opening extract from

Big Numbers

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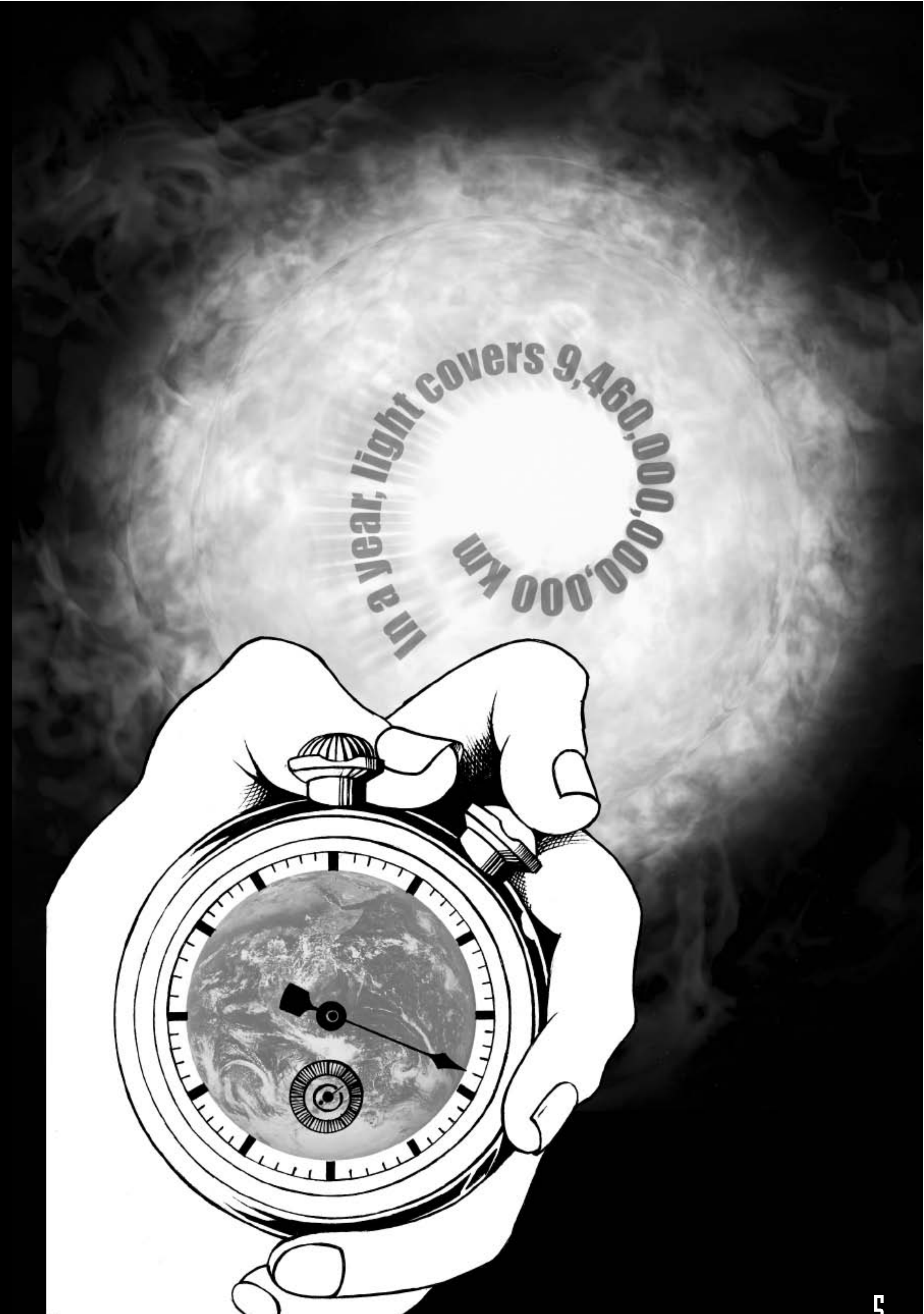
The scale of space

