The Rome' Pantheon as an astronomical instrument

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"Quise que este santuario de todos los dioses representase el globo terrestre y la esfera celeste, un globo dentro del cual se encierra la semilla del fuego eterno, todo contenido en la cueva esférica"
Marguerita Yourcenar

Abstract
The cycle of the Sun is repeated every year and that implies that the duration of the days and nights are different according to the time of that cycle because the path that it makes over the horizon is different; likewise it also varies its height above the horizon. Thus, the greater the trajectory is, the greater the maximum height above the horizon will be. As a consequence, the rays of the Sun do not impinge the same way in a certain place. When the Sun is high, the rays fall with more inclination (more perpendicularly) on the ground than when the Sun is lower since the angle that these rays form with the horizon is less, which causes longer shadows. The Pantheon in Rome, a closed building, offers us to observe the behavior of the Sun during the year without directly observing our star. With a slightly more detailed study we want to show in these pages that we can consider the Roma's Pantheon as an astronomical instrument.

Abstract
El ciclo del Sol se repite cada año y eso conlleva que la duración de los días y las noches sean diferentes según la época de ese período ya que el recorrido que hace sobre el horizonte es distinto; así mismo también varía su altura sobre el horizonte. A mayor recorrido corresponde mayor altura máxima sobre el horizonte. Como consecuencia de esto, los rayos del Sol no inciden de la misma manera en un lugar determinado. Cuando el Sol está alto los rayos caen con más inclinación (más perpendicularmente) sobre el suelo que cuando el Sol está más bajo puesto que el ángulo que forman esos rayos con el horizonte es menor, lo que provoca sombras más largas. El Panteón de Roma, un edificio cerrado, nos ofrece observar el comportamiento del Sol durante el año sin observar directamente nuestro estrella. Con un estudio un poco más detallado queremos mostrar en estas páginas que podemos considerar a el Panteón de Roma como un instrumento astronómico.

Introduction
The Pantheon of Rome, also called Agrippa, was built in 27 BC by order of this friend and general of the Emperor Augustus. It was later burned and Hadrian rebuilt it later in 20 AC maintaining the facade and preserving in the frieze the inscription:

M.AGRIPPA.L.F.COS.TERTIUM.FECIT
(Marco Agrippa, son of Light, built it in his third consulate)

which attributes the construction of the building to Marco Vipsanio Agrippa. The third consulate of Agrippa, indicates the year 27 BC. It is also part of the works carried out by Agrippa in the area of the field of Mars in 25 BC.

The Pantheon of Rome. Presentation
All the characteristics of Roman architecture are reflected in the Pantheon in Rome: the systematic use of the arch and vault, monumental proportions, decorative arts, mosaics and frescoes are essential. The materials used range from stone - stonework or masonry - to

brick or concrete mortar. It is one of the most important buildings in the history of Westerny architecture and the architect was Apollodorus of Damascus, who wanted to create a grandiose building. It has a circular plan, although the facade is rectangular. This characteristic of combining the circular with the rectangular is very innovative for that time. The model of a circular space covered by a vault had been used around the same time in the great thermal rooms, but it was a novelty to use it in a temple.

Thus, the Pantheon consists of two clearly differentiated parts, the first of them consists of a portico supported by eight columns that presents the classic lintelled structure with a pediment. The second is a circular space covered by a dome that is supported inside by a ring. The interior vault has coffered ceilings - square- that give it greater decoration and thus revolutionize the play of light because it is only introduced through an zenithal oculus on the ceiling of about 8.2 meters in diameter, creating a very special effect. **The study of the movement of that light that enters through the oculus is the objective of this work.**

