



PAUL MURDIN

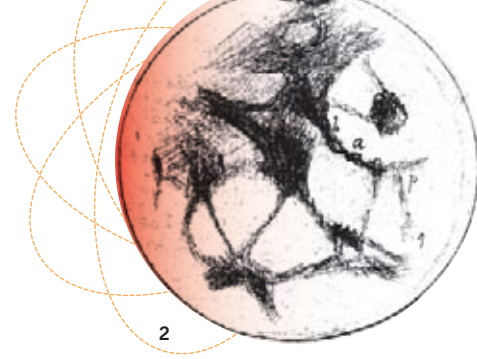
Secrets *of the* Universe

HOW WE DISCOVERED THE COSMOS

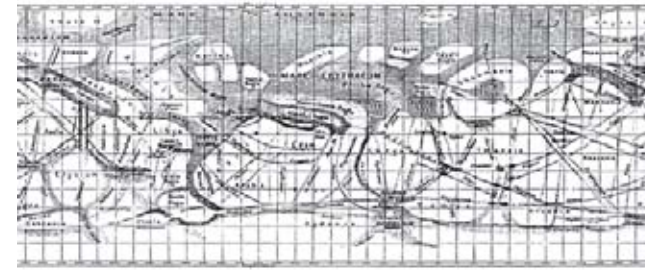
Mars

The dying planet

Why did Mars – the planet in the Solar System most similar to the Earth – fail to sustain life? Early science-fiction writers portrayed Mars as a dying planet inhabited by desperate, warlike aliens. We now know that Mars suffered a global climatic catastrophe early in its development.



The Climate of Mars



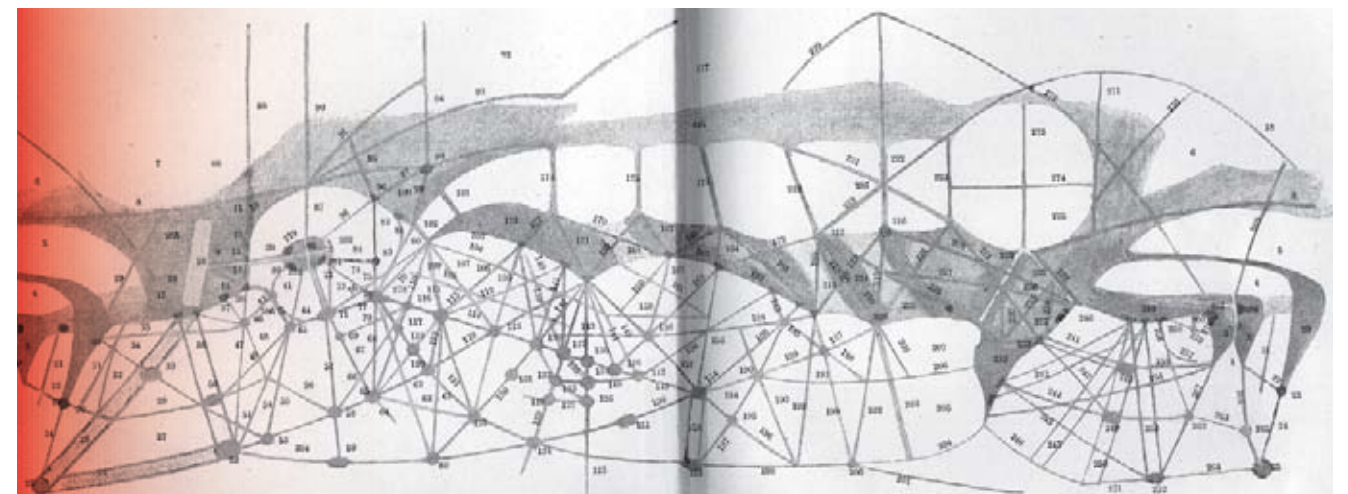
- 1 Mars pictured by the Viking Orbiter in 1976** The hazy red lines over the horizon are due to dust in the Martian atmosphere.
- 2 Mars as sketched by Giovanni Schiaparelli** in his observation notebook on 26 December 1879. He measured the positions of features that he labelled with letters to transcribe the features onto a map (see Fig. 3).
- 3 Giovanni Schiaparelli's map of Mars**, compiled between 1877 and 1886. Some of the names that he gave to surface markings are still in use.
- 4 Percival Lowell's map of Mars** Lowell made Schiaparelli's 'canals' straighter and thinner, adding unwarranted credibility to the idea that they were artificial irrigation canals carrying water between darker 'cultivated' areas.

