A MISSION UNDER THE AUTHORITY OF

ARAB REPUBLIC OF EGYPT
MINISTRY OF ANTIQUITIES

CONCEIVED AND COORDINATED BY

FACULTY OF ENGINEERING
CAIRO UNIVERSITY

HIP
HERITAGE
INNOVATION
PRESERVATION
HIP.INSTITUTE

ABOUT "SCANPYRAMIDS"

www.scanpyramids.org

ENGLISH VERSION

Introduction

Just because a mystery is 4500 years old doesn't mean it can't be solved..."

This could be the motto of the exceptional scientific mission launched October 25, 2015, under the authority of the Egyptian Ministry of Antiquities, initiated, designed and coordinated by the Faculty of Engineering of Cairo and the French HIP Institute (Heritage, Innovation and Preservation). Radiographic muons, aka cosmic particles, infrared thermography, photogrammetry, scanner and 3D reconstruction: the most innovative technologies will be used by researchers of international renown and three major universities: the Faculty of Engineering of Cairo University, Université Laval of Quebec and Nagoya University of Japan. Their goal: to probe the heart of the largest pyramids of Egypt, without drilling the slightest opening.

Four millennia after their construction, these ancient giants are far from having yielded their secrets. The first mystery concerns their construction, especially Khufu, the last of the Seven Wonders of the Ancient World still existing: it is still impossible to describe with certainty how this stone monument, the largest ever built by humans, was erected.

With a base of more than 5 hectares, its original height of almost 150 meters and a mass of 5 million tons, how was it possible to construct such a wonder in only 25 years? Another mystery: the internal structure of the pyramids. When comparing the plans of different pyramids, we encounter inexplicable anomalies. Being the last home of the pharaohs in the Old Kingdom (2575 - 2134 BC), they had to be inviolable. Builders have therefore multiplied tricks and obstacles to protect the remains of their sovereigns. Thus various explorations conducted in the past, with less sophisticated means than today, have caught strange images that could correspond to hidden chambers.

The scientific mission "Scan Pyramids" is an unprecedented, large-scale project and will begin early November. It will focus on four masterpieces of the Fourth Dynasty (2575-2465 BC): on the site of Dahshur, about fifteen kilometers south of Saqqara, the mission will study the South pyramid, called the Bent, and the North pyramid, called the Red, both built by Snefru (2575 - 2551 BC). On the Giza plateau at about twenty kilometers from Cairo (see map), it will study the pyramids of Khufu and Khafre, built by the son and grand-son of Snefru.

Non-destructive high technologies will be implemented. Two infrared thermography missions will establish a thermal map of the pyramids to reveal differences in density: one brief conducted by the expert Jean-Claude Barré from LedLiquid, whereas the other, running for at least a year, will be led by Université Laval of Quebec. Their goal is to identify if there are any voids behind the faces of the pyramids. Two missions using muons radiography also aim to verify and accurately visualize the presence of unknown structures within the monuments. These techniques are being developed in Japan by the teams of KEK (High Energy Accelerator research Organization) and Nagoya University. "Many theories have been proposed, either explaining their construction or their structural anomalies, but we are physicists and engineers, not archaeologists", insists Hany Helal, Professor at Cairo University and former Minister of Research and the higher education and Coordinator of the project, head of mission for the Faculty of Engineering of Cairo. "Our goal is to use techniques to get concrete results. Then the Egyptologists will interpret them."

In parallel to the exploration missions, the company Iconem will realize a photogrammetry campaign using drones, to rebuild the Giza plateau and the site of Dahshur with all their monuments in 3D, with a unique centimeter precision. These models will be made available to researchers and the public in open data by the HIP Institute, a non-profit structure of general interest.

