# 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 ...**


100 v. Chr.

0

1000

2000

1400 jaar!!


- **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 ... ?

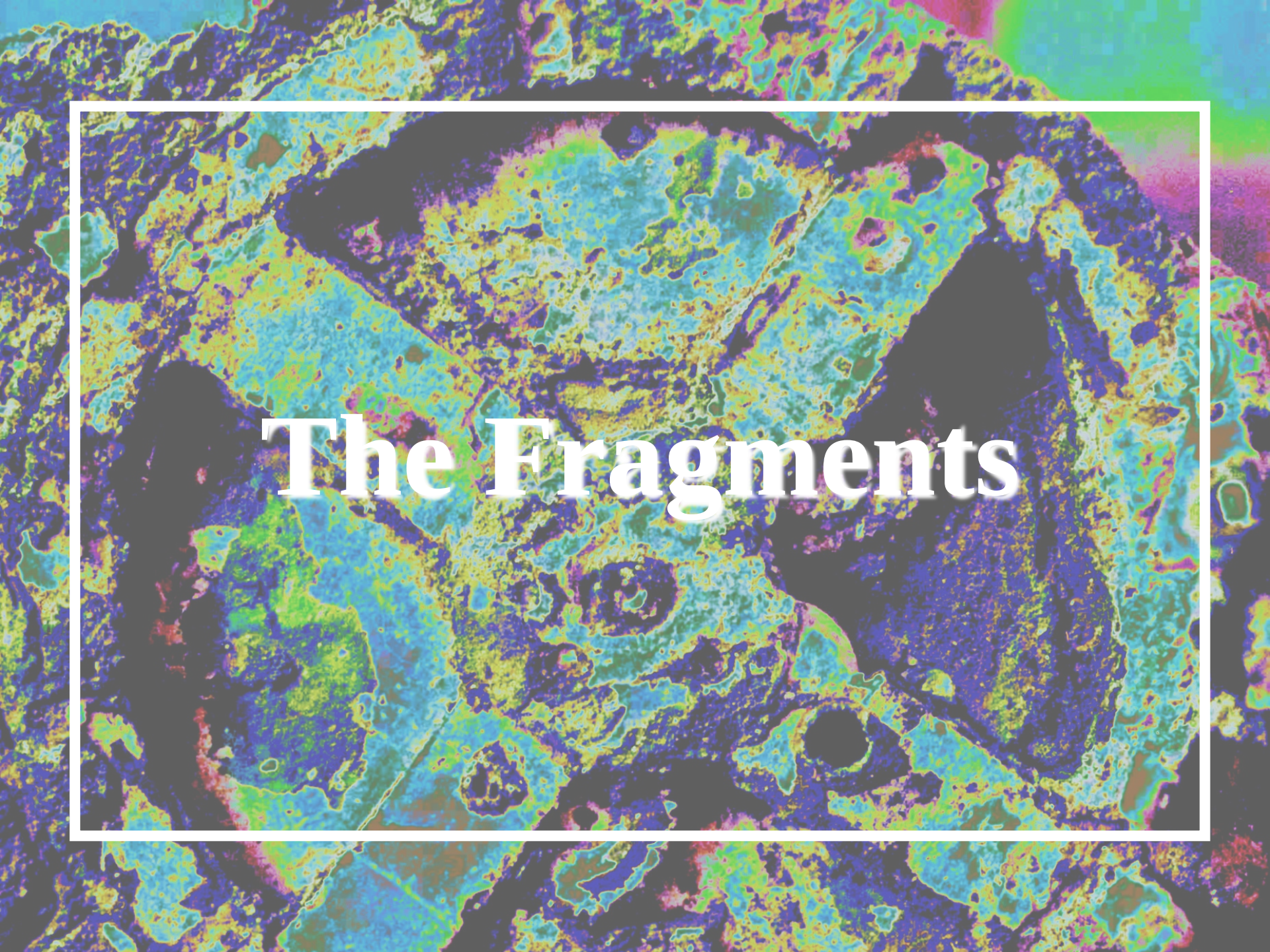
## a Hellenistic Scientific Revolution ?

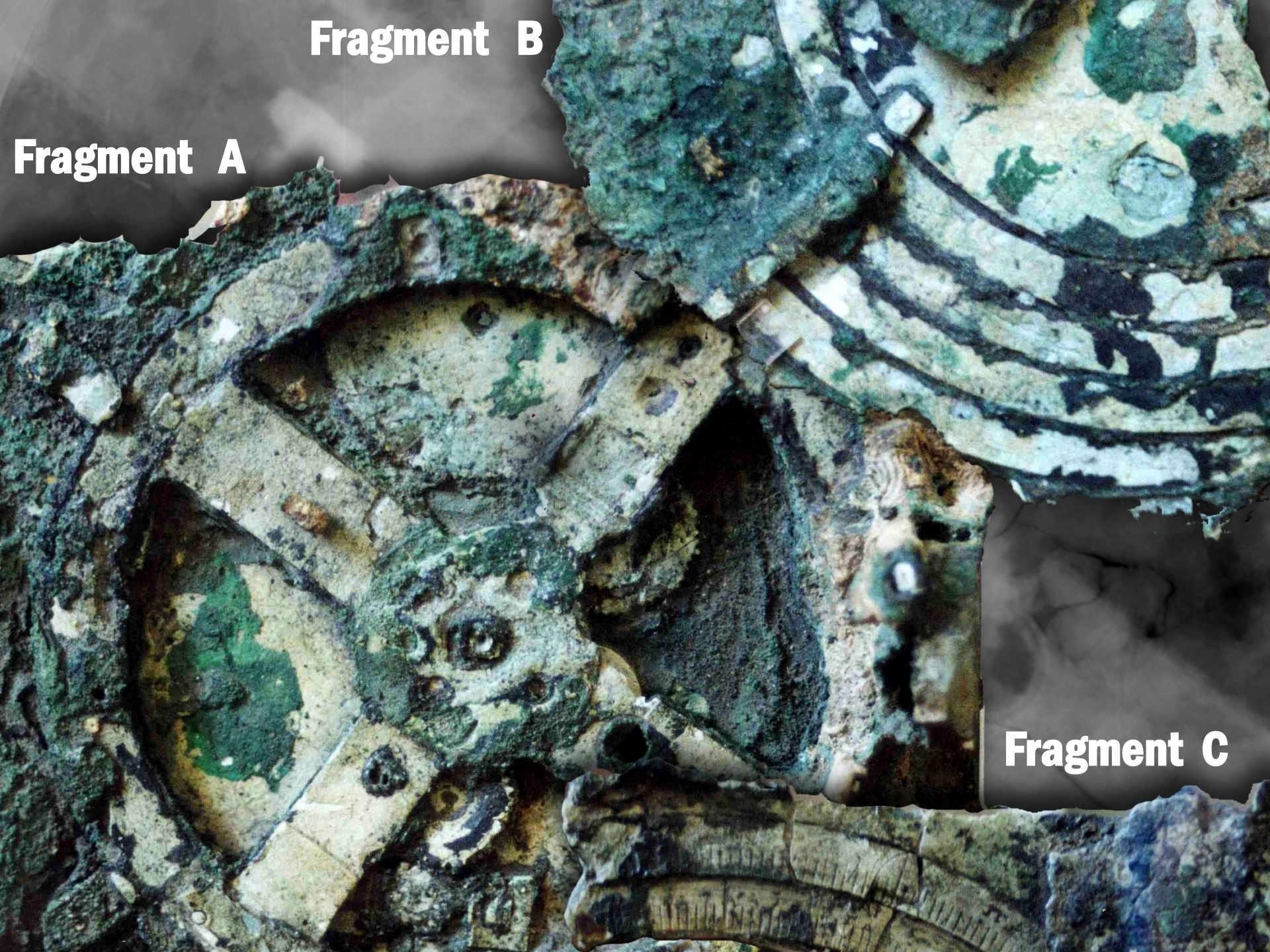
- Known was that Greeks pondered deeply on the workings and laws of nature ... Greek natural philosophy

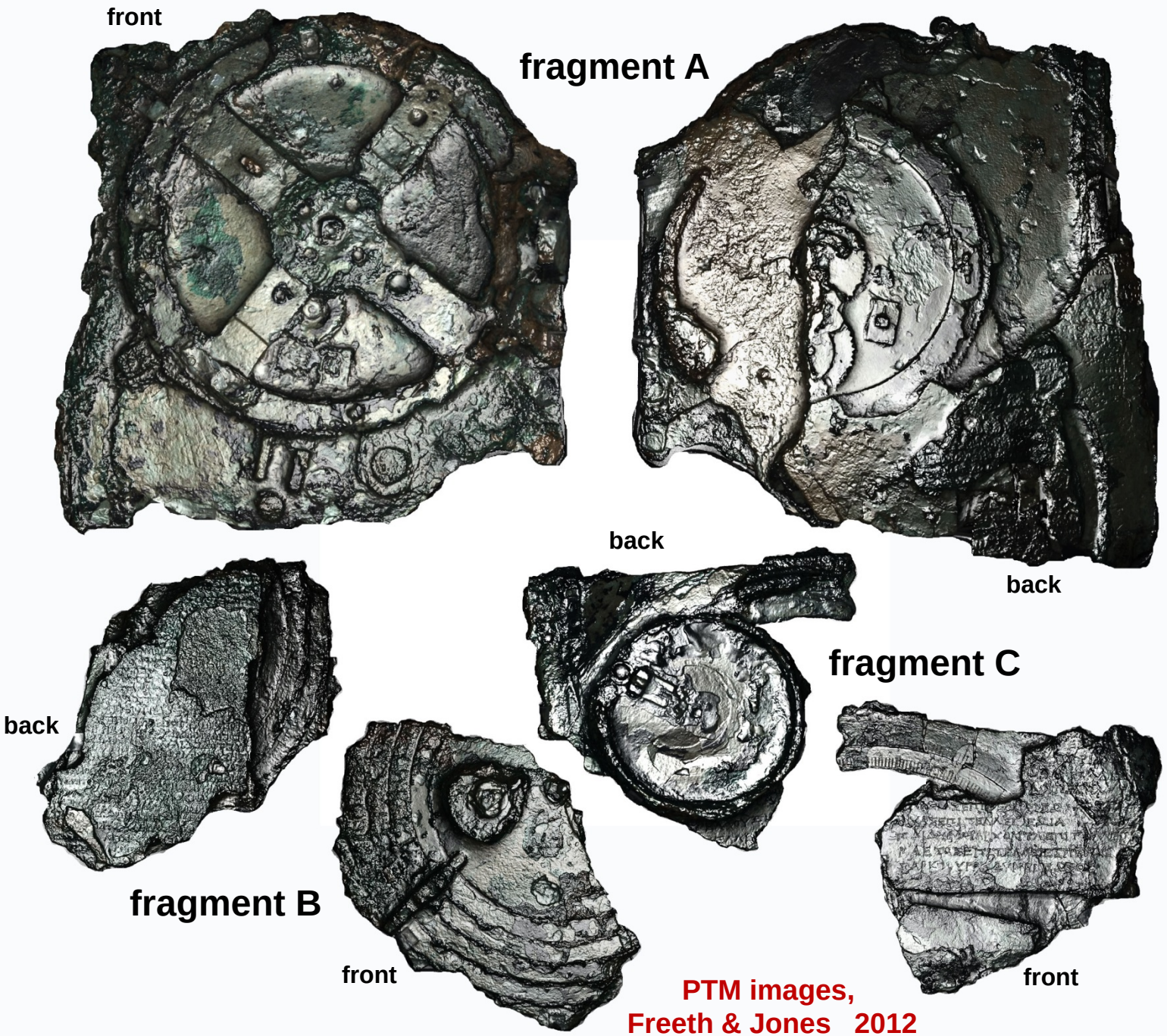
- Known was that the Hellenistic Greeks managed to combine sophisticated geometric models of the heavens with observational data (mostly Babylonian), into a genuine theory of nature.

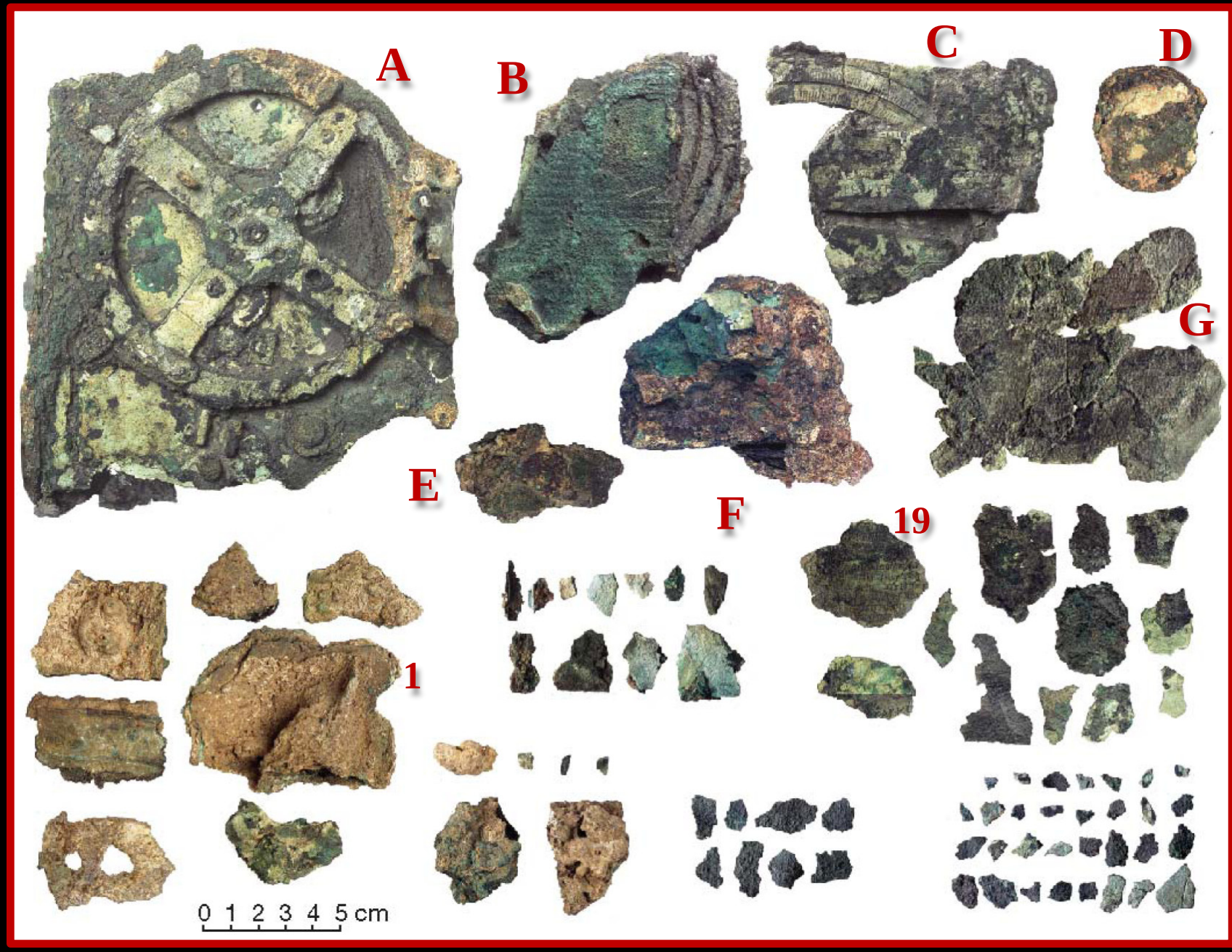
- However,
  we never imagined they would be able to translate this model into a sophisticated mechanical device,
  translating mathematical theory into a mechanical representation of reality.

- 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 Fragments


Fragment B
Fragment A
Fragment C


front
fragment A
back
back
fragment C
back
fragment B
front
front
PTM images,
Freeth & Jones 2012


A
B
C
D
E
F
G
19
1
0 1 2 3 4 5 cm

**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


151 km
© 2012 Cnes/Spot Image
Data SIO, NOAA, U.S. Navy, NGA, GEBCO
8.04 km

**October 1900:**

- **Group (sponge) divers,**

  lead by Elias Stadiatos

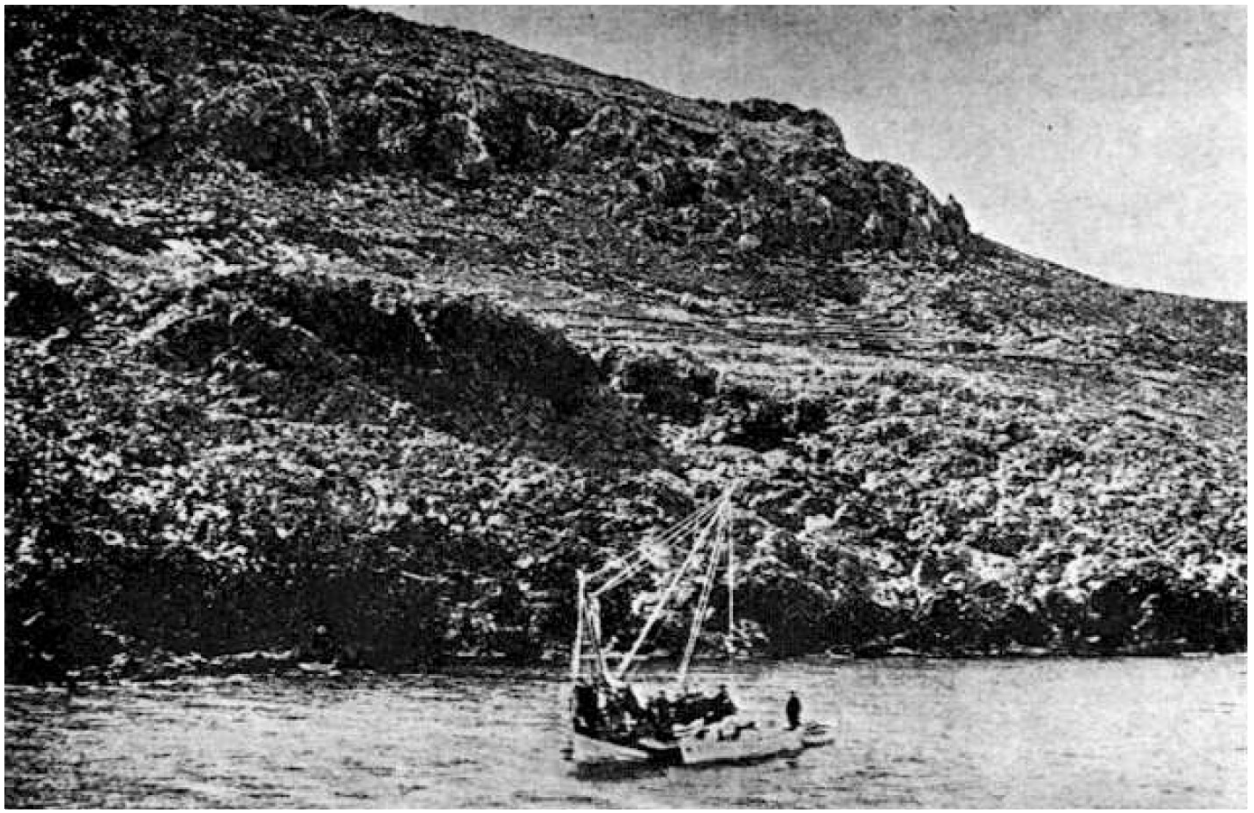
- **Shipwreck 43m deep :**

  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

WOODS HOLE OCEANOGRAPHIC INSTITUTION
1930

GREEK MINISTRY OF CULTURE
EPHORATE OF UNDERWATER ANTIQUITIES

image: Alexandros Sotiriou


the Antikythera
shipwreck

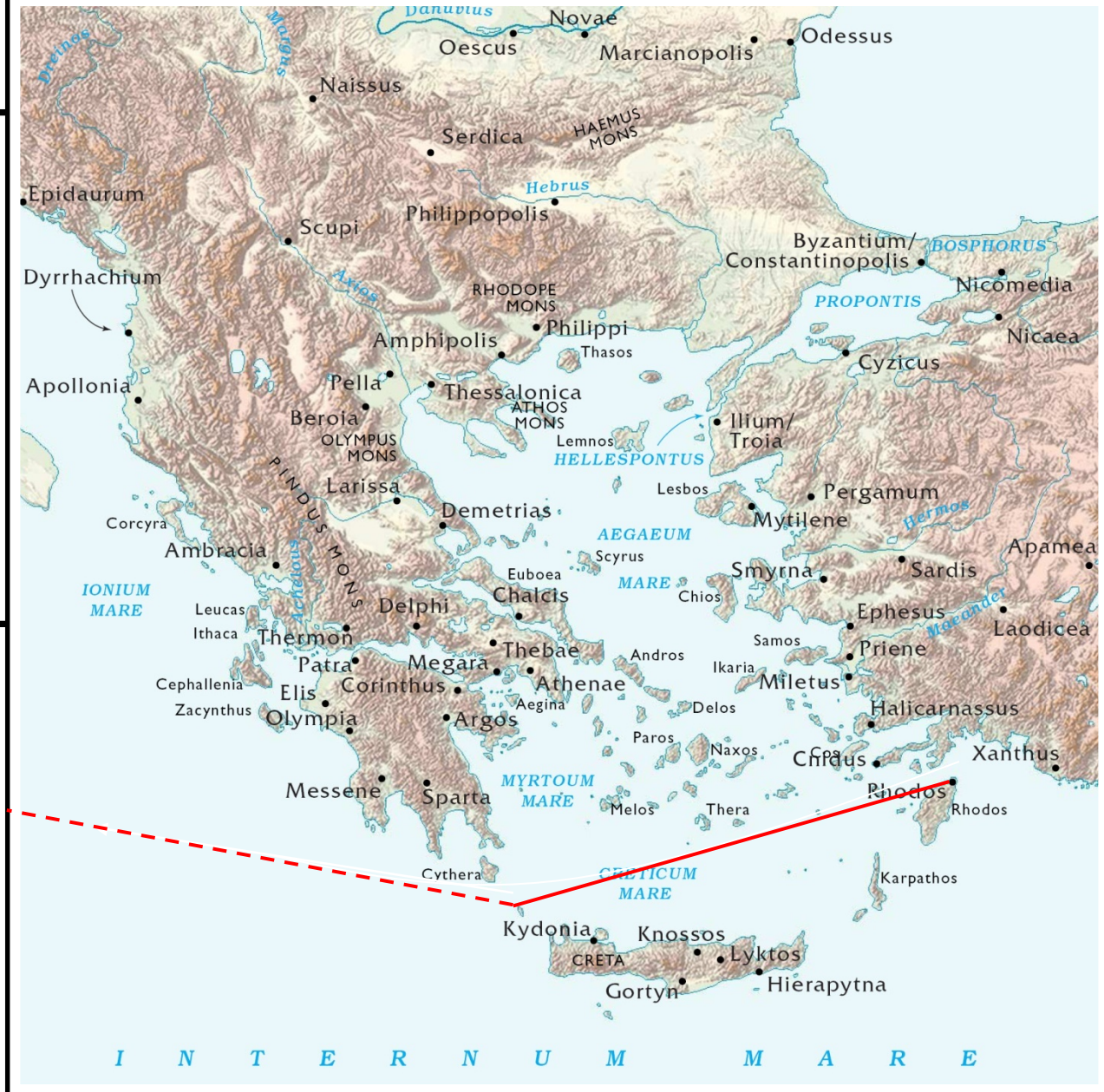
# Roman Shipwreck

## 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 !

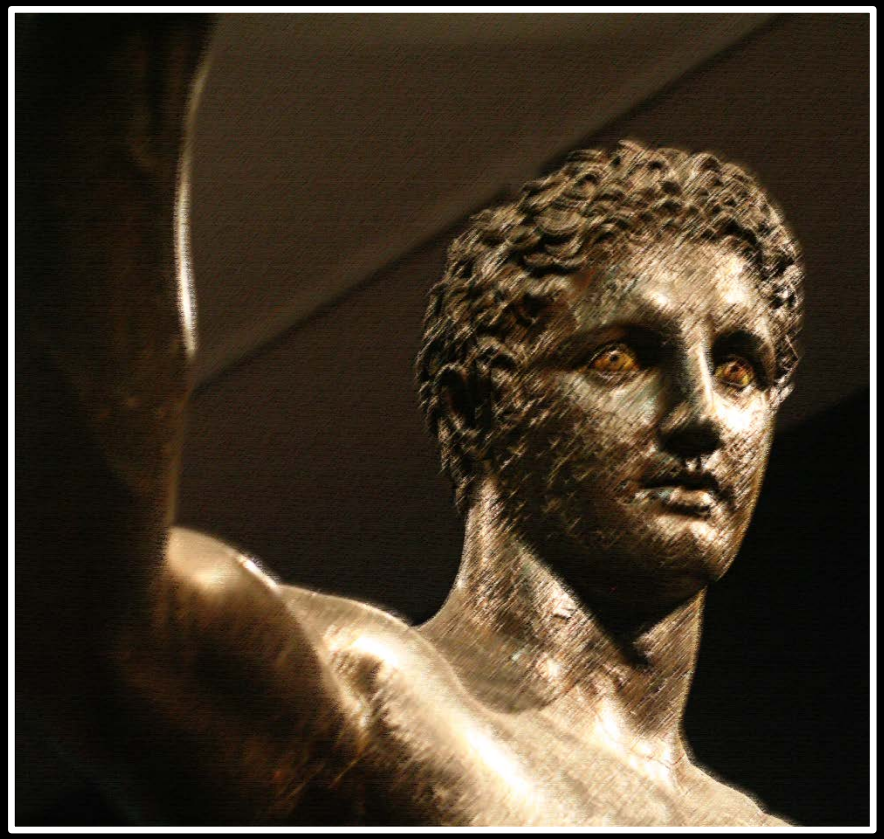



the Antikythera Ship
Roman cargo ship (Olkas, ~ 50 x 15m)


The Antikythera Shipwreck.
The Ship, the Treasures, the Mechanism
National Archaeological Museum, Athens
A hull plank, bronze spikes and fragments of metal sheathing

# the Marbles

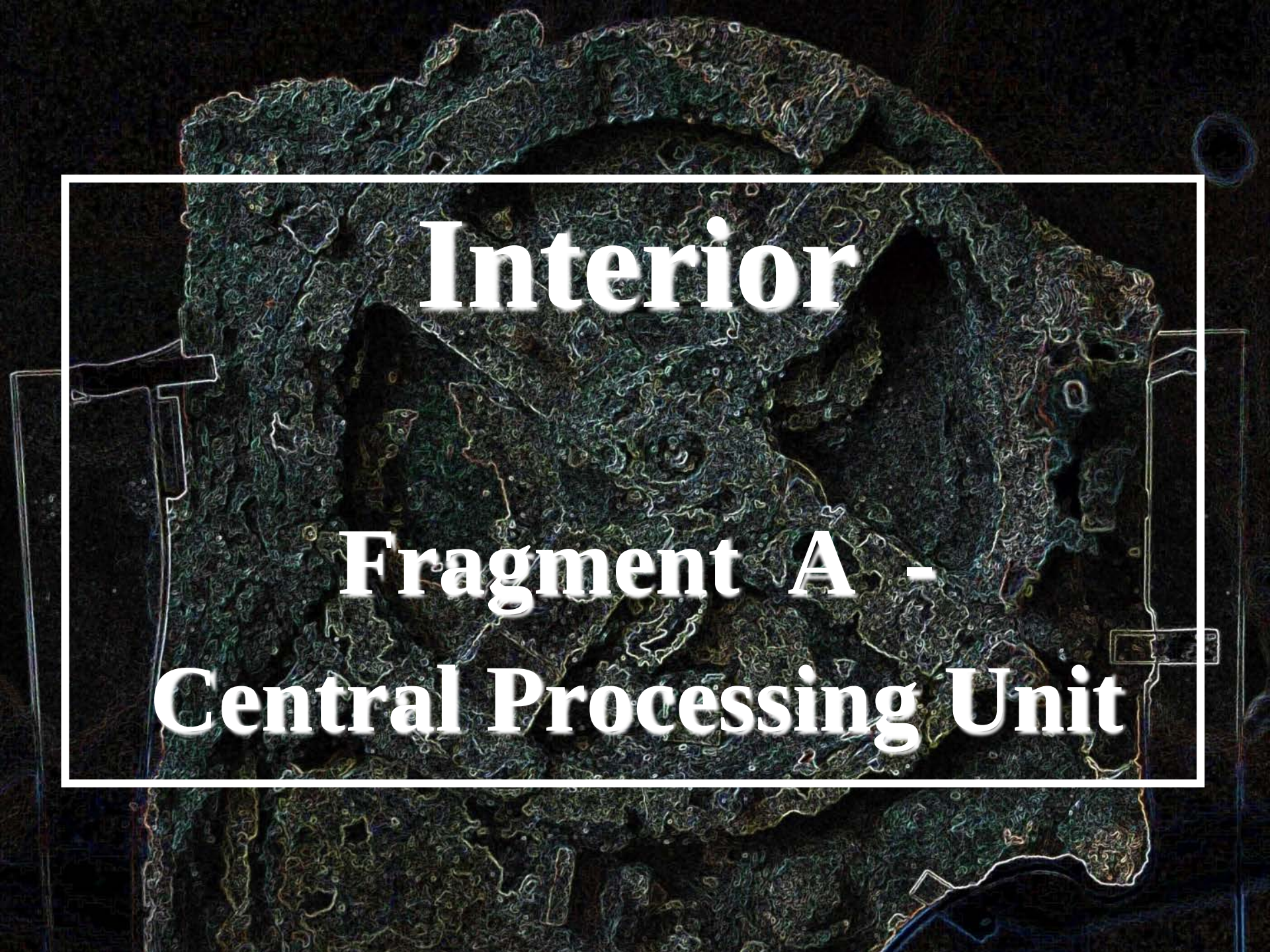
# Ephebe of Antikythera



# Coins & Jewelry

Pergamon. Silver cistophoric tetradrachme 85-76 BC.

