Space telescopes of the FUTURE

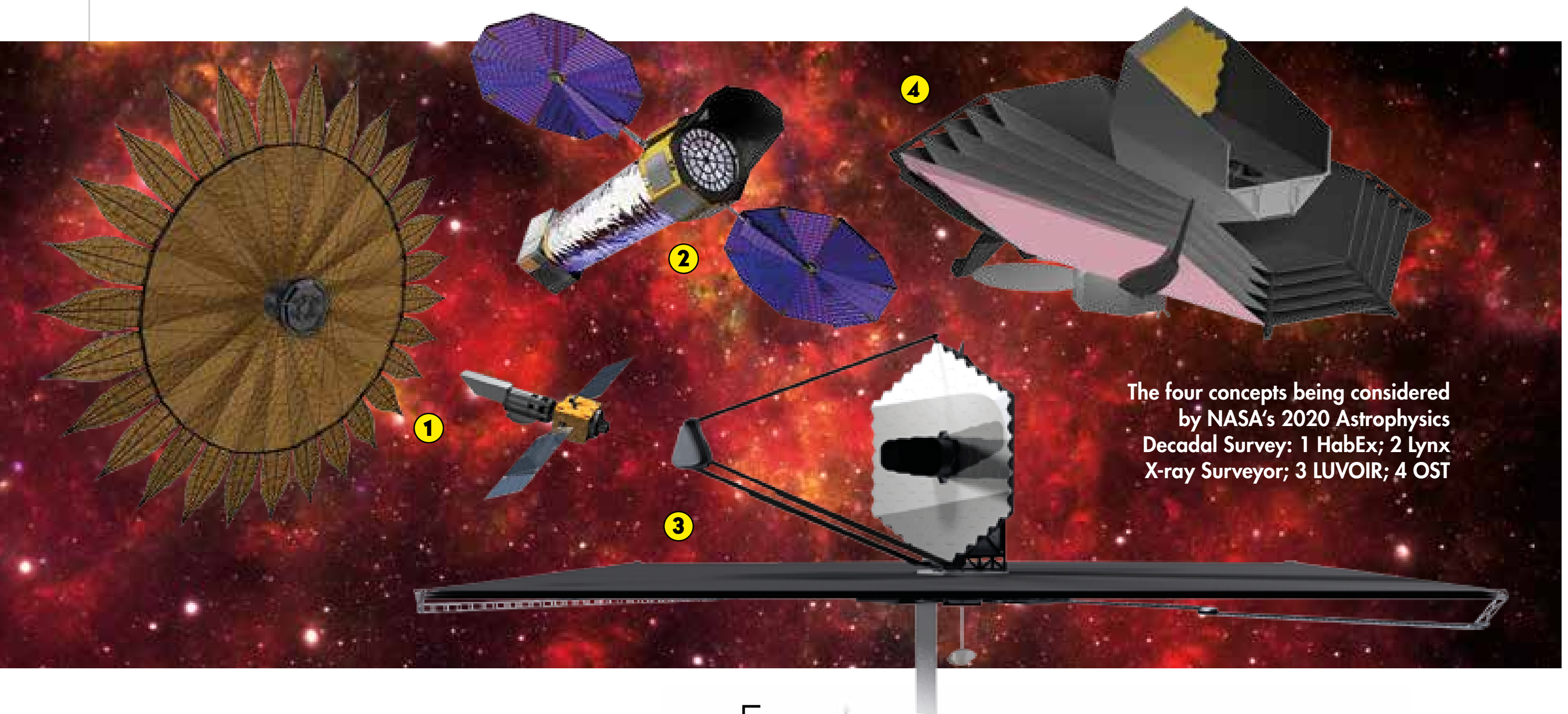
Looking ever deeper into the Universe doesn't have to mean building increasingly bigger Hubble and JWST-style reflectors. Ben Skuse considers whether there's another way

ISTOCK, LOCKHEED MARTIN

The $8 billion-plus James Webb Space Telescope (JWST) will be the most advanced telescope ever sent into space when it's launched in 2020. Its discoveries will no doubt stagger humanity, just as the Hubble Space Telescope's have for the past 27 years. Yet the basic design and components for JWST, Hubble and almost all other space telescopes ever launched would easily be understood by Newton and his 17th-century contemporaries.

