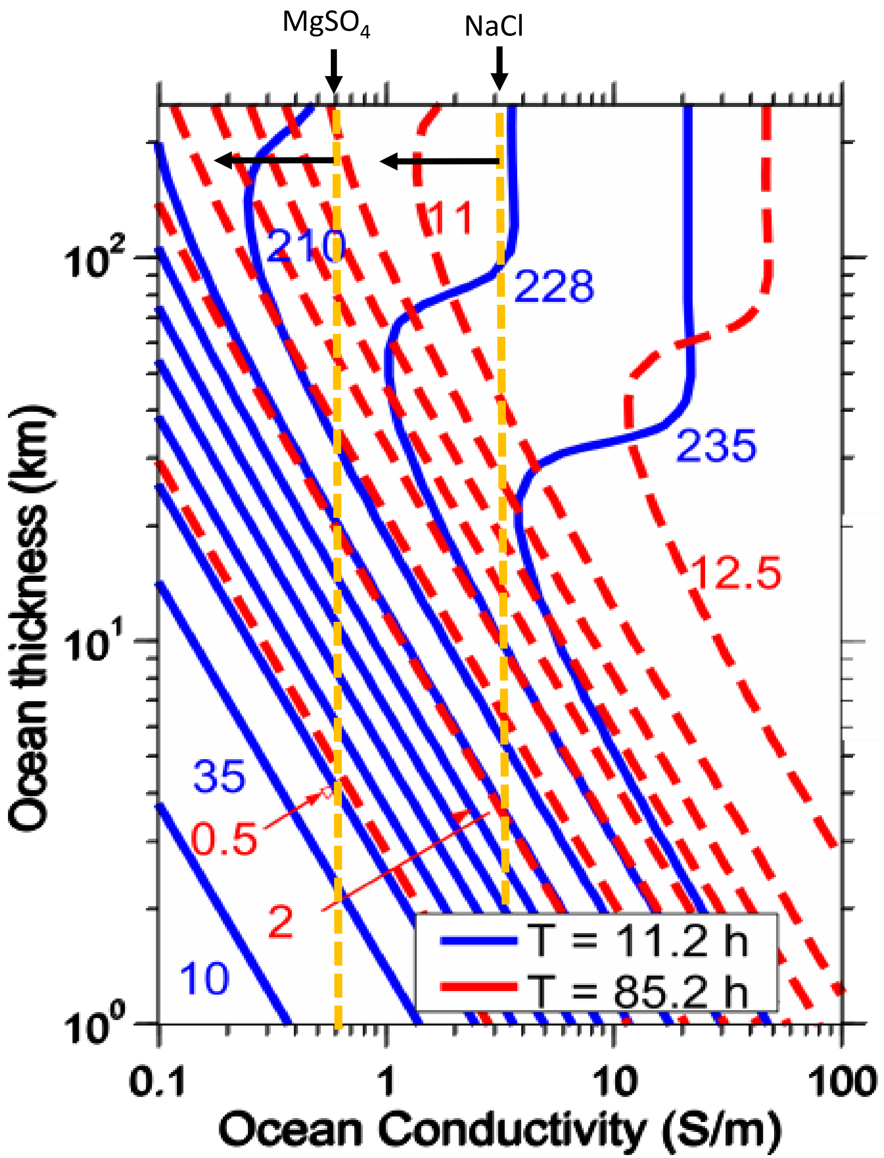


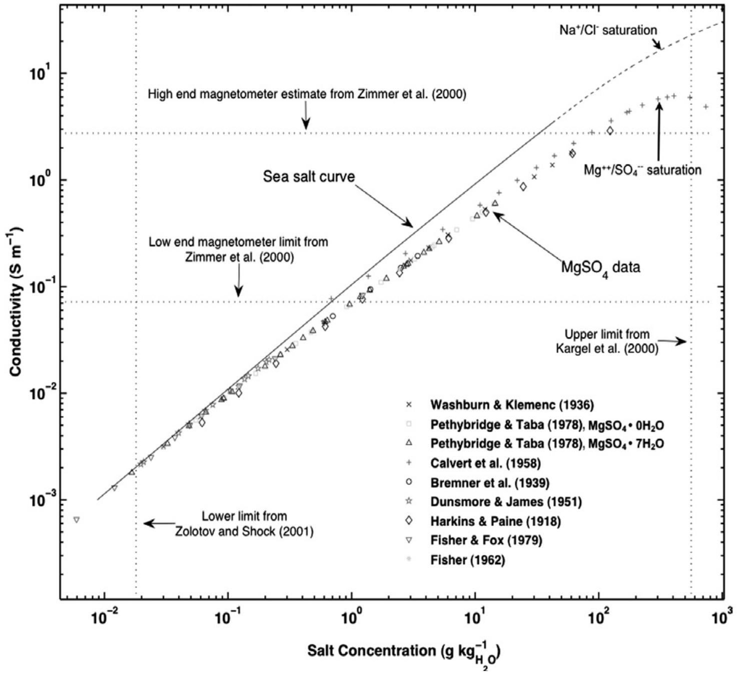
Measuring Ocean Properties

Constrain the average thickness of the ice shell, and the average thickness and salinity of the ocean, each to within 50%.

- For ocean thickness and salinity, margin is difficult to calculate because it depends on the thickness/salinity regime

Composition of surface material, and sputtered or vented material provide independent constraints on conductivity, and in turn, ocean thickness

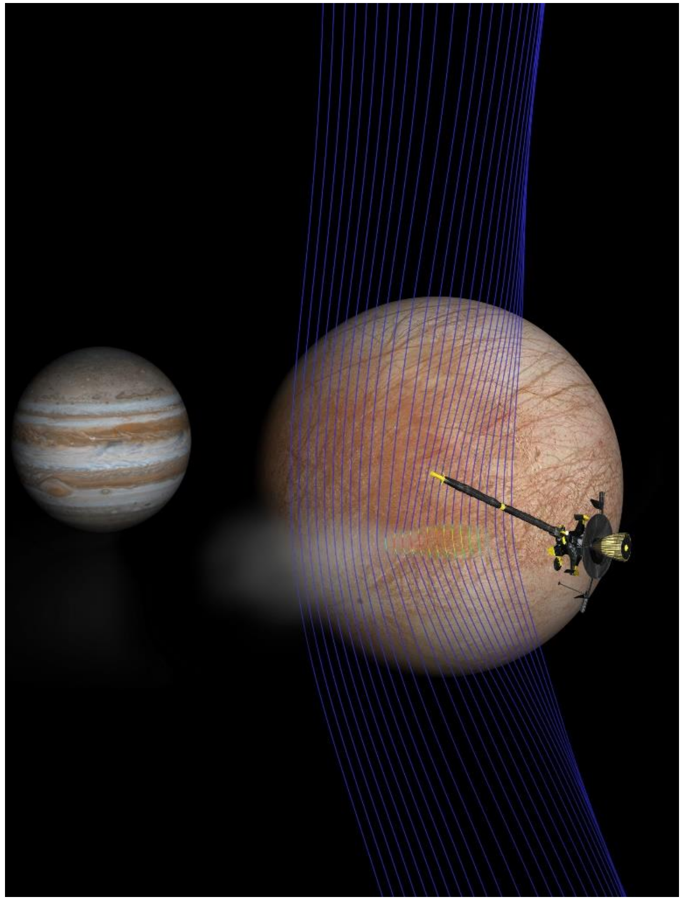




Empirical range of salt concentrations permitted for Europa's ocean from existing data (Hand and Chyba, 2007). Conductivity estimates are based on three Galileo flybys