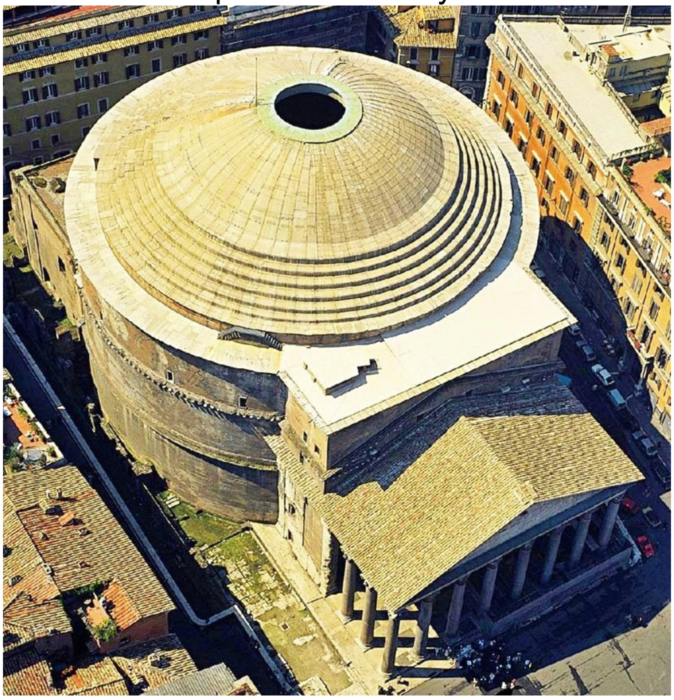


Figure 1: Aerial view of the Pantheon.

The height of the dome is 43.5 meters, exactly the same measurement as the diameter of the circular base. The dome rests on a cylinder whose diameter and height coincide with the height of the dome itself. This sector is made with the famous Roman mortar or cement, combined with brick. In the portico, on the contrary, the use of marble predominates, both in the shafts and in the capitals of the columns.

The complexity of the plan lies in joining the curved plan with the rectilinear shape of the facade. The architect solves this joint problem by creating a new form of lock, with an element of surprise on the outside. The solution will be that of the walls and pillars that achieve the union. And the surprise is that if you only see the facade, you cannot imagine the circular shape of the interior of the building.

Marco Agrippa made this building as an analogy with the celestial sphere, based on the model of his teacher Anaximander. The construction, of cosmic proportions, reproduces in its dimensions the sphere in which the seven stars or main divinities of the Roman pantheon witness the actions of men since if we imagine it completes, the sphere that is inscribed in the great circular room and that determines the dome, we would have represented the celestial globe resting on the ground. The Pantheon meant for the Romans *the temple of all the gods.*

"*Above is below; as below is above.*" It was the philosophy of Roman architects, who charged the Pantheon with a very specific cosmic symbolism. This basic geometry always does reference to the image and similarity of the Universe and the celestial movement: *"In the plane geometry, the circle is the symbol of the sky, the square of the Earth and the octagon intermediates between one and other, and through this, it is achieves the squaring of the circle, the indissoluble union of spirit and matter ”.*

Astronomy in Pantheon

On the plan of the building we can see that in the circular part there are seven apses, with the entrance door, which were consecrated to the seven astral divinities, the sun, the Moon and the five planets of antiquity: Mercury, Venus, Mars, Jupiter and Saturn (Fig. 3).

Figure 2: Front picture of the Pantheon.

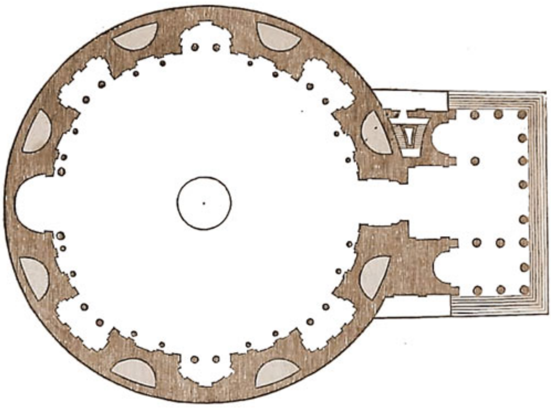


Figure 3: Plan of Pantheon with the seven doors.

