Astro

Telescopes:

Optical

~~optical:~~

u_o: d from lens to object

v_i: d from lens to image

lenses: when $u_o < v_i$

↳ real and laterally inverted

can be seen by screen

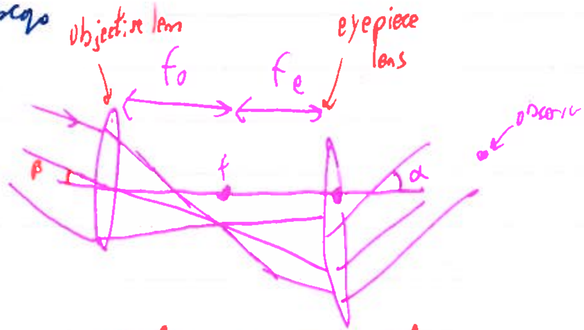
$$\frac{1}{f} = \frac{1}{u} + \frac{1}{v}$$

when $u_o > v_i$

↳ ~~large~~ → Magnified + virtual

cannot be seen by screen

refracting telescope



angular magnification: $\underline{\underline{M}}$

$$M = \frac{\alpha}{\beta} \quad \text{or} \quad M = \frac{f_o}{f_e}$$

~~fo over~~ $\frac{\text{Objective}}{\text{eyepiece}}$

or $M = \dfrac{\angle \text{ got by image at eye}}{\angle \text{ subtended by object at } \cancel{\text{unaided}} \text{ eye}}$

Measuring how big the object appears to be to the unaided eye.

$$M = \frac{\theta_i}{\theta_o}$$

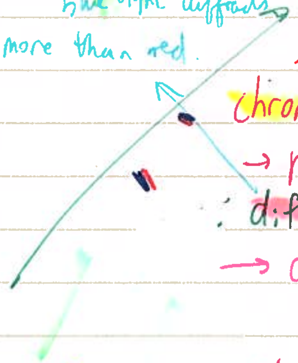
Refractive telescopes

Problems & solutions : chromatic & spherical abberation

blue light diffracts more than red.

X chromatic & spherical abberatio. X heavy, fulan, 變形 move quickly

X large magnification required → 大 lens, 長 focal length



chromatic abberation [coloured fringe effect due to lens focusing colours to diff focal lengths]

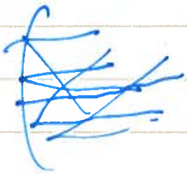
→ producing coloured edges to the image 藍外 紅內

∴ diff λ of light diffract at diff ∠s.

→ corrected by → careful design & choice of high quality ~~otical materials~~ optical material

小心 設計 → 用品質好的 材料

(large diameter lenses) spherical abberation [blurring : focus not 一致]



→ light rays in a // beam focused at diff positions

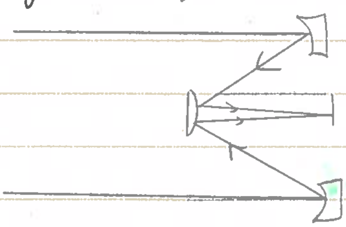
[focus but mirred]

↳ minimized by making both surface of the lens ~~contribute equally~~ to ray deviation

Reflecting telescopes ✓

- large single mirrors
  - → light & supportable from behind [易 supp]
- made few nanometres thicc
  - → excellent image properties [jeng shit quality]
- only front surface for reflection [冇 lens 咁 on 9]
  - → remove problems from lenses
- X chromatic X spherical abberation
- light mirrors
  - → rapid response to astronomical events [轉 , 快]

Cassegrain arrangement



X Refractive telescopes

- difficult to mount
- large diameter lenses are heavy
  - ↳ tend to distort under their own weight

chromatic abberation

↳ diff λs diffract @ diff ∠s

→ coloured fringe

fixed by careful design and use of high quali materials

Spherical abberation

↳ light rays in a // beam focused at diff positions

→ minimized by making d2/3 / lens

CCDs (resolution depends on size of pixels and no. of pixels)

efficiency > 80%

Charged couple devices

Quantum efficiency

$$= \frac{\text{number of photons detected}}{\text{number of photons incident}} \times 100\%$$

~~human eye~~ → ≤ 1%

~~human eye~~ = 1%

→ made up of millions of silicon chips ✓

↳ elec photons hit → electron released → alter charge of chips / pixel

→ measured then create a digital signal

↳ gives brightness / intensity (accurate measurements)

– Info can be stored digitally → transmitted for remote image processing & analysis.

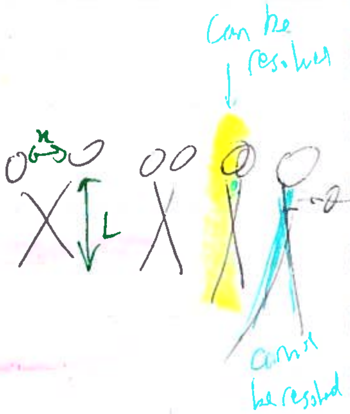
Resolving power: smallest θ

$\theta = \frac{\lambda}{D}$ That you can see thru L

$\frac{x}{L} = \frac{\lambda}{D}$

[minimum angular resolution]

Rayleigh criterion: two point objects can be resolved if their angular seperation... at least



Collecting power: (LGP)

$P = \frac{1}{4}\pi d^2$ ability to collect EM radiation

collecting power $\propto$ (objective diameter)^2

$P \propto D^2$

Concept?