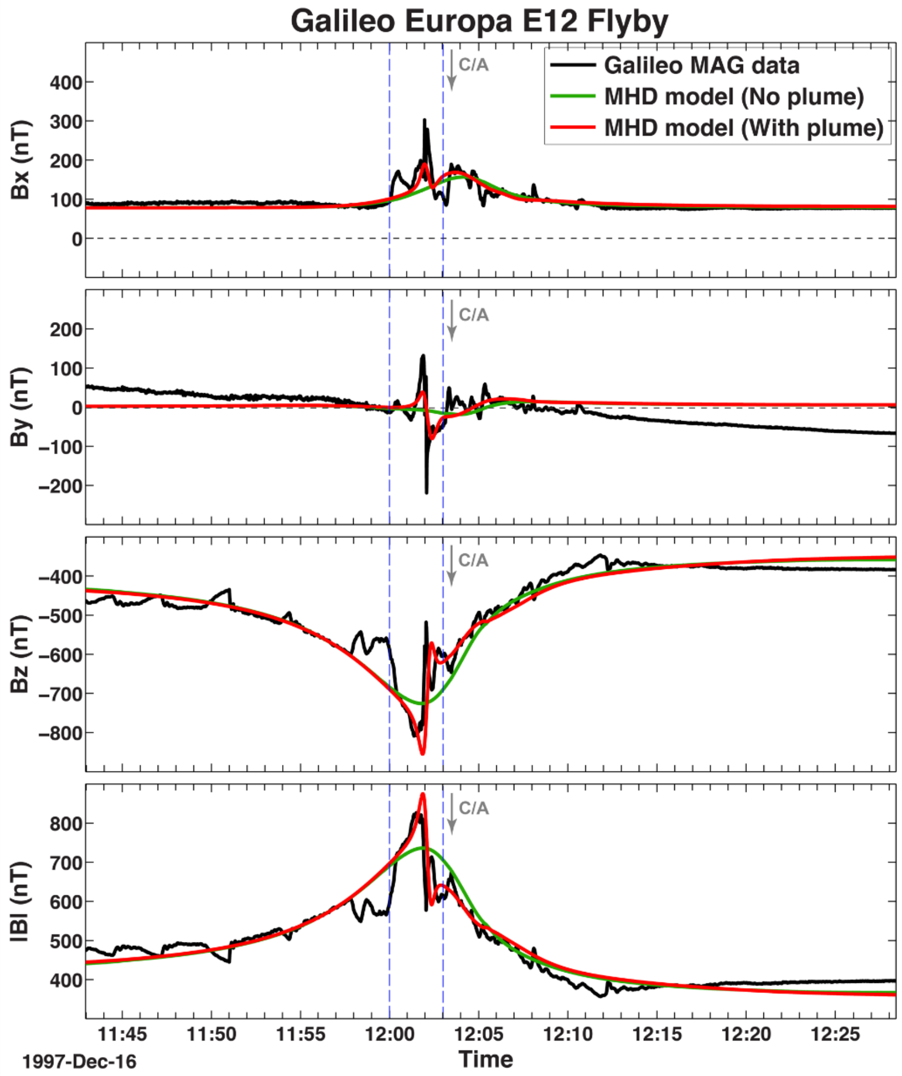
Plume Magnetic Field Signature

Search for and characterize any current activity, notably plumes or thermal anomalies, in regions that are globally distributed.



New analysis of Galileo magnetic field and plasma data show signatures consistent with a plume of the dimensions inferred by Hubble observations

Codes used are the same as those to be used for ICEMAG and PIMS analyses



Jia, X., M. G. Kivelson, K. K. Khurana, W.S. Kurth, *Nature Astronomy*, 2018

PIMS Science Investigations

PIMS Investigation 1:
Determine the plasma contributions to Europa's magnetic induction response to estimate the ocean's location, thickness, and salinity.

PIMS Investigation 2:
Determine the plasma contributions to Europa's magnetic induction response to estimate the ice shell thickness.

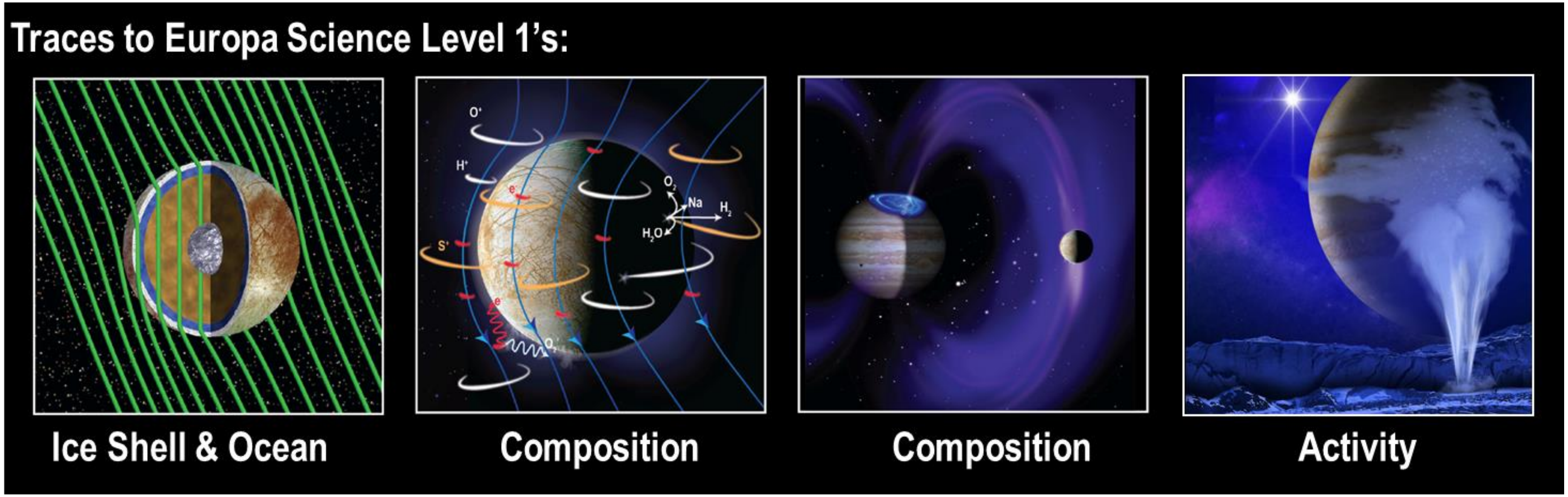
PIMS Investigation 3:
Constrain the composition and chemistry of Europa's ionosphere.

PIMS Investigation 4:
Understand the mechanisms responsible for weathering and releasing material from Europa's surface into the atmosphere and ionosphere.

PIMS Investigation 5:
Understand how Europa influences its local space environment, the structure of the Europa-associated partial torus, and the possible existence of Europa plumes and their temporal variability.

PIMS Investigation 6:
Determine the temporal variation of Europa's particle source and any active plumes.

