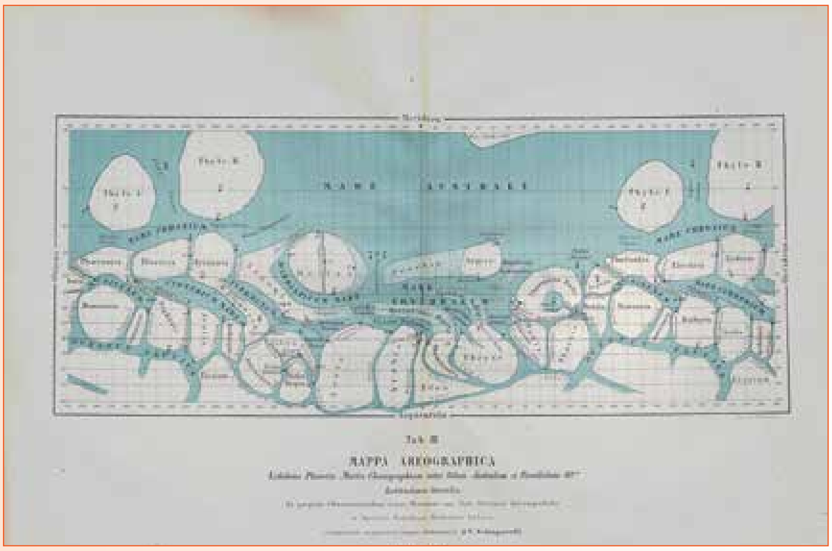
Exploring the Solar System: from mapping to prospecting

by Fabrizio Bernardini, FBIS



The Italian Giovanni Schiaparelli, astronomer and engineer, in the second half of the 19th century drew the maps that assigned, to features he could barely detect, the names we are still using today. (Map is reversed, with south at the top).
Credits: INAF Osservatorio Astronomico di Brera, Biblioteca, Foto: Mario Carpino. The assistance of Agnese Mandrino is gratefully acknowledged.

Solar System exploration is changing, opening the field to prospectors and then miners after a long phase of mapping. This is a process we have already seen many times on our planet, but for the first time in human history we are witnessing a revolution that hold the keys to a new frontier outside the boundaries of our planet.

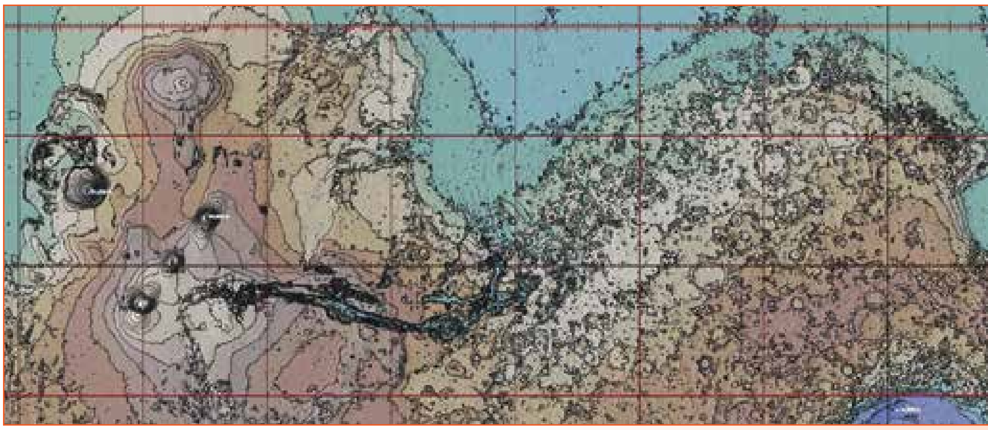
There has been a first revolution when humankind started exploring the solar system sending automated emissaries, also known as deep space probes, to the Moon first and then the other main celestial bodies that orbit the Sun. After the first attempts at the very dawn of the space age, attempts which produced grainy images and few precious amounts of data, we had a steady increase in the return of science data, with larger missions until we sent flagship missions to orbit Mars, Jupiter and Saturn, with landers on the Moon, Mars, Titan. And then, other orbiters around Venus, Mercury and even to comets and asteroids: many missions that helped characterize our Solar System from Mercury and way beyond Pluto.

