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Problem 1

a) What's the significance of the first supernova Tycho Brahe observed? (1 pt)

The first supernova not only challenged the old belief that the "heavenly skies" were permanent, perfect and fixed, but it effectively disproved the geocentric model touted by Aristotle and Ptolemy.

b) Why didn't Tycho detect stellar parallax? (1 pt)

Stellar Parallax is defined as the apparent displacement of a nearby star as seen from an observer on Earth. Tycho Brahe's existence was just before the first telescope was invented and used for celestial observation by Galileo Galilei. As a result of his observations of distant objects being done with the naked eye, his view was too far away for him to notice any parallax.

c) Why do we sometimes see Mars moving backward in the sky? (1 pt)

Mars is farther away from the sun than Earth, which means it moves slower, allowing Earth to catch up to its orbital position, and pass it. Once the Earth passes Mars, Mars appears to be moving backwards; however, it is actually just an illusion that is viewed when the position of Mars is observed with respect to nearby constellations over the time that Earth catches up to and passes the orbital position of Mars.

d) List at least 2 pieces of evidence ancient philosophers/astronomers used to support the Sun-centered model instead of the earth-centered model as we discussed in class. (2 pts)

[1] In relation to the previous question, the so-called "apparent retrograde" of Mars, or its apparent backward motion, is one of the concepts that imposed a challenge to the geocentric theory, favoring a heliocentric model where varying orbital planes could allow for such a perceived motion from Earth, developed by Coperncus.

[2] Using Tycho Brahe's observational data, Johannes Kepler found an 8 arcminute variance between the observed data and a theoretical model composed of orbits that exhibited perfect circular patterns. Instead of ignoring this small error, Kepler analyzed the data, and ultimately found that planets have elliptical orbital patterns with respect to the sun.

[3] Galileo's observations with a skyward facing telescope allowed him to explore various features of the nearby universe with a much better resolution. This included the rings of Saturn, Jupiter's moons and the characteristics of the phases of Venus that can only be explained if it orbits the Sun not Earth. Through his observations with a better viewing resolution, the concept of Stellar Parallax was observed. These observations favored a heliocentric model that would support stellar parallax, as the observable position of stars would change as the Earth's orbital position around the sun changed.

Problem 2 (3 pts) A planet is orbiting a star of 1 solar mass with an orbital period of 60 months. What is the semimajor axis of the planet's orbit?

Using Kepler's Third Law (Newton's Two-Body Problem can also be applied, more specifically if the star has a mass that is not equal to 1 solar mass): $p^2=a^3$ where p = orbital period in years and a = the semimajor axis in AU (1 AU = 1.5E8 km)

p = 60/12 = 5 years

Solve for a:

a = $p^{2/3}$ = $(5)^{2/3}$ = 2.92 AU or 438E6 km

Problem 3 (6 pts) NASA's OSIRIS-REx mission is the first US mission to retrieve a sample from an asteroid (Bennu, mass 7.8e10 kg, radius 250 m) and return it to Earth. OSIRIS-REx was launched in 2016, arrived at Bennu in 2018, and touched down on the asteroid on Oct. 20, 2020. Before the touchdown, OSIRIS-Rex was orbiting the asteroid at a height of 2.0 km above the surface of the asteroid. What was the orbital speed of the spacecraft in m/s? You can assume the asteroid is spherical and the orbit is perfectly circular. (Feel free to review the lecture slides/notes where we derived the expression for orbital speed.)

Using the concept of centripetal force, orbital speed can be obtained.

F_c = $(mv^2)/r$

Gravitational Force:

F_G = $(GMm)/(r^2)$

G = 6.67E-11 $m^3/kg*s^2$

To solve for orbital speed:

v = sqrt([GM]/r) when m <<<<<<<<< M
v = sqrt([(6.67E-11)(7.8E10)]/(2000+250))
v = 0.048 m/s

Problem 4 (8 pts) In class we discussed how to use conservation of energy to figure out escape speed, the initial speed needed for a "satellite" object to escape (i.e. speed reduces to 0 when it reaches infinity). Recall that the total orbital energy is the sum of kinetic energy (mv2 /2) and gravitational potential energy (−GMm/r).

Now, let's use the same method to figure out the "impact speed". Imagine a meteorite heading towards Mars. If the meteorite's speed is 0 when it's infinitely far away from Mars, what would its speed be when it hits the surface of Mars?

You can think of it as the reverse of the "escape problem" discussed in class. List the initial kinetic energy and potential energy at infinity, as well as the final kinetic energy and potential energy at impact. And you might want to look up the radius and mass of Mars.

At infinity, v = 0 m/s (Escape velocity has been reached), so Kinetic Energy (KE) = $(mv^2)/2 = 0$
At infinity, r = infinity, so Gravitational Potential Energy (U_G) = -(GMm)/r = 0

Conservation of energy can be used to represent the meteorite from infinity to the surface of Mars.

$E_f - E_i = 0$
If $E_i = 0$ (At infinity) and $E_f = (mv^2)/2 - (GMm)/r$ (Sum of KE and U)
Then $(mv^2)/2 - (GMm)/r = 0$, so $(mv^2)/2 = (GMm)/r$

The radius of Mars can be used as r, representing the radius at the moment of impact.
According to NASA, the volumetric mean radius of Mars = 3389.5 km
From that data, the mass of Mars (M) = 6.4169E23 kg

Since m is much smaller than M, it can be neglected.

By rearranging the equation to solve for v, we acquire the same equation that would be used to find the escape velocity, except a different radius is being used in this case.

v = sqrt([2GM]/r) = sqrt([2(6.67E-11)(6.4169E23)]/[3389.5E3]) = 5025.42 m/s

Problem 5 (4 pts) If the surface of Earth on average has a temperature of 15oC, what is the wavelength (in nm) at which its blackbody radiation intensity is the highest? Which portion of the electromagnetic spectrum is it (e.g. visible, radio, etc.)? Hint: Wien's law of blackbody radiation. Remember to convert the temperature into Kelvin.

A blackbody represent an idealized object:
—absorbs all photons that strike them;
—does not let light escape easily.

Using Wien's Law of Blackbody Radiation:

l_{max} = 2900000/(T [in Kelvin]) = 2900000/(15 + 273.15) = 10064.20 = 1.00642E4 nm

This places it in the infrared range based on its wavelength.

Problem 6 (2 pts) In class we discussed the fundamental angular resolution limit of telescopes due to the wave nature of light. If you were to make an observation in the mm wavelength range (say centered at wavelength λ = 1 mm) with a 10 m telescope, what is the best angular resolution you can reach (in arcmin)?

Angular Resolution (In Radians) = 1.22(λ/D) = 1.22(0.001/10) = 1.22E-4 rad

Angular Resolution (In Arcsec) = 2.5E5(λ/D) = 2.5E5(0.001/10) = 25 arcsec

If there are 60 arcseconds in 1 arcminute:

Angular Resolution (In Arcmin) = (1/60)*(25) = 0.4167 arcmin