A NASA technician prepares six of the James Webb Space Telescope's mirror segments for cryogenic testing.

NASA/MSFC/D. HIGGINBOTHAM/E. GIVEN

# THE TELESCOPE THAT ATE ASTRONOMY

*NASA's next-generation space observatory promises to open new windows on the Universe — but its cost could close many more.*

BY LEE BILLINGS

It has to work — for astronomers, there is no plan B. NASA's James Webb Space Telescope (JWST), scheduled to launch in 2014, is the successor to the Hubble Space Telescope and the key to almost every big question that astronomers hope to answer in the coming decades. Its promised ability to peer back through space and time to the formation of the first galaxies made it the top priority in the 2001 astronomy and astrophysics decadal survey, one of a series of authoritative, ten-year plans drafted by the US astronomy community. And now, the stakes are even higher. Without the JWST, the bulk of the science goals listed in the 2010 decadal survey, released this August, will be unattainable.

"We took it as a given that the JWST would be launched and would be a big success," says Michael Turner, a cosmologist at the University of Chicago, Illinois, and a member of the committee for the past two decadal surveys. "Things are built around it."

Hence the astronomers' anxiety: the risks are also astronomical. The JWST's 6.5-metre primary mirror, nearly three times the diameter of Hubble's, will be the largest ever launched into space. The telescope will rely on a host of untried technologies, ranging from its sensitive light-detecting instrumentation to the cooling system that will keep the huge spacecraft below 50 kelvin. And it will have to operate perfectly on the first try, some 1.5 million kilometres from Earth — four times farther than the Moon and beyond the reach of any repair mission. If the JWST — named after the administrator who guided NASA through the development of the Apollo missions — fails, the progress of astronomy could be set back by a generation.

And yet, as critical as it is for them, astronomers' feelings about the JWST are mixed. To support a price tag that now stands at roughly US$5 billion, the JWST has devoured resources meant for other major projects, none of which can begin serious development until the binge is over. Missions such as the Wide-Field Infrared Survey Telescope, designed to study the Universe's dark energy and designated the top-priority space-astronomy project in the most recent decadal survey, will have to wait until after the JWST has launched. "Until then, we're not projecting being able to afford large investments" in new missions, says Jon Morse, director of NASA's astrophysics division. And all the space telescopes currently operated by NASA and the European Space Agency will reach the end of their planned lifetimes in the next few years.

Worse, the JWST's costs keep growing. In 2009, NASA required an extra $95 million to cover cost overruns on the telescope. In 2010 it needed a further $20 million. And for 2011 it has requested another $60 million — even as rumours are swirling that still more cash infusions will be required (see 'Cost curve').

Senator Barbara Mikulski (Democrat, Maryland), chairwoman of the government subcommittee that oversees NASA's budget, responded to these requests in June by calling for an independent panel to investigate the causes of the JWST's spiralling cost and delays, and to find a way to bring them to resolution. "Building the JWST is an awesome technical challenge," Mikulski says. "But we're not in the business of cost overruns."

John Casani, chairman of Mikulski's investigative panel and a former project manager for NASA's Voyager, Galileo and Cassini missions, emphasizes that the panel is making suggestions, not decisions. Those will be up to NASA, which is expected to announce a budgetary plan incorporating the panel's suggestions on 2 November. But in considering potential solutions for the JWST's woes, Casani says that "everything will be on the table" — including, conceivably, scrapping instruments or otherwise downgrading the programme.

## THE GOLDIN OPPORTUNITY

The first concept for a Hubble replacement emerged in 1989, when Hubble was still a year away from launch. Astronomers already knew that its vision would not quite reach back to the 'cosmic dawn', 500 million years after the Big Bang, when the first stars and galaxies formed. So a next-generation space telescope that could fill the gap seemed like the logical next step.

In 1993, NASA asked a committee of astronomers, chaired by Alan Dressler of the Carnegie Observatories in Pasadena, California, to define what such a telescope would need. The new telescope's mirror would have to be big to gather the dim light of those first galaxies. So the committee recommended that the primary mirror be at least 4 metres across.

