

The Birth of Astronomy

Full moon over Cape Sounio
Photo by Anthony Ayiomitas



Peter Watson, Dept. of Physics

This is Ephesus



Picture by Tunc Tezel



Peter Watson

Sky view : Stars seem to rotate in circles, centred on the North Celestial Pole



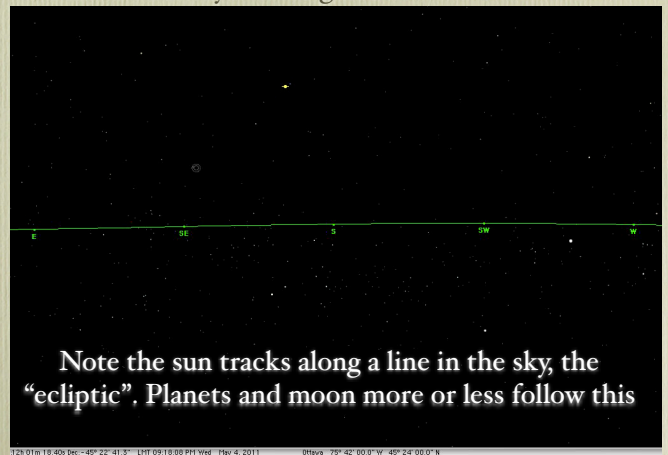
Lets turn off the sun, and track the planets now



Stars near the equator set 4 minutes earlier each night.



We can make things a bit easier by freezing the stars and always looking South



The first observatory (or the earliest we know about)

- Stonehenge
- Prehistoric



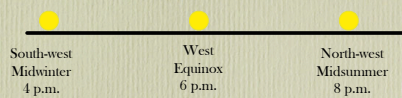
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- Midsummer day: when the sun rises/sets in most northerly position: sunrise aligns with "heel stone"
- Measured at Stonehenge: important to define seasons and hence time to plant crops



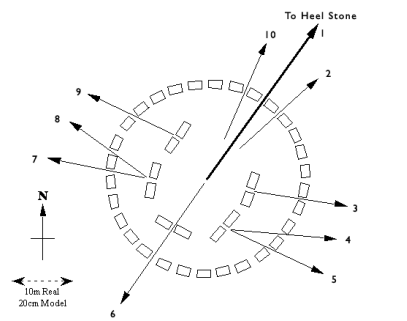
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Sunset



- Note that position varies more as you move away from the equator

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- Alignments let you measure summer solstice

Midsummer sunrise
Winter moonrise low point
Midwinter Sunrise
Southern moonrise (minimum)
Southern moonrise (maximum)
Midwinter sunset
Northern moonset (minimum)
Northern moonset (maximum)
Winter moonrise high point

<http://www.fas.harvard.edu/~scidemos/Astronomy/Astrophysics/Stonehenge/Stonehenge.html>

Peter Watson

Colin Cole points out Carahunge, Armenia's Stonehenge.

<http://www.carahunge.com/>



Supposedly dates to 5500 BC, and also shows astronomical alignments through holes in stones



- Note many other stone circles: e.g
- Avebury (Wiltshire)
- Callanish (Isle of Lewis)
- Carnac (Brittany)



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• 3200 BC

Newgrange, Ireland



- Sun illuminates long corridor on Winter Solstice



BoyneValleyTours.com



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- Much later
- Row of 13 towers on a ridge in a desert in Peru

Chankillo



COURTESY IVAN GHEZZI

- From observation sites the towers line up with sunrise and sunset
- Can tell date to within 2-3 days. (Ivan Ghezzi and Clive Ruggles)



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Babylon

- The questions:
- (Easy) Why do you believe the earth is not flat?
- Why do you believe the earth rotates?
- (Very hard) Why do you believe the earth orbits the sun?
- Why Babylon?



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- Most detailed ancient observations.
- Star Catalogs 1600 BC.
- Eclipse Observed 1500 BC.
- Continuous Records 900 BC.
- Records on stone/clay tablets.