Space is so big that astronomers have to use special kinds of measurements to describe how far away things are. On Earth, 1,000 kilometres would be a long distance. But a beam of light covers 300,000 kilometres in a single second. The speed of light is always the same, everywhere in space, so it's used to measure distances across the Universe. The Sun is 150 million kilometres away from us, and light covers that distance in 499 seconds. So the distance from the Earth to the Sun can be described as 499 light seconds, or 8.3 light minutes. In a year, light covers 9,460,000,000,000 km. This distance is known as a light year – a light year is a measurement of *distance*, not a measurement of time.

Light years are useful for measuring distances to other stars. The nearest star to the Sun is 4.29 light years away. This looks like a small number when we measure in light years, but it's definitely a big number – 405,834,000,000,000 km – when we measure in everyday units. It's always important to choose the right units when measuring things. It would take a gigantic amount of numbers to measure distances to stars in kilometres, so these vast distances are measured in light years. If we tried to measure distances on Earth in light years, it would mean that instead of saying that the walk to school is 3 km long, we could say that it is 0.00001 light seconds long!



The length of light

Light travels as waves, like ripples on a pond. But the wavelength of light is much smaller than the wavelength of ripples on water. The wavelength of light is related to its colour. Violet light, at one end of the rainbow spectrum, has a wavelength of about 380 billionths of a metre (0.00000038 m, or 3.8×10^{-7} m). Red light, at the other end of the spectrum that is visible to our eyes, has a wavelength of about 750 billionths of a metre (7.5×10^{-7} m). Light waves are made of varying electric and magnetic fields, and are part of a much larger electromagnetic spectrum which extends to longer and shorter wavelengths than visible light. The longer wavelengths are called infrared and radio waves. In principle, they can be indefinitely long, and radio waves with wavelengths of hundreds of kilometres are nothing special. Electromagnetic radiation with wavelengths shorter than visible light is known as ultraviolet light, X-rays and gamma radiation. Any electromagnetic waves shorter than 0.1 billionths of a metre (1×10^{-10} m) is gamma radiation. Gamma rays with wavelengths as short as 10^{-14} m (0.00000000000001 m) are produced in hypernovae (see pages 32–3).

1 nanometre (nm) = one billionth of a metre

X-rays: Between 0.1 and 10 nanometres.

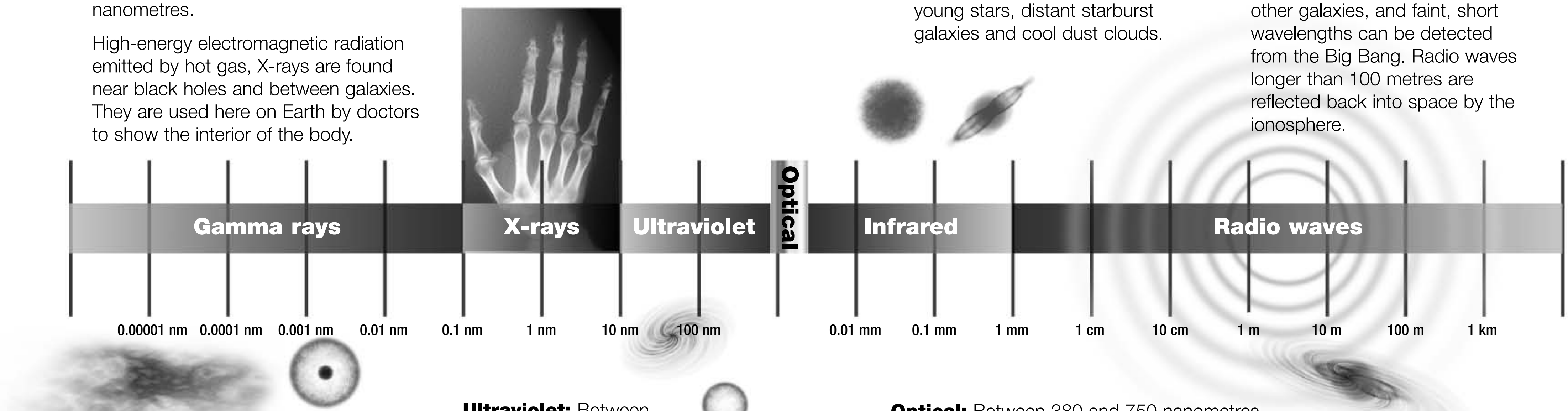
High-energy electromagnetic radiation emitted by hot gas, X-rays are found near black holes and between galaxies. They are used here on Earth by doctors to show the interior of the body.