Mars is the red planet, the fourth from the Sun. It is smaller, colder and drier than the Earth and has a much thinner atmosphere. Galileo saw the disc of Mars with his telescope, but could not see its surface markings, which were discovered in 1659 by the Dutch astronomer Christiaan Huygens, who determined that Mars had a rotation period of about 24 hours – its days were almost the same length as the Earth's. In 1666 the Italian-French astronomer Gian Cassini discovered Mars's polar caps, which were assumed to be ice caps like the Earth's; 350 years later, space probes confirmed that the polar caps are deposits of ice and dry ice, 2 to 3 km thick.

In 1840 the German banker and amateur astronomer Wilhelm Beer and his colleague Johann H. von Madler made the first maps of Mars, showing dark areas that seemed variable in colour and intensity. Initially these dark areas were thought to be seas, but the French astronomer Emmanuel Liais suggested in 1860 that they could be large patches of vegetation, showing seasonal variations in colour. When Giovanni Schiaparelli mapped Mars in 1877, he labelled the dark patches as 'continents', 'islands' and 'bays', linked by numerous long, straight *canali* ('channels').

The *canali* led to speculation that Mars was inhabited by intelligent life. The American astronomer Percival Lowell (**13**) interpreted the *canali* as artificial canals, built as an irrigation system. Although other astronomers scorned Schiaparelli's overly detailed maps as works of fantasy, his vision of Mars took hold in science fiction and popular culture, where the planet was depicted as an old world, inhabited by warlike aliens looking to colonize the Earth because, despite their efforts at irrigation, their own world was dying. But Turkish-born French astronomer Eugenios Antoniadi proposed that the canals were only psychological interpretations of faint, blotchy structures seen through the terrestrial atmosphere. In 1903, the Greenwich astronomer Edward Maunder used schoolboys as test subjects to demonstrate that a defective telescope causes an area with many point-like features (such as a group of craters) to appear as a network of lines.

During a fly-by mission in 1964, the US space probe Mariner 4 discovered that Mars's surface is indeed heavily cratered. Mars has no tectonic plates, so its surface is not regularly churned over in the same way as the Earth's, and weather erosion of the landscape is minimal because of the



Supernova 1987A

The whisper and the vision



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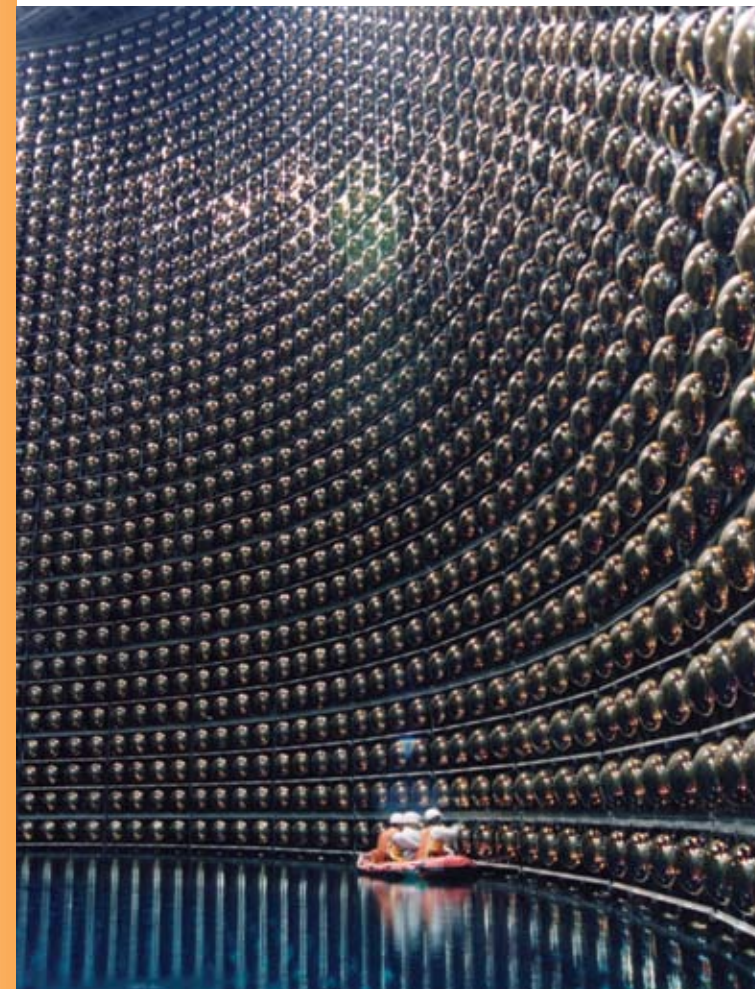
Most supernovae are in distant galaxies and therefore rather faint. The appearance of a bright, nearby supernova like Tycho Brahe's 'new star' is always an occasion for excitement, and a source of valuable astronomical information. The most recent supernova that could be seen on Earth with the unaided eye was called SN 1987A (indicating that it was the first supernova of 1987). In 2005 astronomers studying the supernova witnessed an astoundingly beautiful and unprecedented event.