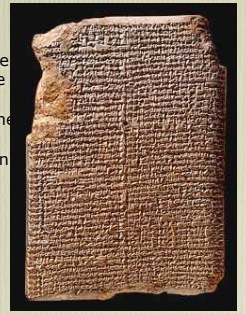


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Babylon: Mul Apin tablet

http://www.mesopotamia.co.uk/astromer/exlore/evn_set.html

On the 1st of Nisannu the Hired Man becomes visible.
 On the 20th of Nisannu the Crook becomes visible.
 On the 1st of Ayyaru the Stars become visible.
 On the 20th of Ayyaru the Jaw of the Bull becomes visible.
 On the 10th of Simanu the True Shepherd of Anu and the Great Twins become visible.
 On the 5th of Du'uzu the Little Twins and the Crab become visible.
 On the 15th of Du'uzu the Arrow, the Snake, and the Lion become visible; 4 minas is a daytime watch, 2 minas is a nighttime watch.
 On the 5th of Abu the Bow and the King become visible.
 On the 1st of Ululu [. . .]
 On the 10th of Ululu the star of Eridu and the Raven become visible.
 On the 15th of Ululu Shu-pa, Enlil, becomes visible.
 On the 25th of Ululu the Furrow becomes visible



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Enuma Elish tablets : the first (written) Creation Myth

From The First Tablet

When in the height heaven was not named,
 And the earth beneath did not yet bear a name,
 And the primeval Apsu, who begat them,
 And chaos, Tiamut, the mother of them both
 Their waters were mingled together,
 And no field was formed, no marsh was to be seen;
 When of the gods none had been called into being,
 And none bore a name, and no destinies were ordained;
 Then were created the gods in the midst of heaven,

Lahmu and Lahamu were called into being...
 Ages increased,...
 Then Ansar and Kisar were created, and over them...
 Long were the days, then there came forth...
 Anu, their son,...
 Ansar and Anu...
 And the god Anu...
 Nudimmud, whom his fathers, his begetters....
 Abounding in all wisdom,...
 He was exceeding strong...
 He had no rival --



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Need some definitions (roughly as the Babylonians might have used them)

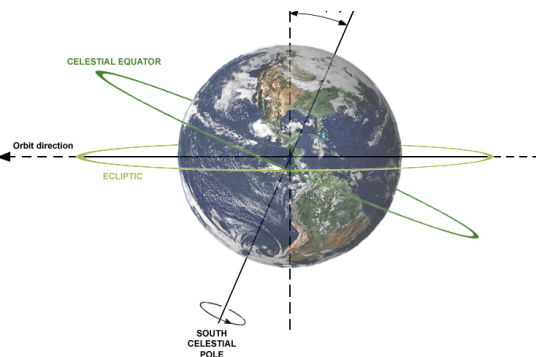
- Year: interval between (e.g.) most northerly sunrises. ~365 1/4 days
- (lunar) Month: interval between (e.g.) full moons ~ 29 1/2 days
- Solar day: interval between times when the sun is due south = 24 hours (defn)
- Sidereal day: interval between (e.g.) Sirius being due south = solar day - 4 minutes

Peter Watson

- Midsun longest position

- 20th or
- Midwin
- 21st/22

- Spring/fall equinox: sun is over equator, night & day are equal (roughly)
- 20th/21st March 22nd/23rd Sept



Peter Watson

But note

- Year is not a whole # of days
- Year is not a whole # of lunar months
- However 19 years = 235 lunar months (+ 2 hours): Metonic cycle
- Most societies fudge 12 months = 1 year by adding in extra days.

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Babylonian

12 lunar months + extra short month



MS 4151
List of month names for the Lagash (Larsa?) calendar, including the extra 13th month.
Babylonia, 2000-1600 BC

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Sundials

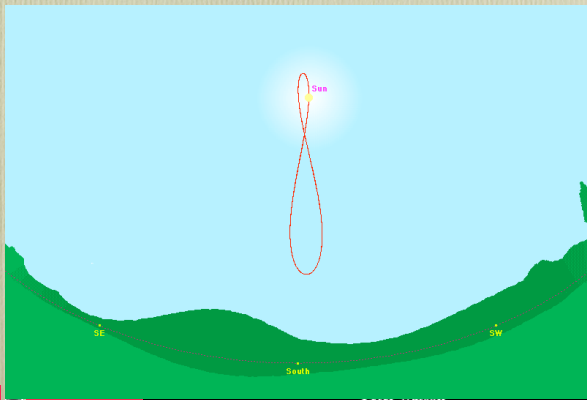
- Good to few minutes but
- ...Position of the [noon sun](#) in the sky varies throughout the year:

It moves against the fixed stars because the earth orbits the sun



Peter Watson

- Sun is not due south at noon (time varies by about 8 minutes) because the earth moves at varying speeds in its orbit,
- so we actually need a **better** clock than the sun to



A tutulemma.

