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STARDUST & SHORTCUTS

A fast, illustrated guide to astrophysics — written for people who intend to go further than a quick read.

38 chapters · 75 illustrations · one universe

Concepts · Case files · Worked numbers · Career map

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What Is In Here

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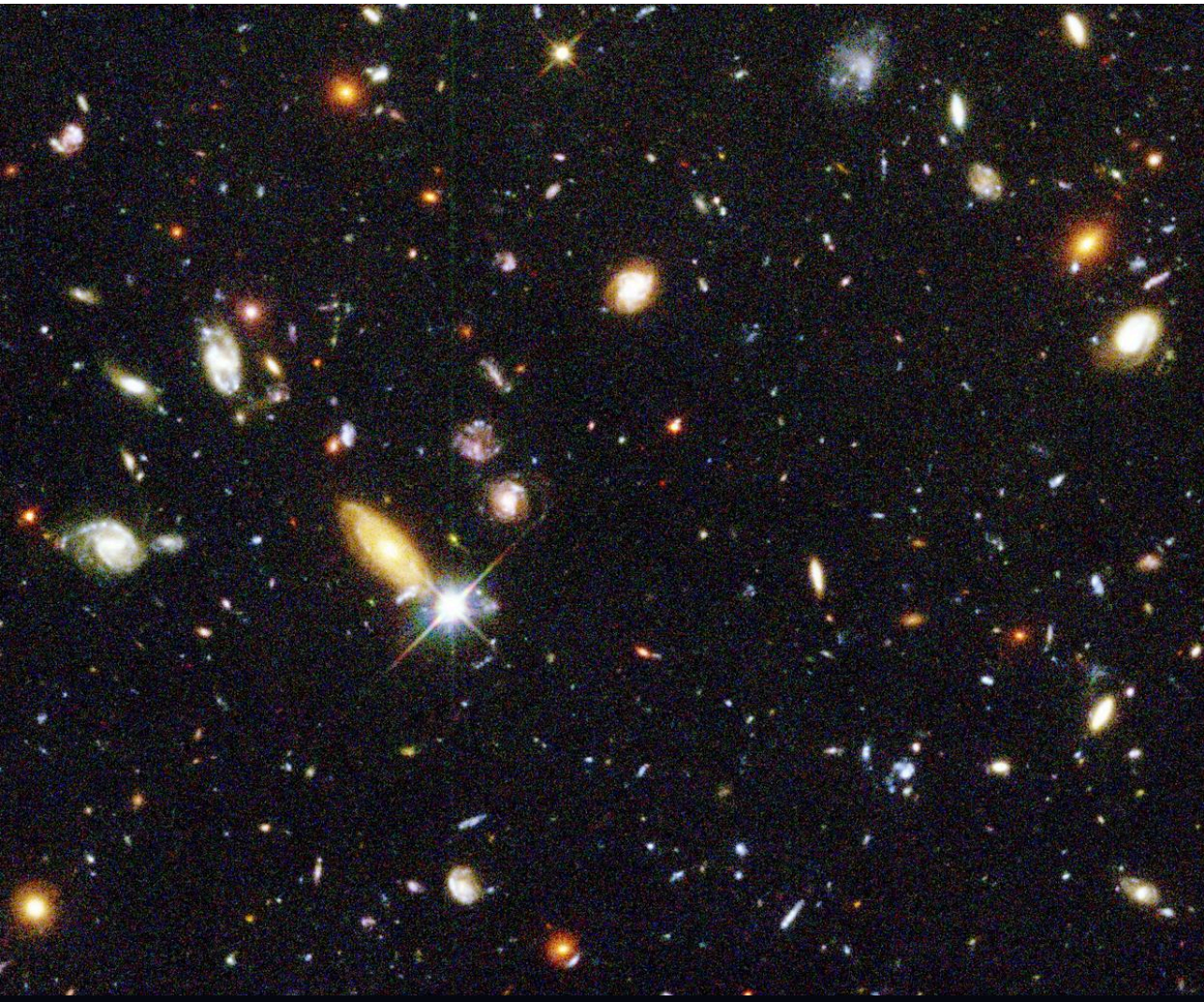
Stars being born, right now

The “Cosmic Cliffs” of the Carina Nebula, photographed by the James Webb Space Telescope in the infrared. The ridge is the edge of a gas cavity being carved out by the radiation of young massive stars above the frame. The peaks are denser clumps resisting erosion — and inside several of them, protostars are collapsing. The tiny jets visible at the tips are stage 3 of Figure 14.1, caught in the act.

