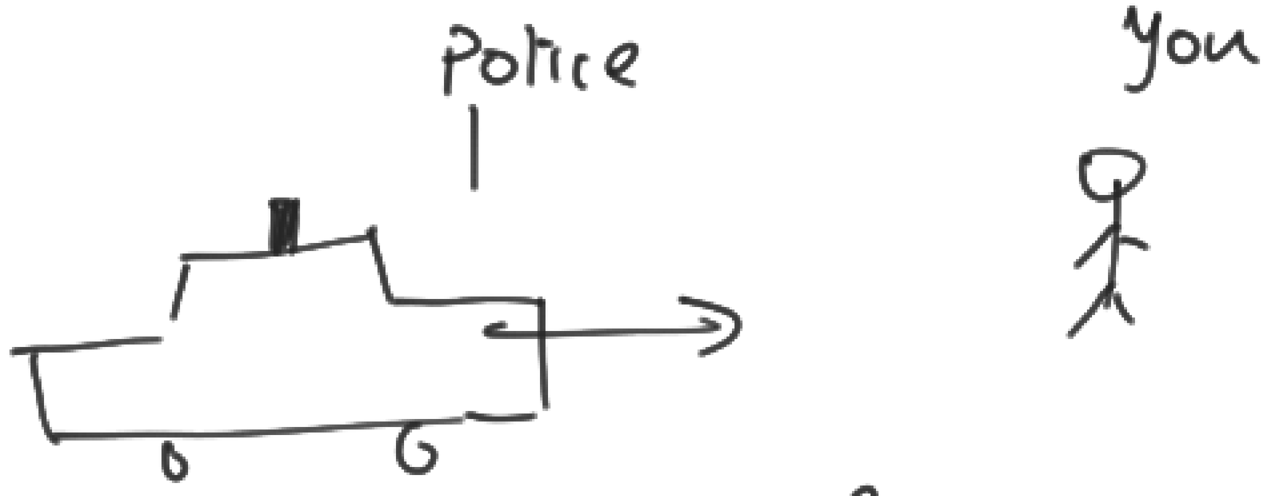
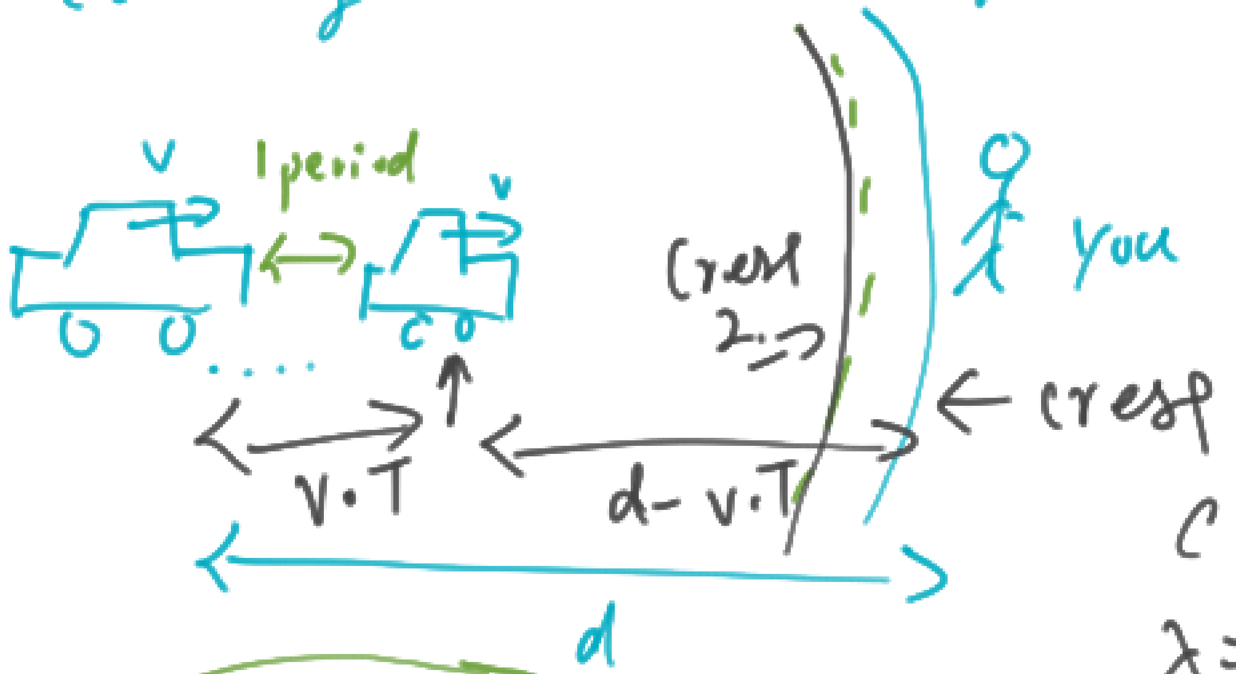
Cosmology

