Antikythera Mechanism as evidence for Hellenistic technology excellence

by Xenophon Moussas

The Antikythera Mechanism is the oldest computer, the oldest known complex mechanical instrument and automaton, a mechanical Cosmos, a clockwork universe. Made during the second half of the 2nd century BC, somewhere in Greece, by a philosopher.

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* '*Pythagoras doctrine is that mathematics have maximal power to describe and understand nature and he is always referred to numbers, as for example the periods of celestial bodies*' Plutarch

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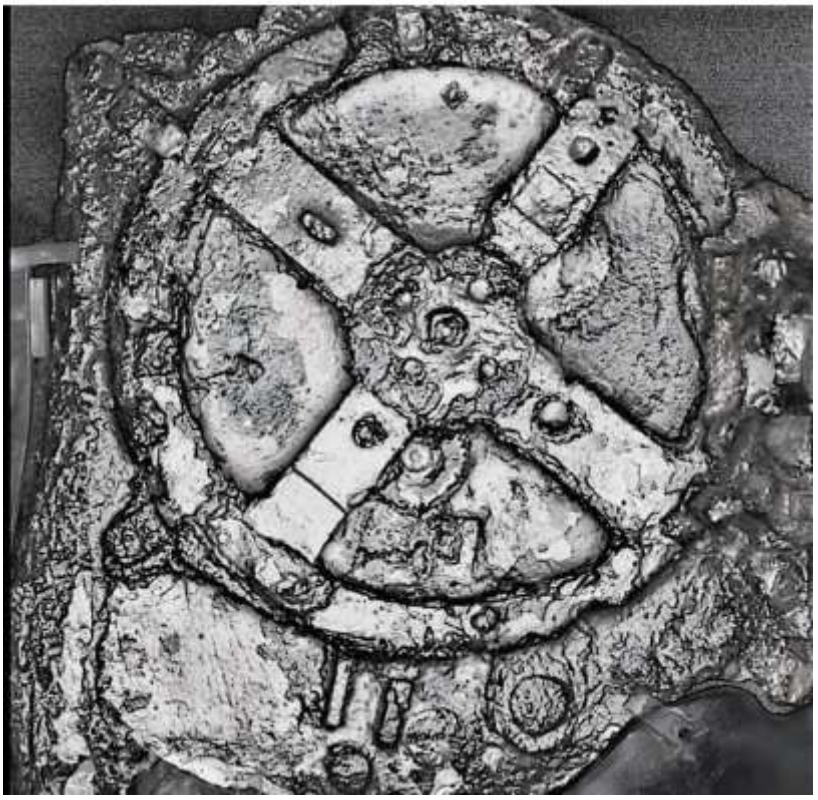

Figure 1 the solar gear

Summary

The Antikythera Mechanism is the oldest computer, the oldest known complex mechanical instrument and automaton, a mechanical Cosmos, a clockwork universe. Made during the second half of the 2nd century BC, somewhere in Greece, by a philosopher.

The Antikythera Mechanism, found in an ancient shipwreck, looks like an oxidized grandmother's clock made of bronze gears. It calculates: the position of the Sun, the position of the Moon, the phases of the Moon any time during the month. The mechanism has many totally unexpected features and functions for its era of construction. This mechanism was originally called PINAKIDION, tablet in Greek.

key words:

Antikythera Mechanism, ancient technology, ancient astronomy, Hellenistic Astronomy, Greek Astronomy, Pythagoras, Plato, Archimedes, Hipparchus, Hero, history of Philosophy, history of science, epistemology, ancient gears, automation, robots, ancient computers, ancient shipwrecks, ancient ships.

Introduction

Philosophy, science and technology have changed human life radically over the last three to ten thousand years, and especially over the last two hundred years. We consider all new technological applications as very natural and self-evident. Every day many new ones appear, some of them unexpected and often very successful. All of these technological applications are based on scientific applications, like computers and the internet with its applications.

The mechanism is the oldest known planetarium too; it had dials for the planets and pointers that show the position of every planet in the sky for a given time.

The instrument has a user's manual with instructions as all scientific instruments. The manual is written on copper sheets that are the doors of the mechanism and has instructions on how to use it.

The mechanism is an excellent example of Hellenistic technology, technology based on science developed at the Museum and the Library of Alexandria, with some roots on science established by Archimedes. The mechanism is the oldest known computer working with gears that perform

calculations with integer ratios, with rational numbers using trains of gears appropriately designed.

It has several accurate and complicated calendars, based on the: Solar year, the Egyptian Calendar, the four year Olympiad period and its double, the octaetiris and 19 year calendar of the Metonic cycle, with Epirotic months (a Corinthian Doric calendar).

The mechanism is the epitome, compendium, and the best example, of Greek philosophy. In the article it will be discussed how humans conceived the idea to construct such a mechanism and how they managed to construct a mechanical cosmos, the role of causality, the notion of laws of physics, and modeling will be presented and discussed too in relation to the mechanism. The role of Pythagorean philosophy to the development of the mechanism, the notion that the Cosmos «is» mathematics [can be described properly by physics and mathematics], will be discussed too.

The mechanism proves that the Greeks had advanced technology and even nanotechnology, advanced ways to perform mathematical calculations using gears programming the train of gears, i.e. to create computers. The mechanism is the forefather of all technology. The bits and bytes of all computers, automations and robots of today have their roots deep in the Antikythera Mechanism and the

Alexandrian the science and technology. The mechanism has the optimal size that can work without breaking. If it was larger the use of bearings would have been a necessity.

The achievements of Science and Technology, the advanced visions of the ancient philosophers, raise the basic question of how man has made and made incredible advances, philosophical, scientific, how we built computers and the internet, how medicine heals so many diseases, how humans went to the Moon. But how did science and science based technology begun? How did science and philosophy develop? To make a flashback, we should go to legendary personalities such as the semi-god Prometheus who gave fire to humans, the legendary king and scientist Orpheus that tames nature with science, Thales that sets the basis of theoretical mathematical reasoning with proofs of theorems and predicts eclipses with mathematics, the laws of periodicities of eclipses, based on observations over centuries if not millennia, and Plato. Plato to show the importance of Science refers to the Pythia giving an oracle on how the Athenians and humans in general can mitigate dangerous situations like the typhoid that killed half of the population, among them Pericles, the creator of Athens, and how the liberation of the humanity from the suffering of diseases, from hunger and pestilence can be made using science based on mathematics. Thus, the Oracle at Delphi Pythia, with the words of Plato proposes philosophers to solve the famous mathematical Delian problem, that is, the

doubling of the volume of the cubic altar of Apollo in Delos, using a ruler and compass, ie with theoretical geometry! Plato wants to stress the importance of science that is based on mathematics. Apollo does not ask for offers, sacrifices and carcasses, but tells us to sit down in desks and research centers and universities and become better at school and then in science. Plato says emphatically, using the words of god Apollo, that Science will give the solution to all the problems of humanity.

Eudoxus gives a wonderful example of divine curiosity that guides humans to science and philosophy that lead men to the study of Cosmos and the prediction of celestial phenomena that the mechanism predicts. This important component of progress the divine curiosity of humans is described by Plutarch with a passage concerning Eudoxus who says *Let me go to the Sun, provided what I will understand of what the Sun is made of, even if this way I will be burned like Phaethon*[1]. Phaethon is a mythical figure that went to the Sun and was burned. The description of Phaethon shows that in fact it is a comet that is destroyed as it heats up approaching the Sun. Divine curiosity is a gift humans have that enables them to study and understand nature under the guidance of *Anange,* Necessity, that urges humans from problems to solutions. Solution of problems

[1] in the book of Plutarch Non posse suaviter vivi secundum Epicurum

of humanity become more and more scientific at the Hellenistic period, centered at Alexandria.

The Antikythera Mechanism, an automatic machine that imitates the cosmic phenomena, is the result of many generations of scientists that have started to study natural phenomena and predict some of them using mathematics and gears that perform the calculations. The mechanism is the distillate of natural philosophy, the result of an excellent combination of theoretical reasoning, causality, with laws of physics, mathematics and engineering. During the second century BC science and technology in the Greek world that Alexander has inherited humanity is at its apogee. All great scientists, like Epicurus, Straton, Zenon, Euclid, Eudoxus, Eratosthenes, Apollonius, Aristarchus, Ctesibius, Archimedes, Philo, Hipparchus and later Hero, Ptolemy, Pappus work and advance science, technology and philosophy at the Museum and the Library of Alexandria where the 400000 books helped to establish the grandeur and legacy of Alexandria.

In this cultural, scientific and technological environment the Antikythera mechanism has been conceived and developed which is an excellent example of Hellenistic Alexandria amongst many other technological products. Weapon and shipping technology continuously improves and in parallel many other applications like the Antikythera Mechanism.

