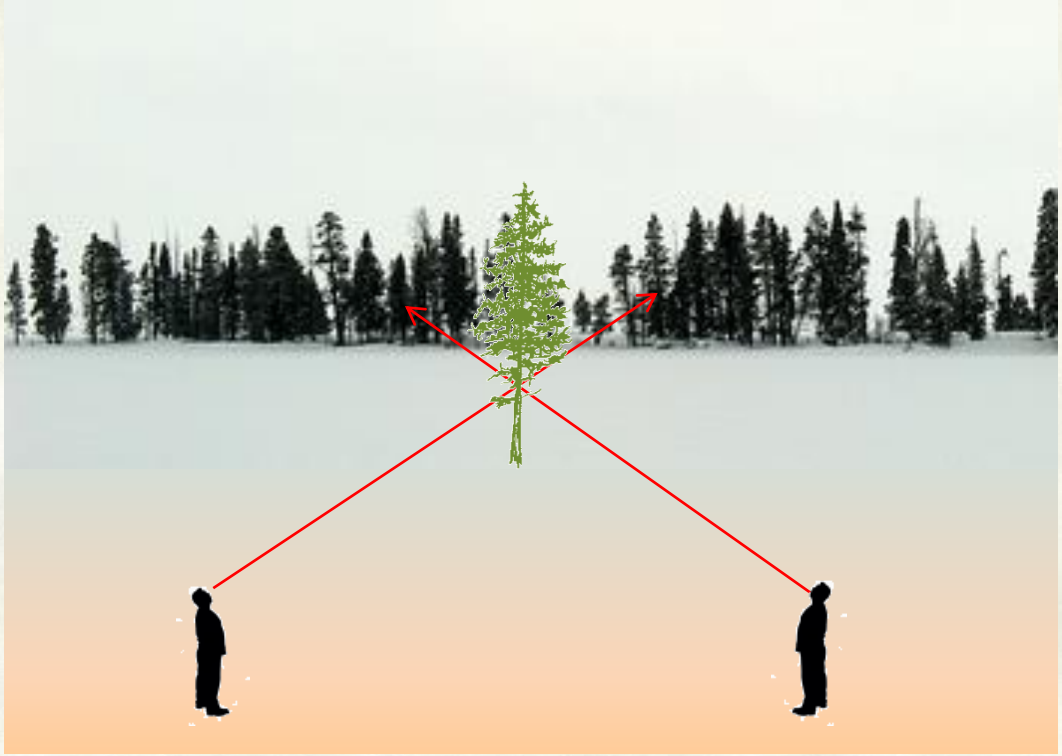
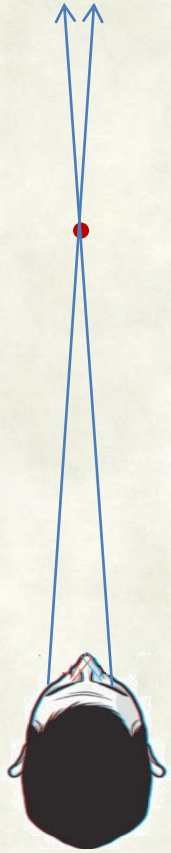
More on Stars and the Sky

ASTR 101
February 7, 2018

parallax
ecliptic
zodiac
precession

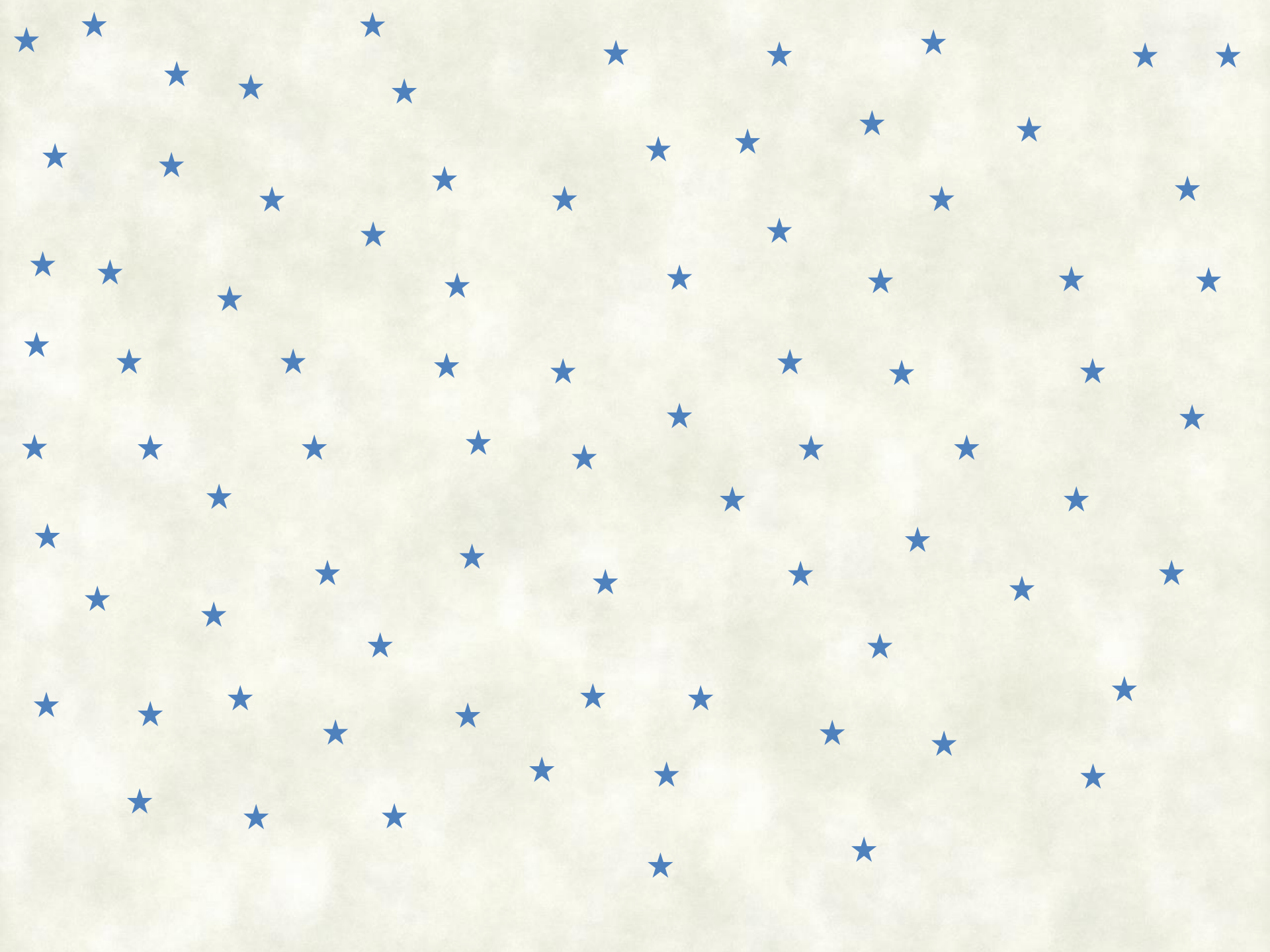
Parallax





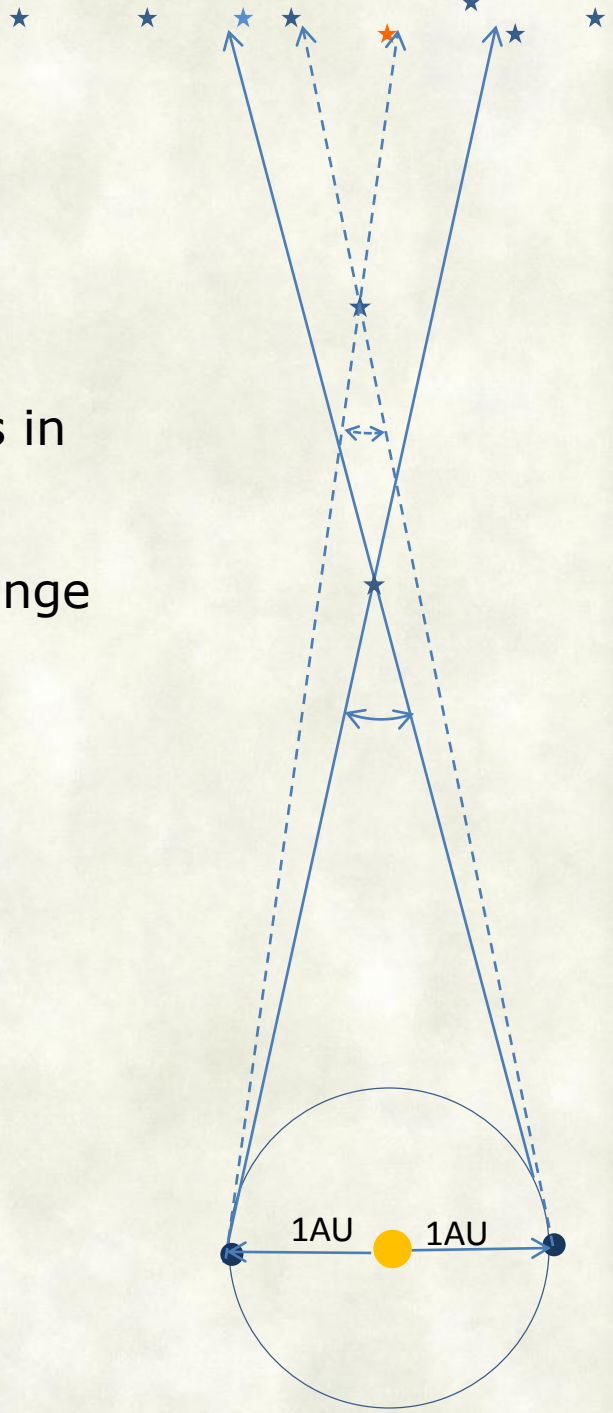
Shift in position of an object when viewed with one eye and then the other.

