



**A tiny device pregnant with the world, a portable sky,
a compendium of the universe, a mirror of nature
which reflects the heavens.**

– Cassiodorus, 6th century AD

National Archaeological Museum, Athens

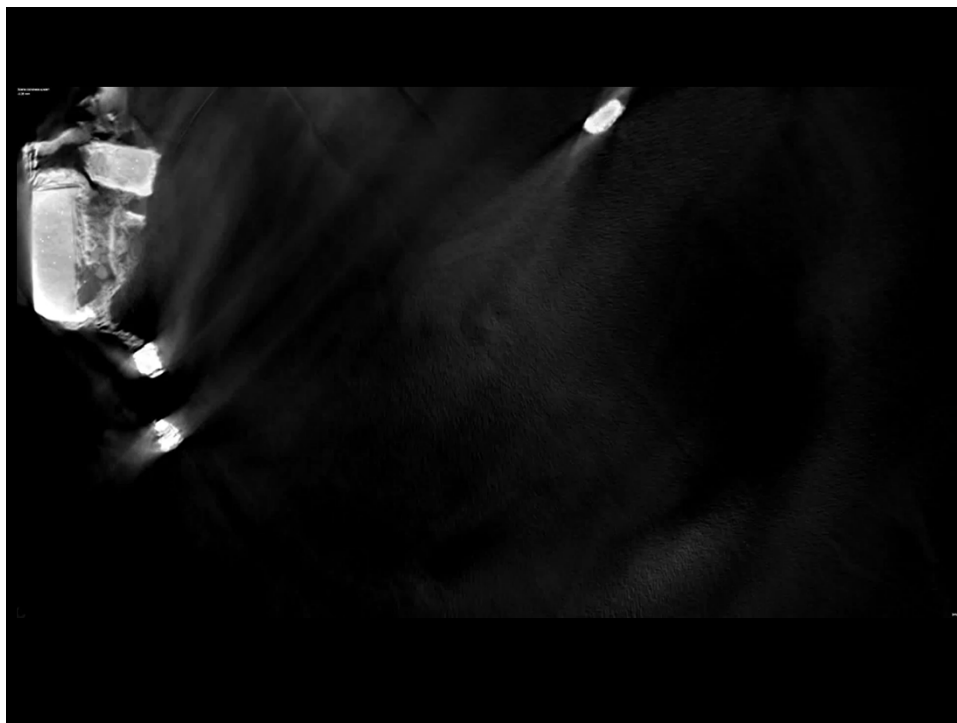


Fragment C, Fragment A, Fragment B

Mike Edmunds (astronomer & PI of AMRP):

“This device is just extraordinary, the only thing of its kind, The design is beautiful, the astronomy is exactly right ...

In terms of historical and scarcity value, I have to regard this mechanism as being more valuable than the Mona Lisa”



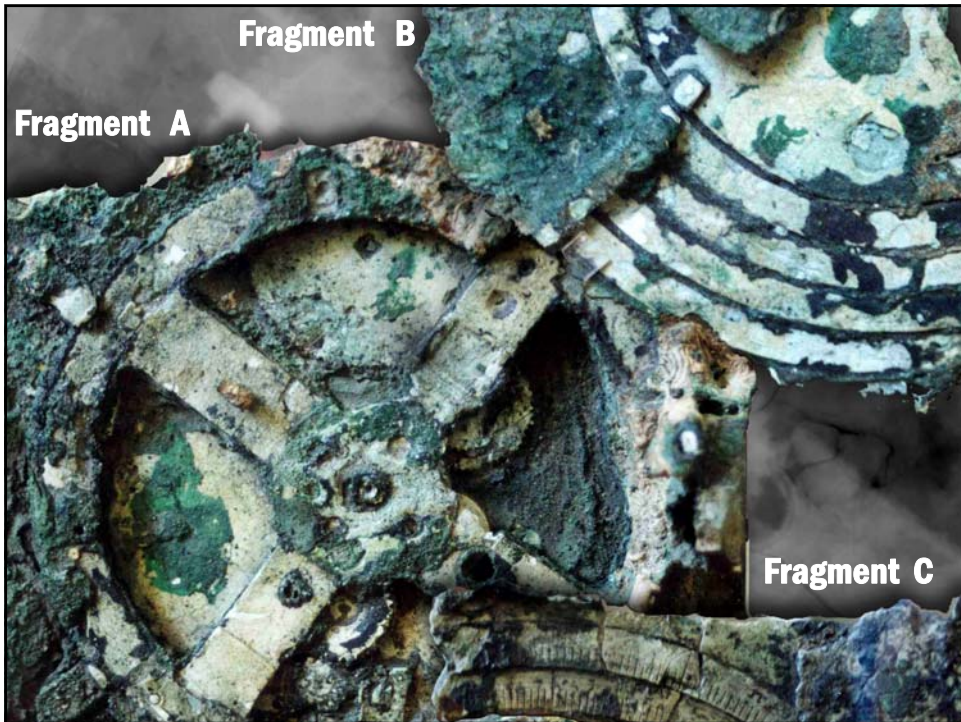
**Most sophisticated and intricate piece of technology
for over almost 1400 years !**

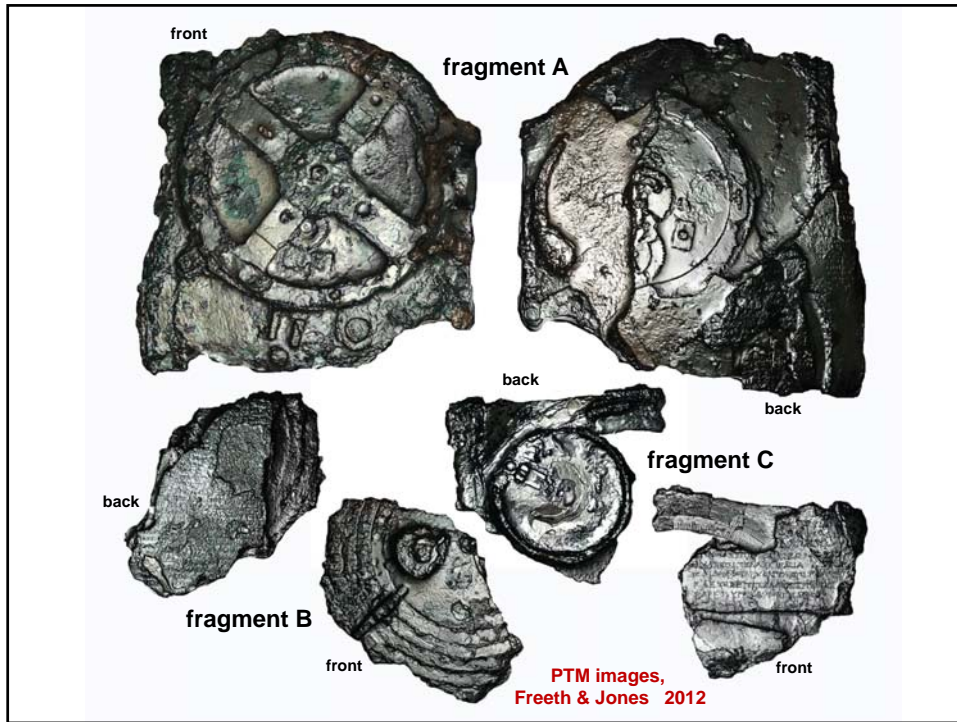
**Up to the appearance of mechanical astronomical
clocks towards the end of the 13th century, we do
not know anything as complex ...**

- **Where did this technology come from ?**
who invented this ... ?
- **Testimony and Manifestation of Hellenistic Scientific Revolution ?**
- **Innovation:**
Why did this not propagate into economic and social applications?
- **What happened with this knowledge ?**
 - Disappeared ? Implications for our idea of progress & advance
 - or, is there a direct link over the many centuries to our clocks ... ?

a Hellenistic Scientific Revolution ?

- Known was that Greeks pondered deeply on the workings and laws of nature ... Greek natural philosophy
- Known was that the Hellenistic Greeks managed to combine sophisticated geometric models of the heavens with observational data (mostly Babylonian), into a genuine theory of nature.
- However,
we never imagined they would be able to translate this model into a sophisticated mechanical device,
translating mathematical theory into a mechanical representation of reality.
- What does this imply ?
 - testing theories by computation ? This is true science in modern sense !
 - how did it affect their view of the world ? Mechanical Worldview ?






**Most sophisticated technological artefact of antiquity,
more complex than ANY device for at least Millennium afterwards !!!!**

- Bronze Mechanism
- 82 fragments identified (major fragments A,B,C,D,E,F,G sure)
- Contains at least 32 gear wheels (30 identified !!!!)
- Sophisticated internal gearhouse (central processing unit)
- Pin-Slot mechanism for lunar epicyclic orbit (Hipparcos) !!!!
- Calculating Panhellenic Games (incl. Olympic games)
- Originally housed in wooden-framed case
- Size: 315x190x100 mm (laptop size)
- Front and Back doors
- Astronomical Inscriptions covering much of the exterior
- Probably Hand-driven



image courtesy: Tony Freeth/Images First Ltd.



