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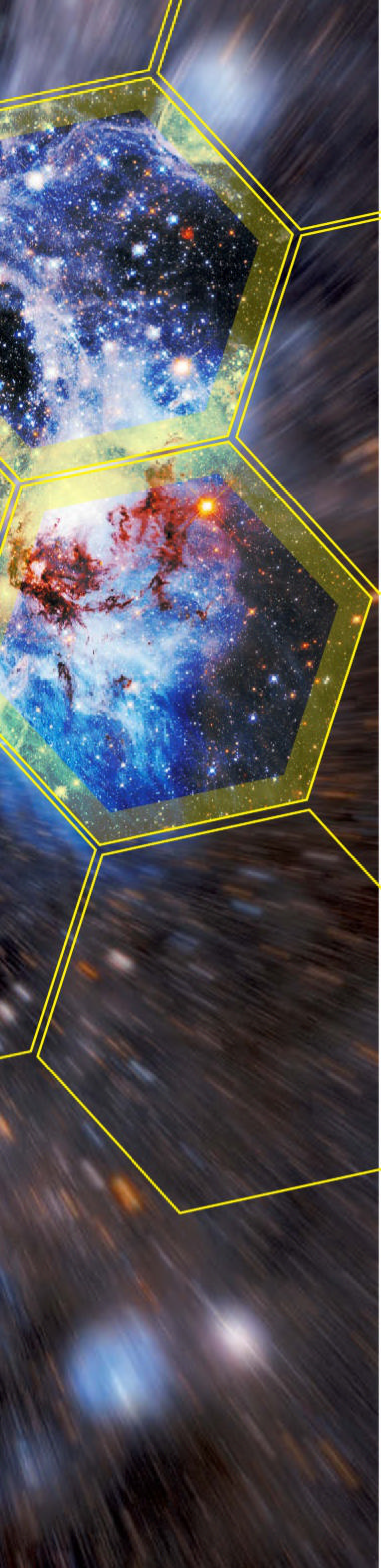
Launch of a time machine

The most powerful telescope ever made is about to blast off. It will show us the first stars and the atmospheres of alien worlds, says **Colin Stuart**

IN EARLY October, a cargo ship steered to starboard, leaving the Atlantic Ocean off the east coast of South America and entering the muddy waters of the Korou river. It was the final phase of the voyage and no effort had been spared to protect the prized item on board. It was housed inside a specially designed case to keep it safe from the pitch and roll of the waves. The river had been dredged to ensure the ship didn't get stuck in the shallows. Even the exact date of the voyage had been kept secret, to avoid the attention of pirates.

The precious cargo was the James Webb Space Telescope, perhaps the most hotly anticipated scientific instrument ever. Known as the JWST, the telescope has been more than 25 years in the making and its launch has been delayed countless times. But it has now completed its voyage to the launch site in French Guiana and, if all goes smoothly, it will finally leave Earth in late December. "I still haven't wrapped my head around it," says Torsten Böker, deputy project scientist for the JWST at the European Space Agency (ESA). "It seems a little bit unreal."

Unreal not only because it has often looked like the telescope might never take off, but also because this device is designed to be a time machine that will help us see back to the enigmatic era of the universe's first stars, which we know precious little about. Unreal, too, because it will reveal the atmospheres of



“We’ll make 400 years’ worth of discoveries in a decade”

potentially habitable planets orbiting other stars more clearly than ever before. It is no exaggeration to say that this telescope, with its gigantic gold-plated mirror, will transform our view of the universe and our place in it.

The JWST’s story begins around Christmas 1995. That year, the world was gripped by O. J. Simpson’s murder trial, Bridget Jones first appeared in print and *Forrest Gump* won big at the Oscars. For 10 December days, the Hubble Space Telescope stared at a patch of featureless sky that could be covered by a pinhead held at arm’s length. As far as ground-based telescopes were concerned, this region of the sky was empty. But some astronomers suspected that a closer look was warranted.

What emerged, now known as the Hubble Deep Field image, showed that this patch of space is crammed with 3000 galaxies, each about 4 billion times fainter than the human eye can see. Among them were the oldest galaxies we had ever viewed.