Supernova 1987A



- Supernova 1987A in the Large Magellanic Cloud** SN 1987A is the very bright star in the middle right, then visible with the unaided eye. The massive nebula in the left half of the picture is the Tarantula Nebula, full of bright, massive, relatively young stars similar to the one that exploded.
- SN 1987A and its precursor** This 'before and after' pair of pictures made by David Malin with the Anglo-Australian Telescope was used to identify the star that exploded in 1987. The cross-shape on the image of the supernova was generated by structures that support the camera within the telescope, which are usually regarded as a nuisance by astronomers, but in this case helped to locate the massively overexposed supernova image on the fainter background stars and to make the identification firm.
- Kamiokande (Kamioka Neutron Decay Experiment)** was a neutrino detector that detected neutrinos from SN 1987A. In 1996 it was superseded by a larger detector called SuperKamiokande (shown here), a cylindrical tank, 40 metres tall and 40 metres in diameter, filled with 50 million litres of purified water. Hemispherical photomultiplier tubes lining its inside wall catch flashes of light produced when neutrinos are absorbed by the water. Technical staff access the photomultipliers by boat after draining the water.

2



Supernova 1987A was discovered by Ian Shelton at 05:40 GMT on 24 February 1987 at Las Campanas Observatory in Chile. He had taken a photograph of the Large Magellanic Cloud (54) and developed it before going to bed. To his surprise there was a black spot on the photograph, which at first he thought was some sort of blemish. Then he realised that it was actually a bright star where none was indicated on the charts. The spot was a supernova.

Shelton wanted to share his discovery with someone and went to another telescope to talk to his colleagues. A fellow astronomer, Oscar Duhalde, mentioned that he had seen the star earlier that night with his own eyes, while strolling about outside during a break, but when he returned to the telescope he had been immediately harassed by another researcher about some problem with the equipment and had forgotten to mention the strange object. Later it transpired that the supernova had in fact been photographed the day before by astronomer Rob McNaught in Australia, but he put off looking at his photographs and thus failed to discover the nova before Shelton.

Shelton's discovery made it possible to identify the first neutrino particles from a supernova. When a Type II supernova collapses, its protons and electrons are jammed so close

3



1

The discovery of pulsars was a serendipitous by-product of an investigation with completely different aims, which was intended to study the twinkling of radio stars. Then a young PhD student noticed an odd ‘bit of scruff’ on a data chart. Among the twinkling stars was a strange astronomical object that had never before been seen.



2



3

1 Crab Nebula and its pulsar The Hubble Space Telescope and the Chandra Observatory combined in 2001 to make an optical and X-ray image of the centre of the Crab Nebula, showing how the pulsar (central, brighter star) generates concentric bright rings around a central cavity. A turbulent jet lies perpendicular to the rings (lower left to upper right corners of the picture).

2 Jocelyn Bell and the 4½ acre telescope in Cambridge with which she observed twinkling quasars and discovered pulsars.

3 Antony Hewish (left) and Martin Ryle shared the Nobel Prize in 1974 for the discovery of pulsars and the development of radio astronomy techniques.