- Nearby objects seem to shift their position against more distant objects when viewed from different vantage points.
- Apparent displacement of an object, caused by the position of observer's view point is called **Parallax.**



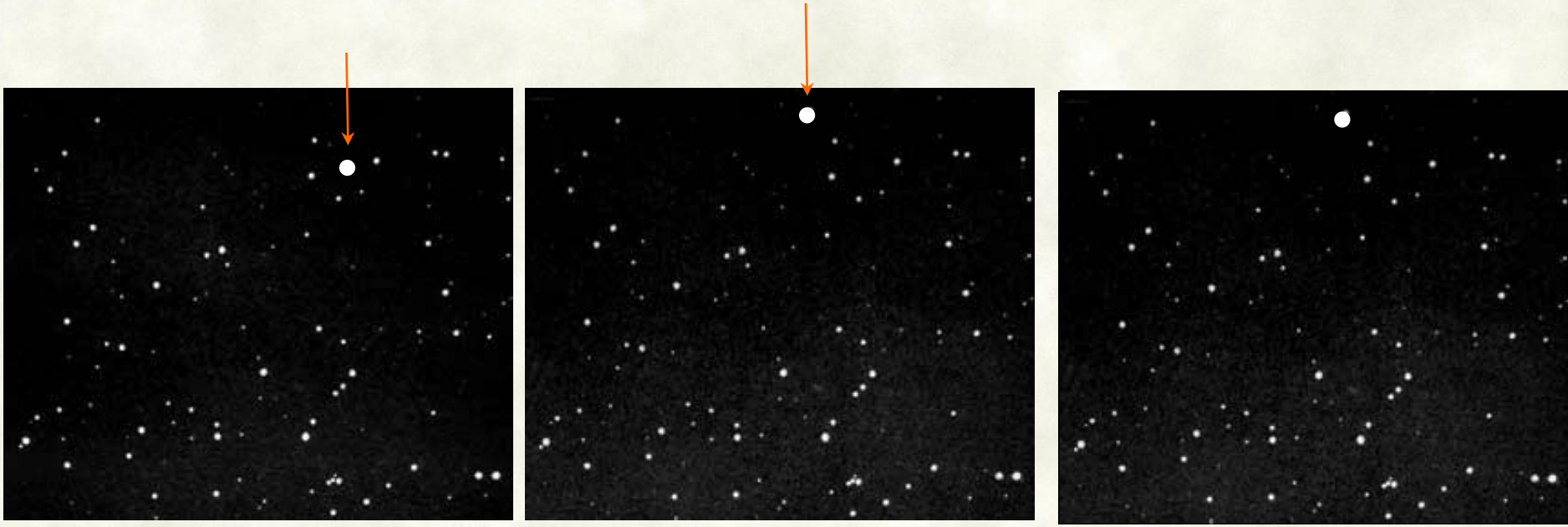
Parallax Motion of Stars

- As the Earth goes around the Sun, its position changes by 2AU every six months.
- This motion changes the positions of nearby stars in the sky against more distant background stars.
- Since stars are located at large distances, this change is extremely small.
  - It can be measured for nearby stars (less than 1”)
- The amount of parallax depends on the distance
  - greater the distance to a star smaller its parallax



Stellar parallax- and distance

- This gives a method to measure distances to stars directly by measuring their parallaxes as the Earth goes around the Sun.
  - The position of a star in the sky is observed over a year.
  - Between a certain six month interval, nearby stars show a shift in their position with respect to more distant background stars.



Change of the position of a nearby star over 6 months due to parallax

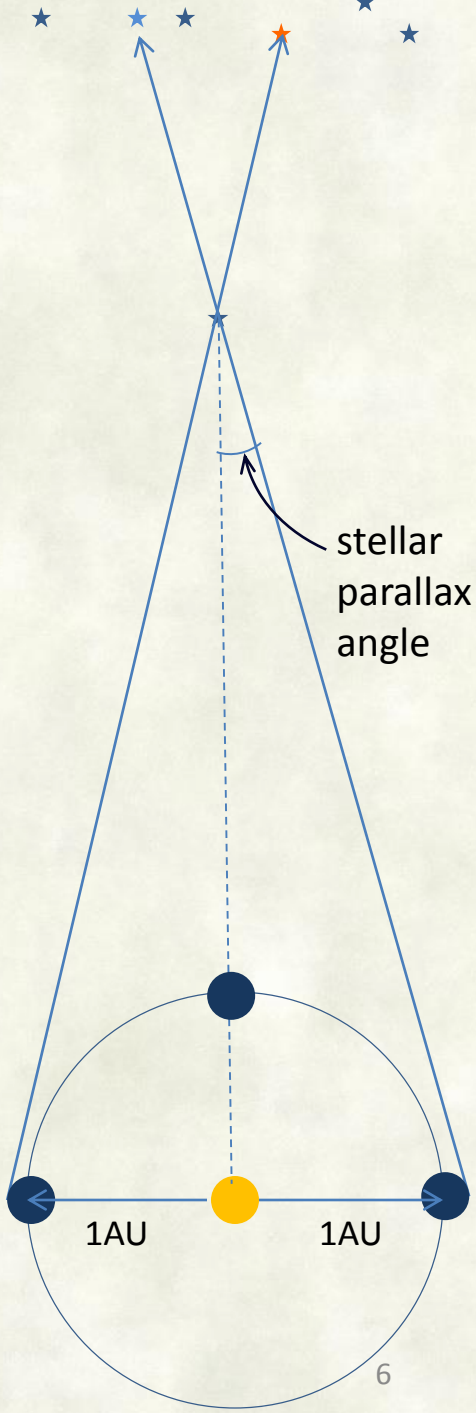
Stellar parallax - The parsec

- **Stellar parallax** is formally defined as the angular shift in the star position due to 1 AU change in Earth's position.
- When the parallax is 1 arc second (1"), corresponding distance is called a **parsec** (**par**allax of an arc **sec**ond)
- 1 parsec is about 3.26 light years (or 3.086×10^{13} km)
- If a star has a parallax *p arc seconds* its distance in parsecs is given by $\boldsymbol{D = \frac{1}{p}}$

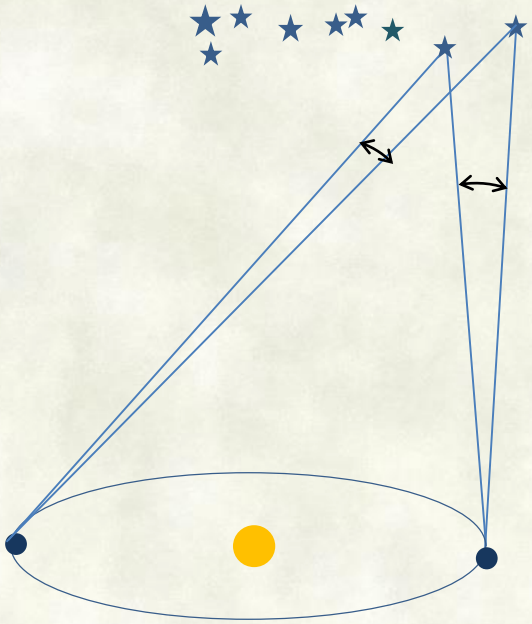
(greater the distance to a star smaller its parallax)

Example:

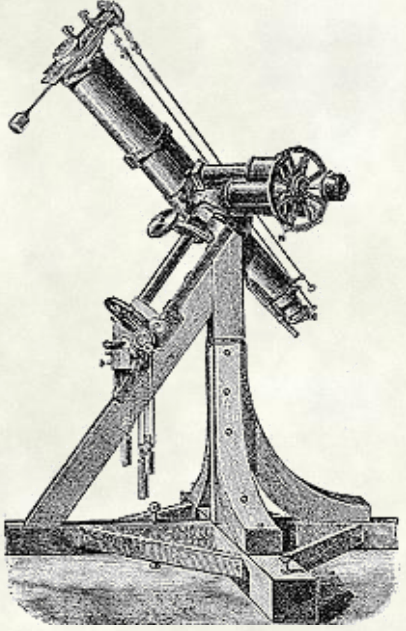
Parallax of Polaris (north star) is 0.0075" so its distance $= \frac{1}{0.0075} = 133$ parsecs



Measuring parallax



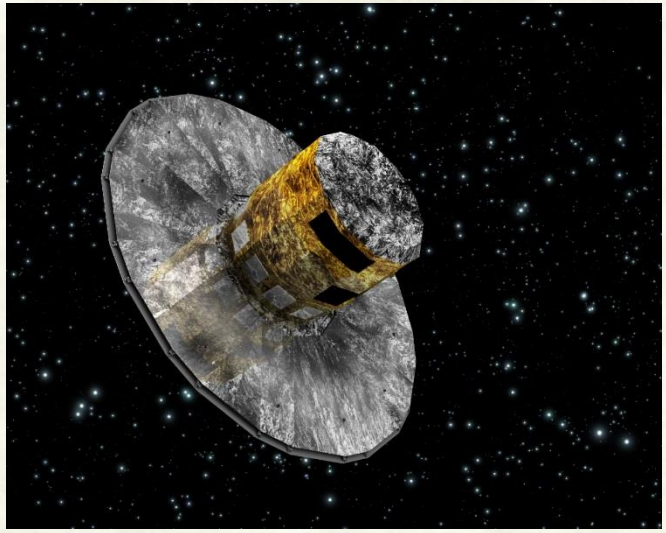
size or shape of constellations did not change over a year as ancient astronomers expected.



Friedrich Bessel and the "heliometer" he used to measure stellar parallax

- Many astronomers tried to measure stellar parallaxes since ancient times, but failed.
  - Failure to detect stellar parallax was used as an evidence supporting the **geo-centric** theory (Earth is at the center of universe) against the **heliocentric** theory (Sun is at the center).
- In 1838 Friedrich Bessel was able to measure the parallax of a star (Cygni 61, parallax 0.33")
  - First time distance to an object outside the solar system measured.
- By the end of 19th century about 60 stellar parallaxes had been measured by Bessel and other astronomers.

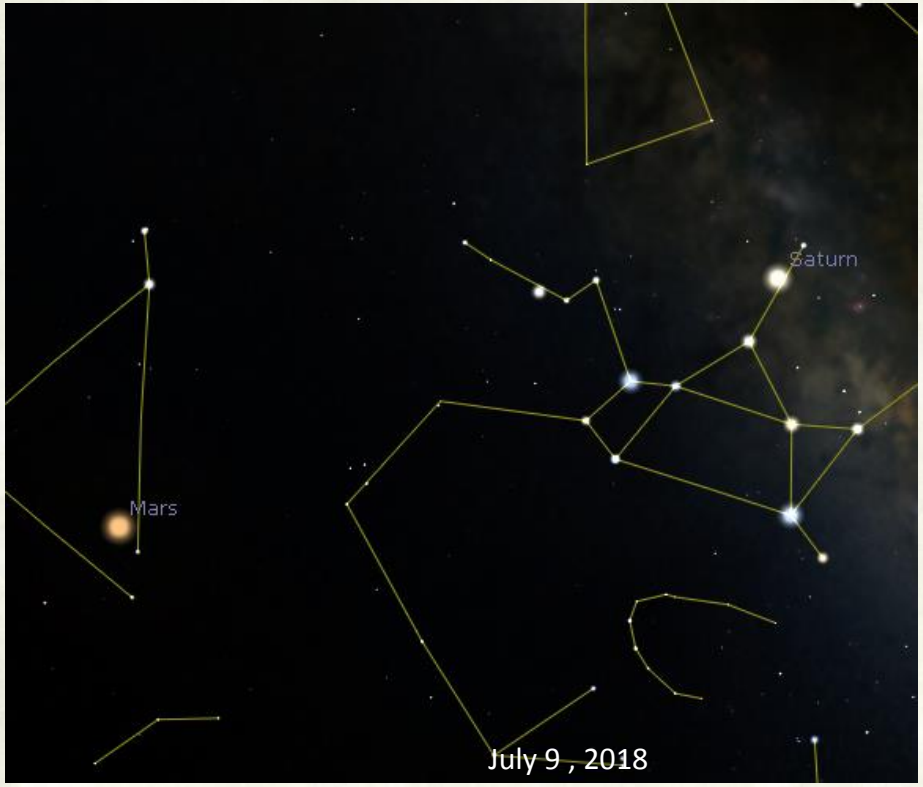
Hipparcos Satellite,
(1989 -1993) for
precision astrometry