The circular room itself is a perfect sphere, representing Aristotle's cosmogonic conception. On the one hand, the infralunar world corresponds to the lower half of the building. The supralunar world, the celestial sphere is the vault, in which the central oculus acts as the Sun. The building was designed to unite man with divinity, but above all to the emperor, who was proclaimed a god in the eyes of the people.

Figure 4: Vault with coffered ceiling and oculus.

As already mentioned, the cupola with its exact proportions represents the celestial vault and the five levels of the coffered ceiling represent the five concentric spheres of the ancient planetary system (Fig. 4).

On the other hand, the central oculus dominates the interior space and is the only light in the entire building (Fig. 4). It represents the Sun during the day and the Moon at night. The light of the Moon as a solar reflection, dominates the entire space and travels it cyclically. Let’s not forget that the temple was conceived like a cosmogony, like an observatory of the cosmos, hence its orientation to the north, fixed point of the celestial vault that allows us to understand the movement and variation of the stars throughout the days and nights.

In what follows, we will deal with the behavior of sunlight within the Pantheon.
The two days of the equinoxes, the only days of the year when day and night have the same length, have been very important since ancient times. Mainly the spring was considered as a safe reference to start certain agricultural works; so many days after the equinox, for example, some plants had to be pruned; after so many days, certain seeds had to be sown, and so on.
On the other hand, the equinoxes allowed to control the accuracy of the calendar. Some civilized peoples even at the time of the Roman conquest, in the second century AD, used a calendar based on a 360-day year and it was necessary to correct it periodically, which was carried out with the fixed "arrival" of the equinoxes. For this reason, ancient peoples built special monuments to control the date of the equinoxes.

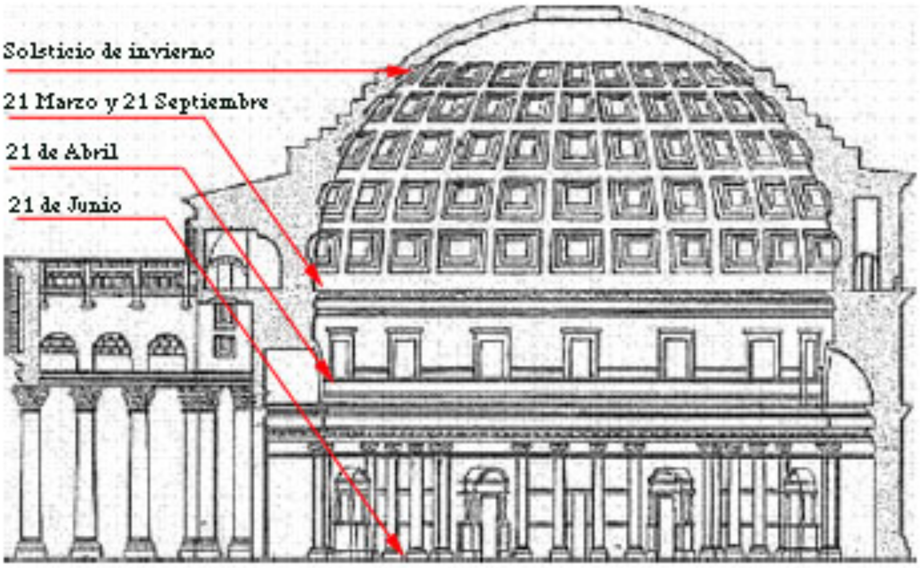


Figure 5: Elevation section of the Pantheon where it represents how impinging rays of the Sun at the solstices and equinoxes.

As can easily be seen, the Sun does not rise on any consecutive day from the same point on the horizon. On the day of the spring equinox (around March 21) and the day of the autumn equinox (around September 21) the Sun rises exactly from the east cardinal point and sets from the west. From the day of the spring equinox, the Sun will rise, each day, a little further north until the day of the summer solstice (approximately for June 21), which rises from the furthest point from the east cardinal point (NE). As of the day of the summer solstice, a retreat of the sunrise positions on the horizon begins and undoes the entire journey from the spring equinox to the summer solstice to again occupy the east cardinal point on the day of the autumn equinox (by September 21 or so). After that day, the Sun rises a little further south each day until it reaches, on the day of the winter solstice, the farthest point from the east (SE) by which the Sun can appear on the horizon. In the first days of winter, the points of sunrise on the horizon begin to recede towards the east until, again, on the day of the spring equinox, the Sun appears precisely from the east cardinal point and the cycle repeats.

