Physical Astronomy

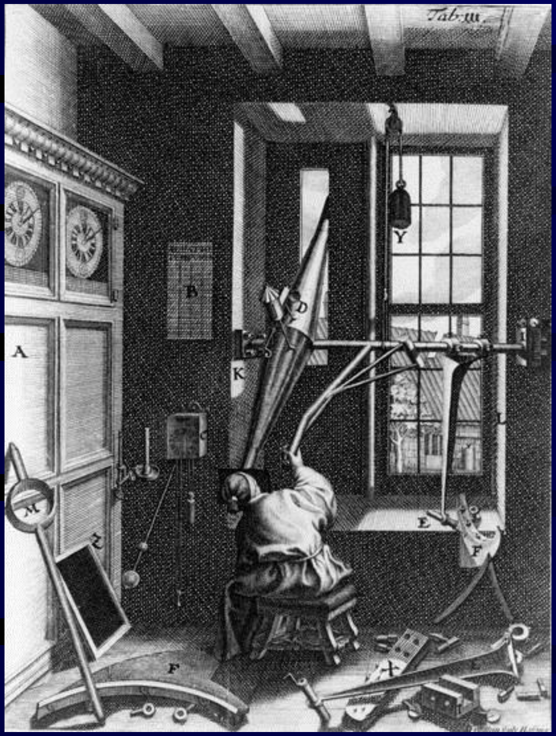
Starry Monday Tonight!

- 7pm lecture in Science 238
- 8pm Rooftop observing
- Counts for observing credit

Physical Astronomy

- With the telescope the specks of light turn out to be “real objects”: planets, mountains of the moon, etc.
- Conclusion: Celestial objects can be modeled after things on Earth, i.e. physical reasons for behavior and appearance is to be expected

→ The terrestrial machine



Physical Astronomy

- The speed of light is finite!
- This has consequences: eclipses of the Galilean moon's are not "on time"
- Ole Roemer measures the speed of light to be c = 11 min/AU

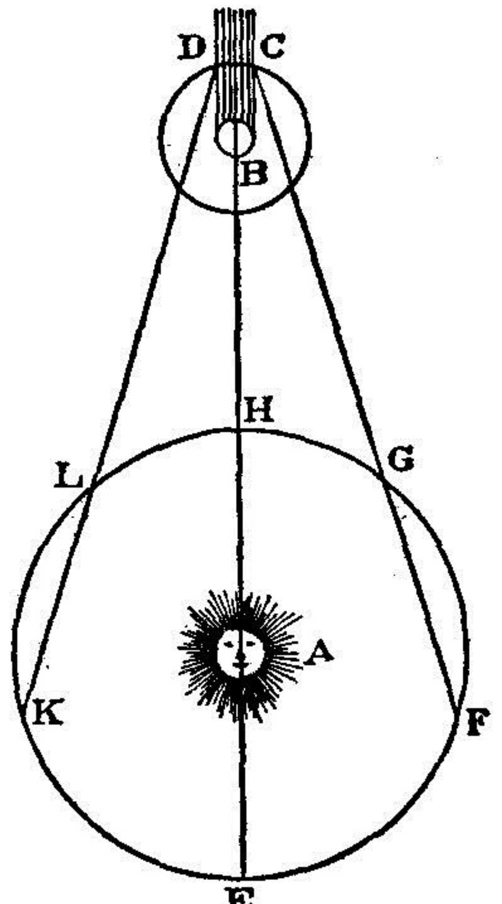


Fig. 70.

The Mass of Celestial Objects

- Newton's law is universal – but its ingredients are still missing
  - Mass of the earth, sun, moon: unknown
  - Distance to the sun very inaccurate
  - Gravitational constant G: total mystery
- Newton did what he could: compute ratios of masses: Sun, planet masses in units of the earth mass

Computing relative Masses of Celestial Objects

- Insight from Newton's gravity law: the more mass, the stronger the force, the faster the satellite
- Consider planets satellites of the sun
- Known moons: the moon, 4 Galilean moons, Titan of Saturn
- Newton gets distance to sun factor 2 too small
- Still surprise: sun 1000x more mass than Jupiter, Saturn 50x more mass than earth
- are still missing

1727: Newton dies – was he correct?

