

# NASA/ESA Hubble Space Telescope press pack

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## The history of Hubble

**1923:** The rocket scientist Hermann Oberth publishes an article in which he proposes the idea of a telescope in orbit of Earth.

**1946:** The astronomer Lyman Spitzer writes a report on the advantages of an extra-terrestrial observatory.

**1977:** The American congress approves the funding for the Large Space Telescope.

**1978:** Astronauts begin the training for space telescope missions.

**1979:** Work begins on the 2.4-metre main mirror of the telescope.

**1981:** The Space Telescope Science Institute (STScI) begins its operations on the campus of the John Hopkins University in Baltimore, USA.

**1983:** The Large Space Telescope is renamed the Hubble Space Telescope, after the renowned astronomer Edwin Powell Hubble, who proved the existence of other galaxies and discovered the first evidence for an expanding Universe.

**1984:** The Space Telescope-European Coordinating Facility begins its operation in Garching at Munich, Germany.

**1985:** The work on building Hubble is completed.

**1986:** Hubble's launch is delayed after the Challenger disaster, which puts all shuttle flights on hold.

**1990:** The shuttle Discovery (STS-31) is launched on 24 April 1990 and brings Hubble into space. On 25 April Hubble is deployed into its orbit by the space shuttle crew. The first images made on 25 June reveal that the main mirror of Hubble has a spherical aberration which causes all images to be blurred. Within the same year COSTAR is approved: This instrument is a complex package of five optical mirror pairs which are going to rectify the spherical aberration of Hubble's main mirror.

**1993:** The space shuttle Endeavour is launched on 2 December to conduct the first servicing mission on Hubble. During the mission the corrective optics of COSTAR are installed which replace the High Speed Photometer. The WFPC2 (Wide Field and Planetary Camera 2), which was built with its own corrective optics, replaced the WFPC1 (Wide Field and Planetary Camera 1)

**1994:** Hubble provides detailed observations of the comet Shoemaker–Levy 9 as it collides with the planet Jupiter [\[1\]](#). In addition, by observing the galaxy M87 Hubble provides conclusive evidence for the existence of Supermassive Black Holes in the centres of galaxies [\[2\]](#).

**1995:** Hubble takes the famous photo of the Eagle Nebula which later will be called “the pillars of creation” [\[3\]](#).

**1996:** The first Hubble Deep Field, which was observed by the end of 1995, is revealed and allows astronomers to study galaxies in the early Universe [\[4\]](#). In the same year Hubble resolves the host galaxies of quasars [\[5\]](#).

**1997:** Servicing Mission 2 (STS-82) is launched on 11 February. The crew of the space shuttle Discovery replace the instruments FOS (Faint Object Spectrograph) and GHRS (Goddard High Resolution Spectrograph) with STIS (Space Telescope Imaging Spectrograph) and NICMOS (Near Infrared Camera and Multi-Object Spectrograph). Within 1997 Hubble also observes the visible afterglow of a gamma-ray burst in a distant galaxy [\[6\]](#).

**1998:** On 29 October the HST Orbital System Test (HOST) is launched with the space shuttle Discovery (STS-95). The HOST mission is testing new technologies to be used in Hubble on the third Servicing Mission and beyond.

**1999:** The Servicing Mission 3A (STS-103) is launched on 19 December. The astronauts on board the Discovery replace the six gyroscopes of the telescope, which help it pointing at celestial objects, and conduct a general maintenance. This is the first servicing mission which is not replacing any older science instruments.

**2001:** Hubble is able to measure the elements on the atmosphere of the exoplanet HD 209458b [\[7\]](#).

**2002:** The Servicing Mission 3B which is launched on 1 March. During the Mission the ACS (Advanced Camera for Surveys), the NICMOS Cooling System (NCS) and new solar panels are installed. Hubble also detects an object in the Kuiper belt at the edge of our Solar System which is larger than Pluto [\[8\]](#). This discovery leads to a debate on Pluto's status as a planet.

**2003:** The space shuttle Columbia disintegrates during the atmospheric re-entry, no crew members survive and the shuttle programme is grounded.

**2004:** The Hubble Ultra Deep Field is released allowing astronomers to look even further back in the time of the cosmos [\[9\]](#). Another servicing mission is cancelled out of concern for shuttle safety and the power supply on STIS (Space Telescope Imaging Spectrograph) fails.

**2005:** Hubble images two previously unknown moons orbiting Pluto [\[10\]](#).

**2006:** It is decided that servicing mission 4 will go ahead [\[11\]](#).

**2007:** Hubble observations show that the dwarf planet Eris is bigger than Pluto [\[12\]](#). A 3D-map, based on images by Hubble, showing the distribution of dark matter in the Universe is revealed [\[13\]](#). Also in 2007 the power supply on the Advanced Camera for Surveys, one of Hubble's key instruments, fails.

**2008:** Hubble takes a picture of the exoplanet Formalhaut b, the first visual image of an exoplanet [\[14\]](#). In the same year Hubble finds organic molecules on an extrasolar planet and the telescope's 100 000th orbit around Earth is celebrated [\[15\]](#).