Doppler effect



Siren has frequency f

Coming towards you



$c = f\lambda$

$\lambda = \frac{c}{f} = cT$

New wave length:

$$\lambda' = \lambda_s - V_s T_s$$

$$c\,T_{obs} = c\,T_s - v_s T_s$$

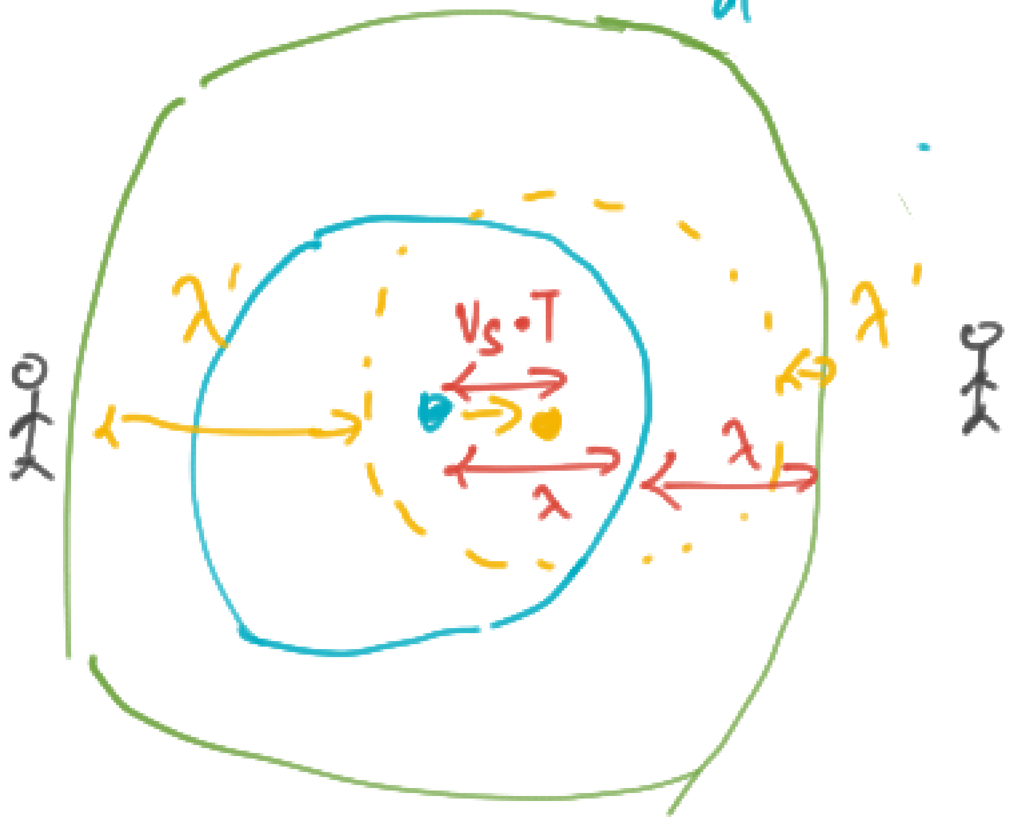
$$\frac{c}{f_{obs}} = \frac{c}{f_s} - \frac{v_s}{f_s}$$

$$\frac{c}{f_{obs}} = \frac{c - v_s}{f_s}$$

$$f_{obs} = \frac{c}{c - v_s} f_s$$

here $v_s > 0$ when moving towards the observer.

generally, $f_{obs} > f_s$ if the object moves towards the observer.

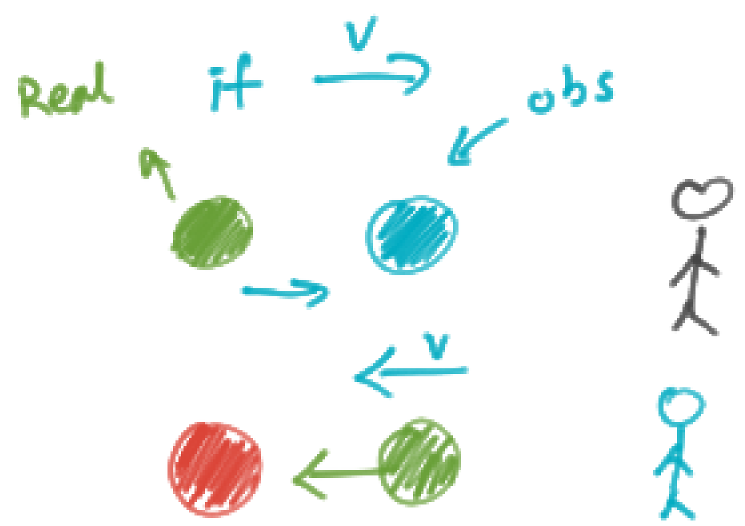


Δt_1 for crest 1 to reach u:

$$\Delta t_1 = \frac{d}{c}$$

Δt_2 for crest 2 to reach you

$$\Delta t_2 = \frac{d - vT}{c}$$



Cont.

$$\lambda = \frac{c}{f}$$

$$\frac{c}{f_{obs}} = \frac{c - v_s}{f_s}$$

$$\lambda_{obs}' = \frac{c}{f_s} - \frac{v_s}{f_s}$$

$$\lambda_{obs}' = \lambda_s - \frac{c_s}{f_s} \cdot \frac{v_s}{c}$$

$$\lambda_{obs} = \lambda_s - \frac{v_s}{c} \lambda_s$$

$$\lambda_{obs} = \lambda_s \left(1 - \frac{v_s}{c}\right)$$

$$\Delta\lambda = -\frac{v_s}{c}\lambda_s = \lambda_{obs} - \lambda_s$$

$$\frac{\Delta\lambda}{\lambda_s} = -\frac{v_s}{c}$$

$$z = \frac{v}{c}$$

again if V_s moving away, $\Delta\lambda$ should be positive.
(Red shift)

Moving towards observer, $\Delta\lambda < 0$.
(Blue Shift)

Assumption : $V << c$ since relativistic effects are ignored.