Credit: STScI (Webb). NASA — free to use with credit.



Ten days of looking at nothing

The Hubble Deep Field, 1995. Robert Williams pointed the telescope at a patch of apparently empty sky about one-thirtieth the width of the full Moon and left the shutter open for ten days. **Almost every object here is a galaxy**, not a star. The faintest are being seen as they were within a couple of billion years of the Big Bang. This single image implied tens of billions of galaxies in the observable universe.

Credit: NASA/JPL/STScI Hubble Deep Field Team. NASA — free to use with credit.

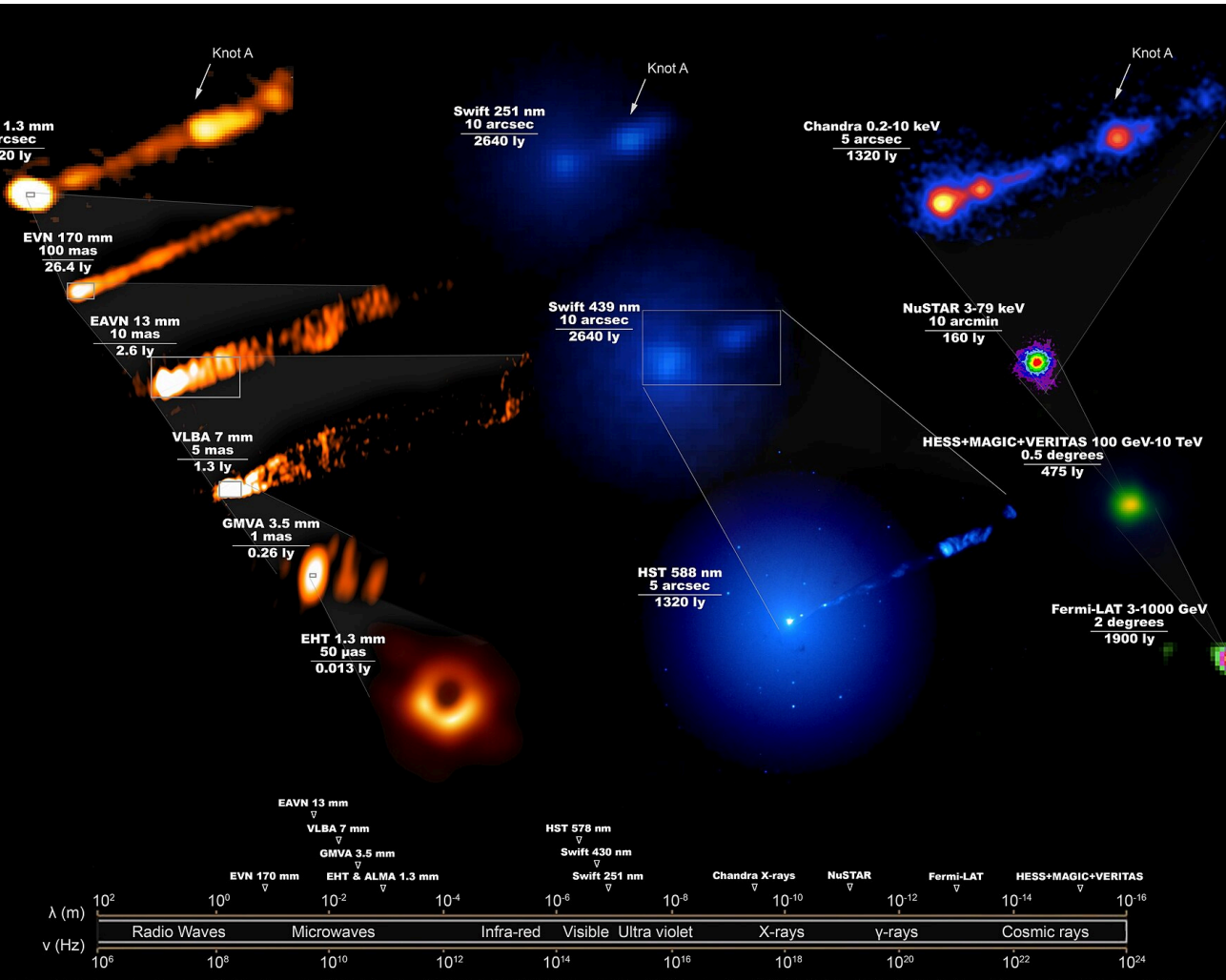
CHAPTER 16 · STARS

The H–R Diagram

> Plot two easily measured properties of stars against each other and they do not scatter randomly. They fall into narrow, sharply defined regions — and the pattern turns out to be the life story of every star that exists.

Around 1911, the Danish chemist-turned-astronomer Ejnar Hertzsprung plotted stellar brightness against colour. Two years later, and independently, the American Henry Norris Russell did the same. Both found the same thing, and it was not what anyone expected: the points were not scattered across the graph. Roughly ninety per cent of them lay along a single sweeping diagonal band.

The **Hertzsprung–Russell diagram** is the most important chart in stellar astronomy, and learning to read it is the closest thing this subject has to a rite of passage.

