COMPARATIVE STUDY OF IMPACT CRATERS ON EARTH AND TITAN USING RADAR IMAGES.

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Introduction: Impact craters, a common geological feature throughout the solar system, contain information about the composition, interior structure and surface processes of planetary bodies [1, 2]. As a result, significant effort has been put into mapping and identifying impact craters in our solar system.

For example, the LRO [3] mission has mapped thousands of craters on the lunar surface [4], which has led to a more accurate surface age [5, 6, 7]. Optical imagery has been effective for the Moon given the lack of any substantial atmosphere, but it does not work well for bodies with thick atmospheres such as Earth, Venus, and Titan. In this case, synthetic aperture radar (SAR) instruments are used to image the surface because radio waves are able to penetrate atmospheres that are opaque at visible wavelengths due to clouds or haze [8]. SAR is an active form of remote sensing that produces images by transmitting a radio wave towards a target (e.g., the Earth's surface) and measuring the backscattered echoes [9]. These radar images highlight differences in slope, composition, and roughness of a surface, key properties in crater mapping.

The RADAR instrument [10] on board the Cassini spacecraft mapped much of the surface of Titan, the only natural satellite with a dense atmosphere in the solar system. Hedgepeth et al. [11] presented a final count of 90 craters on the surface of Titan, with 69% surface coverage. This is an extremely small number compared to the crater populations documented on other nearby Saturnian satellites [12]. The low crater count on Titan may be a result of several factors including atmospheric shielding, erosion and burial of craters by active geologic process, impacts into marine environments, and/or a rapid resurfacing mechanism on Titan in the recent past [13]. The low crater count on Titan compared to nearby satellites is similar to the reduction seen on Earth compared to the heavily cratered lunar surface. Indeed, Earth is an excellent analogue for Titan because both worlds have active hydrological systems, and erosion and burial are dominant processes responsible for crater degradation on both surfaces.

There are approximately 190 confirmed craters on Earth, which have been identified by a combination of field and laboratory studies [14]. Of these craters, 60 are buried and therefore unobservable from orbit. In addition, craters formed in marine environments (also present on Titan) lack significant surface topography that may prevent them from being recognized from orbit [13, 15]. On Earth, these craters are identified from drill cores, detailed gravity surveys, and seismic profiling [16]. However, field studies and drill cores are not available for Titan. In order to properly compare the terrestrial impact crater population to that of Titan, Earth impacts have to be analyzed using the same instrumentation that is available for Titan, i.e., radar remote sensing. The number of craters on Earth distinctly visible in radar will help to determine the number of "missing" craters on Titan, and hence, give us a more accurate crater population there. This, in turn, will help determine constraints on the age of Titan's surface, a value which is critical for models of the formation and evolution of Titan [5, 17]. In addition, crater counts may provide insight on the changing atmospheric density of Titan over time [18]. All these factors will help to determine a comprehensive history and understanding of Titan, an astrobiologically significant planetary body in our solar system [19].

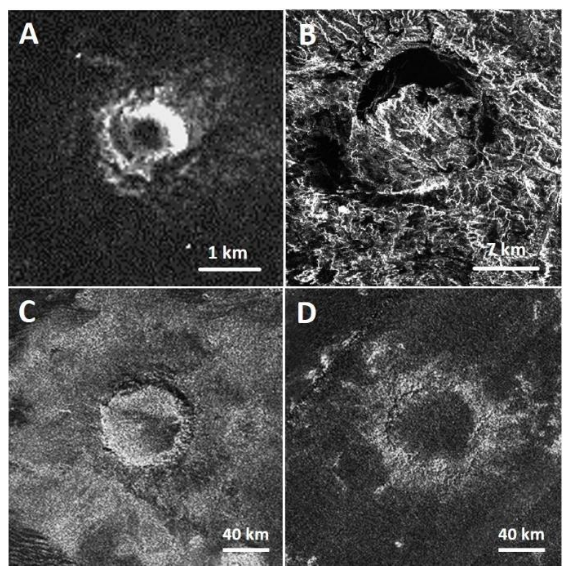

Fig.1: (A) Sentinel-1 C-Band radar image of Barringer crater (Arizona, U.S.A) and (B) ALOS PALSAR L-Band radar image of Aorounga crater (Chad). Cassini RADAR images of (C) Sinlap and (D) Soi craters on Titan [24].

