Morphology of the IPT inferred from dual link calibration during Juno mission

Alessandro Moirano[1*], Marco Zannoni[1], Luis Gomez Casajus[1], Paolo Tortora[1], Paul Whiters[2], Phillip H. Phipps[2], Dustin Buccino[3], Kamal Oudhriri[3]

1. The Juno mission

Juno is currently orbiting Jupiter following a low altitude and highly eccentric orbit, with a period of 53.5 days. During each Jupiter encounter, Doppler measurements between Juno and the Earth are acquired for about eight hours centered around Jupiter's closest approach. Due to the orbital geometry, the radio signal crosses the Io Plasma Torus (IPT), a toroidal cloud of plasma centered on the centrifugal equator of Jupiter at Io's orbital distance. The torus induces a path delay and a carrier frequency shift on radio frequency signals, yielding a non-dynamical Doppler shift, which in turn can be fitted with a density model [1] to infer the morphology of the IPT.

2. Radio signal through the IPT

The Juno gravity science instrument comprehends a Ka-band Translator System (KaTS), which provides a coherent two-way Ka/Ka link (34-32 GHz). In addition, Juno spacecraft telecommunications subsystem supports a standard two-way X/X (7.2-8.4 GHz) link. This equipment allows for the identification of the dispersive contribution to the path delay due to the plasma of the interplanetary medium (IPM) and the IPT [2]. Thanks to the relation between path delay and Total Electron Content (TEC), it is possible to exploit the many occultations Juno is performing to study azimuthal and temporal variability of the torus.

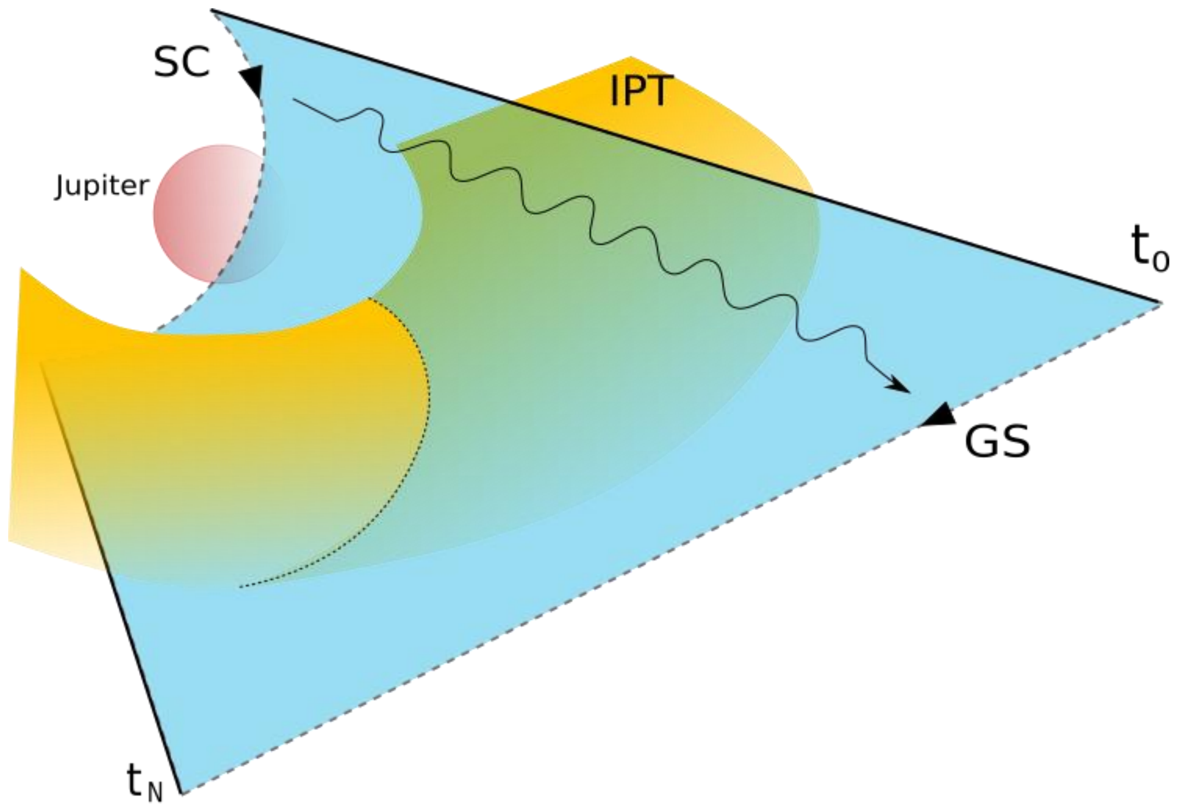


Figure 1: Schematic representation of the an occultation performed by Juno seen in an IPT-fixed frame (i.e: corotating with Jupiter, but around the centrifugal axis).