**2009:** Servicing Mission 4 (STS-125) is launched on 11 May [\[16\]](#). The astronauts install two new instruments, WFC3 (Wide Field Camera 3) and COS (Cosmic Origins Spectrograph) which make Hubble 100 times more powerful than when it was launched. During the servicing mission the damaged instruments are repaired, the gyroscopes and batteries are replaced, and the Soft Capture Mechanism as well as NBLs (New Outer Blanket Layers) are installed.

**2010:** Hubble images reveal distant galaxies with likely redshifts greater than 8, showing the Universe as it was when it was less than a tenth of its current age [\[17\]](#). Hubble also photographs a never-before-seen evidence of a collision between two asteroids [\[18\]](#).

**2011:** Hubble makes its millionth observation, a spectroscopic analysis of the exoplanet HAT-P-7b. The 10 000th scientific paper using Hubble data is published [\[19\]](#).

**2012:** Images taken by Hubble show seven primitive galaxies from a distant population that formed more than 13 billion years ago. The galaxies are seen as they were when the Universe was less than 4 percent of its present age. Later in the year even that record is broken as Hubble finds an object back from a time when the Universe was only 3 percent of its present age, only 470 million years after the Big Bang [\[20\]](#). Hubble observations also lead to a new class of exoplanet [\[21\]](#).

**2013:** Hubble is also used in this year to determine for the first time the true colour of a planet orbiting another star [22] and finds water vapour erupting off the surface of Jupiter's moon Europa [23]

**2014:** Hubble becomes the first telescope ever to observe an asteroid disintegrating [24] and it reveals the most detailed weather map for an exoplanet ever [25].

**2015:** Hubble observes, for the first time, four images of a distant exploding star arranged in a cross-shaped pattern by the powerful gravity of a foreground galaxy embedded in a massive cluster of galaxies [26]. It also celebrates its 25th year in orbit with celebrations across the globe! [27] [28]

## Links

- [1] <http://hubblesite.org/newscenter/archive/releases/1994/1994/48/>
- [2] <http://hubblesite.org/newscenter/archive/releases/1994/1994/23/>
- [3] <http://hubblesite.org/newscenter/archive/releases/1995/1995/44/>
- [4] <http://hubblesite.org/newscenter/archive/releases/1996/1996/01/>
- [5] <http://hubblesite.org/newscenter/archive/releases/1996/1996/35/>
- [6] <http://hubblesite.org/newscenter/archive/releases/1997/1997/10/>
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- [9] <http://www.spacetelescope.org/news/heic0406/>
- [10] <http://hubblesite.org/newscenter/archive/releases/2005/2005/19/>
- [11] <http://www.spacetelescope.org/news/heic0618/>
- [12] <http://hubblesite.org/newscenter/archive/releases/2007/24/>
- [13] <http://www.spacetelescope.org/news/heic0701/>
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- [18] <http://www.spacetelescope.org/news/heic1016/>
- [19] <http://hubblesite.org/newscenter/archive/releases/2011/40/>
- [20] <http://www.spacetelescope.org/news/heic1219/>
- [21] <http://www.spacetelescope.org/news/heic1204/>
- [22] <http://www.spacetelescope.org/news/heic1312/>
- [23] <http://spacetelescope.org/news/heic1322/>
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- [25] <http://spacetelescope.org/news/heic1422/>
- [26] <http://spacetelescope.org/news/heic1505/>
- [27] <https://www.spacetelescope.org/Hubble25/>
- [28] <http://hubble25th.org/>

## Hubble – greatest discoveries

During its 25 year long mission the NASA/ESA Hubble Space Telescope has changed our view of the Universe significantly. Some of the most ground-breaking discoveries made in astronomy in the 20th century were made by Hubble, which allows astronomers to better understand the world we live in and investigate its mysteries even further.

### **The Hubble Deep Fields: How Hubble has observed the furthest away galaxies and the most ancient starlight ever seen by humankind**

One of the main scientific justifications for building Hubble was to measure the size and age of the Universe and test theories about its origin. Images of faint galaxies give “fossil” clues as to how the Universe looked in the remote past and how it may have evolved with time. The Deep Fields gave astronomers the first really clear look back to the time when galaxies were forming. The first deep fields — Hubble Deep Field North and South — gave astronomers a peephole to the ancient Universe for the first time, and caused a real revolution in modern astronomy [1].

Subsequent deep imagery from Hubble, including the Hubble Ultra Deep Field, has revealed the most distant galaxies ever observed. Because of the time it has taken their light to reach us, we see some of these galaxies as they were just half a billion years after the Big Bang.

Deep field observations are long-lasting observations of a particular region of the sky intended to reveal faint objects by collecting the light from them for an appropriately long time. The 'deeper' the observation is (i.e. longer exposure time), the fainter are the objects that become visible on the images. Astronomical objects can either look faint because their natural brightness is low, or because of their distance. In the case of the Hubble Deep and Ultra Deep Fields, it is the extreme distances involved which make them faint, and hence make observations challenging [2].

Using the different Hubble Deep fields astronomers were able to study young galaxies in the early Universe [3] and the most distant primeval galaxies [4]. The different deep fields are also a good gathering grounds to find the most distant objects ever observed [5] [6] [7].