Once the point on the horizon where the Sun appears at the equinoxes was determined, it was easy to control when it would happen again; It was enough to place two vertical objects on the line that joined the eye with that point on the horizon. This is what was done, for example, at Stonehenge, where two stone monoliths mark the line of sight to establish the point on the horizon where the Sun rises on the days of the equinoxes.
Something similar was done in the construction of the Pantheon.

This cycle of the Sun, which repeats itself, means that the duration of the days and nights are different depending on the epoch of year since the path it makes over the horizon is different; likewise, its height above the horizon also varies. To a greater distance also corresponds to a greater maximum height above the horizon. As a consequence of this, the Sun's rays do not strike a certain place in the same way. When the Sun is high, the rays fall with more inclination (more perpendicularly) on the ground than when the Sun is lower since the angle that these rays form with the horizon is smaller, which causes longer shadows. In figure 5 it can be seen, in an approximate way, how the Sun's rays impinge over the Pantheon when it reaches its maximum height above the horizon on the days of the solstices and equinoxes.

The orientation of the Pantheon

But the astronomical phenomena previously described would have no validity if we did not endow the building with an orientation. Thus, the main axis of the Pantheon is oriented in the North-South direction (the entrance door is towards the North). This is essential for it to serve us as a solar clock and an astronomical observatory. We must remember that the Sun in its diurnal journey reaches its maximum height just when it is over the South cardinal point. That precise moment of the day is that allows us to take references and measurements to calculate, determine and reference observations at other moments of the day or epochs of the year.

Figure 6: Cylindrical beam of rays impinging over the wall inside the building and the elliptical shape that its projection takes.

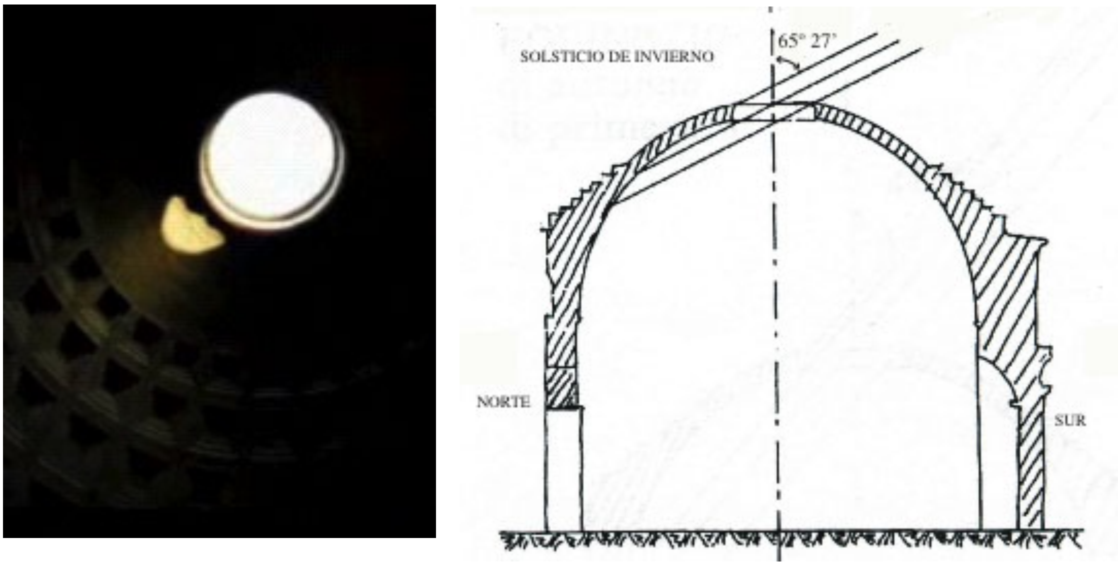


Figure 7: Winter Solstice. The light spot falls on the top of the dome.