- For several decades in the 18th century: Newton (England) vs Descartes (Continent)
- Newton's mathematical physics (Laws of Motion) vs Descartes's physical physics (Vortex theory)
- Need to test the predictions of the two theories

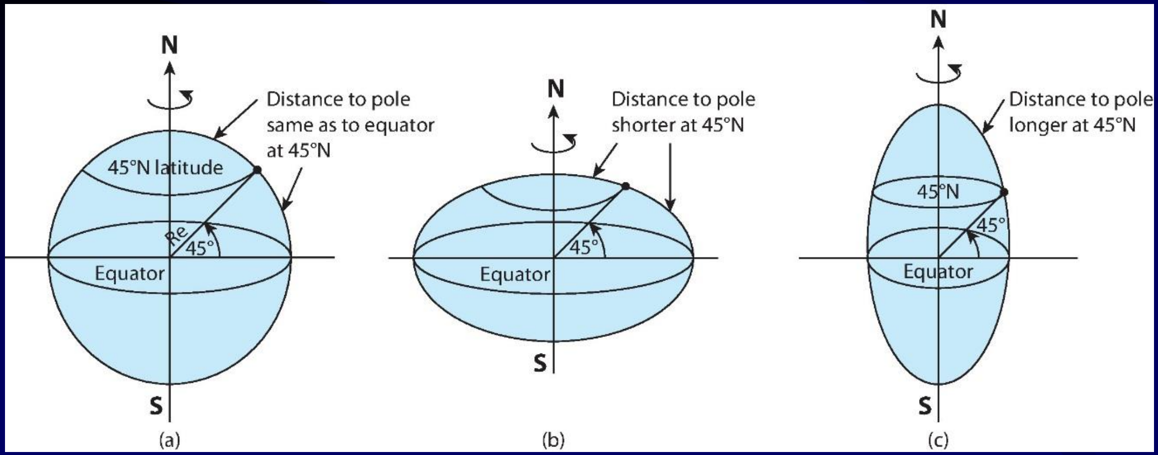
Three Tests

- Shape of the Earth
- Motion of the Moon
- Return of Halley's comet

Comet Halley over the river Thames near London, England in 1759. Painting by Samuel Scott.

Measuring the Shape of the Earth

- Depending on the shape, the distance to the pole is longer or shorter from a given latitude
- Maximal discrepancy: pole vs equator
- Two expeditions: one to Lapland (northern Sweden), the other to Peru (equator)
- Result (after many years): Newton is correct, the earth is oblate ("Ernie")