$1^\circ = \frac{1}{360}$ of circle

1 arcminute $: 1' = \frac{1}{60}$ of a degree

1 arcsecond $: 1'' = \frac{1}{60}$ of an arcminute

1 arcsecond $= \frac{1}{3600}$ of a degree

arcsecond $\xrightarrow{\times 3600}$ degree

degree $\xrightarrow{\div 3600}$ arcsecond

~~NON~~ - DP2

NON-OPTICAL TELESCOPES

- Radio
- infrared
- UV light
- X-RAY
- GAMMA RAY

atmospheric opacity: absorption of EM radiation by the atmosphere
↳ UV, IR, X-ray gamma all absorbed (radio wave)
most visible and some IR ~~also~~ can go through
~~Radiowaves can & pass through~~
microwaves ✓✓

- Radio telescope → lower θ
∴ dependence of λ
→ to resolve objects w/ small angular sizes.
∴ Need large dish → large diameter aperture
- away from artificial sources of interference ↳ in isolated areas
- operate day + night
- ground based ∵ atmosphere is transparent to large range of radio λ

IR

- infrared telescopes: → make observation of cool region - cool region
[observe astronomical (e.g.) interstellar gas, cooler star, active galaxies.
object at IR λ] - space based
(0.7 - 450 μm) → Earth atmosphere absorb IR radiation: water vapor, O_2
↳ space-based observations
↳ IR detector is kept cold

- UV telescopes → in space ∵ atmospheric absorption of wavelength
(10 nm - 400 nm) → Cassegrain mirror system
λ
- using photoelectric effect to convert UV photons → electrons
- chem composition - determine chemical composition and temp of interstellar medium
- temp - determine temp and composition of stars - young stars
- solar corona - reveal hot gaseous halo surrounding - old stars
our galaxy - white dwarfs
- help understand solar corona - active galaxies
↓ - quasars
aura of plasma that surrounds the Sun

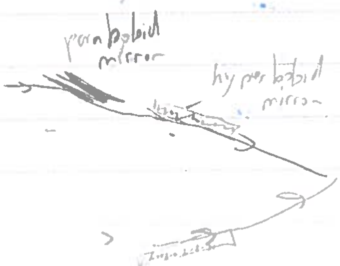
X-ray : - observed from space [space based]

0.01nm - 10nm - X ray from extremely hot gas (10^6 - 10^8K)

↳ highly energetic process - binary stars
- active galaxies
- galaxy clusters
- supernova remnants
- pulsars
- neutron stars
- black holes

- extremely hot gas from highly energetic process.

skim off w/o penetrating
↳ grazing incidence



- Gamma ray - do not use mirrors

sudden burst last for 0.1s - 1000s

~~0.01nm~~

> 0.01nm

from - solar flares
- pulsars
- quasars
- active galaxies
- Supernova remnants

Kirchoff's laws of spectroscopy

(Emmision)

line spectrum : (有色，黑背景)
[Hot tendon gas produces light w/ spectral lines at discrete wavelengths depending on the energy levels of the atoms in the gas]
temp↑↑ → more atomic collisions → e's raised to excited state
→ e's de excite → falls down energy levels, → emitting photon with precise energy
↳ corresponds exactly to spacing of energy levels within atoms of gas
→ spectrum recorded : bright light on a dark background
intensity & position of lines → particular electronic transition in atoms of gas

Continuous spectrum : (彩虹) [A hot solid object or dense gas produces light with a continuous thermal spectrum]
atoms have KE, undergo multiple collisions, e's at excited states
↳ excited e's fall back into discrete energy levels BUT during this, multiple collisions occured
↳ results in blurring + loss of info about atoms in gas
↳ Continuous spectrum @ photosphere → outer shell of star where light is formed
→ source of visible light

Absorption spectrum: light passes thru outer layers ↳ which are cooler & mainly H
photons absorbed, electrons raised to excited state
↳ fall down to ground state → photons emitted in random directions
↳ spectrum comprised of dark lines
有黑线吸 seen when light from a continuous spectrum passes ~~through a~~ cooler gas which absorbs at discrete λs depending on the energy levels of the atoms

Emission line spectrum: a hot luminous gas produces light with spectral lines with discrete λs depending on energy levels of atoms in the gas

↳ seen from low density gas clouds according to their temp & composition

e.g. - hot interstellar gas in star-forming regions
- spiral arms of galaxies

· planetary nebulae : evolved stars which have gaseous envelopes

· quasars : emission from gas spiraling into the central massive black hole

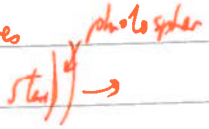
Continuous spectrum: hot solid object or gas produces light w/ a continuous thermal spectrum

eg. - spectrum of a light bulb spans all visible λs
- stars : radiation emerging from a stellar interior has a continuum using SED get Teff
- normal galaxies : spectrum is the combination of all stellar population
- quasars w/ black holes : radiation is non-thermal, but still has continuous spectrum