Infrared: Between 750 nanometres and 1 millimetre.

As the name suggests, infrared lies just beyond visible red light. It is emitted by jets of gas from young stars, distant starburst galaxies and cool dust clouds.

Radio waves: Longer than 1 millimetre.

Radio waves are emitted by hot clouds of interstellar gas, hydrogen in the Milky Way and other galaxies, and faint, short wavelengths can be detected from the Big Bang. Radio waves longer than 100 metres are reflected back into space by the ionosphere.



Gamma rays: Less than 0.1 nanometres.

The most energetic form of radiation, gamma rays are emitted by interstellar gas clouds, neutron star collisions, supernovae.

Ultraviolet: Between 10 and 380 nanometres.

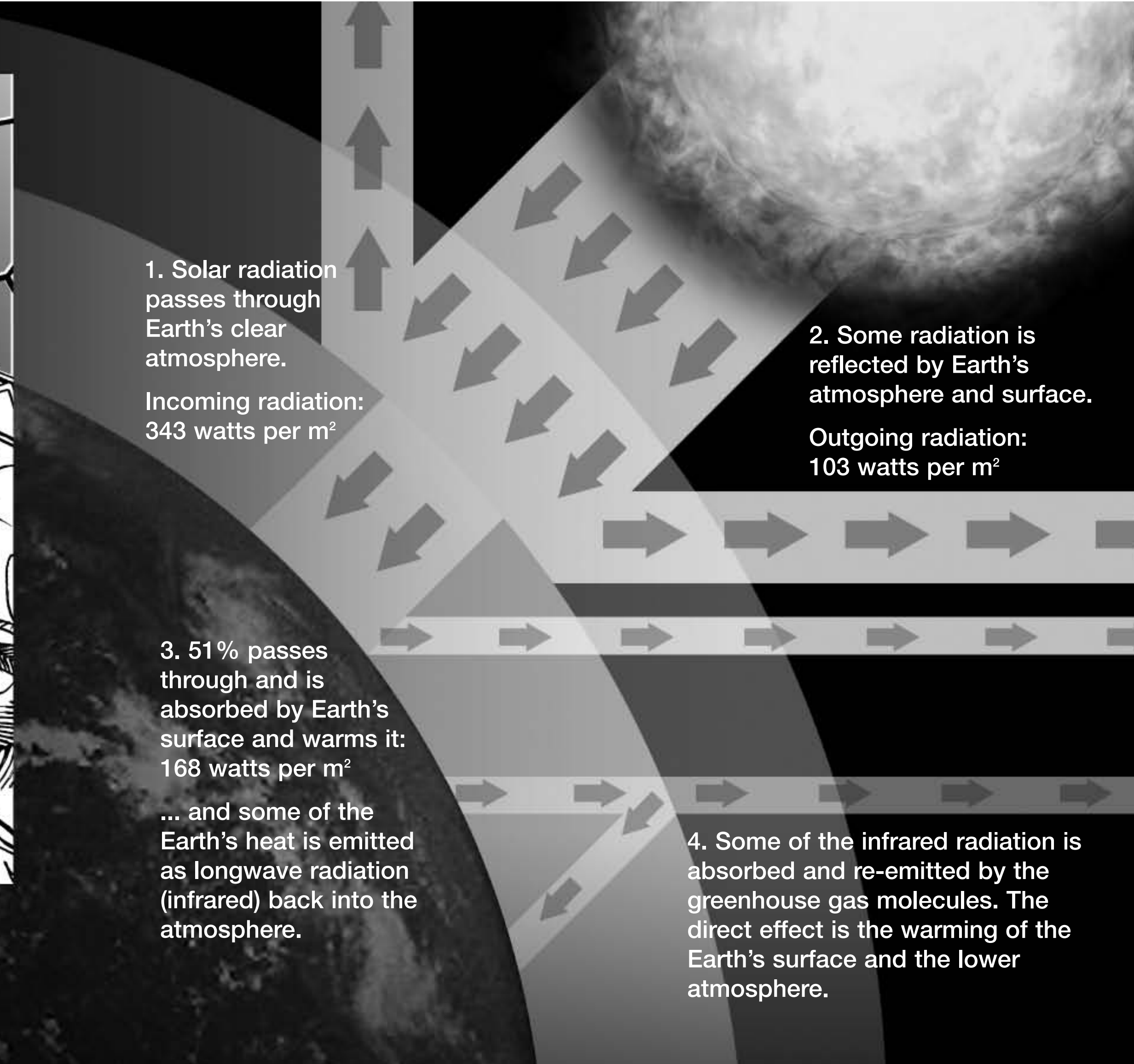
Very hot stars release most of the energy at these wavelengths. The Earth's atmosphere protects us from most of the Sun's harmful ultraviolet radiation.

