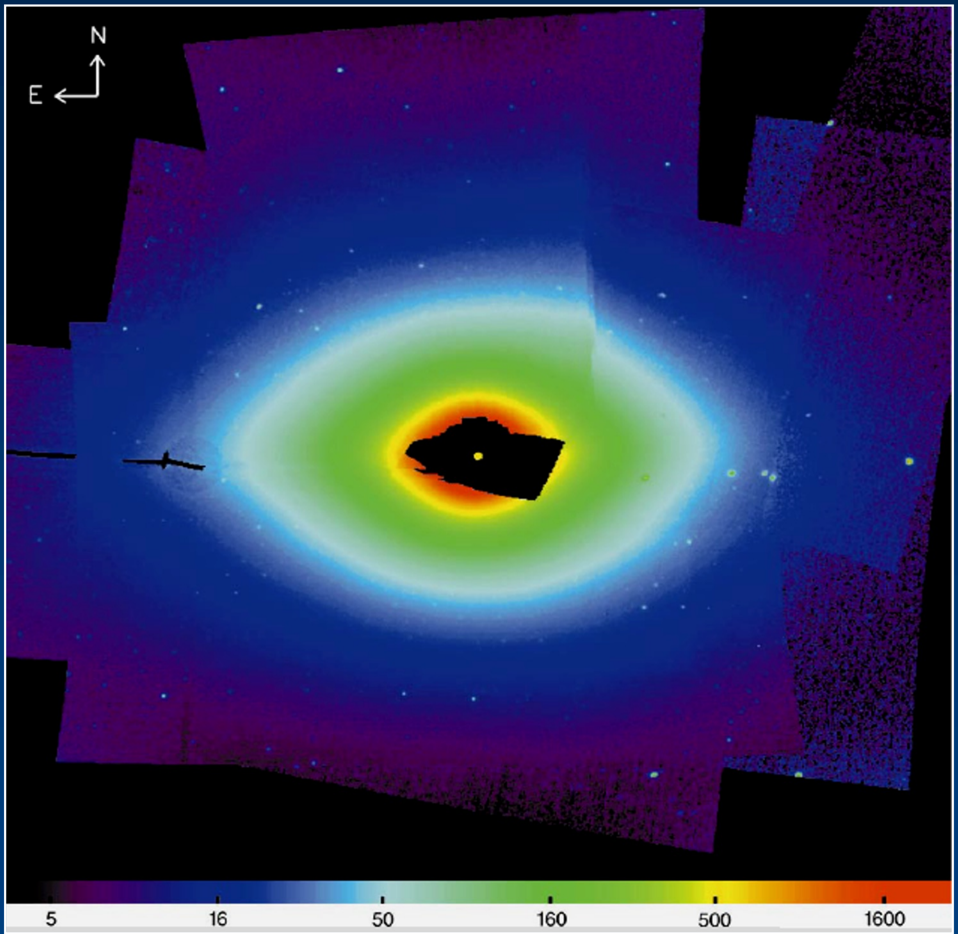
Zodiacal Dust

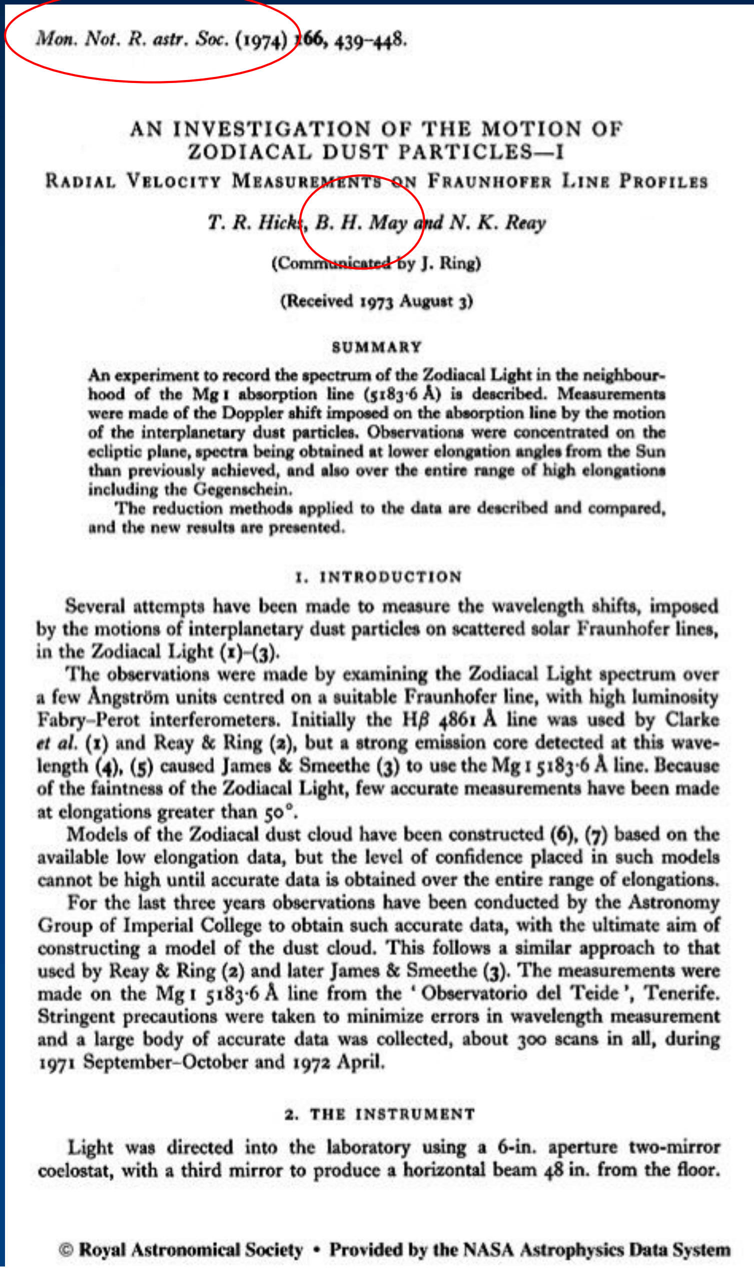
Looking outwards
(away from the sun)



Looking inwards (in infrared)

Zodiacal dust

Dust particles on the plane of the orbits of the planets. (size: 1 to 300 x 10^{-6} m)



Mon. Not. R. astr. Soc. (1974) **166**, 439–448.

AN INVESTIGATION OF THE MOTION OF ZODIACAL DUST PARTICLES—I

RADIAL VELOCITY MEASUREMENTS ON FRAUNHOFER LINE PROFILES

T. R. Hicks, B. H. May and N. K. Reay

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SUMMARY

An experiment to record the spectrum of the Zodiacal Light in the neighbourhood of the Mg I absorption line (5183·6 Å) is described. Measurements were made of the Doppler shift imposed on the absorption line by the motion of the interplanetary dust particles. Observations were concentrated on the ecliptic plane, spectra being obtained at lower elongation angles from the Sun than previously achieved, and also over the entire range of high elongations including the Gegenschein.

The reduction methods applied to the data are described and compared, and the new results are presented.

1. INTRODUCTION

Several attempts have been made to measure the wavelength shifts, imposed by the motions of interplanetary dust particles on scattered solar Fraunhofer lines, in the Zodiacal Light (1)–(3).

The observations were made by examining the Zodiacal Light spectrum over a few Ångström units centred on a suitable Fraunhofer line, with high luminosity Fabry–Perot interferometers. Initially the Hβ 4861 Å line was used by Clarke *et al.* (1) and Reay & Ring (2), but a strong emission core detected at this wavelength (4), (5) caused James & Smeethe (3) to use the Mg I 5183·6 Å line. Because of the faintness of the Zodiacal Light, few accurate measurements have been made at elongations greater than 50°.

Models of the Zodiacal dust cloud have been constructed (6), (7) based on the available low elongation data, but the level of confidence placed in such models cannot be high until accurate data is obtained over the entire range of elongations.

For the last three years observations have been conducted by the Astronomy Group of Imperial College to obtain such accurate data, with the ultimate aim of constructing a model of the dust cloud. This follows a similar approach to that used by Reay & Ring (2) and later James & Smeethe (3). The measurements were made on the Mg I 5183·6 Å line from the 'Observatorio del Teide', Tenerife. Stringent precautions were taken to minimize errors in wavelength measurement and a large body of accurate data was collected, about 300 scans in all, during 1971 September–October and 1972 April.

2. THE INSTRUMENT

Light was directed into the laboratory using a 6-in. aperture two-mirror coelostat, with a third mirror to produce a horizontal beam 48 in. from the floor.