Absorption line spectrum: seen when light from a continuous spectrum passes through a cooler gas which absorbs at discrete λs depending on energy levels of the atoms

a cloud of intervening cooler gas can absorb the continuum from a background source at specific wavelengths leaving dark absorption lines in the spectrum

eg all classes of stars due to cooler photospheres



Interstellar gas clouds along the sight line
intergalactic gas clouds along the sight line to quasars

Distance & Magnitude:

standard candle
↳ 知 absolute magnitude (fixed)
求 apparent magnitude (~~far~~ from earth)
→ 出 d (pc)

Luminosity (brightness) $b = \frac{L}{4\pi r^2}$ (Wm^{-2})

- Amount of energy emitted per second at the surface of the star.
  ↳ depend on luminosity and ~~the~~ distance

Apparent magnitude: → how Bright things Appear on Earth

Using Pogson's Law

$$\underbrace{m_2 - m_1}_{\text{apparent magnitude of } m_2 - m_1 \text{ (stars)}} = -2.5 \log_{10}\left(\frac{b_2}{b_1}\right)$$

$\frac{b_2}{b_1}$ → brightness of stars

負數 (-ve) → brighter
正數 (+ve) → dimmer

1pc = distance of which the observed parallax of the star is equal to 1 arcsecond = $\frac{1}{3600}$th of a degree

distances

- 1 AU = 1.5×10^{11} (distance from sun to earth)
- 1 ly = 9.46×10^{15} m (distance EM wave travels through a vacuum in one year)
- 1 parsec = 3.26 ly = 206265 AU = 3.08×10^{16} m
  ↳ distance which the observed parallax of the stars is equal to 1 ~~second~~ arcsecond

Absolute magnitude: its apparent magnitude if it were located at a distance of 10 pc from earth

- based only on the luminosity of the star (standard distance)

Using:

$$\underbrace{m - M}_{\text{distance modulus}} = 5 \log\left(\frac{d}{10}\right)$$

d → distance in pc

m: apparent magnitude [from earth]
M: absolute magnitude [from 10pc of earth]

determining distances to star clusters / galaxies which cannot be determined by parallax measurements

✲ Standard candle:
- objects that you can calculate the luminosity directly

↳ cepheid variable stars:
periodic variation in luminosity has a (constant known relationship) with (max luminosity)
→ measure this → absolute magnitude can be calculated

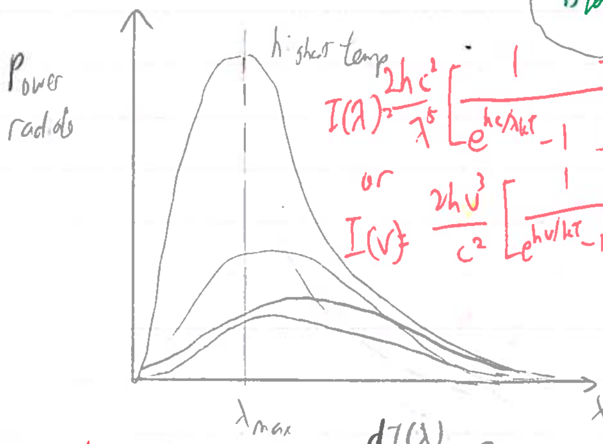
Stars as Black Bodies [perfect absorber / emitter]

Black body: idealized body which absorbs all radiation incident upon it

For thermal equilibrium: it must also emit radiation at same rate it absorbs for temp to be maintained

↳ gases inside stars are opaque to all radiation so stellar surfaces approximate a blackbody

– Using Kirchoff's law of thermal radiation



$$I(\lambda) = \frac{2hc^2}{\lambda^5}\left[\frac{1}{e^{hc/\lambda kT}-1}\right]$$

or

$$I(\nu) = \frac{2h\nu^3}{c^2}\left[\frac{1}{e^{h\nu/kT}-1}\right]$$

using $L = 4\pi d^2 F$, $F = \sigma T^4$

$$L = 4\pi d^2 \sigma T^4$$

for $T = T_{eff}$ 和 L ↓ 求 stellar radius

- Find Temp: $\frac{dI(\lambda)}{d\lambda} = 0$

using Wien's displacement law.

$\nu_{max} \approx 10^{11} T$

$$\lambda_{max} T = 2.9 \times 10^{-3}\, mK$$

- Find Power output: (Total flux of a blackbody)

↳ by integration over all λs / fs

[Stefan-

$$F = \sigma \cancel{A} T^4$$

Area, temp, Stefan Boltzmann constant

[Stefan - Boltzmann law

for a black body:

- $P \propto$ surface area
- $P \propto T^4$

Stellar spectroscopy: - analysing spectrum of stars

- emission line spectrum
- Emission continuous spectrum
- absorption spectrum

- Find intensity or flux

[inverse square law] $F = I = \frac{L}{4\pi d^2}$

Flux: energy flowing through unit area of surface

Luminosity: total amount of energy radiated per unit time

~~Ezt~~

Spectral Class:

			temp T_{eff}	absorption lines
blue	O	50	50000 - ~~25000~~ 30000	He^+, He, H
	B	25	30000 - 11000	He, H
	A	11	11000 - 7500	H, M^+ M^{x+}
white	F	75	7500 - 6000	metal ions → M^{x+}
yellow	G	60	6000 - 5000	M^{x+}
to (vary)	K	50	5000 - 4000	division into subclasses
red	M	35	4000 >	Metal atoms (T:0)
LA	L		2000	molecular bands.
TA	T		~700	