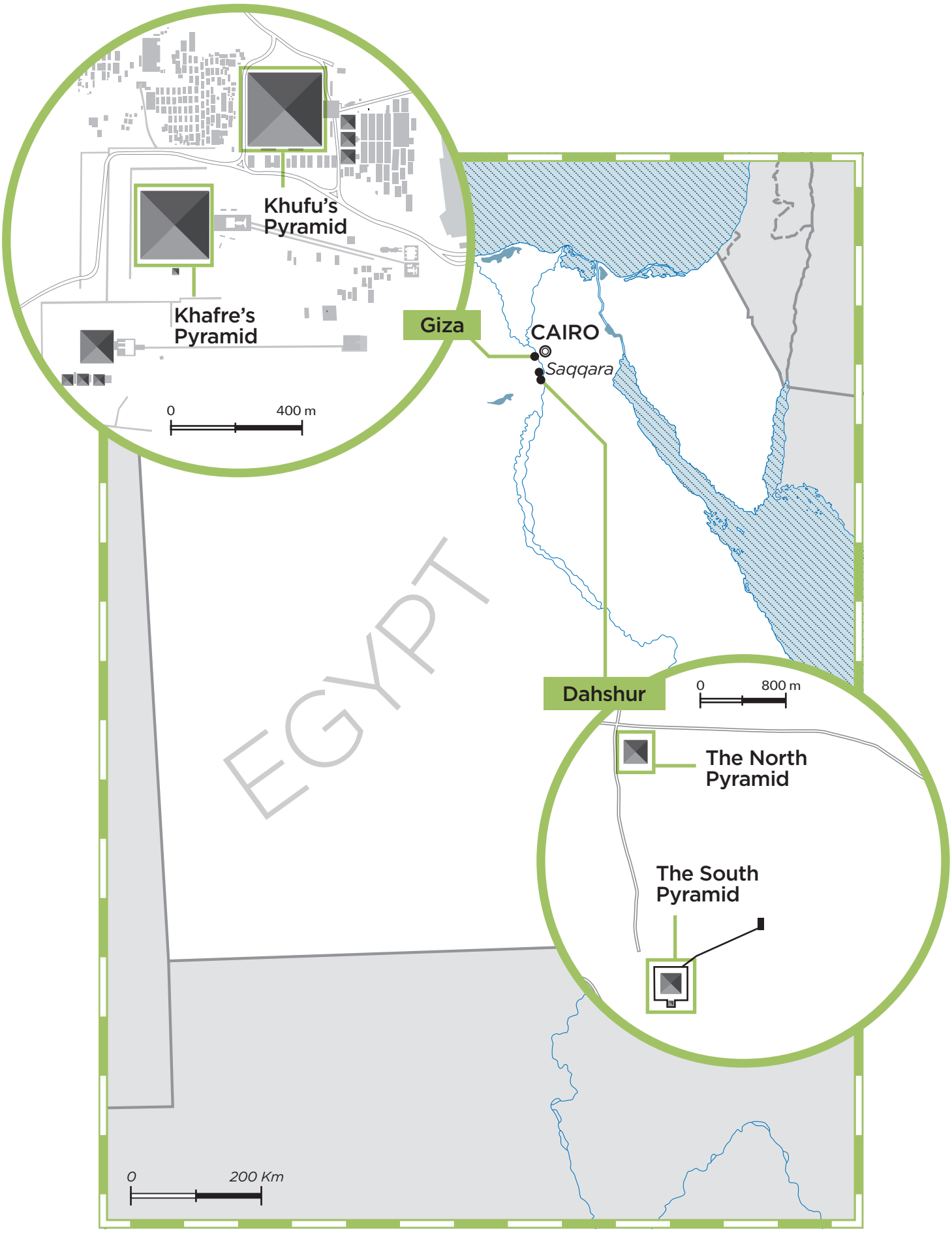
This campaign, supported by the Egyptian authorities, is entirely dedicated to the advancement of knowledge. Sharing and transfer are the key words. "Our desire is to form a team of international experts, says Mehdi Tayoubi, HIP Institute president and co-director of the mission, then discuss and confront the theoretical and technological approaches to the archaeological ground reality."

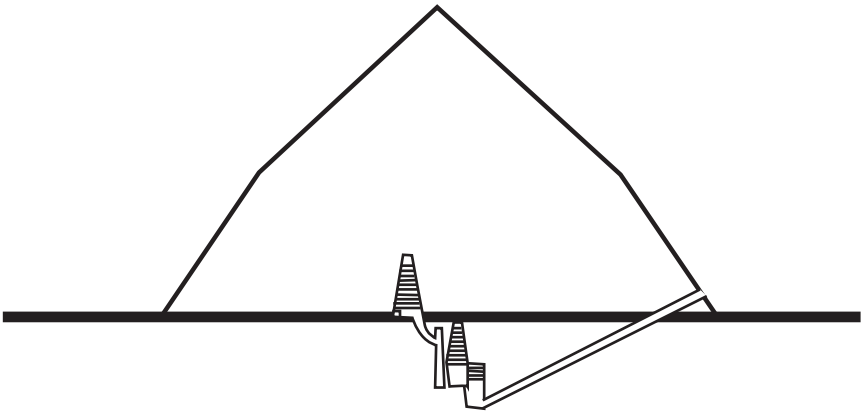
The laboratory of the Japanese team, dedicated to the development and analysis of the images captured by muons radiography, has already been installed in Cairo. "In the longer term, given the archaeological wealth of Egypt, we imagine applying these techniques to other monuments, Hany Helal concludes. Either to restore or to discover them. If these technologies are effective, they can even be implemented in other countries."

