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on the cover

Front: Data from three of the four space telescopes in NASA's Great Observatories program make up this composite image of spiral galaxy M101. Infrared radiation from the Spitzer Space Telescope is in red, visible light from the Hubble Space Telescope is in yellow, and X-rays from Chandra Space Observatory is in blue. *[NASA, ESA, CXC, SSC, and STScI]*

Back: Our Milky Way Galaxy rises above the European Space Observatory's Very Large Telescope (VLT) at Paranal Observatory in Chile. Notice the triangular-shape haze above the horizon at the right of the image; that's the *zodiacal light*, and it's the glow from sunlight scattering off dust in the plane of the Solar System. *[Y. Beletsky (LCO)/ESO]*

The Astronaut Astronomers

Human space crews have conducted astronomy experiments for over 50 years. Their role has changed with the technology — and it may be changing again.

By Steve Murray

The International Space Station's Cupola module provides stunning views of Earth from space. [NASA]

When the crew of Apollo 16 landed on the Moon in April 1972, they set up the first astronomical telescope on another world, an instrument that explored the lunar skies in the ultraviolet (UV) band. While science and technology have changed dramatically in the decades that followed, astronomy has always been woven into the fabric of human spaceflight. Telescopes are still installed onboard today's spacecraft, but the astronauts who accompany them have much different roles.

Astrophysics with Apollo

In the 1960s and 1970s, only the US and the Soviet Union could launch humans into space. It was a political and scientific competition, so things moved fast and costs were steep. Carrying science experiments onboard human space missions leveraged the return on these costs, so astronomy payloads often launched with astronaut crews.

Between 1969 and 1972, five Apollo missions each deployed a Solar Wind Composition Experiment on the Moon. The apparatus consisted of a metallic sheet mounted on a pole to collect particles from the Sun. Astronauts brought the experiment back with them, so data collection was limited to the duration of each surface mission. Nevertheless, the device yielded greatly improved measures of solar wind components. The Far Ultraviolet Camera/Spectrograph set up by the Apollo 16 crew was mounted on a tripod in the shadow of the lunar module, and the astronauts had to re-point the instrument periodically to capture different parts of the sky. They returned to Earth with 178 frames of precious camera film, demonstrating that humans could conduct astronomy research outside Earth's atmosphere, a feat impossible for the robotic spacecraft technologies of the time.

Five months separated the final Apollo flight from the launch of the Skylab space station (May 1973). Skylab was the first spacecraft big enough to carry a major observatory: the Apollo Telescope Mount (ATM), whose four solar arrays gave the space station its iconic X-wing appearance. The ATM housed an array of scientific instruments to study the Sun. Astronaut crews manually operated the instruments and, as before, data were collected on photographic film that was brought to Earth after each mission. Film canisters were located outside the space station, so astronauts had to manually change them

Apollo 11 astronaut Edwin ("Buzz") Aldrin stands next to the Solar Wind Composition Experiment. *[NASA]*

On a spacewalk, astronaut Owen K. Garriott, retrieves an imagery experiment from the Apollo Telescope Mount, which was attached to the Skylab in Earth orbit. *[NASA]*

during spacewalks. Data from these observing sessions later contributed to Riccardo Giacconi's share of the 2002 Nobel Prize in Physics.

Science on the Salyuts

When Apollo 11 effectively ended the race for the Moon in 1969, the Soviet Union redirected its efforts toward developing long-duration capabilities in near-Earth space using a series of Salyut space stations. The Soyuz vehicles, first launched in 1967 as part of Soviet lunar landing goals, were reconfigured for ferry operations to the Salyuts — a service they still provide to the International Space Station (ISS) today.

Salyut 1, which flew in 1971, was the first space mission by any nation devoted to a single science instrument — the Orion 1 ultraviolet telescope. The observatory measured the UV spectra of stars on film carried back to Earth with the crew. Because the Orion-1 required manual operation, cosmonaut Viktor Patsayev became the first human to actually control a telescope from orbit. The Soviets modified Soyuz 13 to carry the Orion 2 space observatory for its flight in late 1973. This included improved versions of the instruments used on Salyut 1, but they still required the crew to operate them.