Strong hydrogen Balmer lines

metal absorption

See H-R Diagram → 有 Red Supergiants, main sequence stars, white dwarfs

Stellar Evolution

Proto stars

- convective
→ cool $T_{eff} < 4000K$
- Pre MS era last $10^5 - 10^7$ yrs
depending on initial mass

- between interstellar medium:
molecular clouds → cold hydrogen gas (10-50K)
$10^8 - 10^{15}$ molecules per m^3
form a rotating clump of gas dust → silicates & graphites
through gravitation attraction

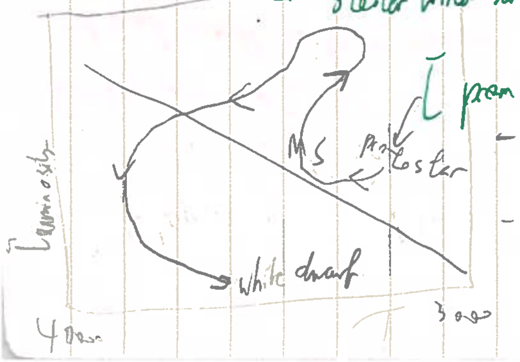
~~movement on HR diagram cell ... / dissociate~~

angular momentum spins the clumped material with a circumstellar disc

↓

temp in core ↑↑
- thermonuclear reactions begin (fusion)
- stellar wind is produced

[pre main sequence]
- movement continues on HR diagram until ... zone
- further collapse ↑↑ core temp until nuclear ignition occurs at which point star stabilize on the main sequence.



Main Sequence

H - burning

1). pressure produced by hydrogen fusion in core
fusion = gravity
balances gravitational compression
[core hydrogen burning]

2.) depends on mass
more massive stars have hotter cores
high mass high temp → shorter lifetime
low mass low temp → longer lifetime
$\sim 10 \times 10^9$ years.

CNO energy generation rate is a stronger power of temperature ($\propto T^{17}$) than pp rate ($\propto T^4$)

3. [illegible] 到有 hydrogen

CNO cycle ↑ $> 1.3 M_\odot$

catalyst CNO

$^{12}C + {}^1H \rightarrow {}^{13}N + \gamma$
$^{13}N \rightarrow {}^{13}C + e^+ + \nu_e$
$^{13}C + {}^1H \rightarrow {}^{14}N + \gamma$
$^{14}N + {}^1H \rightarrow {}^{15}O + \gamma$
$^{15}O \rightarrow {}^{15}N + e^+ + \nu_e$
$^{15}N + {}^1H \rightarrow {}^{12}C + {}^4He$

post main sequence →

Red Giant: (1.4 - 3 M_{sun})

~~CNO energy generation rate~~ critical situation → no nuclear energy → star must collapse

- appear red
∵ cooling down

X hydrogen
↳ nuclear fusion stops.
↳ outward pressure stops.
↳ Helium core contracts + heats up due to the weight of star
↓
outer layers expand and cool
(Red giant)

- shell hydrogen burning
heat from heating of the helium core fuse hydrogen

$T_c \approx 10^8 K$ - Core helium burning
→ heat & contraction of helium core
hot & dense enough to fusion
endo
$^4He + {}^4He \rightleftharpoons {}^8Be + \gamma$
$^4He + {}^8Be \rightleftharpoons {}^{12}C^*$
$^{12}C^* \rightarrow {}^{12}C + 2\gamma$ core
Carbon → oxygen
↳ release energy and pushes outer layer of star

- Shell helium burning
X helium → C-O core contracts
↳ heating the shell around it → helium fuses.

OR

→ Redsupergiant (> 3 M_{sun})

- fusion all the way up to iron ∵ 够多 pressure 够多 heat

Mystery for Type I SNe

- Red giant would transfer hydrogen but NO HYDROGEN seen in spectra of Type I SNe
  - ↳ Perhaps other companion is ~~star~~ a white dwarf
    - ↳ companion white dwarfs are too rare to match the rate of Type I SNe

If Find as Red Giant :

- ✱ Luminosity & homogeneity of SNe
  - ↳ can be seen to great distances to chart expansion history of Universe

Gamma ray burst

- narrow beam of intense radiation
- 10^{48} J
- maybe source of mass extinction

evidence :

1: Remarkably homogeneous in peak luminosity, consistent w/ explosion of a system of fix mass

2: No remnant in Type I events in Milky Way

Chandrasekhar limit

- Explode at same critical mass

Neutron star

1 per 100yrs in large galaxies [rare]

Type II Supernova

Supernova : (rapid, massive increase in brightness)

$M > 8M_{\odot}$

- star that suddenly and very rapidly INCREASES in absolute magnitude ∵ explosion

ejects most of its mass

2 types:

Type I supernova

- star that accretes (draws in) matter from another star in a binary system until it becomes compressed and nuclear reactions are set off, blasting matter into space.
- 10^{44} J of energy released
- roughly same energy output of the Sun over its entire lifetime
- model predict collapse c'
  - → entire white dwarf destroyed in a thermonuclear explosion

- emits bursts of high energy gamma rays [core collapse]

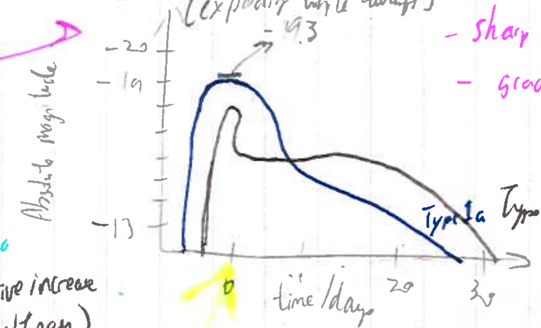
Type II Supernova

- Star that runs out of nuclear fuel and collapses readily under own gravity
  - ↳ ejecting its outer layers w/ enormous energy (10^{46} J) (5000-10000 kms^{-1})
- ✱ ~~seve~~ has to be several times more massive than the Sun

完蛋 变成 neutron star

Type Ia Supernova (Standard candles)

[exploding white dwarfs]



- sharp initial peak
- gradually decreasing curve

~~cited as~~ - used as a standard candle

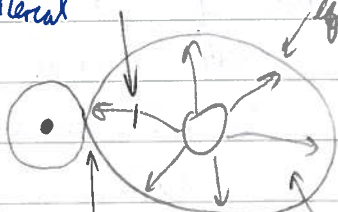
(known luminosity & distance)

∵ every Type Ia supernovae has the same absolute magnitude curve (-19.3)

- bright of
  - ↳ distances up to 1000 Mpc
    - ↳ for cosmological distances

Observing Black Hole:

↳ detect its influence via nearby material



matter falling into black hole loses potential energy

→ thermally or non-thermally radiate

very hot gas → X-ray emission

eg. binary system where more massive stellar companion fills its Roche lobe

↳ leading to accretion onto black hole → accreted material has $\vec{L}$, form an accretion disk around the black hole [viscosity in the disk can heat up]

accretion disk : flattened band of spinning matter around the event horizon

---

eg. Cygnus X-1 – Black hole in Binary System

→ most luminous X-ray source in the sky

↳ accurate radio position indicated a blue supergiant star which was too cool to emit X-rays

↳ use Doppler 'wobble' of the supergiant star

↳ deduce there was a dark orbiting object w/ mass $\sim 14 M_\odot$

↳ first black hole encounter

X-ray Binaries (XRBs) contain either black hole or neutron star

- Low mass : ~~companion~~ companion fills its Roche lobe
- High mass : stellar wind from hot companion captured
- transient phenomena can be observed — short time or impermanent

↳ associated w/ intermittent hot spots along accretion stream (intermittent: occurring @ irregular intervals)

including nucleosynthetic explosions

Gravitational Wave Astronomy   see ~~ne~~ ppt for diagram
LIGO

- merge of a pair of neutron stars / black holes
  ↳ creates a ~~mg~~ major gravitational distortion in waves
    ↳ generating low frequency Gravity wave
      ↳ detected by sensitive interferometer
- time-dependent signal ['strain'] contains key information
  on mass of 2 merge ~~or~~ sources ~~bx~~
- can be used to measure mass distribution of black hole & neutron stars

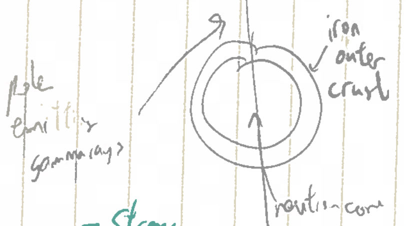
core mass of $1\text{-}3M_\odot$ → stable degenerate neutron star

→ **Neutron stars:** $>1.4M$

- great gravitational contraction
  ↳ electrons forced into protons
  ↳ neutrons formed. → collapsed core of neutrons
  ∴ composed entirely of neutrons.

$p + e^- \to n + \nu_e$

- upper stable mass limit → $M_{neutron} < 3.1 M_\odot$
  - similar to e^- degeneracy in white dwarfs
  - rest mass contributes to KE
  - interparticle distance within range of strong force
- dense at ($4\times10^{17}\ kgm^{-3}$)
- small (20km)
- rotate v. fast (600 times a second)
- low intensity luminosity
- strong gravitational field ($v_{esc} = 0.8c$)



CNO:

$^{15}_{8}O + ^{1}_{1}H \to ^{14}_{7}N + ^{4}_{2}He$

if ~~binary star systems~~

↳ **pulsars**

$\vec{L}$ and $\vec{B}$ are conserved

surface of a neutron star has protons and neutrons of which G-field not strong enough to ~~be~~ push them tgt forming neutrons
↳ accelerating towards the magnetic poles of neutron star. [relativistic speeds]
↳ emitting EM waves at poles. e^-'s spiral around B field → creating synchrotron radiation