From planets to places

All these missions are associated by a common science goal, that to explore to improve our science knowledge (many models were based only on the Earth) and to better understand the evolution and the possible futures of our Solar System. These missions, however, also achieved an important practical result, transforming far worlds from astronomical targets into places. Wherever and whenever humans have explored, they first traced the boundary of the land, then the contours of the topography, while at the same time giving names to features: this is called mapping. Mapping is essential to continue the exploration, but also as an aid to describe the characteristics of a new territory. The names on the maps will be foreign ones initially, but soon they will have a very practical sense when resource exploitation or the establishment of settlements will take place.
In the Solar System, we have done the same: we have pictured distance planetary bodies, we have established a reference system, and then we have mapped the surfaces and the topography giving names to outstanding features and regions. What we have been doing since the very first deep space probes started exploring, has been transforming planets in places.

From science to resources

The tools available to the researcher are more complex than just simple images. Even images are studied at pixel level, considering the characteristics of the light received by the detectors, to extract, or infer, additional data from them. More than just visible imagery, we have seen the importance of other instruments, like spectrometers, able

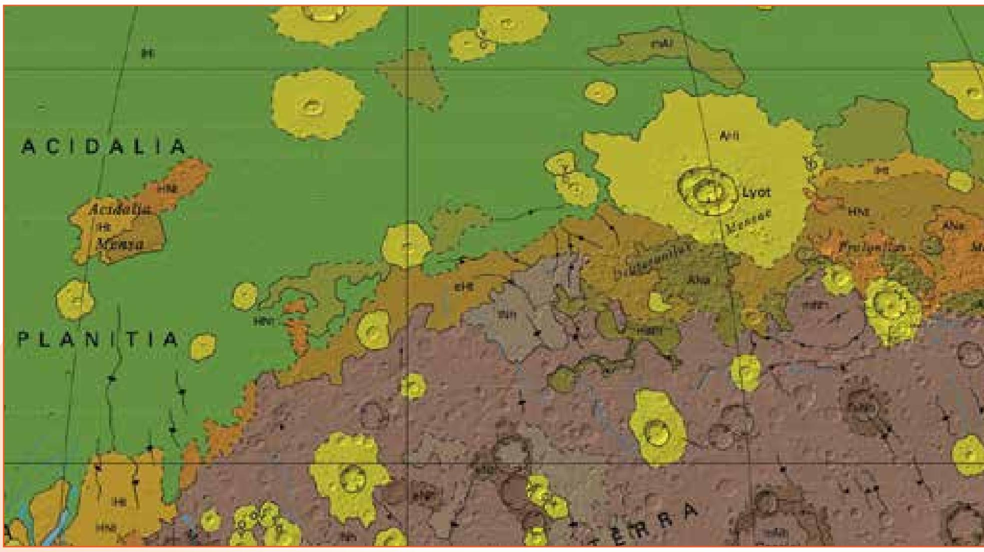


The Mars Orbiting Laser Altimeter provided enough data points to create full topographic maps of Mars of unprecedented accuracy (on a global scale) in the whole Solar System, the Earth included. MOLA data are the basis for innumerable analysis and also to enable science investigations with other instruments.
Credits: Color-Coded Contour Map of Mars, 2003, US Geological Survey Astrogeology Team