The telescope would also have to be cryogenically cold, because at any temperature higher than 50 kelvin, infrared heat radiation from the telescope itself would wash out the faint photons that the astronomers were looking for. "That was the science that propelled the whole thing," says Dressler.

Finally, it would have to operate far from Earth. At infrared wavelengths, this planet glows like a light bulb. So the committee recommended that the telescope be placed 1.5 million kilometres outside Earth's orbit, at the second Lagrangian point ($L_2$), where the combined gravitational pull of the Sun and Earth creates a region of stability. Any spacecraft at $L_2$ will also lie in the shadow cast by Earth, making it easier to keep cool (see 'The James Webb Space Telescope').

In December 1995, Dressler briefed NASA's then administrator, Daniel Goldin, on the recommendations. Goldin was intrigued. He was shaking up NASA's science programmes, pushing a 'faster, better, cheaper' strategy to deliver more capable and inspiring missions at lower costs. Taking his cues from Silicon Valley and aerospace 'skunkworks' projects — small, highly autonomous ventures pursuing innovation within larger organizations — Goldin was pushing for miniaturization of bulky electronics, more off-the-shelf components, lower organizational overheads, and a continuous expansion of the technological boundaries with each mission. Dressler's proposal seemed like a perfect opportunity to test that approach.

Instead of a 4-metre telescope, Goldin asked, why not try one with a primary mirror 6–8 metres in diameter? Some of the technology was in hand: NASA was developing the cryogenic infrared Spitzer Space Telescope with a 0.85-metre mirror made of beryllium, a metal that needs special handling — it corrodes skin at a touch — but is lightweight and keeps its shape through extreme temperature changes. That and other innovations could give the JWST a mega-mirror while reducing costs. As Goldin put it in a speech: "Let's throw away glass. Glass is for the ground."

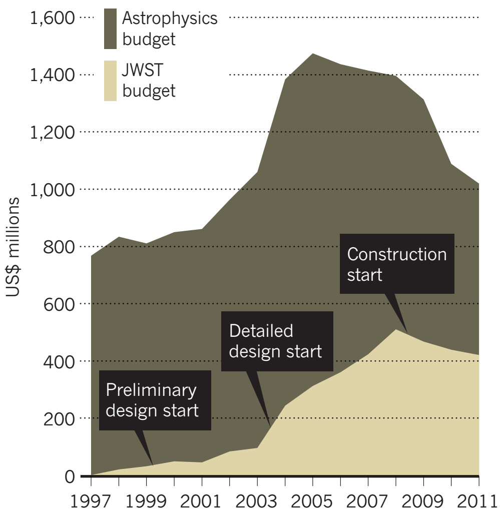
Some astronomers were dubious about initial cost estimates for the ambitious mission, which ranged from \$500 million to \$1 billion. But in the beginning, Goldin's methods seemed to deliver: the first missions using the approach were wildly successful. Among them were 1997's landmark Mars Pathfinder mission and its accompanying rover, Sojourner, and the 1998 Lunar Prospector mission that found evidence of water ice on the Moon. But they were followed in 1999 by the disastrous losses of the Wide-Field Infrared Explorer telescope and two planetary missions, the Mars Climate Orbiter and the Mars Polar Lander. This string of failures tarnished the agency's reputation, and reminded everyone that 'faster, better, cheaper' was also riskier. By the end of Goldin's tenure in 2001, NASA had already begun shifting back to its traditional, risk-averse and far more expensive strategy of exhaustive testing and extensive oversight.

That shift would send the cost of the JWST soaring past the billion-dollar mark. The mirror diameter would be cut from 8 metres to 6.5 metres to help reduce costs. But in the meantime, as NASA carried out the many engineering trade-off studies and scientific working groups required to solidify the telescope's design, a more insidious factor came into play: scientists started to pile on complexity.

It happens with almost every major mission, says Peter Stockman, former head of the JWST mission office at the Space Telescope Science Institute in Baltimore, Maryland. "Everyone fears it will be the last opportunity in their scientific lifetime." And there seemed little reason for restraint: in the 1990s, when the bulk of the design work was done, NASA's astrophysics budget was projected to keep growing by a few per cent a year.