The mission should last at least until the end of 2016. Will the millennium mystery that intrigues archaeologists and Egyptology lovers then be solved?

"The key is to move forward by implementing new approaches, says Mehdi Tayoubi. Many previous missions have attempted to unravel the mysteries of the pyramids and even if they were unsuccessful, they were helping advance knowledge. For example that was the case 30 years ago, when EDF foundation detected a density anomaly in the form of a spiral in Khufu. Our goal is to make our contribution and to prepare, in humility, the path for future scientific research missions."

Antique Giants

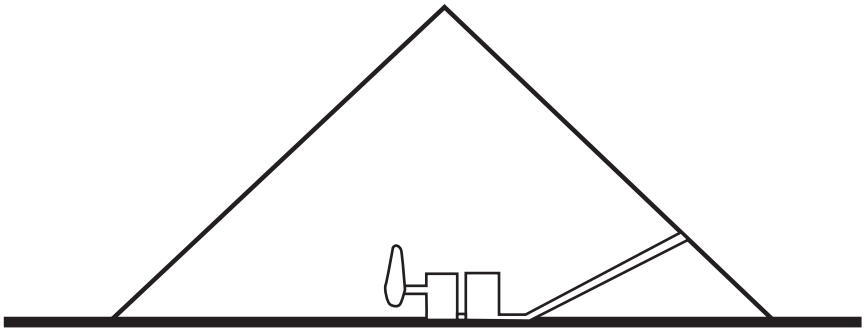

Khufu's Pyramid
Khafre's Pyramid
0
400 m
Giza
CAIRO
Saqqara
EGYPT
Dahshur
0
800 m
The North Pyramid
The South Pyramid
0
200 Km



The South Pyramid, *called The Bent, Dahshur*

Built by Snefru, founder of the Fourth Dynasty, this is the first pyramid with smooth faces after generations of stepped pyramids. Its particular shape, with a double slope, could be the consequence of a Change in Plan, according to some. Facing structural problems, the builders would have been forced to change its slope, from 54 ° to about 43 °. Another feature of this pyramid: it has two entrances, one on the north side and one on the west side. These entries open on two corridors leading to two burial chambers arranged one above the other.

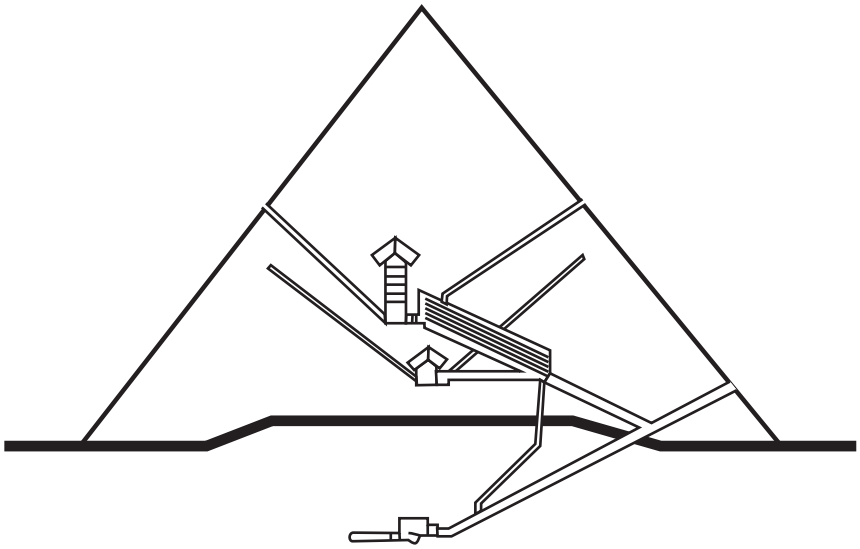
Sides at the base: **188 m**
Height: **105 m**
Angle: **of 54° 27 '44" on the bottom and 43° 22'.**



The North Pyramid, *called The Red, Dahshur*

This is the second pyramid built by Snefru at Dahshur. It is located about one kilometer north of the Bent, which would have been abandoned because of its instability. By keeping the 43 ° slope experienced earlier, the builders achieved this time a perfect geometric figure. Its entrance is located on the north face, at a height of twenty-eight meters. A descending corridor gives access to two antechambers. The second one, located exactly in the center of the pyramid, is overlooking a long passage of seven meters that leads to a single burial chamber.