In order to determine the morphology of the IPT, we adopted the parametric density model given by:

$$n_e(r,z) = \sum_{i=1}^{2} N_i \, exp\left[-\left(\frac{r-R_i}{W_i^2}\right)^2 - \left(\frac{z-Z_i}{H_i^2}\right)^2\right]$$

Where N is the peak density, R and W the radial position and extension respectively, Z the offset from the centrifugal equator and H is the scale height.

3. Corrections

Exploiting the slight tilt of the radio signal with respect to the centrifugal equator and the multiple occultations make possible to constrain the radial position and extension of the IPT. Besides, as seen in a corotational frame, the radio signal between the ground station (G/S) and Juno has crossed the IPT in many different longitudinal sectors during the gravity passages: this allow us to inspect the longitudinal structure of the IPT.

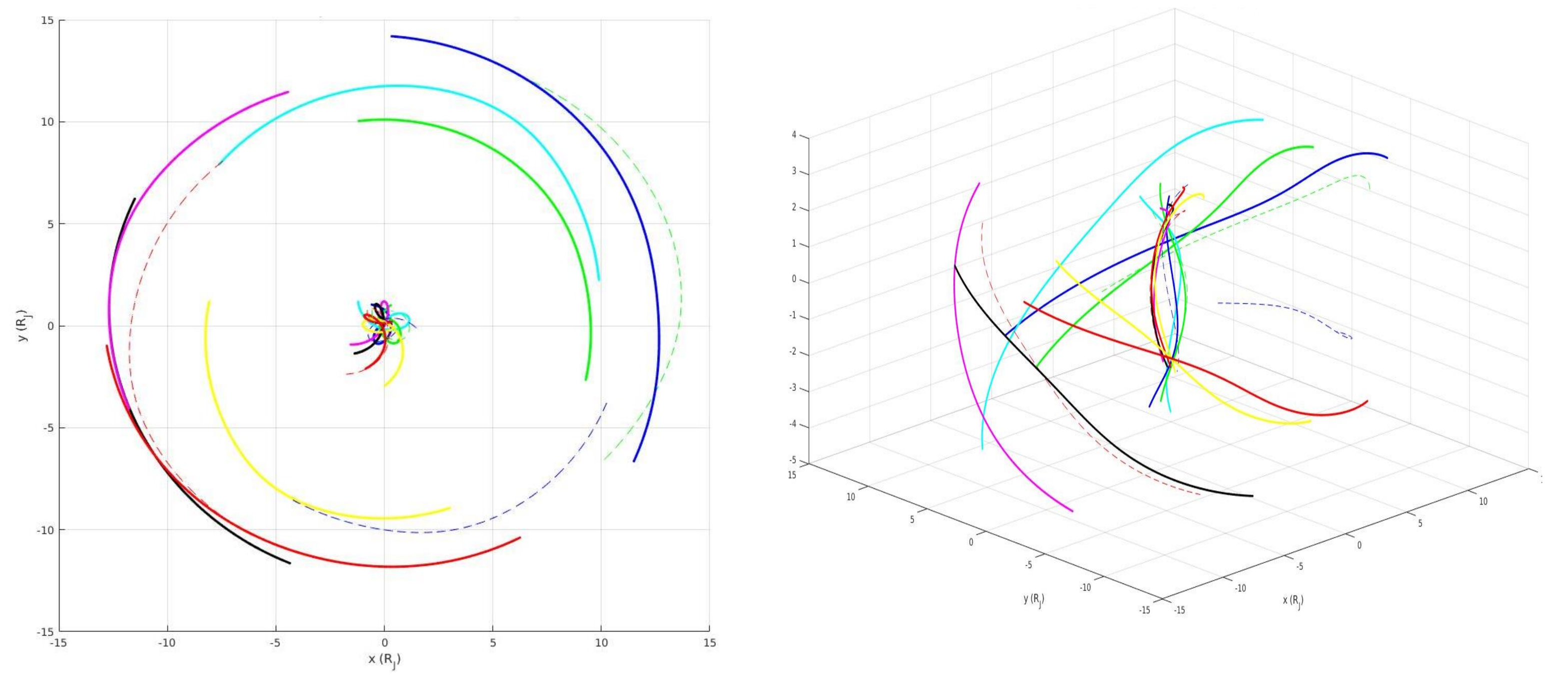


Figure 2: Trajectories of Juno and the ground station (projected near the IPT) as seen from an IPT-fixed frame. Each pair of lines for a given linestyle corresponds to an occultation.