Photo from Side, by Tunc Tezel
Combines sun's position through year with an eclipse



Eclipses

Tablet with a list of eclipses between 518 BC and 465 BC, mentioning the death of king Xerxes.

British Museum, London



Why do these matter?

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GLOUCESTER These late eclipses in the sun and moon portend no good to us:.....

EDMUND I am thinking, brother, of a prediction I read this other day, what should follow these eclipses....

I promise you, the effects he writes of succeed unhappily; as of unnaturalness between the child and the parent; death, dearth, dissolutions of ancient amities; divisions in state, menaces and maledictions against king and nobles; needless diffidences, banishment of friends, dissipation of cohorts, nuptial breaches, and I know not what.

EDGAR How long have you been a sectary astronomical?

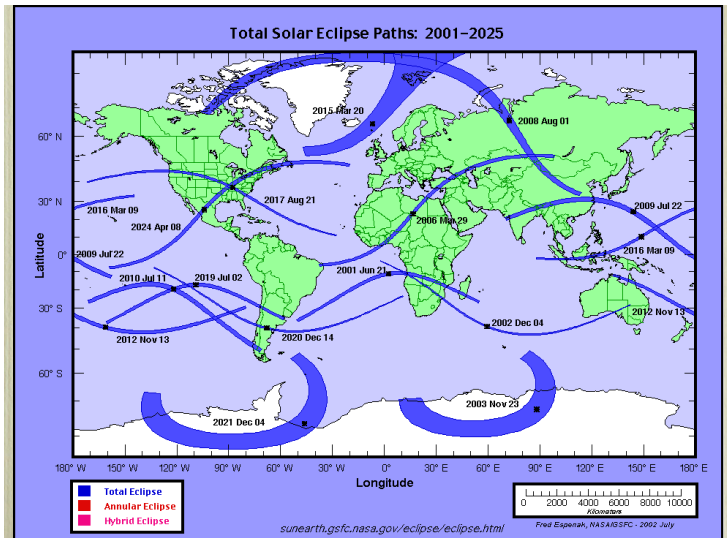
Chinese astronomers Hi and Ho executed for failing to predict eclipse.

And they even mattered to artists



St Benedict, by Cosmas Damian Asam 1735

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sunearth.gsfc.nasa.gov/eclipse/eclipse.html

Fred Espenak, NASA/USF - 2002 July

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Saros cycle

- Eclipses repeat after 18 years and 11.3 days.
- The .3 days shifts the eclipse about 110° degrees west.
- Some saros sequences start at the south and drift North, others at the North and drift South, so can only see cycle after many years.
- Why is it so complicated? Need to combine
 - Earth's rotation
 - Moon's orbit (not quite circular)
 - Earth's orbit (ditto)
 - and the plane of the moon's orbit precesses

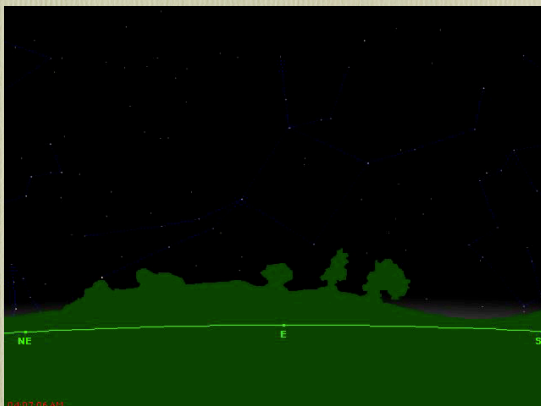
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Eclipse of 1999 seen from Mir