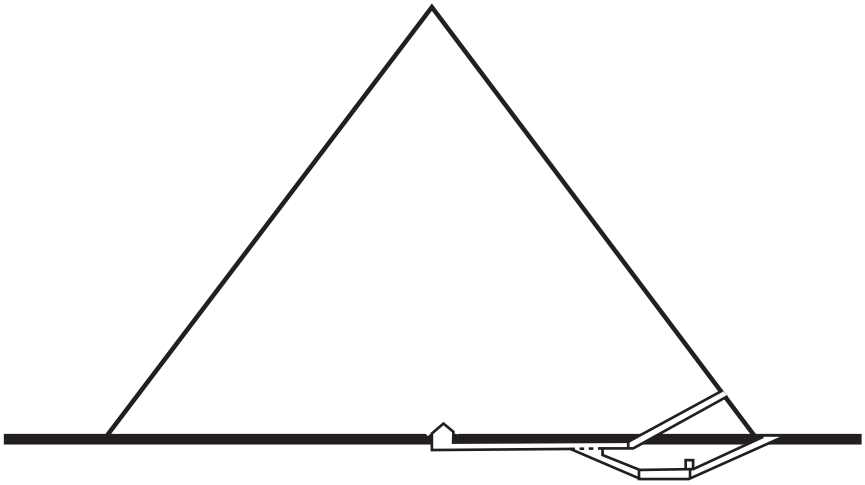
Sides at the base: **220 m**
Height: **105 meters**
Angle: **43° 22' 05"**



Khufu's Pyramid, *Giza Plateau*

Built by the son of Snefru, it is the highest of all the pyramids. It was expected to be over 146 meters high, before its smooth outer coating was stripped off by carriers in the Middle Ages and as well as the capstone on the top. It is the only one with three chambers staged in its massive stone body: an underground chamber dug 30 meters under its base, abandoned; a second chamber called the Queen's chamber, whose function remains controversial; and a third chamber called the King's chamber with an empty sarcophagus, which is the only chamber open to the visitors today. Khufu pyramid was plundered in antiquity. The current access, located ten meters below the original entrance, is also an opening carved by ancient looters. It is traditionally called "Gallery of Al-Mamun", the name of a caliph who led an exploration of the pyramid in the year 820 AD.

Sides at the base: **230 m**
Height: **146.59 m**
Angle: **51° 50 '40"**



Khafre's Pyramid, *Giza Plateau*

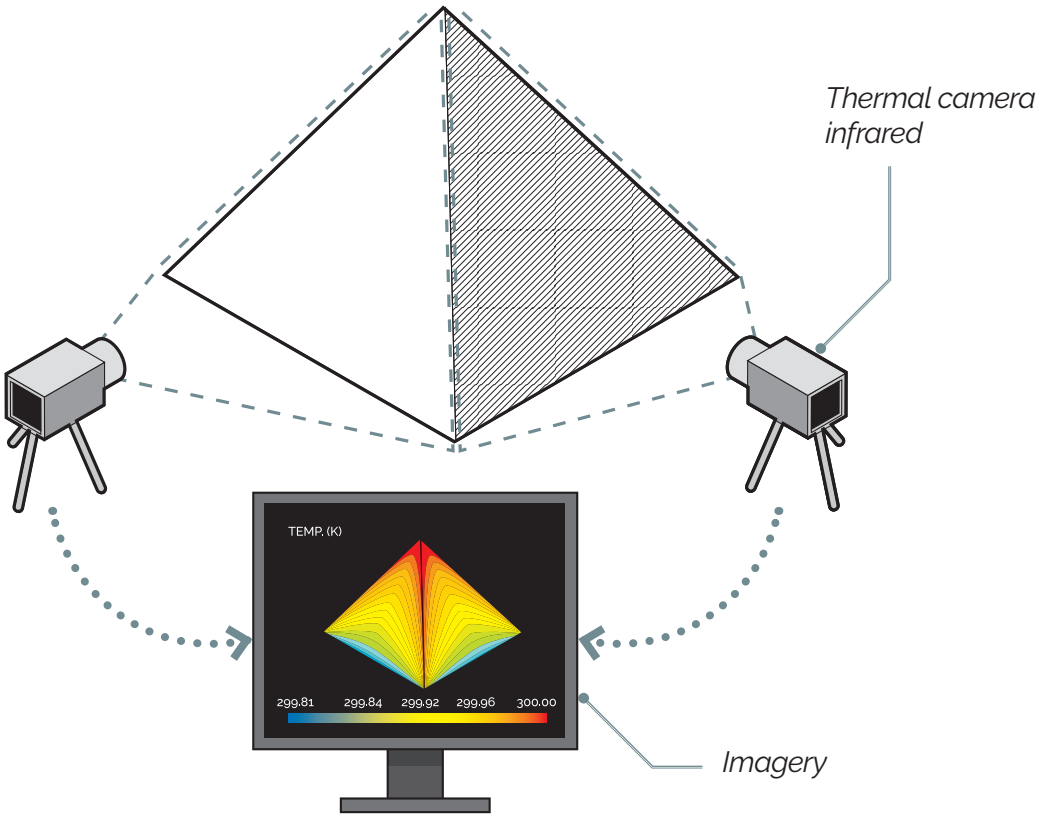
Built by the son of Khufu, this is the second largest Egyptian pyramid. Its original height was 143.5 meters. It has two entrances on the north side, one at the ground level, the other 11 meters above. The first entrance opens onto a corridor overlooking a subsidiary chamber whose function remains unknown. The corridor then makes an angle to reach the upper passage, an anomaly that would suggest a change during the construction plan. The single funeral chamber was not located in the heights of the pyramid, unlike in the previous three pyramids, but excavated in the rock at the base. A stone sarcophagus is located inside this chamber, like the one located in Khufu, but is nicer.