### COST CURVE

The James Webb Space Telescope has consumed an ever-increasing fraction of NASA's astrophysics budget.




## STRETCHED CAPABILITIES

With each iteration, the JWST's science objectives swelled. The core instrument package came to include a large-field-of-view near-infrared camera (NIRCam) and a multi-object near-infrared spectrograph (NIRSpec), primarily for investigating the earliest stars and galaxies; a general-purpose mid-infrared camera and spectrograph for observing dust-shrouded objects in the Milky Way; and a fine guidance sensor and tunable-filter imager to support the other three.

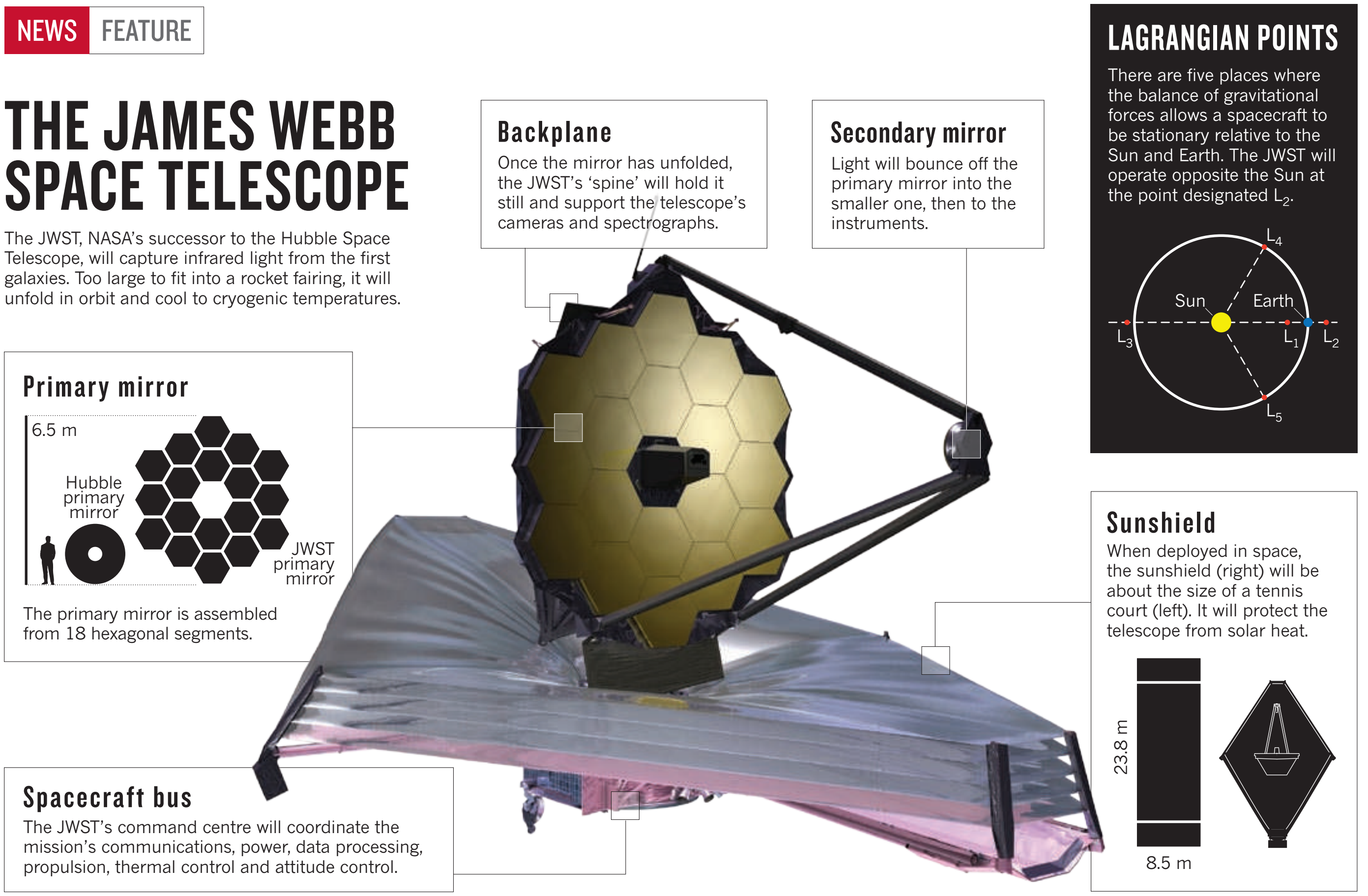
These expanded capabilities would have to be supported by expensive and largely unproven technologies. The instruments needed extra-large, ultra-stable infrared detectors. A five-layered membranous sunshield would have to be folded around the spacecraft before launch, then deployed in space to allow the telescope to cool to cryogenic temperatures. Unfurled, each layer would be about the same area as a tennis court. The primary mirror, too large to fit into any existing rocket fairing, would have to be assembled in 18 hexagonal, adjustable segments that would also unfold in orbit. Each segment would be painstakingly chiselled from beryllium, then coated with gold and polished. Arrays of electromechanical devices called microshutters would allow NIRSpec to take spectra from up to 100 objects simultaneously, even if some of those objects were faint and lay next to brighter stars. Each individually controllable microshutter would be the width of a few human hairs, and NIRSpec would require more than 62,000 of them.