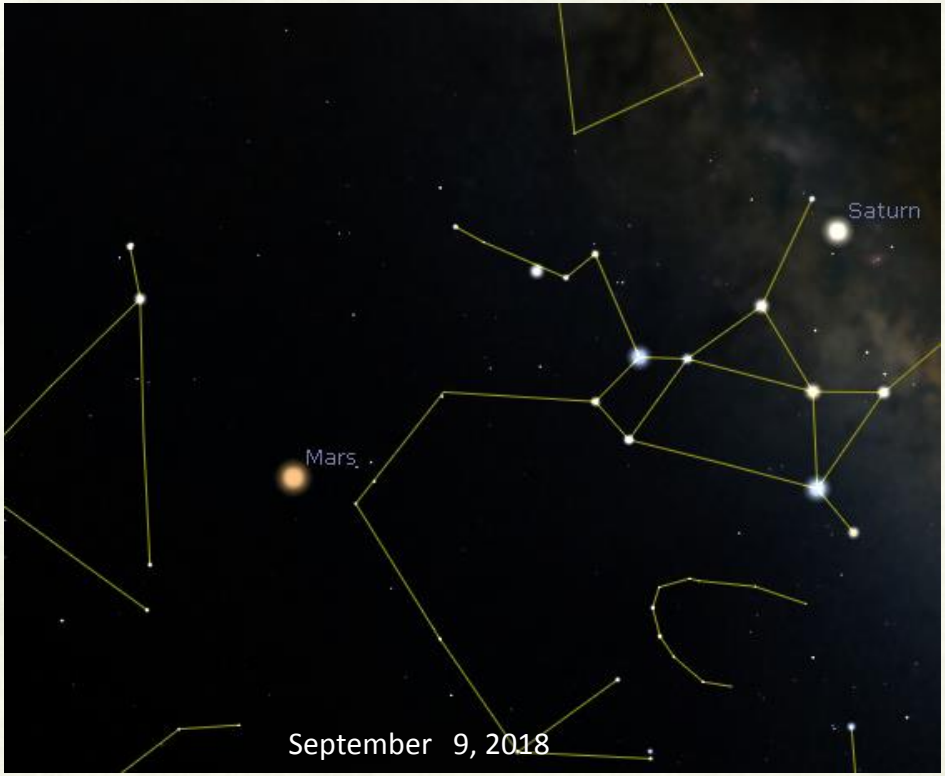


Gaia space observatory

- The smallest parallax measurable from ground is about 0.01-arcsec (100 parsec)
- Better resolution can be obtain from space, thus smaller parallax measurements.
- Hipparcos Satellite, operated 1989-1993 had a resolution of 0.001”
  - Hipparcos measured parallaxes for over 100,000 stars
  - for bright stars out to 1000 pc.
  - Got 10% accuracy distances out to about 100 pc
- ***Gaia*** space observatory launched in 2013 has measured parallax of one billion stars so far.

Fixed stars

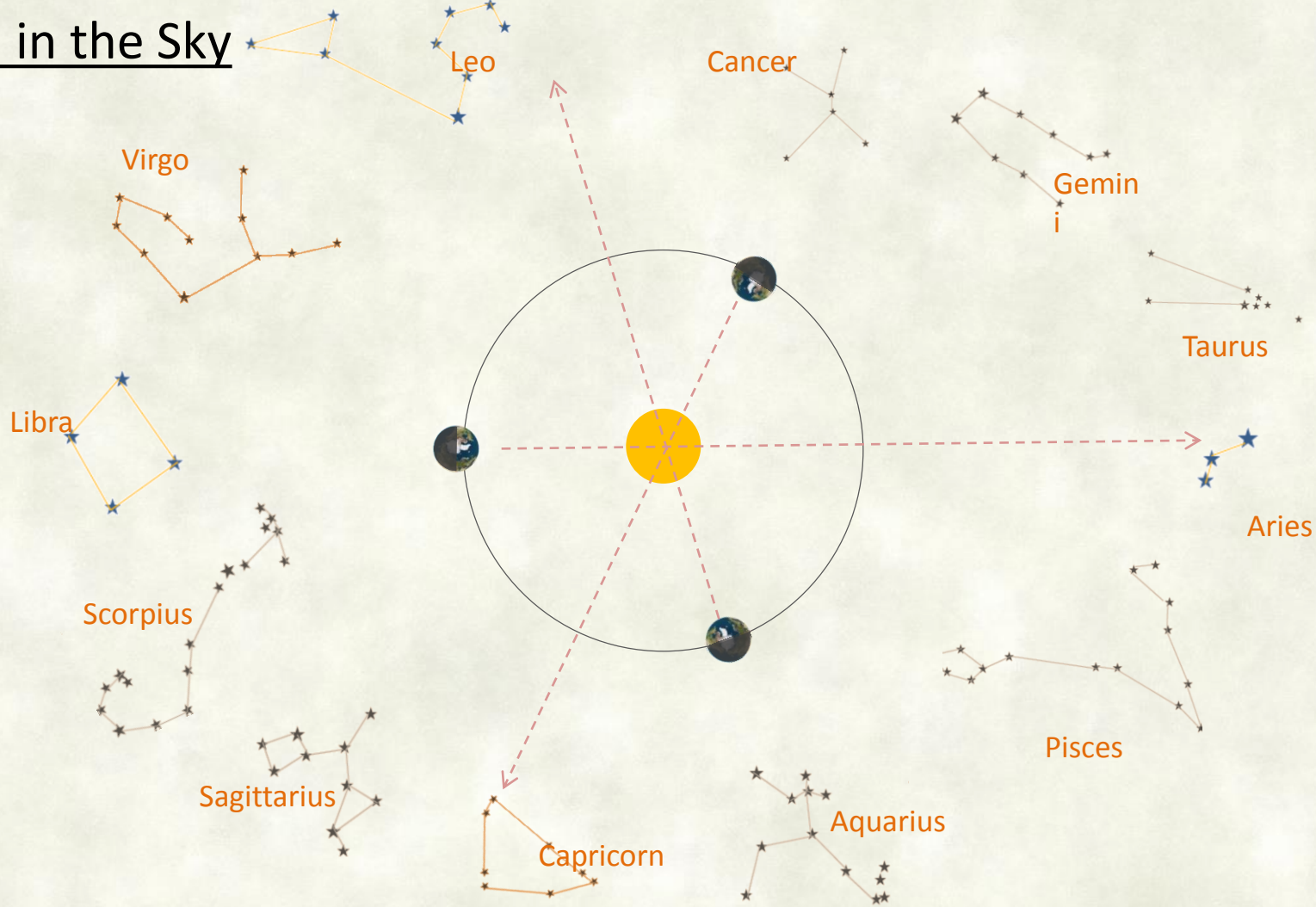




position of Mars and Saturn in the sky 2 months apart

- So stars seem to have almost fixed positions in the sky (on the celestial sphere) unaffected by their motions or the earth's motion.
  - They appear to go around the Earth as the celestial sphere rotates, without changing relative positions with each other.
- Ancient astronomers called them the **"fixed stars".**
- Other celestial objects, like the Sun, Moon and planets belong to the solar system are much closer to us, and their position in the sky change against the background of fixed stars.

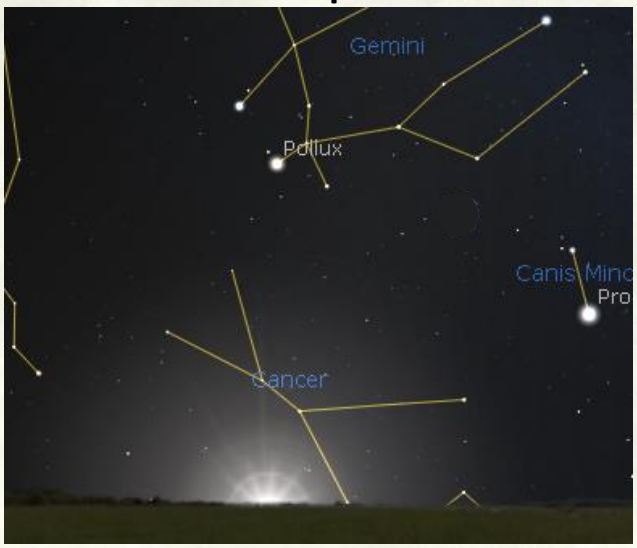
The Sun in the Sky



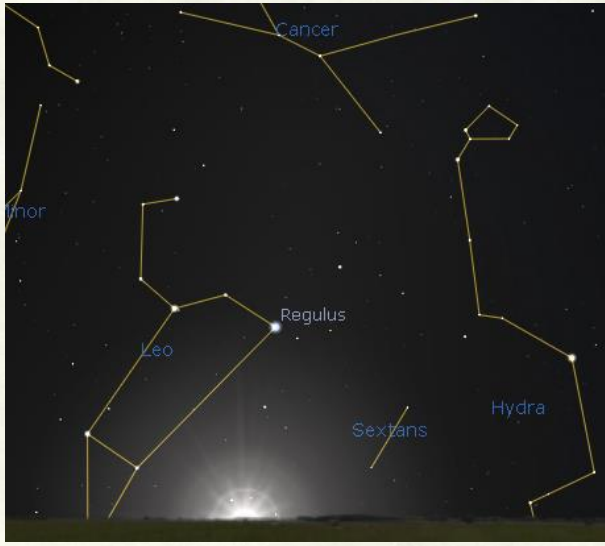
- As the Earth goes around the Sun, we see the Sun in different directions in the sky, and against different constellations.
- So the Sun appears to move among fixed stars in the sky in an annual cycle.