Within 2012 and 2014 Hubble created two new deep fields: The Hubble eXtreme Deep Field is so far the deepest image ever taken of the sky so far and combines the light of one million seconds of observation [8]. The last Hubble Ultra Deep Field released in 2014 was observed in ultraviolet. This image allowed astronomers to study star formation in a region 5 to 10 light-years away from us [9].

### **More Information on Hubble Deep Fields**

[http://spacetelescope.org/science/deep\\_fields/](http://spacetelescope.org/science/deep_fields/)

### **Related news releases**

[1] <http://hubblesite.org/newscenter/archive/releases/1996/1996/01/>

[2] <http://www.spacetelescope.org/news/heic0406/>

[3] <http://www.spacetelescope.org/news/heic0611/>

- [4] <http://www.spacetelescope.org/news/heic1001/>
- [5] <http://www.spacetelescope.org/news/heic1103/>
- [6] (<http://www.spacetelescope.org/news/heic1217/>)
- [7] <http://www.spacetelescope.org/news/heic1219/>
- [8] <http://www.spacetelescope.org/news/heic1214/>
- [9] <http://spacetelescope.org/news/heic1411/>

## **Age and size of the Universe: How Hubble has calculated the age of the cosmos and discovered the Universe is expanding at an ever faster rate**

The top ranked scientific justification for building Hubble was to determine the size and age of the Universe through observations of Cepheid variables. The periodic brightness variations of these stars depends on physical properties of the stars such as their mass and true brightness. This means that astronomers, just by looking at the variability of their light, can find out about the Cepheids' physical nature, which then can be used to determine their distance.

Astronomers have used Hubble to observe Cepheids with extraordinary results. The Cepheids have then been used as stepping-stones to make distance measurements for supernovae, which have, in turn, given a measure for the scale of the Universe. Today we know the age of the Universe to a much higher precision than before Hubble: around 13.7 billion years.

### **The expansion of the Universe**

Another purposes of Hubble was to determine the rate of expansion of the Universe, known as the Hubble Constant. After eight years of Cepheid observations this work was concluded by finding that the expansion increases with 70 km/second for every 3.26 million light-years you look further out into space.

For many years cosmologists have discussed whether the expansion of the Universe would stop in some distant future or continue ever more slowly. The observations of distant supernovae made by Hubble indicate that the expansion is nowhere near slowing down. In fact, due to some mysterious property of space itself, called dark energy, the expansion is accelerating [1] [2]. This surprising conclusion came from combined measurements of remote supernovae with most of the world's top-class telescopes, including Hubble.

The discovery of the accelerating expansion of the Universe led to three astronomers, Saul Perlmutter, Adam Riess and Brian Schmidt, being awarded the 2011 Nobel Prize in Physics.

### **More Information on what Hubble has found about the size and age of the Universe**

[http://www.spacetelescope.org/science/age\\_size/](http://www.spacetelescope.org/science/age_size/)

### **Related news releases**

- [1] <http://www.spacetelescope.org/news/heic1005/>
- [2] <http://www.spacetelescope.org/news/heic1014/>

## **The lives of stars: How Hubble has revolutionised our understanding of the birth and death of stars**

Most of the light and radiation we can observe in the Universe originates in stars — individual stars, clusters of stars, nebulae lit by stars and galaxies composed of billions of stars. Like human beings stars are born, mature and eventually die. Hubble has gone beyond what can be achieved by other observatories by linking together studies of the births, lives and deaths of individual stars with theories of stellar evolution [1] [2].

In particular Hubble's ability to probe stars in other galaxies enables scientists to investigate the influence of different environments on the lives of stars. This is crucial in order to be able to complement our understanding of the Milky Way galaxy with that of other galaxies.

### **Uncovering the Galaxy's stellar nurseries**

Hubble's work allowed it to link star formation with stellar evolution. Its infrared instruments are capable of looking through the dust clouds surrounding newly born stars [3]. Some of the most surprising discoveries so far have come about by peering through the clouds of dust surrounding the centre of our Milky Way. Astronomers found that this centre, which was thought to be a calm and almost dead region, is in fact populated with massive infant stars gathered into clusters [4].

### **Stellar skeletons**

The last phases of solar-like stars have been investigated through observations of planetary nebulae and proto-planetary nebulae. These are colourful shells of gas expelled into space by dying stars. The varying shapes and colours of these intricate structures with different colours tracing different, often newly created, chemical elements, have shown that the final stages of the lives of stars are more complex than once thought and there also seems to exist a bizarre alignment of planetary nebula [5].

### **Gamma Ray Bursts**

Gamma Ray Bursts emit very intense gamma-ray radiation for short periods and are observed a few times per day by special gamma-ray detectors on observatories in space. Today, partly due to Hubble, we know that these bursts originate in other galaxies — often at very large distances [6].

Their origin has eluded scientists for a long time, but, after Hubble observations of the atypical supernova SN1998bw and the Gamma Ray Burst GRB 980425 a physical connection of these became probable [7].

An unusual burst of radiation detected in early 2011 may tell a different story: rather than a star ending its life in a supernova, this burst may be evidence of a star being ripped apart as it falls into a supermassive black hole. If confirmed by further observations, this would be the first time this phenomenon has ever been spotted.

