Observations of the Io Plasma Torus with Juno radio science experiment

Marco Zannoni[1*], Luis Gomez Casajus[1], Alessandro Moirano[1], Paolo Tortora[1], Phillip H. Phipps[2], Paul Whiters[2,3], Dustin Buccino[4], Kamal Oudhriri[4], Daniele Durante[5], Luciano Iess[5].

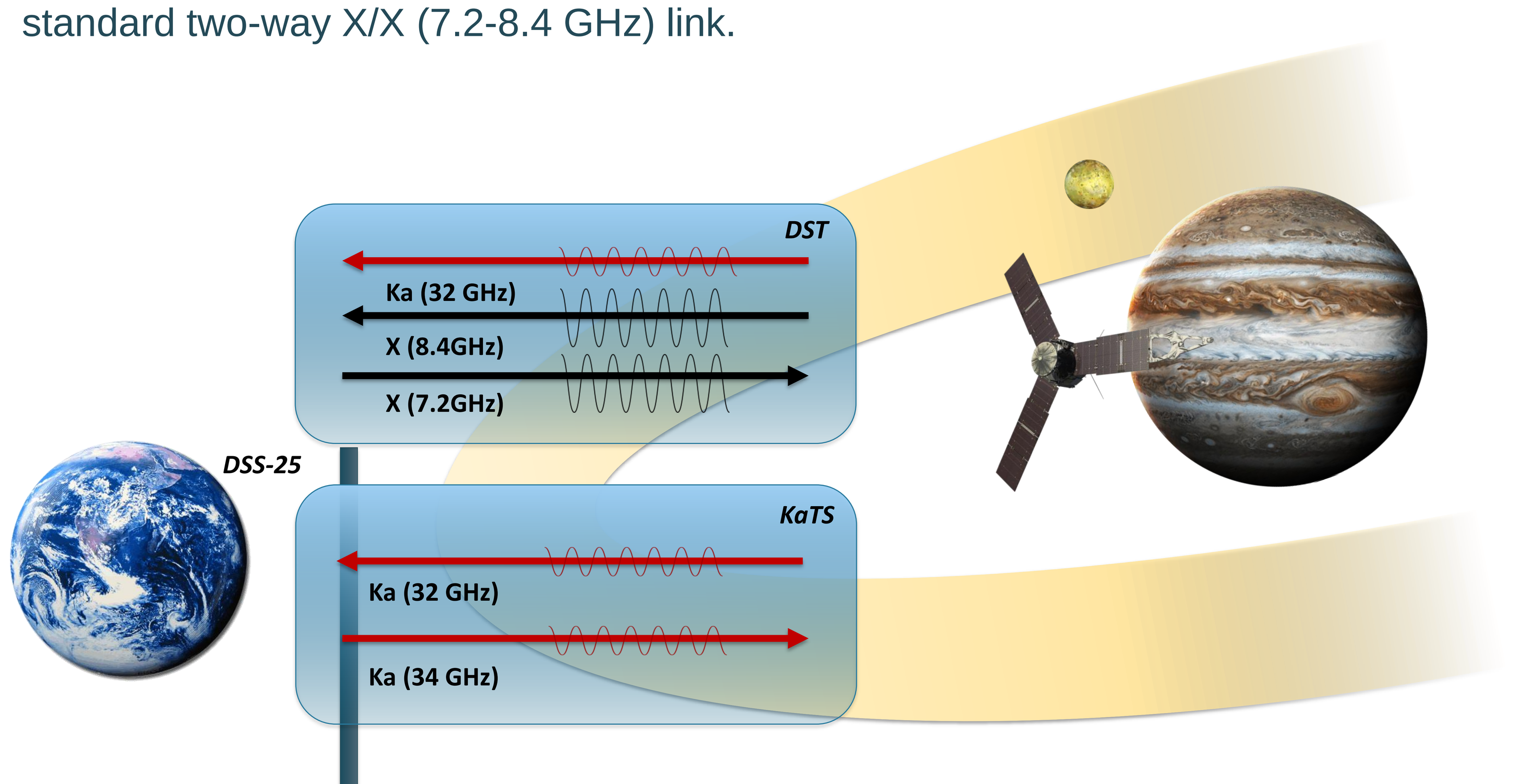
1. The Juno mission

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 frequency 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, that, if not properly calibrated, can be a potential source of bias in the Jupiter estimated gravity field coefficients.

