# A Mirror in the Sky: The Story of the Hubble Space Telescope

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The dream of a telescope in space – a mirror in the sky - goes back to before the space age started. Being above the atmosphere brings with it the advantage of being able to access wavelengths of light, for example in the ultraviolet region of the spectrum, which do not reach us on the ground. It also, crucially, frees the astronomer from the task of dealing with the twinkling – technically, the scintillation – that affects objects when viewed through the murk of our planet's atmosphere. Any telescope larger than about a meter in diameter would see more crisply if only it could be placed in space.

Such ideas were, for a long time, the preserve of a few visionaries, most notably the eminent Lyman Spitzer[1] whose post-second world war sketch for the RAND corporation in the 1945 was the first serious sketch of a design. Those involved had a serious case of aperture fever[2], suggesting a telescope of at least 200" (a shade over 5 meters), as large as any on the surface of the Earth at the time. Even when NASA, as a space agency in search of a new purpose after the end of the Apollo program, took things more seriously in the early 1970s, deciding on the design of such a telescope was a fraught and difficult process, with arguments about size and cost only partly resolved by a decision to a design already used for several US spy satellites. The astronomers ended up with a 2.4-meter aperture, but importantly the design of what would become the *Hubble Space Telescope* allowed for frequent changes of instrument, with the assumption that space shuttle astronauts would visit often, whenever required. The European and Canadian space agencies signed on, lending international support and credibility to NASA's plan.

By the time the telescope launched aboard *Discovery* in April 1990 it was clear this would be impossible. The trauma of the loss of *Challenger* in 1986, and more generally the much higher than expected cost of each shuttle mission, meant that visits to *Hubble* would be rare. The ability to service the telescope did, however, prove to be important. Soon after launch, it was clear that the telescope's vision was not as crisp as had been expected; it was, in fact, not much better than could be achieved with a telescope of the same size on a good site on the ground. This fact quickly became apparent to the media, and NASA and its partners quickly became objects of ridicule.

The problem affected each of *Hubble*'s instruments, making it clear that it was the telescope's optical system rather than a camera malfunction that was responsible. A hastily arranged investigation found the problem in a test rig which was still set up at Perkin-Elmer, the main contractor for the telescope. A washer, no more than a millimetre thick, had been left in place in the equipment used to check the progress of the mirror shaping process, leading the team polishing the primary mirror to carefully fashion it precisely into exactly the wrong shape.

Had the telescope been anywhere but in low Earth orbit, the mission would have been fatally flawed. Though the telescope could carry out scientifically valuable spectroscopy without too many problems, there is no substitute, for science or for PR purposes, for imagery. After much thought, a set of corrective optics,

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[1] He gave up a research career to be the person promoting the idea of a space telescope, only to be ignored when it really took off. He did get NASA's infrared space telescope, launched a few years after Hubble, named after him.

[2] A chronic condition common in astronomers whose main symptom is a desire for ever larger telescopes.

known as COSTAR and inspired, partly, by the design of a hotel showerhead[3], were hastily manufactured and installed by astronauts on board *Endeavour*, who visited in December 1993.

The effect of this intervention was immediately obvious, and Hubble produced a set of eye-catching images over the next few years. This delighted scientists and the public, and also the agency's managers, who were counting the telescope's success in the number of images featuring above the fold of the *New York Times.* Early highlights included unprecedented observations of scars left in Jupiter's cloud-tops following the impact of Comet Shoemaker-Levy 9 in 1994, the success of the Hubble Deep Field which showed us the Universe as it was within its first few billion years, and a sequence of portraits of planetary nebulae.

These enigmatic objects, which represent a brief, late stage in the lives of intermediate mass stars such as the Sun. As they start to run out of hydrogen to fuel the nuclear fusion in their cores, such systems lose their outer layers and briefly – for 10,000 years or so – these are visible in a bright shell. From the ground, it is hard to see much detail in these small objects (their name comes from their resemblance to the disk of a planet), but with Hubble vision they reveal a remarkable diversity of forms, gaining names that range from the fanciful (the 'red spider' or 'butterfly' nebulae) to the prosaic (the mysterious 'red rectangle').

The shapes are explained by a variety of complex processes, often involving the interplay of magnetic fields or multiple star systems at the nebulae's core. Introducing complexity into our ideas of how stars behave has been something of a speciality for Hubble, particularly in studying star formation. The textbook description of this process, in which a cloud of gas and dust collapses under its own gravity until a sufficient density for nuclear reactions to proceed is reached, is adequate. But when faced with images like that taken by Hubble of the Carina nebula, a complex landscape sculpted by the activity of the multiple massive stars which have already formed within it. One look at this image will convince even the casual viewer that we need complex answers to apparently simple questions: what triggers star formation? What controls how massive the resulting stars are? How many stars will form in any given environment?

All of these have less obvious answers since Hubble was first lifted into orbit, and this is, perhaps, the great observatory's true legacy. When, sometime in the next decade, its aging systems begin to fail and it is deorbited, left to burn up in the atmosphere, it will leave us not with more answers, but with more, and more interesting questions.



**Reading List**

1. The definitive history of the space telescope project is 'The Universe in a mirror', by Robert Zimmerman, Princeton University Press (2008)

2. It draws in its early stages on the more technical 'The Space Telescope: A Study of Nasa, Science, Technology, and Politics', by Smith, Hanle, Kargon & Tatarewicz (Cambridge University Press, 1989). A more recent effort is 'Hubble's Legacy' (Launius & Devorkin, eds, Smithsonian Press, 2015).

3. A series of coffee table books have followed the telescope's progress, with selections of images from Hubble. The best of them, and still worth consulting nearly twenty years after publication, is 'Universe in Focus: The Story of the Hubble Space Telescope', by Stuart Clark (Barnes & Noble 1997).

4. The world wide web grew up with Hubble, and has always been used to disseminate the telescope's results. I recommend in particular ESA's spectacular compilation of the observatory's top 100 images: https://esahubble.org/images/archive/top100/. NASA's 30th anniversary minisite is also a good place to start: https://hubblesite.org/mission-and-telescope/hubble-30th-anniversary. http://stephenwilkins.co.uk/HubbleLegacy/ is also a useful introductory guide.

5. The Hubble archive (https://hla.stsci.edu/) is a rich source of scientific data and content, with more papers now being published each year using archive data than from the telescope itself. For those who want to try their own hand at working with Hubble images, ESA have a good guide to the process (and the required software) here: https://noirlab.edu/public/media/archives/techdocs/pdf/techdoc028.pdf

[3] Its canter-levered design provided a solution to how to insert the optics into the light path through the barrel of the telescope.