Light may be fast, but it still takes a lot of time to reach us when travelling across the universe. Because of this, we know that the further objects are from us, the older the light from them is. But how to tell the age of any given star or galaxy? Fortunately, a quirk of starlight can help. Because the universe has been expanding since the big bang, light travelling long distances gets stretched out as it goes. This changes its wavelength, pushing it from the visible spectrum further into the infrared. This “redshift” was extreme for some of the galaxies Hubble had discovered, showing that they were more than 10 billion years old. That takes us a long way back towards the big bang 13.8 billion years ago.

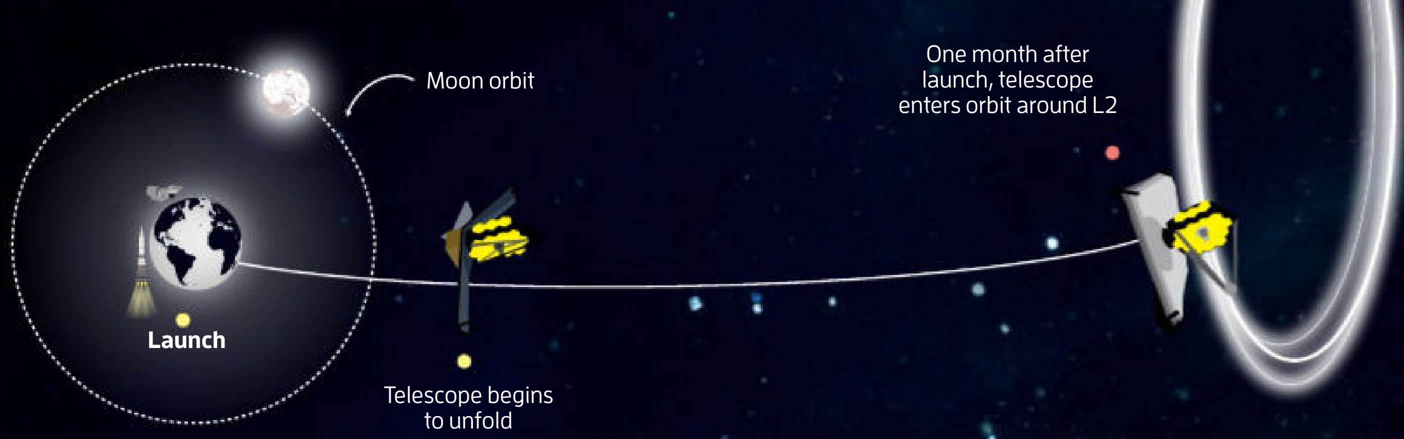
Astronomers hadn’t expected that galaxies this ancient would be detectable, especially not in such numbers. Appetites whetted, they hatched a plan to get a better look at the universe in its flush of youth. In early 1996, a group of stargazers convened to kick-start work on what was then called the Next Generation Space Telescope. That became the JWST, which is now a joint project between NASA, ESA and the Canadian Space Agency. It is only now getting its chance on the launchpad; scientists have wrinkled and greyed as a single telescope project took up most of their career.

As they waited, the thirst to see the universe’s first stars deepened. A star produces chemical elements inside it as it burns, then spews them into space as it dies, often in an explosive supernova. Some of that debris eventually coalesces into a new generation of stars – and the cycle repeats. Going back in time, it is thought that stars would have been made of mixtures of simpler elements. The first stars would have formed from clouds of hydrogen and helium, the simplest elements, at a point called the cosmic dawn. They would have started to form heavier elements, but ›

The James Webb Space Telescope

How it works and what it will see

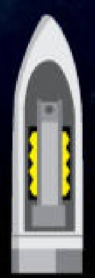
The James Webb Space Telescope (JWST) will be the largest, most powerful telescope ever launched into space. After it blasts off, it will travel 1.5 million kilometres from Earth to a spot called Lagrange point 2 (L2). Here, the gravitational pulls of our planet and the sun cancel out and the telescope will orbit this point, remaining in an almost static position with respect to us and the sun.