Things were more complicated for Salyut 4, however, after it launched in late 1974 with the Orbiting Solar Telescope (OST-1), a far-UV spectrometer, and other optical sensors and X-ray detectors. When Soyuz 17 docked with the Salyut 17 days later, the crew found that the telescope's mirror had been ruined by exposure to direct sunlight. In a remarkable display of ingenuity, the cosmonauts resurfaced the mirror themselves and then manually pointed the telescope using a stopwatch, a stethoscope, and the noises the mirror made as it moved in its casing. The value of human presence in space had never been demonstrated so clearly.

Salyut 6 was an upgraded "second generation" space station, designed for longer occupation, when it launched in 1977. Its primary scientific instrument was the BST-1M multispectral telescope that could make observations in the infrared (IR), UV, and submillimeter bands. Although the instrument could operate only when the station was on the night side of Earth, and it had to stay closed the rest of the time, the BST-1M succeeded in gathering both IR Earth science data and UV characteristics of 28 celestial objects.

Evolving in the '80s

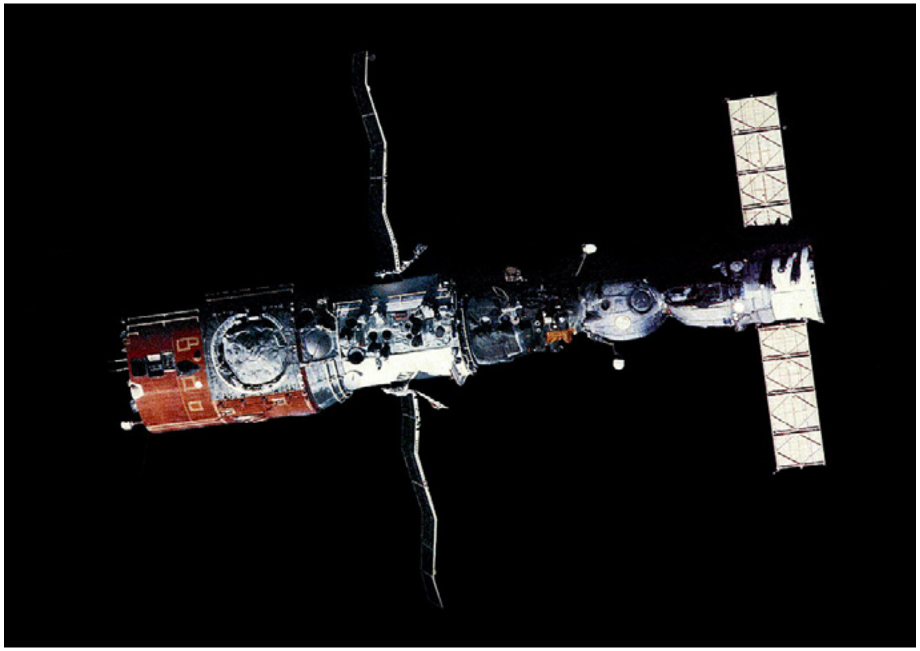
Skylab deorbited in 1979, marking the end of a decade that demonstrated the value of long-duration human presence in space. Astronauts and cosmonauts had established a clear role in operating and repairing space instruments, and had gathered knowledge that would have been lost without their presence. The '80s, however, would be the decade of the Space Shuttle and the Mir space station, two systems with much greater capabilities for hosting human science activities in orbit.

The first Shuttle (*Columbia*) launched in 1981, but astronomy missions didn't commence until the summer of 1985 when *Atlantis* carried Spacelab 2, a reusable module developed by the European Space Agency (ESA) in its payload bay. Spacelab 2 experiments included both an X-ray telescope (XRT) and an infrared telescope (IRT) among its equipment set. Although the XRT performed well, however, experiences with the IRT taught astronomers important lessons about limitations of the Shuttle as an astronomical telescope base. Giovanni Fazio, Senior Physicist at the Harvard-Smithsonian Center for Astrophysics, was the Principal Investigator for the IRT. "Water vapor, which absorbs IR radiation, was being emitted from the tiles of the Shuttle, and small particles, probably paint, appeared in our telescope field of view," says Fazio The solar experiments also had pointing trouble in the beginning, too, due to astronauts' motion.