precious and intricate golden jewelry

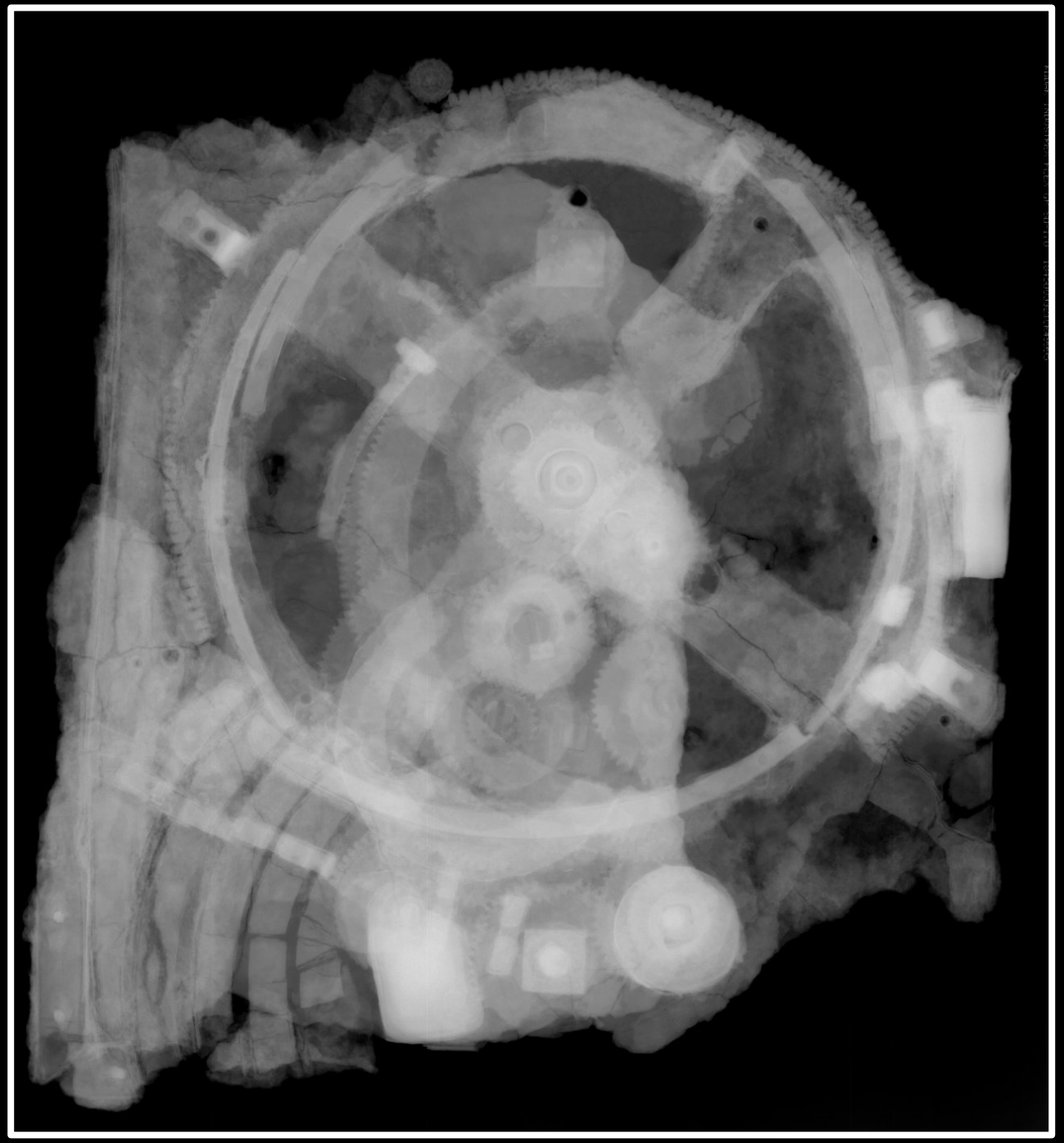

Interior
Fragment A -
Central Processing Unit

# Central Mechanism

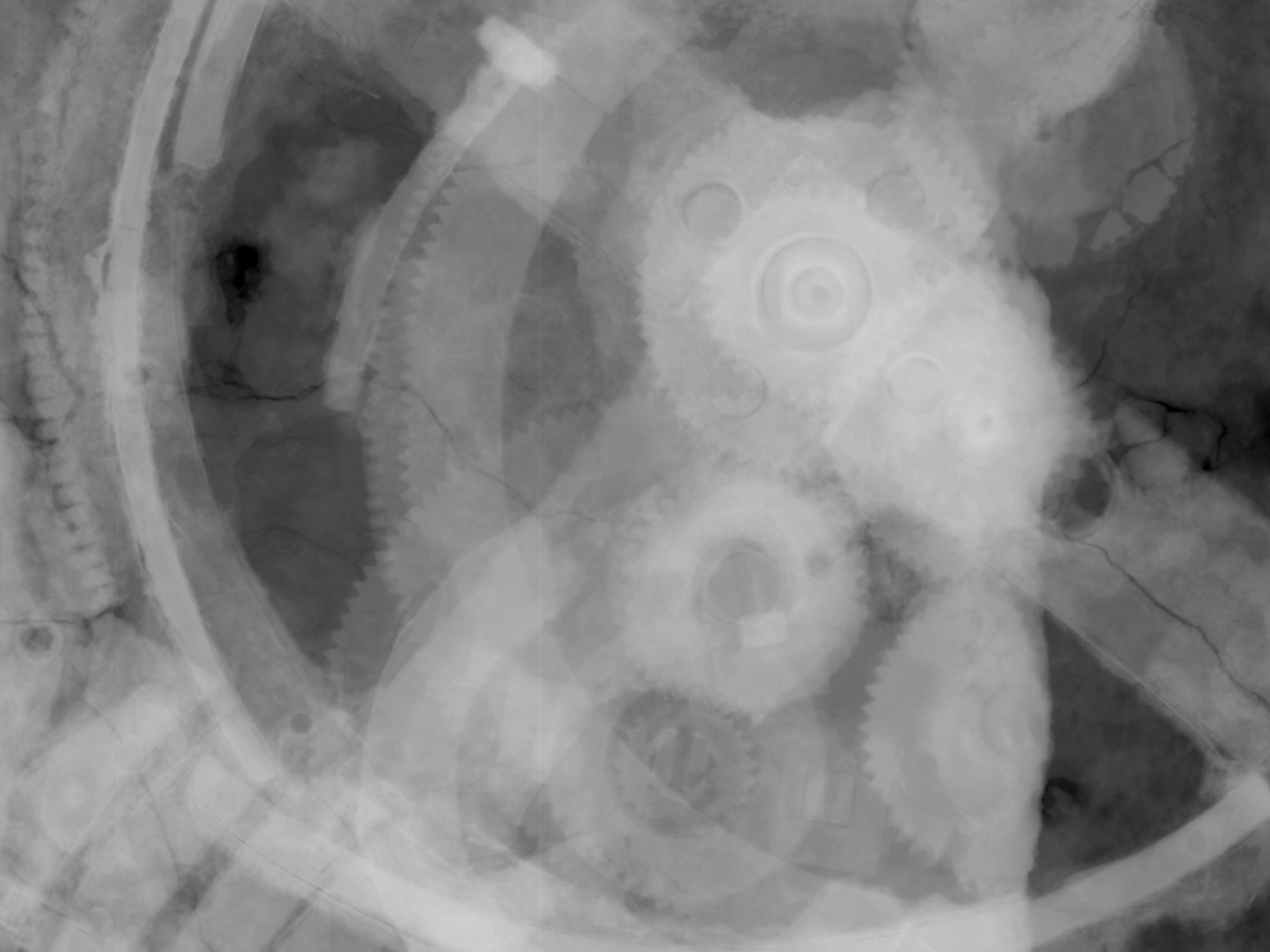
## Fragment A:

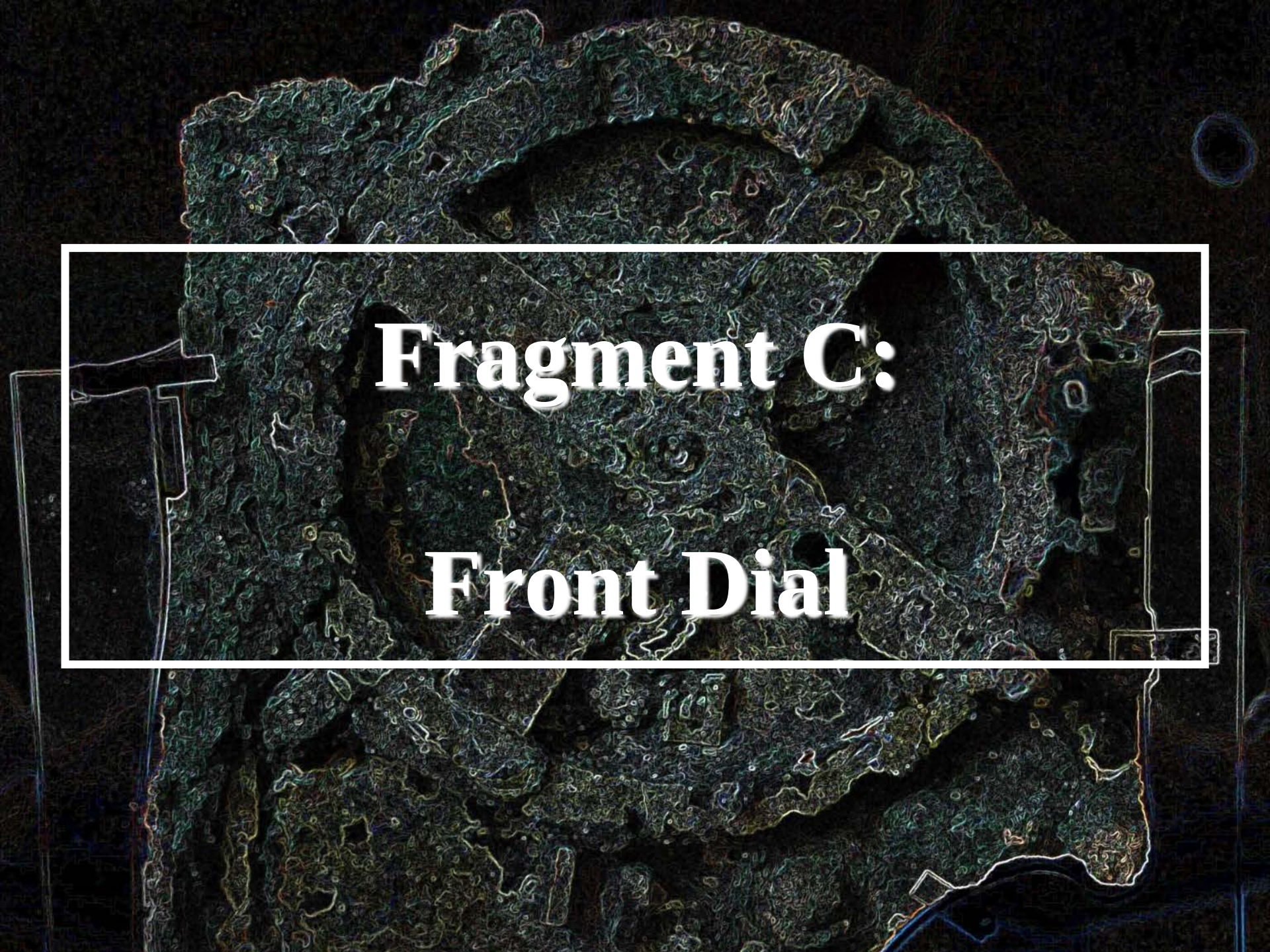
## 27 gearwheels !

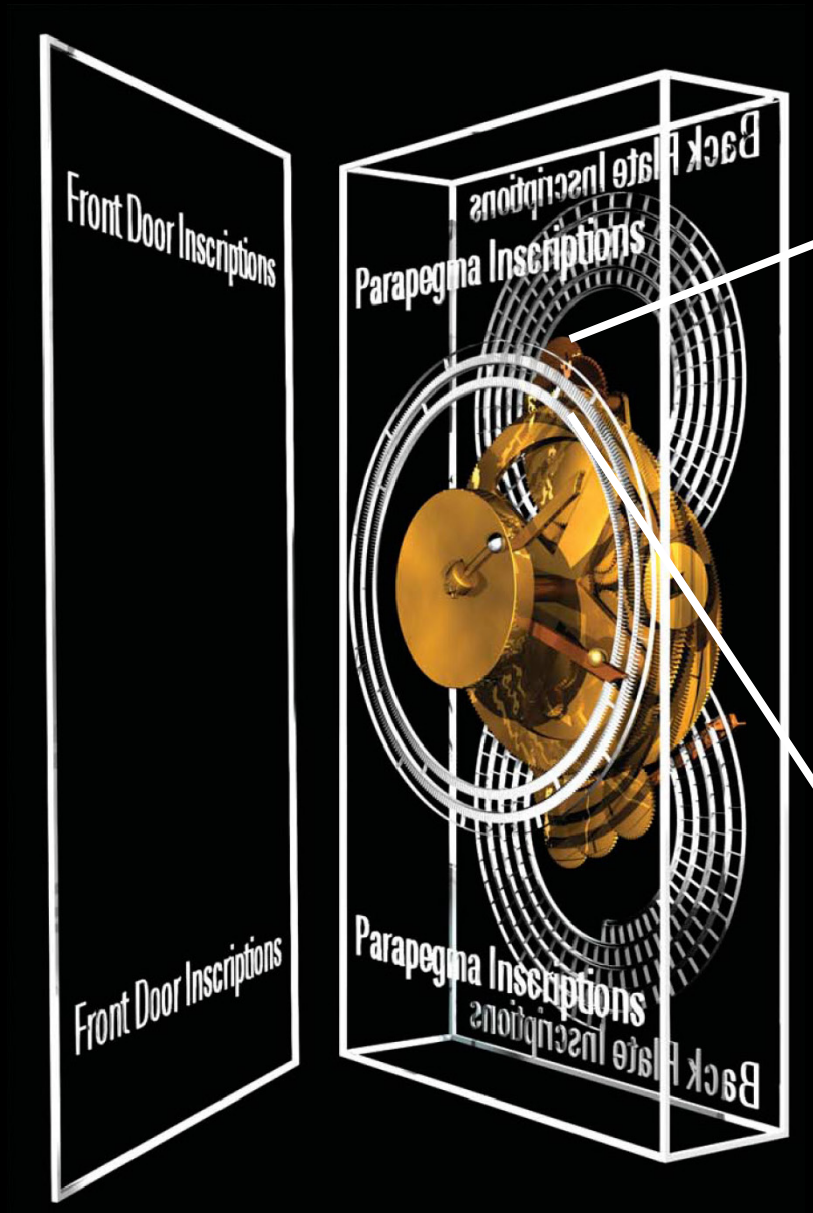
# Interior



AMRP
X-Tek X-ray
Tomography




Fragment C:
Front Dial




# Fragment C

# Front Dial (part)

# Front Dial

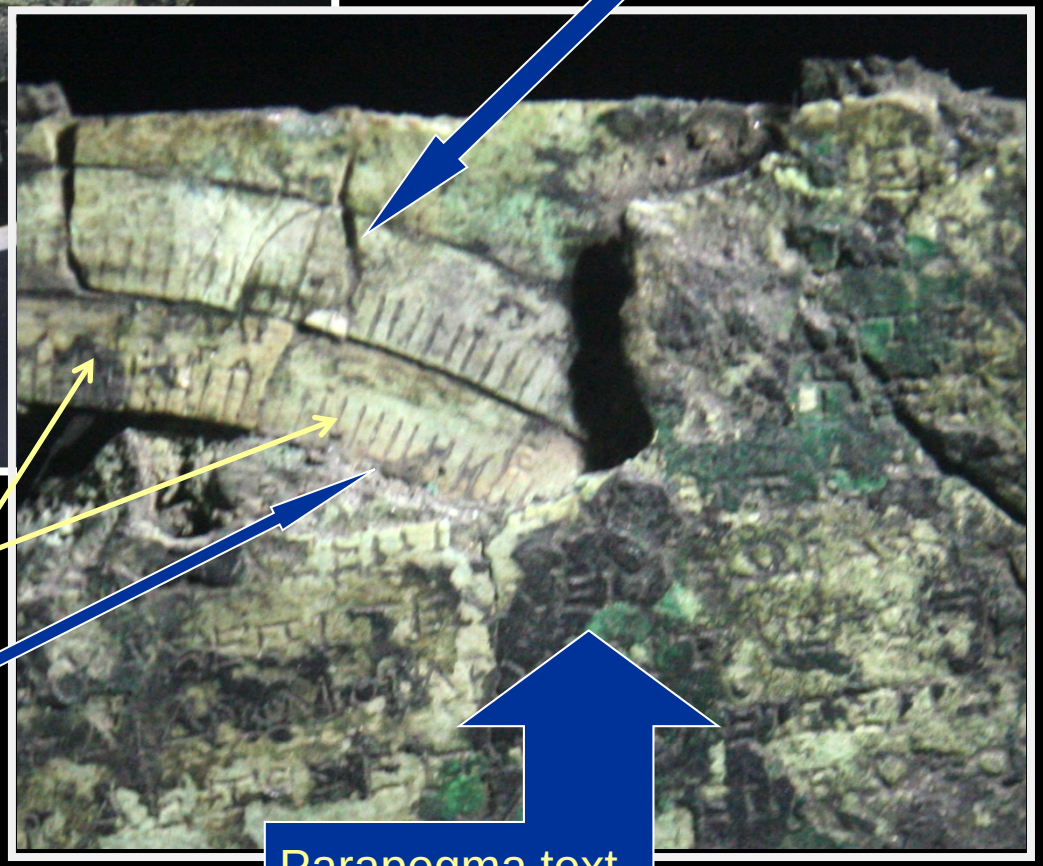
- Front dial, inner scale

  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

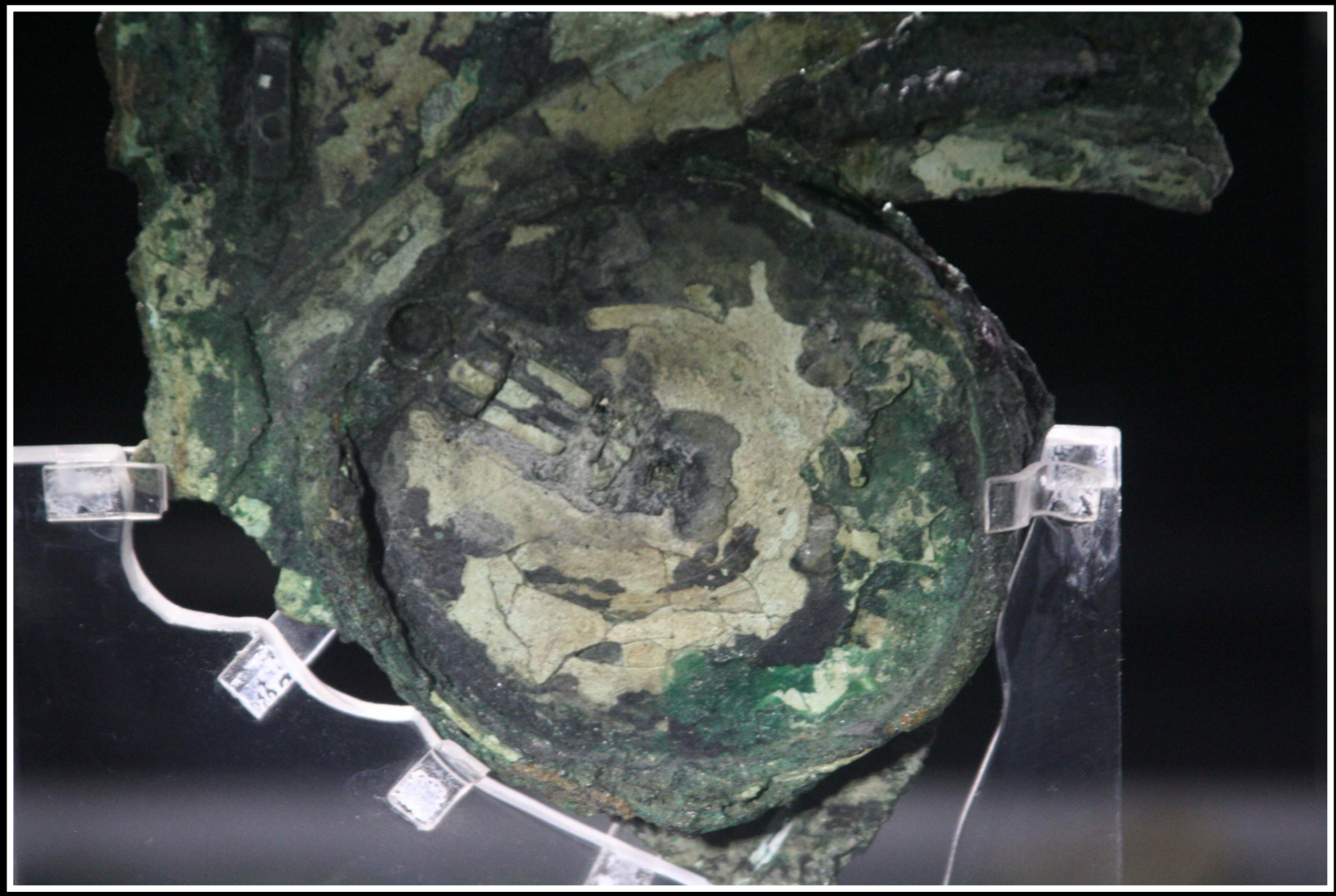
Parthenos (Virgo)

Xilai (Libra)

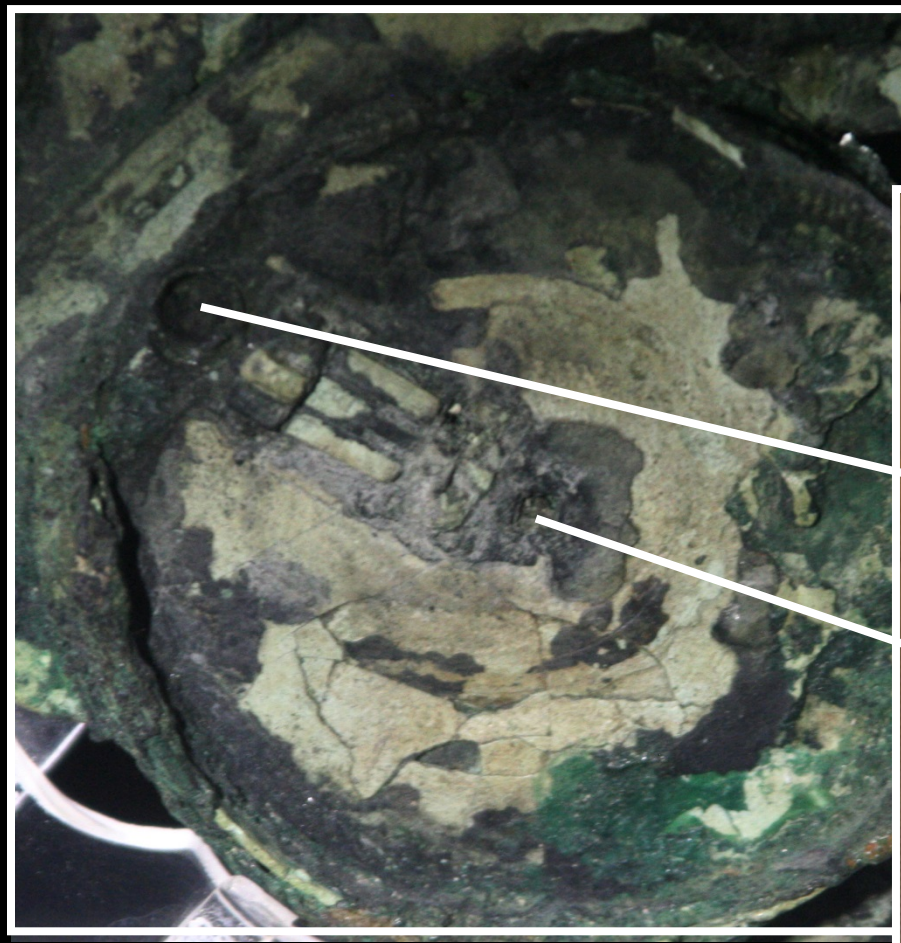
Zodiac scale

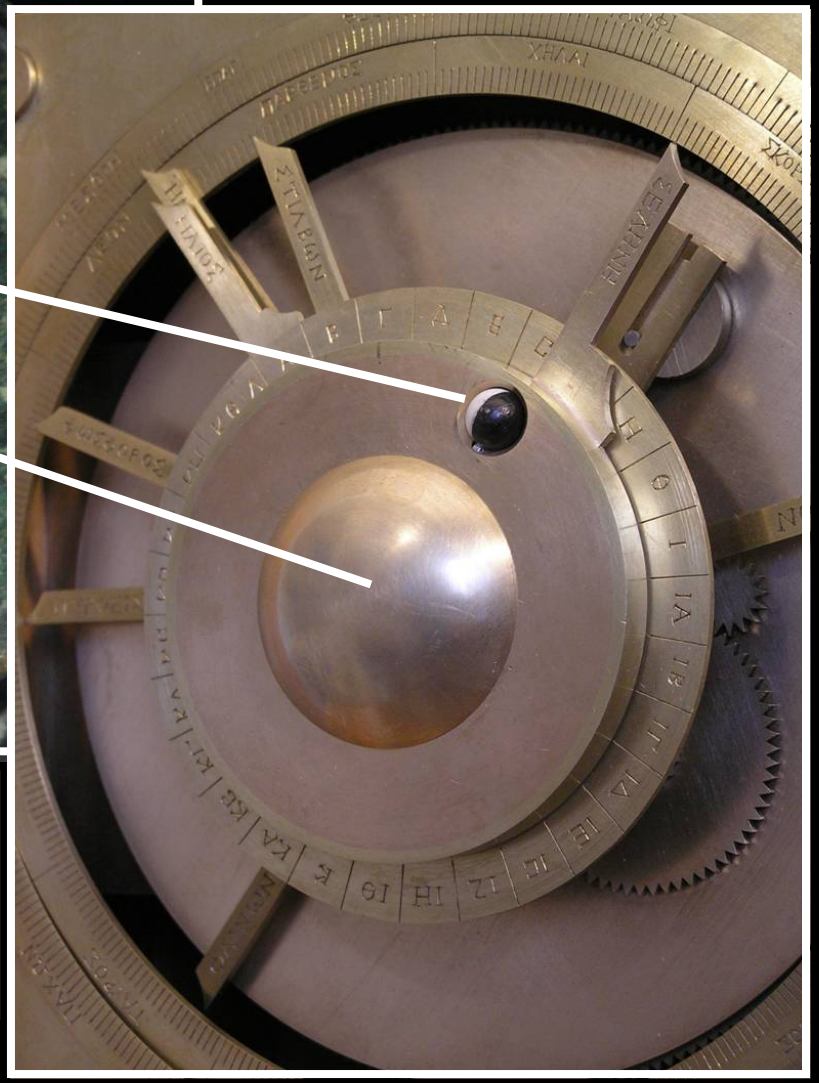
Parapegma text

# Fragment C, back



# Silver Moon Sphere





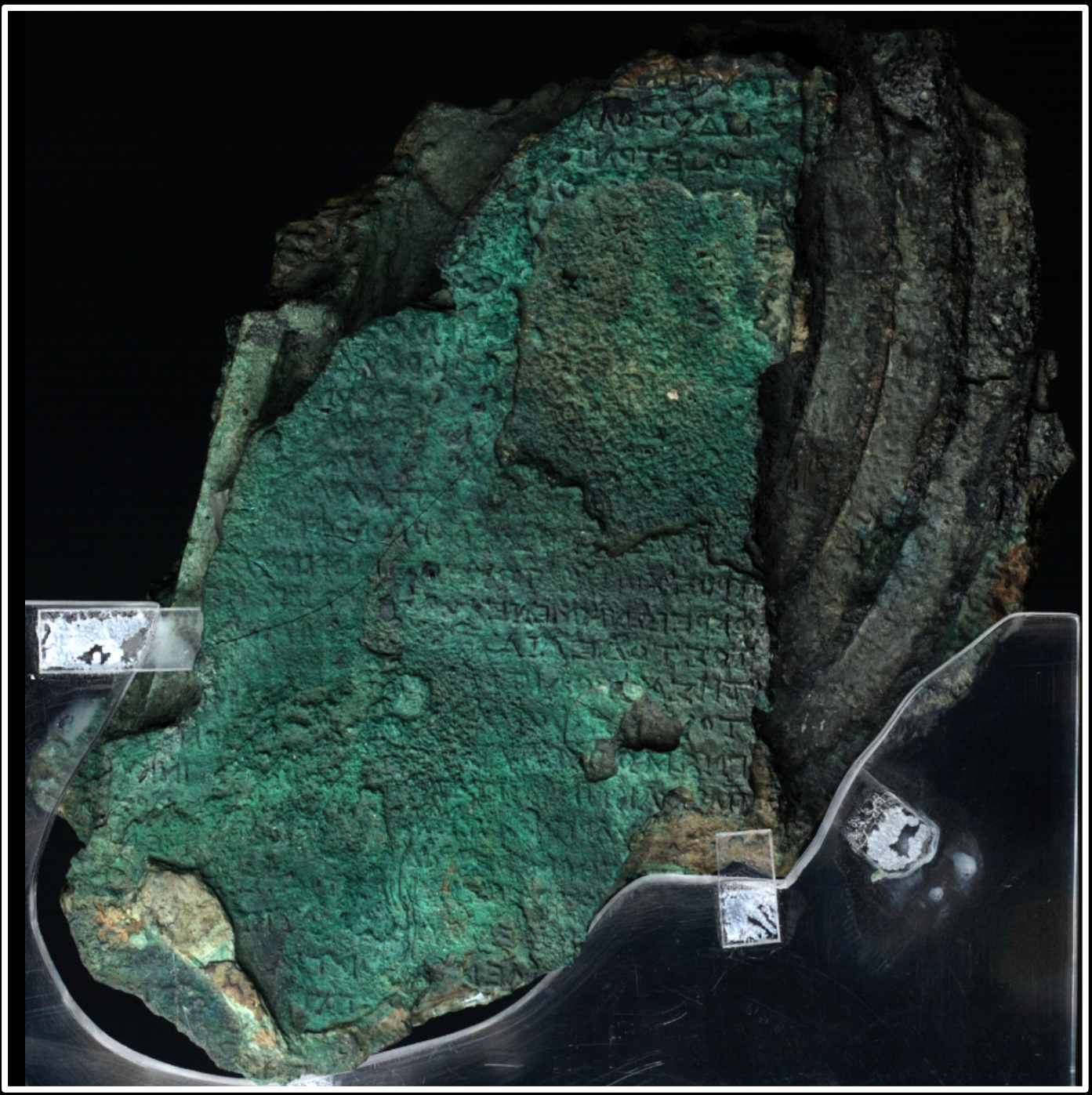
discovered by

M. Wright


Inscriptions

Fragment B:

Backdoor Inscriptions



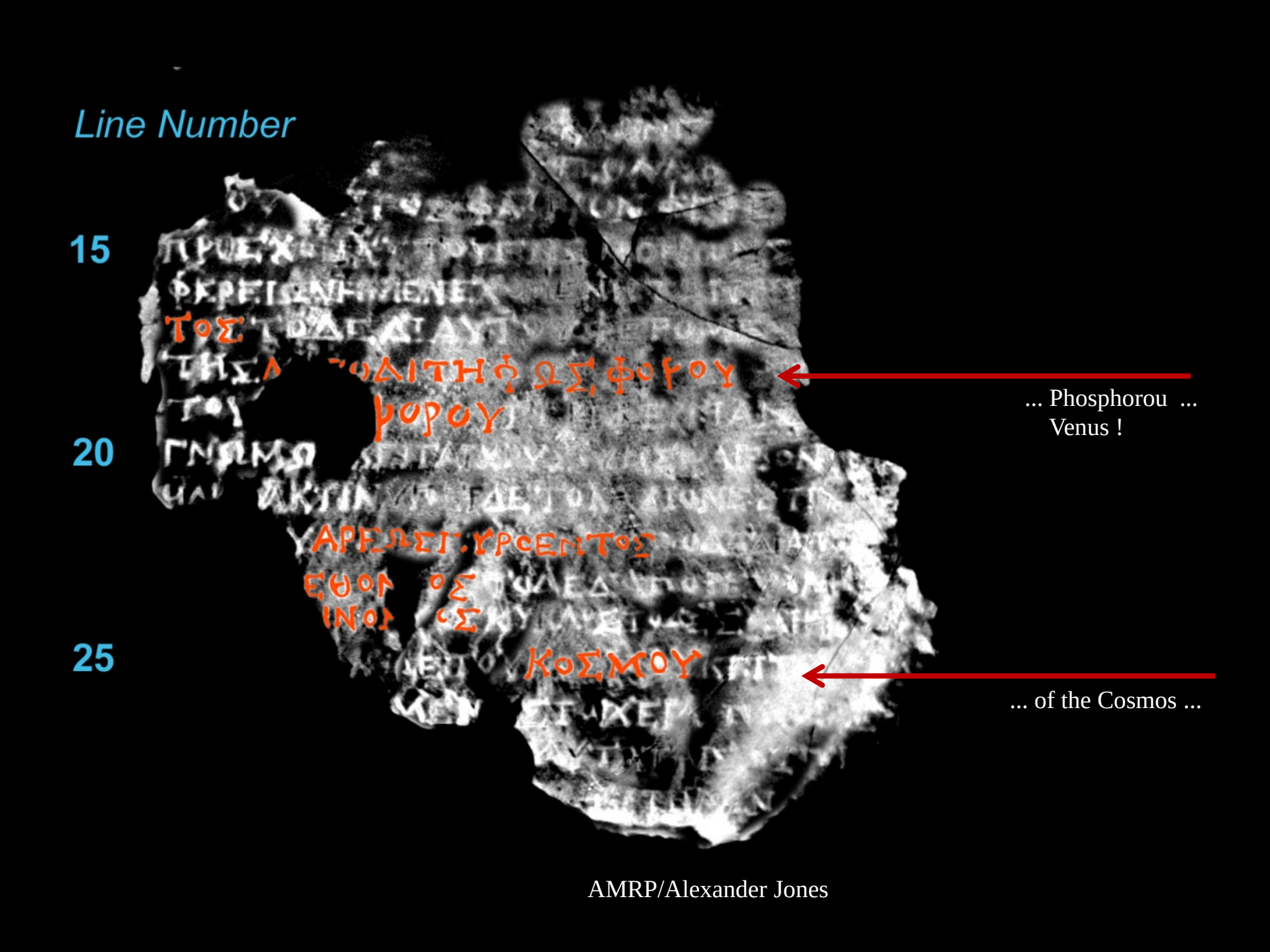
Instrument covered with inscriptions:

- 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 ...
AMRP/Alexander Jones

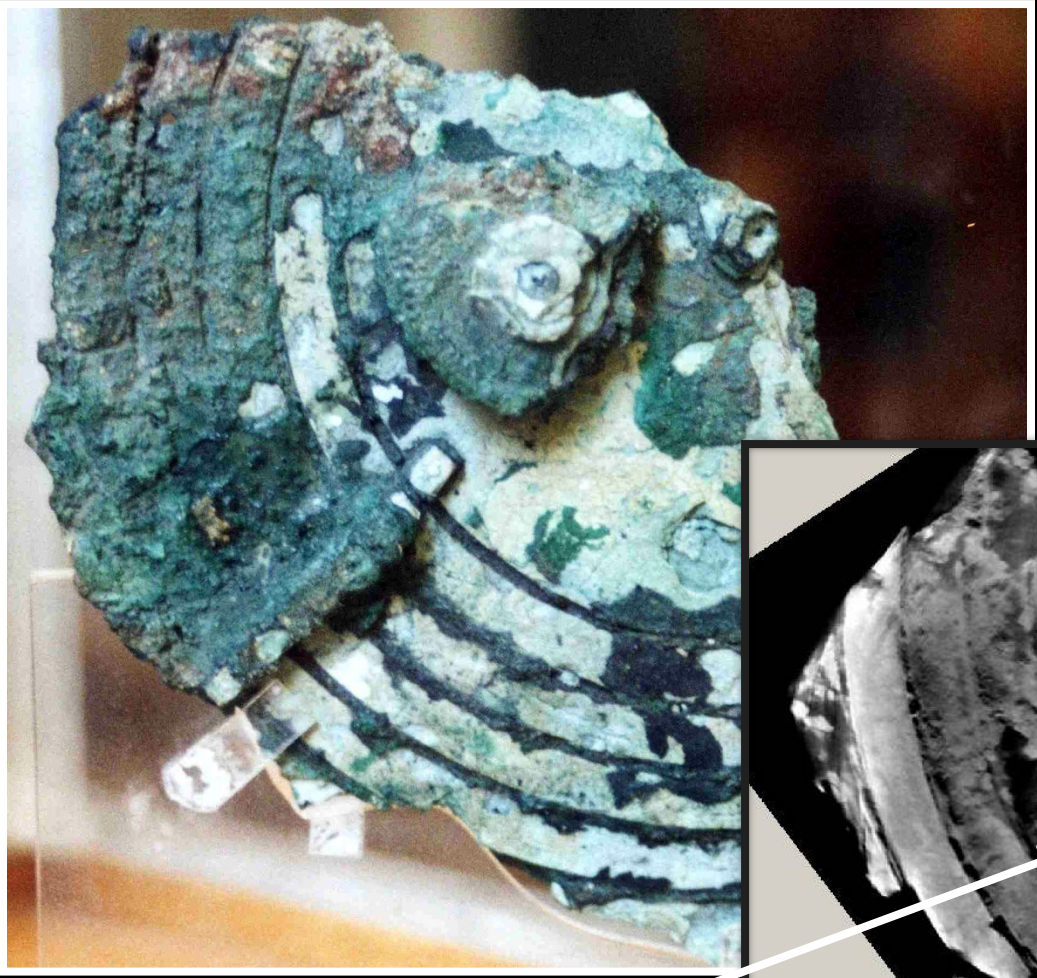
Technical Inscriptions:

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

Astronomical Inscriptions:

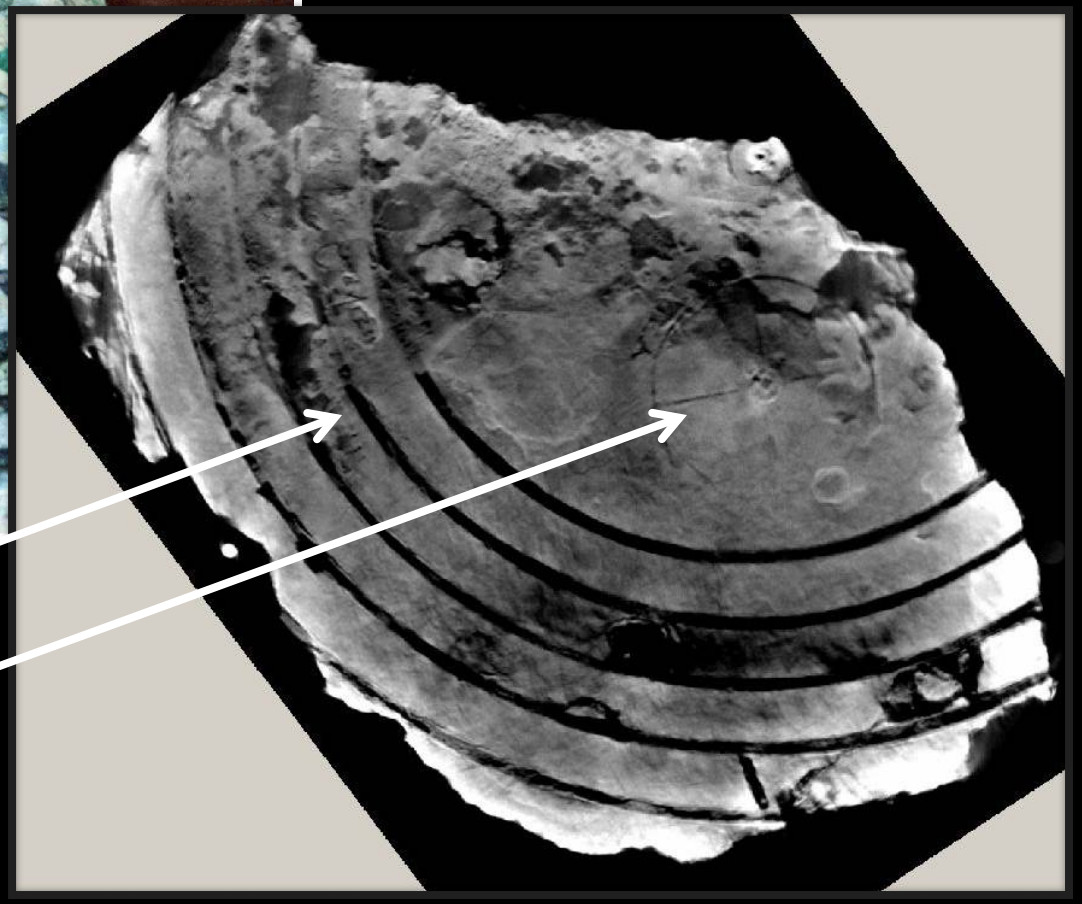
- “□□□□□□□□□”: stationary point planets’ retrograde motion
- “Venus approaches the Sun”
- “The Hyades set in the evening”
- “Gemini begins to rise”, …
- “ the 76 years, 19 years of the …”


Back Dials



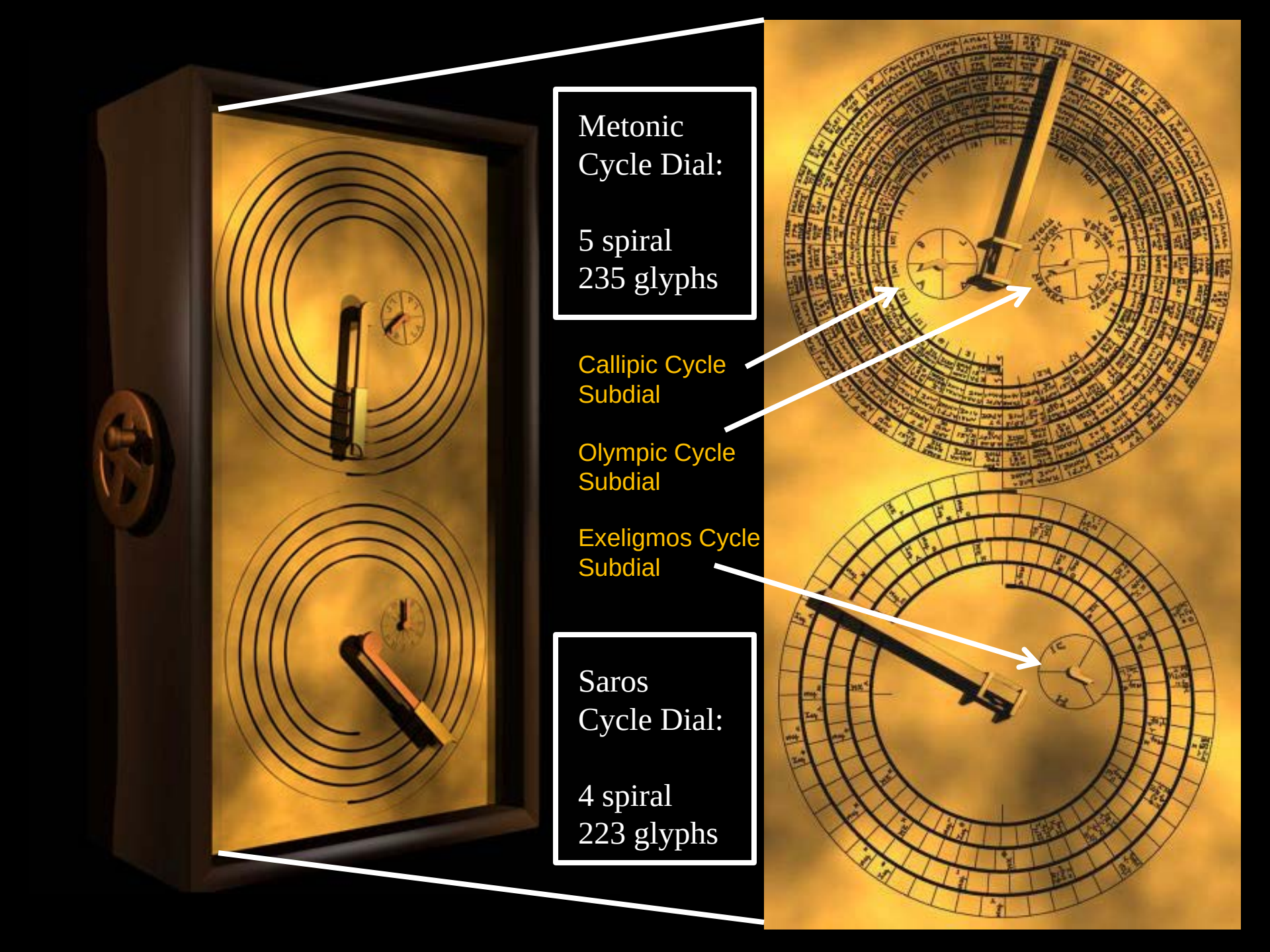
# Fragment B

## 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

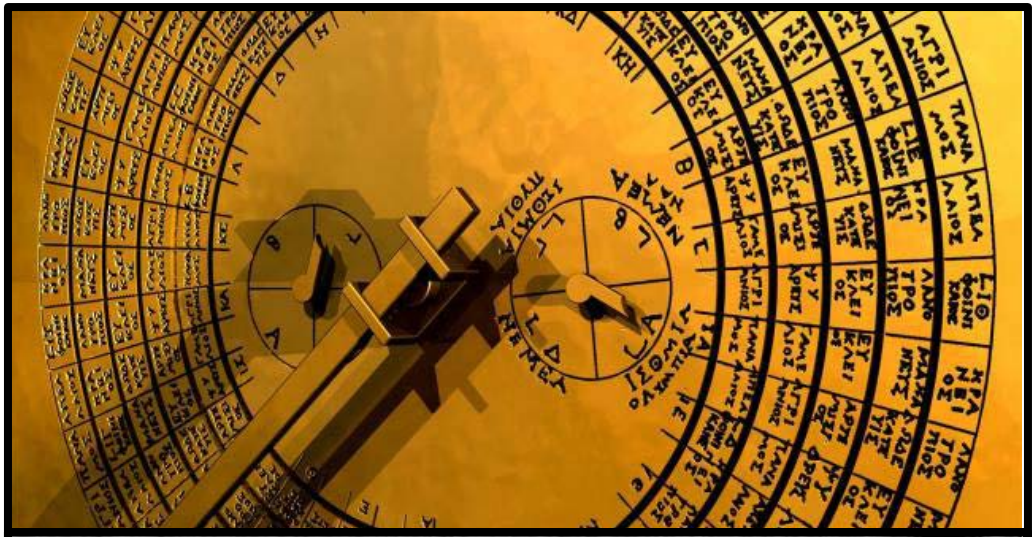
223 synodic;
242 draconic;
239 anomalistic:
18 yrs, 11 days, 8 hrs (6585 1/3 days)

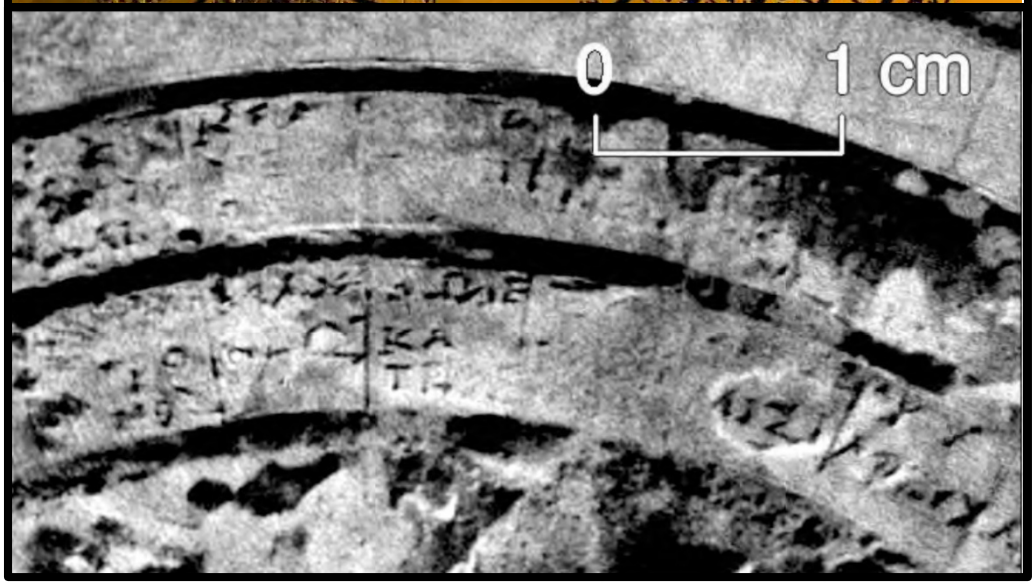
## Exeligmos Cycle

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

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

# Metonic Cycle Dial






125 A-3.2

Σ H\M ω\ρ H
H ω\ρ Γ
Z

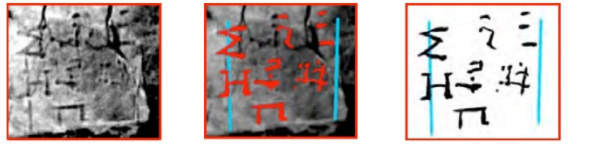
131 F-3.1

Σ B
H N\Y ω\ρ Θ
-
H

137 F-3.7

Σ H\M ω\ρ E
H ω\ρ IB
Θ

172 E-4.2



Σ
H ω\ρ
Π

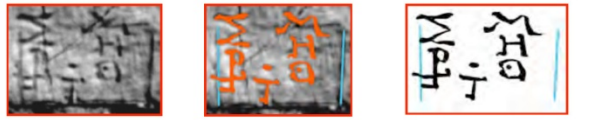
178 A-4.2

Σ ω\ρ Θ
H ω\ρ Θ
-
P

184 A-4.8

Σ H\M ω\ρ Δ
H A
Σ

190 F-4.5



Σ H\M
ω\ρ Θ
-
T

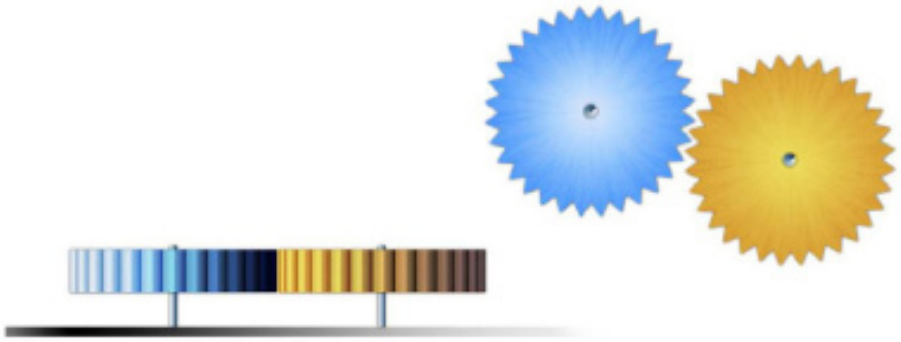
# Saros Dial


Saros Dial

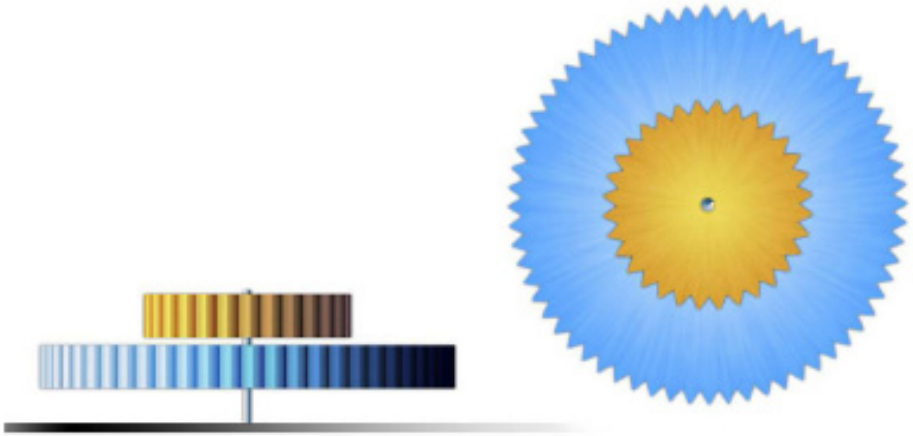
# Saros Dial


Antikythera Mechanism:
Gear Train Reconstruction

# Gear Transmissions



Division

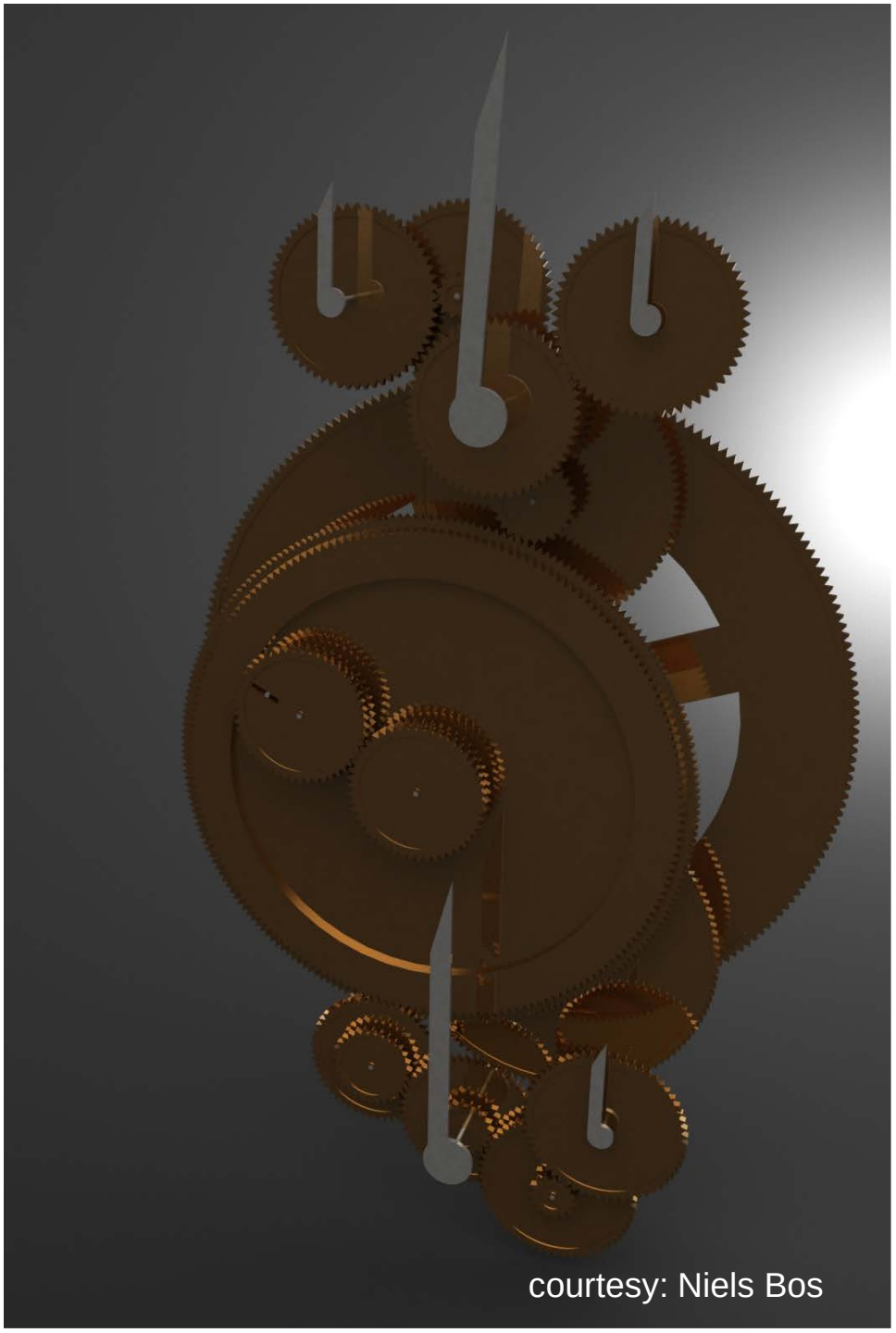


Multiplication

Example:

6 coupled gear wheels,
# teeth: r1,r2,s1,s2,t1,t2:

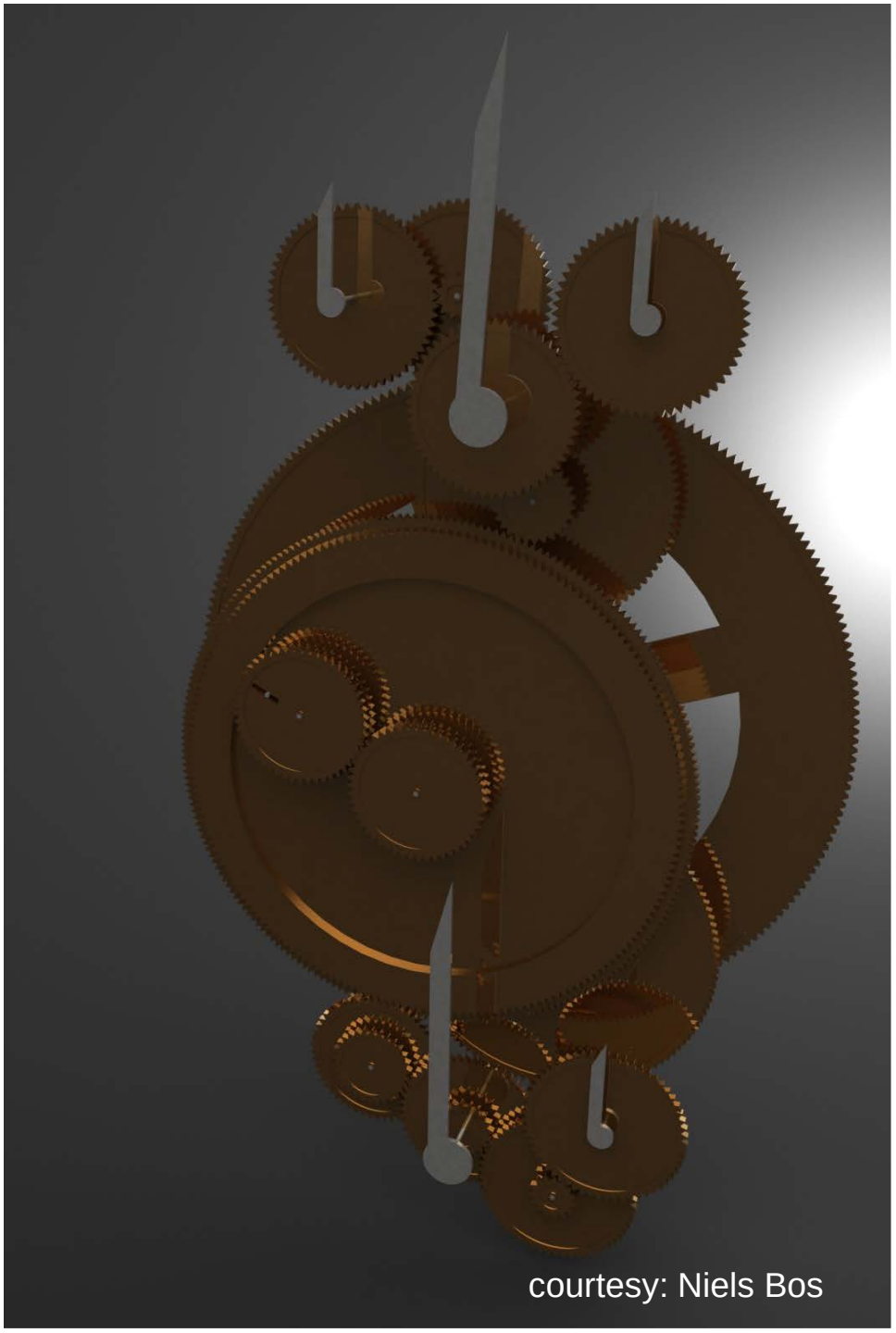
$$f = \frac{r1}{r2} \times \frac{s1}{s2} \times \frac{t1}{t2}$$


courtesy: Niels Bos

# Gear Train

| gear | #teeth |
|---|---|
| b | 64 |
| l1 | 38 |
| l2 | 53 |
| m1 | 96 |
| m2 | 15 |
| n1 | 53 |

