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6 BEYOND EARTH

ASTRONAUTS AT WORK ON THE HUBBLE SPACE TELESCOPE

In December 1999, the Earth-orbiting Hubble Space Telescope was fitted with new gyroscopes, a new computer, and many other parts and instruments during a Space Shuttle Servicing Mission. Our home planet serves as a stunning backdrop for this wide-angle photo, which shows astronauts Steven Smith and John Grunsfeld at the tip of the Shuttle's robotic arm.

There's no better place for a telescope than space itself. Above the Earth's atmosphere observations are no longer hampered by air turbulence, so telescopic images of distant stars and galaxies are razor-sharp. Unlike a ground-based telescope, an instrument in Earth orbit can operate twenty-four hours a day and reach every part of the sky. Observing from space also makes it possible to study types of radiation that are otherwise absorbed by the atmosphere. Little wonder that the Hubble Space Telescope has made so many contributions to astronomy. And Hubble is not alone — more than 100 space observatories have been launched since the 1960s.

“Hubble has revolutionised every single field in astronomy”

YOUNG STARS SCULPT GAS WITH POWERFUL OUTFLOWS

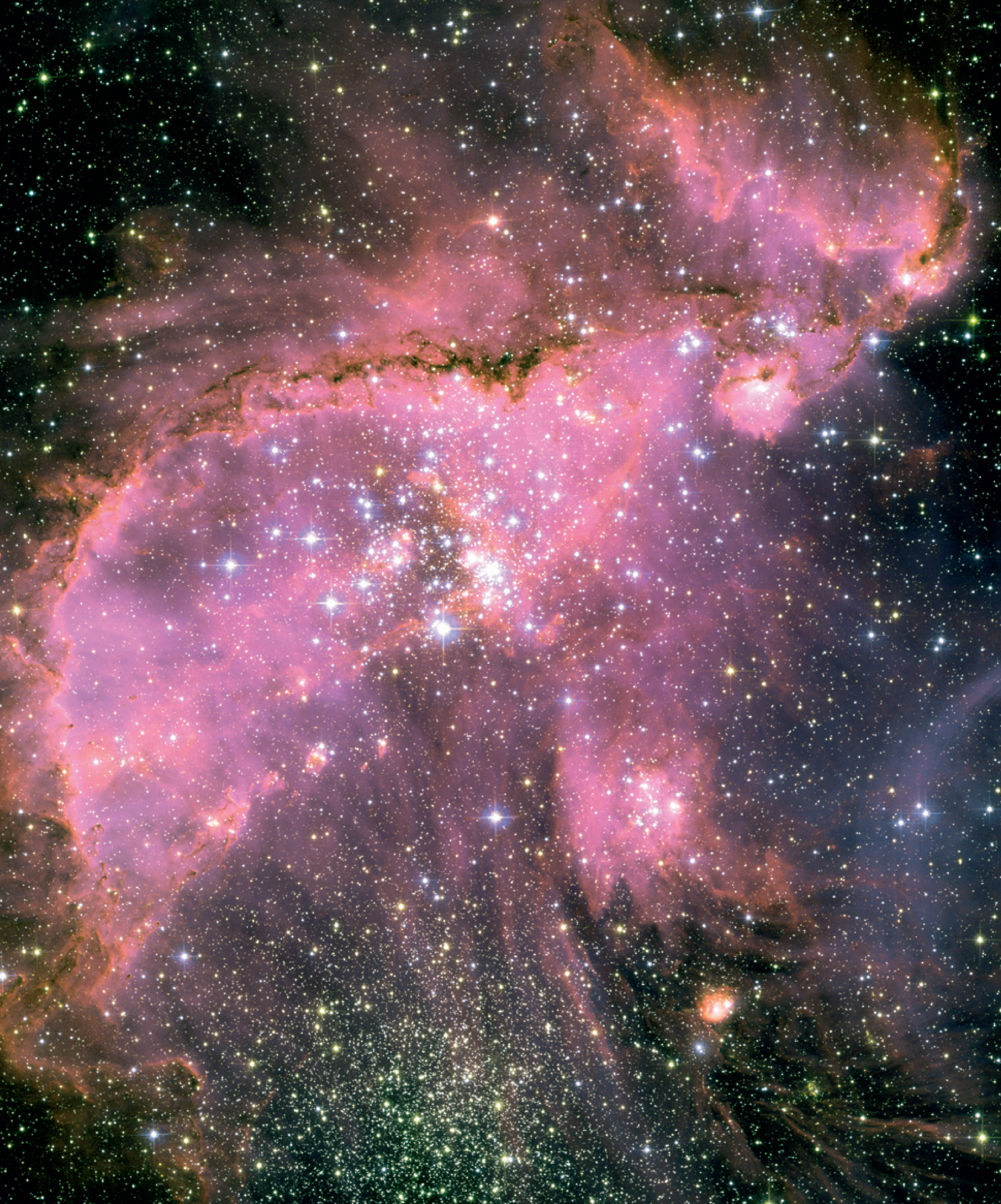
From high above the Earth’s atmosphere, the Hubble Space Telescope has provided astronomers with razor-sharp images of the Universe. Here, energetic radiation from a young cluster of stars eats into its dusty surroundings, creating dramatic structures of arched, ragged filaments. This star-forming region is located 210 000 light-years away in the Small Magellanic Cloud, a satellite galaxy of our Milky Way.

