INVESTIGATING EUROPA'S PLASMA ENVIRONMENT FROM RADAR SOUNDING

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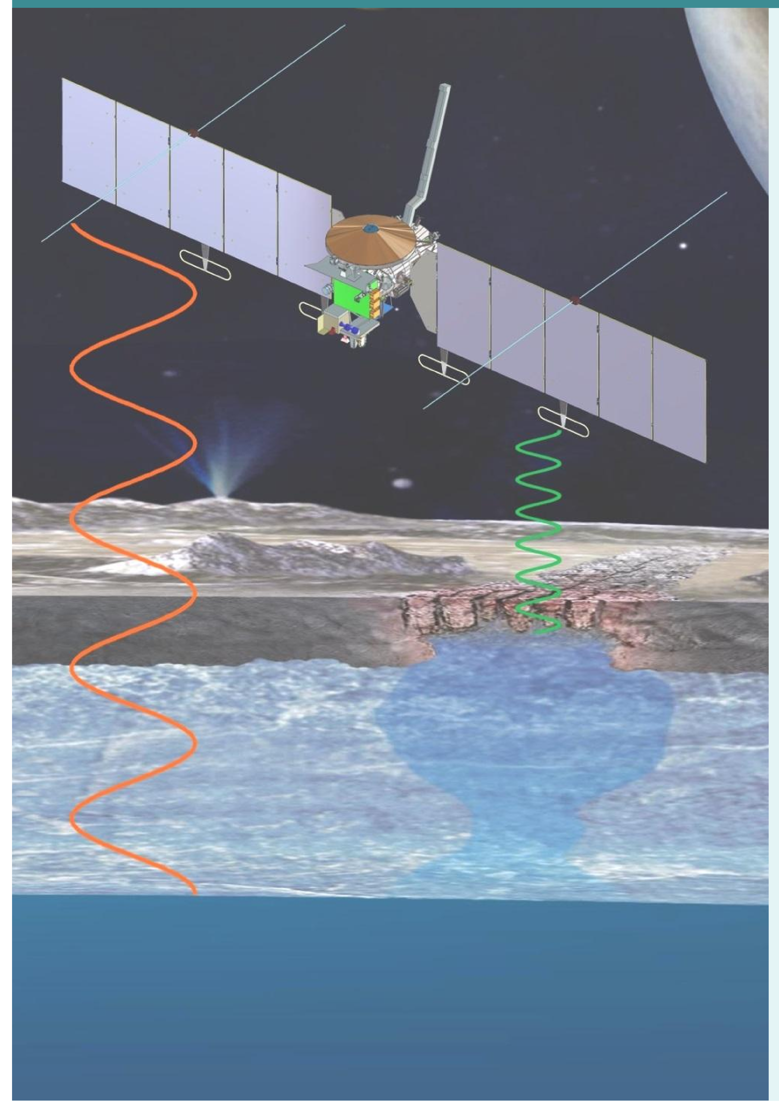
REASON



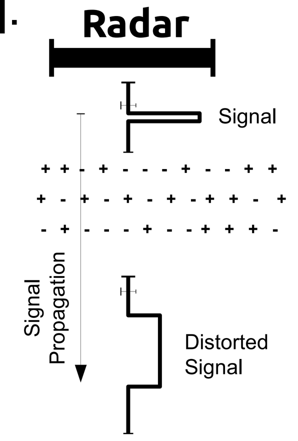
The Radar for Europa Assessment and Sounding: Ocean to Near-surface (**REASON**) has been selected for the scientific payload of the NASA's **Europa Clipper** to explore the ice-covered ocean moon through a series of 40-45 flybys from Jovian orbit. **REASON** is an active **dual-frequency** (9 and 60 MHz, with 1 MHz and 10 MHz bandwidth resp.) instrument led by the University of Texas Institute for Geophysics (UTIG). **REASON** is designed to search for subsurface water and investigate the ice shell structure (**SOUNDING**), measure the surface elevation and tides (**ALTIMETRY**), and characterize the surface physical properties (**REFLECTOMETRY**), and the ionospheric environment (**PLASMA**).

Here we present the concept, targets, and capabilities behind the PLASMA measurements.

PLASMA MEASUREMENT

PRINCIPLE

REASON will measure the plasma below the spacecraft utilizing the distortion effect: A plasma as a highly **dispersive index** for radar waves. When a multi-chromatic (bandwidth) signal propagates through a plasma, it is **delayed**, and **enlarged** **[1]**.