$l \qquad -\frac{64}{38} = -\frac{32}{19}$

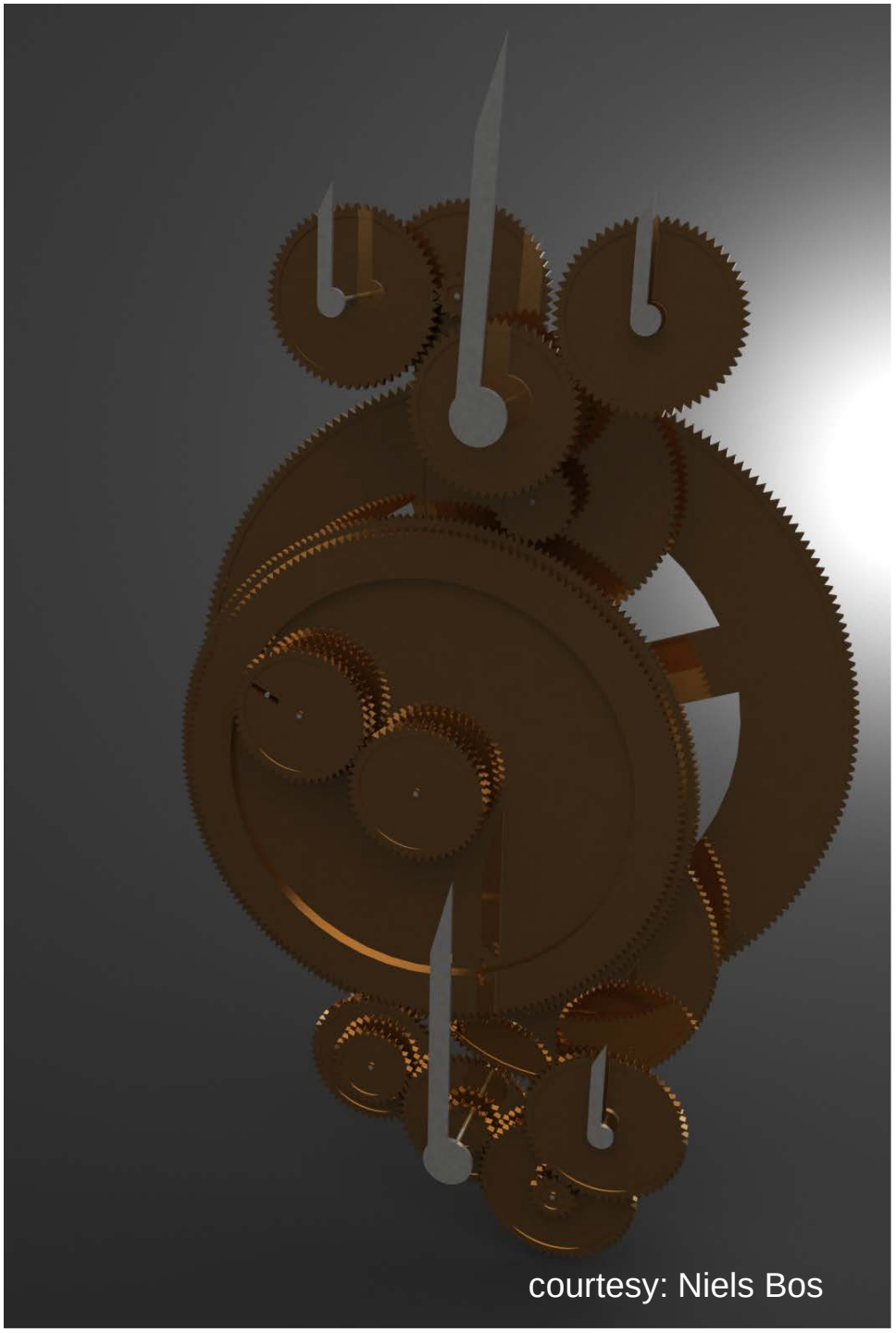



# Gear Train

| gear | #teeth |
|---|---|
| b | 64 |
| l1 | 38 |
| l2 | 53 |
| m1 | 96 |
| m2 | 15 |
| n1 | 53 |

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

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



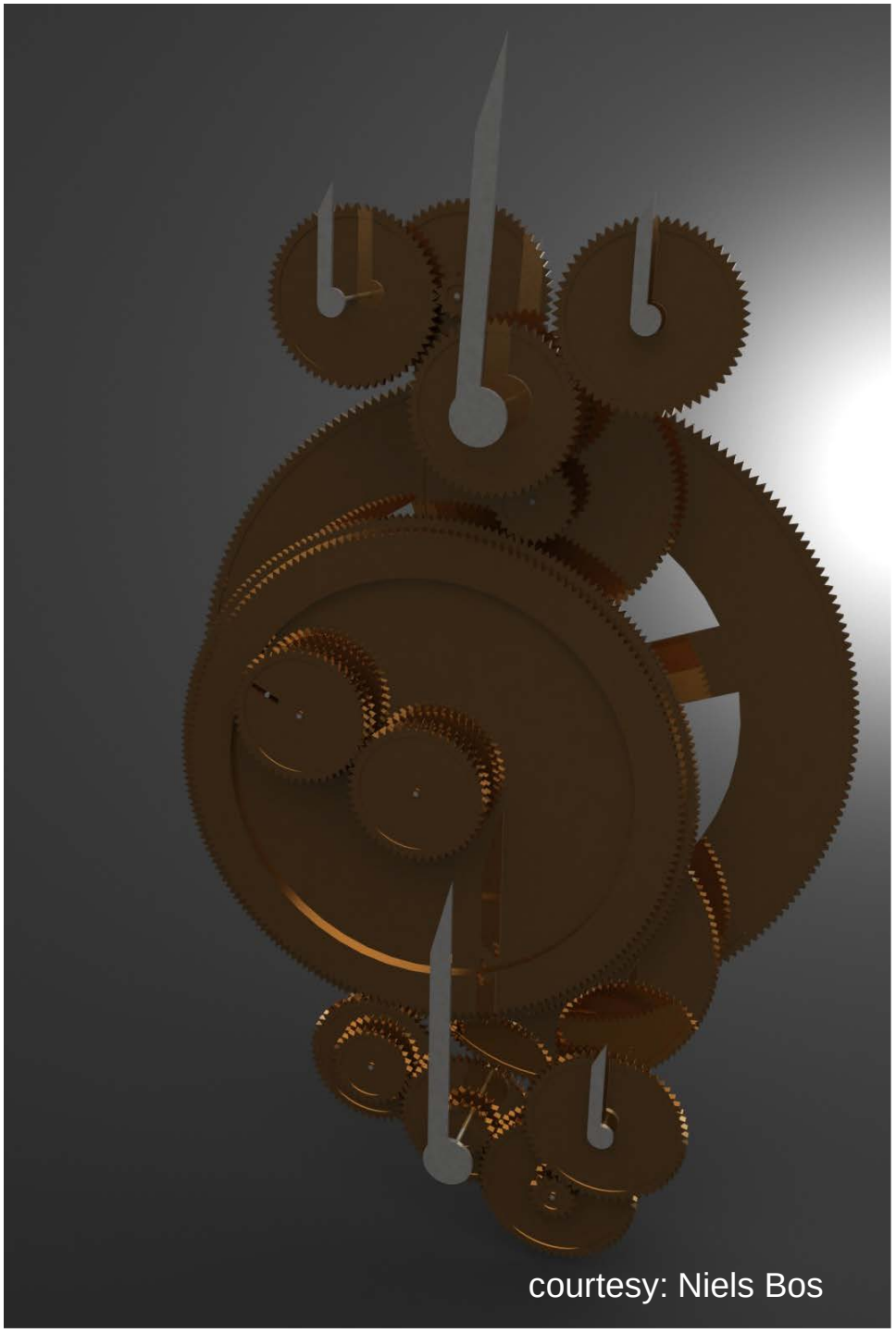

# Gear Train

| gear | #teeth |
|---|---|
| b | 64 |
| l1 | 38 |
| l2 | 53 |
| m1 | 96 |
| m2 | 15 |
| n1 | 53 |

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

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

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




# Gear Train

| gear | #teeth |
|---|---|
| b | 64 |
| l1 | 38 |
| l2 | 53 |
| m1 | 96 |
| m2 | 15 |
| n1 | 53 |

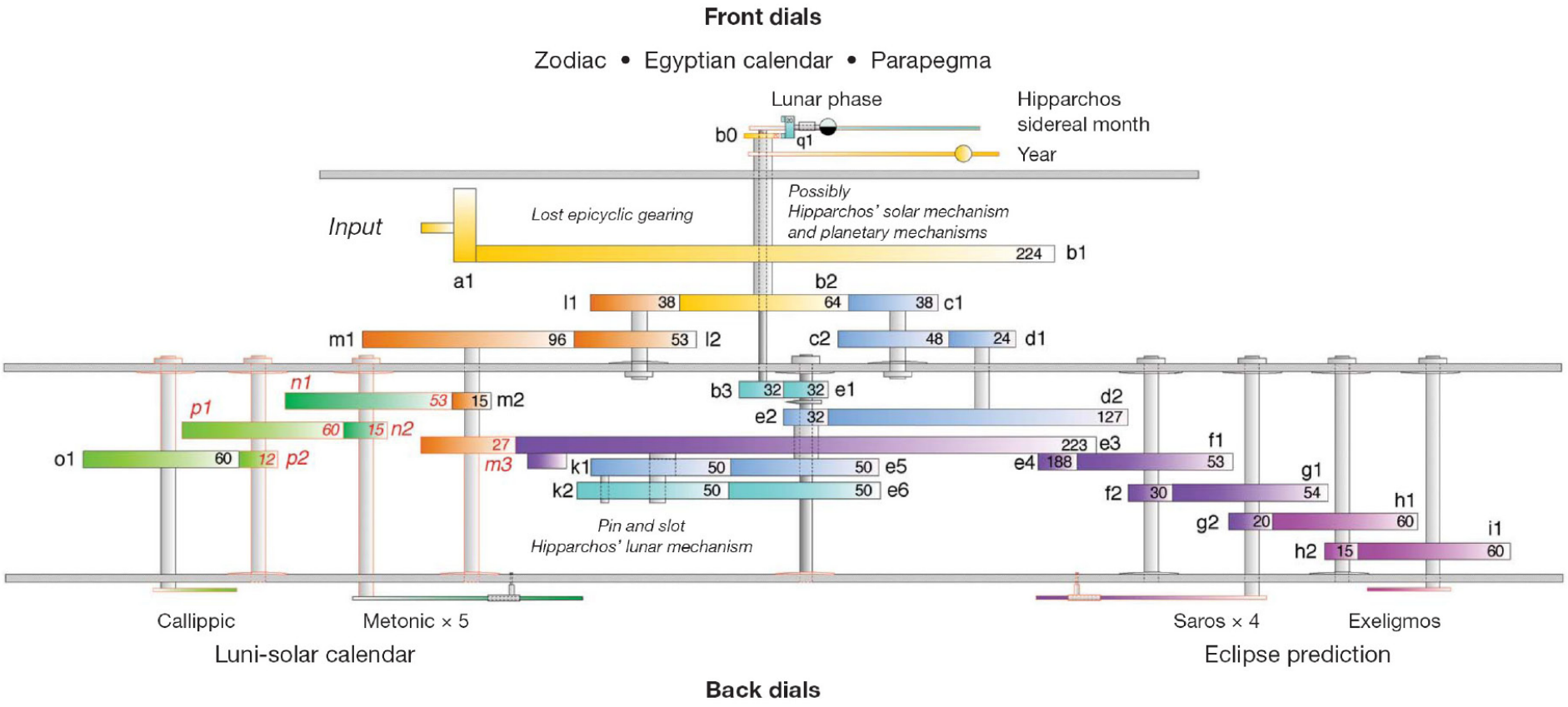
$l$ $\quad -\frac{64}{38} = -\frac{32}{19}$

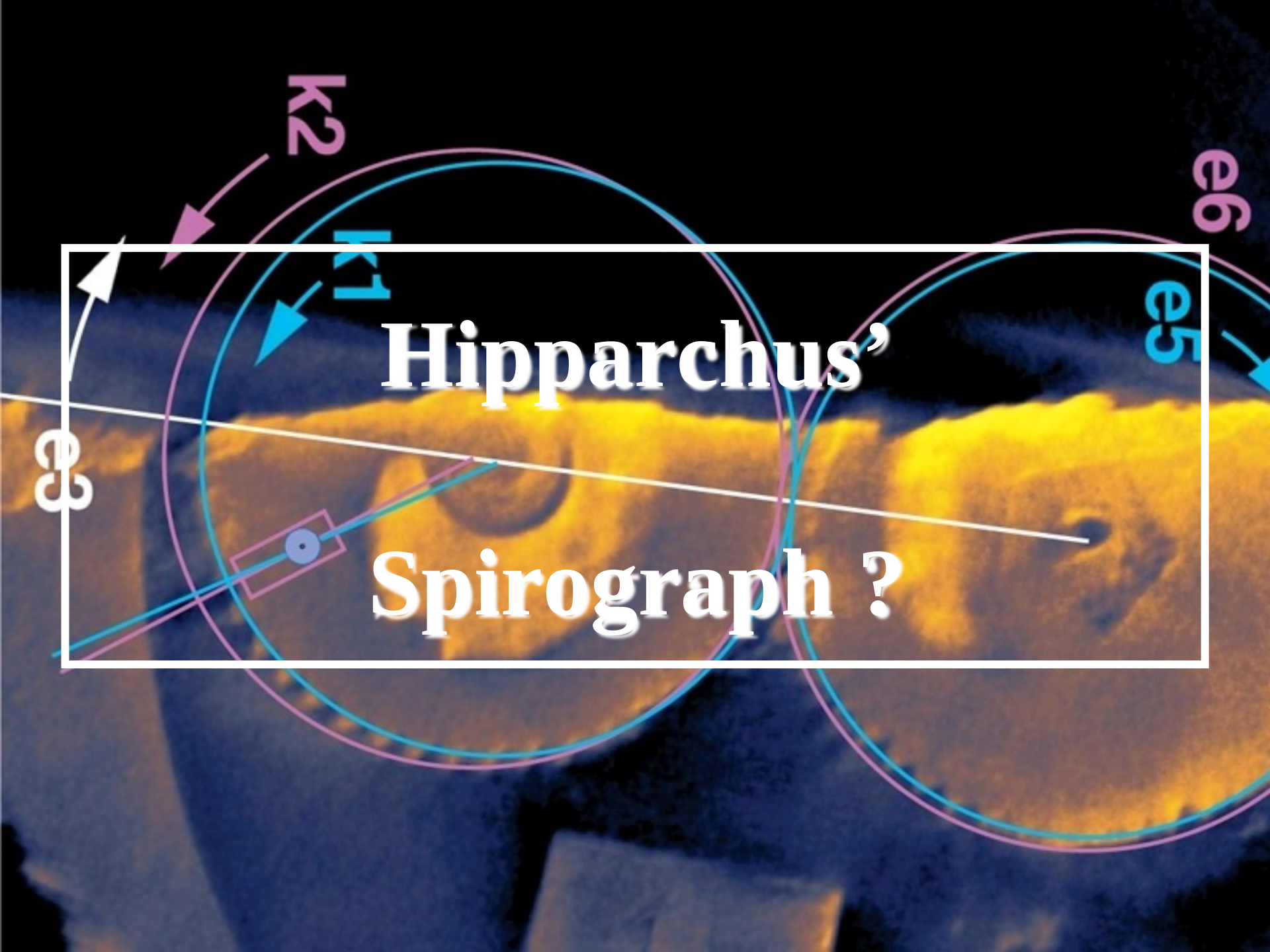
$m$ $\quad -\frac{32}{19} \times -\frac{53}{96} = \frac{53}{3 \times 19}$

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

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

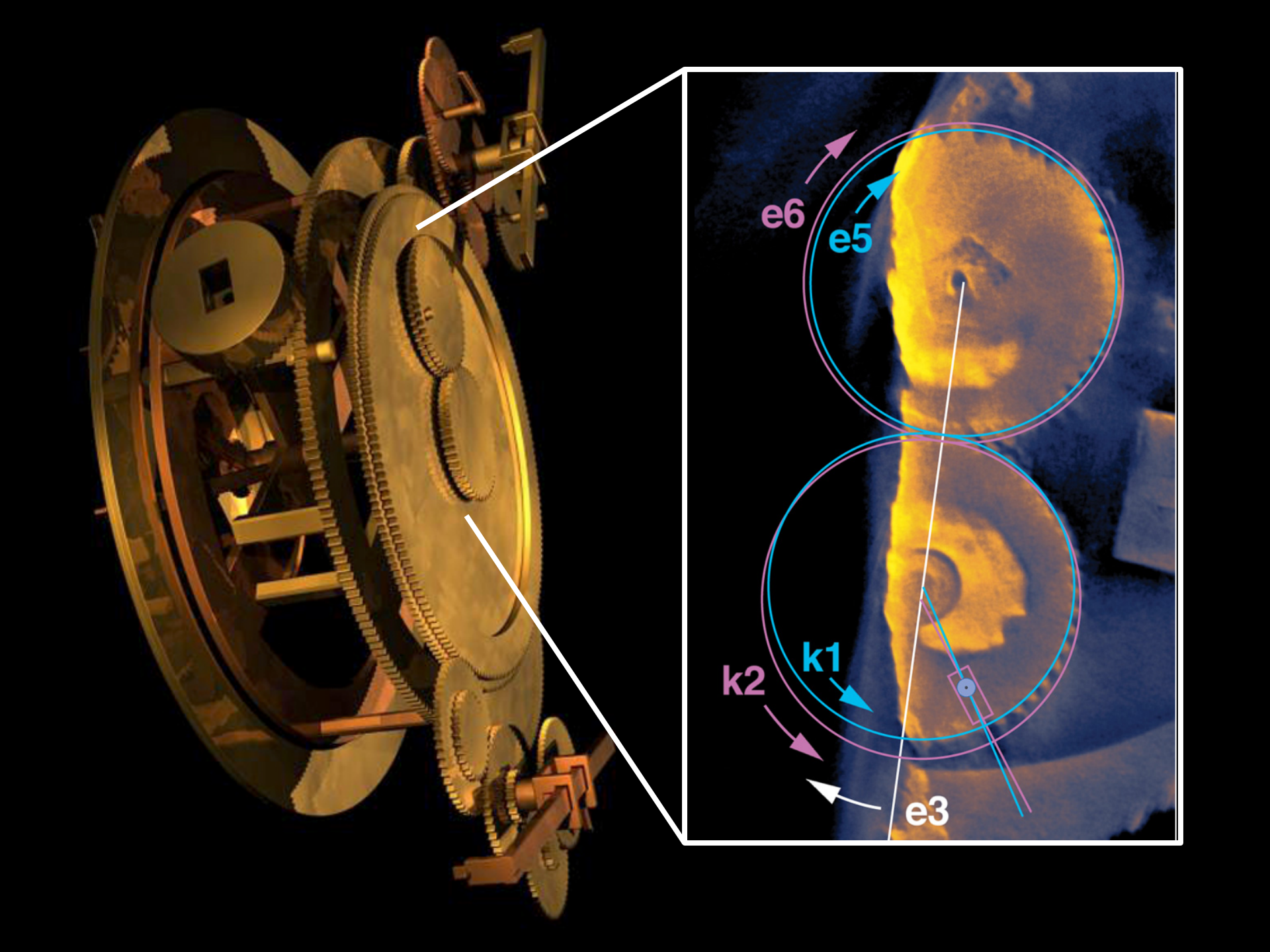
# AMRP Gear Train

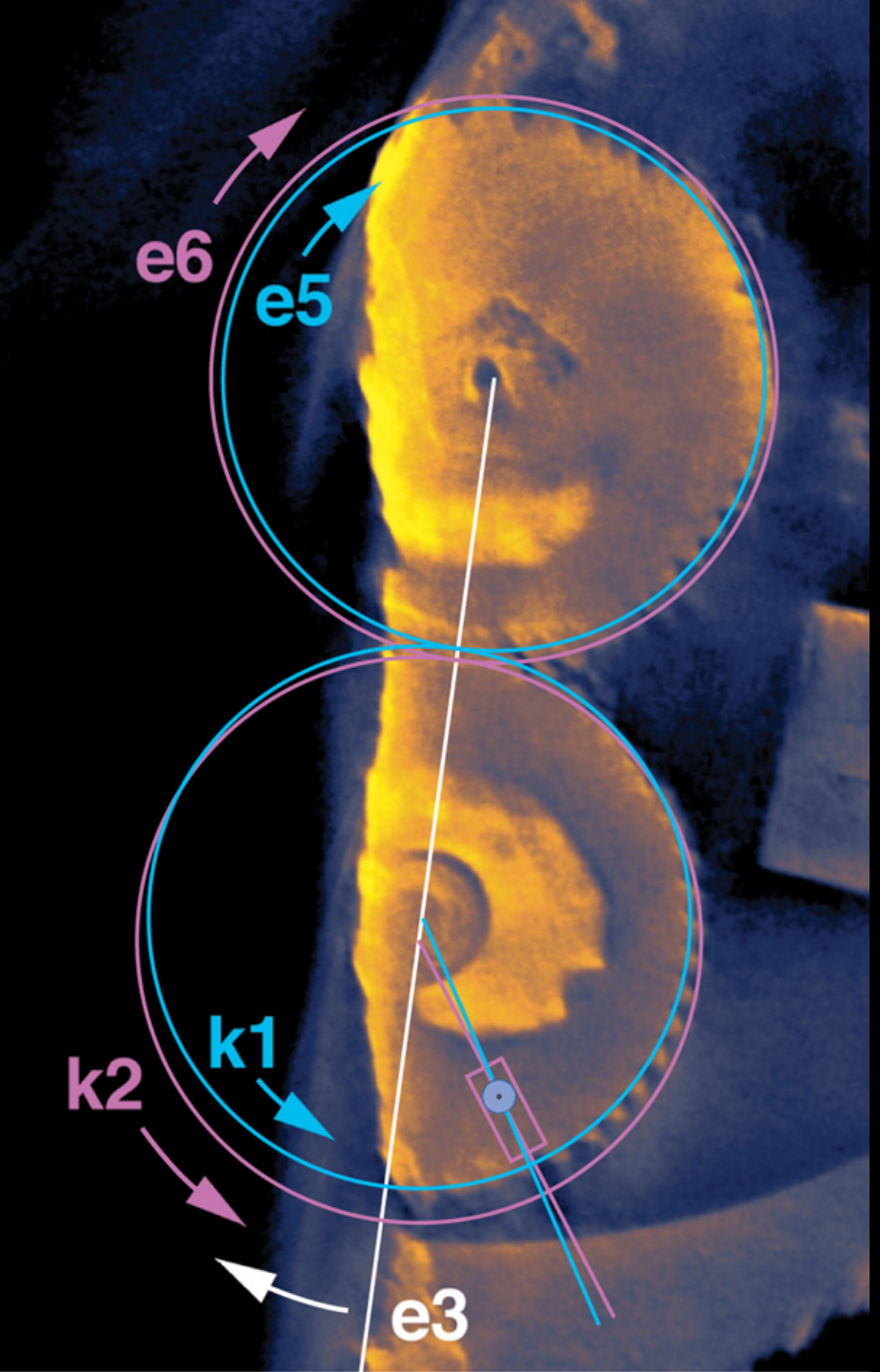





# Hipparchus'

# Spirograph ?


e6
e5
k1
k2
e3




# Pin-and-Slot Mechanism

**Hipparchus'**

**Lunar Mechanism**

## Epicycle Theory

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

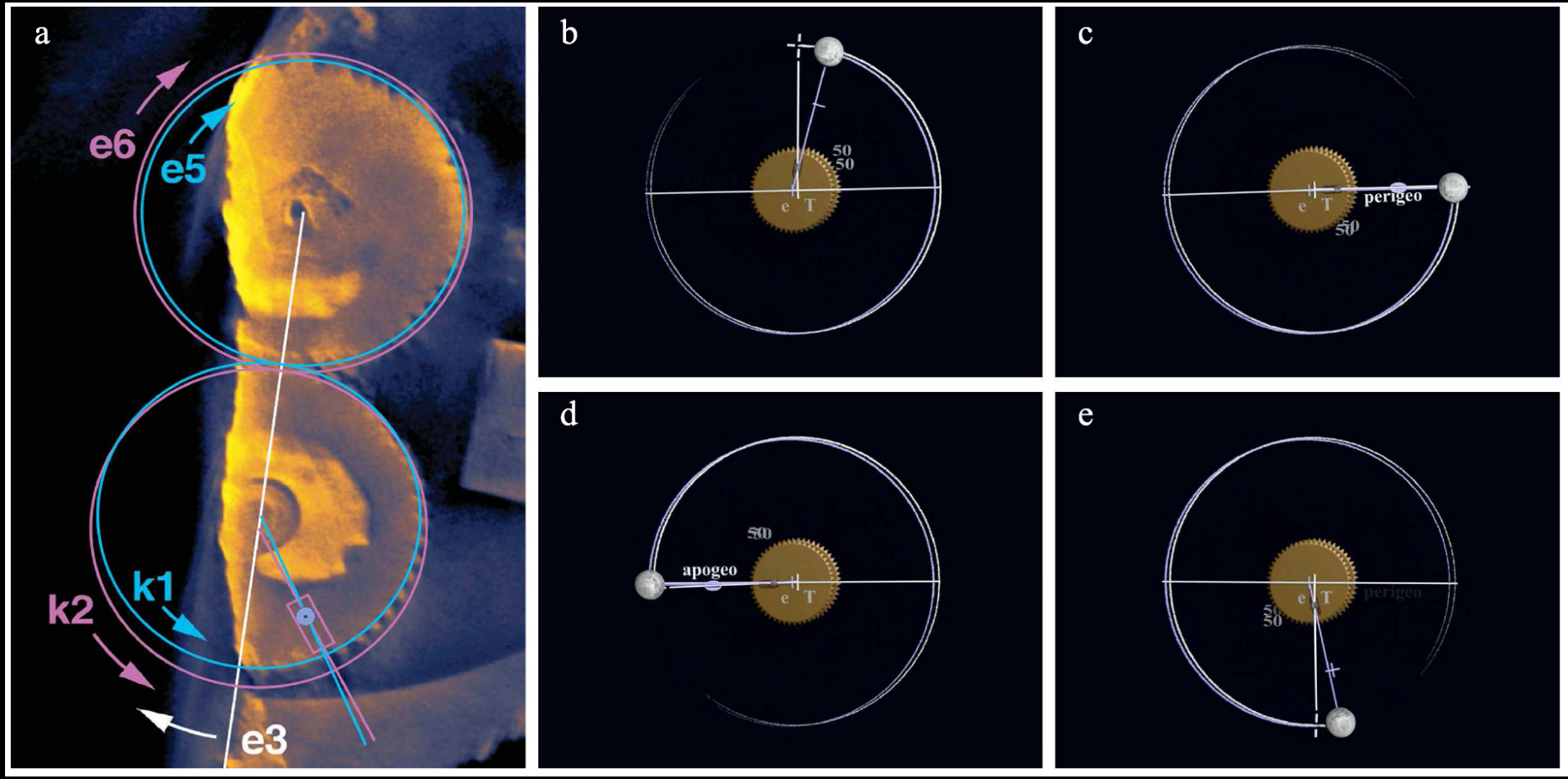
# Moon Size


different distance along orbit Moon

# Moon Libration

We can see more than ½ of Moon surface, due to its elliptical orbit

# Hipparchus' Pin-Slot Gears

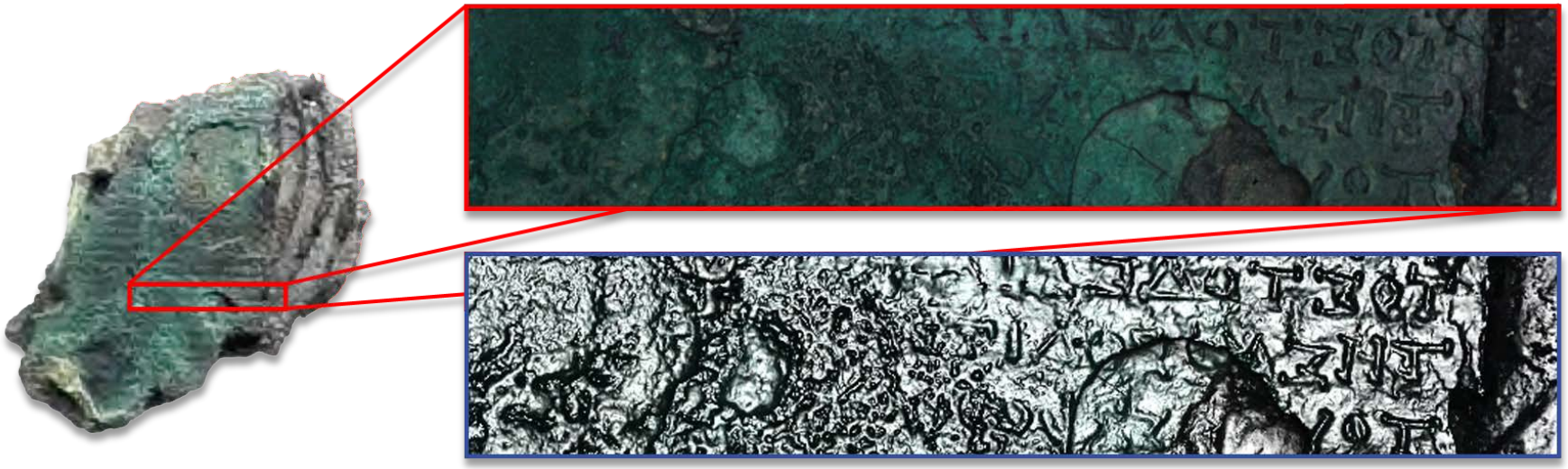


# the Antikythera Planetarium ?

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

# the Antikythera Planetarium: indications

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



# the Antikythera Planetarium: indications

- Inscriptions on the surviving fragments
  - Early reading of ``ΤΗΣΑΦΡΟΔΙΤΗ'' (..of Venus..)
  - Freeth & Jones (2012)
- Fragment A
  - Large size of the Sun wheel
  - Irregular features