Solar system formation

- All objects formed from the same cloud of gas and dust
- Composition determined by cosmic history
- Different objects formed in different environments depending on their distance to the Sun

Exam #1

- Covers material from first day of class, all the way through “Tides” and “Nature of Light”
- Supporting reading chapters 1-6
- Some questions are “concept” questions, some involve working with equations, calculations
- Study your lecture notes, homeworks, worksheets, review supporting reading
- Know equations/constants on the sheet just handed out.
- Bring calculator, something to write with. Closed book, closed notes

Collect your old HW + WSs

- New stuff on lecturers left
- Old stuff on lecturers right
- N = No Name

Pro Tips

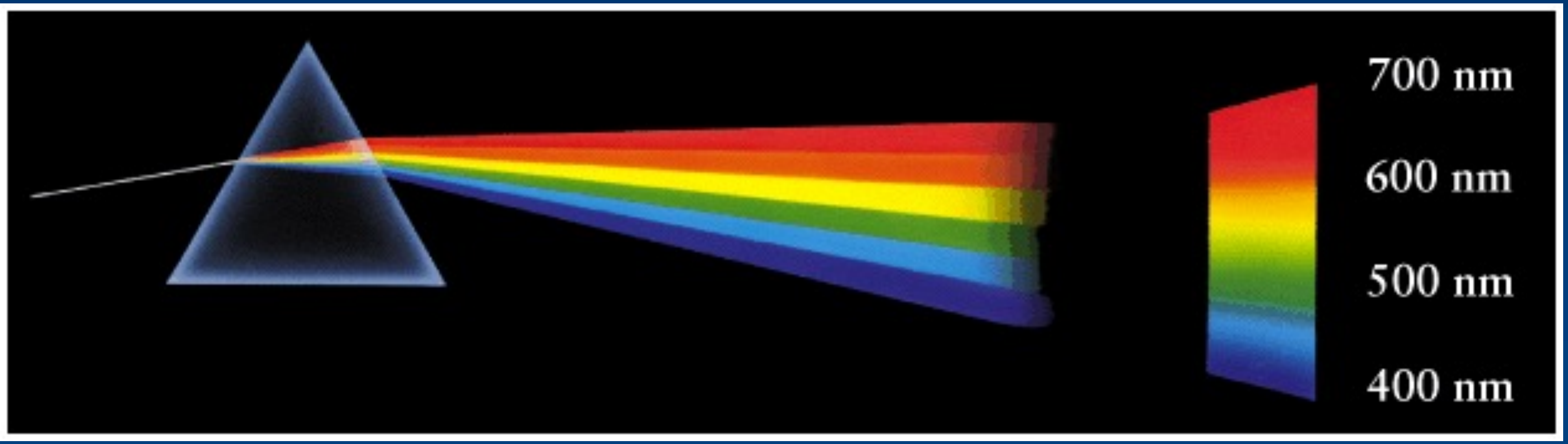
- Start with a problem you know how to solve – good for ”warming up”
- Draw Pictures – helps to visualize problem
- Don’t get hung up on one problem for more than 15 minutes, skip to the next and come back to it.
- Leave no problem blank, show some knowledge to get partial credit
- Check your answers to see if they are reasonable
- Watch your units and make sure you give the answer in the desired units.

- Angular measure, small angle formula, powers of ten, light-year, definition of AU
- Positional astronomy: diurnal motion, why we see different constellations over year, celestial sphere, celestial equator, celestial poles, zenith, meridian, horizon, Equatorial coordinate system, RA, Dec, what defines RA=0, precession, seasons, apparent motions of the Sun, ecliptic, equinoxes, solstices, solar vs. sidereal time
- Sample question: What was the Declination of the Sun on Sept 23?

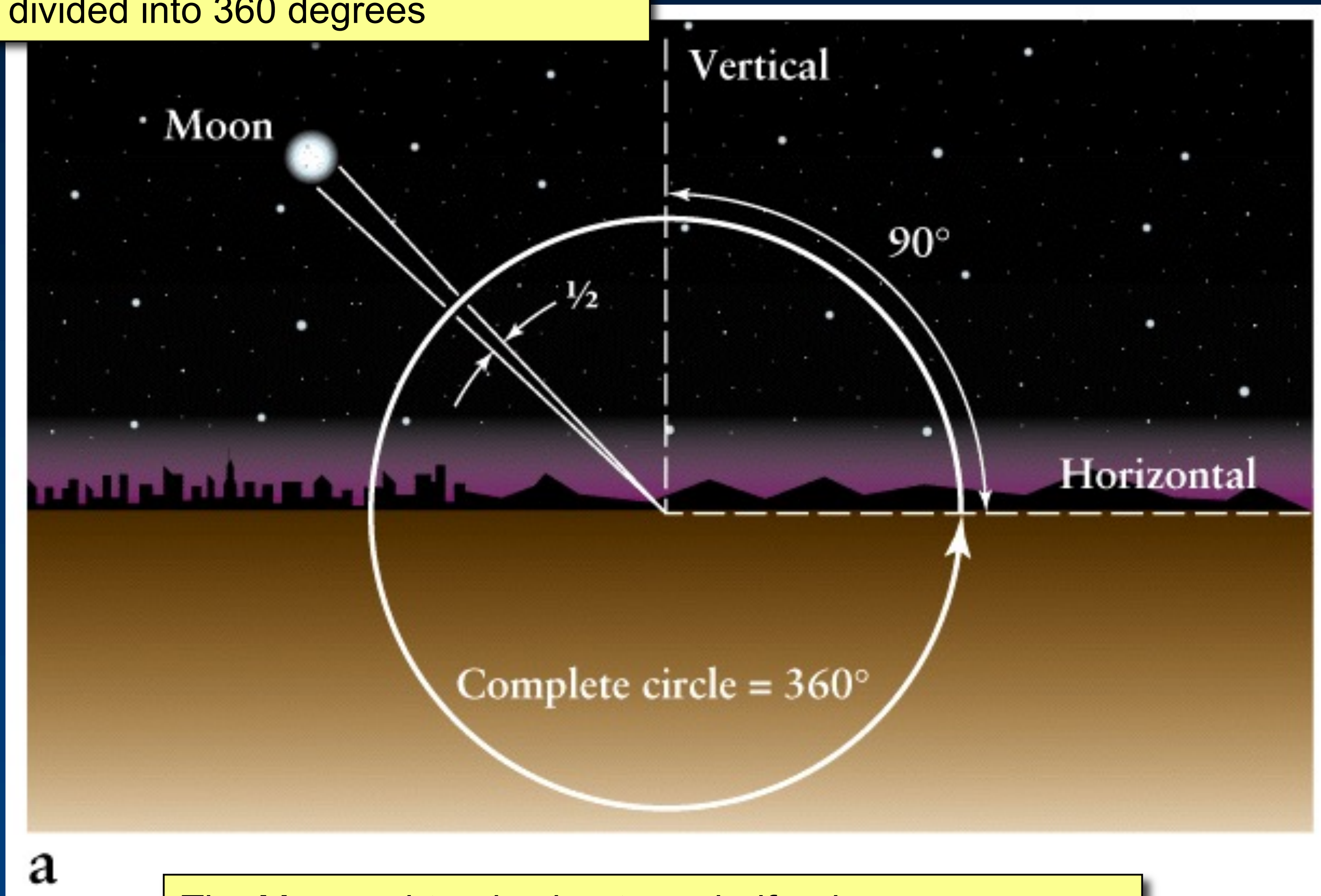
More about light:

The Sun's surface temperature of about 5800 K produces peak emission at 500 nm.

This is greenish! What's going on?



A circle is divided into 360 degrees



The Moon subtends about one-half a degree

Another way of saying this: the Moon has an angular diameter of one-half a degree

The small-angle formula

Relation between angular size, physical size, and distance to an object:

$$D = \frac{\alpha d}{206265}$$

where

D = linear size of an object

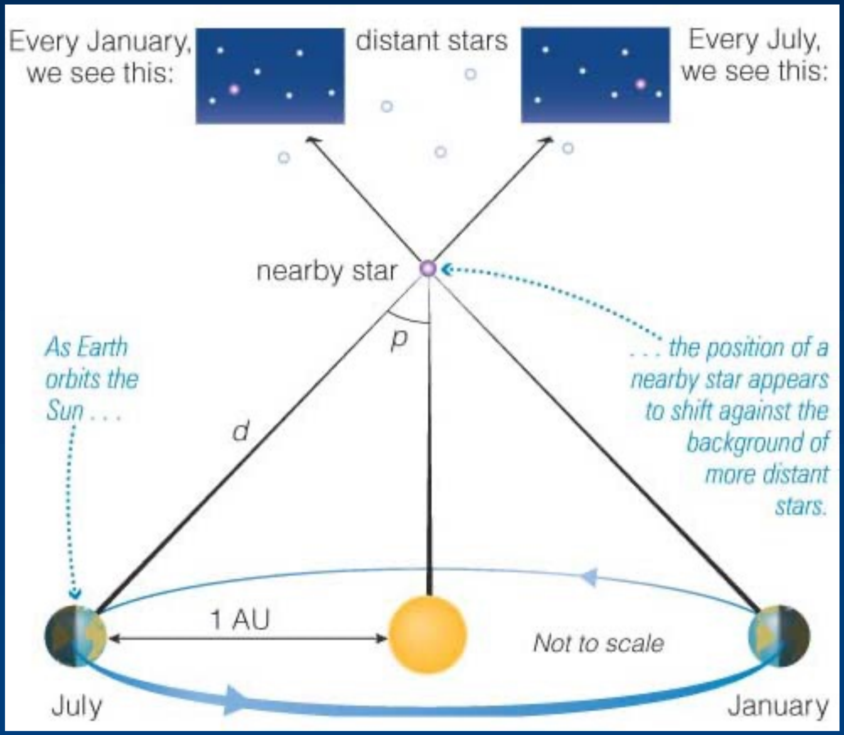
α = angular size of the object (in arcsec)

d = distance to the object (in same units as D)

The parsec

- Short for "parallax of one second of arc"
- It is the distance to a star which has a "trigonometric parallax" of 1", when observed at two opposite positions in the orbit of the Earth around the Sun, taken 6 months apart.
- If the trigonometric parallax is p, then d(pc) = 1/p(arcsec)

Note: diagram not to scale!