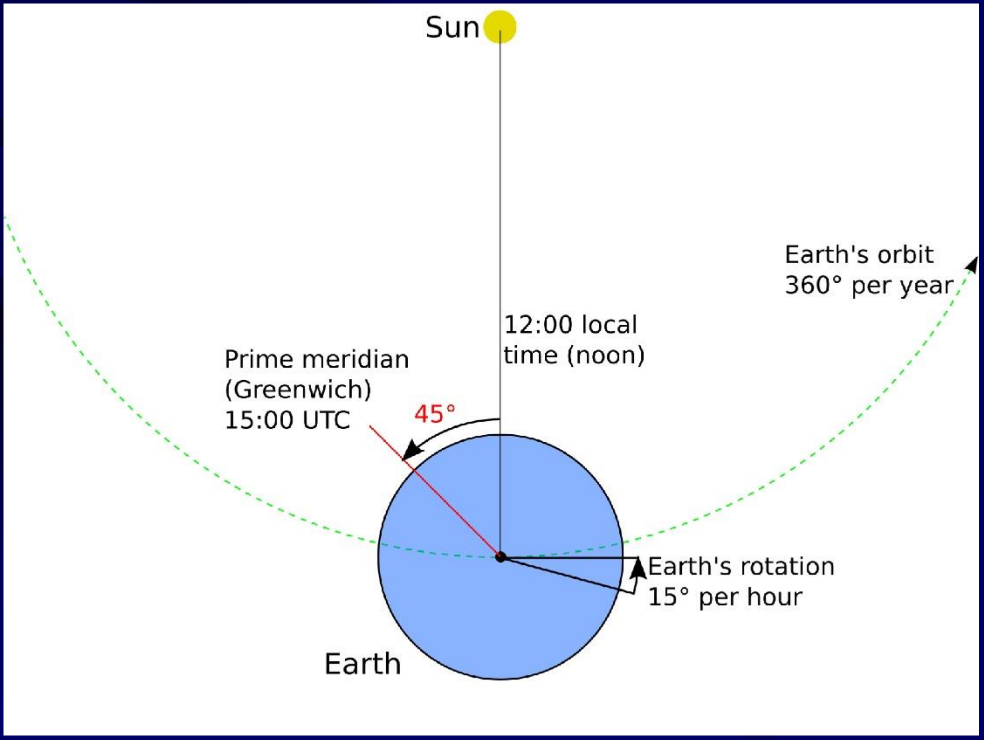


Two expeditions are sent out in the 1730s to measure the shape of the Earth

- One to Lapland near the arctic circle (included Celsius) returns several years later
- One sent to Peru near the equator returns after more than a decade
- They agree: The Earth is oblate (Ernie),
- ➔ Newton is right!
  - Difference only 43km or 3.3%

Determining Longitude

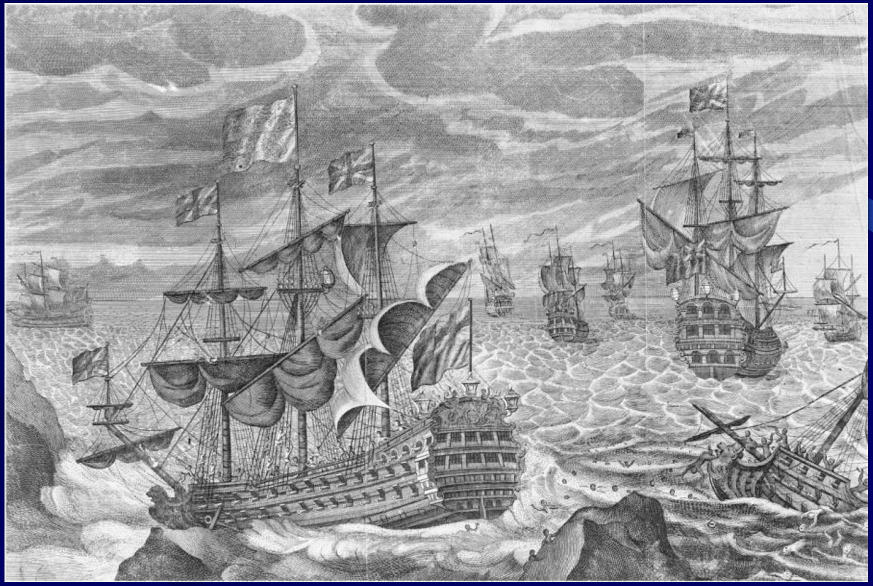
- The moon can be used as a cosmic clock!
- (If its motion can be predicted well enough)



Scilly Naval Disaster of 1707 causes establishment of the Longitude Prize

- 1500 sailors die due to navigation error
- British government established the Longitude board
- Tobias Meyer wins

part of the price for his lunar theory



Edmond Halley predicts in 1705 that "his" comet will return late in 1758

It is his comet, because he found out that the comets of 1066 (William the Conqueror, Bayeux), 1531, 1607 are on and the same comet!

(Halley died in 1742)

Halley’s comet returns triumphantly – as predicted

- The orbit of the comet is perturbed by Jupiter's gravitational field – in accordance with Newton!
- Clairaut in France embarks on the first ever large-scale numerical computation and predicts mid-April 1759 plus or minus a month
- Observed March 13, 1759

➔Newton is right!