While the materials may be superior and detectors more sensitive, light is still collected by a big primary mirror, reflected to a smaller secondary mirror and then reflected back to a hole in the middle of the primary where – after bouncing off a small tertiary mirror and a fine steering mirror to cancel out optical aberrations – the viewing apparatus (scientific instruments replacing the human eye) finally 'sees' the collected image. But with deeper imaging requiring telescopes with ever larger primary mirrors, how long will it be before space telescopes are simply too expensive or too big to fit in a rocket's nose cone? ▸

It may look like a satellite but SPIDER is actually a new concept in telescopes based on vast arrays of tiny lenses



The four concepts being considered by NASA's 2020 Astrophysics Decadal Survey: 1 HabEx; 2 Lynx X-ray Surveyor; 3 LUVOIR; 4 OST

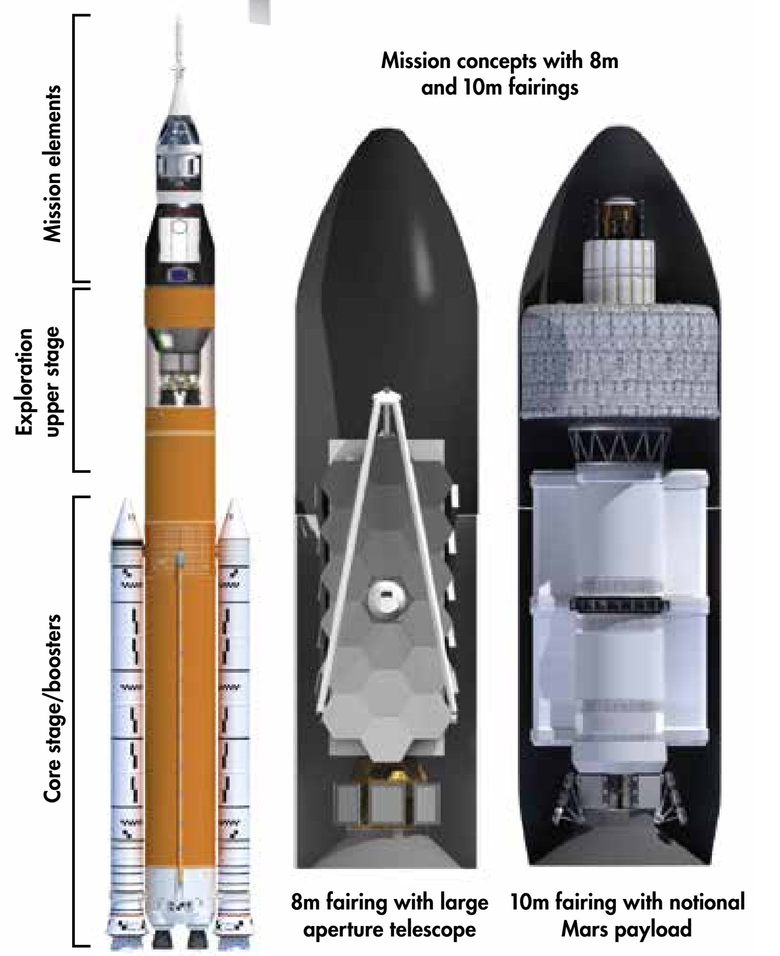
The immediate future

▸ Four mission concepts are being studied in preparation for NASA's 2020 Astrophysics Decadal Survey, the outcome of which could determine what NASA's flagship astrophysics mission for the mid-2030s will be. Two of these – Habitable Exoplanet Imaging Mission (HabEx) and Lynx X-ray Surveyor – are comparable or smaller in size to JWST and could be launched on an Ariane 5 rocket. The remaining pair – Large UV/Optical/IR Surveyor (LUVOIR) and Origins Space Telescope (OST) – both with proposed 8-15m primary mirrors, are simply too big.

