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The Glitter of Distant Seas

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It has long been known that Saturn's largest moon, Titan, has a thick nitrogen atmosphere, which obscures the underlying surface. In his Perspective, Lorenz highlights the report by Campbell *et al*., who have used the giant Arecibo and Green Bank radio telescopes as a radar to probe Titan's hidden surface. The surface appears to be distinct from those of the icy satellites of Jupiter, in both brightness and polarization. The new data show sharp spikes in the reflected microwave spectrum, indicating large, smooth areas of radar-dark material. These features suggest the widespread existence of lakes or seas of liquid hydrocarbons on Titan.

In *Star Wars*, a gas giant's jungle moon, Yavin 4, drifts inexorably into the powerful beam of the Death Star. This scene closely mirrors a recent development in radar astronomy. Planetary alignments now expose Saturn's giant, haze-shrouded moon Titan to the recently upgraded 300-m Arecibo radar dish.

Campbell *et al*. have used this dish to blast Titan with hundreds of kilowatts of microwave power. As they report on page xxxx of this issue (*1*), 2 hours later they received a faint echo at the rebuilt 100-m Green Bank radio telescope. Because the results have a much higher signal-to-noise ratio than previous efforts with smaller dishes (*2*, *3*), they carry much more information. The results confirm that Titan is like nowhere else in the solar system (*4*).

It has been known for 60 years that Titan, between Mercury and Mars in size, has a thick atmosphere. The source of this atmosphere—the only thick nitrogen atmosphere in the solar system apart from the one we are breathing—is not yet understood. Clues to its origin and evolution doubtless lie beneath on Titan's hidden surface.

Water ice is prevalent on moons in the outer solar system. Titan's bulk density is between that of rock and water, suggesting that its solid surface should be made of ice. However, this ice, if it is there, may be obscured by other materials. Titan's thick atmosphere contains a photochemical haze of methane and other hydrocarbons, which drizzle down to accumulate on the surface. The resulting hydrocarbon layer may be many hundreds of meters thick.

A decade ago, radar observations (*2*, *3*) pointed to an icy (but dirty) surface, but ruled out a deep global ocean (*5*, *6*) of ethane and methane on Titan. More recently, near-infrared images (*7*, *8*) have shown that Titan's surface is heterogeneous, a characteristic reproduced in the new radar data reported by Campbell *et al.* (*1*). The radar albedo correlates well with the infrared albedo: The large infrared-bright region on Titan's leading side (*7*) is also the place where the diffuse part of the radar echo is strongest.

Exactly what "bright" and "dark" mean for Titan's constitution (*9*) is not clear. Last year, Black *et al*. reported (*10*) that the optically bright side of Saturn's satellite Iapetus is radar-dark, much like the surface of Titan. The texture and composition of these moons—which might also be found in other Saturnian moons—must be different from the clean, cold ice that makes Jupiter's icy satellites up to 15 times brighter than Titan to radar. Perhaps ammonia, a microwave-absorbing nitrogen compound that may have been the source of Titan's atmosphere, is locked in ices on Titan and Iapetus, making them radar-dark but optically bright. As for Titan's dark regions, quantitative analysis (*8*) of infrared data suggests that they are <5% reflective, consistent with organic matter like tar or seas of liquid hydrocarbons.

This interpretation is consistent with the most striking feature in the new radar data: the transient sharp spikes in the reflected spectrum, which suggest specular reflections (see the figure) from smooth, dark areas 50 to 150 km across. These features may be impact craters—of which, extrapolating from other Saturnian moons (*11*), one might expect around 80 with a diameter of 150 km and thousands of smaller ones—that have filled to form lakes and seas (*12*). The radar data suggest that as much as 75% of Titan's surface could be covered in this way.

Further subtleties and surprises will undoubtedly emerge from further studies, and no single data set is unambiguous. The conversion of infrared observations (*13*) into reflectivities that can be compared with laboratory materials is hampered by uncertainties in the absorption by atmospheric methane and the absorption and scattering by the haze. Furthermore, these effects themselves are not uniform across Titan, which has a strong seasonal cycle. The existence of discrete, time-variable methane clouds beneath the haze poses another challenge to infrared observations.

In contrast, radar can penetrate the atmosphere completely, returning an echo from the surface and perhaps the first few meters below it. Like fishermen using polarized sunglasses, surface reflections can be discriminated from subsurface scattering using the polarization of the radar echo. Campbell *et al*. found a low polarization ratio for Titan, suggesting that most of the echo is from surface reflection. In contrast, highly polarized radar echoes have been received from the icy Galilean satellites, where subsurface scattering is important.

Better signal-to-noise ratios and spatial resolution are needed to make more confident interpretations. The limits of what can be achieved from Earth have essentially been reached. Further advances can be expected when the Cassini spacecraft makes its first close reconnaissance of Titan in October 2004—the first of over 40 flybys in its 4-year nominal mission.