Stellar Parallax and Stellar Aberration

- The big price: find the stellar parallax
  - to measure the distance to the stars
  - to show that the earth is moving: Eppur se muove
- Problem: stars are very far away, the parallax is very small
- Serendipity: Bradley finds instead stellar aberration

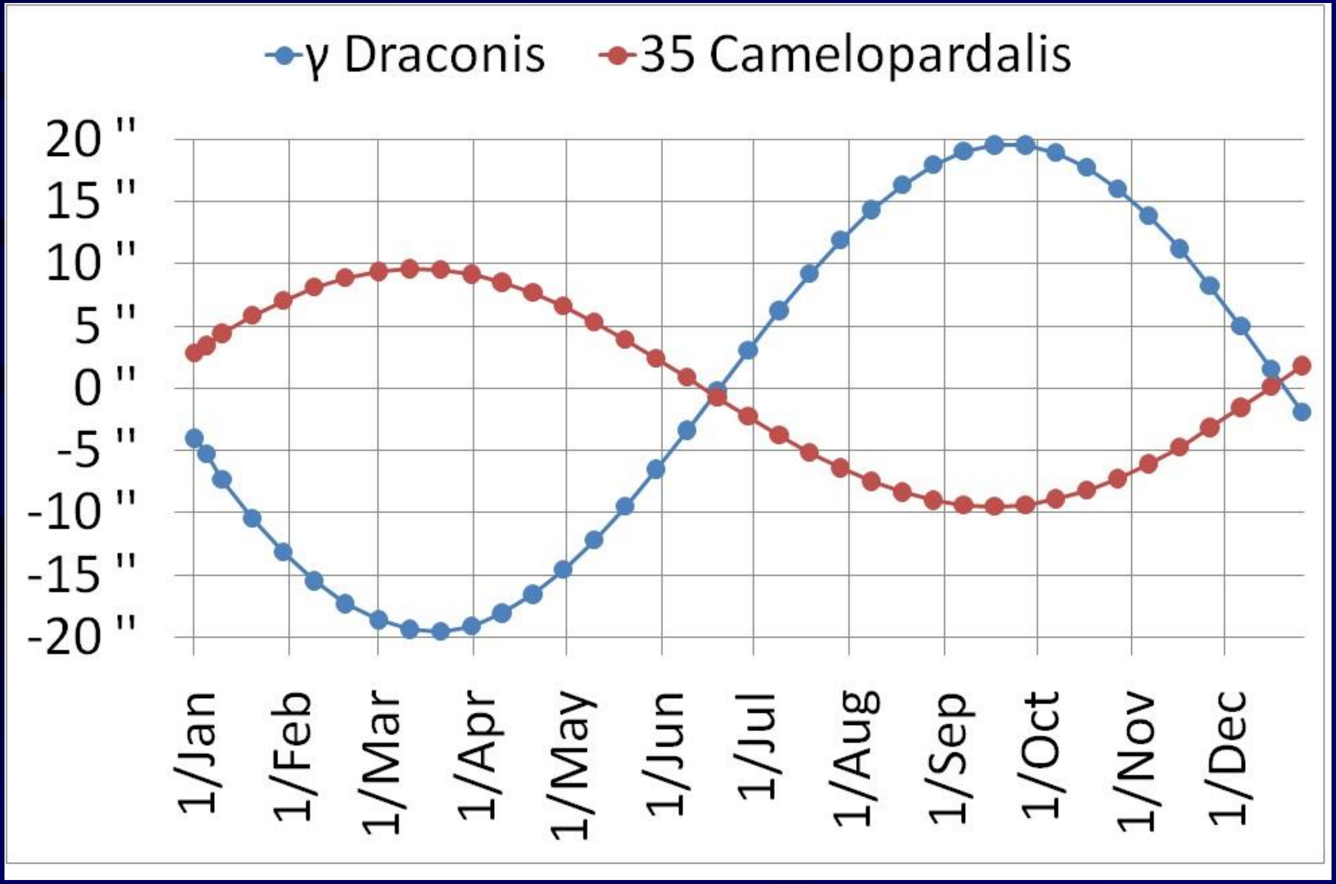
The hunt for Stellar Parallax yields Stellar Aberration

- Hooke: Delta Draconis appears to move
- Why this star? It is at the zenith in London (51.5 N) → no need to correct for atmospheric refraction
- How big is the effect? 20” - that is almost 100x smaller than the full moon!
- Flamsteed: parallax(?) of Polaris
- Bradley investigates and finds instead stellar aberration