The telescope is designed to pick up the tiniest specks of infrared radiation, or heat, from ancient stars and galaxies. Orbiting so far from Earth, the sun and moon makes it easier to avoid heat coming from those bodies. Nonetheless, the JWST will need a huge heat shield, which will be unfurled on its journey through space.

1

The JWST's 6.5- metre-wide mirrors are too large to fit aboard a rocket, so it launches in a folded up configuration



2

Once on its way, the telescope begins to unfold. The first step is to separate out and tension the five layers of the sun shield

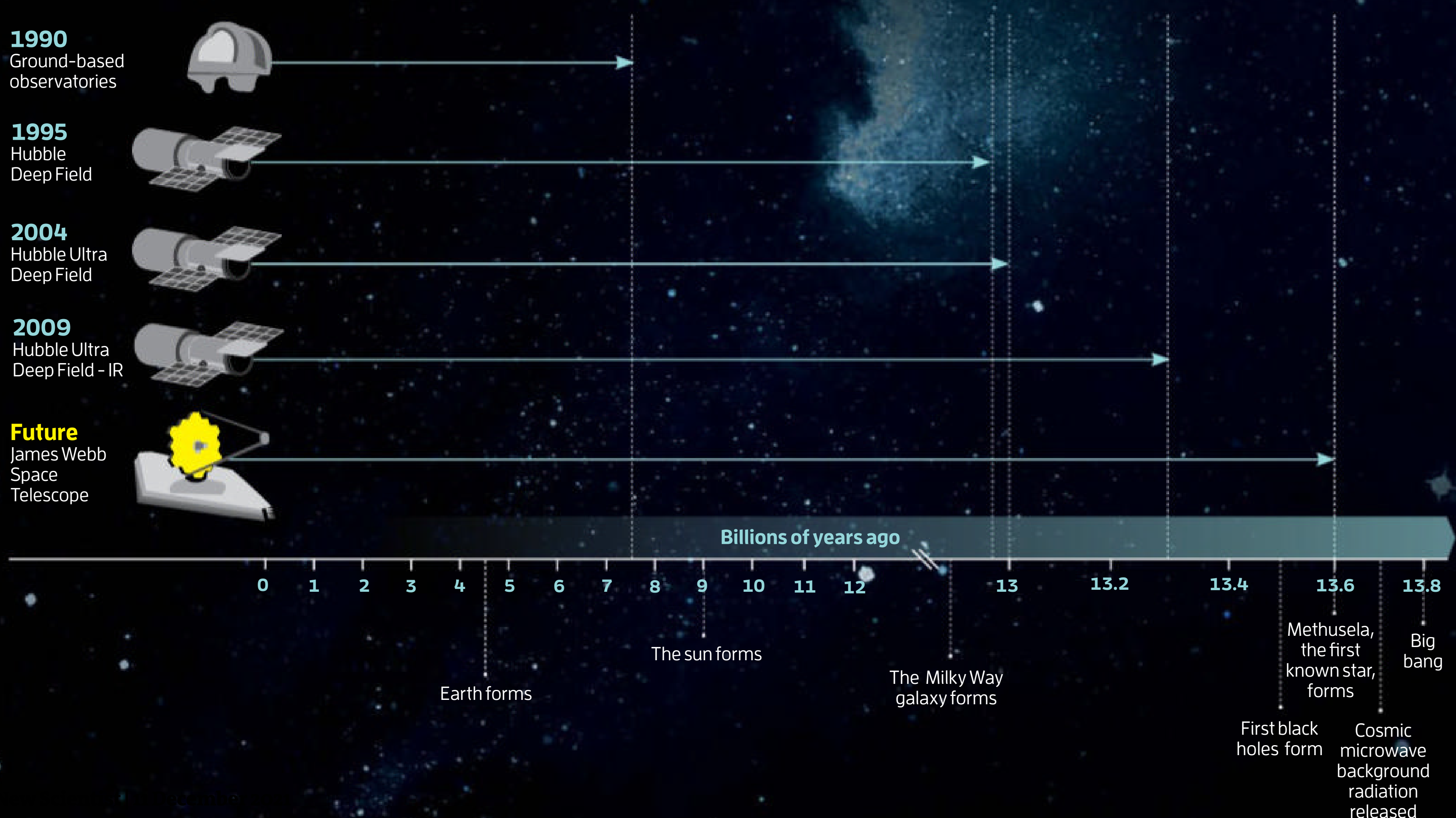
3

Next, the secondary mirror and support structure are unfolded. It is crucial that the alignment is just right

