



the Universe Mechanized:

the Antikythera Mechanism,

ancient Greek astronomical computer

**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

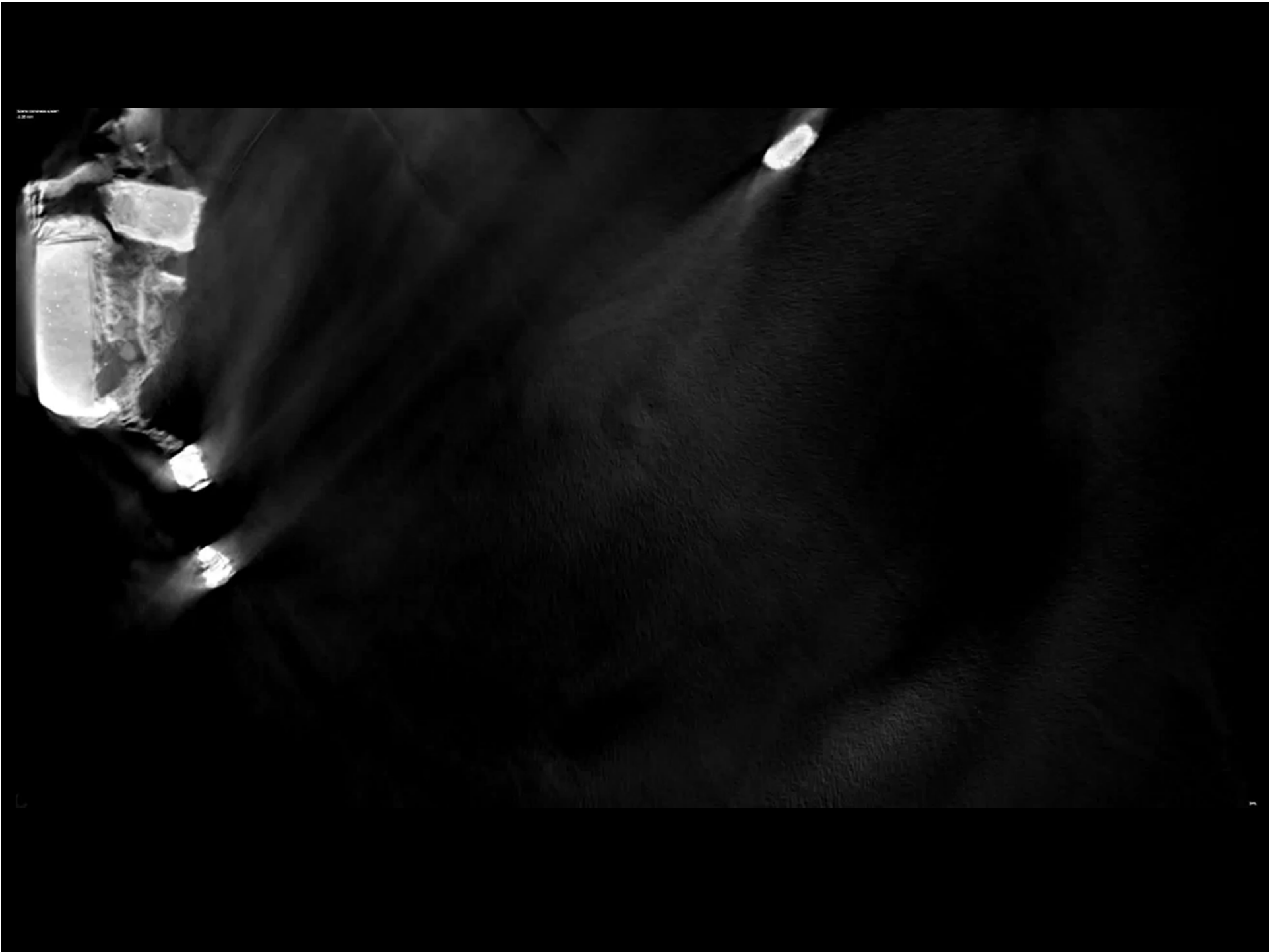


Fragment C, Fragment A, Fragment B

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 ?

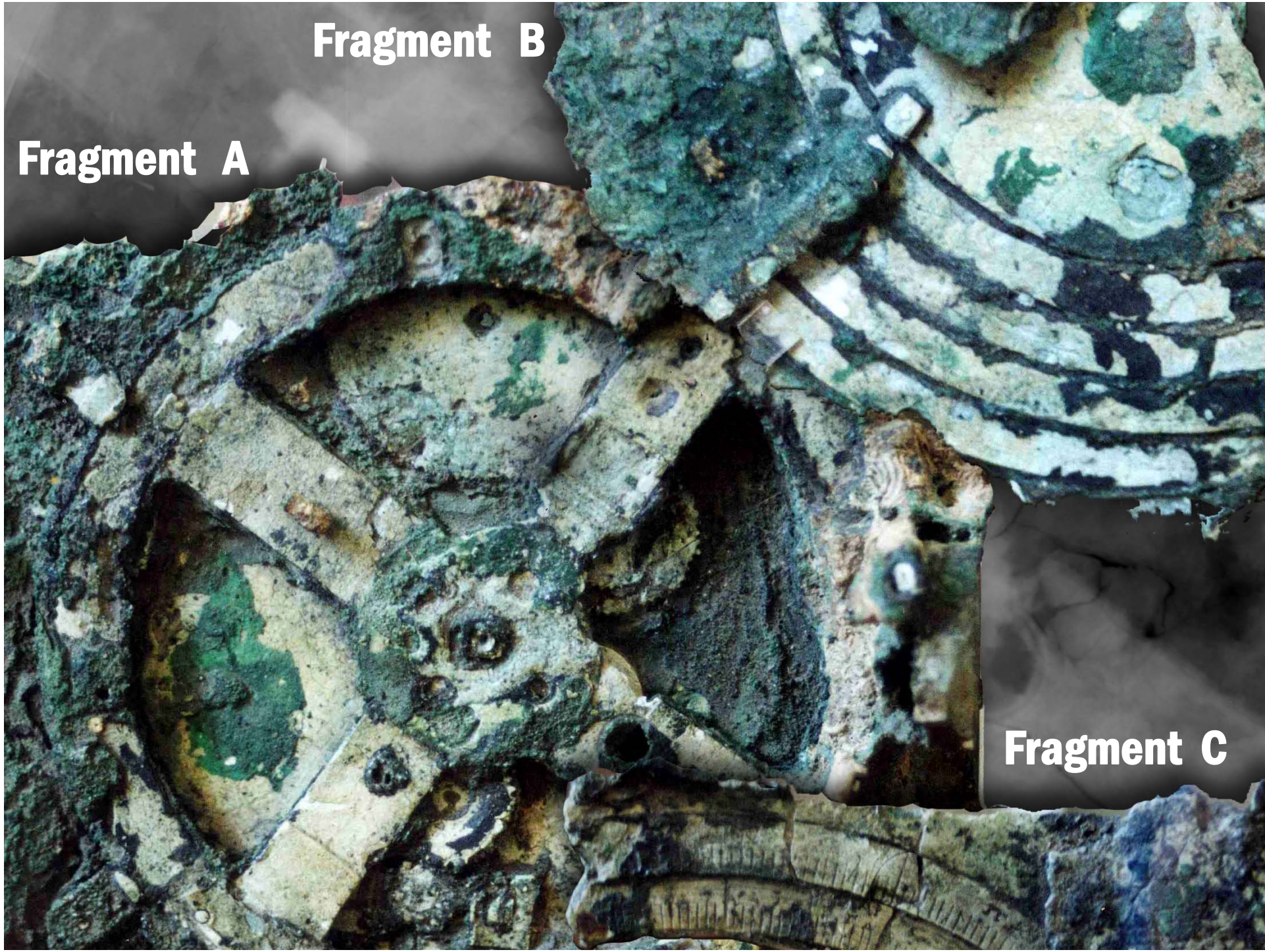
The background is a complex, multi-colored abstract pattern. It features a mix of bright colors including cyan, magenta, yellow, and blue, set against a dark, almost black base. The colors are arranged in irregular, organic shapes that resemble a microscopic view of a material or a digital fractal. A thin white border frames the central area where the text is located.

The Fragments

Fragment A

Fragment B

Fragment C



front



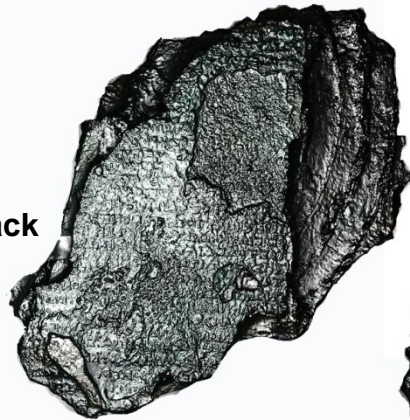
fragment A



back

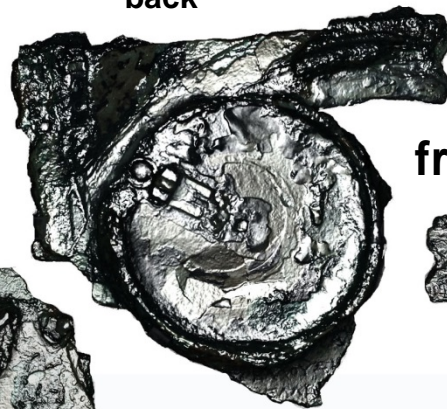
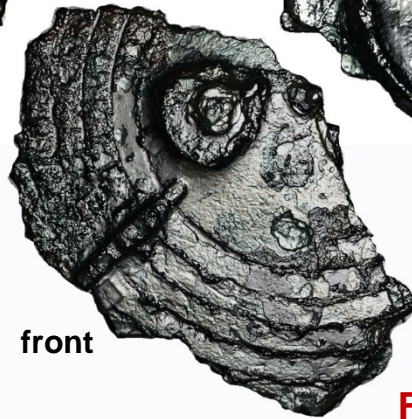
back

back



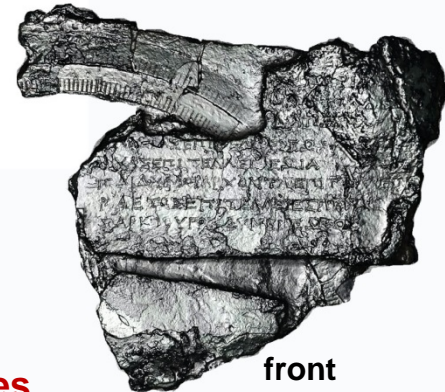
fragment B

front



fragment C

front



PTM images,
Freeth & Jones 2012



**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



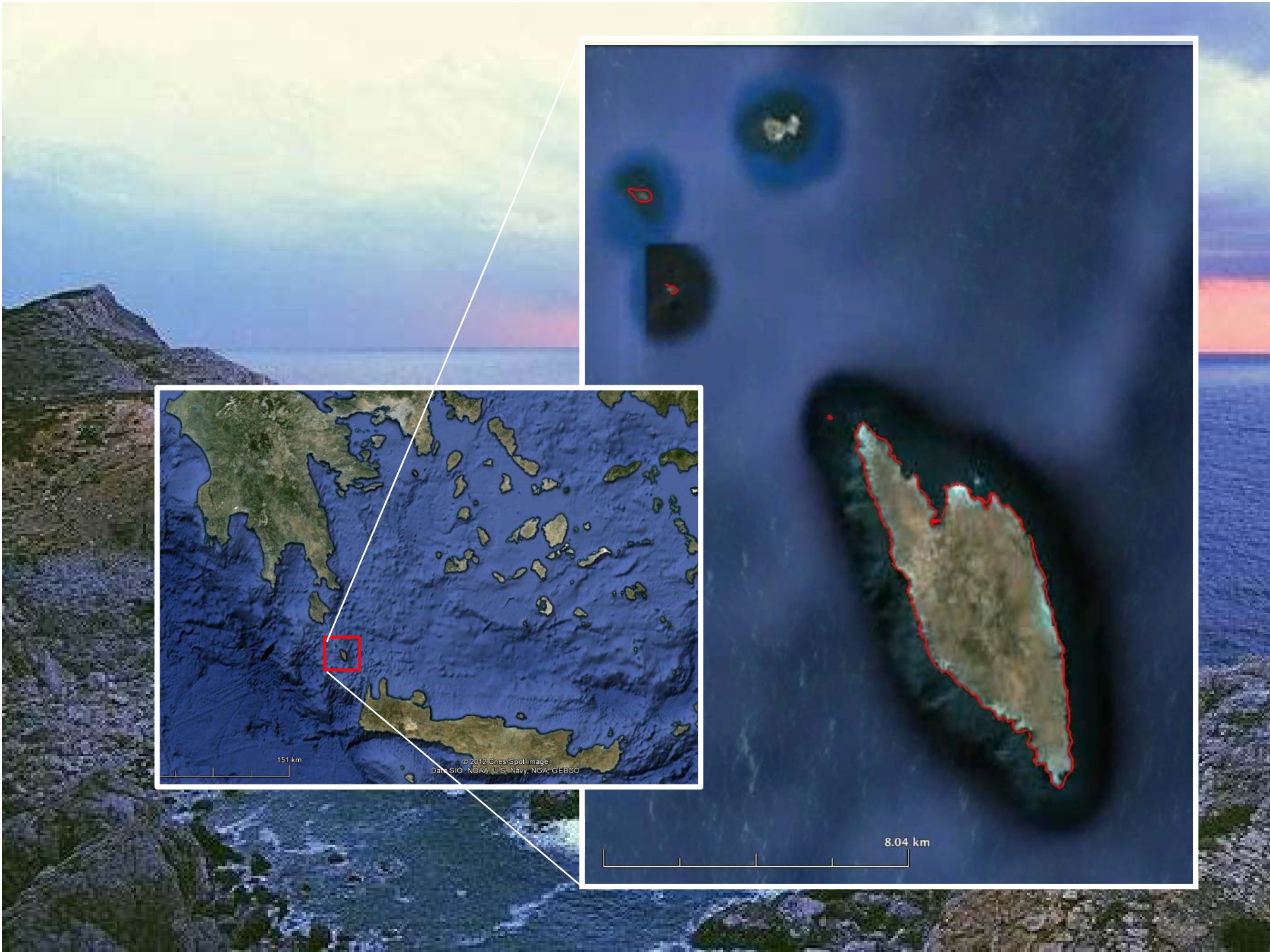
image courtesy: Tony Freeth/Images First Ltd.



Antikythera

&

the ship's discovery

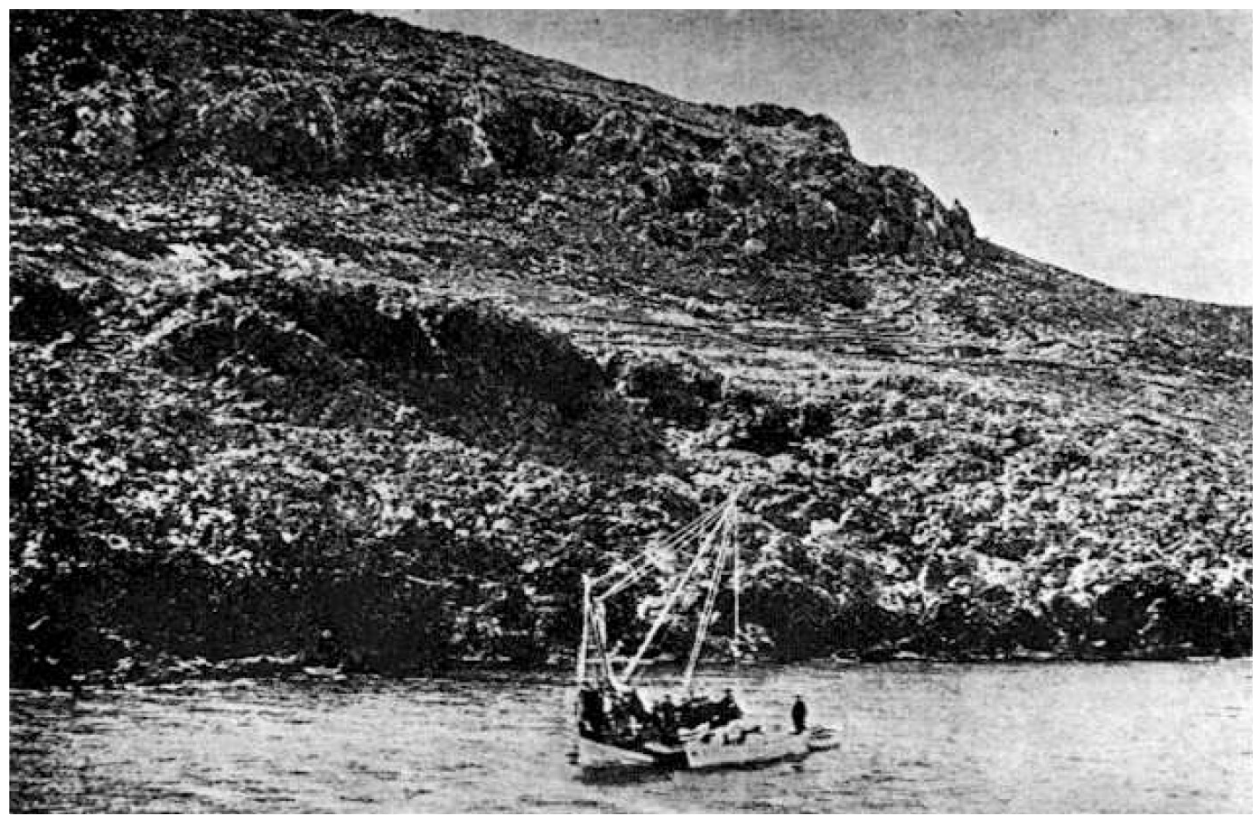


October 1900:

- **Group (sponge) divers,**
lead by *Elias Stadiatos*
- **Shipwreck 43m deep :**
50 m long, 30 tons
15-25 m off Cape Glyphadia

Until 1902:

- **Salvaging numerous artefacts ...**



- 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

Note: - In those days no scuba diving:

- 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



**the Antikythera
shipwreck**

Roman Shipwreck

Dating Ship nontrivial:

- bronze statues: 4th c. BC
- marble status: 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 !



the Antikythera Ship

Roman cargo ship (Olkas, ~ 50 x 15m)



*The Antikythera Shipwreck.
The Ship, the Treasures, the Mechanism*

National Archaeological Museum, Athens

A hull plank, bronze spikes and fragments of metal sheathing

1. Ψάγμα πλοίου από το ελαστικό ξύλο της ελιάς
220 π.Χ. (643)
Εργαστήριο Αρχαιολογίας ΒΕ 2013/11

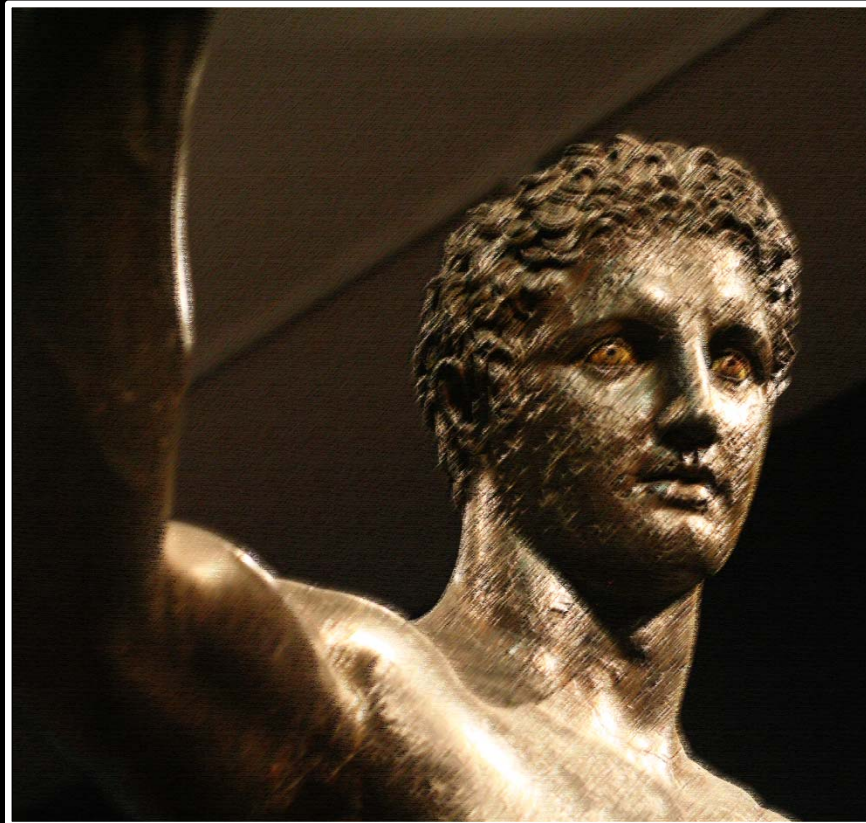
2. Τμήματα πολυθήλων σπείρων
Αποκόμματα των επιπέδων της ελαστικής επιφάνειας του κίτους
του πλοίου για τη στεγανοποίησή του κάτω από την τελική γραμμή.