Optical: Between 380 and 750 nanometres.

This is light we see, which is made up of seven colours: red, orange, yellow, green, blue, indigo and violet. Their order in the spectrum can be remembered using this phrase: **R**ichard **O**f **Y**ork **G**ave **B**attle **I**n **V**ain.

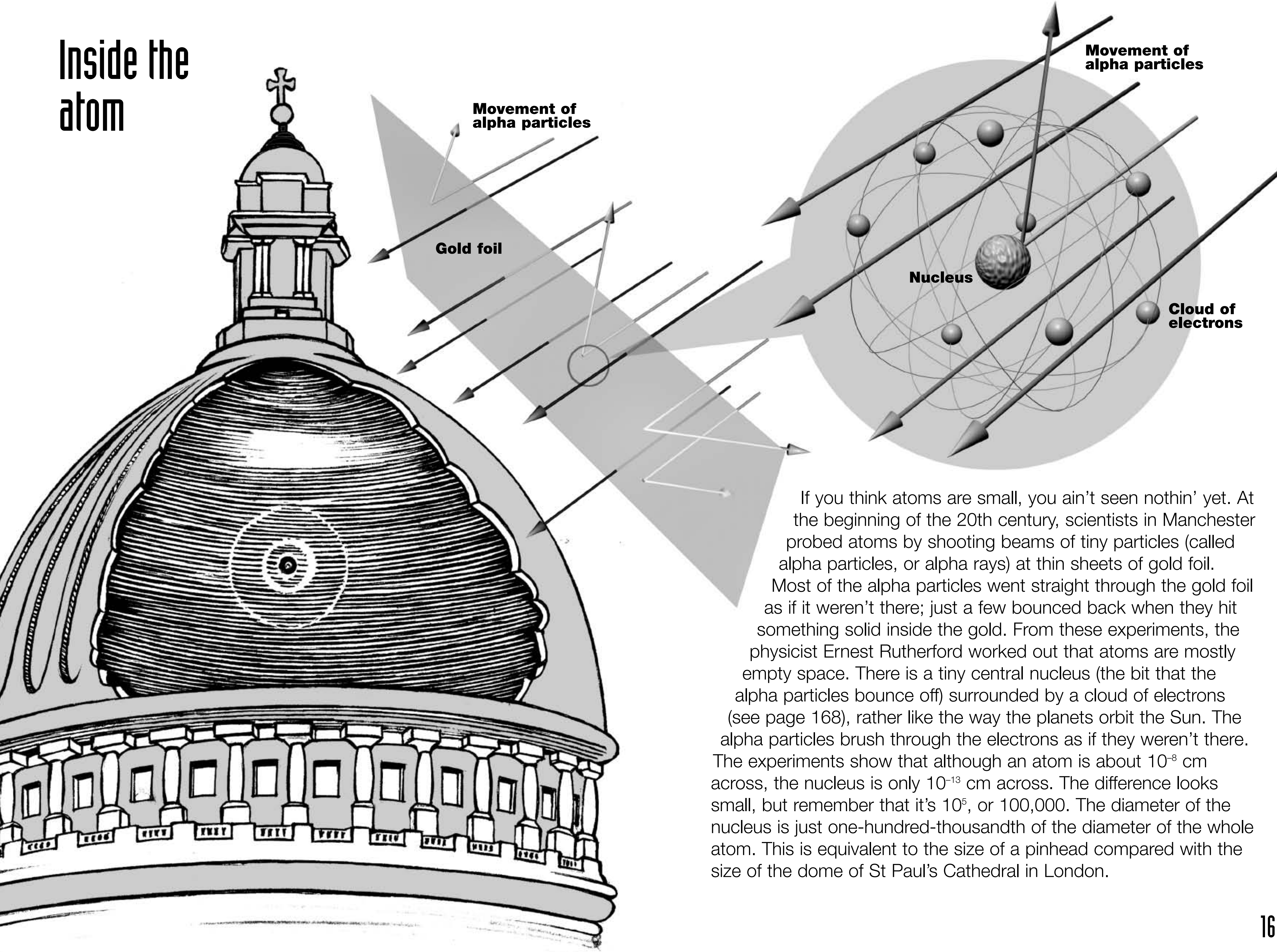
Our living planet

The atmosphere of Venus is so thick that it contains nearly a hundred times as much gas as the atmosphere of Earth. This gas is mostly carbon dioxide. On Earth, just 0.035% of the atmosphere is carbon dioxide. But there is almost exactly as much carbon dioxide as there is in the air of Venus locked up in carbonate rocks, like limestone, on Earth. It got there because carbon dioxide dissolves in the sea and rainwater, and from there it reacts with other chemicals to form carbonate rocks. Without water, there would be no carbonates. There are no seas on Venus, and no water in its atmosphere, so all of its carbon dioxide stays in the air.



Carbon dioxide traps heat from the Sun by the greenhouse effect. When there is more carbon dioxide, the world is warmer. Astronomers know that in the past 3.6 billion years the Sun has got 25% hotter. But geologists know that the temperature stayed more or less the same on Earth for all that time. The reason seems to be that plants control the amount of carbon dioxide in the air. When it gets hotter, plants flourish and take up more carbon dioxide, so the greenhouse effect gets weaker. All life on Earth interacts with its surroundings in this kind of way, as well as with other living things, to make one huge network, a single living planet. This network is known as Gaia.

Inside the atom



If you think atoms are small, you ain't seen nothin' yet. At the beginning of the 20th century, scientists in Manchester probed atoms by shooting beams of tiny particles (called alpha particles, or alpha rays) at thin sheets of gold foil. Most of the alpha particles went straight through the gold foil as if it weren't there; just a few bounced back when they hit something solid inside the gold. From these experiments, the physicist Ernest Rutherford worked out that atoms are mostly empty space. There is a tiny central nucleus (the bit that the alpha particles bounce off) surrounded by a cloud of electrons (see page 168), rather like the way the planets orbit the Sun. The alpha particles brush through the electrons as if they weren't there. The experiments show that although an atom is about 10^{-8} cm across, the nucleus is only 10^{-13} cm across. The difference looks small, but remember that it's 10^5, or 100,000. The diameter of the nucleus is just one-hundred-thousandth of the diameter of the whole atom. This is equivalent to the size of a pinhead compared with the size of the dome of St Paul's Cathedral in London.