→ rotate rapidly ($P \sim 10^{-3}$ - 1sec)
→ strong B-field (10^8 Tesla)
lighthouse
— if magnetic & rotation axes not aligned & rotation axis pt towards Earth → bursts of radiation every rotation period

white dwarfs: old stars that have a high surface temp. but not luminous (low mass stars)
↳ Sirius B $< 8M_\odot$

- how products of fusion such as He, C, O, N,
  → blue, $T_{eff} \sim 10 \sim 20{,}000$ K
∴ small, no longer generate energy by fusion
→ dense
↳ ~~will~~ cooled to a pt of (lose energy source) emitting no heat/light
↳ black dwarfs

less massive stars cannot raise their core temp sufficiently to ignite the next fuel ∴ must collapse to form a stable e^-/degenerate remnant

Black hole: $>3M$ [$M \sim 20\text{-}50 M_\odot$]

- strong G-field
- no EM wave/particles can escape.

Schwarzschild radius:

$$R_s = \frac{2GM}{c^2}$$

→ for a given mass, how small if an object has for it to trap light around it ∴ appearing black

→ boundary formed: event horizon
laws of phy. breaks down

event horizon
↳ region of the black hole of which no matter & ~~nonradiation~~ can escape unless they have v > c

$$R_s = \frac{2(6.67\times10^{-11})(?)(1.99\times10^{30})}{(3\times10^8)^2}$$

$=$

COSMOLOGY

red shift: observed λ > emitted λ

∴ - expansion of universe
- galaxies moving apart

Doppler shift → change of frequency of light due to motion of observe

observer

$\lambda\downarrow$, $f\uparrow$ $\lambda\uparrow$, $f\downarrow$

observer - furthest galaxies move furthest.

降 [近藍]

陰態 ↳ 遠紅

moving closer

moving further

Blue shift → 移到埋身

Red shift = 離我遠去

~~for v<<c~~ Doppler shift

for v<<c

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

有時分别

amount of blue / red shift

doppler shift

$$z = \frac{f_{emitted} - f_{observed}}{f_{emitted}} = \frac{\Delta f}{f} = \frac{v}{c}$$

$$z = -\frac{\lambda_{emitted} - \lambda_{observed}}{\lambda_{emitted}} = \frac{\Delta\lambda}{\lambda} = \frac{v}{c}$$

$$\frac{650nm - 540nm}{650nm} = \frac{v}{c}$$

$$v = \cancel{50.}\,51.8 \times 10^{7}\,ms^{-1}$$

planet and star orbit around common centre of mass

↳ star moves toward or away from earth

↳ causes shift of wavelength of light receiving from stars.

observed λ | rest λ | radial velocity of emitter

$$z = \frac{\lambda - \lambda_0}{\lambda_0} = \frac{\Delta\lambda}{\lambda_0} = \frac{v}{c}$$

$\lambda\uparrow$ red

$\lambda\downarrow$ blue

$v > 0$, $\lambda > \lambda_0$ → 遠紅 red shift

$v < 0$, $\lambda < \lambda_0$ → 近藍 blue shift

- Kinematics of stars in galaxies → getting true space velocities of stars
- large scale structures → drawing 3D large scale structures of galaxies of universe
- cosmic Evolution → measure red shift in galaxies allow to study the universe in periods of cosmic time

Quasars & Exoplanets.

$$\frac{P_{quasar}}{d_{quasar}^2} = \frac{P_{galaxy}}{d_{galaxy}^2}$$

Quasars

Balmer lines of hydrogen shift enormously

→ extremely luminous objects → shoots out jets of material (active radio sources)

→ high red shifts (most distant)

→ they lie at great distances → 10 suns per year to produce energy observed

[core of distant galaxies, powered by matter falling into a supermassive black hole]

→ produced a continuous spectrum × black body × absorption lines ↳ emission lines

Exoplanets:

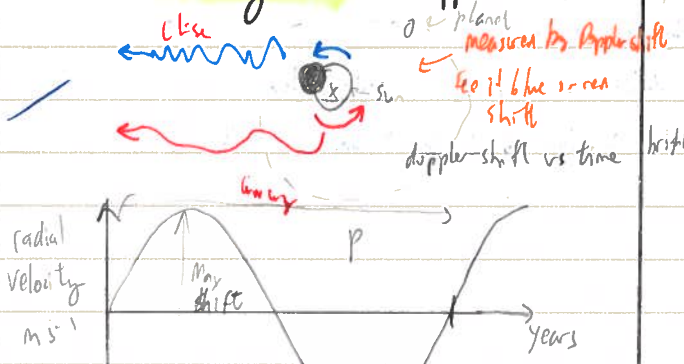
→ planet that orbits a star other than the Sun.