The Ecliptic

July 8

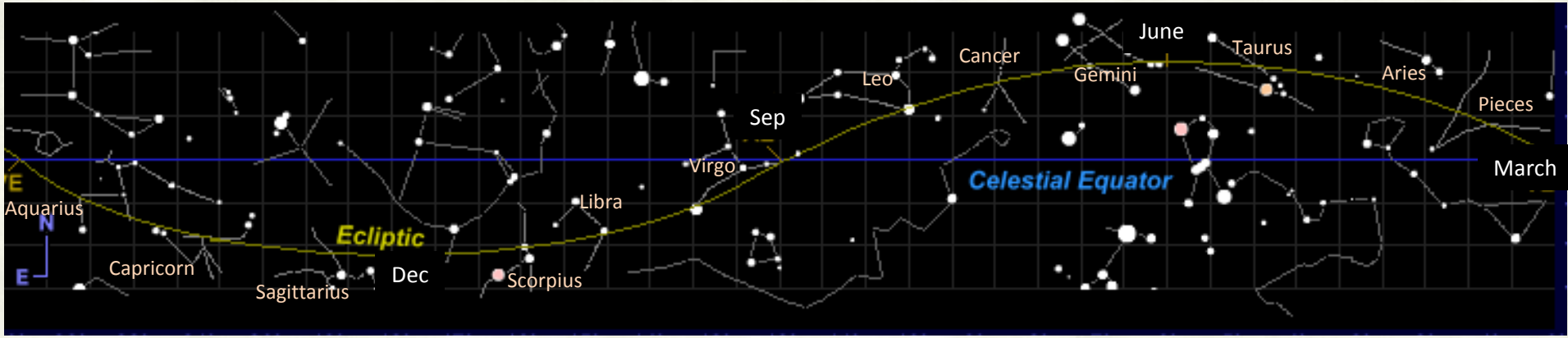


August 8



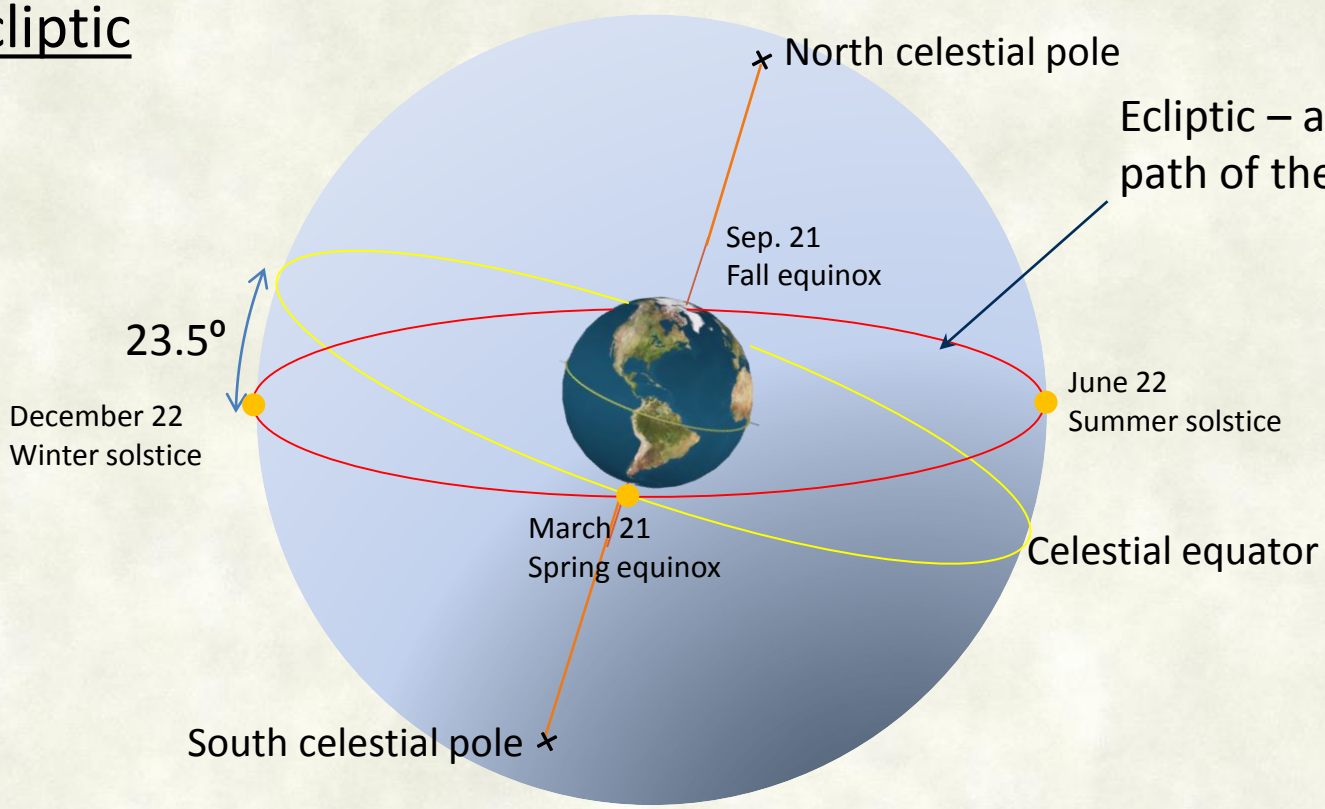
September 10

the Eastern sky before sunrise. The Sun rises with different stars (constellations) over the year



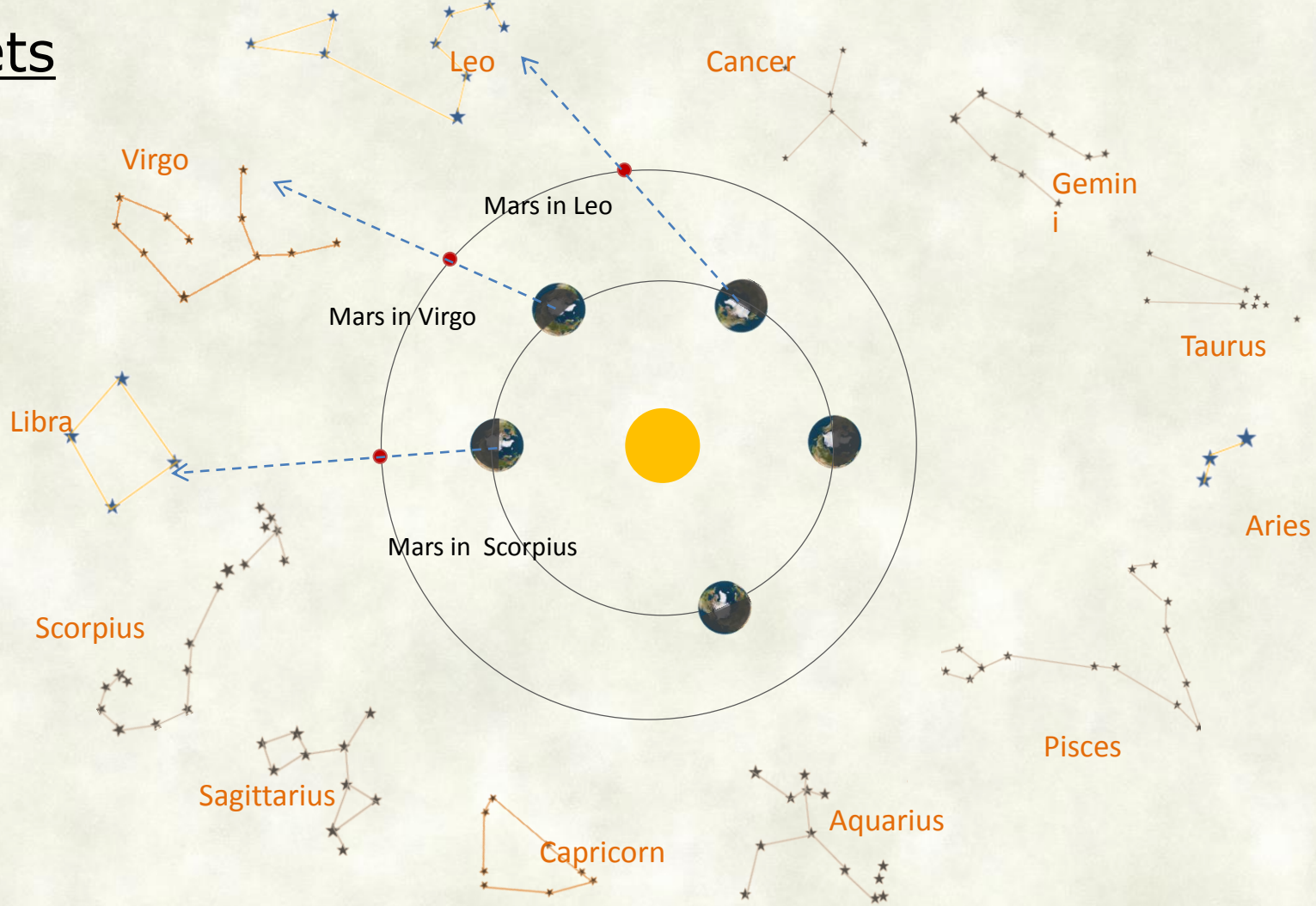
- Sun appears to be moving among stars
- The apparent path followed by the Sun in the sky is called the Ecliptic.

The Ecliptic



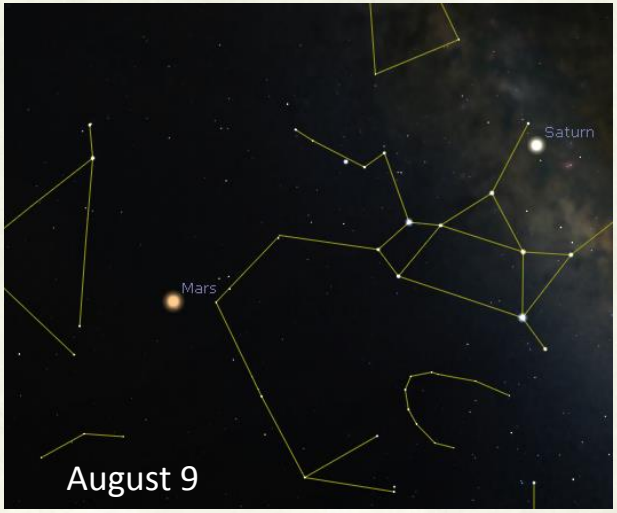
- It is just the projection of Earth's orbital plane to the celestial sphere
- Earth is tilted by an angle 23.5° to the orbital plane, so the celestial equator is tilted by the same angle with respect to Ecliptic.
- Therefore Ecliptic, the apparent path of the Sun's annual motion in the sky also tilted by 23.5° with respect to the celestial equator.
  - From Spring equinox to Fall equinox sun in the northern celestial hemisphere
  - From Fall equinox to Spring equinox sun in the southern celestial hemisphere