Optional

Relativistic case $v \sim c$

Time between successive event emitted: (in lab frame)

$$\Delta\tau' = \gamma \underbrace{\Delta\tau_0}_{\text{Rest frame of rocket.}}$$

distance covered by spaceship.

$$\Delta S = v\Delta\tau' = \beta c \gamma \Delta\tau_0 \qquad \gamma = \frac{1}{\sqrt{1-\beta^2}}$$

$$T' = \frac{S - \Delta S}{c}$$

$$T' = \gamma\Delta\tau_0 - \beta\gamma\Delta\tau_0$$

$$T' = \gamma\Delta\tau_0(1-\beta)$$

$$f' = \frac{1}{T'} = \frac{1}{\gamma}(1-\beta)^{-1}\frac{1}{\Delta\tau_0}$$

$$f' = f_0\sqrt{(1+\beta)(1-\beta)}\frac{1}{1-\beta}$$

$$f' = f_0\sqrt{\frac{1+\beta}{1-\beta}}$$

$\beta > 0$ if moving towards observer.

Q3. The red shift of a galaxy's spectrum can be used to determine its velocity, relative to the Earth.

(a) The wavelength of the hydrogen alpha line in the spectrum of the galaxy NGC 1357 is 660.86 nm. The wavelength of the same line from a laboratory based source is 656.28 nm. Calculate the velocity of galaxy NGC 1357.

$$\frac{\Delta\lambda}{\lambda} = -\frac{V_s}{c}$$

$$\frac{4.58}{656.28} = -\frac{V_s}{c}$$

$$V_s = -2090 \text{ kms}^{-1}$$

(2)

Treated as a single source, the Andromeda galaxy has an apparent magnitude of 3.54 and an absolute magnitude of –20.62.

(a) Calculate the distance to the Andromeda galaxy.

$m - M = 5 \log \frac{d}{10}$

$5 \log \frac{d}{10} = 24{,}16$

$\log \frac{d}{10} = 4{,}832$

$d = 6{,}79 \cdot 10^{5}\ pc$

(2)

(b) The Andromeda galaxy is believed to be approaching the Milky Way at a speed of $105\ km\ s^{-1}$.

Calculate the wavelength of the radio waves produced by atomic hydrogen which would be detected from a source approaching the observer at a speed of $105\ km\ s^{-1}$.

wavelength of atomic hydrogen measured in a laboratory = 0.21121 m.

$\frac{\Delta\lambda}{\lambda} = -\frac{v_s}{c}$ $\quad v_s = +105 \cdot 10^{3}$

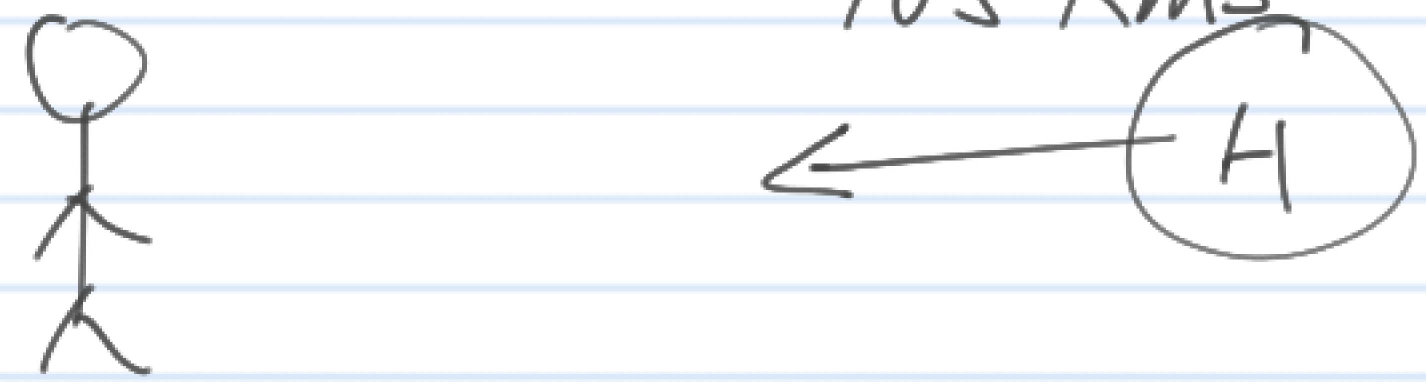
$\frac{\Delta\lambda}{\lambda} = -3{,}5 \cdot 10^{-4}$

$\Delta\lambda = -7{,}39 \cdot 10^{-5}\ m$

$\lambda' = \lambda + \Delta\lambda = 0{,}21114\ m$

(2)

$105\ kms^{-1}$



(c) Some astronomers believe the Andromeda galaxy may collide with the Milky Way in the distant future. Estimate a time, in s, which will elapse before a possible impact with the Milky Way.