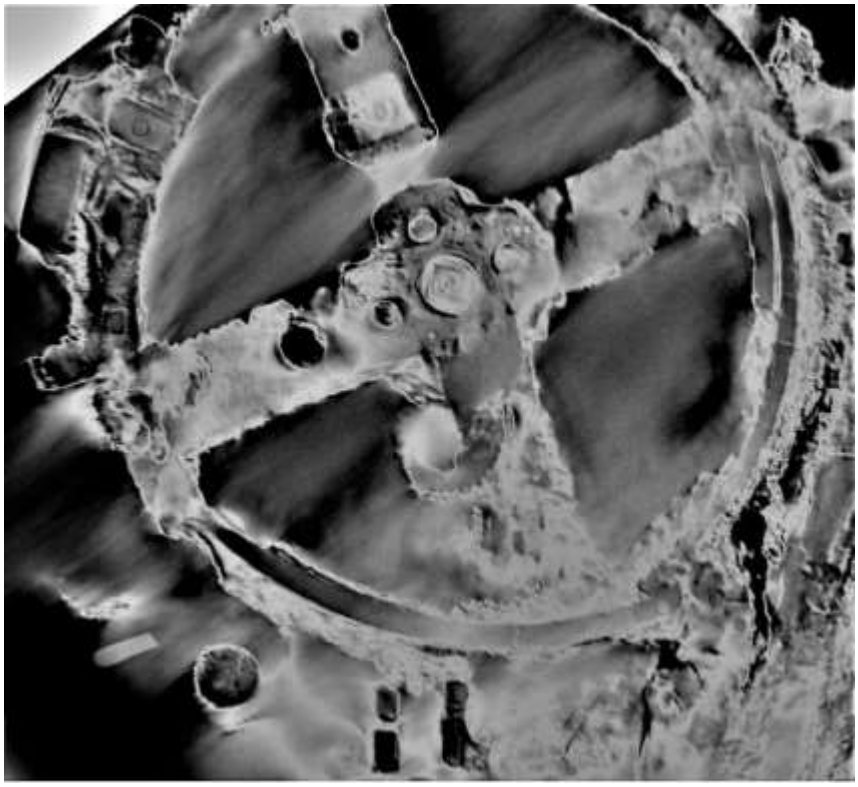

Figure 2 Computer tomography of the largest gear, the gear of the Sun

What is the mechanism

The Antikythera Mechanism is the oldest known computer that we have today. It is a complex astronomical instrument, a dedicated astronomical computer, a mechanical Cosmos, a portable planetarium. The name of the instrument was originally called Sphere (automatic mechanized celestial sphere) at the time of Archimedes (early 3rd century BC) and sometime later (3 rd century AD and thereafter) it is named tablet, ΠΙΝΑΚΙΔΙΟΝ, PINAKIDION in Greek which means little table, i.e. tablet, in Greek. The mechanism is on display at the National Archaeological Museum in Athens. The mechanism is the dream of any astronomer of that time or even of today, as it predicts all celestial phenomena.

It is a remarkable clockwork instrument that works with gears that are carefully designed, cut and assembled. It has been made by some Greek philosopher, probably during the second half of the 2nd century BC, somewhere in the Greek World. It performs the appropriate astronomical calculations with carefully designed bronze gears that accomplish the appropriate mathematical operations to predict astronomical phenomena.

It shows the position of the Sun and the Moon in the sky. It gives the date in several calendars and possibly the hour. It shows the age (phase) of the Moon, with an ingenious

method that is a good approximation of Kepler's second law using an equivalent of a two term Fourier series, it gives the perigee and apogee of the moon. It predicts solar and lunar eclipses. It probably gives the position of the planets using the same mathematical method with various combinations of gears, what we call planetary gears. We have discovered a set of gears that I interpret as planetary gear that predicts the motion and position of planet Jupiter using an equivalent of Fourier series with two terms.

Is the mechanism a computer?

The mechanism is really a computer. It is a device that has been programmed to do some calculations. It receives some input. The input parameters are longitude, latitude, time. Several constant parameters are permanently if the device. The period of the year, the period of eclipses (Saros cycle), the periods of the moon, of the planets. Even the distances of the planets are in, as if one knows the retrograde motion and time, between stationary points that are frequently mentioned in the computer manual, it already has the appropriate distances of the planet in astronomical units (the distance of the Earth to the Sun). The mechanism is a mechanical special purpose digital computer based on the

unary arithmetic representation2, and not the binary as most computers (Ioannis Kontos, Emeritus Professor of Artificial Intelligence, Private communication, 2017).

Every computer is and has to be programmable. The Antikythera Mechanism is programmed with the gears that perform the calculations. The programmer designs the machine with appropriate gears with number of teeth and in an appropriate train of gears that as they turn finally give the output with pointers on scales, six circular and two spirals, divided in appropriate divisions, in days, months or degrees and possibly one more divided in hours.

The gears have been designed to perform appropriate mathematical operations to predict all the then known astronomical phenomena. It really is realistic clockwork Cosmos, with the Moon following Kepler's second law. The mechanism probably was very luxurious in appearance, with ornaments like a Rococo clock, because the taste of that era was similar. We can magine that it was made of gold, silver and precious stones. In the manual we read "*little golden sphere*" [ΧΡΥΣΟΥΝ ΣΦΑΙΡΙΟΝ, chyssoun sphaerion] probably is referred to the pointer of the Sun

[2] mechanical special purpose digital computer based on the unary and not the binary arithmetic representation, Prof. Ioannis Kontos, private communication University of Athens, 2017

and again something like silver little sphere, which is perhaps the pointer of the moon.

The mechanism is much more advanced than any other ancient device, like astrolabes. It has many similarities with the clocks of the Byzantium and the Arabs and the astronomical clocks that appeared in Western Europe for the first time around the 14th century.

The Pythagorean view of the Cosmos at work in Alexandria

The study of the mechanism permits to understand much better the way humans use science in antiquity and one of our conclusions is that the advancement of mathematics, physics, and mechanics in particular, astronomy and engineering is much higher than estimated so far by the scientific community, even by specialists.

To imagine that you can predict natural phenomena, to conceive the construction of such a machine, a computer, an automaton, is a big step for humanity, that was only possible with the notion of causality with its natural extend the laws of physics expressed with mathematics and the practice of modeling of natural phenomena.

The Antikythera Mechanism is the epitome, the best example, of Greek Philosophy, the Natural Philosophy of the Greek philosophers, mainly the Ionian philosophers, the

Pythagoreans that at the time of the construction of the mechanism is the mainstream philosophy spread all around the Mediterranean with Alexandria being its center.

The machine which reproduces the movements of celestial bodies predicts the phases of the Moon, the eclipses, is required for a civilization that havs developed and practice:

a) the notion of determinism (all events have a cause),

b) the notion of laws of nature ("*celestial law that set the stars in their position*" [OYPANION NOMON ΑΣΤΡΟΘΕΤΗΝ], Orphic Hymns,

c) that the laws of nature are expressed with precision only with appropriate mathematics (Pythagoras, the elements of nature are mathematics, or nature started with mathematics, [Πυθαγόρας τῶν ἀρχῶν τὰ στοιχεῖα ἀριθμοὺς καλεῖ, Diogenes Laertius, *Vitae philosophorum*]),

d) that natural phenomena are understood and interpreted with the laws of physics, Pythagoras understood the importance of laws of a physics when he discovered the law of vibration experimenting with a chord using mathematics [Πυθαγόραν περὶ τὸ ἀριθμητικὸν εἶδος αὐτῆς· τόν τε κανόνα τὸν ἐκ μιᾶς χορδῆς εὑρεῖν, Diogenes Laertius, *Vitae philosophorum*].

e) and sometimes some phenomena are predicted by the laws of nature.

To construct such a mechanism a civilization has to have developed what is now called modeling in science, i.e. in reality to conceive, develop and put in operation the doctrine of the Pythagorean philosophy that everything is properly described with mathematics that the laws of physics have to be expressed with.

This scientific reasoning inside the mechanism that is accurately written in the trains of gear of the mechanism make it an excellent instrument to teach introduction to science, the notion of causality, the laws of physics, the importance of mathematics and modeling and in fact we use today the mechanism at schools for this purpose with lecture and exhibitions.

Figure 3 The lunar dial. The moon is the hollow hemisphere where originally a little sphere represented the Moon.

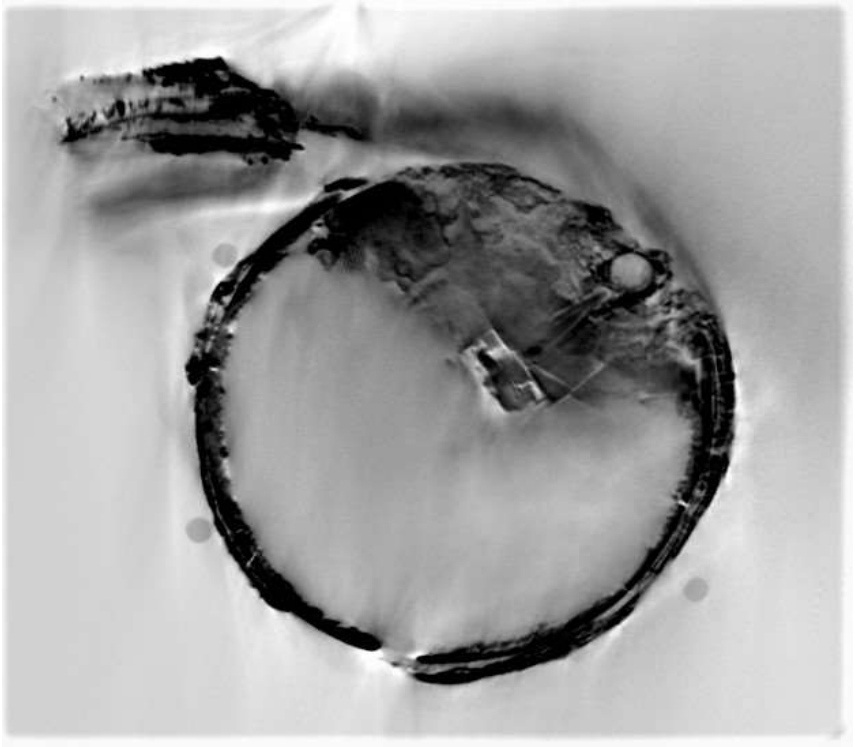

Figure 4. The lunar gear that turns the moon around itself so that it changes phases during the month. The dial of the moon, a semispherical structure is visible too.