3. Τάλασσα ξύλου
Τμήματα από την περιοχή του σπείρου,
σε σπείρες διαμέτρου 3 cm.



the Marbles

Ephebe of Antikythera



Coins & Jewelry



Pergamon. Silver cistophoric tetradrachme 85-76 BC.

precious and intricate golden jewelry

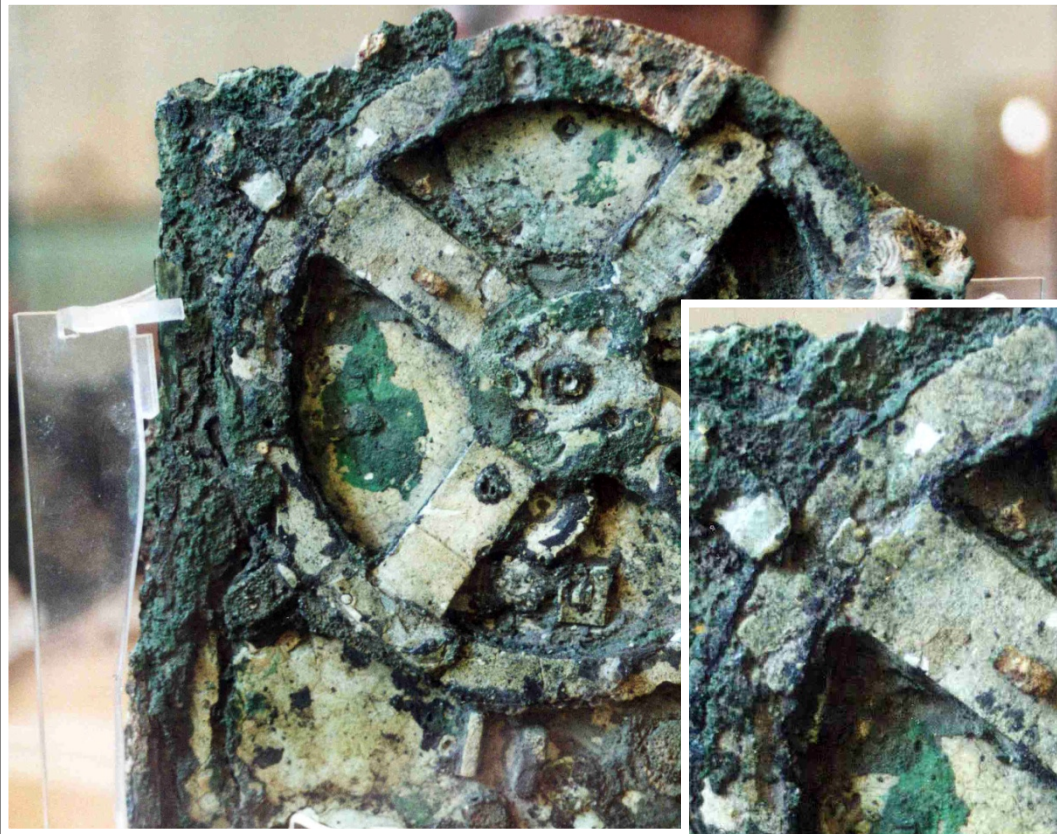




Interior

**Fragment A -
Central Processing Unit**

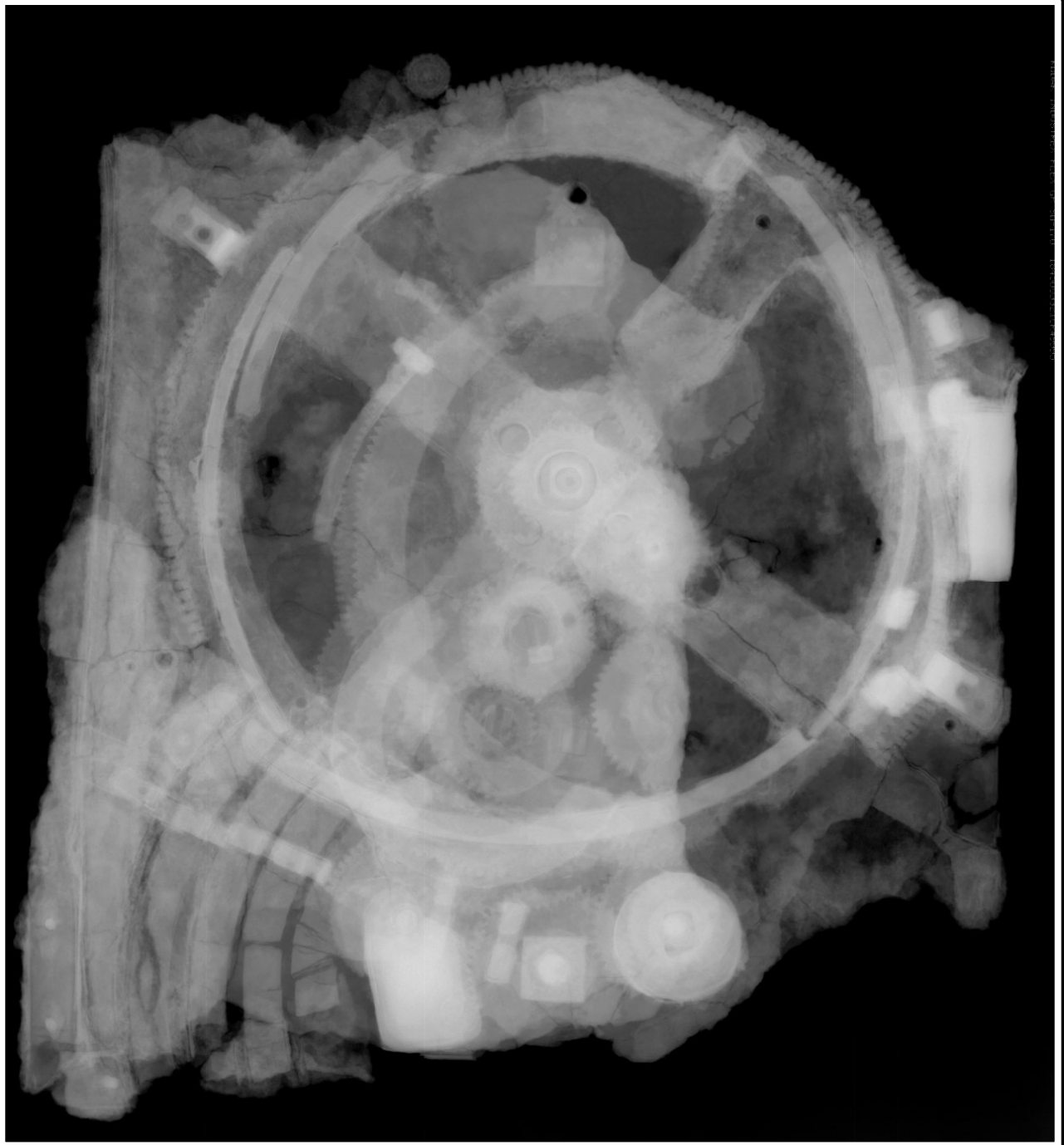
**Central
Mechanism**

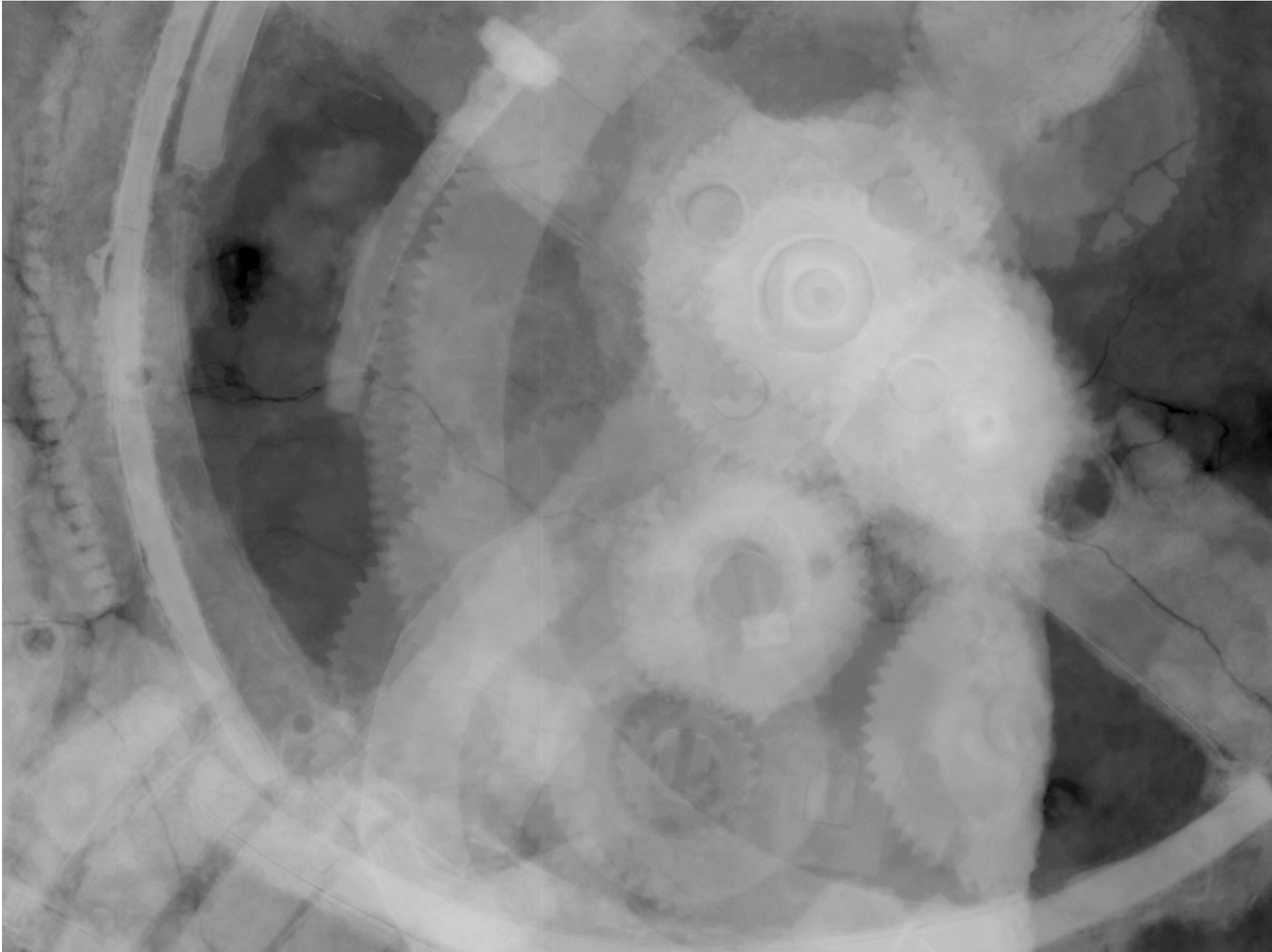


**Fragment A:
27 gearwheels !**

Interior

**AMRP
X-Tek X-ray
Tomography**







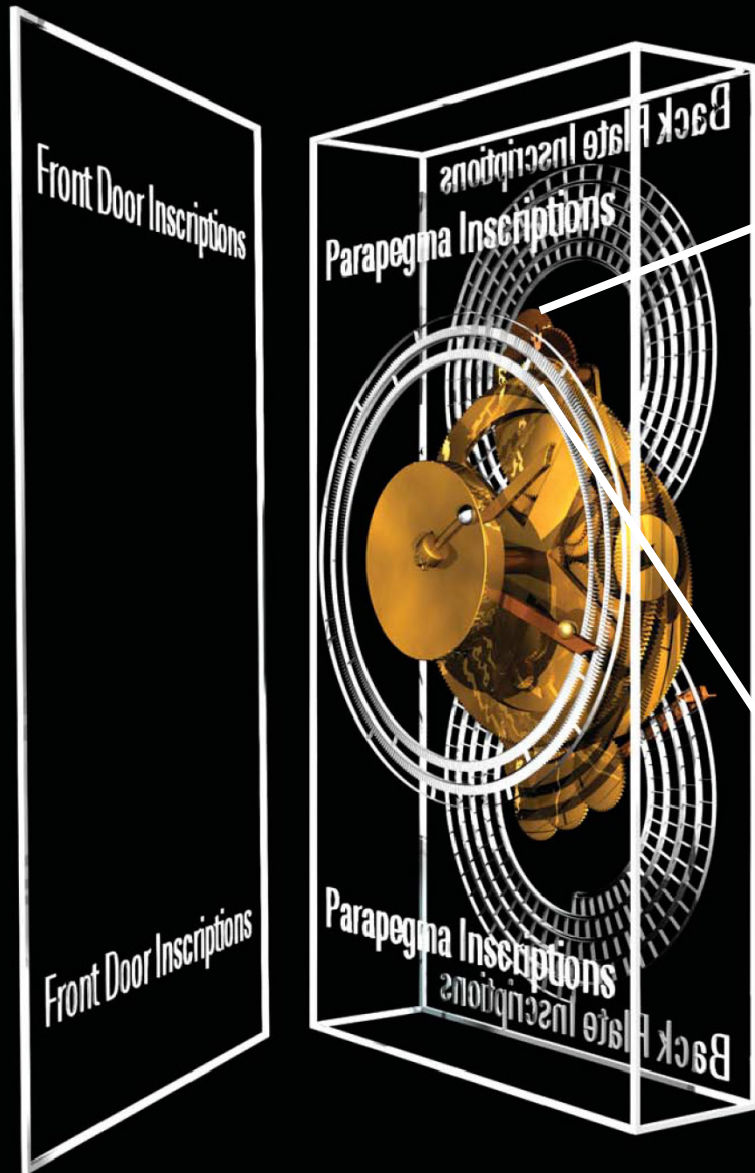
Fragment C:

Front Dial

Fragment C



Front Dial (part)



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),

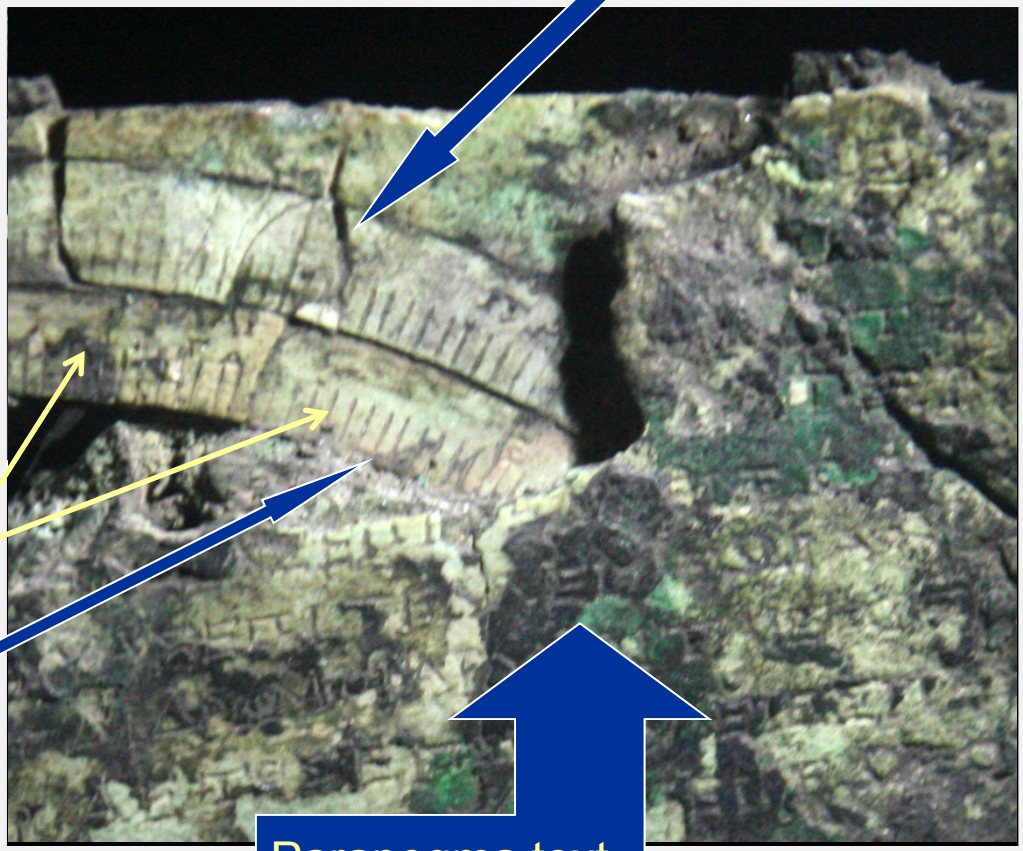
corresponding calendar of 365 days

adjustable for leap year



Front Dial (segment)

Egyptian Month
scale

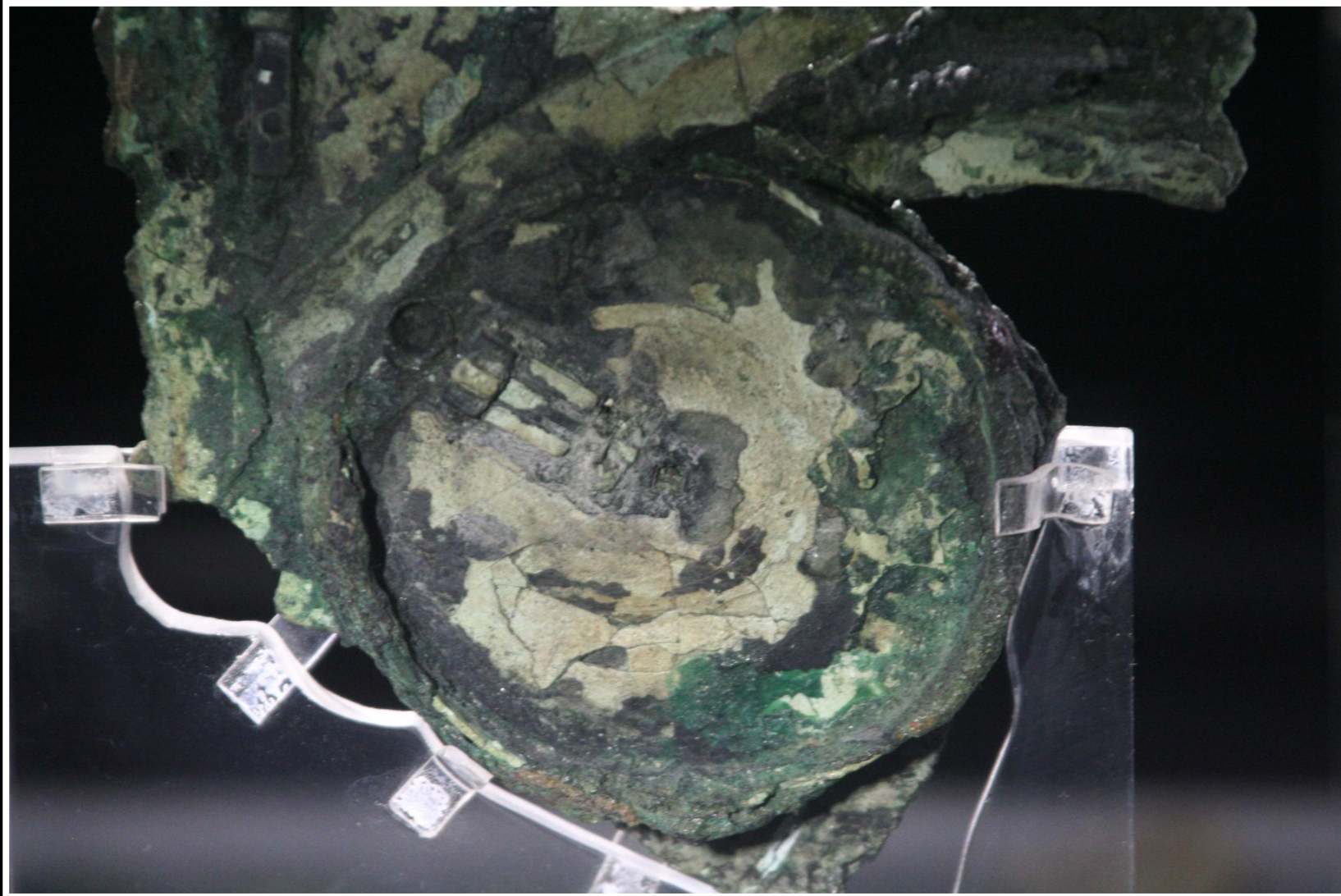


Parthenos (Virgo)
Xilai (Libra)