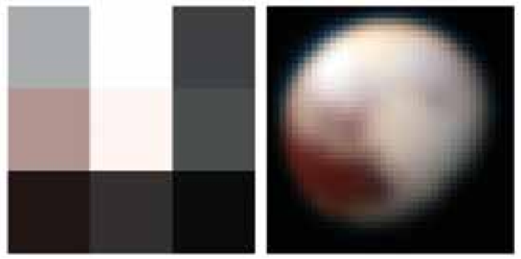
For these concepts to be realised, bigger rocket nose cones (known as fairings) are required. Taking LUVOIR as an example; the study team is exploring two designs with either an 8m or 15m mirror depending on how big the available rockets will be in the 2030s. "The 8m LUVOIR mirror is the largest you can fit into a moderate-sized launch fairing, such as United Launch Alliance's Delta IV Heavy or Blue Origin's planned New Glenn," explains Aki Roberge, study scientist for the LUVOIR project. "The 15m version is the largest segmented mirror you can fold up (like the 6.5m JWST mirror) and fit into NASA's planned Space Launch System (SLS) fairing."

Ultimately designed for human missions to Mars, SLS will be the most powerful rocket ever built. "It's hard to imagine the need for a rocket larger than SLS, so telescopes larger than LUVOIR will have to be assembled in space, similar to the way the International Space Station was built," says Roberge. As a result, he believes LUVOIR – if commissioned – will likely be the last and largest telescope assembled on the ground and launched on a single rocket.

With its huge collecting area, LUVOIR will be able to perform studies impossible through Hubble and JWST, peering deeper in space and time to reveal new insights about cosmic mysteries like dark matter and galaxy formation. It will also detect and characterise exoplanets around nearby stars, including potentially habitable worlds, while probing closer to home in order to monitor outer Solar System objects like Europa and Enceladus in fine detail.