In the 1960s radio-astronomer Antony Hewish and his colleagues in Cambridge built a radio telescope known (in splendidly archaic units) as the ‘4½ Acre Telescope’. The telescope was intended to look at the scintillation, or twinkling, of radio ‘stars’. The twinkling of ordinary stars is caused by irregularities in the Earth’s atmosphere; the scintillation of radio stars is caused by irregularities in the plasma from the Sun that pervades the Solar System. Radio sources scintillate if they appear point-like, which is often the case if they are a long way away. Hewish’s telescope was meant to identify twinkling radio sources that were quasars, exploding black holes, embedded in galaxies at vast distances. To see the twinkles, the telescope had to respond to changes in a radio source’s intensity on a very short time scale, which required a large collecting area – hence the 4½ acre surface of wire netting that covered the stationary radio telescope. The enormous ‘mirror’ looked straight up and surveyed a strip of the sky as it rotated above the telescope.

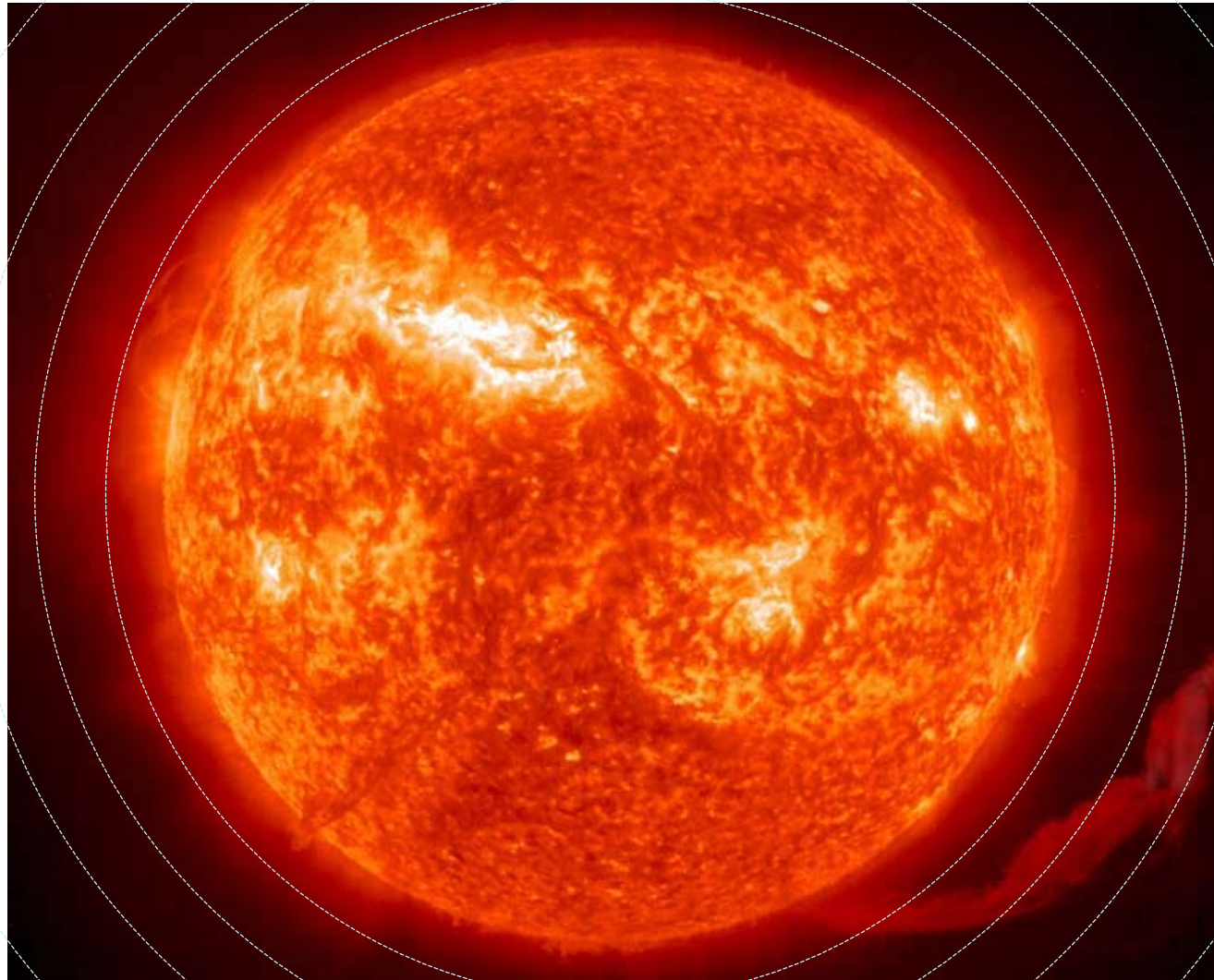
By 1967 the telescope was ready and Hewish assigned a PhD student, Jocelyn Bell, to the job of analysing the data. She surveyed a 400-foot strip of chart paper for signs of the scintillating radio sources, rejecting terrestrial radio interference such as aircraft or TV stations. In October 1967 she noticed what she called ‘a bit of scruff’. It was passing through the beam of the radio telescope in the middle of the night when scintillation caused by the Sun was at a minimum, which pointed to it being terrestrial interference. However, Bell was not convinced: ‘Sometimes within the record there were signals that I could not quite classify. They weren’t either twinkling or manmade interference. I began to remember that I had seen this particular bit of scruff before ...’