Stellar Aberration

- The discovery and explanation of stellar aberration by James Bradley in 1728 was a milestone in the history of astronomy.
- Pattern:
  - Same maximal aberration for every star
  - Some show circular aberration path, some elliptical

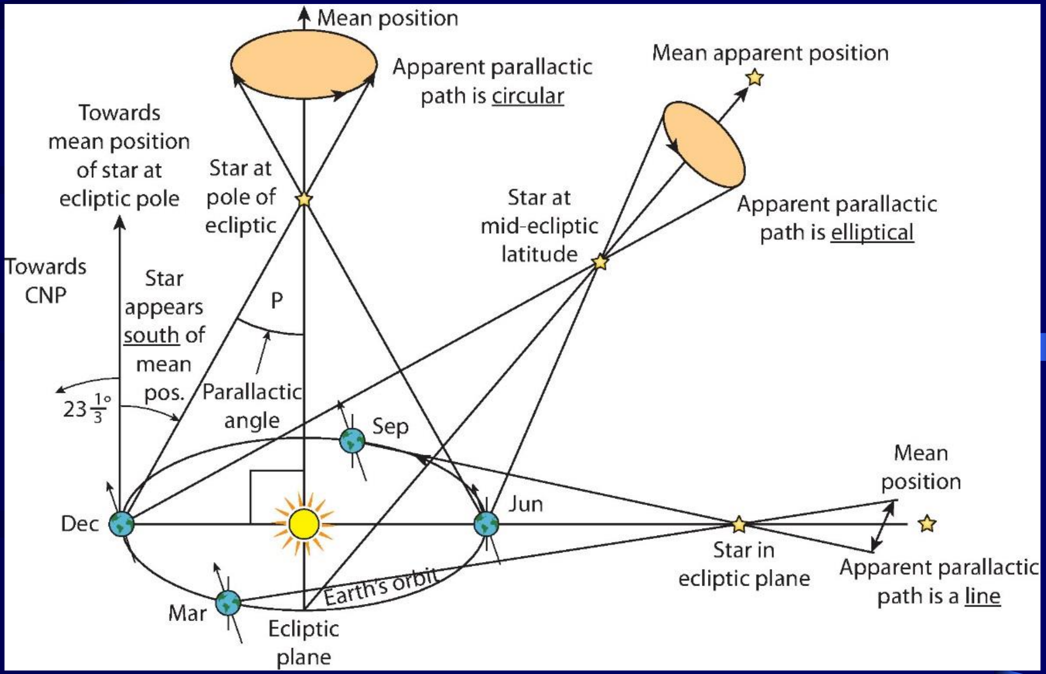
Bradley's observation of the positions of two stars



A Detective Case

- Is this the long-sought parallax?
- Suspicious: the two stars show the same size of the effect in RA (and half in declination)
- If it is parallax, then we must conclude that they are equally distant – unlikely!