In addition, every piece of technology in the spacecraft would have to be engineered to endure the violent vibrations of launch, the hard vacuum of outer space and the slow cool-down to cryogenic temperatures. The telescope's optical surfaces, in particular, would have to survive all this while staying aligned to a precision of nanometres. And everything would have to perform nearly flawlessly for a minimum of five years, the baseline mission length.

Small wonder, then, that NASA ended up spending almost \$2 billion just on the JWST's initial technology development. Nonetheless, the agency did not substantially cut any of the telescope's capabilities to bring

# THE JAMES WEBB SPACE TELESCOPE

The JWST, NASA's successor to the Hubble Space Telescope, will capture infrared light from the first galaxies. Too large to fit into a rocket fairing, it will unfold in orbit and cool to cryogenic temperatures.




the costs back under control. Instead, it looked for partnerships, securing major contributions from the European and Canadian space agencies. NASA also maximized support for the project on Capitol Hill by awarding contracts for spacecraft components to a small army of companies and universities scattered through many congressional districts. Aerospace giant Northrop Grumman of Los Angeles, California, became the JWST's prime contractor, under NASA's Goddard Space Flight Center in Greenbelt, Maryland, which would manage the overall project.

By the time the JWST passed its preliminary design reviews in spring 2008 and NASA had officially committed to building it, the project had been transformed from its comparatively modest 'faster, better, cheaper' origins into an audacious multibillion-dollar, multi-instrument mission spanning institutions, countries and continents.

## PASSING THE TEST

For nearly a year now, engineering models of the JWST's various components have been trickling into the clean room in Goddard's Building 29 for testing. (The centre's white-suited technicians can be seen at work on Internet 'Webb-cams'.) Pieces of actual flight hardware are supposed to start arriving in the same room in spring and summer 2011. All of the JWST's riskiest technologies have met their critical milestones and are on schedule for the 2014 launch.

The most substantial challenge remaining before launch is to integrate and test the flight components to ensure that they function as a whole — and, of course, to do all that without exceeding the remaining budget. NASA's traditional method is to 'test as you fly' — to operate the integrated flight hardware in conditions as close as possible to those it will experience in space. The problem is that the fully assembled telescope will be far too large to fit into any available thermal vacuum chamber. Just as the JWST's scientific objectives required new technology, mission planners have had to devise entirely new protocols to test it.

"With the JWST we have to do incremental modelling, building and testing, validating our model at each stage and then moving up to the next level of assembly," says Phil Sabelhaus, the JWST project manager at Goddard. "We aren't only testing — we're also proving our ability to model correctly, which is how we will evaluate the JWST's absolute performance on-orbit." This hierarchical assembly, testing and modelling is laborious and time-consuming, more like building several telescopes than one, and is a major contributor to the JWST's remaining costs. So, unsurprisingly, it is one of the most probable targets for cost-cutting.

