HUBBLE'S REDE

MPTION

BY CLIFFORD MCMURRAY

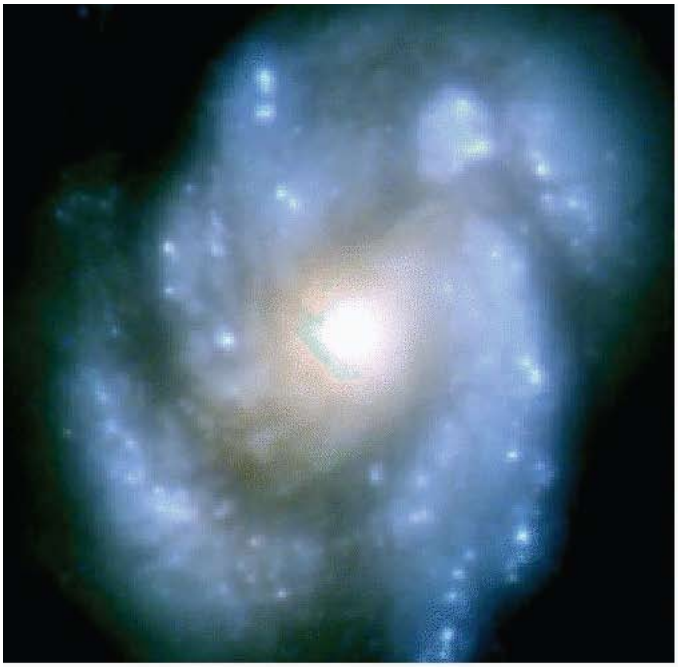
"Hubble is working perfectly, but the universe is blurry," Johnny Carson told his television audience in the summer of 1990. The audience was laughing, but NASA and the astronomers who hoped to use the newly launched Hubble Space Telescope (HST) were not. They had just taken the first photos with what NASA had told the world would be the most powerful telescope in history, only to discover that the primary mirror suffered from spherical aberration. Like a nearsighted man without glasses, it couldn't bring the image into focus.

At 2.4 meters (94.5 inches), the HST mirror was just slightly smaller than the 100-inch telescope at Mt. Wilson which Edwin Hubble, for whom the orbiting observatory was named, had used in the 1920s to prove that the "nebulae" astronomers had thought were clusters of stars within our galaxy were really galaxies themselves, lying millions of light-years beyond the Milky Way in a much bigger universe that is expanding in all directions. Astronomers hoped that the space telescope would yield discoveries as fundamental as those of its namesake. The mirror used by the HST was the most perfect mirror ever built. If it were blown up to the diameter of North America, its largest imperfection would be only inches tall, compared to the skyscraper-sized imperfections of a typical telescope mirror at the same scale. And now—too late—NASA found that the $437 million mirror (which originally was supposed to cost only $70 million) had been perfectly cast and meticulously polished to the wrong curve. The outer edge of the mirror was too flat by 0.0001 inches: 1/50th the width of a human hair.

The idea of an orbiting telescope was as old as the idea of spaceflight itself. Hermann Oberth had proposed it in *The Rocket into Interplanetary Space* in 1923. It was obvious that such a telescope could see in wavelengths blocked by Earth's atmosphere—the ultraviolet that is almost totally blocked by the ozone layer, and the infrared that is reduced by water vapor and carbon dioxide—and wouldn't suffer from the skyglow from city lights or the blurring caused by air molecules in motion. But it took a 1946 RAND study by a Princeton astrophysicist, Lyman Spitzer Jr., to provide a detailed proposal for such a telescope and outline its research goals: to measure the extent of the universe, observe the structure of galaxies and globular clusters, and study the planets of our solar system in detail. Nearly half a century later, Spitzer was on hand at Cape Canaveral to see his brainchild lofted into orbit on April 24, 1990, aboard space shuttle Discovery. The next day, with pilot Charles Bolden recording the event on an IMAX camera, mission specialist Steve Hawley (an astronomer himself) used the shuttle's manipulator arm to lift the telescope out of Discovery's cargo bay and set it free in orbit 330 nautical miles above Earth.

Two months later, Hubble was fodder for every comedian in the country. Carson told his audience that Hubble had given NASA the "clearest image of nothing that they ever saw." Editorial cartoons showing Mr. Magoo as the man who built Hubble, newspaper headlines like "Pix Nixed As Hubble Sees Double," and the cover of Newsweek announcing "NASA's $1.5 Billion Blunder" were an embarrassment for NASA and the space industry. But more than that, Hubble was a public relations disaster with consequences. Congress, marking up the 1991 federal budget, cut all funding for President Bush's Space Exploration Initiative, which aimed to send humans back to the Moon and on to Mars, and began hearings to find and punish the culprits.

