INVESTIGATING EUROPA'S PLASMA ENVIRONMENT FROM RADAR SOUNDING. **Cyril Grima**[1], Don Blankenship[1], Carol Paty[2], Young Gim[3], William Kurth[4], Elaine Chapin[3], Dustin M Schroeder[5], Jeffrey J Plaut[3], Gerald Patterson[6], Alina Moussessian[3], Duncan Young[1], [1]University of Texas at Austin, Austin, TX, United States, [2]School of Earth & Atmospheric Sciences, Georgia Institute of Technology, Atlanta, GA, [3]NASA Jet Propulsion Laboratory, Pasadena, CA, United States, [4]Dpt of Physics and Astronomy, University of Iowa, Iowa City, IA, [5]Department of Geophysics, Stanford University, Stanford, CA, USA, [6]Applied Physics Laboratory Johns Hopkins, Laurel, MD, United States,

Introduction: The Europa Clipper is a recently approved NASA project to study this ice-covered moon of Jupiter, through a series of 40-45 fly-by observations from a spacecraft in Jovian orbit. The science goal is to "explore Europa to investigate its habitability". The Radar for Europa Assessment and Sounding: Ocean to Near-surface (REASON) is one of the primary instruments of the scientific payload. REASON is an active dual-frequency (9 and 60 MHz) instrument led by the University of Texas Institute for Geophysics (UTIG) [1, 2]. It is designed to achieve multi-disciplinary measurements to investigate subsurface waters and the ice shell structure (Sounding), the surface elevation and tides (Altimetry), the surface physical properties (Reflectometry), and the ionospheric environment (Plasma/Particles).

The Plasma measurement relies on the dispersive signal delays induced by the ionospheric content integrated along the radio propagation path at 9 MHz. Correction of this delay with existing techniques inherited from the Mars Advanced Radar for subsurface and Ionosphere Sounding (MARSIS) [3], provides the total electron content below the spacecraft [4]. Plasma measurements will constrain the ionosphere's shape and variability along the acquisition track and might detect transient plume-induced ionosphere when active.

Europa's Ionosphere: 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 (Fig.1). 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 total electron content (TEC) that could reach 4×10^{15} m^{-2} [5, 6], lower but similar in magnitude to the Martian day-side values, with typical plasma frequencies and TEC of 1×10^{16} m^{-2}, respectively [7]. 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 [8].

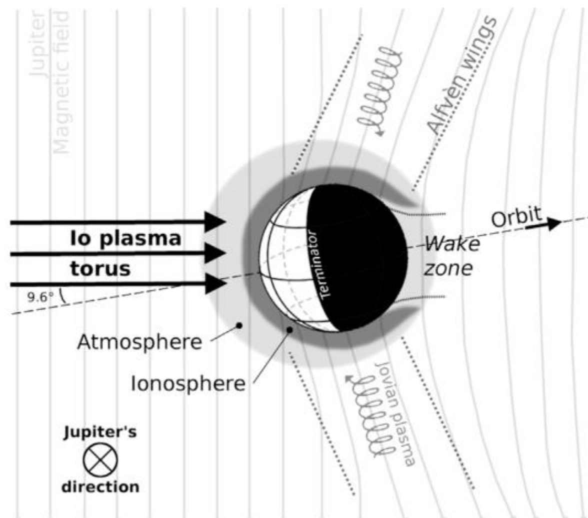

Fig.1: Schematic view of the geometry and main contributors to the space environment of Europa [4].

Plasma Measurements: The main impacts of the ionosphere to radio signals are dispersive phase shifts and Faraday rotation. REASON would be affected mainly on its 9 MHz channel while the 60 MHz should be safe from any ionospheric distortions [4]. Faraday rotation of the signal polarization plan will appear as a signal fading, but it is not expected to be a major effect for most of the Galileo-measured ionospheric profiles.

Dispersive phase shift. The phase velocity of radar waves is affected by the plasma refractive index that is directly dependent on the plasma density and the electromagnetic wave frequency. The effect on a polychromatic signal such as the chirp transmitted by REASON, is a distortion of the information content, including a general delay of the received echoes along with a signal widening that can be assimilated to a degradation of the radar range resolution [4] (Fig.2).

TEC inversion. The ionosphere signal distortion from dispersive phase shift can be corrected from existing techniques inherited from MARSIS [12]. The by-product of this correction is an estimation of the TEC within the vertical column below the S/C [3, 7].