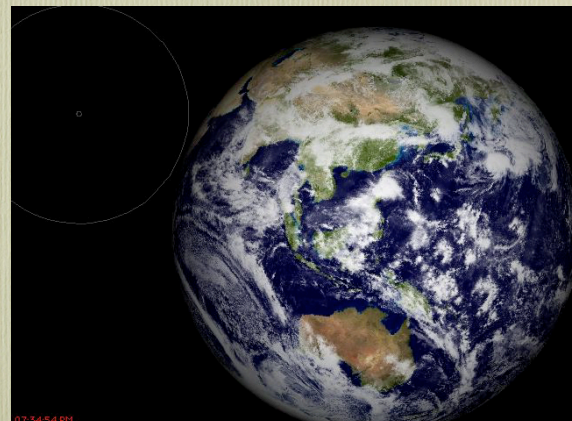
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Babylonians observed total eclipse 15 April 136 BC.



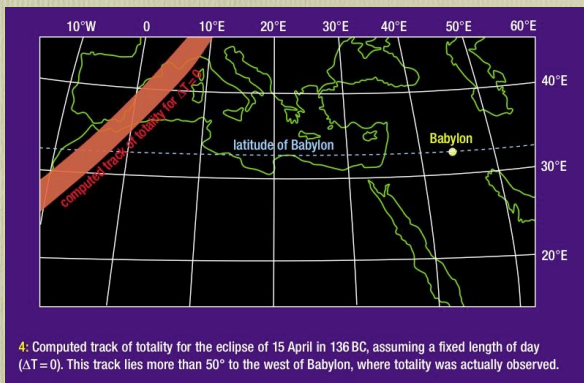
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and they would even have seen it from the moon !



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But they shouldn't have!



- Earth's rotation has slowed down, by ~ 0.01 sec/century, because of tidal effects! i.e. earth isn't a very good time-keeper

Peter Watson

• What was wrong with Babylonian Astronomy?

- They had no model (but they were very good at arithmetic!)
- e.g. the month
- Kidinnu arrived at 29.530594 days, which is only 0.432 seconds more than the modern estimate of 29.530589 days.

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- Chinese
- Records from 2000 BC.
- Eclipses predicted
- Comets (Halley's comet in 467BC).
- Measured year to be 365 $\frac{1}{4}$ days, lunar month to be 28 days.

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The Dunhuang star-atlas 649-684

• [J.-M. Bonnet-Bidaud \(CEA, Saclay\)](#)

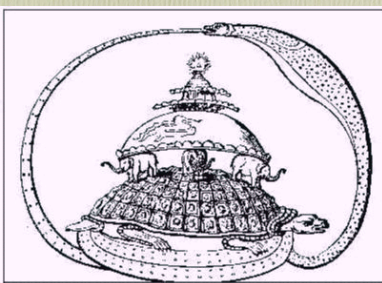
- Oldest complete star atlas
- 1300 stars:
Positions accurate to a few degrees
- Note Big Dipper & Cassiopeia



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Hindu

- Not very systematic observations
- cosmology mixed in with mythology!



Peter Watson

- Fortunately now revived:
- Great A'tuin the turtle comes, swimming through the interstellar gulf, hydrogen frost on his ponderous limbs, his huge and ancient shell pocked with meteor craters. He thinks only of the weight. Most of the weight is accounted for by Berilia, Tubul, Great T'phon and Jerakeen, the four great elephants upon whose shoulders the world rests.
-The Colour of Magic, Terry Pratchett

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The Greeks

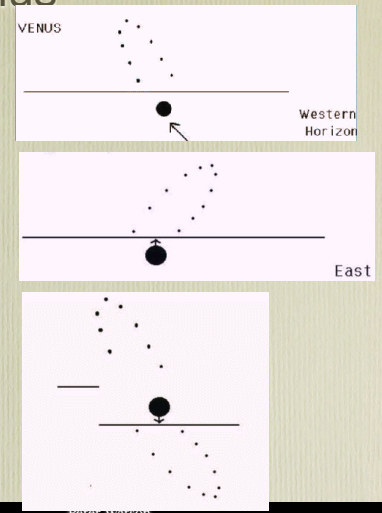
- Pythagoras:
- First Cosmos Model: Motions of the Spheres.



