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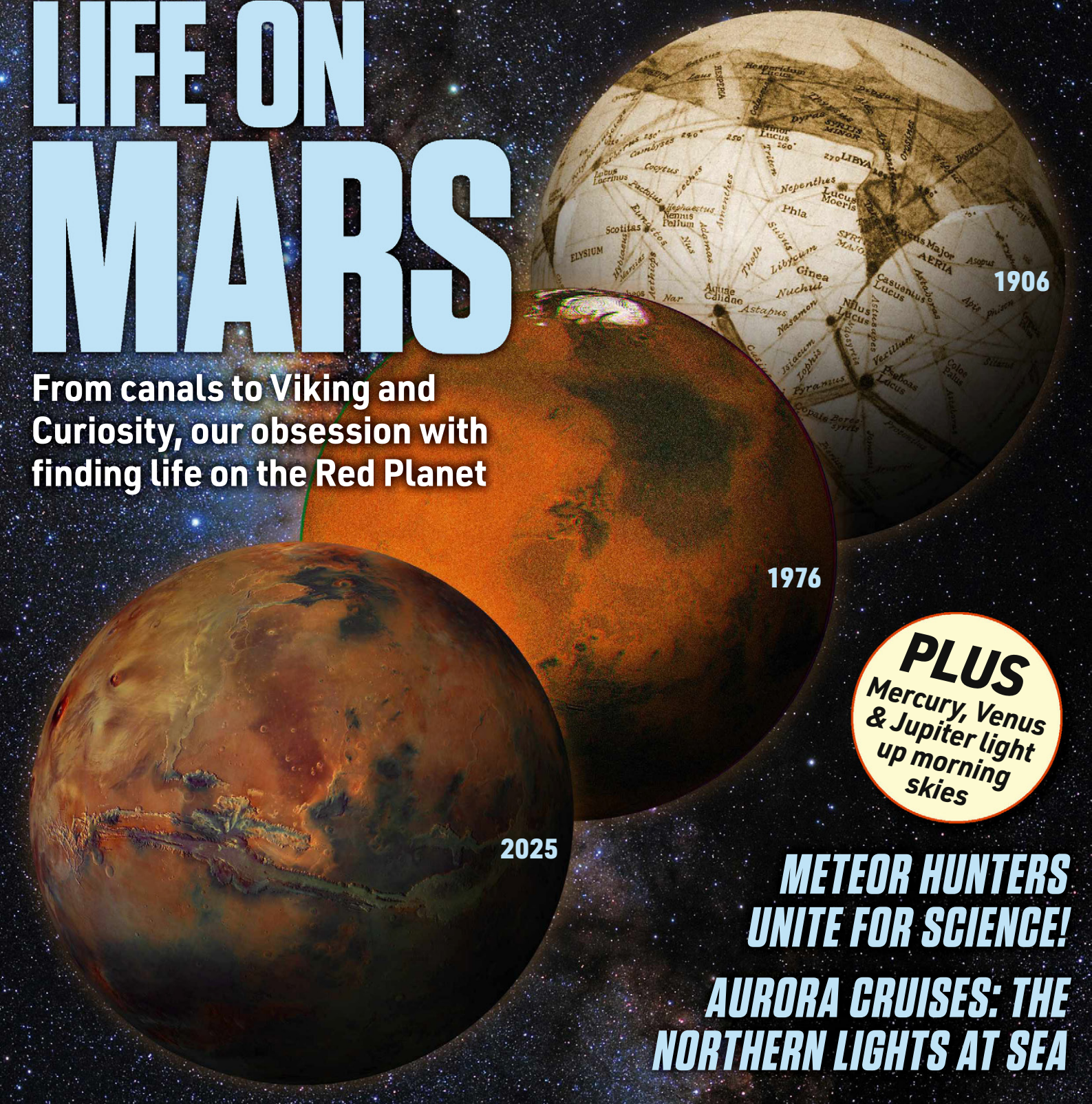