The prediction of eclipses

The mechanism predicts both solar and lunar eclipses and shows the result on two dials one spiral dial that shows the time during a Saros3 cycle that lasts 18 years, 11 days and 8 hours and an Exeligmos cycle of 54 years and one month.

Figure 6.

The prediction of an eclipse of the Moon and an eclipse of the Sun that will take place at 9 hour.

[3] The Greek Historian Abydenus who lived during sometime between the 4 th century BC and 4 th century AD and chronographer Georgius Syncellus give the definition of Saros (in Greek means sweeping, scanning). The term Saros has been introduced in western European science by Halley.

Another great surprise is the fact that the mechanism predicts not only the time of an eclipse, but it additionally predicts where every eclipse is visible. The time of the eclipse is shown by the eclipse pointer on a spiral scale that lasts 223 months and an ancillary pointer on a small circular scale that adds 0, 8, or 16 hours to the indication of the time, depending upon which 223 year cycle we are. One has to add 0 hours for the first 223 months, 8 hours for the next 23 months and 16 hours for the last 223 months of the 54 year and one months period. The position of the Moon in the sky is visible too on the front side of the mechanism, with the ecliptic, divided with the zodiac and in 360 degrees and this shows the part of the Earth the eclipse is visible. The position is also visible on the scale of the phases of the moon.

Calendars and social life in antiquity

Since the dawn of humanity on Earth people understand that their life depends on weather and the climate. Humans understand that weather depends upon the season of the year. Food collectors have to move from one region to another depending on the crops that are available and which change with the seasons. The same applies for pasture and shepherds have to move with their herds. Hunting[4] and especially fishing strongly depend upon the

[4] Penteriani, V., Kuparinen, A., del Mar Delgado, M., Lourenço, R., & Campioni, L. 2011. Individual status, foraging effort and need for conspicuousness shape

phases of the moon. It is no coincidence the fact that the menstrual cycle of women is so close to the synodic period of the moon5. This is probably due to the fact that selectively only women with a cycle locked and with appropriate phase with the lunar cycle could hunt effectively and eventually survive. Calendars based on the Sun and the Moon have been developed to regulate social life and to develop calendars astronomy based on causality and mathematics are created,6 and civilization comes with the study of the cosmos, as Plato states: we become humans, we develop civilization, as we watch the sky, we

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behavioural responses of a predator to moon phases. Animal Behaviour, 82(2), 413-420.

Poisson, F., Gaertner, J. C., Taquet, M., Durbec, J. P., & Bigelow, K. 2010. Effects of lunar cycle and fishing operations on longline-caught pelagic fish: fishing performance, capture time, and survival of fish. Fishery Bulletin, 108(3), 268-281.

[5] Cutler, W. B. (1980). Lunar and menstrual phase locking. *American journal of obstetrics and gynecology*, *137*(7), 834-839.

Law, S. P. (1986). The regulation of menstrual cycle and its relationship to the moon. *Acta obstetricia et gynecologica Scandinavica*, *65*(1), 45-48.

Zimecki, M. (2006). The lunar cycle: effects on human and animal behavior and physiology Cykl księżycowy: wpływ na zachowanie ludzi i zwierząt i ich fizjologię. *Postepy Hig Med Dosw.(online)*, *60*, 1-7.

[6] Calendars and Astronomy Ruggles, Clive L. N., Pages 15-30 In: Ruggles C. (eds) Handbook of Archaeoastronomy and Ethnoastronomy. Springer, New York, NY

admire the celestial bodies, we wonder and in our effort to understand what they are we develop civilization.

The oldest known record on a bone that has 29 marks is possibly a representation of lunar "calendar" dates to the 35 th millennium BC from South Africa7 and a similar more spectacular painting appears in the cave La-Tete-du-Lion, in France, that represents the lunar cycle together with several star patterns, probably Aldebaran in the Taurus, the Pleiades, dated from the Solutrean epoch around 19,000–20,000 BC.8

Greek calendars are very old too. There are indications from archaeoastronomy of the existence of solar calendars in Greece as early as 6000 BC at Sesklo and Dimini9

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[7] Naidoo, K., & Webb, J. (1987). 71.36 The oldest mathematical artefact. The Mathematical Gazette, 71(458), 294-294. doi:10.2307/3617049, see also F Graham - Mineola, 2002, Numbers: Their history and meaning, Courier Dover, NY.

[8] Rappenglück, M.A. 1999, Palaeolithic Timekeepers Looking At The Golden Gate Of The Ecliptic; The Lunar Cycle And The Pleiades In The Cave Of La-Tete-Du-Lion (Ardéche, France) – 21,000 BP, Earth, Moon, and Planets () 85: 391. https://doi.org/10.1023/A:1017069411495 and Rappenglück M.A. (2015) Possible Astronomical Depictions in Franco-Cantabrian Paleolithic Rock Art. In: Ruggles C. (eds) Handbook of Archaeoastronomy and Ethnoastronomy. Springer, New York, NY

[9] Moussas, X. 2017, Antikythera Mechanism: from the Cycladic Frying pan vessels to the oldest tablet (in Greek) Naxiaka

(Thessaly) as the Megaron and the Acropolis of both these small towns are oriented towards the sunrise and sunset respectively of the summer solstice and this is probably the earliest known calendar. Similar finds come from the Aegean10 where the numbers of repeating patterns on terracottae give astronomical numbers related to lunisolar calendars and even the octaetiris an eight year calendar, with leap years and Venus synodic period included. The months of a lunisolar year have been named already from at least the late Bronze Age11 around 1370 BC as tablets from Knossos that contains eight month names and from Pylos 1200 BC with another six months, which shows an advanced calendar with a sequence of named months, with similar patterns of the names of the months with calendars of classic times, that are better known.

Every Greek city state has different names for the months although all of them follow the same cycle. Two lunisolar

[10] Tsikritsis, M., Moussas, X., and Tsikritsis, D. 2015, Astronomical and mathematical knowledge and calendars during the early Helladic era in Aegean" frying pan" vessels. Mediterranean Archaeology & Archaeometry, 15 (2), and Moussas, X. (2014). Early Greek astrophysics: the foundations of modern science and technology. *American Journal of Space Science*, *1 Samuel A.E., 1972, Greek and Roman Chronology, Munich, C.H. Beck'sche Verlagsbuchhandlung*, 129.

[11] See Samuel A.E., 1972, Greek and Roman Chronology, Munich, C.H. Becksche Verlagsbuchhandlung and Robert Hannah 2005, Greek and Roman calendars: constructions of time in the classical world Duckworth

calendars are in use in Greece. These are the Octaetiris and the Meton cycle or *enneakaidecaetiris* (19 year). The Octaetiris is 8 tropical (solar) years equal to 2921.93754 days, which is equal to 99 synodic lunar month or 2923.528230 days, 107 sidereal [with respect to the stars] lunar months, equal to 5 synodic periods of Venus around the Sun, as we see the planet from the Earth, or 13 Venus sidereal periods. Octaetiris is an excellent calendar that a peasant, a sailor can follow easily, as one can have a sign on the horizon that when Venus rises or sets there usually at the longest distance from the Sun, is the beginning of Octaetiris. Octaetiris is the calendar used for the Olympic Games in the Mechanism and it was in use probably from prehistoric times, although historical sources attribute this calendar to Eudoxus (407BC-335BC) and Censorinus attributes this calendar to older times to Cleostratus of Tenedos (520BC-432BC). Indications from ancient vases can show that octaetiris is in use from prehistoric times and the existence of Olympic Games proves that it was in use from at least since 776 BC. This eight-year period consists of five years with 12 months and three years with 13 months. Every eight years are added to three out of eight years and one extra month of 30 days during the third, fifth and eight year of this calendar[12]. These three months correct the difference between the lunar year that consists of six

[12] Hannah, Robert, 2005, Greek and Roman calendars: constructions of time in the classical world. Front Cover. Duckworth

months of 29 days and six months of 30 days, taking into account the period of the moon that is 29.5 days approximately and the solar year of 365.25 days. The difference between the solar year and the lunar year is approximately 11 days (365.25-6x29+6x30=365.25-354=11.25 days). The addition of an extra 13 th month every three or two years makes the Octaetiris consistent with both the solar and a lunar calendar and predicts the phase of the moon with an accuracy of one to two days in a period of 8 years. Octaetiris is a lunisolar relatively accurate calendar that was in use by the Christians for Easter till the 11 th to the 13 th century, when it was replaced gradually by a new Paschalion based on the calendar of Meton. Both the Octaetiris and the Metonic calendar are in use in the Antikythera Mechanism.

Planet Venus is has a 5/8 resonance with the Earth and the Sun. This resonance of 5/8 exists in some ancient vessels, and the eight-year period used by ancient Greeks to be the basic period of authority of some rulers. This 5:8 resonance is commonly used in, music and dance, Greek and elsewhere. I suggest that the Octaetiris was the Minoan calendar.

