esa

The HUBBLE Space Telescope

European Space Agency
Agence spatiale europ ene

About ESA

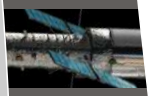
The European Space Agency (ESA) was formed on 31 May 1975. It currently has 15 Member States: Austria, Belgium, Denmark, Finland, France, Germany, Ireland, Italy, Netherlands, Norway, Spain, Sweden Switzerland and the United Kingdom. Canada is also a partner in some of the ESA programmes.

The ESA Science Programme has launched a series of innovative and successful missions. Highlights of the programme include:

Cluster,
a four-spacecraft mission to investigate the interaction between the Sun and the Earth's magnetosphere in unprecedented detail.

Giotto,
took the first close-up pictures of a comet nucleus (Halley) and completed flybys of comets Halley and Grigg-Skjellerup.comets Halley and Grigg-Skjellerup.

Hipparcos,
fixed the positions of the stars far more accurately than ever before and changed astronomers' ideas about the scale of the Universe.astronomer's ideas about the scale of the Universe.



Hubble Space Telescope,
a collaboration with NASA, the world's most important and successful orbital observatory.

Huygens,
a probe to land on the mysterious surface of Saturn's largest moon, Titan, in 2004. Part of the international Cassini mission.

ISO,
studied cool gas clouds and planetary atmospheres, finding water in surprising abundance everywhere it looked.

IUE,
the first space observatory ever launched, marking the real beginning of ultraviolet astronomy.

SOHO,
providing new views of the Sun's atmosphere and interior, revealing solar tornadoes and the probable cause of the supersonic solar wind.

Ulysses,
the first spacecraft to fly over the Sun's poles.

XMM-Newton,
solving many cosmic mysteries of the violent X–ray Universe with its sophisticated mirrors, from enigmatic black holes to the formation of the galaxies.

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THE HUBBLE Space Telescope

The Universe As Seen By Hubble

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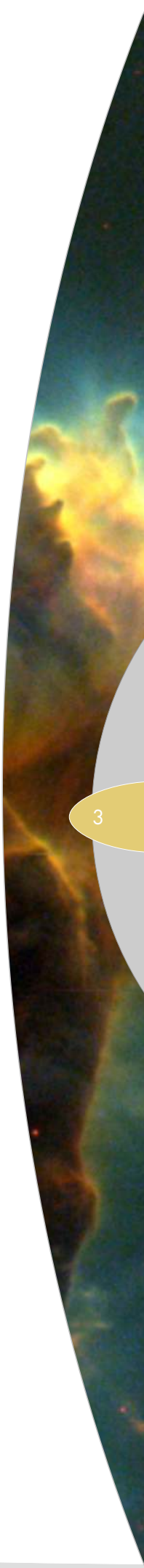


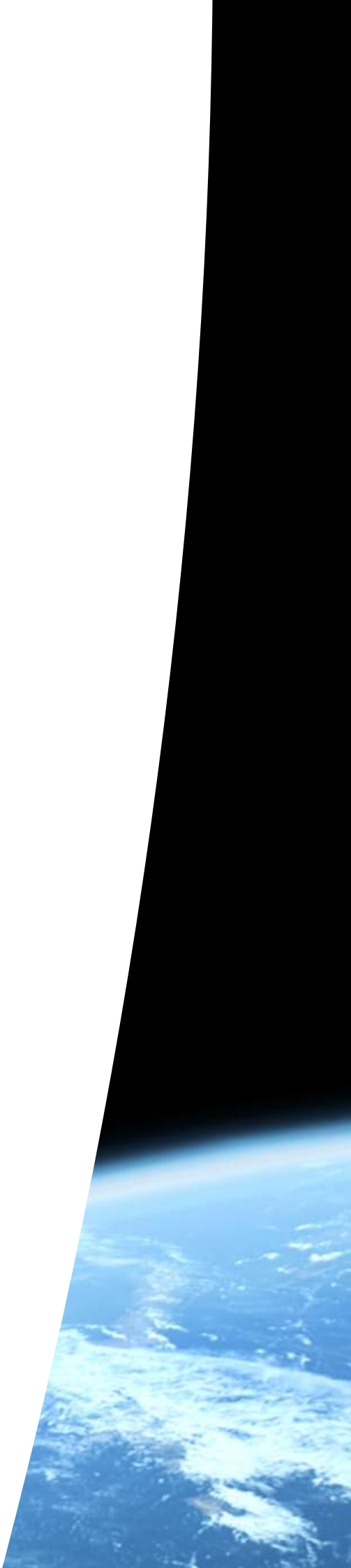
Introduction

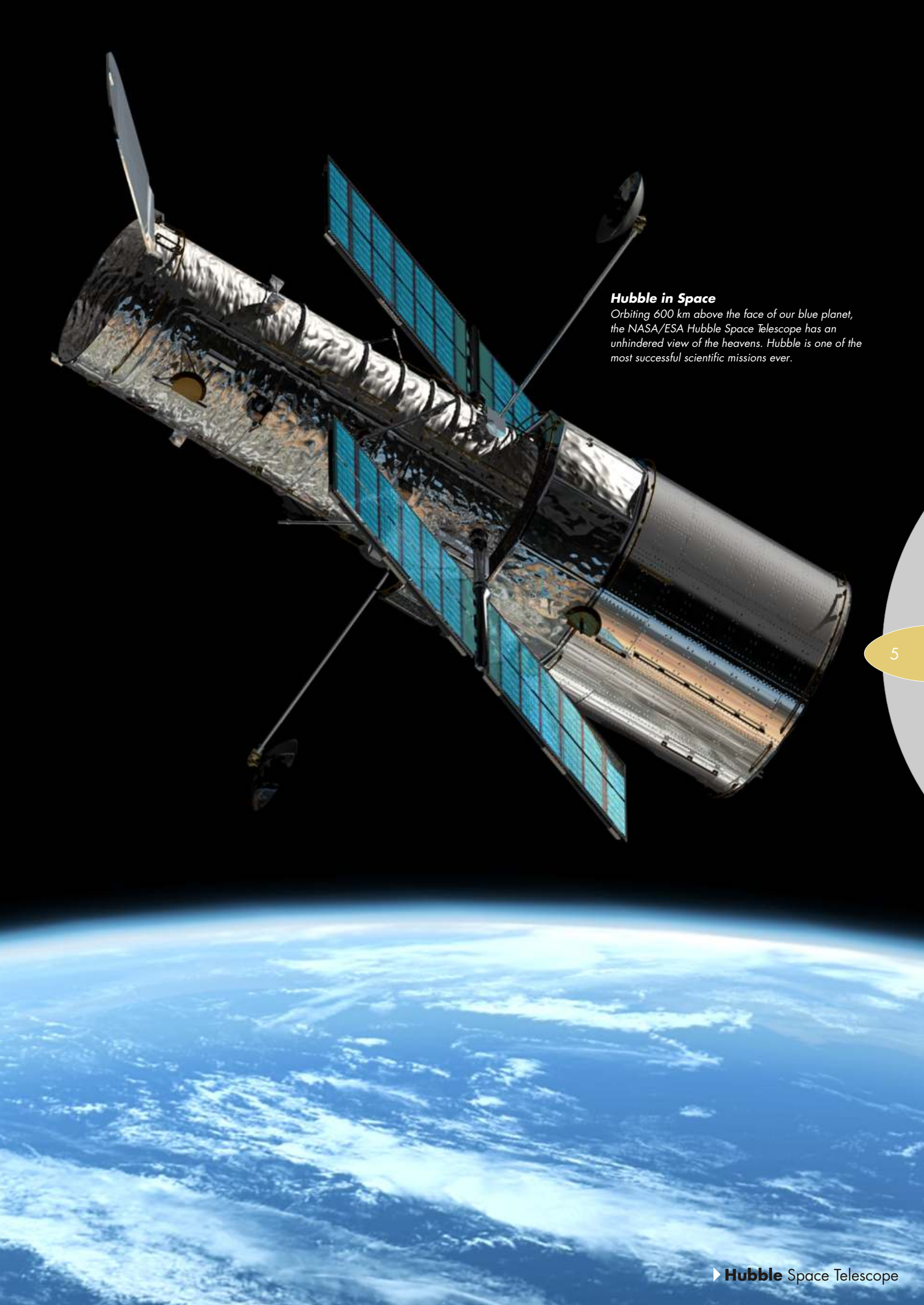
The NASA/ESA Hubble Space Telescope is one of the most successful scientific projects of all time, based on a collaboration between the American space agency, NASA (85%) and the European Space Agency, ESA (15%), a collaboration that extends across country boundaries and between different scientific and engineering communities.