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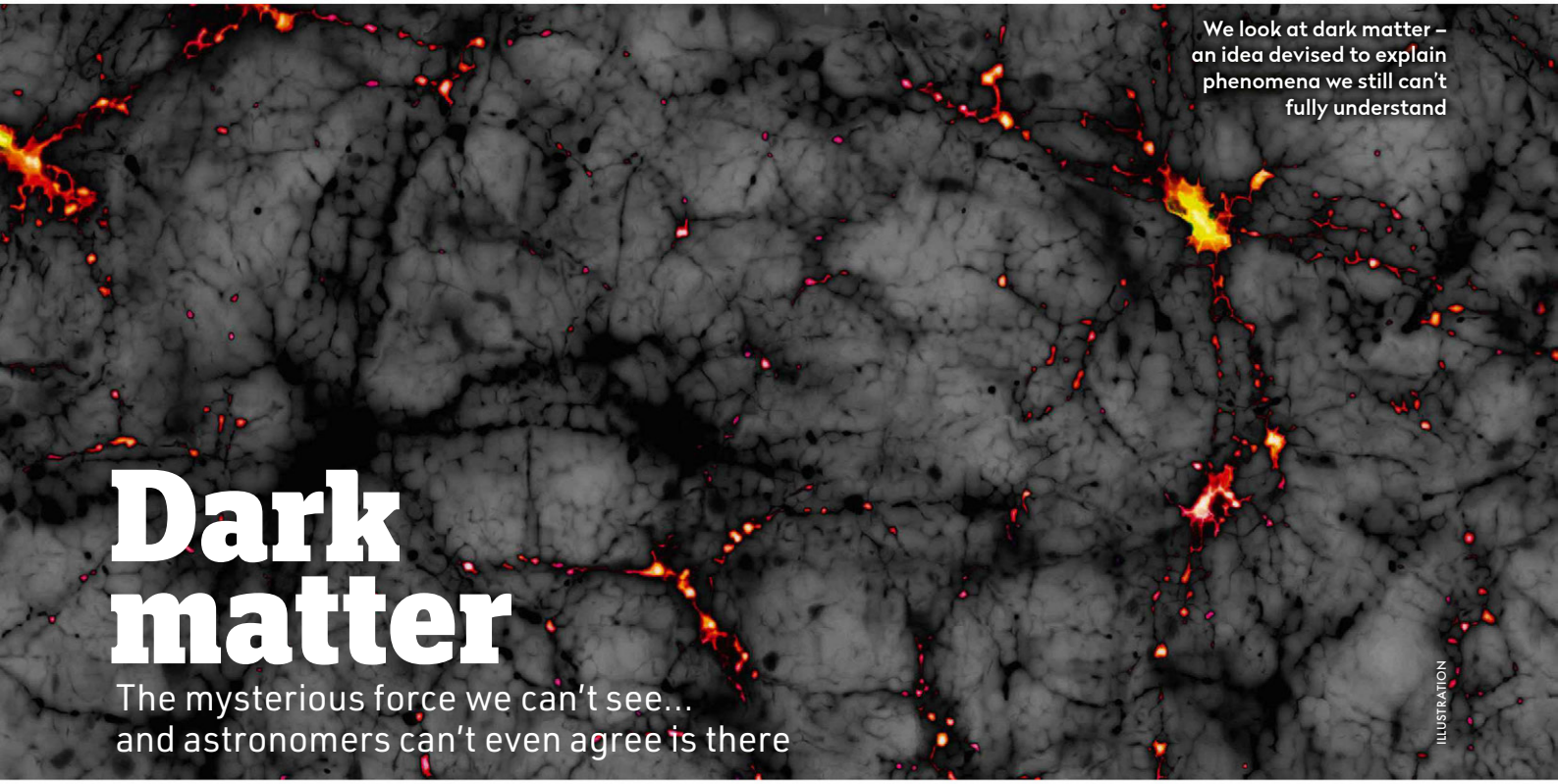
EXPLAINER



We look at dark matter – an idea devised to explain phenomena we still can't fully understand