### **More Information on the lives of stars**

[http://www.spacetelescope.org/science/stellar\\_evolution/](http://www.spacetelescope.org/science/stellar_evolution/)

**Related news releases**

- [1] <http://spacetelescope.org/news/heic0707/>
- [2] <http://spacetelescope.org/news/heic0703/>
- [3] <http://www.spacetelescope.org/news/heic0601/>
- [4] <http://spacetelescope.org/news/heic0104/>
- [5] <http://www.spacetelescope.org/news/heic1316/>
- [6] <http://hubblesite.org/newscenter/archive/releases/1997/1997/10/>
- [7] <http://spacetelescope.org/news/heic0003/>

**The solar neighbourhood: What Hubble has taught us about planets, asteroids and comets in our own Solar System**

Hubble's high resolution images of the planets and moons in our Solar System can only be surpassed by pictures taken from spacecraft that actually visit them. Hubble even has one advantage over these probes: it can look at these objects periodically and so observe them over much longer periods than any passing probe could. Regular monitoring of planetary surfaces is vital in the study of planetary atmospheres and geology, where evolving weather patterns such as dust storms can reveal much about the underlying processes.

In comparison with probes that have to travel vast distances and require years of planning to visit the planets Hubble is also able to react quickly to sudden dramatic events occurring in the Solar System. This allowed it to witness the stunning plunge of comet Shoemaker-Levy 9 into Jupiter's atmosphere during the period 16-22 July 1994 [1]. Hubble followed the comet fragments on their last journey and delivered incredible high-resolution images of the impact scars. The consequences of the impact could be seen for several days afterwards, and by studying the Hubble data astronomers were able to gain fundamental information about the composition and density of the giant planet's atmosphere. Since the impact of Shoemaker-Levy 9, Hubble has continued to study impacts and events on Jupiter, improving our understanding of the Solar System's largest planet [2] [3].

Pluto and its surrounding moons have also been the target of Hubble's observations. Several new moons have been discovered as well as a dwarf planet beyond Pluto, which led to the discussion of Pluto being a planet [4] [5] [6].

Hubble also observed the spectacular break up of comet 73P/Schwassmann-Wachmann 3 as it visited the inner Solar System, the asteroid collision P2010/A2 and a mysterious disintegrating asteroid [7] [8] [9].

**More Information on the Solar System**

[http://www.spacetelescope.org/science/our\\_solar\\_system/](http://www.spacetelescope.org/science/our_solar_system/)

**Related Hubblecast episode: What has Hubble taught us about the planets?**

<http://www.spacetelescope.org/videos/hubblecast27a/>



**Related news releases**

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- [3] <http://www.spacetelescope.org/news/heic1410/>
- [4] <http://hubblesite.org/newscenter/archive/releases/2002/2002/17/>
- [5] <http://hubblesite.org/newscenter/archive/releases/2007/24/>
- [6] <http://www.spacetelescope.org/news/heic1212/>
- [7] <http://www.spacetelescope.org/news/heic0605/>
- [8] <http://www.spacetelescope.org/news/heic1016/>
- [9] <http://www.spacetelescope.org/news/heic1405/>

**Exoplanets and proto-planetary discs: How Hubble has made the first ever image of an exoplanet in visible light, and spotted planetary systems as they form**

Hubble's high resolution has been indispensable in the investigation of the gas and dust disks, dubbed proplyds, around the newly born stars in the Orion Nebula [1]. The proplyds may very well be young planetary systems in the early stages of creation. Also thanks to Hubble we have visual proof today that dusty disks around young stars are common [2].

The first detection of an atmosphere around an extrasolar planet was seen in a gas-giant planet orbiting the Sun-like star HD 209458, 150 light-years from Earth [3]. The presence of sodium as well as evaporating hydrogen, oxygen and carbon was detected in light filtered through the planet's atmosphere when it passed in front of its star as seen from Earth. The details revealed by Hubble are superior to anything seen to date with ground-based instruments.

Hubble has been instrumental in studying these extra-solar planets but it has also helped to detect them as well [4]. In 2008, Hubble made an image of the planet Fomalhaut b, a gas giant planet about three times the mass of Jupiter, which orbits the star Fomalhaut [5]. This was the first ever image made of an exoplanet in visible light. Within the same year the first organic molecule on an extrasolar planet was detected by Hubble [6].

In 2012 Hubble even discovered a complete new type of extra-solar planet: a water world enshrouded by a thick, steamy atmosphere [7]. Later Hubble was able to measure for the first time the colour and to create the most detailed weather map an exoplanet [8] [9].

**More Information on exoplanets and proto-planetary discs**

[http://www.spacetelescope.org/science/protoplanetary\\_extrasolar/](http://www.spacetelescope.org/science/protoplanetary_extrasolar/)

**Related Hubblecast episode: Born in beauty — proplyds in the Orion Nebula**

<http://spacetelescope.org/videos/heic0917a/>

**Related news releases**

- [1] <http://spacetelescope.org/news/heic0917/>
- [2] <http://www.spacetelescope.org/news/heic0613/>

[3] <http://hubblesite.org/newscenter/archive/releases/2001/2001/38/>

[4] <http://www.spacetelescope.org/news/heic0612/>

[5] <http://www.spacetelescope.org/news/heic0821/>

[6] <http://www.spacetelescope.org/news/heic0807/>

[7] <http://www.spacetelescope.org/news/heic1204/>

[8] <http://www.spacetelescope.org/news/heic1312/>

[9] <http://www.spacetelescope.org/news/heic1422/>

## **Black Holes, Quasars, and Active Galaxies: How Hubble found black holes at the heart of all large galaxies**

Black holes are objects so dense, and with so much mass, that even light cannot escape their gravity. It is in the study of supermassive black holes that Hubble has made its biggest contribution.