<p>October 1900:</p> <ul style="list-style-type: none"> • Group (sponge) divers, lead by Elias Stadiatos • Shipwreck 43m deep : 50 m long, 30 tons 15-25 m off Cape Glyphadia <p>Until 1902:</p> <ul style="list-style-type: none"> • Salvaging numerous artefacts ... 	
<ol style="list-style-type: none"> 1) Ephebe of Antikythera ~ 340 BC 2) Hercules, marble bull, bronze lyre 3) Philosopher Antikythera 4) Golden jewellery, utensils, statues 5) May 17, 1902, Valerios Stais: Antikythera Mechanism 	<p>Note: - In those days no scuba diving:</p> <ul style="list-style-type: none"> - cold water, currents, $p > 5$ atm. - 9 min dive, 4 min descent+ascent, 5 min bottom time - 10 divers, 1 diver died, 2 permanently disabled

2012-2015: Brendan Foley






image: Alexandros Sotiriou



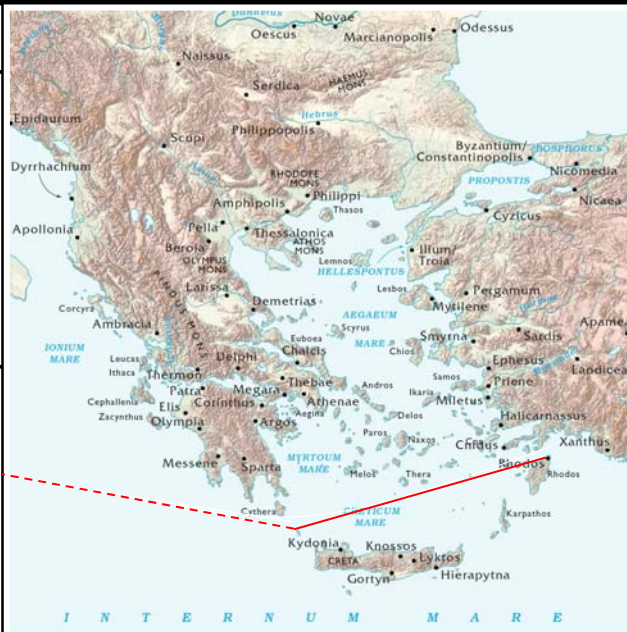
Roman Shipwreck

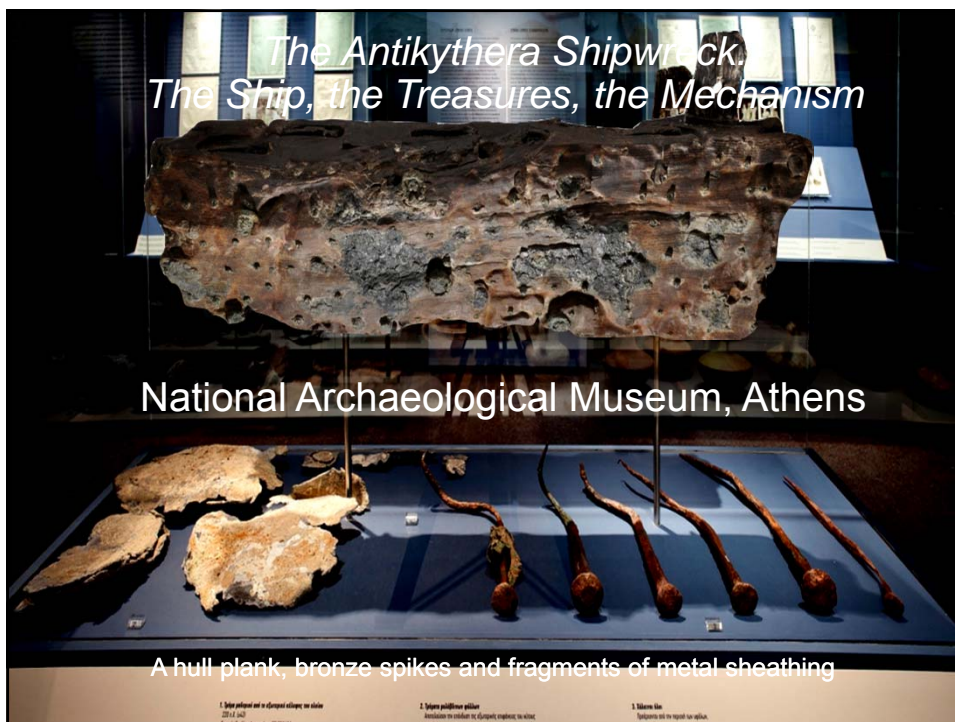
Dating Ship nontrivial:

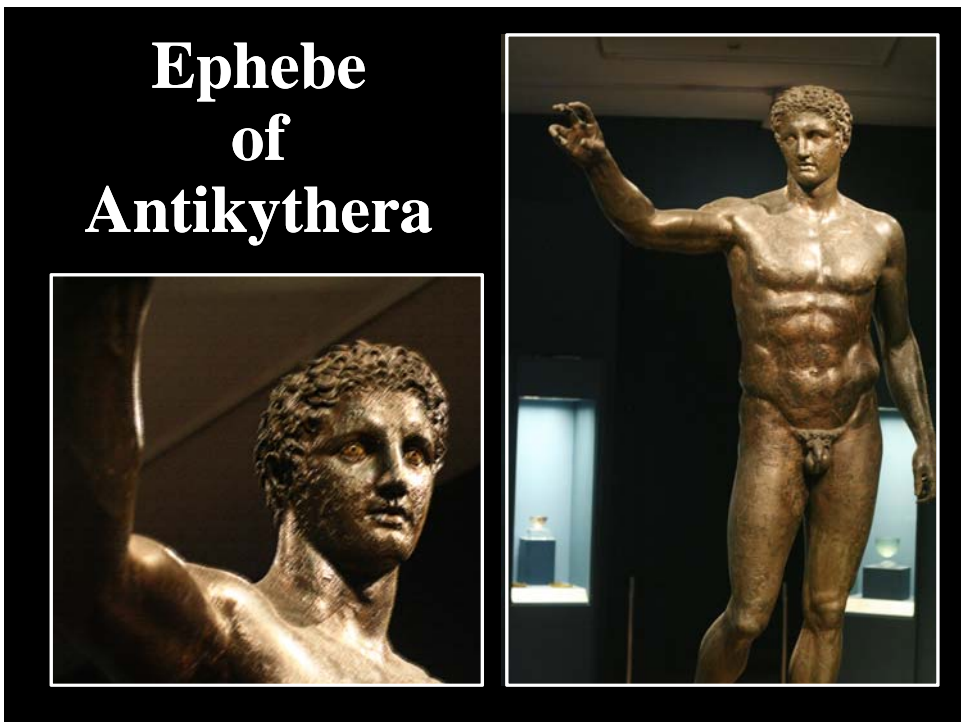
- bronze statues: 4th c. BC
- marble statues: 1st c. BC
copies earlier originals
- coins Pergamom ~ 60-80 BC
- carbon dating utensils: 65 BC
- ship of elm, wood often used by Roman for ships

Speculation:

- Loot by Sulla from Athens (86 BC), 1st Mithridatic War
- Destined for Rome (loved marvels Greek culture...)
- Lucian mentions loss one Sulla ship near Antikythera !







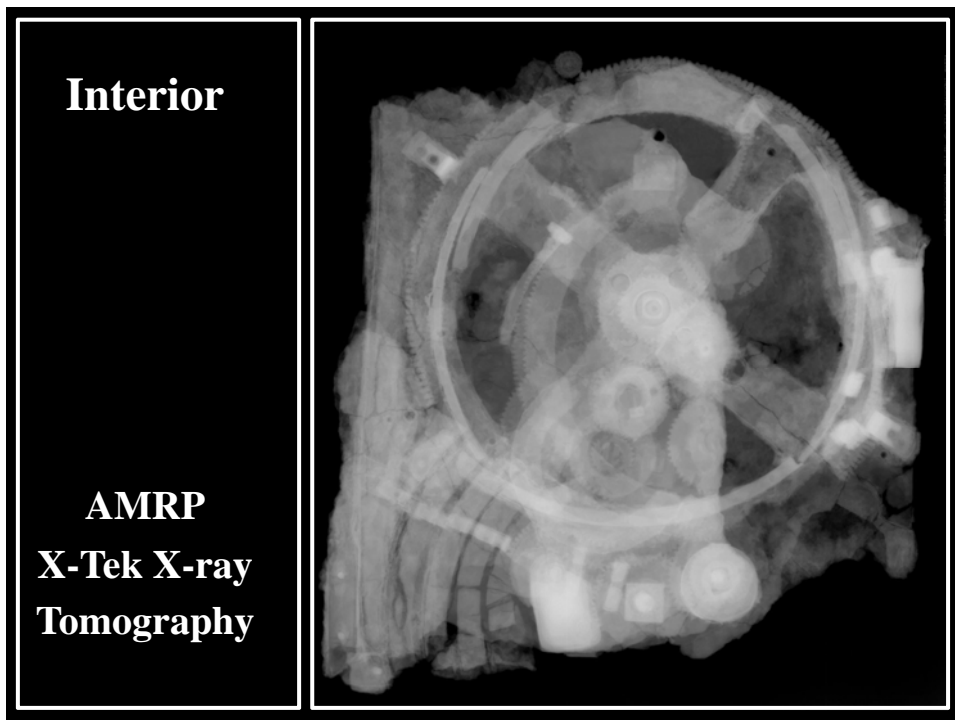
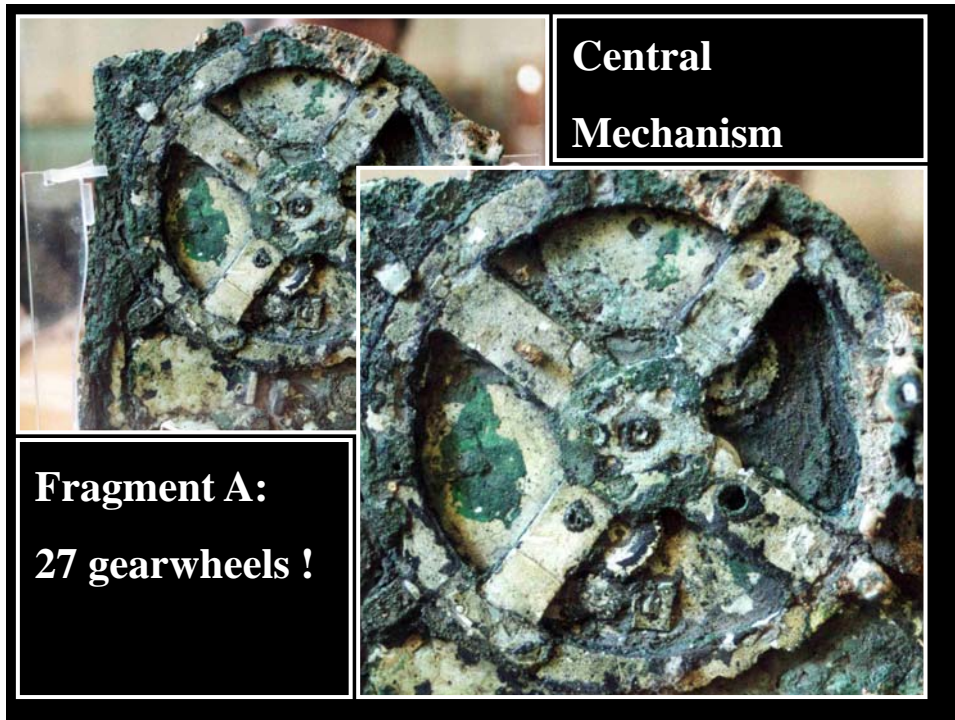
Coins & Jewelry