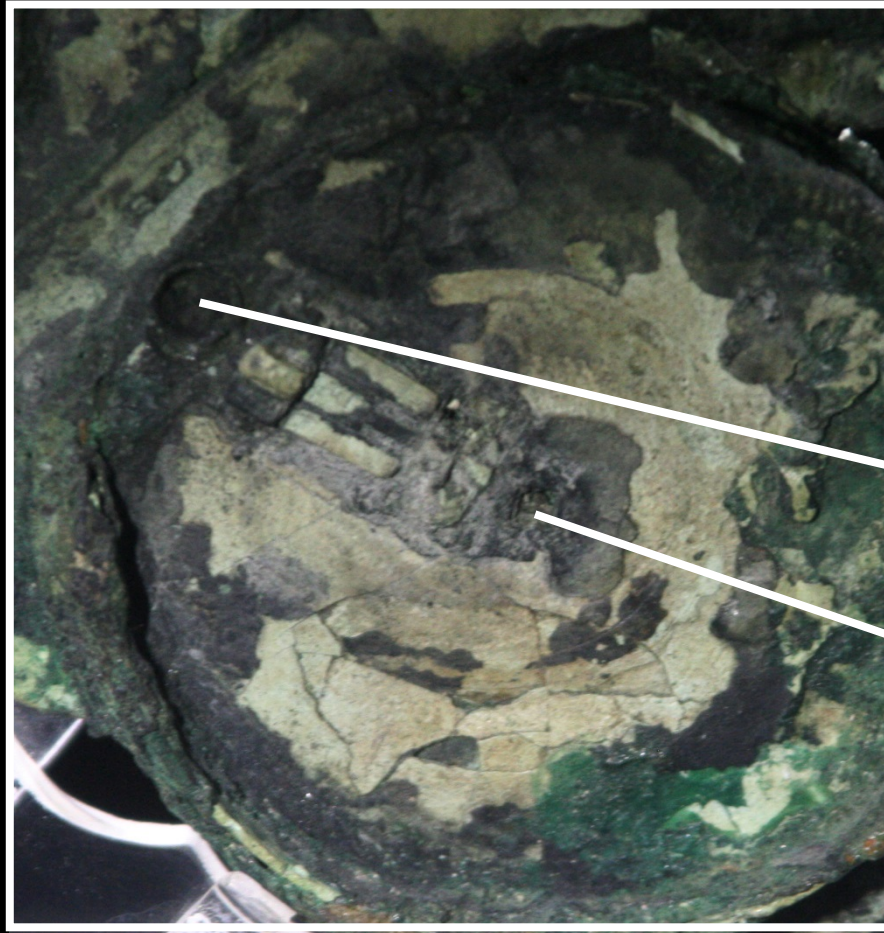
Zodiac scale

Parapegma text

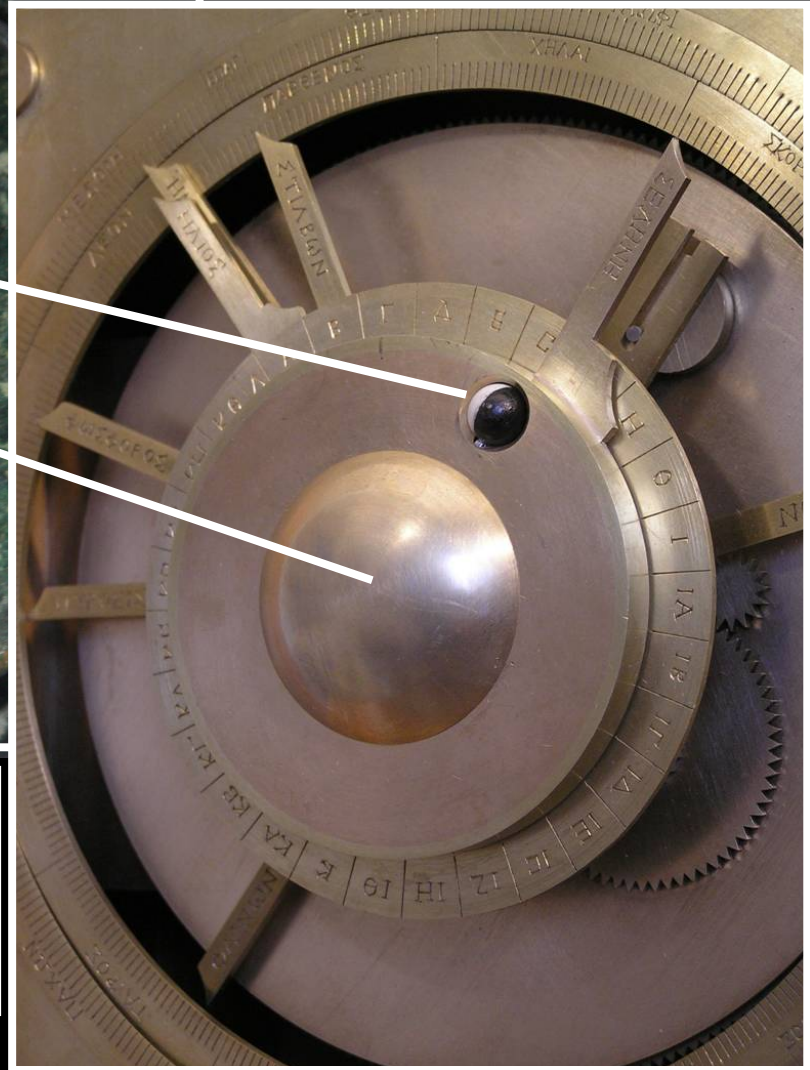
Fragment C, back



Silver Moon Sphere



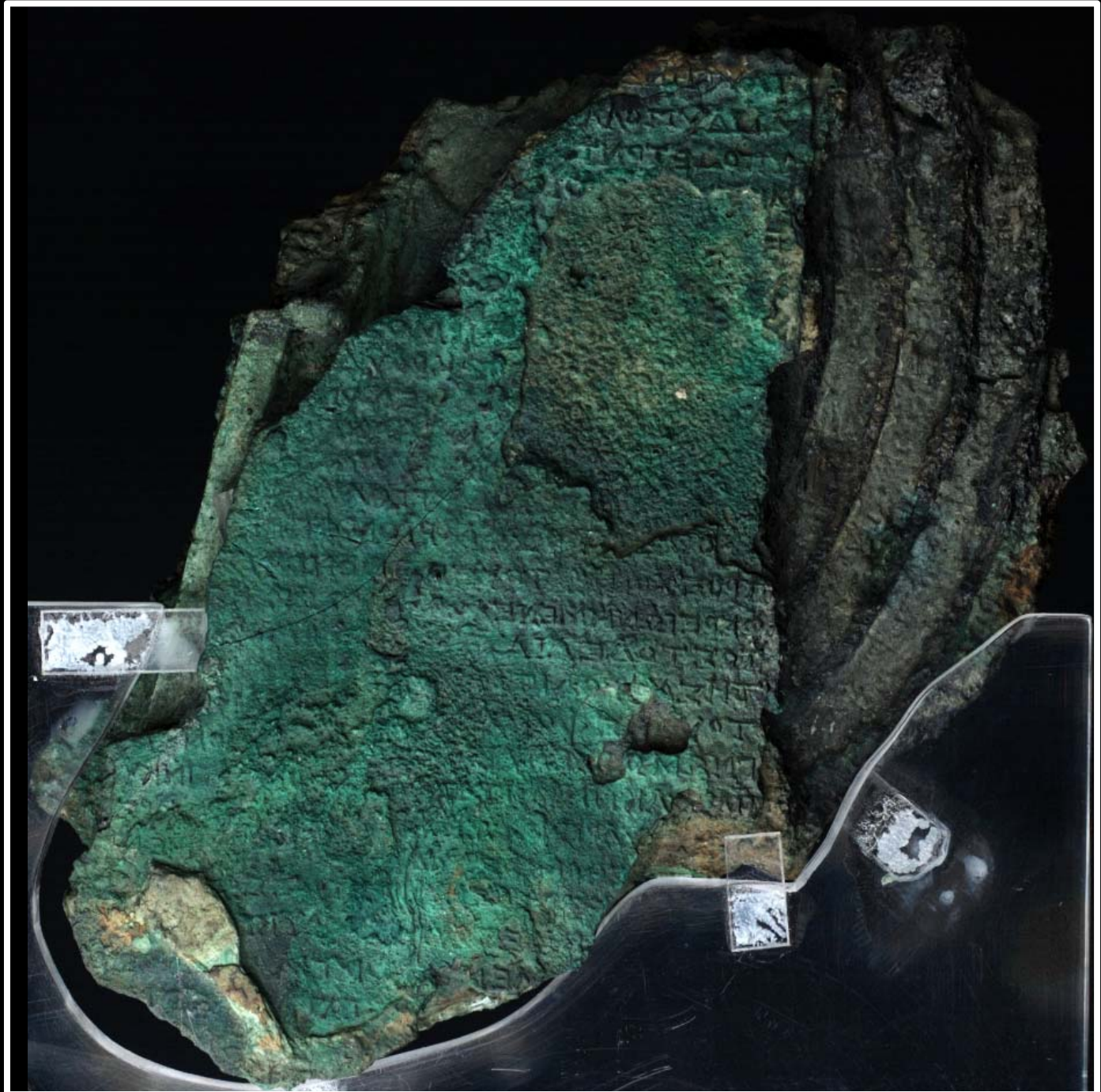
discovered by
M. Wright



The image features a dark, almost black background with a complex, organic texture. This texture is composed of numerous fine, interconnected lines and shapes in shades of green, blue, and yellow, resembling a microscopic view of a material or a highly detailed map. A prominent white rectangular box is centered horizontally and vertically, containing the word "Inscriptions" in a large, white, serif font. The box has a thin white border. The overall composition is abstract and visually striking due to the contrast between the dark, textured background and the clean, white text and box.

Fragment B:

Backdoor
Inscriptions



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

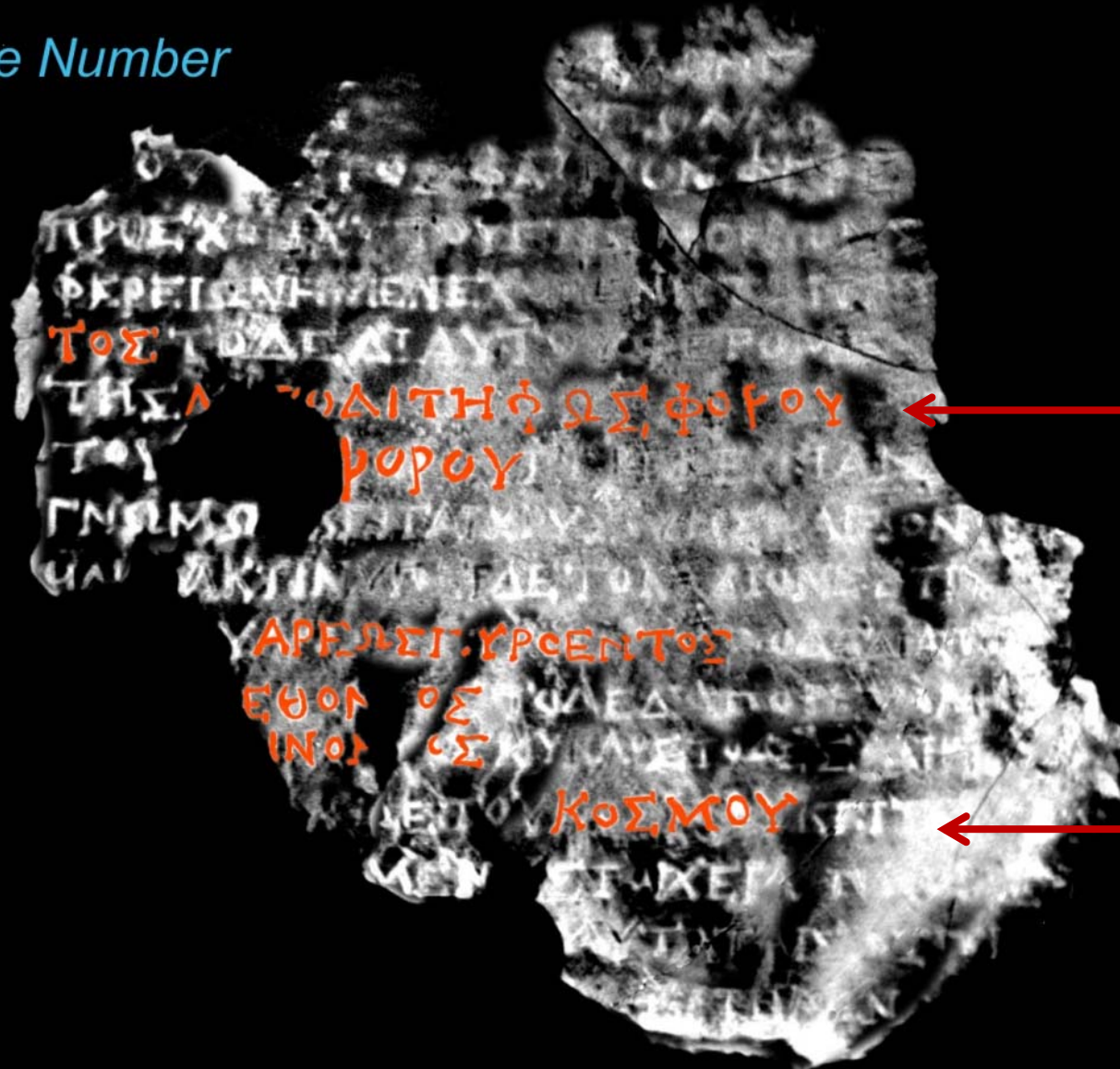
- Inscriptions as dating tool, ie. they identify the time of manufacture:
 - type lettering: 2nd half second century BC
 - used old name planet Venus: changed around 100 BC

Line Number

15

20

25



... Phosphorou ...
Venus !

... of the Cosmos ...

Technical Inscriptions:

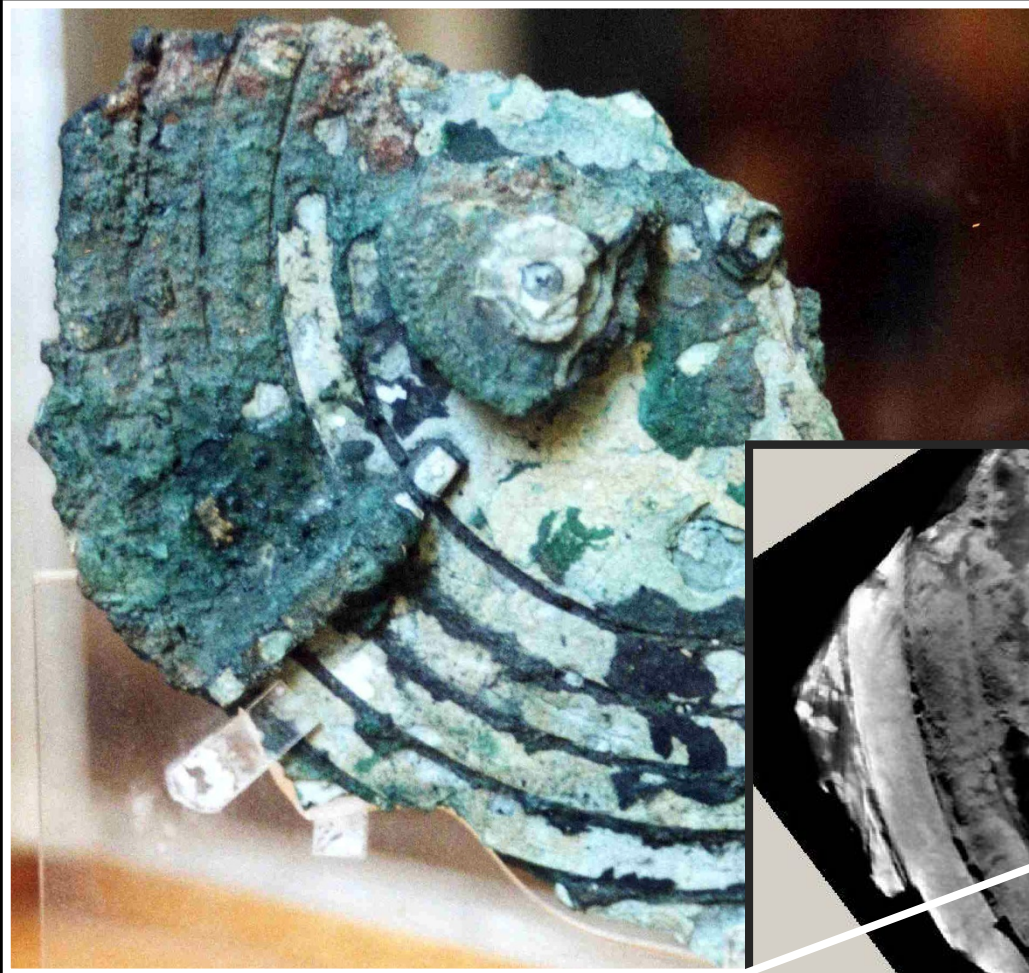
- “Tap”; “Gnomon”; “Perforations”; “Pointers”; “Gears”;
- “Spiral divided in 235 sections ...”
- “small golden ball”
- “small ball”

Astronomical Inscriptions:

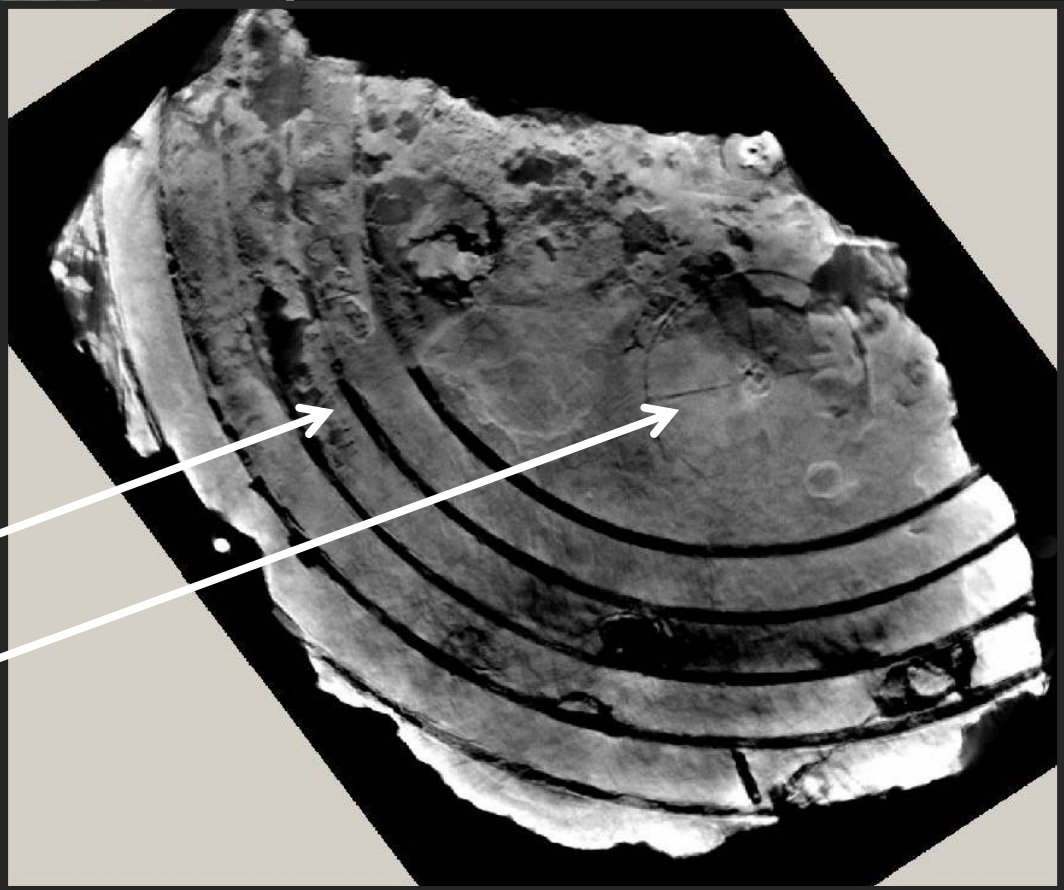
- “ΣΤΗΡΙΓΜΟΣ”: stationary point planets’ retrograde motion
- “Venus approaches the Sun”
- “The Hyades set in the evening”
- “Gemini begins to rise”, ...
- “ the 76 years, 19 years of the ...”



Back Dials



Fragment B
Back Dial (part)



Spiral Dial

Subsidiary Dial



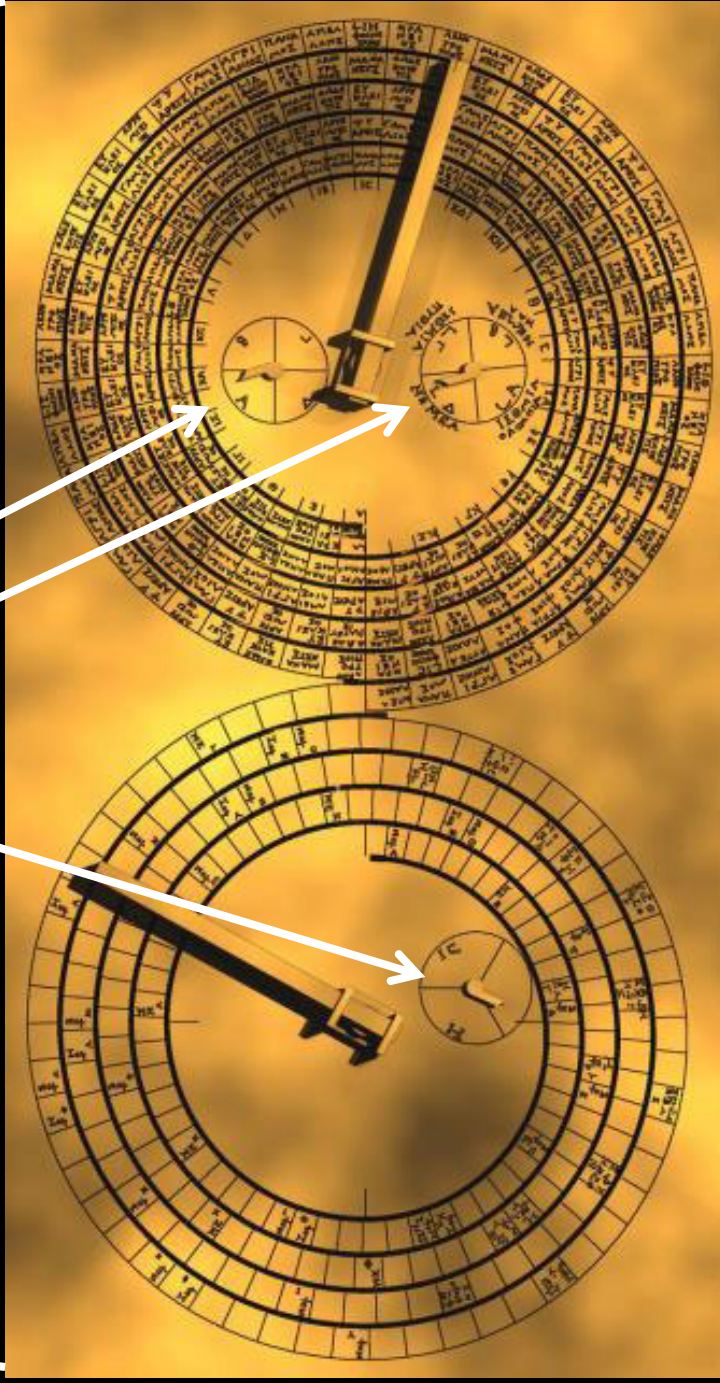
Metonic
Cycle Dial:
5 spiral
235 glyphs

Callipic Cycle
Subdial

Olympic Cycle
Subdial

Exeligmos Cycle
Subdial

Saros
Cycle Dial:
4 spiral
223 glyphs



Astronomical Cycles

- **Metonic Cycle**

multiple of Tropical Year and Synodic Month

19 tropical years;
235 synodic months
254 siderial 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)

