GROUNDBASED RADAR RECONNAISSANCE OF EUROPA; S . J . Ost 1o, JPL/Caltech

1 t has been known for 20 years that the radar echoes from Europa, Ganymede , and Calli st_o are extraordinarily different from those of other radar - detected solar system targets and that Europa ' s signature is the most extreme of all . 1 '11 summarize the available observations, outline our understanding of them, anti preview investigations that can be conducted during the next. decade.

At wavelengths of 3.5 and 13 c:m, when the radar transmission is circularly polarized, the icy satellites ret-urn echoes with the incident handedness preserved: The circular polarization ratio, of echo power in the same sense of circular polarization as transmitted (the SC sense) to that in the opposite (OC) sense, is about, 1 .5, 1 .4, and 1.2 for Europa, Ganymede and Callisto (l), in contrast with only ~0.1 for the Moon and less than 0.4 for most other planetary radar targets. The linear polarization ratio (01,/S1,) is about one half for all three sat. ellites, again considerably larger than for other targets. The satellites' radar backscattering law at these wavelengths is in bet, ween geometric: and Lambertian, with Europa ' s the closest to Lambertian.

As shown in the following table, the satellites' 3.5- and 13- cm radar albedoes (radar cross section divided by target projected area) arc? enormous compared t-o the Moon's. However, t-he albedoes plummet from 13 cm to "/0 cm, with Europa showing t_he most precipitous drop. [References for the lunar results can be found in (2,3), the Galilean satellite '/0- cm results arc! from (4), and the rest. of the results are from (l).]

Total- Power (OC+ SC) Radar Albedo

λ cm	Europa	Ganymede	Callisto	Moon
3.5	2.34 0.4	1.6 ± 0.2	0."1 ± 0.1	0.08 + 0.02
13	2.6 ± 0.2	1.4 ± 0.1	0.'/ ± 0.1	0.08 ± 0.02
70	< 0.3	0.4 ±0.1	< 0.2	0.08 ± 0.02

A sequence of Doppler echo spectra that provides good rotational coverage can be inverted to constrain the global distribution of albedo (5) . Results indicate that the satellites' albedo dispersions increase in the order Callisto -> Ganymede -> Europa. Virtually all of Europa is brighter than the brightest regions on Callisto, and about half of Europa is brighter than the brightest, regions on Ganymede. The brightest regions on Europa are located at temperate latitudes (1) .

The icy *satellites'* echoes are due not to external surface reflections but to subsurface volume scattering. The high radar transparency of ice compared with that of silicates permits deeper radar sounding, longer photon path lengths, and higher-order scattering from randomly disordered regolith heterogeneities -- radar is seeing Europa, Ganymede, and Callisto in a way that the Moon has never been seen (6) . As first suggested by Hapke (-/),

the sat ellites' radar behavior apparently involves the coherent backscatter effect, which, as discussed by (8), "is a universal physics] phenomenon, accom pani es any mu] tipl e- scat teri ng process, and occurs for particles of any si ze, shape, and refractive index." His calculations of the radar signature of a homogeneous, semi- infinite scattering medium of polydisperse spherical part icles demonst rate that. such a model can explain the satellites' backscattering properties anti also that. many combinations of free parameters can yield the same properties, even within the context of the model 's assumptions .

It. seems likely that. at least the uppermost few meters of Europa's surface is extremely clean (and perhaps rather porous) i ce and posse sses density variations (particles?) at structural scales that produce efficient. multiple scattering of 3.5-to- 13- cm waves. The severe drop in Europa 's albedo from 13 cm to 70 cm indicates that multiple Scattering has become drastically less efficient. at the longer wavelength]. 70- cm waves are expected penetrate further into either ice or rock than arc shorter wavelengths. Perhaps there has not been enough time since Europa was last flooded for meteoritic bombardment to create heterogeneities at the larger scales.

There are similarities between the icy Galilean satellites' radar properti es ancl those of the radar- bright polar caps on Mars (9), features inside perpetually shadowed craters at the poles of Mercury (10), anti the percolation zone in the Greenland ice sheet (11,12). However, the subsurface configuration in the Greenland zone, where heterogeneities are the product of seasonal melting anti refreezing, are unlikely to resemble those on the satellites, demonstrating that a variety of natural subsurface configurations can yield similar radar signatures.

Observations' of Europa with the upgraded Arecibo radar will be possible during 1999-2004, after Jupiter returns to northern declinations. It. should be possible to obtain range measurements with uncertainties approaching 1 km as well as refined constraints on the global albedo distribution. New '/0- cm measurements are also desirable.

REFERENCES

(1) Ostro, S. J., et al. (1992), .7. *Geophys.Res.* 97, 1822'/.
(2) Pettengill, G. H. (19"/8), *Ann. Rev.Astron.Astrophys* 17, 265.
(3) Harmon, J. K., and S. J. Ostro (1985), *Icarus* 62, 110.
(4) Black, G. J., D. B. *Campbell, S.* J. Ostro (1996), LPSC Abstracts 27, 121 .
(5) Hudson, R. S., and S. J. Ostro (1990), *J. Geophys. Res.* 95(B7), 1094"/.
(6) Ostro, S. J., anti E. M. Shoemaker (1990), *Icarus* 85, 335.
(7) Hapke, B. (1990), *Icarus* 88, 407.
(8) Mishchenko, M. 1 . (1996), *J. Quant. Spectrosc. Radiat.Transfer*, in press.
(9) Muhleman, D. O., B. J. Butler, A. W. Grossman, and M. A. Slade (1 991) , *Science* 253, 1508.
(10) Harmon, J. K., anti M. A. Slad e (1992), *Science* 258, 640.
(11) Rignot, E. J., et al . (1993), *Science* 261, 1710.
(12) Rignot, E. J. (1995), *J. Geophys. Res.* 100, 9389.