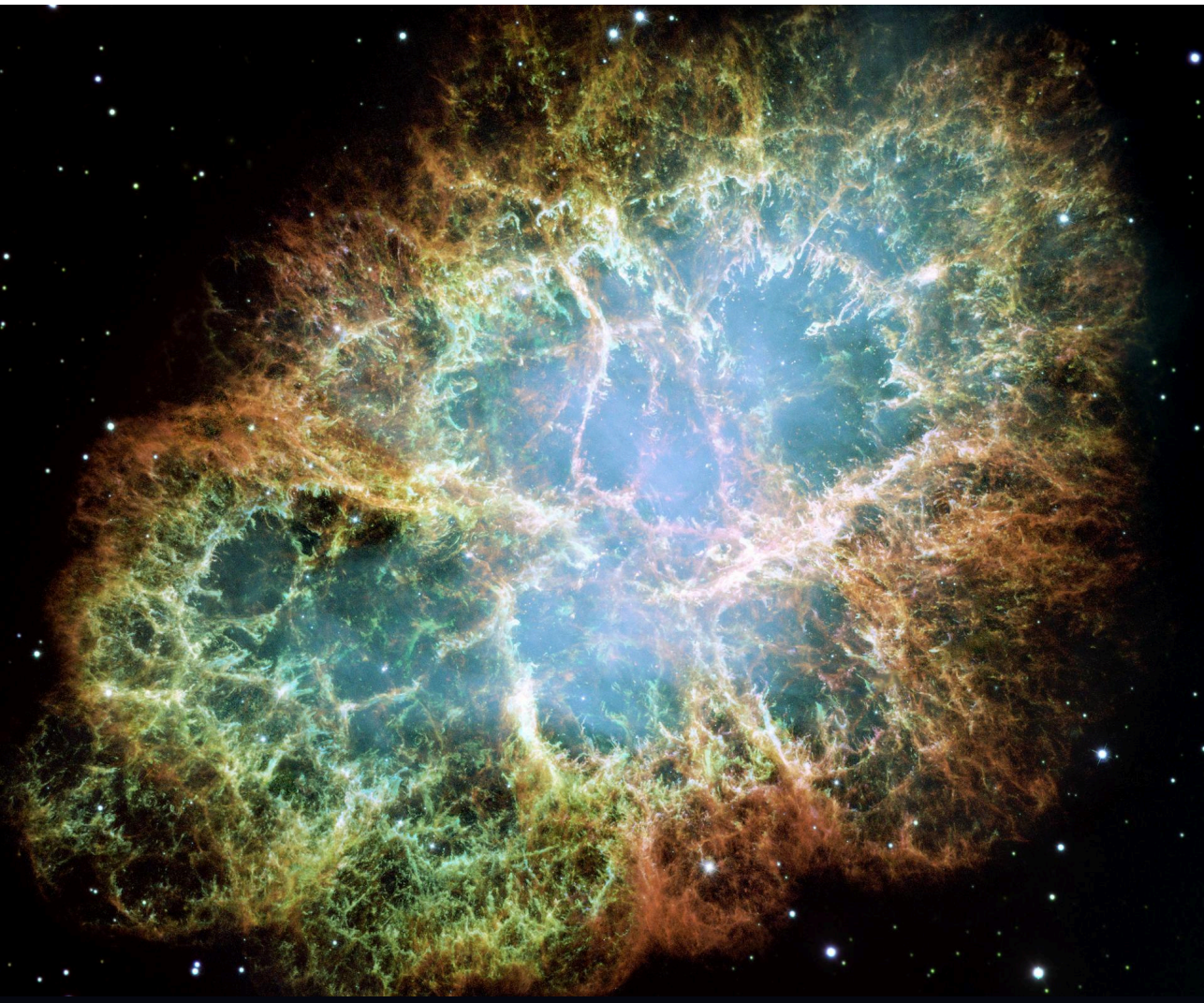


edit: The EHT Multi-wavelength Science Working Group; the EHT Collaboration; ALMA (ESO/NAOJ/NRAO); the EVN; the EAVN Collaboration; VLBA (NRAO); the GMVA; the Hubble Space Telescope; the Neil Gehrels Swift Observatory dra X-ray Observatory; the Nuclear Spectroscopic Telescope Array; the Fermi-LAT Collaboration; the H.E.S.S collaboration; the MAGIC collaboration; the VERITAS collaboration; NASA and ESA. Composition by J. C. Algaba

The photograph this chapter is about

