JUICE's window into Jupiter: Decoding the Atmosphere with Radio Science

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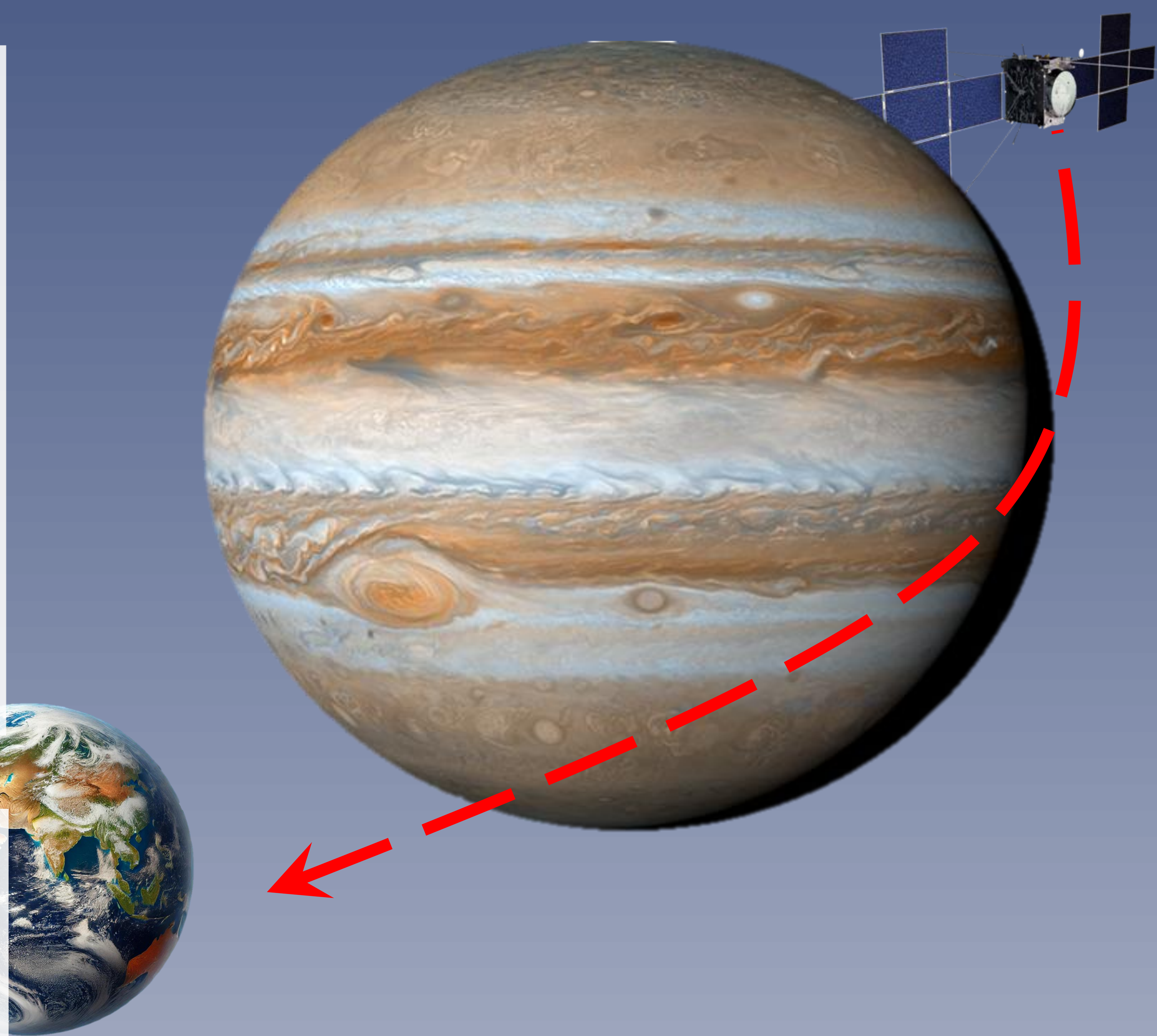
Abstract

