Modelling the electron density distribution in the Io Plasma Torus using Juno radio occultations

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 Juno 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 KaKa 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.

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 (GSS) and Juno has crossed the IPT in many different longitudinal sectors during the gravity passages: this allows us to inspect the longitudinal structure of the IPT.

Past observations of the IPT revealed that it has longitudinal modulation (e.g. [3]) as well as temporal variability (e.g. [4]). The typical time scales of the latter can range from hours to years. To investigate potential periodicities, we considered the Fourier expansion of the parameters of the density model nₑ. We focused on the scale height Hₑ and peak density Nₑ of the outer region of the torus, which are the main responsible for the width and depth of the path delay signature. We modeled Hₑ and Nₑ as a 2-dimensional Fourier expansion up to the second order:

\[ Q(λ, t) = \sum_{m,n} A_{mn} \cos\left(\frac{m \lambda}{2}\right) \cos\left(\frac{n t}{360°/27}ight) + B_{mn} \sin\left(\frac{m \lambda}{2}\right) \sin\left(\frac{n t}{360°/27}\right) + C_{mn} \cos\left(\frac{m \lambda}{2}\right) \sin\left(\frac{n t}{360°/27}\right) + D_{mn} \sin\left(\frac{m \lambda}{2}\right) \cos\left(\frac{n t}{360°/27}\right) \]

4. Results

Our results pointed out that a purely temporal or longitudinal correction didn’t properly fit the data, while taking both into account improved the sum of the residuals by about 30%. Besides, the model with temporal and longitudinal corrections (i.e. \(M_{n=1}, N_{n=1}\)) predicts a density fluctuation of about 40%, half of which is due to the second order correction. In the left, we left the characteristic period T as a free parameter. Indeed, the orbital period of Juno allowed us to investigate periodic features of the IPT which ranges from a few months to yearly variations. We found approximately T=400 days. These values is about 10% less than the main period of orbital changes of Io, which may be related to volcanic activity on this moon [5] and thus on mass loading in the IPT. Nevertheless, this result should be taken very carefully because more investigation are needed about the response of the IPT to different types of volcanism that took place on Io, such as eruptions, lava flows and plumes.

5. Data fit

Figure 2: longitudinal sections scanned by Juno during the gravity experiment from RTG to RTG.

Figure 3: fit to the path delay signature. About: data with uncertainty (grey area); blue fit with an axisymmetric model (i.e., zero-order Fourier expansion); red fit including longitudinal and temporal variability (second-order Fourier expansion).

6. Future Work

The IPT shows a substantial variability of its electron content in both time and longitude, but its origin is still unknown. Nevertheless, our work showed they are both relevant on the morphology of the IPT. The intense volcanic activity of Io and the strong interaction between the moon, the IPT and Jupiter’s magnetosphere may be responsible for such variability, but further modelling is required to better understand the underlying physical processes at play.

References