The Cosmos

Planets & Life

PHYS 214

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Please start all class related emails with “214:”

Pop Quiz 4

- On lectures 16-20 (I'm not including the guest lecture)
- 10 minutes
- Solutions for assignment 2 are up the in solutions cabinet on the 3rd floor of Stirling

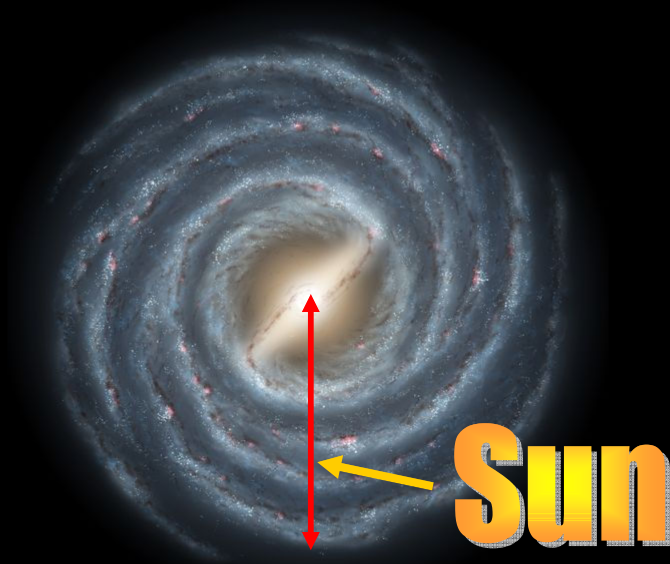
Week	Mon	Wed	Fri
1			
2			
3			
4			
5			
6			
7			
8			
9	Mid term review	Earth History (geological issues)	Rare Earth hypothesis
10	Mars (Book: 85)	Titan (Book: 171)	Icy bodies (Book: 127)
11	Broadcasts & ETI (Book 281)	Drake Equation in retrospective (Book: 199)	SETI I (Book: 281)
12	SETI II (Book: 281)	Kardyshev classification & Dyson spheres	Review

Today's Lecture

- Review of midterm short answer questions

(a)(i) 8 marks

- (a) (i) *Carefully* draw a diagram of the Milky Way galaxy and indicate approximately where the Sun lies. Explain the concept of a galactic habitable zone, what processes contribute to it, and use your diagram to help illustrate this idea.



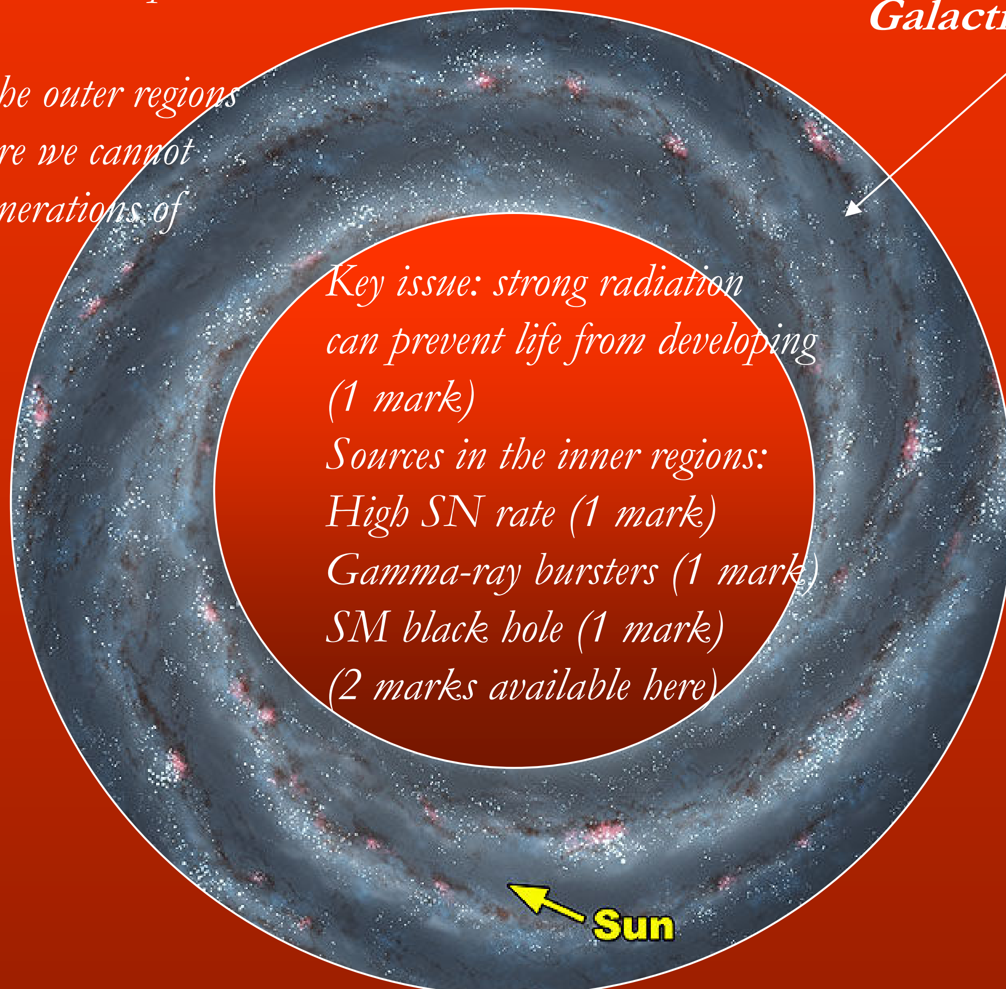
1 mark for spiral structure
1 mark for nucleus
1 mark for Sun positions (approx 2/3 of the way to the edge)