ILLUSTRATION

Dark matter

The mysterious force we can't see... and astronomers can't even agree is there

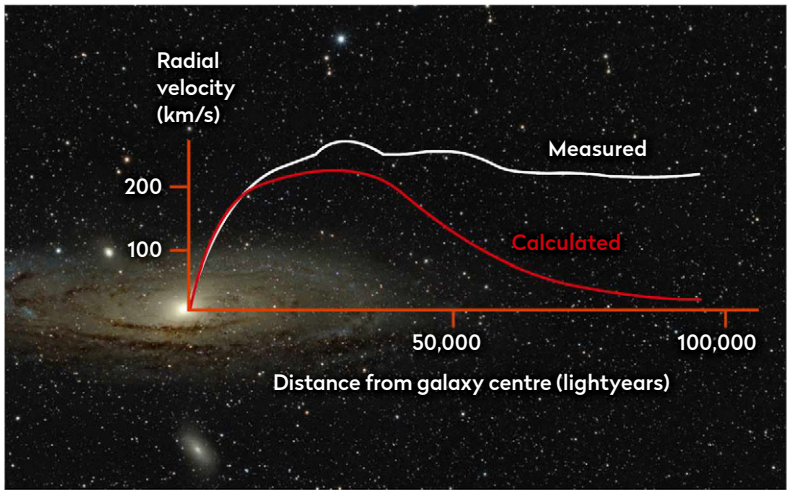
Our eyes paint such vivid portraits of the world around us that it's easy to forget how much of our surroundings go unseen. Wi-Fi signals pinging this way and that, subatomic particles and radiation zipping about. And, if astronomers are to be believed, there's another invisible interloper to throw into the mix: dark matter.

A cosmic glue thought to help bind the Universe together, dark matter is so prevalent that about a milligram (3.5oz) will pass through your body throughout your life. But where did this notion of 'dark matter' come from?

Its story starts in the 1930s. Astronomer Fritz Zwicky was measuring the speeds of galaxies within a big group called the Coma Cluster. He found many were moving so fast that he would have expected them to break free of the cluster's gravitational shackles and head off on their own. Curiously, they didn't. Zwicky suggested there might be some extra, invisible stuff in the cluster providing an additional gravitational glue. Zwicky called this stuff *dunkle materie* – dark matter.

Around the same time, the Dutch astronomer Jan Oort was observing stars on the outskirts of our own Milky Way Galaxy. He also found them to be moving faster than expected, meaning they too should be able to break away. But again, they didn't.

These two key findings were largely overlooked until the 1970s, when US astronomer Vera Rubin picked up the proverbial baton. By 1980, Rubin was ready to publish detailed observations of 21 galaxies.



▼ **The rotation problem: stars at the edge of galaxies orbit much faster than predicted**

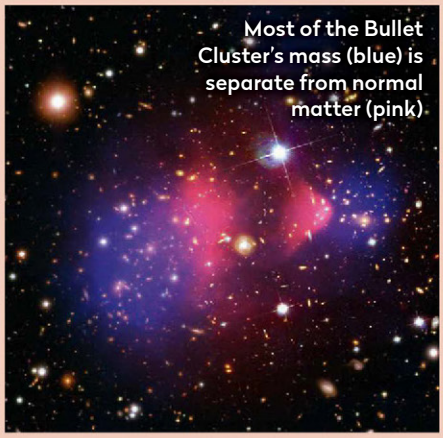
Dark matter's smoking gun?

Lensing around one cosmic collision shows something invisible must be at play

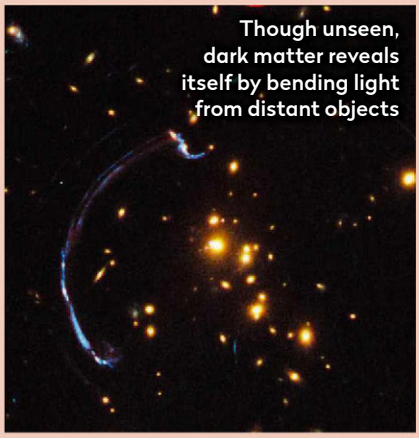
The Bullet Cluster is two separate groups of galaxies entwined in a calamitous collision. The enormous energies involved in the clash have superheated the gas within the galaxies, producing copious amounts of X-rays. However, as well as being able to observe these X-rays, astronomers can also work out where most of the cluster's mass is located, using a technique called gravitational lensing.