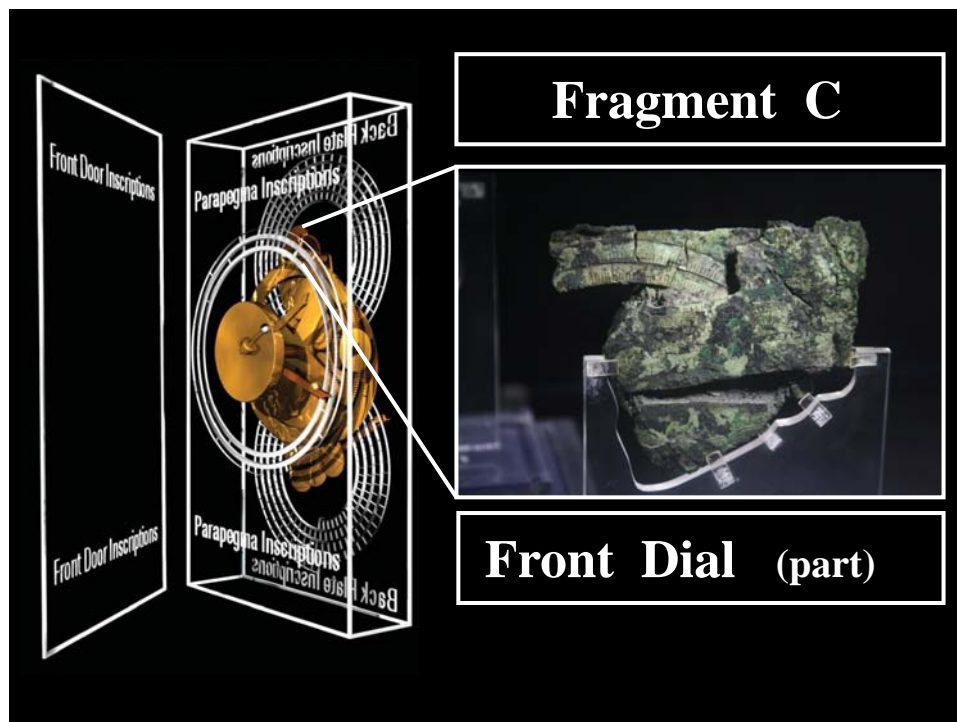
Pergamon. Silver cistophoric tetradrachme 85-76 BC.

precious and intricate golden jewelry





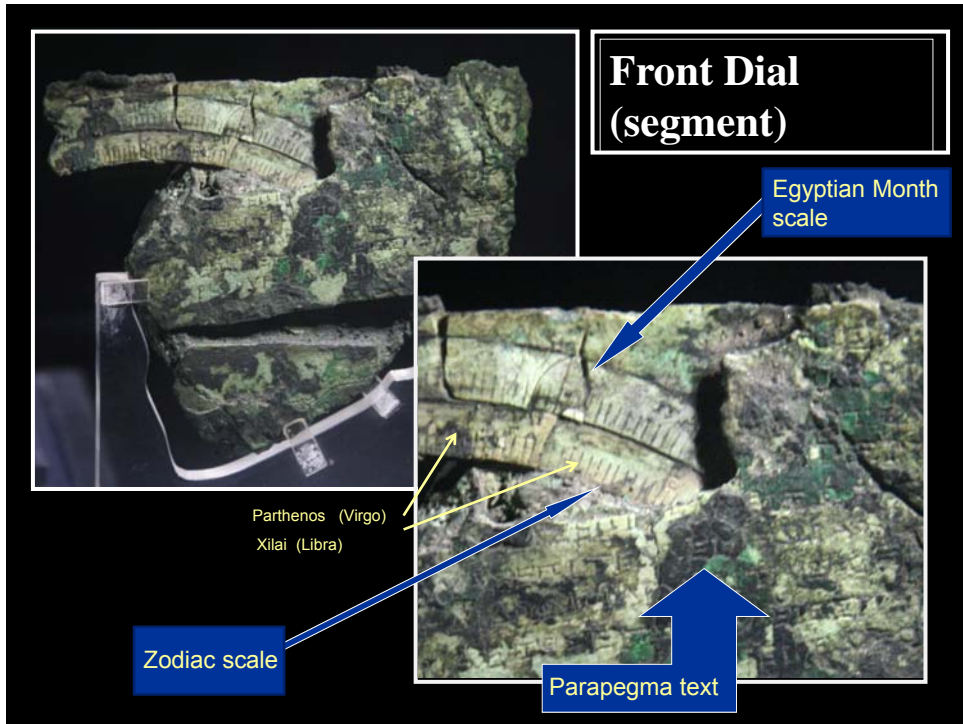


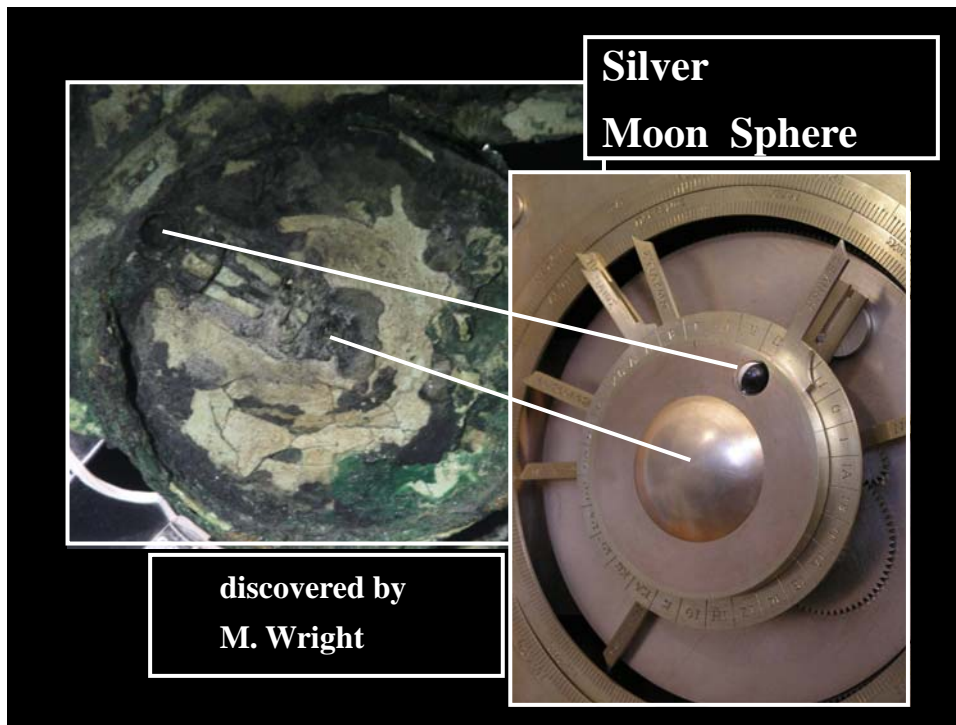


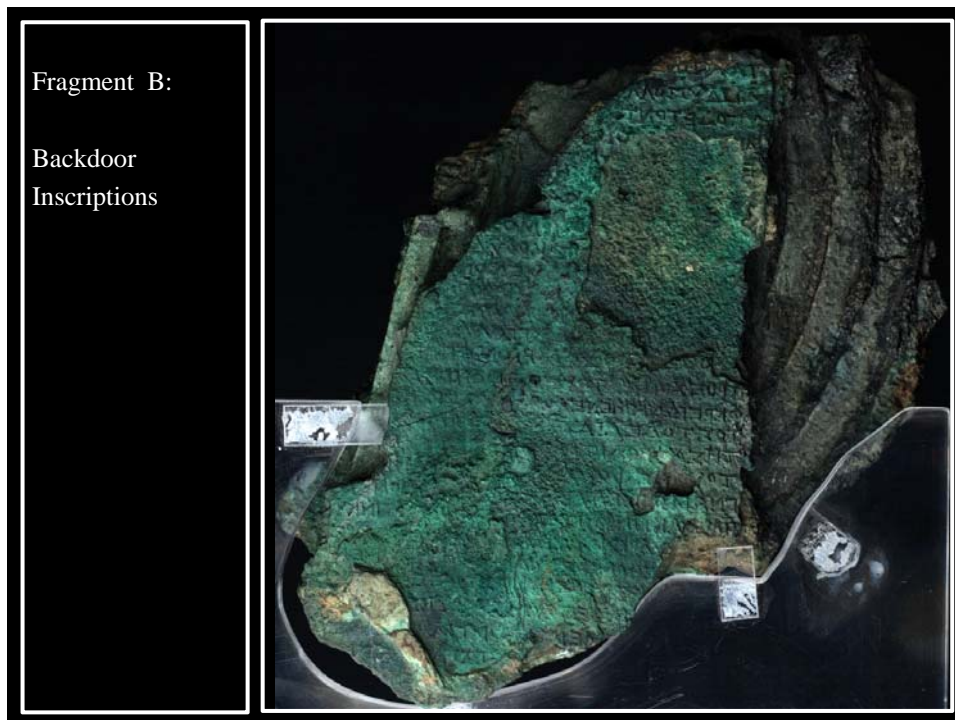
Front Dial

- Front dial, inner scale
position Sun and Moon in zodiac

- Front dial, outer scale:
calendar Egyptian names months in Greek letters
(Egyptian calendar standard use Greek astronomy),
corresponding calendar of 365 days
adjustable for leap year







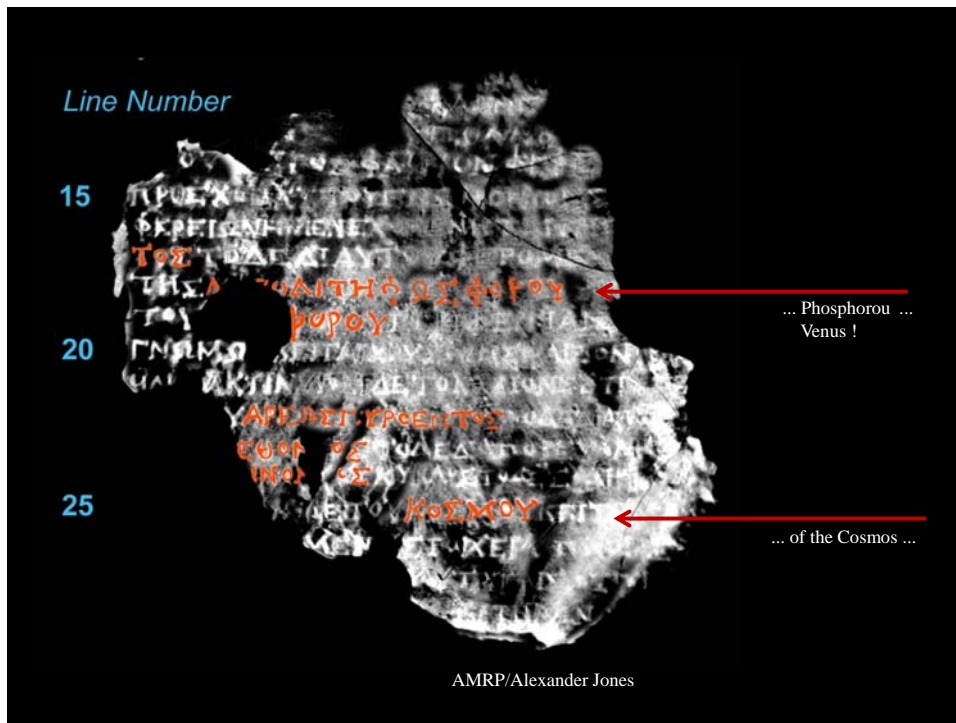
Instrument covered with inscriptions:

- Doors
- Front- and Backside of instrument (outside dials)
- Dials
- Internally, on gear wheels

Inscriptions concern 3 different aspects:

- Technical, manual for the use of the instrument
- Astronomical
- Parapegma: “almanac”,
relating earthly matters (weather, harvest) to events on sky

- Inscriptions as dating tool, ie. they identify the time of manufacture:
 - type lettering: 2nd half second century BC
 - used old name planet Venus: changed around 100 BC

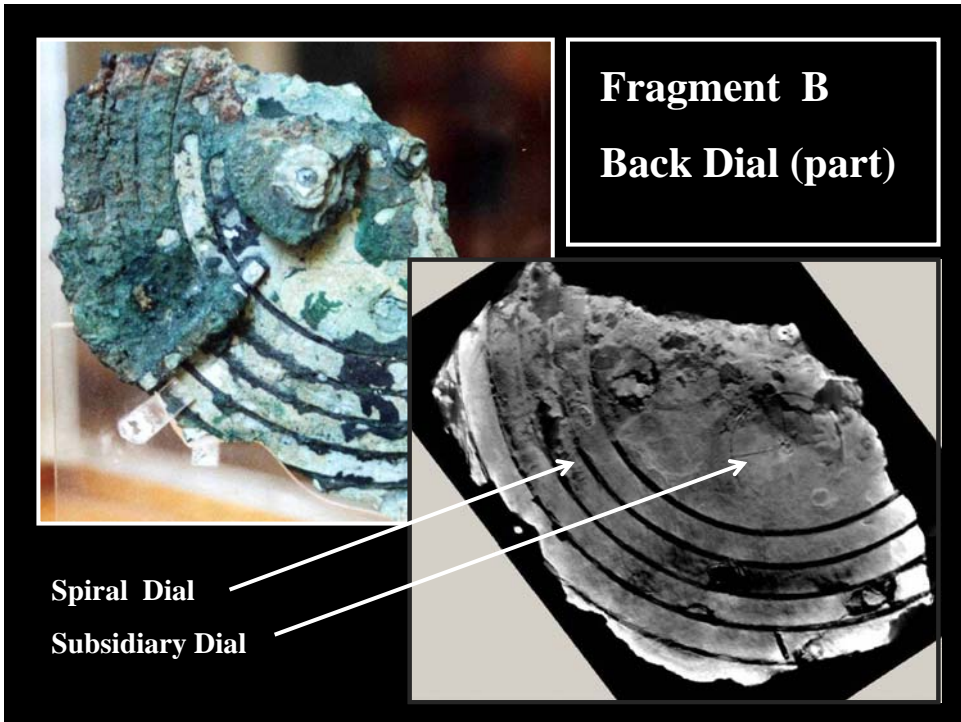


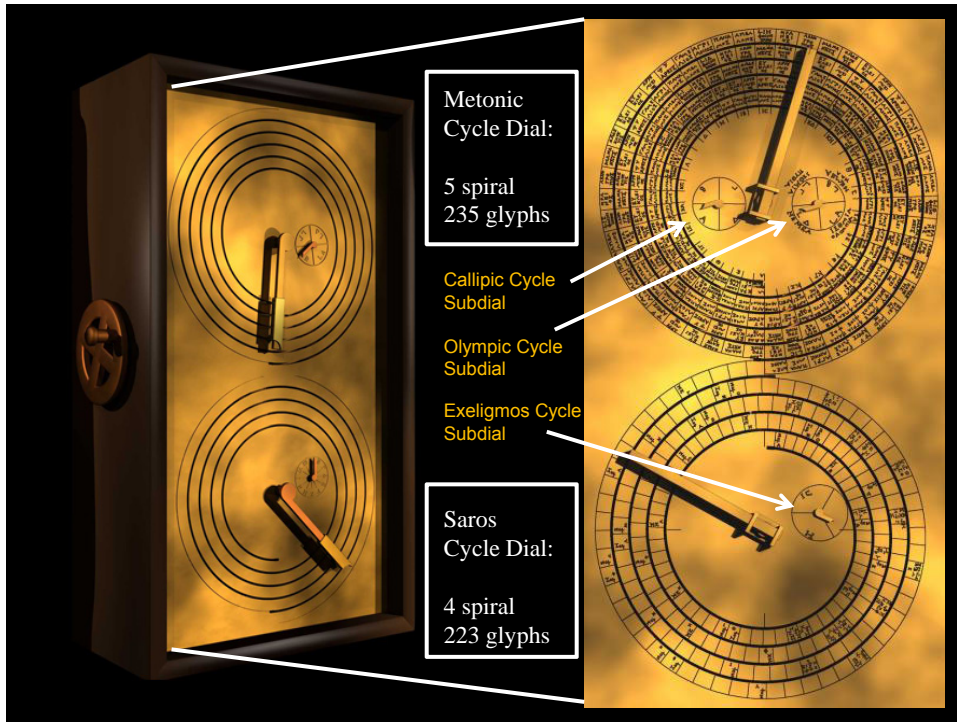
Technical Inscriptions:

- “Tap”; “Gnomon”; “Perforations”; “Pointers”; “Gears”;
- “Spiral divided in 235 sections ...”
- “small golden ball”
- “small ball”

Astronomical Inscriptions:

- “ΣΤΗΡΙΓΜΟΣ”: stationary point planets’ retrograde motion
- “Venus approaches the Sun”
- “The Hyades set in the evening”
- “Gemini begins to rise”, ...
- “ the 76 years, 19 years of the ...”





Astronomical Cycles

- **Metonic Cycle**

multiple of Tropical Year and Synodic Month

19 tropical years;
235 synodic months
254 sidereal months
6940 days

- **Callippic Cycle**

more accurate multiple
Tropical Year & Synodic Month

4 Metonic cycles - 1 days;
76 tropical years;
940 synodic months

- **Saros Cycle**

Eclipse cycle:
multiple of
Synodic, Draconic and Anomalistic month

223 synodic;
242 draconic;
239 anomalistic;
18 yrs, 11 days, 8 hrs (6585 1/3 days)

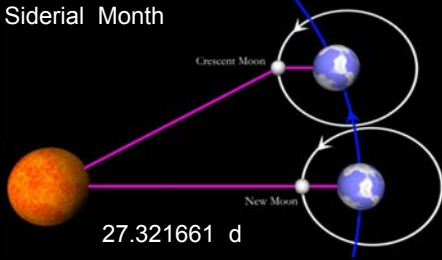
- **Exeligmos Cycle**

3 Saros cycles:
following Exeligmos cycle, eclipse returns
at same location Earth

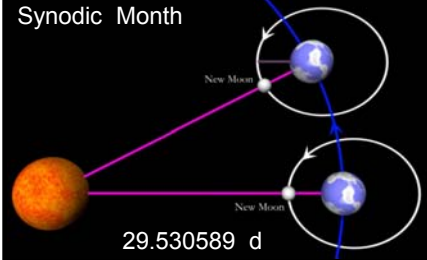
669 synodic;
726 draconic;
717 anomalistic;
54 yrs, 34 days (19756 days)