"We did manage to map the galactic plane," he adds, "but the main conclusion was that the Shuttle environment wasn't very good for IR astronomy."

The Space Shuttle may have revealed some shortcomings as an observing platform, but its crews demonstrated solid skills for boosting free-flyer space telescopes into distant orbits. *Atlantis* launched

Paul J. Weitz, Skylab 2 pilot, sits at the Apollo Telescope Mount's control and display panel. *[NASA]*



The Salyut 6 space station launched in 1977. Here it's shown with a docked Soyuz. *[spacefacts.de/TASS]*

This photo, looking down one of the Mir space station's solar panels, shows a Kvant module at the diagonal. *[NASA]*

the Magellan spacecraft, for example, in May 1989 on a mission to map the surface of Venus by radar. Magellan was the first interplanetary mission launched from the Space Shuttle, and ended an 11-year gap in U.S. interplanetary probe missions. In October of the same year, *Atlantis* launched Galileo to study Jupiter and its moons.

When Mir commenced operation in early 1986, it became the world's only active space station. (Salyut 7 remained in orbit until 1991, but it wasn't occupied after 1982.) Two "Kvant" expansion modules formed the backbone of Mir's astronomy work. Kvant-1 launched to join Mir in early 1987 carrying the Glazar UV telescope, an X-ray telescope, a wide-angle camera, and a series of high-energy detectors. Kvant-2 added a high-resolution camera, spectrometers, and X-ray sensors to the station's astronomy suite when it arrived in late 1989.

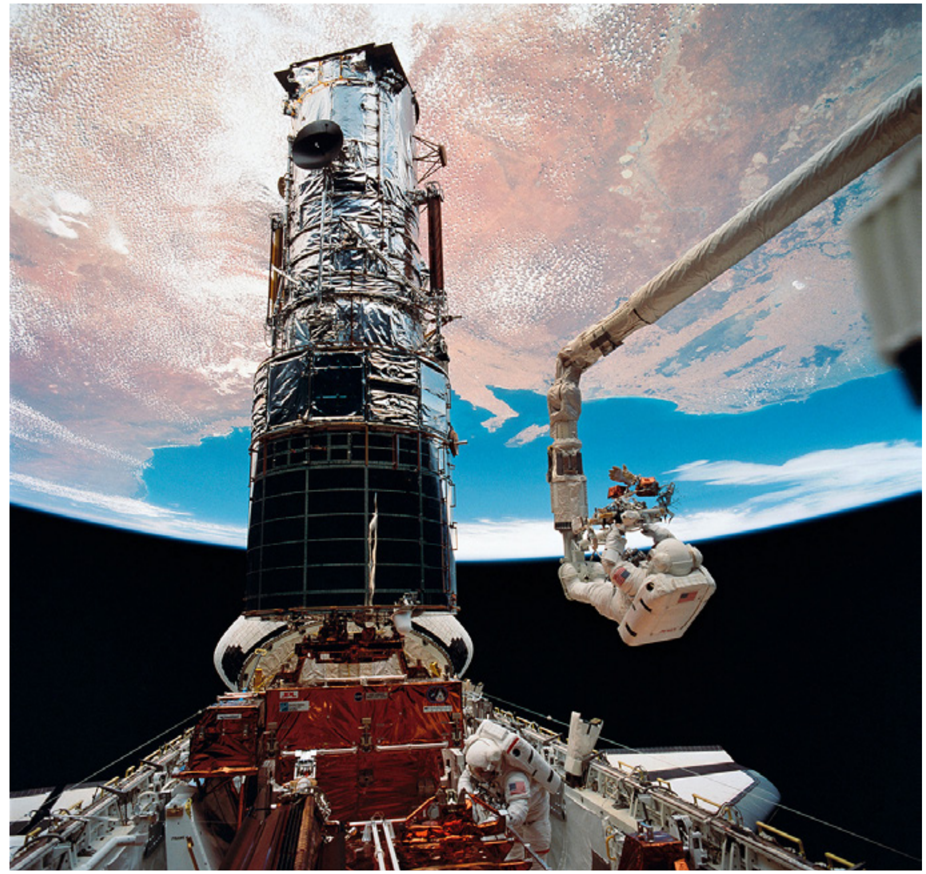
Crews were now well-equipped to gather data from orbit about the physics of active galaxies and neutron stars. A cosmonaut worked from a pressurized cabin and pointed all of the X-ray instruments at the same source during operations. The period and inclination of the Mir orbit limited telescope use to about 20 minutes during each circuit, when Mir was near the equator and above Earth's interfering radiation belts. Cosmonauts also had to strap into their seats during Glazar operation, as any movement within the station could ruin photographs, which required exposures of up to eight minutes each.