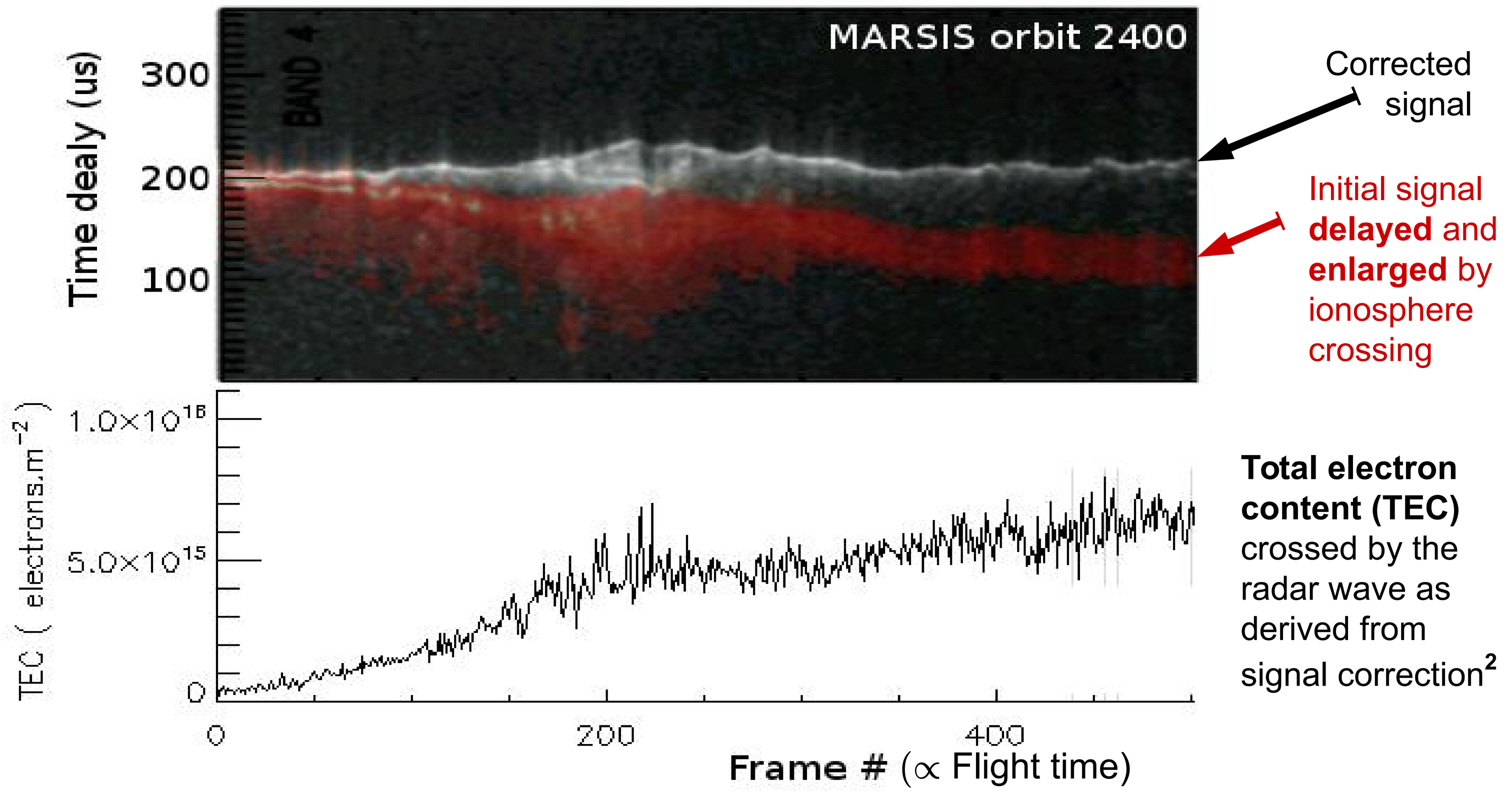


This distortion can be corrected through techniques inherited from MARSIS and SHARAD **[2,3]**. The by-product is the **total electron content (TEC)**, i.e., the integrated number of electrons along the propagation path.

The primary method employed by REASON is to correct the **9-Mhz surface echo distortion** by using the 60-MHz signal as a reference. Indeed, the Europan ionosphere is not dense enough to delay 60 MHz waves by more than REASON's time resolution.

