ANOMALOUS RADAR BACKSCATTER FROM TITAN'S XANADU M.A. Janssen[1], A. Le Gall[1], L.C. Wye[2], H.A. Zebker[2], R.D. Lorenz[3], P. Paillou[4], F. Paganelli[5], and the Cassini Radar Team. [1] Jet Propulsion Laboratory, California Institute of Technology, Pasadena, CA, [2] Department of Electrical Engineering, Stanford University, Palo Alto CA, [3]Johns Hopkins University Applied Physics Lab, MD, [4] Laboratoire d'Astrophysique de Bordeaux, Floirac, France, [5] Proxemy Research, MD

Introduction and Summary: The comparison of an observed surface's microwave reflectivity and its passive emission directly addresses the relationship of the measured radar backscatter to the overall reflective properties of the surface. The simultaneous radiometry and radar reflectivity obtained by the Cassini Radar instrument has uniquely allowed us to investigate the backscattering enhancement of much of Titan's surface. In this paper we compare one region of Titan with other surfaces in the solar system, particularly those of the icy satellites of the outer planets. These latter surfaces are well known for their unique properties for the scattering of electromagnetic radiation; in particular, they exhibit such enhanced backscattering and unusual polarization compared to the incident signal that their behavior has been called "bizarre" compared to other surfaces in the solar system. Regions of Titan's surface such as Xanadu exhibit reflectivities comparable to those measured for the icy satellites, leading one to suspect that similar mechanisms are at work. However, in this paper we use the simultaneously measured microwave emission to show that the backscattering enhancement for at least these regions is significantly larger than that for the icy satellites, behavior that is bizarre even in this select company and likely requiring new explanations in terms of surface properties.

Scattering Models: Several models have been proposed with varying degrees of success to explain both the high reflectivity and polarization of radar returns from the icy satellites of Jupiter and Saturn (cf ref. 1). The coherent backscatter model [2] has received the most attention and postulates a volume scattering model based on the presence of generalized wavelength-scale scattering centers distributed within a low-loss medium such as low-temperature water ice. The resulting multiple scattering effectively depolarizes the incident wave so that the reflected radiation is generally depolarized. However, the existence of identical paired paths at zero phase angle leads to coherent reinforcement in the backscattering direction that can be shown to increase the backscattered power by a factor of two; further, the polarization of the net backscattered radiation is consistent with the otherwise unexplained asymmetric values observed in the icy satellites.

The reflectivity of a surface, or the total power scattered from a surface for a wave incident from a given direction, is the complement of the emissivity in that direction (Kirchoff's law of radiation). Zebker et al. have derived a relationship between emissivity and *backscattered* power for the coherent backscattering model [3] that depends on general factors such as the angle of incidence, the surface reflection, and the cross section for volume scattering along with its angular distribution (e.g., $f \cos \theta^n$). We use this formulation as the basis for our comparison in the following. While several solar system bodies more or less follow this model's predictions relating brightness temperature and backscatter power, the bright regions on Titan are brighter even than this model predicts.

Data: The Cassini Radar instrument acquires radiometric data at 2.2-cm wavelength in all instrument modes [4]. The radiometer measures the thermal emission from Titan's surface, and has been absolutely calibrated to better than 2 K [5]. The active data obtained in synthetic aperture (SAR) mode have been reduced to obtain high-resolution maps in terms of radar cross section per map pixel compared to an isotropically scattering surface, calibrated to about 1.3 dB (35%) per pixel, neglecting speckle [6]. For the purpose of comparison with the radiometry, which is necessarily obtained with real aperture resolution, the SAR maps have been convolved with their respective real-aperture beams at times coincident with each radiometric integration of ~1 sec duration. This averaging reduces the radar speckle noise to negligible level, while the measurement noise in each radiometric measurement is about 0.1 K. The minimum real-aperture footprint in SAR mode is about 6 km.

Discussion: The relationship between emissivity and backscattering cross section for icy satellites and the Xanadu region of Titan is compared in Fig. 1. The values for the icy satellites are taken from Ostro et al. [7]. These refer to whole-disk measurements made at wavelengths from 3 to 13 cm at both circular and linear polarizations for the Jovian satellites, and at 2.2 cm for Saturn's satellites in same-linear polarization using the Cassini radar, and have been adjusted here to give our best estimates of the same linear cross sections near normal incidence. The blue points are from the SAR swath data from Xanadu obtained in the T13 pass and are based on matched σ^0 and brightness temperature measurements as described above. Emissivities for these points were obtained assuming a surface temperature of 93.6 K.