- cannot detect exoplanets in most situations due to limited angular resolution [<<1 arcsec for all but nearest stars]
- poor brightness contrast w/ parent star

- fainter than the star ∵ only reflect light from the star ∴ difficult to detect / seen directly

TWO METHODS IN FINDING EXOPLANETS

- Radial Velocity Method (Doppler Shift)



- exoplanets orbiting a star has a small effect on star's orbit
  ↳ causing tiny variations (wobbles) → orbiting in a common centre of mass
  ↳ wobbles cause red & blue shifts in star's emissions → detected on earth

→ velocity measurements allow determination of size and shapes of orbits of an exoplanet

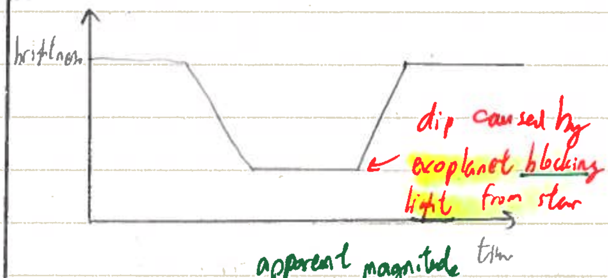
→ can calculate minimum mass

- if planet orbits star ⊥ to the line of sight
  ↳ no detectable shift in the light from the star

exoplanets [star orbiting in a common centre of mass, doppler shift of the star] [detect wobble due to gravitational pull of nearby planet

- Transit Method

↳ detecting a dimming in star's brightness



decrease in observed brightness allow radius of exoplanet to be calculated if radius of parent star is known

$$\frac{\pi r_p^2}{\pi r_s^2} = \left(\frac{r_p}{r_s}\right)^2$$

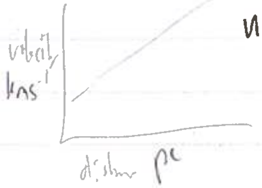
- chances of the planet's path being lined up so that it crosses the line of sight between star & earth v. low → only confirm exoplanets × relevant location

Age of universe (depends on H_0)

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

From Hubble's law

$v = Hd$



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

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

using $H = 67.3\ \text{kms}^{-1}\ \text{Mpc}^{-1}$

$1\ \text{Mpc} = 3.09\times10^{22}\ \text{m}$

$H = \frac{67.3\times1000}{3.09\times10^{22}}$

$= 2.18\times10^{-18}\ \text{s}^{-1}$

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

$= \frac{1}{2.18\times10^{-18}\ \text{s}}$

$t = 4.59\times10^{17}\ \text{s}$

$= 4.59\times10^{17} \div (365\times24\times3600)$

$= 14.5\times10^{9}$ years

→ 14.5 billion years

Universe is same in every direction

By cosmological principle:

on a large scale: → every part is same as the other part

universe is homogeneous

and

isotropic → everything looks the same in every direction

∴ No centre no axis (eg. visual)

EXPANDING UNIVERSE → (galaxies receding → $v \propto d$)

→ spectra from galaxies all show red shift

↳ ∴ giving recessional velocity (v)

$v \propto d$ ← found by standard candles

$v = H_0 d$ ← Mpc

kms^{-1} ↑ Hubble's constant

→ Big Bang model

universe is expanding & cooling down

↳ going back in time → smaller & hotter

H_0 = hubble's constant

- ratio of the speed of recession of a galaxy due to expansion of the universe to its distance from the observer
- does not depend on direction

using balloon analogy → no centre of expansion

More on later parts

- isotropic → everything looks the same in every direction → no centre
- homogeneous → every part is the same as the other part

Big Bang model - Expansion of the Universe
- Cosmic Microwave Background Radiation (CMBR) - ~~Blue shifts~~] Evidence
- Amount of Helium in Universe H : He - evolution of galaxies
↳ abundances of light elements 3 : 1

[CMBR]: [nucleosynthesis in first 3 min]

$T_{uni} > 3000 K$	$T_{uni} < 3000 K$
photons continually scattered, absorbed & re-emitted by fog of free e/s	no more free e/s, photons able to travel freely thru the Universe

HBB (Hot Big Bang) predicts EM radiation was produced in early universe
↳ radiation should still be observed today
↳ ∵ expansion of universe → background radiation have been stretched and in the microwave region (red shifted)

high energy gamma radiation ($t \approx 300000$ years)

coming from all directions (Penzias & Wilson in 1960s)
↳ intensity is coming from all directions — isotropic & homogeneous

1992
from Satellite → Cosmic Background Explorer redshifted $z \sim 1100$ & $T \sim 3000/1100$
(COBE) peak λ → T = ~~2.73~~ 2.725 K

- confirm peak λ (λ_{max}) corresponds to black body temperature of 2.725 K
↳ expected if radiation is emitted after Big Bang when Universe is small & hot

measured by angular power spectrum → measure how much structure there is in background on various scales
- fluctuation in temperature of the microwave background ($\delta T/T \sim 10^{-6}$)
- originate from quantum effects?
T ∝ ρ ∵ tiny energy-density variations in the early Universe ; density cannot be completely uniform @ times
needed for initial 'seeding' of galaxy formation by gravitational forces

- showing a ~~cb~~ Doppler shift: → Earth's motion through space
Andromeda shows blue shift
redshifted $z \sim 1100$ ↳ Earth approaching Andromeda ∵ gravitational attraction
@ a million miles an hour

further planets stars have more redshifts

early universe fully ionized → photons were unable to travel far w/o being scattered by e/s
↳ 380000 yrs after Big Bang, Temp dropped below $T \sim 3000 K$
↳ H atom could form enabling photons to travel freely
↳ We see this thermal glow [last scattering surface]