2. Juno radioscience subsystem

The Juno gravity science instrument comprehends a Ka-band Translator System (KaTS), contributed by the Italian Space Agency, which provides a coherent two-way Ka/Ka link (34-32 GHz). The Ka-band link is less affected by dispersive media effects, allowing to reach an end-to-end noise level on two-way range rate measurements of 3 μm/s over a time scale of 1000 s, and to reduce the Doppler shift induced by the IPT to negligible values.

In addition, the Juno spacecraft telecommunications subsystem supports a standard two-way X/X (7.2-8.4 GHz) link.



$$y_{xx} = y_{ND} + \frac{P_U}{f_x^2} + \frac{P_D}{\alpha_{xx}^2 f_x^2} + \frac{I_U}{f_x^2} + \frac{I_D}{\alpha_{xx}^2 f_x^2}$$

$$y_{kk} = y_{ND} + \frac{P_U}{f_k^2} + \frac{P_D}{\alpha_{kk}^2 f_k^2} + \frac{I_U}{f_k^2} + \frac{I_D}{\alpha_{kk}^2 f_k^2}$$

Integrated path delay Plasma profiles (IPT+ solar plasma)

Figure 1: Schematic representation of the Juno Radio Science subsystem and how through a dual mult-ifrequency link technique, [1],[2], the path delay plasma profiles can be extracted.

During the perijove passes dedicated to gravity investigations a dual-frequency link calibration system [1], [2], at X and Ka band allows a 75% calibration of dispersive noise in range rate measurements with respect to the Ka band.

Moreover, this allows to extract the integrated path delay due to dispersive media, including the one due to the IPT.

3. Additional delay on the Ka-band uplink

Applying the dual-frequency link calibration scheme to Juno data it was discovered that the extracted dispersive path delay was not compatible with the IPT, as shown in *Figure 2* and *Figure 3*. Moreover, this problem did not appear in PJ01 and PJ13, when a direct measurement of downlink plasma contribution was possible by transmitting downlink signals at X and Ka band coherent with a common X-band uplink.

A possible explanation of this unexpected trend was an additional dispersive effect on the link. Among the investigated causes there was a difference between the phase delays of the X and Ka bands, and also between the uplink and the downlink chains.

In order to shed some light on this issue we built a setup in MONTE to directly estimate the different delays that could have affected the link: the station delays at X and Ka- bands, both in up- and downlink, and also the delays induced by the on-board transponder (DST and KaTS).

The setup allowed to estimate a significative additional delay on DSS-25 Ka-band, in uplink. The estimated value is in good agreement with the results obtained by the JPL by means of an instrumental test performed on October 12, 2008 at DSS 25.

Correcting the link using the estimated delay we found that the extracted plasma path delay, in most of the perijoves, is now compatible with the effects of the IPT and the solar plasma, as shown in *Figure 4*, *Figure 5*.

