



## Sky and the Universe

- ❖ Cosmology is as old as humankind, presumably as soon humans developed language and art, ie. the use of symbolism for expressing more profound and abstract thoughts, they started to study the world around them.
- ❖ Very early cosmology was very local ... the Universe was what you immediately interacted with, and involved weather earthquakes, sudden environmental changes etc. Things outside daily experience were supernatural
- ❖ The sky was identified with the supernatural, its serenity and regularity with the action of forces – Gods beyond control of humans
- ❖ At the same time, it was recognized that the celestial phenomena were influencing our daily life:
  - e.g. seasons corresponded to motions of stars on the sky
  - that suggested that ultimate forces in our world were to be seen on the sky

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- 
- ❖ Hence, the key to unravelling the mysteries of the sky and the forces that shape and formed our world and Universe
  - ❖ were to be found in the regularities in the celestial motions.
  - ❖ Hence, astronomy (at the time indistinguishable from astrology) formed the basis for many cosmological ideas and thoughts ...

## The Beginnings of Astronomy

- ❑ Astronomy existed far before
  - Dawn of Civilization**
- ❑ Oldest Science of Humanity
- ❑ Ever since humans became aware of:
  - Patterns in the Night Sky
  - Change and Regularity of the Night Sky





## Astronomy: Importance for civilization

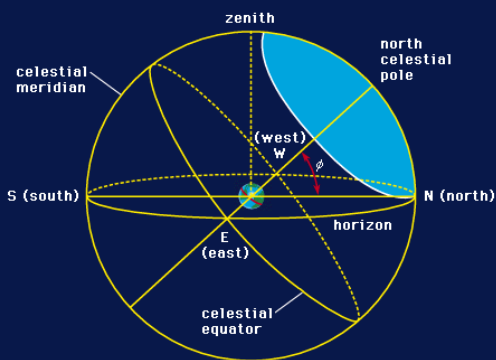
- ▣ Farming (& Hunting):
  - Regularity of nature reflected in the sky !
  - Seasons !
- ▣ Religion:
  - Gods identified with stars & celestial bodies
  - Astrology: human fate connected to heaven
- ▣ Farming & Religion:
  - Calendars and Timekeeping
- ▣ Navigation
- ▣ Land Surveying





## Daily motion:

Sky turns around north celestial pole,  
Along circle parallel to celestial equator

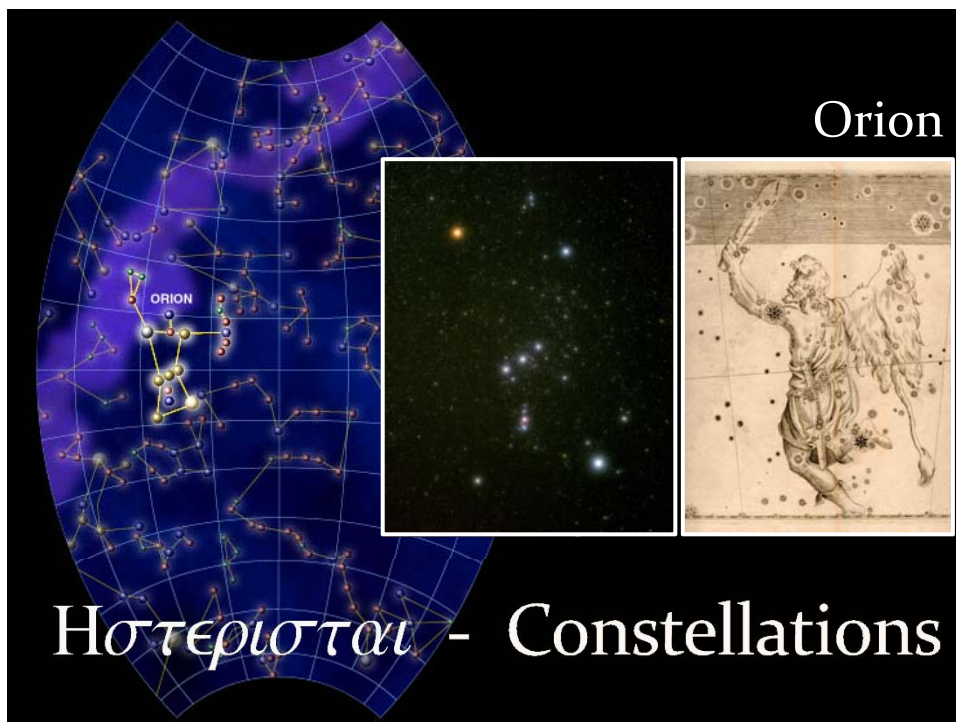


## Lascaux First Starmap: the Pleiades ?

### Lascaux:

- Most beautiful Ice Age cave paintings
- Magdalenean cave art
- 16,500 yrs old
- 2000 figures:
  - 900 animals, of which 364 horses
  - geometric figures
  - Hall of Bulls: 4 huge aurochs/bulls
- Rappenglueck speculated that cave paintings contained astronomy:
  - star map near head bull
  - Pleiades
  - Moon cycle (29 dots) near horse





## Big Dipper – Ursa Major: Oldest Constellation ?

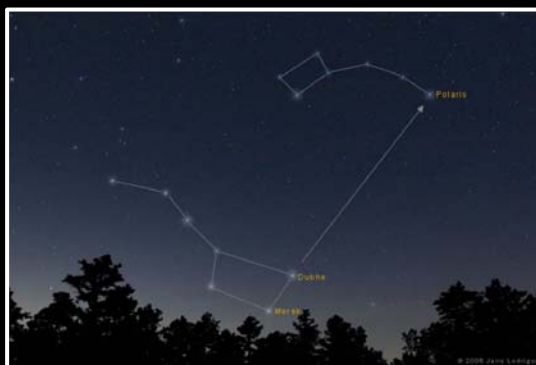
Most well-known constellations have been defined by

- Babylonian
  - Greek
- } astronomers

Not so the **Big Dipper**, known:

- Eurasian continent (incl. Siberians)
- American Indians

Suggests:  
older than 10,000 yrs  
before ancestors American Indians  
crossed Bering Street

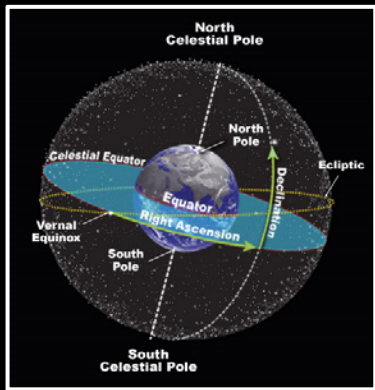




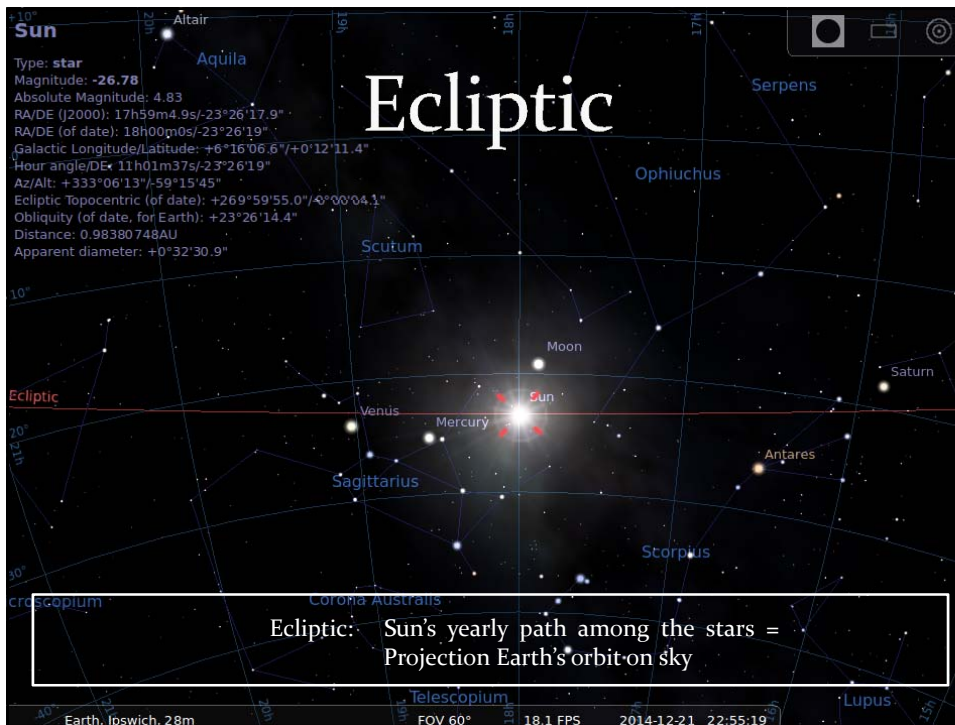
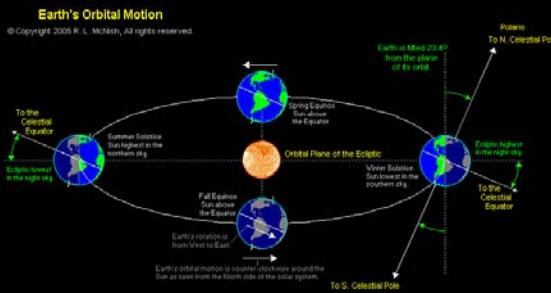