Sides at the base: **215.16 m**
Height: **143.5 m**
Angle: **53° 10'**

Innovative Techniques

Infrared Thermography

(short mission)



Infrared thermography, implemented by Jean-Claude Barré is one ofthe most promising methods to try to understand, looking from the outside, what happens inside a monument just behind the faces. The principle is simple but its implementation requires sophisticated instruments and highly experienced operators.

This technique is based on a physical law: all materials are emitting an energy radiation in function of their temperature. They emit infrared waves measured by cameras equipped with sensors. Thanks to a digital model, the cameras generate images where each color corresponds to a given temperature. Widely used to reveal heat loss in poorly insulated homes, it allows locating the presence of defects in buildings. Thus, a cold air current will be represented in blue, whereas a heat source in red. These specialized cameras are also capable of quantifying the emissivity of materials. No materials absorb, transmit, nor reflect radiation in the same manner.

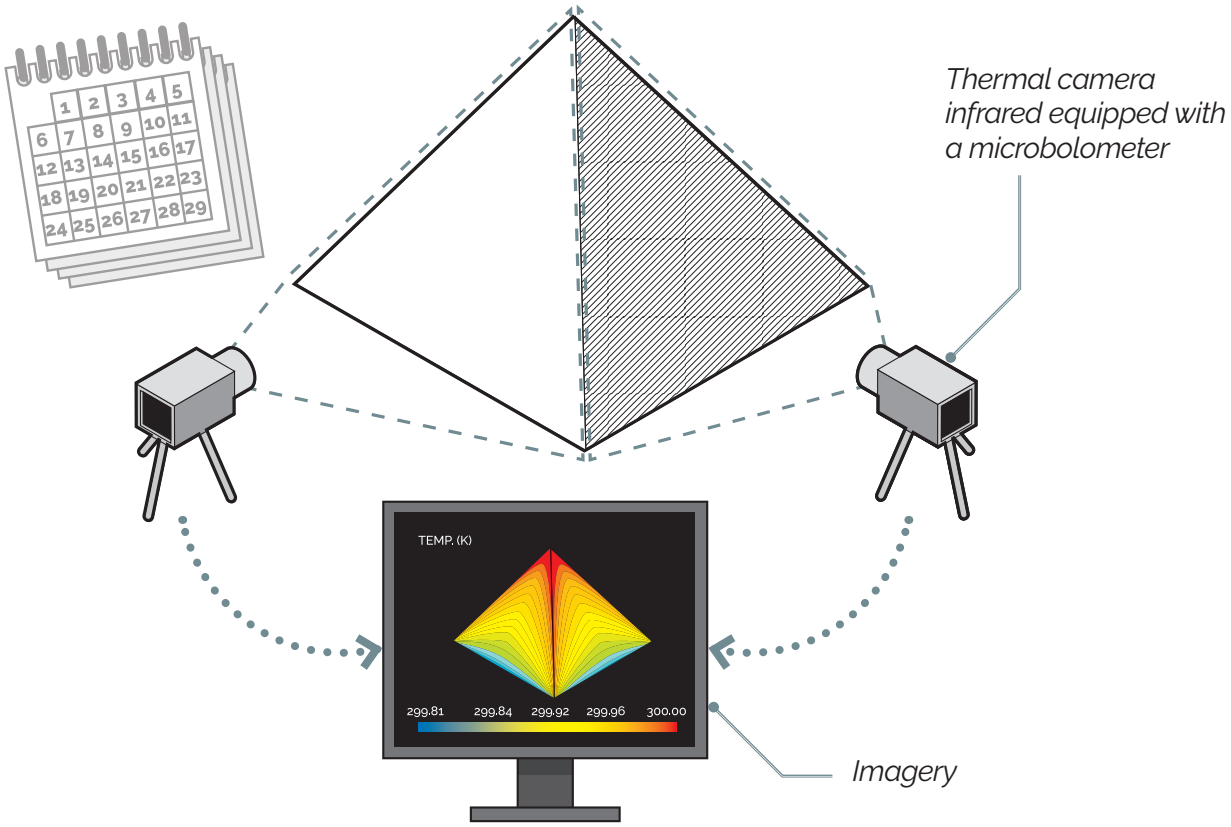
“Under the same sun, the interior of a white car will be cooler than the interior of a black car, explains Jean-Claude Barré. Similarly, in an identical sun, granite and limestone will not return the same temperature.”