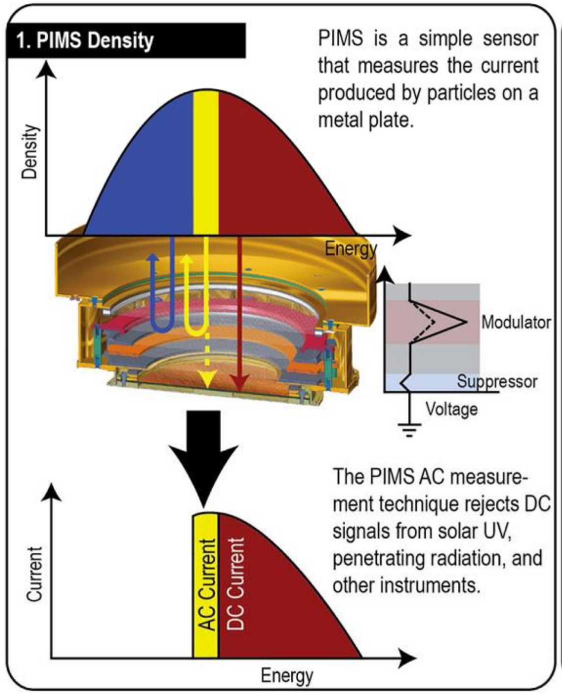
PIMS Investigation 7:
Determine the composition and structure of the ionized component of Europa's atmosphere and putative plumes.

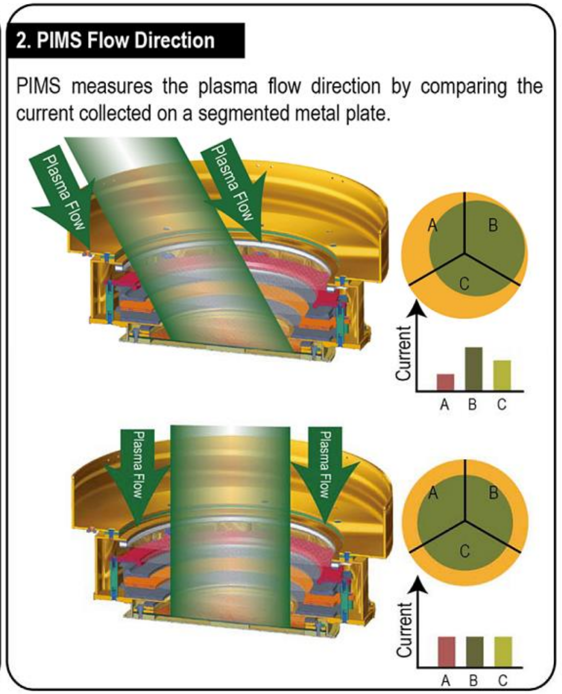


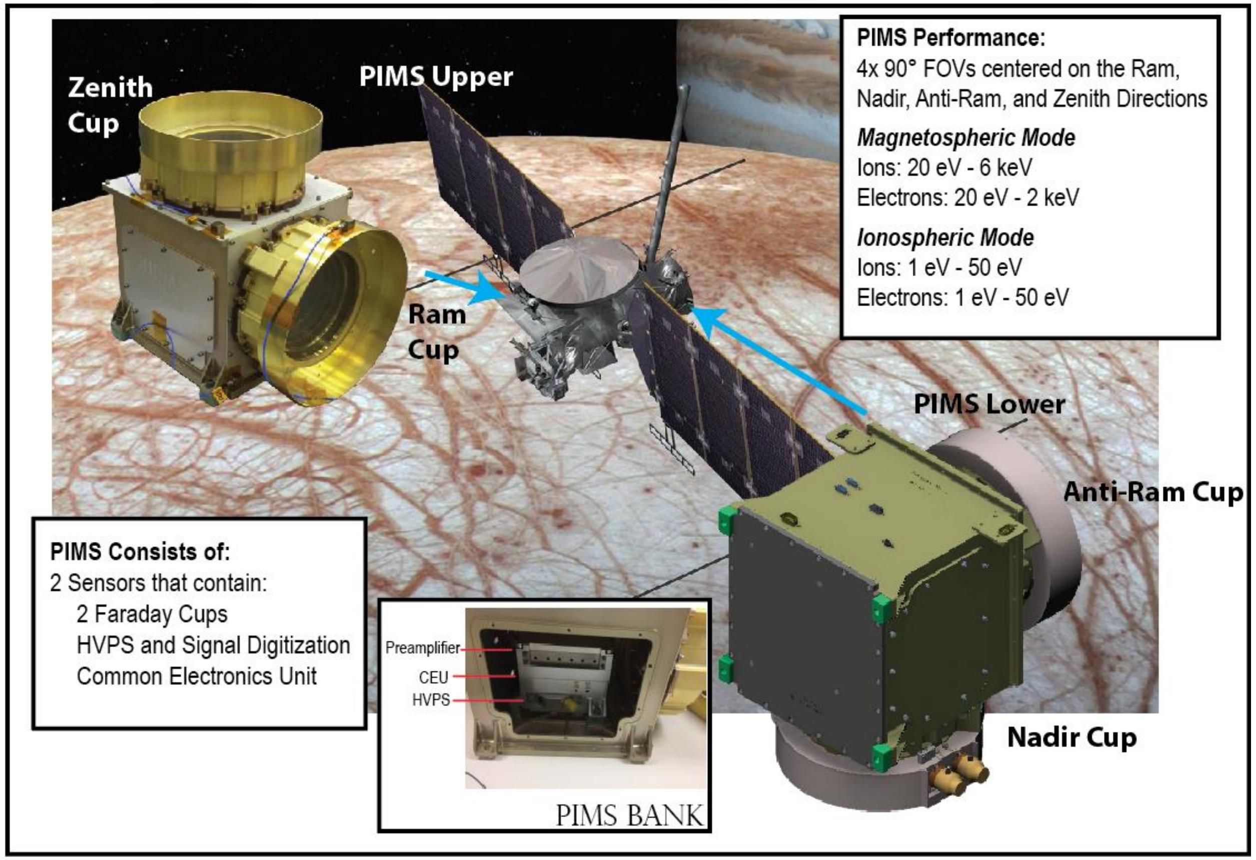
PIMS Operation and Specifications

- Voltage applied to grid, e.g. +500 eV
- All positive particles with energies less than 500 eV are rejected by the HV grid and repelled.
- Equivalently for the negative end.
- Energy range at least +6keV to -2keV
- 7.2 cm^2 Effective Area:
- 8cm OD Limiting Aperture
- 3 Collectors
- 8x 90% Transparent Grids
- Energy Resolution: 15%

Plasma Investigation	PIMS: Key Instrument Parameters	
	Ion Energy Range	0.1 – 50 eV/q, 0.02 – 7 keV/q
	Electron Energy range	0.1 – 50 eV, 0.01 – 2 keV
	Energy Resolution	<15%
	Sensitivity	0.5 – 10^5 pA/cm^2
	Time Resolution	1 – 4 s