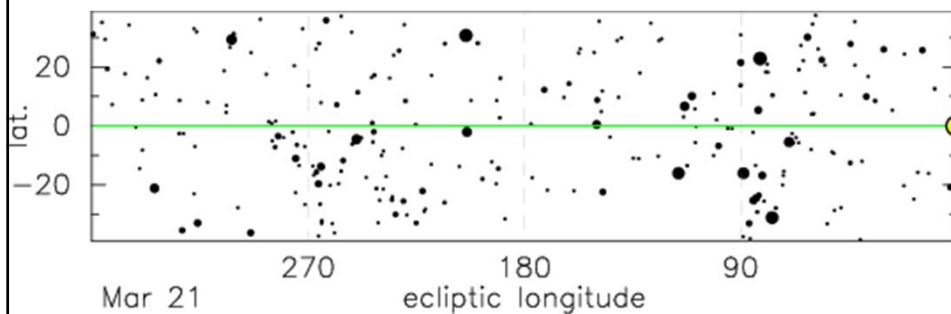
# Sun: annual path



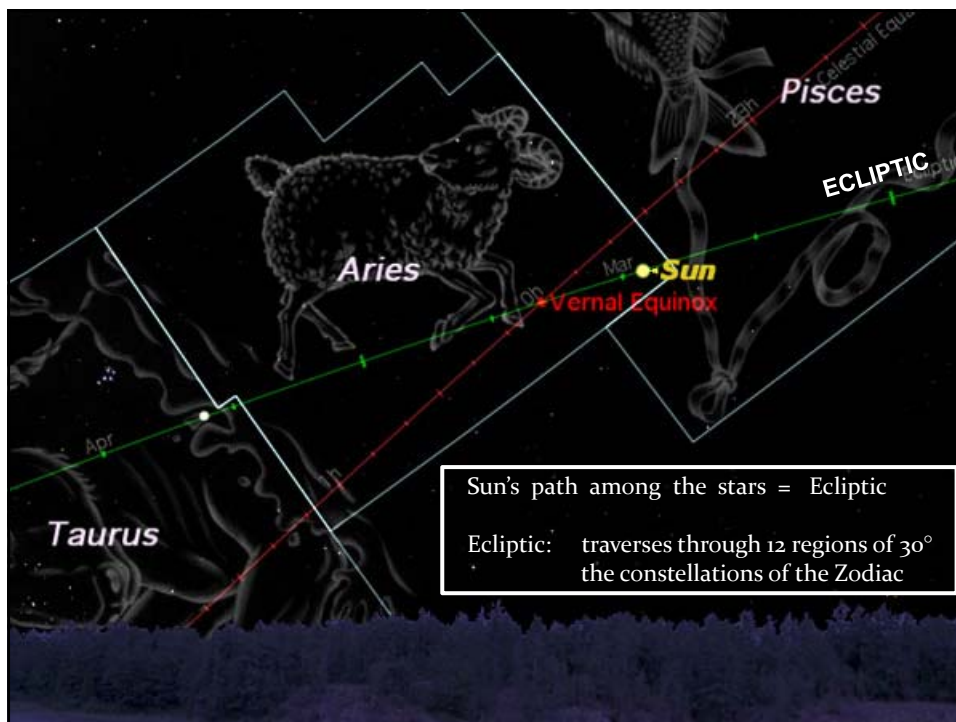
Ecliptic: Sun's yearly path among the stars = Projection Earth's orbit on sky

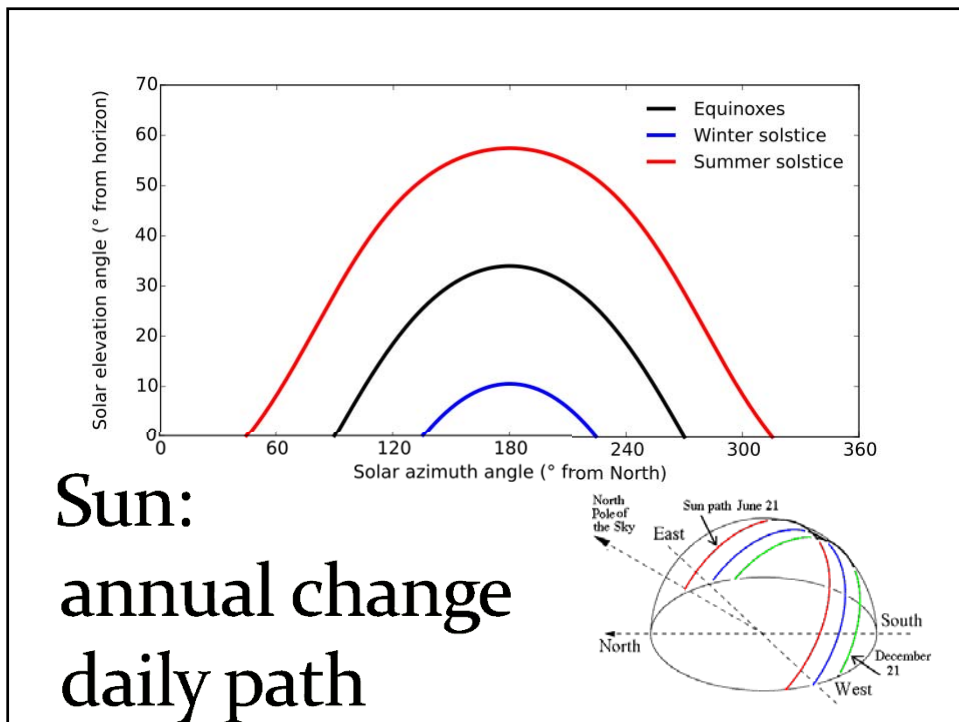


# Sun: annual path



Ecliptic: Sun's yearly path among the stars =  
Projection Earth's orbit on sky







## Nabta - Egypt Oldest Archaeoastronomical Monument ?

### Nabta:

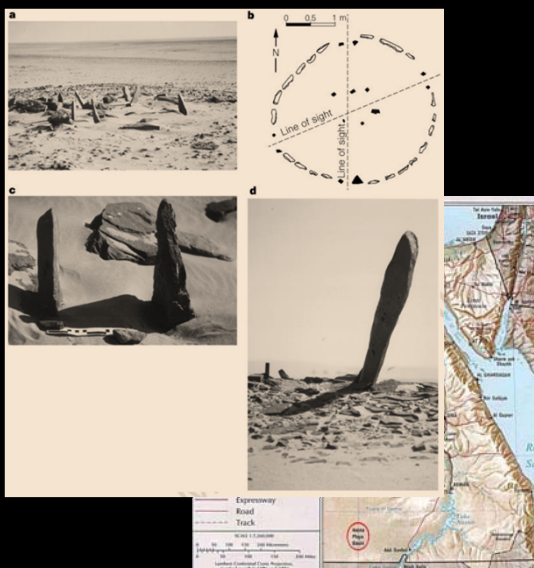
Southwest Egypt

Oldest astronomical megalithic monument: 6,000-6,500 yrs old

- complex not circular: .8-1.8 miles
- 10 slabs 9ft, 30 oval stones,
- calendar circle