Key issue: need several generations of Stars to develop a high enough metallicity to form terrestrial planets. (1 mark)
Star formation in the outer regions is very slow, therefore we cannot have had enough generations of Stars. (1 mark)

Galactic Habitable Zone

(1 mark)

GHZ: A region in a galaxy in which conditions are favourable for the formation of life as we know it.



Key issue: strong radiation can prevent life from developing (1 mark)
Sources in the inner regions:
High SN rate (1 mark)
Gamma-ray bursters (1 mark)
SM black hole (1 mark)
(2 marks available here)

(a)(ii) 7 marks

- The hydrogen β line emission line of the quasar 3c273 is measured on the Earth at a wavelength of 565.7 nm, while it's wavelength when emitted, λ is 486.1 nm. Calculate the speed at which 3c273 is moving away from us. If Hubble's constant is 70 km s^{-1} Mpc^{-1} how far away is 3c273?
- Doppler shift equation $\Delta\lambda/\lambda=v/c$ where $\Delta\lambda=\lambda_{observed}-\lambda_{emitted}$, so $\Delta\lambda=565.7-486.1=79.6$ nm (1 mark)

  Calculate ratio: $\Delta\lambda/\lambda=79.6/486.1=0.163$ (1 mark), Rearrange to give $v= \Delta\lambda c/\lambda$ (1mark), $v=0.163*3.0*105$ km s^{-1}=49 000 km s^{-1} (1 mark)

Common errors: not calculating $\Delta\lambda$ properly or not taking the correct choice of λ