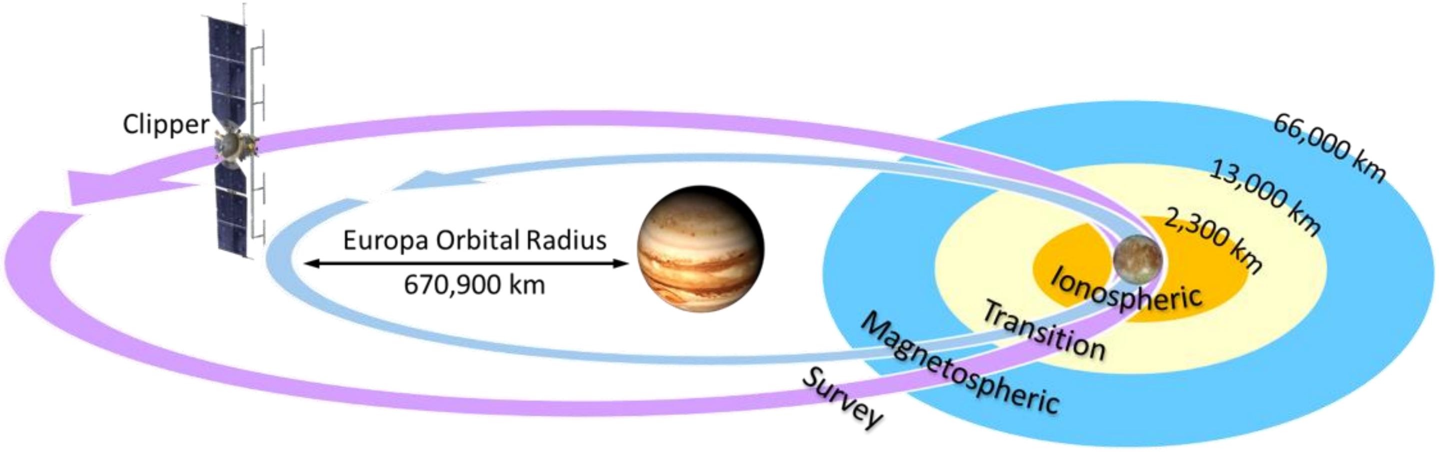




Operational Modes

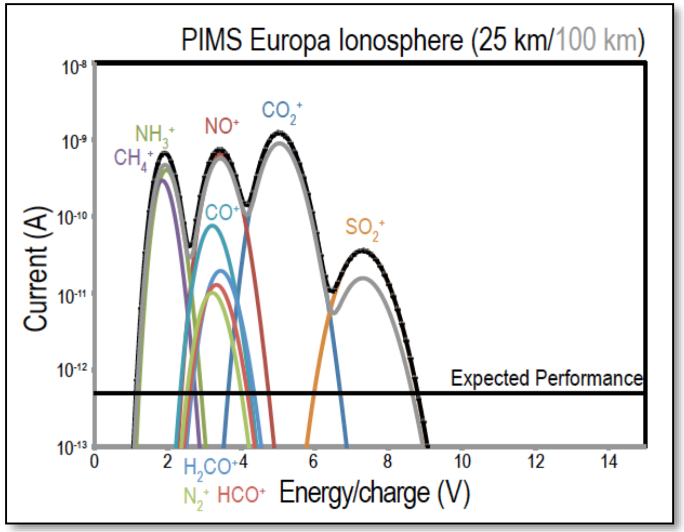
The ion and electron plasma populations around Europa vary significantly as a function distance from the Jovian satellite, the PIMS instrument will be operated in various modes as depicted in the figure below.

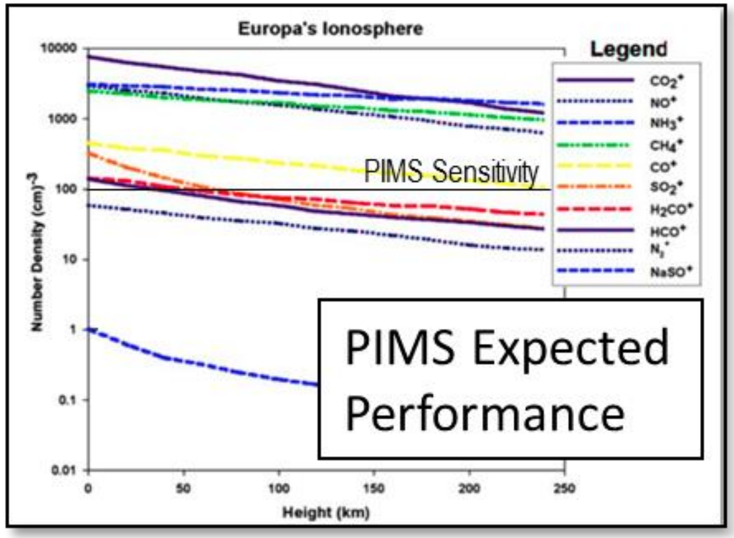
Magnetospheric mode - 13,000 to 66,000km: used to measure the flow velocity and mass density of the Jovian magnetospheric plasma.
Ionospheric mode - < 2,300: is used to measure the various plasma populations within Europa's ionosphere which is required to correct the magnetic induction response used to characterize Europa's ocean parameters.
Transition mode - 2,300 to 13,000 km: interleaves magnetospheric and ionospheric modes for the region between Europa's ionosphere and the Jovian magnetosphere to capture pickup ions and magnetospheric features
Survey mode - > 66,000km: used throughout the rest of the mission to capture the magnetospheric plasma outside the magnetospheric, ionospheric, and transition mode regions. Deconvolving the Europa sourced plasma contributions from magnetospheric dynamics and global magnetospheric structure requires observations of the distant (from Europa) Jovian magnetosphere.



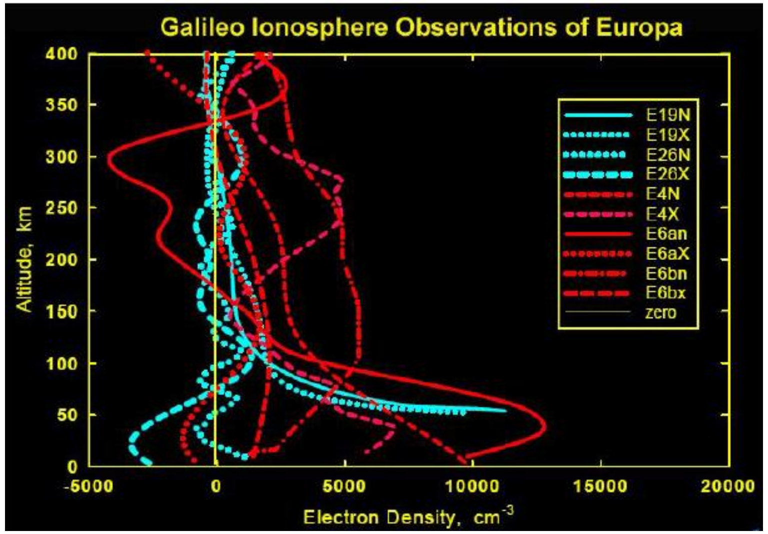
Ionospheric Composition and Structure

- PIMS will be the first direct measurement of the ion content of Europa's atmosphere
- Using the high-speed Europa Clipper flybys PIMS will measure the cold Europa ionosphere
- PIMS measurements consist of measuring the energy per charge content of the ions and electrons in the ionosphere





