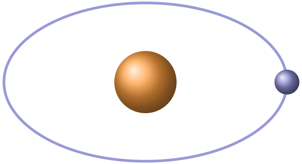
Space Physics

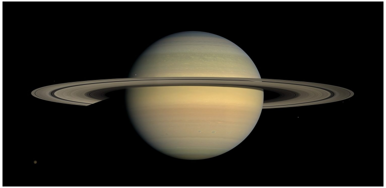
IGCSE Physics ▪ Topic 6

IGCSE Physics



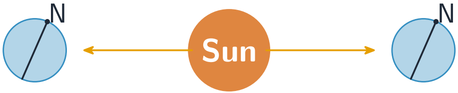
What we will cover

1. Earth Sun & Moon
2. The Solar System
3. The Sun & the stars
4. Life cycle of a star
5. The expanding Universe
6. Recap



1 Earth, Sun and Moon

Earth, Sun and Moon



summer in the north
(N leans towards the Sun)

winter in the north
(N leans away from the Sun)

tilt → ***seasons*** 季节

Day (spin) < month (Moon's orbit) < year (Earth's orbit).

Orbital speed

For one orbit, distance $= 2\pi r$:

$$v = \frac{2\pi r}{T}.$$

Works for planets, moons and satellites.

Station: $r = 7000\,\mathrm{km}$, $T = 5800\,\mathrm{s}$

$$v = \frac{2\pi(7.0 \times 10^6)}{5800} \approx 7600\,\mathrm{m/s}$$

Orbital speed, and why a comet speeds up

The distance	One full orbit covers the **circumference** 周长 $2\pi r$, where r is the orbital radius.
The speed	Orbital speed is that distance divided by the **period** 周期 T: $v = 2\pi r/T$.
Why it changes	By **conservation of energy** 能量守恒: as an object comes closer its gravitational potential energy falls, so its kinetic energy – and its speed – rises.
The field	The **gravitational field strength** 引力场强度 $g = F/m$ says how strong gravity is at that place, and it falls off with distance.

> A comet is fastest at perihelion and slowest at aphelion, and neither needs a force to explain – only the energy it swapped.

2

The Solar System

The Solar System

- four inner **rocky** 岩石 planets; four outer **gaseous** 气态 planets
- Jupiter & Saturn: **gas giants** 气态巨行星; Uranus & Neptune: **ice giants** 冰巨行星
- plus dwarf planets, moons, **asteroids** 小行星, **comets** 彗星

> The Sun's **gravity** 引力 holds the system together.

Orbits and gravity

Gravity is the centripetal force for an orbit. Closer in $\Rightarrow$ stronger field $\Rightarrow$ faster orbit.

> Most orbits are **ellipses** 椭圆. A comet speeds up when closer to the Sun: E_p falls, E_k rises.

Light travel time

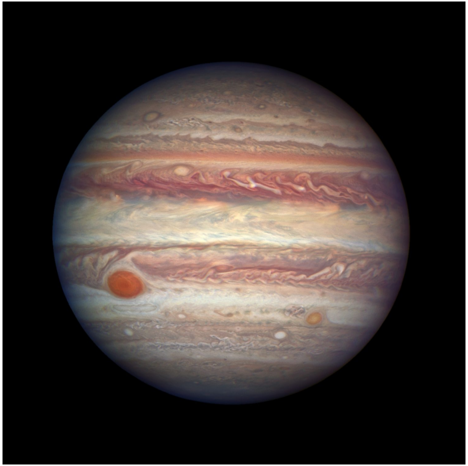
Distances in space are huge, so we often work out how long light takes to cross them.

> Light travels at 3.0×10^8 m/s.

How the Solar System formed

The **accretion** 吸积 model: gravity pulled a spinning cloud of gas and **dust** 尘埃 into a disc.

- most matter formed the Sun
- planets grew from the leftover disc
- hot inner → rocky; cold outer → gaseous



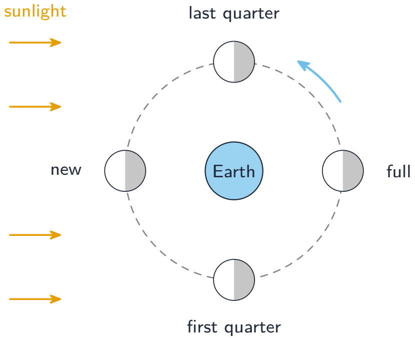
3

Stars

The Sun and the stars

Stars fuse hydrogen to helium in the core. The Sun is a **main-sequence** 主序 star.