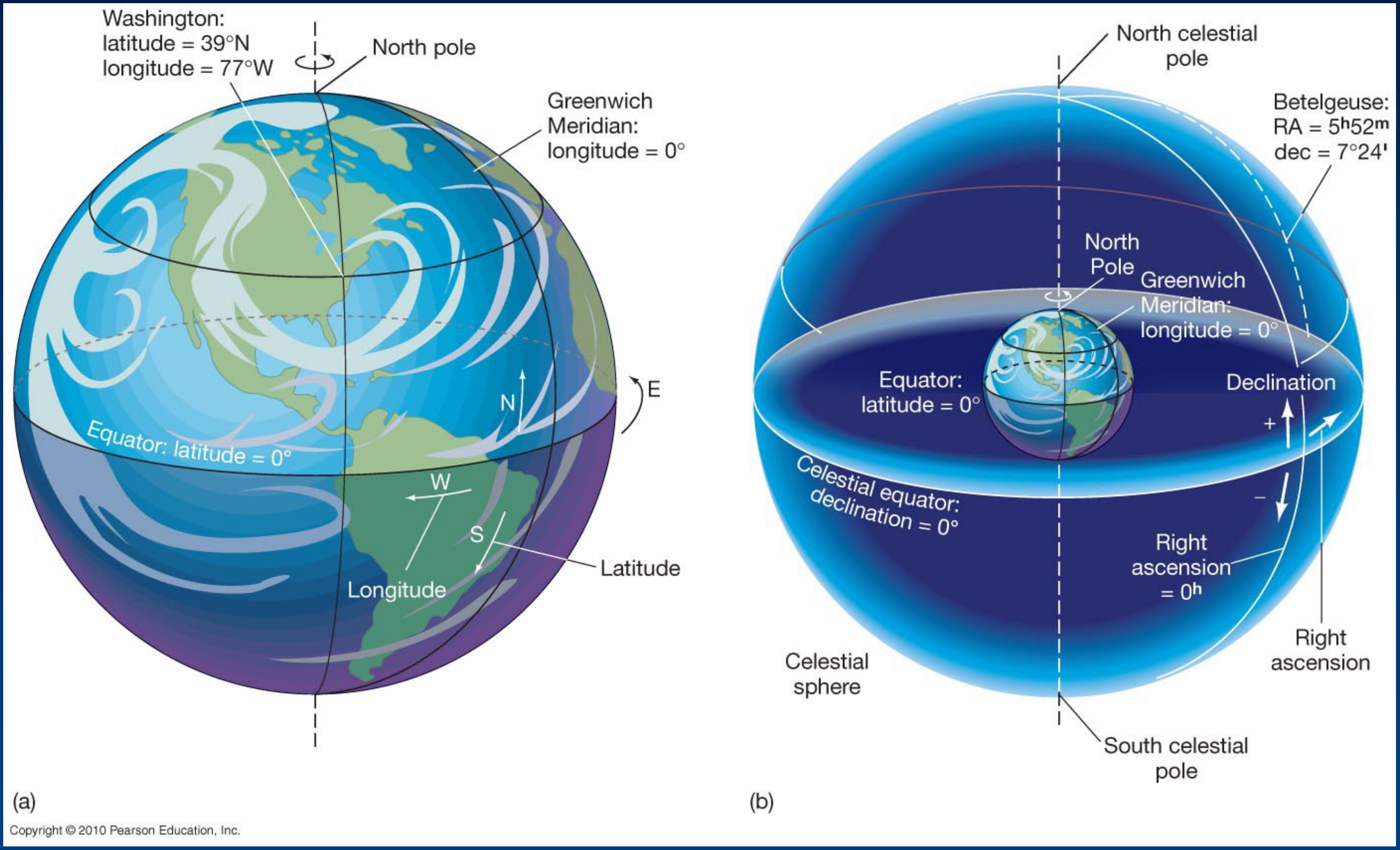


1 pc = 3.1×10^{16} m

= 206,265 AU

= 3.3 light years

The Celestial Sphere



latitude and longitude

Declination and Right Ascension

Declination: +90 (north pole) to -90 (south pole)

Right Ascension: 0 to 24 hours (1 hour = 15 degrees)

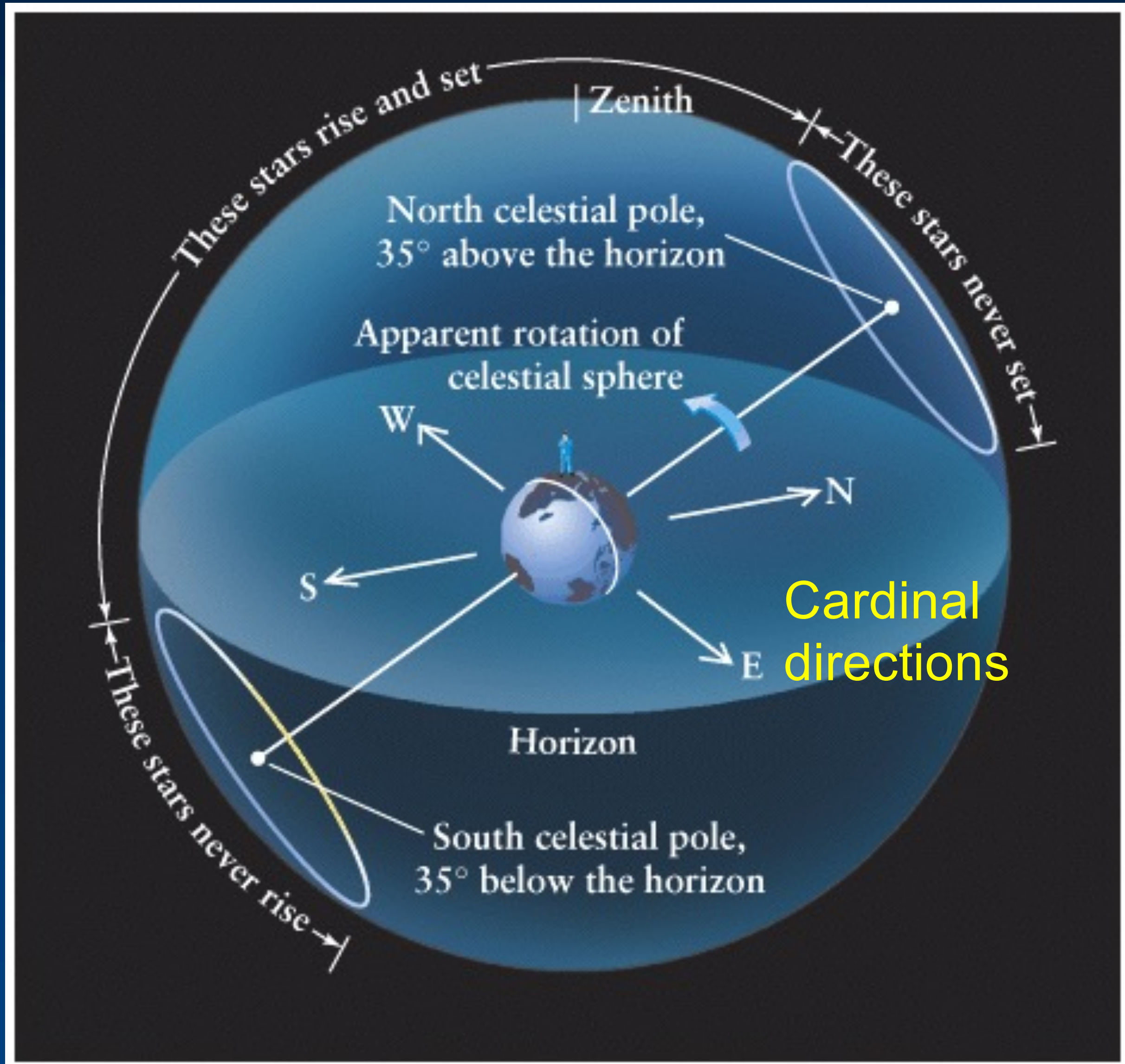
The ***zenith*** is the point directly overhead (cf. nadir).

The ***horizon*** delimits the portions of the sky we can and can't see at any given time.