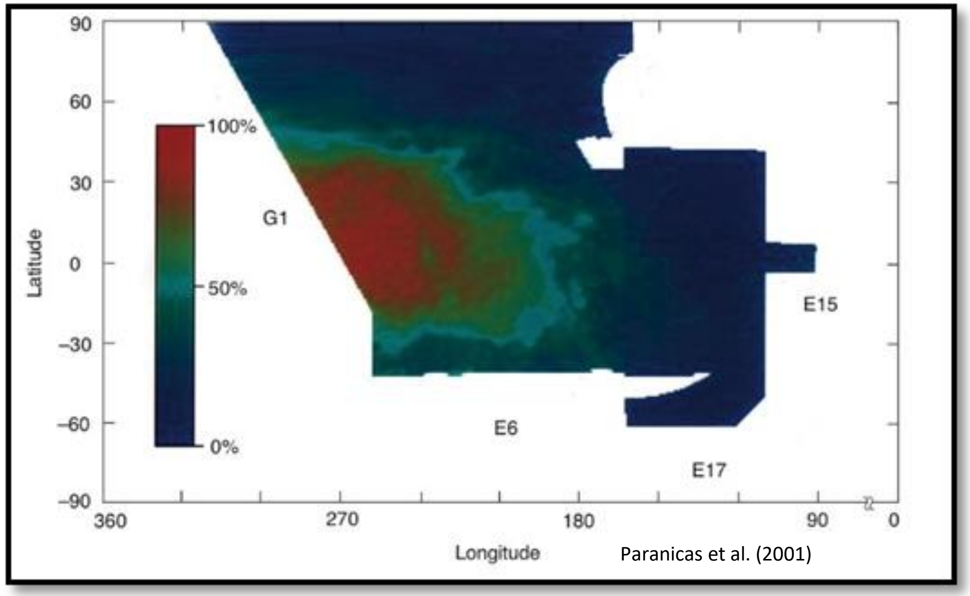
Johnson et al. (1998)



McGrath & Sparks (in press); Kliore et al. (1997)

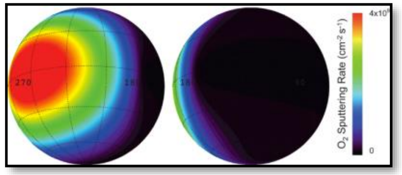
Surface Weathering & Sputtering

PIMS measures the thermal plasma flux that is primarily responsible for the weathering of Europa's surface and the production of the O_2 atmosphere

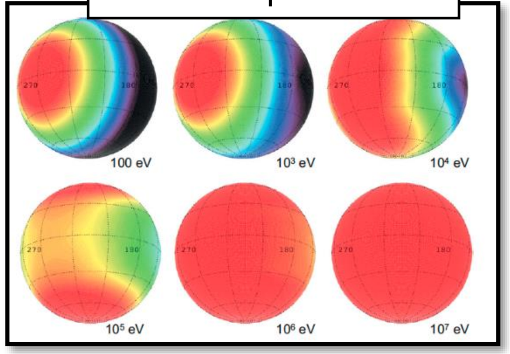


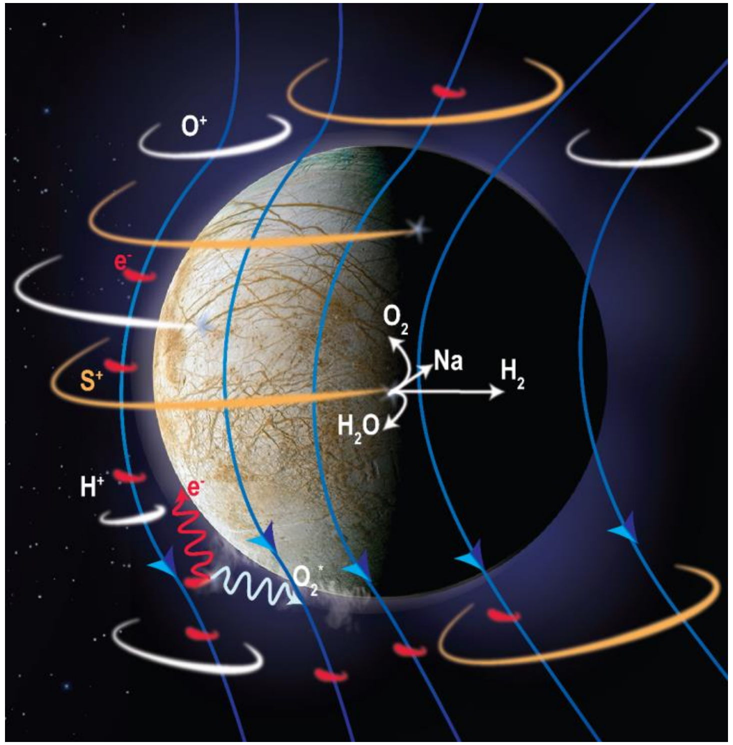
Hydrated SO_2 frost on Europa's surface obtained from Galileo NIMS data (e.g. Carlson et al. 2005). This type of bull's-eye or lens pattern has been correlated with higher charged particle fluxes at both the Jovian and Saturnian satellites.

O_2 Sputtering Rate



Modeled S^+ Flux Onto Europa Surface

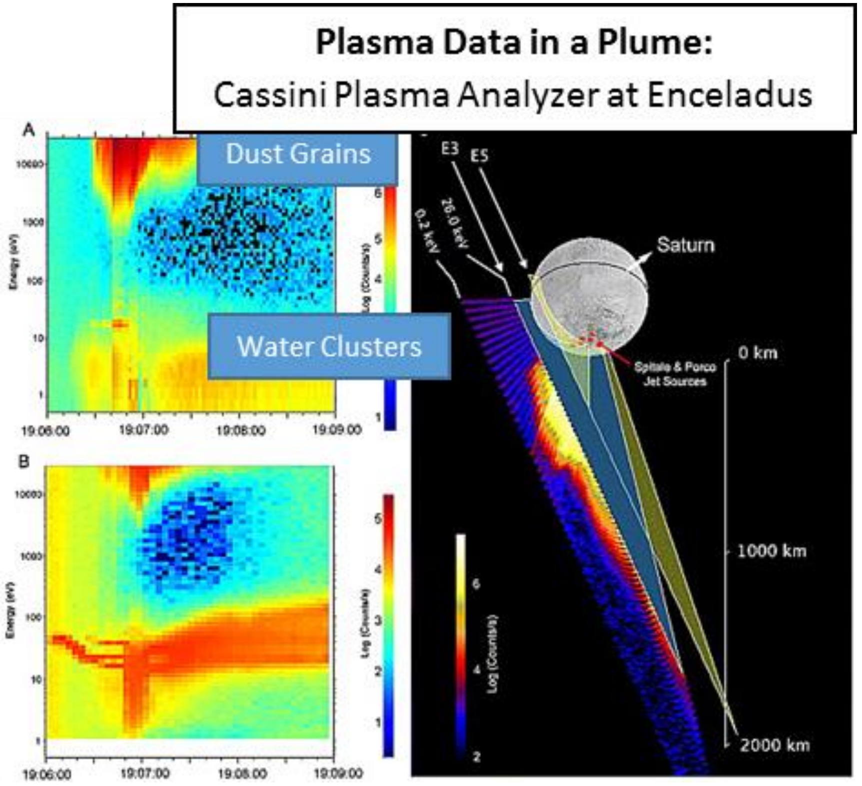




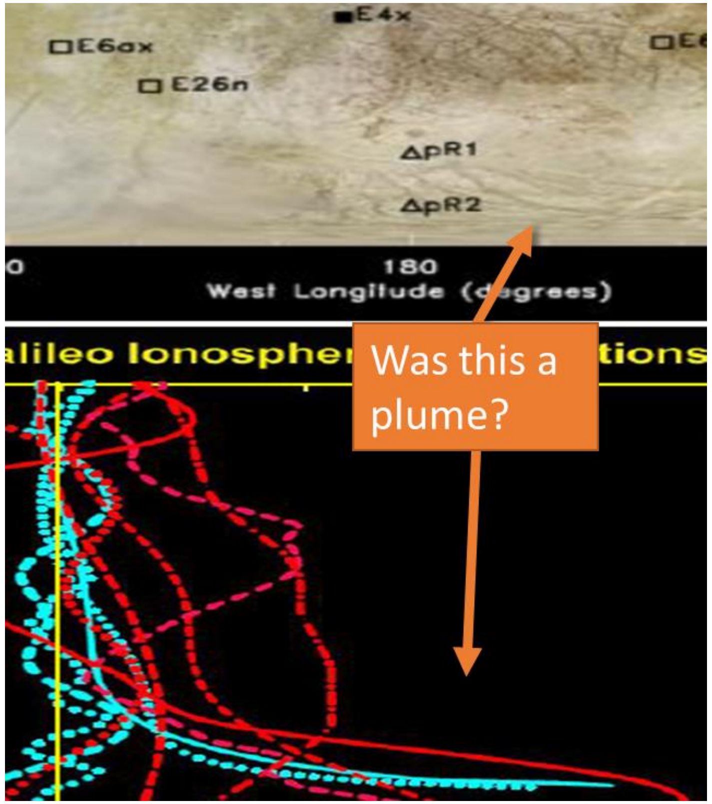
Plumes

- PIMS will measure the ionized component of any plume that we directly fly through