> Colour is temperature: blue-white is hotter; red is cooler.

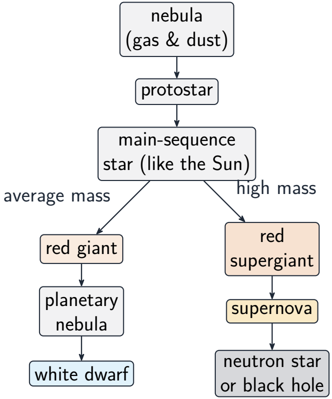


The Moon's lit half always faces the Sun, so as it orbits we see different amounts of it: a new

The life cycle of a star

- nebula → protostar → main sequence
- Sun-like: red giant → planetary nebula → **white dwarf** 白矮星
- massive: red supergiant → **supernova** 超新星 → neutron star or black hole

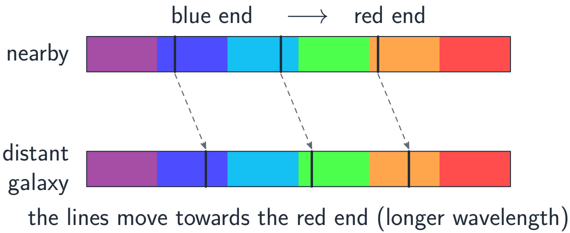
> The star's mass decides how it dies.



Every star begins in a nebula; how it ends depends on its mass

4 The expanding Universe

The expanding Universe

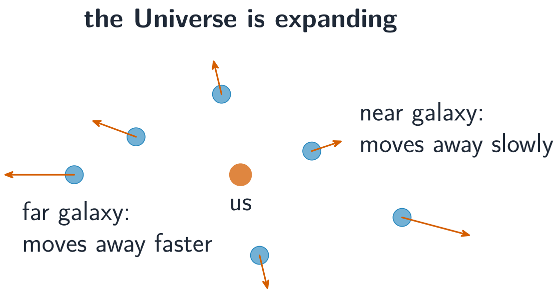


redshift 红移*: lines shift red*

Distant galaxies show redshift – space itself is stretching.

> Redshift $\Rightarrow$ the Universe is expanding $\Rightarrow$ it began in a hot dense state (the Big Bang).

Hubble and the age of the Universe



$$H_0 = \frac{v}{d}, \qquad \text{age} \approx \frac{1}{H_0}.$$

$H_0 = 2.2 \times 10^{-18}\,\mathrm{s}^{-1}$

$\frac{1}{H_0} \approx 4.5 \times 10^{17}\,\mathrm{s} \approx 14$ billion yr

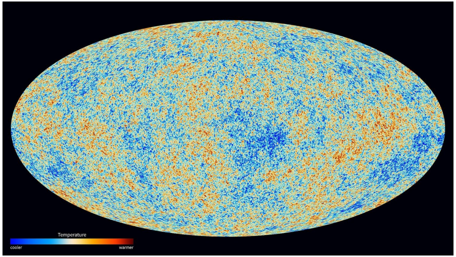
> Every galaxy is moving away from us, and the farther ones move away faster – the Universe is expanding

Redshift, Hubble and the CMBR

Receding	When a galaxy is **receding** 退行, the light we receive has a longer wavelength than normal – shifted towards the red end.
Hubble's law	The further away a galaxy is, the faster it recedes. The **Hubble constant** 哈勃常数 H_0 links the two: $v = H_0 d$.
The age	$1/H_0$ estimates the age of the Universe – how long ago everything was in the same place.
The CMBR	The **cosmic microwave background radiation** 宇宙微波背景辐射: faint microwaves from every direction, the cooled afterglow of the hot early Universe.