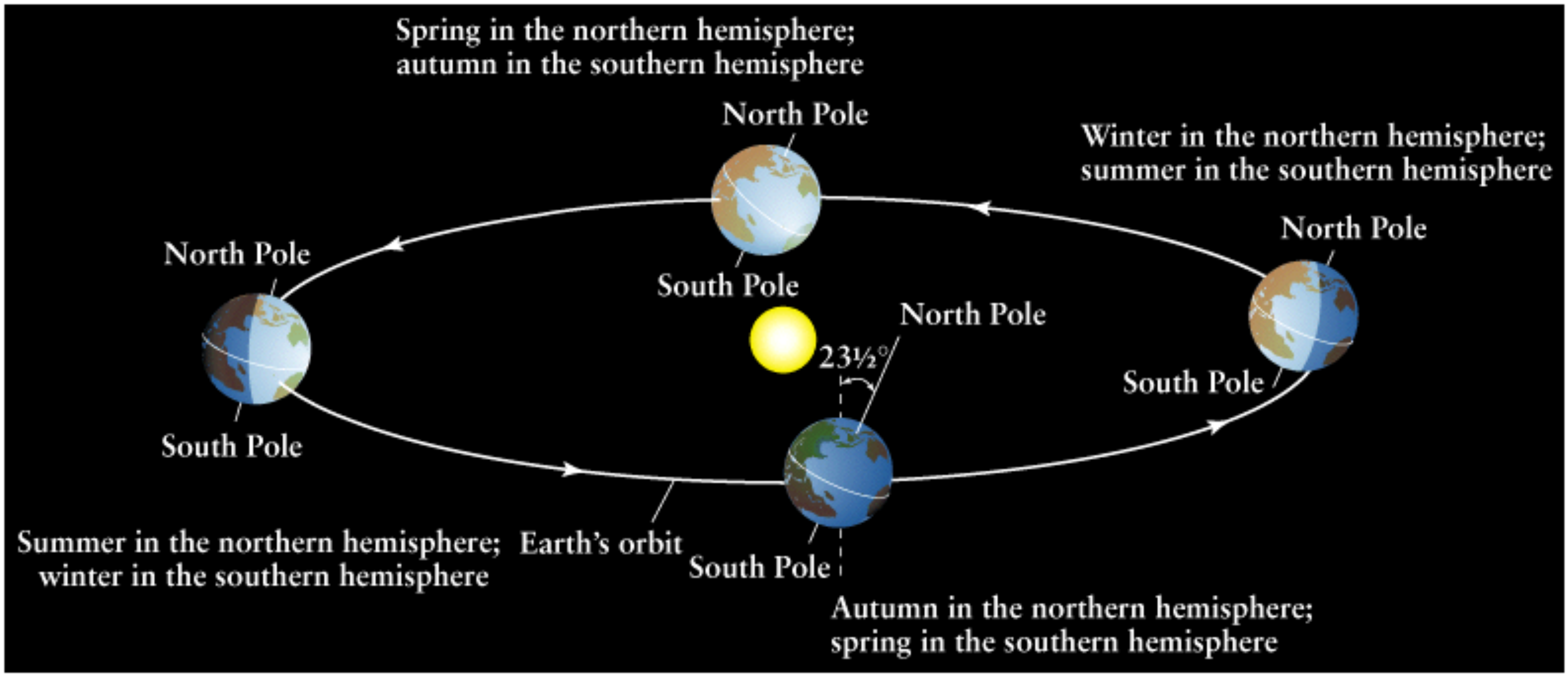
The ***meridian*** is the north-south circle that passes through the zenith and both celestial poles.

Over the course of a night, the celestial sphere appears to rotate around us.

The view from our latitude:



Question: what does A.M. mean? P.M.?

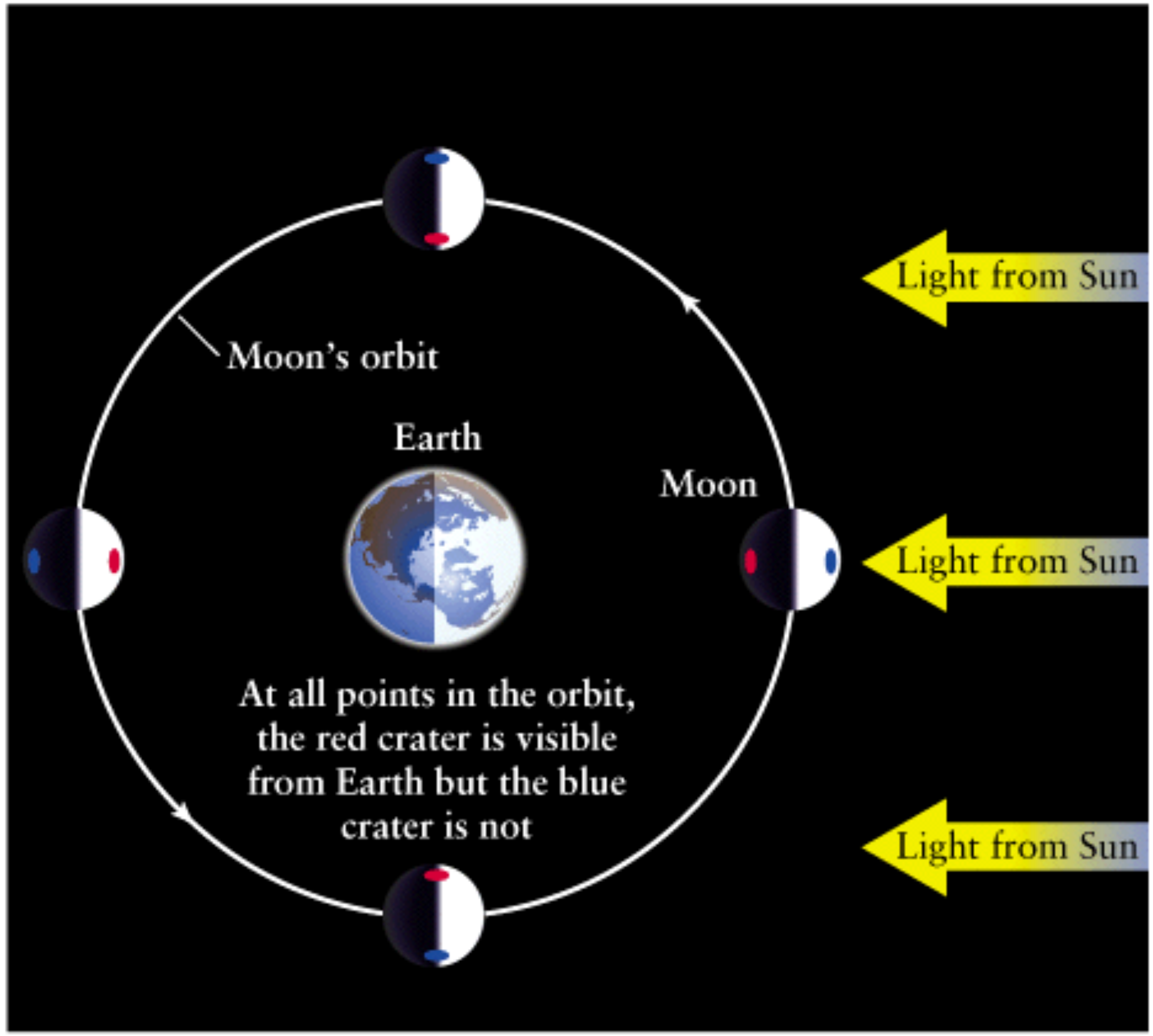

Spring in the northern hemisphere;
autumn in the southern hemisphere
North Pole
Winter in the northern hemisphere;
summer in the southern hemisphere
North Pole
North Pole
South Pole
North Pole
23½°
South Pole
South Pole
Summer in the northern hemisphere;
winter in the southern hemisphere
Earth's orbit
South Pole
Autumn in the northern hemisphere;
spring in the southern hemisphere

- Lunar phases, synchronous rotation, sidereal vs. lunar month, solar and lunar eclipses (and different types: solar: total, partial, annular; lunar: total, partial, penumbral). Why we aren’t guaranteed to have eclipses every month (geometry of orbits). Eclipse seasons

The Moon rotates in exactly the same time it makes one orbit around the Earth.

Rotation and revolution are *synchronous*.

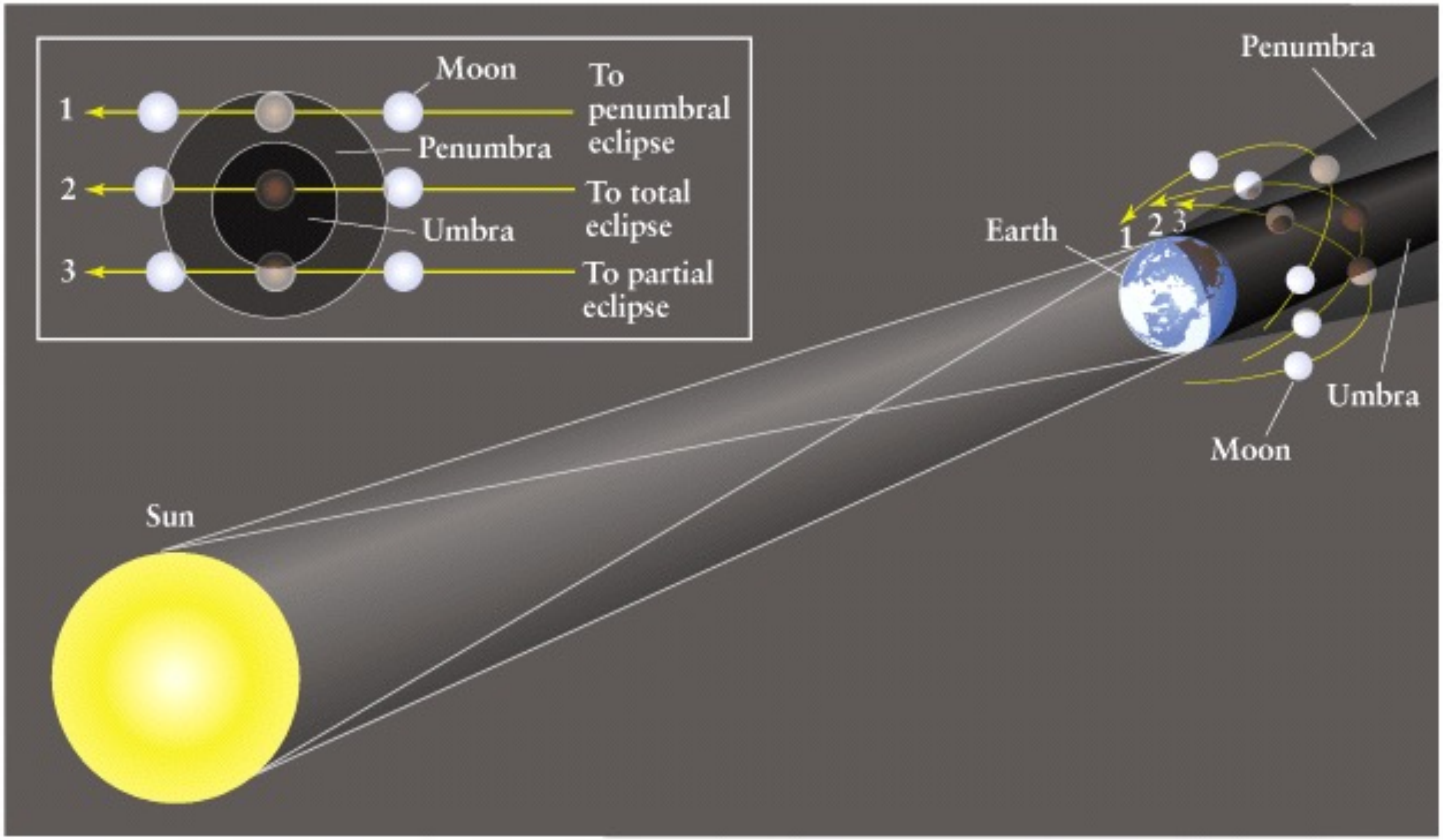
This is very common behavior in the Solar System, called "*synchronous rotation*", or "*tidal locking*". We'll talk about this more when we talk about tidal force.