# the Antikythera Planetarium: indications

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

- Fragment A
  - Large size of the Sun wheel
  - Irregular features

- Fragment D
  - Contains the only gear with no function

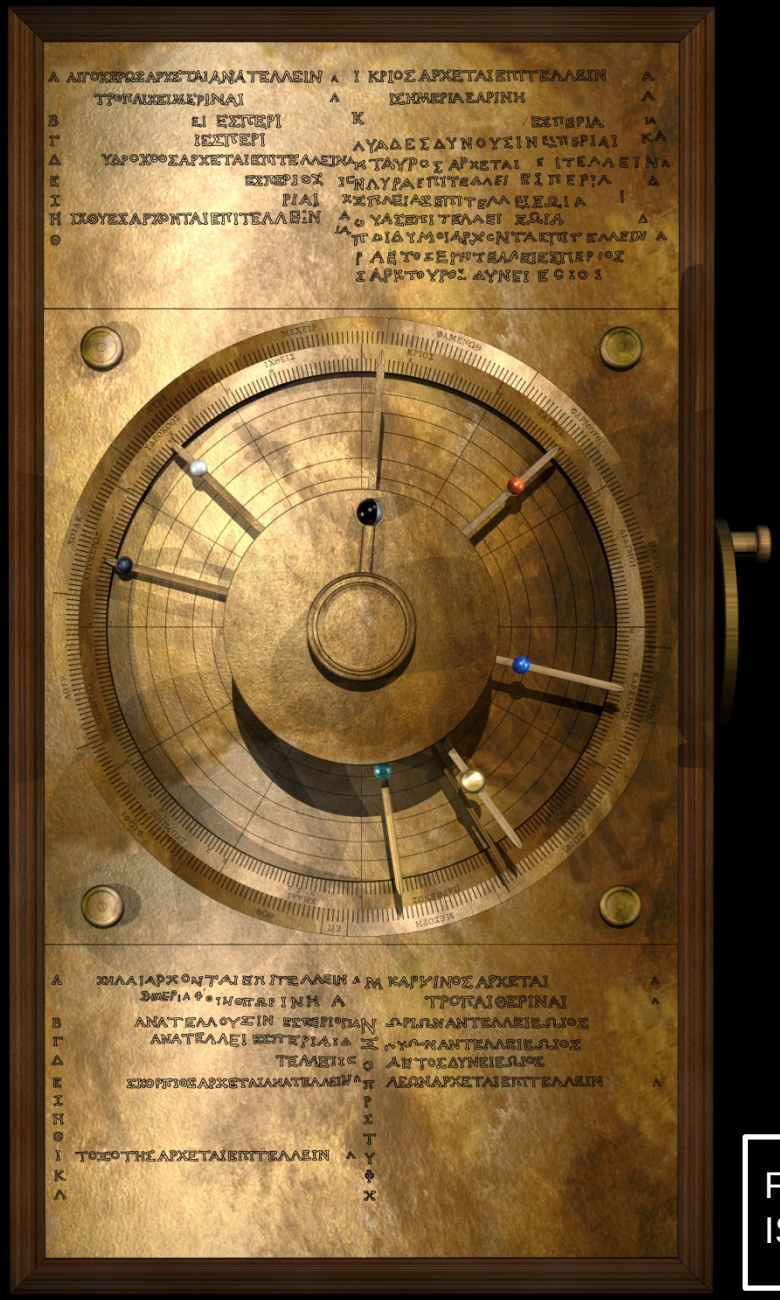
# the Antikythera Planetarium: indications

- Inscriptions on the surviving fragments
  - Early reading of ``ΤΗΣΑΦΡΟΔΙΤΗ'' (..of Venus..)
  - Freeth & Jones (2012)
- Fragment A
  - Large size of the Sun wheel
  - Irregular features
- Fragment D
  - Contains the only gear with no function
- References found in ancient literature

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.

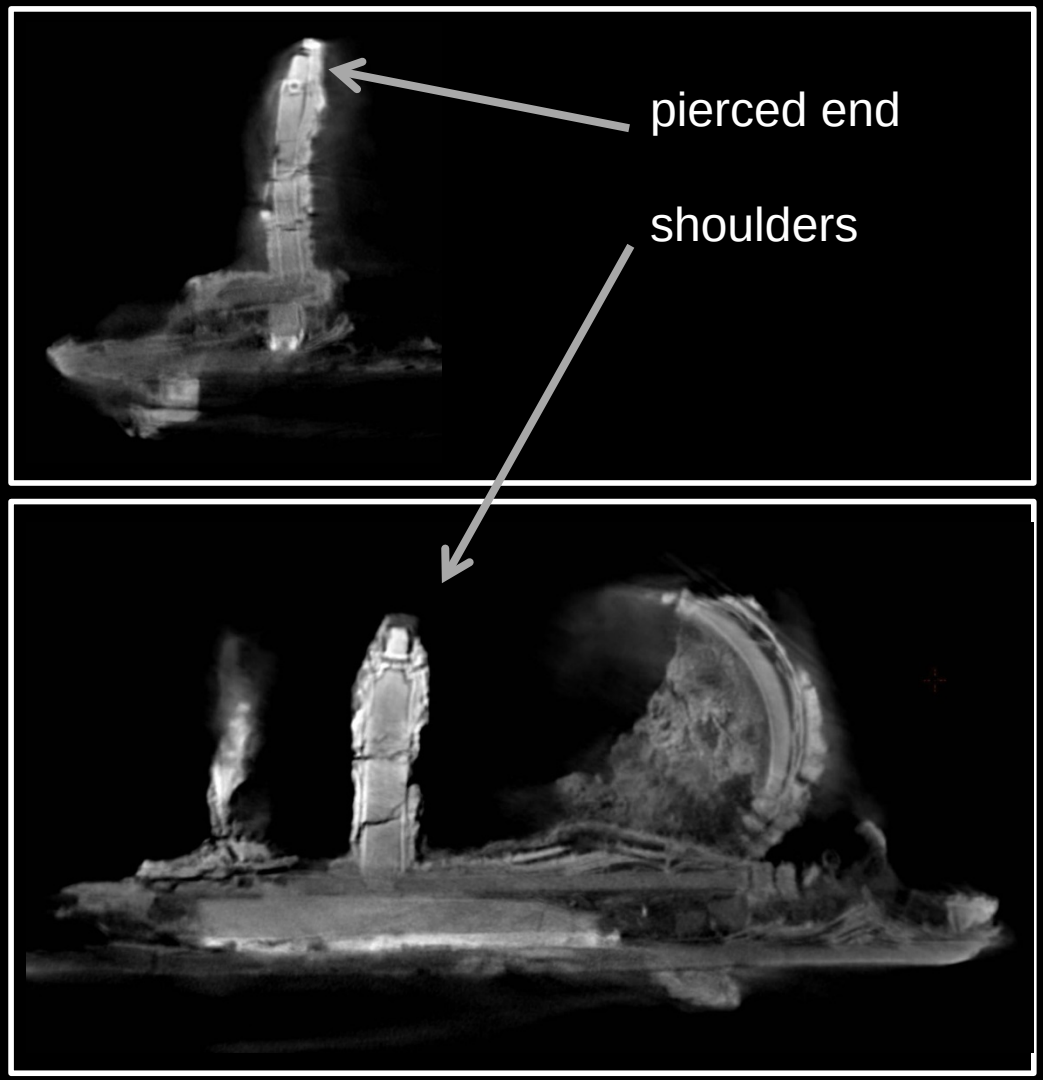
# Mechanical Elements

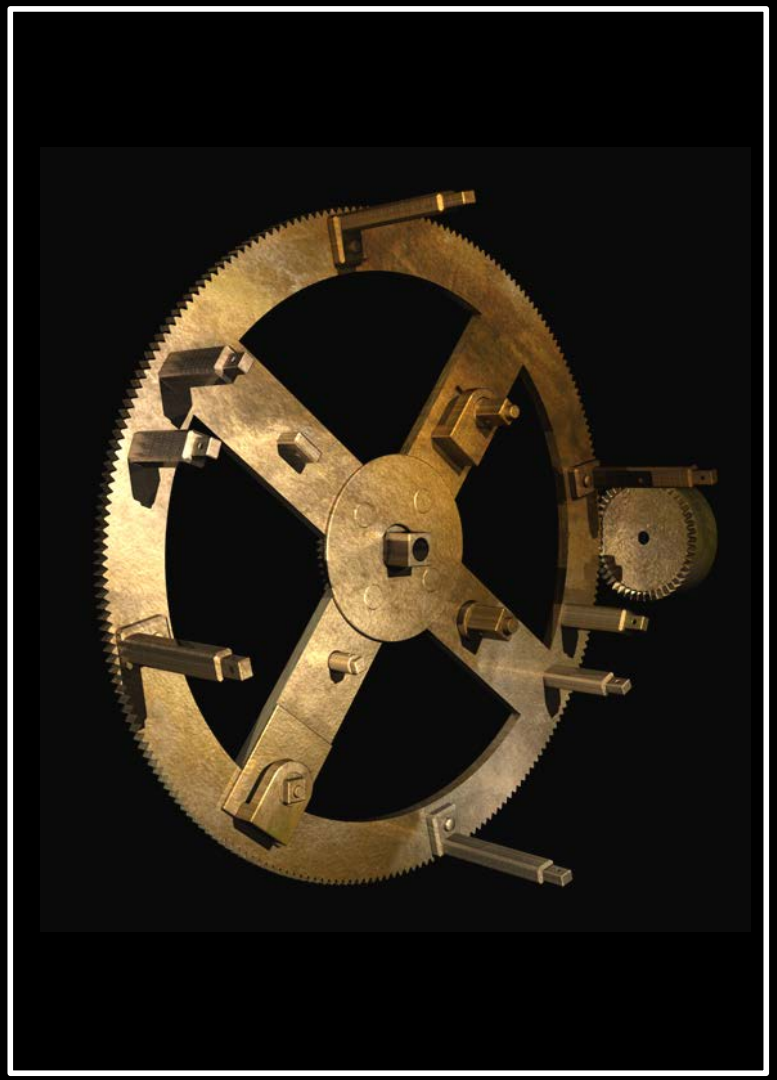
evidence of

pillars, bearing and
other fittings on the

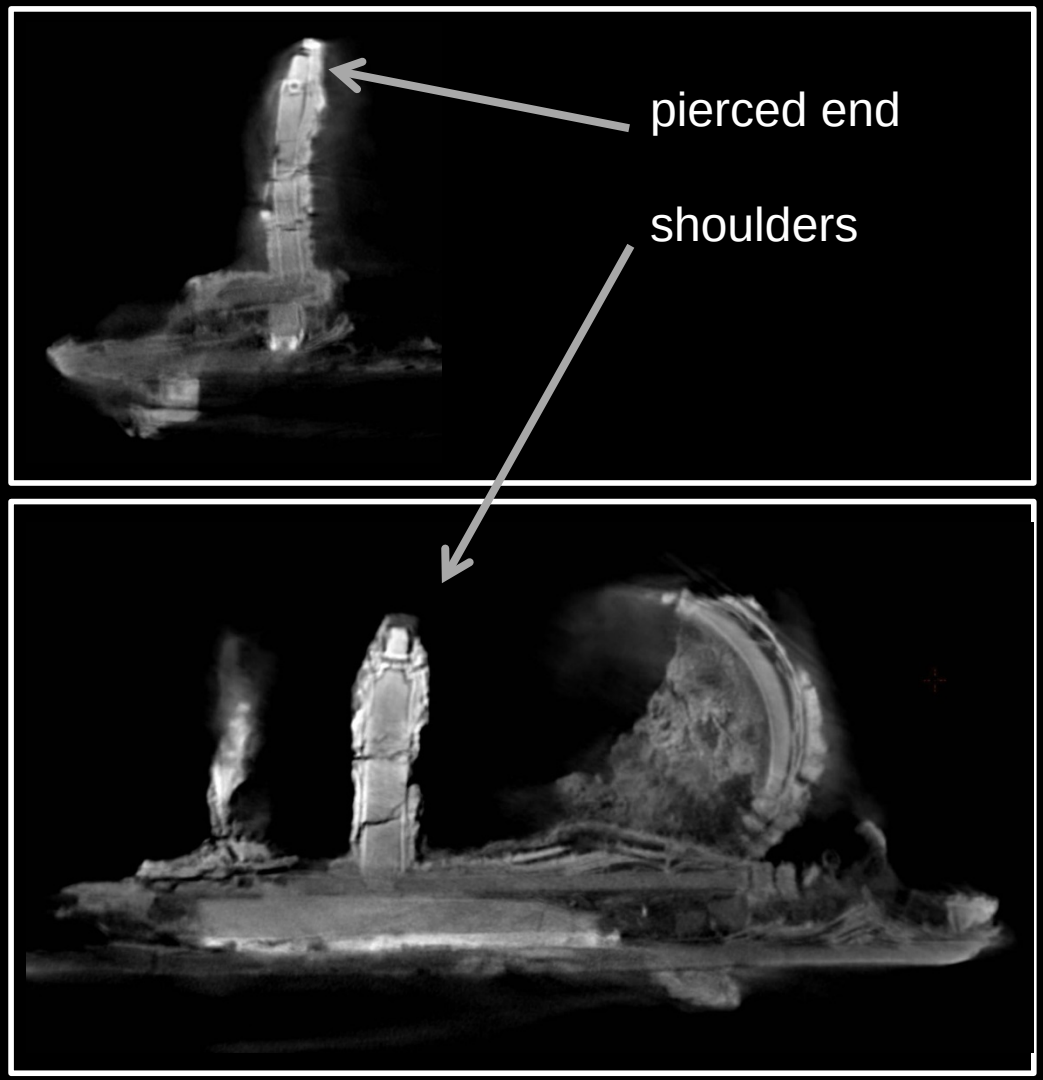
Main Drive Wheel

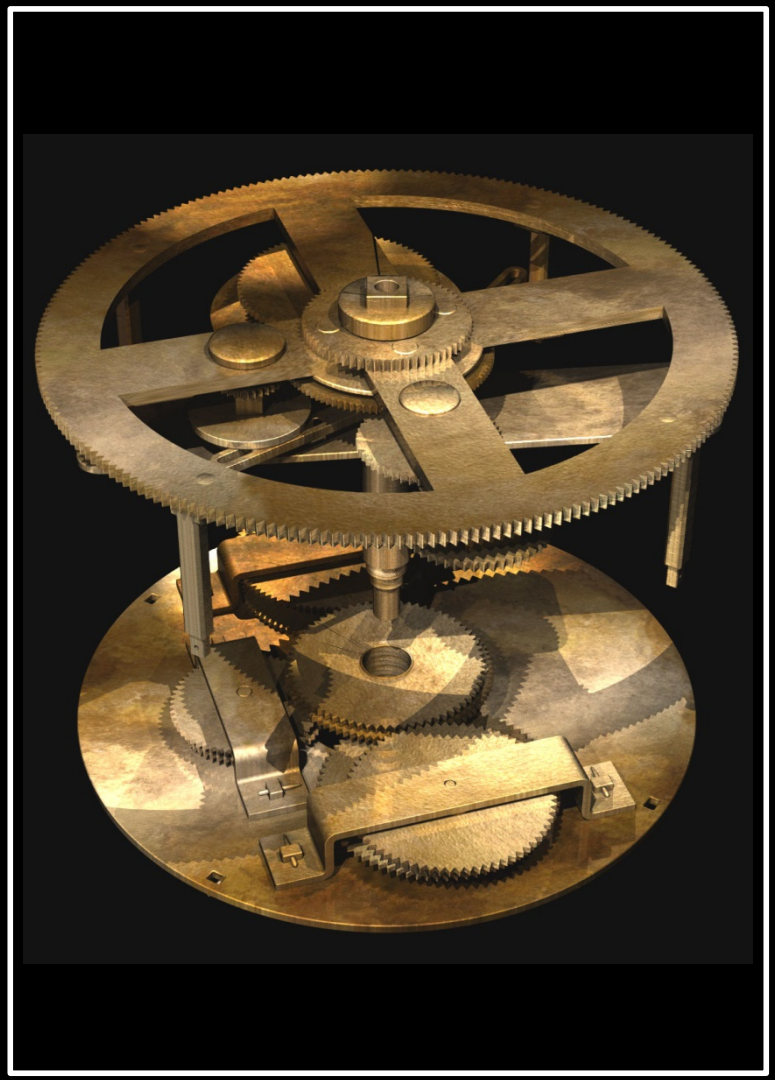
# Mechanical Elements



# Mechanical Elements




# M. Wright

**copper hardware models of**

- **Antikythera planetarium**
- **Archimedes Sphera**

# M. Wright

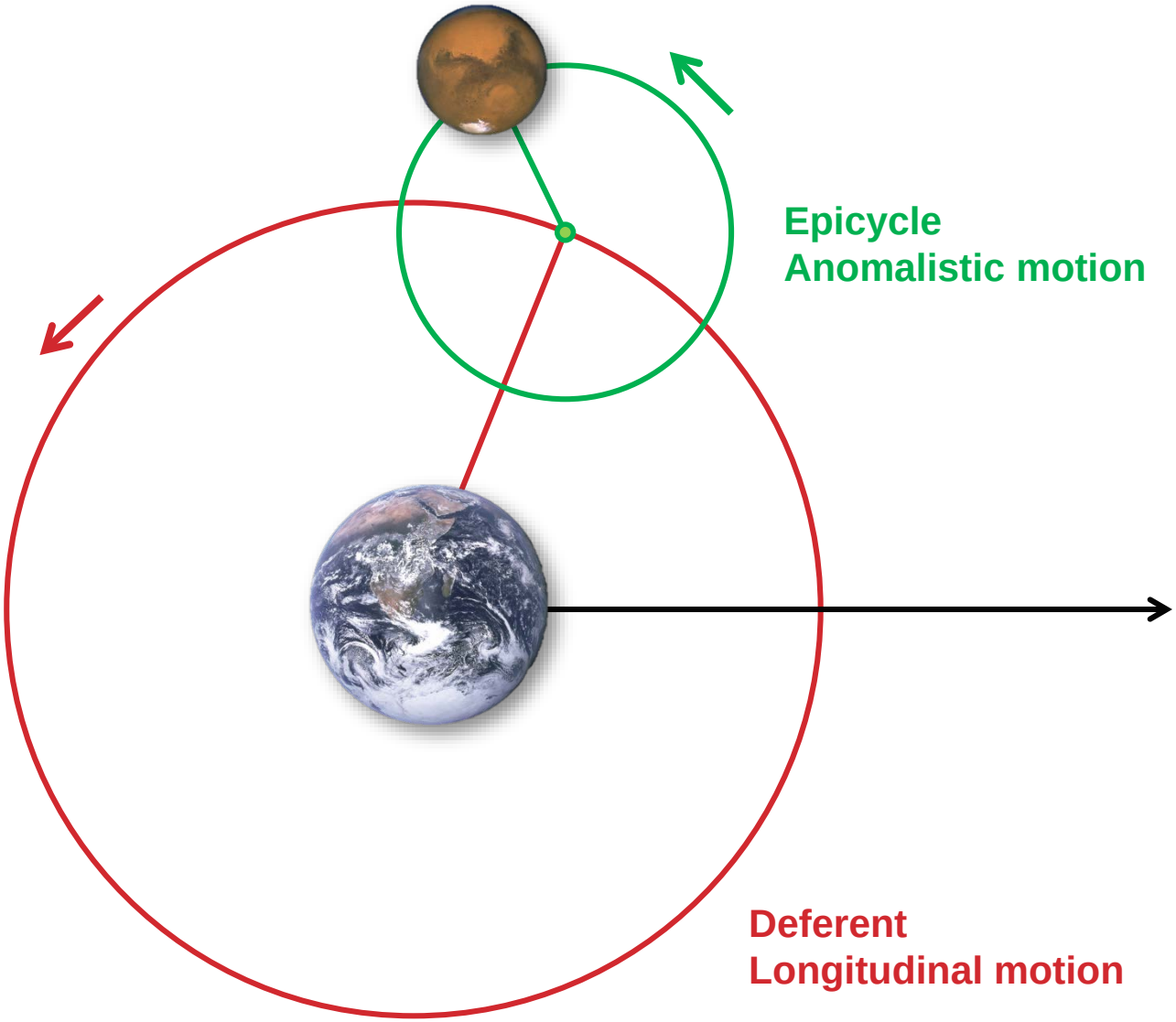
**copper hardware model Antikythera planetarium components**

**M. Wright**

**Science Museum London**

# Geometric (Epicycle) planetary models

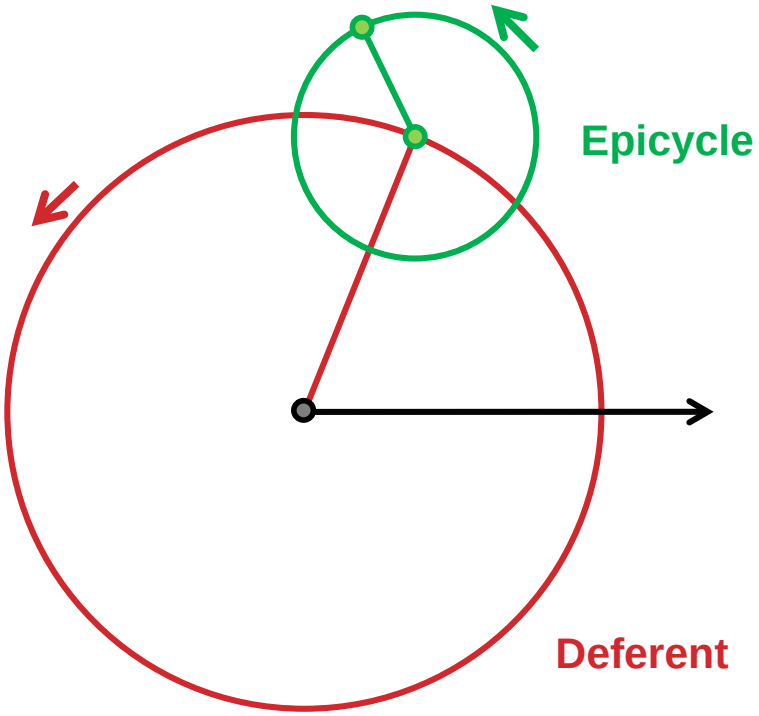
# Geometric (Epicycle) planetary models



# Periods to Gears

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

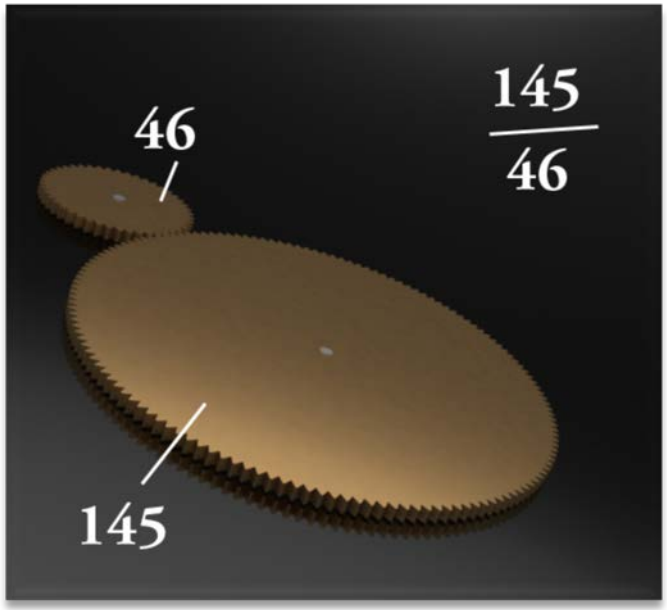
- Geared solution: 145/46

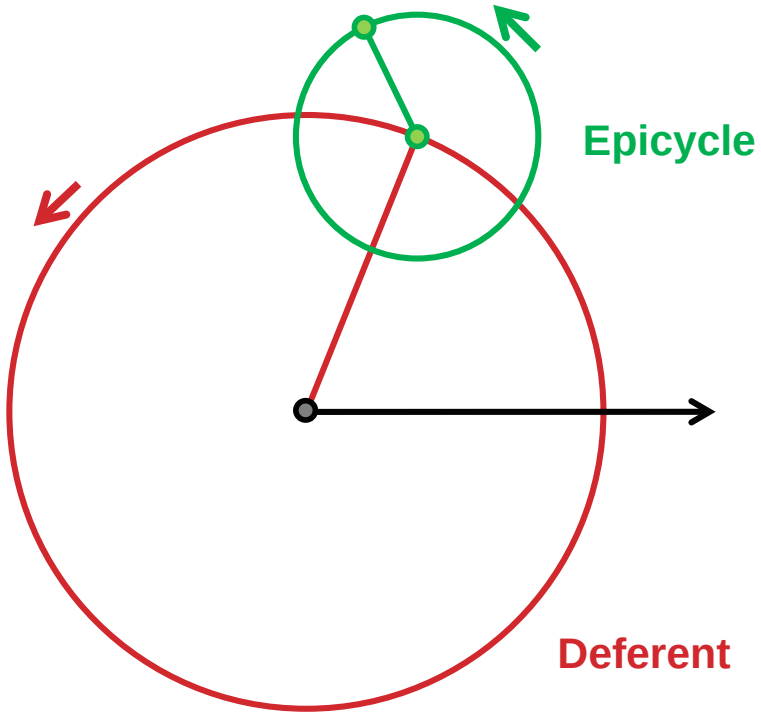


# Periods to Gears

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

- Geared solution: 145/46

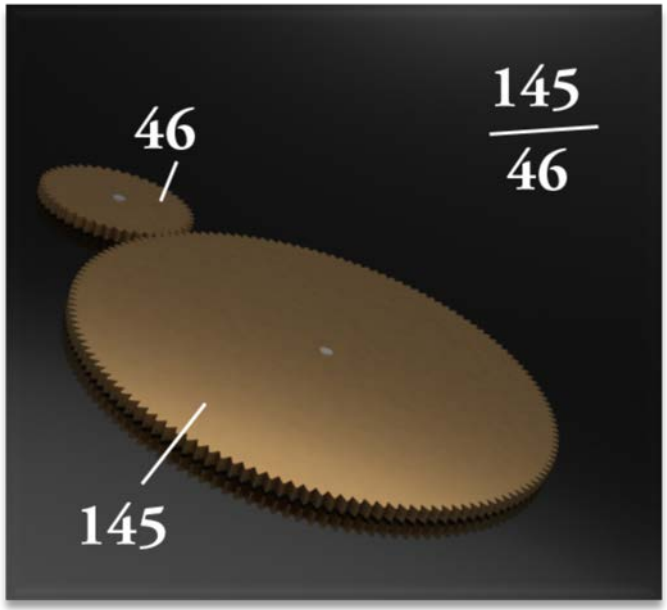


# Periods to Gears

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

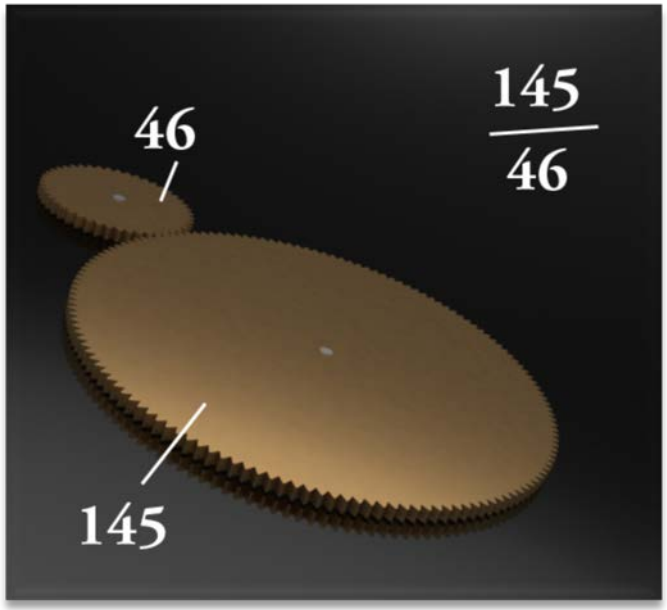
- Geared solution: 145/46
  - Factorizes into: 5 x 29 and 2 x 23