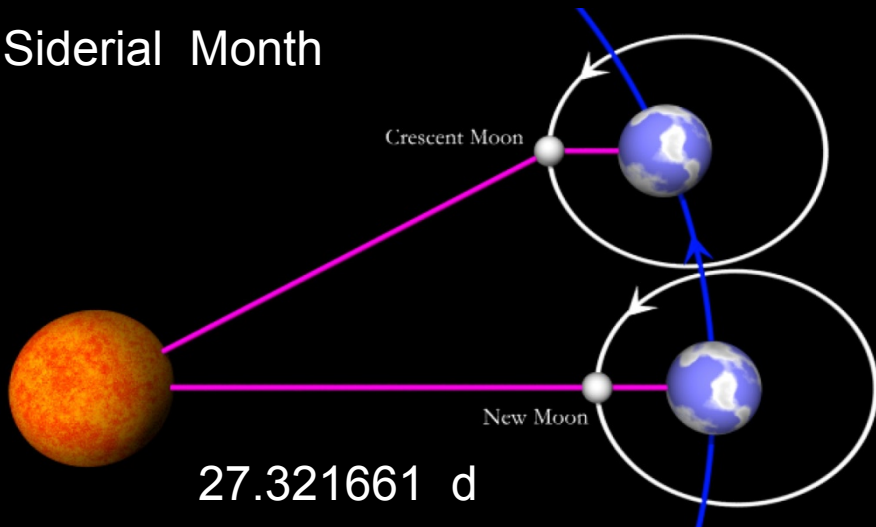
- **Exeligmos Cycle**

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

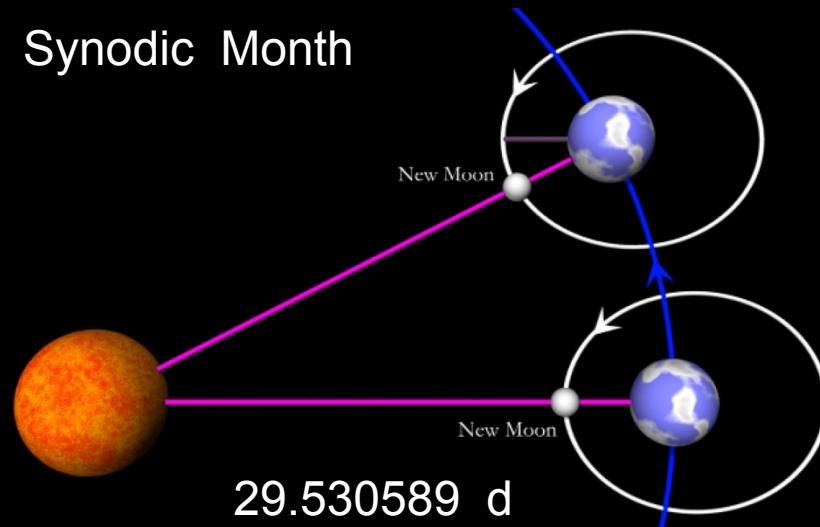
669 synodic;
726 draconic;
717 anomalistic:
54 yrs, 34 days (19756 days)

Months

Siderial Month



Synodic Month

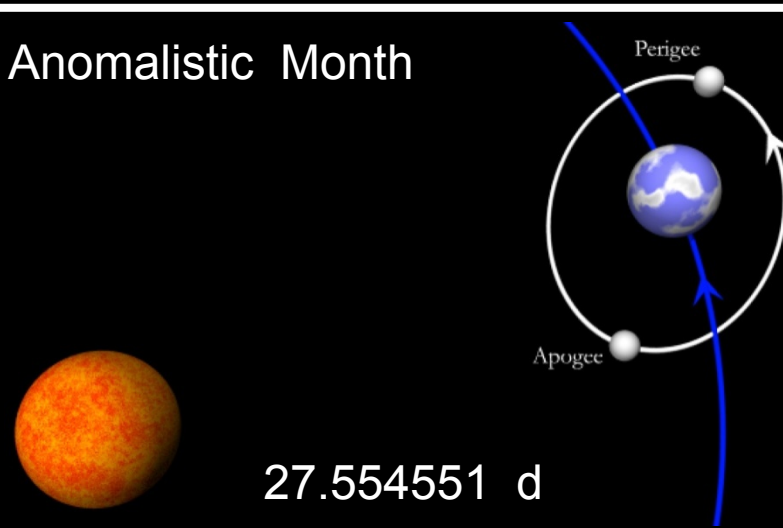


Draconic Month

27.212220 d



Anomalistic Month



Metonic Cycle Dial

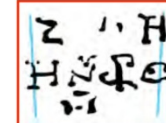
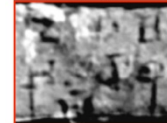


125 A-3.2



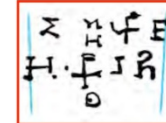
Σ H^M ω^P H
H ω^P Γ
Z

131 F-3.1



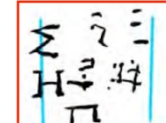
Σ B
H N/Y ω^P Θ
H

137 F-3.7



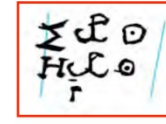
Σ H^M ω^P E
H ω^P IB
Θ

172 E-4.2



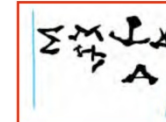
Σ
H ω^P
Π

178 A-4.2



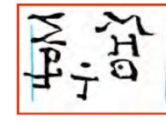
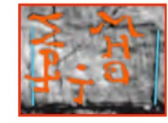
Σ ω^P Θ
H ω^P Θ
P

184 A-4.8



Σ H^M ω^P Δ
H A
Σ

190 F-4.5



Σ H^M
ω^P Θ
T

Saros Dial




Saros Dial



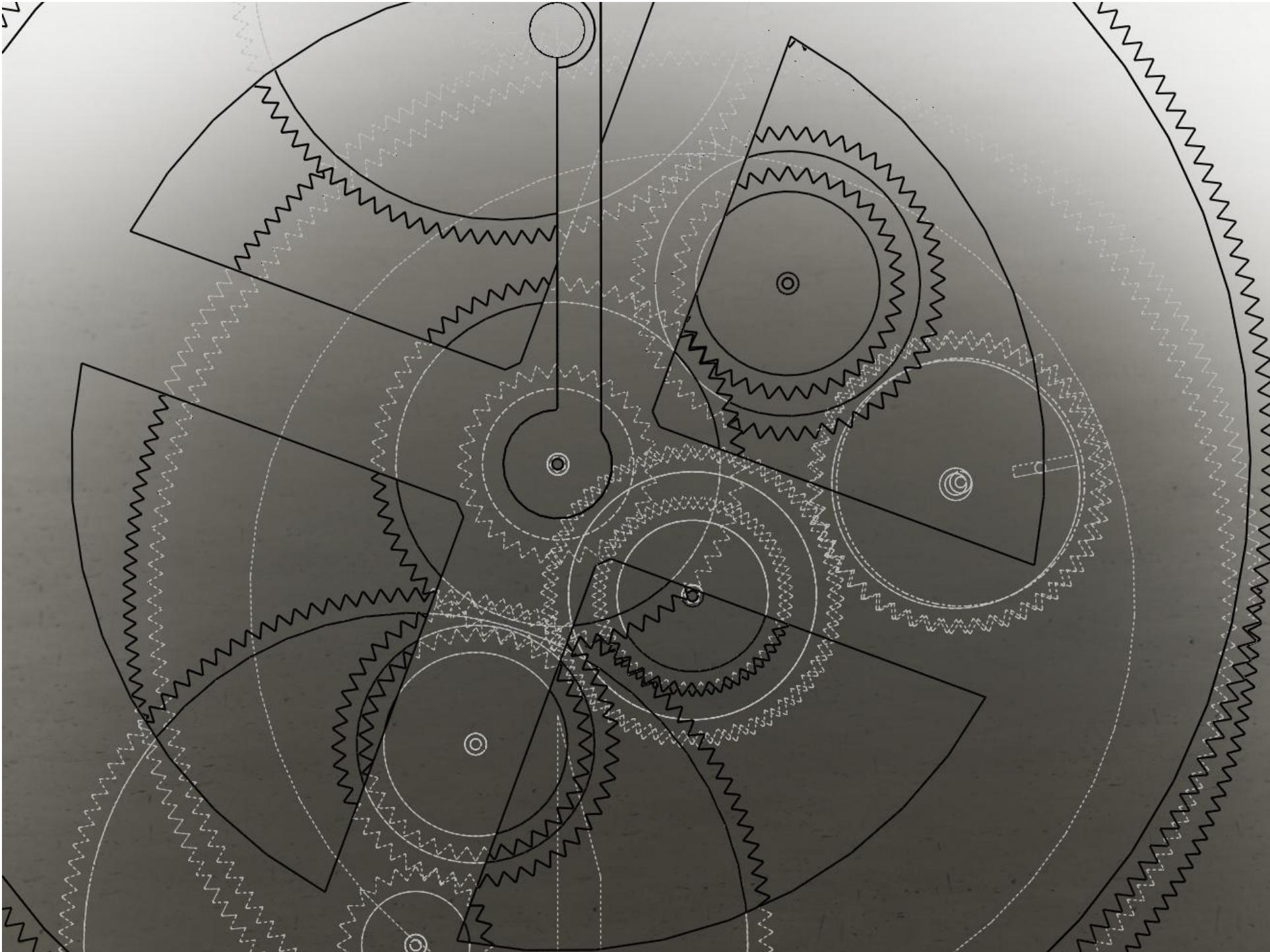
Saros Dial

glyph

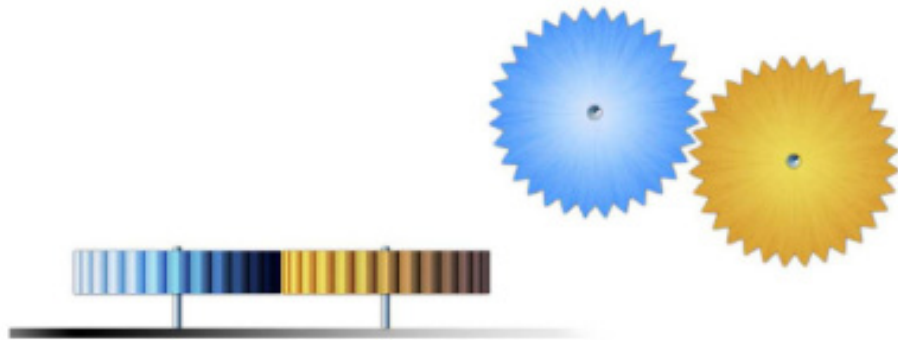


The background of the slide is a detailed, multi-colored reconstruction of the Antikythera mechanism. The device is shown as a complex assembly of interlocking gears, levers, and plates, rendered in shades of green, blue, yellow, and red against a dark, textured background. The reconstruction highlights the intricate mechanical design of this ancient Greek analog computer.

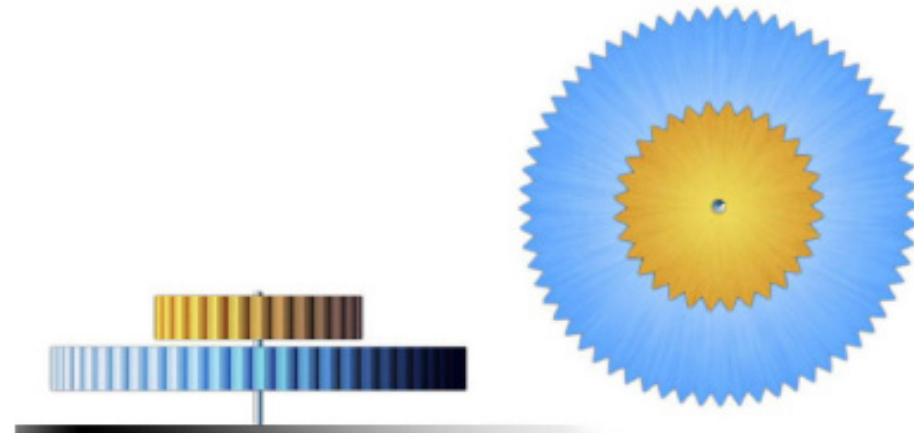
Antikythera Mechanism: Gear Train Reconstruction



Gear Transmissions



Division

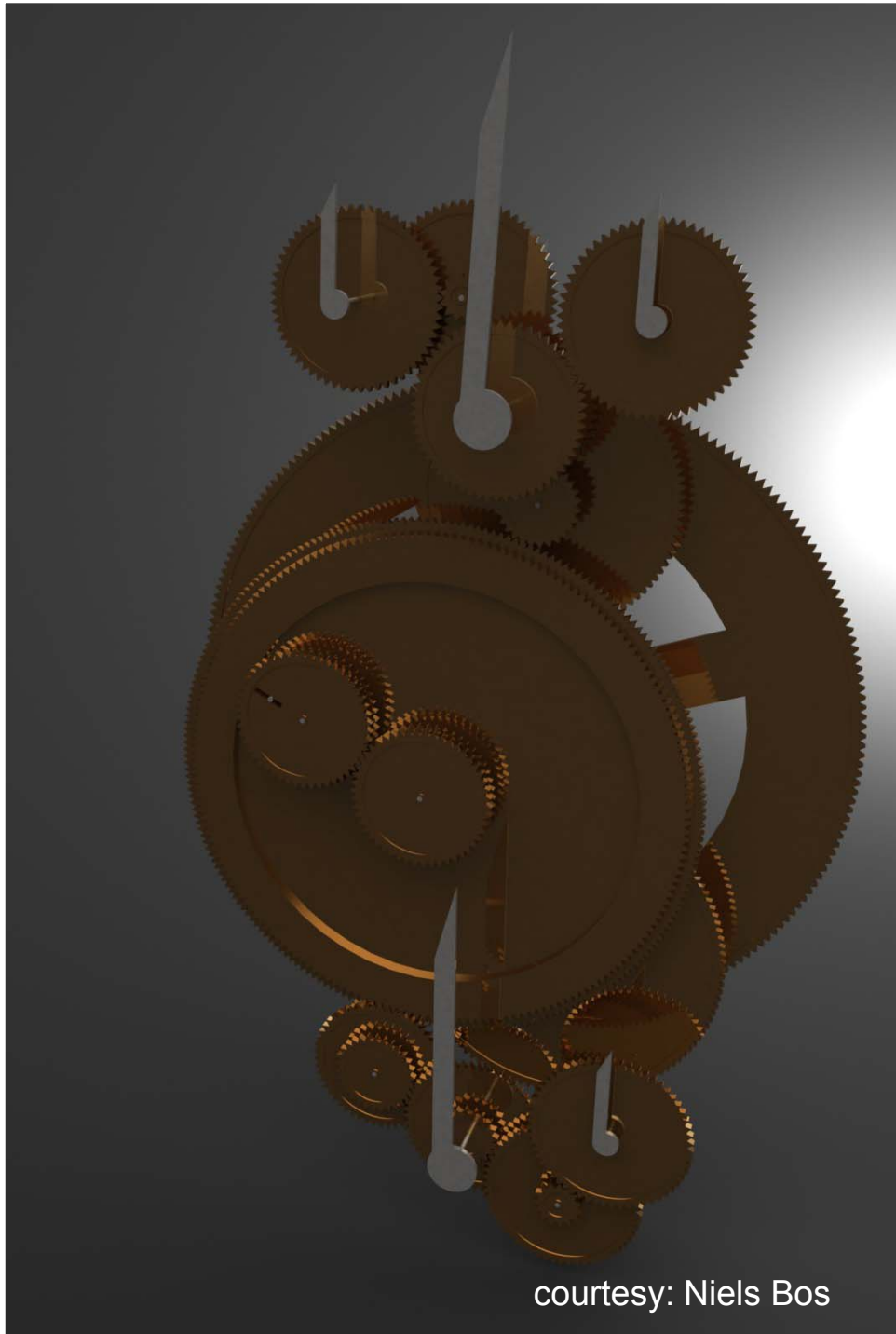


Multiplication

Example:

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

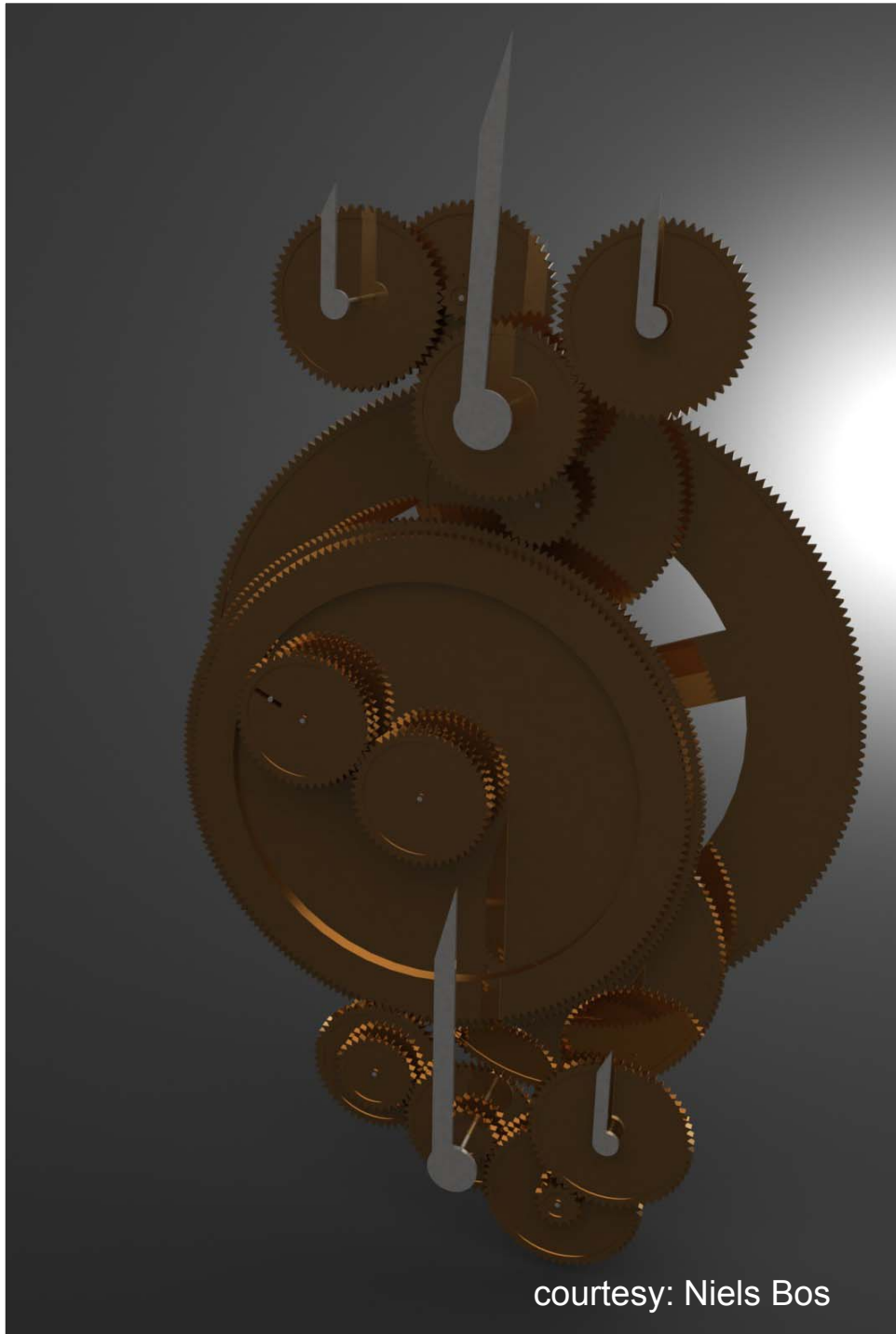
$$f = \frac{r_1}{r_2} \times \frac{s_1}{s_2} \times \frac{t_1}{t_2}$$



courtesy: Niels Bos

Gear Train

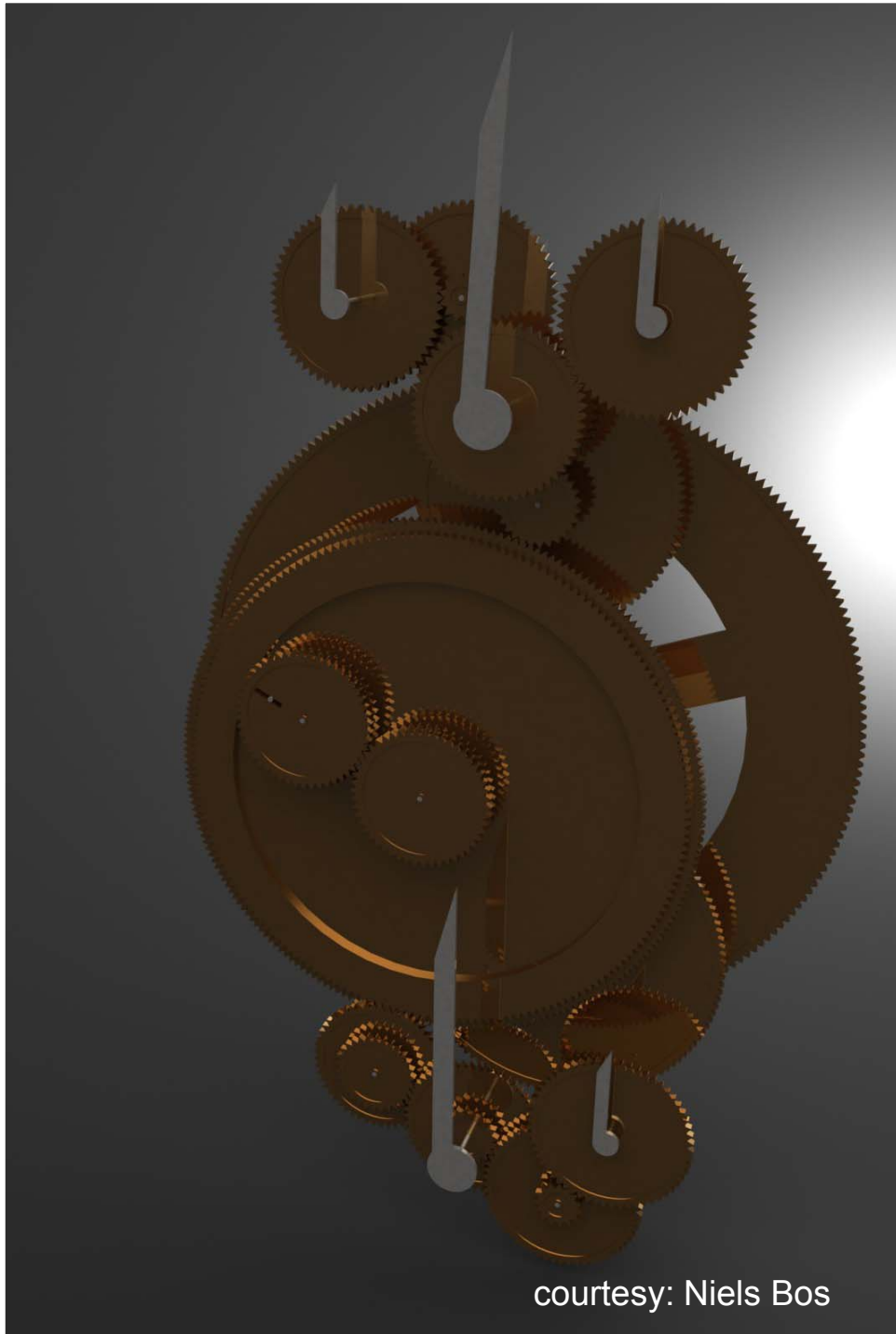
gear	#teeth	
b	64	
l1	38	
l2	53	$l \quad -\frac{64}{38} = -\frac{32}{19}$
m1	96	
m2	15	
n1	53	