Months

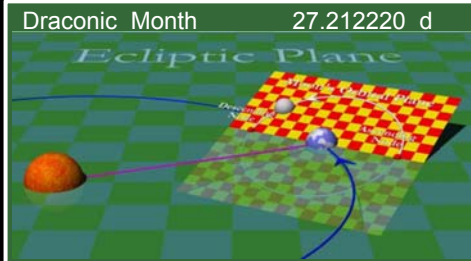
Siderial Month



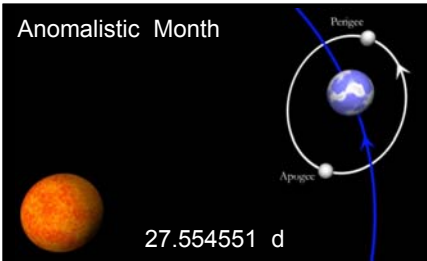
Synodic Month



Draconic Month 27.212220 d



Anomalistic Month



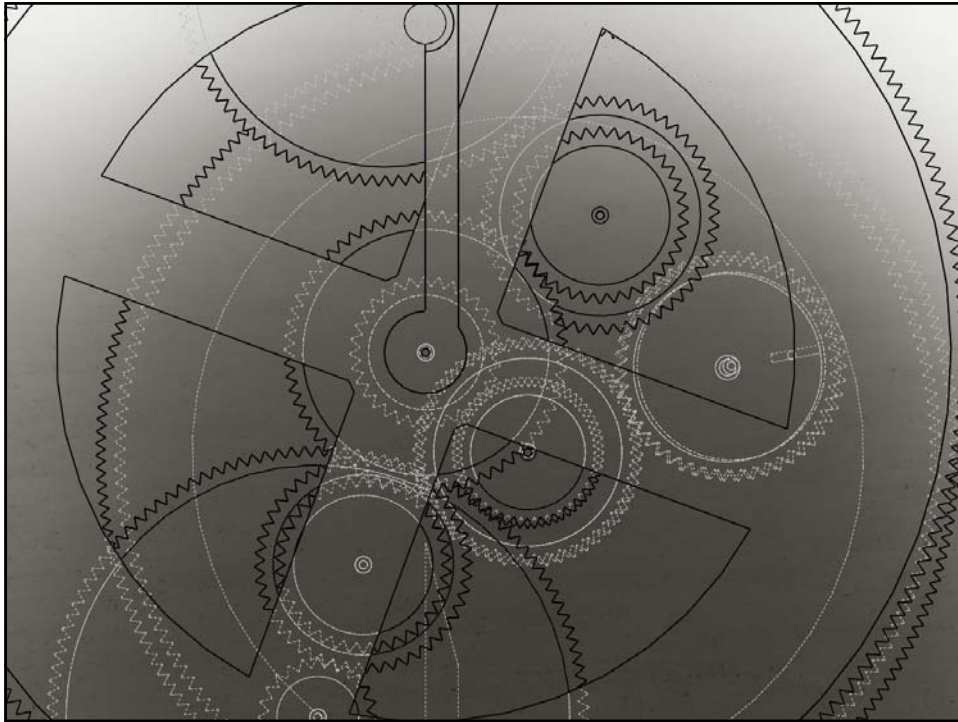
Metonic Cycle Dial



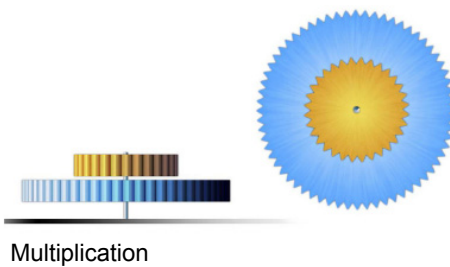
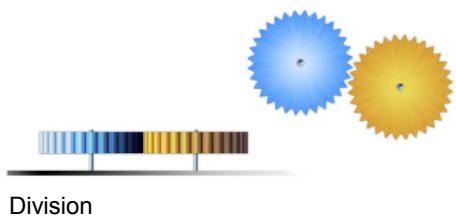
125 A-3.2				Σ H ^M P H H H ^M P Γ Z
131 F-3.1				Σ H ^M B H H ^M P Θ H
137 F-3.7				Σ H ^M P E H H ^M P IB Θ
172 E-4.2				Σ H ^M P H H ^M P Π
178 A-4.2				Σ H ^M P Θ H H ^M P Θ P
184 A-4.3				Σ H ^M P Δ H H ^M P A Σ
190 F-4.5				Σ H ^M P H H ^M P T








Gear Transmissions



Example:

6 coupled gear wheels,
teeth: $r_1, r_2, s_1, s_2, t_1, t_2$:


$$f = \frac{r_1}{r_2} \times \frac{s_1}{s_2} \times \frac{t_1}{t_2}$$



courtesy: Niels Bos

Gear Train


gear	#teeth	
b	64	
l1	38	$l \quad \frac{64}{38} = \frac{32}{19}$
l2	53	
m1	96	
m2	15	
n1	53	



courtesy: Niels Bos

Gear Train

gear	#teeth	
b	64	
l1	38	$l \quad \frac{64}{38} = \frac{32}{19}$
l2	53	
m1	96	$m \quad \frac{32}{19} \times \frac{53}{96} = \frac{53}{3 \times 19}$
m2	15	
n1	53	



courtesy: Niels Bos


Gear Train

gear	#teeth	
b	64	
l1	38	l
l2	53	
m1	96	m
m2	15	
n1	53	n

$$l \quad \frac{64}{38} = \frac{32}{19}$$

$$m \quad \frac{32}{19} \times \frac{53}{96} = \frac{53}{3 \times 19}$$

$$n \quad \frac{53}{3 \times 19} \times \frac{15}{53} = \frac{5}{19}$$



courtesy: Niels Bos

Gear Train

gear	#teeth	
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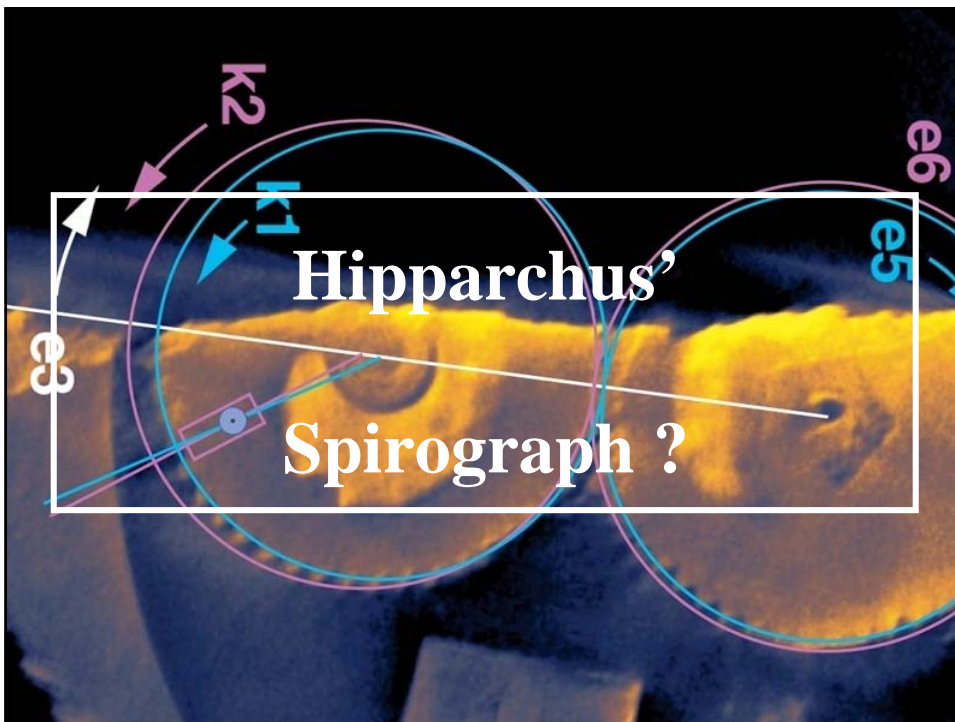
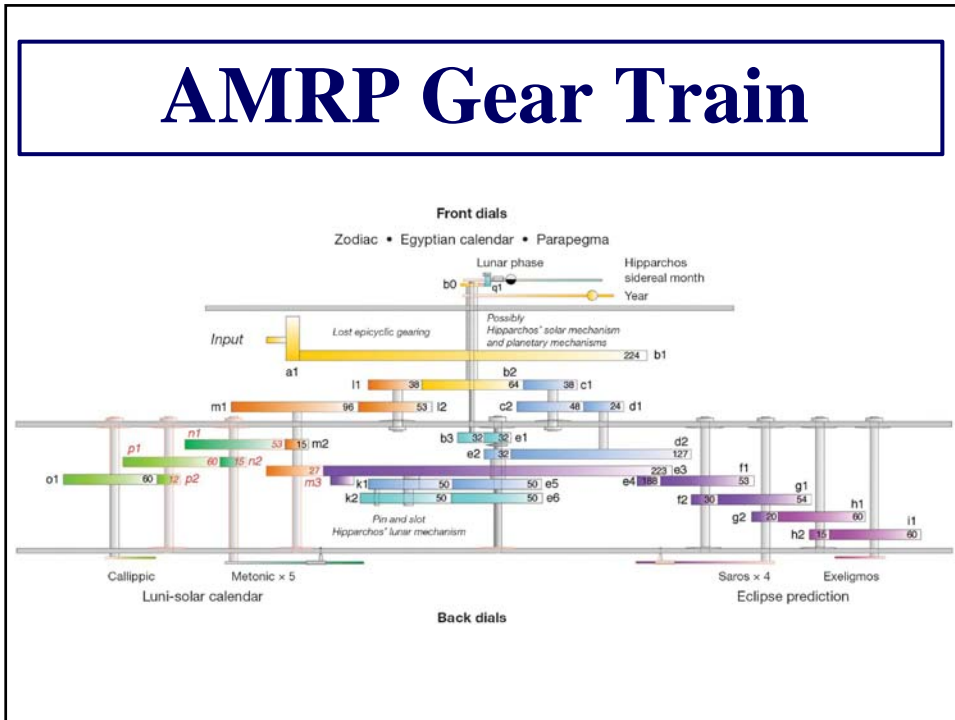
$$l \quad \frac{64}{38} = \frac{32}{19}$$

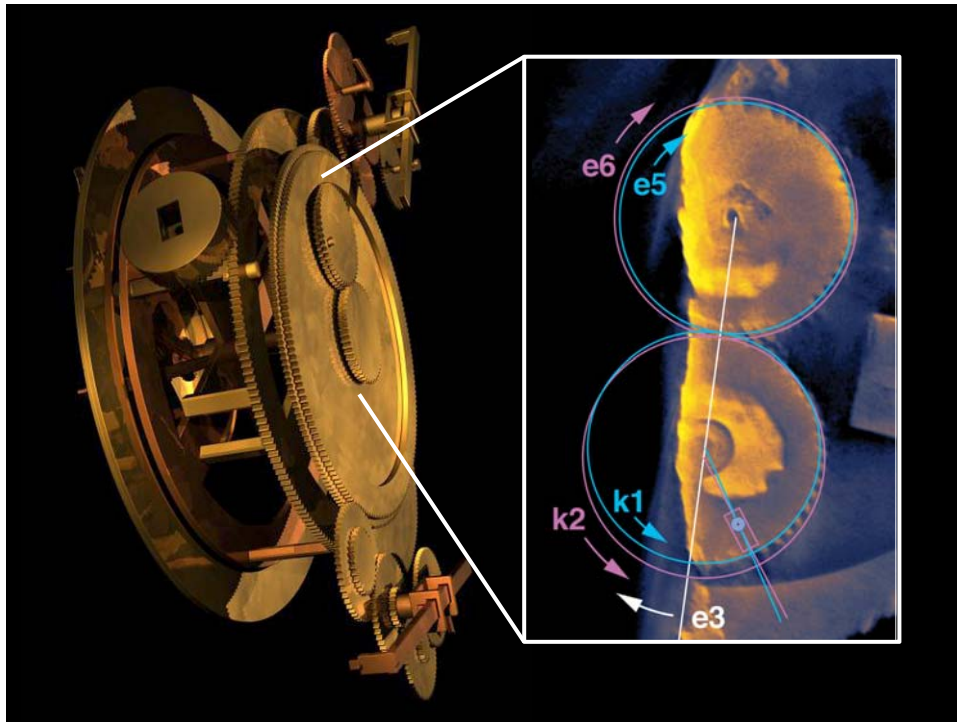
$$m \quad \frac{32}{19} \times \frac{53}{96} = \frac{53}{3 \times 19}$$

$$n \quad \frac{53}{3 \times 19} \times \frac{15}{53} = \frac{5}{19}$$

Exactly what we want for a 19-year 5-turn dial

AMRP Gear Train







Pin-and-Slot Mechanism

Hipparchus'
Lunar Mechanism

Epicyle Theory

- describes non-circular Moon orbit
- non-uniform motion
- differing apparent Moon size
- Noticeable: libration !