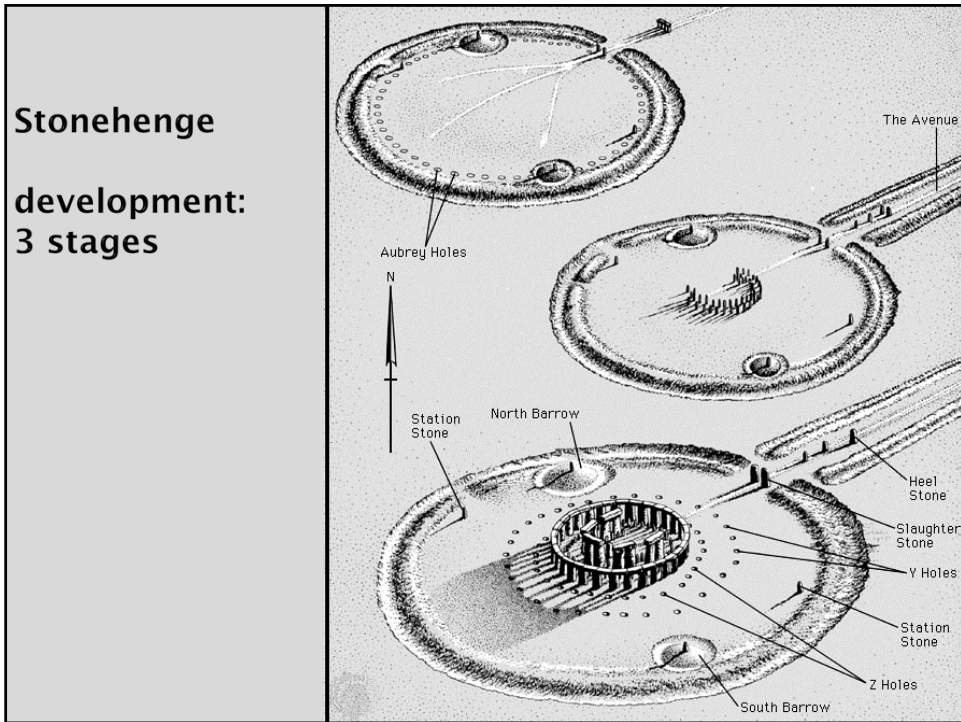
- Prehistoric calendar, marking summer solstice
- perhaps much more:

Brophy: Orion belt + shoulders



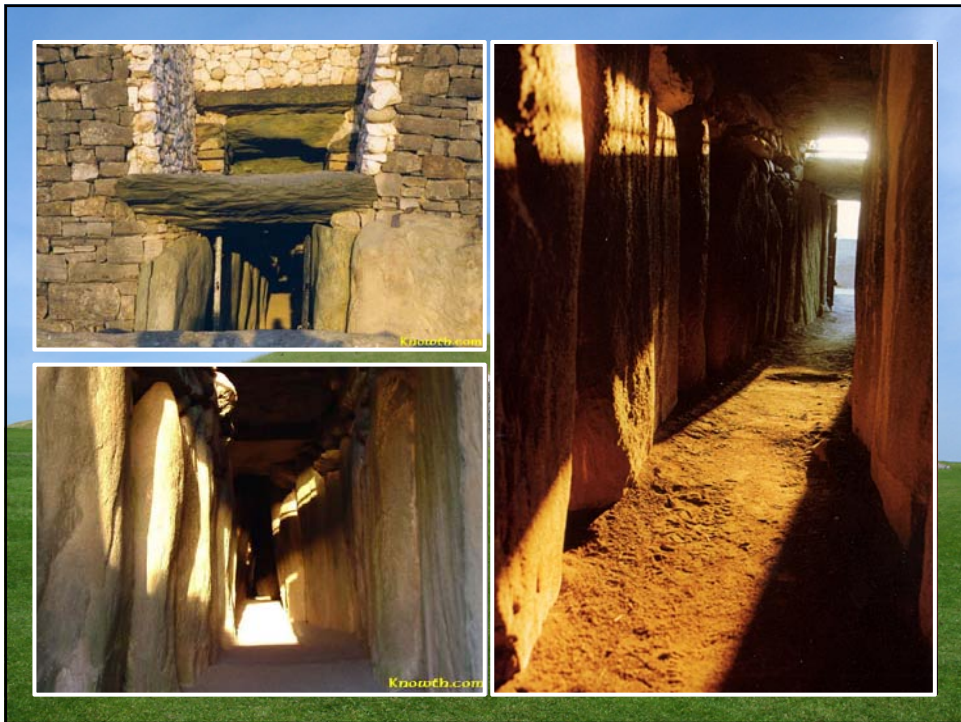












# Goseck:

## Europe's Oldest Observatory



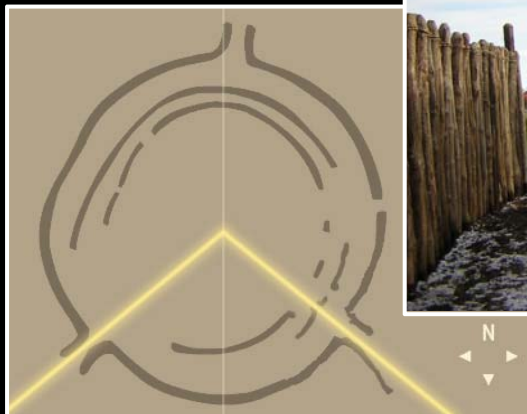
### Goseck Circle:

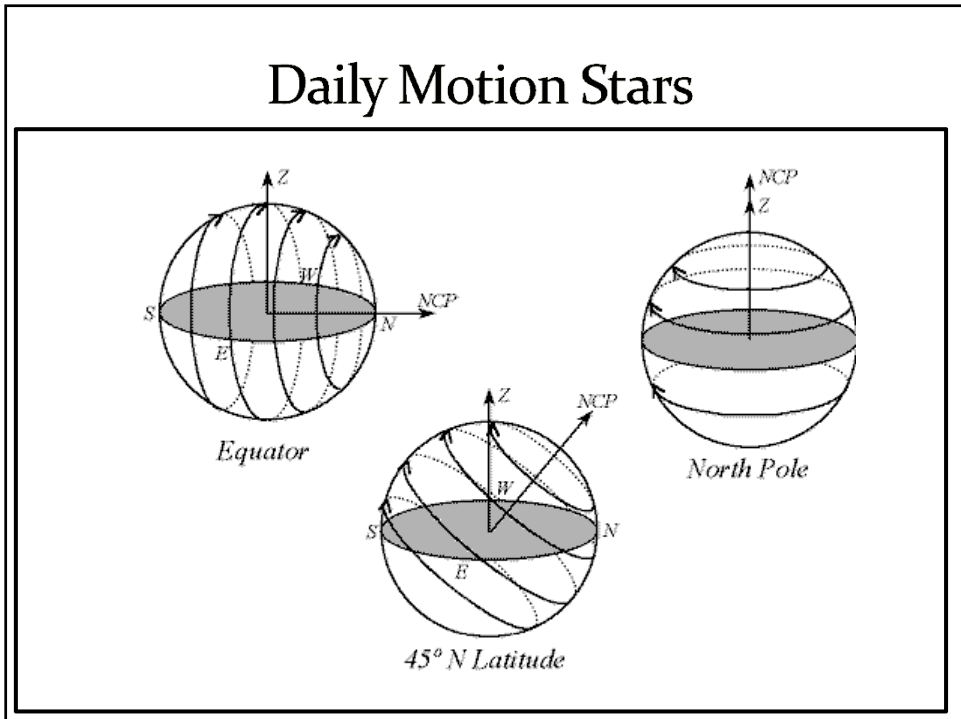
1990s: discovered by aerial photographs (Goseck, Sachsen-Anhalt)  
 circular Henge-construction, 75 m. diameter  
 settlement since 5<sup>th</sup> Millennium BCE (49<sup>th</sup>-47<sup>th</sup> century BCE)  
 Solar Observatory: visor mechanism –  
 determination winter & summer solstice  
 2005: reconstruction