Shuttle runs

The third Shuttle mission of 1990 played to the precise strengths of the spacecraft as a booster of free-flyer telescopes, and again demonstrated the value of astronaut crews to scientific success. The Hubble Space Telescope was released from the *Discovery* payload bay in April. "Actually, the Hubble Space Telescope was one of the important design drivers of the Space Shuttle," says Bob Williams, Visiting Distinguished Osterbrock Professor at the University of California Santa Cruz, and Astronomer Emeritus and former Director at the Space Telescope Science Institute (STScI) in Baltimore, MD. "It was the largest thing you could fit in the payload bay." Still, the concept of using the Shuttle and its crew for handling such a large, delicate payload was new and carried risks. "We had never undertaken anything quite so complex in space," added Williams.

The now-famous problem with Hubble's optics was apparent within weeks of its deployment as an aberration in the primary mirror degraded the clarity of its images. Computer reconstruction partially compensated for the issue, but a real solution had to wait until December 1993 when the crew of *Endeavor* was able to conduct a repair mission. The success of their efforts is now a part of astronomy and spaceflight lore. Astronauts repaired and upgraded the telescope on four additional Shuttle missions through May 2009, maintaining it as one of the most productive astronomical observatories to the present day (detailed in *Mercury*, Spring 2020). "NASA performed what is, without a doubt, the most important work ever accomplished in human spaceflight apart from the Apollo program," says Williams.

Shuttles carried two Spacelab payloads during the decade on other missions dedicated entirely to astronomy. The first, Astro-1, flew aboard *Columbia* in late 1990 equipped with one X-ray and three UV telescopes that operated continuously during the nine-day mission. Although pointing system problems required ground teams to help aim the instruments, the observatory yielded the first accurate data of UV distribution in the universe. The second mission, Astro-2, flew aboard *Endeavor* in early 1995 with the same three UV telescopes but, because Astro 2 flew at a different time of year than Astro 1, the instruments could collect data from new regions of the sky.



In 1993, astronauts performed the first servicing mission on the Hubble Space Telescope and fixed the telescope's flawed optics. *[NASA]*

New approach for a new millennium

The last crew left Mir in June 2000 and the first crew arrived at the International Space Station (ISS) barely five months later. That crew was delivered aboard a Soyuz spacecraft; Space Shuttle flights initially ferried several crews to the ISS, but the 2003 *Columbia* disaster cut the fleet's capabilities, leaving the Russian Soyuz as the workhorse for human transportation, especially after the Shuttle fleet ceased operation in 2011. Although the ISS offered powerful new science capabilities, the astronaut role had shifted; now, their interaction with astronomy experiments was minimal.