$s = vt$

$\Delta t = \frac{d \cdot 3{,}08 \cdot 10^{16}}{v}$

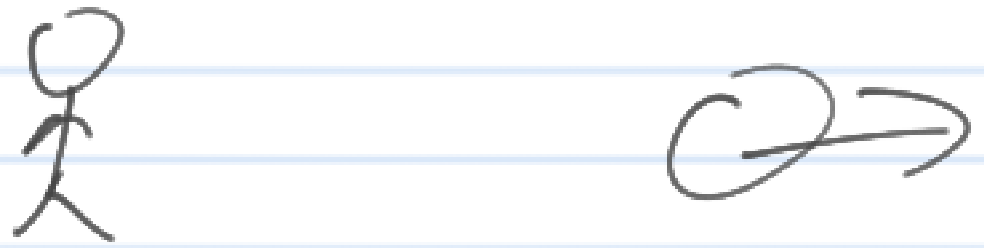
$= 1{,}99 \cdot 10^{17}\ \cancel{kms^{-1}}\ s$

(2)

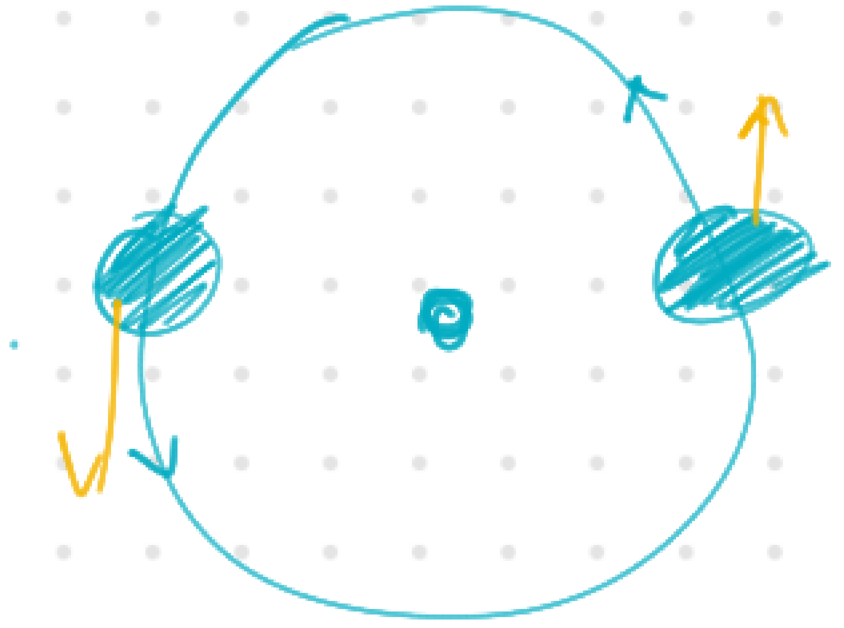
$v_s = -105\ kms^{-1}$

$\downarrow$

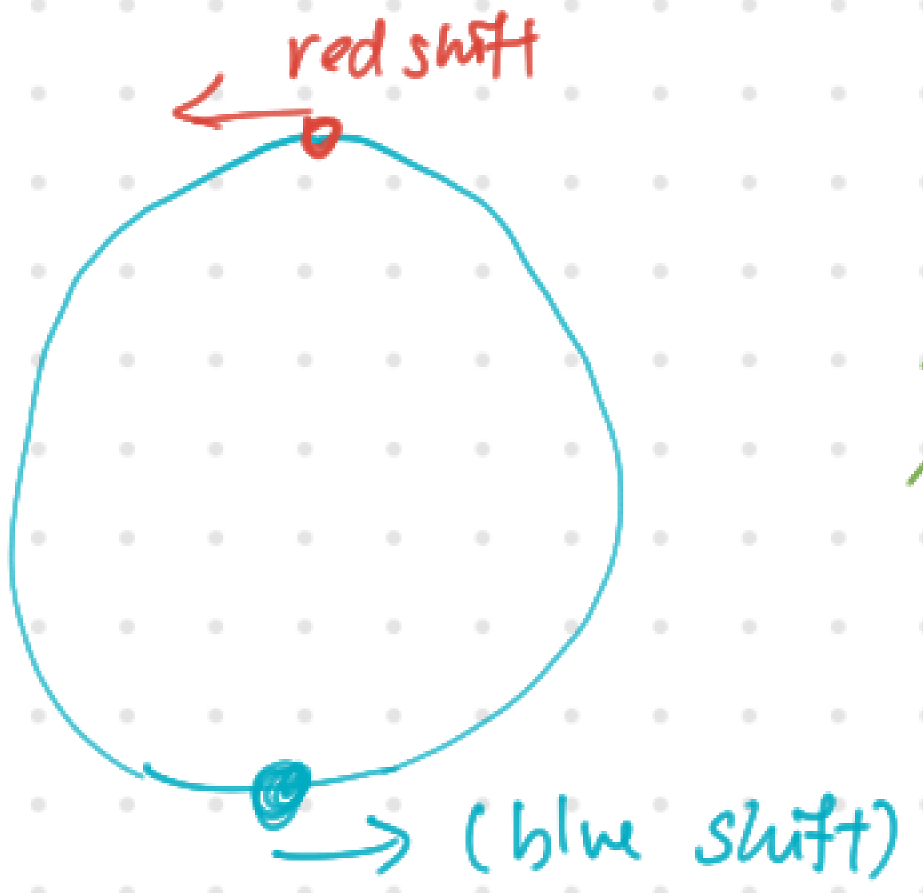
$-\frac{v_s}{c}$



Doppler → Binary stars.



$V_{//} = 0$ → no doppler.