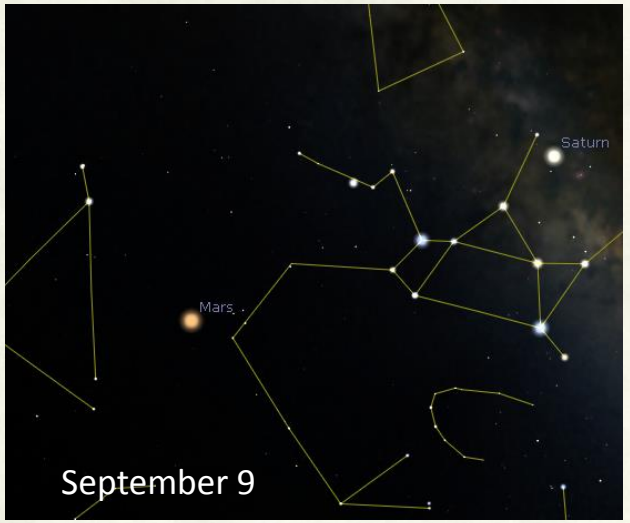
Planets



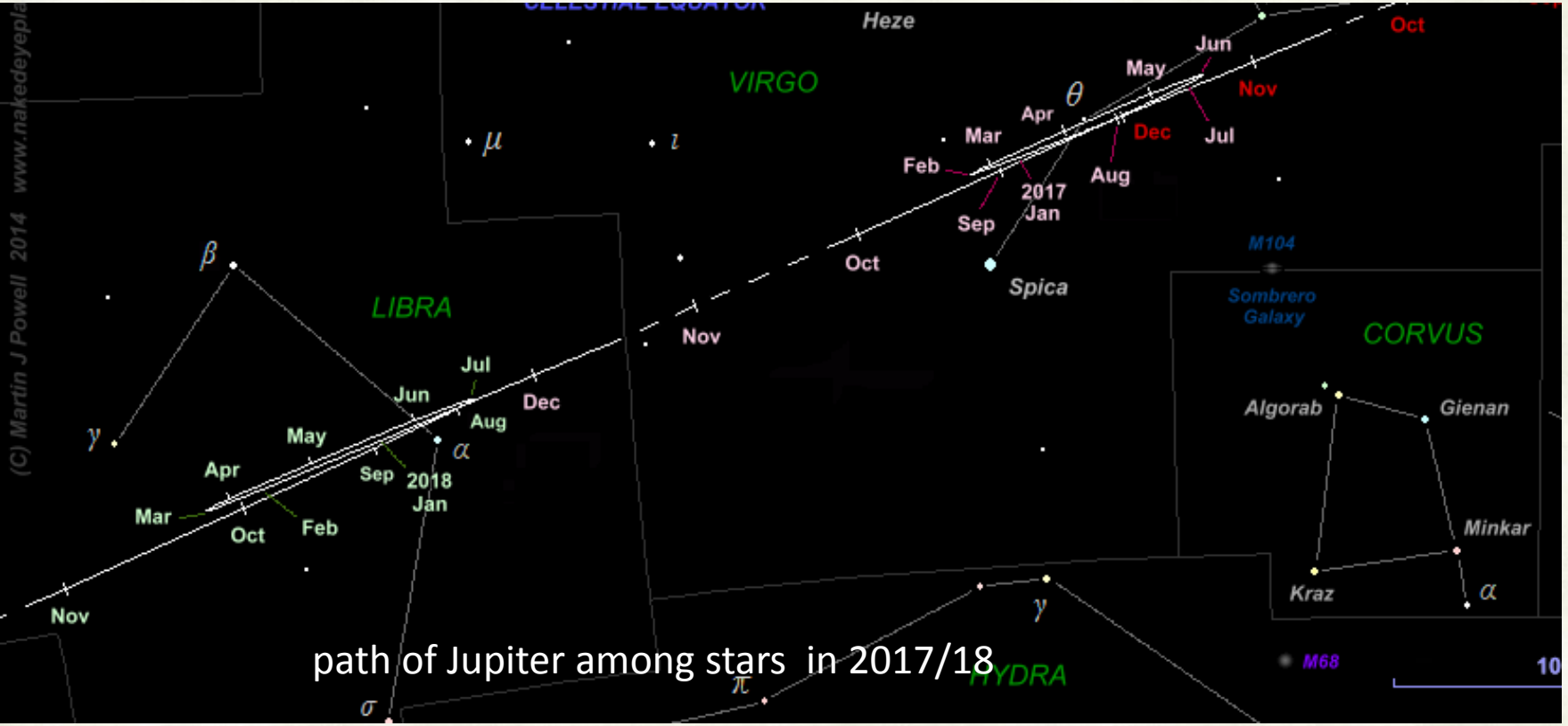
- Depending on the relative position of the Earth and planets, (all are going around the sun), planets are visible in different directions, among different stars and constellations.