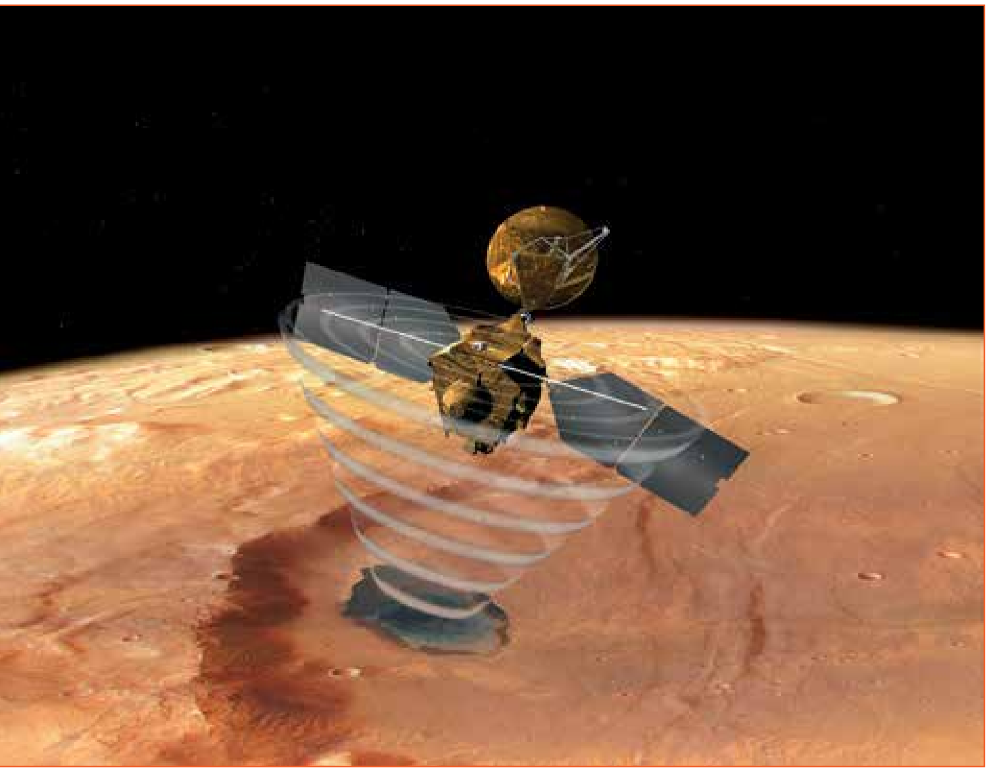
to discern the chemical composition from a distance, and sounding radars that provided incredible results, as on Mars, with the detection of underground features not otherwise discernible from the orbit, and even from a rover. Variation detected in the radio waves for communications, helped understand the inner structure of distance bodies with important clues about subterranean oceans and other features. The collection of all this data has enabled a better understanding of surface conditions and characteristics, and particularly its composition.
The amount of data collected on specific planetary bodies, like the Moon and Mars, has reached such a volume that is transforming our use of the same data. While science data collected so far can keep planetary scientist busy for many years to come, the realization that we can now draw map of minerals and other resources with unprecedented precision, has opened an entire new avenue of applications. In fact, after more than 50 years of Solar System exploration, we are now approaching a second revolution: the shift from mapping to prospecting, that is looking for, and quantifying, the available local resources. And the resources looked for are those specific ones that will be able to support a permanent human presence on other worlds.
In order to facilitate the next steps in human exploration of the Solar System, we need to start building new deep space probes that will have a focus on local resources characterization. Technically speaking, these will not be much different from science-oriented missions, but practically speaking they will be cheaper and quicker to build and their operations will be initially constrained to reduce the uncertainties in specific areas of a planet. In this respect, it will be not necessary to design a spacecraft to explore for many years a whole planet, but limit its performances to the achievements of resource-driven goals, at least for the main part of its mission.
Prospecting missions can be designed for specific kind of resources, like a better characterization of water ice deposits on Mars (or finding better proof of the elusive water ice traces on the Moon), while others can target the composition of surface materials. Smaller, specific, missions mean also an increase in operational flexibility, also for what regards simplifications in the communications and propulsion needs, and will be characterized by a high level of autonomy, to reduce ground operations costs substantially.