Bell and Hewish decided to use a faster recorder to get a clearer view. By November she had got a satisfactory recording which showed clearly that the ‘scruff’ was a burst of pulses almost exactly 1.5 seconds apart, similar to many kinds of terrestrial interference. When Bell told Hewish he said ‘Oh that settles it. It must be man-made.’ Nothing of the sort had been seen in astrophysics before that varied so quickly and with such regularity.

However, as Bell studied the ‘bit of scruff’ further, it became obvious that it wasn’t man-made. It stayed exactly in the same position in the sky, so it was celestial. It exhibited no signs of motion, so it was not in orbit around the Sun – it lay beyond the Solar System, among the stars. Bell had soon discovered three more sources of ‘scruff’, which she

The Energy of the Sun and Stars

Discovery of nuclear fusion



1

How does the Sun shine, and how long has it been shining? Could the fuel ever run out? These questions have perplexed scientists since they first began to comprehend the awesome size and age of the Solar System. The secrets of the Sun's power system – for better or for worse – have made nuclear technology possible on Earth.

As soon as the scale of the Solar System and the distances of the stars became apparent, it became clear that the amount of heat and light emitted by the Sun and stars was extraordinarily great. When astronomers calculated the mass of the Sun using Newton's laws of gravity, it too was enormous. If the Sun is a kind of a normal fire, providing power by chemical means (for example, by chemically combining carbon and oxygen to make carbon dioxide, as happens when wood or coal is burnt), there is a lot of fuel available to feed the fire that we see. But for how long could the fuel last?

Presumably the Sun is at least as old as the Earth – the one depends on the other. In 1650, to determine the age of the Earth, Archbishop James Ussher published an analysis of the chronology of events in the Bible, which was reproduced in the standard edition of the Bible used in England for centuries and so became widely accepted. He set the date of the creation of

the Earth at 4004 BCE. If the Sun really had been created along with the Earth just 6000 years ago and chemical energy was the source of its power, the amount of material consumed as the Sun shone was only a small fraction of its total mass. But in the 19th century, British geologists like Charles Lyell and John Phillips began to estimate that the Earth was actually millions of years old, based on calculations of how long it would take for sedimentary rocks to be laid down from sea deposits or for rocks to be eroded away (20).

This created a problem for the idea that chemical energy was the source of the Sun's power – a conventional fire or chemical reaction would not be able to continue burning for millions of years. The discrepancy was made worse when calculations by physicist Lord Kelvin and biologist Thomas Huxley suggested that the Earth was actually hundreds of millions of years old. Even this seemed short, considering

1 The Sun The only star whose surface we can view in any detail, the Sun has a surface temperature of 6,000 °K. In this ultraviolet image from the SOHO satellite, prominences leap and arch above the surface at temperatures even ten times higher. The radiation and the motions of the outer part of the Sun are driven by nuclear energy generated deep in its inner core.