The NASA/ESA Hubble Space Telescope is by far the most famous telescope in history. For good reason. It has revolutionised every field in astronomy. Hubble’s mirror is small by current standards: only 2.4 metres across. But its location is — literally — out of this world. High above the blurring effects of the atmosphere, Hubble has the best possible view of the Universe. What’s more: Hubble sees near-infrared and ultraviolet radiation that doesn’t reach the ground. Cameras and spectrographs, some as large as a telephone booth, dissect and register the light from distant cosmic havens.

Like a telescope on the ground, Hubble can be upgraded. It was launched in April 1990 into a relatively low Earth orbit where it could easily be visited by NASA’s Space Shuttle. Since then spacewalking astronauts have carried out Servicing Missions every few years. Broken parts have been fixed or replaced and older instruments have made way for new, state-of-the-art detectors. Hubble has become the workhorse of observational astronomy and has transformed our understanding of the cosmos.

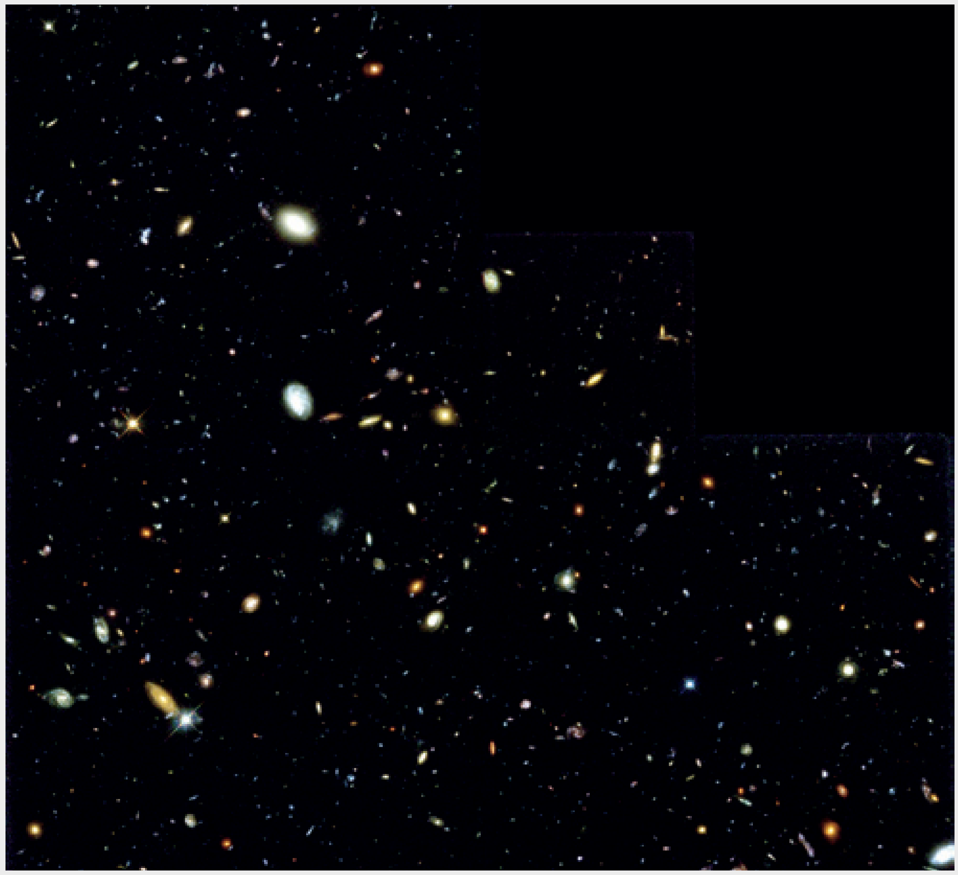
Hubble has observed seasonal changes on Mars and a Saturn ring plane crossing, but the most spectacular event witnessed by the telescope was the impact of a comet on Jupiter in July 1994. The twenty fragments of comet Shoemaker-Levy 9 plunged into the atmosphere of the giant planet, producing huge fireballs and leaving giant dark markings that could easily be seen with an amateur telescope.

Looking beyond the Solar System, Hubble has followed the life cycle of stars from their birth and infancy in dust-laden clouds of gas to their final farewells as delicate planetary nebulae, slowly blown into space by dying stars or titanic supernova explosions that almost outshine their home galaxy. The famous “Pillars of Creation” in the Eagle Nebula have been shown to be the sites of future star formation. Deep in the Orion Nebula, Hubble has seen a breeding ground for new solar systems: dusty discs around newborn stars that may soon condense into planets.



