# Deep Space Weather radio sounding observations of the solar corona by VLBI radio telescopes.

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PRIDE is a multi-purpose, multi-disciplinary enhancement of planetary mission's science return 🚀, which can provide ultra-precise estimates of spacecraft state vectors based on the phase-referenced VLBI tracking and radial Doppler measurements. **PRIDE exploits the technique of VLBI observations of spacecraft and natural celestial radio sources by a network of Earth-based radio telescopes** 📡.

PRIDE-JUICE is **an enhancement of the JUICE science return** achievable with minimum PRIDE-specific requirements to the on-board science payload [1]. We can study the gravitational field of the planetary bodies 🪐 and investigate the interiors of Jupiter's satellites. Measurements of tidal accelerations of the satellites may be possible. Powerful constraints on the interior structure of the moons 🌑 can be obtained from the joint analysis of topography and gravity field data. Multiple flybys can be used to define the low order gravity field parameters. Furthermore, PRIDE brings in multi-antenna detections enabling "stereoscopic" view on the phenomena under study. Such measurements will address some of the prime objectives of the JUICE mission – investigation of interiors and origins of the Jovian satellites.

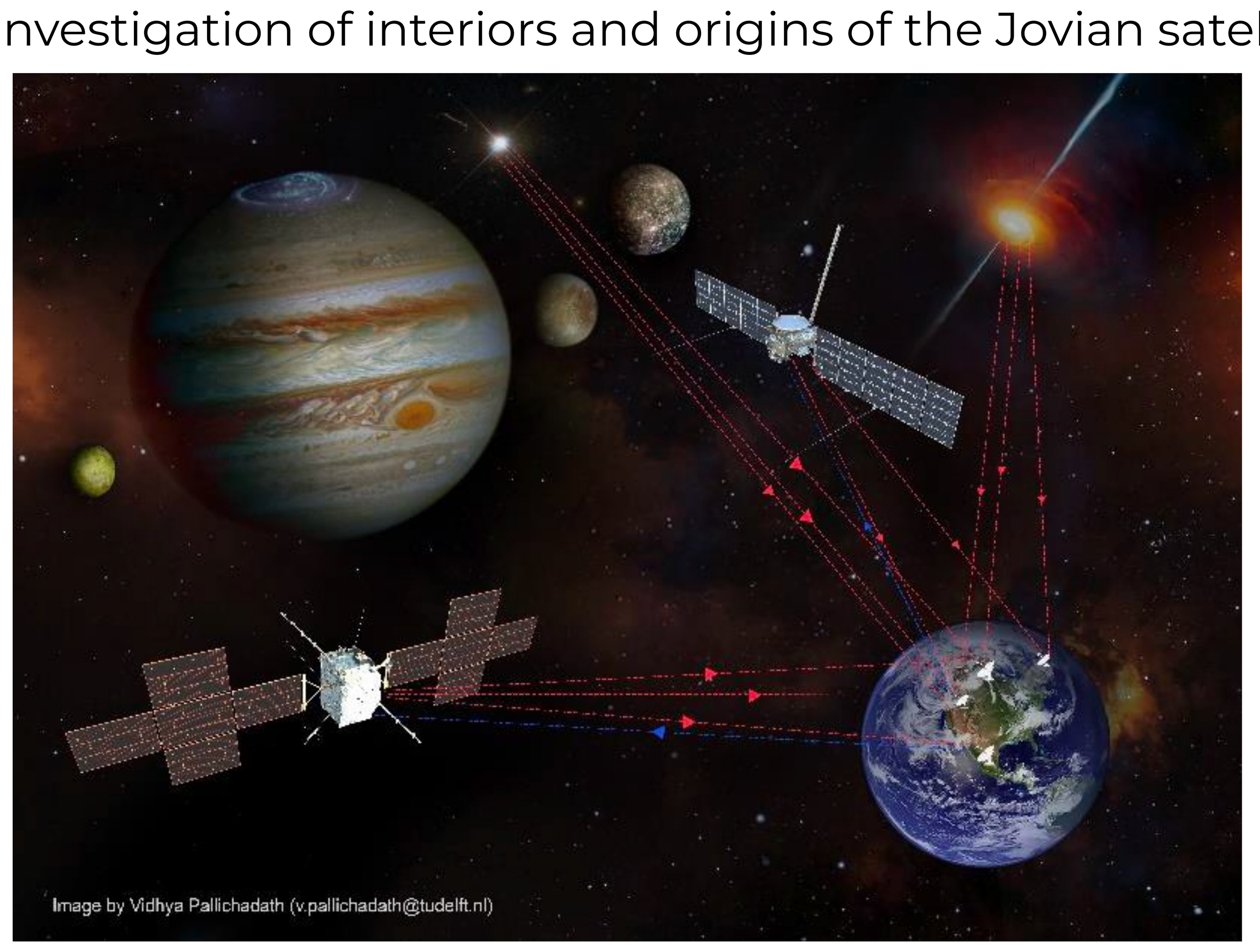


***Figure 1.*** *Concept of the PRIDE activities in the framework of the JUICE mission.*

## Space Weather

The **phase scintillation** of planetary spacecraft signals have been analysed with SDtracker to detect and characterise phenomena such as interplanetary **coronal mass ejections** [4]. JUICE presents an excellent opportunity to continue studies of the inner solar corona 🌅.