b In fact the Moon does rotate and we see only one face of the Moon

The *near side* is the hemisphere facing toward us, and the *far side* is the hemisphere facing away from us.

There isn't a permanent dark side of the moon



Path 1 produces a penumbral lunar eclipse.

Path 2 produces a total lunar eclipse.

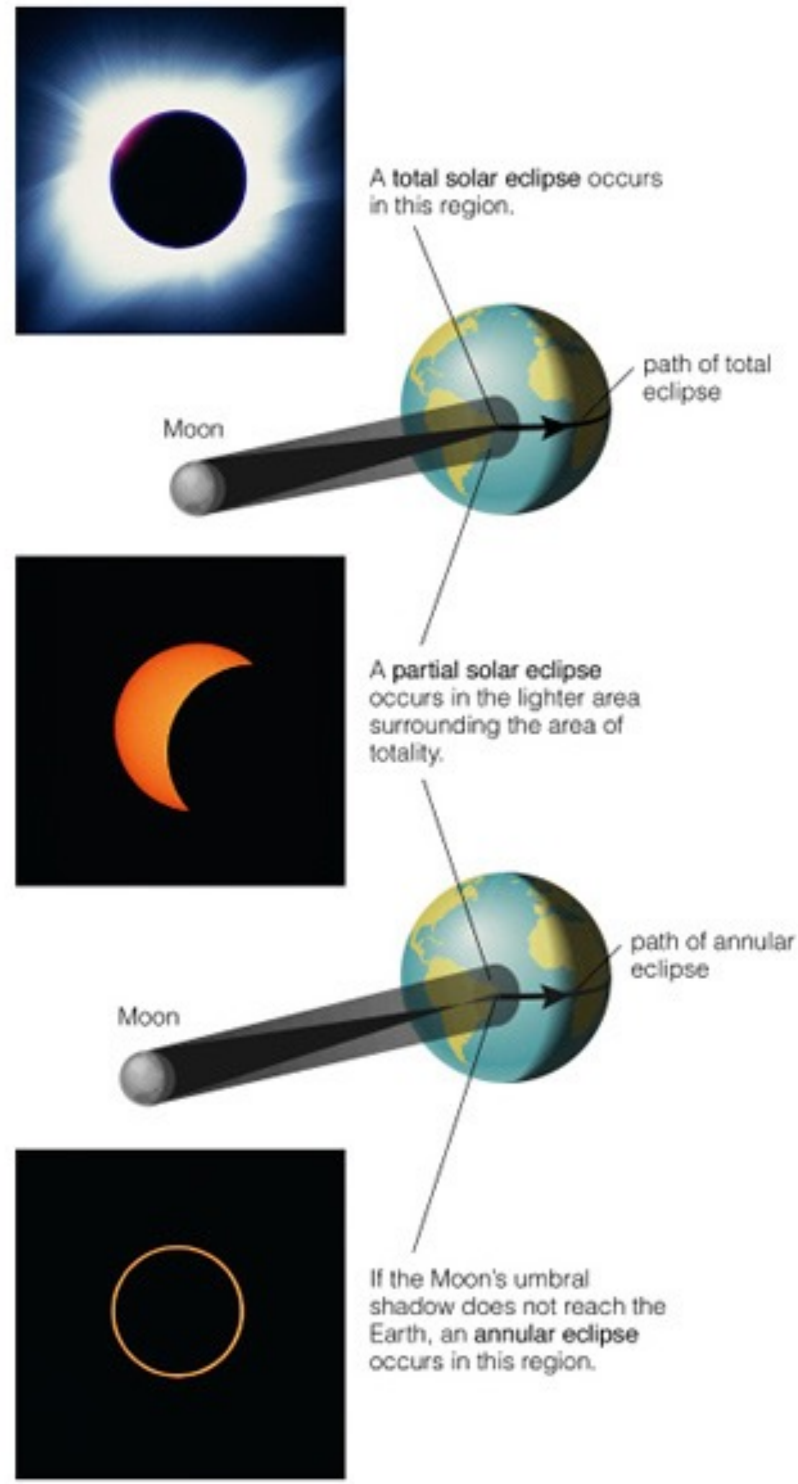
Path 3 produces a partial lunar eclipse.

Question: will lunar eclipses be visible in daytime or nighttime?

Types of solar eclipses

- Solar eclipses can be *total*, *partial*, or *annular*, depending on geometry.

- Angular diameter of Moon is about 1/2° = angular diameter of Sun
- ⇒ can block the Sun's disk from view.

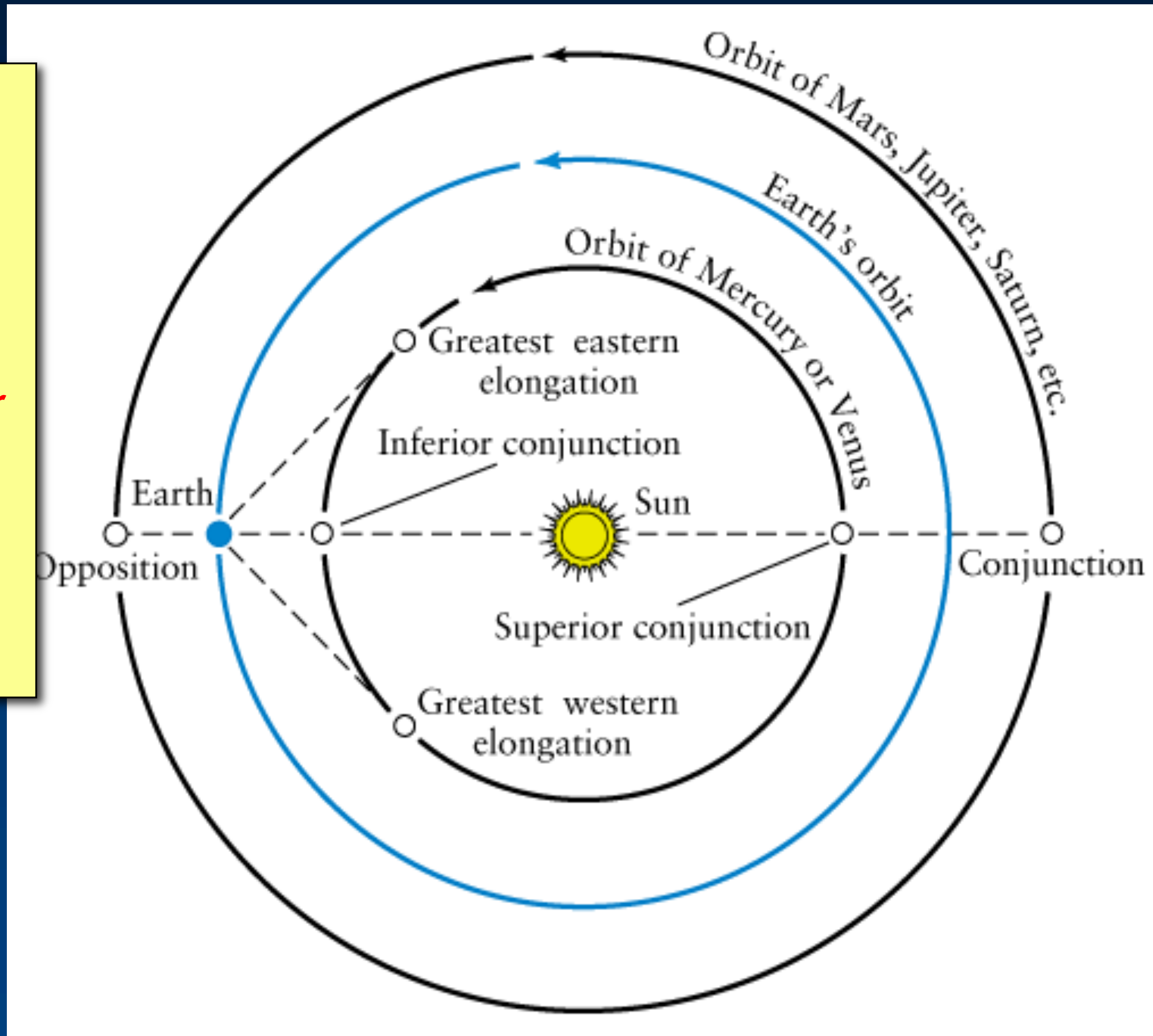


- Ptolemaic system (geocentric), retrograde motion, Copernicus (heliocentric), Galileo's observations. Inferior, superior planets, size of inferior's orbit. Brahe (observer), Kepler
- Kepler's 3 laws – know these!
- Newton's 3 laws of motion, and gravitation. Know these! Newton's form of Kepler's 3rd law

Copernicus noticed Mercury and Venus are never far in angle from the Sun. They are the *inferior* planets, which have orbits smaller than Earth's.