The Jupiter Icy Moons Explorer (**JUICE**) is ESA's flagship mission to the Jovian system, launched in April 2023 and scheduled to arrive at Jupiter in December 2031. Among its suite of instruments, the 3GM experiment, led by Israeli and Italian scientists, is crucial for understanding the gravity fields of Europa, Ganymede, and Callisto, and the structure of Jupiter's atmosphere. Using radio occultation enabled by the Ka-T and Ultra Stable Oscillator technologies, 3GM will generate unprecedented vertical profiles of Jupiter's atmospheric density, pressure, and temperature. Leveraging hundreds of planned occultations, JUICE will map Jupiter's atmosphere in 3D, reaching depths of ~2 bars. Methods for JUICE are currently being refined with data from NASA's Juno spacecraft. This synergy will provide groundbreaking insights into Jupiter's atmospheric structure and dynamics.



The JUICE mission

- **ESA's flagship to Jupiter** and the Galilean Satellites
- **Launch - April 14th 2023**
- **Arrival at Jupiter - December 2031**
- Payload – GALA, 3GM, J-MAG, PEP, RPWI, JANUS, MAJIS, UVS, SWI, RIME, PRIDE → **11 instruments**
- **3GM Experiment** (Gravity and Geophysics of Jupiter and the Galilean Moons) -> **Israeli-Italian experiment**
- **3GM goals** - Determine the global temperature map of Jupiter's upper atmosphere up to 2 bars and the gravity fields of Europa, Ganymede and Calisto.

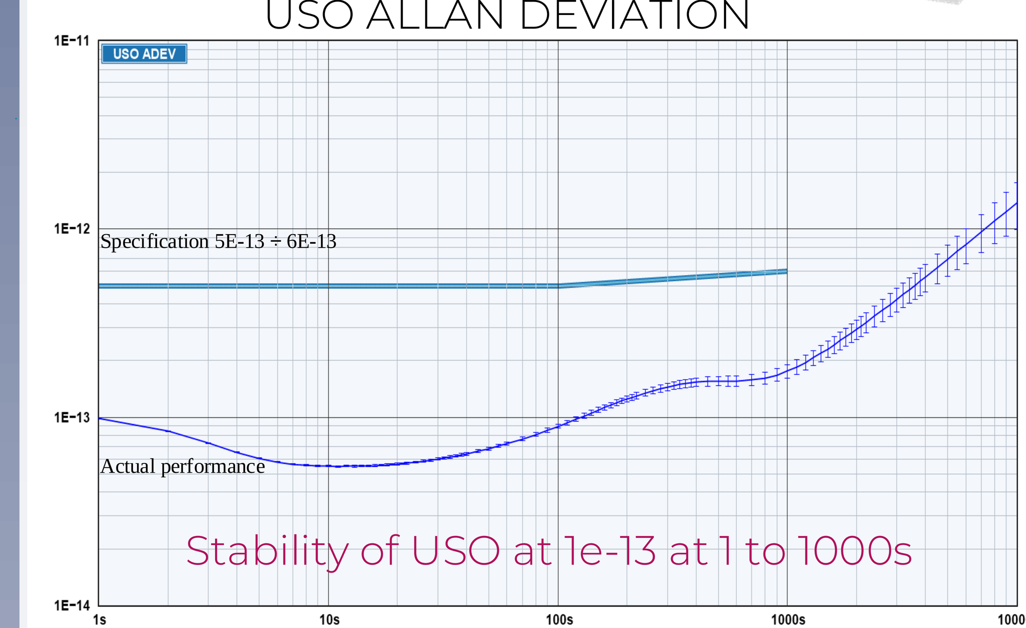
International Collaboration

- ESA-led mission
- Contributed one instrument (UVS) and hardware (RIME, PEP)
- Contributed hardware (RPWI, GALA, PEP)
- Contributed hardware (3GM)

The USO

AccuBeat provided an ultra stable oscillator to the JUICE spacecraft (3GM)