(a)(ii) cont

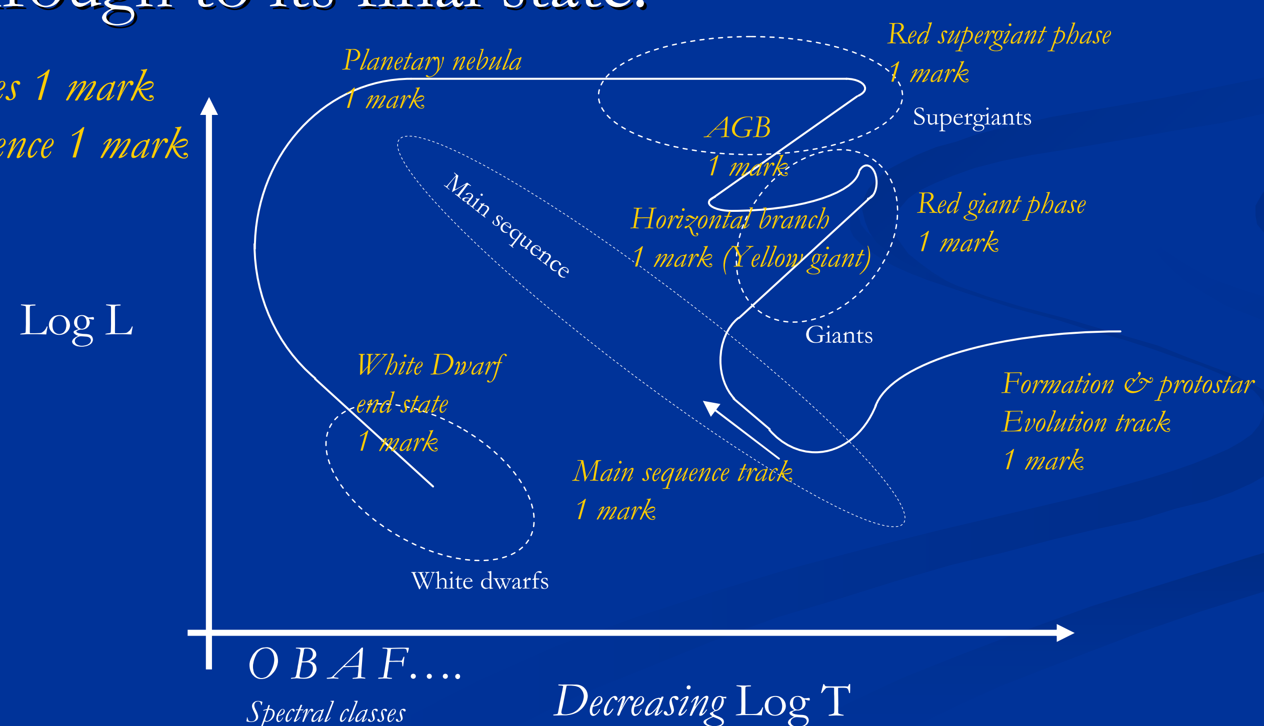
- Hubble's Law (not given on formula sheet)
  $v=H_0d$ (1 mark)
  rearrange for d: $d=v/H_0$ (1 mark)
  $d=49\ 000/70=702$ Mpc (1 mark)

Most common error: not remembering Hubble's Law

(b)(i) 8 marks

- Using the Hertzsprung-Russell diagram of temperature versus luminosity, explain the evolutionary stages of a star like the Sun. Ensure you discuss its formation through to its final state.