The Octaetiris a period used in the Antikythera Mechanism (the Olympic dial and the moon dial). Octaetiris is the calendar; it is the period that king Minos rules in Crete. To keep the proper calendar the Greeks sacrifice seven boys

and seven girls at the beginning of the Octaetiris during the mythical period, as the myth of Theseus describes. It seems that it was a pan European calendar. With similar sacrifices in Scandinavia at the plane of old Uppsala there are several artificial hills that re marks on the horizon where the a royal observatory, keeps the proper lunisolar calendar of Octaetiris observing the rise of the Moon, Venus and the Sun. They sacrifice eight young men, eight male animals of various species (8 bulls, 8 stallions, 8 rams, 8 male dogs, etc) are also sacrificed. These sacrifices are stopped when Christianity becomes the dominant religion and in 1084 they stop the midwinter sacrifices. [Henriksson, G. 2003. The pagan Great Midwinter Sacrifice and the 'royal' mounds at Old Uppsala. In Blomberg, M, Blomberg, P. and Henriksson G. (eds), Calendars, Symbols, and Orientations: Legacies of Astronomy in Culture. Uppsala: Uppsala Astronomical Observatory Report No. 59. and G. Henricksson private communication, 2009]. A similar midwinter sacrifice has been pracrtice till recently by the Iroquois Indians to keep a calendar[13]. It seems that humans to keep good calendars that everybody observes use sacrifices and that this might very well be a prehistoric habit common for all people that predates the time humans went to the Americas.

[13] Blau, Harold , 1964 The Iroquois White Dog Sacrifice: Its Evolution and Symbolism, Ethnohistory, Vol. 11, pp. 97-119.

The most useful lunisolar calendar is the Metonic cycle, developed or refined during the 5th century BC at the astronomical observatory that is behind the speaker of the Pnyx, one of the ancient parliaments of Athens that was called ecclesia, the popular assembly of some 6000 citizens. This shows the significance of astronomy and of a good calendar in the economic, social, and political life of people. This calendar has been developed, probably refined, by astronomer Meton in Athens, as there are indications that a 19-year calendar was in use in prehistoric Greece. The Metonic calendar is a 19-year cycle, which is equal to 235 synodic months of which 7 embolismic or intercalary months, which are added at the end of the years with 13 months. The Epirotic calendar we have discovered at the Antikythera Mechanism is the first complete Metonic calendar with the sequence of all months that is known.

The Metonic 19-year and Octaetris 8-year calendars are in the Antikythera Mechanism. The calendar of Meton that exists in Antikythera Mechanism has the following names of months: FINIKAIOS, KRENEOS, LANOTROPOS, MACHANEUS, DODEKATES, EKKLIOUS, ARTEMISIOS, PSYDREUS, GEMELIUS, AGRIANIOS, PANAMOS, PELEOS, who are probably an Epirus calendar. Epirus calendars belong to Corinthian calendars, calendars that have cities that are under the influence of Corinth which in turn belong to the larger category of Dorian calendars. It is hard to identify the calendar of a mechanism with a city.

Very few ancient calendars are known, and not even complete. Corinth's calendar is incomplete, perhaps because the Romans devastated the city causing a real disaster, similar to the Athens demolition.

Seven months of the Mechanism's calendar coincide with the calendars of Corfu, Taormina, Bouthroton (now in Albania), Dodona, Ambracia and Rhodes, 4 months with Heraclea, and three months common with the Spartan calendar, with the Macedonian, Sicilian and Seleucian, two months with Corinthian (only a few months are known), and one common month with Athens, Ephesus, Smyrna, Miletus, Athens and dozens of other Greek cities across all the Mediterranean. It is noted that we do not know even a few months of the calendars of only a few Greek cities in the Mediterranean, including the main Greek region. It is difficult to interpret the use of this Epirotic calendar to pinpoint the city where the mechanism was in use. Perhaps it reflects the origin of the rich person that had in possession this very expensive mechanism. Perhaps the owner of the mechanism was a rich man from Epirus that was in a very rich city like Rhodes.

Callippus (370BC-300BC), successor of Meton, studied and worked at the Academy of Plato, under the guidance of Eudoxus, continued astronomical worked with his friend of Aristotle, and has modelled the motion of all celestial bodies, the five planets, with 4 spheres for every one of

them and 3 concentric spheres for the Sun and the Moon. Callippus creates what he believes an even more accurate than Meton calendar, that lasts 76 years which four times the Metonic cycle, less by one day. Ths 76 year calendar is based on the assumption that the length of the year is 365¼+1/76 days based on his measuremnts and calculations. With this 76 year period the lunar phases are repeated at the same day and hour. Callippus establishes this as a new long accurate calendar, the Callippic cycle of 76 years. The first Callippic period stared at the summer solstice of 330BC. This 76 year calendar is used by the Antikythera mechanism and predicts the phase of the moon with accuracy of one hour. The 76 year Callipic calendar is considered by some as the great year, Megas Eniautos, for example Aëtius in the book De placitis reliquiae, Stobaei excerpta says that the great year i s the octaetiris, or the metonic period or the Callipic period or a 61 year period, like Eonopedes and Pythagoras believe, while others the time it takes for all the planets to return to the same place,[14] in a line with the Sun and Heraclitus calculates this value to be 80000000 years[15].

[14] Aëtius in the book De placitis reliquiae, Stobaei excerpta, Τὸν δέ γε μέγαν ἐνιαυτὸν οἱ μὲν ἐν τῇ ὀκταετηρίδι τίθενται, οἱ δὲ ἐν τῇ ἐννεακαιδεκαετηρίδι, οἱ δ' ἐν τοῖς τετραπλασίοις ἔτεσιν, οἱ δ' ἐν τοῖς ἑξήκοντα ἐν οἷς Οἰνοπίδης καὶ Πυθαγόρας.

[15] Ἡράκλειτος ἐκ μυρίων ὀκτακις χιλίων ἐνιαυτῶν ἡλιακῶν.

The solar and lunar dials

The solar dial is circular with two concentric discs of the solar year divided in 365 days and 12 months, with the Greek version of the Egyptian months Pachon, Pauni, Epiphi. The other months, Thoth, Paophi, Athyr, Hoiak, Tubi, Mechir, Phamenoth, Pharmuthi, Mesori are missing, as the dial is broken and only ¼ th is in the fragment C, the third largest. The pointer of the Sun is probably a little golden sphere that turns during the year the ecliptic which is has the zodiac divided in the 12 zodiacal signs in Greek language and names and in 360 degrees. The names of the zodiac mentioned mainly in the manual are: Krios Aries, Tauros Taurus, Didymoi Gemini, Karkinos Cancer, Leon Leo, Parthenos Virgo, Chelai Libra, Skorpios Scorpio, Toxotes Sagittarius, Aigokeros Capricorn, Hydrochoos Aquarius, Hychtheis Pisces.

It is possible that the Sun had a variable speed following Kepler's second law with the gear that is in fragment D (the one my study suggests that it is for planet Jupiter).

The prediction of the phases of the moon

The moon is a very impressive and intriguing object that humans use to measure the time and regulate their lives, as many activities depend upon the phase of the moon. The

phase of the moon and the month in a Greek calendar that lasts 19 years which is Meton's cycle, calendar that we use today for Easter determination.

Another totally unexpected function of the mechanism is that the Lunar dial follows the second law of Kepler, moving the moon with variable very realistic velocity, faster at perigee, the closest position of the moon to the Earth and slower at apogee, the most distant position of the moon. The moon of the mechanism was probably a silver little sphere that is fitted in a hollow hemisphere of copper that is at the end of a conical axis that turns with a couple of gears, one of them cylindrical. This shows that the mechanism is very advanced and complicated. The moon of the mechanism moves around the Earth in one synodic month and at the same time the model of the moon turns around itself, in a way that it shows gradually the lunar phases during the month, new moon, first quarter, full moon, etc.

The variable speed of the mechanism is produced by the combination of four gears, all with the same number of teeth. Two of the gears are parallel, one on top of the other, but slightly offset, eccentric, with the eccentricity of the Moon's orbit around the Earth. These two gears are linked with a pin that is fixed in one gear and fits inside an elongated hole that is cut along a radius. As one gear turns it forces the other to turn too, but as they are offset the distance varies, the speed, which is equal to the distance

(which varies during the turning) times the angular speed of the first gear, is variable reproducing realistically the motion of the moon. This mechanically reproduced motion of the gear is very close to the one predicted by Kepler's second law with an accuracy around 0.2 to 0.4%[16].

The Olympic dial

Another great surprise was the Olympiad dial and circular display lasting 4 years with indications of important Greek festivities, the Olympic Games (assumed that they have started in 776 BCE), the Pythian ,the Isthmian, the Nemean, the Naan, the Isthmian and probably the Halieian [Alieian] games. The games in general included theatrical, musical, poetical and other artistic competitions and they had important social and even political influence in the Greek World and later to the Roman Empire.

The user manual and the planets

The mechanism, as all scientific instruments has a user manual with instructions on how to use it, perhaps how to open it, to set it up, what you expect to see in this mechanical Cosmos, how to use it properly, and an

[16] Gourtsoyannis, E., 2010, Hipparchus vs. Ptolemy and the Antikythera Mechanism: Pin-slot device models lunar motions. Adv. Space Res. 46, 540–544 and Gourtsoyannis, E. ,2012, in Science and Culture: Promise, Challenge and Demand, 285–289 (Epikentro Publications, Thessaloniki.

extensive astronomical compendium that contains the laws of physics, as they understand them at the time, to predict the eclipses, solar and lunar, and the phase of the moon, as well as the motions of all the five known planets. From the manual of the computer it is evident for the first time that the Greeks knew very long periodicities of the planets, of the order of 500 years. A great surprise is that the user manual of the Mechanism gives details of the motion of all the planets including some extremely long periodicities of the planets of the order of five centuries, 462 year for Venus and 442 years for Saturn. The emphasis is on the forward-backward motion (retrograde) of all the planets with lots of details that are evident despite the fragmented text.