Hubble is an upgradeable, space-based telescope flying almost 600 km above most of our image-distorting atmosphere. It is designed to take high-resolution images and accurate spectra by concentrating starlight into sharper images than is possible from the ground, where the atmospheric 'twinkling' of the stars limits the clarity of the images. Despite its relatively modest size, 2.4 metres, Hubble is more than able to compete with ground-based telescopes that have light-collecting (mirror) areas that are as much as 10 or 20 times larger.

Hubble's second huge advantage is its ability to collect near-infrared and ultraviolet light, which is otherwise filtered away by the atmosphere before it can reach ground-based telescopes.

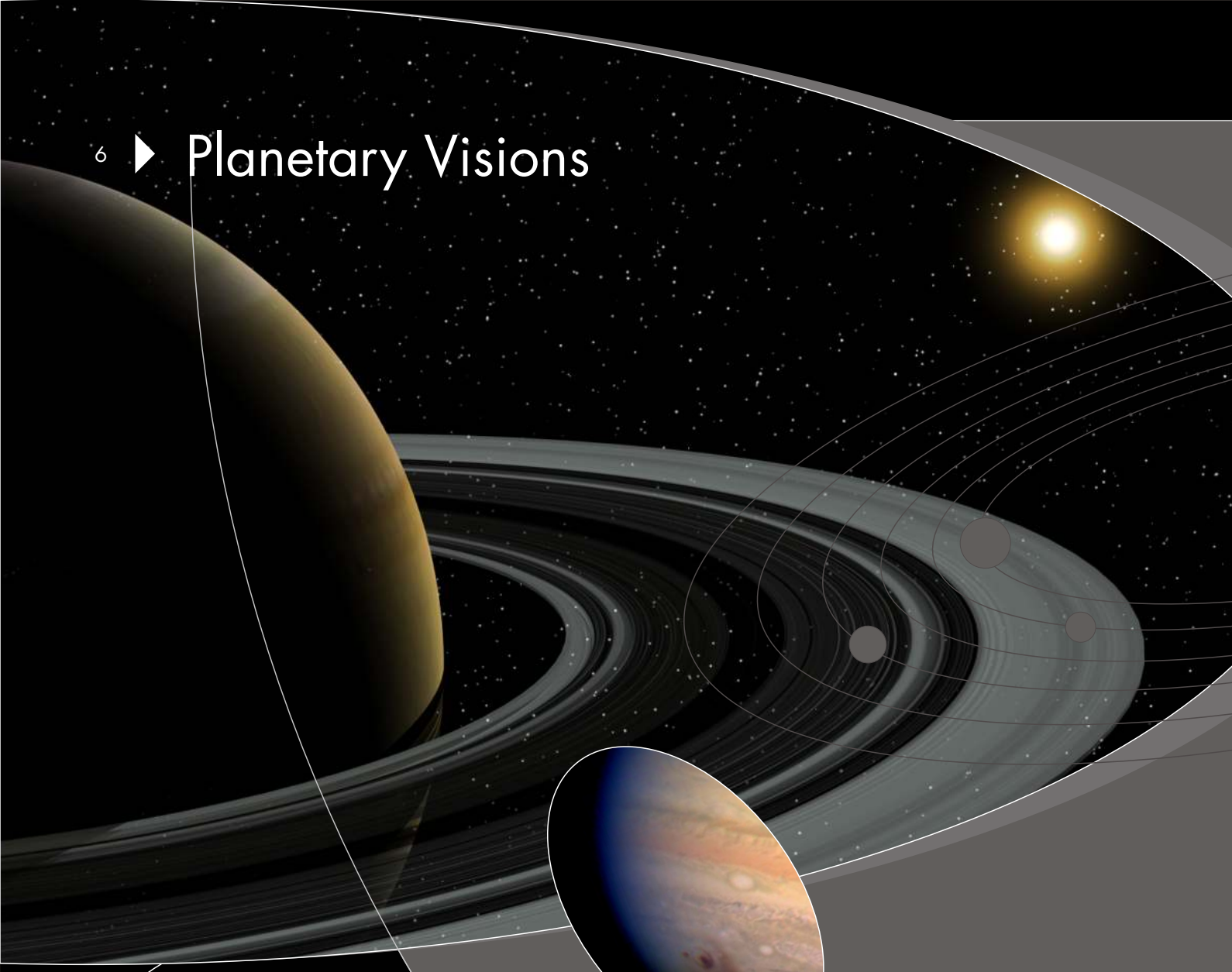
This brochure presents some of Hubble's magnificent results and tells the story of the project.



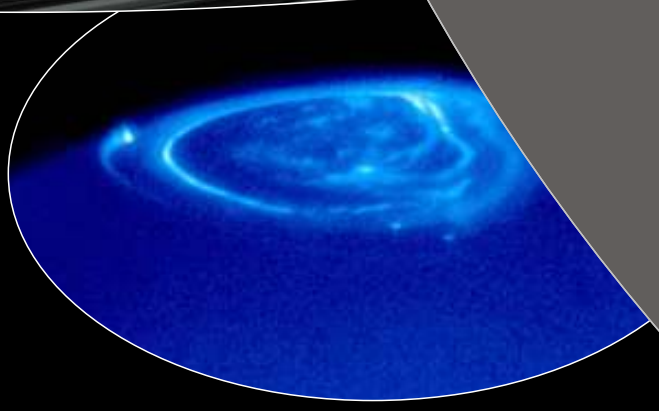


Hubble in Space
Orbiting 600 km above the face of our blue planet, the NASA/ESA Hubble Space Telescope has an unhindered view of the heavens. Hubble is one of the most successful scientific missions ever.

Planetary Visions



Impact on Jupiter!
In 1994 astronomers had front row seats at one of the most astounding spectacles nature has to offer: the impact of a comet on a planet. The villain was comet Shoemaker-Levy 9 and the victim Jupiter. Hubble was watching the scene of the crime and used its high-resolution cameras to provide clues to the nature of the unexpected phenomena observed during the impact.