USO ALLAN DEVIATION

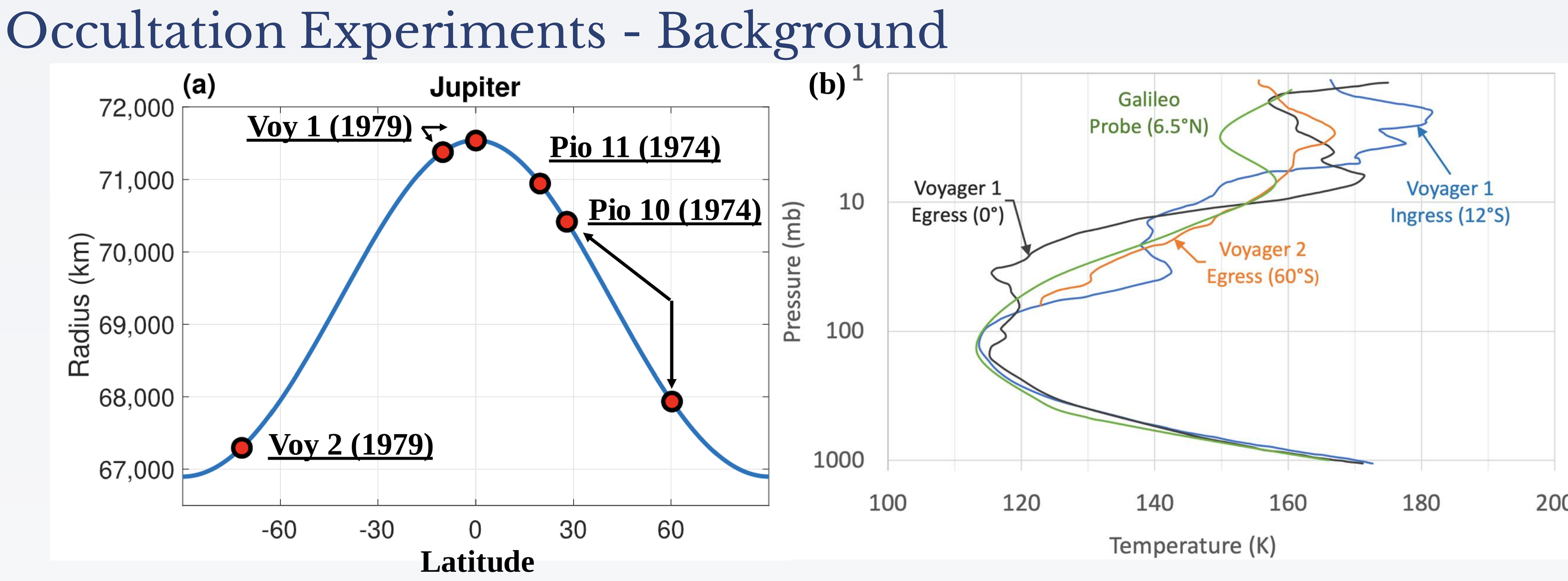


Radio Occultation Experiments - Background

Radio Occultation is the **transmission** of an electromagnetic signal, thereby passing the atmosphere of a target object. This causes refraction (measured as a **Doppler Shift**) on the signal, used to retrieve **atmospheric properties** of planetary atmospheres in the form of vertical profiles.

→ Scope is to have a global temperature map of the upper atmosphere so widespread coverage in latitude and longitude is important

→ JUICE will offer 164 opportunities for radio occultation experiments



Only 6 radio occultations of Jovian atmosphere before Juno (d)