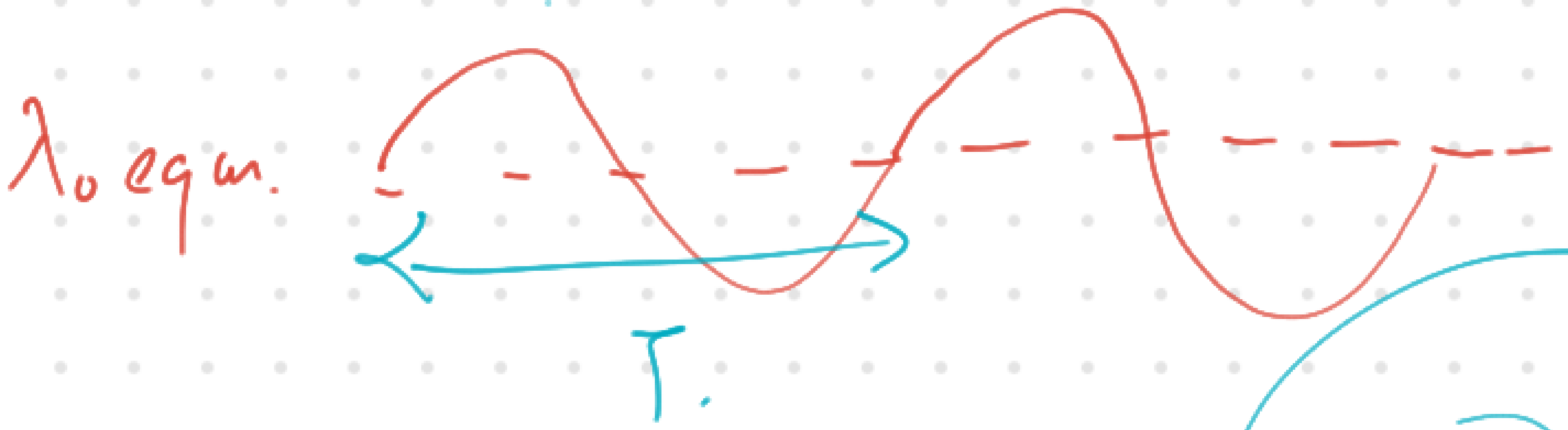


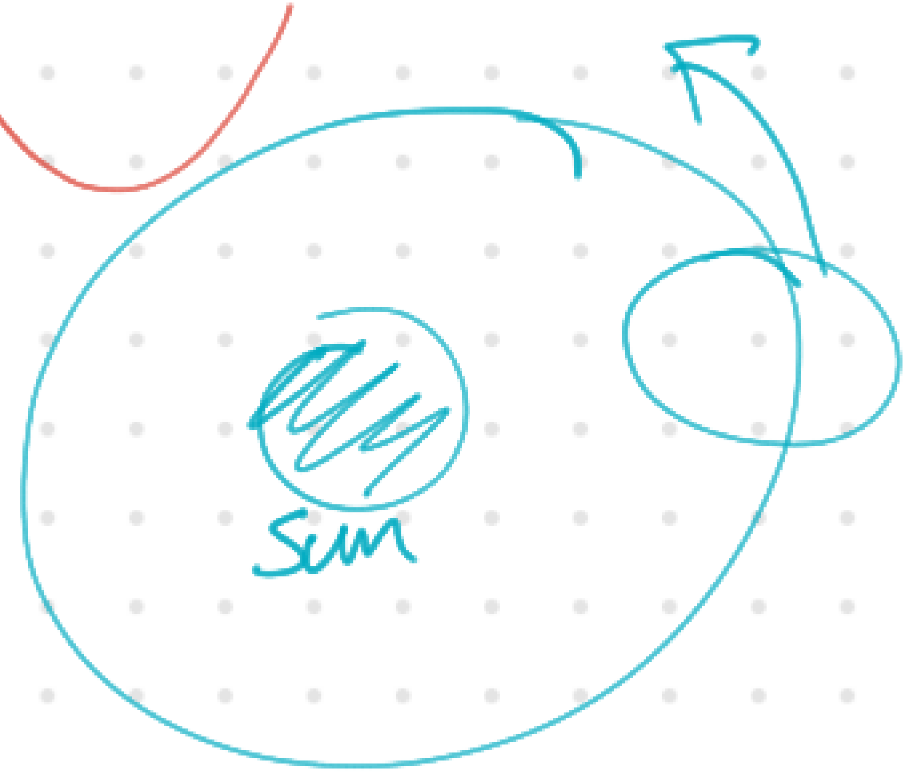
Time taken to turn from red shift to blue shift