In the remains of the mechanism some 20% of the front plate of the mechanism that includes some 90 degrees of the zodiac and very important part of the so called *parapegma*, a series of 36 rising or setting of stars at sunrise or sunset that mark correctly the date of the year, every 10 degrees on the ecliptic or 10 days apart, to keep an accurate calendar, has been saved, 25% for the back plate approximately with 1/3 rd of the Metonic cycle which was sufficient to know all the Epirotic months of this 19 year lunisolar calendar which is the traditional Greek calendar, which is the same we use for Easter and Passover today, almost all the four year or more correct the 8 year calendar of the Olympic and of the important Greek games, 1/3 rd of the scale of Saros, the eclipse calendar of 18 years, 11 days

and 8 hours, 2/3 rds of the auxiliary dial of 0, 8 (Θ) or 16 (Ις) hours that have to be added to the indication of the helicoidal (spiral) dial of eclipses, but unfortunately the sign for zero is missing, which probably was 0 (omicron, initial of the term *OUDEN* that etymologically means *not one*, for zero). Approximately another 20% of the back cover door has been saved, with a part of the astronomical compendium.

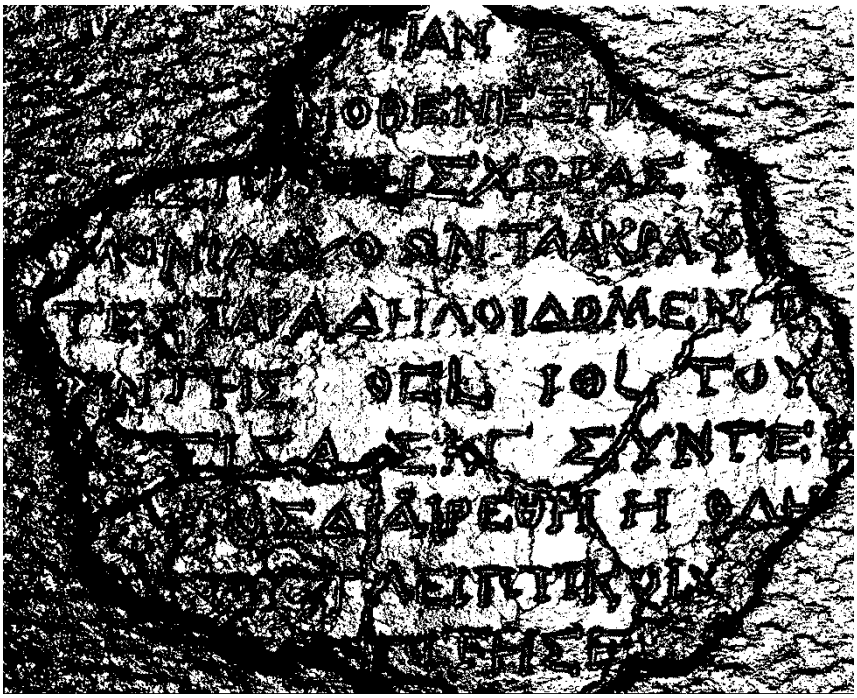

Figure 5 Part of the manual with the laws of physics they use to predicts the phases of the moon, the metonic cycle and Callippic cycle, and the Saros cycle for the eclipses.

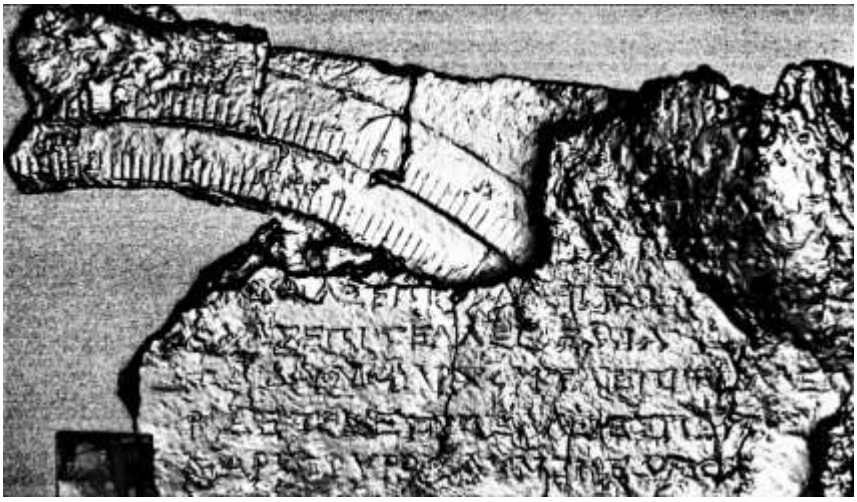

Figure 7. Fragment C, scales and part of the PARAPEGMA. Part of the scale of the year and the scale of the zodiac.

The texts of the manual are written on all available plane surfaces on copper sheets that are the two covers of this double faced astronomical clock. This includes not only the doors of the mechanism that protect the instrument when in transport but also the plates with the dials. Despite the sheets of copper the manual is written on have been partly lost, perhaps still at the bottom of the sea where I am sure the archaeologist working there will eventually find, there is sufficient material that enabled us to read a lot of characters and work out a great part of the text that is still in all the broken fragments, even inside the rust.

The text is written with almost classical capital Greek letters (Serif type) that have been dated based on the form of the letters (private communication Char. Kritzas, 2006) around

150 to 100 BC. The size of the letters is extremely small, around 1.2 mm to 3.0 mm. They have been written with a chisel with two blades one with straight cutting and another with a semicircle that enables the experienced writer to write these capital letters at ease making them extremely uniform as possible, serif type with a stroke at the end of the letters that makes the unequal letters appear equal in size. The language is the common Greek of the time, which is close to the Attica dialect, which was common for scientific texts of that era.

The planetarium

Humans notice the difference of the motion of planets very early in the history of humankind[17] and gradually develop advanced mathematical means to model and predict the motion of the planets. Astronomy is important already in the first European texts of Homer and Hesiod. The first scientific description of the heavens in human history is made by the pre-Socratic philosophers by the introduction of geometry. A sphere for the firmament, with the fixed stars, that returns around the Earth in one day is a very natural element that many cosmologies have in this the Greeks introduce a rotating sphere for every planet and

[17] Tsikritsis, M., Moussas, X., and Tsikritsis, D. 2015, Astronomical and mathematical knowledge and calendars during the early Helladic era in Aegean" frying pan" vessels. Mediterranean Archaeology & Archaeometry, 15 (2).

have models of the Cosmos with concentric spheres around the Earth. The Pythagoreans at the time of Socrates with Philolaus (c. 470–385BC), student of Pythagoras, introduce a non-geocentric model with the planets moving on homocentric spheres around the central fire, probably because they understand that the distances of the planets vary with time. Philolaus puts the central fire at the centre of the Cosmos (the solar system) and the Earth moves around it as all the planets, the Sun too. So the Pythagoreans[18] introduce a non-geocentric model with eccentric orbits for the Earth and every planet. Pythagoras and his disciples probably know well all these motions and periodicities and he even creates the musical scale taking into account of the resonances and periods of the planets. Humans at that era already know all the parameters of the retrograde motions of the planets, which are probably

[18] Simplicius Aristotelis quattuor libros de caelo commentaria, Κατεγνωκότες οὖν τῆς τῶν ἀνελιττουσῶν ὑποθέσεως οἱ μεταγενέστεροι μάλιστα διὰ τὸ τὴν κατὰ βάθος διαφορὰν καὶ τὴν ἀνωμαλίαν τῶν κινήσεων μὴ ἀποσώζειν τὰς μὲν ὁμοκέντρους ἀνελιττούσας παρῃτήσαντο, ἐκκέντρους δὲ καὶ ἐπικύκλους ὑπέθεντο· **εἰ μὴ ἄρα ἡ τῶν ἐκκέντρων κύκλων ὑπόθεσις ὑπὸ τῶν Πυθαγορείων ἐπενοήθη**, ὡς ἄλλοι τέ τινες ἱστοροῦσι καὶ Νικόμαχος καὶ Νικομάχῳ κατακολουθῶν Ἰάμβλιχος.

known since prehistoric times[19] as the periodicities of planets are depicted by repeating patterns with the exact numbers on ancient terracotae (frying pan vessels, 4 th and 3 rd millennium BC in Greece). The Pythagorean musical scale, the music of the spheres[20] that even Kepler and his followers use till the 19 th century.

[19]Tsikritsis, M., Moussas, X., and Tsikritsis, D. 2015, Astronomical and mathematical knowledge and calendars during the early Helladic era in Aegean" frying pan" vessels. Mediterranean Archaeology & Archaeometry, 15 (2).

[20] Joannes Laurentius De mensibus writes on Planets and musical notes:
Πάντας τοὺς ῥυθμοὺς ἐκ τῆς τῶν πλανήτων κινήσεως εἶναι συμβαίνει· ὁ μὲν γὰρ Κρόνος τῷ Δωρίῳ, ὁ δὲ Ζεὺς τῷ Φρυγίῳ, ὁ δ' Ἄρης τῷ Λυδίῳ καὶ οἱ λοιποὶ τοῖς λοιποῖς κινοῦνται κατὰ τὸν Πυθαγόραν

πρὸς τὸν ἦχον τῶν φωνηέντων· ὁ μὲν γὰρ Ἑρμοῦ τὸν α , ὁ δ' Ἀφροδίτης τὸν ε , ὁ δ' Ἥλιος τὸν η , καὶ ὁ μὲν τοῦ Κρόνου τὸν ι , ὁ δὲ τοῦ Ἄρεος τὸν ο , καὶ Σελήνη τὸν υ ,

ὅ γε μὴν τοῦ Διὸς ἀστὴρ τὸν ω ῥυθμὸν ἀποτελοῦσιν· ὁ δὲ ἦχος τῶν ῥυθμῶν ὡς ἡμᾶς οὐκ ἀφικνεῖται διὰ τὴν ἀπόστασιν.