Methods: In order to characterize terrestrial craters with radar images, data from ESA's Sentinel-1 [20] and Japan's ALOS PALSAR [21] were used. Sentinel-1 uses a shorter wavelength (5.6 cm) compared to ALOS (24 cm), which allows for the investigation of surface roughness at both the centimeter and decimeter scales. There terrestrial radar images were processed in the Sentinel Applications Platform (SNAP).

Fig.1 shows radar images of a fresh (A) and a degraded/infilled (B) terrestrial crater; a fresh (C) and a degraded (D) crater on Titan. The level of visibility of the crater in the radar image depends in part on the level of crater degradation. For example, the fresh crater has a more circular and defined rim compared to the degraded crater, making it easier to identify from orbit. The main objective is to characterize all the exposed terrestrial craters based on visibility in radar, from certain to probable to not visible; craters on Titan have been characterized in a similar manner [11].

In addition to radar images, visible imagery (Landsat 8) and topography (Shuttle Radar Topography Mission) data were also used to aid in crater identification.

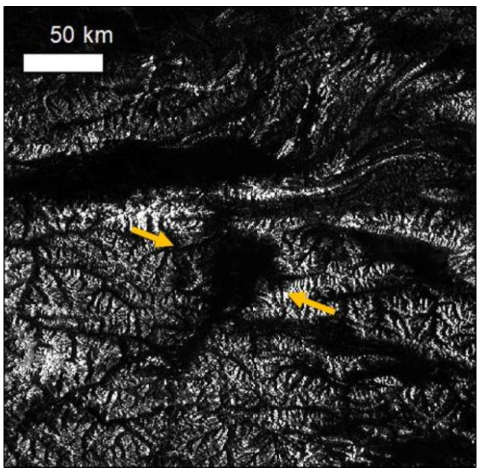

Fig.2: Sentinel-1 radar image of the Kara-Kul crater (Tajikistan). Arrows highlight the position of the crater.

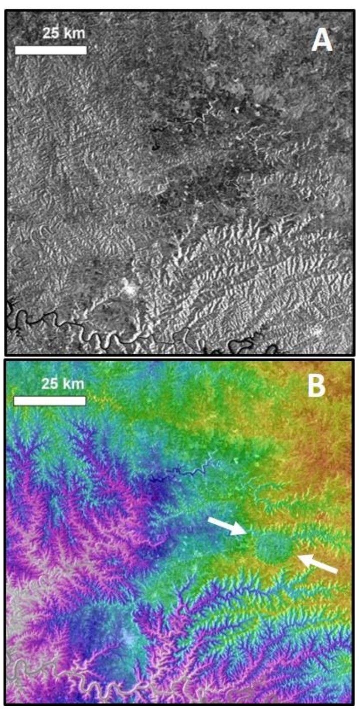

Fig.3: (A) Sentinel-1 radar image and (B) a 30 m resolution DEM overlaid on the radar image of the Vargeão Dome crater (Brazil). Arrows highlight the position of the crater.

Results: Preliminary characterization of 20 craters on Earth shows that only 45% of the craters are clearly visible in radar images. An example of an easily identifiable crater, the Kara-Kul crater in Tajikistan, is shown in Fig.2. In some cases, it is difficult to identify craters in radar images alone, but the addition of a DEM enhances crater visibility (see the Vargeão Dome crater in Fig.3). There is extensive vegetation coverage in this region of Brazil, resulting in a brighter overall radar image (Fig.3A), which makes it difficult to identify craters. We will continue to characterize all the 106 exposed terrestrial craters based on their visibility in radar.

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