HUBBLE ULTRA DEEP FIELD

Almost 10 000 remote galaxies light up in the Hubble Ultra Deep Field, the deepest visible-light image of the cosmos ever created. Cutting across billions of light-years, the snapshot includes galaxies of various ages, sizes, shapes, and colours. The smallest, reddest galaxies seen in this picture may be among the most distant known, existing when the Universe was just 800 million years old.



Hubble's Deep Fields

On 9 March 2004 astronomers at NASA and ESA released the deepest-ever image of the distant Universe, showing no less than ten thousand galaxies out to distances of some thirteen billion light-years. This Hubble Ultra Deep Field (left) still serves as a rich cosmological goldmine, providing scientists with a unique way of studying the evolution of the Universe. But the Deep Field story started much earlier.

After the unfortunate near-sightedness of the Hubble Space Telescope's primary mirror had been corrected, Robert Williams, then director of the Space Telescope Science Institute, decided to use a large part of his director's discretionary observing time on a unique study of extremely remote galaxies. The idea was simple: take an extremely long exposure of one small, "empty" patch of sky, and see what comes out. Using Hubble's Wide Field and Planetary Camera 2 over a ten-day period in December 1995, 342 exposures of a small area in the constellation Ursa Major were made. The resulting image (above) revealed some three thousand distant galaxies, some of which turned out to be around twelve billion light-years away.

The strength of this first Hubble Deep Field was its use as a benchmark for follow-up studies with other telescopes, like the James Clerk Maxwell millimetre-telescope on Mauna Kea, Hawaii, the Very Large Array radio telescope in New Mexico, the European Infrared Space Observatory and NASA's Chandra X-ray Observatory. A similar approach was used in autumn 1998 to image the Hubble Deep Field South — a region of sky accessible to large optical and infrared telescopes in the southern hemisphere. In total, the two original Hubble Deep Fields have yielded hundreds of scientific papers, focusing on the early evolution and changing morphology of galaxies and on the star formation history of the Universe.

When the Hubble Space Telescope was fitted with the new, more sensitive Advanced Camera for Surveys in March 2002, it seemed only logical to carry out an improved version of the Deep Field study. A small area on the sky in the southern constellation of Fornax was imaged eight hundred times during autumn 2003, for a total exposure time of over eleven days. This Hubble Ultra Deep Field is still the best view of the distant Universe we have ever obtained.

> *“Without space telescopes, astronomers would be blind to energetic forms of radiation”*