It is impossible to observe black holes directly, and astronomers had no way to test their theories until Hubble started its work. The high resolution of Hubble made it possible to see the effects of the gravitational attraction of some of these objects on their surroundings. Hubble has also proved that supermassive black holes are most likely present at the centres of most, if not all, large galaxies [1]. This has important implications for the theories of galaxy formation and evolution.

As black holes themselves, by definition, cannot be observed, astronomers have to study their effects on their surroundings. These include powerful jets of electrons that travel many thousands of light years from the centres of the galaxies [2]. Matter falling towards a black hole can also be seen emitting bright light and if the speed of this falling matter can be measured, it is possible to determine the mass of the black hole itself. This is not an easy task and it requires the extraordinary capabilities of Hubble to carry out these sophisticated measurements. Hubble observations have been fundamental in the study of the jets and discs of matter around a number of black holes. Accurate measurements of the masses have been possible for the first time. Hubble has found black holes 3 billion times as massive as our Sun at the centre of some galaxies. While this might have been expected, Hubble has surprised everyone by providing strong evidence that black holes exist at the centres of all large and even small galaxies [3] [4]. Hubble also managed not only to observe the jets created by black holes but also the glowing discs of material surrounding a supermassive black hole [5].

Furthermore, it appears that larger galaxies are the hosts of larger black holes. There must be some mechanism that links the formation of the galaxy to that of its black hole and vice versa [6]. This has profound implications for theories of galaxy formation and evolution and is an ongoing area of research in astronomy.

### **Black holes and the quasar connection**

Before Hubble, quasars were considered to be isolated star-like objects of a mysterious nature. Hubble has observed several quasars and found that they all reside at galactic centres [7] [8]. Today most scientists believe that supermassive black holes at the galactic centres are the

"engines" that power the quasars. They also believe that quasars, radio galaxies and the centres of so-called active galaxies just are different views of more or less the same phenomenon: a black hole with energetic jets beaming out from two sides. When the beam is directed towards us we see the bright lighthouse of a quasar. When the orientation of the system is different we observe it as an active galaxy or a radio galaxy. This unified model has gained considerable support through a number of Hubble observational programmes.

### **More Information on black holes and quasars**

[http://www.spacetelescope.org/science/black\\_holes/](http://www.spacetelescope.org/science/black_holes/)

### **Related news releases**

- [1] <http://www.spacetelescope.org/news/heic0002/>
- [2] <http://hubblesite.org/newscenter/archive/releases/1994/1994/23/>
- [3] <http://www.spacetelescope.org/news/heic1419/>
- [4] <http://www.spacetelescope.org/news/heic0512/>
- [5] <http://www.spacetelescope.org/news/heic1116/>
- [6] <http://www.spacetelescope.org/news/heic0614/>
- [7] <http://hubblesite.org/newscenter/archive/releases/1996/1996/35/>
- [8] <http://www.spacetelescope.org/news/heic0511/>

### **Formation of stars: How Hubble observes stars as they form from huge dust clouds**

The important clues about star formation lie hidden behind the veil of the dusty, and often very beautiful, star forming molecular clouds. Astronomers turn their eyes to the birth of other stars and stellar systems in neighbouring stellar 'maternity wards' and use these to see a replay of the events that created our own Solar System [\[1\]](#).

### **Inside the Orion Nebula**

The large mosaic of 15 Hubble images showing the central part of the Orion complex is one of the most detailed images of a star forming region ever made [\[2\]](#).

### **Peering through dust**

Dust clouds scatter visible light, but let infrared light through unimpeded, meaning infrared observations are often the only way to see young stars. During the servicing mission in 2009 the Wide Field Camera 3 (WFC3) was installed. An instrument designed to make detailed images both in visible light and in infrared. The WFC3 offers greatly improved capabilities in the infrared compared to what was possible before.

WFC3's images of the Carina Nebula made in visible light show dense clouds of dust and gas [\[3\]](#). But the images taken by the camera of the same region in infrared make the dust fade, leaving just a faint outline of its location. The young stars forming inside the cloud are suddenly revealed.

### **Star formation and the history of the cosmos**

Hubble has also contributed to our understanding of star formation beyond the confines of the Milky Way [4]. Neither Hubble nor any other telescope is able to see individual stars outside of the Milky Way and a handful of nearby galaxies. However, the telescope has contributed to major discoveries about star formation in the far reaches of the Universe [5] [6]. Studying starlight from the most distant objects Hubble has observed gives clues about how stars formed in the early years of the Universe, and how they have changed over time.

Hubble discoveries in the field of star formation in the early Universe include the realisation that stars and galaxies formed earlier in cosmic history than previously thought [7].