Planets



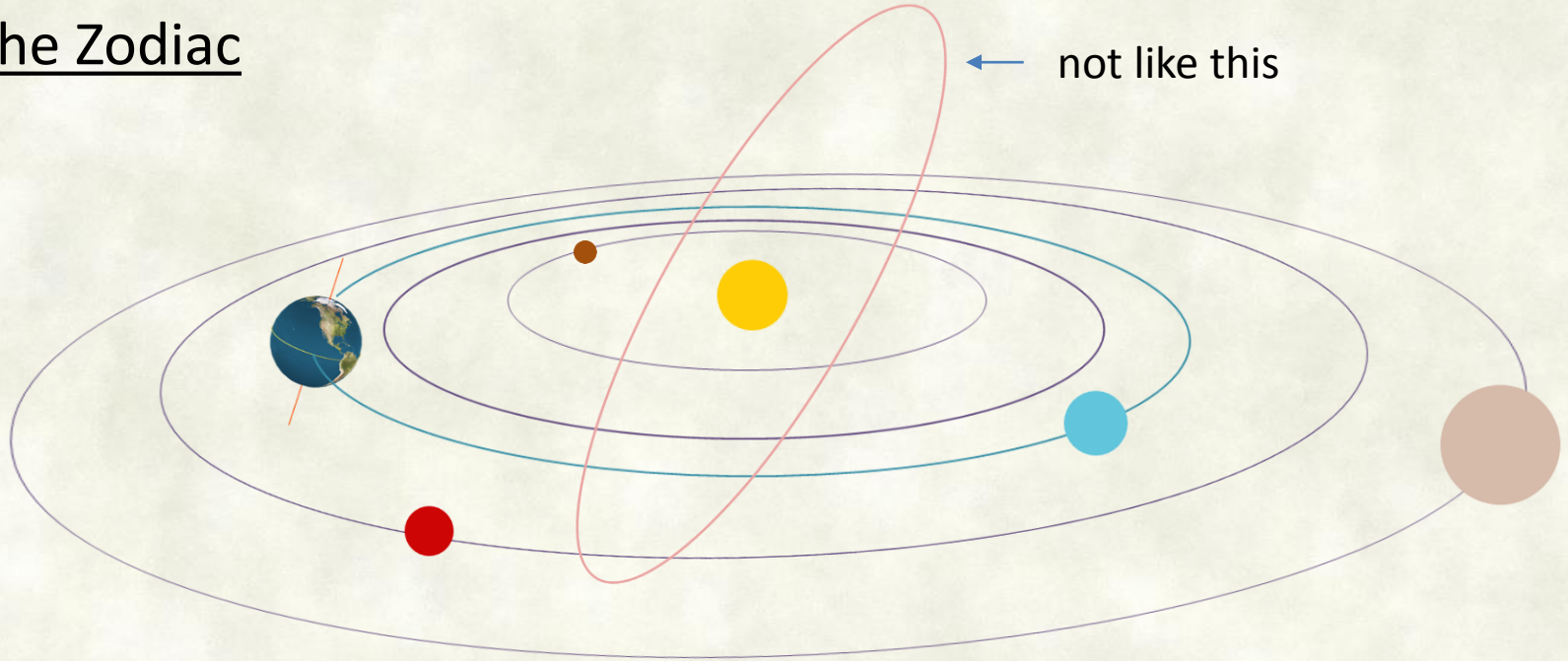


Locations of Saturn and Mars among stars over last two months



path of Jupiter among stars in 2017/18

The Zodiac

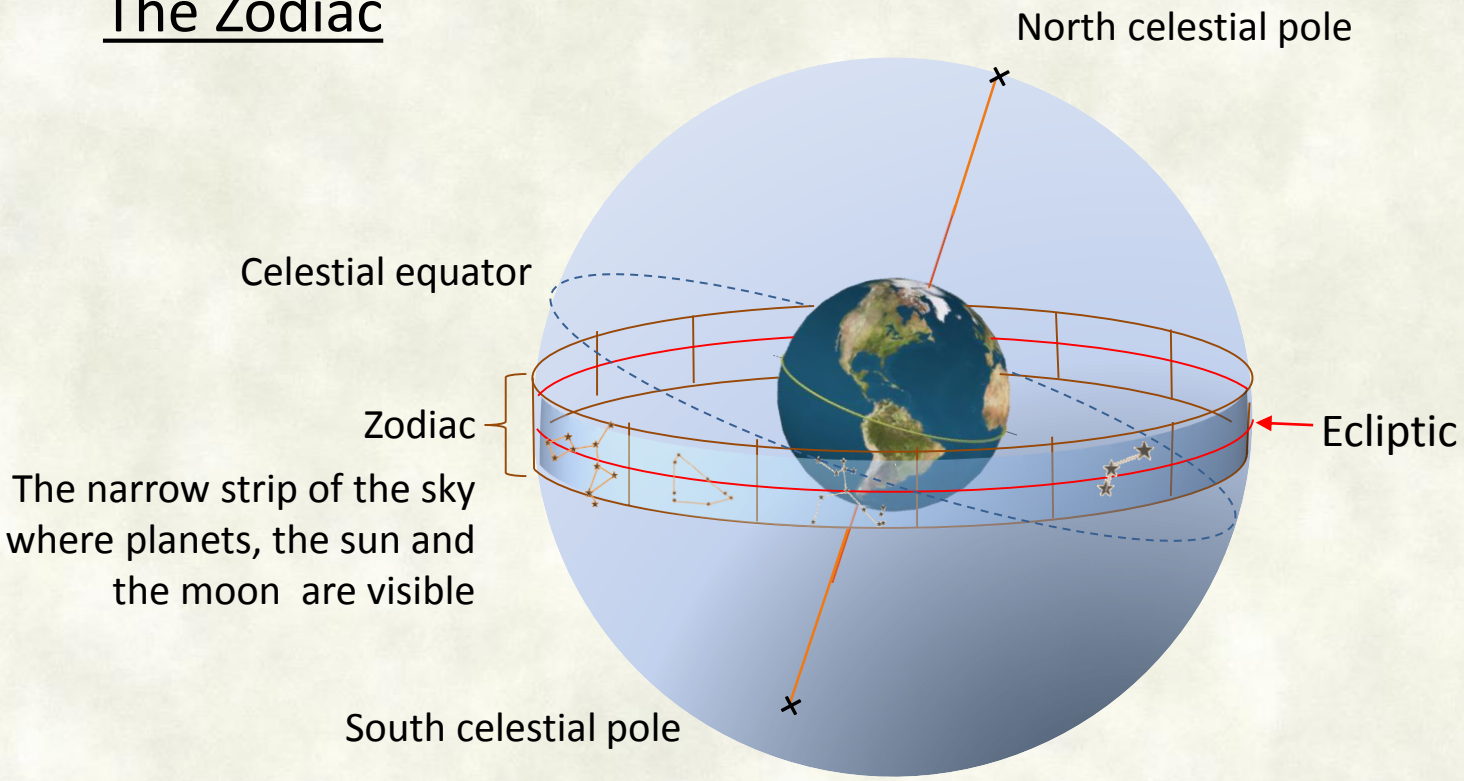


Solar system: Planets orbit the Sun in nearly the same plane

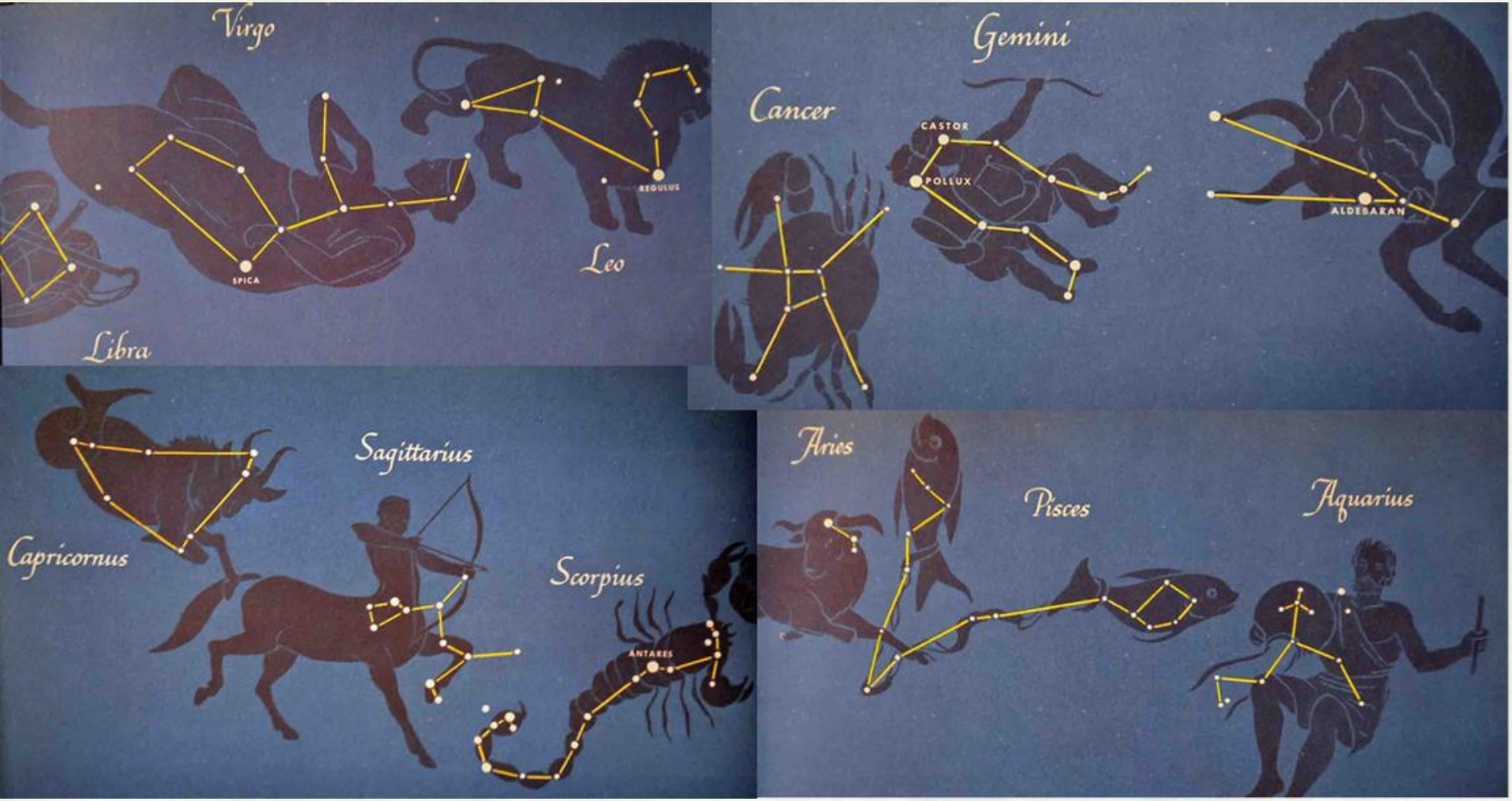
- Orbits of all planets (including Earth) are approximately in the same plane.
- Therefore planets are always visible in a narrow band of the sky.
- This region of the sky where planets (and the Sun) are seen is called the **Zodiac**. It is a 16° wide band centered around the Ecliptic.
- See the animation for the positions of planets in 2018-2021

  http://www.phy.olemiss.edu/~perera/animations/paths.html

The Zodiac

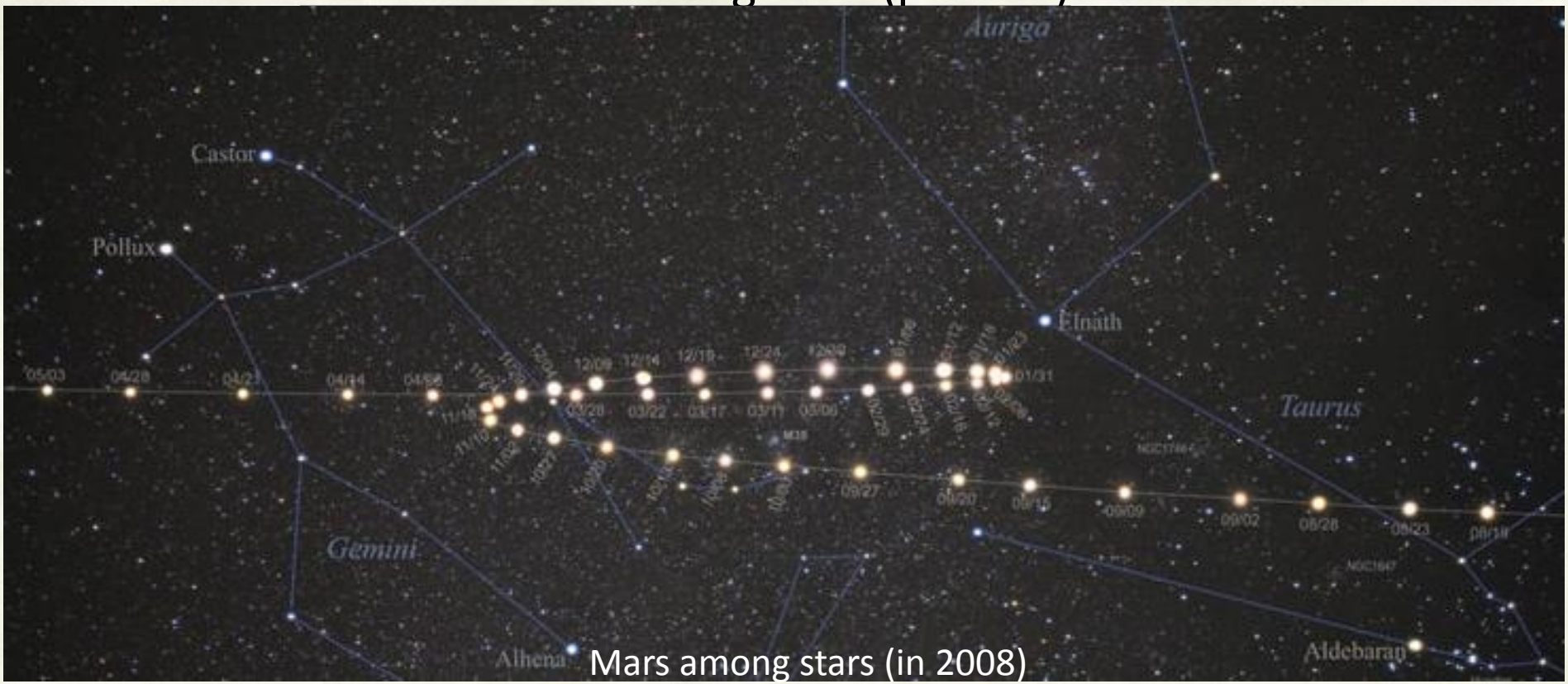


- Ancient observers noticed this movement of the Sun, Moon and planets in a narrow band in the sky, which they called the **Zodiac**.
- They divided it to 12 parts and named them according to constellations along the Zodiac.
- When someone says that a planet is in a certain zodiacal sign, what it really means is that we see the planet in that zodiacal constellation. (more correctly in that direction)
  - For example these days Venus is in Aquarius Saturn is in Sagittarius, Jupiter and Mars are in Scorpius



Zodiacal constellations dates back to ancient Babylonian/Sumerian times.

Fixed and wandering stars (planets)



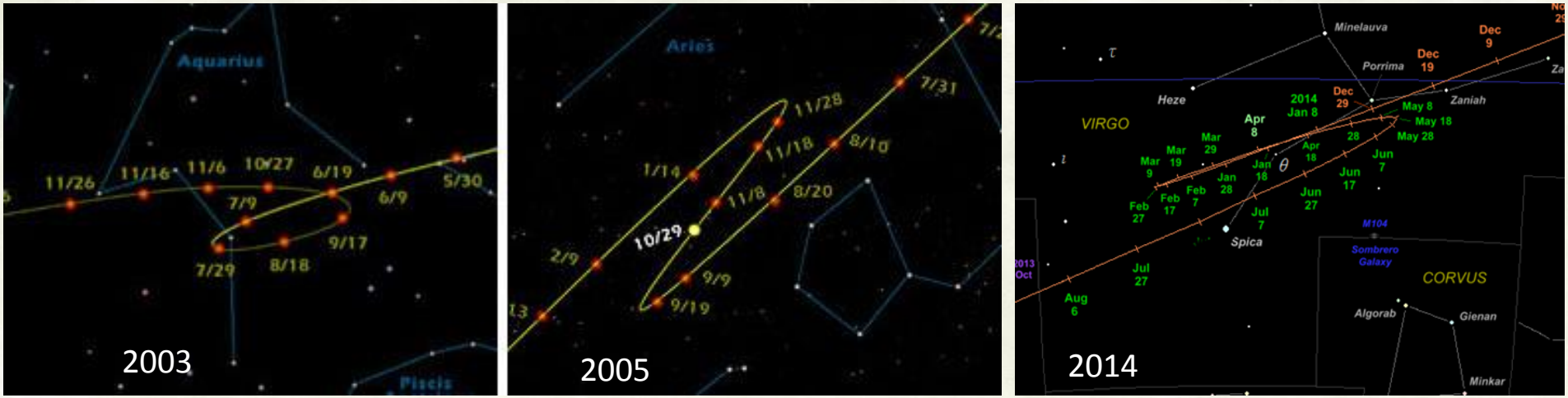
Mars among stars (in 2008)

http://apod.nasa.gov/apod/ap080511.html

- Ancient observes noticed two types of stars:
  - **Fixed stars** which have fixed positions on the celestial sphere (sky).
  - **Wandering stars**: Five bright star like objects (Mercury, Venus, Mars, Jupiter and Saturn) which did not have fixed position in the sky and wandering among fixed stars in an irregular manner.
    - What we now call **planets**:

      from Ancient Greek *"aster planets"* meaning "wandering star"

Astronomy and Astrology



path of Mars among stars

- Highly unpredictable positions of those "wandering stars" in the sky puzzled the ancients:
- The sky had an important religious significance in ancient civilizations.
  - To them natural forces and phenomena were influenced by supernatural powers of deities, and the sky was the abode to many of them.
  - Sun's apparent motions in the sky and different stars in the night sky over a the course of a year had a direct relation to seasons.
  - So it was natural that they thought the influence of celestial objects affected events and the life on earth, and what is in the sky reflected that influence.
- The unpredictable nature of the movement of planets in the sky seemed to have related to similarly unpredictable nature of life to them.