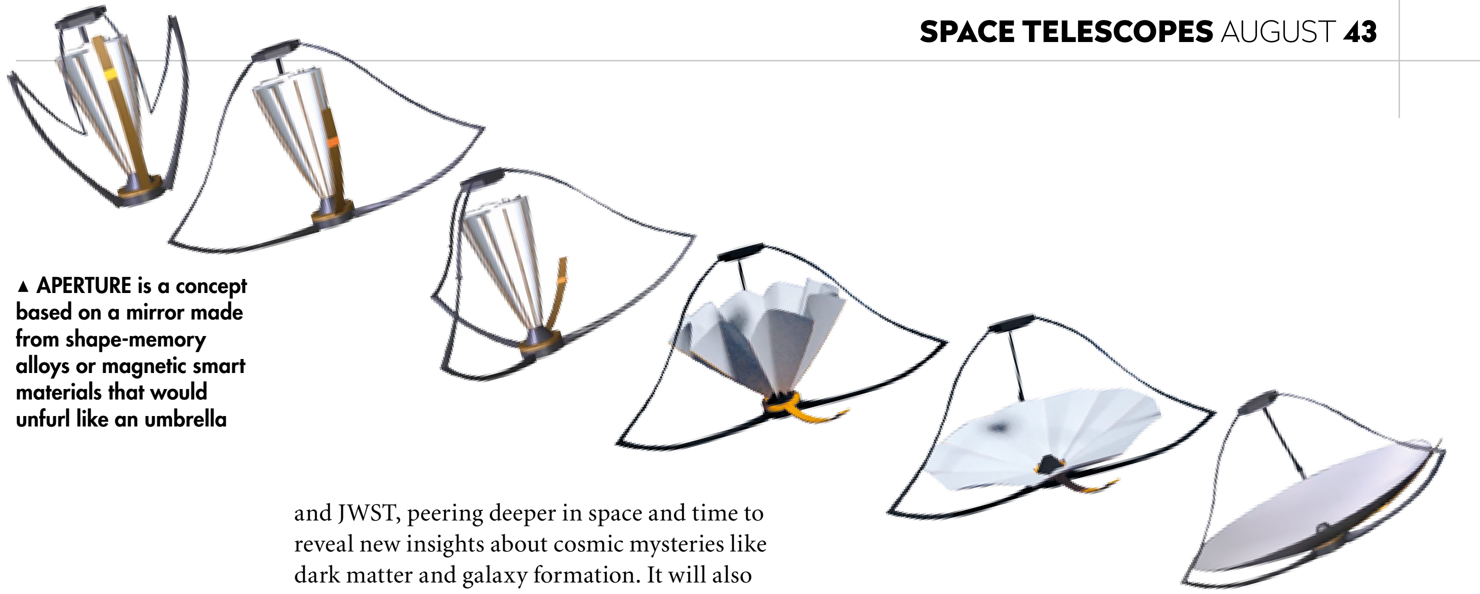


▲ NASA's planned SLS rocket will probably be the biggest rocket operating in the 2030s but the size of its fairing – the cargo-holding nose cone – will restrict the physical size of telescopes that can be taken into space



Pluto with Hubble | Pluto with LUVOIR

▲ The LUVOIR telescope might give us better views of Pluto, but even folded up it will barely fit in NASA's SLS



▲ APERTURE is a concept based on a mirror made from shape-memory alloys or magnetic smart materials that would unfurl like an umbrella

Extending reflecting telescopes

Though LUVOIR may signal the end of foldable telescopes like JWST, it may not be the last reflecting space telescope. Addressing how to build bigger reflecting telescopes, 'A Precise Extremely large Reflective Telescope Using Re-configurable Elements' (APERTURE) is an idea to engineer mirrors that unfurl like an umbrella. "But the process is not capable of producing mirrors of the quality necessary to image visible light," says Northwestern University's Melville Ulmer, who's leading the study.

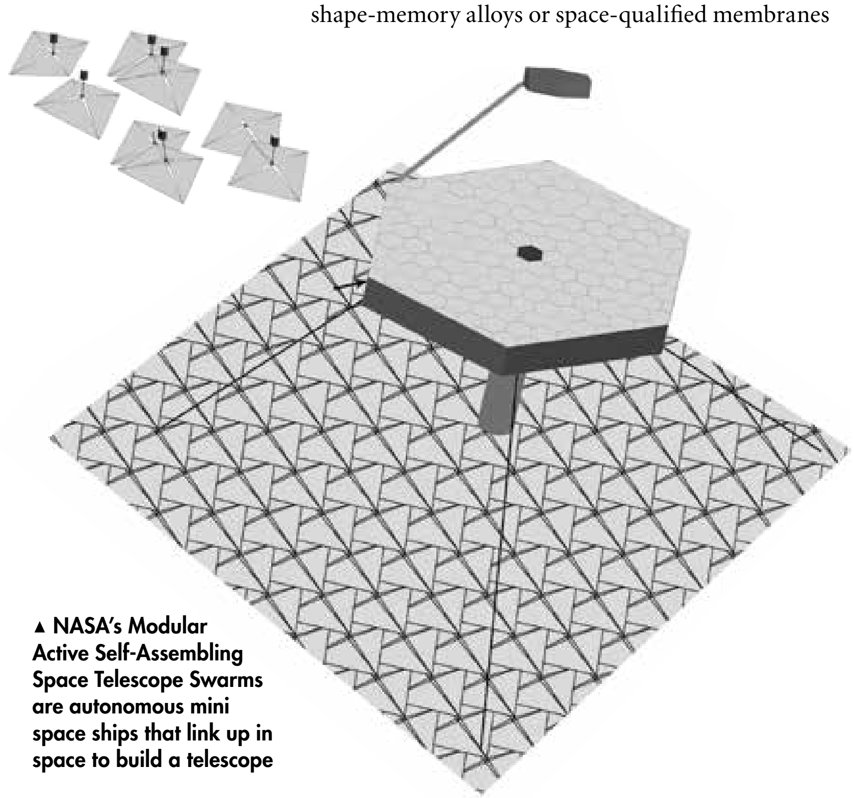
Therefore, Ulmer and his team – funded by NASA Innovative Advanced Concepts (NIAC) – have been working on how to iron out the kinks in the mirror after deployment. Possibly made from shape-memory alloys or space-qualified membranes and coated with magnetic smart materials, the mirror will be serviced by magnetic write heads that produce stress in the material and improve its shape post-deployment.