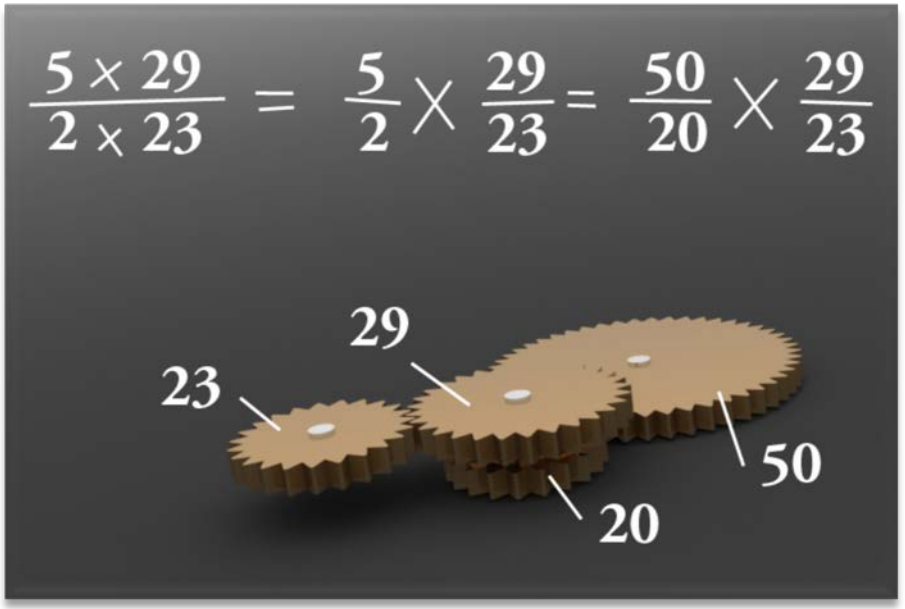


# Periods to Gears

- 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 > 1e6:
  - 1 | 4500800.99764 | 97 | 3519.0 | 5626.0 | 2.22182673823e-07 | [3, 3, 17, 23]/[2, 29, 97] | [0]
  - 2 | 3884799.00183 | 67 | 2881.0 | 4606.0 | 2.7138522332e-07 | [43, 67]/[2, 7, 7, 47] | [0]
  - 3 | 2454400.99972 | 101 | 1919.0 | [illegible] | [illegible] | [illegible] | [illegible]
  - 4 | 2149999.00033 | 43 | 3362
  - 5 | 2045120.99964 | 83 | 7995
  - 6 | 1638399.0002 | 61 | 1281
  - 7 | 1433759.00019 | 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 | 326144.999994 | 17 | 6375
  - 9 | 322856.142858 | 113 | 1767
  - 10 | 314982.818173 | 71 | 2709
  - 11 | 312075.999993 | 73 | 7808
  - 12 | 298312.428569 | 71 | 6532
  - 13 | 294312.111101 | 109 | 2071
  - 14 | 289635.363643 | 59 | 4982
  - 15 | 287775.00001 | 23 | 5625
  - 16 | 271574.333324 | 67 | 3185
  - 17 | 232595.285709 | 67 | 6365
  - 18 | 231587.206895 | 89 | 5251
  - 19 | 221964.636362 | 109 | 1909
  - 20 | 205919.000001 | 23 | 805.0
  - 21 | 203360.999999 | 53 | 795.0
  - 22 | 190298.872337 | 43 | 6993
  - 23 | 186882.720932 | 103 | 6283
  - 24 | 185566.21739 | 97 | 3337
  - 25 | 182896.999999 | 71 | 7150
  - 26 | 182306.692308 | 109 | 3706
  - 27 | 165664.157893 | 107 | 4922
  - 28 | 162629.769233 | 31 | 6612
  - 29 | 157885.444444 | 107 | 5555
  - 30 | 154759.000003 | 73 | 2420
  - 31 | 151561.500001 | 97 | 7584
  - 32 | 146232.333335 | 107 | 2744
  - 33 | 141079.260867 | 59 | 2537
  - 34 | 140141.857144 | 109 | 3068
  - 35 | 135574.000002 | 53 | 3392
  - 36 | 131899.412697 | 89 | 6497
  - 37 | 125842.478261 | 73 | 2263
  - 38 | 123531.467534 | 67 | 7437
  - 39 | 122846.901639 | 31 | 5859
  - 40 | 117633.432432 | 83 | 6806
  - 41 | 116389.0 | 113 | 7280
  - 42 | 113251.83019 | 61 | 4693
  - 43 | 108527.829268 | 103 | 3479
  - 44 | 107862.333333 | 79 | 6325
  - 45 | 106426.263156 | 89 | 7905
  - 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, 3]/[7, 37] | [0]

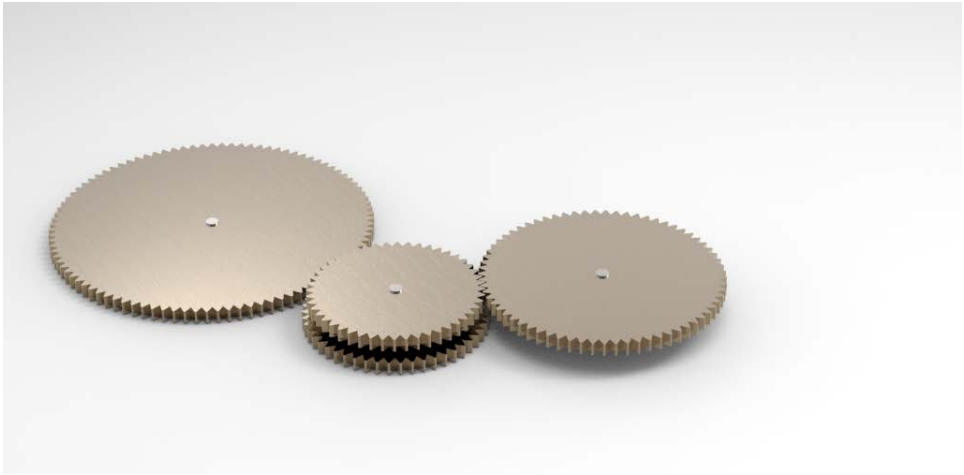
## Best approximation

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

Period = 5626 / 3519

= (2 x 29 x 97) / (3 x 3 x 17 x 23)

= (97 / 51) x (48 / 69)



# 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, 7, 47] | [0] |
| 3 | 2454400.99972 | 101 | 1919.0 | | | | |
| 4 | 2149999.00033 | 43 | 3362 | | | | |
| 5 | 2045125.99984 | 83 | 7995 | | | | |
| 6 | 1638399.0002 | 61 | 1281 | | | | |
| 7 | 1433749.00015 | 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 | 326144.999994 | 17 | 6375 | | | | |
| 9 | 322856.142858 | 113 | 1767 | | | | |
| 10 | 314982.818173 | 71 | 2709 | | | | |
| 11 | 312075.999993 | 73 | 7808 | | | | |
| 12 | 298372.428569 | 71 | 6532 | | | | |
| 13 | 294312.111101 | 109 | 2071 | | | | |
| 14 | 289635.363643 | 59 | 4982 | | | | |
| 15 | 287775.00001 | 23 | 5625 | | | | |
| 16 | 271574.333324 | 67 | 3185 | | | | |
| 17 | 232595.285709 | 67 | 6365 | | | | |
| 18 | 231587.208895 | 89 | 5251 | | | | |
| 19 | 221964.636362 | 109 | 1909 | | | | |
| 20 | 205919.000001 | 23 | 805.0 | | | | |
| 21 | 203360.999999 | 53 | 795.0 | | | | |
| 22 | 190298.872337 | 43 | 6993 | | | | |
| 23 | 186882.720932 | 103 | 6283 | | | | |
| 24 | 185566.21739 | 97 | 3337 | | | | |
| 25 | 182896.999999 | 71 | 7150 | | | | |
| 26 | 182306.692308 | 109 | 3706 | | | | |
| 27 | 165664.157893 | 107 | 4922 | | | | |
| 28 | 162629.769233 | 31 | 6612 | | | | |
| 29 | 157885.444444 | 107 | 5555 | | | | |
| 30 | 154759.000003 | 73 | 2420 | | | | |
| 31 | 151561.500001 | 97 | 7584 | | | | |
| 32 | 146232.333335 | 107 | 2744 | | | | |
| 33 | 141079.260867 | 59 | 2537 | | | | |
| 34 | 140141.857144 | 109 | 3068 | | | | |
| 35 | 135574.000002 | 53 | 3392 | | | | |
| 36 | 131899.412697 | 89 | 6497 | | | | |
| 37 | 125842.478261 | 73 | 2263 | | | | |
| 38 | 123531.467534 | 67 | 7437 | | | | |
| 39 | 122846.901639 | 31 | 5859 | | | | |
| 40 | 117633.432432 | 83 | 6806 | | | | |
| 41 | 116389.0 | 113 | 7280 | | | | |
| 42 | 113251.83019 | 61 | 4693 | | | | |
| 43 | 108527.829268 | 103 | 3479 | | | | |
| 44 | 107862.333333 | 79 | 6325 | | | | |
| 45 | 106426.263156 | 89 | 7905 | | | | |
| 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, 3]/[7, 37] | [0] |

## Sixth best approximation

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

Period = 2048 / 1281

$= 2^{11} / (3 \times 7 \times 61)$

$= (32 / 61) \times (64 / 21)$

$= (96 / 61) \times (64 / 63)$

# 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, 7, 47] | [0] |
| 3 | 2454400.99972 | 101 | 1919.0 | | | | |
| 4 | 2149999.00033 | 43 | 3362 | | | | |
| 5 | 2045125.99984 | 83 | 7995 | | | | |
| 6 | 1638399.0002 | 61 | 1281 | | | | |
| 7 | 1433749.00015 | 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 | 326144.999994 | 17 | 6375 | | | | |
| 9 | 322856.142858 | 113 | 1767 | | | | |
| 10 | 314982.818173 | 71 | 2709 | | | | |
| 11 | 312075.999993 | 73 | 7808 | | | | |
| 12 | 298372.428569 | 71 | 6532 | | | | |
| 13 | 294312.111101 | 109 | 2071 | | | | |
| 14 | 289635.363643 | 59 | 4982 | | | | |
| 15 | 287775.00001 | 23 | 5625 | | | | |
| 16 | 271574.333324 | 67 | 3185 | | | | |
| 17 | 232595.285709 | 67 | 6365 | | | | |
| 18 | 231587.208895 | 89 | 5251 | | | | |
| 19 | 221964.636362 | 109 | 1909 | | | | |
| 20 | 205919.000001 | 23 | 805.0 | | | | |
| 21 | 203360.999999 | 53 | 795.0 | | | | |
| 22 | 190298.872337 | 43 | 6993 | | | | |
| 23 | 186882.720932 | 103 | 6283 | | | | |
| 24 | 185566.21739 | 97 | 3337 | | | | |
| 25 | 182896.999999 | 71 | 7150 | | | | |
| 26 | 182306.692308 | 109 | 3706 | | | | |
| 27 | 165664.157893 | 107 | 4922 | | | | |
| 28 | 162629.769233 | 31 | 6612 | | | | |
| 29 | 157885.444444 | 107 | 5555 | | | | |
| 30 | 154759.000003 | 73 | 2420 | | | | |
| 31 | 151561.500001 | 97 | 7584 | | | | |
| 32 | 146232.333335 | 107 | 2744 | | | | |
| 33 | 141079.260867 | 59 | 2537 | | | | |
| 34 | 140141.857144 | 109 | 3068 | | | | |
| 35 | 135574.000002 | 53 | 3392 | | | | |
| 36 | 131899.412697 | 89 | 6497 | | | | |
| 37 | 125842.478261 | 73 | 2263 | | | | |
| 38 | 123531.467534 | 67 | 7437 | | | | |
| 39 | 122846.901639 | 31 | 5859 | | | | |
| 40 | 117633.432432 | 83 | 6806 | | | | |
| 41 | 116389.0 | 113 | 7280 | | | | |
| 42 | 113251.83019 | 61 | 4693 | | | | |
| 43 | 108527.829268 | 103 | 3479 | | | | |
| 44 | 107862.333333 | 79 | 6325 | | | | |
| 45 | 106426.263156 | 89 | 7905 | | | | |
| 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, 3]/[7, 37] | [0] |

## Sixth best approximation

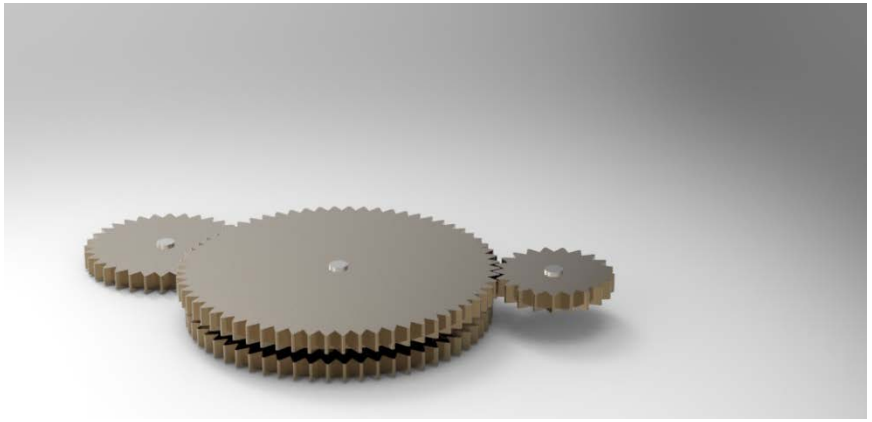
Accuracy = $6{,}10 \times 10^{-7}$

Period = 2048 / 1281

$= 2^{11} / (3 \times 7 \times 61)$

$= (32 / 61) \times (64 / 21)$

$= (96 / 61) \times (64 / 63)$



# 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, 7, 47] | [0] |
| 3 | 2454400.99972 | 101 | 1919.0 | | | | |
| 4 | 2149999.00033 | 43 | 3362 | | | | |
| 5 | 2045125.99984 | 83 | 7995 | | | | |
| 6 | 1638399.0002 | 61 | 1281 | | | | |
| 7 | 1433749.00015 | 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 | 326144.999994 | 17 | 6375 | | | | |
| 9 | 322856.142858 | 113 | 1767 | | | | |
| 10 | 314982.818173 | 71 | 2709 | | | | |
| 11 | 312075.999993 | 73 | 7808 | | | | |
| 12 | 298372.428569 | 71 | 6532 | | | | |
| 13 | 294312.111101 | 109 | 2071 | | | | |
| 14 | 289635.363643 | 59 | 4982 | | | | |
| 15 | 287775.00001 | 23 | 5625 | | | | |
| 16 | 271574.333324 | 67 | 3185 | | | | |
| 17 | 232595.285709 | 67 | 6365 | | | | |
| 18 | 231587.208895 | 89 | 5251 | | | | |
| 19 | 221964.636362 | 109 | 1909 | | | | |
| 20 | 205919.000001 | 23 | 805.0 | | | | |
| 21 | 203360.999999 | 53 | 795.0 | | | | |
| 22 | 190298.872337 | 43 | 6993 | | | | |
| 23 | 186882.720932 | 103 | 6283 | | | | |
| 24 | 185566.21739 | 97 | 3337 | | | | |
| 25 | 182896.999999 | 71 | 7150 | | | | |
| 26 | 182306.692308 | 109 | 3706 | | | | |
| 27 | 165664.157893 | 107 | 4922 | | | | |
| 28 | 162629.769233 | 31 | 6612 | | | | |
| 29 | 157885.444444 | 107 | 5555 | | | | |
| 30 | 154759.000003 | 73 | 2420 | | | | |
| 31 | 151561.500001 | 97 | 7584 | | | | |
| 32 | 146232.333335 | 107 | 2744 | | | | |
| 33 | 141079.260867 | 59 | 2537 | | | | |
| 34 | 140141.857144 | 109 | 3068 | | | | |
| 35 | 135574.000002 | 53 | 3392 | | | | |
| 36 | 131899.412697 | 89 | 6497 | | | | |
| 37 | 125842.478261 | 73 | 2263 | | | | |
| 38 | 123531.467534 | 67 | 7437 | | | | |
| 39 | 122846.901639 | 31 | 5859 | | | | |
| 40 | 117633.432432 | 83 | 6806 | | | | |
| 41 | 116389.0 | 113 | 7280 | | | | |
| 42 | 113251.83019 | 61 | 4693 | | | | |
| 43 | 108527.829268 | 103 | 3479 | | | | |
| 44 | 107862.333333 | 79 | 6325 | | | | |
| 45 | 106426.263156 | 89 | 7905 | | | | |
| 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, 3]/[7, 37] | [0] |

## Sixth best approximation

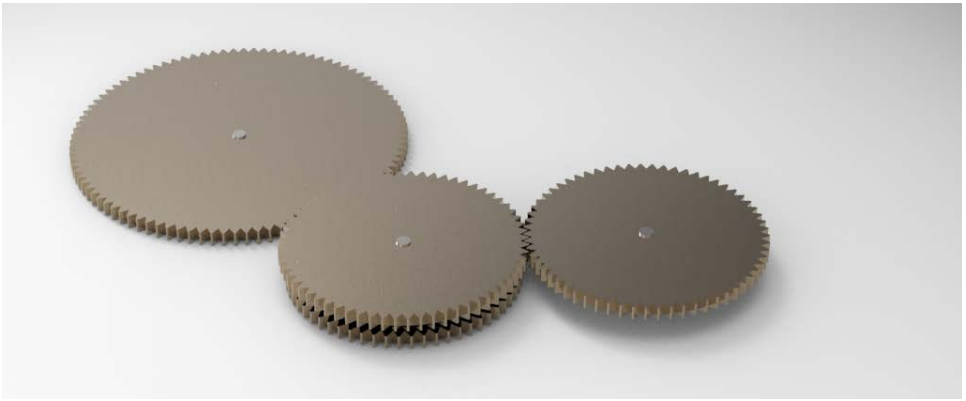
Accuracy = $6{,}10 \times 10^{-7}$

Period = 2048 / 1281

$= 2^{11} / (3 \times 7 \times 61)$

$= (32 / 61) \times (64 / 21)$

$= (96 / 61) \times (64 / 63)$



# 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, 7, 47] [0]
  - 3 2454400.99972 101 1919.0 [illegible] [illegible] [illegible] [illegible]
  - 4 2149999.00033 43 3362 [illegible] [illegible] [illegible] [illegible]
  - 5 2045120.99984 83 7995 [illegible] [illegible] [illegible] [illegible]
  - 6 1638399.0002 61 1281 [illegible] [illegible] [illegible] [illegible]
  - 7 1433599.00015 103 5605 [illegible] [illegible] [illegible] [illegible]

- Accuracy > 1e5:
  - 1 785732.333369 97 3686 [illegible] [illegible] [illegible] [illegible]
  - 2 700465.666715 79 6572 [illegible] [illegible] [illegible] [illegible]
  - 3 599850.999955 67 7504 [illegible] [illegible] [illegible] [illegible]
  - 4 461719.000006 97 7220 [illegible] [illegible] [illegible] [illegible]
  - 5 420303.761922 103 6901 [illegible] [illegible] [illegible] [illegible]
  - 6 408000.999978 29 319.0 [illegible] [illegible] [illegible] [illegible]
  - 7 374446.058831 109 4977 [illegible] [illegible] [illegible] [illegible]
  - 8 326144.999994 17 6375 [illegible] [illegible] [illegible] [illegible]
  - 9 322856.142858 113 1767 [illegible] [illegible] [illegible] [illegible]
  - 10 [illegible] 71 2709 [illegible] [illegible] [illegible] [illegible]
  - 11 [illegible] 73 7808 [illegible] [illegible] [illegible] [illegible]
  - 12 [illegible] 71 6532 [illegible] [illegible] [illegible] [illegible]
  - [illegible] 2071 [illegible] [illegible] [illegible] [illegible]
  - [illegible] 4982 [illegible] [illegible] [illegible] [illegible]
  - [illegible] 5625 [illegible] [illegible] [illegible] [illegible]
  - [illegible] 3185 [illegible] [illegible] [illegible] [illegible]
  - [illegible] 6365 [illegible] [illegible] [illegible] [illegible]
  - [illegible] 5251 [illegible] [illegible] [illegible] [illegible]
  - [illegible] 1909 [illegible] [illegible] [illegible] [illegible]
  - [illegible] 805.0 [illegible] [illegible] [illegible] [illegible]
  - [illegible] 795.0 [illegible] [illegible] [illegible] [illegible]
  - [illegible] 6993 [illegible] [illegible] [illegible] [illegible]
  - [illegible] 6283 [illegible] [illegible] [illegible] [illegible]
  - [illegible] 3337 [illegible] [illegible] [illegible] [illegible]
  - [illegible] 7150 [illegible] [illegible] [illegible] [illegible]
  - [illegible] 3706 [illegible] [illegible] [illegible] [illegible]
  - [illegible] 4922 [illegible] [illegible] [illegible] [illegible]
  - [illegible] 6612 [illegible] [illegible] [illegible] [illegible]
  - [illegible] 5555 [illegible] [illegible] [illegible] [illegible]
  - [illegible] 2420 [illegible] [illegible] [illegible] [illegible]
  - [illegible] 7584 [illegible] [illegible] [illegible] [illegible]
  - [illegible] 2744 [illegible] [illegible] [illegible] [illegible]
  - [illegible] 2537 [illegible] [illegible] [illegible] [illegible]
  - [illegible] 3068 [illegible] [illegible] [illegible] [illegible]
  - [illegible] 3392 [illegible] [illegible] [illegible] [illegible]
  - [illegible] 6497 [illegible] [illegible] [illegible] [illegible]
  - [illegible] 2263 [illegible] [illegible] [illegible] [illegible]
  - [illegible] 7437 [illegible] [illegible] [illegible] [illegible]
  - [illegible] 5859 [illegible] [illegible] [illegible] [illegible]
  - [illegible] 6806 [illegible] [illegible] [illegible] [illegible]
  - [illegible] 7280 [illegible] 13 [illegible] [illegible] [illegible] [illegible]
  - [illegible] 4693 [illegible] 1 [illegible] [illegible] [illegible] [illegible]
  - [illegible] 3479 [illegible] 103 [illegible] [illegible] [illegible] [illegible]
  - [illegible] 6325 [illegible] 79 [illegible] [illegible] [illegible] [illegible]
  - [illegible] 7905 [illegible] 89 [illegible] [illegible] [illegible] [illegible]
  - .. 104414.186812 107 7429.0 11877.0 9.57724261936e-06 [17, 19, 23]/[3, 37, 107] [0]
  - .. 103599.000001 37 162.0 259.0 9.65260282428e-06 [2, 3, 3, 3, 3]/[7, 37] [0]

## Sixth best approximation

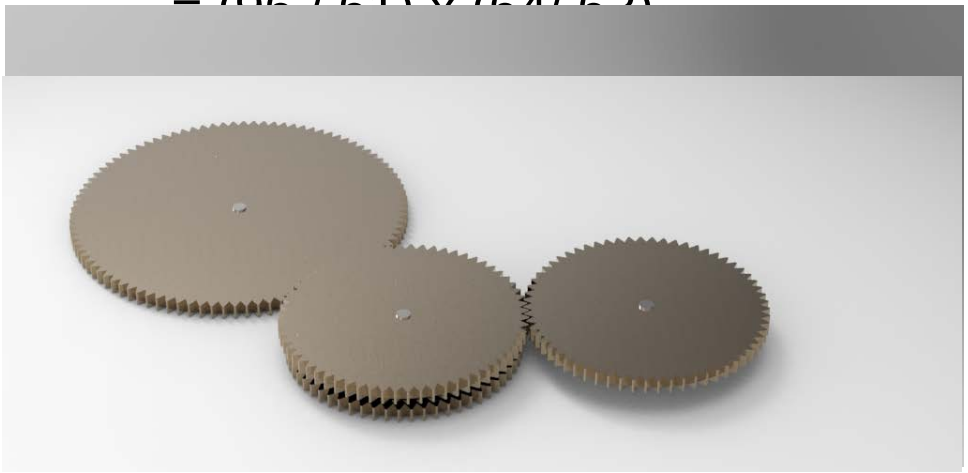
Accuracy = $6{,}10 \times 10^{-7}$

Period = 2048 / 1281

= $2^{11}$ / (3 x 7 x 61)

= (32 / 61) x (64/ 21)

= (96 / 61) x (64/ 63)



# 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, 7, 47] [0]
  - 3 2454400.99972 101 1919.0 [illegible] [illegible] [illegible] [illegible]
  - 4 2149999.00033 43 3362 [illegible] [illegible] [illegible] [illegible]
  - 5 2045120.99984 83 7995 [illegible] [illegible] [illegible] [illegible]
  - 6 1638399.0002 61 1281 [illegible] [illegible] [illegible] [illegible]
  - 7 1433599.00015 103 5605 [illegible] [illegible] [illegible] [illegible]

- Accuracy > 1e5:
  - 1 785732.333369 97 3686 [illegible] [illegible] [illegible] [illegible]
  - 2 700465.666715 79 6572 [illegible] [illegible] [illegible] [illegible]
  - 3 599850.999955 67 7504 [illegible] [illegible] [illegible] [illegible]
  - 4 461719.000006 97 7220 [illegible] [illegible] [illegible] [illegible]
  - 5 420303.761922 103 6901 [illegible] [illegible] [illegible] [illegible]
  - 6 408000.999978 29 319.0 [illegible] [illegible] [illegible] [illegible]
  - 7 374446.058831 109 4977 [illegible] [illegible] [illegible] [illegible]
  - 8 326144.999994 17 6375 [illegible] [illegible] [illegible] [illegible]
  - 9 322856.142858 113 1767 [illegible] [illegible] [illegible] [illegible]
  - 10 [illegible] 71 2709 [illegible] [illegible] [illegible] [illegible]
  - 11 [illegible] 73 7808 [illegible] [illegible] [illegible] [illegible]
  - 12 [illegible] 71 6532 [illegible] [illegible] [illegible] [illegible]
  - [illegible] 2071 [illegible] [illegible] [illegible] [illegible]
  - [illegible] 4982 [illegible] [illegible] [illegible] [illegible]
  - [illegible] 5625 [illegible] [illegible] [illegible] [illegible]
  - [illegible] 3185 [illegible] [illegible] [illegible] [illegible]
  - [illegible] 6365 [illegible] [illegible] [illegible] [illegible]
  - [illegible] 5251 [illegible] [illegible] [illegible] [illegible]
  - [illegible] 1909 [illegible] [illegible] [illegible] [illegible]
  - [illegible] 805.0 [illegible] [illegible] [illegible] [illegible]
  - [illegible] 795.0 [illegible] [illegible] [illegible] [illegible]
  - [illegible] 6993 [illegible] [illegible] [illegible] [illegible]
  - [illegible] 6283 [illegible] [illegible] [illegible] [illegible]
  - [illegible] 3337 [illegible] [illegible] [illegible] [illegible]
  - [illegible] 7150 [illegible] [illegible] [illegible] [illegible]
  - [illegible] 3706 [illegible] [illegible] [illegible] [illegible]
  - [illegible] 4922 [illegible] [illegible] [illegible] [illegible]
  - [illegible] 6612 [illegible] [illegible] [illegible] [illegible]
  - [illegible] 5555 [illegible] [illegible] [illegible] [illegible]
  - [illegible] 2420 [illegible] [illegible] [illegible] [illegible]
  - [illegible] 7584 [illegible] [illegible] [illegible] [illegible]
  - [illegible] 2744 [illegible] [illegible] [illegible] [illegible]
  - [illegible] 2537 [illegible] [illegible] [illegible] [illegible]
  - [illegible] 3068 [illegible] [illegible] [illegible] [illegible]
  - [illegible] 3392 [illegible] [illegible] [illegible] [illegible]
  - [illegible] 6497 [illegible] [illegible] [illegible] [illegible]
  - [illegible] 2263 [illegible] [illegible] [illegible] [illegible]
  - [illegible] 7437 [illegible] [illegible] [illegible] [illegible]
  - [illegible] 5859 [illegible] [illegible] [illegible] [illegible]
  - [illegible] 6806 [illegible] [illegible] [illegible] [illegible]
  - [illegible] 7280 [illegible] 13 [illegible] [illegible] [illegible] [illegible]
  - [illegible] 4693 [illegible] 1 [illegible] [illegible] [illegible] [illegible]
  - [illegible] 3479 [illegible] 103 [illegible] [illegible] [illegible] [illegible]
  - [illegible] 6325 [illegible] 79 [illegible] [illegible] [illegible] [illegible]
  - [illegible] 7905 [illegible] 89 [illegible] [illegible] [illegible] [illegible]
  - .. 104414.186812 107 7429.0 11877.0 9.57724261936e-06 [17, 19, 23]/[3, 37, 107] [0]
  - .. 103599.000001 37 162.0 259.0 9.65260282428e-06 [2, 3, 3, 3, 3]/[7, 37] [0]