The Cassini-Huygens mission will investigate Titan with optical, infrared, and radar remote sensing—the first time all three techniques have been used simultaneously to explore a planetary or lunar surface. In January 2005, the Huygens probe will parachute down through the haze to one of Titan's darker spots. The radar data of Campbell *et al.* (*1*) suggest that on Titan itself, as well as in the terrestrial media, this event will make quite a splash.

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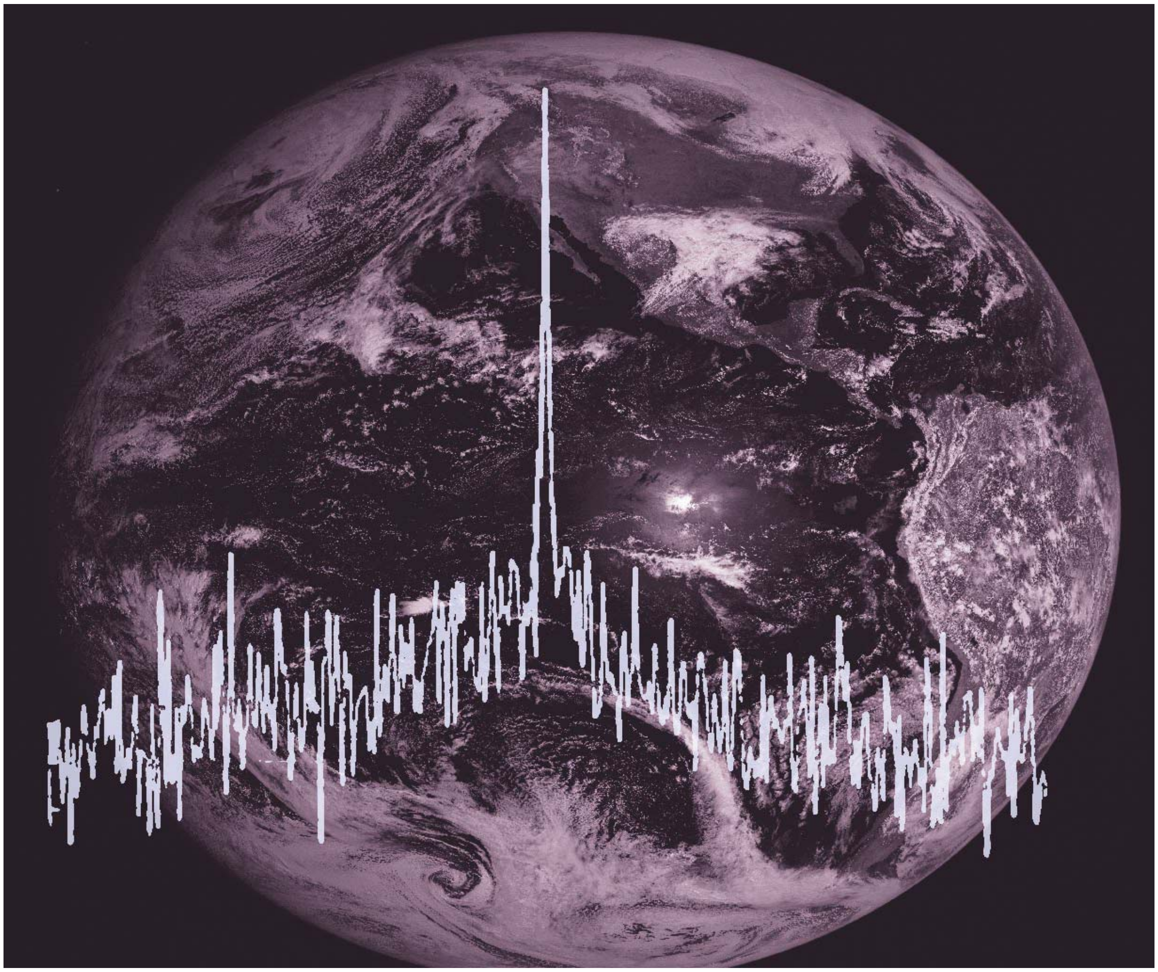
Reflections on two complex worlds. The optical image of Earth was acquired by the GOES meteorological satellite. Clouds have a higher albedo than land, which in turn is brighter than the ocean, except for the striking specular reflection of the Sun just to the right of the center. Titan, with its heterogeneous surface and tropospheric clouds, is likely to present a similar range of optical appearance. The backdrop curve, a radar spectrum of Titan from Campbell *et al.* (*1*), is a one-dimensional equivalent of the Earth image. The sharp spike indicates a strong specular reflection from a smooth surface, probably a hydrocarbon sea, on Titan.



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