M87*, the supermassive black hole at the centre of the galaxy Messier 87 — 6.5 billion solar masses, 55 million light-years away. The bright ring is light bent around the hole; the dark centre is the shadow, about 5.2 Schwarzschild radii across, exactly as general relativity predicts. The ring is brighter at the bottom because material there is moving towards us at a large fraction of the speed of light.

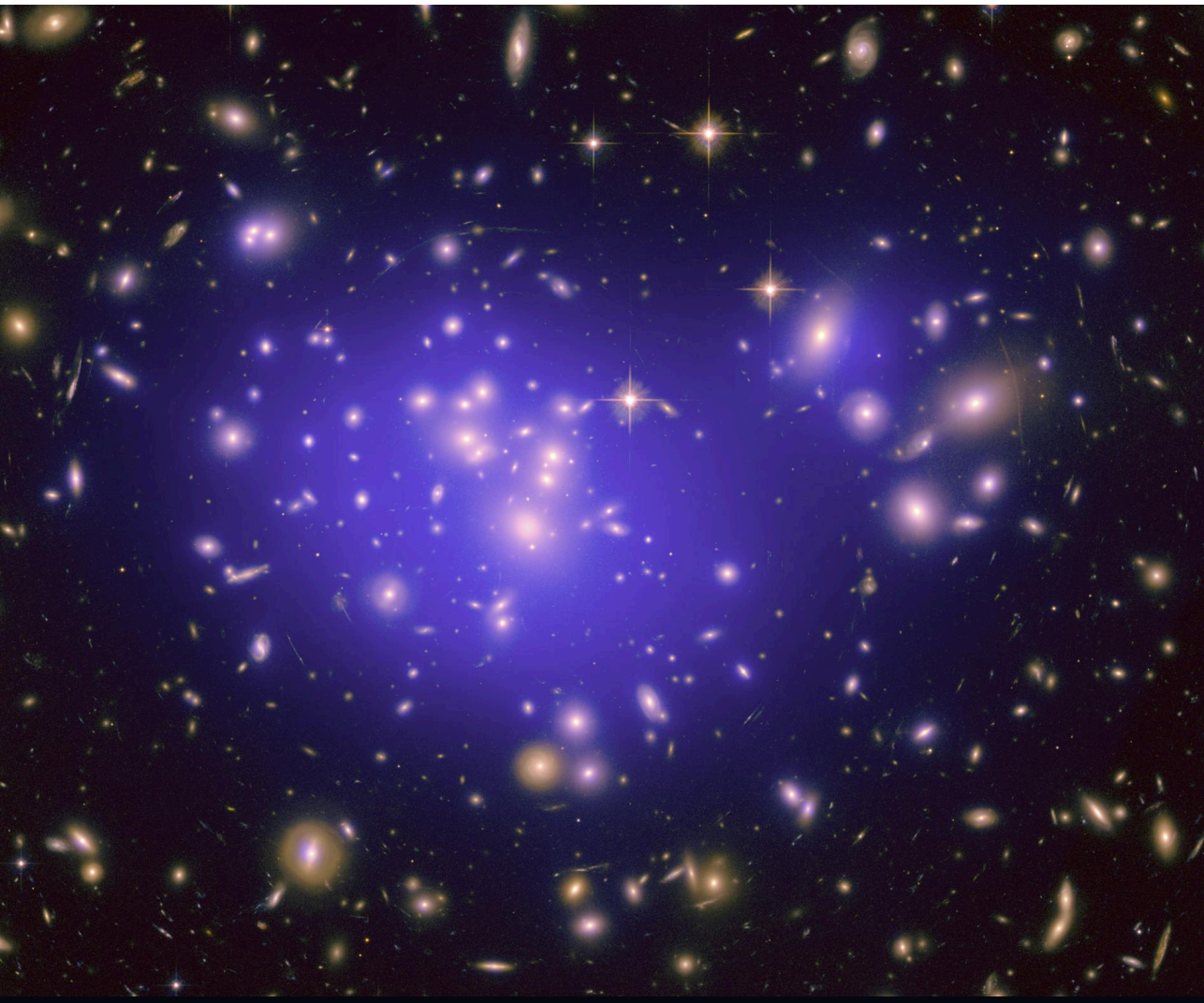
Credit: The EHT Multi-wavelength Science Working Group; the EHT Collaboration; ALMA (ESO/NAOJ/NRAO); the EVN; the EAVN Collaboration; VLBA (NRAO); the GMVA; the Hubble. CC BY 4.0.