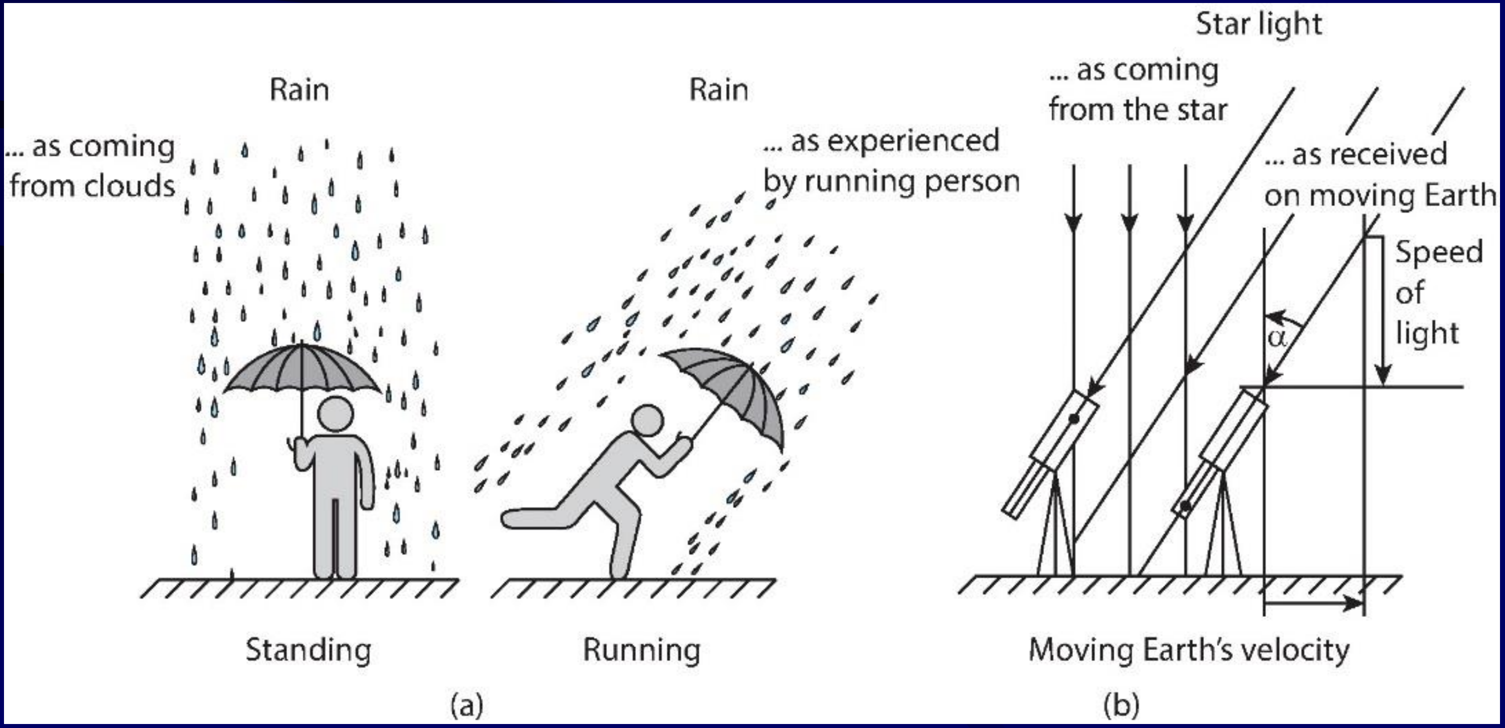
Review: Features of Stellar Parallax



- Stars appear to move around a mean position
- Depending on the star's ecliptic latitude, the path is circular, elliptical or a line
- The parallactic angle ("radius" of apparent path) depends on the distance to the star: farther star, smaller parallax
- The star reaches the southernmost point of its annular parallactic path in December