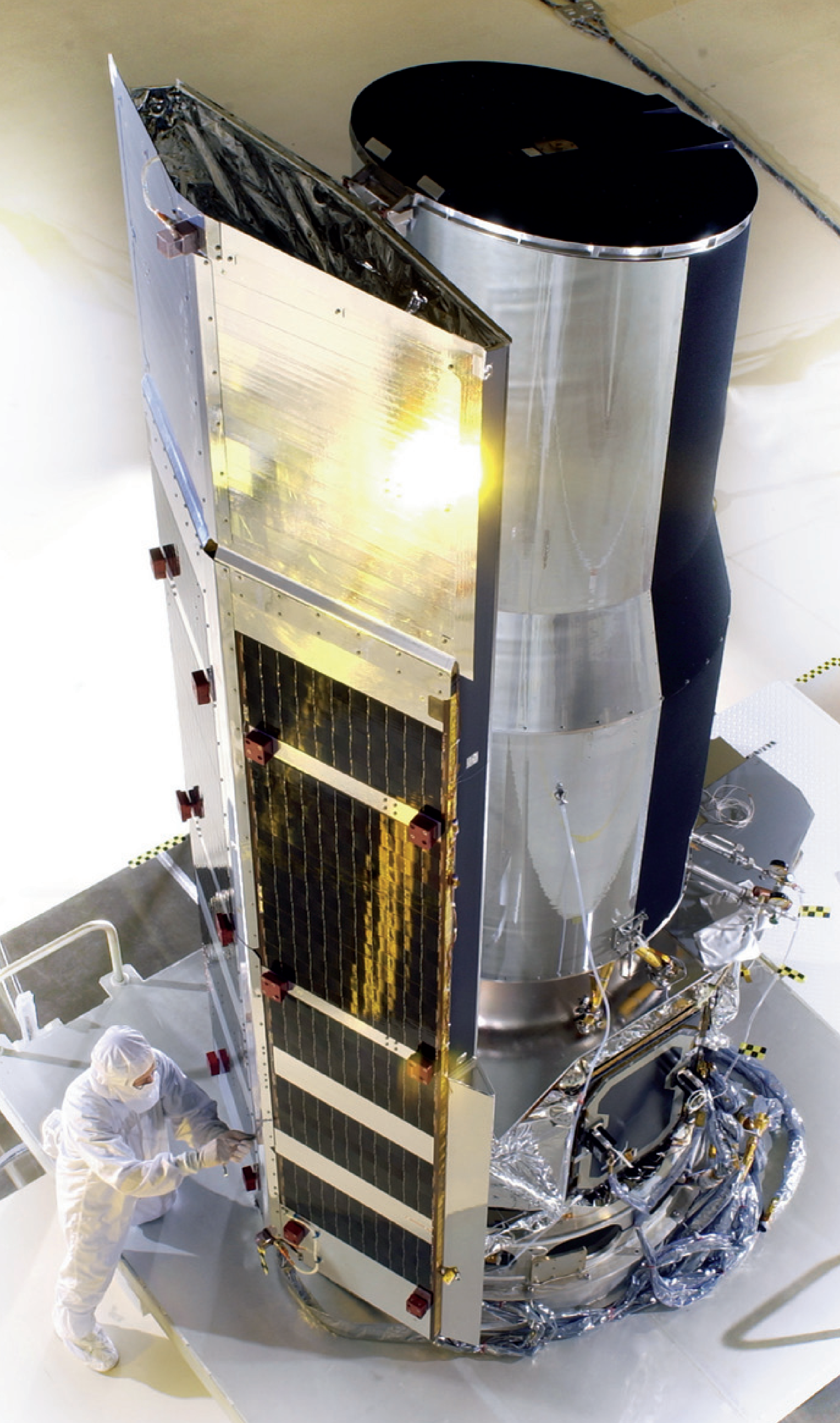
Near-sighted Hubble

Right after the launch of the Hubble Space Telescope, in the spring of 1990, horrified astronomers and technicians discovered that the Space Telescope’s primary mirror had a minute deformation. The result: Hubble’s images were not as sharp as planned. During the first Servicing Mission in December 1993, astronauts fitted Hubble with corrective optics to solve the problem and the Space Telescope has been performing beyond expectations ever since. The latest generation of cameras is designed to compensate for the spherical aberration of the primary, so the corrective optics are no longer necessary.

Hubble has studied thousands of individual stars in giant globular clusters — the oldest stellar families in the Universe. And galaxies. Astronomers have never seen so much detail. Majestic spirals, absorbing dust lanes, violent collisions. Extremely long exposures of blank regions of sky have revealed thousands of faint galaxies billions of light-years away by capturing photons that were emitted when the Universe was still in its infancy. These Hubble Deep Fields are astronomical windows into the distant past, shedding new light on the ever-evolving cosmos.

Hubble is not the only telescope in space — NASA’s Spitzer Space Telescope, launched in August 2003, could be described as an infrared Hubble. Spitzer has an even smaller mirror than Hubble: just 85 centimetres across. The telescope itself is tucked away in a vacuum flask filled with liquid helium and its detectors, cooled to just a few degrees above absolute zero, are the most sensitive infrared detectors ever launched in space.

Spitzer has revealed a dust-filled Universe. Dark, opaque clouds of dust, invisible at optical wavelengths, glow in the infrared when heated from within. Shockwaves from galaxy collisions sweep up dust in spiral arms or in telltale rings announcing new sites of excessive star formation. Dust is also produced in the aftermath of a star’s death. Spitzer has found that planetary nebulae and supernova remnants are laden with dust particles — the building blocks of future planets. Dust is even swirling in the strong winds of distant supermassive black holes. Using spectroscopy, Spitzer has been able to determine the chemical and mineralogical makeup of these cosmic dust particles.



SPITZER UNDER CONSTRUCTION AT LOCKHEED MARTIN

NASA's Spitzer Space Telescope, the most powerful infrared space observatory to date, receives a final check-up at Lockheed Martin Space Systems before its August 2003 launch. The 85-centimetre telescope is placed in a flask of liquid helium to keep it cool enough to detect the faint heat radiation from distant extrasolar planets, star-forming regions, and dusty galaxies.

> *“Energetic radiation passes right through a conventional telescope mirror”*

At other infrared wavelengths Spitzer can look *through* the dust clouds and see the young stars hidden in their dark cores. Obscured star-forming regions, hidden from view by dark dust, become transparent. Spitzer’s sensitive spectrographs have also studied the atmospheres of extrasolar planets — gas giants like Jupiter, racing around their parent stars in just a few days — to establish the existence of water vapour and sodium in these scorchingly hot atmospheres.

What about ultraviolet radiation, X-rays and gamma rays? They are completely blocked by the Earth’s atmosphere. Without space telescopes, astronomers would be blind to these higher energy forms of radiation. Studying them is important to help understand the violent Universe of hot stars, supernova explosions, black holes, colliding galaxies and merging clusters. NASA’s ultraviolet space telescope GALEX, launched in April 2003, has studied young, hot stars in hundreds of thousands of galaxies, showing astronomers how these cosmic building blocks evolve and change.