2 Pegwell Bay: a recollection of October 5th, 1858 by William Dyce (1858) The chalk cliffs of the coast in the south-east of England show strata that were laid down over many millions of years. In the upper left of the painting is Comet Donati; both it and the Sun, setting from view beyond the horizon, must have been shining for at least as long. Dyce (who depicts himself standing at the foot of the cliff at the extreme right) contrasts their vast ages with the brief lifespans of the people who comb the beach for small treasures and paint on fragile canvas, oblivious to the evidence of the near-eternal things around them.



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The Crab Nebula

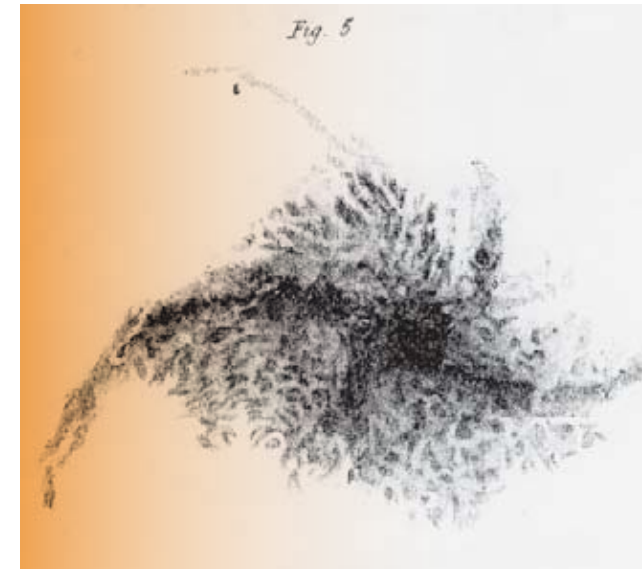
A supernova remnant



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Chinese imperial astrologers and Native Americans in the Southwestern United States recorded the appearance of a 'new star' in 1054. 1,000 years later, Knut Lundmark and Edwin Hubble realized that these early observers had witnessed the birth of the Crab Nebula, a magnificent supernova remnant that has intrigued astronomers since it was first mapped in the 18th-century.

The Crab Nebula



2

- 1 The Crab Nebula** An ellipsoidal network of red and orange filaments is what remains of the star that exploded in 1054. The ellipsoid encloses a luminous white glow from electrons trapped inside. They are injected into the nebula by the pulsar at the centre of this supernova remnant.
- 2 The sketch that named the Crab.** Made with Lord Rosse's 6-foot reflector in Ireland, the picture looks at first sight little like the nebula that we see on photographs, except that the mottling is reminiscent of the network of filaments.

Like the planet Uranus, the Crab Nebula was found as a result of a systematic whole-sky survey, conducted by an 18th-century British doctor, John Bevis, who had an observatory near London. In 1745 he compiled his observations into an atlas called *Uranographia Britannica*, but the etched plates were costly to produce and the printer went bankrupt before printing it so only a few proof copies survive. On the map of the constellation Taurus, near the star (zeta) Tauri, Bevis drew a patch to represent a misty nebula that he had discovered.

The French astronomer Charles Messier used a copy of Bevis's atlas on his search for the predicted return of Halley's Comet in 1758. He found another comet, a new one, which through Taurus and drew his attention the misty nebula. Comets and nebulae look much the same in a small telescope, so to



3

- 3 The 'Leviathan of Parsonstown'** Lord Rosse's massive 6-ft telescope at Parsonstown was slung on ropes and chains between two masonry walls. It could track for a limited time while viewing an object that was crossing the meridian (due south). Ladders gave access to the eyepieces. Lieutenant-Colonel Harry J Watson, the project leader of the telescope, is seated on a ladder.

avoid confusion Messier, who was known as the 'Ferret of the Comets', decided to make a list of known nebulae. The first item in Messier's catalogue was M1, Bevis's nebula, which became known as the 'Crab Nebula' after a weird sketch showed its 'claws'. The sketch had been made in the 1840s by William Parsons, the Earl of Rosse, after viewing the nebula through his 'Six-foot' telescope (the 'Leviathan of Parsonstown') at Birr Castle in Ireland. Modern pictures show the nebula as a generally oval shape of white light surrounded by a lacy network of filaments. The filaments are fragments of the body of an exploding star, and the white light comes from electrons spiralling around the star's magnetic field within the filaments.