The solid line is based on a coherent backscatter thermal model using the Zebker et al. formulation for a surface with assumed isotropic volume scattering (i.e., n = 1 in the above equation) and no surface reflection (consistent with the lack of polarization seen in the thermal emission from Xanadu [5] but debatable based on scatterometry observations near normal incidence [8]). The volume scattering parameter f is allowed to vary to produce the dependences on emissivity and σ^0. The slope of the curve is only weakly dependent on the assumed value of n and insignificant in the present context.

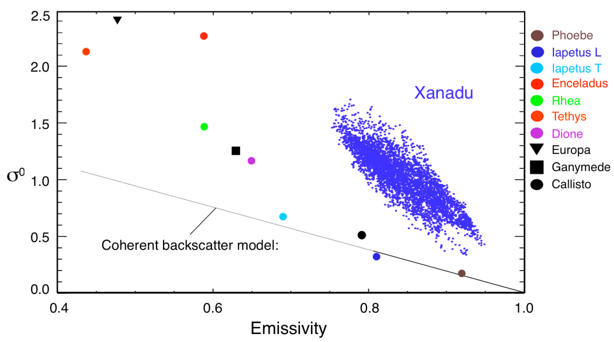

Fig. 1: Relation between measured backscatter and emissivity for the icy satellites and by Cassini in SAR mode during the T13 pass. Most of the T13 pass was through Xanadu, and all of the points shown were selected to lie within its nominal boundary. The solid line shows a thermal emission model [3] for a coherent backscattering surface [2]. Beyond the observation that the backscattering from Xanadu must be highly enhanced with respect to this model, the difference shown here is unexplained.

Allowing for reasonable uncertainties (~50 %), the values for the icy satellites are mostly consistent with the coherent backscatter thermal model, although there is a distinct trend toward more enhanced backscatter as emissivity decreases. The Xanadu values are clearly inconsistent with this model, however, failing by at least a factor of three to match the observed slope.

Conclusions: The results show that, irrespective of any theoretical arguments to the contrary, radar backscattering from Xanadu at 2-cm wavelength must be significantly enhanced, even compared to the coherent backscatter model. In particular, if the bistatic reflection (i.e., off zero phase) on average were to be anything approaching ½ of the observed backscatter, Kirchoff's law would insist that the emissivity be smaller than observed.

There are many mechanisms that produce backscattering that is enhanced over the factor of two that arises from the coherent backscatter model (cf ref 9); e.g., although obviously implausible, an array of corner cubes could produce a huge enhancement. Such mechanisms generally involve single scattering models, in which case polarization would be preserved in the reflection. This would help explain a factor of two in the enhancement since Kirchoff's law would not have to account for the reflected power in the second polarization, although we lose this factor again if the coherent backscattering model is not otherwise applicable.

A companion paper [10] discusses the possible presence of ice spheroids such as might be found in fluvial deposits. Transparent spheres are well known to produce a backscatter enhancement approaching that of corner cube reflectors, an effect that is exploited for example in the manufacture of reflective paint. Nevertheless, it remains to be argued whether this or other as yet unexplored mechanisms are plausible over the full extent of Xanadu (and other regions on Titan that may display this enhancement). In summary, the surface of Xanadu appears to become "curiouser and curiouser" as we continue to investigate it, and caution must be applied to any presumption that it may be understood from simple models based on limited data sets.

Acknowledgement: This research was conducted at the Jet Propulsion Laboratory (JPL), California Institute of Technology, under contract with the National Aeronautics and Space Administration (NASA). We gratefully acknowledge those who designed, developed and operate the Cassini/Huygens mission, which is a joint endeavor of NASA, the European Space Agency (ESA), and the Italian Space Agency (ASI) and is managed by JPL/Caltech under a contract with NASA.

References: [1] Hagfors et al. (1997) *Icarus, 130*, 313-322, [2] Hapke (1990) *Icarus, 88*, 407-417, [3] Zebker et al. (2008) *Icarus, 194*, 704-710, [4] Elachi et al., 2004) *Space Science Reviews 115,* 71-110, [5] Janssen M.A. et al. *Icarus* (2008), doi:10.1016/j.icarus.2008.10.017, [6] West et al., (2008) *IEEE Trans. Geosci. Remote Sensing, in press*, [7] Ostro et al. (2006) *Icarus, 183*, 479-490, [8] Wye (2008), AGU Fall Meeting, P21A-1318 (abstract) [9] Ulaby et al., Microwave Remote Sensing, vol II (1982), Addison-Wesley, NY, 771-779, [10] Le Gall et al. (2009), this meeting.