"Current rocket fairings would allow us to deliver 17m diameter mirrors," adds Ulmer. If the team can realise its ambition, not only will space telescopes that can see further and deeper into space become possible, but so will small (5x5cm), precisely controlled, deformable mirrors for coronagraphs used in exoplanet imaging as well as super-resolution, large area X-ray space telescopes (around 1km²).

Another NIAC-funded study called 'Modular Active Self-Assembling Space Telescope Swarms' takes a different approach. This project aims to explore a space telescope that fits together like Lego bricks in space. The idea is that these small 1m-wide parts will be added as extra payloads to pre-planned missions, and then travel by solar sail to a chosen site, where they will autonomously accrue and self-assemble into a fully-fledged telescope.

"The concept is an attempt to address the inherent difficulties in constructing and launching a giant space telescope," adds Dmitry Savransky, Cornell University scientist and project lead. "Mass producing these parts will bring down costs, and the use of multiple launches (and especially payloads of opportunity) means there is no single point of failure in the system, so the overall mission is likely to succeed even with the failure of an individual module or launch."

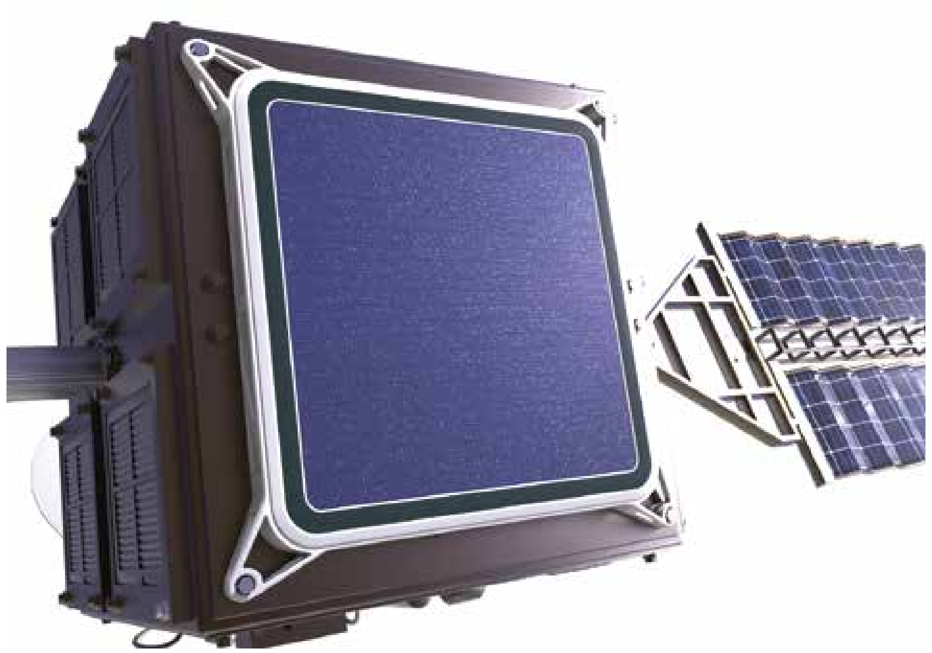
Savransky believes the concept could be employed to construct Hubble-style reflector telescopes of over 30m in space. Such huge apertures would be able to explore the nature of dark matter and energy, and observe much fainter and distant sources, such as potentially life-accommodating exoplanets.



