Automated crater detection technique: To access to the crater population of this size range at a planetary scale, the automation of this process is therefore essential. Some of studies have addressed automated crater detection [3] but none have achieved the ultimate goal of counting and measuring craters in a reliable and timely fashion. In previous works, we described our technique to develop a crater detection algorithm (CDA) [4, 5, 6] with subsequent improvements with ongoing advances in machine learning. Our CDA has been trained by selecting 889 tiled THEMIS Day IR imagery dataset at 100m/px except on Mare Boreum and Mare Australe, thus corresponding to a latitude band of ±65deg. The ratio between the number of craters detected by the CDA and impact craters contained in the manual database [1] is close to 0.95 [6]. Moreover, both CSFDs are similar, thus indicating an acceptable estimation of diameter for all size range [6].

Introduction: Impact craters on rocky and icy bodies of the solar system are widely used to determine the ages of planetary surfaces. Absolute dating of meteorites or in-situ geochronology provide a few essential reference points, but these techniques rare not yet applicable at the planetary scale. Therefore, the impact crater counting techniques will remain, for several decades, the major tool of “celestial geologists” to decipher the history of planetary surfaces. This approach requires a tedious mapping and morphological inspection of a large number of circular features to distinguish true and primary impact craters from other surface features and secondary impact craters; in particular on Mars whose the surface exhibits a large variety of pseudo-circular features (e.g. mounds, collapse pits of lava tubes, circular grabens, glacial cirques, calderas...). Currently, the most complete catalog of Martian craters has been compiled by S. Robbins and B. Hynek (2012) [1]. It includes more than 384,000 impact structures larger than 1 km in diameter, and is considered to be complete for this diameter range. Nevertheless, young and/or small surface age dating on Mars are performed by taking into account smaller impact craters, typically a hundred meters in diameter, superposed on the area of interest [2]. Because crater number scales as a power law, the number of impact craters larger than this size range over the entire surface of Mars could reach the millions. This makes the precise analysis of local variations of the surface age, over the entire surface, impossible to perform by manual counting.

Detection completeness: The CDA has been applied on all Mars quadrangles by using THEMIS Day IR imagery dataset at 100m/px except on Mare Boreum and Mare Australe, thus corresponding to a latitude band of ±65deg. The ratio between the number of craters detected by the CDA and impact craters contained in the manual database [1] is close to 0.95 [6]. Moreover, both CSFDs are similar, thus indicating an acceptable estimation of diameter for all size range [6].
by [7], in black on Fig.1). This lack of secondaries detection make the crater population detected by the CDA more accurate to use for dating purpose. Conversely, the CDA detect several collapse pits within tectonic and volcanic areas (yellow areas on Fig.1), these detections should therefore be removed before any using of our automatic database.

**Detect them all:** While the crater population detected by the CDA by using THEMIS imagery at 100m/px could be considered as complete, we tested the efficiency of our algorithm trained on THEMIS imagery on higher resolution datasets such as CTX images (5m/px). For this purpose, we used the beta01 version of the Murray Lab global CTX mosaic (NASA/JPL/MSSS/The Murray Lab). Results obtained for this dataset without retraining are encouraging. Not only the rate of good detections is high but in addition, the diameters of detected craters are, in most cases, more relevant than large craters detected with THEMIS dataset.

Further, we have focused on the Gusev impact crater region to compare crater population and associated ages, previously manually measured by [8], with results of our CDA. More than 60,000 impact craters larger than 40m in diameter have been detected on this area.

Further, we have focused on the Gusev impact crater region to compare crater population and associated ages, previously manually measured by [8], with results of our CDA. More than 60,000 impact craters larger than 40m in diameter have been detected on 4 tiles of the CTX global mosaic, thus covering an area of 8° x 8°. Among this crater population, we selected impact craters intersecting four distinct counting areas (outlined in Fig. 2) defined and dated by [8] between 2.89 and 4.04 Ga, thus offering a large panel of ages from the Early Amazonian to the Early Noachian [8]. CSFDs for on the craters counted in areas 3 and 5 (Fig.3.a-b) show similar ages to those found by manual counting. Areas 7 and 10 show a difference of 0.1 Ga, corresponding only to 3% difference (Fig.3.c-d).

**Fig.2** | Gusev impact crater (D ≈ 160 km) and counting areas with their IDs from Parker, M.P. et al. (2010) [7]. The CTX image at the top left corner of the figure show the CDA detections, the largest crater visible on this image measure 10 km of diameter. More than 900 craters larger than 40m have been detected on this area.

**Ongoing works:** We are applying our CDA to the entire CTX mosaic dataset, currently covering more than 97% of the surface of Mars. In this way, most of impact craters larger than 100m in diameter should be detected and local variations of the emplacement and resurfacing ages of geological units should be identified and measured. By retraining our detection model to detect other circular geological features, we will be able to clean our crater database of misidentification. A retraining on other imagery dataset covering the surface of other terrestrial bodies could also allow to detect smaller impact craters on their surface.