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3GM: Gravity and Geophysics of Jupiter and the Galilean Moons

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Abstract

3GM (Gravity and Geophysics of Jupiter and the Galilean Moons) addresses JUICE scientific goals pertaining to gravity, geophysics and atmospheric science with radio occultations. The 3GM payload comprises two elements, namely a high performance Ka-band transponder (KaT) and an ultra-stable oscillator (USO). Thanks to the adoption of an advanced microwave tracking system, the gravity fields of Ganymede, Callisto and Europa will be determined to the best accuracy allowed by the spacecraft design and mission profile. Probing of Jupiter's atmosphere will be enhanced by the use of two frequencies (8.4 and 32.5 GHz) and by the proposed onboard recording of the uplink signal.

1. Gravity and Dynamics

This 3GM on JUICE will revolutionize our understanding of the origin, evolution and structure of the Galilean icy satellites through highly precise spacecraft tracking. By itself and in combination with altimetry and other measurements, radio tracking will provide information on the static gravity fields of Ganymede, Callisto and Europa, on the rotational state and tidal deformation of Ganymede and Callisto, on the presence of density variations within the ice shell of Ganymede, and on dissipation within the Jovian interior. Specifically, 3GM will:

• Determine the gravity field of Ganymede to degree and order 10 or higher, enabling the identification of density anomalies within the body. In combination with altimetry, this will determine the extent to which topography is expressed on the gravity field or is instead well compensated, the role of a silicate core, the possible role of convection, and the presence of regional differences in the outermost ice shell. This will be the first time that the high degree gravity field of a large, mostly solid icy body will be characterized.

• Determine the nature and extent of the likely internal ocean within Ganymede and the thickness of the overlying ice shell through four different methods: (1) Time-dependence of gravity at degree 2 arising from the eccentricity tide; (2) Combination of this result with the corresponding change in topography from this tide; (3) Determination of the obliquity of Ganymede and its possible time variation; (4) Detection and determination of the amplitude of libration of the deep interior and the outermost ice shell, and possible asynchronous rotation of the satellite.

• Determine or set a lower bound to the tidal Q of Ganymede through measurement of the phase lag in response to the eccentricity tide.

• Determine the degree 2 and 3 gravity field of Callisto with a precision sufficient to assess the extent of differentiation within that body and extent of hydrostatic equilibrium, thus removing the current ambiguity in the interpretation of Galileo results. Extent of differentiation plays a central role in our understanding of the timescales and energetics of satellite formation.

• Determine the presence or absence of an internal ocean within Callisto by measuring the time-dependence of gravity at degree 2 arising from the eccentricity tide.

• Independently determine the J2 and C22 of Europa, further constraining the moment of inertia and extent of hydrostaticity for that body.

• Significantly improve the determination of the dissipative properties of the Jovian system as a whole, in particular the tidal Q of Jupiter.

• Improve the ephemerides of the Jovian system and carry out tests of laws of gravity.

In advancing our understanding of the interior structure, formation and evolution of the Galilean icy moons, 3GM will ensure that JUICE will address in depth two key questions of ESA's Cosmic Vision program: (1) What are the conditions for planet formation and the emergence of life? and (2) How does the Solar System work?

2. Atmospheres and Surfaces

A key component of the 3GM experiment is the radio occultation measurements of neutral atmospheres and ionospheres of Jupiter, Ganymede, Callisto and Europa. Additional science goals will be achieved by means of ring occultations and bistatic radar observations. 3GM will:

• Measure vertical profiles of atmospheric densities in Jupiter's troposphere and stratosphere, enabling us to infer vertical profiles of atmospheric pressure and temperature. These measurements will allow us to infer zonal wind velocities and determine the latitudinal shape of Jupiter's atmosphere.

• Identify atmospheric wave characteristics and infer their roles on atmospheric temperatures and winds.

• Probe Jupiter's ionosphere to determine horizontal and vertical structures and variability of electron densities, constraining chemical processes as well as ionization sources and enabling to study magnetosphere-ionosphere coupling processes on Jupiter.

• Measure ionospheric electron densities of the Galilean icy moons, in particular Ganymede, and use models to infer neutral densities.

• Since the tenuous atmospheres of the icy moons are generated mostly from surface sputtering and sublimation (and possibly cryovolcanic activity on Europa), determine surface sputtering rates and thereby basic surface properties from radio occultations.

• Using numerical atmosphere models in tandem with observations, infer ionization processes and examine atmosphere-magnetosphere coupling processes.

• Use radio occultations to probe Jupiter's rings, especially during relative geometries allowing low opening angles and using the uplink one-way mode, which ensures a high signal-to-noise ratio.

• Use bistatic radar experiments to complement surface remote sensing observations of the icy moons (in particular Ganymede and Callisto), as they allow a more complete characterization of target scattering properties (surface slope, near-surface dielectric constant and, under certain assumptions, the surface porosity), sometimes not apparent from monostatic observations.

3. Experimental Configuration

3GM observable quantities will be obtained from spacecraft tracking at microwave frequencies. Gravity science requires precision measurements of the spacecraft's two-way range and range rate, while one-way open loop samples of the signal carrier (recorded at the ground station or on-board) are the fundamental observables for atmospheric science, rings, and bistatic radar experiments. 3GM is designed to provide radio-metric observables that approach the ultimate capabilities of microwave radio systems. The 3GM in its full configuration entails two independent elements:

• A Ka-band uplink, Ka-band downlink (34.3-32.5 GHz) transponder (KaT) with an intrinsic frequency stability (Allan deviation) of 4 x 10-16 or better (at 1000 s integration time) and an internal range delay calibration system. The KaT enables two-way range and range rate measurement accurate respectively to 0.2 m and 3x10-6 m/s (at 1000 s integration times).

• An ultra-stable oscillator (USO), with a frequency stability (Allan deviation) of 2×10^{-13} or better at 10 s integration time (6×10^{-13} at 1000 s), enabling occultation and bistatic radar experiments.

Enhanced uplink radio occultation experiments are possible if the X/Ka, TT&C deep space transponder (DST) is augmented by a light (200 g), sample decimation board (uplink radio science processor, URSP).

Gravity measurements will rely mainly on the Ka/Ka link enabled by the KaT. This radio link is highly immune to interplanetary plasma noise over a broad range of solar elongation angles. The TT&C, X/X and X/Ka radio link can be used together with the Ka/Ka link to reduce or even cancel plasma noise and to separate neutral and charged particles effects in uplink occultation experiments. Occasional (one per month to one per week) VLBI observations of the spacecraft and a quasar by multiple ground antennas will be carried out for the improvement of the ephemerides of Jupiter and the Jovian system.

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