What the Chinese saw in 1054

The Crab Nebula, 6,500 light-years away in Taurus. On 4 July 1054, court astronomers recorded a "guest star" here bright enough to be seen in daylight for 23 days. This is what is left: debris still expanding at about 1,500 km/s, wrapped around a neutron star that rotates 30 times a second. It is the only supernova remnant whose explosion date is known from written records.

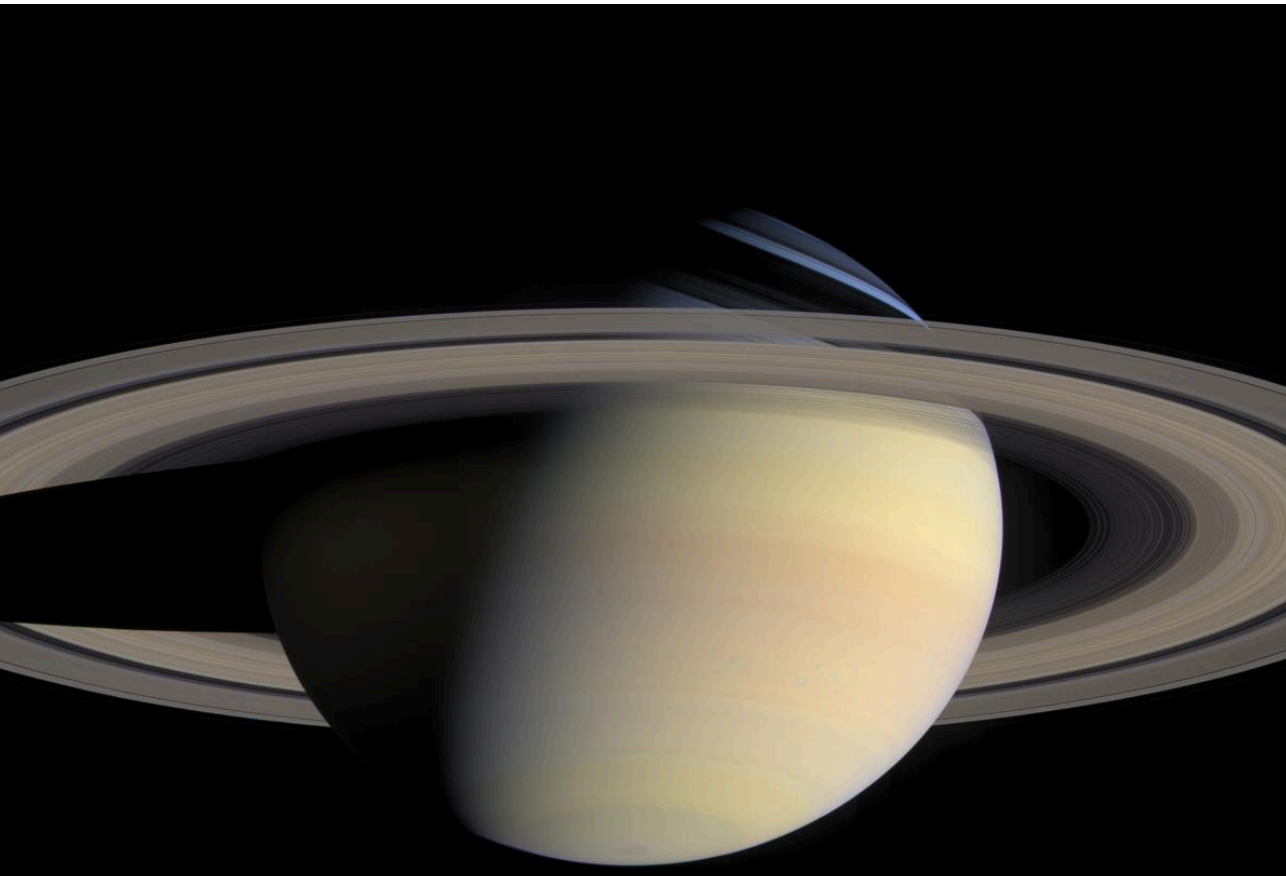
Credit: NASA/ESA/JPL/Arizona State Univ. NASA — free to use with credit.