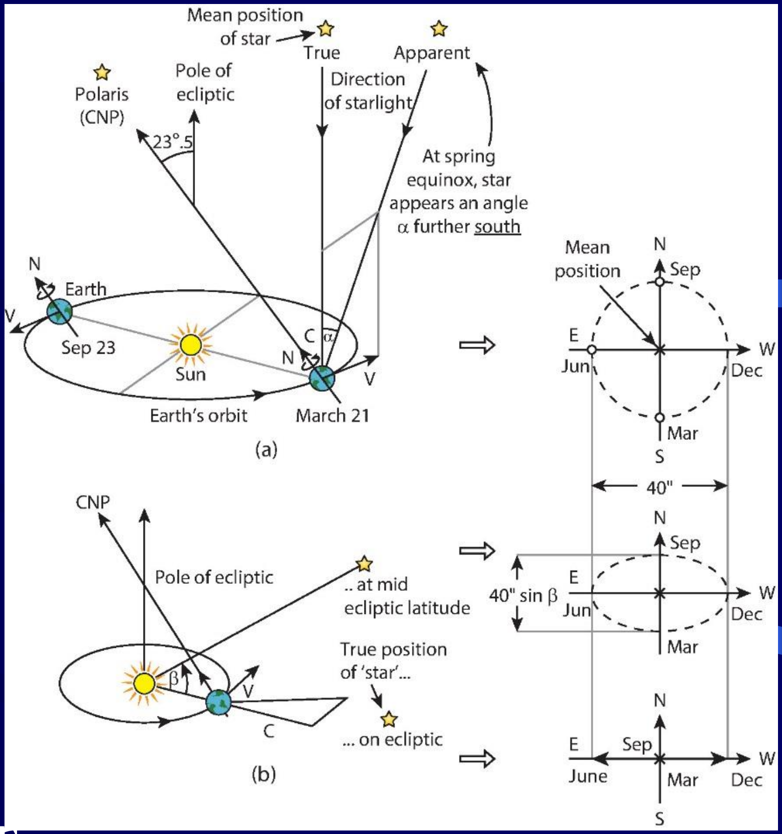
The Aberration Effect

- A moving observer sees raindrops or starlight come from a different direction than a stationary observer



Features of Stellar Aberration

- Stars appear to move around a mean position
- Depending on the star's ecliptic latitude, the path is circular, elliptical or a line
- The aberration constant ("radius" of apparent path) is the SAME for every star
- The star reaches the southernmost point of its annular apparent path in March

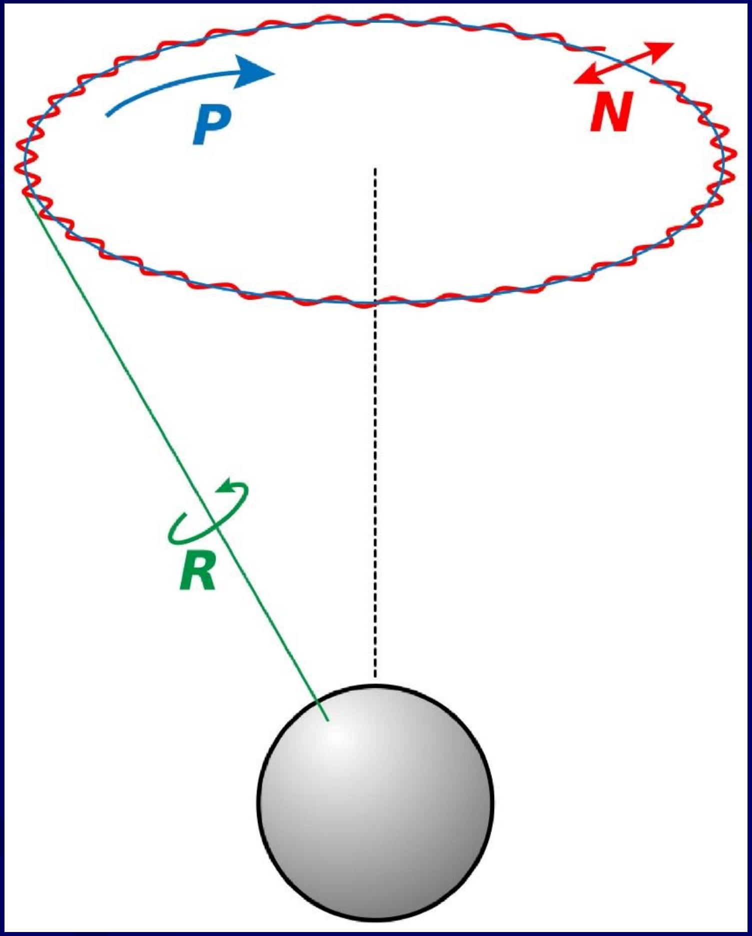


Understanding Stellar Aberration leads to measurement of the speed of light

- Bradley measures the maximal shif due to aberration to be 20.5”
- Since this is v/c (in rad) and 20.5” = 1/10,000 rad, we conclude c = 10,000 v
- The speed of light is 10,000 times the orbital speed of the earth
- But: AU unknown, so express speed of light as time it takes light from the sun to reach us on Earth: 8 min 20 sec: c = 8.33 min/AU

Physical Astronomy: The Earth behaves like a spinning top!

- Euler: So we can describe it with the spinning-top-equations of physics
- Rotates around axis, axis rotates around pole of the ecliptic
- It “nods” nutation



Motion of the moon's orbit is the cause for nutation

- Nutation happens on a 18.6 year cycle
- Node of moon's orbit rotates in 18.6 years
- You connect the dots…