N92-10849

SURFACE PROPERTIES OF GALILEAN SATELLITES FROM BISTATIC RADAR EXPERIMENTS

R.A. Simpson and G.L. Tyler
Center for Radar Astronomy, Stanford University, Stanford, CA

The icy moons of Jupiter were the first to show unusual radar backscatter behavior in earth-based experiments. Arecibo studies of Europa, Ganymede, and Callisto revealed strong echoes and a "reversed" sense of circular polarization (Campbell, *et al.*, 1978). In addition, no quasi-specular component has been detected to date, although that mechanism cannot be ruled out. Explanations have varied; dense hemispherical ice craters (Ostro and Pettengill, 1978), "crazed and fissured (surfaces) covered by jagged ice boulders" (Goldstein and Green, 1980), refractive scattering (Hagfors, *et al.*, 1985), mode decoupling (Eshleman, 1986a; Eshleman, 1986b; Eshleman, 1987), and bidirectional coherence (Hapke, 1990) have been proposed. No explanation has been entirely satisfactory because of the difficult constraints imposed by the existing data.

The (scalar) bidirectional coherence model (Hapke, 1990) predicts an opposition effect, or enhancement in the backscatter direction, resulting from coherent addition of backscatter from identical (but oppositely directed) ray paths (Fig. 1). The mode decoupling model yields a similar, vector result in which the observed polarization properties of the backscattered wave can also be obtained (Eshleman, 1986a; Eshleman, 1986b; Eshleman, 1987). The half-width of the enhanced backscatter lobe which results from either model, $\theta_B=\lambda/2\pi L$, may be related to a "photon diffusion length" L in the medium which can be measured by performing bistatic experiments (Hapke, 1990).

We have considered the possibilities for conducting such experiments using the Galileo spacecraft, now en route to Jupiter. Both conventional oblique-forward bistatic experiments (to determine basic electrical and physical properties of the surface material on centimeter-meter scales) and near-backscatter experiments (to sample the enhanced backscatter lobe) have been considered.

The forward scatter conditions in a conventional downlink bistatic experiment with Galileo are illustrated in Fig. 2. In this example the spacecraft approaches the earth-facing hemisphere of Europa at approximately 6.2 km/sec and passes within 152 km of the surface before continuing on (proposed Galileo tour 83-01, Europa encounter #4). The angle of incidence changes by one degree every six seconds 1-2 minutes before closest approach (ϕ=77.91° at t=0; Fig. 2a). At λ=3.6 cm (X-band) intrinsic Doppler spread-

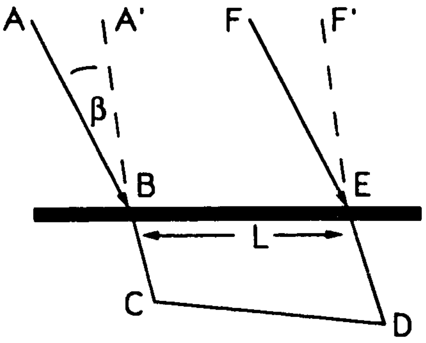

Fig. 1: The bidirectional coherent backscatter model predicts enhancement because waves traveling along path ABCDEF and along FEDCBA add coherently at the receiver. For such enhancement in a bistatic configuration, angle β must be small enough that paths A'BCDEF and F'EDCBA differ by no more than a small fraction of the wavelength λ. Measuring the angle β at which the enhancement has been reduced by 50% gives the photon diffusion length L in the material.

ing for the assumed rms surface slope (ξ=5.7°) exceeds 36 kHz during the encounter, but the narrow spacecraft antenna beamwidth limits the observed spread to about 2700 Hz. The strength of the echo signal, as well as its width, is also reduced because of the narrow antenna beam. The detectability[1] is plotted in Fig. 2d for both wavelengths[2] available to Galileo and for both circular polarizations received on the ground, assuming right-circularly polarized (RCP) waves are transmitted (an elliptically polarized wave is actually transmitted at S-band). The detectability at the two wavelengths is similar until about 1700 seconds after closest approach, when the beam-limiting ceases to be a factor at S-band (beam limiting continues at X-band until about 7000 sec)[3]. Detection of the Brewster angle (ϕ_B=51.7° for assumed dielectric constant ε=1.6) would independently confirm estimates of surface dielectric constant derived from overall echo strength. Passage through the Brewster angle occurs, however, during one of the times when the signal is most dynamic ($t \approx -170$ sec).

In a near-backscatter geometry Galileo can be used to probe the anomalous backscatter lobe -- mapping its strength as a function of the bistatic angle β within a few degrees of zero. Various combinations of frequencies and receiving sites give detectabilities $0.1 < D < 0.8$ for these echoes when we assume that the spacecraft antenna (half-power half-beamwidth θ_T) underilluminates the satellite disk (radius R_p at distance d from the spacecraft), that the radar cross section for the illuminated area is $\sigma \approx \pi(d\theta_T)^2\eta(\beta)$, and that $\eta \approx 1$ for $\beta = 0$. The underillumination condition is satisfied when the spacecraft to target distance is $d \leq R_p/\theta_T$. In the Europa encounter used here, Galileo X-band sampling of the backscatter lobe is thus possible for $d \leq 3\ 10^8$ m, and more than 12 hours are available prior to closest approach during which $\eta(\beta)$ can be investigated. Averaging many measurements would increase the "effective" detectability above the $0.1 < D < 0.8$ level for one second observations.