Direct application for the pyramids: the differences in emissivity allow to verify if the surface of stones, which have now the same color due to bad weather, sand and pollution, are similar. “But what interests us most are potential cold spots on the surface, which could be drafty, therefore reveal cavities, rooms or hallways, within the monuments,” says Jean-Claude Barré.

The goal is to realize a true thermal map of the giants in Dahshur and Giza. A dynamic map, as the pyramids, like any building, will absorb the sun’s heat in the daytime, and restore it during the night. The operator’s program is therefore to make images on the four sides of the pyramids half an hour before sunrise, when the monument, having evacuated maximum energy during the night will be the coldest. And from this point 0, which will serve as a standard, he is planning to repeat the operation at noon and the evenings. In a few days, Jean-Claude Barré will record hundreds of thousands of images that will be compared with each other by a computer program. The pyramids may finally reveal some of their secrets, in blue or red!

Modulated thermography

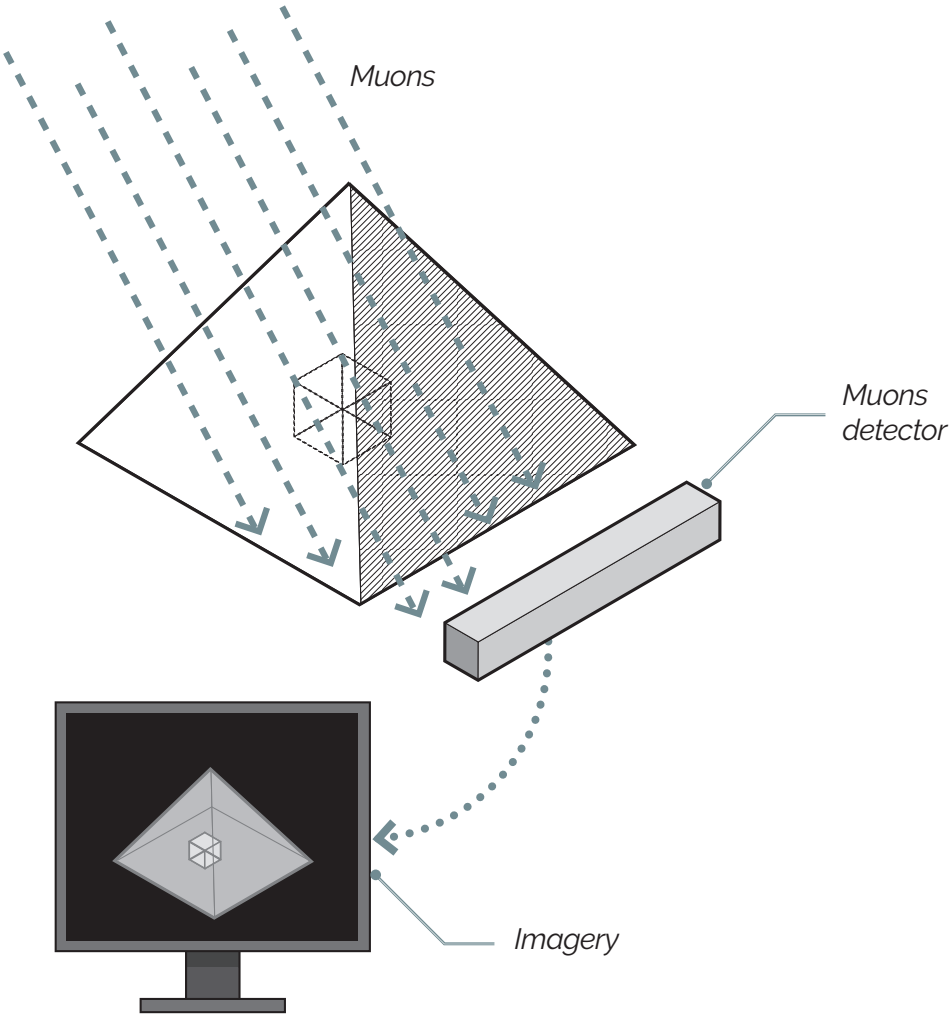
(long mission)



