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Bistatic Radar Observations of Europa: Peering Beneath the Galilean Ice

Space * Astronomy * Solar System

Introduction: Probing the Galilean Ice Shell via Bistatic Radar

Within our Solar System, planetary science has long focused on Jupiter's icy Galilean moon Europa as a premier target for astrobiology and comparative oceanography due to strong geophysical evidence that it harbors a global subsurface liquid ocean beneath a tectonically deformed icy crust[1][2]. Because optical, ultraviolet, and infrared wavelengths penetrate only micrometers to millimeters into water ice, researchers rely on centimeter-to-meter wavelength radar astronomy to probe the porosity, purity, and structural heterogeneities of the subsurface shell[2][3].

Presented at the 248th meeting of the American Astronomical Society and detailed in an August 2026 technical manuscript, researchers Tunhui Xie and Jean-Luc Margot of the University of California, Los Angeles (UCLA) completed a 13-year Earth-based radar campaign (2011-2024) bridging a three-decade observational gap since the late-1980s Arecibo and Goldstone studies[2][6][12]. By pairing NASA's Goldstone Solar System Radar with the National Science Foundation's Robert C. Byrd Green Bank Telescope in a bistatic 3.5-centimeter X-band configuration, the team established rigorous empirical constraints on Europa's coherent backscatter opposition effect, upper-crustal microwave transparency, and hemispheric radiation weathering[2][5][6].

Geophysical Context of Europa's Upper Crust

Maintained by internal tidal dissipation driven by its Laplace orbital resonance with Io and Ganymede, Europa exhibits a geologically young surface (<200 million years) largely devoid of large impact craters[13][23]. During its September 29, 2022 close flyby (360 km altitude), NASA's Juno spacecraft used its Microwave Radiometer to estimate that Europa's cold, rigid, conductive outer pure-ice shell averages ~29 kilometers in thickness, while identifying centimeter-scale shallow "scatterers" -- cracks, pores, and voids -- that impede vertical transport of surface oxygen and oxidants toward the underlying ocean[9]. Meanwhile, a 2026 re-analysis of Hubble Space Telescope ultraviolet datasets (1999-2020) confirmed a persistent hydrogen exosphere but found that earlier reports of transient water vapor plumes fell below a 90% confidence threshold -- underscoring the need to sound the ice shell directly via radar[10].

Bistatic Radar Methodology and the 2011-2024 Campaign

Planetary radar characterizes subsurface structure through two primary observables: total radar albedo (radar cross-section normalized by projected area) and the circular polarization ratio (C), defined as the ratio of returning echo power in the Same Sense (SC) circular polarization to that in the Opposite Sense (OC) channel[11][12]. Whereas single-bounce specular reflections off silicate bodies

reverse wave helicity -- yielding low radar albedos (<0.10) and C < 0.3 -- foundational observations by Steven Ostro et al. revealed that Europa's total radar albedo reaches 2.60 with C = 1.53, meaning returning echoes are dominated by intense multiple volume scattering[12][13].

| Target Body | | Typical Total Radar Albedo | | Typical Circular Polarization Ratio | | Primary Scattering Mechanism |

| Main-Belt Asteroids (e.g., Ceres, Pallas) | | 0.04 to 0.08 | | 0.05 to 0.10 | | Specular reflection off smooth regolith |

| Earth's Moon | | < 0.10 | | ~ 0.10 | | Single-bounce surface reflection |

| Ganymede (Galilean Moon) | | 1.39 | | 1.43 | | Moderate multiple volume scattering |

| Europa (Galilean Moon) | | 2.60 | | 1.53 | | Intense multiple volume scattering |

To measure how this backscatter varies across non-zero phase angles, Xie and Margot transmitted 450-500 kW of continuous-wave 8.56 GHz (3.5 cm) radiation from the 70-meter Goldstone DSS-14 antenna in California and recorded echoes simultaneously at Goldstone (monostatic, zero phase angle) and the 100-meter unblocked-aperture Green Bank Telescope in West Virginia (bistatic)[2][6][14][15].