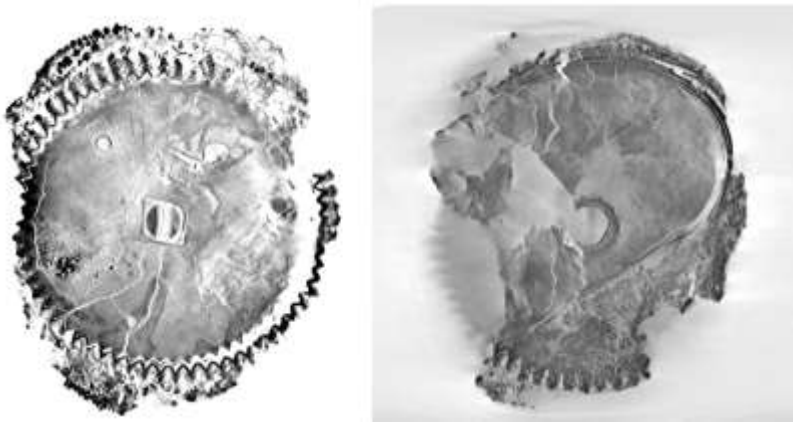

Figure 8. The planetary gear of Jupiter. It turns inside the hollow gear and a pointer attached to it performs an epicycloidal motion

The first fully mathematical model known with many details is the one of 27 homocentric spheres by Eudoxus, in which Callippus adds seven more spheres. These spheres try to imitate the motions of the planets as seen from Earth. Each sphere rotates around an axis through the centre of the Earth.

The Eudoxus model uses three spheres for the Sun and the Moon and for every planet four spheres, the celestial sphere that accounts for the daily rotation of the Earth, the ecliptic sphere for the yearly trajectory of the Earth around the Sun, the planetary sphere for the trajectory of this planet around the Sun and one more of the inclination of the planet of the orbit of this planet to the plane of the trajectory of the Earth around the Sun.

The Antikythera shipwreck

The mechanism has been found in a huge ancient shipwreck[21] that sunk probably around 60 to 80 BC, as the archaeologists estimate from the coins found. It shank near the little Greek island of Antikythera, between Peloponnese and Crete, in a spot that was in the sea route between Greece mainland, and Asia Minor, the Aegean Sea in general, and Italy. Most probably Rome was the destination of the huge ship that was full of Greek treasures, either "official" war loot or merchandise. The ship was a very expensive vessel, covered with sheets of lead, very thick planks 14 cm, huge copper nails around 40cm, many of them recovered by archaeologists. In the literature the description of the only ship that can be compared is the Syrakossia, or *Alexandria* or Alexandris, a legendary ship that Archimedes designed and instructed the ship-builder

[21] I.N.Svoronos, Ho thesauròs ton Antikytheron, Athens, in Greek, 1903.

Weinberg, G. D., Grace, V. R., Edwards, G. R., Robinson, H. S., Throckmorton, P., Ralph, E. K. 1965, The Antikythera shipwreck reconsidered. Transactions of the American Philosophical Society, 55(3), 3-48.

Kaltsás, N. E., Vlachogianni, E., & Bougia, P. (Eds.). 2012. The Antikythera Shipwreck: The Ship, the Treasures, the Mechanism:[exposition,] National Archaeological Museum, April 2012-April 2013. National Archaeological Museum. Christopoulou, A., Gadolou, A., & Bouyla, P. (Eds.). (2012). The Antikythera Shipwreck: The technology of the ship, the cargo, the mechanism. Kapon Editions.

Archias from Corinth constructed by order of Hieron II, tyrant (king) of Syracuse to be sent as a gift to king Ptolemy III in Alexandria. The ship, probably 120 m long (Aelian says 400 feet long), with a capacity of some 2000 tons, 8 towers with archers. It could carry 1940 men. It had a gigantic catapult and it was very well equipped, armored with lead at the boat hulls for stability and safety has been sent to Alexandria around 240 BC. Syracuse had a log and very good tradition in ship building. Dionysius, tyrant of Syracuse, builds tetrereis "fours" and pentereis "fives", that was his invention. The Antikythera vessel is similar, probably in many ways, certainly in terms of construction with lead armor.

The Antikythera shipwreck was a very large vessel, at least 40 to 50 m long and some 9 to 12 wide, with a minimum of 300 tons, while a specialist, admiral I. Theofanides (priv. comm. 2007) who dived many times there training marines he insisted that the ship was around 60 m long and that a part of the shipwreck was off a cliff went down the “abyss” at some 125m. Part of the ship was covered with huge roof tiles of Corinthian type (70 cm long).

The ship remains at the bottom of the ship cover an area of 45m X 10m approximately, as the new underwater archaeological excavation show (priv. Comm. A. Simosi,

2017, public talk Brendan Foley[22], 2016). They consist of a conglomerate that contains lots of statues and other treasures. It has been discovered April 1900 by sponge divers from Syme and half a year later the first, largest, richest and most interesting by far underwater archaeological research started that still 118 years later still gives extremely interesting results and it will continue to give for at least one more century. In fact a new similar shipwreck few tens of meters away have been discovered that will give too lots of important finds.

Probably more than 100 fine marble from Paros statues were on the ship together with at least another 10 or so made of bronze, including the very expressive Antikythera Philosopher, estimated to have been made around 240 BC, probably a Cynic philosopher, the very wit Bion the Borysthenite (c. 325-246 BC), who holds with his left hand a "pen" (chisel) with his left hand, to write on a waxed tablet and the Antikythera youth, probably Paris giving an apple to Venus or holding the Antikythera Mechanism? Many more broken parts of bronze statues, including a boxer have been found in the past and especially during the very successful recent campaign's. An eye witness in 1901 when the Symian

[22] Brendan Foley, talk "New Underwater Research at Antikythera", at The American School of Classical Studies at Athens, February 18, 2016. http://www.ascsa.edu.gr/index.php/News/newsDetails/videocast-new-underwater-research-at-antikythera

divers with the help of the Greek navy have been saving the very heavy antiquities from the sea bottom said that a huge complex statue, probably the Laocoön Group and his children with the serpents, was that heavy that the rope with a diameter around 10 cm broke and went down the abyss, waiting modern archaeologist to salve it again.

Astronomical clock

A very important question is whether the mechanism is actually a clock with continuous motion that shows the hour. The answer is based on ancient Greek texts that describe automata and similar clocks that predate the Antikythera mechanism, like the famous clock of Archimedes. The motion of these Greek clocks is regulated by the motion of a float that is inside a prismatic container of water where the level of water increases at a constant rate. Water drips in the prismatic container of water, the level goes up and the buoyancy lifts a float made of cork, as Hero describes, the float goes up at the same constant rate. The float is linked with a weight and this with a string of a chain, like the one of a bicycle or the cuckoo clocks. The chain or the string is around a gear or a cylinder like the one of bicycles. The other end of the chain is a counterweight. All this system float-weight-chain-gear-counterweight moves as the level of water increases. This type of automata are described in ancient Greek texts like the ones of the

Alexandrian philosopher and renown mathematician, Hero, mostly well known as an engineer for his automata.

The assumption that the Antikythera mechanism is static is not very logical. The Antikythera mechanism is the most advanced artifact from ancient times for millennia. Much more advanced that we could have imagined. If the Greeks have continuously working clocks is it possible to have the most advanced and extremely expensive clockwork system without motion? Improbable! Proclus states that instruments like this called tables or tablets if they are small show continuously the motion of the Sun, so they are clocks[23].

Use of the Antikythera Mechanism

What uses does the Antikythera Mechanism have? The Antikythera Mechanism was used by astronomers, philosophers in universities of the time, the philosophical schools, by rulers and wealthy people to show and to impress friends and especially enemies, from the military in land and sea, from geographers to make accurate maps, and from travelers, naturally from captains of ships. I argue that the excellent maps that evolve greatly from the era of Alexander to the geographies of Eratosthenes, Hipparchus

[23] Πρόκλου, Υποτύπωσις αστρονομικών υποθέσεων, «Τούτων δὴ οὖν ηὑρημένων δυνατὸν ἔσται σοι καὶ πίνακα ποιῆσαι δεικνύναι δυνάμενον ἀδιαλείπτως τὴν τοῦ ἡλίου κίνησιν».

and especially the eight volume geography of Claudius Ptolemy, which contains a few thousand cities with coordinates that are relatively accurate, despite the fact that the coordinates show systematic deviations for many reasons, including a larger value for the perimeter of the Earth. All these excellent maps can not be created with measurements taken during eclipses because this is technically extremely painful and practically impossible. It is difficult to have thousands of well-trained scientists all over the world at the right time of the eclipse.

The measurement of the longitude of a point on Earth is possible using machines such as the Antikythera Mechanism and appropriate astronomical tables. Seafarers till recently, before the GPS era coud only calculate the longitude and latitude in a similar astronomical observation and method, and students of naval schools, particularly military schools, are still taught these astronomical methods to determine the coordinates, especially in case of war when GPS satellites are cut off or even jammed electronically.