4

The unfolding finishes with the deployment of the telescope's lateral wings

Once the telescope is unfolded, it will begin taking test images and adjusting the alignment of its primary mirrors. After six months, it should be ready to start science observations. It will be able to see further back in time than we have ever managed before.



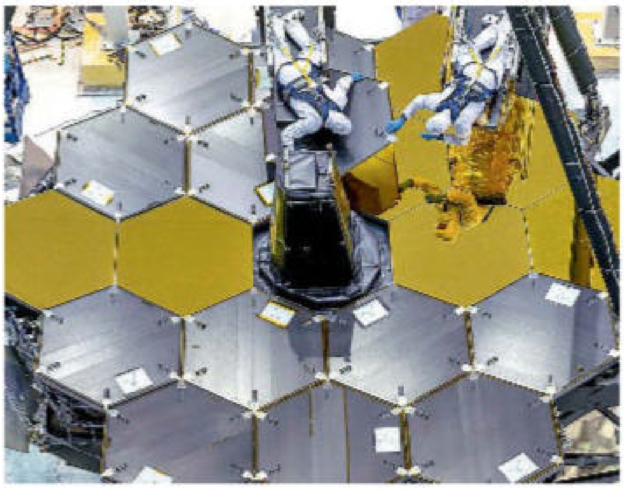
only slowly. The trouble is, our accounting for where the universe's heavy elements came from doesn't add up. One idea is that the mysterious first stars had a more important role in creating them than we thought.

So far, we haven't been able to properly see stars that lived in the first few 100 million years after the big bang – all we have had are indirect glimpses. Light from the first stars is thought to have interacted with leftover hydrogen in the early universe, changing the way that gas absorbed the cosmic microwave background (CMB), remnant radiation from the big bang that we can still detect. In 2018, the researchers behind a radio-astronomy experiment known as EDGES announced that they had managed to see this change in the CMB and so get an indirect signal from the first stars. Some scientists saw this finding as ambiguous, however, because the signal is subtle and it didn't look exactly as had been predicted.

Meanwhile, the light from a few of the first stars shines towards us on a path that takes it close to a cluster of galaxies. The gravity of these galaxies acts like a magnifying glass that allows us to see the starlight. But this only happens in a few lucky cases.

The JWST should sweep all this aside and give us a better look. While Hubble is known for producing incredible visuals, the JWST is primarily designed to see infrared light from the earliest stars. We have already had infrared telescopes in space, such as ESA's Herschel Space Observatory, which was retired in 2013. But we are getting quite the upgrade. "The sensitivity of JWST is 100 to 1000 times higher than current or previous infrared telescopes," says Roberto Maiolino at the University of Cambridge. He sees it as akin to jumping from Galileo Galilei's telescope to modern mountaintop observatories. "We'll make 400 years' worth of discoveries in a decade," he says.

Maiolino works on the JWST's near-infrared spectrometer, one of the key pieces of tech that will help make those discoveries. The instrument splits up starlight into its constituent frequencies, enabling us to measure the intensity of light at each one. Certain elements absorb light at characteristic frequencies and so the missing chunks of light will show us what elements are present in the oldest stars and galaxies. "We're going to spend a lot of time taking deep spectra of the first galaxies," says Maiolino. "We want to know how early key elements formed in the universe."