Aurorae on Jupiter
This eerie glow on Jupiter is an aurora, similar to those seen above the Earth's polar regions and also known as northern and southern lights. This lightshow is a result of a violent exchange of energy as a stream of energetic particles from the Sun hammers into atoms and molecules in Jupiter's atmosphere. The display can change noticeably on timescales of less than an hour.
Apart from the main auroral oval this ultraviolet Hubble image shows the interesting 'magnetic footprints' of three of the largest of Jupiter's moons, Io (along left-hand limb), Ganymede (near the centre, just below the reference oval) and Europa (just below and to the right of the Ganymede footprint).

The planets of our Solar System have captured the imagination and interest of scientists and thinkers from the earliest times. Almost all of the nine planets have had extensive visits from space probes. Although these robotic pioneers have explored the planets in detail, Hubble has used its steady eye and acute vision to make an important impact in the area of planetary astronomy.

Scientists have been able to use Hubble to monitor the planets over more than a decade, looking at surface features at regular intervals, or at short notice when especially interesting events come up. Hubble has observed cyclonic storms on Mars, the changing seasons on Saturn and the progress of Jupiter's Great Red Spot.

Cloud bands on Jupiter
The planet Jupiter is a gas giant. Its gaseous surface is in constant motion and the cloud bands and vortices change both on short and longer timescales. Here the moon Io is seen high above Jupiter's clouds, its shadow painted on the clouds far below.

Cyclone on Mars
Although Mars' atmosphere is much thinner than the Earth's – its pressure being less than 1% of the air pressure on Earth – a new area of science has emerged: Martian meteorology. Here a cyclonic storm cloud (upper left) is imaged by Hubble. Also seen are early morning clouds along the left limb of the planet.

Rings of Saturn
Saturn's equator is tilted relative to its orbit around the Sun by 27 degrees, similar to the 23-degree tilt of the Earth. As Saturn moves along its orbit the seasons change, just as the changing orientation of the Earth's tilt causes seasons here. Saturn's ring system consists mostly of chunks of water ice. Scientists study Saturn and ist ring system to gain insight into the birth of our solar system.

Stars — A Matter of Life and Death

Thackeray's Globules
These strange dark clouds are dense dust clouds floating in a busy star-forming region. The clouds are called globules and astronomers know very little about their origin and nature. It is likely that globules like these are associated closely with starbirth and may, at a later stage, actively take part in the birth of a star. The red light in this image comes from glowing hydrogen energised by the intense ultraviolet radiation from young, hot stars.

Stars are remarkable objects. They are huge glowing balls of gas varying greatly in size and mass and produce nearly all the light we observe in the Universe. Many generations of the heaviest stars have lived and died since the Universe was created in the Big Bang, whereas the first generation of the lightest stars has barely reached puberty.

A star continually reprocesses lighter elements to heavier ones. When stars die they expel the heavy elements and leave this heritage of processed material floating between the stars. The enriched gas and dust often ends up in new generations of stars when these are born in the giant clouds in space.

Hubble's investigations of the stellar life cycle have shown intricate and unexpected details of star nurseries and graveyards. It has imaged the brightest and the feeblest stars in star clusters near and far, as well as compared stars in our own Milky Way with stars in many other galaxies.

The Globular Cluster Messier 22
Globular clusters are spherical swarms of stars containing many stars – up to 100 000 or even 1 million. Messier 22 is a very bright globular and is treasured by amateur astronomers. Hubble can look into the very heart of a globular cluster and, despite the multitude of stars, detect even the faintest individual stars there.

Our Neighbourhood Galaxies

Stars are social objects. They like to hang out together – in star clusters, or as large islands of stars each containing hundreds of billions of stars called galaxies. Galaxies are found in many different shapes: elliptical, almost featureless blobs, spirals with more or less tightly wound arms and irregulars with curious curls and twirls.

We still do not know exactly how galaxies are created, but we do know that spiral galaxies with their hot, blue stars and dust are still actively creating stars, and that in elliptical galaxies, with their populations of predominantly old red stars, no new stars are being born. We also know that violent encounters between galaxies spark flurries of starbirth activity and that the great diversity in the shapes of galaxies is often caused by these intergalactic collisions.

Hubble is famous for its highly detailed studies of the galaxies in our neighbourhood. Its sharp vision can discern individual stars hundreds of millions of light-years away, and by studying actively star-forming galaxies in ultraviolet light the hottest and most exciting regions of nearby galaxies have been revealed.

NGC 7673 – a Hyperactive Galaxy
Telltale patches of blue light are signs of the formation of millions of new stars in the tangled spiral galaxy NGC 7673. Each of the bluish areas in this image consists of immense star clusters containing thousands of young stars.

Starbirth Pinwheel
All the available clues point towards a collision with a high-speed interloping galaxy as the origin of this beautiful wheel of newborn stars. The image only depicts the central parts of NGC 1512. The ring of new stars is likely to have been created when the incoming galaxy sped through and left a ring-like shockwave pulsing through the gas and dust in NGC 1512. As can be seen in this example, violence in space often sparks the birth of new stars as shocks compress gas.

Central part of the Whirlpool
The Whirlpool Galaxy has one of the most classical spiral patterns known. Star clusters and red hydrogen nebulae are interspaced along its spiral arms, blending with dark dust lanes. This celestial beauty has already been studied extensively with many different telescopes, but Hubble's image shows unprecedented detail.

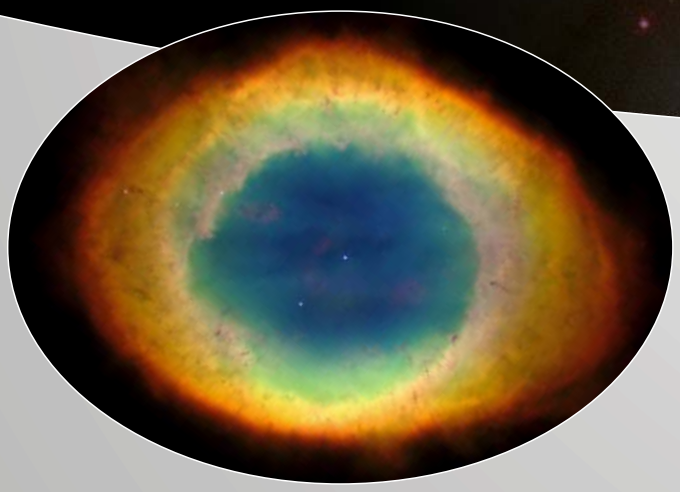
Heavenly Vistas

"What does the Universe really look like?" is a question asked by many people. Hubble was originally designed as a super-high quality imaging machine and so should be able to show astronomers and the public the 'real' image of space. But what is the 'real' image like?

Human eyes see only what we call 'visible light'. Hubble's capabilities go far beyond this region, as it is also sensitive to near-infrared and ultraviolet light, both of which are invisible to humans.

The colour images from Hubble are combined from single images exposed through filters. These can be broad filters letting through a whole colour, like green, or they can be very narrow filters singling out the light from one atomic process in the object under scrutiny. Astronomers can therefore use Hubble to uncover the physics that takes place in the nooks and crannies of the Universe.

Images from Hubble do not show the Universe as it would look if we could observe it with our own eyes through Hubble. They certainly reveal a true story, although it is a slightly different version of reality from the one that we are used to.