# Goseck:

## Europe's Oldest Observatory

49<sup>th</sup>-47<sup>th</sup> century BCE





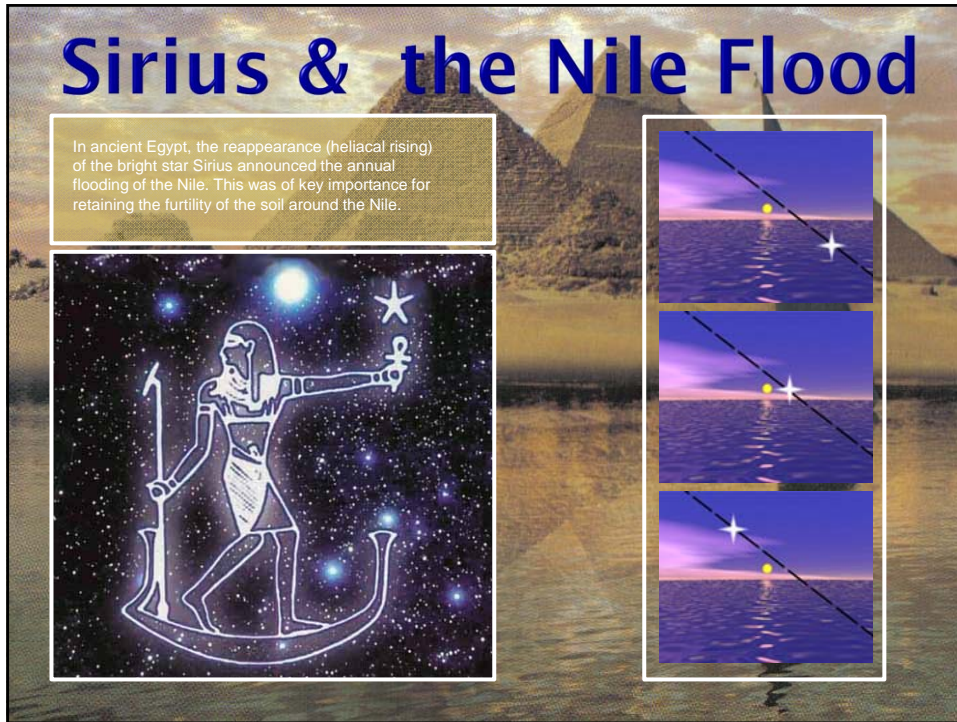
# Circumpolar Stars

	<p><b>Circumpolar Star:</b></p> <p>Any star closer than your latitude to your visible celestial pole (north or south) will always be <b>above</b> your local horizon.</p> <p>These are the <b>Circumpolar Stars</b></p> <p>Ursa Major, Ursa Minor, &amp; Draco are circumpolar constellations as seen from Groningen</p>
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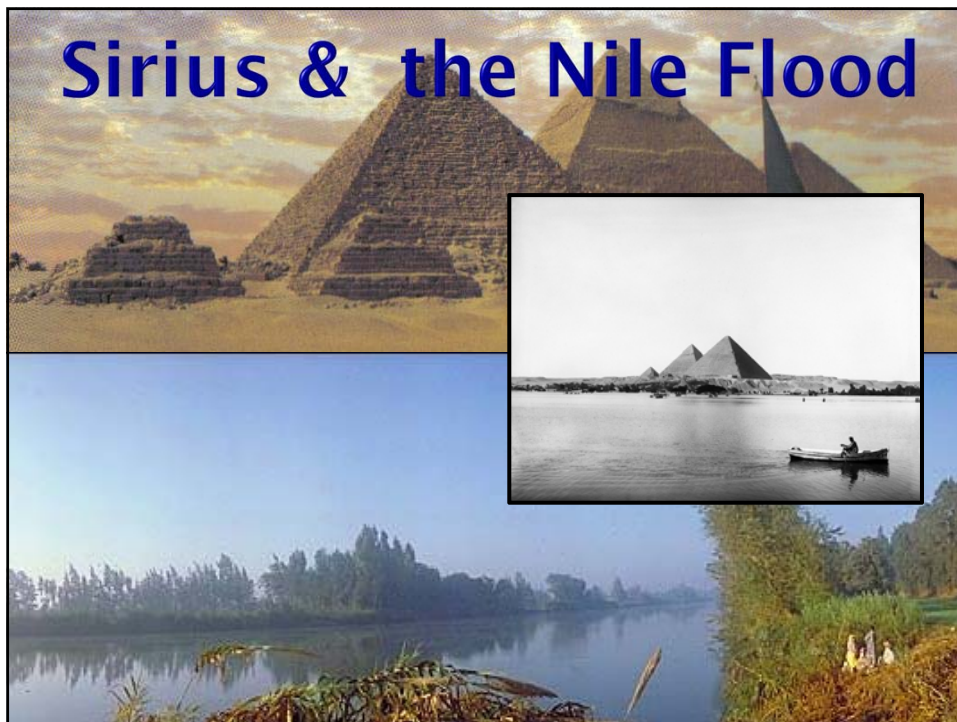
# Sirius & the Nile Flood

# Sirius & the Nile Flood

In ancient Egypt, the reappearance (heliacal rising) of the bright star Sirius announced the annual flooding of the Nile. This was of key importance for retaining the fertility of the soil around the Nile.



# Sirius & the Nile Flood





### Moon: Orbit & Phases

The image displays the Moon's phases in a 5x4 grid on the left. On the right, a diagram shows the Moon's orbit around Earth, with labels for the phases: WAXING GIBBOUS, FIRST QUARTER, WAXING CRESCENT, NEW, WANING CRESCENT, THIRD QUARTER, and WANING GIBBOUS. A vertical scale on the right is labeled 'SUNLIGHT'.

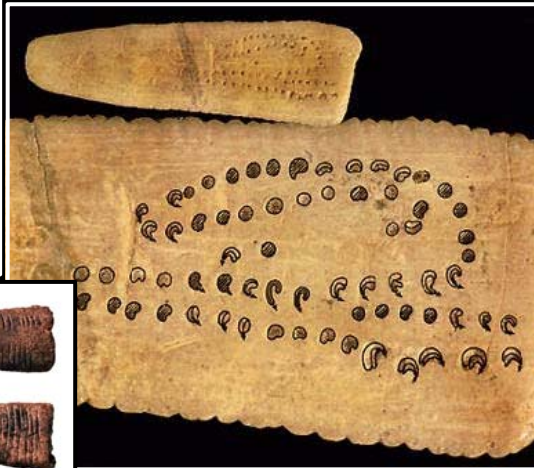
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## Palaeolithic Lunar Calendars: Ishango & Blanchard bones

Blanchard bone (France):  
reindeer bone,  
30,000 yrs. old  
69 notches, in 27 shapes,  
along winding pattern

Suggestion (Marshack):  
Lunar Calendars

Ishango bone (Congo)  
20,000-25,000 yrs old  
linear notches in 3 rows



## the Month



Time interval related to periodic return of the Moon

Complications arise in defining "return":

- ◇ several different concepts of month exist ,  
related to the complex dynamics of Moon-Earth-Sun system
  - Moon orbits Earth
  - Earth orbits Sun
  - Moon orbit elliptical
  - Moon orbit's plane oscillates
- ◇ These, and their mutual interplay defines the different Months
- ◇ The different months were first recognized by the Babylonians



## Moon Size

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°

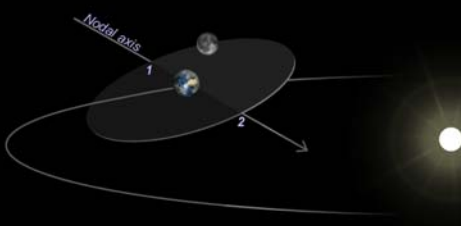
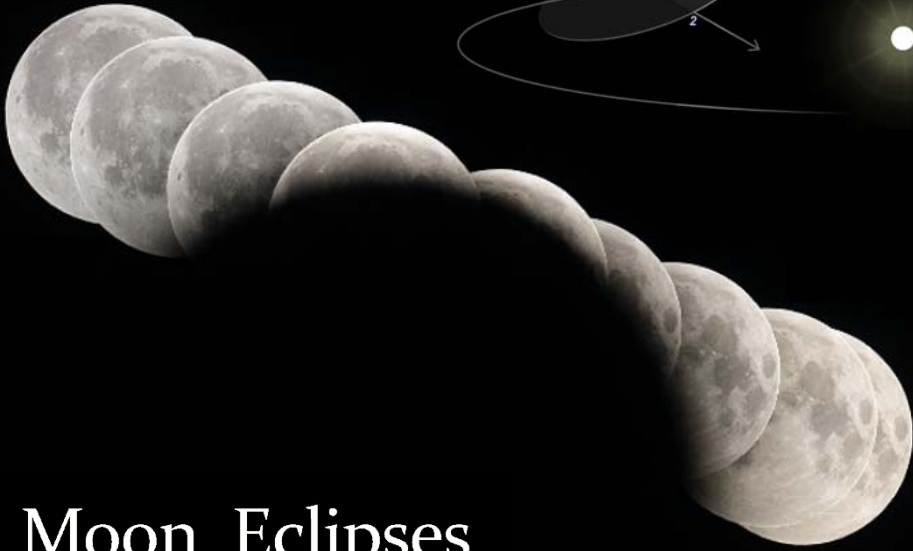