Apogee	Perigee
	
2004-12-26 405,363 km 29.94 arc-secs Altitude @ 77.81°	2004-07-02 357,448 km 33.66 arc-secs Altitude @ 21.72°


Moon Size

different distance along orbit Moon

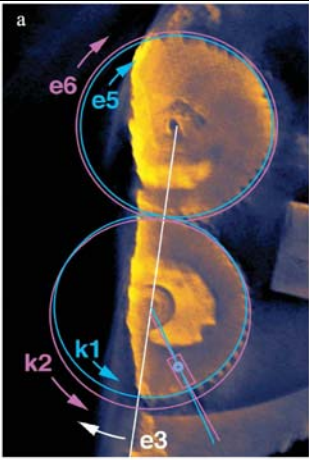
Moon Libration

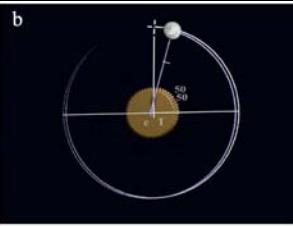
We can see more than 1/2 of Moon surface, due to its elliptical orbit

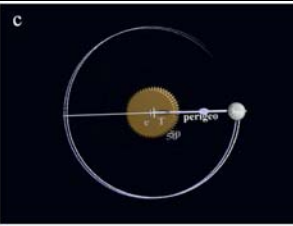
Date: 2005 Sep 1 02:23:28 UT




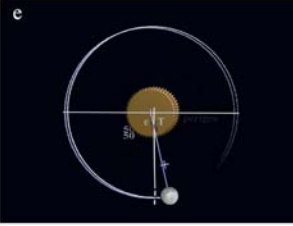
Hipparchus' Pin-Slot Gears













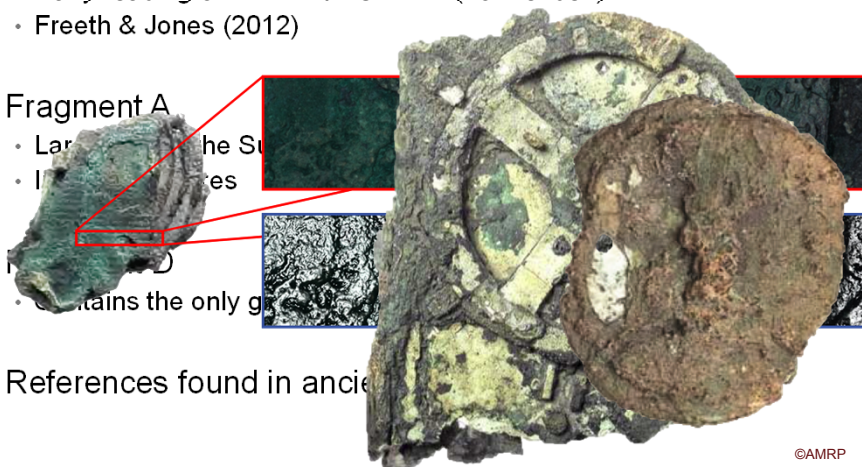
Planetarium ? - Indications

- Inscriptions on the surviving fragments
 - Early reading of "ΤΗΣΑΦΡΟΔΙΤΗ" (..of Venus..)
 - Freeth & Jones (2012)

- Fragment A
 - Large fragment of the Sun
 - Includes the names of the planets

- Fragment B
 - Contains the only g

- References found in ancient



Antikythera Mechanism

may be a planetarium following the Cosmos of Aristoteles

- Moon
- Mercury
- Venus
- Sun
- Mars
- Jupiter
- Saturn



A. Jones found all

5 planet names & Moon and Sun

- in inscriptions:
 - ordered like Cosmos
 - each with descriptive & theophoric name
 - e.g. Venus: + Phosphoros + star of Aphrodite

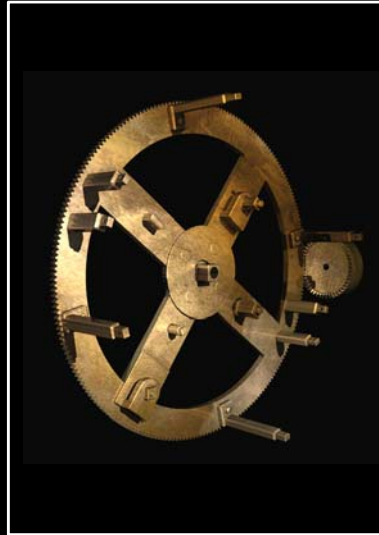
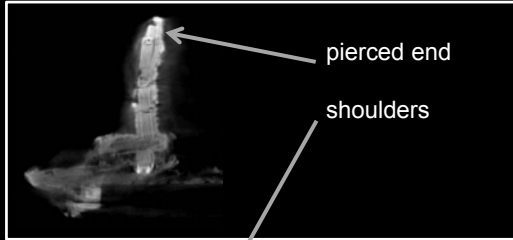
Freeth & Jones 2012 ISAW publ.

Mechanical Elements

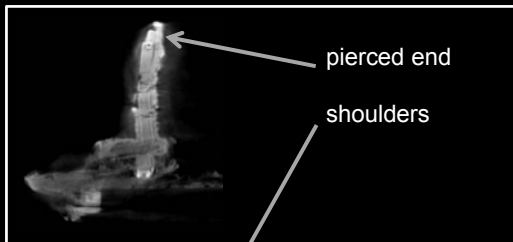
evidence of pillars, bearing and other fittings on the Main Drive Wheel

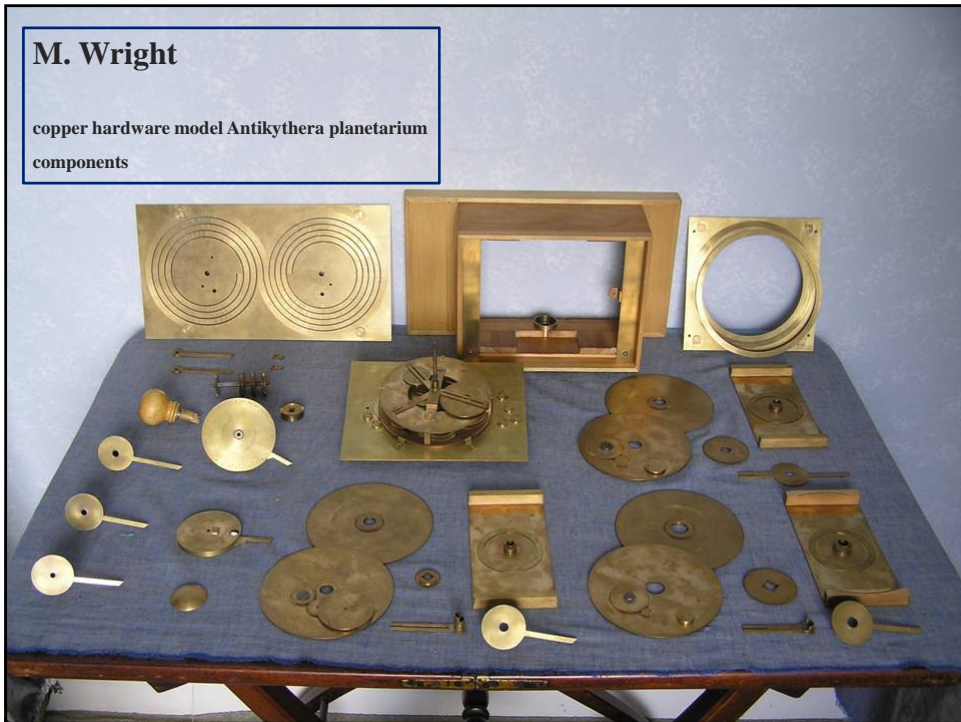


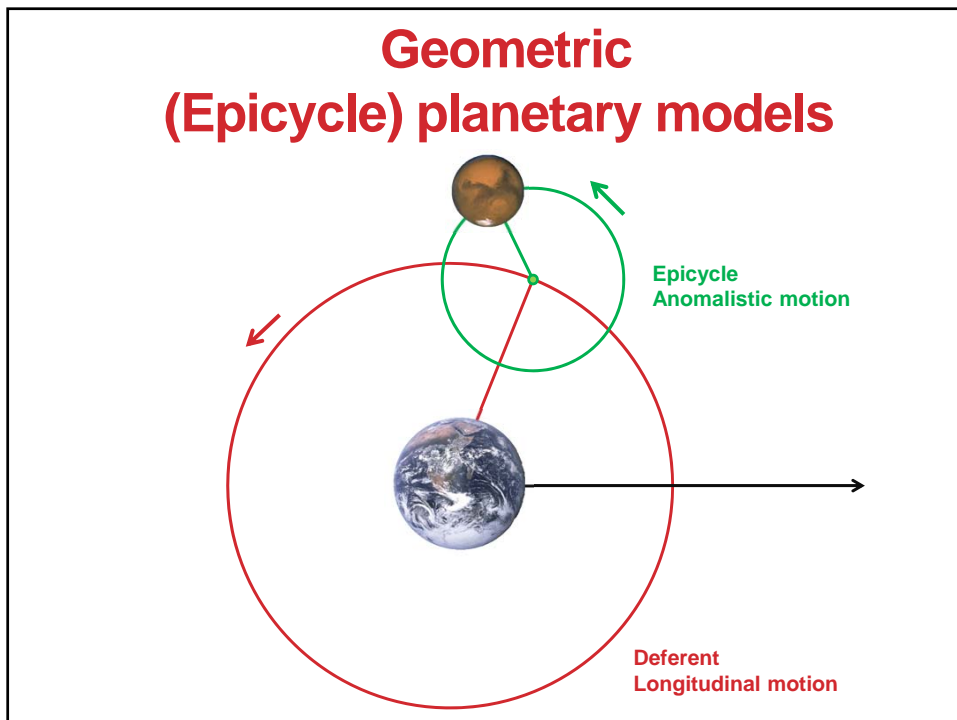
Mechanical Elements



Mechanical Elements

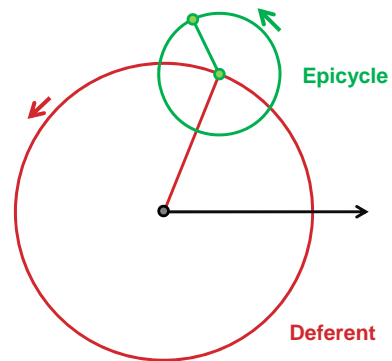






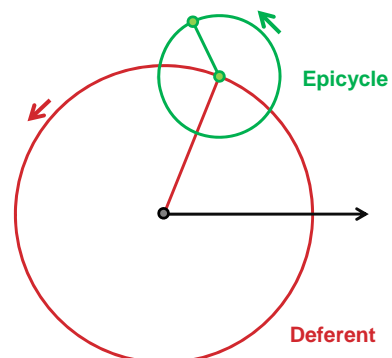
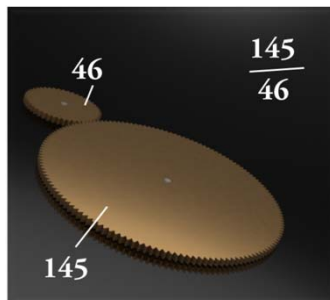
Periods to Gears