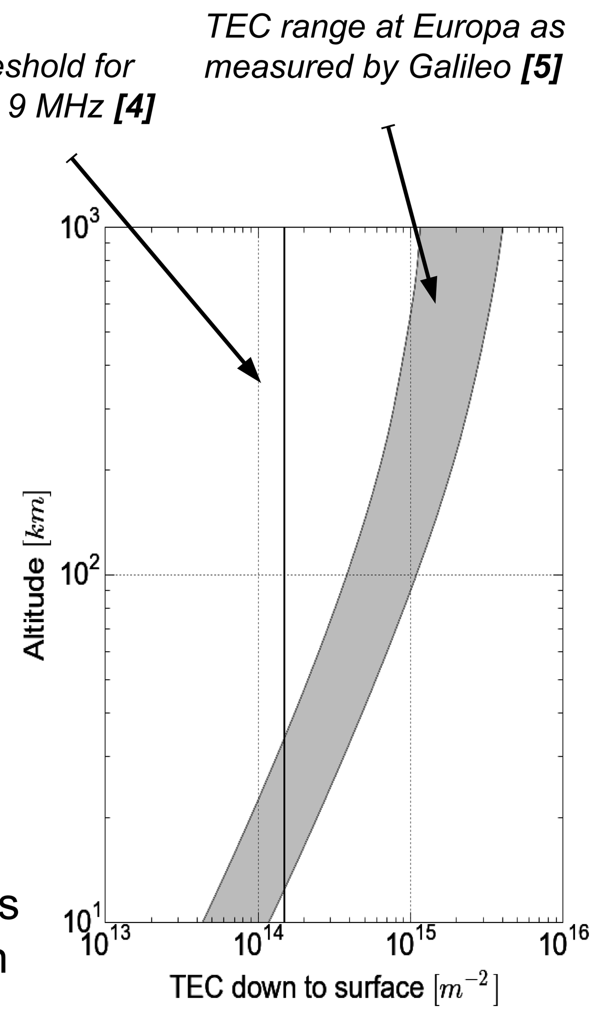
EXAMPLE

MARSIS (ASI) is a 1.8-5 MHz central-frequencies, 1-MHz bandwidth, sounder operating around Mars since 2005 onboard the Mars Express (ESA) orbiter. Below is a **radargram** over the Martian south polar cap **before and after correction** of the ionosphere distortion. Here, MARSIS uses MOLA's elevations as a reference to estimate the travel time of a non-distorted signal.

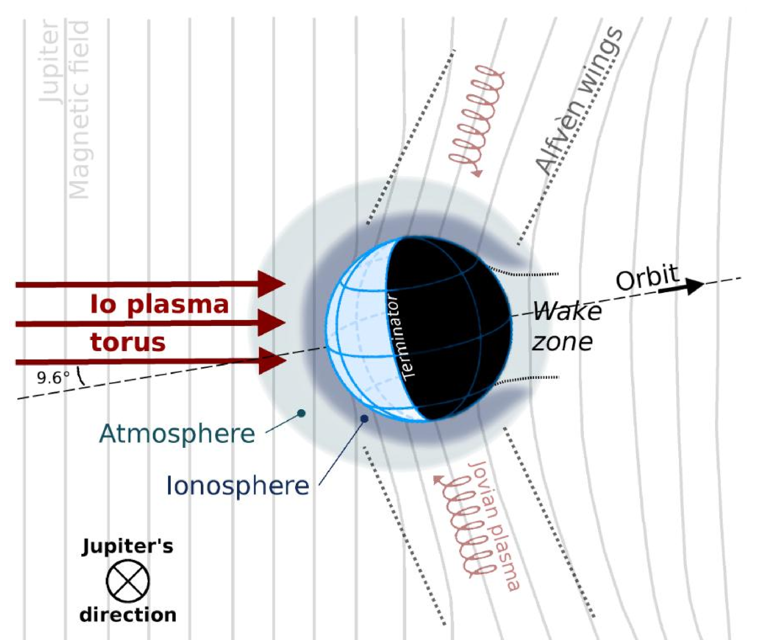


PERFORMANCE

- The **vertical time resolution** of the 9 MHz channel after pulse compression is **5 x10^{-7} s**.
- The **TEC detection threshold** is the TEC needed to delay the signal by the time resolution and equals **1.5 x10^{14} m^{-2}** **[4]**.
- Based on Galileo measurements, that TEC is reached **above ~ 30 km** in altitude **[5]**.