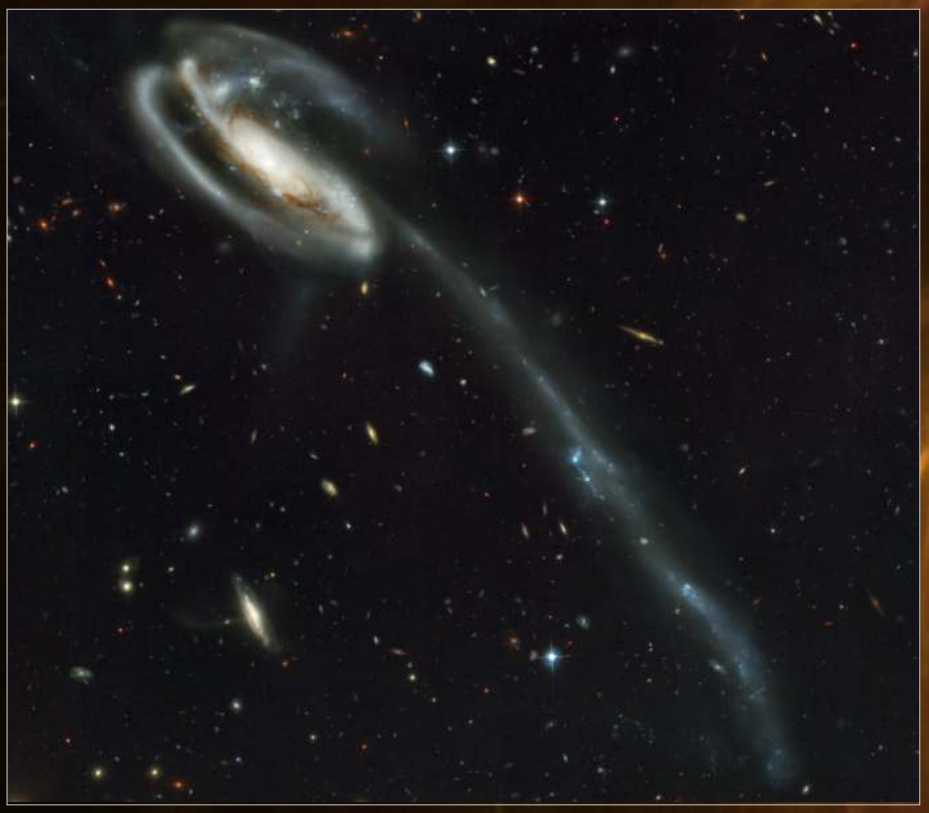
The Ring Nebula
One of Hubble's favourite targets has been stellar deaths: glowing gases expelled from Sun-like stars as planetary nebulae. Ground-based images suggested that many of these objects had simple shapes, but Hubble has revealed that the reality is much more complex.

The Keyhole Nebula
This magnificent vista portrays the innermost parts of the Eta Carina Nebula - a mysterious, complex structure. The colour image was composed from exposures taken through six different colour filters.

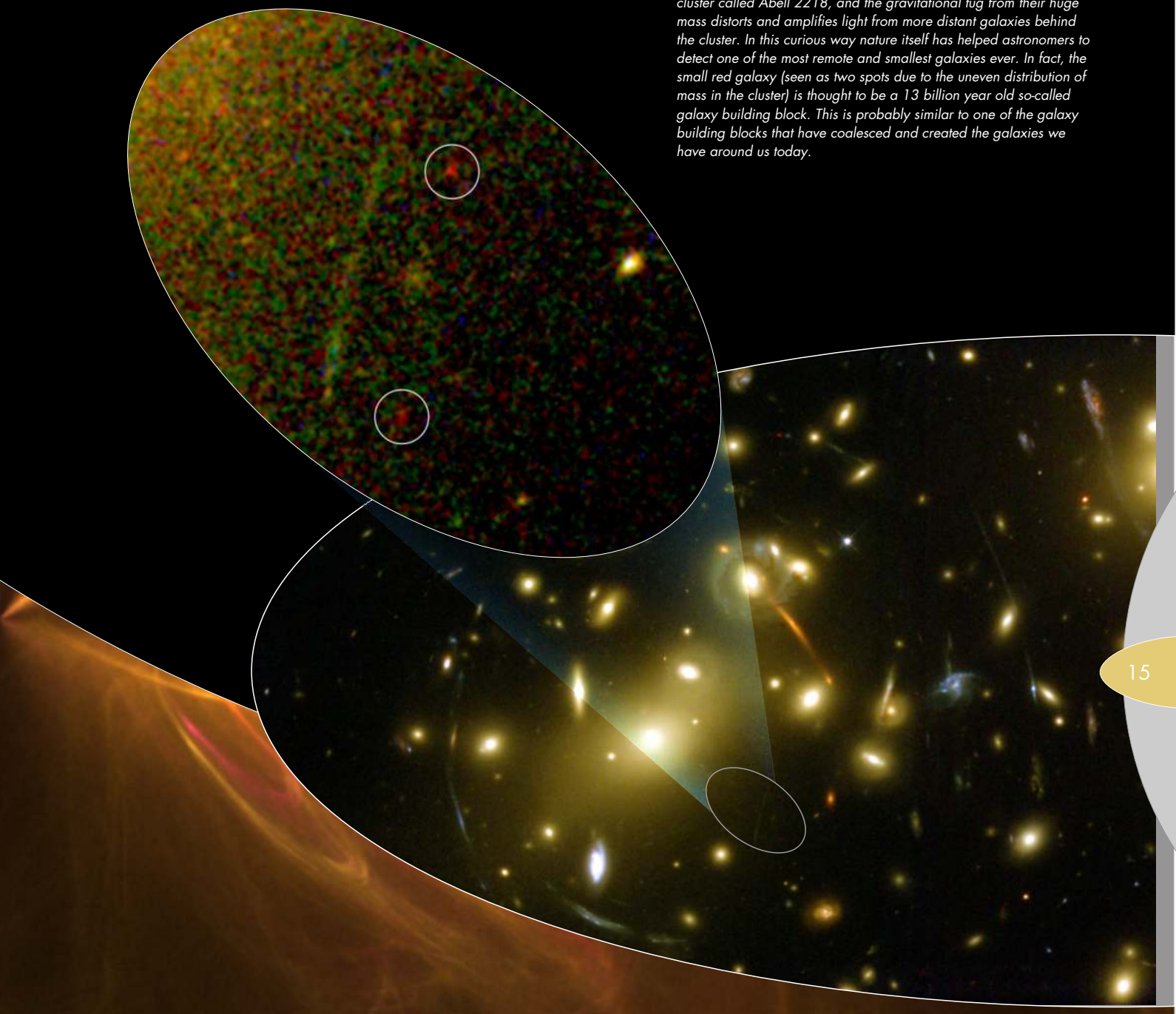
The Nebula N44C
This region of glowing hydrogen gas surrounds an association of young stars in the Large Magellanic Cloud, a nearby, small companion galaxy to the Milky Way. Powerful 'winds' from newly born stars in the nebula create the nebulous filaments seen.

The Expanding Universe

Some of the most profound and fascinating discoveries in recent years have been made in the field of cosmology – the area of astronomy that deals with the largest topic of all: the beginning and end of the Universe. Telescopes all over the globe have been collaborating with Hubble to reveal that the Universe not only expands, but accelerates in its expansion. This means that the expansion may continue forever, leaving the Universe to a boring, desolate future in some hundred billion years with immense spaces between the galaxies and very little action.