They discovered that most of the mass is not in the same places the X-rays are coming from – it is separated from the gas. If the galaxies were made of ordinary matter alone, most of the mass would be where most of the gas is. Instead, the usual explanation is that the dark matter in the two galaxies silently passed through the gas, leading to the clear separation.

For advocates of Modified Newtonian Dynamics (MOND), the Bullet Cluster presents a challenge and, while they have tried to get their theory to fit, most astronomers see the cluster as evidence in favour of dark matter.



Most of the Bullet Cluster's mass (blue) is separate from normal matter (pink)



Though unseen, dark matter reveals itself by bending light from distant objects

She found the same thing – that stars on the edges of these galaxies were orbiting too fast – naming this discrepancy 'the rotation problem'.

It's a problem because galaxies don't seem to behave like our Solar System. Move outwards from the Sun and the speeds of the planets wane as the strength of the Sun's gravity drops off. The same thing doesn't appear to be true for galaxies – far-out stars spin around the galaxy at similar speeds to those much closer-in.

The most widely accepted solution to the rotation problem is that what we see as a galaxy is merely a light dusting of visible material on top of a gargantuan scaffold of invisible dark matter.

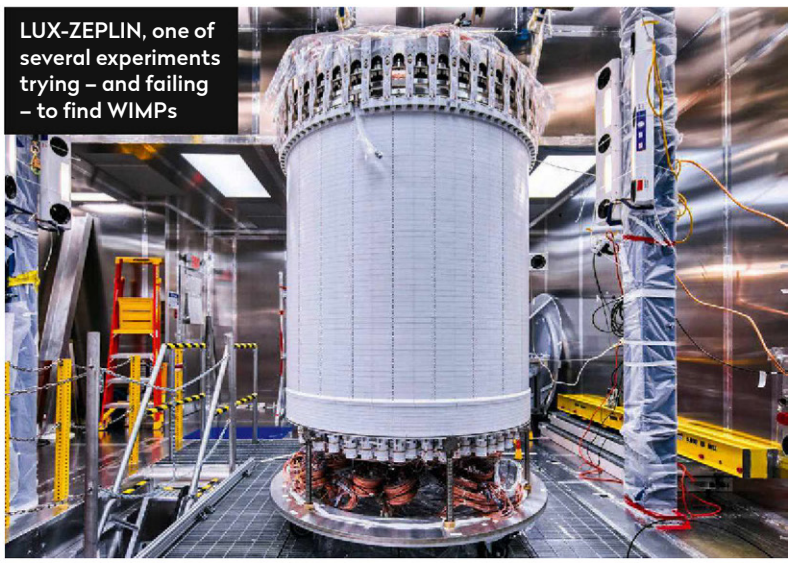
What – and where – is it?

Around 90 per cent of a galaxy's mass is thought to consist of dark matter. With this spread throughout the galaxy, gravity doesn't drop off in the same way that it does in the Solar System, and so the speeds of the stars observed by Zwicky, Oort and Rubin don't drop off either.

Except if dark matter really does outnumber the ordinary matter that stars, planets and people are made of by 9:1, surely we should be able to find it?

A big part of the puzzle is working out what dark matter is actually made of. Astronomers wondered whether it could be a conglomeration of heavy, invisible objects like black holes and planet/star hybrids known as brown dwarfs – but there simply aren't enough of them.

The most fashionable idea in recent decades suggests that dark matter is made of Weakly Interacting Massive Particles (WIMPs), but astronomers and physicists have never seen one, despite exhaustive – and expensive – searches.



LUX-ZEPLIN, one of several experiments trying – and failing – to find WIMPs

A completely different idea is that dark matter is a figment of our collective imaginations. Instead, a theory called Modified Newtonian Dynamics (MOND) argues that gravity itself works differently on the scale of a galaxy compared to the scale of the Solar System. Only by applying the wrong set of rules to the wrong situation does it look like the stars are moving too fast.

However, this notion too is contested, particularly as a group of galaxies called the Bullet Cluster is usually held up as significant evidence against MOND (see above).

So, for now, the true nature of dark matter remains a confounding mystery, one of the biggest in all of astronomy. When it comes to knowing what the Universe is really made of, astronomers are still well and truly in the dark.

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