| Campaign Specification | | Details |

| Transmitting Facility | | NASA Goldstone DSS-14 (California) |

| Receiving Facilities | | Goldstone DSS-14 & NSF Green Bank Telescope (West Virginia) |

| Antenna Diameters | | 70 meters (Goldstone) / 100 meters (Green Bank) |

| Transmitter Output Power | | ~450 - 500 kilowatts |

| Operating Frequency | | 8.56 Gigahertz (X-band) |

| Radar Wavelength | | 3.5 centimeters |

| Observation Modality | | Bistatic, Continuous Wave |

Coherent Backscatter, Mean Free Path, and Hemispheric Asymmetry

Europa's extreme radar reflectivity and polarization inversion are governed by the coherent backscatter opposition effect (CBOE)[2][4][18]. Because cold, pure water ice exhibits a very low dielectric loss tangent, 3.5-centimeter microwaves penetrate into the upper crust and undergo multiple Rayleigh and Mie scattering off centimeter-scale voids and fractures[11][17][19][20]. Along the exact retro-reflection vector, every internal multiple-scattering path interferes constructively with its time-reversed conjugate path, doubling backscatter intensity in the Same Sense polarization channel via circular polarization memory[12][18] -- a mechanism corroborated in terrestrial Ku- and X-band bistatic radar studies of Alpine snowpacks[16].

In radiative transfer theory, the angular half-width of the CBOE peak is inversely proportional to the transport mean free path within the medium[16][18]. Across the bistatic angles sampled between California and West Virginia, Europa's radar

brightness remained invariant, proving that the opposition peak is broader than the Earth-baseline angular separation[2][6]. This broad angular width constrains the 3.5-centimeter transport mean free path to a short distance (meters to tens of meters), demonstrating that Europa's shallow crust is densely packed with centimeter-scale fractures and pores[2][3][6].

Comparing the 2011-2024 dataset against 1987-1991 observations also confirmed decadal stability in disk-integrated scattering while revealing a tentative polarization-dependent brightness enhancement on Europa's trailing hemisphere[5][6]. Because Europa experiences tidal locking in synchronous rotation (85.2-hour period) inside Jupiter's rapidly rotating magnetosphere (10-hour period), energetic magnetospheric electrons and Io-derived sulfur and oxygen ions preferentially bombard the trailing hemisphere, driving radiolytic formation of hydrated sulfates and altering shallow dielectric structure[7][8][13].

Calibrating Orbital Sounding: Europa Clipper and JUICE

These Earth-based scattering constraints directly inform the ice-penetrating radar investigations aboard NASA's Europa Clipper (REASON) and ESA's Jupiter Icy Moons Explorer (RIME)[21][22]. Because centimeter-scale porosity generates intense shallow volume clutter at gigahertz frequencies, both REASON and RIME operate at a 9 MHz (33-meter wavelength) High Frequency band -- complemented on REASON by a 60 MHz (5-meter) VHF channel -- to bypass centimeter-scale scatterers and sound up to 9 kilometers toward the ice-ocean interface[21][22][23].

| Mission | | Spacecraft | | Radar Instrument | | Operating Frequencies | | Bandwidth | | Primary Antenna |

| NASA | | Europa Clipper | | REASON | | 9 MHz (HF) & 60 MHz (VHF) | | 1 MHz / 3 MHz (HF) | | 16-meter dipole (HF) |

| ESA | | JUICE | | RIME | | 9 MHz (HF) | | 1 MHz to 3 MHz | | 16-meter dipole |

Conclusion: Clearing the Path to the Subsurface Ocean

The 2011-2024 Goldstone-Green Bank bistatic radar campaign provides a definitive pre-arrival baseline for Galilean subsurface exploration. By leveraging high-power continuous-wave X-band transmissions alongside the 100-meter collecting aperture of the Green Bank Telescope, Xie and Margot's observations rigorously quantify how coherent backscatter opposition physics and circular polarization memory govern microwave reflection within low-loss, disordered planetary water ice[2][6][12]. Constraining the transport mean free path of 3.5-centimeter waves confirms that Europa's shallow crust is intensely fractured and porous across meter-to-decameter depths, while three-decade scattering stability and tentative trailing-hemisphere brightness enhancements underscore the persistent interplay between internal tidal tectonics and Jovian magnetospheric radiolysis[2][5][7]. Together, these empirical boundary conditions will enable the REASON and RIME radar sounders aboard Europa Clipper and JUICE to filter shallow volume clutter and resolve the deep ice-ocean interface[2][21][22].

Updates... (Nov 22, 2026): Corrected author attributions against CrossRef and OpenAlex metadata for Stefko et al. (2022) [16], Kofman, Orosei, & Pettinelli (2010)

[17], Mishchenko, Rosenbush, & Kiselev (2006) [18], and Scanlan et al. (2021) [21], and added exact publication dates across Works Cited.

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