We find out that the density and the scale height modulation are nearly anticorrelated, as expected by their dependance on the temperature. Indeed, we have

$$H \sim \sqrt{T} \qquad N \sim T^{-1}$$

and we observed that the peak density occurs near λ_{III}=120°, while the peak of the scale height lies near λ_{III}=300°. These result are similar to the one obtained by *Cassini* [3], but shifted to lower latitude of about 40°.

Besides the above-mentioned stationary modulations, the torus exhibits also non-stationary azimuthal variations [3][4]. These latters appears to be modulated by System IV or by both System III and System IV and have a period which varies roughly between 10 to 25 days (it's worth noticing that the frequency corresponding to the latter is the beat frequency between System III and System IV).

In the end, we also included a periodic density enhancement of plasma in the IPT to take into account a possible overall inflation of the torus (*pulsations*). The purpose of this correction is taking into account a periodic mass load from Io, whose volcanic activity is mostly governed by tidal interaction with Jupiter. Such inclusion showed a slight improvement of the residuals and two possible periods for the pulsations: a strong peak at 300 days and a poorly-constrained one at about 500 days.

The amplitude of all the corrections ranges between 5 to 15%, depending on the corrections included.

4. Results

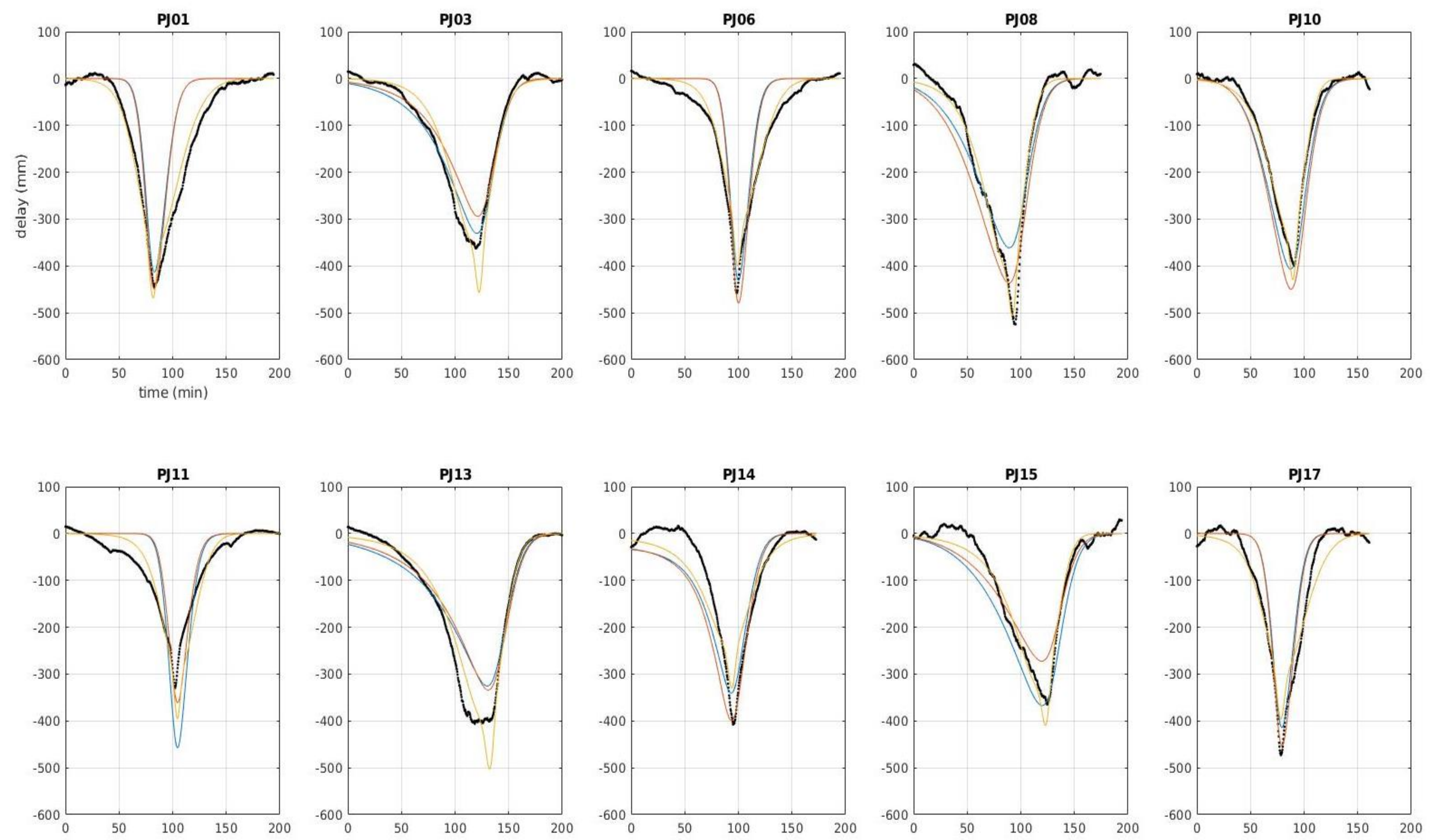


Figure 3: Fit to the path delay signature. *Black*: data. *Blue*: stationary longitudinal modulation. *Red*: non-stationary longitudinal modulation. *Orange*: Pulsations