Mars as a case in point

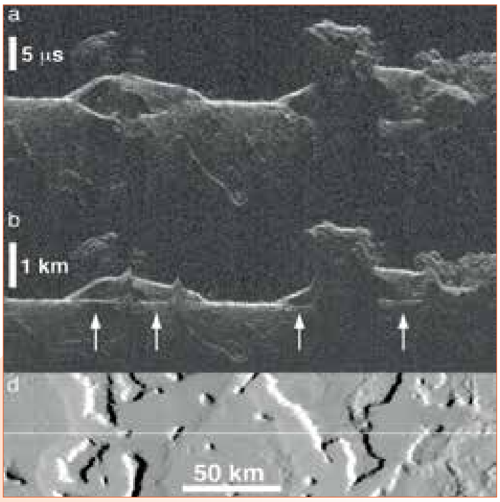
Going to another world and li-



The recently released new geological map of Mars integrates many layers of information from Viking to the most recent missions. It can be considered the basis cartographical product for a future Mars resources map based on existing and prospecting missions data.
Credits: Geological Map of Mars, 2014, Tanaka et al., US Geological Survey Astrogeology Team



NASA/JPL flagship orbiting mission around Mars, is providing since 2006 and incredible quantity of data thanks to its powerful instrument and its very high performances communications system. It is also a key element for landed asset, as it is their main relay platform to Earth. University of Arizona HiRISE camera, the Italian SHARAD sounding radar, and all other instruments, have transformed the way we see and understand Mars and its resources.
Credits: NASA/JPL-Caltech



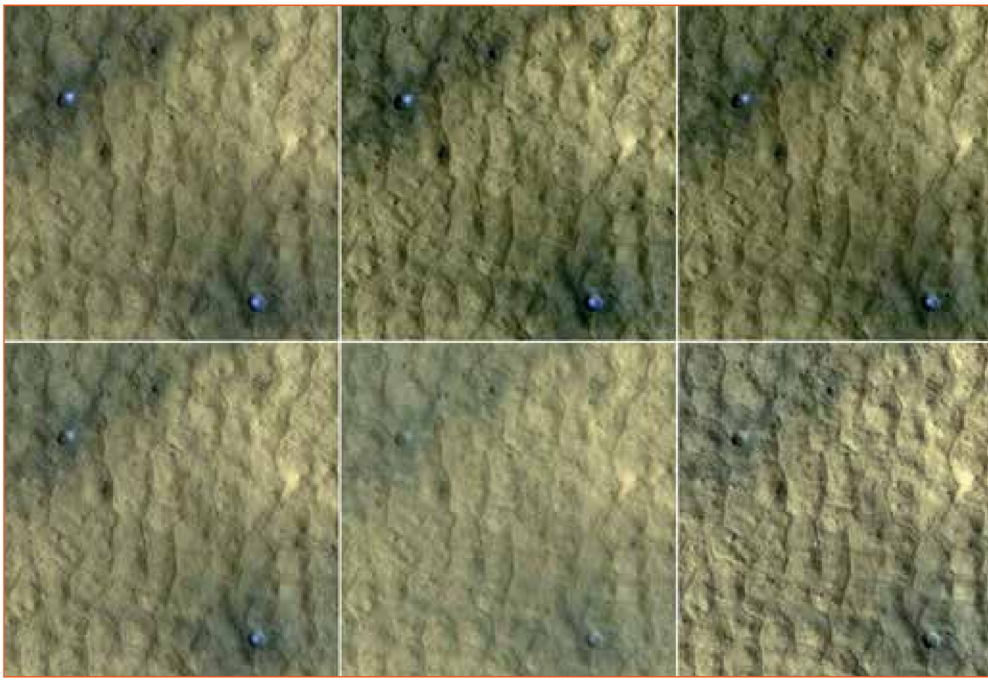
The discovery of debris covered glacier is entirely due to radar sounding techniques. Water ice is invisible at SHARAD frequencies and assuming its presence the radargram in (a) has been corrected for the dielectric constant. The correction produced a flattened bottom of the glacier coherent with the rest of the plain. There are hundreds of similar features in the same area with an average thickness of 450 meters of 90% pure ice.
Credits: NASA/JPL