▲ NASA's Modular Active Self-Assembling Space Telescope Swarms are autonomous mini space ships that link up in space to build a telescope

The future is flat

Lockheed Martin's Segmented Planar Imaging Detector for Electro-Optical Reconnaissance (SPIDER) concept posits another approach to reducing the size of space telescopes, ditching large, bulky mirrors in favour of a thin array of tiny lenses. Borrowing a concept from large-scale interferometer arrays located in observatories ▸



► around the world, the idea is to combine the light the telescope collects in pairs to form interference fringes. The amplitude and phase of these fringes are measured and used to digitally construct the image.

Interferometry is a well-known technique, but SPIDER's unique selling point is its diminutive size and weight. Replacing complex combining optics with silicon-chip photonic integrated circuits, "we take pieces of a scene directly into our micro lenses, which connect directly into circuits that will process the signals into an image," says SPIDER programme manager Greg Feller. This makes the instrument completely flat and shrinks its weight by 90 per cent, while maintaining excellent resolution.

Though not a replacement for traditional reflecting telescopes conducting deep space imaging – because the interferometer requires a well-lit and extended scene in order to generate the best images – SPIDER's weight, size and affordability make it ideal for planetary missions.

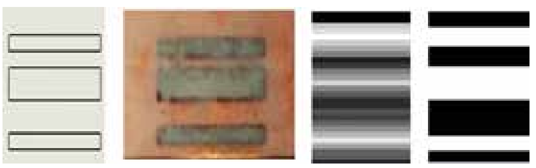
Last year, the team built a prototype of the SPIDER system, engineering a row of 30 lenses each less than a millimetre wide. They then created two scenes – a standard bar test pattern and an overhead view of a complex railway yard – and made them seem 450km distant using a mirror assembly. By rotating the two scenes viewed by the row of tiny lenses, they managed to simulate what a larger instrument would be able to see.

Feller is now overseeing the construction of the full instrument, which will boast over 500 lenses, to show how the device can operate when fully integrated. He's optimistic about SPIDER's future: "We could launch the first SPIDER in space on an experimental mission early in the coming decade."

Elsewhere, serial inventor Ali Hajimiri from the California Institute of Technology has designed a small phased array capable of forming images from a flat surface without any lenses at all – a lensless camera. Reversing the way in which phased array communication transmitters focus and steer radio waves in a particular direction, the device controls the relative timing of a large number of receiving elements to create 'gazing beams' that selectively look at a small part of the field of view.

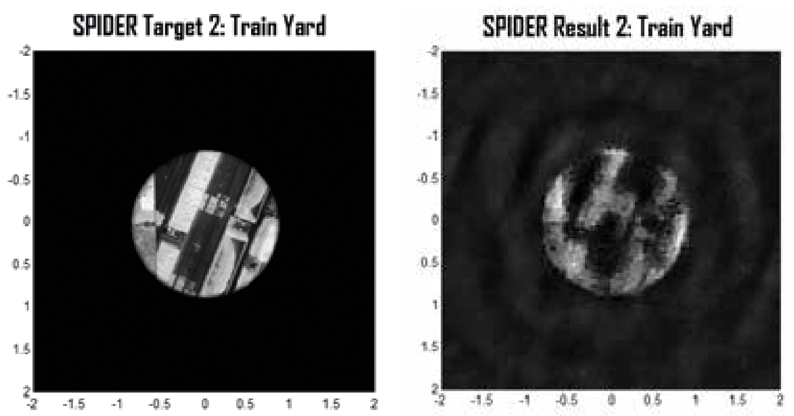
Last year, Hajimiri and his team demonstrated the technology by engineering a chip consisting of an 8x8 grid with 64 sensors. The chip managed to capture a low-resolution image of a barcode. But with more light-collecting elements, its sensitivity and resolution will increase dramatically.