The others are the *superior* planets, with orbits larger than Earth's.

Stars much further away – no apparent motion except due to Earth's rotation.

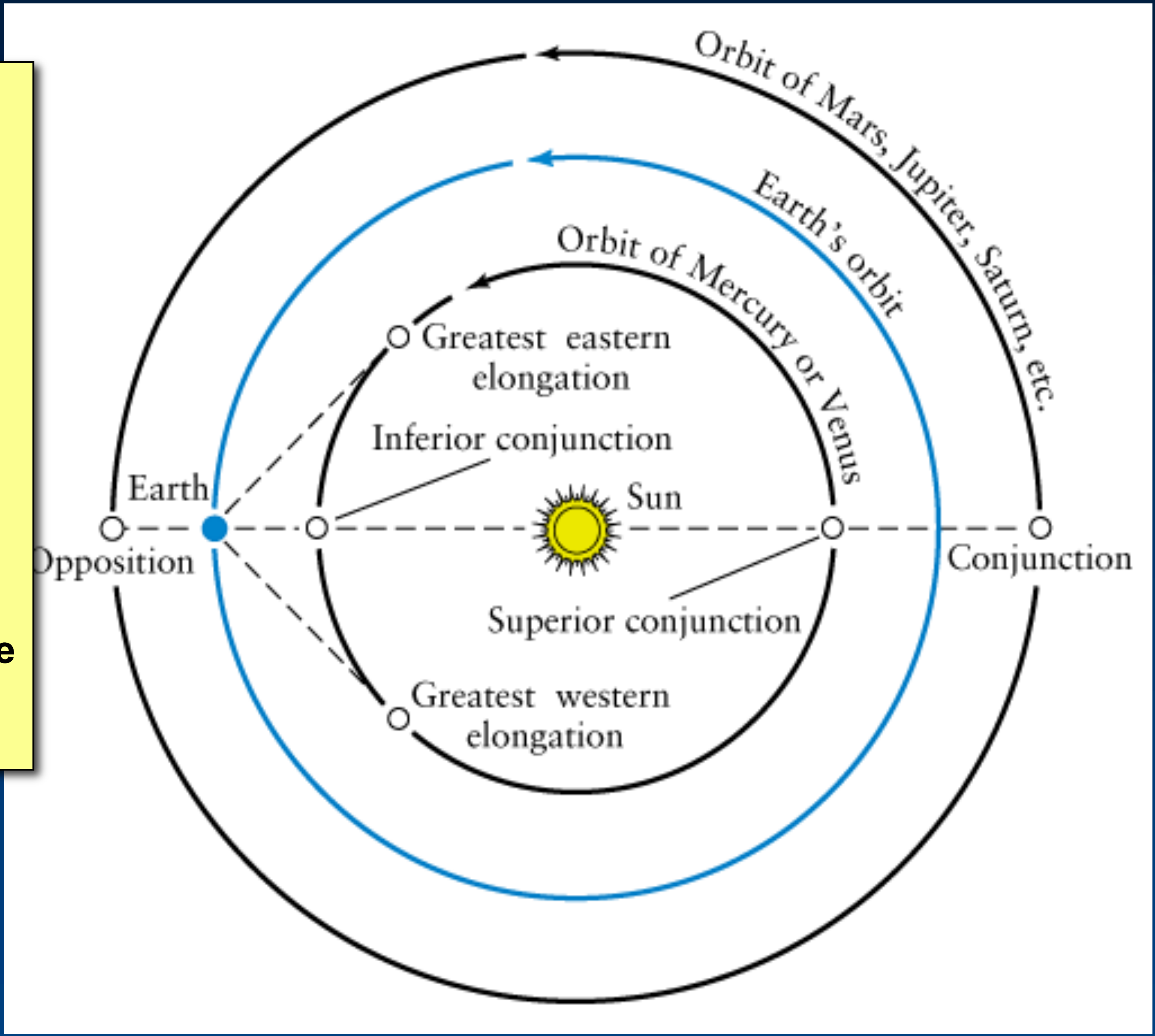


The angle between the Sun and a planet viewed from Earth is the planet's ***elongation***.

When a planet is at ***inferior conjunction***, it is between us and the Sun.

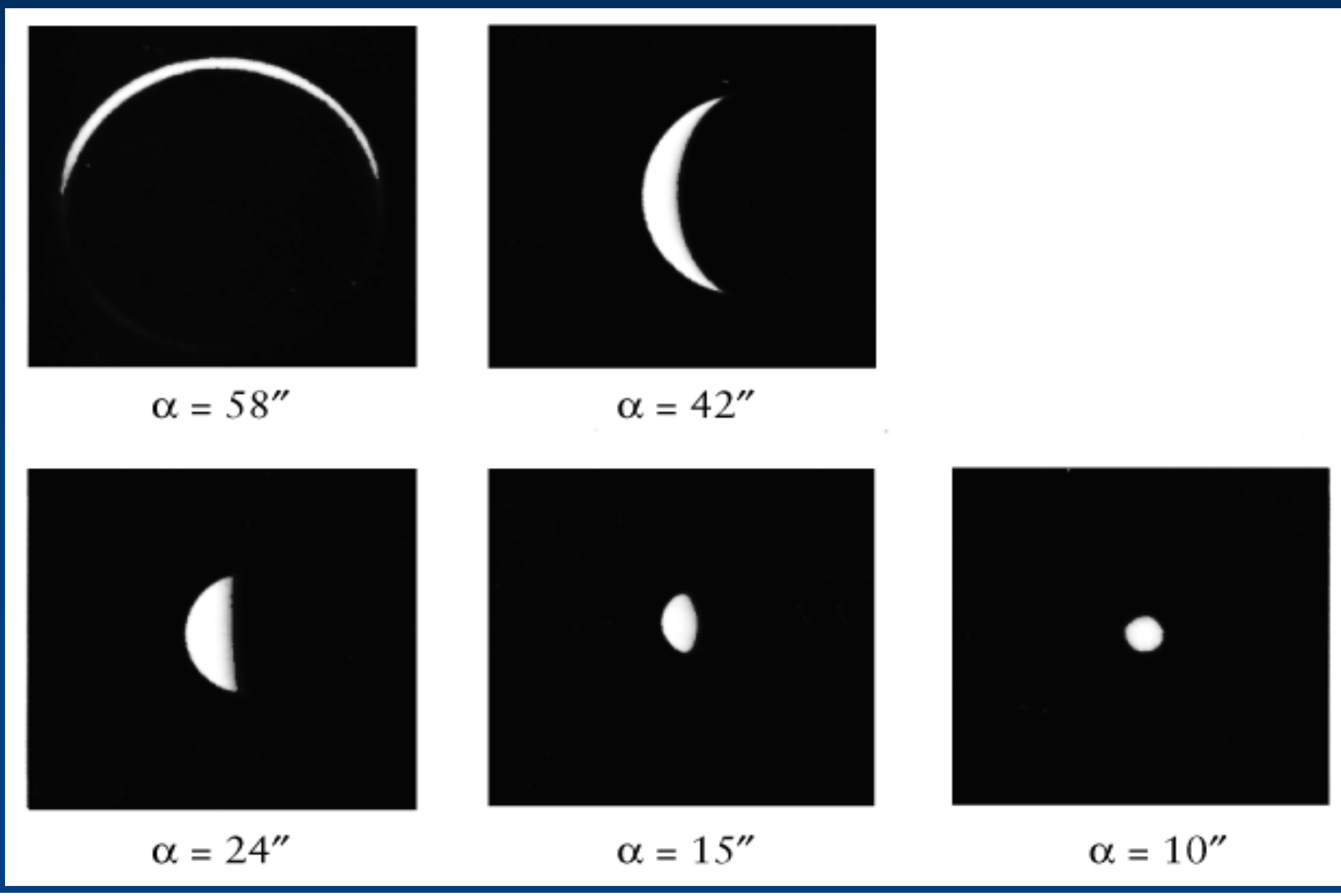
Q: which planets can be at inferior conjunction?

At ***superior conjunction***, the inferior planet is on the opposite side of the Sun.



Galileo's other observations:

Venus goes through phases, and the angular size changes (these are related. The Ptolemaic model can't explain this.)



Newton's Second Law of Motion

When a force, F, acts on an object with a mass, m, it produces an acceleration, a, equal to the force divided by the mass.

$$a = \frac{F}{m}$$

or $F = ma$

acceleration is a change in velocity or a change in direction of velocity.

In equation form:

$$F = G\frac{m_1 m_2}{r^2}$$

where:

F = gravitational force between 2 objects,

m_1 = mass of first object,

m_2 = mass of second object,

r = distance between objects,

G = Newton's gravitational constant

= 6.67×10^{-11} Nm^2/kg^2

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- Orbits. Apogee, Perigee, Shapes: elliptical (includes circular – circular speed), parabolic, hyperbolic. Which are open, which are closed? Energies: zero, negative, positive. Escape velocity.
- Tides. What causes? Tidal force proportional to $1/r^3$ rather than $1/r^2$

Example: How fast do you need to throw a rock to get it into circular orbit?