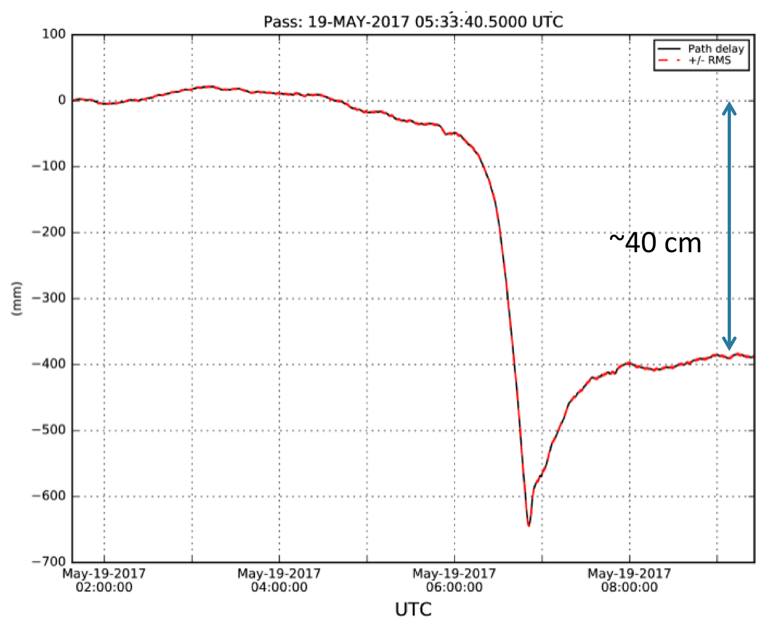


Figure 2: Original PJ3 Path Delay.

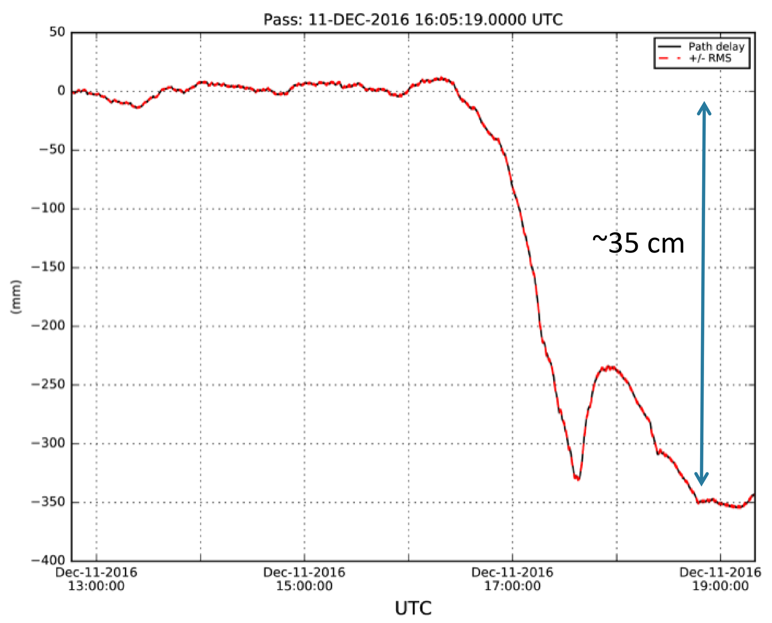


Figure 3: Original PJ6 Path Delay.

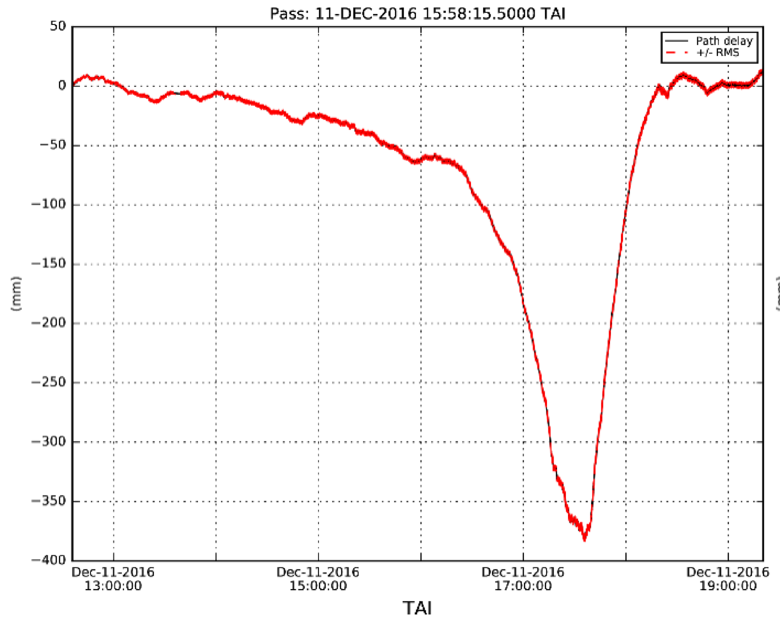


Figure 4: Corrected PJ3 Path Delay.