### **More Information on star formation**

[http://www.spacetelescope.org/science/formation\\_of\\_stars/](http://www.spacetelescope.org/science/formation_of_stars/)

### **Related Hubblecast episode: Star-forming region S 106**

<http://www.spacetelescope.org/videos/heic1118a/>

### **Related news releases**

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[4] <http://spacetelescope.org/news/heic0819/>

[5] <http://spacetelescope.org/news/heic0306/>

[6] <http://www.spacetelescope.org/news/heic1412/>

[7] <http://spacetelescope.org/news/heic1106/>

## **Composition of the Universe: How Hubble studied what the Universe is made of, and came to some startling conclusions**

All over the Universe stars work as giant reprocessing plants taking light chemical elements and transforming them into heavier ones. The original, primordial, composition of the Universe is studied in such fine detail because it is one of the keys to our understanding of processes in the very early Universe.

Astronomers investigated the nature of the gaseous matter that fills the vast volume of intergalactic space. By observing ultraviolet light from a distant quasar, which would otherwise have been absorbed by the Earth's atmosphere, scientists found the long-sought signature of helium in the early Universe. This was an important piece of supporting evidence for the Big Bang theory. It also confirmed scientists' expectation that, in the very early Universe, matter not yet locked up in stars and galaxies was nearly completely ionised (the atoms were stripped of their electrons). This was an important step forward for cosmology.

### **Dark Matter**

Today astronomers believe that around three quarters of the mass of the Universe consists of dark matter, a substance quite different from the normal matter that makes up the familiar world

around us. Hubble has played an important part in work intended to establish the amount of dark matter in the Universe and to determine where it is [\[1\]](#).

The riddle of what the ghostly dark matter is made of is still far from solved, but Hubble's incredibly sharp observations of gravitational lenses have provided stepping stones for future work in this area [\[2\]](#). Dark matter only interacts with gravity, which means it neither reflects, emits nor obstructs light. Because of this, it cannot be observed directly. However, Hubble studies of how clusters of galaxies bend the light that passes through them lets astronomers deduce where the hidden mass lies. This means that they are able to make maps of where the dark matter lies in a cluster.

One of Hubble's big breakthroughs in this area is the discovery of how dark matter behaves when clusters collide with each other. Studies of a number of these clusters have shown that the location of dark matter does not match the distribution of hot gas. This strongly supports theories about dark matter: we expect hot gases to slow down as they hit each other and the pressure increases. Dark matter, on the other hand, should not experience friction or pressure, so we would expect it to pass through the collision relatively unhindered. Hubble and Chandra observations have indeed confirmed that this is the case [\[3\]](#) [\[4\]](#).

### **A 3D map of the dark matter distribution in the Universe**

In 2007 an international team of astronomers used Hubble to create the first three-dimensional map of the large-scale distribution of dark matter in the Universe [\[5\]](#). It was constructed by measuring the shapes of half a million galaxies observed by Hubble. The light of these galaxies travelled — until it reached Hubble — down a path interrupted by clumps of dark matter which deformed the appearance of the galaxies. Astronomers used the observed distortion of the galaxies shapes to reconstruct their original shape and could therefore also calculate the distribution of dark matter in between.

This map showed that normal matter, largely in the form of galaxies, accumulates along the densest concentrations of dark matter. The created map stretches halfway back to the beginning of the Universe and shows how dark matter grew increasingly clumpy as it collapsed under gravity. Mapping dark matter distribution down to even smaller scales is fundamental for our understanding of how galaxies grew and clustered over billions of years [\[6\]](#). Tracing the growth of clustering in dark matter may eventually also shed light on dark energy.

### **Dark energy**

More intriguing still than dark matter is dark energy. Hubble studies of the expansion rate of the Universe have found that the expansion is actually speeding up. Astronomers have explained this using the theory of dark energy, as a sort of negative gravity that pushes the Universe apart ever faster. Studies of the rate of expansion of the cosmos suggests that dark energy is by far the largest part of the Universe's mass-energy content, far outweighing both normal matter and dark matter. While astronomers have been able to take steps along the path to understanding how dark energy works and what it does, its true nature is still a mystery [\[7\]](#).

**More Information on the composition of the Universe**

[https://www.spacetelescope.org/science/composition\\_of\\_universe/](https://www.spacetelescope.org/science/composition_of_universe/)

**Related Hubblecast episode: Hubble finds a ring of dark matter**

<http://spacetelescope.org/videos/heic0709a/>

**Related news releases**

[1] <http://spacetelescope.org/news/heic0309/>

[2] <http://spacetelescope.org/news/heic0709/>

[3] <http://spacetelescope.org/news/heic0818/>

[4] <http://spacetelescope.org/news/heic1506/>

[5] <http://spacetelescope.org/news/heic0701/>

[6] <http://spacetelescope.org/news/heic1215/>

[7] <http://spacetelescope.org/news/heic1014/>

**Gravitational lenses: How astronomers use a helping hand from Einstein to increase Hubble's range**

Light does not always travel in straight lines. Einstein predicted in his Theory of General Relativity that massive objects will deform the fabric of space itself. When light passes one of these objects, such as a cluster of galaxies, its path is changed slightly. This effect, called gravitational lensing, is only visible in rare cases and only the best telescopes can observe the related phenomena. Hubble's sensitivity and high resolution allow it to see faint and distant gravitational lenses that cannot be detected with ground-based telescopes [1]. The gravitational lensing results in multiple images of the original galaxy each with a characteristically distorted banana-like shape or even into rings [2].