The Tadpole Galaxy – a Deep Look Back in Time
This picture was taken by Hubble's Advanced Camera for Surveys and shows around "6000 galaxies" in the background of the Tadpole Galaxy. This gallery of galaxies is a sample of galaxy types that stretches all the way back to the earliest times. They represent an incredible fossil record of the Universe's 13-14 billion year evolution. The distorted shape of the Tadpole itself was caused by a collision with a small 'hit and run' galaxy.



Small, Distant Galaxy Behind Abell 2218
The bright yellow galaxies in the image below belong to a galaxy cluster called Abell 2218, and the gravitational tug from their huge mass distorts and amplifies light from more distant galaxies behind the cluster. In this curious way nature itself has helped astronomers to detect one of the most remote and smallest galaxies ever. In fact, the small red galaxy (seen as two spots due to the uneven distribution of mass in the cluster) is thought to be a 13 billion year old so-called galaxy building block. This is probably similar to one of the galaxy building blocks that have coalesced and created the galaxies we have around us today.

The reason for this eternal expansion is thought to be the existence of a mysterious form of 'dark energy' that pervades the Universe. A source of energy found in the emptiness of space itself working as a kind of repulsive gravity.
Another cosmological surprise came in 2001, when a supernova - an exploding star - was found by Hubble at the tremendous distance of 10 billion light-years from Earth. Astronomers believe that this one object shows that the Universe actually slowed down in its expansion (instead of accelerating) in the first few billion years after the Big Bang. This is a natural thing to expect, since the mutual gravity from all objects in the Universe should manifest itself in exactly such a deceleration of the expansion. But the observations show that the 'dark energy' 'kicked in' at some point, for so far unexplained reasons, and started the acceleration that we observe at later times in the Universe. The following years of observations will show if this theory holds, or if the Universe has even more surprises in store for us.

Seeing the Invisible — Ultraviolet observations

Hubble is above the distorting effects of the Earth's atmosphere in its 600 km high orbit, but it also flies above the protection that the atmosphere provides. The air protects us, among other things, from X-rays and ultraviolet rays from the Sun and other more distant objects.

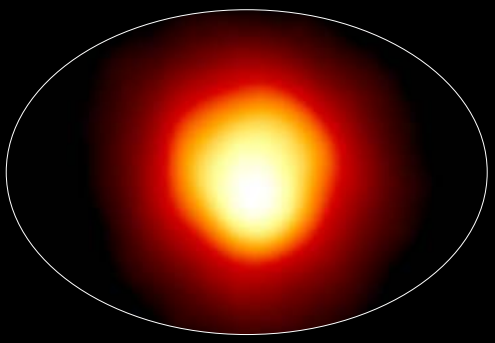
Aurora on Saturn
In 1994 Hubble took the first images of the ultraviolet aurora on Saturn.



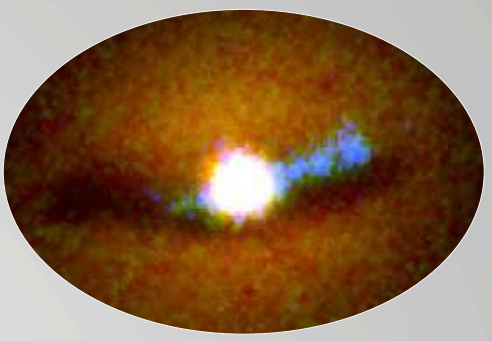
Ultraviolet Galaxies
Astronomers have used these three ultraviolet Hubble telescope images of nearby galaxies to help tackle the question of why their distant relatives have such odd shapes, appearing markedly different from the typical elliptical and spiral galaxies seen in the nearby Universe.

Hubble is designed to observe the ultraviolet radiation from hot young stars, from cores of galaxies and from the planets in our Solar System.

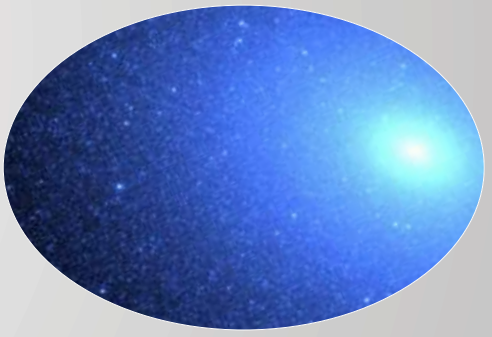
Hubble's ultraviolet investigations have opened new windows on energetic and violent parts of the Universe that had barely been explored before.



Close-up of a Star
This is the first direct image of a star other than the Sun and was made with Hubble's Faint Object Camera, built by the European Space Agency. The image shows the surface of the star Betelgeuse and was taken in ultraviolet light.



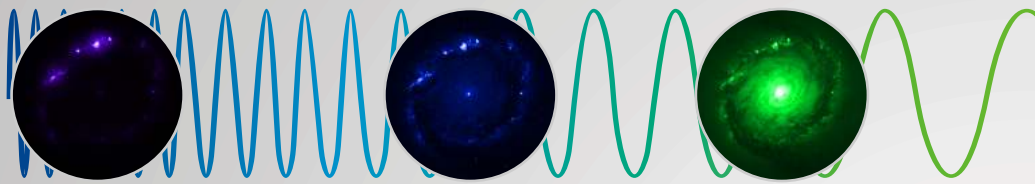
Unmasking a Black Hole
Hubble used the European Faint Object Camera to look into the heart of a galaxy and found hot gas swirling around a suspected massive black hole. The gas is so hot that it mainly emits ultraviolet light.



Hot Blue Stars in M32
The Hubble Space Telescope's exquisite resolution has allowed astronomers to resolve hot blue stars deep inside an elliptical galaxy for the first time. The observations confirm that the ultraviolet light comes from a population of extremely hot helium-burning stars at a late stage in their lives.

Journeys into the Infrared Universe

A large fraction of the infrared light that comes from space is absorbed by the Earth's atmosphere and is therefore difficult to observe from the ground.



Covering the Full Range
These seven images of the galaxy NGC 1512 have been taken through specially designed filters and cover nearly the entire range of light that Hubble can see. From the ultraviolet (on the left) to the infrared (on the right).
A full-colour composite image (seen to the left) made by combining the seven individual images.

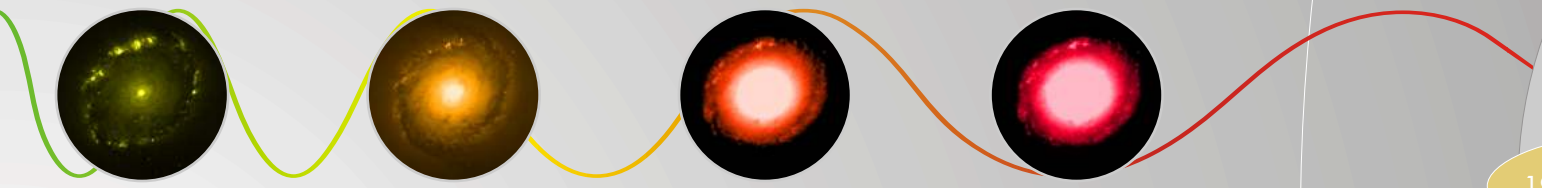
Infrared light holds the key to the exploration of four different and interesting types of astronomical objects:

- Cold objects — aging stars, star-forming clouds and planets
- Dusty objects — centres of galaxies, star-forming regions and planetary nebulae
- Distant objects — galaxies whose light is redshifted as a result of the expansion of the Universe ?
- Objects containing large and complex molecules — comets containing crystals or stardust among the planets.