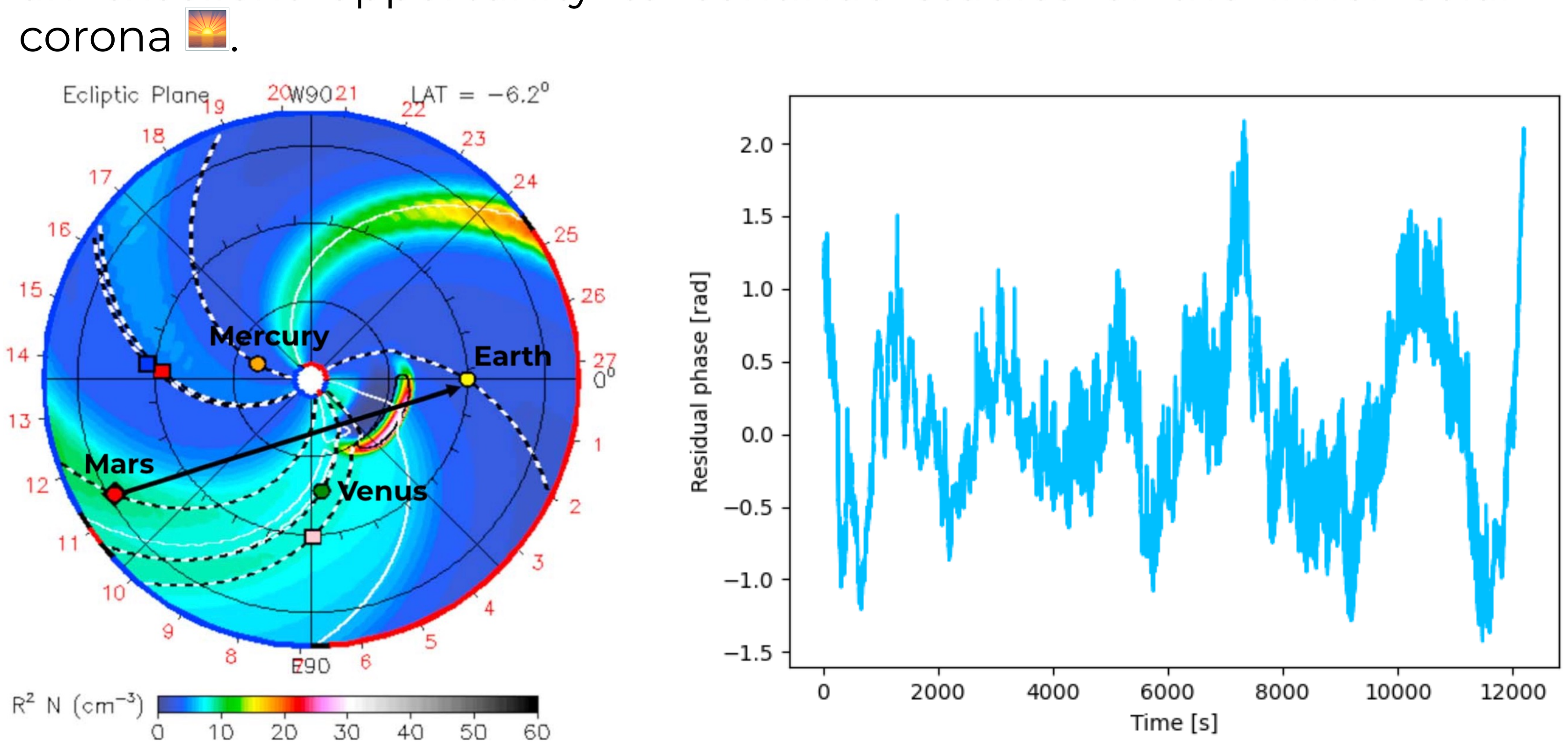


***Figure 2.*** *Left panel: The $R^2$ times electron density at the time of a detected ICME. The path of the transmission used is shown by the black arrow*