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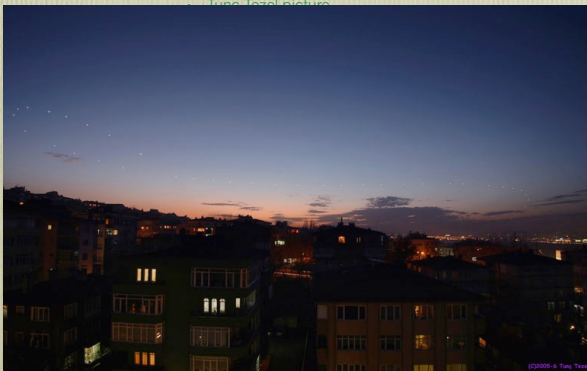
Discovery of Venus

- Hisperus appears as an evening star (very bright) for about 8 months.
- Followed by Phosphorus (morning star) by a similar period in the Eastern sky at dawn
- become Venus, -497 BC.



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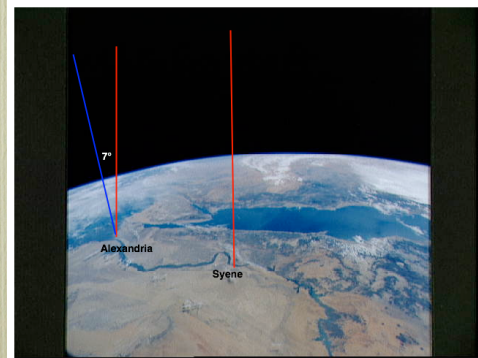
- Note that this is much more difficult to study than it sounds, because the orbit is tilted to the horizon, and the orbit is distorted.



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Eratosthenes: 276-195 BC

- How big is the earth?



Peter Watson

- Sun is vertically above Syene (Aswan) whereas it is 7° off the vertical at Alexandria,
- Distance is 720 km
- Gives ~5900 km instead of 6400.
- First step into finding how big the universe is!
- How far is the Moon?



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- Moon is about $1/2^\circ$ in the sky
- Can use the moon as a "Screen" on which the shadow of the earth is projected:
- The shadow of the Earth $\sim 2^\circ$ wide.

Photo by Anthony
Ayiomitas



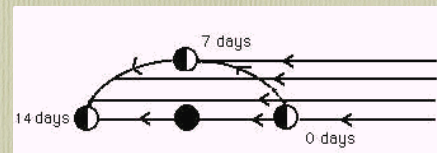
- Radius of the earth ~6500 km (4000 mi).
- This gives $d \sim 375,000$ km
- $d = 384,400$ km by modern methods.

• How far is the sun?

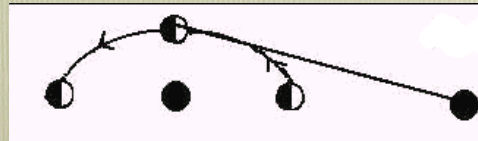


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- Much harder: If the sun was infinitely far away, then half-moon would occur exactly half way through month.



- If the sun is closer, half-moon will occur earlier



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- **Very** hard to estimate when half moon occurs

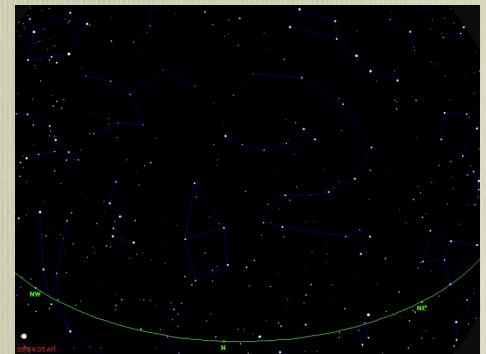
- Get earth-sun distance ~20 times Earth-Moon distance ~7,500,000 km. (actually ~150,000,000 km)
- Implies the sun is a red-hot stone bigger than Greece! (Anaxagoras)



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One more discovery by the Babylonians/Greeks