ving there off local resources has always been a theme very dear to science fiction and to space exploration visionaries. The concept is sound, but in practice too many unknowns prevented transforming these visions into reality. Until now. Despite the recent talks and actions toward establishing a more permanent human presence in lunar orbit, and maybe even on the surface, the reality is that lunar resources are still a big unknown. Water ice is a major factor for human exploration, and as of today there is not a single paper that clearly identifies a Moon ice deposit with some hope of being accessible for extraction. Mars on the other hand, is a completely different story.
Mars is the best-known planet of the Solar System (after the Earth) in the sense that its topography is better known that Earth's (because of the lack of oceans). We have landed in different zones of the planet and many missions are orbiting it. A small fleet of more missions is expected to reach Mars in the next two years, turning its orbital environment the busiest (after Earth's of course) in the Solar System.
What it is not well perceived by the general public, is that Mars is extremely rich in the most important resource for space exploration, which is of course water ice. And we are not talking about the polar caps, we are talking of vastly abundant reservoirs of water ice, in multiple zones of the planet, and in particular at those latitudes that are of particular interest for human exploration.
Italian-built sounding radars, and in particular SHARAD on Mars Reconnaissance Orbiter, have unlocked the knowledge of these water ice deposits.
Of primary importance is the discovery, in 2008, of large debris covered glaciers concentrated in mid-latitude zones like Deuteronilus Mensae and Hellas Basin. These glaciers, composed of 90% pure water ice, have been mapped to reach a current estimate (which is growing) of 400000 cubic kilometres of ice, available over the surface. Other glaciers, in less practical areas have also been found, while it is known the presence of multiple layers of water ice in the polar caps.
Radar data studies also provided strong evidence to support that the soil of northern plains, like Arcadia and Utopia, is mixed with water ice. In Arcadia, there are evidences of ground ice down to about 40

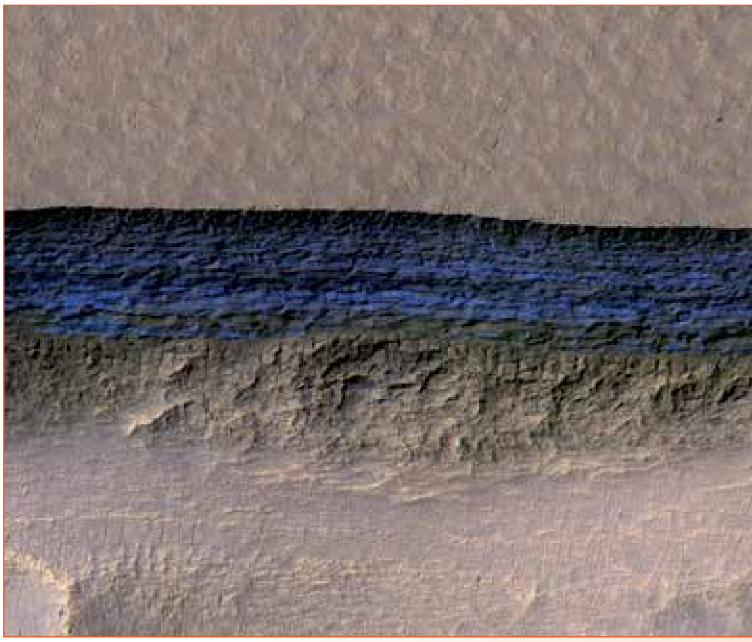
meters, in an area about 1 million square kilometres in size. In Utopia, soil characteristics provided clues for another 14000 cubic kilometres of ice underground. And if in these cases radar data are not enough convincing, there are also images from the powerful HiRISE camera on MRO, that has pictured both ice exposed after meteoroids impacts and effects of melting ice on cliffs and slopes. Of the many high-resolution pictures provided by MRO, one of the most spectacular one is that of a scarp in which underground ice layers are clearly exposed and the presence of ice can be seen just one meter below ground.
NASA's SWIM study, carried out by the Planetary Science Institute, is integrating neutron data, thermal data and radar data to complete a mapping of water ice resources in shallow (< 5 meters) and deep (> 5 meters, down to 100) zones.
While the interpretation of resulting "data sets is to a degree subjective and does not lend itself to precise calculation of probabilities" but the "identification and mapping of ice is warranted and highly desirable for planning future landing sites that rely on the presence of ice for resources".
This study, like the ongoing ones for the characterization of Mars resources (thanks also to the rovers that crawled over its surface determined that many useful minerals are available, complementing the data of spectrometers flown on various orbiting missions) have a clear accent on the implications that the results will have for the human exploration of the Red Planet.