So far, the most used and robust technique to correct the signal is to match the broadened echo with the arrival time expected from a free-of-charge environment. For MARSIS, this reference is the Mars Orbiter Laser Altimeter. REASON will not rely on a third-party instrument for plasma correction since we will use the concurrent measurement of the quasi-undisturbed 60 Mhz signal. The resolution for the TEC measurements is function of the bandwidth for the 9 MHz channel, i.e., $3 \times 10^{14}\, m^2$ with the currently considered 1-MHz bandwidth.

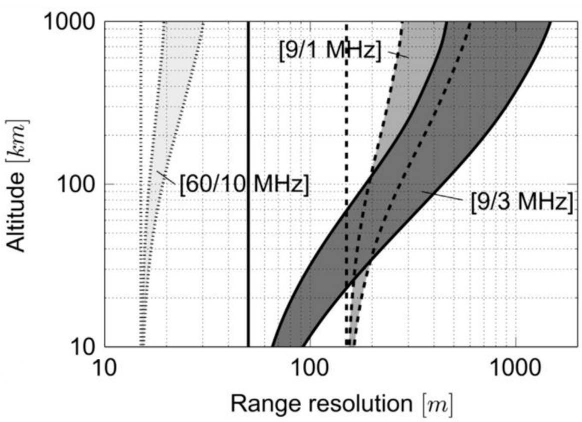

Fig.2: Altered range resolution as a function of the altitude for various radar system configurations ([central frequency/bandwidth]). The bounded gray areas account for the spectra of TECs measured by Galileo [5]. Vertical lines are the initial range resolution without distortion for each radar configuration (respectively 15 m, 50 m, and 150 m).

Plume-induced ionosphere: Recent observations with the Hubble Space Telescope (HST) reported transient ultraviolet emissions from Europa's exosphere consistent with 200-km high plumes of water vapor venting upward materials from the sub-surface [9]. Plume activity adds neutrals in the exosphere that can in turn be ionized by the incident Jovian magnetospheric flow, creating a plume-induced ionosphere as shown at Enceladus with the Cassini Spacecraft [10, 11], increasing the local TEC. 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 characteristic when flying over it from the distortion induced on the surface echo (Fig.3).

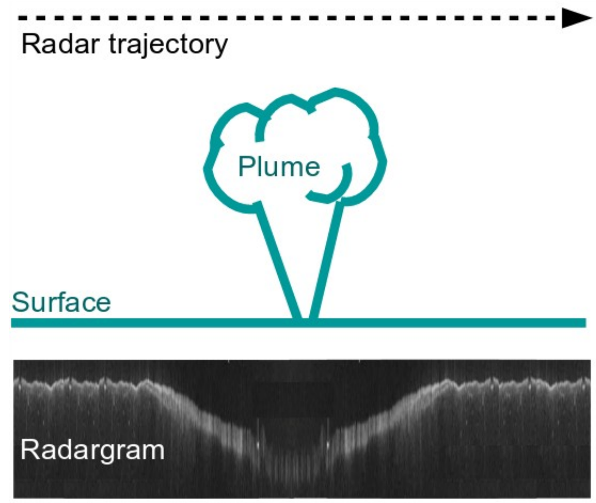

Fig.3: Schematic view illustrating the effect of a plume-induced plasma cloud to the 9 Mhz radar signal. While the surface is flat along the S/C trajectory, the surface echo appears locally delayed and enlarged as the plasma density increases. The radargram is a montage from MARSIS observations. The amplitude of the distortion might be different at Europa.

REASON/PIMS Synergies: The Plasma Instrument for Magnetic Sounding (PIMS) is part of the Europa Clipper payload [13]. 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 constrain the various models for the ionospheric vertical profile and to better understand the complex phenomenon responsible for the production and dynamic of Europa's ionosphere.

References: [1] Blankenship et al. (1999) *JPL*, Tech. Report. [2] Moussessian et al. (1995) *AGU* 2015, P13E-05. [3] Mouginot et al. (2008) *PSS* 56, 917-26. [4] Grima et al. (2015) *PSS* 117, 421-28. [5] Kliore et al. (1997) *Science* 277, 355-58, [6] McGrath et al. (2009) in *Europa*, Univ. of Ariz. Press. [7] Safaeinili et al. (2003) *PSS* 51, 505-515. [8] Acuna et al. (1999) *Science* 284, 790. [9] Roth et al. (2014) *Science* 343, 171-174. [10] Cravens (2009) *GRL* 36, L08106. [11] Tokar et al. (2009) *GRL* 36, L13203. [12] Sánchez-Cano et al. (2015) JGR 120(3), 2166-82. [13] Westlake (2016) AAS DPS #48, id.123.27.