Exploration of the infrared, or at least the near-infrared, part of the spectrum has been an important task for Hubble's near-infrared camera, NICMOS.

The Heart of the Orion Nebula
Some objects found in star-forming regions have failed to gather enough material from the surrounding cloud to start to shine. These objects are called brown dwarfs and, because of the surrounding dust cloud and their low temperature, are very difficult to see in visible light (Hubble image in visible light, left). NICMOS, Hubble's near-infrared camera, has uncovered a swarm of newly-born brown dwarfs throughout the Trapezium cluster in the Orion Nebula, about 1500 light-years from Earth (right).

Discs around Young Stars
Near-infrared images of young stars have shown them as surrounded by dust-filled discs, dark regions where planetary systems are likely to form. In visible light the glare from the central stars is often too bright for the discs to be visible and so near-infrared observations are ideal to find these objects.

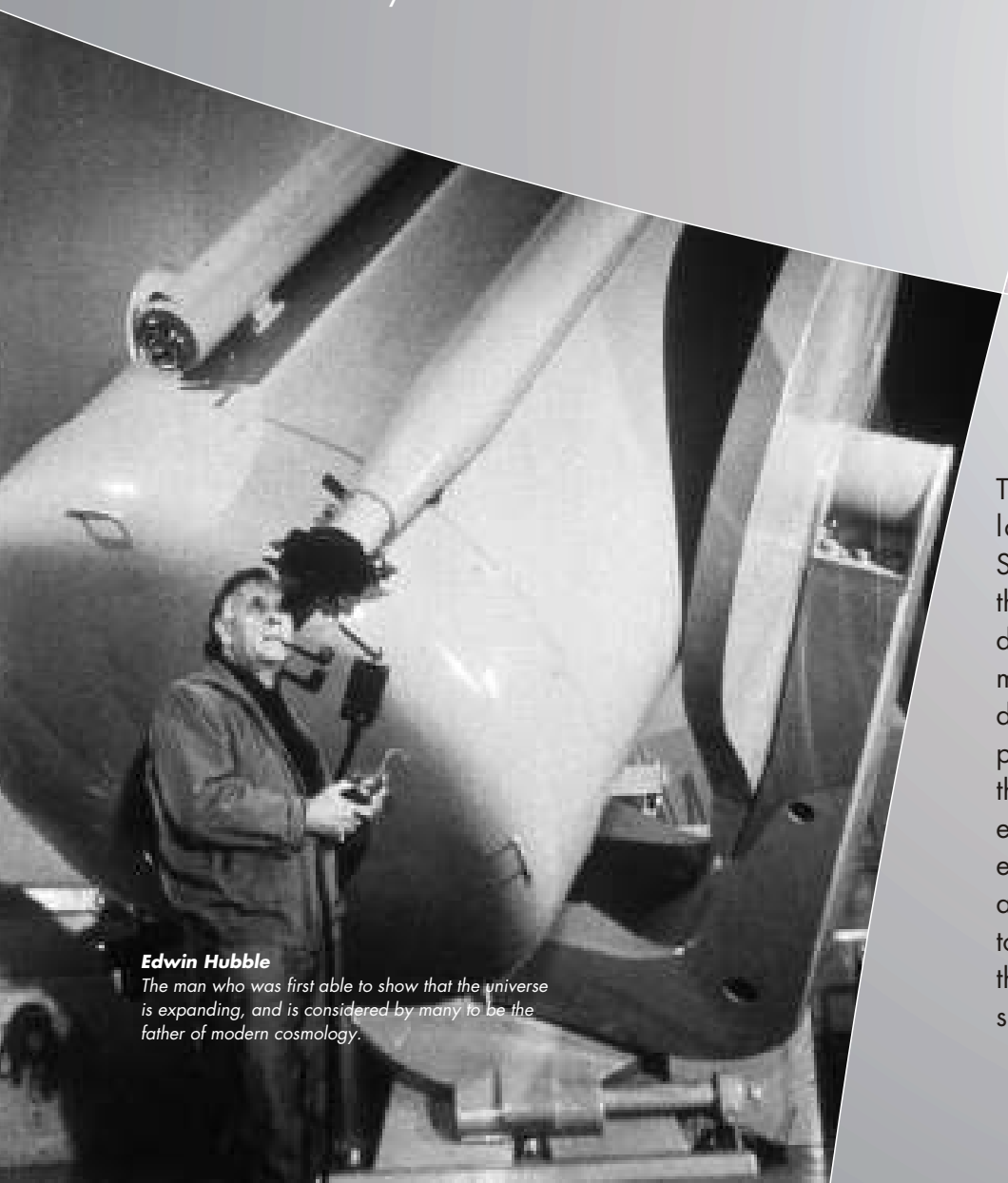


Spying the Centre of Galaxy M82
By studying the 'star-bursting' galaxy Messier 82 in near-infrared light it was possible to look through its dust lanes and discover one hundred super-star clusters.

Hubbles History

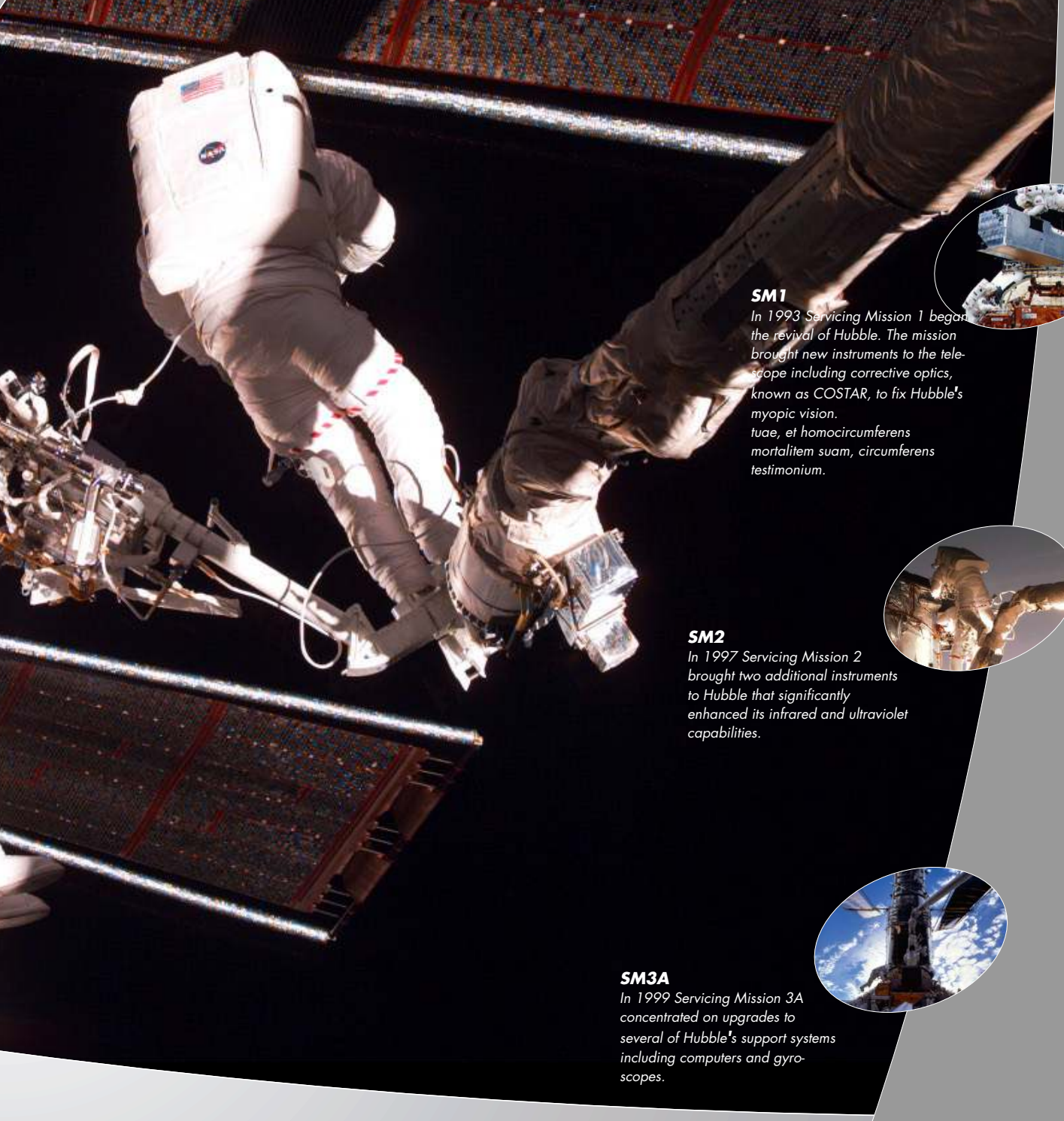
The first idea of a space telescope was first proposed in 1923 by the German space pioneer Herman Oberth, but it took 67 years before Oberth's dream became reality with the launch of the NASA/ESA Hubble Space Telescope.