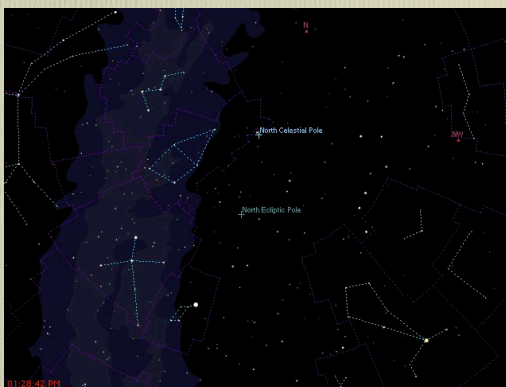
- What is the North star
- The point the stars appear to rotate round



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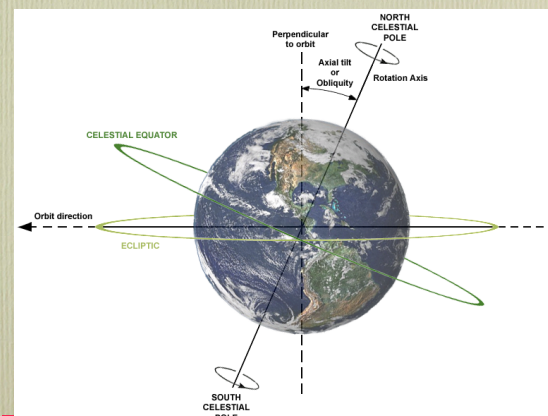
Hipparchus: 160-127 BC. Precession of the Equinoxes

Earth's axis is tilted, but doesn't always point to the same place (i.e. the North Star isn't always!)



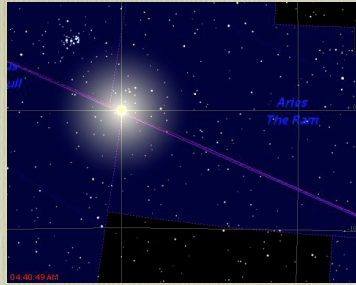
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- March 21st & Sept 21st are special days: the equinoxes
- Sun is above the equator, but where on the equator?



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- Aries 2000 BC
- Pisces 100 BC
- (which is why the Christians chose the fish as their symbol)

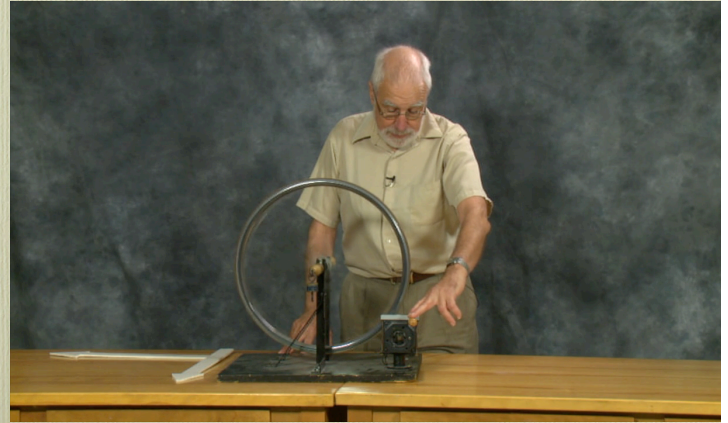


- And now
- This is the dawning of the age of Aquarius



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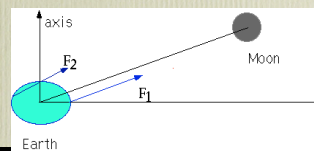
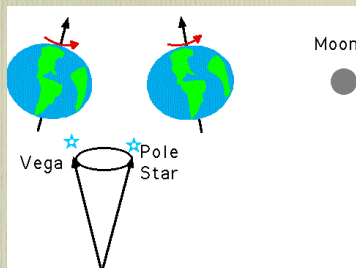
Why?