courtesy: Niels Bos

Gear Train

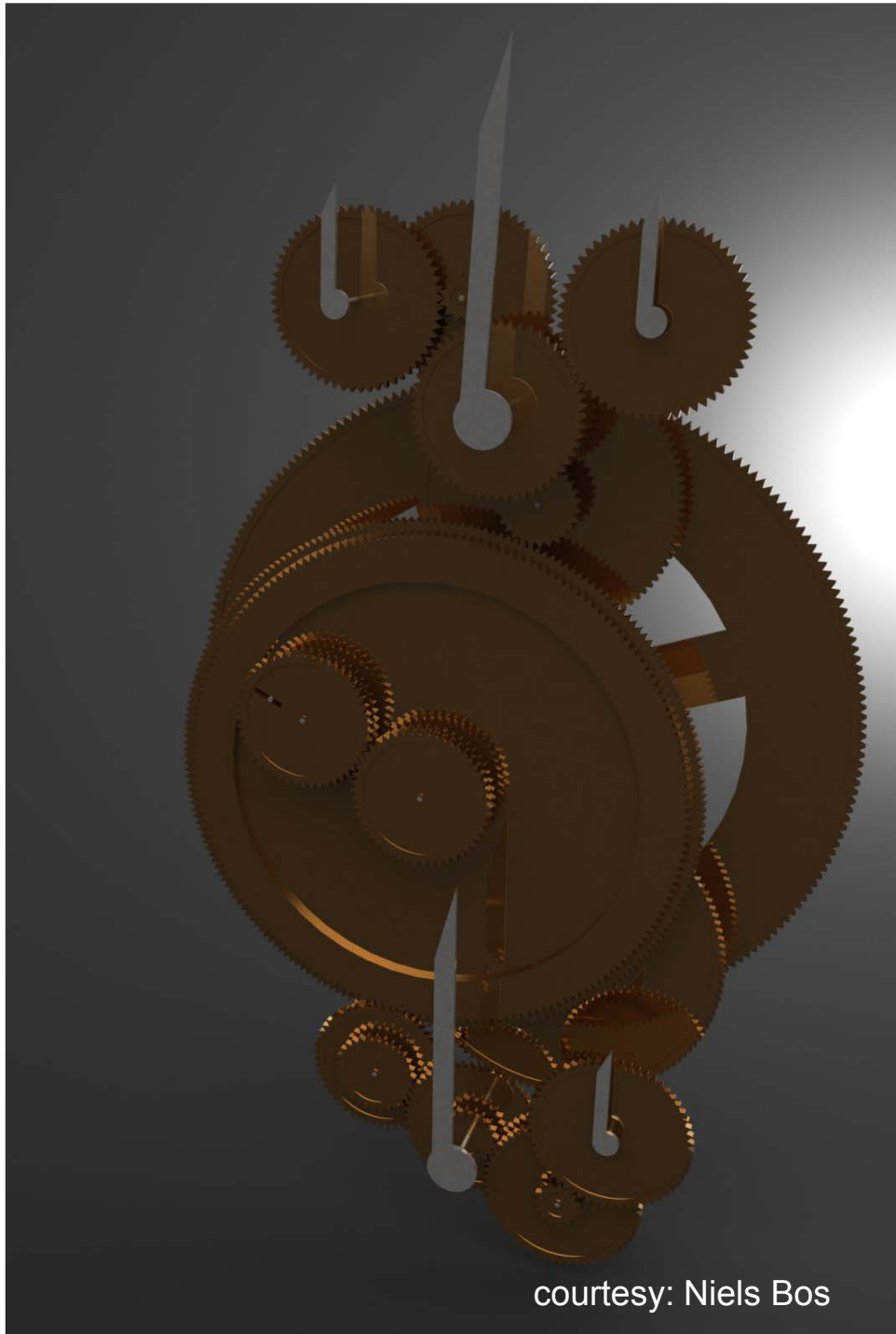
gear	#teeth	
b	64	
l1	38	
l2	53	$l \quad -\frac{64}{38} = -\frac{32}{19}$
m1	96	
m2	15	$m \quad -\frac{32}{19} \times -\frac{53}{96} = \frac{53}{3 \times 19}$
n1	53	



courtesy: Niels Bos

Gear Train

gear	#teeth	
b	64	
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m1	96	
m2	15	$m \quad -\frac{32}{19} \times -\frac{53}{96} = \frac{53}{3 \times 19}$
n1	53	$n \quad \frac{53}{3 \times 19} \times -\frac{15}{53} = -\frac{5}{19}$



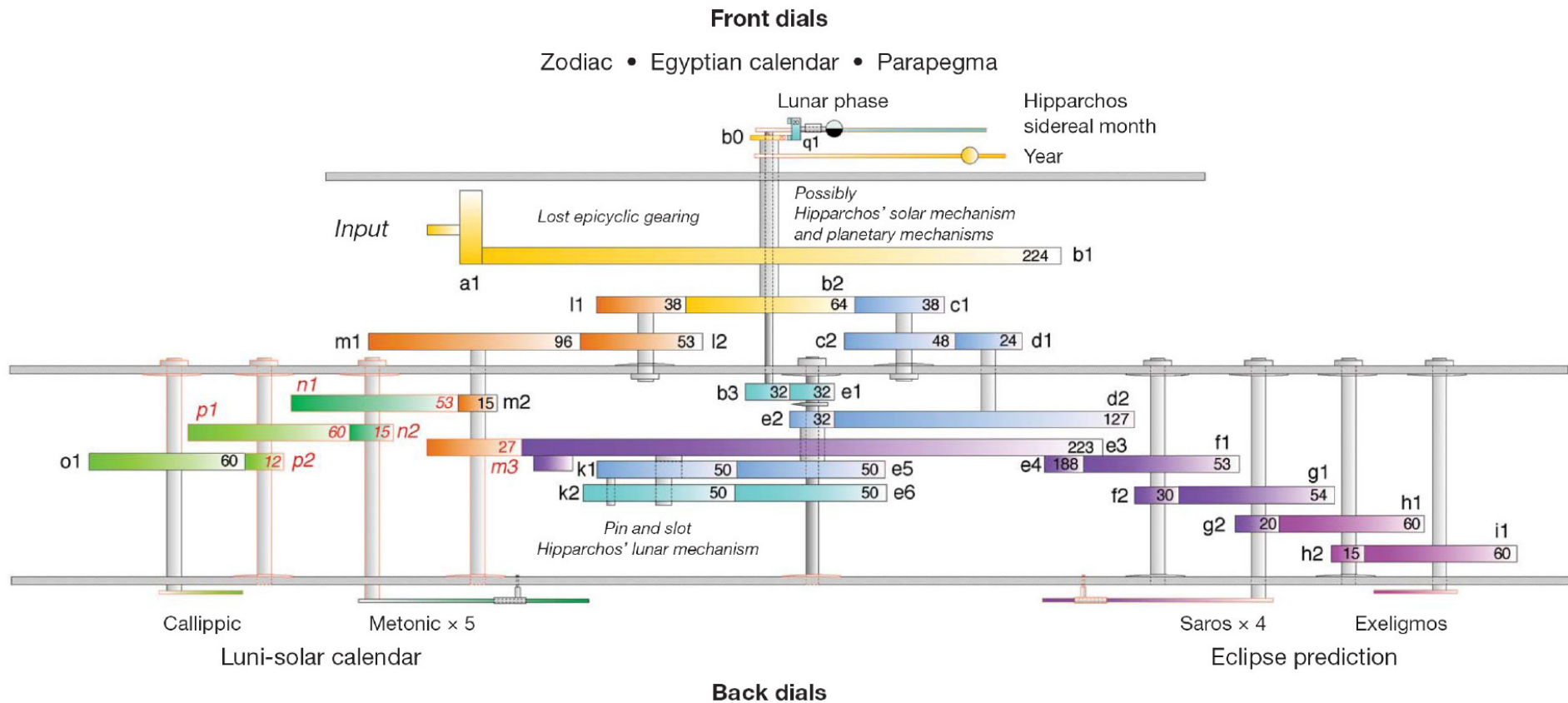
courtesy: Niels Bos

Gear Train

gear	#teeth	
b	64	
l1	38	
l2	53	$l \quad -\frac{64}{38} = -\frac{32}{19}$
m1	96	
m2	15	$m \quad -\frac{32}{19} \times -\frac{53}{96} = \frac{53}{3 \times 19}$
n1	53	$n \quad \frac{53}{3 \times 19} \times -\frac{15}{53} = -\frac{5}{19}$

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

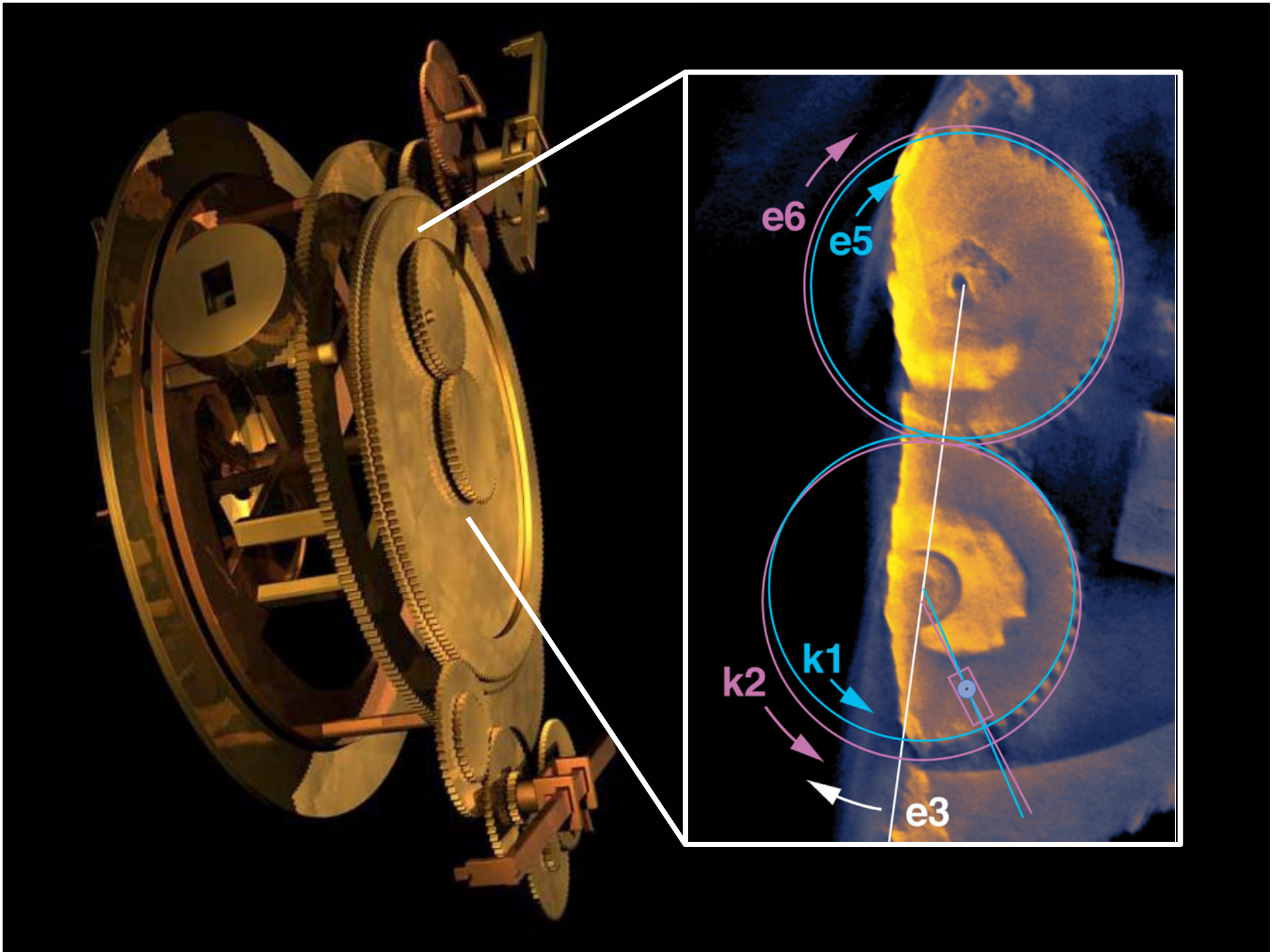
AMRP Gear Train

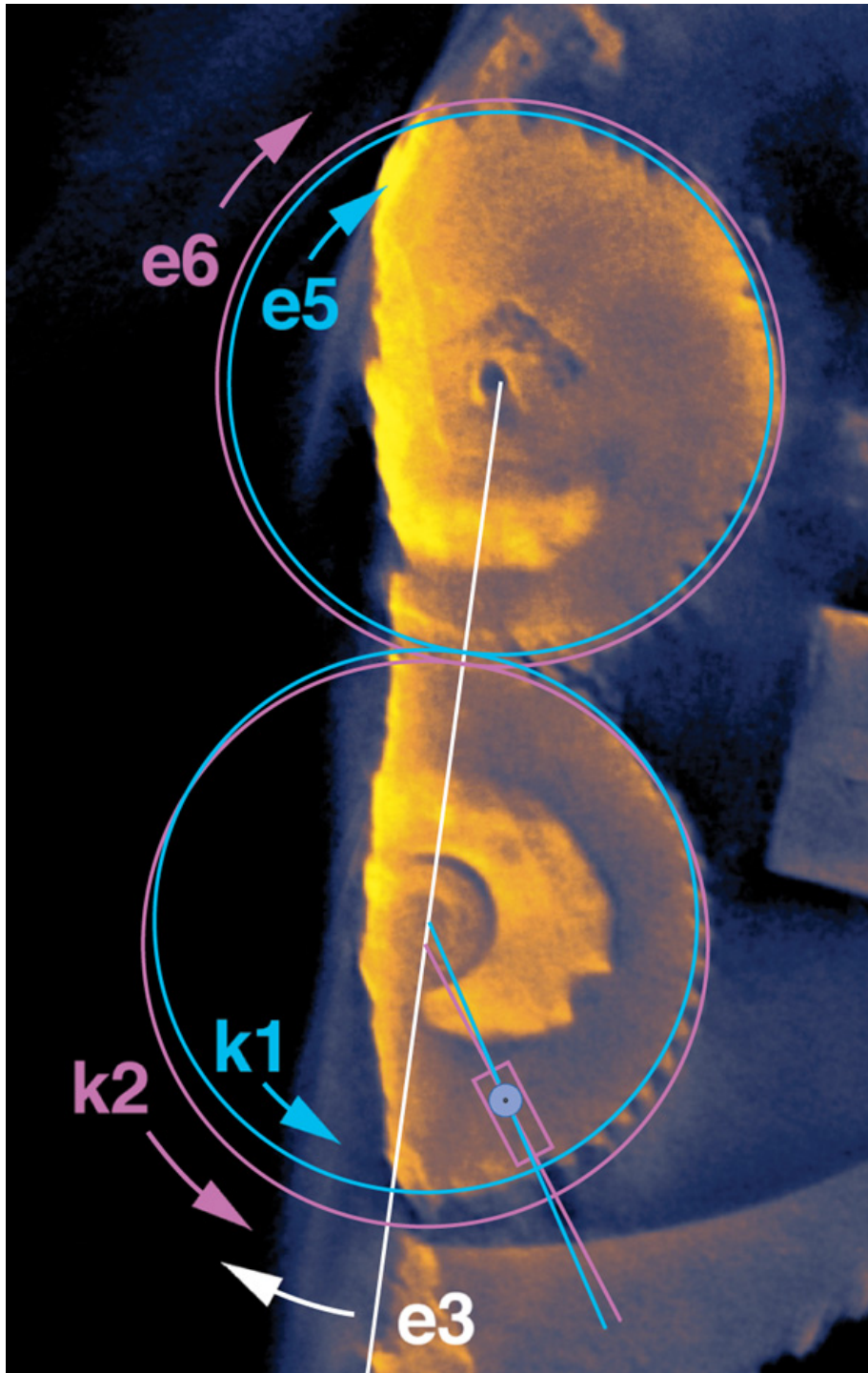




Hipparchus'

Spirograph ?





Pin-and-Slot Mechanism

Hipparchus'
Lunar Mechanism

Epicycle 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

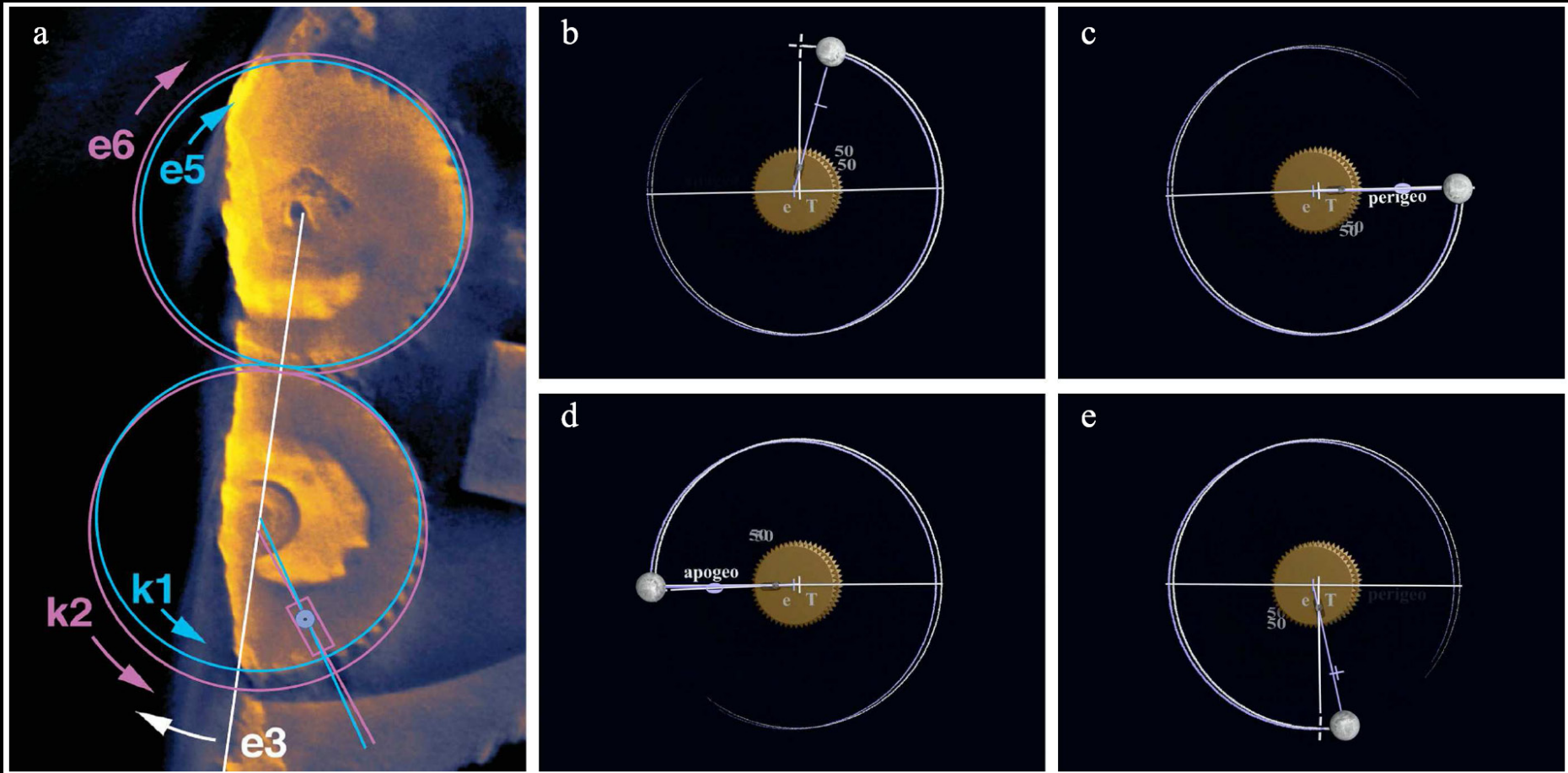
Date: 2005 Sep 1 02:23:28 UT

Moon Libration

We can see more than $\frac{1}{2}$ of
Moon surface, due to its
elliptical orbit



Hipparchus' Pin-Slot Gears





the Antikythera Planetarium ?