Correct axes 1 mark
Main sequence 1 mark

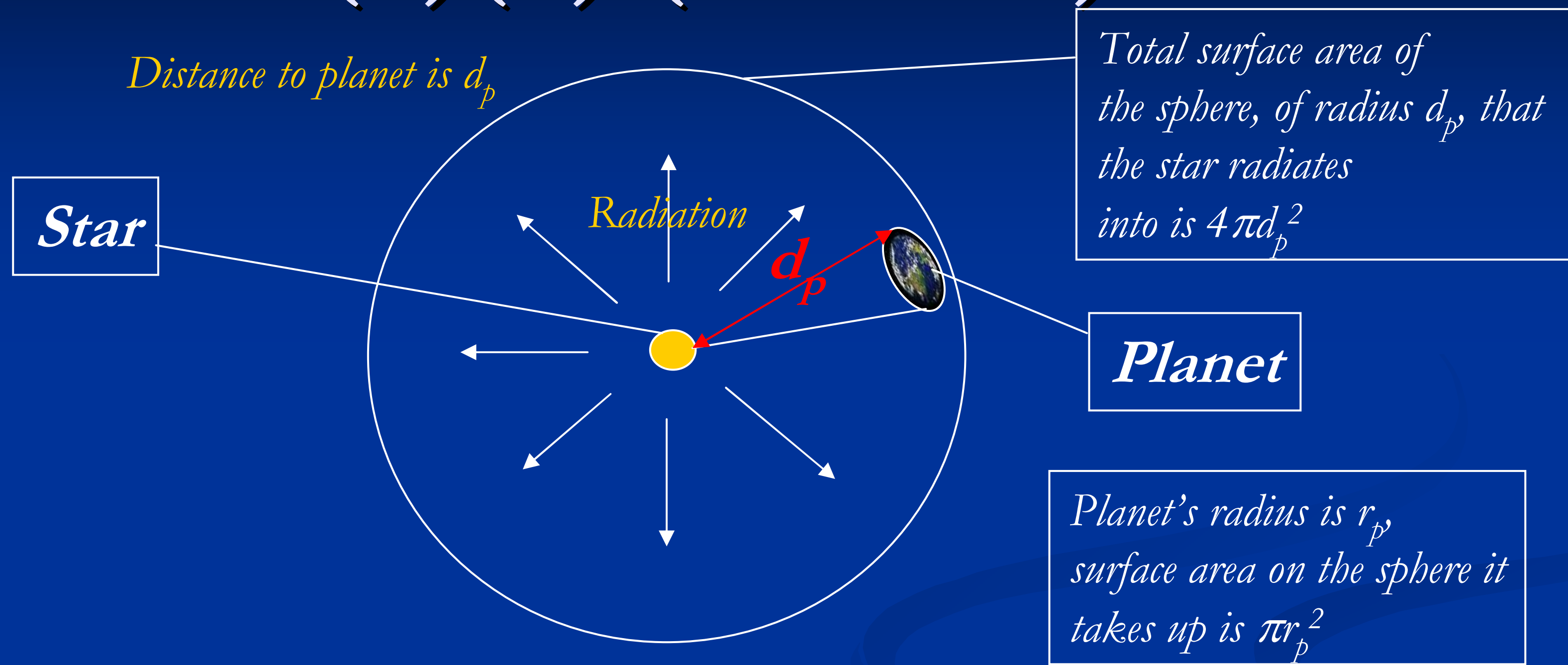


Marks also given for labelling various parts of the HR diagram.
Marks also available for mentioning which fuel is burnt at a given stage (e.g. H or He).

(b)(ii) (7 marks)

- Suppose a planet of radius r_p, and temperature T_p, orbits a star, of luminosity L^*, at a distance d_p. Write an equation for the fraction of the stars luminosity, L^* that arrives at the planets surface. If the albedo is represented by *a*, write down the total amount of radiation arriving at the planet. Equate this to the luminosity of the planet to derive the equation behind the radiation balance model.

(b)(ii) (7 marks)



- Fraction of radiation arriving: To get this we just divide the area of the planet, by the total area of the sphere, and multiply by the stars luminosity (2 marks)

$$\text{fraction of luminosity} = L^* \times \frac{\pi r_p^2}{4\pi d_p^2} = L^* \times \frac{r_p^2}{4 d_p^2}$$

(b)(ii) (7 marks)

- Fraction arriving at planet after albedo (1 mark)

$$\text{fraction of luminosity} = L^* \frac{r_p^2}{4d_p^2}(1-a)$$

- Luminosity of planet (2 marks)

$$L_p = 4\pi r_p{}^2 \sigma T^4$$

- Equate (1 mark)

$$4\pi \mathrm{r_p}{}^2 \sigma T^4 = L^* \frac{r_p^2}{4d_p^2}(1-a)$$

(b)(ii) (7 marks)

- Simplify by cancelling like factors & rearrange (1 mark)

$$16\pi\sigma T^4 = \frac{L^*}{d_p^2}(1-a)$$

(c)(i) (9 marks)

- Explain the key features of the solar nebula theory: where does the material in the solar nebula come from, what does it explain in relation to the structure of the solar system. Ensure you mention differentiation and how it affects the formation of planets.

(c)(i) (9 marks)

- 1 mark is available for each of the following
  - Material comes from the interstellar medium which is enriched with heavy elements from previous SN events
  - Cloud collapses under mutual gravitation and under conservation of angular momentum it speeds up its rotation
  - Centrifugal forces prevent material in the equatorial plane from falling in and a disk is formed
  - Radiation from the protostar keeps the interior regions of the disk hotter than the outer regions
  - In the interior only materials with a high melting point such as silicates and metals can condense to form solids
  - At larger distances ices (both water and ammonia) can condense due to the lower temperatures

Differentiation of the Solar system

(c)(i) (9 marks)

  - Formation of planets begins from dust grains which merge to form ever larger systems and so on (up to plantesimals)
  - Planets form in “disks within disks” and gain satellites in this process
  - Planetary differentiation means that they should have rocky cores with volatile gases being outgassed
  - Protostars T-Tauri phase blows out remaining gas as star begins nuclear burning
- What does the theory explain:
  - Why planets orbit in a plane around the Sun
  - Also why planets tend rotate in the plane of the solar system
  - Differentiation ensures rocky planets are found in the inner regions while outer planets are gas giants
  - Asteriod belt is left over planetesimals
  - Expect icy bodies in the outer solar system
  - Can also have mentioned how exceptions are explained within the theory

(c)(ii) (6 marks)

- A protostellar nebula has a mass of 3 solar masses and a diameter of 0.30 light years. What is the density of this nebula in g cm^{-3}? If the nebula rotate once every two million years what is the speed of the outer edge of the nebula in km s^{-1}?