NASA/CHRIS GUNN


NASA/CHRIS GUNN


NASA/CHRIS GUNN

Removing covers from the mirrors of the James Webb Space Telescope (top), the telescope folded (middle), and after cryogenic testing (bottom)

There is, however, a major problem when it comes to observing infrared light. It isn't just given off by ancient stars and galaxies, but by warm objects of all kinds – including the sun and our planet. This means that a space telescope can't simply be placed in a typical Earth orbit. Heat from Earth would blind it to the faint glimmers from ancient stars. It would be like trying to hear a whisper at the universe's loudest rock concert. That's why the JWST has a huge sun shield and why it will be placed at a special point in space about four times further from Earth than the moon is (see diagrams, left). If the first phase of the telescope's journey by sea was tense, then the 1.5-million-kilometre passage through space is truly epic.

Transformer in space

This new eye in the sky is also the largest space telescope in history. Its 6.5-metre mirror – taller than a four-storey building – couldn't fit inside a rocket in its final configuration. So it is made of 18 hexagonal segments that will be folded up for launch, only to unfurl when the telescope reaches space. "It's like a giant Transformer going up into space," says Knicole Colón, a deputy project scientist for the JWST at NASA. Each mirror segment is covered in an incredibly thin layer of gold, which significantly increases the mirror's ability to reflect and focus infrared light.

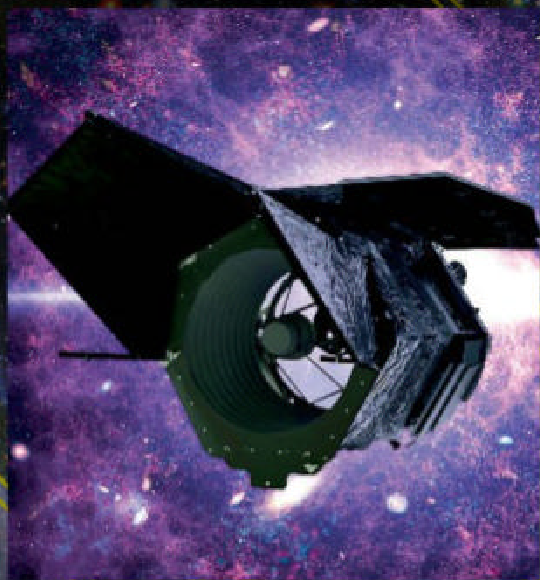
The telescope has been dogged by setbacks and controversy. Original estimates suggested that it would cost $500 million. That has ballooned to $9.7 billion. In 2011, a US House of Representatives committee attempted to pull the mission's funding due to it being "billions of dollars over budget and plagued by poor management". Then a planned launch date in 2018 was pushed back due to technical problems with the telescope's sun shield and thrusters. The covid-19 pandemic resulted in more delays. Even in the past few weeks, problems have cropped up. In late November, NASA announced that the "sudden unplanned release of a clamp" had sent vibrations through the telescope and it needed time to ensure no damage had been done. As this story went to press, the launch was scheduled for no earlier than 22 December.

Even the name has caused issues. James Webb was the NASA administrator in the early days of human space flight. He was a politician, not a scientist. Worse, some accuse him of having being involved in the lavender scare of the mid-20th century, an effort to oust ›

Eyes in the sky

Several space telescopes slated for launch after the James Webb one promise to deliver incredible science. Here are three of the most important

ESA/ATG MEDIALAB



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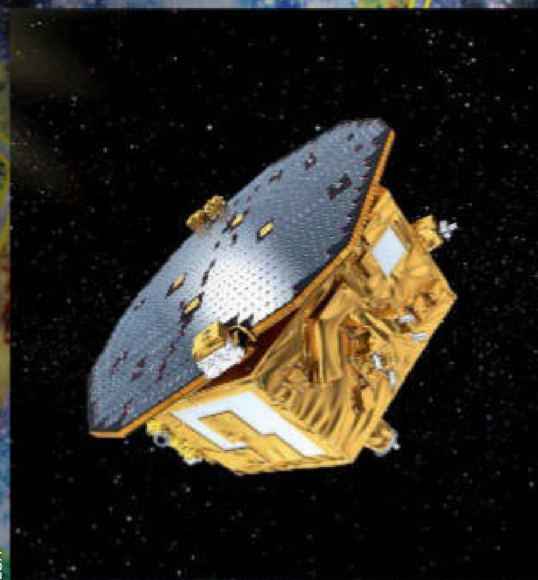