The event that created the nebula was identified by the Swedish astronomer Knut Lundmark in 1931 as he listed the

Interstellar Dust

Curtains of diamonds and graphite that hide the discoveries beyond

Imagine a cathedral, with a shaft of sunlight shining through the window. Specks of dust are floating in the sunlight. Imagine the cathedral cleaned so scrupulously that there is only one speck of dust inside it. This represents the density of grains of dust that float in interstellar space, oxygen- and carbon-rich material expelled from supernovae and the interiors of red giant stars. Interstellar space is indeed filled with stardust.

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Interstellar Dust

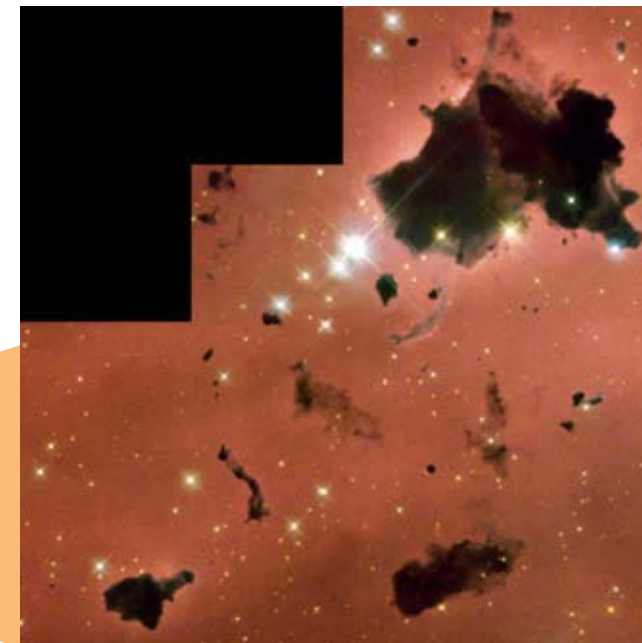


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- 1 North America Nebula (NGC 7000)** is an emission nebula (left), shaped like the continent of North America. The 'Gulf of Mexico' is a dark cloud that appears to separate the North America Nebula from the Pelican Nebula (IC5070 and IC5067, right), but actually lies in front of both, which are connected.
- 2 Robert Trumpler** The Swiss-born American astronomer, known for his work on star clusters.
- 3 Edward Barnard** American photographer-turned-astronomer, who made a number of discoveries by application of photography to astronomy and compiled a catalogue of dark nebulae, now known by his name.
- 4 Thackeray's globules** IC 2944 is a star-forming region in Centaurus. Silhouetted on the nebula are dense, opaque clouds of interstellar dust, first spotted by South African astronomer A. D. Thackeray in 1950. Thackeray's globules are shredded by intense ultraviolet radiation from the young, hot stars, and might disperse, rather than forming new stars themselves.



4

There is not much dust in space but there is a lot of space. The number of cathedral-sized volumes that stack one behind another in the line of sight to a star is very large, so the individual dust grains can accumulate to an opaque screen.

In 1847, the Prussian astronomer Wilhelm Struve, who was working at the Tartu Observatory in what is now Estonia, first proposed that something inhabited the space between the stars. He had discovered that the number of visible stars per unit volume in the Galaxy decreases with distance from the Sun, and therefore inferred that the light from distant stars was being absorbed by something in space. More evidence for the presence of this interstellar substance was discovered in 1909 by Dutch astronomer Jacobus Kapteyn, when he found that bluer stars moved across the sky more quickly than redder ones. Fast-moving stars are on average closer than slower ones, so Kapteyn concluded that the more distant stars were being reddened by a larger amount of interstellar dust, much as dust in the lower atmosphere of the Earth reddens the setting Sun. Similar work was carried out in 1930 by Robert Trumpler, then at the Lick Observatory, on clusters of stars (**40**): he found that the clusters with smaller diameters are more distant than larger ones, but still fainter than their distances alone would account for, because some of their light is absorbed by interstellar dust.