The cylindrical beam of rays that enters through the hole in the dome hits the interior of the building at variable points with the epoch of year and time of day (Fig. 6). At astronomical noon, the vertical axis of the luminous ellipse that the Sun traces on the wall of the temple coincides with the axis of the entrance door (North), but it a move vertically as the seasons change. At the winter solstice, when the Sun is very low on the horizon, the light spot falls completely on the upper part of the interior of the dome; but at noon on the summer solstice it falls completely on the pavement (Fig. 7 and 8).

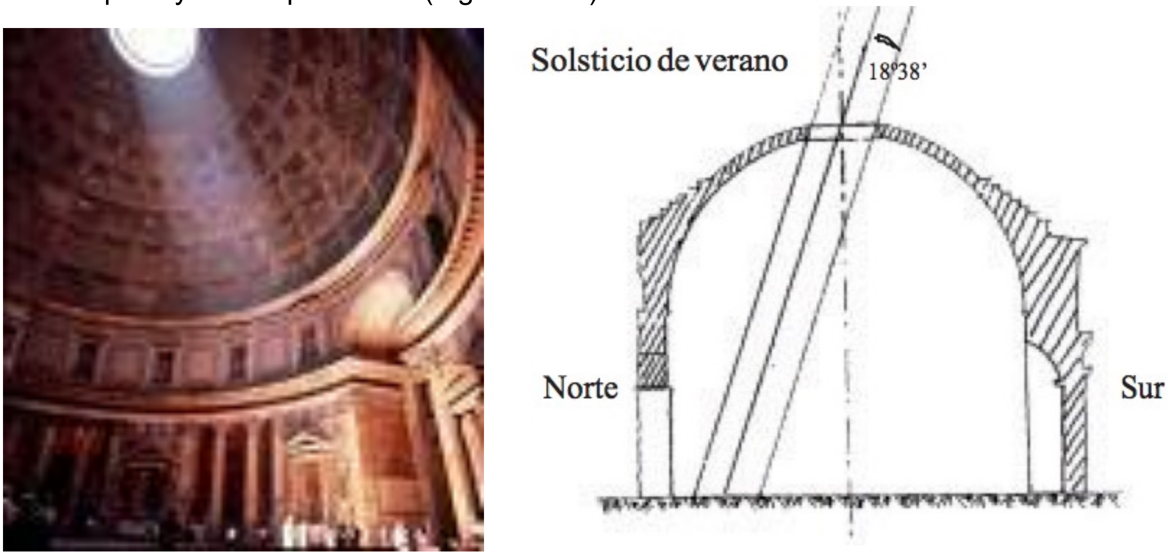


Figure 8: Summer Solstice. The light spot falls on the pavement of the dome.

At the summer solstice the Sun reaches its maximum height above the horizon; at noon, the elliptical stain that forms the light source is observed on the pavement of the Pantheon, with its axis coinciding with the axis of the entrance door, as can be seen in the first image of figure 8.

At the spring and autumn equinoxes, at noon the light beam hits the cylindrical wall of the building above the entrance door with a stain whose vertical axis coincides with the axis of the door (Fig. 9).