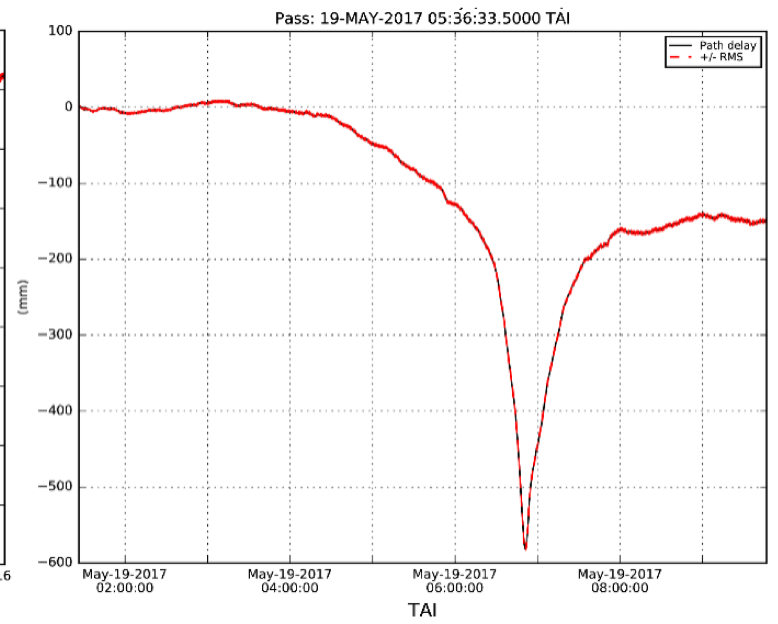


Figure 5: Corrected PJ6 Path Delay.

4. Updated Path Delay Profiles

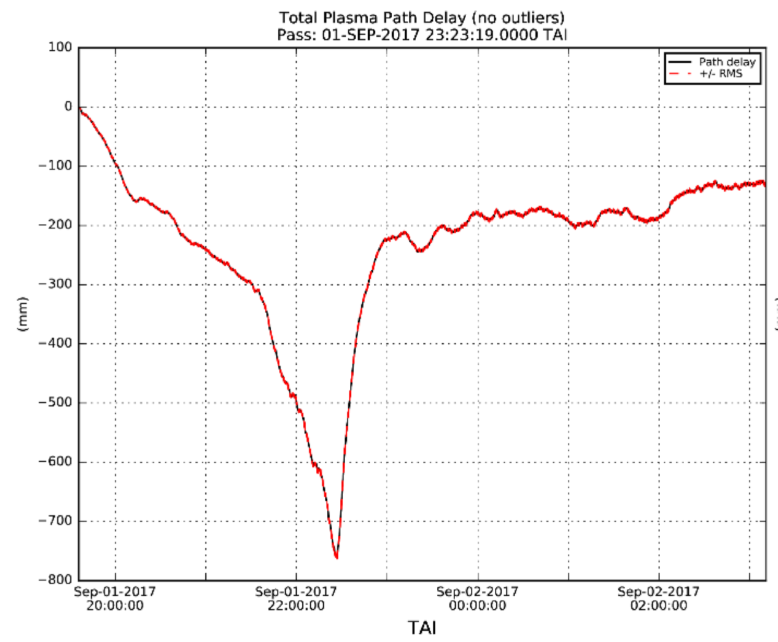


Figure 6: PJ8 Path Delay.