- -

Campbell, D. B., J. F. Chandler, S. J. Ostro, G. H. Pettengill and I. I. Shapiro (1978). Galilean satellites: 1976 radar results. *Icarus* **34**, 254-267.

Eshleman, V. R. (1986a). Mode decoupling during retrorefraction as an explanation for bizarre radar echoes from icy moons. *Nature* **319**, 755-757.

Eshleman, V. R. (1986b). Radar glory from buried craters on icy moons. *Science* **234**, 587-590.

Eshleman, V. R. (1987). The radar-glory theory for icy moons with implications for radar mapping. *Adv. Space Sci.* **7**, 133-136.

Goldstein, R. M. and R. R. Green (1980). Ganymede: radar surface characteristics. *Science* **207**, 179-180.

Hagfors, T., T. Gold and M. Ierkic (1985). Refraction scattering origin of the anomalous radar returns of Jupiter's satellites. *Nature* **315**, 637-640.

Hapke, B. (1990). Coherent backscattering and the radar characteristics of the outer planet satellites. *Icarus* **88**, 407-417.

Ostro, S. J. and G. H. Pettengill (1978). Icy craters on the Galilean satellites? *Icarus* **34**, 268-279.

---

[1] Detectability D is defined as the ratio of received echo power at a 70-m antenna of NASA's Deep Space Network to the receiver noise power in the bandwidth occupied by the echo signal multiplied by the square root of the bandwidth (one second measurements).

[2] The second wavelength is 13.1 cm (S-band)

[3] For comparison, Viking bistatic echoes from Mars were highly useful at the D~20 dB level.

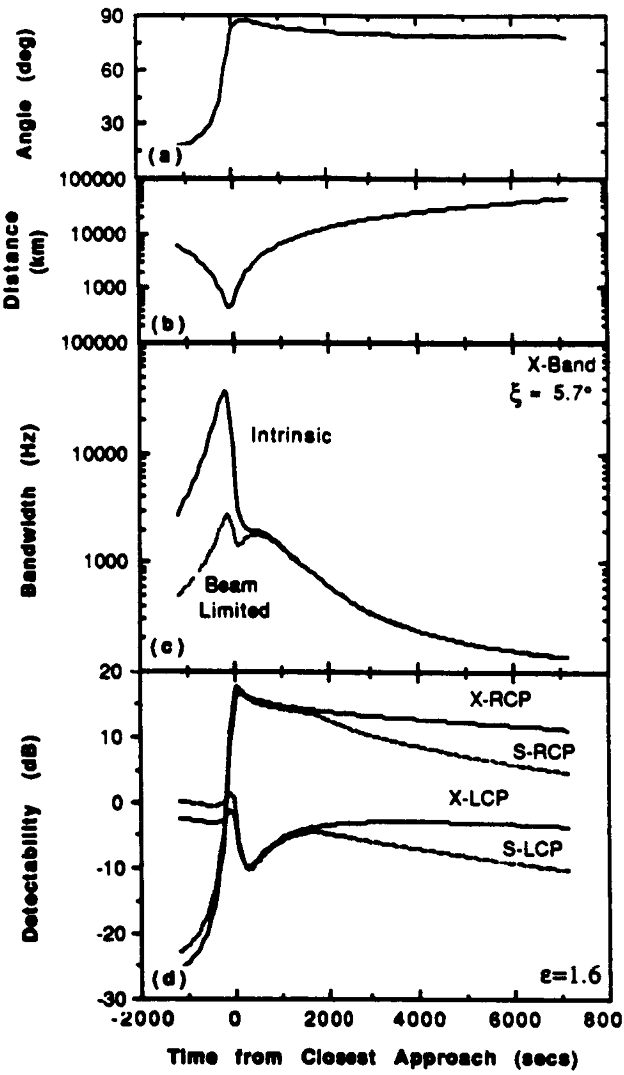

Fig. 2: Galileo bistatic geometry and performance for a hypothetical close Europa encounter (Europa encounter #4 of proposed tour 83-01). At closest approach the spacecraft is 152 km above Europa's surface, moving at 6.2 km/sec. The incidence angle (a) at closest approach is 77.91° and is increasing at 0.12°/sec. Slant range to the specular point is shown in panel (b). Doppler spreading of the intrinsic echo signal (without regard to the spacecraft antenna pattern) reaches 36 kHz (c), but the antenna beam reduces the observed echo width to about 2700 Hz. The detectability of the echo signal D is maximum shortly after closest approach (d), but less dynamic observing conditions an hour or more later may facilitate observations.