- PIMS will also measure any increased ion content in the vicinity of Europa and within Europa's ionosphere to search for increased activity even if Clipper doesn't directly fly through a plumen



Jones et al. (2009)



McGrath & Sparks (2017); Kliore et al. (1997)

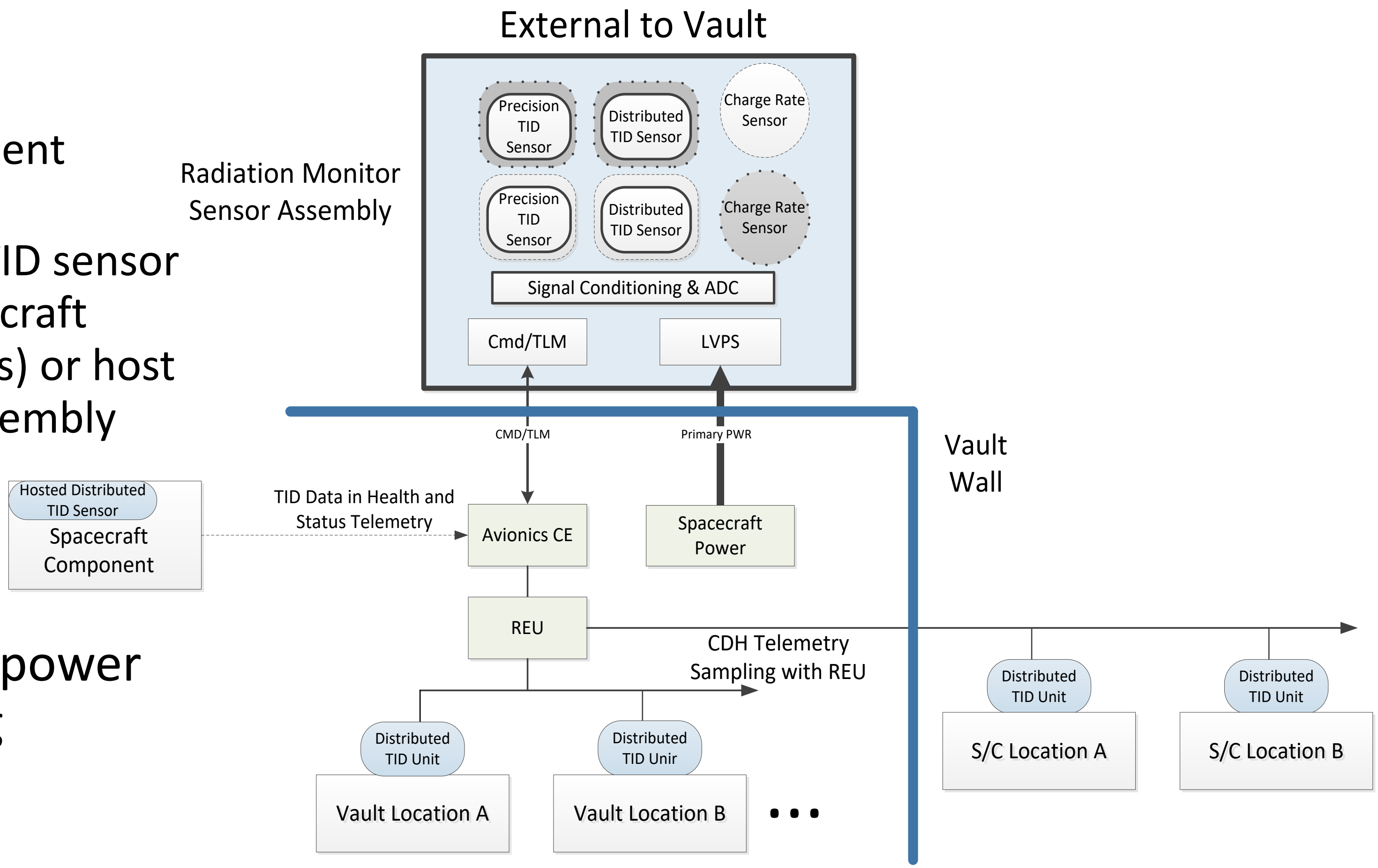
Radiation Monitor

- The Radiation Monitor is primarily a spacecraft resource
  - Measure radiation effects that can result in degradation or incorrect operation of electronic components
  - Support anomaly investigations
  - Aid in mission planning (with radiation dose viewed as a consumable); help justify extended missions
- Requirements focused on measuring effects that are particularly stressing conditions in the Europa environment
  - Total Ionizing Dose (TID) – directly measured
  - Internal Electrostatic Discharge (IESD) – measure electron charging rate as an IESD event predictor
  - Low rate telemetry, ground-only analysis (e.g., not used for spacecraft autonomy)
- Secondary objectives can include other considerations, where feasible
  - Extended energy range ("hot plasma" and high-energy electrons)
  - Orbit profiling (local shadowing effects)
  - Mapping radiation environment (inform landing site selection?)
  - Model validation – assist future mission designs to Jupiter and Europa