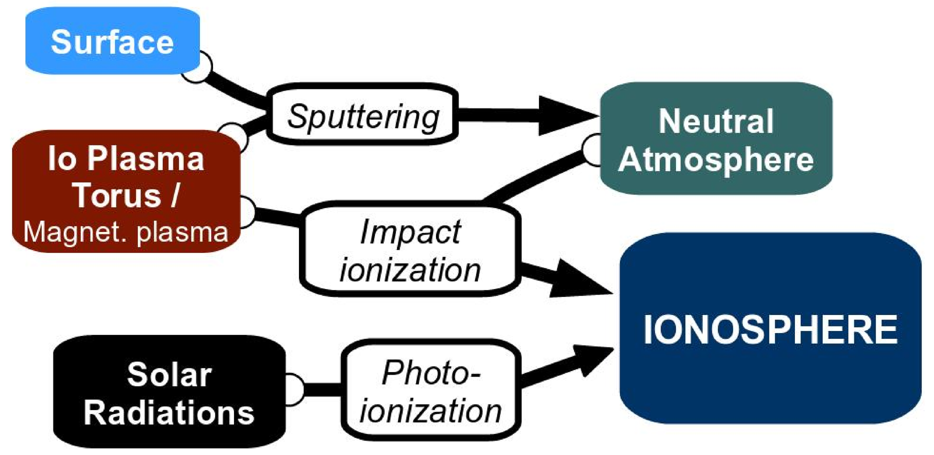
EUROPA'S IONOSPHERE

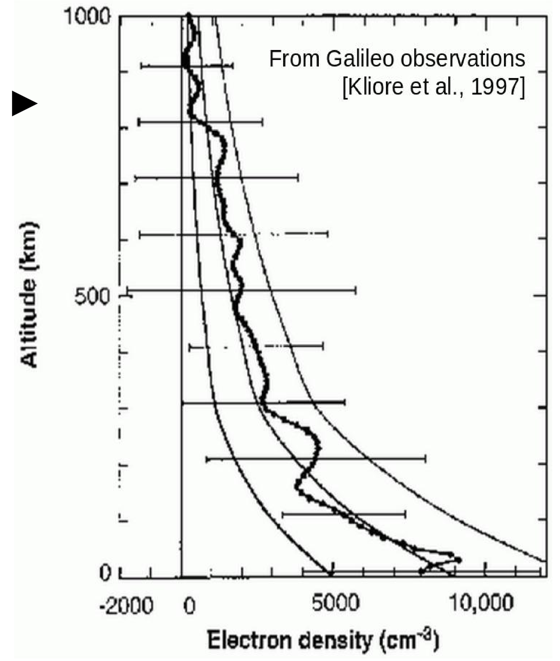


◄ *Schematic geometry of the space environment of Europa* **[4]**

Range of ionosphere profiles measured by Galileo **[5]** ►

▼ *Primary ionosphere-production processes at Europa.*





The ionosphere of Europa is produced in two independently rotating hemispheres by **photo-ionization** of the neutral exosphere on the day-side and **impact** with the Io plasma torus on the trailing side. This combination contributes to **poorly-known temporal and longitudinal disparities** of the ionosphere that vary with Europa's orbital position. The few radio occultation observations from the Galileo Spacecraft describe a **surface-bounded ionosphere** with density decreasing with altitude **[5]**. The maximum observed **plasma frequency can reach 1 MHz** near the surface, preventing any signal below this frequency from penetrating the ice crust. Galileo measurements reported a **TEC that could reach 4x10^{15} m^{-2}** **[5, 6]**, lower but similar in magnitude to the Martian day-side values. Europa's space environment is also embedded in the nearly uniform Jovian magnetic field of ~ 420 nT while the Martian plasma is virtually free of external magnetic sources except above crustal magnetic anomalies **[7]**.

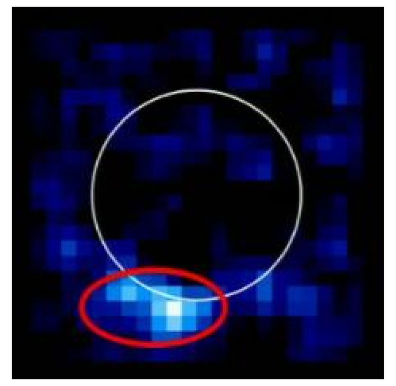
⏩ REASON will investigate the ionosphere temporal and longitudinal variations throughout the mission.

PLUME-INDUCED IONOSPHERE

Recent observations with the Hubble Space Telescope (HST) reported transient ultraviolet emissions from Europa's exosphere consistent with 200-km high and 270-km wide **plume(s) of water vapor** venting upward materials from the sub-surface **[8]**.