## Observation methodology

The University of Tasmania's radio telescopes located at Hobart, Ceduna, Yarragadee and Katherine (see Figure 1), were used to observe the X-band (8.4 GHz) **coherent two-way communications link from the Mars Express (MEX) and Tianwen-1 (TIW-1) spacecraft** during the 2021 and 2023 **Martian superior solar conjunctions**. The observations were conducted from Sun-Target distances ranging from approximately 40 solar radii ingress to 40 solar radii egress

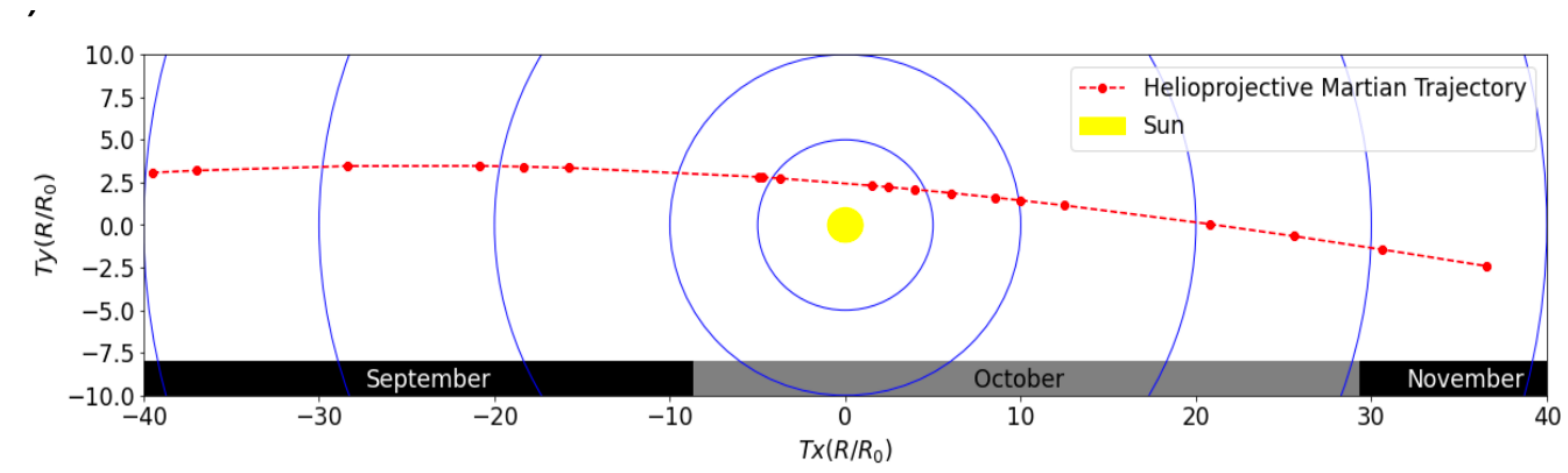


***Figure 3.*** *Martian trajectory during the 2021 superior solar conjunction, as observed from Earth's geocentric.*

## Results

Scintillation of spacecraft radio signals can be used to determine the following parameters of the solar Corona, in particular, during transient events such as CMEs, as shown in Figure 3.

- Solar wind and CME velocities can be inferred from the cross-correlation of phase residuals measured at each station.
- Electron column densities can be inferred from the gradient of the phase residual power spectrum ($W\ \phi(f)$) or the scintillation index, the integral of the phase residual power spectrum between the low frequency cut-off and high frequency noise band.
- Finally, the spectral broadening and phase scintillation structure function defined is directly related to the observable statistics and is a more intuitive measure relating density fluctuations directly to their physical scale in space.

Spacecraft radio science observations complement in situ measurements as well as scintillation measurements made with natural radio sources

## Summary

- **S/C differential lateral position** with the accuracy of 100-10 uas.🛰
- **Doppler range-rate measurements** with an accuracy 0.015 mm/s.
- **Occultations:** Characterization of the ionosphere and neutral atmosphere.
- **Space Weather**: IPS plasma diagnostics.

### References

**[1]** Gurvits. L.I. et al. (2023). **Planetary Radio Interferometry and Doppler Experiment (PRIDE) of the JUICE Mission**, Space Science Review, doi:10.1007/s11214-023-01026-1

**[2]** Duev, D. A. et al. (2016). **PRIDE technique: A test case of the Mars Express Phobos fly-by.** *A&A*, doi:10.1051/0004-6361/201628869

**[3]** Molera Calvés, G. et al. (2021). **High spectral resolution multi-tone Spacecraft Doppler tracking software: Algorithms and implementations.** *PASA*, 38, E065. doi:10.1017/pasa.2021.56

**gitlab.com/gofrito/sctracker**

**[4]** Molera Calvés, G. et al. (2017). **Analysis of an Interplanetary Coronal Mass Ejection by a Spacecraft Radio Signal: A Case Study.** *Space Weather*, 15, 11. doi:10.1002/2017SW001701

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