CRATERING ON TITAN: PROJECTILES, CRATERS AND IMPACT MELT. N. Artemieva\textsuperscript{1} and J. Lunine\textsuperscript{2}, 
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Introducion: In July 2004, NASA’s Cassini spacecraft will reach Saturn and on-board instruments will allow us to take a detailed look at the surface of the largest Saturn’s moon, Titan. Later, in January 2005, planetary scientists will get even a closer look at Titan’s atmosphere and surface when the European Space Agency’s Huygens probe floats to the surface (http://saturn.jpl.nasa.gov/index.cfm).

Titan is the only natural satellite in the solar system that possesses an extensive, thick atmosphere. It also exhibits a surface that, on scales of hundreds of kilometers, is highly variegated, with very dark areas that in whole or in part could be layers of organic detritus from the prodigious methane photochemistry of the stratosphere \cite{1}. We continue our three-dimensional hydrodynamic simulations of hypervelocity cometary impacts into the atmosphere and the crust of Titan \cite{2} to determine the projectile fate, the cratering growth and the melt production after an impact of strongly disrupted and dispersed projectile, mixing of organic material with melt and their possible ejection into space. We also estimate cooling history of the melt layer and the total amount of melt on the surface, based on the Titan’s impact rate \cite{3}.

Numerical methods. The 3D simulations of oblique impacts are carried out using the SOVA hydrocode \cite{4}. SOVA is a two-step Eulerian code that can model multidimensional, multi-material, large deformation, and strong shock wave physics. The code allows to model particle motion in the evolving ejecta-gas plume in the frame of multi-phase gasdynamics \cite{5}: each particle is characterized by its individual parameters (mass, density, shape, position, velocity) and exchanges momentum and energy with a surrounding vapor-air mixture. The later stage of crater collapse is modeled with the 2D SALEB hydrocode \cite{6,7}, which includes a strength routine that employs different failure mechanisms to treat solid materials, including gradual shear damage accumulation, thermal softening, and acoustic fluidization. Both codes are coupled to ANEOS-derived \cite{8} equation of state tables for the materials used. A few millions of tracers (massless particles) are used to reconstruct dynamic (trajectories, velocities), and thermodynamic (pressure, temperature) histories in any part of the cratering flow.

Passage of the projectile through atmosphere. Simple estimate with the “pancake” model \cite{9} of comet disruption shows that for the projectiles larger than 1 km-in diameter some atmospheric influence does exist, but it is not strong enough to change the impact velocity and impact angle \cite{2}. However, numerical modeling of a 2-km-diameter comet flight with initial velocity of 7-11 km/s reveals strong deformations below an altitude of 20 km (Fig.1). Not a spherical, but a pancake-shaped comet strikes the surface, creating more shallow and elongated crater.

![Fig.1: Passage of a 2-km-diameter 11 km/s comet through Titan’s atmosphere and an impact by pancake-shaped comet. The projectile is in gray color, Titan’s surface is green, and Titan’s atmosphere – yellow.](image_url)

Melt production in a single impact event. The ANEOS-based shock pressures for incipient melting, complete melting and incipient vaporization of nonporous ice on Titan (deep target layers) are 6, 9.1 and 14.2 GPa. For 20% porous ice (“average” porosity of upper Titan’s layer) the ANEOS-based shock pressures are lower and equal to 2.4, 4.2 and 6.8 GPa. The calculations of the total melt production for different impact velocities and different impact angles are summarized in the Fig.2. Obviously, the ratio of the melt volume to the projectile volume increases with the impact velocity increase and decreases with the impact angle decrease (90° corresponds to a vertical impact). However, the ratio of the melt volume to the final crater volume (which is estimated by scaling laws \cite{10}) shows that an average impact angle of 45° gives reasonable estimates for any impact angle with the single exception for a very low impact angle of 15° or less. The probability of impacts at shallow impact angles is less than 7% and they may be excluded from the total...
flux. The ratio of the impact melt to the projectile volume for the impact velocity range 7-15 km/s may be interpolated as log(Vm/Vpr)=-2.8+1.1log(U2/Em), i.e. µ=0.73. Our value of µ is the upper limit for ice in [11]. At the same time the a-value is lower (-2.8 versus 1.36 in [11]), because of a colder ice on Titan in comparison with Earth’s conditions.

Ejecta fate. To describe accurately the motion of the ejecta from the top layer over a long time interval, the continuous medium is broken into particles of various sizes: from microns up to 10 cm for the solid material and up to 1 cm for the melt [15]. Then, the motion of these particles and their interaction with the post-impact gas flow is modeled numerically in the framework of two-phase hydrodynamics [5]. The initial ejection velocity may be rather high (well above escape velocity of 2.6 km/s), but the dense Titan atmosphere decelerates ejecta quickly. In a few seconds after an impact, the velocity drops below escape and the ejected material will be redeposit not far from the impact site, but onto the cold icy surface. A huge impact is needed to create “blowout” postimpact vapor plume, allowing escaping of the fast ejecta. Estimates similar to [16, p.212] give the “blowout” regime at 11 km/s for 12-km-diameter comet. Such impacts may occur once in 250 Myr [3].