Mass you cannot see, bending light you can

The galaxy cluster Abell 1689. The thin arcs scattered around the centre are not features of the cluster — they are **distorted images of galaxies far behind it**, smeared by the cluster's gravity acting as a lens. Measuring the distortion weighs the cluster, including everything invisible. The answer comes out roughly five times the mass of everything that shines.

Credit: GSFC. NASA — free to use with credit.



The Solar System's best argument for going and looking

Saturn photographed by Cassini, which orbited the planet from 2004 to 2017 and ended by deliberately burning up in its atmosphere to avoid contaminating the moons. The rings are almost pure water ice, tens of metres thick and 280,000 km wide — proportionally far thinner than a sheet of paper the size of a cricket ground.

Credit: NASA/JPL/Space Science Institute. NASA — free to use with credit.

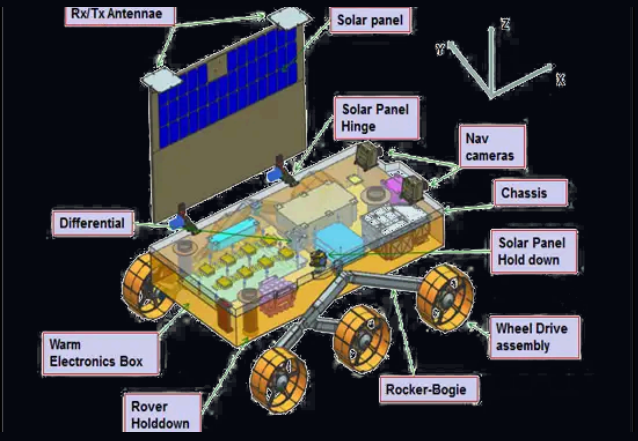
Chandrayaan-3 leaves the pad

LVM3-M4 lifting off from the Second Launch Pad at Sriharikota on 14 July 2023. Forty-one days later its lander touched down near the lunar south pole, making India the fourth country to land on the Moon and the first anywhere near that terrain. The vehicle is the heaviest India operates — 640 tonnes at lift-off, with two solid boosters, a liquid core and a cryogenic upper stage.

Credit: Indian Space Research Organisation / derivative work: UnpetitproleX. GODL-India.

India looks up

Four facilities, from a launch pad on the Bay of Bengal to a telescope at 4,500 metres in Ladakh.



Pragyan, laid out
— ISRO's own diagram of the Chandrayaan-3 rover: 26 kg, solar powered, six wheels.

PSLV at Sriharikota
— ISRO's workhorse, with over 55 successful launches.

The GMRT, near Pune
— thirty 45-metre dishes over 25 km; world-class at metre wavelengths.

Hanle, Ladakh
— the Indian Astronomical Observatory at 4,500 m, one of the highest on Earth.