X-ray and gamma-ray telescopes are hard to build. Energetic radiation passes right through a conventional telescope mirror, while soft X-rays, with relatively low energy, can only be focused with nested mirror shells made of pure gold. Hard X-rays and gamma rays are studied with sophisticated pinhole cameras, or stacks of scintillators that produce brief flashes of light when hit by a high-energy photon. Despite these difficulties, astronomers have been lofting X-ray and gamma-ray instruments above the atmosphere since the early days of the space age. The first sources of cosmic X-rays were discovered by a Geiger counter on board a rocket probe in 1964.

Over the past decade, sophisticated high-energy space telescopes have been launched on board Earth-orbiting satellites. NASA's Compton Gamma Ray Observatory flew in the 1990s. At the time, it was the biggest and most massive scientific satellite ever launched — a full-fledged physics laboratory in Earth orbit. It made headlines with its detailed study of gamma-ray bursts — brief explosions of high-energy radiation, first detected by military surveillance satellites. In 2002 the European Space Agency launched its own gamma-ray observatory, INTEGRAL and in the spring of 2008, NASA deployed GLAST — the Gamma Ray Large Area Space Telescope.

X-RAY IMAGE OF THE MILKY WAY'S CENTRE

Hundreds of hot white dwarf stars, compact neutron stars, and gluttonous black holes light up as bright spots in this X-ray image of the central regions of our Milky Way Galaxy. The supermassive black hole at the centre of the Galaxy is located inside the bright white patch at the left of the image. This mosaic of Chandra X-ray Observatory images also shows the background glow of an incandescent fog of multimillion-degree hot gas.

Pinpointing gamma-ray bursts

NASA's Compton Gamma Ray Observatory confirmed that the mysterious cosmic gamma-ray bursts that occur on average once or twice per day are uniformly distributed across the sky. For many years astronomers weren't sure what this meant: the bursts could be relatively nearby phenomena in or around our own Milky Way galaxy or they could be titanic explosions in extremely remote galaxies. Astronomers using data from the Italian-Dutch satellite BeppoSAX observed the first optical afterglow of a gamma-ray burst in 1997 and found that the bursts do indeed occur billions of light-years away, making them the most powerful explosions in the Universe by far.

“ Hot gas glows in X-rays, just before it plunges into the black hole and out of sight ”

THE SOUTHERN PINWHEEL GALAXY

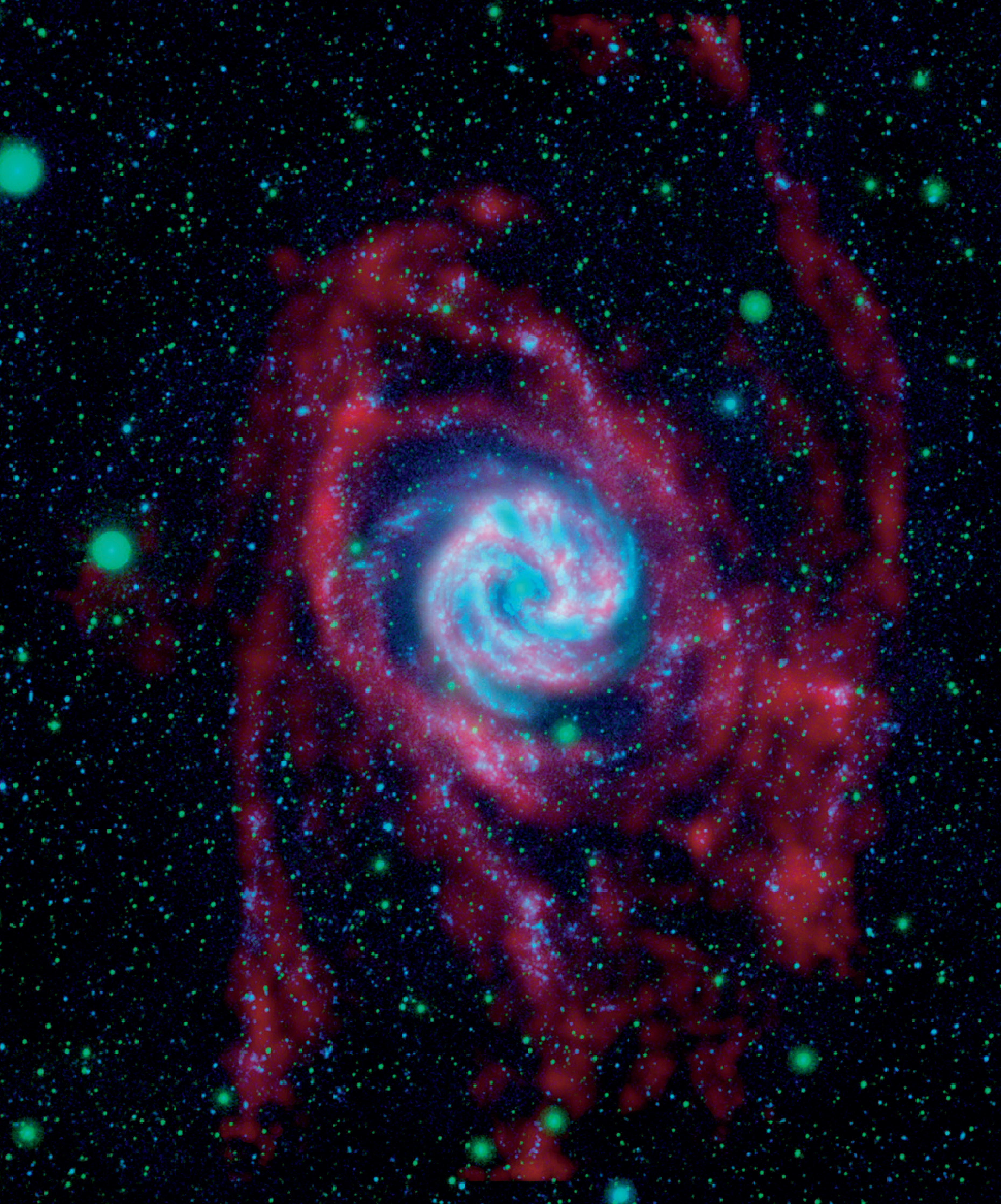
Ultraviolet radiation from the cosmos cannot penetrate our atmosphere. The Galaxy Evolution Explorer (GALEX) satellite detected the energetic UV radiation from clusters of young stars up to 140 000 light-years from the centre of the Southern Pinwheel Galaxy. GALEX's observations, shown here in blue and green, are combined with Very Large Array observations (red) that show radio emission from cool clouds of neutral hydrogen gas.