Conclusions

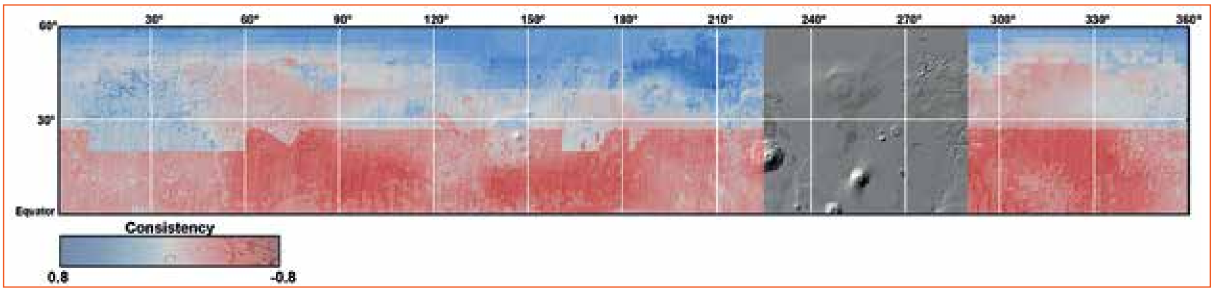
What about the other "places" we have identified in the Solar System? An extensive mapping of asteroids is in the agenda also of private entrepreneurs while NASA is now focusing its objectives on the Moon, despite its evident shortcomings in term of easily available resources. The search for life has found new hope in the Jovian moon Europa (even if the Mars discoveries may shed new light in this same arena), while also Titan is on the list of the most interesting places of the Solar System (thanks again also to Italian instruments and science).
Do we still need pure science



The occurrence of new meteoroid impact craters on Mars, monitored continuously by MRO CTX and HiRISE cameras, provided clues about ground ice just below the surface in many regions. In this sequence it is seen that exposed ice is seen dissipate slowly via sublimation processes, confirming its nature.
Credits: NASA/JPL-Caltech/University of Arizona



In both Mars hemispheres, steep scarps gave evidence of layers of underground water ice in the proximity of the surface. It is estimated that one third of Mars surface contains shallow deposits of water ice in the ground.
Credits: NASA/JPL-Caltech/University of Arizona



Current status of SWIM study (https://swim.psi.edu) points at the abundance of water resources in the northern hemisphere of Mars by combining results from multiple sensors. Mars can provide many resources to support human exploration, but in particular it has an unbelievable abundance of the most critical of all resources: water. An abundance of water means the ability to create breathable air, manufacture propellants, grow crops and of course enable many other activities, simplifying and improving the living conditions of the settlers.

missions to explore the Solar System? Yes, but it is also time to think more about simpler, quicker, prospecting missions. Mapping the results of these missions will permit creating the resource maps that will guide the selection of landing sites and that the first settlers will use to find them. That step will be the next revolution: extracting and processing the resources, a next step that is not too far as many would like to think.

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KEYWORDS

Solar System; Mapping; Mars; Sharad

ABSTRACT

Solar System exploration is changing, opening the field to prospectors and then miners. This is a process we have already seen many times on our planet and for the first time in human history we are witnessing the revolution that hold the keys to a new frontier.