The Hubble Space Telescope is named after one of the great pioneers of modern astronomy, the American astronomer Edwin Powell Hubble (1889-1953). One of Edwin Hubble's many contributions to astronomy was the discovery that the Universe is expanding – one of the intellectual triumphs of the 20th century.



Edwin Hubble
The man who was first able to show that the universe is expanding, and is considered by many to be the father of modern cosmology.

The Hubble Space Telescope was launched into orbit by NASA's Space Shuttle in 1990 and went through three turbulent initial years due to problems with the primary mirror. A faulty measurement procedure meant that the mirror, although perfectly figured, was originally just the wrong thickness at the edge, an error of a mere 2 microns, roughly equal to one-fiftieth the thickness of a human hair. The mirror was able to collect and focus light, but not in the right place, a phenomenon very similar to human short-sightedness



SM1
In 1993 Servicing Mission 1 began the revival of Hubble. The mission brought new instruments to the telescope including corrective optics, known as COSTAR, to fix Hubble's myopic vision.
tuae, et homocircumferens mortalitem suam, circumferens testimonium.

SM2
In 1997 Servicing Mission 2 brought two additional instruments to Hubble that significantly enhanced its infrared and ultraviolet capabilities.

SM3A
In 1999 Servicing Mission 3A concentrated on upgrades to several of Hubble's support systems including computers and gyroscopes.

or myopia. Just as myopia can be corrected by spectacles, so could Hubble's optics be corrected by inserting a suitable arrangement of mirrors. The First Servicing Mission in 1993 installed such corrective optics, known as COSTAR. On subsequent Servicing Missions Hubble has undergone extensive upgrades of instruments and systems, and thus continues to be at the forefront of scientific discovery.

SM3B
Servicing Mission 3B gave Hubble another scientific boost by the installation of a more powerful camera and also a cooling unit for NICMOS, its near-infrared instrument.

Hubble and Europe

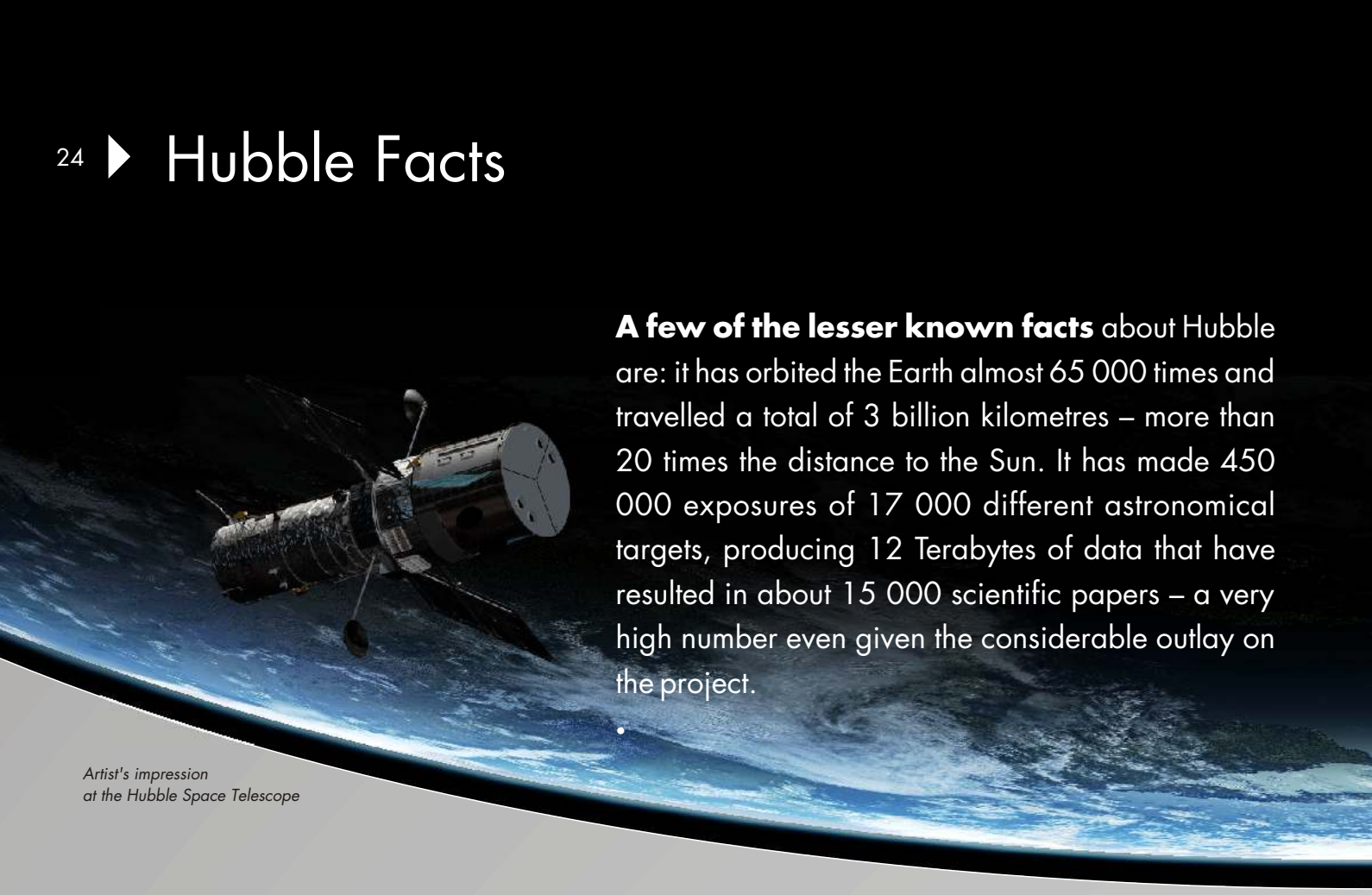
No single nation could undertake such an enormous project alone. From an early stage Hubble has been a collaboration between NASA, the American space agency, and ESA, the European Space Agency.