Very limited information about upper atmosphere from existing profiles

Radio Occultation Experiments - Technique

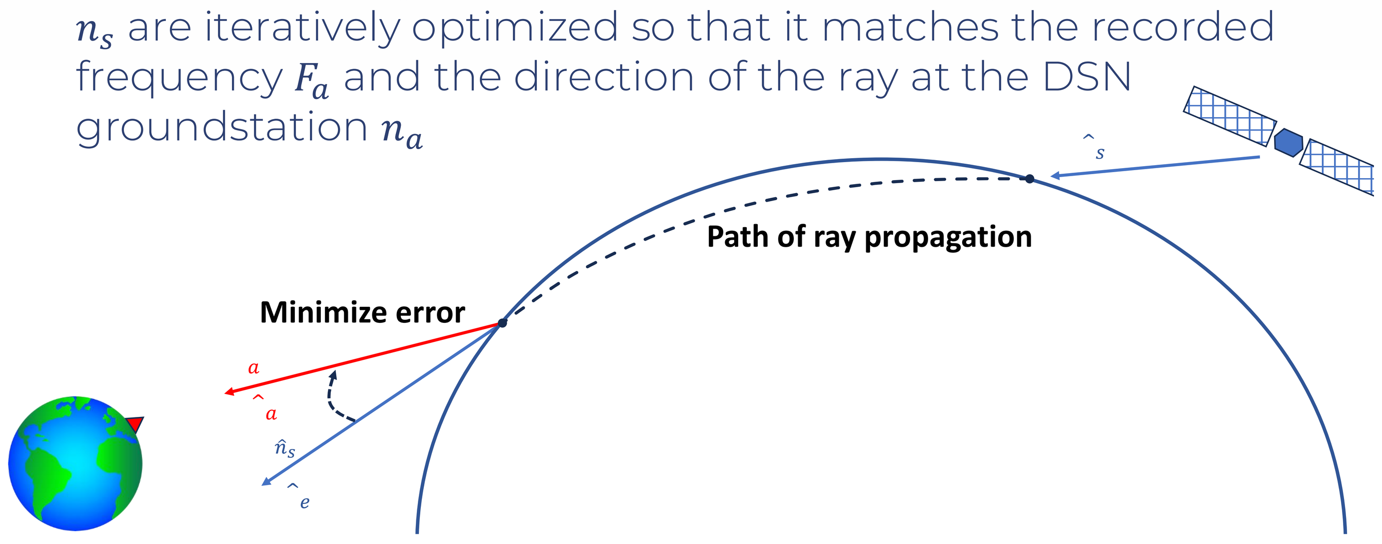
- **USO on board** so one way ray tracing technique is used (Linking signal to ultra stable reference frame)
- Based on shell definition depending on **predefined map of equipotential surfaces** (Following (c)) using equation,

$$U = \frac{GM}{r}[-1 + J_2P_2(\cos\theta)(\frac{a}{r})^2 + J_4P_4(\cos\theta)(\frac{a}{r})^4 + J_6P_6(\cos\theta)(\frac{a}{r})^6] + Q,$$

Where, $Q = -\int \omega^2 \mathrm{R} d\mathrm{R}$ → $\omega = \omega_m + \frac{V_w}{r\cos\phi}$,

Solid body rotation (ω_m); Winds at cloud level (V_w)