Infrared thermography is commonly used in the aerospace industry for the nondestructive testing of materials. The measurement principle is as follows: the material, the object or the test structure is heated slightly at first. If an internal, therefore non-visible, anomaly is present, the corresponding thermal signature reveals its presence by slight surface temperature differences. This signature is not instantly measurable, but appears after a given time in function of the depth of the anomaly and its own characteristics. Thermal measurements are performed by an infrared camera which records the changes of the surface temperature in the form of thermal images versus time. A number of techniques are available to then improve the thermal images obtained, detecting and characterizing defects. Similarly, various heating techniques also exist to stimulate the object or the test structure. One of these techniques consists in modulating the heating source repeatedly in a predetermined pattern (e.g. a sinus) and record the thermal response obtained with the infrared camera. The recorded images are then processed (e.g., Fourier transform) and reduced to a single image that condenses all the information related

to the internal defects of the object. In the case of large objects such as a building, the solar radiation is an interesting modulated heat source, offering natural periodic variations over a large area (for example the daily cycle: day / night). Interestingly, the slower will be the periodic variation of the heating, the deeper will the generated thermal wave penetrate into the material. Thus, a thermal wave generated by a day / night cycle is able to probe several centimeters in a concrete wall, while the thermal shock caused by the annual cycle of seasons (hot temperature in summer and cold in winter) generate heat waves penetrating deeper. That's why the annual seasonal variations in temperature are the preferred approach to the study of the Pyramids in search of possible internal cavities near their surface.