Meanwhile, astronomers have two large X-ray telescopes in space. NASA's Chandra X-ray Observatory and ESA's XMM-Newton Observatory keep watch over the hottest places in the cosmos. While Chandra produces spectacular X-ray images of the Universe, XMM-Newton is more sensitive and concentrates on X-ray spectroscopy.

These high-energy space telescopes observe clouds of gas, heated to millions of degrees by shockwaves in supernova remnants. They also detect X-ray bina vries: neutron stars or black holes that suck in matter from a companion star. Likewise, supermassive black holes in the cores of distant galaxies are revealed in the final X-ray glow of hot gas spiralling into them.

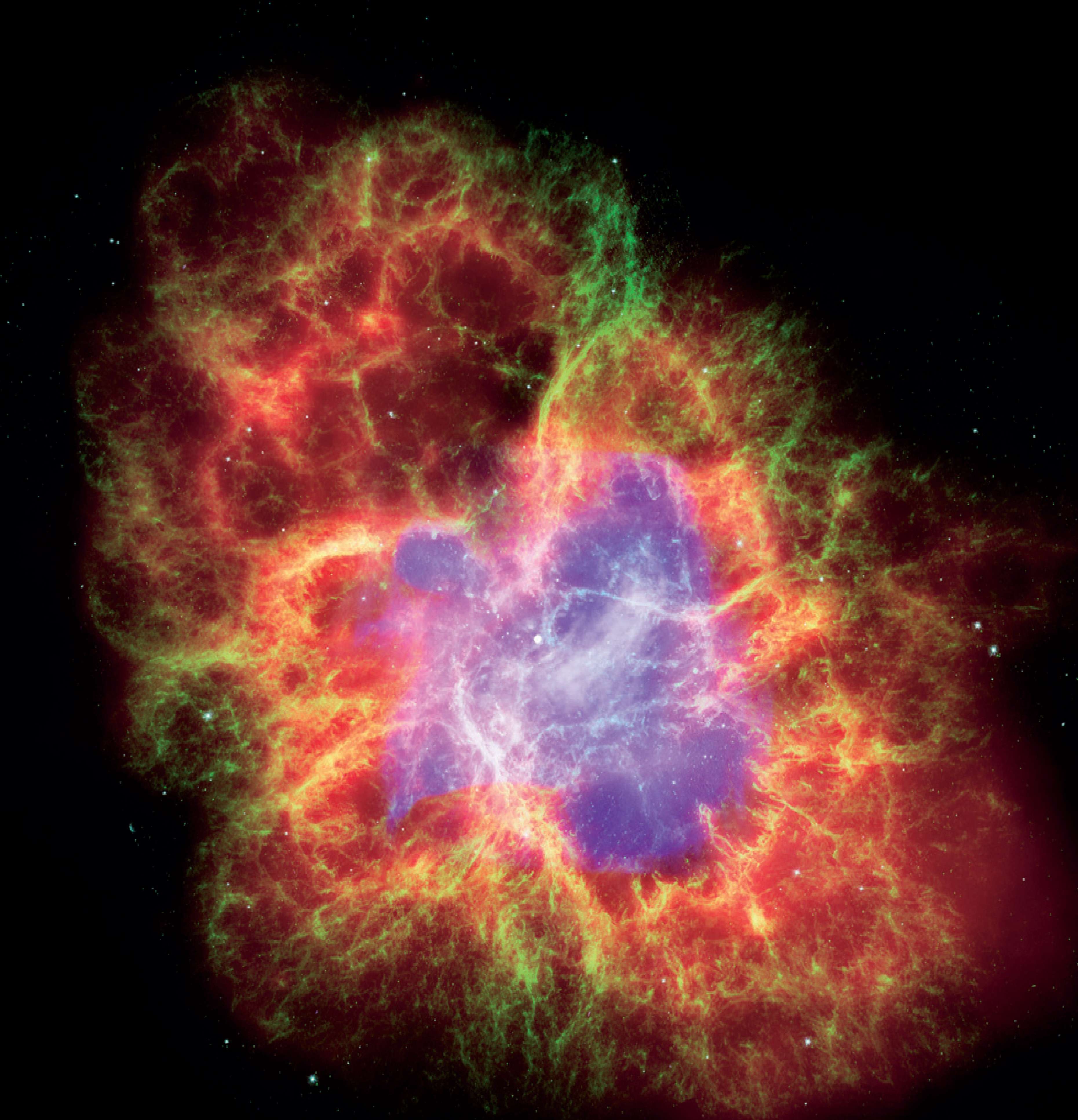
Hot but tenuous gas also fills the space between individual galaxies in a cluster. Sometimes, this intracluster gas is shocked and heated even more by the monstrous collisions and mergers of galaxy clusters. Studying the resulting X-rays yields clues to the history of cluster evolution and the origin of the large-scale structure of the Universe. By far the most energetic events in the Universe are the gamma-ray bursts: catastrophic terminal explosions of very massive, rapidly spinning stars. In less than a second, they release more energy than the Sun does in ten billion years.