Primordial Nucleosynthesis [PN]

For fixed density of baryonic matter
↳ all observed abundances for these light elements can be reproduced

Hydrogen & Helium abundances:

universe expands from the Big Bang → $n + p + \gamma$ plasma cools

Universe:
- 25% Helium
- 73% Hydrogen
- 2% others

↳ PN occurs in first 3 min

↳ consistent with HBB model of ~~hydrogen formation~~ and fusion of hydrogen into Helium

↓

which is primordial nucleosynthesis fusing H and fusing 2H to He

lightest elements such as H and He are formed: (100s after Big Bang)

↳ ∵ immense / high temp & helium

↳ H → He (for 3 min)

∴ H : He
3 : 1

high temp → fusion
H : He
3 : 1

- ∵ rapid expansion
↳ cools down → no fusion
No heavier elements
↳ formed

elements are produced by fusion and dispersed across interstellar medium by supernovae

↳ ∵ rapid expansion of Universe

↳ temp ↓↓ below those required to sustain fusion

No heavier elements than Lithium are produced

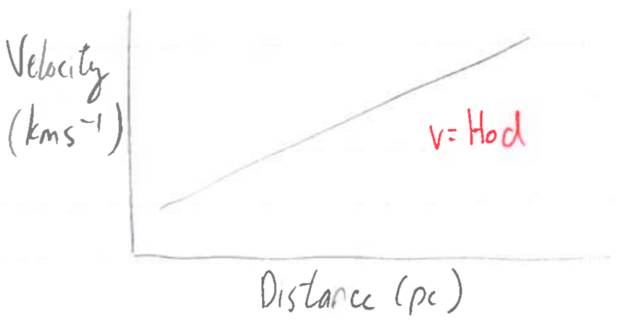
elements produced thru fusion in supernova
↳ spread by the fusion explosion

Expansion of the Universe

receding Doppler Shifts in 25 galaxies [by Slipher]

Made Hubble Diagram [1929 by Hubble]

1927 Lemaître
→ General Relativity permitted cosmic expansion && the linear relation



Again on Hubble's Law

H_0: → measures the rate of cosmic expansion

for more accurate measure
→ ~~ex~~ needs extend the velocity-distance relation as far as possible
because:

- Cannot resolve Cepheid stars beyond 20Mpc
  ↳ ∵ become too faint for accurate period measurements
- galaxies have their own peculiar velocities [$w \sim 200\,kms^{-1}$]
  ↳ adds scatter to the Hubble diagram
  ~~Exc~~ EXCEPT @ Large distances where cosmic expansion velocity dominates

↳ adds more noise to the relation when $w \sim v$ at low d
@ large d, $v \gg w$

Solution → using cosmic distance ladder:
- use Cepheids to get distances to $d \sim 20Mpc$
- & use them to calibrate luminosity of type I Supernovae
  ↳ seen to $d \sim 200\,Mpc$

Results & Implication ...

$$\boxed{H_0 = 68\text{-}72\ kms^{-1}\,Mpc^{-1}}$$

↳ for each extra Mpc^{-1}, galaxies are receding $\sim 70\,kms^{-1}$ faster

Age of universe $T \sim 1/H_0$ (units of time)

✱ Assuming expansion is constant w/time [k$_s$ 錯 ga]

$1Mpc = 3.1\times10^{19}\,kms^{-1}$

$T \sim 4.4\times10^{17}s \sim 14\,Gyr$

✱ Expansion is isotropic
↳ everything looks the same in every direction
↳ ✱ Value of H_0 does not depend on direction

every galaxy sees all the galaxies receding from it
∴ No centre of expansion

First Peak → Curvature:

* sound is relativistic in the dense plasma

↳ represents the sound horizon @ the last scattering surface
↳ close to 380000 light years in scale

↳ testing the overall geometry of the Universe
↳ SPACE is FLAT

curvature of space: constrains energy density of the Universe
- $\Omega_0 < 1$: Empty universe [open] → ~~+ve~~ -ve curved → hyperbolic
- $\Omega_0 = 1$: critical density universe [closed] → flat space → flat
- $\Omega_0 > 1$: Overdense universe → +ve curved → spherical

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Overall for CMBR

- confirm existence of Big Bang → evolutionary Universe
- detected level of density fluctuations → structures of stars galaxies
- determined a spatially-flat Universe → provide independent measures of other cosmological parameters

puzzles : - homogeneity & isotropy over the sky
↳ defies causality ∵ horizon scale is smaller
- why flat space? 'fine tuned'
∵ any departure from flatness would increase with time
- origin of density fluctuations

* proposing cosmological inflation [hypothesis]
↳ universe underwent rapid Inflationary period [$t \sim 10^{-36} - 10^{-32}$ sec]
↳ expand exponentially by $\times 10^{26}$

- explains :
- homogeneity & isotropy → area of contact much larger than the horizon
- space flat → enormous expansion
- density fluctuations → smooths out naturally occuring quantum-scale fluctuations to ones we detect in EM CMBR