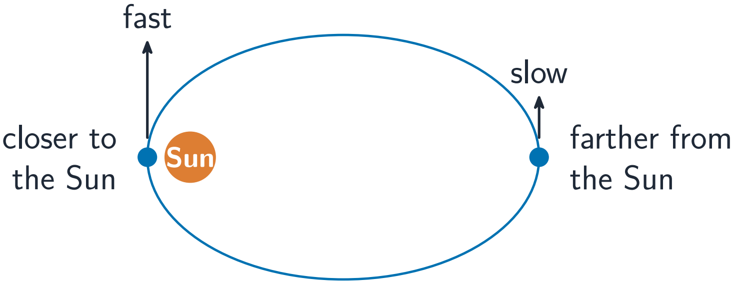
> Two independent pieces of evidence pointing the same way – redshift and the CMBR – is what makes the Big Bang model hard to argue with.

More evidence and the age of the Universe



The whole sky mapped in microwaves: this faint glow reaches us from every direction as the leftover heat of the young Universe – strong evidence for the Big Bang

Orbits and gravity, continued

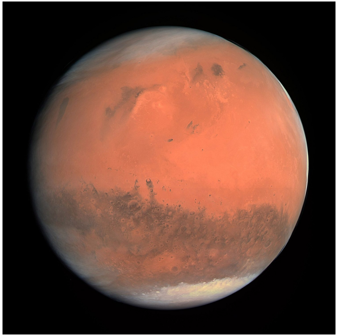


The Sun sits at one focus of the ellipse; the planet speeds up as it comes closer and slows down as it moves away

Orbital speed, continued

The ISS in orbit: orbital speed is the speed that keeps a satellite in free-fall circular motion

The Solar System, continued



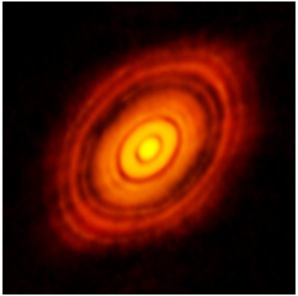
Mars, the red planet, one of the rocky inner planets

The Earth, the Sun and the Solar System

the Earth rotates 自转	on its **axis 轴** once in about 24 hours – which gives day and night
the axis is tilted 倾斜	which gives the seasons as the Earth orbits the Sun in about 365 days
the four inner planets	small and rocky, close to the Sun
the four outer planets	large and **gaseous** 气态 – made mostly of gas, and far colder
the Sun	a **star** 恒星 of medium size, made mostly of **hydrogen** 氢 and **helium** 氦
how it shines	it radiates most of its energy in the infrared, visible and ultraviolet, from nuclear fusion of hydrogen into helium

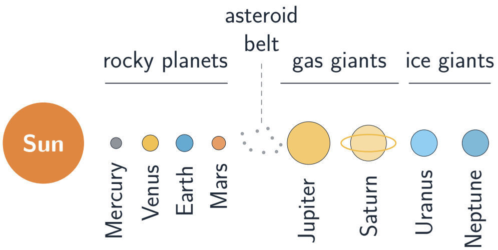
> The Milky Way is about 100 000 light-years in **diameter** 直径, and it is one of many billions of galaxies.

How the Solar System formed, continued



A real accretion disc around the young star HL Tauri: the dark gaps are where new planets are gathering up the dust – our Solar System began the same way

The Solar System, continued (2)

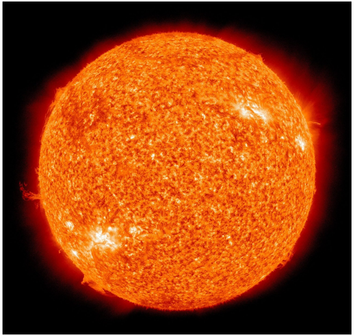


The Sun and its eight planets in order: four small rocky planets, then the asteroid belt, then four large gaseous planets – the gas giants Jupiter and Saturn and the ice giants Uranus and Neptune (not to scale)

The Earth, the Sun and the Moon

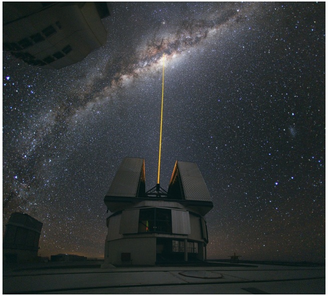
The full Moon, Earth's natural satellite