Volume of sphere $= 4\pi r^3/3$ *(not given on formula sheet)*

$r=D/2=0.15\ ly=0.15*63240*1.5*10^{11}*100\ cm=1.42*10^{17}\ cm$ *(1 mark)*

$V=4 * 3.141 * (1.42*10^{17})^3 = 1.21*10^{52}\ cm$ *(1 mark)*

Density=mass/volume so find mass in g

$m=3*1.99*10^{30}*1000\ g = 5.97*10^{33}\ g$

Density $= m/V = 5.97*10^{33}/1.21*10^{52}\ g\ cm^{-3} = 4.95*10^{-19}\ g\ cm^{-3}$ *(1 mark)*

Common errors: not remembering what density is, or volume of sphere

(c)(ii) (6 marks)

- For the speed of the outer edge (two possible ways to do this, I'll use the simple one, see solutions to assignment 2 for alternative)

Circumference $= 2\pi r = \pi D$

$\pi D = 3.141*0.3*63240*1.5*10^{11} / 1000\ km = 8.94*10^{12}\ km$ *(1 mark)*

Period in seconds, T

$T = 2*10^6\ yr = 2*10^6*365*86400 = 6.31*10^{13}\ s$ *(1 mark)*

Speed $= \pi D/T = 8.94*1012\ /\ 6.31*10^{13}\ km\ s\text{-}1 = 0.14\ km\ s^{-1}$ *(1 mark)*

Alternative solutions where $v=\omega r$ *is used are also acceptable.*

(d)(i) (9 marks)

- The greenhouse effect may well be necessary for life to develop on the Earth. Explain the mechanism behind the greenhouse effect. Be sure to mention the underlying key physical concepts (such as the parts of the electromagnetic spectrum that are relevant), the gases which do and don't contribute, and also the net flow of energy in and out of the planet.

(d)(i) (9 marks)

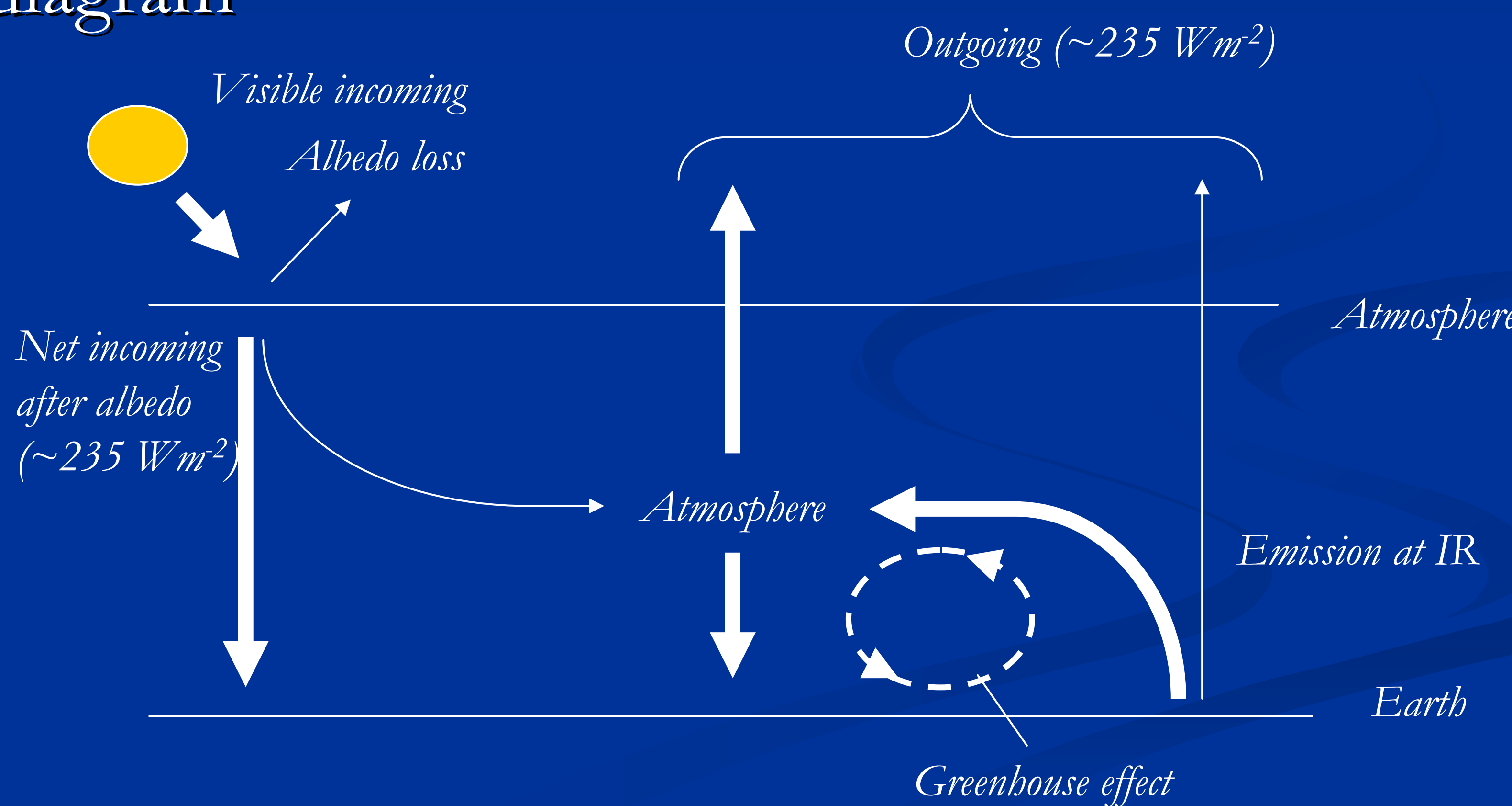
- Again 1 mark for any of the following factors in the greenhouse effect
  - Incoming radiation is largely at *visible wavelengths* (peak of Sun's emission from Wien's Law) which is transmitted *well* by the atmosphere
  - Black-body temperature of the Earth corresponds to *infrared wavelength* which are *strongly absorbed* and effectively reflected by the greenhouse gases in the atmosphere
  - H_2O and CO_2 are the dominant ghg's although CH_4 and O_3 also play smaller roles along with more exotic man made molecules
  - N_2 and O_2 are not ghg's which is important since they make up the bulk of the atmosphere
  - Overall the system is in equilibrium with the net emission from the Earth balancing the net incoming radiation, which includes contributions from both the atmosphere and the Sun (after albedo)