"The technology does not need a depth associated with a refractive (lens-based) or reflective (mirror-based) telescope and hence can be deployed as a large, thin sail serving as a telescope," says Hajimiri.



▲ Tests for Ali Hajimiri's lensless camera – which takes its inspiration from phased array transmitters – managed to scan and reconstruct a specially designed barcode

LOCKHEED MARTIN X 3, A. HAJIMIRI, PAUL WOOTTON, D.CROWE



▲ Above are the results of the prototype SPIDER system, which used 30 lenses each under a millimetre wide. Left is the target image – a railway yard – and on the right is SPIDER's reconstruction

Cosmic concepts

Early-stage conceptual studies of ideas that would be unrecognisable to today's astronomers are also being performed. The Kilometer Space Telescope (KST), for instance, is another NIAC-funded project that would have over three times the diameter and 10 times the collecting area of the Arecibo radio telescope in Puerto Rico.

As the name suggests, the main component of the KST is a single, vast kilometre-diameter filled aperture. The key to realising such a huge collecting area is designing inflatable polymer bubbles which become rigid upon sufficient exposure to UV radiation from the Sun. The bubbles would then be cut in space and given a highly reflective coating to form a vast spherical mirror.

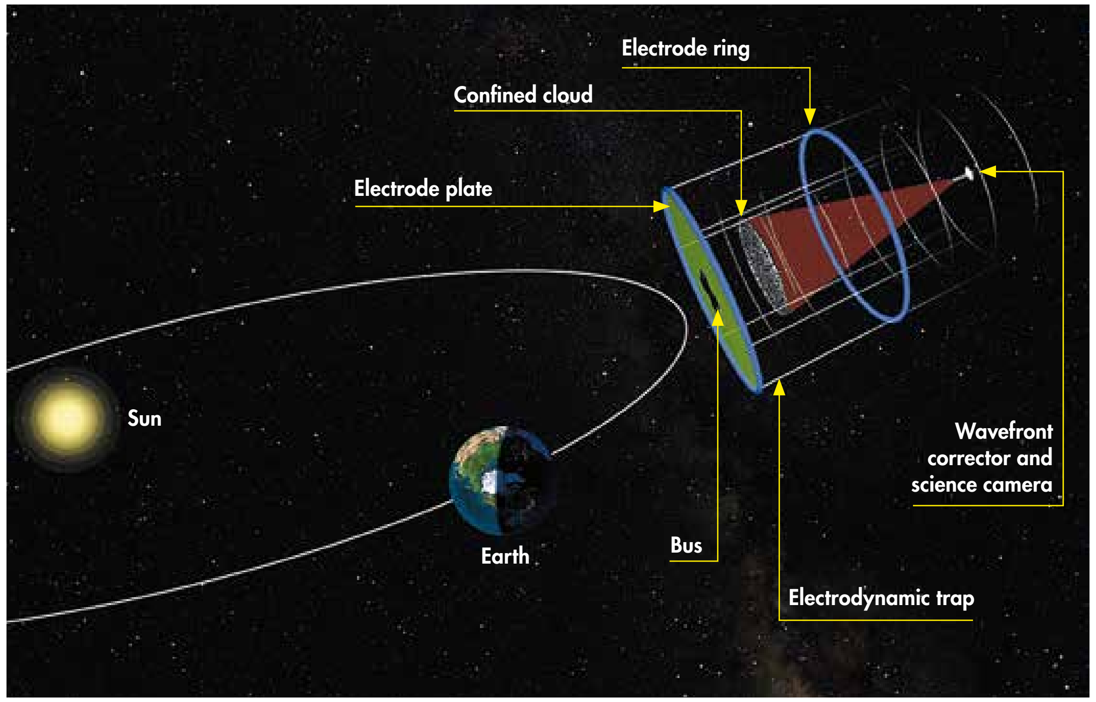
"We expect KST technology will give us 400 times better resolution than Hubble, using a light collection area 160,000 times greater," says Wallis Laughrey, vice president of Space Systems at Raytheon Space and Airborne Systems. "To use an analogy, Hubble sees 'toddler galaxies', Webb will see 'babies' and KST will see galaxies before they were born."