Hubble, Spitzer, Chandra, XMM-Newton, Integral and GLAST are versatile giants. Other space telescopes are smaller and have more focused missions. Take COROT, for example — a French satellite devoted to stellar seismology and the search for extrasolar planets. Like NASA's future Kepler mission, COROT studies planetary transits: small, regular dips in the brightness of a star that occur when an orbiting planet is passing in front of the star's disc, as seen from the Earth.



THE SOMBRERO GALAXY OBSERVED WITH THE SPITZER SPACE TELESCOPE

The Spitzer Space Telescope and the Hubble Space Telescope joined forces to produce this striking image of one of the most popular sights in the Universe, the Sombrero Galaxy. It resembles a broad-brimmed Mexican hat when viewed in visible light, but the galaxy looks more like a “bull’s eye” at infrared wavelengths.



HUBBLE AND CHANDRA MOSAIC OF THE CRAB NEBULA

The result of a supernova explosion in the year 1054, the famous Crab Nebula in the constellation of Taurus, the Bull, is seen here in data from the Hubble Space Telescope (green and dark blue), the Chandra X-ray Observatory (light blue) and the Spitzer Space Telescope (red). The bright white dot in the centre of the image is the corpse of an exploded star: a rapidly rotating and highly energetic neutron star with a mass equivalent to the Sun crammed into a sphere only twenty kilometres across.

“WMAP gave cosmologists their best view yet of the birth of the Universe”