Hubble was the first telescope to resolve details within these multiple banana-shaped arcs [3]. Its sharp vision can reveal the shape and internal structure of the lensed background galaxies directly and in this way one can easily match the different arcs coming from the same background object — be it a galaxy or even a supernova [4] — by eye. Since the amount of lensing depends on the total mass of the cluster, gravitational lensing can be used to “weigh” clusters [5]. This has considerably improved our understanding of the distribution of the dark matter in galaxy clusters and hence in the Universe as a whole. The effect of gravitational lensing also allowed a first step towards revealing the mystery of the dark energy [6].

As gravitational lenses function as magnification glasses it is possible to use them to study distant galaxies from the early Universe, which otherwise would be impossible to see [7] [8].

**Animation of gravitational lensing effect**

<http://www.spacetelescope.org/videos/heic0814f/>

**Related news releases**

[1] <http://spacetelescope.org/news/heic0404/>

[2] <http://spacetelescope.org/news/heic0803/>

- [3] <http://spacetelescope.org/news/heic0606/>
- [4] <http://spacetelescope.org/news/heic1505/>
- [5] <http://spacetelescope.org/news/heic1319/>
- [6] <http://spacetelescope.org/news/heic1014/>
- [7] <http://spacetelescope.org/news/heic1106/>
- [8] <http://spacetelescope.org/news/heic0814/>

## Hubble Space Telescope fact sheet

**Dimensions:** Length: 13.2 metres, diameter: 4.2 metres. In addition two solar panels each of which are 2.45 x 7.56 metres.

**Mass:** 11 110 kg (at the time of launch).

**Mirror:** 2.4 metres in diameter.

**Orbit:** Circular orbit, approximately 543 km above the ground, inclined at 28.5 degrees to the Equator. The telescope orbits the Earth at 28 000 kilometres an hour and takes 96 minutes to complete one orbit.

**Instruments:** Hubble is equipped with several different instruments.

- **WFC3** — Wide Field Camera 3: The main camera of the telescope which was installed during Servicing Mission 4.
- **COS** — Cosmic Origins Spectrograph: The spectrograph was installed during Servicing Mission 4, and restored spectroscopy to Hubble's scientific arsenal, while providing unique new capabilities.
- **ACS** — Advanced Camera for Surveys: Repaired during Servicing Mission 4 this instrument replaced Hubble's Faint Object Camera during Servicing Mission 3B. Its wavelength range extends from the ultraviolet, through the visible and out to the near-infrared. Its wide field of view is nearly twice that of Hubble's former workhorse camera, WFPC2. Its name comes from its particular ability to map large areas of the sky in great detail. ACS can also perform spectroscopy with a special optical tool called a 'grism'.
- **STIS** — Space Telescope Imaging Spectrograph: Repaired during Servicing Mission 4 this is a versatile "combi-instrument" taking advantage of modern technologies and combines a camera with a spectrograph. It covers a wide range of wavelengths from the near-infrared region into the ultraviolet.
- **NICMOS** — Near Infrared Camera and Multi-object Spectrometer: Though not currently operational this provides the capability for infrared imaging and spectroscopic observations of astronomical targets. NICMOS detects light with wavelengths between 800 to 2500 nanometres. These wavelengths are infrared and thus invisible to our human eyes.
- **FGS** — Fine Guidance Sensors: An optical sensor used to provide pointing information for the spacecraft and as a scientific instrument for astrometric science.

**Power:** Power for the computers and scientific instruments on board is provided by two 2.45 x 7.56 metre solar panels. The power generated by the panels is also used to charge six nickel-hydrogen batteries that provide power to the spacecraft for about 25 minutes per orbit while Hubble flies through the Earth's shadow. The solar panels were already renewed twice and replaced with more modern, more efficient versions.

**Maneuvering:** The telescope uses an elaborate system of direction controls to improve its stability during observations. A set of reaction wheels manoeuvres the telescope into place and its position in space is monitored by gyroscopes. Fine Guidance Sensors (FGS) are used to lock onto guide stars to ensure the extremely high pointing accuracy needed to make very accurate observations. The telescope does not have any rockets on board. Boosting the spacecraft's orbit can only be done during servicing missions, when the telescope is attached to the Space Shuttle.



**Observations & Data:** In the summer of 2011, Hubble passed the landmark of its millionth observation, and had gathered at that stage 60 Terabytes of data. Hubble sends about 120 GB of data to Earth every week. That's about 26 DVDs. As of January 2015 astronomers using Hubble data have published almost 13 000 scientific papers, making it one of the most productive scientific instruments ever built.

## Edwin P. Hubble – the man behind the name

When talking about the Hubble Space Telescope one man is often forgotten: That man who gave the space telescope its name: Edwin Powell Hubble. Today, most astronomers see him as the most important observational cosmologist in the 20th century and he played a crucial role in establishing the field of extragalactic astronomy.

As a result of Hubble's work, our perception of mankind's place in the Universe has changed forever: humans have once again been set aside from the centre of the Universe. When scientists decided to name the Space Telescope after the founder of modern cosmology the choice could not have been more appropriate.