For circular motion, the acceleration is the centripetal acceleration:

$$a_{centripetal} = \frac{V_{circular}^{\;2}}{r}$$

So

$$F_{gravity} = m a_{centripetal}$$

$$\frac{G M_{Earth} m_{rock}}{r^2} = m_{rock} \frac{V_{circular}^{\;2}}{r}$$

Canceling m_{rock} and one factor of 1/r,

$$\frac{GM_{Earth}}{r} = V_{circular}{}^{2}$$

or

$$V_{circular} = \sqrt{\frac{GM_{Earth}}{r}}$$

This circular speed is the magnitude of the injection velocity, perpendicular to direction to center of Earth, needed for a circular orbit at distance r from the Earth.

- Kinetic and Potential energy
- Conservation of energy
- Scaling relations (how things go)

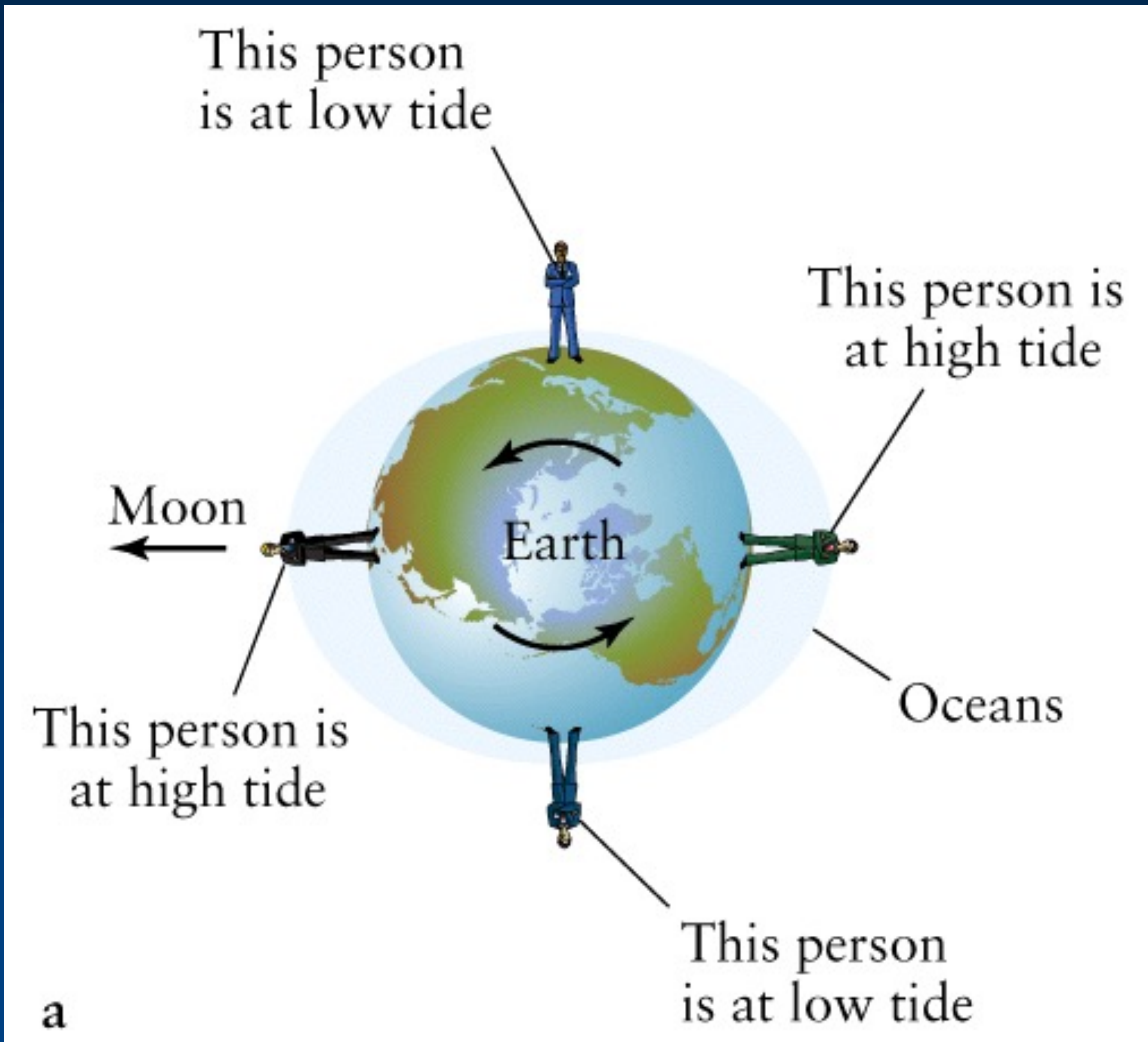
Escape Velocity

Velocity needed to completely escape the gravity of a planet.
The stronger the gravity, the higher the escape velocity.
Examples:

Earth	11.2 km/s
Jupiter	60 km/s
Deimos (moon of Mars)	7 m/s = 15 miles/hour

Consider Helium Gas at room temperature (300 K)
$E = kT = 4.1 \times 10^{-14}$ erg
$E = 0.5\ m\ v^2 = 4.1 \times 10^{-14}$ erg
so v = 1 km/sec on average, but sometimes more

As the Earth rotates underneath the oceans, any particular place gets alternating low- and high tides.



Quantitative example: Why is tidal force on Earth from Moon more important than from Sun?

Tidal force on Earth by Sun:

$$\Delta F_{Earth-Sun} = 2GM_E M_S \frac{D_E}{r_{E-S}^{3}}$$

Similarly, tidal force on Earth by the Moon:

$$\Delta F_{Earth-Moon} = 2GM_E M_M \frac{D_E}{r_{E-M}^{3}}$$

- Wavelength and Frequency of a Photon
- Electromagnetic Spectrum
- Kirchoff’s Laws
- Planck’s Law, Wien’s Law, Stefan-Boltzmann’s Law

Blackbody characteristics review

- Wien's Law: $\lambda_{max} = 0.0029/T$
- Stefan-Boltzmann's law $F = \sigma T^4$

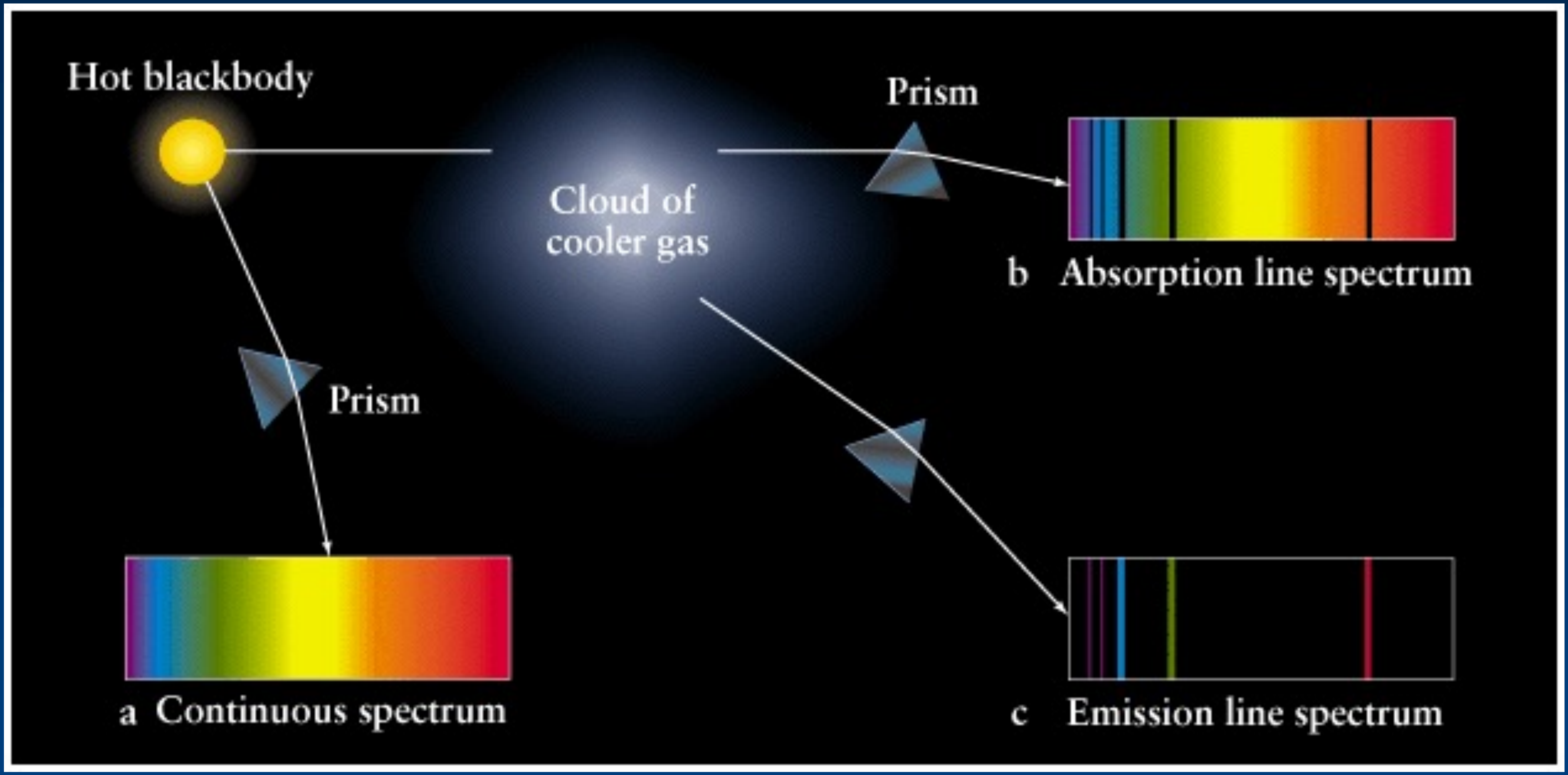
- The hotter the blackbody, the shorter the peak wavelength of the emission (bluer)

- The hotter the blackbody, the more radiation it gives off at all wavelengths.