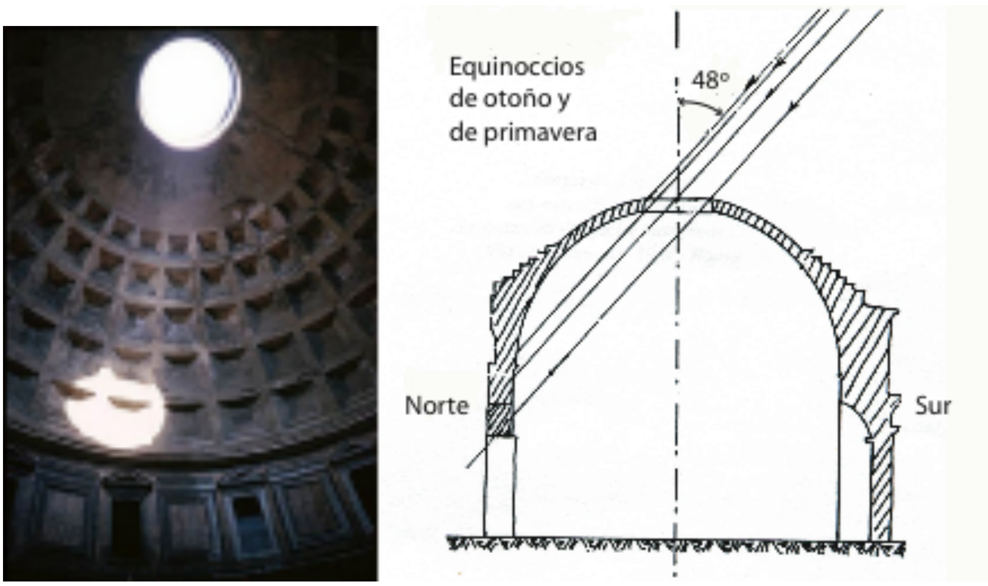
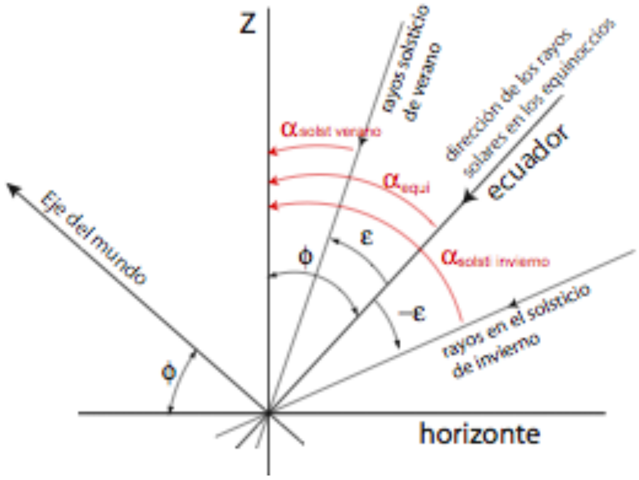


Figure 9: Equinoccios de otoño y primavera. La mancha luminosa sobre la puerta de entrada.

<u>It should be noted</u> that the photo that appears in figure 9 does not correspond exactly to any of the equinoxes, but to the next few days, since as can be seen the stain impinges, not on the cylinder but just above it, already at the beginning of the vault.

The orientation of the Pantheon axis does not strictly follow the North-South line, but the deviation is so small that it only causes the phenomenon described above to occur approximately one minute earlier.
In months when daylight saving time is in effect, the phenomenon occurs one hour later.

In the images to the right of figures 7, 8 and 9, the values of the angles that the sun's rays form with the vertical of the place on the days of the winter and summer solstices and of the equinoxes respectively have been written. These values, which we will call α, are obtained by observing figure 10 through the expressions:



$\alpha_{equi} = 90 - \phi$ for the equinoxes

$\alpha_{sols\ verano} = 90 - \varepsilon$ for the summer solstice

$\alpha_{sols\ invierno} = 90 + \varepsilon$ for the winter solstice,

Figure 10: Angles formed by the vertical of the place and the solar rays at the solstices and equinoxes.

where ϕ is the latitude of the place, in the case of the Pantheon 42º and ε = 23º 27 ’ the angle formed by the earth's axis with the normal to the plane of the ecliptic.

Thus it results that α = 48º on the equinoxes, in the summer solstice α = 18º 33 'and for the winter solstice α = 65º 27'.

In conclusion, we could say that the temple of the Pantheon was conceived as a cosmogony, as an observatory of the Cosmos, hence its orientation to the North, a fixed point of the celestial vault and that allows us to understand the variation of the stars throughout the days and the nights.

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