In brief the possible uses of the Antikythera Mechanism might have been:

- Astronomical computer,
- Astronomical instrument
- A device to Show up to friends
- Calendaric mechanism,

- Meteorological instrument, to predict weather with the Parapegma
- Festival date determination (Olympic, Pythia,Nemea, Isthmia, Naa, etc.) (Olympic, Pythia,Nemea, Isthmia, Naa, etc.)
- Teaching device Teaching device
- Anaphoric clock
- Mechanical Universe
- Planetarium
- A device to Measure Geographic latitude and longitude
- A device to be used in Cartography A device to be used in Cartography
- A device to be used in Navigation A device to be used in Navigation
- Clock

Automations and the existence of other similar mechanisms

The machine that is the first known computer is really based on the same principles of science that Pythagoras or Plato describes: laws of physics expressed with mathematics. The Greeks have mechanisms, automata, advanced arms, weapons, like ballistic machines. It is known that the ballista and the *polybolos*, a Greek repeating ballista created the 3rd-century BC, have been constructed by Dionysius of Alexandria a mechanic that had excellent

experience from Rhodes workshops that it seems that were the best.

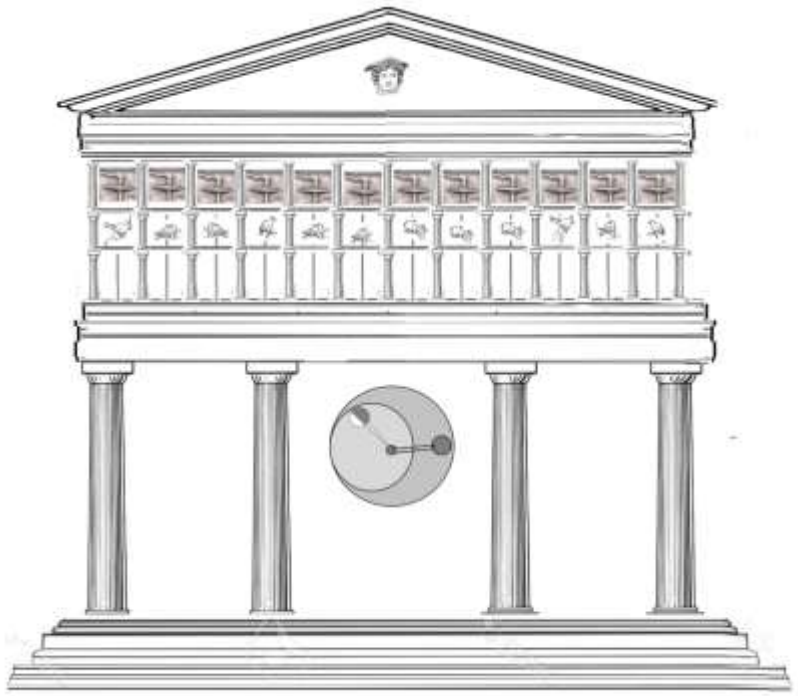

Figure 9 A drawing of the famous Gaza clock that performs several automations to show the time with 12 doors opening during the day and birds singing on the hour every hour, and 12 lights the show the time at night at the top.

The inheritance, the heritage, the legacy of Archimedes in science, especially in mathematics and in technology at the time of the construction of mechanism is already enormous. It is no surprise that the Archimedes screw-pump revolutionizes agriculture worldwide, especially in Africa,

where it is still at work. The same applies for inventions concerning clock-making and functioning. The escapement of clocks, usually considered to be a much later invention that regulates clock is described by Philo of Byzantium24, in his book Pneumatics, who lived and worked in Alexandria. Philo's escapement is a system of a turning spoon with a counterweight that, when filled up with water, or whe a spere drops, its weight makes it turn and this turn triggers an action. This can be done at a constant rate. We know that the Archimedes (287BC–212BC) clock had such a mechanism, not as an escapement, but to trigger an automaton every hour. Ctesibius (c285–c222 BC), who lives and works in Alexandria, probably a disciple of Philo, describes many interesting machines, including clocks. It is almost certain that as Archimedes who also lived and worked for a period at the Museum of Alexnandria and the Library and is a contemporary of Ctesibius mst have interacted for lnog with and that both are probably somewhat students of Eratosthenes (276BC–195BC) who is older and with whom Archimedes exchanges several extremely interesting letters. Alexandria has been for centuries the center of science, mathematics, technology and philosophy.

[24] Lewis, Michael, 2000. Theoretical Hydraulics, Automata, and Water Clocks. In Wikander, Örjan. Handbook of Ancient Water Technology. Technology and Change in History. 2. Leiden. pp. 343–369 (356f.). ISBN 90-04-11123-9.

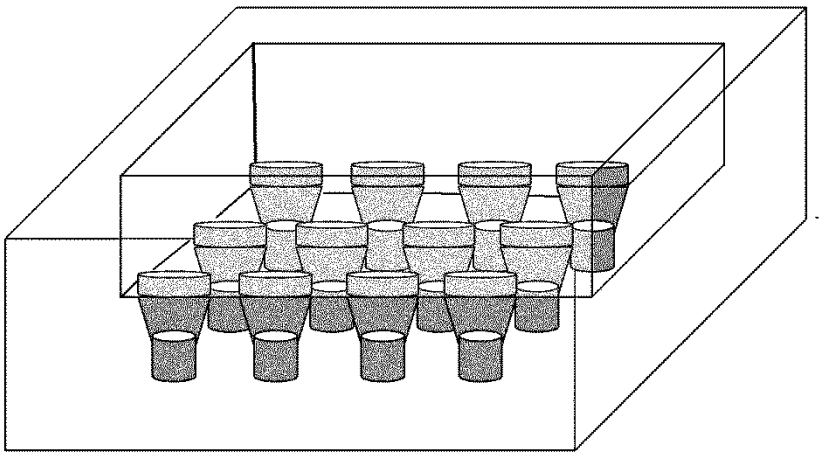

Figure 10 The 12 conical ‘valves’ that were used for automations of the mechanism. The structure of a peculiar stone discovered by the archaeologist at Antikythera that perhaps strigers 12 acts a give times.

It is well known from the literature that ancient Greek clocks had several automations, as it is evident from the study of the clock of Archimedes[25] or the clock of Gaza described by Procopius in his book *De Aedificiis* (Peri ktismaton). Numerous Automata have been developed by the Greeks over the centuries including water regulated clocks. The oldest one mentioned in the literature is one by

[25] Archimedis opera omnia cum commentaris Eutocii, J. L. Heiberg, ed. corrections by E. S. Stamatis, B. G. Teubner, Stuttgart, 1972; reprint of the 1913 edition.

Plato and one from Aristotle, followed by a seemingly more advanced the clock of Ctesibius and most famous the constructions of many automata by Hero of Alexandria and Vitruvius.

At the Antikythera shipwreck the archaeologist discovered one statuette of the size of the mechanism that rotates around itself. It is possible that this statuette is an automaton that rotates every hour and shows the time in a scale like the one of Ctesibius.

Greek automata like the one of Archimedes clock work with weights, strings or chains and a float, and also with little spheres that drop in a spoon-like mechanism that trigger every hour an act of a gimmick, automation. Similar acts we have in the Islamic clock the castle clock of al-Jazari and western European medieval monumental clocks, towers in central squares, churches and city halls.

The team of archaeologists under the guidance of the Greek Ephorate of Underwater Antiquities (Dr A. Simosi Dr. T. Theodoulou, Dr D. Kourkoumelis and Prof. B. Foley) have discovered many new important finds. Of particular importance is for me one rectangular curved stone hollow construction with a system of 12 parallel holes (3x4). These parallel holes start like conical valves and become cylindrical as the go out of the rectangular construction. Every one of these conical cylindrical holes is similar to the

valves of many of the automata by Hero or the valves of every car. If every valve has a conical tap attached to a string that has a length that is proportional to the time the automation has to happen and all strings are attached to a turning axis then every valve opens at the predetermined time. If the length of the strings is proportional to the hour we select to trigger, say every hour, then an action can start at the hour, as we have at the Gaza clock. Special thanks are due to Dr A. Simosi, Prof. B. Foley and colleagues, the Aikaterini Laskaridis Foundation and especially Mr P. Laskaridis for continuation of the underwater archaeological excavations and the new finds from Antikythera.

Archimedes is the first to study mechanics with mathematics, like the levers, that he uses in his clock for automations. This clock is described by three books, and in detail is several Arabic ones named the Archimedes clock. At least ten authors, Greek and Roman describe the spheres of Archimedes. Pappus, Proclus, Sextus Empiricus, the great Cicero that gives four detailed descriptions, Martianus Capella, Ovid, Tertullian. Sexctus states that he admires not the wooden parts of the complex automaton, but the creator Archimedes that gives automatic motions for the Sun and the moon and the other stars (planets). Unfortunately the book of Archimedes *on [automatic celestial] sphere making* has been lost.

Archimedes 'works are considered to be of great importance over time, so that the historian John Skylitzis (1040 to 1101) writing the biography of the Byzantine Emperor Leo the Philosopher says that he had read Archimedes' works, which he had understood as no other, so difficult these were, suitable only for the specialist. This very difficulty made Archimedes' books as well as other scientific books been lost because they had no readers and the libraries did not order them, they were not copied and have been lost forever.

Instruments like the Antikythera Mechanism, named tablet, made of expensive material including gold, ivory, ebony, silver, it is clear from ancient books that there were cheaper constructions, e.g. made of wood, which was, as I estimate, much simpler versions of the mechanism. Scientists need some rather simpler mechanisms, with fewer functions, intended for a particular use. This instruments were in use by philosophers, teachers, astronomers in their schools, that is, at the universities of the ancient age, as Cicero tells us on his description of Posidonius philosophical school at Rhodes where the great philosopher has studied, and naturally by the military, geographers, but perhaps even captains of large ships.