$= \frac{1}{2}T$

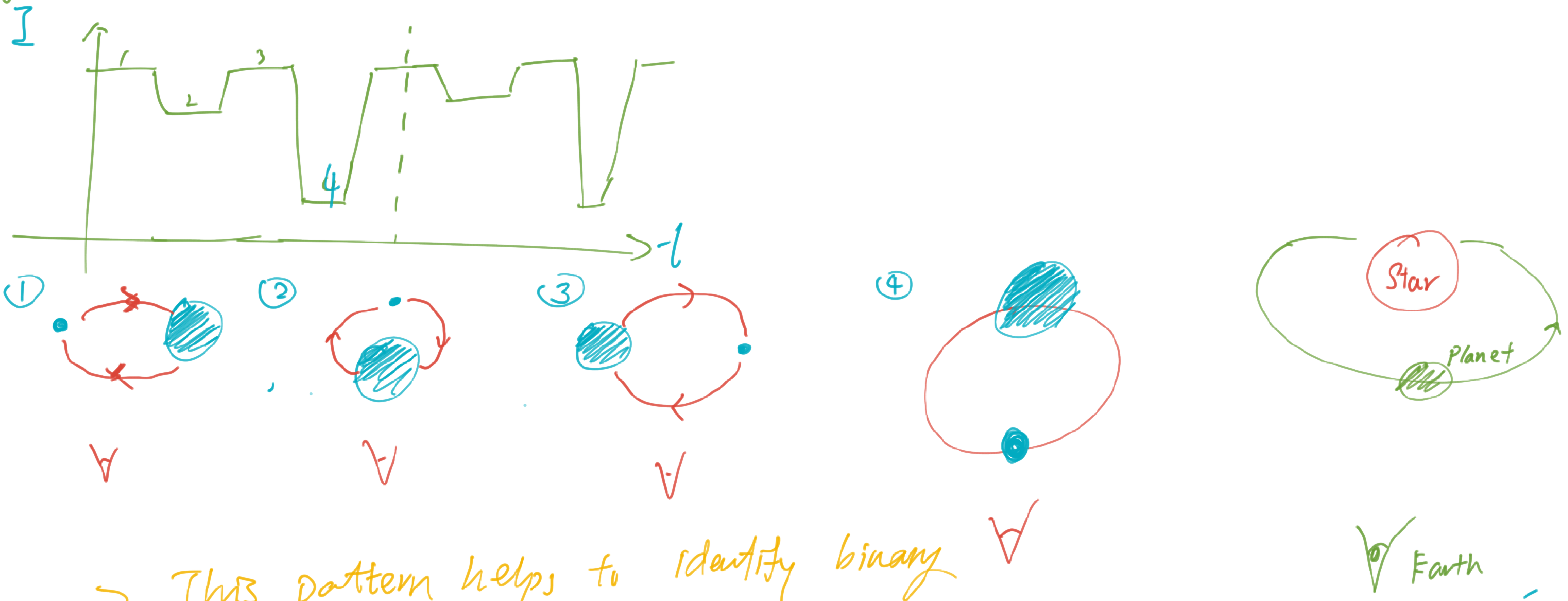
or time taken between 2 instances where $\Delta\lambda = 0$

$= \frac{1}{2}T$





light curve of binary stars



→ This pattern helps to identify binary stars.

→ Can we do the same for planets?
only if the planet is sufficiently large

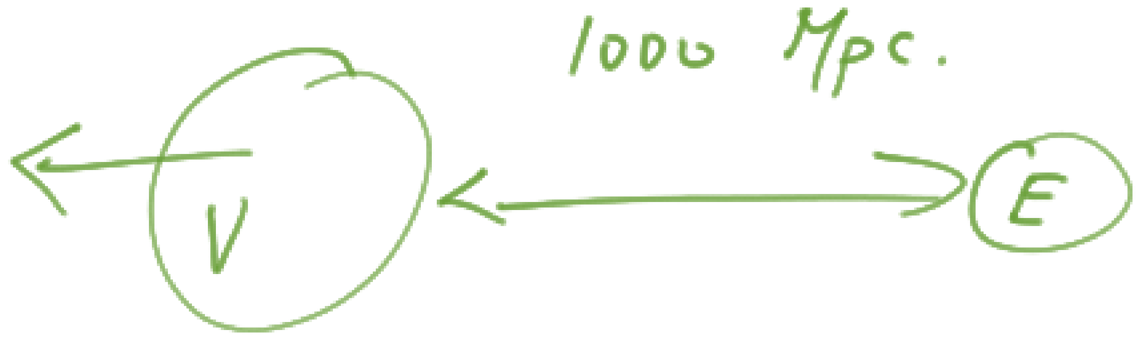
Hubble's law

$$V_r = Hd$$

$H = 65\ km\,s^{-1}\,Mpc^{-1}$ (H_0)

d = distance of planet from Earth (Mpc)

V_r is given in $km\,s^{-1}$



Estimate age of universe.

$$v = Hd$$

$$\frac{v}{d} = H$$

$$\frac{d}{v} = \frac{1}{H}$$

$$t = \frac{1}{H}$$

$$t = \frac{1}{65\ km s^{-1} Mpc^{-1}}$$

Convert to SI units (m)

According to NASA nearly 2000 exoplanets had been discovered by 2016, and the search continues. One aim of this search is to find an Earth-like planet orbiting a Sun-like star.

Discuss the difficulties associated with the detection of an Earth-like planet orbiting a Sun-like star.

In your answer you should compare the methods that are used in the search and suggest which may be the most successful.

6 marks

Quasars

Quasars — Supermassive blackholes that emit jets of radiation from objects falling into it.

Quasars:

- Extremely large red shift → very distant
- Very powerful light output (bright)
- Not much larger than a star.

To find power of quasar, we can observe the doppler shifts to find distance → inverse square law.

$$I_{received} = \frac{P}{4\pi r^2}.$$

Quasars are the most distant observable objects owing to their immense brightness
Quasars typically have the power output of hundreds of galaxies COMBINED

1. (a) Describe the links between galaxies, black holes and quasars.