Indian Space Research Organisation. GODL-India. · Indian Space Research Organisation. GODL-India. · Svenlafe (Wikimedia Commons). CC BY-SA 3.0. · Alin Dev. Public domain.

The new space industry

Private companies now build and fly launch vehicles that only governments once could.

Vikram-S, November 2022
— Skyroot's vehicle, the first privately built Indian rocket to reach space.

Falcon 9 lands
— reusing the first stage cut launch costs roughly sevenfold.

Starbase, Texas
— SpaceX's Starship tower, designed for far heavier payloads still.

Rocket Lab Electron
— small dedicated launches, frequent enough to make student satellites realistic.

ISRO. GODL-India. · SpaceX. CC0. · Alexander Hatley. CC BY 2.0. · NASA Kennedy Space Center / Rocket Lab. Public domain.

CHAPTER 37 · YOUR TURN

How to Become an Astrophysicist

> A specific, honest plan from Class 9 onwards — including the parts nobody mentions, such as how few permanent jobs there are and what else the training is good for.

This chapter is deliberately practical. It also tries to be honest, which means it contains some discouraging numbers. Read them as information rather than as advice to stop: people who go in knowing the shape of the path do considerably better than people who find out at 26.

Right now — Class 9 and 10

Nothing you do at this stage is an entrance exam. What matters is building three things: fluency, evidence of genuine interest, and the habit of finishing.

Do the mathematics from Chapter 36 until it is automatic. This is the single highest- return activity available to you, and it is almost entirely within your school syllabus.

Enter the olympiad pipeline. In India the astronomy route runs through HBCSE: **NSEA** (National Standard Examination in Astronomy, usually taken in Class 11 or 12) → **INAO** → an orientation camp → the national team for the **International Olympiad on Astronomy and Astrophysics**. Class 9 is the right time to start preparing, not the right time to sit it. There is also NSEP for physics and the RMO/INMO mathematics pipeline, and doing well in any of these is taken seriously by every institute in the country. Check current dates and eligibility on the HBCSE site, because the schemes change.

Learn Python properly. Chapter 36 lists four projects. Do them.

Actually look at the sky. Learn ten constellations. Find Andromeda. Watch Jupiter's moons through binoculars over four nights and see them move. A student who has

CHAPTER 38 · YOUR TURN

Ten Questions Waiting For You

> Everything in this book is settled enough to teach. These ten are not. Each is open, each is being worked on now, and several will be answered within your career.

A textbook can give the impression that a subject is finished — that the work was done by people with statues and the rest is revision. Astrophysics is not remotely finished. What follows is a list of things nobody knows, ordered roughly by how likely they are to fall in the next few decades.

1 · WHAT IS DARK MATTER MADE OF?

Five-sixths of the matter in the universe, detected six independent ways, and completely unidentified. WIMP searches have excluded most of the once-favoured parameter space; axions are now the leading candidate, with primordial black holes and sterile neutrinos still alive. **It is also possible that all of it is wrong and gravity needs modifying** — although the Bullet Cluster makes that very hard. Chapter 26.

2 · WHAT IS DARK ENERGY, AND WHY IS IT SO ABSURDLY SMALL?

Sixty-eight per cent of the universe. The simplest model — a cosmological constant — is consistent with all data but disagrees with quantum field theory's estimate by a factor of 10^{120}, the worst prediction in physics. DESI's 2024–25 results hint that dark energy may be *weakening* with time, which would rule out a constant entirely and reopen the question of how the universe ends. Chapters 27 and 28.

DEDICATION

For the early learner — the one who asks the next question after the lesson has ended.

This book began with my own son. He is fourteen, and he has decided he wants to be an astrophysicist. I went looking for something that would take that decision seriously — real physics, real numbers, an honest account of the work — and found plenty written down to him, and little written as though he might one day do it.

So we made this instead. Almost everything in these pages was discovered by someone who began exactly where you are: curious, under-equipped, and unwilling to accept "nobody knows" as the end of a conversation. Chandrasekhar was nineteen, on a boat from Madras. Jocelyn Bell read thirty metres of chart paper a day by eye. Cecilia Payne was told her greatest result was impossible, and published it anyway.

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And if somewhere in it you meet a question that will not leave you alone — follow it. That is how every discovery described here began.

Girish Manchanda

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