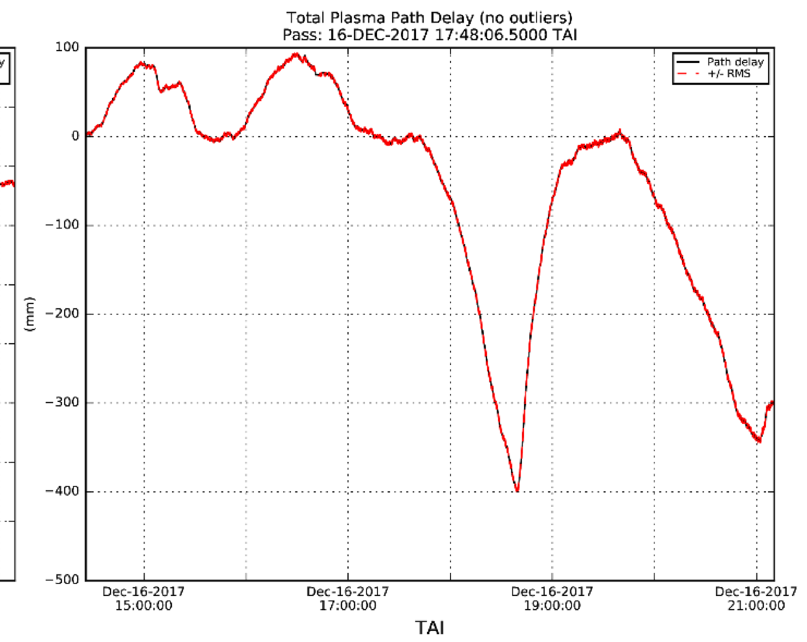


Figure 7: PJ10 Path Delay.

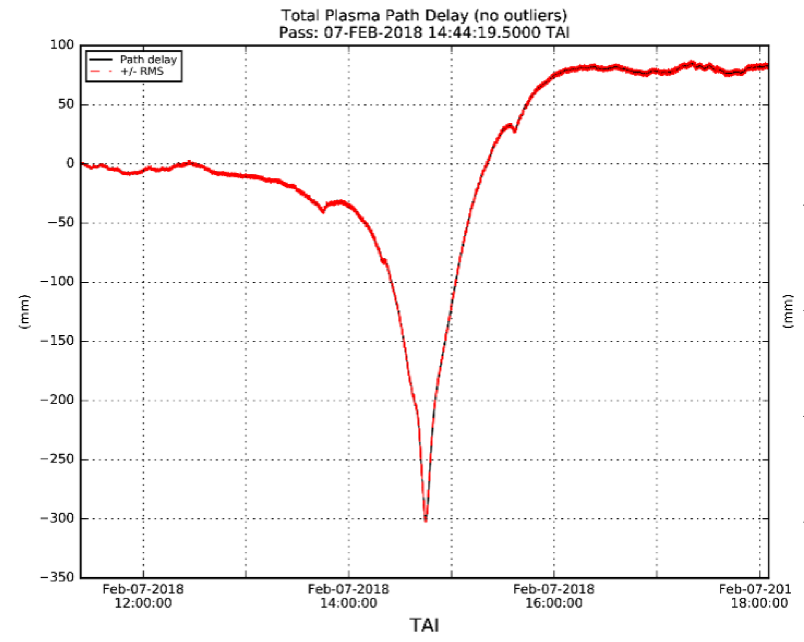


Figure 8: Corrected PJ11 Path Delay.