different distance along orbit Moon

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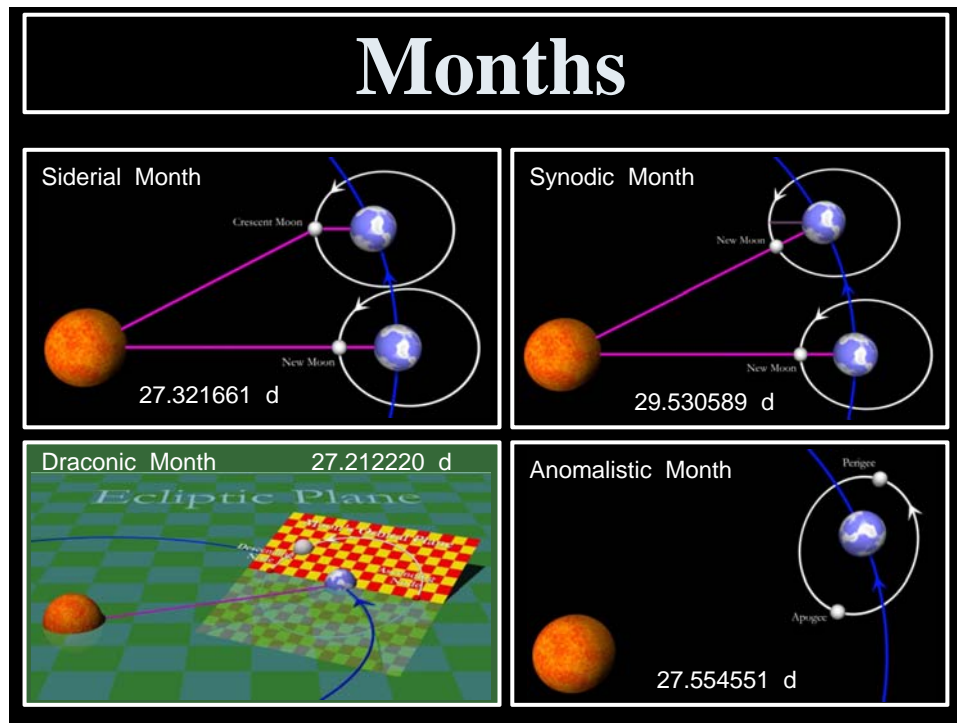
Date: 2005 Sep 1 02:23:28 UT

## Moon Libration

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



## Moon Eclipses



## Month: the Concept

- **Sidereal Month**  
return moon to same point of sky wrt. Zodiac (same star),  
i.e. return to the same star on the ecliptic 27<sup>d</sup>07<sup>h</sup>43<sup>m</sup>12<sup>s</sup>
- **Tropical Month**  
return moon to the same declination 27<sup>d</sup>07<sup>h</sup>43<sup>m</sup>05<sup>s</sup>
- **Anomalistic Month**  
return to same speed, i.e. interval moon between  
apsis (perigee, apogee) Moon's orbit 27<sup>d</sup>13<sup>h</sup>18<sup>m</sup>33<sup>s</sup>
- **Draconic Month**  
average interval between transits ascending node,  
ie. interval successive transits ecliptic (Nodical Month) 27<sup>d</sup>05<sup>h</sup>05<sup>m</sup>36<sup>s</sup>
- **Synodic Month**  
return to same angle from the Sun,  
interval between Moon at same phase 27<sup>d</sup>12<sup>h</sup>44<sup>m</sup>03<sup>s</sup>

## Astronomical Cycles: Solar & Lunar Calendar

- Not all societies use the Solar calendar of 365 days (+ ¼ day) per year that we have (the Gregorian calendar). Our calendar is based on the motion of the Sun along the sky.
- Other societies (cf. eg. the Islamic calendar) base themselves on the motion of the Moon, and use a Lunar calendar. Already the ancient Babylonians had managed to establish a link between them. To accomplish this, we need to identify a time period that is both
  - a multiple of a Solar period (a year) and of a Lunar period (a month).
- The time period that establishes this is called after the 5<sup>th</sup> century BCE Athenian astronomer Meton. It is almost certain he got this from the Babylonians. This important time period, still of key importance to translate between Solar and Lunar calendar, is called the Metonic Cycle.

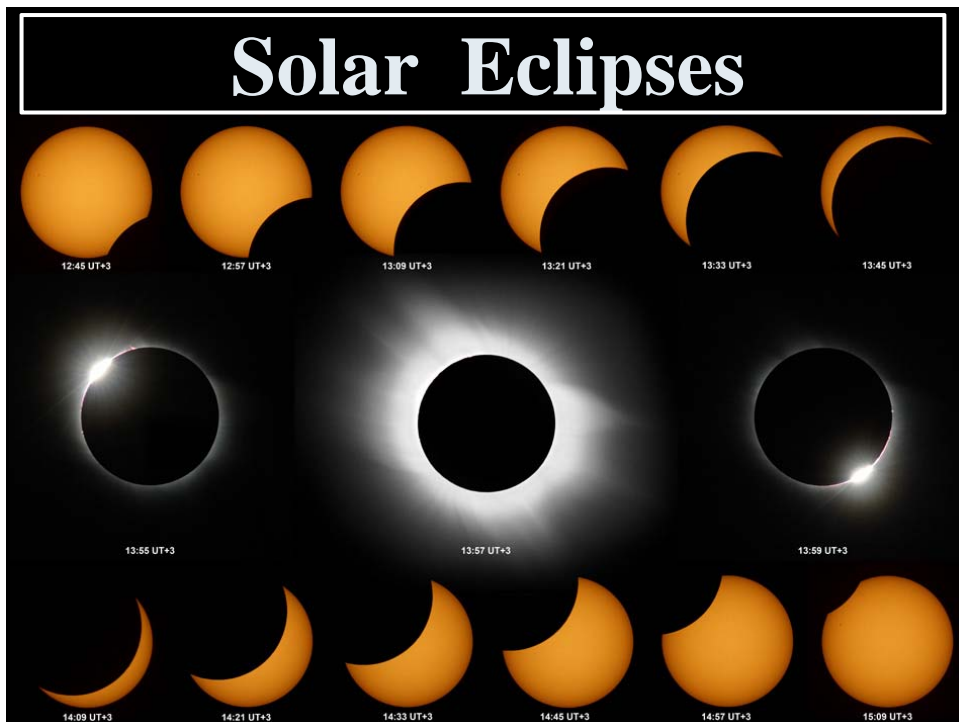
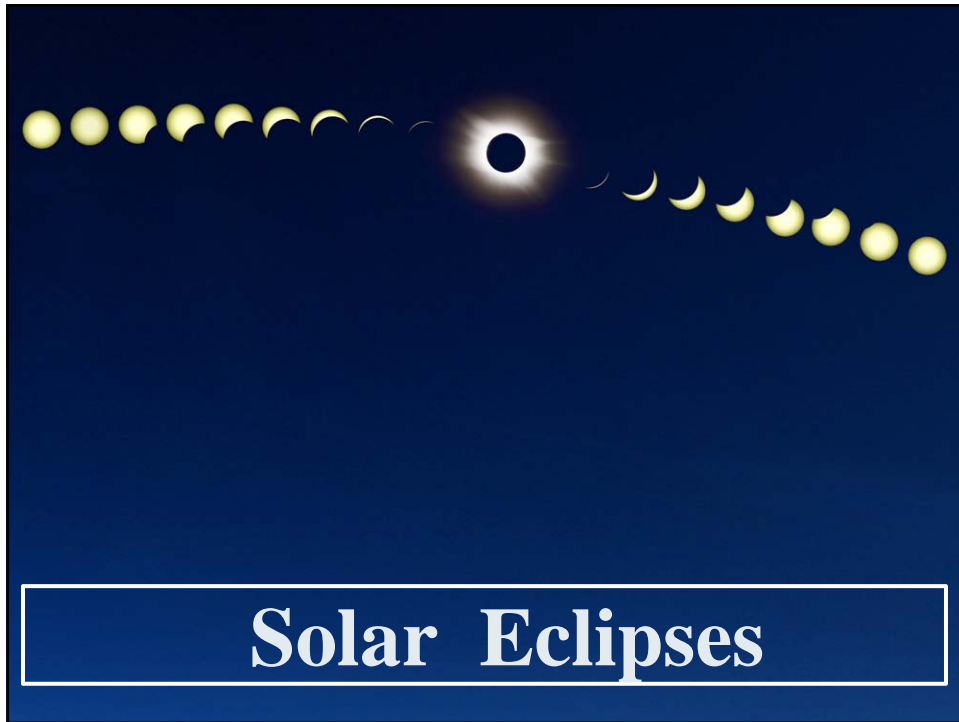
- **Metonic Cycle**  
multiple of Tropical Year and Synodic Month