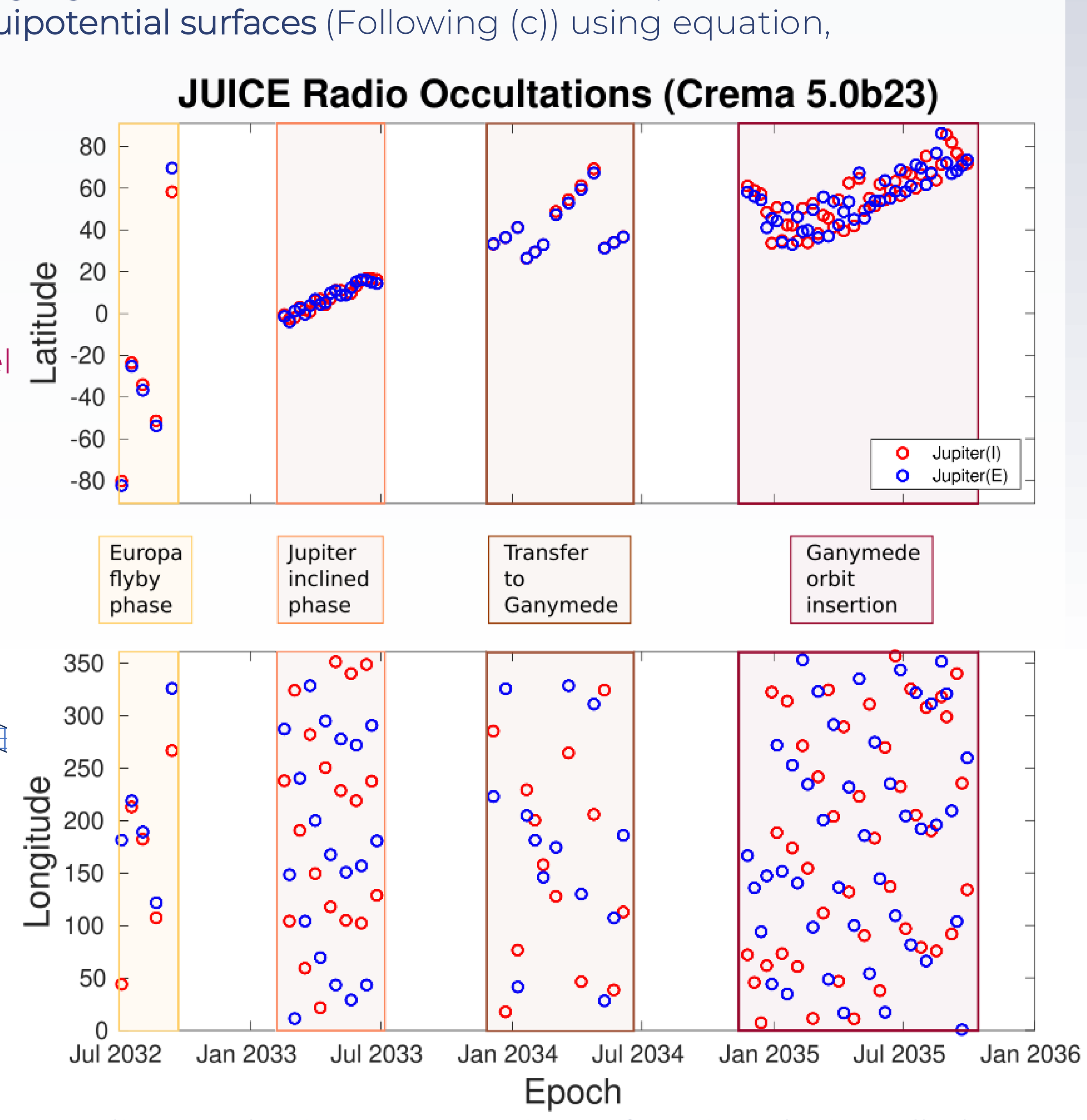
- Refractivity of layer $\mathbf{dN/d\Phi}$ and direction of ray at spacecraft n_s are iteratively optimized so that it matches the recorded frequency F_a and the direction of the ray at the DSN groundstation n_a



- Cost function equations

$$f(\hat{\mathbf{n}}_s) - f_a(t) \to 0$$

$$\hat{\mathbf{n}}_e(\hat{\mathbf{n}}_s, dN/d\Phi) - \hat{\mathbf{n}}_a(t) \to 0$$



Radio Occultation opportunities of Jupiter during all phases of the JUICE mission, indicating Ingress (red) and Egress (blue) experiments in Jovian latitude and longitude

Current Activities

- Every month possibility for Juno Radio Occultation (Benchmarks and tool optimization)
- Iterate on operational needs for future radio occultations of JUICE according to Juno
- Perform ADEV analysis each checkout phase of JUICE mission
- Make prediction model for pointing of antenna to achieve deepest temperature profiles
- Study shape of Jupiter via the effect of top temperature and winds

References

(a) Galanti, E. et al (2023). The shape of Jupiter and Saturn based on atmospheric dynamics, radio occultations and gravity measurements. *Geophysical Research Letters,*

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