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"There are tests that are really essential to do, and tests that would be nice to do," says Dressler. "With something of this magnitude, there is a natural tendency to double-check and triple-check, and maybe we can't afford that." On the other hand, he says, maybe they can't afford not to: it was a decision to save money on testing that allowed a defect in Hubble's primary mirror to go undetected until it was in orbit, nearly dooming the entire mission.

The JWST's supporters contend that, even with further budget overruns, the telescope will still break the historical cost pattern for large space telescopes. "Not even including its four space-shuttle servicing missions, Hubble cost \$4 billion or \$5 billion in today's dollars just to build and launch," Dressler notes. "Here we are, building a telescope that is almost seven times bigger, it is cryogenic, it is operating 1.5 million kilometres away, and it is costing the same amount as Hubble did, if not less. That is remarkable, and this is probably the biggest scale on which we will consider building such things in this country."

Even so, ambivalence still surrounds the JWST. Failure is not an option, either for NASA or for the astronomers it supports. Yet, in the face of flat or declining budgets, a dwindling docket of near-term astrophysics missions and rising public outrage over perceptions of runaway government spending, tough questions are inevitable. At a mid-September meeting of the agency's astrophysics subcommittee, efforts to nail down just how many extra dollars lie between the JWST and its eventual arrival at $L_2$ were met with silence. Until the announcement of a new budget and schedule, informed by recent panel reviews, that is the best answer anyone is likely to get. ■

**Lee Billings** *is a freelance writer based in New York.*

CELL BIOLOGY

# There will be blood

*Direct conversion of cell types could offer safer, simpler treatments than stem cells.*

BY EWEN CALLAWAY

In a feat of cellular alchemy, human skin cells have been transformed into blood cells without first being sent through a primordial, stem-cell-like state. For the developers of patient-specific cell therapies, the result could be safer and simpler than induced pluripotent stem (iPS) cells — reprogrammed adult cells that can differentiate into many cell types.

Published in *Nature*[1], the study follows work earlier this year showing that fibroblast cells from mouse skin can be transformed into neurons[2] and heart muscle[3]. However, it is the first study to accomplish direct reprogramming with human cells, and the first to create progenitor cells — in this case for blood. "It takes us a step along the line to believing that you can produce anything from almost anything," says Ian Wilmut, director of the Medical Research Council Centre for Regenerative Medicine in Edinburgh, UK, who was not involved in the study.

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Mickie Bhatia, a stem-cell researcher at McMaster University in Hamilton, Canada, and his colleagues infected skin cells with a virus that inserted the *OCT4* gene, then they grew the cells in a soup of immune-system stimulating proteins called cytokines. The gene's product, the OCT4 protein, is one of a handful of factors used to transform fibroblasts into iPS cells, but Bhatia's team found no evidence that the blood progenitor cells they made went through an embryonic state. For instance, the cells did not cause mice to develop teratomas — tumours that are characteristic of pluripotent cells, making iPS cells less attractive as a therapeutic option. The progenitors did, however, produce all three classes of blood cells — white, red and platelets — all of which were functional. The red blood cells also produced the adult form of haemoglobin, whereas iPS-cell-derived blood cells make the fetal form. "This is the most encouraging result we've seen for using blood cells for cell-replacement therapy," says Bhatia.

Converted cells aren't without their drawbacks, though. Unlike iPS and embryonic stem cells, they cannot easily multiply in the lab, so producing the large quantities needed for screening drugs, for example, could be difficult, says Wilmut. It is also too early to tell whether they will be as good as the real thing when inside a person, says George Daley, a stem-cell biologist at Children's Hospital Boston in Massachusetts. Transplanting the cells into humans is still years away, says Bhatia. "The clinical side is going to be a lot of work." ■

1. Szabo, E. *et al. Nature* advance online publication doi:10.1038/nature09591 (2010).
2. Vierbuchen, T. *et al. Nature* **463,** 1035–1041 (2010).
3. Ieda, M. *et al. Cell* **142,** 375–386 (2010).

**CORRECTION**

The News Feature 'The telescope that ate astronomy' (*Nature* **467,** 1028–1030; 2010) wrongly said that a revised budgetary plan for the James Webb Space Telescope could come as early as 2 November. In fact, the plan is not likely to be unveiled before the president's budget request in February 2011.