Radiation Monitor Implementation Overview

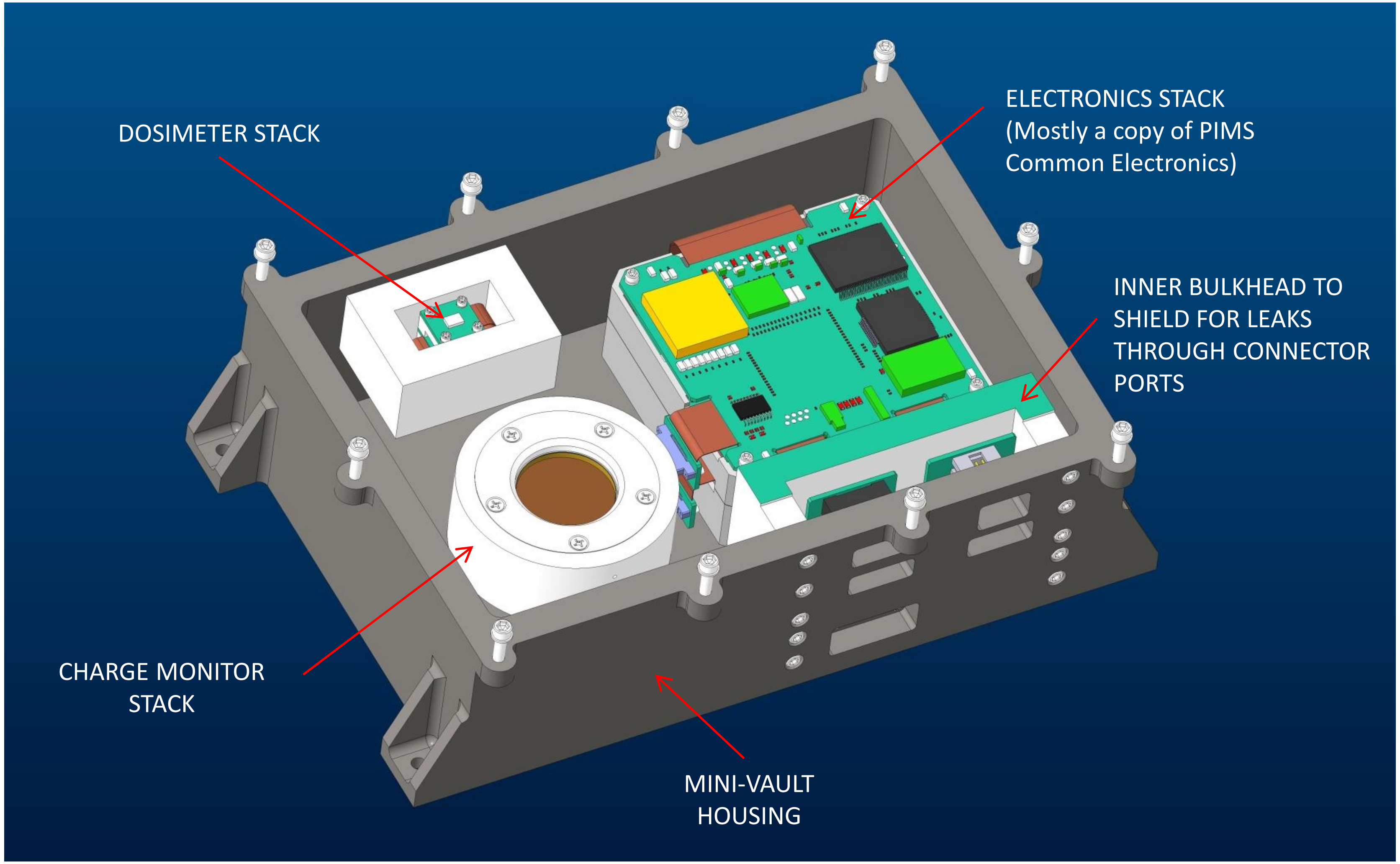
- The Radiation Monitor consists of two components
  - Sensor Assembly
    - External to vault
    - Measures both TID and charging
    - Connectivity to Avionics Compute Element
  - Distributed TID Monitors
    - Small, simple assemblies containing a TID sensor
    - Placed at various locations in the spacecraft
    - Read out via the REU (for separate units) or host
    - No connectivity to the main Sensor Assembly

- RadMon not mission-critical
  - Single-string sensor assembly
  - Redundant connections to C&DH and power
  - Redundant distributed TID monitoring



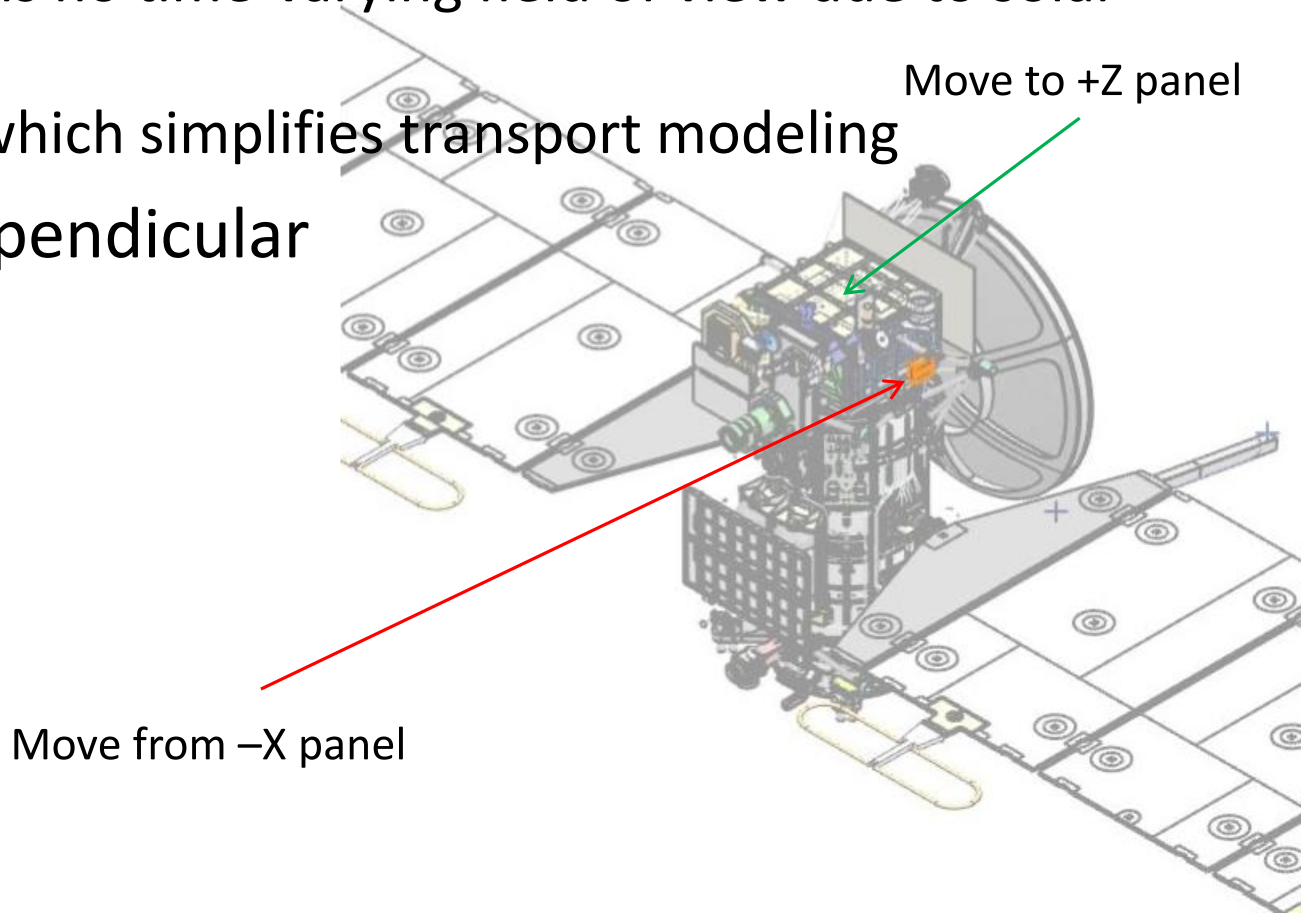
RadMon External Assembly

- Cover removed for clarity
- Apertures in cover over dosimeter and charge monitor stacks along with side shielding define FOV
- Updated mechanical configuration has stacks attached directly to top cover (lower mass and wider FOV)
- FOV ~ π sr (TBD)
- 8 kg mass allocation
- 5 W power allocation