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

- **Callippic Cycle**  
more accurate multiple  
of Tropical Year & Synodic Month

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





# Solar & Lunar Eclipses

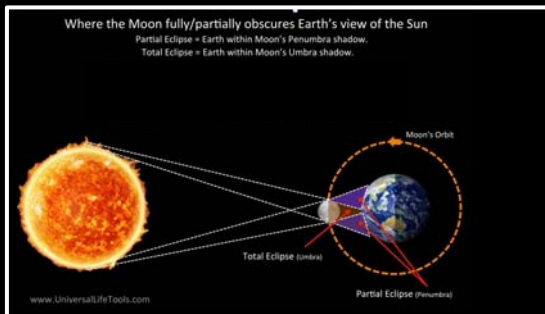
- By sheer coincidence, the angular diameter of the Moon disk on the sky is approximately equal to that of the solar disk. As a result, when the moon moves in front of Sun, it blocks the light of the Sun.
- It leads to one of the most awesome natural phenomena we know of, a Solar Eclipse.
- Within our heliocentric understanding of the solar system, it is not difficult to appreciate what happens: the moon moves in between Earth and the Sun, and casts a shadow on Earth
- the resulting shadow of the Moon on the surface of planet Earth marks the location on Earth where people will experience and see a Solar Eclipse.



- in ancient societies, Solar Eclipses were of tremendous importance. After all, the source of life suddenly had disappeared. Rulers would fear for their lives and government. Predicting when they would occur was of major importance..

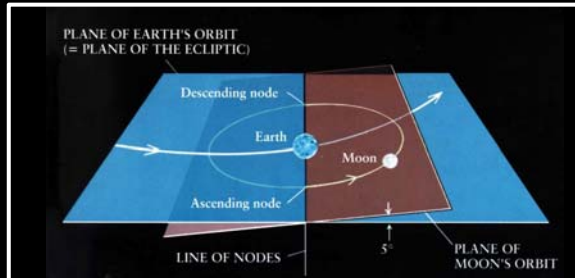


# Solar Eclipse: Geometry



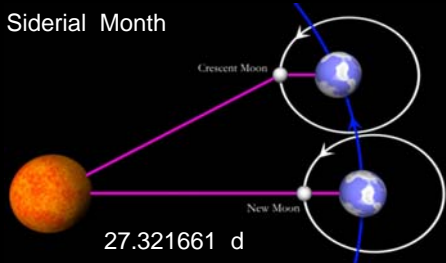
- However, to decipher an eclipse is far from trivial.
- It is the result of the combination of different orbital factors:
  - the moon moves in between Earth and Sun once each month (at New Moon)
  - the Moon orbit is slightly inclined wrt. the Ecliptic, the orbit of the planets over the sky (and of the Sun, reflecting the Earth's motion around the Sun along the ecliptic plane).
  - The moon can only stand right in front of the Sun when it just moves through the nodes of its orbit, ie. the crossing point of its plane with the ecliptic

- the moon orbit is not circular, but elliptic (notice that the ancients did not know this even while having identified the resulting shift)
- the moon orbit also rotates itself wrt. the ecliptic plane, resulting in a systematic (circular) shift of the nodes
- The regularity in the occurrence of an Eclipse is therefore the result of 3 periods:
  - synodic month: motion of moon around earth, wrt. Sun)
  - draconic month: time between passes of the moon through nodes of its orbit
  - anomalistic month: shift of moon orbit, ie. of its perigee and apogee



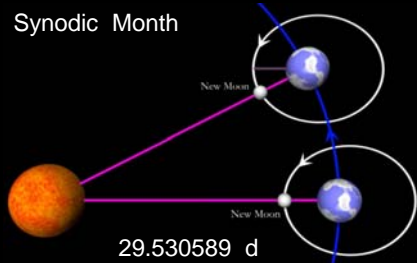
# Months

Siderial Month



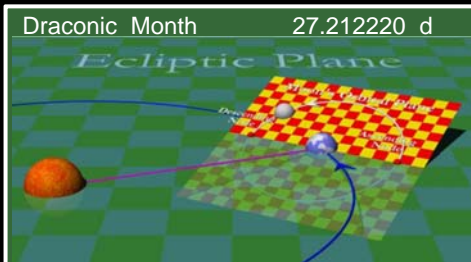
27.321661 d

Synodic Month



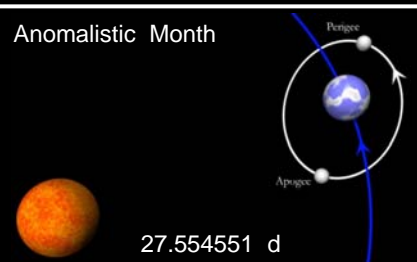
29.530589 d

Draconic Month 27.212220 d



Ecliptic Plane

Anomalistic Month



27.554551 d

## Astronomical Cycles: Saros

Given the complexity of the Eclipse cycle, the combination of 3 periods, it is an outstanding and awesome accomplishment of the ancient Babylonian astronomers that they identified the Saros cycle

(on the basis of centuries of observations reported on clay tablet)

- **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)

## the Dance of the Wandering Stars

Πλανητοι - Planets

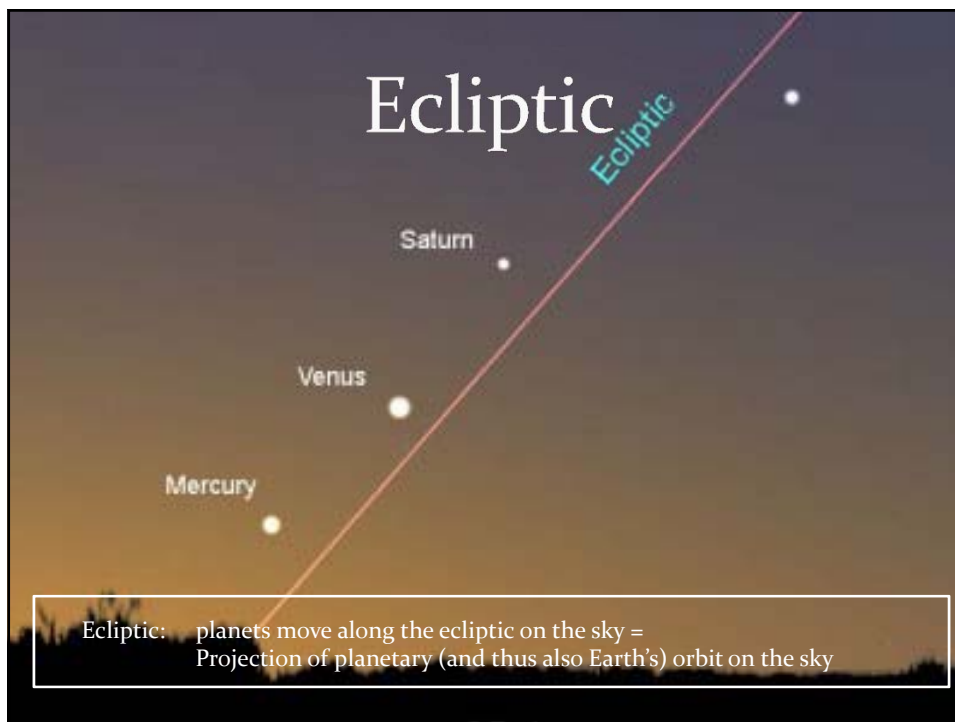
## Πλανητοι - Planets

### THE WANDERING STARS

Lights moving across the sky with respect to other stars

Five known planets of Antiquity:

♿	Mercurius	star of Hermes
♀	Venus	Aphrodite
♂	Mars	Ares
♃	Jupiter	Zeus
♄	Saturn	Kronos



## Dance of the Wandering Stars

- Planets move along the ecliptic (along which also the Sun moves on the sky),  
- which of course defines the plane of the Solar system

the most conspicuous aspects of planetary motion:

- Different planets move at different speeds wrt. the stars on the sky  
- we know this is because they are at different distances from the Sun, with an outer planet moving slower than an inner planet.
- The planets show retrograde motion loops  
- apparent motion on the sky comes to a standstill, planet moves backward then stops again, and resumes forward motion  
- we know this is a reflection of planet and Earth moving at different speeds around the Sun



## Retrograde Planetary Motion

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the most conspicuous aspects of planetary motion:

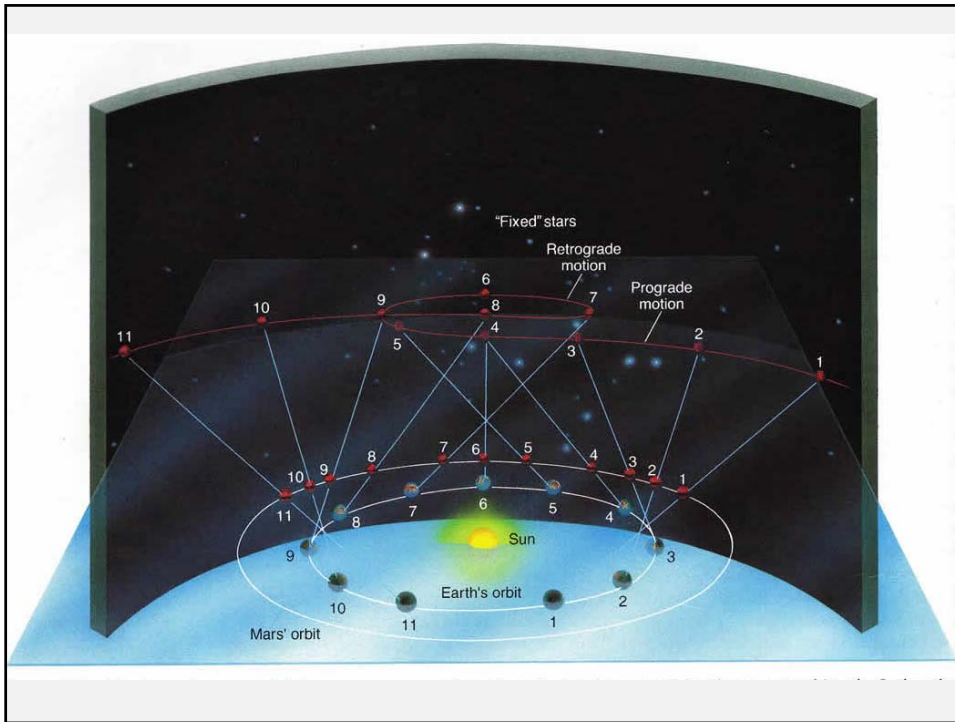
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(C) 2011

## Πλανητοι - Planets

### THE WANDERING STARS

- irregular planetary dance: sometimes halts, retrograde path, halts, prograde motion...
- non-uniform velocity along their paths
- within Heliocentric world model easy to understand:  
differential planetary orbiting –  
changing projection of planet wrt. Sky
- within Geocentric world model difficult ...  
Apollonius of Perga  
Hipparcus  
Ptolemaeus  
} Epicycle Theory



The main part of the image is an astronomical chart showing the path of Mars in the sky. The path is a wavy line of orange dots, with arrows indicating the direction of motion. Key dates are marked: Nov. 15, 2007; Jan. 29, 2008; Dec. 12, 2005; and Oct. 3, 2005. The chart also shows the constellation Taurus and labels for 'East' and 'West'. A red line indicates the ecliptic. A text box labeled '2a' explains that simple uniform circular motion centered on Earth could not explain retrograde motion, so ancient astronomers used epicycle motion.

Diagram illustrating the geocentric model of planetary motion. It shows a large circle labeled 'Deferent' with 'Earth' at its center. A smaller circle labeled 'Epicycle' is attached to the deferent. A 'Planet' is shown moving along the epicycle. A dashed line indicates the path of the planet, showing a loop where 'Retrograde motion occurs here'. Other labels include 'Equant'.

**2a** Simple uniform circular motion centered on Earth could not explain retrograde motion, so ancient astronomers combined uniformly rotating circles much like gears in a machine to try to reproduce the motion of the planets.

- Simple uniform circular motion centered on Earth could not explain retrograde motion.
- Ancient Greek astronomers solved this with epicycle motion:
  - superimposed rotating circles, much like gears in a machine
  - forwarded by Apollonius, its final formulation in Ptolemaeus' *Almagest* (2nd century AD), has been the basis for all astronomical studies and understanding until the 16th century.

# Ptolemaeus Epicycle Theory

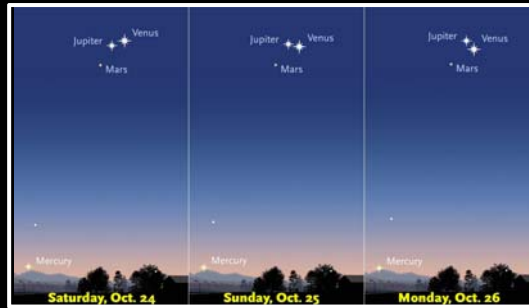
# Planetary Conjunctions

## CONJUNCTIONS

- At occasions, several planets would group in a small region on the sky
- This leads to conspicuous planetary **CONJUNCTIONS**

### Examples:

recent conjunction of Venus, Jupiter & Mars



# Planetary Conjunctions

## STAR OF BETHLEHEM

According to some theories, the star of Bethlehem was actually a rare triple conjunction of the major planets Saturn and Jupiter





# Stars with Tails: Comets

## Comets

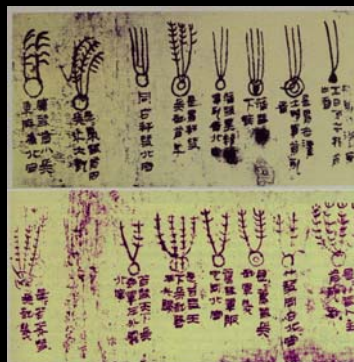
Completely random and erratically, to the ancient observers, stars with tails – comets – appeared on the sky.

They disturbed the serenity and regularity of the heavens, and thus often were identified with messengers of bad signs/bad omens.

Comets were unlike any other object in the night sky. Whereas most celestial bodies travel across the skies at regular, predictable intervals, comets' movements have always seemed very erratic and unpredictable.

This led people in many cultures to believe that the gods dictated their motions and were sending them as a message.

Comets thus inspired dread, fear, and awe in many different cultures and societies around the world and throughout time. They have been branded with such titles as "the Harbinger of Doom" and "the Menace of the Universe."



Korean record of various comets, and the bad message they entailed.

## Halley's Comet & Bayeux Tapestry



**Bayeux Tapestry.** It shows Halley's comet appearance just before 1066. Perhaps the most famous example of a comet's identification with bad news: the English king Harold will soon thereafter lose his throne as the Norman king William conquers Britain.

## Earth's Precession

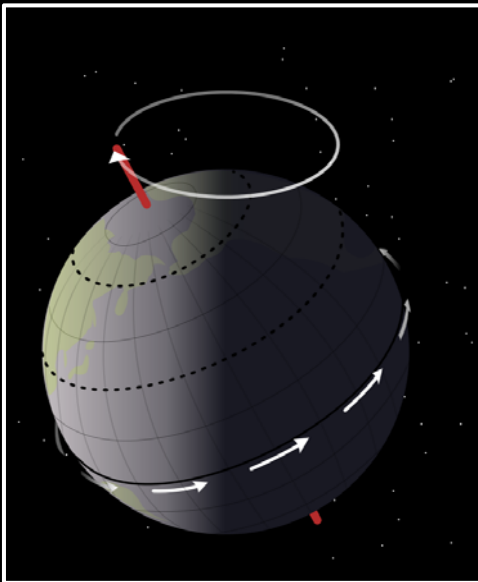
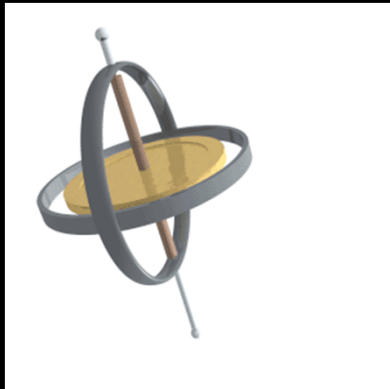


# Earth's Precession

The Earth's rotation axis subtly rotates, like the precession of a gyroscope, changing its tilt wrt. the orbital plane.