- If something happened when planets were in a particular pattern in the sky, they may have thought that there was some correlation, or due to the influence of planets in that positions.
  - naturally they expected similar thing would happen if planets and stars come back to same configuration in the sky in the future.
- So if one could predict the positions of planets in the sky, they believed that that it was possible to foretell future events.
- It was an incentive to study and understand planetary movements in the sky, that indirectly led to the advancement of astronomy.
  - Earliest attempts for observations and keeping records was motived by astrological beliefs.
  - Early astronomers were astrologers as well, it provided a livelihood for many astronomers.
- But today astronomy is a well-founded science based on observation, experimentation and logical interpretation of results, while astrology remains as an unfounded set of superstitious beliefs.
- There is no mystery about planets or other celestial objects any more, we have a good understanding about what they are and their behavior in the sky.
  - No need to be superstitious. Stars cannot affect your life or predict the future!

(a)

www.mesopotamia.co.uk/astronomer/explore/mulapin1.html

(b)

(a) Mul Apin tablet(1100 BCE): Describing the appearance of different constellations and stars.

(b) Babylonian clay tablets listing observation of Venus c. 7th century BCE.

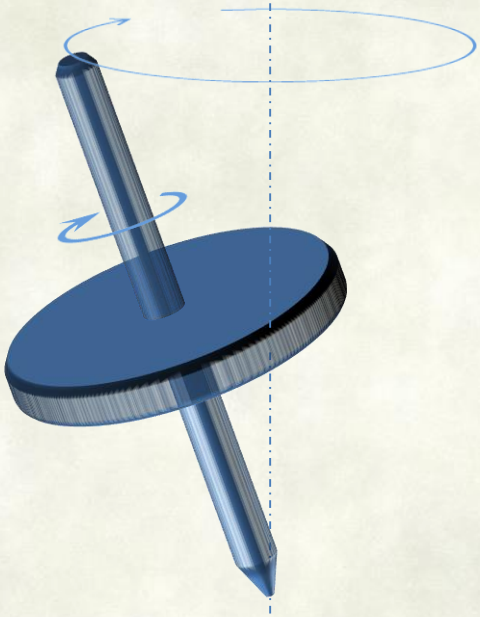
Bright star Sirius rises just before sunrise

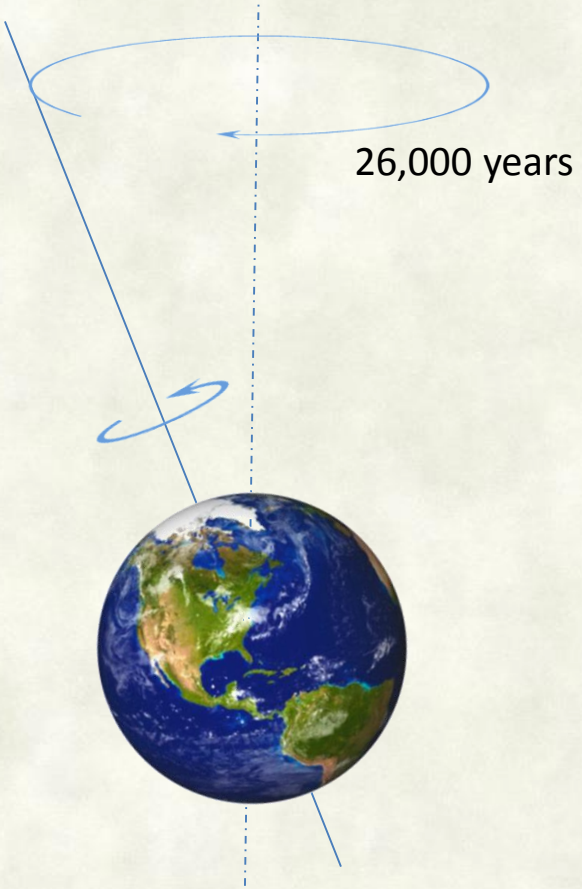
Within weeks Nile floods

Giza Digital Library Boston museum of fine arts

- Ancient Egyptians had observed that shortly after the bright star Sirius (Sothis) appeared in the Eastern predawn sky, Nile river flooded.
- Flooding of Nile was an important event for ancient Egyptians. Water, mud and silt from the river was washed up over the river banks fertilizing the ground.
- So Egyptian "priest astronomers" watched the sky, when finally they saw Sirius in the morning sky, they knew flood would soon happen, and save the crops for another year.
  - They may have thought that the star Sirius was responsible for this or some kind of divine sign.
- Real reason: flooding was due to heavy Summer rains hundreds miles upstream in the Ethiopian highlands. By coincidence this was the same time of the year Sirius appeared in the morning sky.

Precession of the Earth

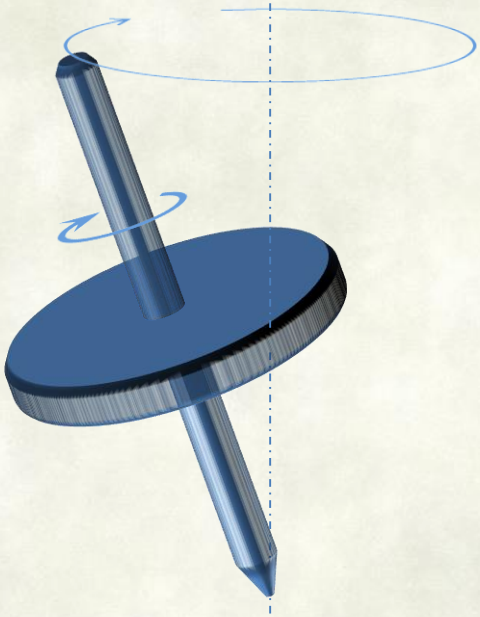




- A spinning top wobbles while rotating on its axis.
- The Earth is like a large top, spinning in space.
  - so it is natural to expect the Earth to wobble just like a top
  - In fact it does so.

- Therefore the direction of the Earth's rotation axis is not fixed, it precesses slowly with a period of approximately 26,000 years.

Precession of the Earth



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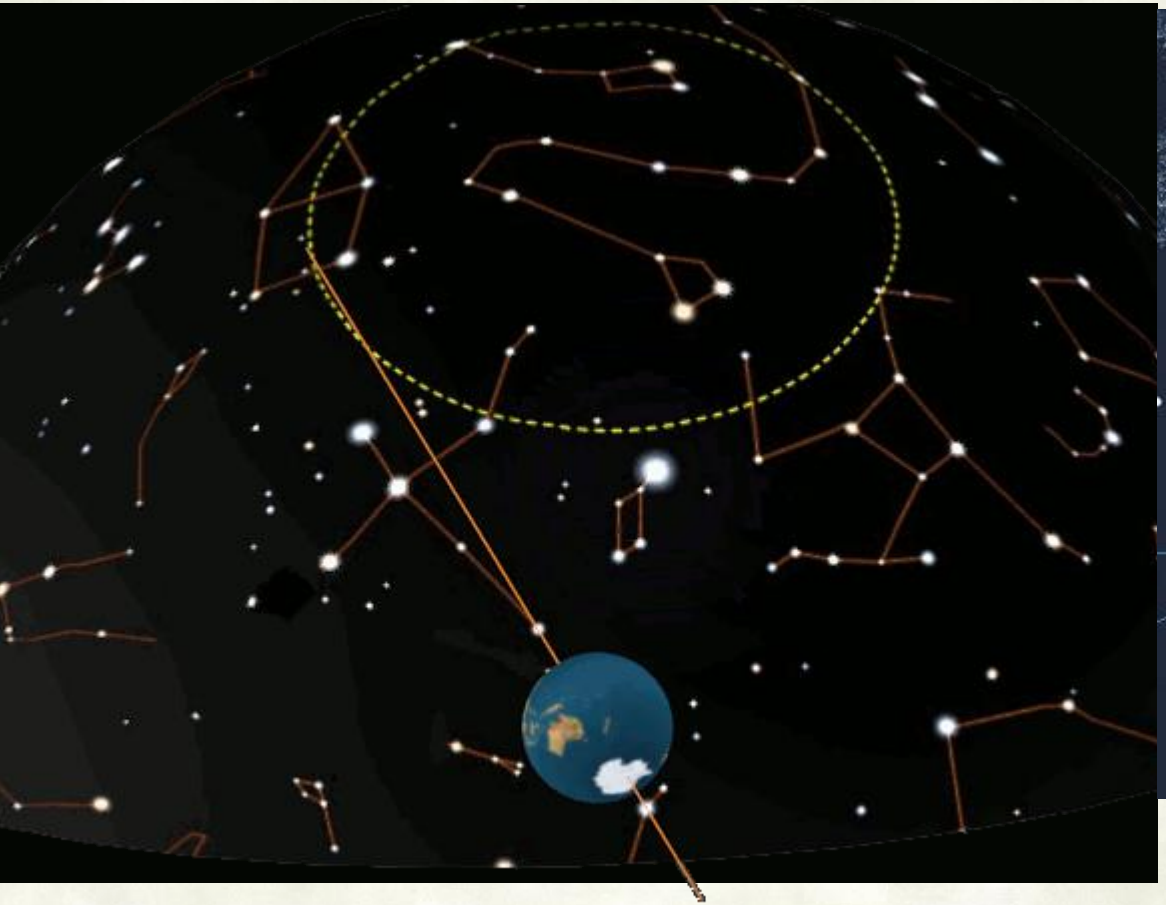
Change in celestial poles due to precession