- Mercury's anomalistic motion: 145 cycles in 46 years.
- It makes $145/46$ cycles per year.
- Geared solution: $145/46$



Periods to Gears

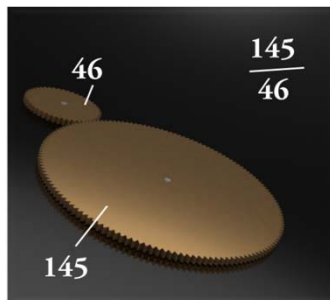
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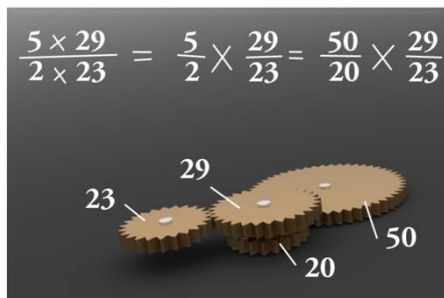
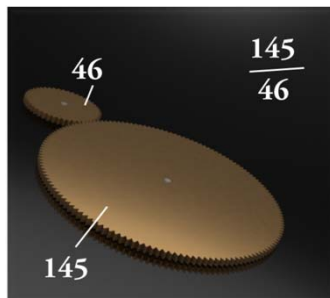
- Geared solution: $145/46$
 - Factorizes into: 5×29 and 2×23



Periods to Gears

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Venus: case study planetary geartrain

Accuracy > 1e6:	4506805.90764	97	3519.0	5666.0	2.22162673823e-07	{3, 3, 17, 23}{2, 29, 97}	{9}
1	3999999.99999	87	2881.0	4606.0	2.7138522332e-07	{43, 67}{2, 7, 43}	{9}
2	2454402.99972	101	1914.0				
3	2149999.00033	43	3362				
4	2045120.99964	83	7999				
5	1636999.0002	61	1281				
6	1432759.00019	103	5605				
Accuracy > 1e5:							
1	785732.333369	97	3686				
2	700465.666715	79	6572				
3	599650.999955	67	7504				
4	481719.000006	97	7220				
5	420303.761922	103	6901				
6	408002.999978	29	3142				
7	374448.058831	109	4977				
8	325144.999994	17	6375				
9	322856.142858	113	1767				
10	31482.818173	71	2709				
11	312475.999993	73	7656				
12	298372.428569	71	6532				
13	294372.111101	109	2071				
14	289635.363643	59	4963				
15	287775.0001	23	5629				
16	275124.999993	67	3166				
17	232295.285701	67	6365				
18	231927.999999	89	5251				
19	221964.636362	109	1909				
20	205919.000001	23	8054				
21	203580.999999	53	7954				
22	190288.872337	43	8993				
23	188832.703032	103	6263				
24	185566.21739	97	3337				
25	182896.999999	71	7150				
26	182260.662268	109	3706				
27	165864.157893	107	4922				
28	162629.703233	31	6612				
29	157885.444444	107	5555				
30	154759.000003	73	2420				
31	151561.000001	97	7584				
32	146232.333335	107	2744				
33	141979.268687	59	2537				
34	140741.857144	109	3068				
35	139574.000002	53	3392				
36	131994.423697	89	6497				
37	125842.472621	73	2263				
38	122331.487334	67	7437				
39	122846.901629	31	5859				
40	117633.424242	83	8906				
41	116289.0	113	7284				
42	113251.83019	61	4953				
43	108827.802048	103	7476				
44	107862.333333	79	6335				
45	106426.262196	89	7909				
46	104614.166812	107	7420				
47	103599.000001	37	1620				

Best approximation

Accuracy = $2,22 \times 10^{-7}$

Period = $5626 / 3519$
 $= (2 \times 29 \times 97) / (3 \times 3 \times 17 \times 23)$
 $= (97 / 51) \times (48 / 69)$





Venus: case study planetary geartrain

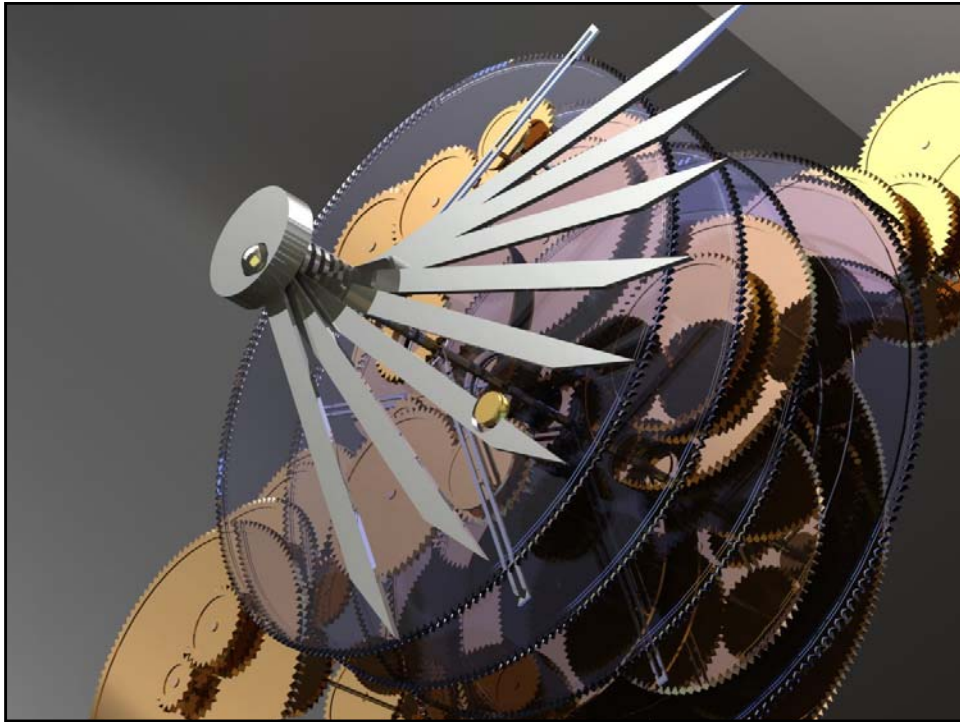
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13	294372.111101	109	2071				
14	289635.363643	59	4963				
15	287775.0001	23	5629				
16	275124.999993	67	3166				
17	232295.285701	67	6365				
18	231927.999999	89	5251				
19	221964.636362	109	1909				
20	205919.000001	23	8054				
21	203580.999999	53	7954				
22	190288.872337	43	8993				
23	188832.703032	103	6263				
24	185566.21739	97	3337				
25	182896.999999	71	7150				
26	182260.662268	109	3706				
27	165864.157893	107	4922				
28	162629.703233	31	6612				
29	157885.444444	107	5555				
30	154759.000003	73	2420				
31	151561.000001	97	7584				
32	146232.333335	107	2744				
33	141979.268687	59	2537				
34	140741.857144	109	3068				
35	139574.000002	53	3392				
36	131994.423697	89	6497				
37	125842.472621	73	2263				
38	122331.487334	67	7437				
39	122846.901629	31	5859				
40	117633.424242	83	8906				
41	116289.0	113	7284				
42	113251.83019	61	4953				
43	108827.802048	103	7476				
44	107862.333333	79	6335				
45	106426.262196	89	7909				
46	104614.166812	107	7420				
47	103599.000001	37	1620				

Sixth best approximation

Accuracy = $6,10 \times 10^{-7}$

Period = $2048 / 1281$
 $= 2^{11} / (3 \times 7 \times 61)$
 $= (32 / 61) \times (64 / 21)$
 $= (16 / 61) \times (64 / 63)$



AMRP Reconstruction

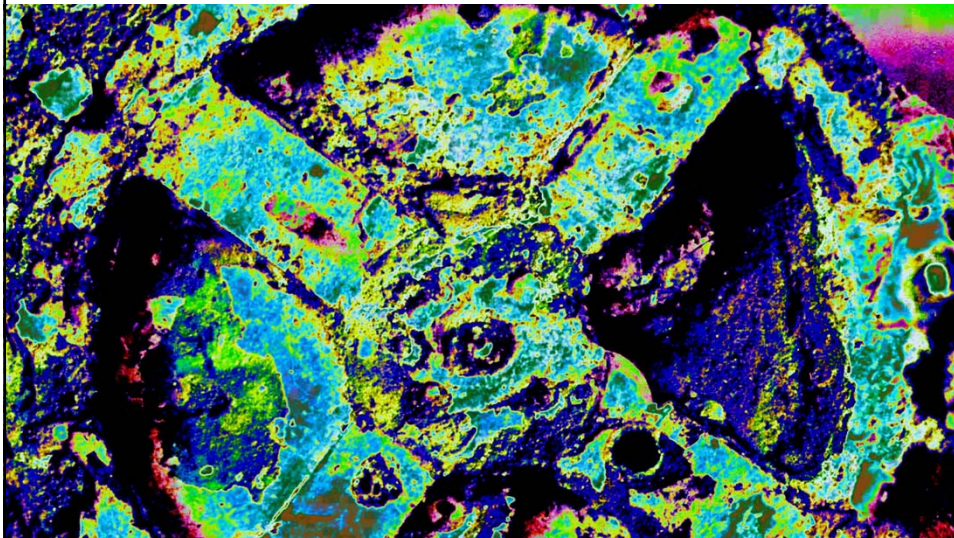
Gear Train Animation

A. Vicentini & M. Wright

Animation Vicentini & Wright



Rien van de Weijgaert



university of
 groningen

faculty of mathematics
 and natural sciences

kapteyn astronomical
 institute



Origin and Manufacture

• Where from ?

- Rhodos ...
- at the time one highly important and central port of the Mediterranean
- important centre of learning:
- ... Hipparchus 140-120 BC, Posidonius 92-51 BC, ...

• Who manufactured the machine ?

