PARABOLIC EJECTA FEATURES ON TITAN ? PROBABLY NOT

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Radar mapping of Venus by Magellan indicated a number of dark parabolic features, associated with impact craters. A suggested [1] mechanism for generating such features is that ejecta from the impact event is 'winnowed' by the zonal wind field, with smaller ejecta particles falling out of the atmosphere more slowly, and hence drifting further. What discriminates such features from simple wind streaks is the 'stingray' or parabolic shape. This is due to the ejecta's spatial distribution prior to being winnowed during fallout, and this distribution is generated by the explosion plume of the impact piercing the atmosphere, allowing the ejecta to disperse pseudoballistically before re-entering the atmosphere, decelerating to terminal velocity and then being winnowed. Here we apply this model to Titan, which has a zonal wind field similar to that of Venus. We find that Cassini will probably not find parabolic features, as the winds stretch the deposition so far that ejecta will form streaks or bands instead.

The first requirement for such features is the generation of an atmosphere-piercing impact. The minimum projectile radius required is $a_p=H(P_0/S\rho_p v^2)^{1/3\gamma}$ with P_0 the surface atmospheric pressure (0.15 MPa), γ the ratio of specific heats (1.4), S a constant (1.6 for ice - see [2] Table AII.2), ρ_p the projectile density (1000 kgm^{-3}) and v the impact velocity (10 kms^{-1}) and scale height H=20km. This gives a_p~730m (close to the value for Venus, 680m [1]) Coincidentally, impactors smaller than this break up in the atmosphere before reaching the surface (crater densities on Titan turn down at diameters < 20km due to atmospheric shielding [3]). It therefore follows that most craters on Titan's surface represent atmosphere-piercing events, and hence might form parabolic ejecta features.

<u>Initial Ejecta Dispersal</u> The ejecta distribution prior to winnowing is the most uncertain aspect of this modelling. Bounds on the altitude of the ejecta are zero, and the altitude h_{term} at which a re-entering particle slows to terminal velocity. This altitude is fairly insensitive [1] to entry angle and velocity and was computed by integrating the equations of motion for entering particles and using a fit to a Titan atmosphere model [4] : results are given in table 1, together with the corresponding numbers for Venus.

The altitudes for Titan and Venus have about the same value of PH/2.6, where P and H are the pressure and scale height at that altitude - and the factor 2.6 reflects that silicate impactors were considered for Venus, whereas ice is more probable for Titan. This is consistent with the altitude depending principally on the column mass of atmosphere above it. The considerably larger scale height, and the rapid increase of scale height with altitude above 50km, make the altitudes for Titan considerably higher than for Venus.

These figures and zero define the vertical range over which particles may be deposited. The horizontal range is rather harder to define. From a point explosion, ejecta of this size would be decelerated extremely rapidly by the surface atmospheric pressure, so their deposition must be mediated to some extent by the expanding plume and/or the 'tunnel' in the atmosphere carved by the hypersonic impactor. Newman et al. [5] showed that the blast wave from a surface explosion would only travel π times the scale height laterally, yet [1] found that a minimum radius of ~100km gave the best fit for ejecta deposition patterns on Venus (where πH is ~50km). Thus ballistic transport must play some role.

On Titan, πH near the surface is also ~50km. However, ballistic ranges on Titan for particles of a given ejection velocity are longer by a factor $\sqrt{(8.6/1.2)}$~2.67. Additionally, the small radius of Titan increases the ground-projected range of ejecta - e.g. the 'flat Titan' range of ejecta at 100 ms^{-1} is 740km, but when the spherical geometry is taken into account, the range is 860km. Thus, to a first order, one might expect ballistic ranges for the same ejection speeds to be ~3 times longer on Titan than on Venus.

However, Titan's much larger scale height at high altitude (20-50km vs. 5-7km on Venus) suggests ejecta on Titan might be retarded more during what might be considered on Venus an exoatmospheric (ballistic) part of the trajectory. Thus lateral transport of ejecta prior to winnowing might be rather smaller on Titan. To a first order, then, we consider horizontal displacements to be the same.

[1] used a power law for the radial distribution of mean particle size $d=d_c(r/r_c)^{\alpha}$, with d the mean particle size at distance r from the crater, radius r_c: d_c is a scale size. [6] found for Venus, α~2.65, somewhat larger than the 2-2.5 range suggested for the Earth by [1]. Notionally, one might expect the value for Titan to be closer to that of Venus than that of Earth. If parabolae are detected on Titan and the value for α estimated, this might help better understand

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how the atmosphere controls the distribution of ejecta (due, presumably, to both acceleration in the impact plume, and atmospheric deceleration after leaving the plume).

Wind Displacement The displacement D_{win} of a falling ejecta particle is computed by summing displacement increments during its descent: each displacement increment equals the product of the fall time over some altitude interval (10km) and the zonal wind speed. The displacements in km calculated for Titan using a wind model in [7] and release altitudes of (a) terminal altitude and (b) an arbitary 50km are shown in table 2. Values for 50km on Venus [1] are shown for comparison.

Table 1. Terminal Velocity Altitude and Wind Displacement of Ejecta Particles (km)

Particle Diameter (cm)	Venus h_{term}	Titan h_{term}	Titan D_{win} (h_{term})	Titan D_{win} (50km)	Venus D_{win} (50km)
10	53	71	100	70	40
1	67	135	418	270	180
.1	78	223	3650	1720	600
.01	87	362	38,000	21,000	8000
.001	96	525	1.7 million	1.3 million	200,000

Thus, even if the ejecta is released from as low as 50km, particles smaller than 1mm in diameter will be transported of the order of 1 planetary radius zonally. Compared with Venus, ejecta is transported considerably farther in a zonal direction. A very large impact on Titan might produce a fallout streak that girdles the planet, forming a zonal band of material. Note that such a band would not appear in the recently-published map of Titan [8], since the background image subtracted from each frame used to make the map is a zonal average.

Conclusions : Feature Morphology and Detectability Titan's zonal wind will disperse ejecta much more effectively than Venus' wind, even if the vertical distribution of ejecta is not extended (as it might well be). Small impact events will lead to simple streaks of ejecta particles deposited on the surface, probably extending to zonal bands. Events violent enough to produce meridonal (N-S) dispersions large enough to be comparable with the zonal dispersions introduced by the wind field would essentially deposit material globally, and a parabolic shape would probably not be recognized.

An impact event might distribute bright crustal material (fresh ice) over the surface of Titan. Impact events large enough (crater diameter >20km) to cause atmosphere-piercing events occur at a rate of only $4x10^{-15}$ $km^{-2}yr^{-1}$ [9], or once every 3 Myr. But, the darkening timescale of surface material due to deposition of photochemical aerosols is ~30 kyr. Thus optical detection of the winnowed ejecta from an impact seems unlikely.

The parabolic features were detected on Venus by radar, and the Cassini mission carries a radar mapper which will cover 15-30% of the surface. The dimensions of 19 halos on the Venusian surface have been reproduced [6] by the 1cm ejecta thickness contour generated by a model [1]. If a similar backscatter contrast between the original surface and the deposited ejecta exists on both Venus and Titan, then there is hope for detecting similar thicknesses of ejecta. However, Venus' surface is very young - if Titan's surface is older (with more abundant regolith), it may be difficult to discriminate ejecta deposits from the background.

Thus, while notional ideas of similarity suggest that parabolic features might be found on Titan, and analysis of such features would be instructive in understanding the impact process, more detailed considerations indicate that the Titan atmosphere may be too extended to allow parabolic features to form, and if they exist, they may be difficult to detect with anticipated Cassini observations.

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