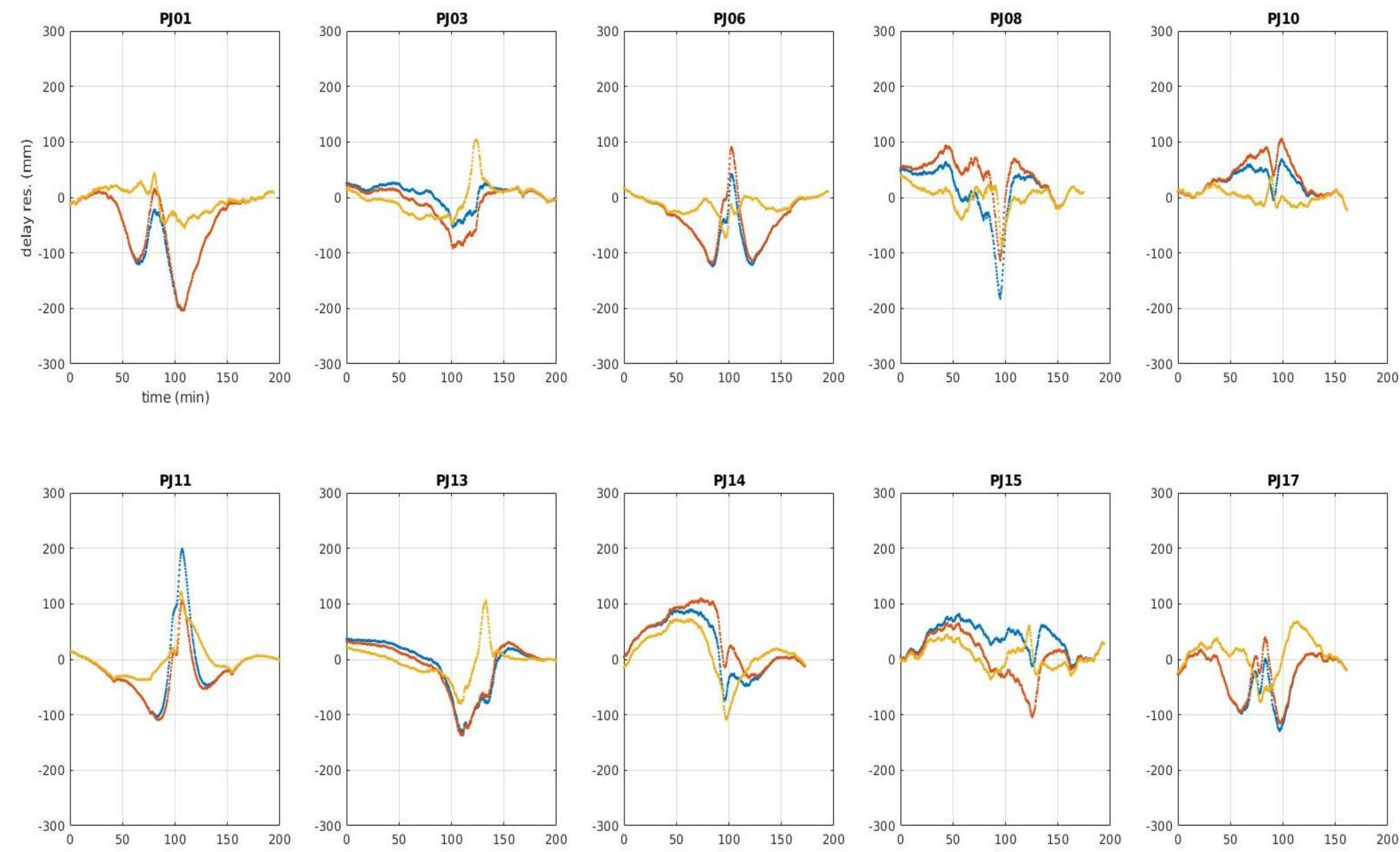


Figure 4: Residuals from fit of Fig.3. The color scheme is the same as in Fig.3.

5. Future Work

The wide range of temporal variabilities of the IPT are a proxy for a very dynamic environment in the Jupiter system. Being able to retrieve informations of characteristic periods and amplitudes can shed light on the planet-moon interaction mediated by Jupiter's magnetosphere and suggest the underlying physical processes of such interaction.

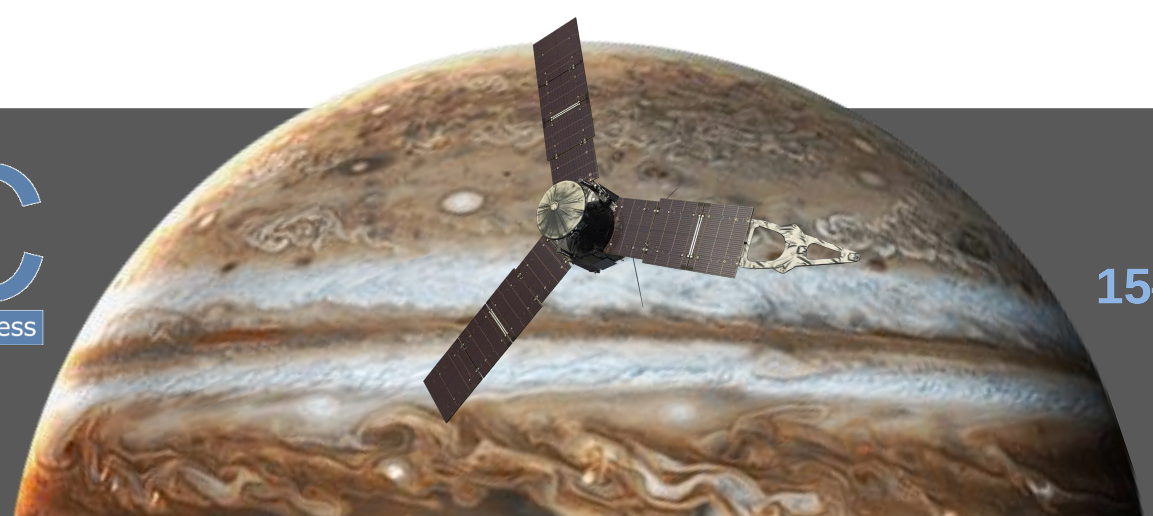
References

[1] Phipps, P.H., Whiters, P., Buccino D. R., Yang Y.M., (2018), *Distribution of plasma in the Io plasma torus as seen by radio occultation during Juno Perijove 1*, J. Geophys. Res. Space Physics, 123, 6207-6222, doi:0.1029/2017JA025113

[2] Mariotti, G., and P. Tortora (2013). *Experimental validation of dual uplink multifrequency dispersive noise calibration scheme for Deep Space tracking*. Radio Science 48, 111-117

[3] Steffl, A.J., Delamere, P.A., Bagenal, F., *Cassini UVIS observations of the Io Plasma Torus. III. Observations of temporal and azimuthal variability*, arXiv: astro-ph/0508055

[4] Brown, M. E. (1995), *Periodicities in the Io plasma torus*, J. Geophys. Res., 100(A11), 21683– 21695, doi:10.1029/95JA01988



EPSC
European Planetary Science Congress

Geneve, Switzerland
15–20 September 2019

(*) alessandro.moirano@unibo.it
1) University of Bologna, Dipartimento di Ingegneria Industriale, Forlì, Italy.
2) Department of Astronomy, Boston University, Boston, MA, USA,
3) Jet Propulsion Laboratory, California Institute of Technology, Pasadena, CA, USA.

RADIO SCIENCE AND PLANETARY EXPLORATION - LABORATORY -