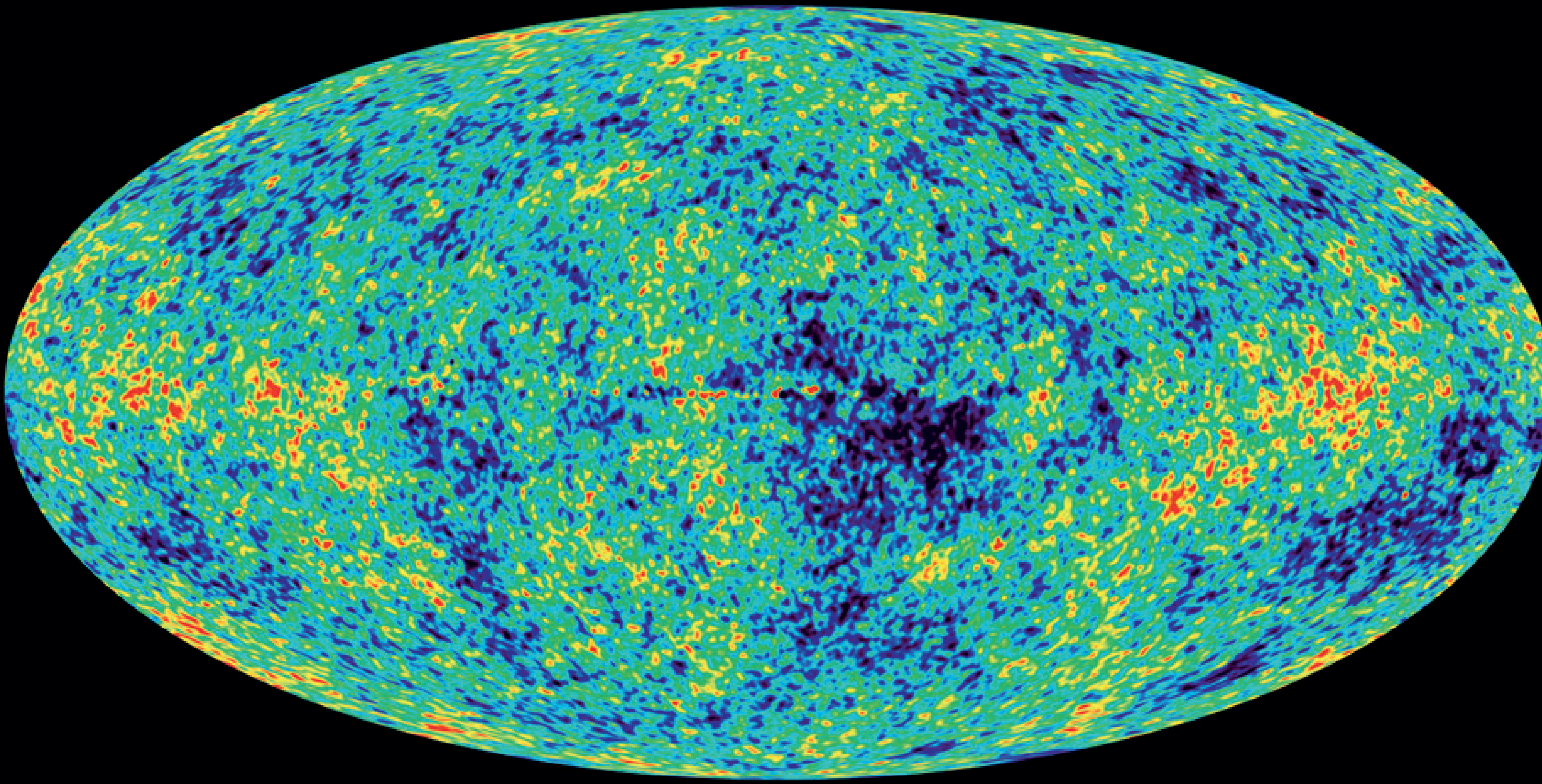
Another small but powerful space telescope is NASA’s Swift satellite — a combined gamma and X-ray observatory designed to unravel the mystery of gamma-ray bursts. Swift detects a few new gamma-ray bursts per week. It can determine the burst’s position within a minute and radios the sky coordinates to robotic telescopes on the ground for follow-up studies at other wavelengths.

Then there is WMAP, the Wilkinson Microwave Anisotropy Probe. It has mapped the cosmic background radiation in unprecedented detail in just two years. Minute temperature fluctuations in this Big Bang afterglow provide information about density ripples in the early Universe that later grew into clusters and superclusters of galaxies. Combined with observations of the current large-scale structure of the Universe and of the expansion history of space — as revealed by the behaviour of distant supernovae — WMAP has given cosmologists their best view yet of the birth of the Universe, almost fourteen billion years ago.

Exploring the electromagnetic spectrum and opening up the space frontier are two of the most exciting developments in the history of the telescope. But the telescope is still young, and history isn’t over. So what’s next? Find out in the last chapter of this book, where we take a look into the future.

Big mirror

Late 2008 or early 2009 will see the launch of Herschel — a powerful infrared space telescope designed and built by the European Space Agency (ESA). Herschel, named after the scientist who discovered infrared radiation, has a primary mirror 3.5 metres across — the largest mirror ever built for a space telescope. Herschel will focus on far-infrared and sub-millimetre wavelengths, a part of the electromagnetic spectrum that hasn’t been studied in detail yet. Its main purpose: to discover how the very first galaxies were born in the early Universe. Herschel will be launched together with ESA’s Planck Surveyor, which is dedicated to studying the cosmic background radiation.



WMAP IMAGE OF THE MICROWAVE SKY

Minute temperature fluctuations in the very early Universe are represented by colour differences in this all-sky picture, which is based on three years of data from the Wilkinson Microwave Anisotropy Probe (WMAP) — a space telescope dedicated to studying the 13.7-billion-year-old cosmic microwave background radiation. The temperature fluctuations correspond to small density variations that grew into galaxies and clusters.

Space telescopes

Launching telescopes into space is expensive, but has allowed astronomers to peer into regions of the night sky they never dreamt would be accessible. These telescopes can view astronomical objects without the distorting effect of the Earth's atmosphere and have unhindered access to types of radiation we often can't observe from the Earth's surface: X-rays, infrared light, ultraviolet light and more. The observations from these telescopes sometimes provide almost unimaginable views of little known phenomena in the depths of space.