### **A promising student**

Edwin Hubble was born in Missouri in 1889, the son of an insurance executive, and moved to Chicago nine years later. At his high school graduation in 1906 he gained a scholarship for the University of Chicago where he finally obtained a degree in Mathematics and Astronomy in 1910.

### **The Rhodes scholar**

A tall, powerfully built young man, Hubble loved basketball and boxing, and the combination of athletic prowess and academic ability earned him a Rhodes scholarship to Oxford. There, a promise made to his dying father, led him to study law rather than science, although he also took up Literature and Spanish.

He studied Roman and English Law at Oxford and returned to the United States only in 1913. Here he passed the bar examination and practised law half-heartedly for a year in Kentucky, where his family was then living.

### **The beloved high school teacher and coach**

He was also hired by New Albany High School (New Albany, Indiana) in the autumn of 1913 to teach Spanish, Physics and Mathematics, and to coach basketball. His popularity as a teacher is recorded in the school yearbook dedicated to him: "To our beloved teacher of Spanish and Physics, who has been a loyal friend to us in our senior year, ever willing to cheer and help us both in school and on the field, we, the class of 1914, lovingly dedicate this book."

When the school term ended in May 1914, Hubble decided to pursue his first passion and so returned to university as a graduate student to study more astronomy.

### **War postpones Hubble's astronomical debut**

Early in 1917, while still finishing the work for his doctorate, Hubble was invited by George Ellery Hale, founder of the Mount Wilson Observatory, in Pasadena, California, to join the staff there. This was a great opportunity, but it came in April of a dreadful year. After sitting up all night to finish his PhD thesis and taking the oral examination the next morning, Hubble enlisted in the infantry and telegraphed Hale: "*Regret cannot accept your invitation. Am off to the war.*"

He served in France and next returned to the United States in 1919. He went immediately to the Mount Wilson Observatory, where the newly discharged Major Hubble, as he invariably introduced himself, arrived, still in uniform, but ready to start observing.

Hubble was lucky enough to be in the right place at the right time. Mount Wilson was the centre of observational work underpinning the new astrophysics, later called cosmology, and the 100-inch Hooker Telescope, then the most powerful on Earth, had just been completed and installed after nearly a decade of work.

On the mountain Hubble encountered his greatest scientific rival, Harlow Shapley, who had already made his reputation by measuring the size of the Milky Way, our own Galaxy. Shapley had used a method pioneered by Henrietta Leavitt at the Harvard College Observatory that relied on the behaviour of standardised light variations from bright stars called Cepheid variables to establish the distance of an object.

His result of 300 000 light-years for the width of the galaxy was roughly 10 times the previously accepted value. However Shapley, like most astronomers of the time, still thought that the Milky Way was all there was to the Universe. Despite a suggestion first made by William Herschel in the 18th century, he shared the accepted view that all nebulae were relatively nearby objects and merely patches of dust and gas in the sky.

### **The turning point**

Hubble had to spend many bitterly cold nights sitting at the powerful Hooker telescope before he could prove Shapley wrong. In October 1923 he spotted what he first thought was a nova star flaring up dramatically in the M31 "nebula" in the constellation of Andromeda. After careful examination of photographic plates of the same area taken previously by other astronomers, including Shapley, he realised that it was a Cepheid star. Hubble used Shapley's method to measure the distance to the new Cepheid. He could then place M31 a million light-years away - far outside the Milky Way and thus itself a galaxy containing millions of stars. The known Universe had expanded dramatically that day and - in a sense - the Cosmos itself had been discovered!

### **Just the beginning**

This discovery was of great importance to the astronomical world, but Hubble's greatest moment was yet to come. He began to classify all the known nebulae and to measure their velocities from the spectra of their emitted light. In 1929 he made another startling find - all galaxies seemed to be receding from us with velocities that increased in proportion to their distance from us - a relationship now known as Hubble's Law.

This discovery was a tremendous breakthrough for the astronomy of that time as it overturned the conventional view of a static Universe and showed that the Universe itself was expanding. More than a decade earlier, Einstein himself had bowed to the observational wisdom of the day and corrected his equations, which had originally predicted an expanding Universe. Now Hubble had demonstrated that Einstein was right in the first place.

The now elderly, world-famous physicist went specially to visit Hubble at Mount Wilson to express his gratitude. He called the original change of his beloved equations "the greatest blunder of my life."

### **Another war stops Hubble again**

Hubble worked on indefatigably at Mount Wilson until the summer of 1942, when he left to serve in World War II. He was awarded the Medal of Merit in 1946. Finally, he went back to his Observatory. His last great contribution to astronomy was a central role in the design and construction of the Hale 200-inch Telescope on Palomar Mountain. Four times as powerful as the Hooker, the Hale would be the largest telescope on Earth for decades. In 1949, he was honoured by being allowed the first use of the telescope.

### **No Nobel Prize for an astronomer**

During his life, Hubble had tried to obtain the Nobel Prize, even hiring a publicity agent to promote his cause in the late 1940s, but all the effort was in vain as there was no category for astronomy. Hubble died in 1953 while preparing for several nights of observations, his last great ambition unfulfilled.

He would have been thrilled had he known that the Space Telescope is named after him, so that astronomers can continue to "*hope to find something we had not expected*", as he said in 1948 during a BBC broadcast in London.