## Sixth best approximation

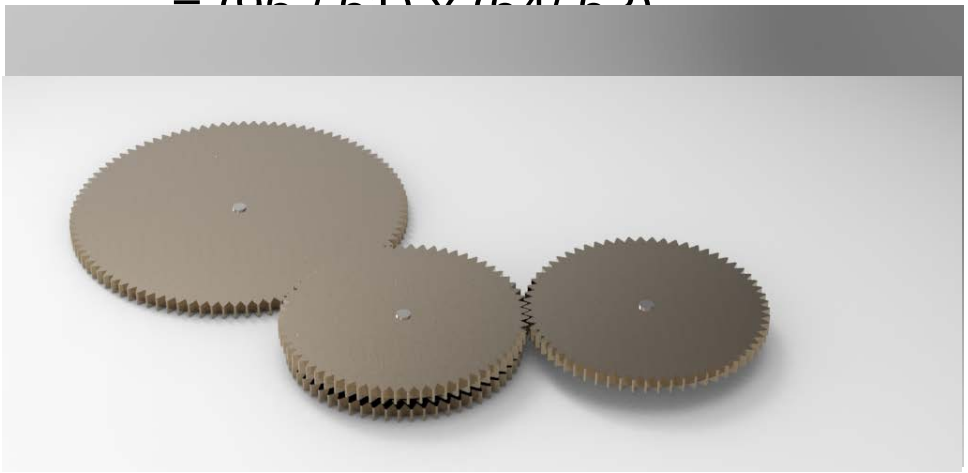
Accuracy = $6{,}10 \times 10^{-7}$

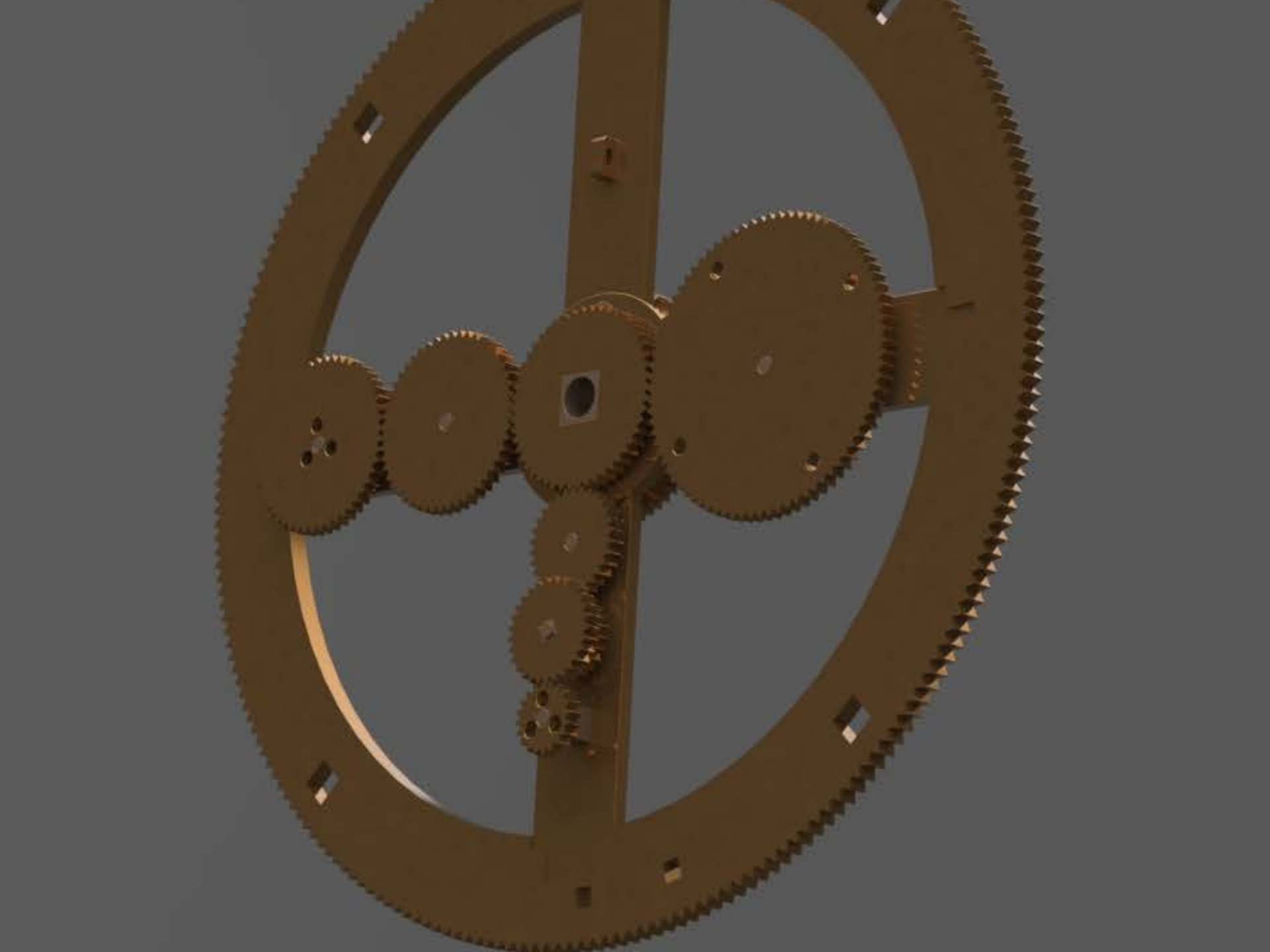
Period = 2048 / 1281

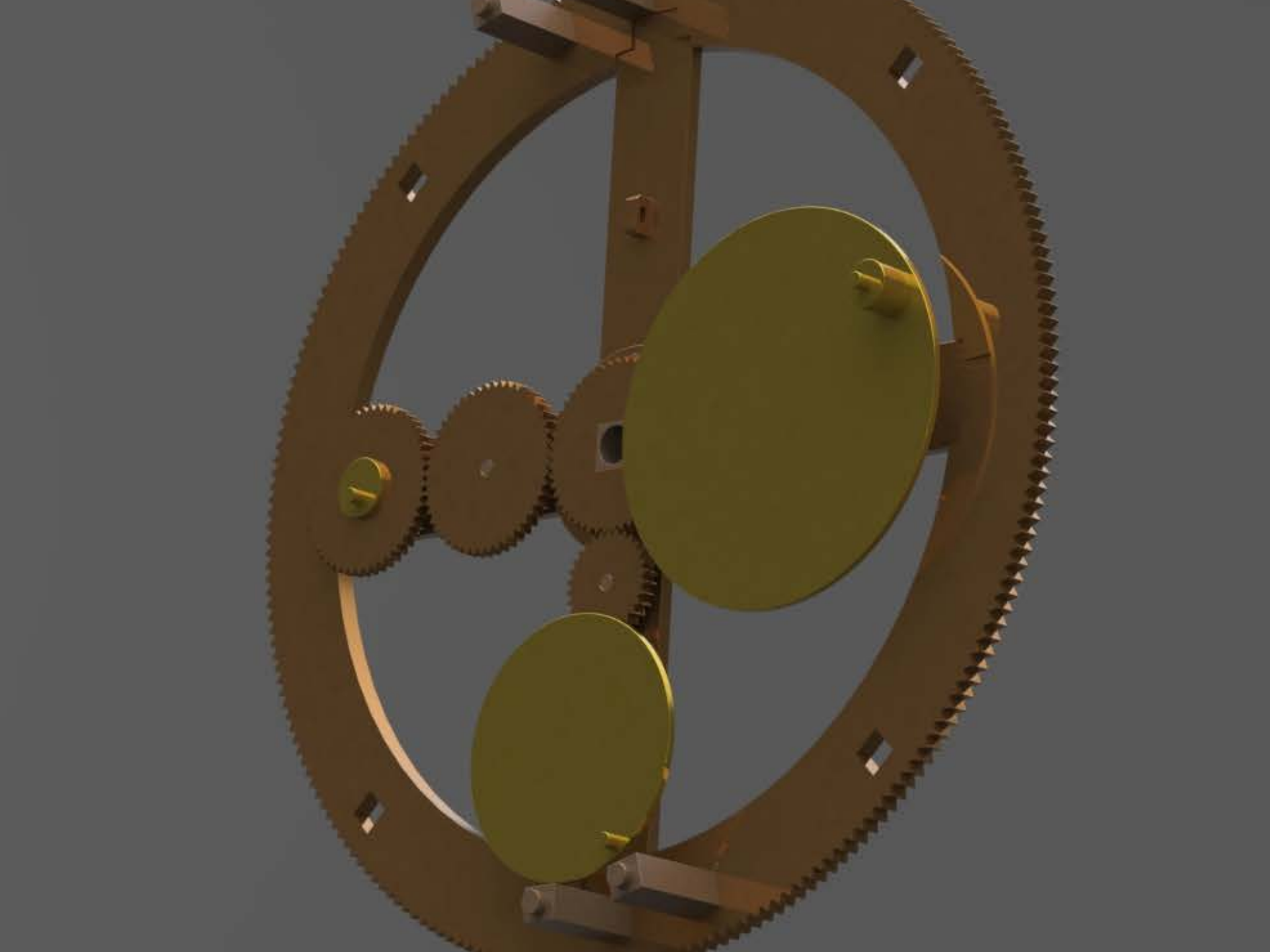
= $2^{11}$ / (3 x 7 x 61)

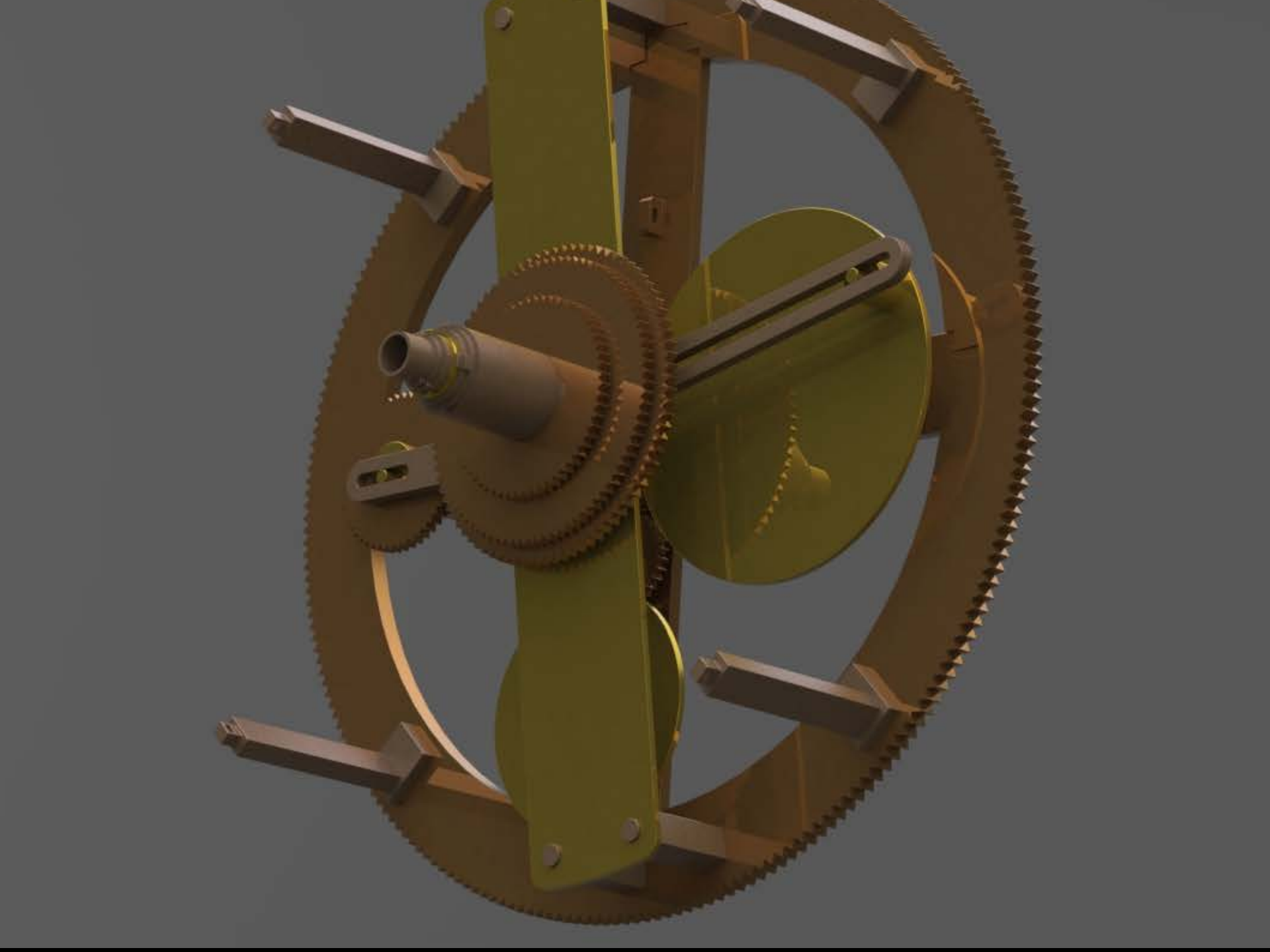
= (32 / 61) x (64/ 21)

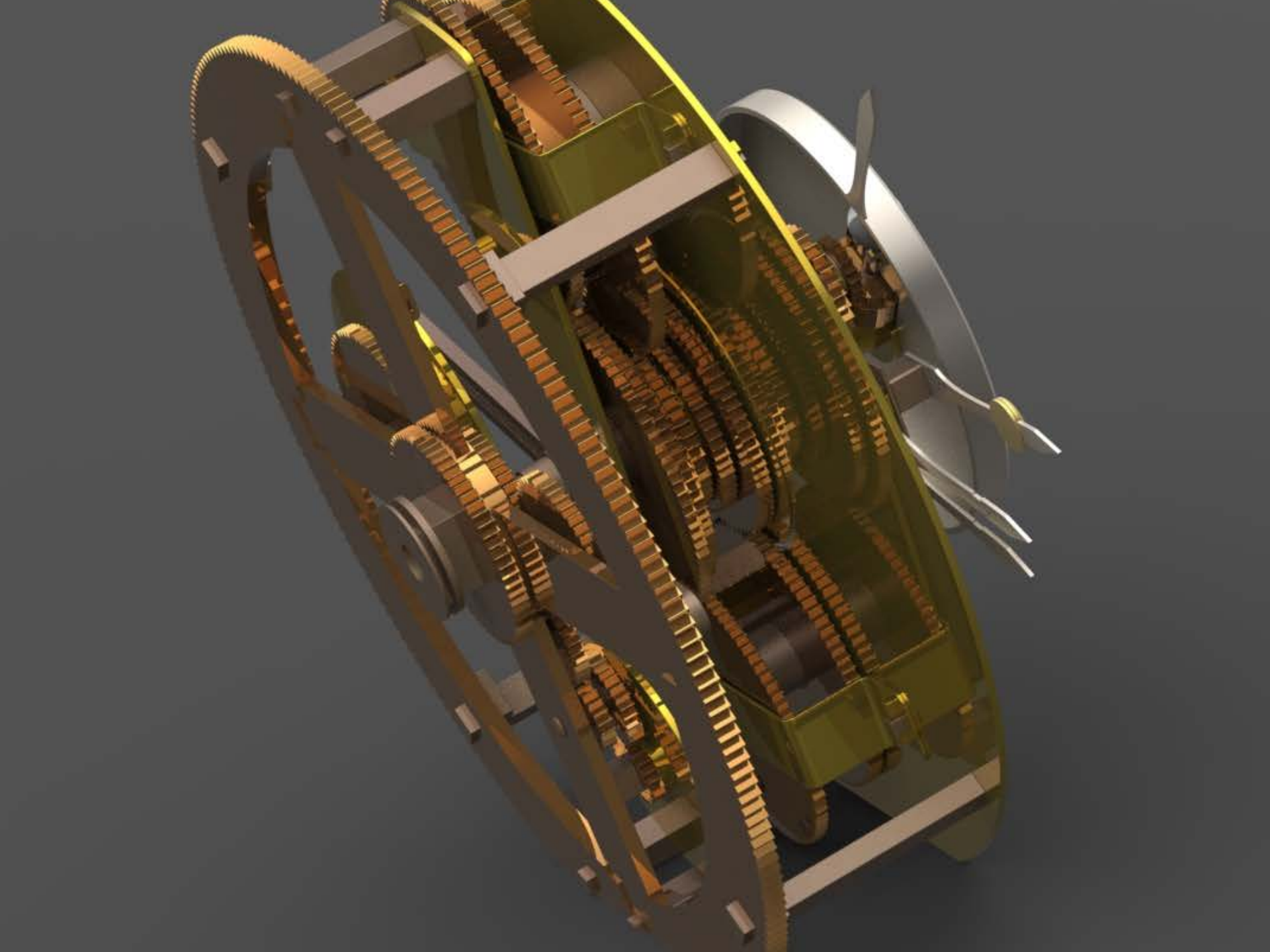
= (96 / 61) x (64/ 63)

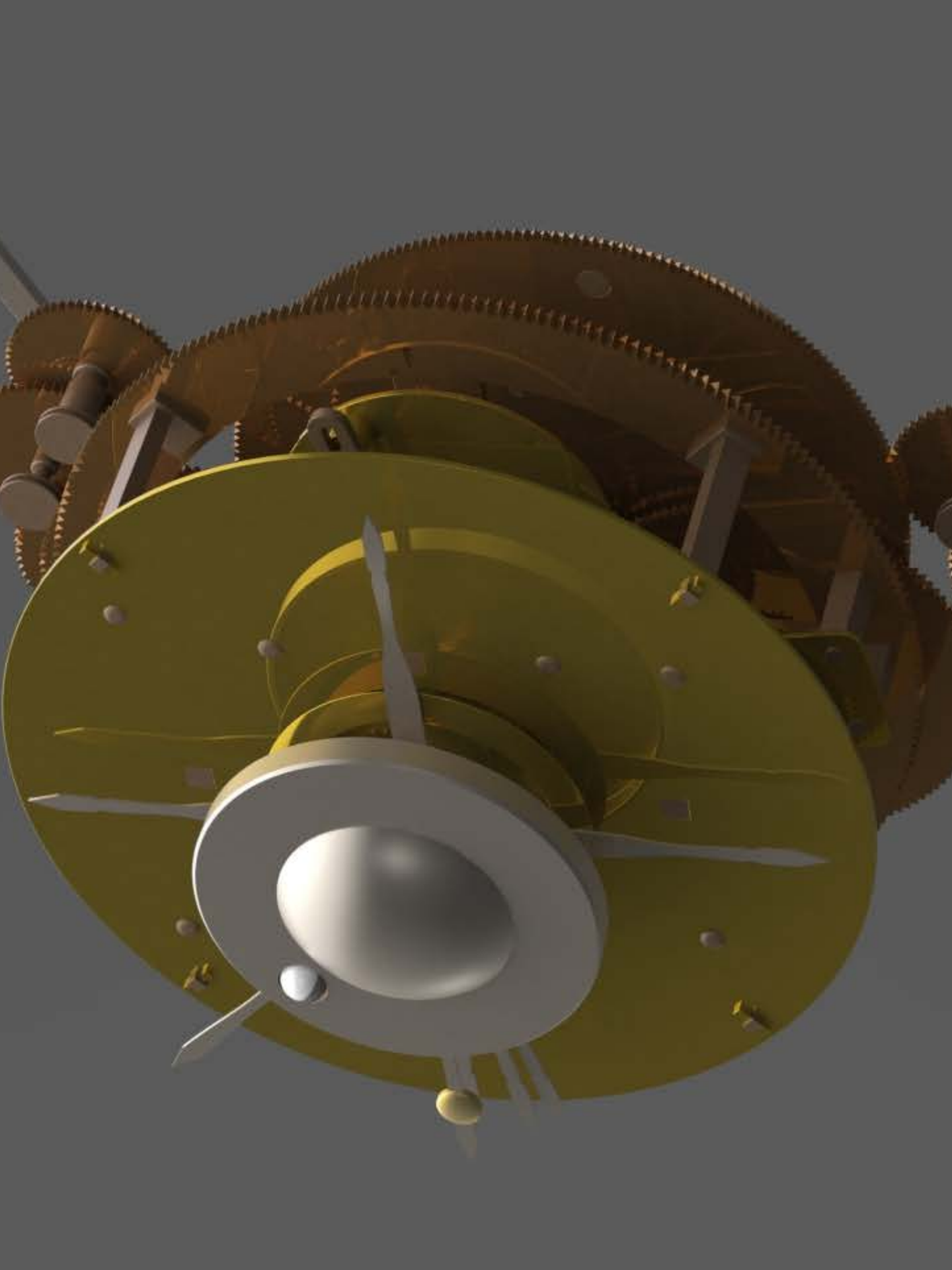












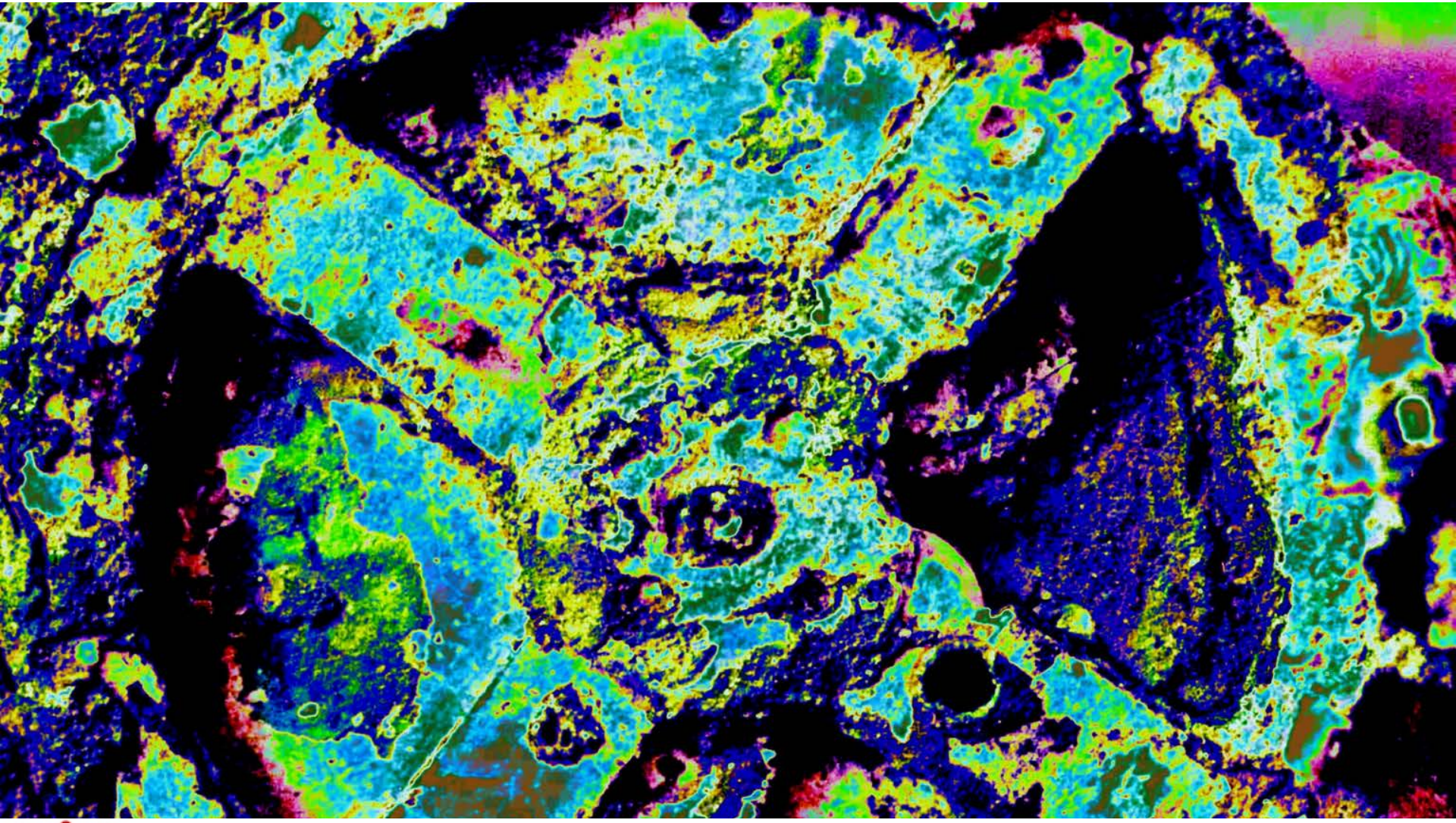
# AMRP Reconstruction

## 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


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 testifimony 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 …

| | | | |
|---|---|---|---|
| 1 | Archimedes | "De Sphaerae" | ca 260? -212 BC |
| 2 | Cicero | De Republica 1,14 | 54-51 BC |
| 3A | Cicero | De natura deorum II, xxxiv | 45 BC |
| 3B | Cicero | De natura deorum II, xcvii | 45 BC |
| 4 | Cicero | Tusculan disputations 1, 36 | ca 45 BC |
| 5 | Vitruvius | De Architectura 10.1.4 | ca 20 BC |
| 6 | Theon of Smyrna | Expositio rerum | ca 70 - ca 135 AD |
| 7 | Ptolomy | Almagest XIII, 2 | 120-150 AD |
| 8 | Ptolomy | Planetary Hypothesis | Mid 2nd C AD |
| 9 | Galen | De Usu Partium | 169-176 AD |
| 10 | Sextus Empiricus | Adversus mathematicos, IX, 115 | 3rd C AD |
| 11 | Pappus | Works VIII, 2 | 3rd C AD |
| 12 | Agrestius Chromatius | quoted by St Sebastian and St Polycarp | 3rd C AD |
| 13 | Lacantius | Institutiones divinae II, 5, 18 | 4th C AD |
| 14 | Claudian | Carmina minora LI (LXVIII) | ca. 400 AD |
| 15 | Proclus | On Providence | ? 432 – ? 485 AD |
| 16 | Martianus Capella | De nuptiis | Early 5th C AD |
| 17 | Nonus | Dionysiaca | 5th C AD |
| 18 | John Philoponus | De Anima 106, 25 | 6th C AD |
| | | | |
| 19 | Ovid | Fasti VI | 8 AD |
| 20 | Manilius | Astronomica Book 2, line 127 | 1st C AD |
| 21 | Mesdomedes | (of Crete) Poem | Early 2nd C AD |

# Archimedes

**Archimedes**

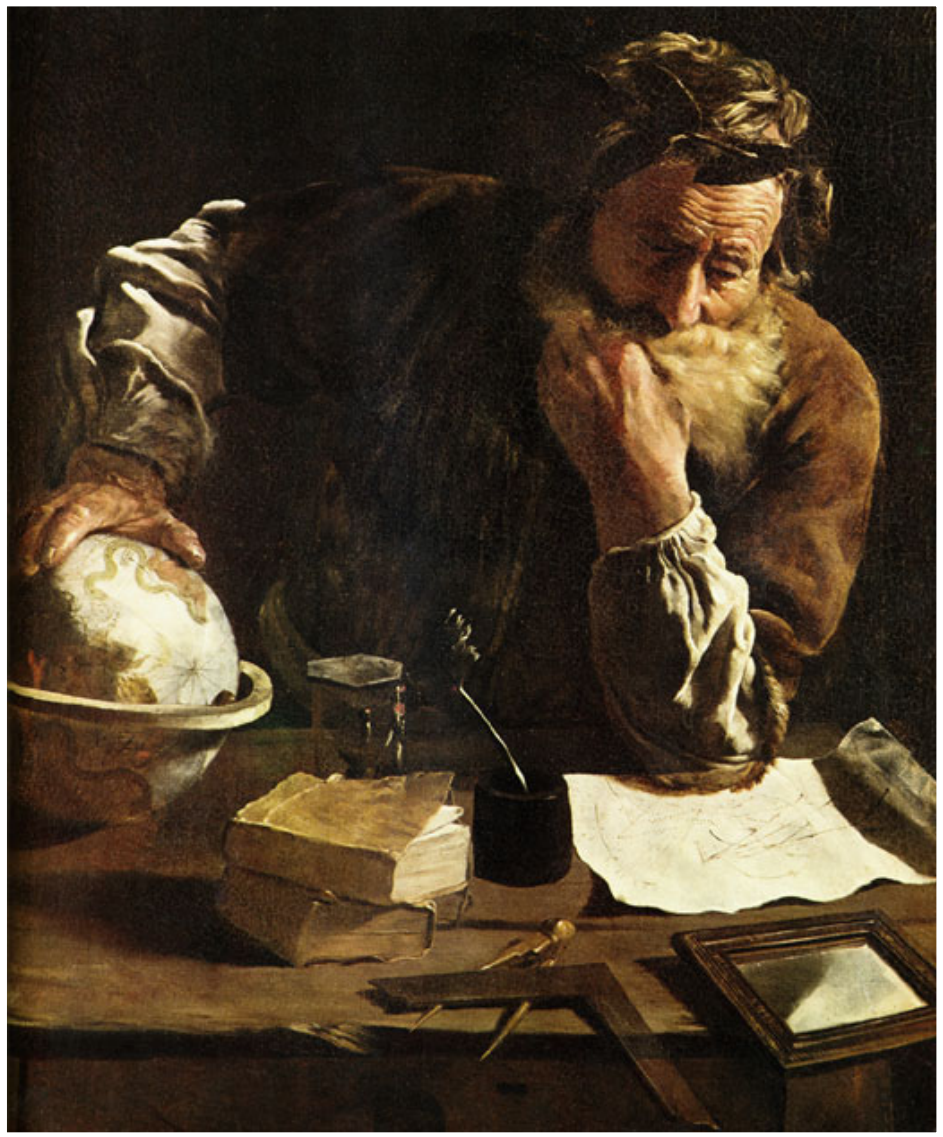
**(287-211/212 BC, Syracuse)**

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

  … is this the key …
- Compare with

  Archimedes Palimpsest: … "On the Method" …

  Fundamentals Calculus, Integral calculus …



The discovery of Archimedes was all the more remarkable, because he had discovered how a single turn action could preserve these unequal orbits with their different speeds. When Galus moved this globe, the moon followed the sun by as many revolutions of the bronze globe as it does by days in the sky itself; the result was that the same eclipse of the sun occurred on the globe, and the moon fell into the space which was in the shadow of the earth. . .