(d)(i) (9 marks)

- In terms of the mechanism, 1 mark is available for (some of these are slight repeats)
  - Incoming radiation reaching the Earth's atmosphere is partial reflected (albedo)
  - A small fraction goes into direct heating of the atmosphere itself rather than the planet
  - Remainder reaches Earth's surface and heats it up
  - Earth reradiates at infrared wavelengths which is strongly absorbed and reradiated back towards the Earth
  - A small fraction of the IR emission from the Earth goes directly into space
  - When the atmosphere radiates some of this radiation goes directly out into space and balances the incoming net solar radiation after albedo losses
  - Earth's temperature is thus maintained above the expected value from the incoming radiation by the Sun combined with the atmosphere
  - Between 35-40 K overall temperature rise

(d)(i) (9 marks)

- Or you could have drawn the energy flow diagram



(d)(ii) (6 marks)

- The star Rigel shows a parallax angle of 4 milli arc seconds. Calculate the distance to Rigel in parsecs. If the diameter of Rigel is 0.56 AU, calculate the angular size of its disc on the sky in arc seconds using the distance you estimated from the parallax measurement.

  Parallax of Rigel $= 4$ *mas* $= 4 * 10^{-3}$ *arcseconds* *(1 mark)*

  $d=1/p=1/4*10^{-3}$ *pc* $=250$ *pc* *(1 mark)*

  To use small angle formula need to convert units to be the same. In this case we consider converting 250 pc to AU (but you can do it the other way)

  250 *pc* $= 250 * 3.26 * 63240 = 51.5 * 10^{6}$ *AU* *(1 mark)*

  $\Theta=D/d=0.56/51.5*106 = 1.09 * 10^{-8}$ *rad* *(1 mark)*

  Convert to milli arc seconds

  $1.09*10^{-8} * 60 * 60 *360 / (2\pi) = 2.2 * 10^{-3}$ *arc seconds* $= 2.2$ *milli arc seconds* *(2 marks)*

  Common errors: not using parallax formula

Next lecture

- History of Earth
  - Early formation issues
  - Water
  - Plate tectonics