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Moon produces torque on bulge of earth

- Causes precession with period of 26000 years
- one sign of zodiac/2100 year
- Sun has similar affect on moon's orbit
- produces saros cycle (18.1 year precession)

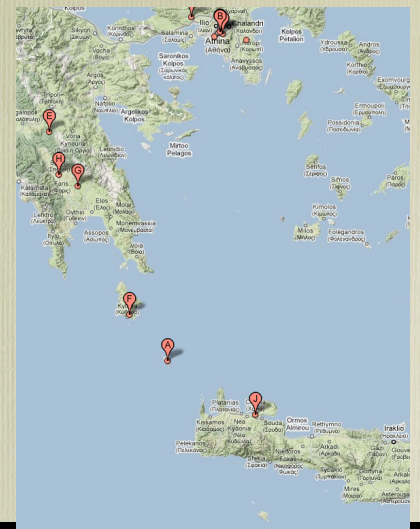


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Antikythera



- Wreck full of sculptures



and a piece of rusted junk: Antikythera Mechanism

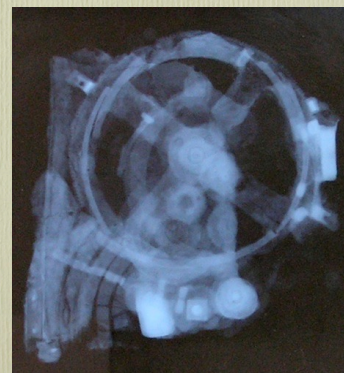
- Found in 1901
- probably late second century BC.
- National Archaeological Museum in Athens
- So what is it?



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X-rays show very complex structure

Many (at least 30) gears: one has 47 teeth !!!!



Peter Watson

This may be how it works



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- Shows Metonic sequence (235 lunar months = 19 solar years + 2 hours)

$$\bullet 235 = 5 \times 47!!!!!!!!!!!!!!!!!!!!!!!!!!!!$$

- Shows Saros eclipse cycle (223 lunar months)



Peter Watson

2010:

A fully functional replica of the Antikythera Mechanism is built



Peter Watson

The descendants



- The Orrery
- (Vatican Museum)



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Armillary Sphere

Antonio Santucci
(Florence)
1588-1593
Museo Galileo



Clocks

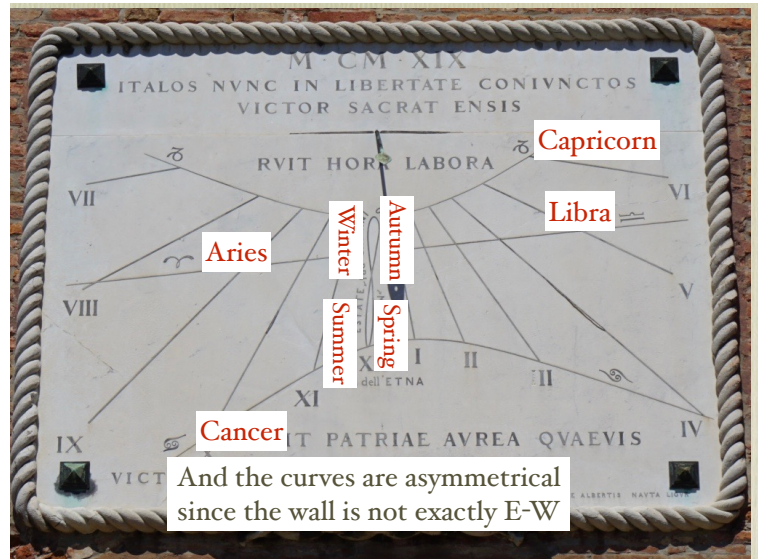
Mantua clock tower (1472)
shows time, lunar phases,
signs of zodiac



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A much more advanced sundial

If you are in Venice. go to the Arsenale



And the curves are asymmetrical since the wall is not exactly E-W

Babbage's Difference Engine

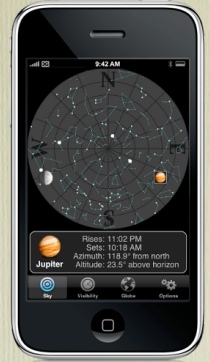
- c 1870
- Science Museum, London
- Whipple Museum, University of Cambridge



And finally

- Your own personal Antikythera!

- location of the sun, moon, and planets
- maps of stars and constellations
- rise and set time of the sun, moon, and planets
- current and future moon phases
- 3D globe view of all planets and the moon



Acknowledgements

Astronomy Picture of the Day (APOD)

Anthony Ayiomitas

Tunc Tezel

Simulations: Voyager 4.1 (Carina software)

Planets: Dana Peters <dana@qcontinuum.org>, Downloadable from the App. Store