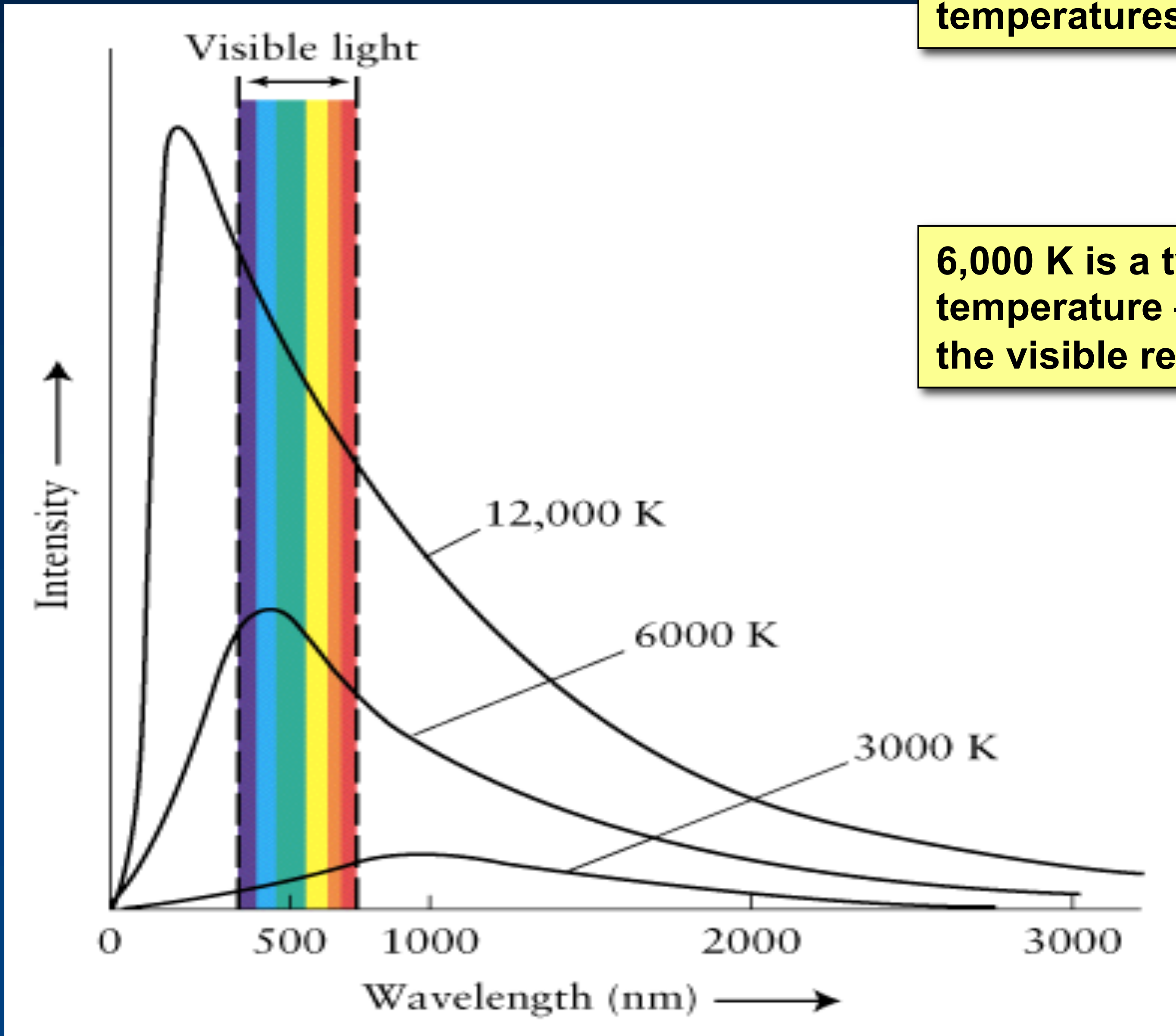
Emission and absorption line spectra

- Hot, low density gas where atoms are isolated will cause emission lines
  - Lines at specific wavelengths, dark between lines
- Light from continuous spectrum through cooler gas causes absorption lines
  - Dark regions corresponding to wavelengths of emission lines seen when the gas is hot, bright between lines

Kirchoff's Laws Illustrated

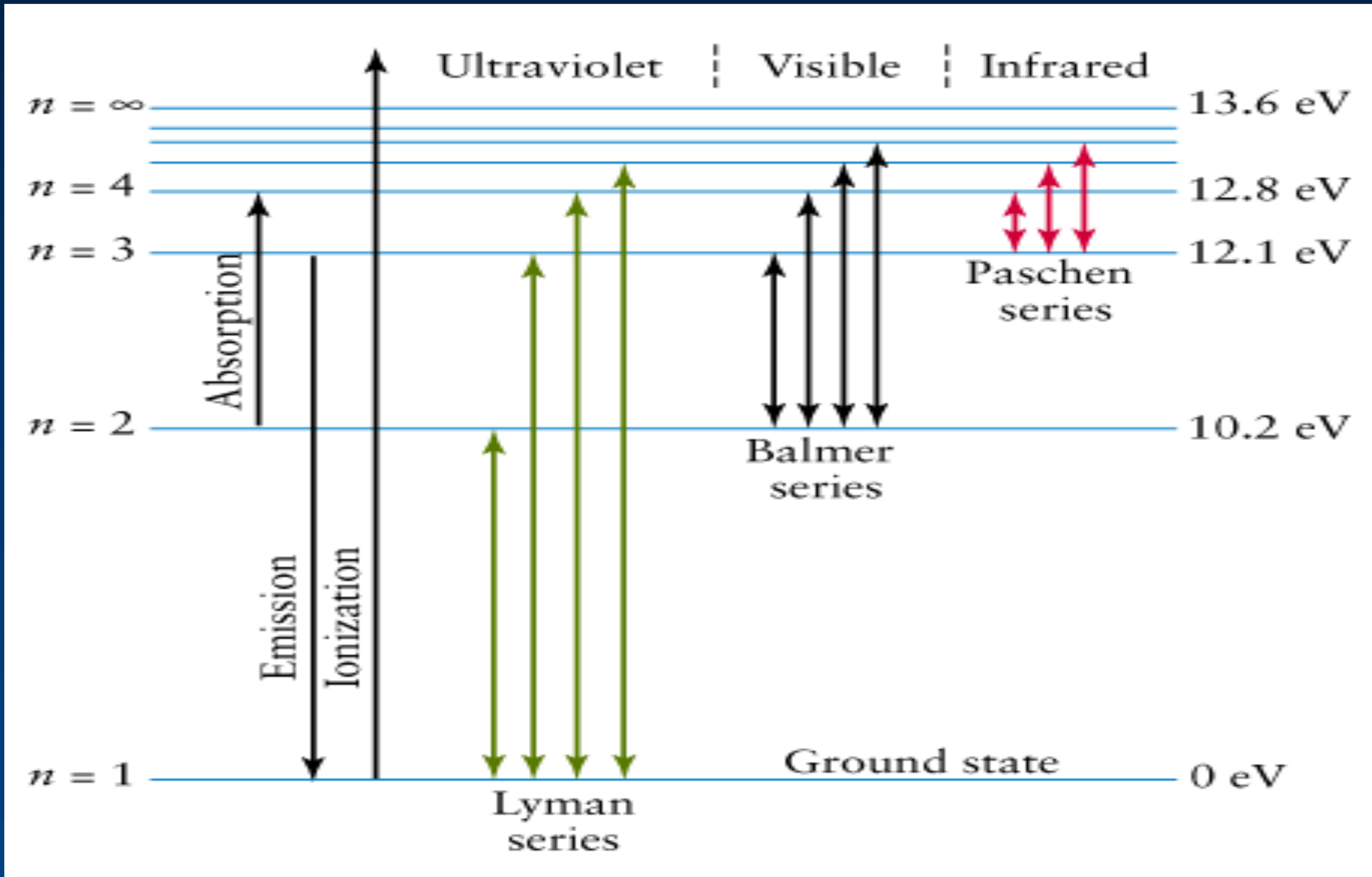


Example: 3 blackbody (Planck curves) for 3 different temperatures.



6,000 K is a typical stellar temperature – many stars peak in the visible regime.

Energy level diagram for hydrogen:



- Telescopes, Overview of Solar System, Terrestrial vs Jovian planets' characteristics, cosmic abundance, where in Solar System it's found, where it's not, why some planets have atmospheres and some don't.

$$V_{esc} = \sqrt{\frac{2GM}{r}}$$

$$\frac{1}{2}mV^2 = \frac{3}{2}\mathrm{kT} \quad \Rightarrow V = \sqrt{\frac{3kT}{m}}$$

- gas will be **retained** in the atmosphere if

$$V_{escape} > 6V$$

Gas will escape if $6V > V_{escape}$