**PhD project Niels Bos
Kapteyn Astron. Institute - Dept. Ancient History, RUG**

Planetarium ? - Indications

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

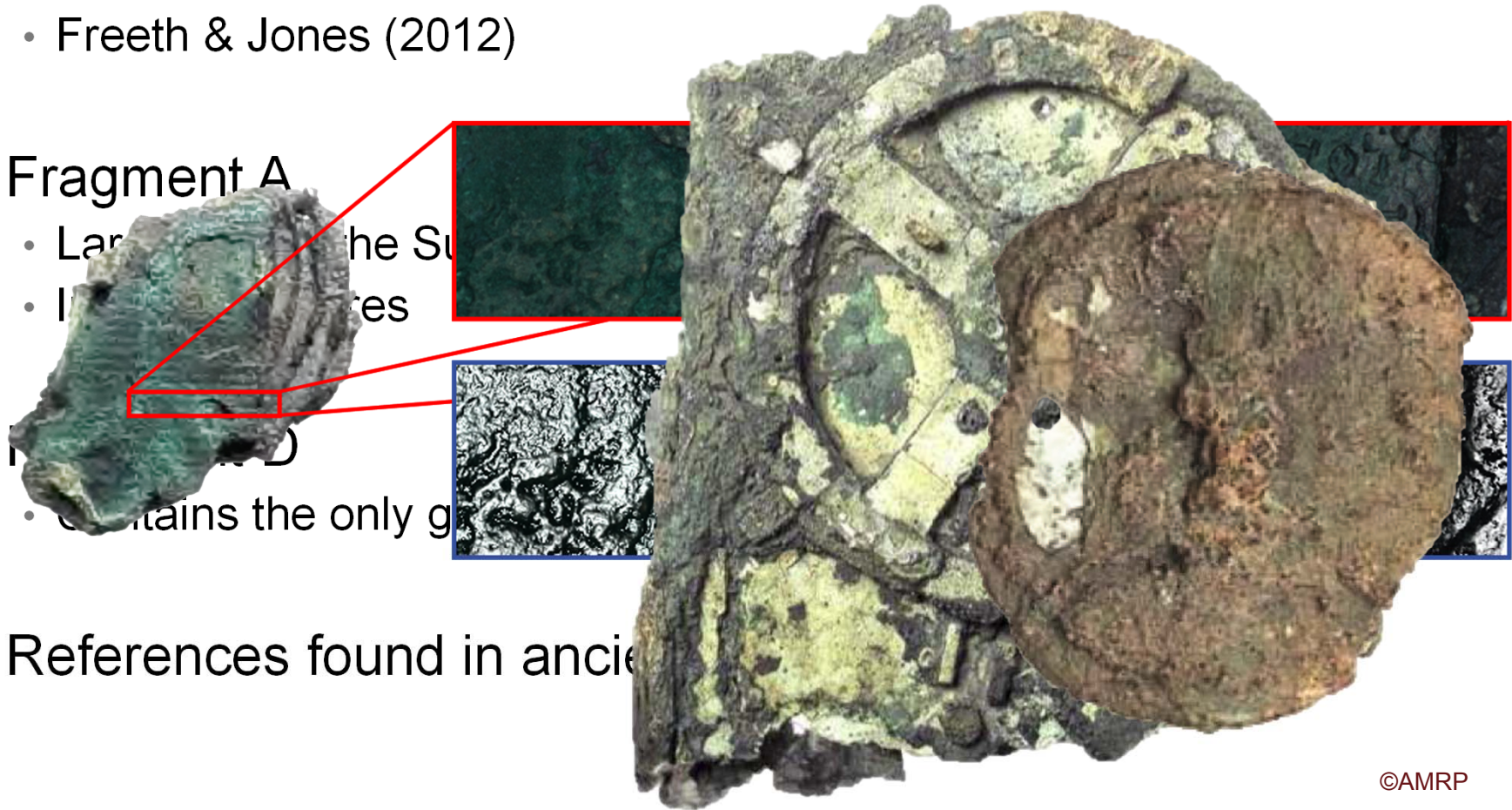
- Fragment A

- Largest of the surviving fragments
 - Contains the only g

- 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

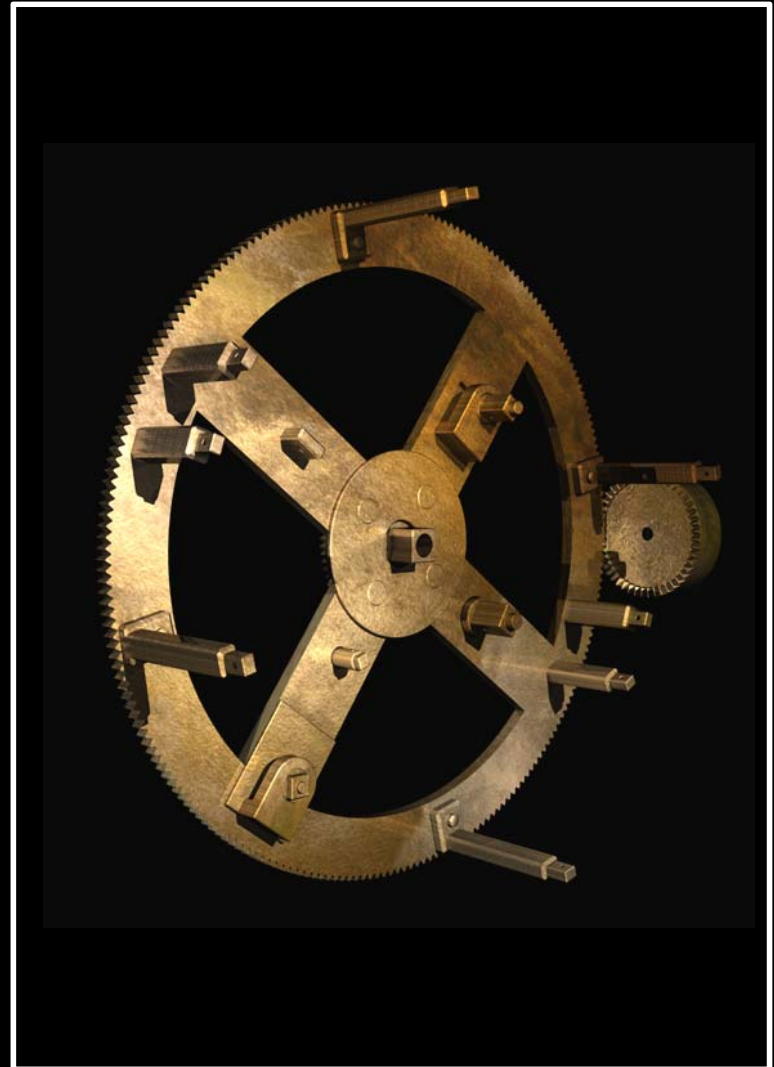
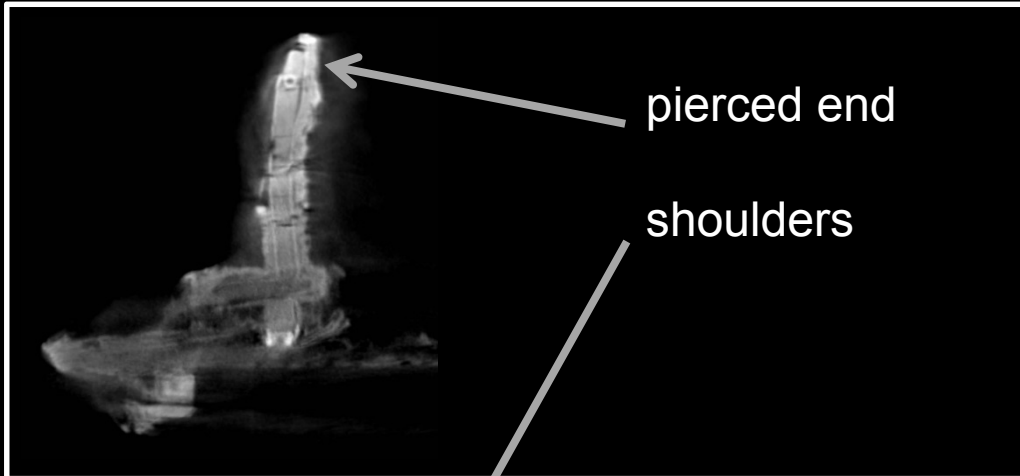
evidence of

pillars, bearing and
other fittings on the

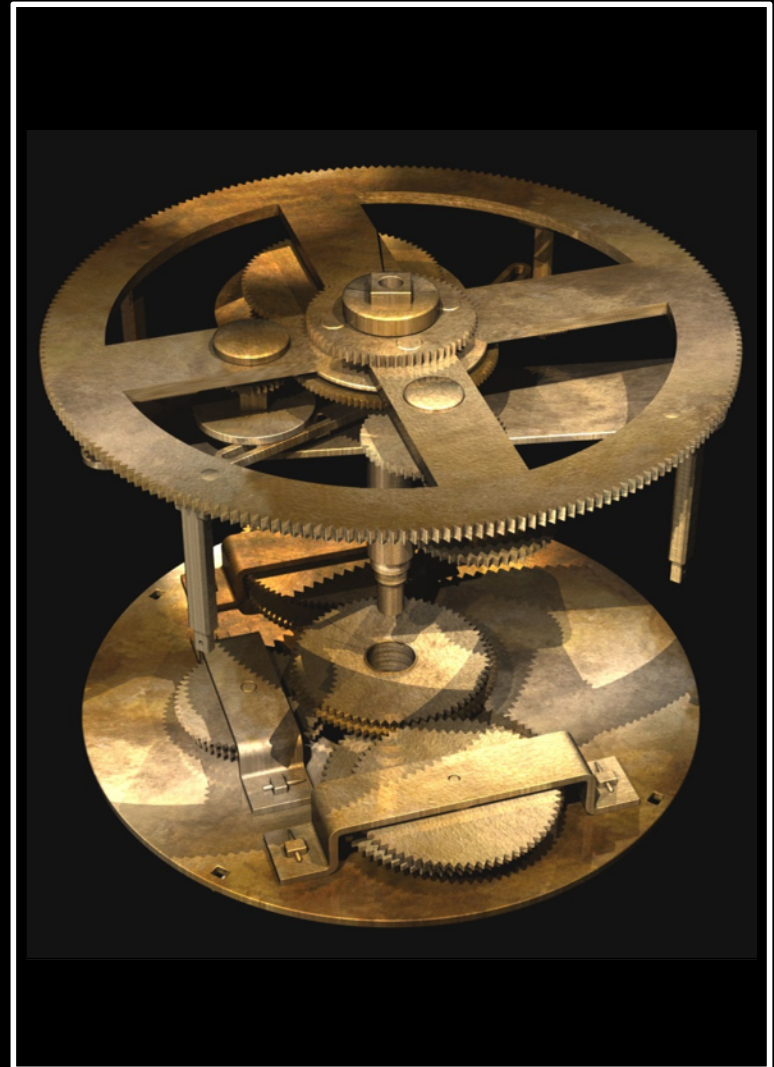
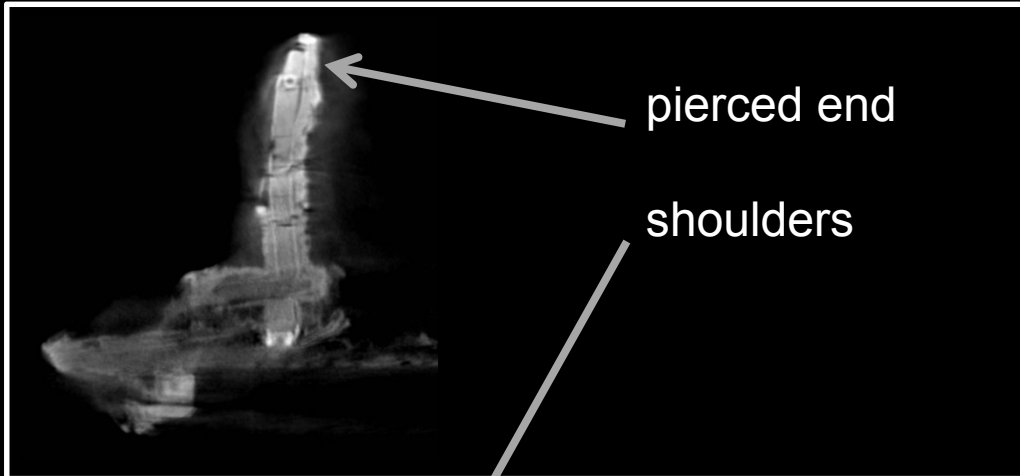
Main Drive Wheel



Mechanical Elements



Mechanical Elements

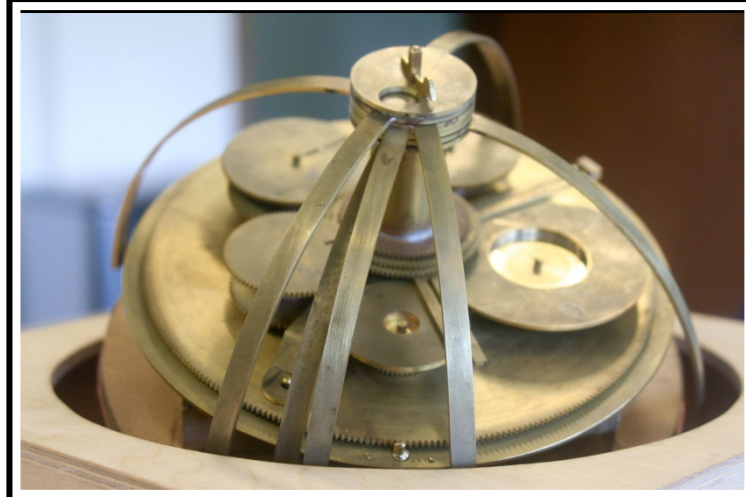




M. Wright

copper hardware models of

- Antikythera planetarium
- Archimedes Sphaera



M. Wright

copper hardware model Antikythera planetarium
components



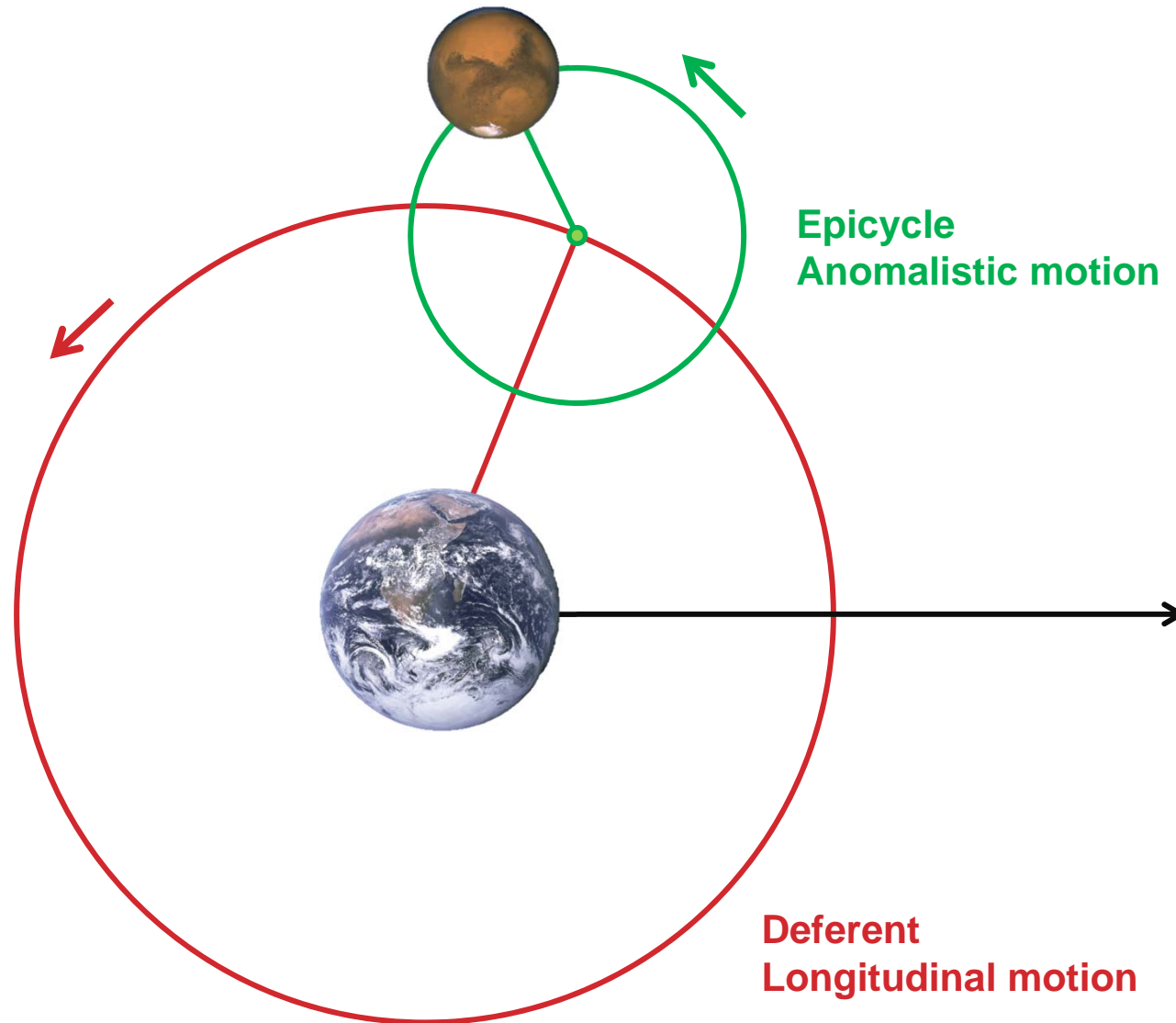


M. Wright

Science Museum London

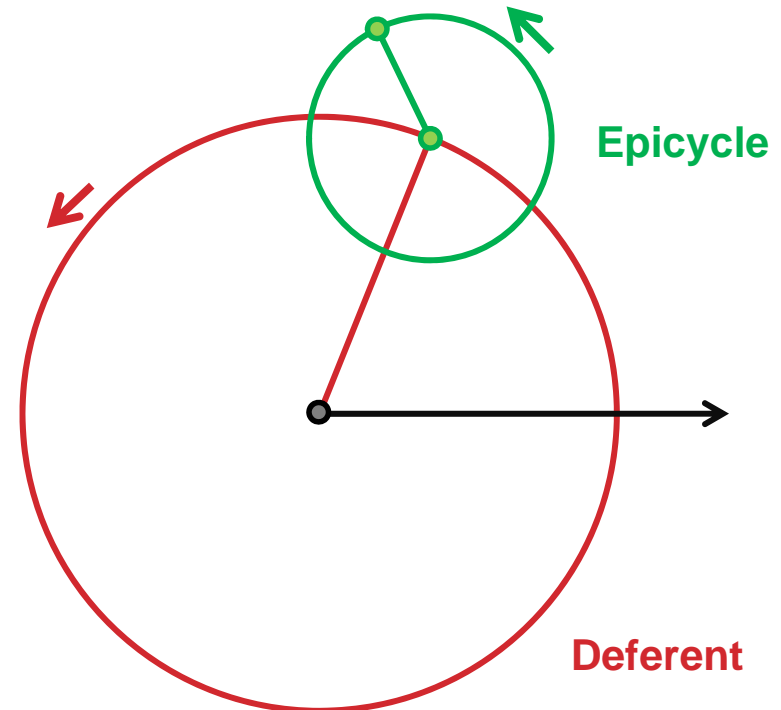


Geometric (Epicyle) planetary models



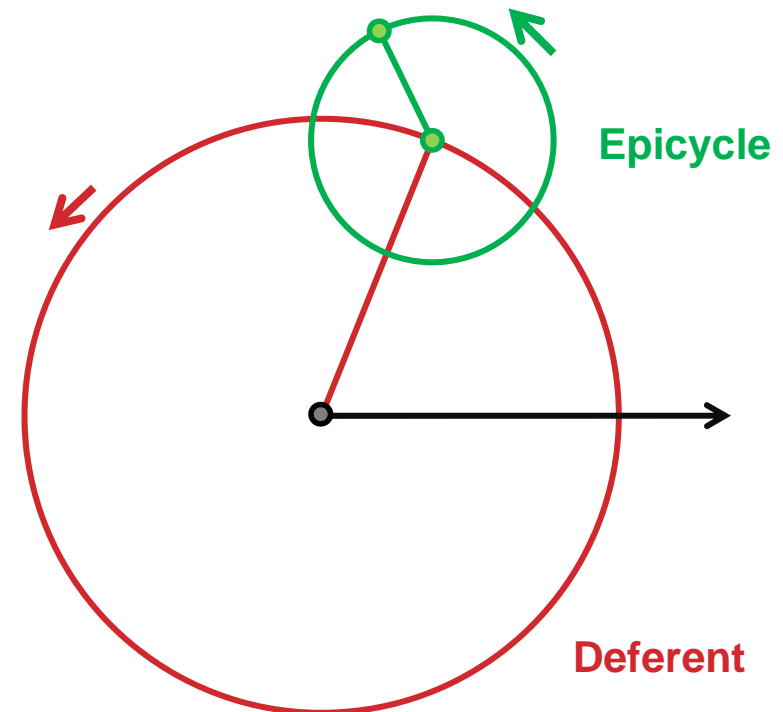
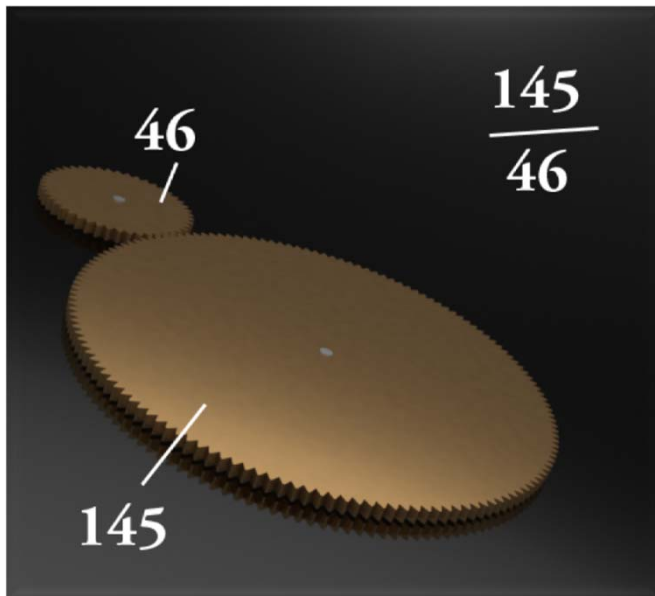
Periods to Gears