In the first two decades of the 20th century, the American astronomer Edward Emerson Barnard carried out a systematic programme to photograph our Galaxy. In his atlas of the Milky Way he identified distinct dark 'holes' in the star clouds. Astronomers since William Herschel had known of their existence, and for a long time thought they were true voids in the distribution of stars. But Barnard discovered that the holes were 'obscuring bodies nearest to us than the distant stars': dark clouds of unusually dense interstellar dust.

These dust clouds concentrate towards the plane of the Galaxy, which is why the Milky Way appears to be cleft along its central line when we view it edge-on from Earth (**03**). One of the most prominent clouds lies in the Southern Cross and is called the Coalsack. In the culture of some Australian aboriginal peoples, the Coalsack represents the head of an emu defined by the straggling form of the Milky Way between Crux and Scorpio, a unique 'constellation' made of dark dust clouds rather than stars.

Dust grains that lie near to bright stars can reflect starlight and form a 'reflection nebula'. There is a prominent example in the Pleiades star cluster, whose stars illuminate a dark cloud that they encountered as they coasted through space. The nature of this nebula, the first reflection nebula found, was

Secrets *of the* Universe

HOW WE DISCOVERED THE COSMOS

PAUL MURDIN

Discoveries in astronomy challenge our fundamental ideas about the universe. Where the astronomers of antiquity once spoke of fixed stars, we now speak of whirling galaxies and giant supernovae. Where we once thought Earth was the center of the universe, we now see it as a small planet among millions of other planetary systems, any number of which could also hold life. These dramatic shifts in our perspective hinge on thousands of individual discoveries: moments when it became clear to someone that some part of the universe—whether a planet or a supermassive black hole—was not as it once seemed.

Secrets of the Universe invites us to participate in these moments of revelation and wonder as scientists first experienced them. Renowned astronomer Paul Murdin here provides an ambitious and exciting overview of astronomy, conveying for newcomers and aficionados alike the most important discoveries of this science and introducing the many people who made them. Lavishly illustrated with more than 400 color images, the book outlines in seventy episodes what humankind has learned about the cosmos—and what scientists around the world are poised to learn in the coming decades. Arranged by types of discovery, it also provides an overarching narrative throughout that explains how the earliest ideas of the cosmos evolved into the cutting-edge astronomy we know today. Along the way, Murdin never forgets that science is a *human* endeavor, and that every discovery was the result of inspiration, hard work, or luck—usually all three.

The first section of *Secrets* explores discoveries made before the advent of the telescope, from stars and constellations to the position of our own sun. The second considers discoveries made within our own solar system, from the phases of Venus and the moons of Jupiter to the comets and asteroids at its distant frontier. The next section delves into discoveries of the dynamic universe, like gravitation, relativity, pulsars, and black holes. A fourth examines discoveries made within our own galaxy, from interstellar nebulae and supernovae to Cepheid variable stars and extrasolar planets. Next Murdin turns to discoveries made within the deepest recesses of the universe, like quasars, supermassive black holes, and gamma ray bursters. In the end, Murdin unveils where astronomy still teeters on the edge of discovery, considering dark matter and alien life.

Paul Murdin is a senior fellow at the Institute of Astronomy at the University of Cambridge and editor in chief of the *Encyclopedia of Astronomy and Astrophysics*. Formerly, he was head of astronomy at the Particle Physics and Astronomy Research Council and director of science at the British National Space Centre.

“Nowhere is the human exploration of our Universe, in all its beauty, complexity and connectedness, explained more elegantly than in this extraordinary book. From our little Earth to the far reaches of the Universe, Paul Murdin sheds light on the darkness.”

GEOFF MARCY, University of California, Berkeley

“A great read—full of interesting stories and snippets, and wonderfully illustrated—with a novel approach that allows one to take it in bite-sized pieces. An essential addition to any library.”

JOCELYN BELL BURNELL, University of Oxford

“In this exquisitely illustrated book, Paul Murdin describes our current conceptions of the cosmos and how they have emerged, engagingly portraying the interplay of astronomy, over many centuries, with literature, art, culture and technology.”

MARTIN REES, Astronomer Royal

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