MODELING IMPACT CRATERING ON TITAN. Natalia L. Rossignoli 1, Romina P. Di Sisto 1,2 and M. Gabriela Parisi2,3, 1Instituto de Astrofísica de La Plata, CCT La Plata - CONICET - UNLP, 1900 La Plata, Argentina (nrossignoli@fcaglp.unlp.edu.ar), 2Facultad de Ciencias Astronómicas y Geofísicas, Universidad Nacional de La Plata, 1900 La Plata, Argentina, 3Instituto Argentino de Radioastronomía, CCT La Plata, CONICET - CICPBA, 1894 Villa Elisa, Argentina.

Introduction: Titan is the second largest satellite in the Solar System and the only one known to possess a dense atmosphere. Before the Cassini mission, its crater size distribution was unknown but estimated to be similar to those of the other Saturnian satellites. Instead, Cassini observations uncovered an unexpected low number of eroded craters [1].

Using a theoretical model previously developed and applied to the small and mid-sized saturnian satellites [2–4], we model the impact cratering process on Titan and calculate its crater size distribution. We then compare our results with the updated crater counts obtained using the Cassini Synthetic Aperture Radar (SAR) dataset [5] and compute the surface age for each crater diameter.

Methodology: Based on a method developed in previous works [2, 3], we study the collisions of Centaur objects on Titan throughout the history of the Solar System in its current configuration. We consider the main impactors to be the Centaurs originated in the Scattered Disk in the Transneptunian Region, as the transient nature of these small bodies favors their encounter with both the planets and their satellites as they migrate inwards through the Solar System. The cumulative size distribution (CSD) of this impactor population is given by:

\[ N(>d) = C_0 \left( \frac{1 \text{ km}}{d} \right)^{s_2-1} \text{ for } d \leq 60 \text{ km}, \]

\[ N(>d) = 3.5 \times 10^5 \left( \frac{100 \text{ km}}{d} \right)^{s_1-1} \text{ for } d > 60 \text{ km}, \]  
(1)

where \(C_0=3.5 \times 10^5\), \(s_2=1.60\), \(s_1=4.7\) and \(s_2=3.5\).

The transient diameter \(D_t\) of a crater generated by an impactor of diameter \(d\) is given by the equation [6]:

\[ D_t = K_1 \left( \frac{\mu d}{2 \pi} \right)^{\frac{2}{\mu}} + K_2 \left( \frac{v}{\mu \epsilon} \right)^{\frac{2+\nu}{1+\nu}} \right) \left( \frac{\rho}{\rho_i} \right)^{\frac{\nu+1}{\nu}} \frac{1}{\mu} d, \]  
(2)

where \(\mu=0.38\), \(\nu=0.397\), \(K_1=1.67\), \(K_2=0.351\) and \(Y=1.5 \times 10^5 \text{ dyn/cm}^2\) [3]. The first term measures the importance of the target gravity (gravity regime) and the second one measures the importance of cohesion (strength regime). In Titan all craters are formed under the gravity regime. The final crater size \(D\) is obtained adapting the results for complex craters [3].

In order to measure the atmospheric effects on the impactors, we use the atmospheric density profile determined by the Huygens Atmospheric Structure Instrument (HASI) [7]. The deceleration of the impactor is modeled via the conventional drag equation:

\[ m \dot{v} = -\frac{1}{2} C_D A \rho(z) v^2, \]  
(3)

where \(m, v\) and \(A = \pi d^2/4\) are the impactor’s mass, velocity and cross section, respectively, \(\rho(z)\) is the atmospheric gas density, and \(C_D=0.71\) [8] is the non-dimensional drag coefficient. We consider the most probable impact angle to be \(\alpha=45^\circ\) with respect to the horizon.

For the ablation effect, the mass variation is modeled with [8]:

\[ \dot{m} = -C_A \rho(z) A v_{imp}, \]  
(4)

where \(C_A=0.71\) is the ablation coefficient.

The cratering time-dependence can be fitted with a logarithmic function [9], which allows for the calculation of the surface age of Titan \(\tau\), with a simple expression:

\[ \tau(>D) = t_f (1 - e^{-\frac{N_0(>D)}{N_i(>D)}}), \]  
(5)

where \(a=0.198406\), \(t_f = 4.5 \times 10^9\) years is the age of the Solar System, \(N_0(>D)\) is the satellite’s cumulative number of observed craters and \(N_i(>D)\) is the theoretical cumulative number of craters obtained with our model.

Results: General results: Collision velocity \(v_i\) in km/s, transition crater diameter \(D_t\), between simple and complex craters: largest impactor diameter \(d_m\) and largest crater diameter \(D_m\), all in km for an airless Titan.

<table>
<thead>
<tr>
<th>(v_i)</th>
<th>(D_t)</th>
<th>(d_m)</th>
<th>(D_m)</th>
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<tbody>
<tr>
<td>7.41</td>
<td>2.11</td>
<td>26.96</td>
<td>249.77</td>
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Following the described method, we compute the cratering rate on Titan by Centaur objects over the age of the Solar System. Fig. 1 shows the cumulative number of craters per square kilometer as a function of crater diameter for both the model for an airless Titan and the model that includes its atmosphere effects, together with the most complete set of crater counts available in the literature [5].

Given the uncertainty of the size frequency distribution of impactors for small sizes, in previous works [2–4] the value \(s_2=2.5\) has also been considered for Eq. 1. However, for Titan the \(s_2=2.5\) distribution fails to predict...
any craters with diameters $D \gtrsim 20$ km, so it is not considered to be a suitable distribution for this work. Our results show that the $s_2=3.5$ distribution overestimates the number of craters for almost all the range of diameters $D$. As complete deceleration and disruption of impactors smaller than 1 km in diameter are expected due to the thickness of Titan’s atmosphere [10], our results for crater diameters lower than 10 km should be considered as upper limits, since these effects could lead to the total disintegration of the impactor, thus reducing the number of small craters. In addition, impact craters on Titan show a variety of degradation states, with aeolian infilling and fluvial erosion being the dominant modification processes [5, 11], which may contribute to reduce the number of detectable small craters.

Our results regarding Titan’s surface age (Fig. 2) show that craters with $D > 50$ km are nearly as old as the Solar System, which may indicate that Titan is a primordial object. On the other hand, craters with $D < 10$ km reach young ages between $\sim 30$ Myr and $\sim 350$ Myr.

Conclusions: These results suggest that the size frequency distribution of impactors with $s_2=3.5$ is more consistent with the observations, especially regarding those craters less affected by erosion and atmosphere effects ($D > 50$ km). For the smaller craters the model overestimates the number of craters even when the main atmosphere effects are included, from which we conclude that these results should be considered as upper limits for the expected cratering rates. As for the surface age calculation, our model shows that Titan’s surface is young and renewed in short time scales.