____

____

____

____

____

____

(2)

(b) At a distance of 5.81×10^8 light year, Markarian-231 is the closest known quasar to the Earth. The red shift z of Markarian-231 is 0.0415

Use these data to estimate an age, in seconds, of the Universe.

Type 1a supernovae can be used as standard candles.

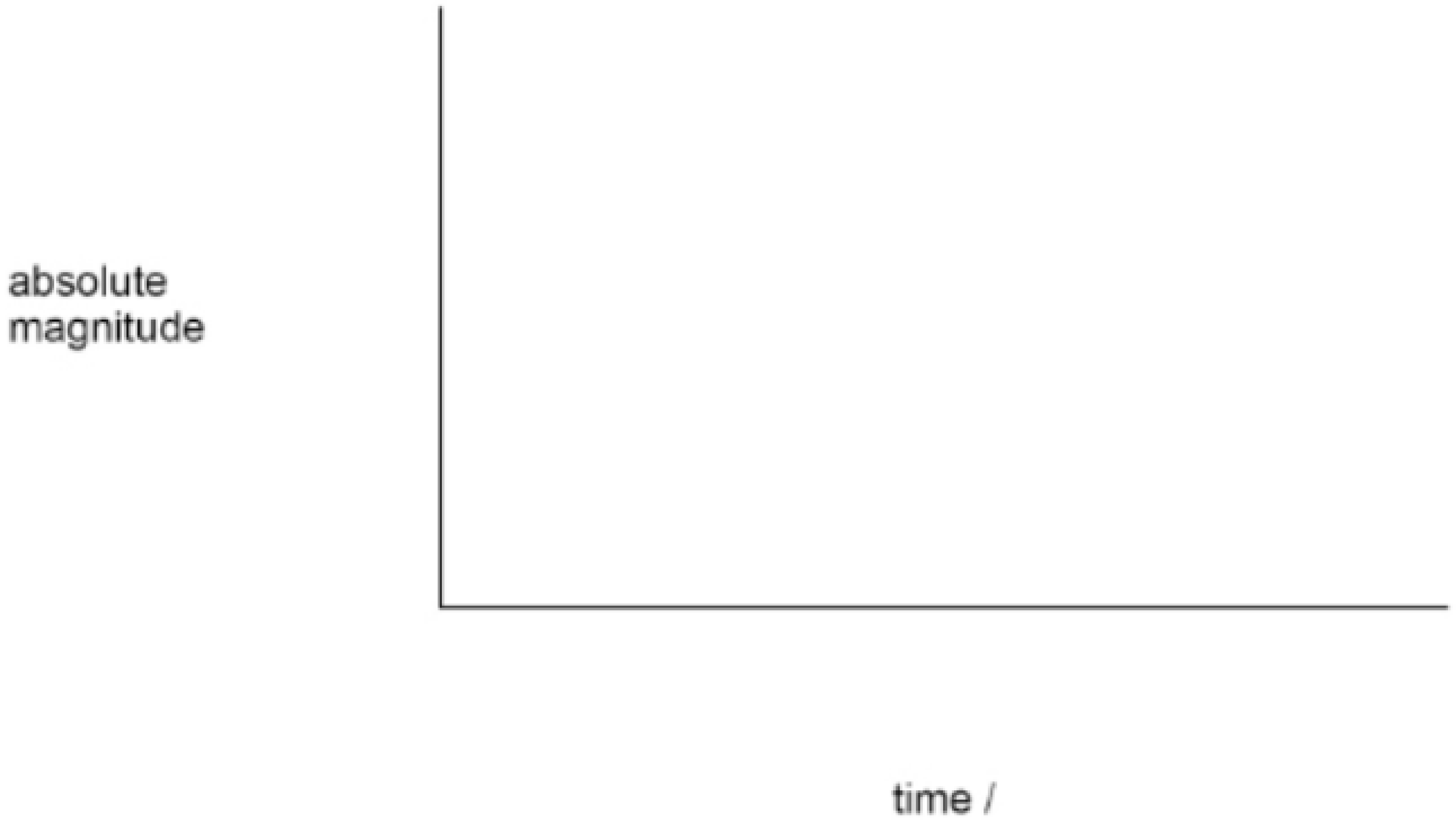
(a) State what is meant by a standard candle.

____

____

(1)

(b) Sketch on the axes below the light curve for a type 1a supernova.
Annotate your graph with suitable scales and a unit for time.



(3)

(c) Measurements of type 1a supernovae are used to find a value for the Hubble constant.

The distance from Earth is known for many type 1a supernovae.

Describe how these values of distance are used, with other data, to find the Hubble constant.

Your answer should include:

- the other data needed and how these data are used
- the graph plotted, including appropriate units for the axes
- how the Hubble constant is obtained and any limitations on the result.

(c) A typical quasar is believed to be approximately the size of the solar system, with a power output similar to that of a thousand galaxies.

Estimate, with reference to the inverse-square law, how much further the most distant visible quasar is likely to be compared to the most distant visible galaxy.