In ~ 26,000 years it revolves around, ie. 1° in 72 yrs.

As a result, the daily motion of stars around the pole shifts along. Millennia ago, Polaris was not the polar star !



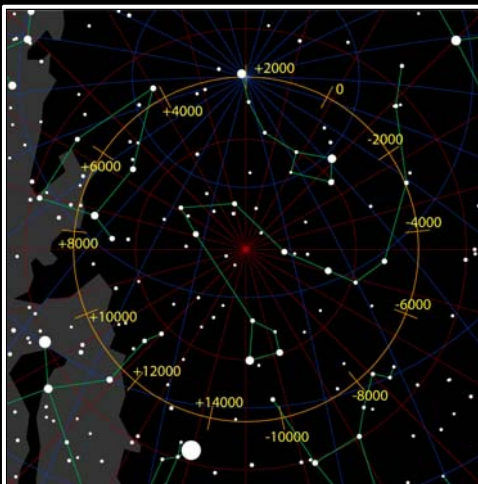
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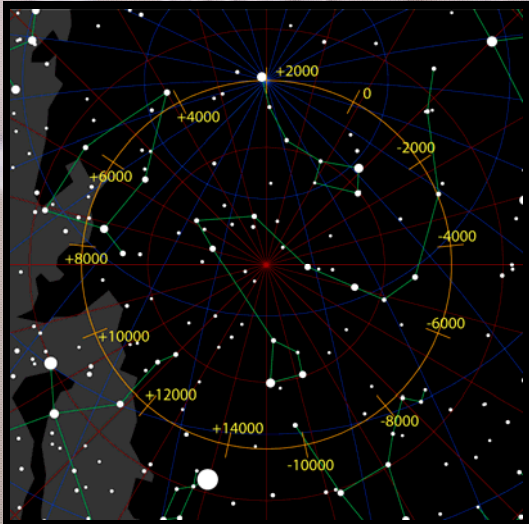
Because of the changing tilt of Earth's rotation axis, we also have a westward shift of the spring and fall equinox. It marks the location of the Sun at the beginning of spring and fall (when day and night are equally long).



As you see in the accompanying figure, the rotation axis of the Earth points at different positions along the millennia. Currently, in +2000, Polaris is the polar star. In 14000 AD, Vega will be the polar star. The plot shows the location of the pole at several years (yellow)

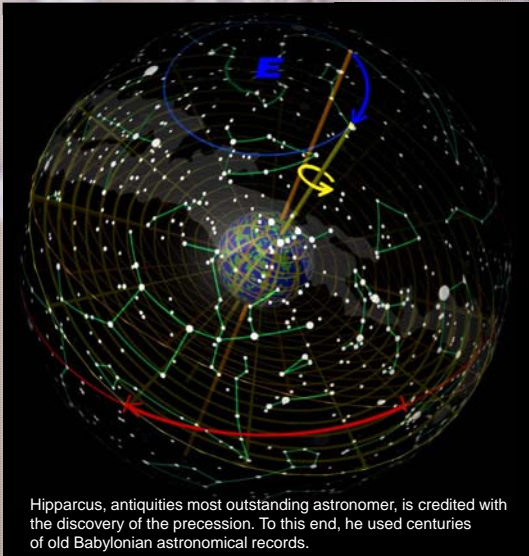
# Precession

Hipparcus  
(Nicaea-Rhodos 190-120 BCE)




# Precession

Hipparcus  
(Nicaea-Rhodos 190-120 BCE)



Hipparcus, antiquities most outstanding astronomer, is credited with the discovery of the precession. To this end, he used centuries of old Babylonian astronomical records.



# Age of Aquarius

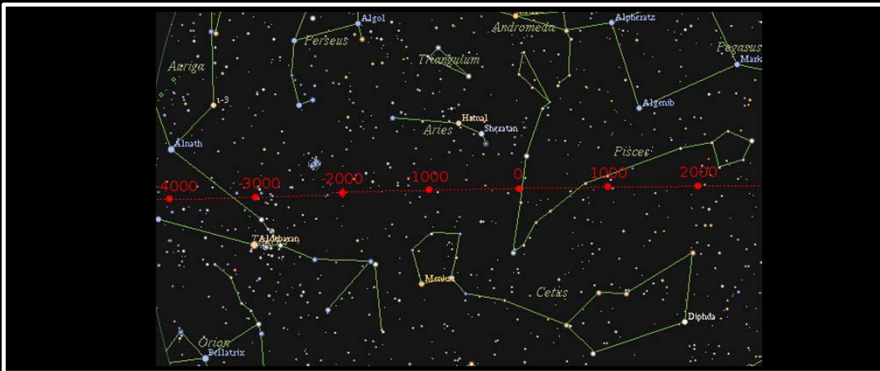


## Precession of Equinoxes

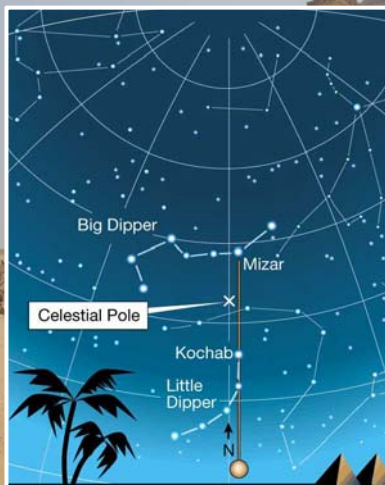
The spring and fall equinox mark the sky location of the Sun at the beginning of spring and fall.

Because of the precession, we have a westward shift of the spring and fall equinox: currently, the equinox is in the Zodiac constellation Pisces, but soon will arrived in Aquarius.

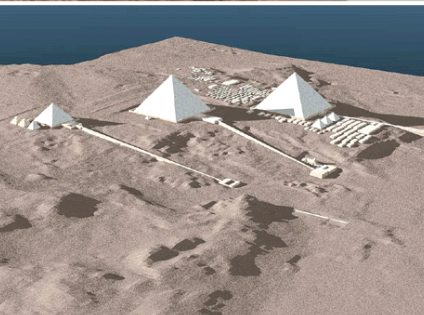
Hence, the famous hippy song of musical Hair !



# Aligning the Pyramids



The architect/historian Kate Spence forwarded the theory that over the centuries in which they were built, the orientation of the great pyramids in Gizeh follows the precession of the polar axis.



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# Aligning the Pyramids

The architect/historian Kate Spence forwarded the theory that over the centuries in which they were built, the orientation of the great pyramids in Gizeh follows the precession of the polar axis.

Time (years BC)	Deviation of Alignment (percent)
2600	-15
2550	-10
2500	-5
2450	0
2400	5
2350	10
2300	15
2250	20
2200	25
2150	30

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## the Nebra Disc: World's Oldest Sky Map ?

### Bronze Disc:

1650 BC  
oldest starmap in the World  
European Bronze Age

Found on Mittelberg (252 m)  
(25 km from Goseck)

1999: discovery  
2001: illegal trade  
thriller ...



## the Nebra Disc: World's Oldest Sky Map ?

### Bronze Disc:

- 30 cm diameter
- patinated blue-green bronze
- inlaid with gold symbols

### Symbols:

- Sun / Full moon
- Lunar crescent
- 32 Stars (incl. Pleiades)
- 2 golden arcs:  
angle between solstices
- extra arc:  
Solar Barge  
Milky Way  
Rainbow



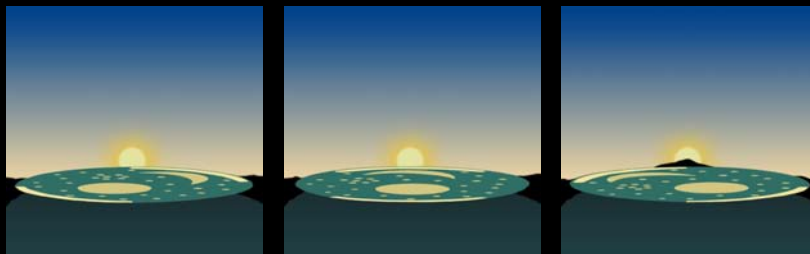
## the Nebra Disc: World's Oldest Sky Map ?



Mittelberg: 252 m. high mountain  
Nebra disk part of  
bronze trove



## the Nebra Disc: World's Oldest Sky Map ?



the arc across the Nebra disk appears to mark the locations between the rise of the Sun at winter and summer solstice, exactly for the location/altitude corresponding to Nebra.