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



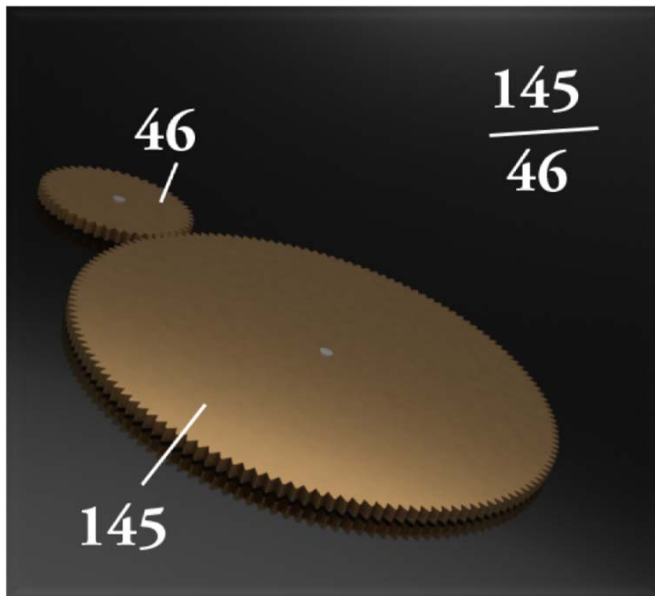
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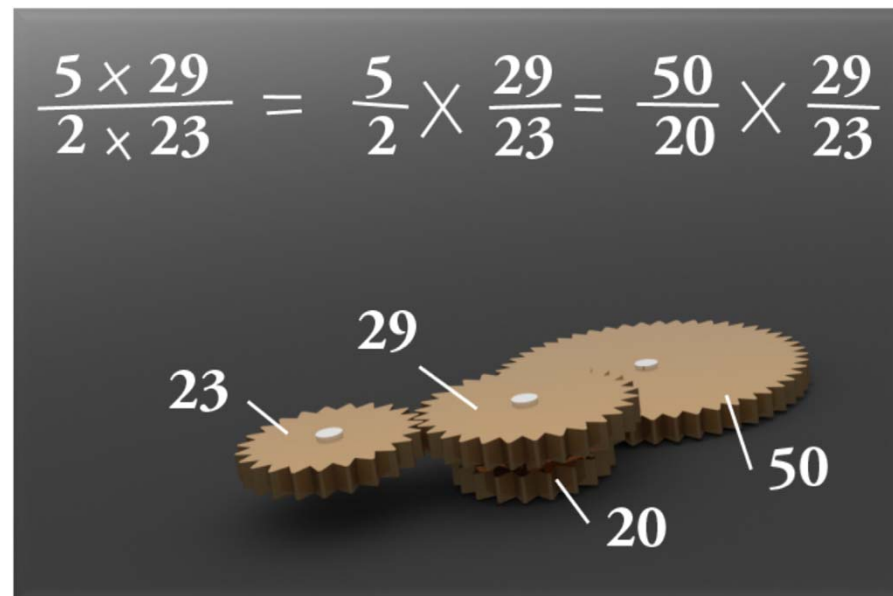
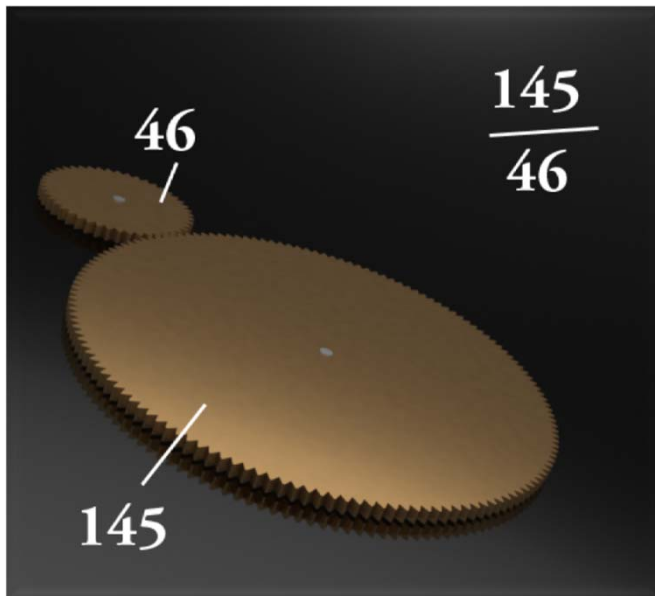
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- Mercury's anomalistic motion: 145 cycles in 46 years.
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 - Factorizes into: 5×29 and 2×23

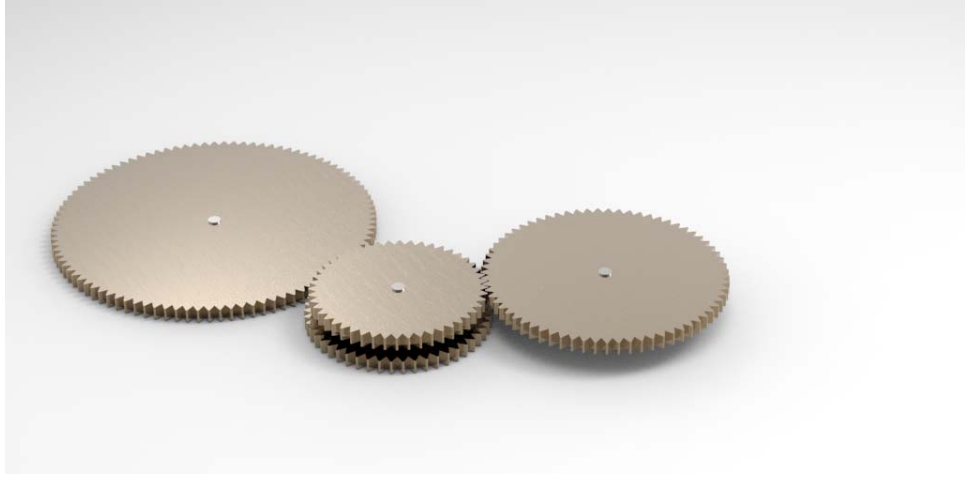


Periods to Gears

- Mercury's anomalistic motion: 145 cycles in 46 years.
- It makes **145/46 cycles per year**.
- Geared solution: **145/46**
 - Factorizes into: **5 x 29 and 2 x 23**



Venus: case study planetary geartrain

Accuracy > 1e0:							
1	4500800.99764	97	3519.0	5626.0	2.22182673823e-07	[3, 3, 17, 23][2, 29, 97]	[0]
2	300799.00185	67	2881.0	4606.0	2.7138522332e-07	[43, 67][2, 7, 7, 47]	[0]
3	2454400.99972	101	1919.0	2880.0	1.6318408551e-07	[16, 16][2, 6, 16, 58]	[0]
4	2149999.00033	43	3362.0				
5	2045120.99964	83	7995.0				
6	1638399.0002	61	1281.0				
7	1433759.00019	103	5605.0				
Best approximation							
Accuracy = $2,22 \times 10^{-7}$							
Period = $5626 / 3519$							
= $(2 \times 29 \times 97) / (3 \times 3 \times 17 \times 23)$							
= $(97 / 51) \times (48 / 69)$							
							
Accuracy > 1e5:							
1	785732.333369	97	3686.0				
2	700465.666715	79	6572.0				
3	599850.999955	67	7504.0				
4	461719.000006	97	7220.0				
5	420303.761922	103	6901.0				
6	408000.999978	29	319.0				
7	374446.058831	109	4977.0				
8	326144.999994	17	6375.0				
9	322856.142858	113	1767.0				
10	314982.818173	71	2709.0				
11	312075.999993	73	7808.0				
12	298372.428569	71	6532.0				
13	294312.111101	109	2071.0				
14	289635.363643	59	4982.0				
15	287775.00001	23	5625.0				
16	271574.333324	67	3185.0				
17	232595.285709	67	6365.0				
18	231587.206895	89	5251.0				
19	221964.636362	109	1909.0				
20	205919.000001	23	805.0				
21	203360.999999	53	795.0				
22	190298.872337	43	6993.0				
23	186882.720932	103	6283.0				
24	185566.21739	97	3337.0				
25	182896.999999	71	7150.0				
26	182306.692308	109	3706.0				
27	165664.157893	107	4922.0				
28	162629.769233	31	6612.0				
29	157885.444444	107	5555.0				
30	154759.000003	73	2420.0				
31	151561.500001	97	7584.0				
32	146232.333335	107	2744.0				
33	141079.260867	59	2537.0				
34	140141.857144	109	3068.0				
35	135574.000002	53	3392.0				
36	131899.412697	89	6497.0				
37	125842.478261	73	2263.0				
38	123531.467534	67	7437.0				
39	122846.901639	31	5859.0				
40	117633.432432	83	6806.0				
41	116389.0	113	7280.0				
42	113251.83019	61	4693.0				
43	108527.829268	103	3479.0				
44	107862.333333	79	6325.0				
45	106426.263156	89	7905.0				
46	104414.186812	107	7429.0	11877.0	9.57724261936e-06	[17, 19, 23][3, 37, 107]	[0]
47	103599.000001	37	162.0	259.0	9.65260282428e-06	[2, 3, 3, 3][7, 37]	[0]

Venus: case study planetary geartrain

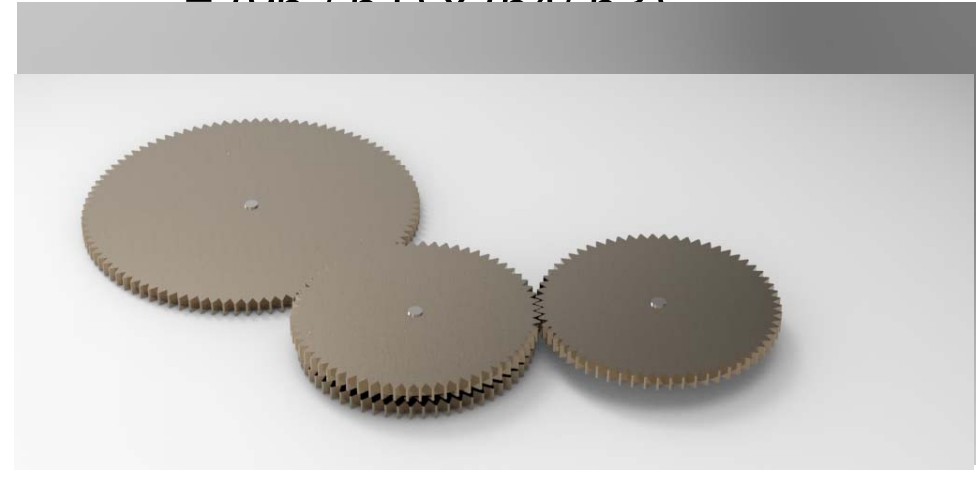
Accuracy > 1e6:							
1	4500800.99764	97	3519.0	5626.0	2.22182673823e-07	[3, 3, 17, 23][2, 29, 97]	[0]
2	3684799.00183	67	2881.0	4606.0	2.7138522332e-07	[43, 67][2, 7, 47]	[0]
3	2454400.99972	101	1049.0	8888.0	1.6318448855e-07	[16, 16][16, 16, 50]	[0]
4	2149999.00000	43	3362				
5	2049120.99904	83	7995				
6	1638399.00002	61	1281				
7	1438799.00010	103	5605				

Accuracy > 1e5:			
1	785732.333369	97	3686
2	700465.666715	79	6572
3	599850.999955	67	7504
4	461719.000006	97	7220
5	420303.761922	103	6901
6	408000.999978	29	319.0
7	374446.058831	109	4977
8	326144.889994	17	6375
9	322856.142858	113	1767
10	2918173	71	2709
11		73	7808
12		71	6532

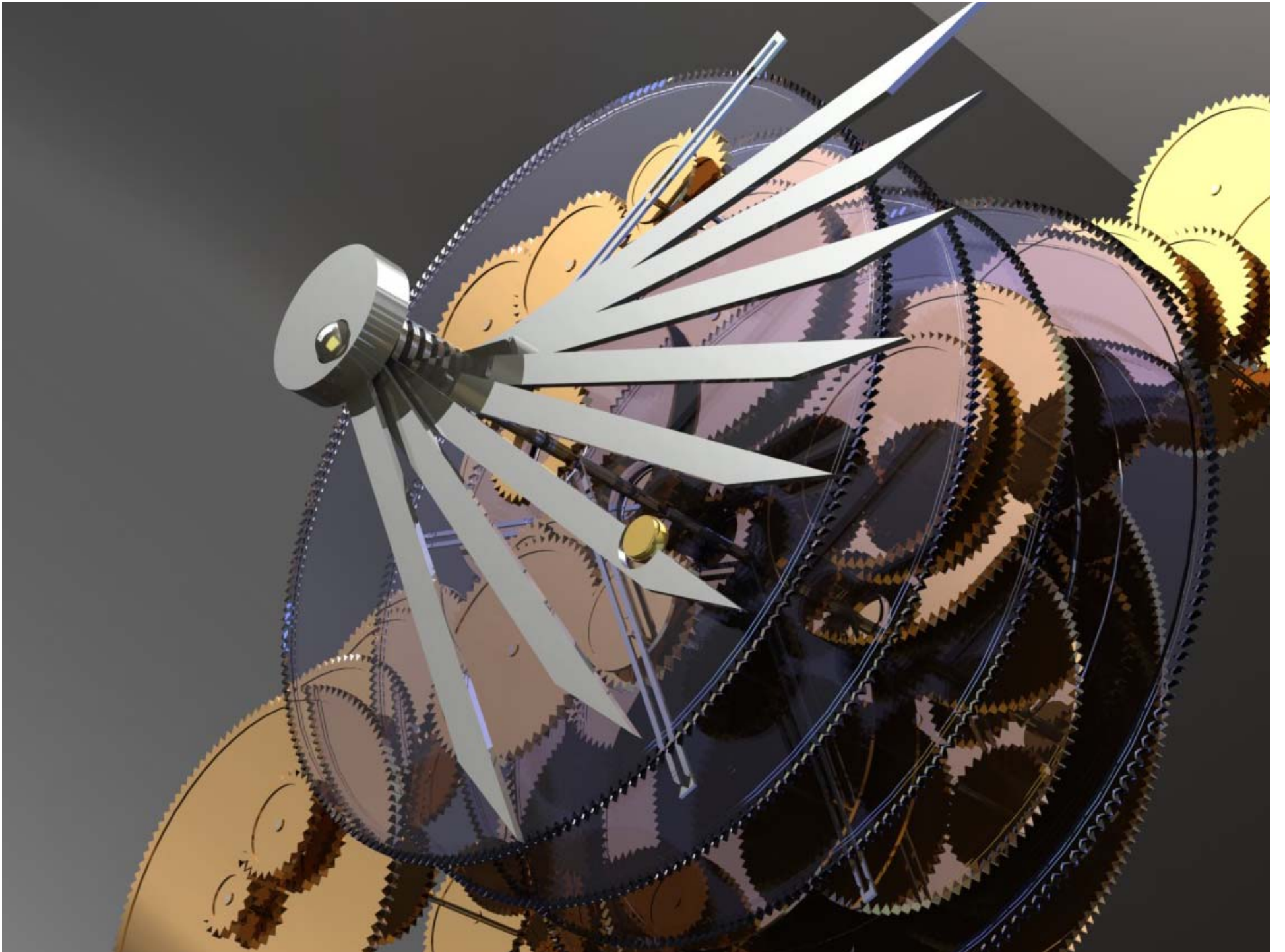
Sixth best approximation

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

$$\begin{aligned} \text{Period} &= 2048 / 1281 \\ &= 2^{11} / (3 \times 7 \times 61) \\ &= (32 / 61) \times (64 / 21) \\ &= (96 / 61) \times (64 / 63) \end{aligned}$$



13	104414.186812	107	7429.0	11877.0	9.57724261936e-06	[17, 19, 23][3, 37, 107]	[0]
14	103599.000001	37	162.0	259.0	9.65260282428e-06	[2, 3, 3, 3][7, 37]	[0]



AMRP Reconstruction

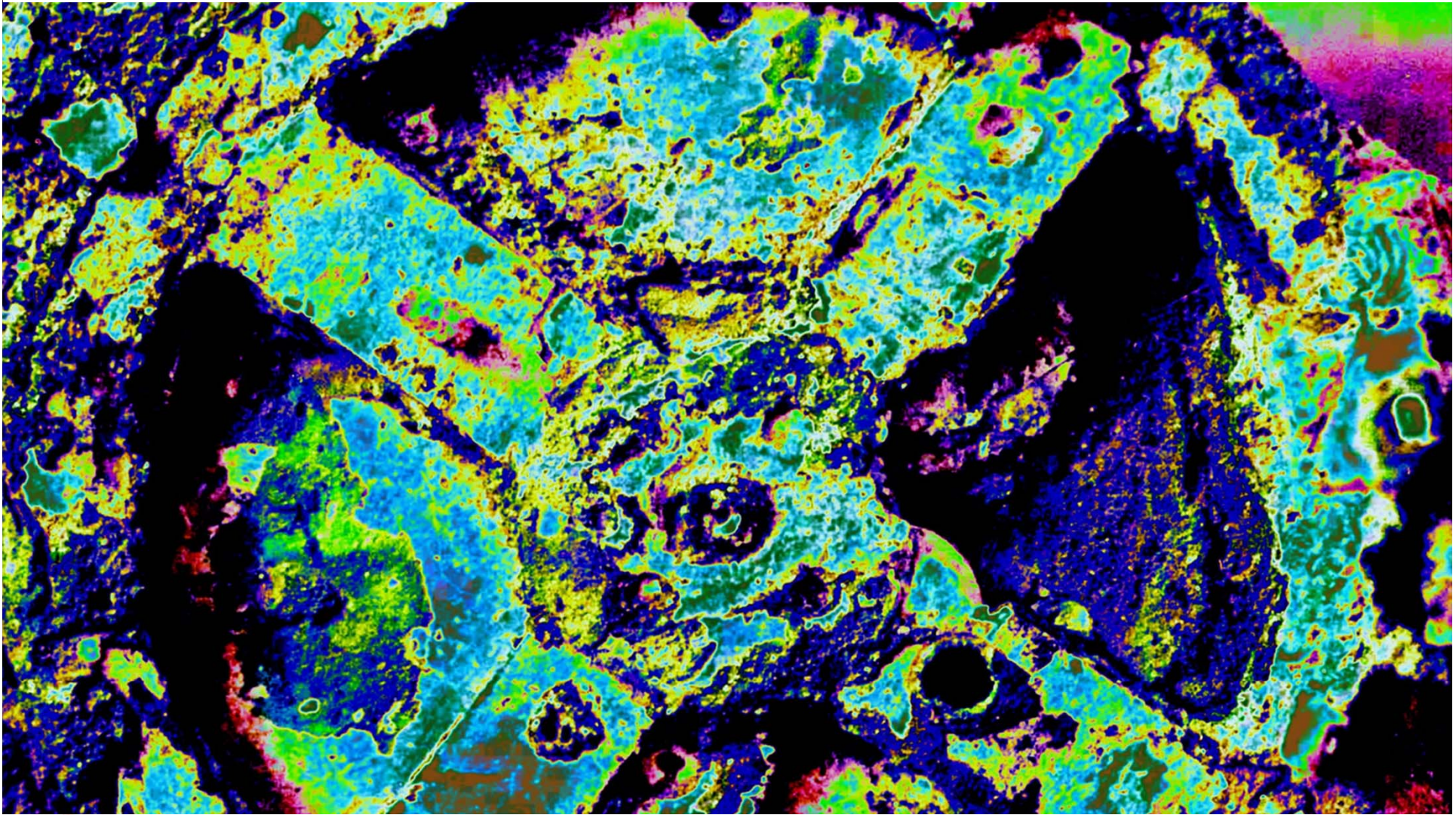
Gear Train Animation

A. Vicentini & M. Wright

Animation Vicentini & Wright



Rien van de Weijgaert



university of
groningen

faculty of mathematics
and natural sciences

kapteyn astronomical
institute



the Instrument Maker

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)