Big Bang

Remaining radiation from the big bang explosion:
Cosmological Microwave Background Radiation (CMBR)

At the start of the universe (big bang), matter is VERY DENSE and HOT
--> Fusion, which caused the high amount of radiation

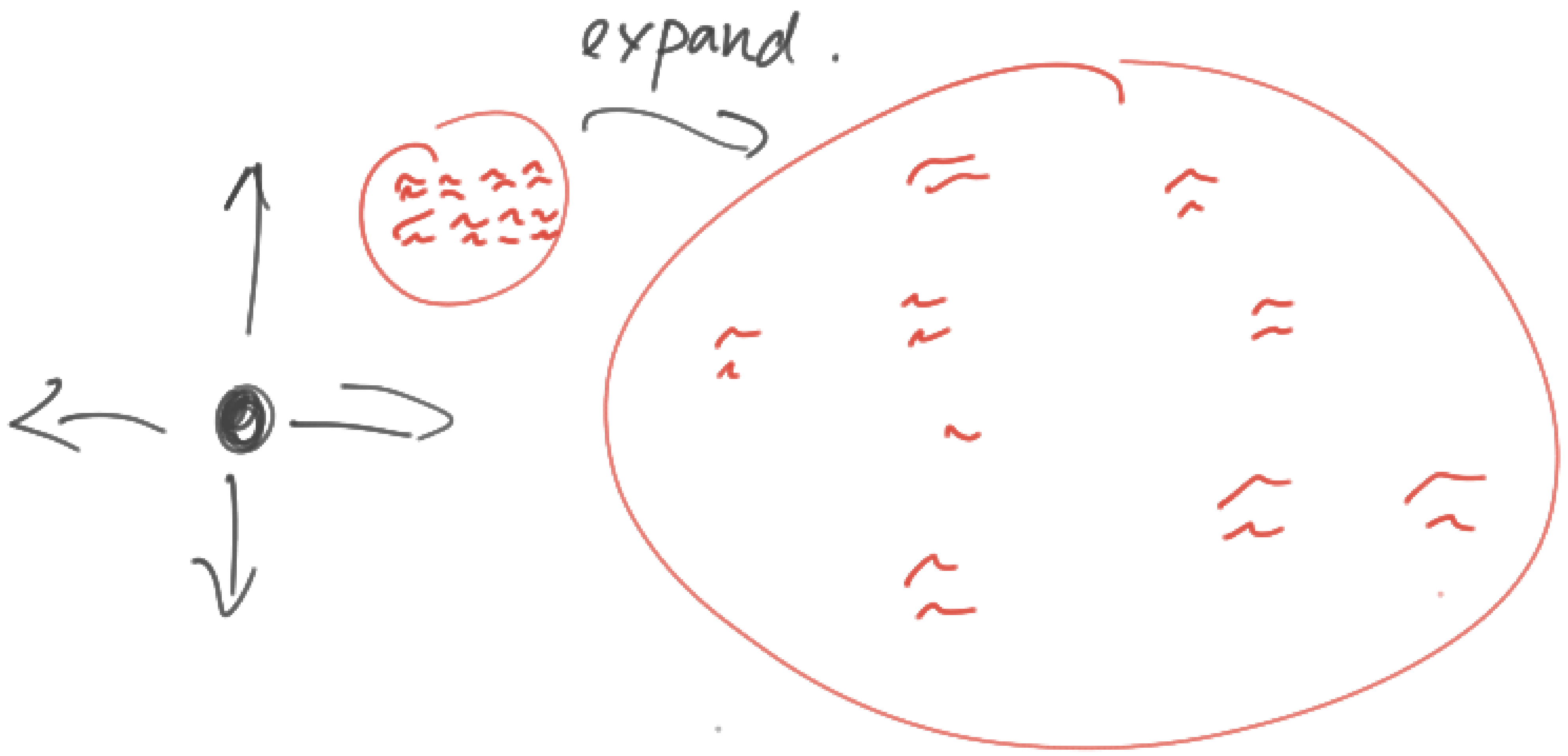
The universe then expands and cools down

(red shifting of distant galaxies)

→ The universe is expanding

→ implies it has always been expanding

→ ~~Expla~~ Consequence : Expanded from a point



(a) The table contains information about two galaxies.

Galaxy	Red shift, z	Distance from Earth / ly
NGC 936	4.8×10^{-3}	6.8×10^{7}
NGC 3379	3.0×10^{-3}	3.2×10^{7}

Discuss whether these data are consistent with Hubble's Law.

$z = \frac{v}{c}$. $|cz| = |v|$

$v_r = Hd$

$cz = Hd$

$\frac{z_1}{d_1} = 7.05 \cdot 10^{-11}$ $\leftarrow$ $\boxed{\frac{z}{d} = \frac{H}{c}} = \text{const}$.

$\frac{z_2}{d_2} = 9.375 \cdot 10^{-11}$

(b) Quasars are the most distant measurable objects.

Discuss **one** problem associated with the determination of the distance from the Earth to a quasar.

The rate of expansion of the universe is expanding. It makes Hubble's law unreliable over large distances.

IC2497 is a galaxy that contained a quasar. It is believed that the quasar stopped emitting radiation several thousand years ago.

(a) Suggest why the quasar stopped emitting radiation.

① Quasars are formed around black holes

② ~~Not~~ No more matter is falling into the black hole so it stopped emitting radiation

(b) IC2497 has a red shift of 0.0516

Determine the distance from the Earth to IC2497.
Give an appropriate unit for your answer.

$$z = \frac{v}{c}$$

$$v = 15480 \text{ kms}^{-1}$$

$$v = Hd$$

$$d = 238 \text{ Mpc}$$

distance = 238 unit = Mpc

(4)

(Total 6 marks)