ESA

PLANETARY TRANSITS AND OSCILLATIONS OF STARS (PLATO)

Expected launch date: 2026

This European Space Agency project will scour a million stars looking for blips in their light that betray the presence of an orbiting planet. Similar kinds of previous telescopes have only been able to see planets that are close to their stars and so pass in front of them frequently. Plato will linger on each star for longer and so has the chance to detect planets that are more distant from their star, with a longer orbital period. In particular, the mission is focused on trying to spot signs of rocky exoplanets in the habitable zone, the narrow region of a star system in which temperatures are right for liquid water. It also has the tools to characterise such worlds, providing clues as to how Earth-like they may be.

NANCY GRACE ROMAN SPACE TELESCOPE

Expected launch date: 2025

Like the James Webb Space Telescope (see main story), the Roman Space Telescope, named after the first female executive at NASA, will observe mainly infrared radiation. But while the JWST focuses on detail, Roman is going for the big picture. The telescope has a panoramic field of view more than 100 times greater than the JWST's. During its first five years, Roman will image more than 50 times as much sky as the Hubble Space Telescope covered in its first 30 years. That will allow it to make the first wide-field infrared maps of the sky. It is hoped this will help solve mysteries like the true identity of dark matter and dark energy. Astronomers can see the influence of these substances on the universe but have not been able to explain what they are.

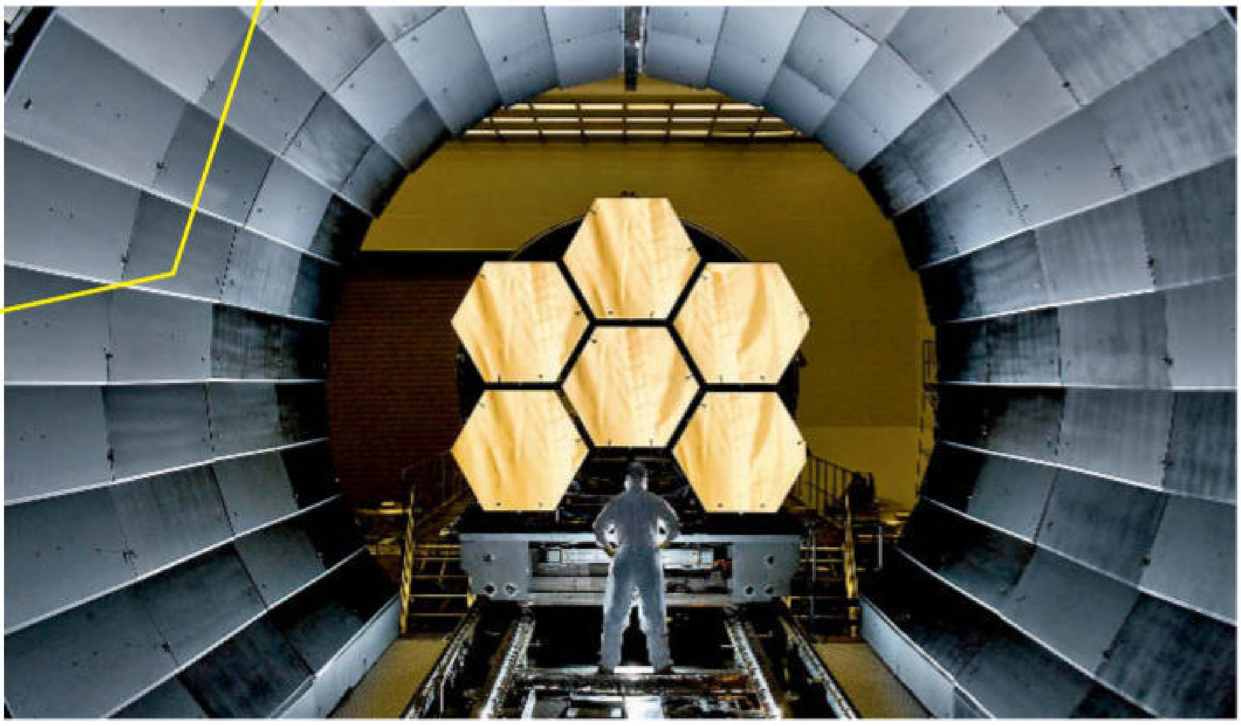
LASER INTERFEROMETER SPACE ANTENNA (LISA)