The mechanized celestial automatic spheres of Archimedes are of great importance[26]. They probably predicted not only the positions of celestial bodies realistically, but perhaps the eclipses based on the period of Saros and Exeligmos and in combination of a celestial map with Meton's cycle they show the actual regions of the Earth that every eclipse is visible. Cicero writes that Gaius Sulpicius Gallus puts in motion the sphere and the moon starts to turn many times around the Earth and finally returns back to the same position with respect to the Sun[27]. The time it takes is realistic, as the one it takes in nature. The moon at time enters in the shadow of the earth, when the three bodies are aligned. At this part of the book eight pages are missing. Equally important is the description of the sphere of Archimedes in a theological book by Lactantius in *Divine Institutes*, where he describes it as a model of the Cosmos where the sun and the moon move with variable speeds that imitate realistically the actual universe that turns too. Equally important is Ovid's description of Archimedes mechanized Cosmos with the Earth, a small sphere at the centre of the universe at equal distances from the stars. Very interesting is the description of the sphere given by Cladian (Claudius Cladianus). The a poem referred

[26] For an excellent review of the work of Archimedes see Wright, M. T., 2017, Archimedes, Astronomy, and the Planetarium. In Archimedes in the 21st Century (pp. 125-141). Birkhäuser, Cham.

[27] Berryman, Sylvia, 2009, *The Mechanical Hypothesis in Ancient Greek Natural Philosophy,* Cambridge University Press

to the laws of nature, influenced by the Orphic Hymns, in which Jupiter sees the transparent sphere of Archimedes. Claudian in Archimedes' Sphere describes Jupiter's surprise when he sees the Cosmos in a sphere of glass made by Archimedes. Jupiter laughs and wonders how humans managed to mimic his work, the Cosmos in a fragile sphere, how the old man of Syracuse has reproduced the laws of nature on Earth, how he knew the distances of the planets (gods) and which secret power directs the motions of the stars as in reality. How the zodiac turns during the year of its own, and a little moon changes phases during the month, how human wit imitates the heavens. The week hand of humans rivals Nature. This description, even in a poem, describes somehow the mechanical sphere of Archimedes.

Few years ago an ancient gear dated around 230 BC has been found in the Agora of the Greek city of Olvia of Sardenia. This ancient gear and has been studied by Giovanni Pastore[28] who gave his first talk about at the university of Athens. Introducing professor Pastore I named this gear *Archimedes gear*. This gear probably belongs to an

[28] Pastore, G. 2006-2010 Il Planetario di Archimede Ritrovato (The Discovery of Archimedes' Orrery), published by Giovanni Pastore, Pastore, G. 2010, Antikythera Calculator advances modern science of 19 centuries. Advances in Space Research, 46(4), 552-556., D'Oriano, Rubens, and Giovanni Pastore. 2010, "Un Frammento del Planetario di Archimede da Olbia.", 1777-1813.

advanced geared instrument made at the time of Archimedes.

A similar device to the Antikythera Mechanism is the PINAX (table) that describes Proclus, which gives information on the construction and operation of the 'table' (mechanical universe) that gives the position of celestial bodies with prediction of the position of the perigee and apogee, which are also what the Antikythera mechanism does for the moon.

Very impressive is the solar and possibly mechano-hydraulic monumental clock of Andronicos of Cyrrhos renowned architect and astronomer that has constructed north of the Acropolis of Athens the enormous octagonal tower of winds[29], 12 m high, with nine solar dials around the faces and one on a cylindrical construction at the southern part, while inside there was a water regulated mechanical clock, possibly an anaphoric clock that show the position of celestial bodies, the sun and the moon, possibly the planets, as on the floor of internal part of the building there are several grooves that possible accommodated the chains for

[29] Noble Joseph V., Derek J. de Solla Price, 1968, The Water Clock in the Tower of the Winds, American Journal of Archaeology, Vol. 72, No. 4. pp. 345-355,

Theodossiou Efstratios, Vassilios N. Manimanis and Petros Mantarakis, 2006, The Tower Of The Winds In Athens The water clock and its eight vertical sundials, The Compendium, 13, 4.

the motion of the pointers of the celestial bodies. A very impressive description of an anaphoric clock, a clockwork cosmos with the planets made of precious stones, covered by a cubicle of glass is the one of Argestius Cromatius, of Rome that his grandfather has payed 200 bounds of gold for it.

Part of an astronomical machine is the Disc of Chevroches (Nièvre) in France studied by archaeologist Frédéric Devevey[30] and his colleagues. The disk of Chevroches is curved with the names of the zodiac and the months in Greek with both their names, the Roman months that we use today and the Egyptian names, dated probably around 230 AD, found in a Roman villa, perhaps of Alexndrian origin (A. Tselikas, priv. comm. 2009). The centre of the disc is offset and the shape is convex, probably part of a sphere. Other similar objects of apparent astronomical use found in various regions of Europe, of various seasons, such as its large Anaphoric Clock in Austria, and which have Greek or Latin inscriptions and which are estimated to be of the early centuries after Christ.

Similar clockwork mechanism was in the famous Gaza clock, described by Procopius that was decorative animated

[30] Frédéric Devevey, Patrice Cauderlier, Claudine Magister-Vernou et Christian Verno, Découverte d'un «disque» astrologique antique à Chevroches (Nièvre) Tome 55, 2006, Frédéric Devevey *Une fille d'Anticythère : La calotte zodiacale de Chevroches et ses cousins bourguignons*, XXIII International Congress of History of Science and Technology, Βουδαπέστη, 2009

clock housed in the Gaza Agora, probably from the Alexandrian of Hellenistic era and the name of the benefactor Timotheus31. The Gaza clockwork three storey building at certain times represented mythological scenes of Theseus, Phaedra, Hippolytus and from the third book of Iliad, that in a clockwork system were performed automatically every hour, the medusa in the middle of the building opens and closes her eyes. Every hour the clock strikes the hour in a sequence of six sounds, it has some large statues that move and perform an act and during the night a light moves and successively stop behind one of 24 doors. Another remarkable clock with automata is the one constructed during the first century AD by Apollonius Tyaneus and is situated next to Hagia Sophia cathedral, next to the palace of Constantinople is described in the Book of Ceremonies at the time of Emperor Constantine VII the Porphyrogenetus (who reigned from 913 to 959). This 1 st century AD Apollonius clock had some figures moving every hour like the Gaza clock.32 The Apollonius Constantinople clock is described by the Arab Hâroûn-ibn-

[31] Eugenio Amato, Pierre Maréchaux, 2014, Procope de Gaza. Discours et fragments. Collection des universities de France. Série grecque, 503. Paris: Les Belles Lettres.

[32] van Rossum, Gerhard Dohrn, 1996, History of the Hour: Clocks and Modern Temporal Orders, University of Chicago Press, 1996

Yahya, that lives there for a time period.33 Hâroûn-ibn-Yahya describes: *… a building in which twenty-four small doors open, each (measuring) one span square; there is one for each of the hours of the day and night. When an hour ends, a door opens by itself…*" 34 This clock was in the part of Hagia Sophia called the Horologion, which was also an astronomical observatory.

All these show that the theoretical and practical knowledge at the time of the construction of the Antikythera mechanism was the appropriate for such a mechanism.

Among the other major objects the archaeologists have recently discovered at the Antikythera shipwreck a very humble orthogonal carved stone object measuring approximately 28 x 18 x 5 cm with a 9 x 8 x 3 cm hollow rectangular parallelogramme carved inside having at its bottom 12 parallel conical holes aligned to three rows, ie 3 x 4 holes. Each conical hole starts as a cone and eventually becomes like a funnel. The large diameter inside the hollow of the stone is about two centimeters, and the small that results in a narrow opening at the base of the stone has a diameter of about 10 to 13 millimeters. These conical holes have similarities with ancient and new self-sealing valves.

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[33] Mehmed Izeddin, 1947, *Un prisonnier arabe à Byzance au IXe siècle: Hâroûn-ibn-Yahya*, Librairie orientaliste P. Geuthner

[34] From https://hagiasophiaturkey.com/horologion/

There are many automations of Hero who have valves similar to theses generalized cones. If we have 12 conical valves attached to strings of various lengths and all unequal strings are attached to a turning cylinder then every valve is released at a certain time proportional to the length of the particular string. Then a small sphere of a bit of sand or equivalent drops and turns a spoon like the one used at the Archimedes clock. The turning of the spoon triggers an action. Perhaps every hour a mechanical bird sings or something, as we have at the clock of Archimedes or the clock of Gaza.

This carved stone was presented in a speech by archaeologist Brendan Foley at the American Archaeological School in Athens. We have preformed computer tomography at the Evgenidion Hospital of the University of Athens and we have studied the internal structure of the carved stone that is filled with an unknown material and mapped the conical holes that I hypothesize that they are valves. In the materil that fills the hollow stone, that is probably sand, the computer tomographies reveal a string made of dense material, probably metal. This possible function presented in the book is a working hypothesis of the author.

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Biography:

Professor Xenophon Moussas is a charismatic lecturer that charms the audience in many subjects.

Famous for his studies of the oldest known computer, the Antikythera Mechanism and known for his research in Space Physics.

Participates in many active and future spacecraft experiments of NASA and ESA.

Awards include: the American Geophysical Union, Boston, 2001, the NASA group achievement award for Ulysses Space Mission, 2009.

Supervised 32 PhDs, many M.Sc. and 250 B.Sc. theses at the University of Athens.

Author of several books (two books about The Antikythera Mechanism, the first computer; Space Physics, Astrophysics Laboratories) more than 110 articles in scientific journals, 150 articles in Encyclopedias, 200 in scientific conferences. Many radio and TV programs, numerous exhibitions and talks around the World including NASA, the Library of Alexandria, many universities, UNECSO, Archaeological Museums, colleges and schools.