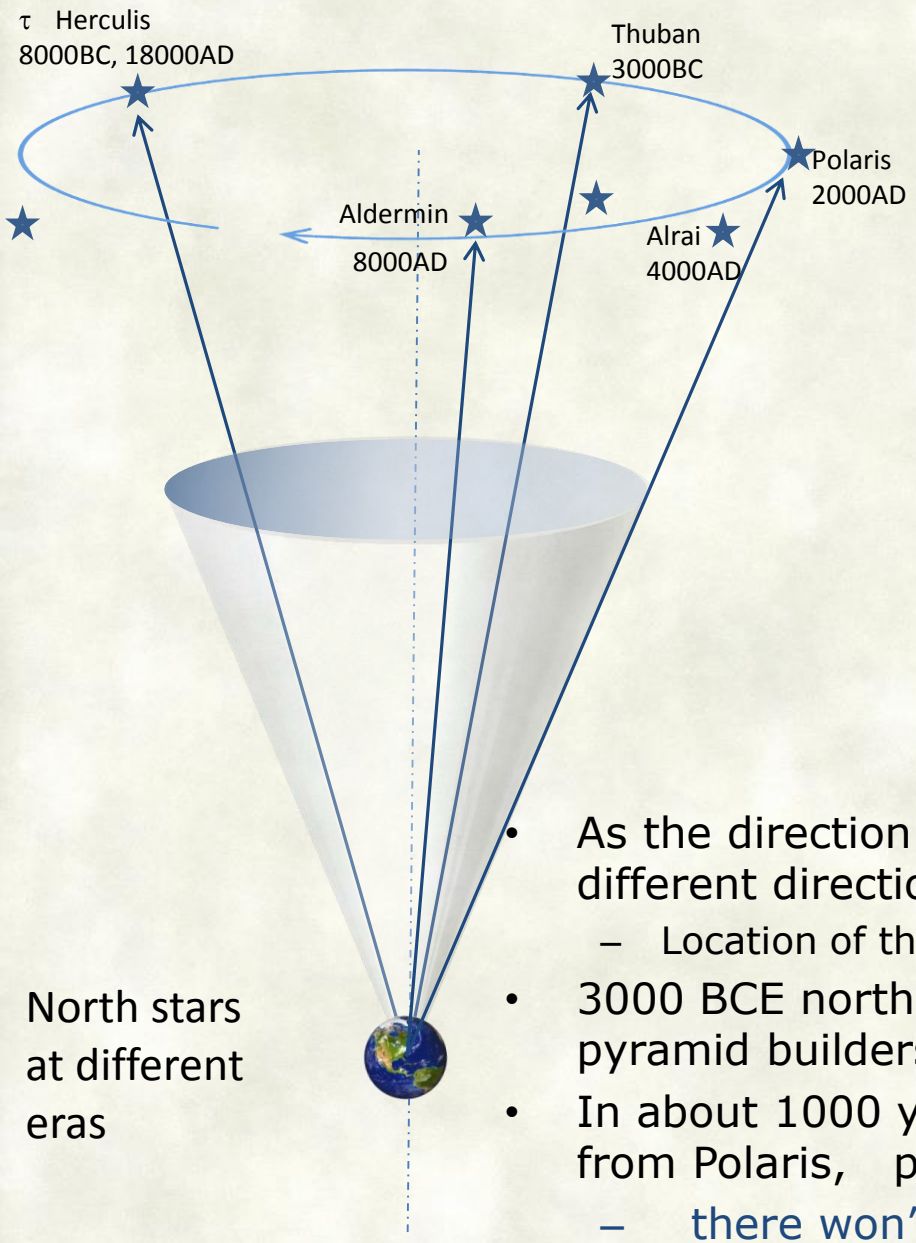


http://www.phy.olemiss.edu/~perera/animations/precession.html

Path of the North celestial pole as the Earth precess and the axis points to different directions in the sky

- As the direction of the Earth axis changes, it points at different directions in the sky.
  - Location of the celestial pole is slowly changing

Change in celestial poles due to precession



North stars at different eras

Path of the North celestial pole as the Earth precess and the axis points to different directions in the sky

- As the direction of the Earth axis changes, it points at different directions in the sky.
  - Location of the celestial pole is slowly changing
- 3000 BCE north star was Thuban, the north star of early pyramid builders
- In about 1000 years north celestial pole will be far away from Polaris, pointing between Polaris and Alrai.
  - there won't be any specific north star

…But I am constant as the northern star,

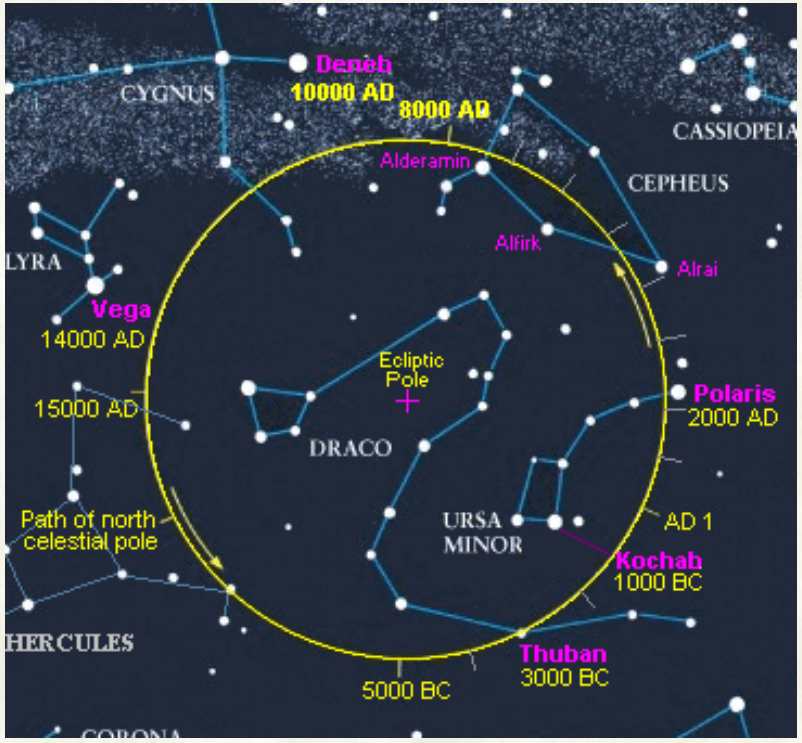
Of whose true-fix'd and resting quality
There is no fellow in the firmament.

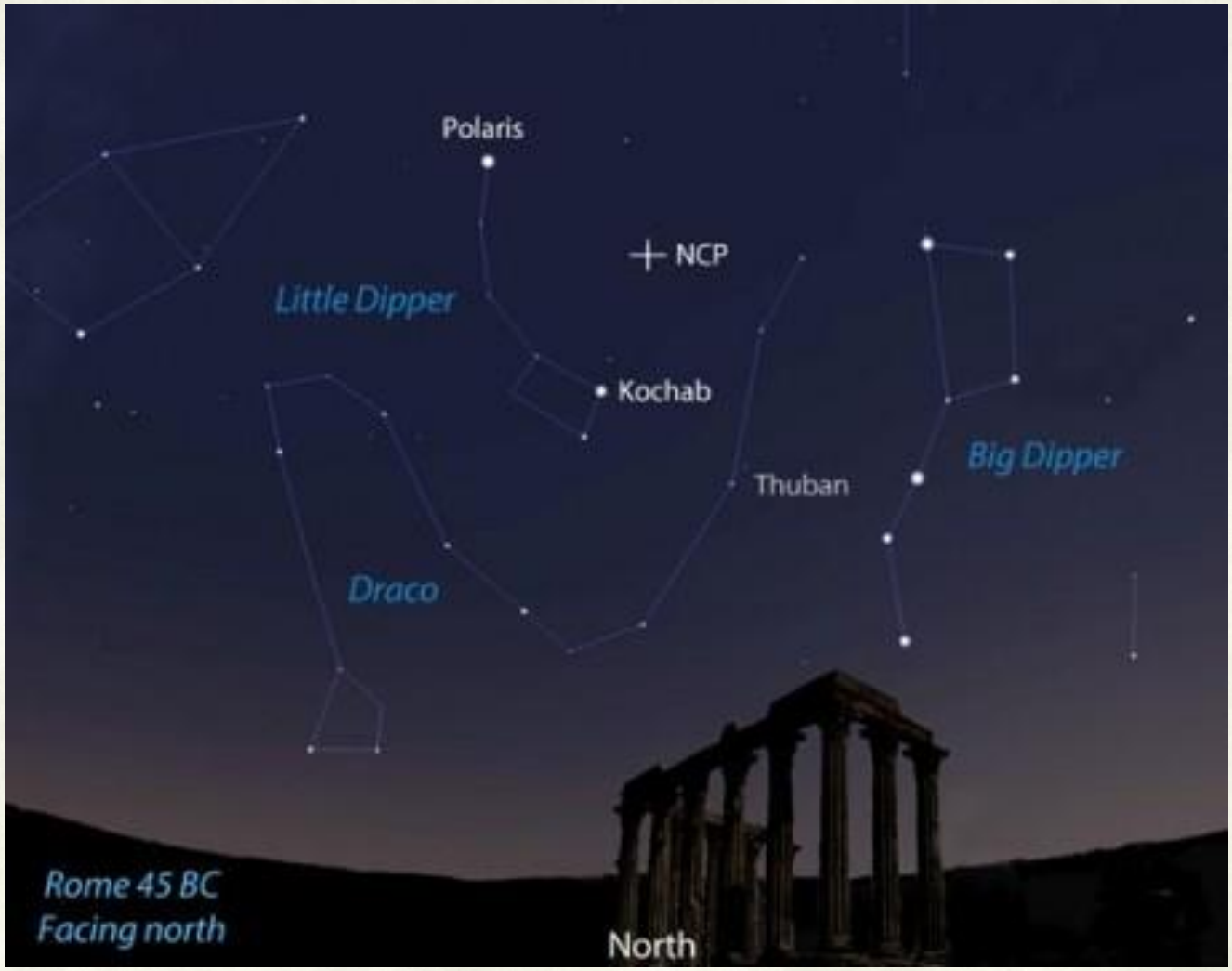
The skies are painted with unnumbered sparks,
They are all fire and every one doth shine,

But there's but one in all doth hold his place…

-Caesar, in Shakespeare's ''Julius Caesar''

Could Caesar had actually said that ?





the sky around 8 PM on January 7, 45 BC over Rome

from: www.skyandtelescope.com/observing/visit-skys-north-pole01072014

- There was no north star during Caesar's reign, 2000 years ago!

Review Questions

- Why do stars seem to have fixed locations in the sky, even though they are moving at considerable speeds in space.
- What is the difference between proper motion of a star and the motion due to parallax.
- Give few examples you experience effects of parallax in daily life
- What is the distance to a star in parsecs if its parallax is 0.1”
- When you drive on the highway, nearby things pass quickly, while far off objects appear stationary. Why?
- What is the typical parallax of a nearby star?
- Why is it not possible to measure the parallax better than 0.01” from ground based instruments, but can be done from space?
- What is the precession of the Earth.
- Which of the following would change due to precession

  celestial poles, north star, celestial equator, zodiac, zenith, cardinal directions on the Earth.
- What is the Ecliptic?
- Why does the Sun appear to move in the sky with respect to Stars?
- Can you see the Sun’s annual movement in the sky? Given an example.
- Why don’t we ever see the planets near the celestial poles?
- What is the Zodiac? How is it different from the Elliptic? What are the Zodiac constellations?
- Why is the Ecliptic (or the Zodiac) inclined with respect to the celestial equator.
- What made ancient people to think (incorrectly) planets, had an influence on the life on Earth?