The inflated structures KST relies on could also form interferometer arrays, or act as giant star shades for exoplanet-hunting telescopes, blocking the line of sight to a host star but not its planets. Though lightweight and capable of forming vast telescope structures compared to today's standards, even KST is limited in terms of size and cost.

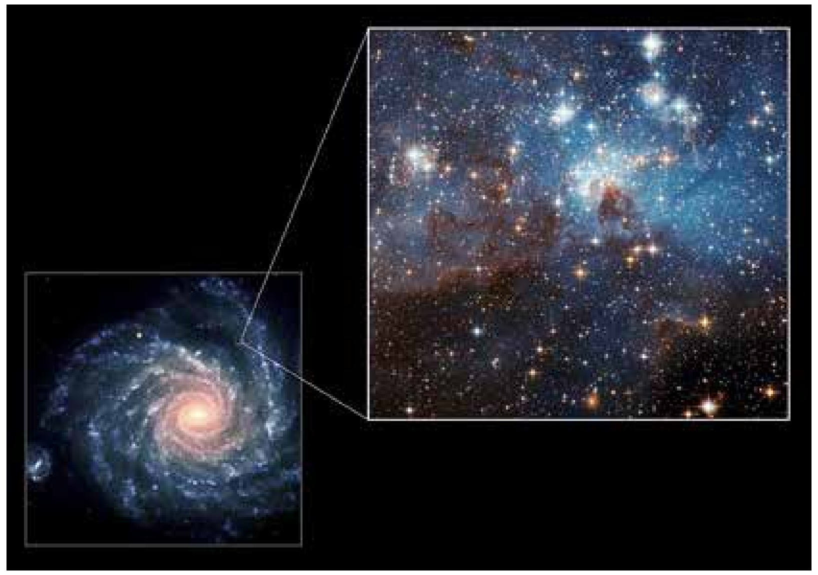
Inspired by how water droplets form rainbows here on Earth, NIAC-funded Orbiting Rainbows, in contrast, envisions replacing solid mirrors with potentially vast clouds of reflective micron-sized glitter-like particles. Consisting of a primary aperture made up of a cloud of millions of particles and a confinement system (electric, magnetic or light pressure); a secondary aperture that would also include a correction system and the science camera; and a module controlling the particle cloud, the various parts of the telescope would be free-flying and kept in formation at the same position where JWST will be parked.

One image from the particle cloud interacting with light from distant objects would be a mess. But studies on Earth using laser light to represent the object and arts-and-crafts glitter to represent the particle cloud have shown that by taking and combining multiple images, then deconvoluting the data using powerful algorithms, a clear picture emerges. "Orbital Rainbows would be relatively simple to package, transport and deploy," says Marco Quadrelli from NASA's Jet Propulsion Laboratory (JPL), the project's principal investigator. "It would be reconfigurable and could be re-targeted; the focal length would be variable, and ultimately it would also be self-healing and disposable."

He suggests the system could be used to detect exoplanets, and then image their surface features and hunt for molecular signs of life. However, with significant advances in adaptive optics and computational imaging required, it will take 10–20 years for the technology to mature to a point where 'cloud optics' is deployed in space.

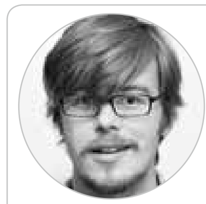


► The concept for NASA's Orbital Rainbows project: a trapped cloud of highly reflective grains operates as the mirror



▼ The Kilometer Space Telescope (KST) will have a resolution 400 times that of Hubble, so a single pixel from a galaxy in the Fornax Cluster (two million lightyears away) could have the detail of a Hubble image of the Large Magellanic Cloud (a mere 163,000 lightyears away)

ABOUT THE WRITER



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