Finding the cause of the error—an improperly calibrated measuring instrument that had been used to guide the mirror polishers—didn't take long. A fix would have to wait more than three years. Hubble had been designed for maintenance in space, and servicing missions by shuttle crews were already planned. The first servicing mission in December 1993 would replace the Wide Field/Planetary Camera with an upgraded version with corrective optics, and install a set of contact lenses for the other instruments called COSTAR (Corrective Optics Space Telescope Axial Replacement). With so much riding on a mission that had changed from servicing to major repair, the crew of STS-61 needed to train hard. They visited the Smithsonian's National Air and Space Museum to practice on its full-scale Hubble replica, and used virtual reality simulations for the first time. Two shuttle missions earlier



Wide Field Planetary Camera 1

Wide Field Planetary Camera 2

Caption TK

in 1993 tested the custom-made tools they would use. By the time they hoisted Hubble into Endeavour's cargo bay, they made the repair work look easy.

Hubble's impairment had never been as bad as the headlines had made it seem. Even its earliest observations were better than those of the best ground-based telescopes. Good science had been accomplished in its first three years on orbit. But now Hubble started to deliver on its original promise—to produce images at 10 times greater resolution than ground-based scopes, the only order-of-magnitude improvement in sight since Galileo turned his first primitive telescope skyward. The words "spectacular" and "Hubble image" were on their way to becoming synonyms.

The improved optics came just in time for Hubble to observe the fragments of comet Shoemaker-Levy punch Earth-sized holes in the atmosphere of Jupiter in July 1994. An awestruck public began to wonder if the same thing could happen to their own planet. Every year since, Hubble has delivered pictures of exquisite beauty as well as unique scientific value. Among Hubble's scientific accomplishments are the following:

- observations of protoplanetary disks—flattened disks of gas and dust that are the birth of new solar systems;
- establishment of the age of the universe at 13.7 billion years, with a measurement error not greater than 10 percent;
- determination that most galaxies, rather than just a few, have massive black holes at their cores;
- first detection and measurement of an atmosphere on a planet outside our solar system (HD 209458b, 150 light-years away);
- examination of the nebulae of supernova stellar explosions in unprecedented detail; and
- first direct measurements of the three-dimensional distribution of dark matter throughout the universe.

One of Hubble's most significant tasks was to take very long exposures of a small patch of sky, to peer as deeply into the universe as possible. The Hubble Deep Field, in 1995, imaged 1,500 galaxies in a single frame, out to a distance of 10.5 billion light-years. The even more ambitious Hubble Ultra Deep Field in 2003–2004 was a million-second exposure taken over the course of 400 orbits. Looking into a patch of sky only 1/10th the diameter of the Moon, this single image revealed 10,000 galaxies, some as far away as 13 billion light-years. Given that looking deep into space is also looking back in time, this meant that Hubble was viewing galaxies as they appeared when the universe was only 5 percent of its present age.

The years since the "Hail Mary" repair mission have seen another four servicing missions, the most recent (and last scheduled) in May 2009. In all, 16 shuttle astronauts have spent nearly 160 hours in 23 extra-vehicular activities (EVAs) to change out failed components and upgrade Hubble with new instruments. With continual upgrades to its scientific instruments, little is left of the original telescope. Its solar panels have been replaced twice, and its memory has gone from a reel-to-reel tape recorder to a digital recorder with 10 times the capacity of the original. When the shuttle is retired, NASA will lose the ability to put hands on Hubble, but the last servicing mission installed a docking collar for a future robot tug to grapple with Hubble and send it to a controlled re-entry. That docking collar could just as easily be used by the next generation of crewed spacecraft, if NASA changes its mind again.

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Since its launch 19 years ago, the Hubble Space Telescope has returned about half a million images of more than 25,000 targets and gathered data for about 800,000 studies. That works out to about three or four images per hour, day in and day out. Every year, the Space Telescope Science Institute at Johns Hopkins University in Baltimore receives about 1,000 requests for viewing time from astronomers around the world. Only about 200 of those proposals can be accepted, but until its electronic eyes finally go dark, Hubble will be busy.

Over the 30 years since its first appearance as a new project start in the 1977 NASA budget, Hubble has cost the American taxpayer about $10 billion. That's about two cents per citizen per week. The doubters of its worth back in the gloomy days of 1990 have all been silenced. Hubble is an American icon, the flagship of NASA's robotic fleet. Hubble images appear as screen savers and as posters on college dorm room walls. Even the blind can gain some appreciation of its magnificent return; 14 of its images have been embossed so that their contours can be traced by touch.

Spitzer's 1946 proposal for a space telescope predicted that "the chief contribution of such a radically new and more powerful instrument would be, not to supplement our present ideas of the universe we live in, but rather to uncover new phenomena not yet imagined, and perhaps modify profoundly our basic concepts of space and time." That prediction has been completely fulfilled.

Clifford McMurray is a former executive vice president of the National Space Society.