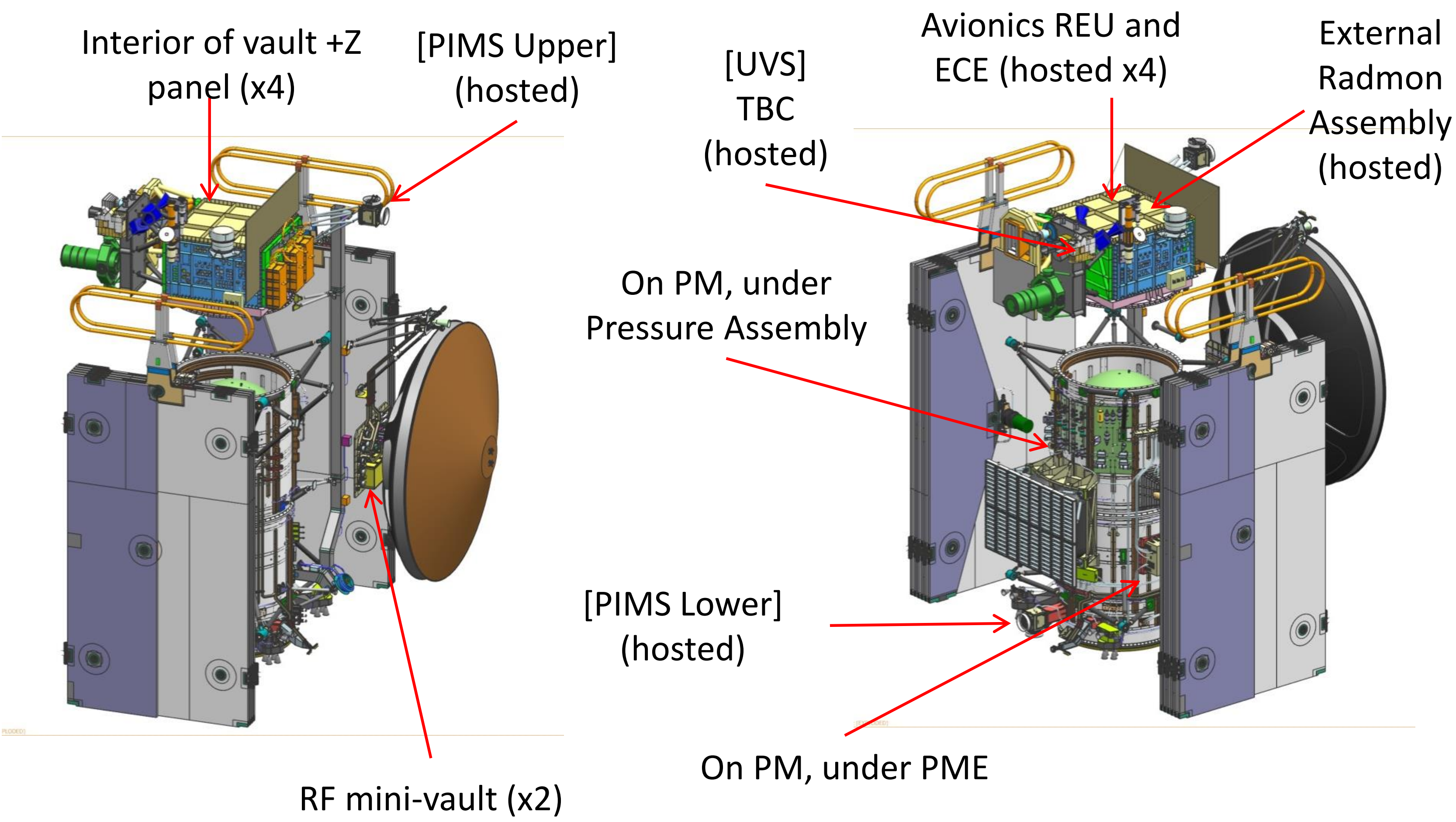


RadMon Location on S/C

- The Sensor Assembly is mounted on the exterior of the vault
  - Moving to +Z panel ensures that there is no time-varying field of view due to solar panel movement
  - +Z panel is less “crowded” in general, which simplifies transport modeling
- FOV could be along field lines or perpendicular
  - Different for different flybys?
  - No one is currently working this aspect
  - Could use help in this area

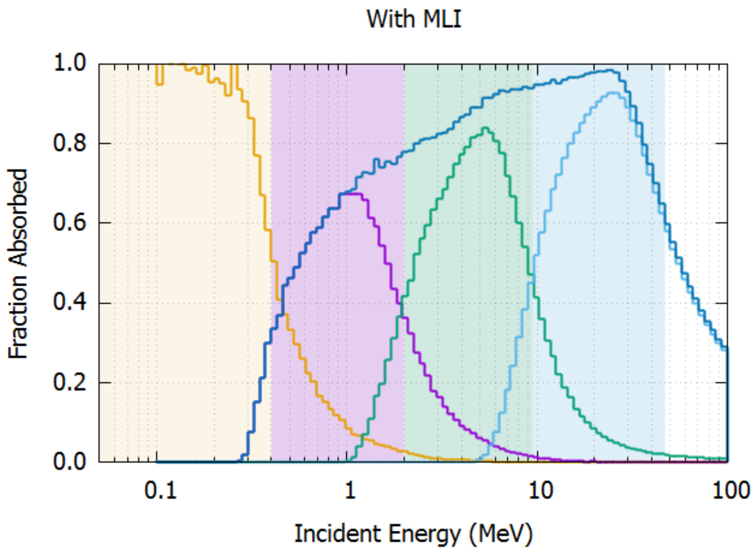


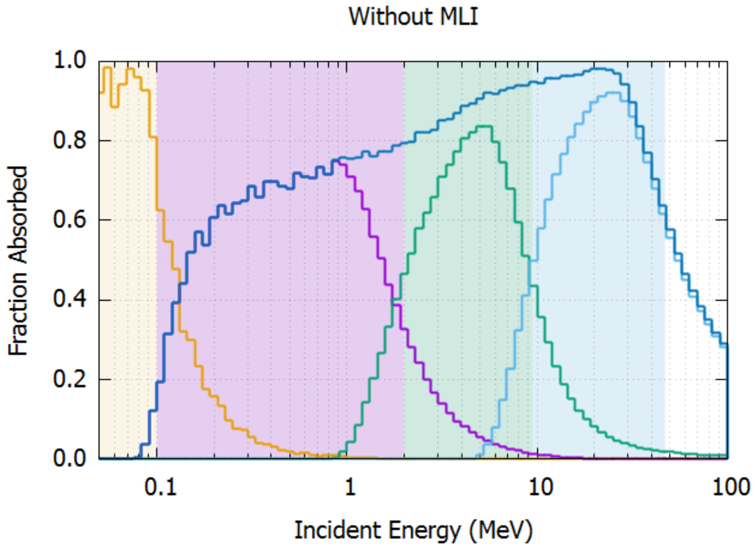
Distributed TID Monitor Locations



Sensitivity

- Plates sized for quasi-log energy spacing
- Thin, aluminized Kapton cover extends low-energy threshold of front plate
  - “Hot plasma” region not well characterized
  - ~100 keV if no MLI around aperture
  - No threshold uncertainty due to MLI
  - Potential accommodation issue
- With MLI blanketing
  - “Simpler”
  - Energy threshold increases to ~400 keV
  - Uncertainty in threshold due to MLI
- Front plate may saturate under “storm” conditions (w/o MLI)
- Plates 1 and 2 are unaffected





This material was presented by John Goldsten and Zach Yokley at the first Radiation Focus Group meeting on January 30th, 2018