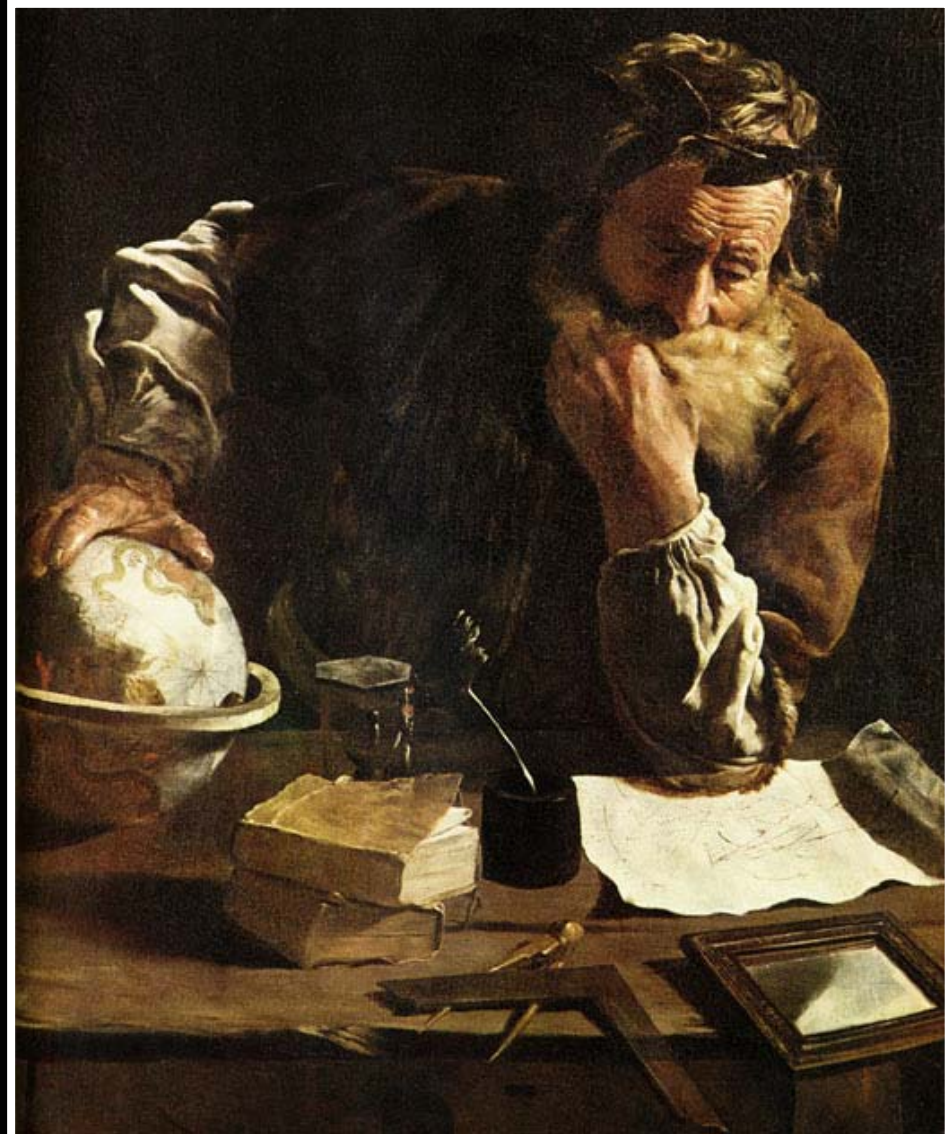
- Pappus of Alexandria:
Archimedes wrote book
“On Sphere-Making”

... 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**



**Is this
Archimedes Sphere ?**

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



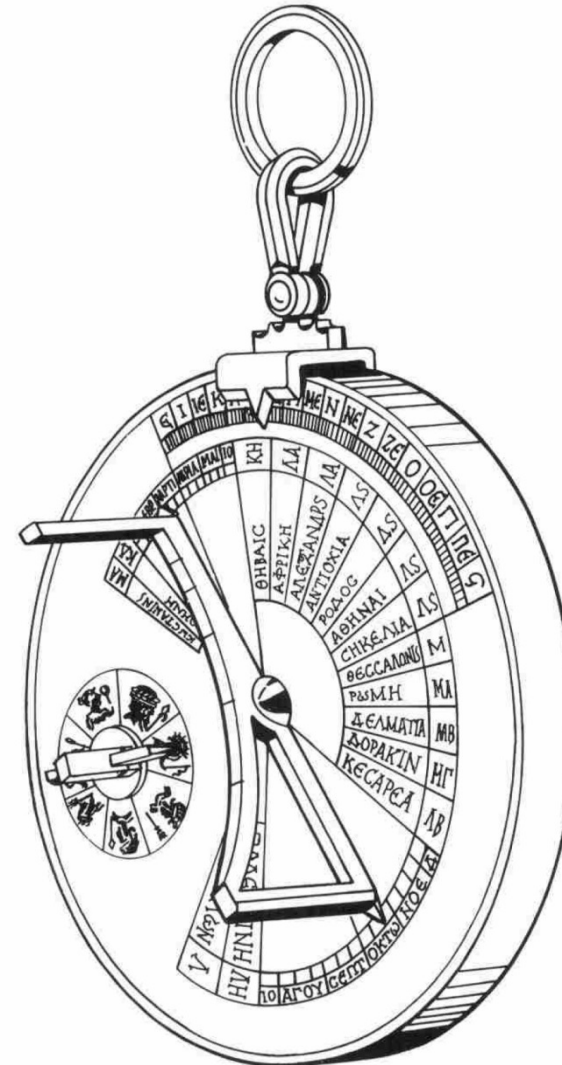
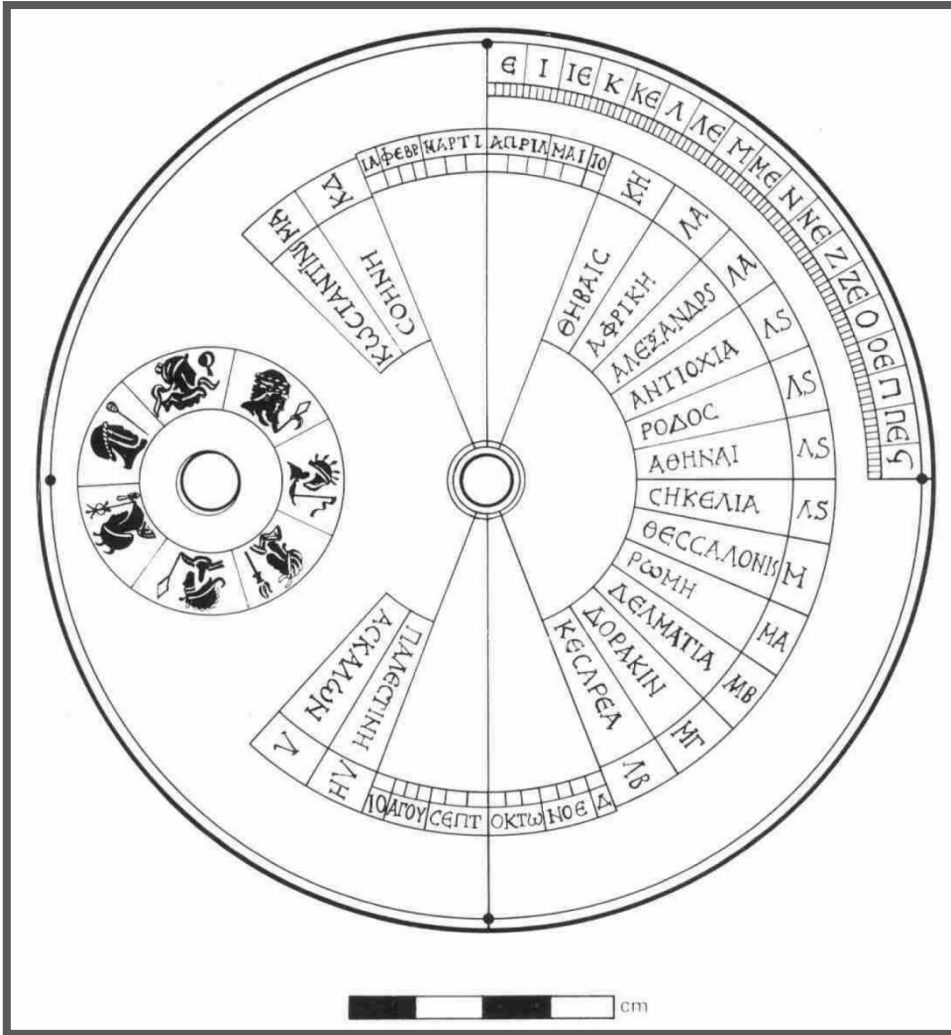
**ancient Technology,
Science & Innovation**

Roman Military Technology



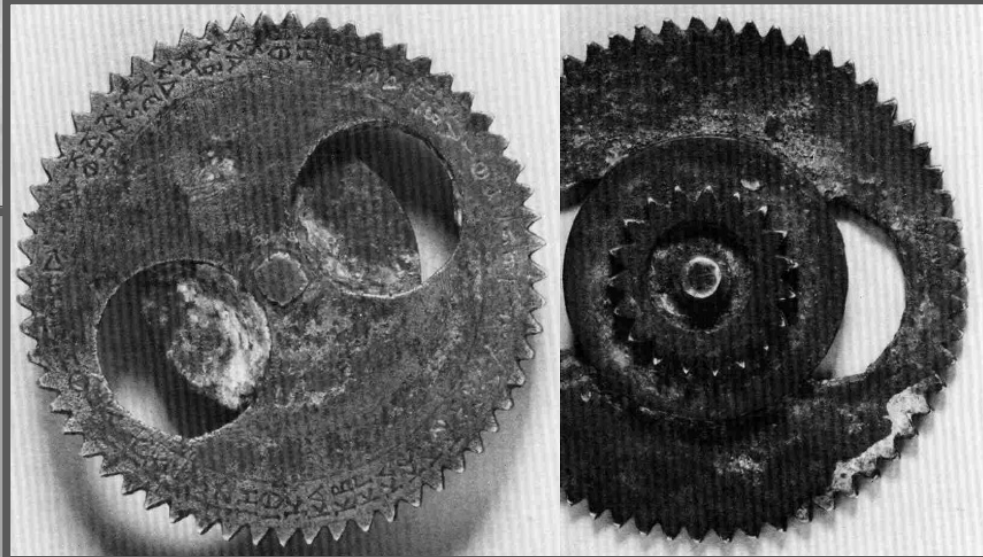
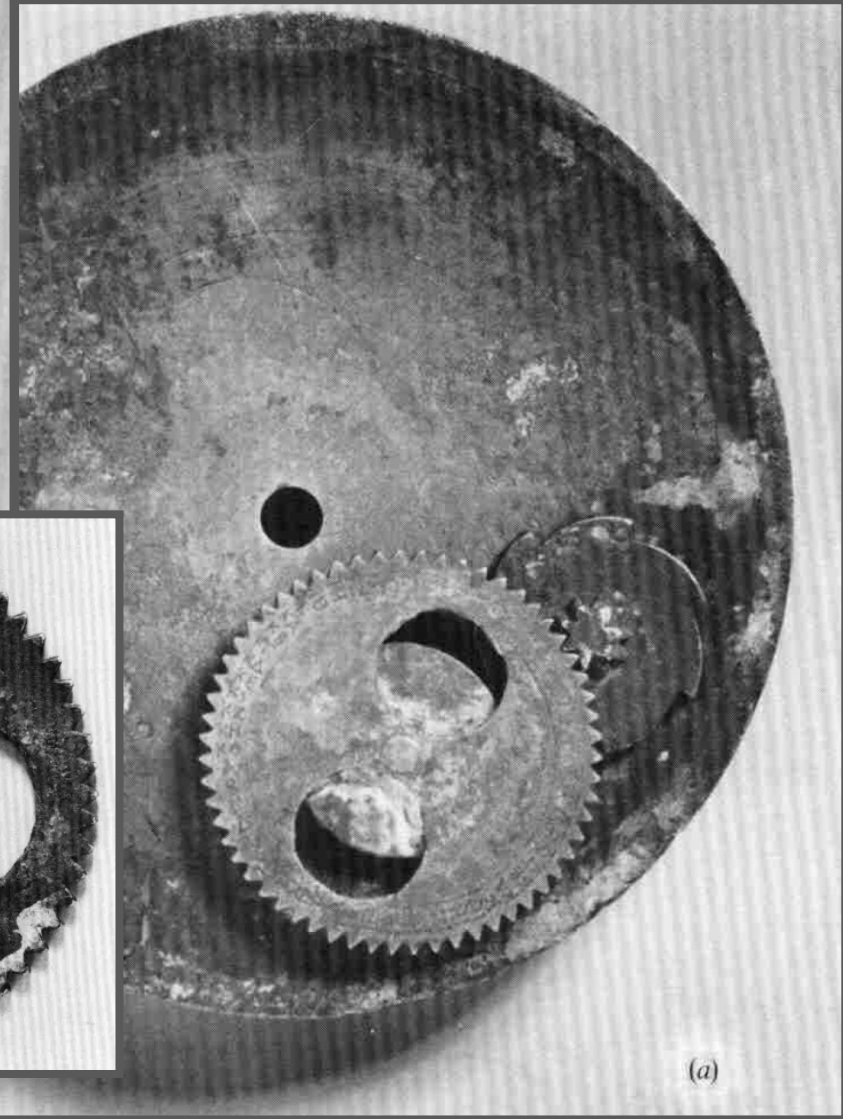
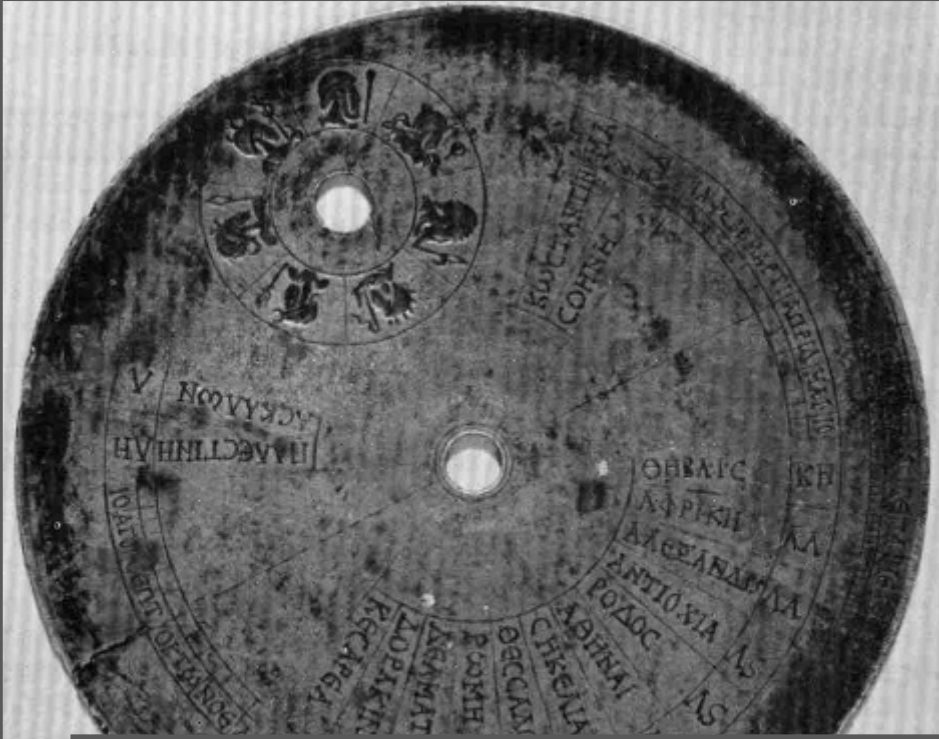
Byzantine “Astrolabe”

6th cent. AD !!!



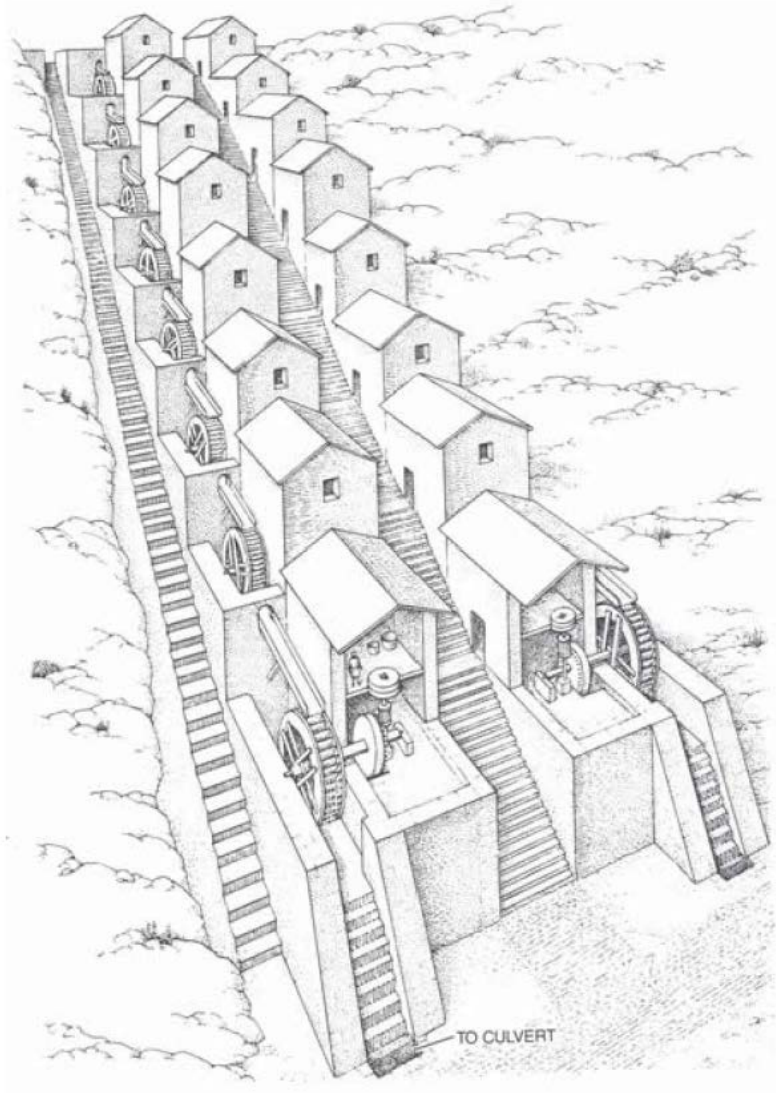
Byzantine "Astrolabe"

6th cent. AD !!!



(a)

Roman Industry

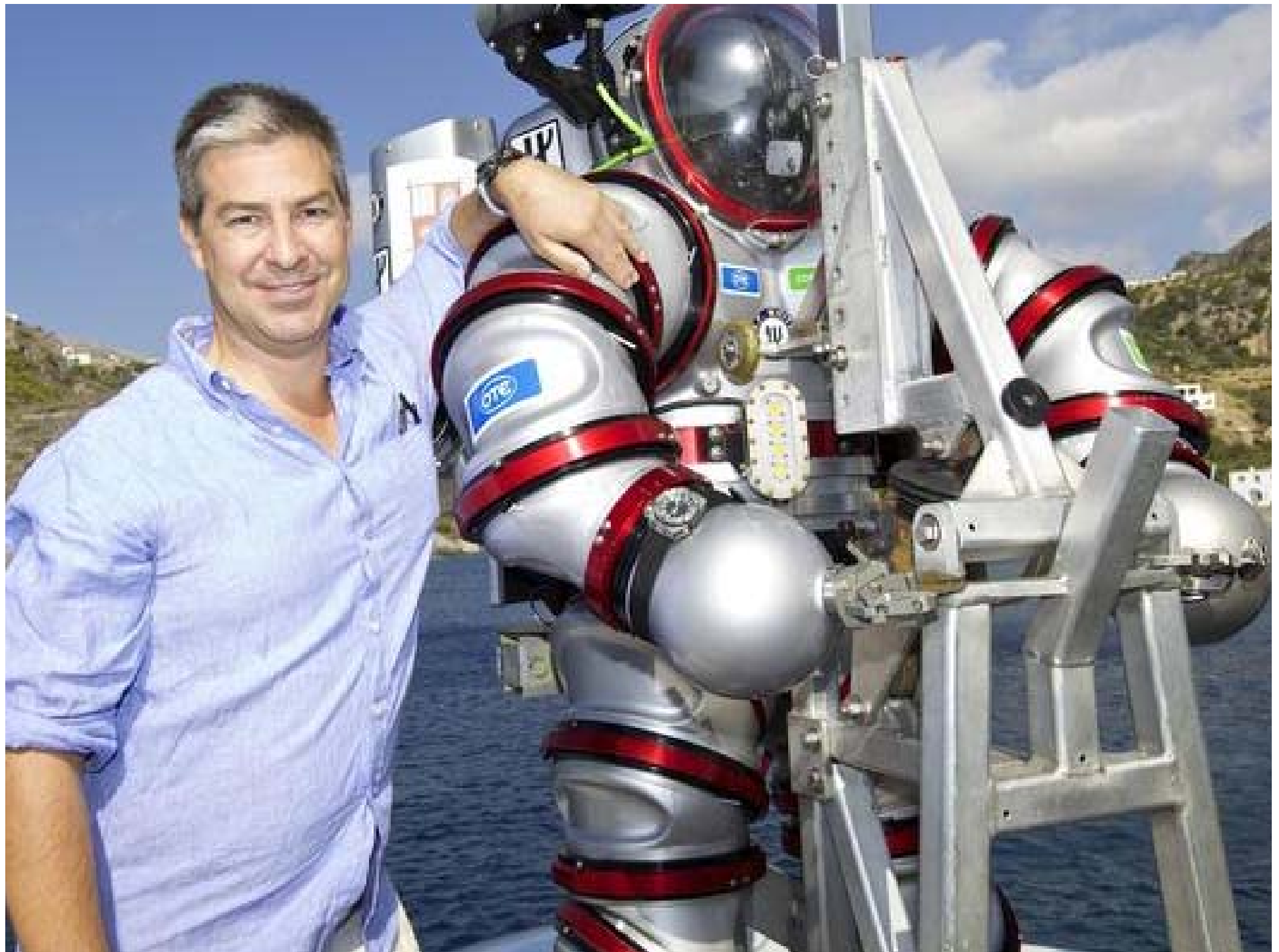


Did hightech find applications
In industrial activities ?

Barbegal:
industrial complex of watermills

A diver in full scuba gear is shown from a top-down perspective underwater. The diver is holding a large, professional camera lens in front of them. The background is a deep blue ocean with some light particles visible. The entire scene is framed by a white border.

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)



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)