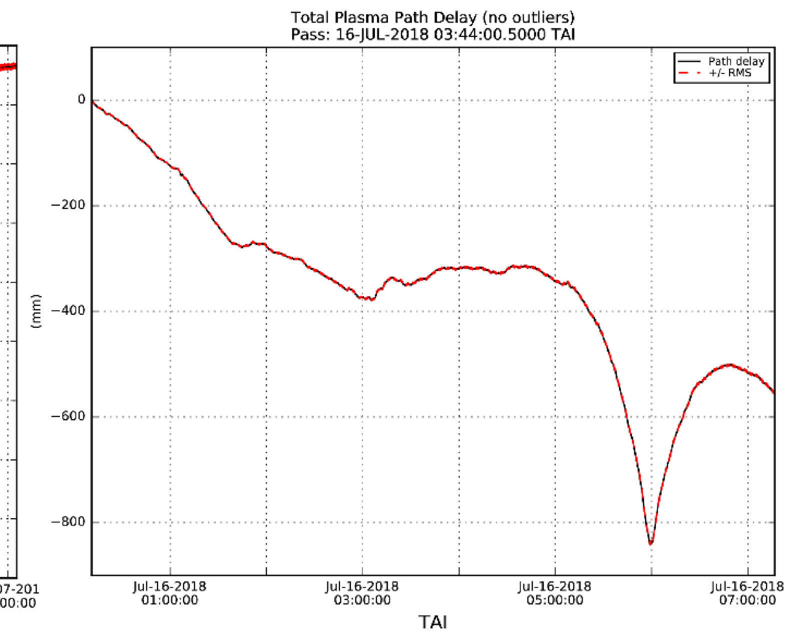


Figure 9: Corrected PJ14 Path Delay.

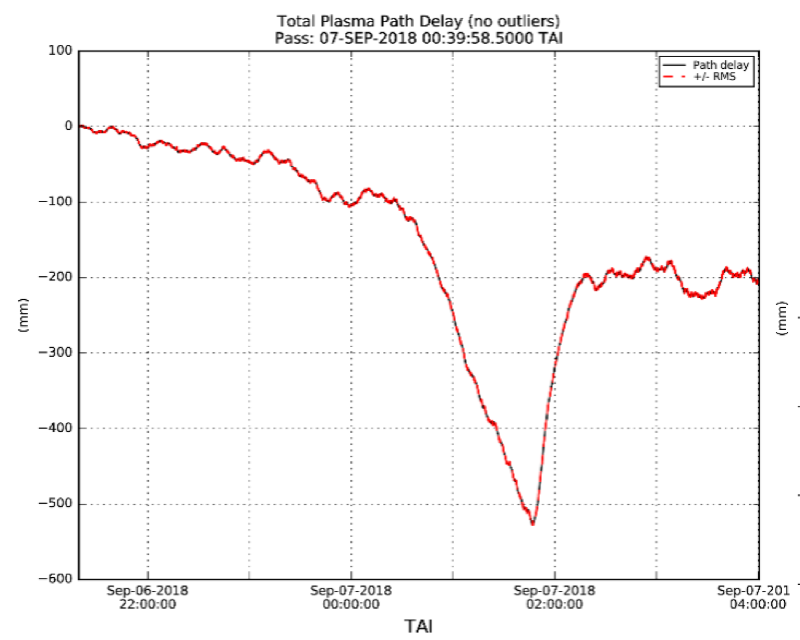


Figure 10: Corrected PJ15 Path Delay.