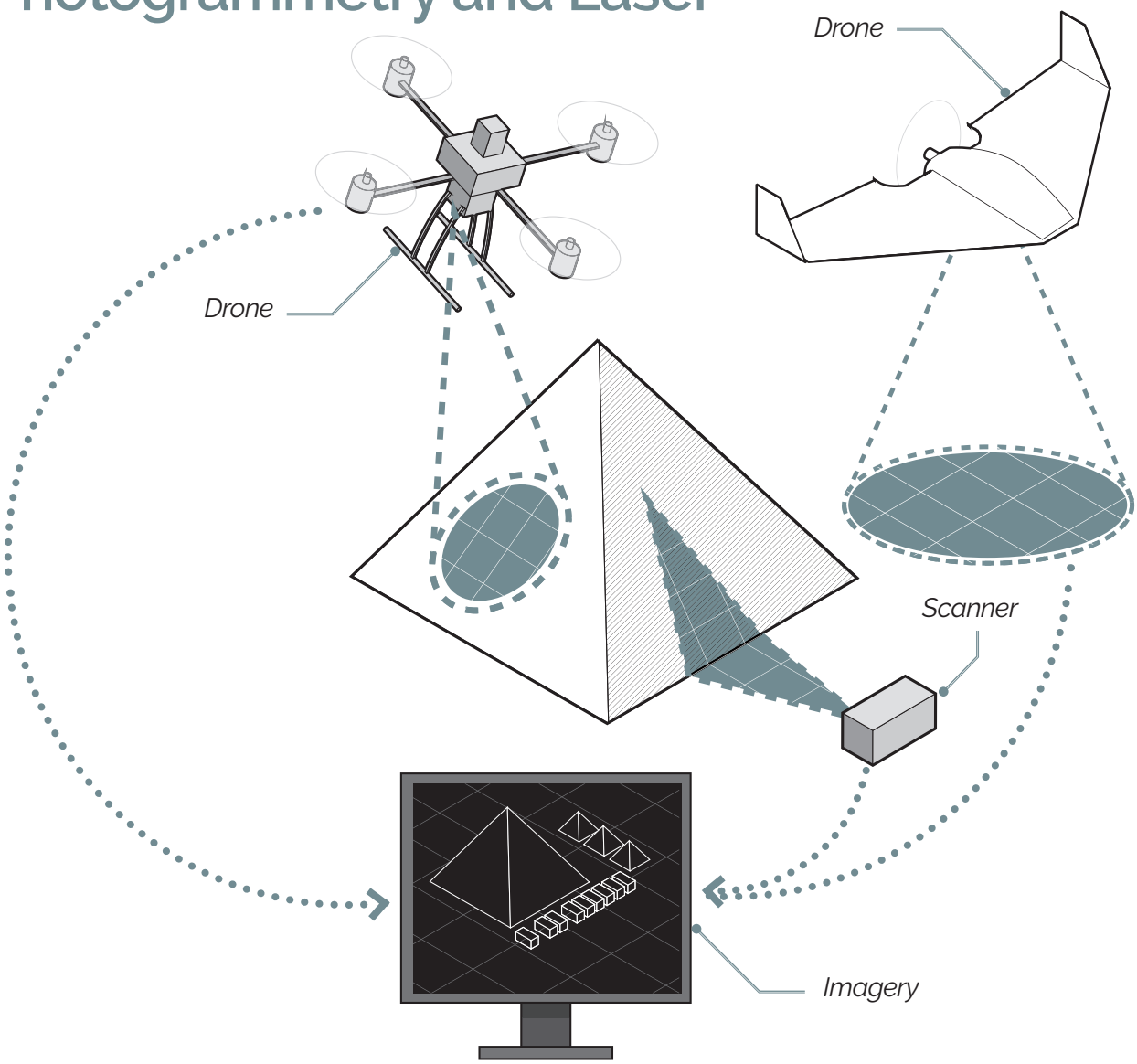
Muons detection



Muons come from the upper layers of Earth's atmosphere where they were created from collisions between cosmic rays of our Galactic environment and the nuclei of atoms in the atmosphere. They fall to the ground at nearly the speed of light with a constant rate of about 10,000 per m2 per minute. As for the X-rays passing through our bodies allowing to visualize our skeleton, these elementary particles, like heavy electrons, can very easily pass through any structure, even large and thick rocks, such as mountains. Detectors, placed at appropriate places (e.g. inside the pyramid, under a possible yet undetected chamber) allow, by accumulation of muons over time, to discern the void areas (that muons crossed without problem) from denser areas where some of them were absorbed or deflected. The difficult aspect of this technique is to create highly sensitive detectors - either gels like the ones used for silver prints

or scintillators. Then to accumulate enough data (in several days or months) to emphasize the contrasts. Muons radiography is now frequently used for the observation of volcanoes, including research teams from the University of Nagoya. More recently KEK developed a detection approach based on electronic scintillators which are resistant to nuclear radiation, unlike chemical emulsions, in order to scan inside the Fukushima nuclear plant reactors.

Photogrammetry and Laser



Dahshur and Giza plateau reconstructed in 3D, with all their monuments, pyramids, temples, Sphinx... To achieve this ambitious goal, Yves Ubelmann of Iconem will combine two technologies: photogrammetry and drones!

At the basis of photogrammetry, there are computer algorithms. They allow, from a large amount of images taken from different viewpoints, to reconstruct a 3D object. The algorithms used by Iconem were developed by INRIA (the French National Institute for computer science and applied mathematics). The great novelty -

already developed by the company Iconem in Pompeii, Syria and Afghanistan, to restore threatened sites - is that the cameras will be shipped aboard unmanned flying vehicles.

For this mission, Iconem will use two types of drones. “First, drones with wings like airplanes, explains Yves Ubelmann. Thanks to their autonomy, they will allow us to obtain the data of large areas and reconstruct the pyramids’ environments with details up to 5 centimeters.” This will allow us to position all the monuments very precisely and to identify levels, slopes and possibly traces of ancient ramps of construction paths. “The details of this micro-topography will also give us clues about the position or shape of unexcavated buildings that are visible only thanks to the shape of the ground.”

The second type of drones looks like helicopters. They have less autonomy but can achieve hovering, take images just meters from the monuments, from highest to lowest and track their grades. The results will be this time detailed on a centimeter scale. This high definition will provide geometric information, especially alignment and assembly of the blocks. But also texture and possibly traces of tools or construction gestures.

“Photogrammetry allows to work and combine different scales, exploited in the same digital model, and propose a global interpretation of the sites,” concludes Yves Ubelmann. To complete this mission, his team will also perform laser scanner analysis inside the monuments, in confined and dark places where photogrammetry is not operative.

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