Expected launch date: 2034

We first detected gravitational waves, ripples in the fabric of space, in 2015. So far, we have seen waves from black hole and neutron star collisions. LISA, a mission led by the European Space Agency, will be a much larger gravitational wave detector than existing ground-based ones. It will consist of three spacecraft positioned 2.5 million kilometres apart in a triangular formation. This space detector will be sensitive to gravitational waves with extremely low frequencies. Among other things, it could allow us to spot planets in other galaxies just from the subtle way in which they influence the gravitational waves produced by their parent stars. Until now, all confirmed discoveries of exoplanets have been in our own Milky Way galaxy.

NASA, ESA, V. KSOLL AND D. GOULIERMIS (UNIVERSITÄT HEIDELBERG), ET AL.; PROCESSING: GLADYS KOBER (NASA/CATHOLIC UNIVERSITY OF AMERICA)

"The chemistry of exoplanet atmospheres will show up clearly in the light the telescope detects"



NASA/MSFC/DAVID HIGGINBOTHAM

suspected members of the gay community from government roles. NASA says it conducted an investigation and has found "no evidence at this time"of a direct connection between Webb and the lavender scare. That hasn't stopped scientists such as *New Scientist* columnist Chanda Prescod-Weinstein calling for a name change.

For the most part, the myriad delays have been a source of frustration. But there has been a silver lining: they mean we will be able to use the telescope in an even more exciting way.

Alien planets

Back in 1995, we barely knew of any planets beyond our solar system. The first exoplanet around a sun-like star was discovered just two months before the Hubble Deep Field image was captured. But in the quarter of a century since, we have tracked down more than 4000 of these alien worlds and begun to find out what they are like. Exoplanets are too dim and distant to be seen directly with existing telescopes. Instead, we tend to spot them by looking at distant stars and seeing when their light dims slightly as a planet moves in front. Some of this light passes through the planet's atmosphere, where certain frequencies are absorbed by the chemicals there. By looking at this light, we can get an idea of what exoplanets are like, learn what their atmospheres are made of and even develop a feel for their weather. All this is so tantalising because it tells us about other planets that might have the right conditions to support life.

NASA/CHRIS GUNN

A technician inspects the James Webb Space Telescope's mirrors (bottom); six mirror segments are prepared for testing in a cold chamber (top)

So far, almost all of our observations of exoplanets have involved visible light. But the chemistry of their atmospheres will show up much more clearly in the infrared, the kind of light that the JWST is optimised to detect. The delays to the telescope's launch allowed its design to be tweaked so it can also observe alien worlds more effectively. "Almost no exoplanets have been studied at these wavelengths before," says Colón. One especially exciting prospect is that bonds between carbon atoms – a telltale sign of the organic chemistry that provides the scaffold for life on Earth – will show up clearly in the infrared.

There are plenty of other telescopes in the works that will complement what the JWST can do (see "Eyes in the sky", left). Even so, some people see this venture as a case of putting too many eggs in one basket. A mountain of cash and 25 years of work have been poured into a single telescope that now faces a risky journey to its destination. Were it to fail, it might seem wiser to have spread that effort across other projects. But for the most part, astronomers are just plain excited. "It'll be revolutionary," says Colón. "It is completely worth it."

The telescope is scheduled to complete its set-up procedures in the middle of 2022 and then begin gazing back in time at the enigmatic lives of the first stars and at Earth-like planets orbiting other stars. New telescopes tend to bring unanticipated discoveries too – just look at how Hubble shocked the world when it stared at that apparently blank patch of sky. "We should expect to be surprised," says Böker. "We'll see things we've never even dreamed of – you can't put a price tag on that." ■

Colin Stuart is an astronomy author and speaker. Follow him on Twitter @skyponderer