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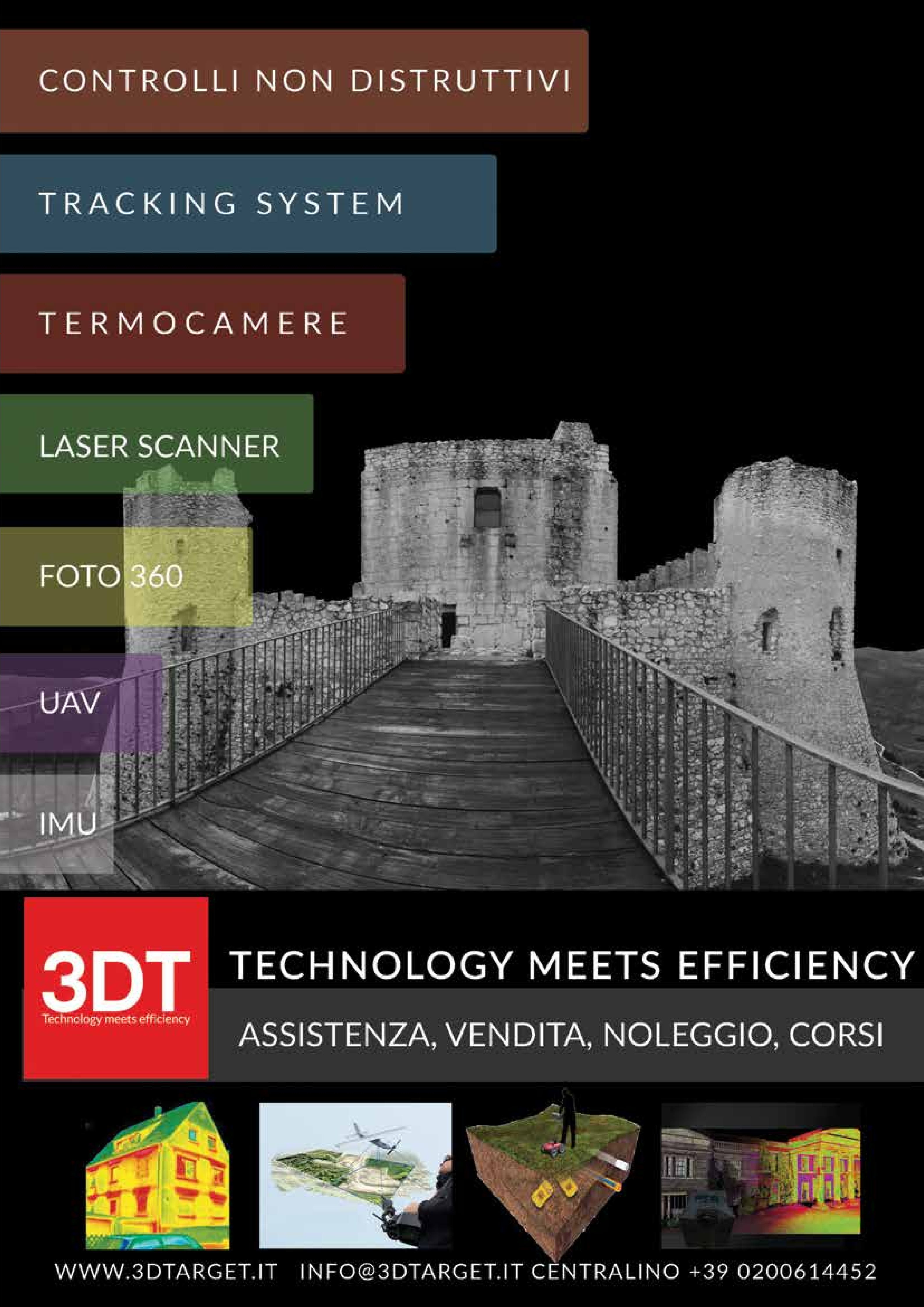
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