The Sun as a star



The Sun, our nearest star, seen in ultraviolet light

Stars, galaxies and the Universe



A giant telescope studies the night sky; the laser helps it make sharp images of distant stars

How a star lives and dies, and the evidence for the Big Bang

1. a nebula	a cloud of hydrogen gas and dust
2. a protostar 原恒星	gravity pulls the cloud inwards and it heats up – the collapsing, heating cloud
3. a stable star	fusion starts, and its outward pressure balances gravity for billions of years
4a. a lighter star	swells into a red giant, then sheds its layers as a planetary nebula, leaving a white dwarf
4b. a much heavier star	swells into a **red supergiant** 红超巨星, then explodes as a **supernova** 超新星, leaving a neutron star or a black hole
the CMB	faint **microwave** 微波 **radiation** 辐射 from every direction – the **cosmic microwave background** 宇宙微波背景

Hubble's law gives the age because every galaxy seems to have started from the same point at the same time: run the expansion backwards and they all meet.

From cloud to star

Interstellar cloud	A star forms from an **interstellar cloud** 星际云 of gas and dust containing hydrogen, pulled together by gravity.
Nuclear reactions	When the core is hot and dense enough, **nuclear reactions** 核反应 begin: hydrogen fuses to helium, and the outward pressure balances gravity.
What it radiates	The star radiates most of its energy in the infrared, visible and **ultraviolet** 紫外线 parts of the **electromagnetic spectrum** 电磁波谱.
Where the elements came from	The planets formed from a giant cloud of gas and **dust** 尘埃 containing many chemical **elements** 元素 – all of them made in earlier stars.

> A main-sequence star is a balance: gravity pulling in against radiation pressure pushing out. Every later stage is that balance failing.

Stars, galaxies and the Universe, continued

A spiral galaxy: billions of stars held together by gravity

Planetary data: reading the table

Planet	Distance / million km	Period	Density / g/cm^3	Surface temp. / °C	Surface g / N/kg
Mercury	58	88 days	5.4	170	3.7
Venus	108	225 days	5.2	460	8.9
Earth	150	365 days	5.5	15	9.8
Mars	228	687 days	3.9	-60	3.7
Jupiter	779	11.9 years	1.3	-110	23
Saturn	1430	29.5 years	0.7	-140	9.0
Uranus	2870	84 years	1.3	-195	8.7
Neptune	4500	165 years	1.6	-200	11

Further out: longer period, colder surface. Inner four dense (rock, metal); outer four low density (gas, ice). Surface g follows the planet's mass and size, not its distance from the Sun.

Exam tips

- In $v = \frac{2\pi r}{T}$, r is the orbit radius and T is the time for one full orbit in seconds – convert km to m and hours to seconds first.
- Planets closer to the Sun feel stronger gravity, so they orbit faster and take less time. In an elliptical orbit a body speeds up as it nears the Sun (gravitational potential energy turns into kinetic energy).
- A **light-year** is a *distance*, not a time – how far light travels in one year.
- A star is **stable** when the inward pull of gravity is balanced by the outward push from the energy released by **fusion** in its core. What it becomes when its fuel runs out depends on its **mass**.
- **Redshift** – light from distant galaxies shifted to longer (redder) wavelengths, with a bigger shift the further away – is the evidence that the Universe is **expanding**, which supports the Big Bang.

5 Recap

Topic 6 – key takeaways

1 Orbits

$v = 2\pi r/T$; ellipses, faster when closer

2 Solar System

rocky inner, gaseous outer; Sun's gravity

3 Stars

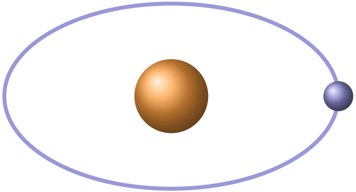
fusion; mass decides the death

4 Universe

redshift $\rightarrow$ expanding $\rightarrow$ Big Bang

Check yourself

1. Why do we have seasons?
2. Are the outer planets rocky or gaseous?
3. What powers a star?
4. What does redshift tell us about the Universe?



Answers **1.** the tilted axis **2.** gaseous **3.** nuclear fusion **4.** it is expanding