Hubble has been of paramount importance to European astronomy. European astronomers are guaranteed 15% of the observing time with Hubble, resulting in several thousand scientific publications over the years.

Two groups of European specialists work with Hubble. There are 15 people from the European Space Agency (ESA) currently working at the Space Telescope Science Institute (STScI) in the USA and in Munich, Germany, 22 people form the Space Telescope-European Coordinating Facility (ST-ECF).

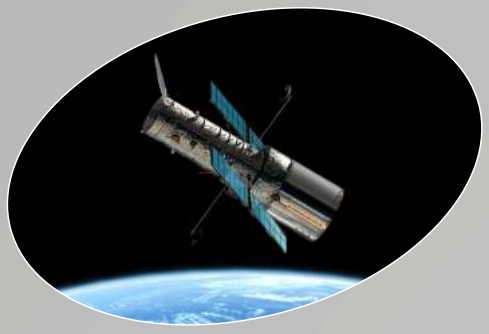
ESA's main hardware contribution to Hubble has been two sets of flexible, high-power solar arrays and the Faint Object Camera (FOC).

Hubble Facts

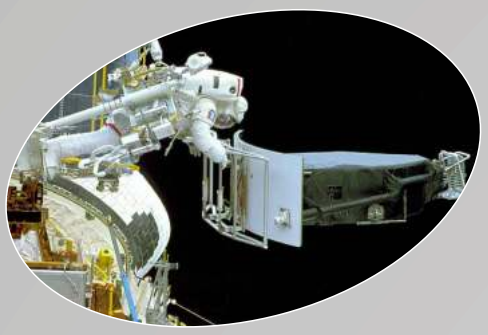


Artist's impression at the Hubble Space Telescope

A few of the lesser known facts about Hubble are: it has orbited the Earth almost 65 000 times and travelled a total of 3 billion kilometres – more than 20 times the distance to the Sun. It has made 450 000 exposures of 17 000 different astronomical targets, producing 12 Terabytes of data that have resulted in about 15 000 scientific papers – a very high number even given the considerable outlay on the project.



Orbital altitude:
593 km
Orbital time:
97 minutes



Mission lifetime:
20 years

Exposures:

Different objects observed:

Data:

Wavelength range:

Distance travelled:

Number of scientific papers:

Angular resolution:

Exposures:

Launch Date:
24 April, 1990, 12:33:51 UT

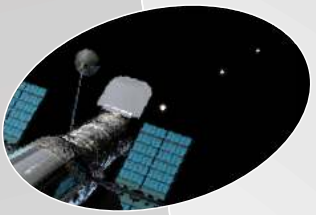
Weight:
11 110 kg

400 000

Mirror:
2.4 m

12 000

more than 12 GB downloaded to Earth



Pointing stability:
Hubble moves less than 0.007 arc-seconds for 24 hours

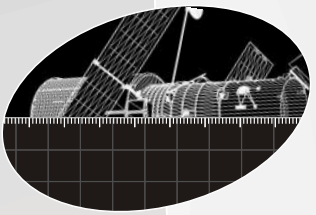
110 – 2400 nm (from ultraviolet to near-infrared)

65 000 times around the Earth
(a total of 3 billion kilometres –
more than 20 times the distance to the Sun)

Costs:
ESA's financial contribution over 20 years is 593 million Euros

approx. 15 000

0.05 arc-seconds



Dimensions:
15.9 x 3.1 x 4.2 metres

approx. 400 000

Hubble's Instruments and Systems

Support Systems
Containing essential support systems such as computers, batteries, gyroscopes, reaction wheels and electronics.

FGS

FGS
Hubble has three Fine Guidance Sensors on board. Two of them are needed to point and lock the telescope on the target and the third can be used for position measurements — also known as astrometry.

STIS

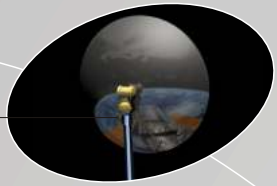
STIS
The Space Telescope Imaging Spectrograph (STIS) is a versatile multi-purpose instrument taking full advantage of modern technology. It combines a camera with a spectrograph and covers a wide range of wavelengths from the near–infrared region into the ultraviolet.

NICMOS

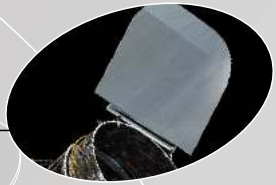
NICMOS
The Near Infrared Camera and Multi-Object Spectrometer (NICMOS) is an instrument for near-infrared imaging and spectroscopic observations of astronomical targets. NICMOS detects light with wavelengths between 8000 to 25000 Angstroms.

ACS

ACS
ACS is a so-called third generation Hubble instrument. Its wide field of view is nearly twice that of Hubble's previous workhorse camera, WFPC2. The name, Advanced Camera for Surveys, comes from its particular ability to map relatively large areas of the sky in great detail.



Communication antennae
Once Hubble observes a celestial object, its onboard computers convert the image or spectrum into long strings of numbers that — via one of Hubble's two antennae — are sent to one of the two satellites that form the Tracking and Data Relay Satellite System (TDRSS).

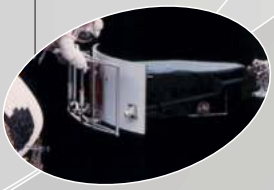


Aperture door
Hubble's aperture door can be closed if Hubble is in danger of letting light from the Sun, Earth or Moon into the telescope.

Secondary mirror
Like the primary mirror, Hubble's secondary mirror is made of special glass coated with aluminium and a special compound to reflect ultraviolet light. It is 1/3 metre in diameter and reflects the light back through a hole in the primary mirror and into the instruments.

Solar Panels
Hubble's third set of solar arrays produces enough power to enable all the science instruments operate simultaneously, thereby making Hubble even more efficient. The panels are rigid and unlike earlier versions of the solar panels, do not vibrate, making it possible to perform stable, sharp pinpoint observations.

Primary mirror
Hubble's primary mirror is made of a special glass coated with aluminium and a special compound that reflects ultraviolet light. It is 2.4 metres in diameter and collects the light from stars and galaxies and reflects it to the secondary mirror.



WFPC2
WFPC2 was Hubble's workhorse camera up to the installation of ACS. It records excellent quality images through a selection of 48 colour filters covering a spectral range from far-ultraviolet to visible and near-infrared wavelengths. WFPC2 has produced most of the stunning pictures that have been released as public outreach images over the years.mortalitem suam, circumferens testimonium.

COSTAR
COSTAR is not really a science instrument: it is the corrective optics package that displaced the High Speed Photometer (HSP) during the first servicing mission. COSTAR was designed to correct the effects of the primary mirror's aberration.

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Webpages for Hubble European Space Agency Information Centre
http://www.spacetelescope.org
Webpages for ESA Science
http://sci.esa.int

Cover picture:
The cover shows a 3D rendering of Hubble in front of the Cone Nebula. The Cone Nebula is a pillar of gas and dust found in a turbulent star–forming region. The picture was taken by Hubble's Advanced Camera for Surveys (ACS).