learning began to explain the workings of this device, I dec[illegible] that Archimedes had more genius than human nature seemed capable of possessing. Galus sai[illegible] that [illegible]he invention of the other one, the solid globe, was old; it had been made by Thales of Mile[illegible]s and then wa[illegible]arked out with the fixed celestial stars by Eudoxus of Cnidus, who he said wa[illegible] a pupil of Plato's. [. . . ] But this new kind of globe included the motions of the sun and moon [illegible]nd the five stars that are known as ``planets'' or ``wandering,'' something that not could be ac[illegible]ved in the solid globe. The discovery of Archimedes was all the more remarkable, because he ha[illegible] discovered how a single turn action could preserve these unequal orbits with their different speeds. When Galus moved this globe, the moon followed the sun by as many revolutions of the bronze globe as it does by days in the sky itself; the result was that the same eclipse of the sun occurred on the globe, and the moon the fell into the space which was in the shadow of the earth. . . (translation: Zetzel, 1999)

# 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''**

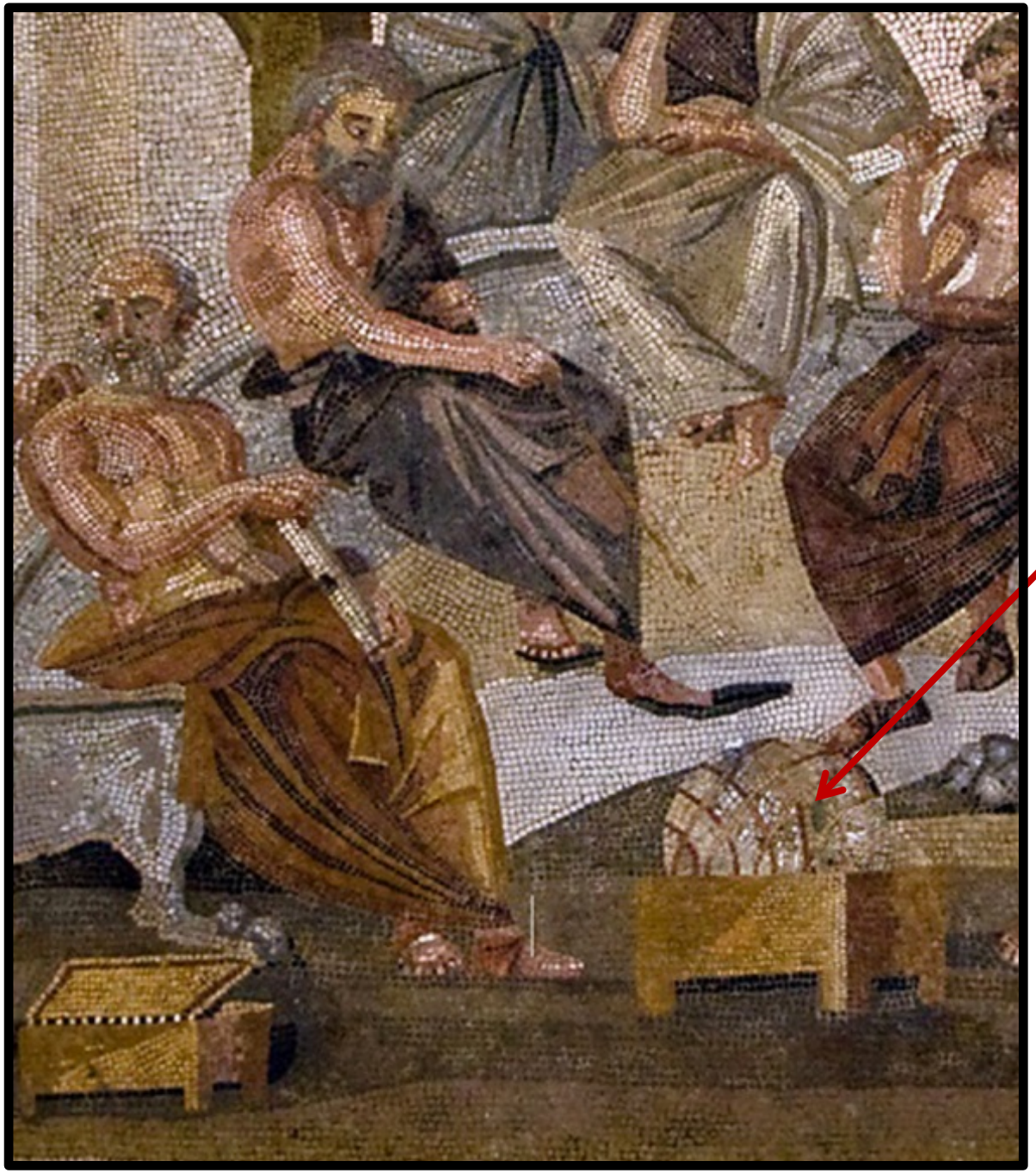
**Cicero,**

**Tusculan Disputations, Book I, Section XXV**



**Plato Academy Mosaic**

**Villa T. Siminius Pompeii**



Is this
Archimedes Sphere ?

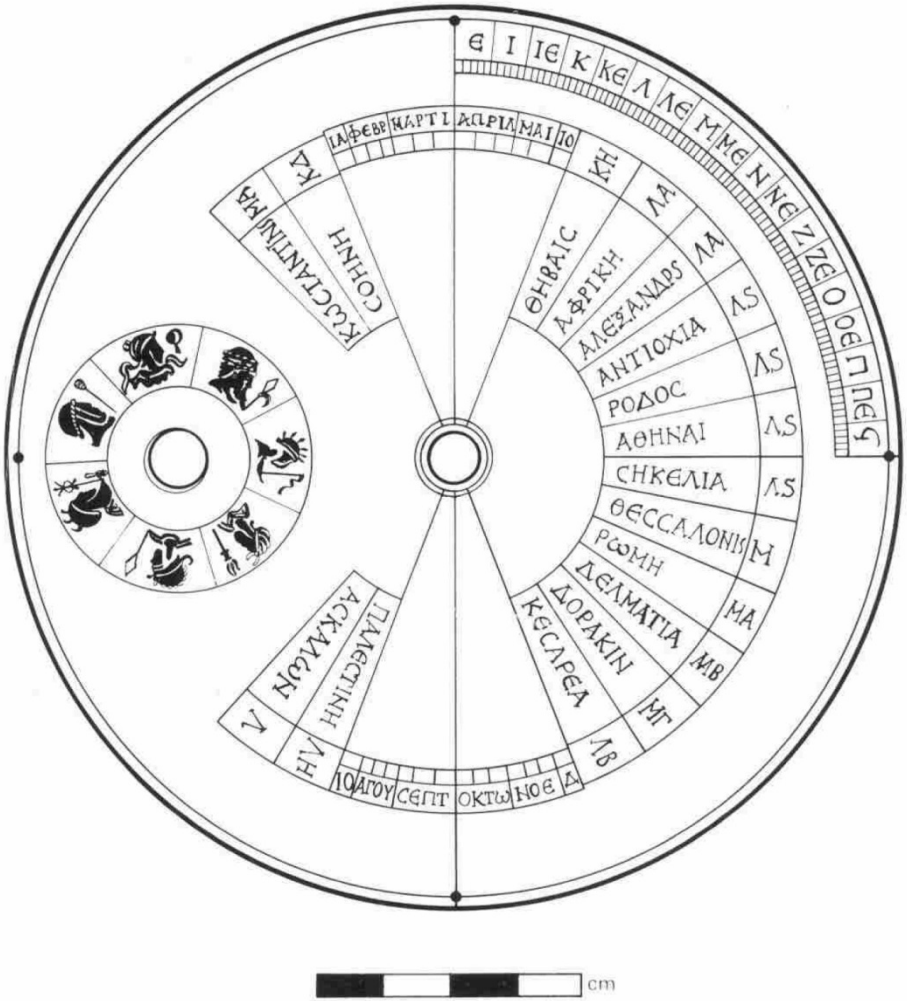
Is this
an image of an
Antikythera Mechanism
related device ?

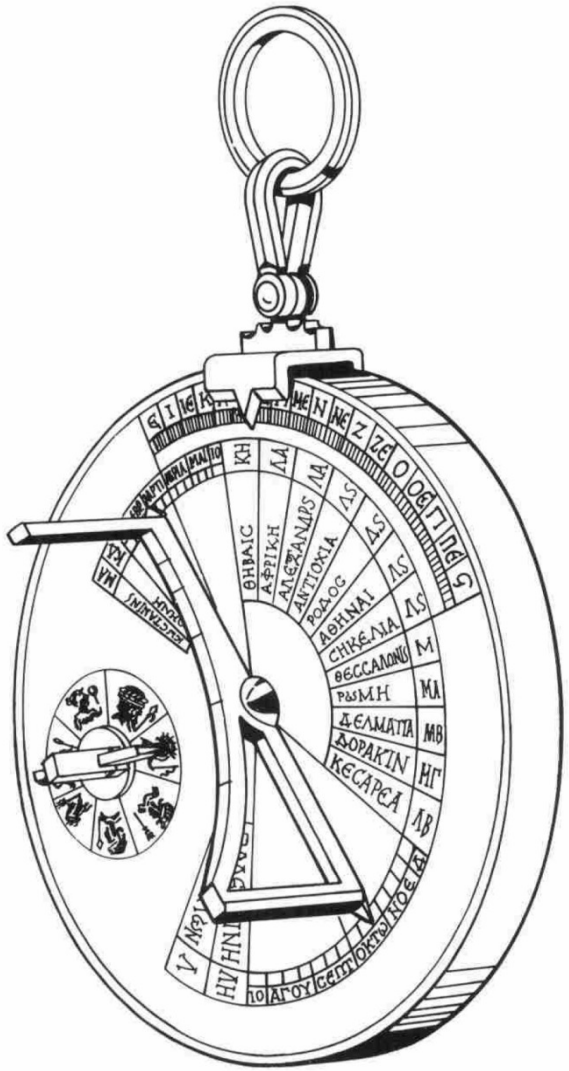

ancient Technology,
Science & Innovation

# Roman Military Technology

# Byzantine “Astrolabe”

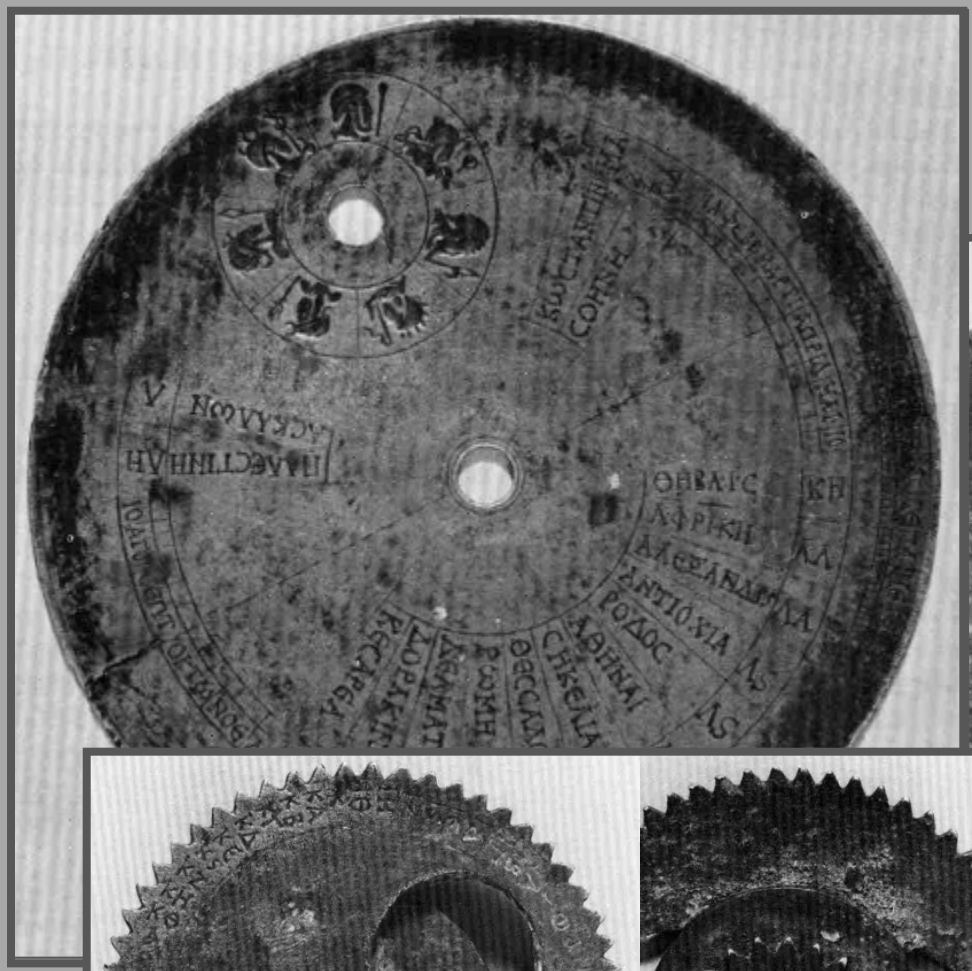
## 6th cent. AD !!!

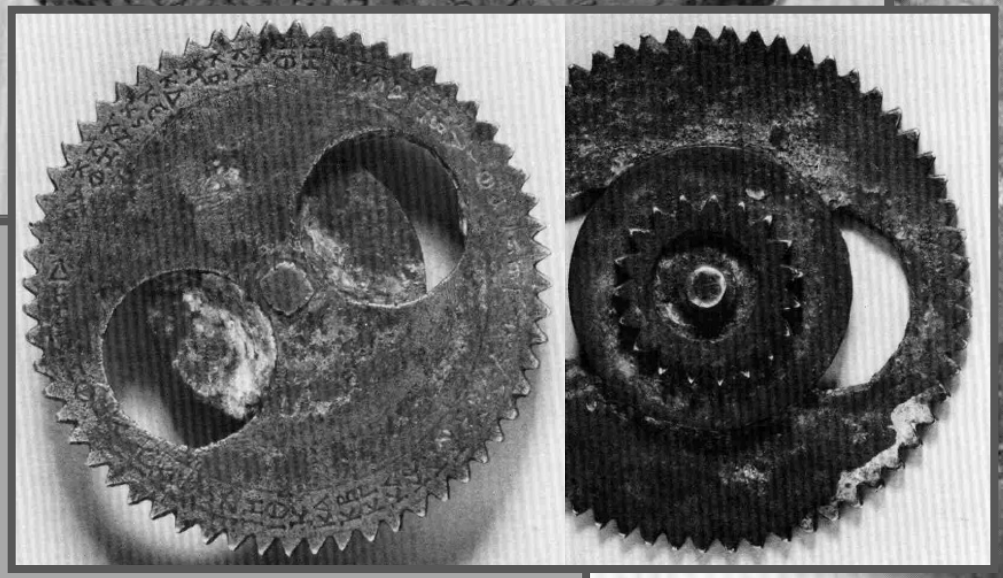


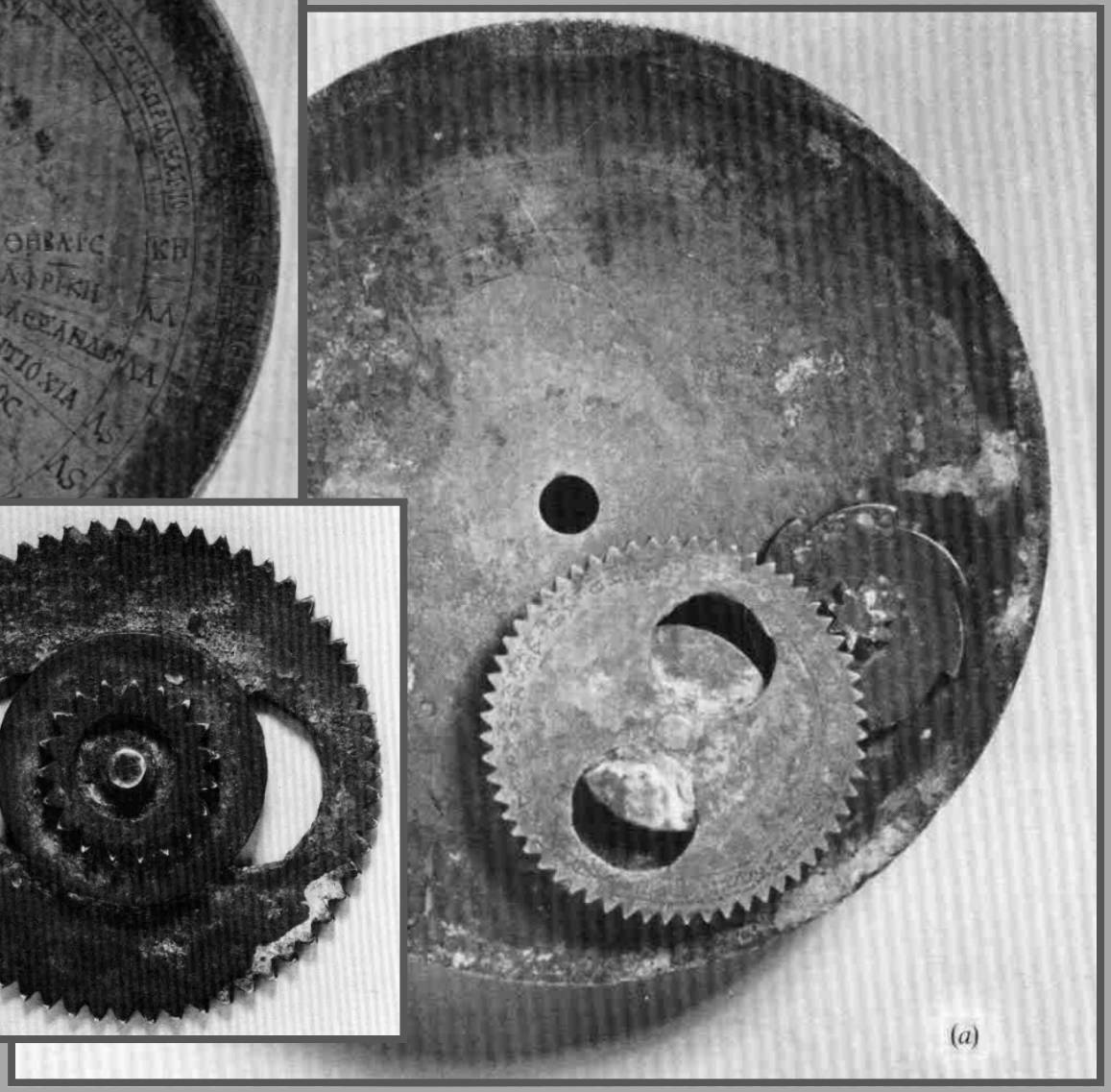



# Byzantine “Astrolabe”

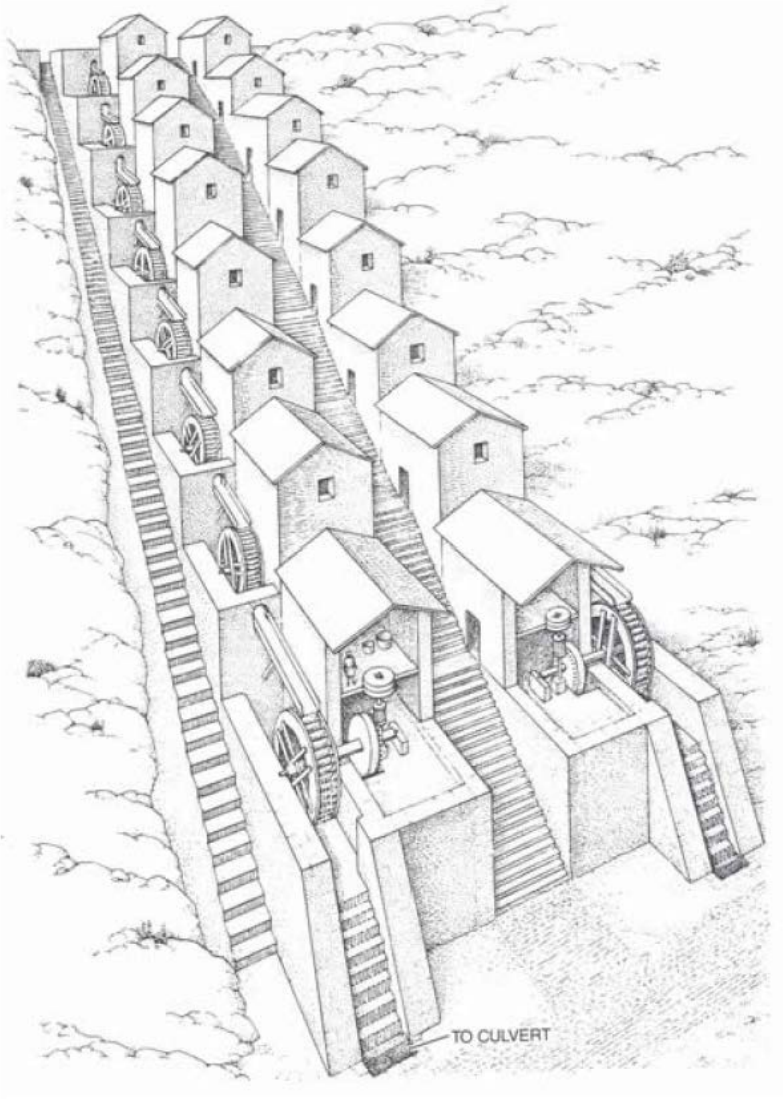
## 6th cent. AD !!!







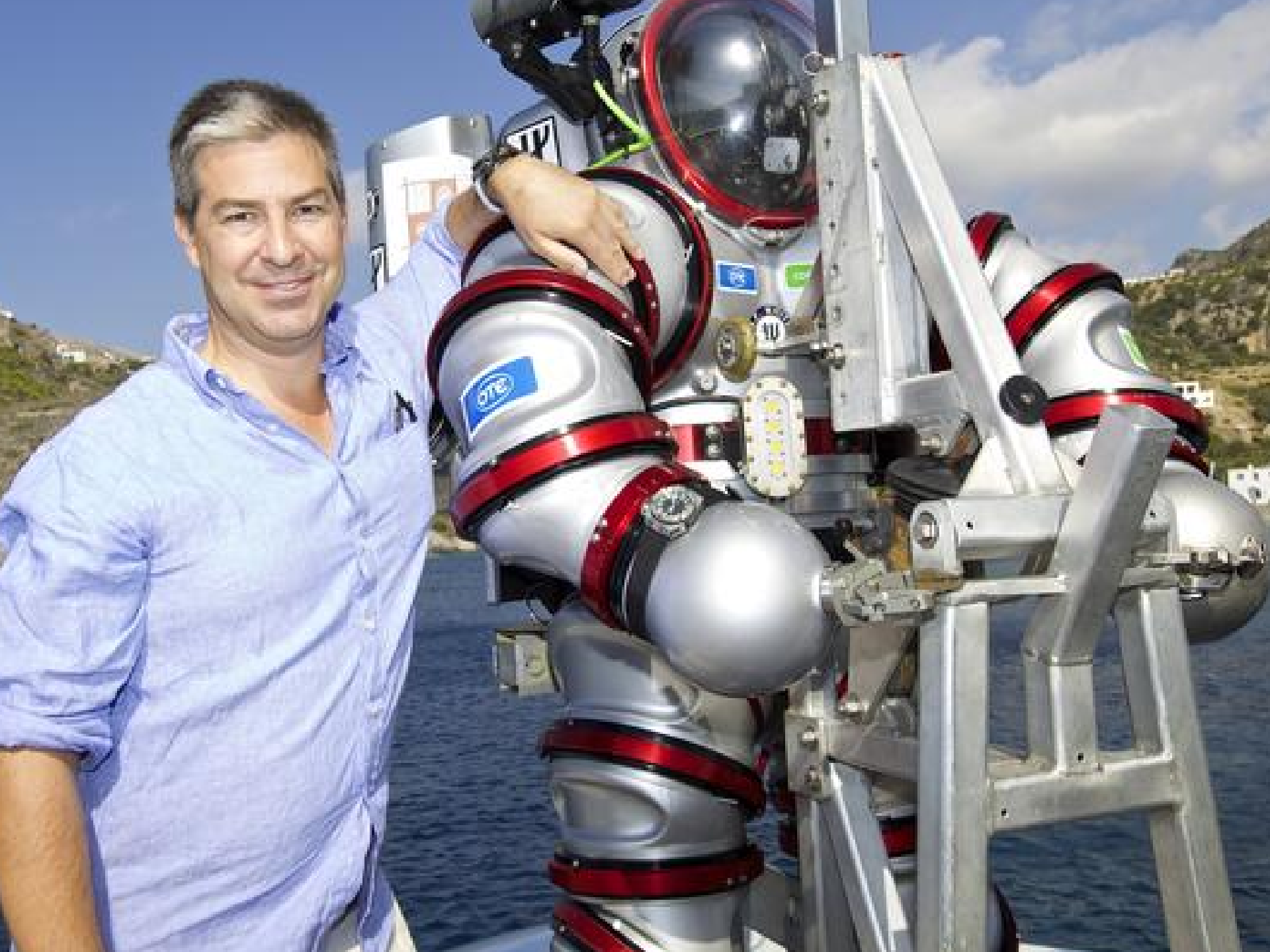
# Roman Industry




**Did hightech find applications**
**In industrial activities ?**

**Barbegal:**
**industrial complex of watermills**

# Return to Antikythera


OTE

# 2013: Antikythera Ship Anchor

Images courtesy: Ephorate of Underwater Antiquities

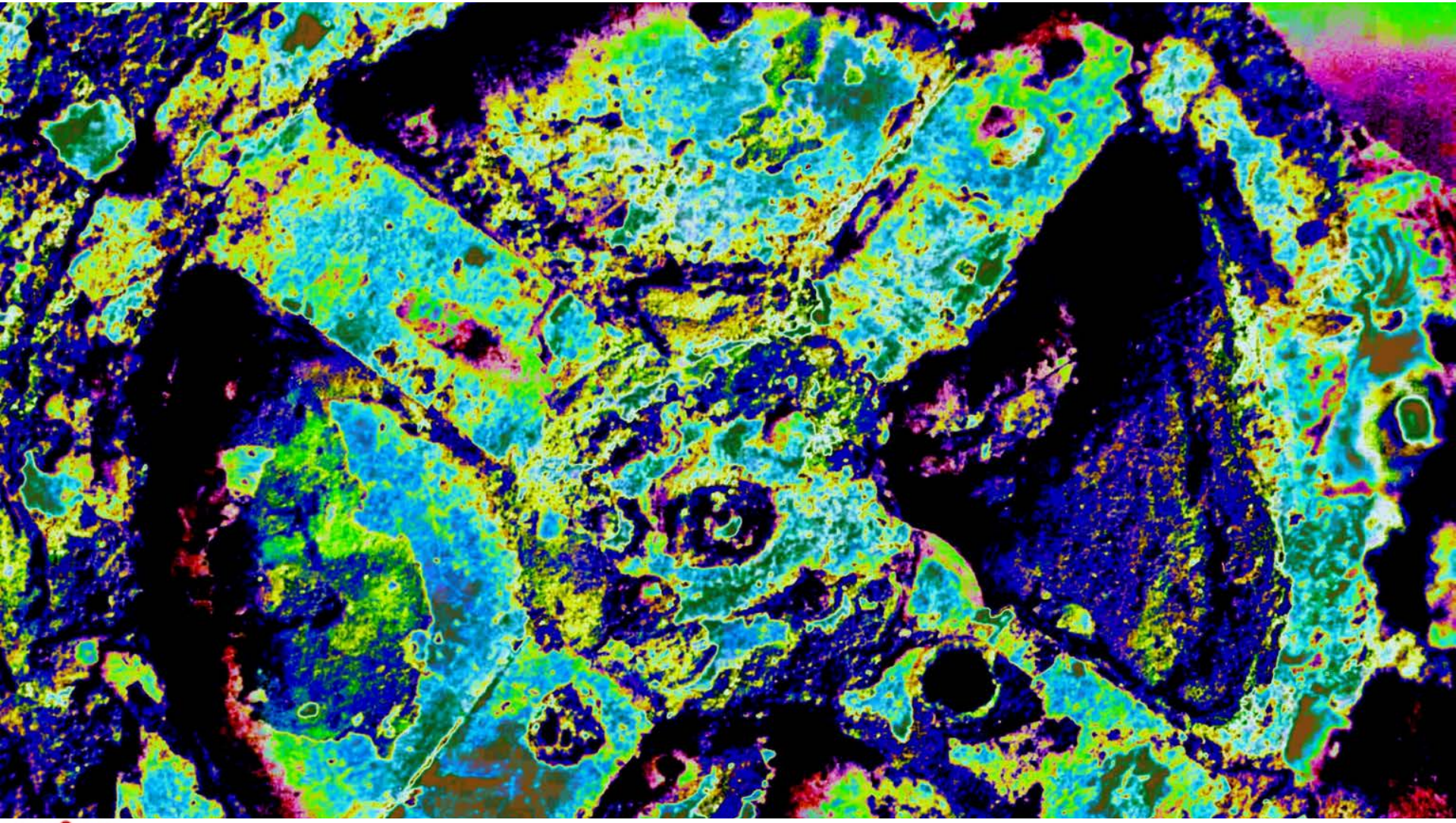

2014: 200 kg 1.4 metre long anchor (by far largest known from antiquity)

# 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)

# Rien van de Weijgaert



university of groningen
faculty of mathematics and natural sciences
kapteyn astronomical institute