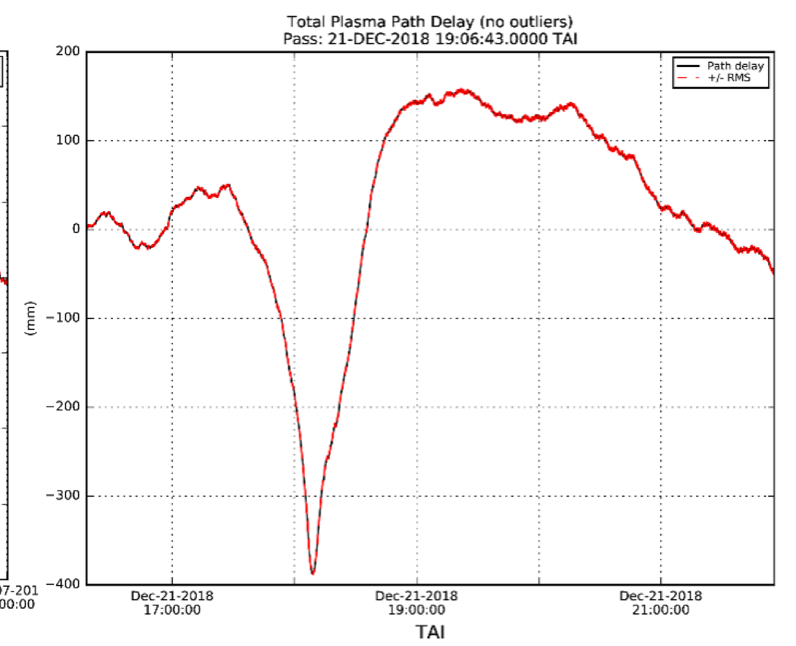


Figure 11: Corrected PJ17 Path Delay.

5. Future Work

The corrected extracted profiles will allow to study the IPT electron density distribution and its spatial and temporal variability during the Juno mission. This would provide additional insight about the different mechanisms affecting the origin and evolution of the plasma material in the Jovian environment.

References

[1] Bertotti, B., G. Comoretto, and L. Iess (1993). "Doppler tracking of spacecraft with multi-frequency links", Astron. Astrophys., 269, 608–616

[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

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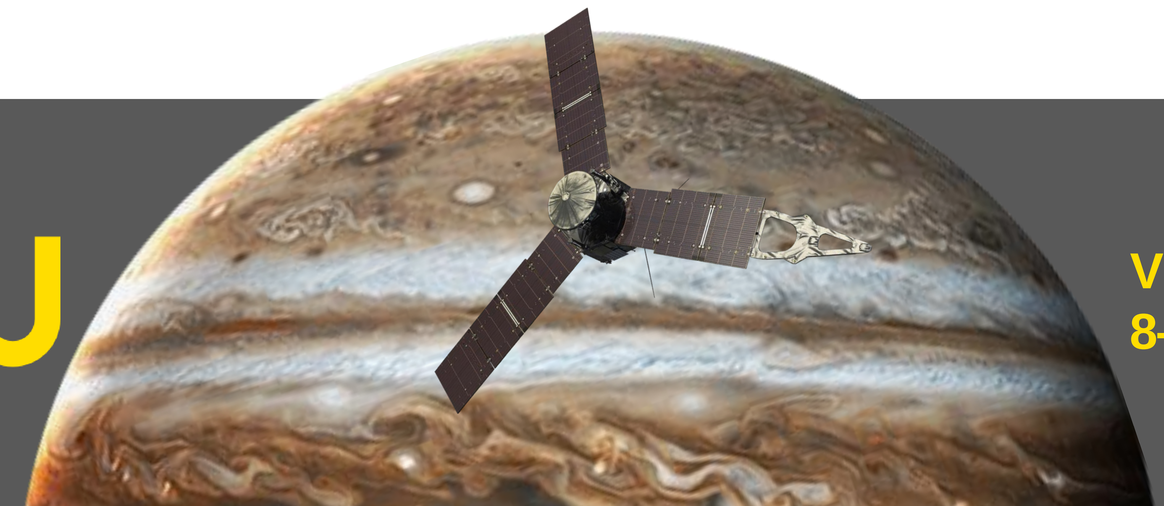

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(*) m.zannoni@unibo.it
(1) University of Bologna, Dipartimento di Ingegneria Industriale, Forlì, Italy.
(2) Department of Astronomy, Boston University, Boston, MA, USA,
(3) Center for Space Physics, Boston University, Boston, MA, USA.
(4) Jet Propulsion Laboratory, California Institute of Technology, Pasadena, CA, USA.
(5) Department of Mechanical and Aerospace Engineering, Sapienza University of Rome, Italy.