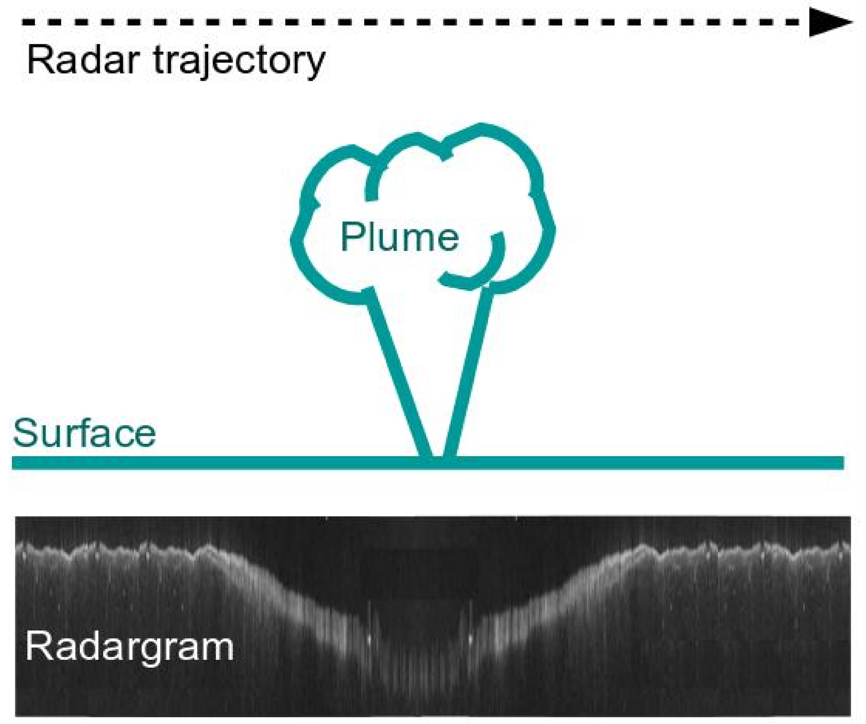
Plume activity adds neutrals in the exosphere that can in turn be ionized by the incident Jovian magnetospheric flow, creating a plume-induced ionosphere **increasing the local TEC**, as shown at Enceladus with the Cassini Spacecraft **[9, 10]**. We expect the resulting plasma cloud to be further reshaped by the incident magnetospheric flow with a combination of plasma pick-ups and accelerations. The **plume ionization timescale and efficiency is not known** but would be a proxy of the global space environment.

REASON will acquire observations from 1000 km above the surface and down to closest approach (25 km). Depending on the added plasma density into the local ionosphere column, REASON might detect and constrain the plume-induced plasma cloud characteristics when flying over it from the distortion induced on the surface echo.



◄ *Localized detection of hydrogen by the HST on December 2012* **[8]**.

▼ *Schematic view illustrating the effect of a plume-induced ionosphere on a radio signal. The expected radargram is a montage from MARSIS observations. The amplitude of the distortion might be different at Europa.*

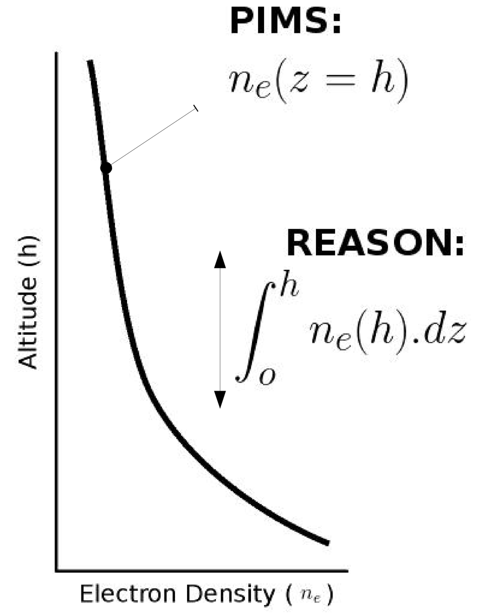


⏩ REASON will search for plume-induced ionosphere and characterize its extent and density.

REASON/PIMS SYNERGIES

The Plasma Instrument for Magnetic Sounding (**PIMS**) is part of the Europa Clipper payload **[11]**. PIMS is a Faraday Cup based plasma instrument who will measure the plasma, including electron density, at the S/C location, while REASON will provide the TEC below the S/C.

Both measurements together are complementary and provide a powerful way to discriminate between the various models for the ionospheric profile and to better understand the complex phenomenon responsible for the production and dynamic of Europa's ionosphere.



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