The ISS hosts five astronomy observatories from NASA, ESA, and the Japanese Aerospace Exploration Agency (JAXA). All are fastened to the exteriors of various ISS modules, all were installed remotely, and none require on-site operation. Astronauts may be nearby on the ISS, but their involvement is something to be avoided if possible. The Neutron Star Interior Composition Explorer (NICER), for example, is a NASA telescope delivered to the ISS in 2017 to study properties of

In 1998, astronauts Jerry Ross and James Newman connected the Unity module to the Russian Zarya module of the International Space Station. *[NASA]*

neutron stars. Independent operation was part of the design, according to Keith Gendreau, the Principal Investigator for NICER at the NASA Goddard Space Flight Center (GSFC). "We wanted to have the minimum astronaut involvement possible," says Gendreau. "In fact, none."

So why not just launch these telescopes as free-flyer satellites? Because other resources come ready-made for new researchers. "The space station has this large infrastructure that I don't have to worry about," says Gendreau. "You just have to connect to it."

And just because the crew don't directly operate these instruments doesn't mean they can't support them in other, sometimes creative ways. The SOLAR telescope was an ESA experiment on ISS to observe solar emission, but "SOLAR can only operate when the Sun is visible to the instrument" said Astrid Orr, Physical Sciences Coordinator at ESA, via email. "These windows are followed by long periods of darkness due to the angle of the ISS." The novel solution: "The ISS was temporarily tilted on five occasions," she added, "so we could 'bridge' periods of sunlight and obtain continuous data across daylight windows."

The new millennium also saw the emergence of an ambitious Chinese crewed space program with the flight of the Shenzhou 5 spacecraft in October 2003 with the nation's first taikonaut. Five more launches with two- and three-person crews followed through 2016.

China launched their first crewed space laboratory, Tiangong 1, in September 2011. A second, upgraded station, Tiangong 2 launched in 2016 equipped with the POLAR gamma-ray burst detector, a cooperative project between Chinese and European scientists. Tiangong 2 also launched a companion microsatellite, Banxing-2, while in orbit — a concept that the Chinese program could build on in the future.

China next plans to construct a modular space station. The Tianhe core module is slated to fly in 2021 (although schedules may slip) with two experiment modules following in 2022. These modules will support external experiments to test exposure to the space environment, high-energy bombarding cosmic rays, the vacuum of space, and the solar wind. Even more interesting is the planned Xuntian space telescope, expected to launch in 2024. The instrument has a design field of view 300 times larger than the Hubble Space Telescope and will orbit close to the Chinese space station so that crews can dock with the instrument for repairs and upgrades.

The final flight of the Space Shuttle returned July 21, 2011. It marked the end of 30 years of this fleet of reusable crewed spacecraft. *[NASA]*

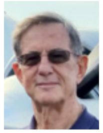
Tianhe, shown in this artist's illustration, is a proposed Chinese space station, slated for launch this decade. *[China Manned Space Engineering Office]*

What comes next?

What began in the last century as a competition between two geopolitical superpowers has expanded to include the space programs and space crews of several nations. And now, non-state agencies are getting involved. The private corporation SpaceX successfully launched two NASA astronauts to the ISS in the summer of 2020, marking the first time a non-government-agency ferried humans to orbit and the United States' return to crewed spaceflight. Commercial companies are a burgeoning source of technical and financial resources, and whether they represent the true future of human spaceflight or only an important adjunct to governmental programs, they will play a major role moving forward.

Astronomical science may or may not be a part of that mix, however. No plans have been announced for new human-tended telescopes as part of the NASA Artemis project or any commercial crewed programs. Designs for new space telescopes through the 2030s appear to all involve direct launch into high orbits by rocket, and even proposals for telescopes on the Moon speak mostly about robotic operation. Bob Williams sees this as the logical path forward. "Robotics technology lags human capabilities in space," he says, "But once you match those capabilities, robots are cheaper, safer, and scale better. That's the future, and the crossover may be coming sooner than we think."

Nevertheless, the history of human support for space observatories is now established: In the early decades when science needed telescopes above Earth's atmosphere, it was working space crews who operated them, gathering the data and delivering the results to astronomers back on the ground. Today, the questions we're asking about the universe would be far less interesting without the help of the human spaceflight program that brought us so far. ✪



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