- the craftsman of the mechanism is (totally) unknown
- a highly skilled technician, the machine testimony of genius ...
- knowledge of astronomy (of the time) meticulous, state-of-the-art
- an advanced piece of equipment like the mechanism cannot be a stand-alone
- rather likely it is a representative of a gradual development ...

Archimedes

Archimedes

(287-211/212 BC, Syracuse)

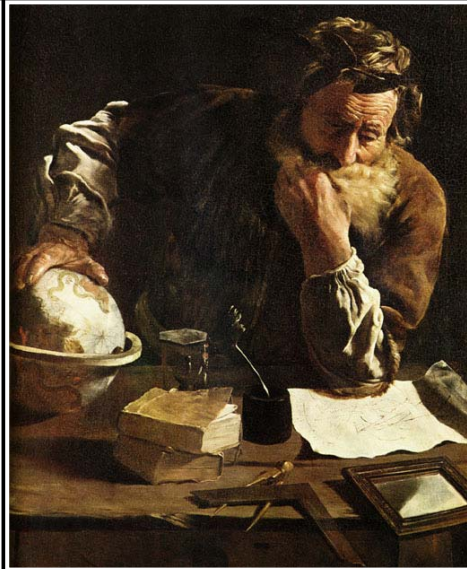
- Pappus of Alexandria:
Archimedes wrote book
"On Sphere-Making"

... is this the key ...

- Compare with

Archimedes Palimpsest:
... "On the Method" ...

Fundamentals Calculus,
Integral calculus ...



Cicero mentions two similar machines

For when Archimedes fastened on a globe the movements of moon, sun and five wandering stars, he, just like Plato's God who built the world in the "Timaeus", made one revolution of the sphere control several movements utterly unlike in slowness and speed. Now if in this world of ours phenomena cannot take place without the act of God, neither could Archimedes have reproduced the same movements upon a globe without divine genius"

Cicero,

Tusculan Disputations, Book I, Section XXV



**Plato Academy
Mosaic**

**Villa T. Siminius
Pompeii**

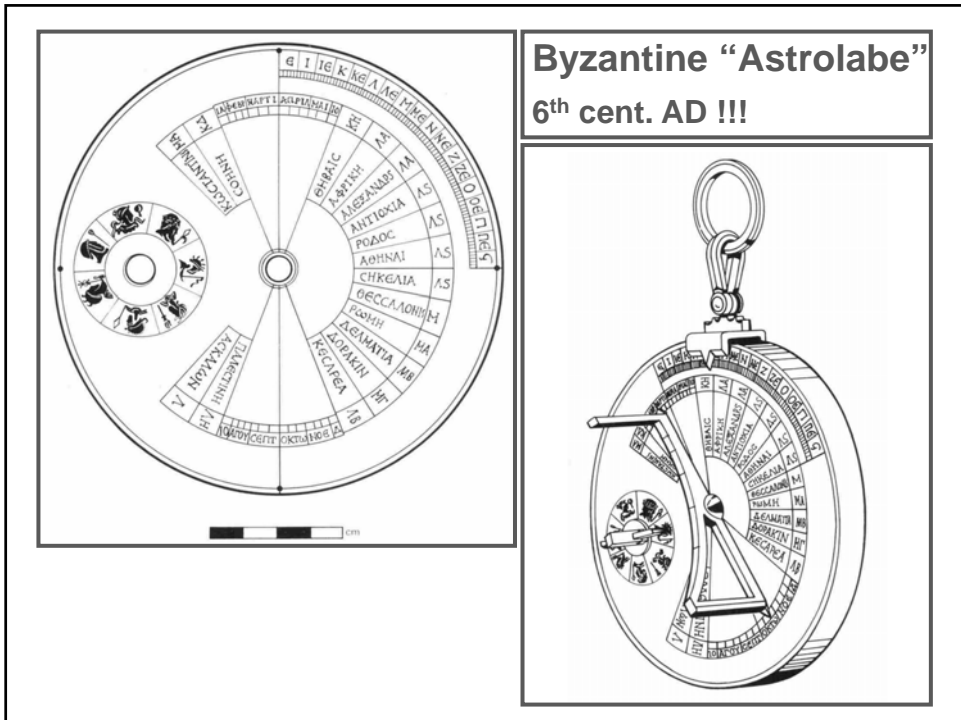
Photo © 2006 Pevinsky L. /Antichy



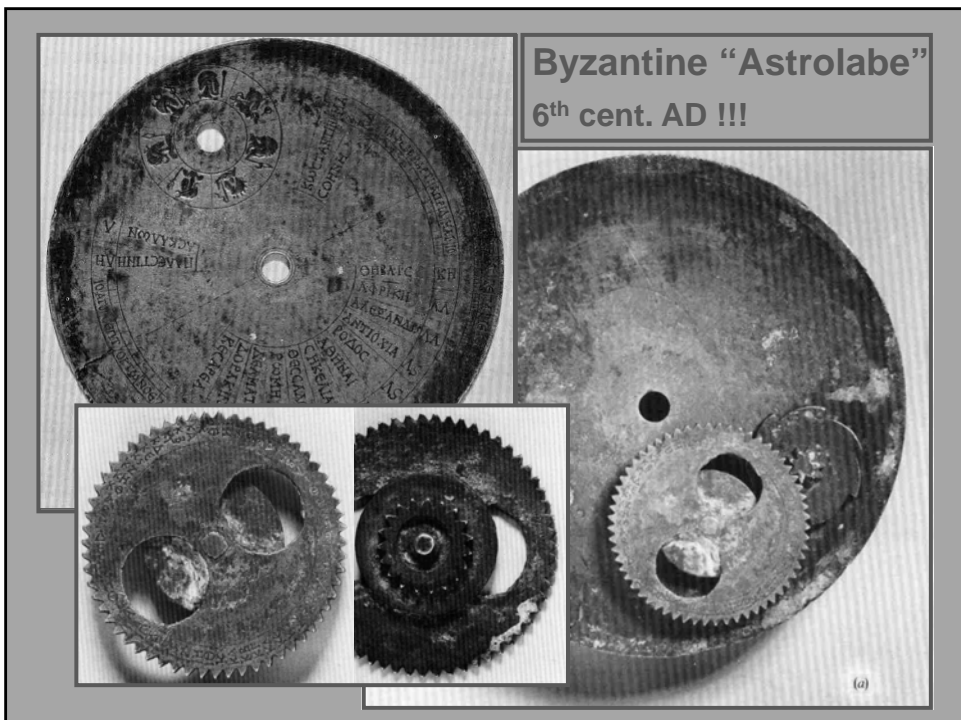
**Is this
Archimedes Sphere ?**

**Is this
an image of an
Antikythera Mechanism
related device ?**



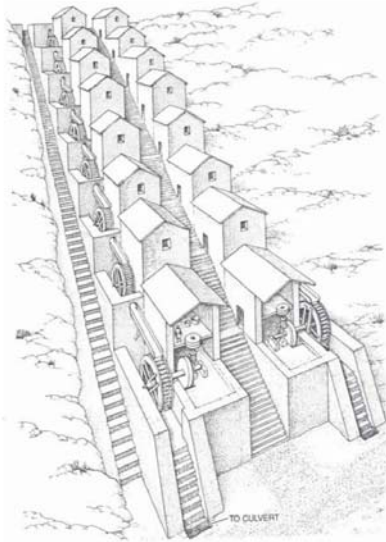


Byzantine "Astrolabe"
6th cent. AD !!!



Byzantine "Astrolabe"
6th cent. AD !!!

Roman Industry

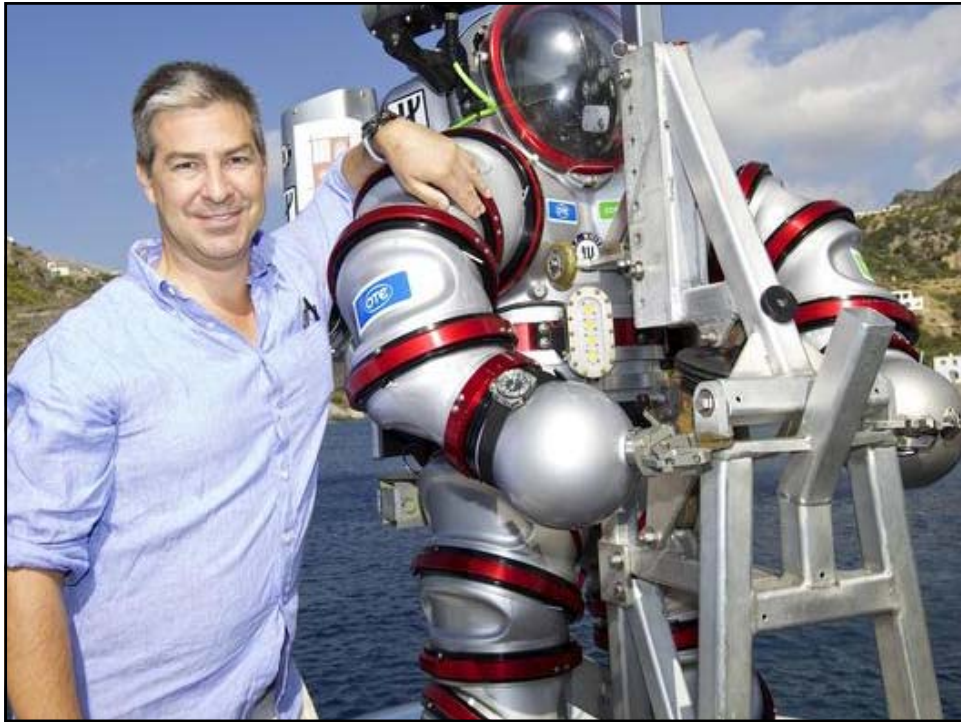


Did hightech find applications
In industrial activities ?

Barbegal:
industrial complex of watermills



Return to Antikythera



2013: Antikythera Ship Anchor



Images courtesy: Ephorate of Underwater Antiquities

2014: 200 kg 1.4 metre long anchor (by far largest known from antiquity)

Antikythera Wreck 2013

digital reconstruction of the roman anchor found at site during the Antikythera project (October 2012)



Designed by A. Tsoumas, 2011
Ephorate of Underwater Antiquities
© Greek State Archaeological Service

Titanic of the Ancient World ?



2014 diving expedition:

- Ceramics, amphorae, anchor 200 metres away from 1901 position.
- 2 Olkas cargo ships, or ...
- a giant 200 m giant grain ship ... (capacity, up to 1000 tons)