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The Sloan Digital Sky Survey

Sloan Digital Sky Survey

Part of a series on

Physical cosmology

- Universe
- Big Bang
- Age of the universe
- Chronology of the universe

- **Astronomy portal**
- **Category: Physical cosmology**

The **Sloan Digital Sky Survey** or **SDSS** is a major multi-filter imaging and spectroscopic redshift survey using a dedicated 2.5-m wide-angle optical telescope at Apache Point Observatory in New Mexico, United States. The project was named after the Alfred P. Sloan Foundation.

Data collection began in 2000, and the final imaging data release covers over 35% of the sky, with photometric observations of around 500 million objects and spectra for more than 1 million objects. The main galaxy sample has a median redshift of $z = 0.1$; there are redshifts for luminous red galaxies as far as $z = 0.7$, and for quasars as far as $z = 5$; and the imaging survey has been involved in the detection of quasars beyond a redshift $z = 6$.

Data release 8 (DR8), released in January 2011,[] includes all photometric observations taken with the SDSS imaging camera, covering 14,555 square degrees on the sky (just over 35% of the full sky). Data release 9 (DR9), released to the public on 31 July 2012,[] includes all data from previous releases, plus the first results from the Baryon Oscillation Spectroscopic Survey (BOSS) spectrograph, including over 800,000 new spectra. Over 500,000 of the new spectra are of objects in the Universe 7 billion years ago (roughly half the age of the universe).[1]

Observations

SDSS uses a dedicated 2.5-m wide-angle optical telescope, and takes images using photometric system of five filters (named **u**, **g**, **r**, **i** and **z**). These images are processed to produce lists of objects observed and various parameters, such as whether they seem pointlike or extended (as a galaxy might) and how the brightness on the CCDs relates to various kinds of astronomical magnitude.

The SDSS telescope uses the drift scanning technique,[2] which keeps the telescope fixed and makes use of the Earth's rotation to record small strips of the sky. The image of the stars in the focal plane drifts along the CCD chip, instead of staying fixed as in tracked telescopes. This method allows consistent astrometry over the widest possible field and precision remains unaffected by telescope tracking errors. The disadvantages are minor distortion effects and the CCD has to be written and read in the same time.

The telescope's camera is made up of thirty CCD chips each with a resolution of 2048×2048 pixels, totaling approximately 120 Megapixels.[3] The chips are arranged in five rows of six chips. Each row has a different optical filter with average wavelengths of 355.1, 468.6, 616.5, 748.1 and 893.1 nm, with 95% completeness in typical seeing to magnitudes of 22.0, 22.2, 22.2, 21.3, and 20.5, for u, g, r, i, z, respectively.[4] The filters are placed on the camera in the order *r,i,u,z,g*. To reduce noise the camera is cooled to 190 kelvin (about −80°C) by liquid nitrogen.

Using these photometric data, stars, galaxies, and quasars are also selected for spectroscopy. The spectrograph[5] operates by feeding an individual optical fibre for each target through a hole drilled in an aluminum plate. Each hole is positioned specifically for a selected target, so every field in which spectra are to be acquired requires a unique plate. The original spectrograph attached to the telescope was capable of recording 640 spectra simultaneously, while the updated spectrograph for SDSS III can record 1000 spectra at once. Over the course of each night, between six and nine plates are typically used for recording spectra.

Every night the telescope produces about 200 GB of data.

SDSS spectroscope cartridge

Projects

SDSS-I: 2000–2005

Quasars Acting as Gravitational Lenses. To find these cases of galaxy–quasar combinations acting as lenses, astronomers selected 23.000 quasar spectra from the SDSS.[6]

During its first phase of operations, 2000–2005, the SDSS imaged more than 8,000 square degrees of the sky in five optical bandpasses, and it obtained spectra of galaxies and quasars selected from 5,700 square degrees of that imaging. It also obtained repeated imaging (roughly 30 scans) of a 300 square degree stripe in the southern Galactic cap.

SDSS-II: 2005–2008

In 2005 the survey entered a new phase, the **SDSS-II**, by extending the observations to explore the structure and stellar makeup of the Milky Way, the SEGUE and the Sloan Supernova Survey, which watches after supernova Ia events to measure the distances to far objects.

Sloan Legacy Survey

The survey covers over 7,500 square degrees of the Northern Galactic Cap with data from nearly 2 million objects and spectra from over 800,000 galaxies and 100,000 quasars. The information on the position and distance of the objects has allowed the large-scale structure of the Universe, with its voids and filaments, to be investigated for the first time.

Almost all of these data were obtained in SDSS-I, but a small part of the footprint was finished in SDSS-II.[7]

Sloan Extension for Galactic Understanding and Exploration (SEGUE)

The Sloan Extension for Galactic Understanding and Exploration obtained spectra of 240,000 stars (with typical radial velocity of 10 km/s) in order to create a detailed three-dimensional map of the Milky Way.[8] SEGUE data provide evidence for the age, composition and phase space distribution of stars within the various Galactic components, providing crucial clues for understanding the structure, formation and evolution of our Galaxy.

The stellar spectra, imaging data, and derived parameter catalogs for this survey are publicly available as part of SDSS Data Release 7 (DR7).[9]

Sloan Supernova Survey

Running until the end of the year 2007, the Supernova Survey searched for Type Ia supernovae. The survey rapidly scans a 300 square degree area to detect variable objects and supernovae. It detected 130 confirmed supernovae Ia events in 2005 and a further 197 in 2006.[10]

SDSS III: 2008–2014

In mid-2008, SDSS-III was started. It comprises four separate surveys, each conducted on the same 2.5m telescope:[11][12]

APO Galactic Evolution Experiment (APOGEE)

The APO Galactic Evolution Experiment (APOGEE) will use high-resolution, high signal-to-noise infrared spectroscopy to penetrate the dust that obscures the inner Galaxy. APOGEE will survey 100,000 red giant stars across the full range of the galactic bulge, bar, disk, and halo. It will use high-resolution, high signal-to-noise infrared spectroscopy. This will be used in order to penetrate the dust obsuring the inner galaxy.[][13] APOGEE will increase the number of stars observed at high spectroscopic resolution (($R \sim 20{,}000$ at $\lambda \sim 1.6\mu m$)) and high signal-to-noise ratio ($S/N \sim 100$) by more than a factor of 100.[] The high resolution spectra will reveal the abundances of about 15 elements which gives information on the composition of the gas clouds they formed from. APOGEE should be collecting data from 2011 to 2014 with first release of data in July 2013.

Baryon Oscillation Spectroscopic Survey (BOSS)

The SDSS-III's Baryon Oscillation Spectroscopic Survey (BOSS) was designed to measure the expansion rate of the Universe.[] It will map the spatial distribution of luminous red galaxies (LRGs) and quasars to map the spatial distribution and detect the characteristic scale imprinted by baryon acoustic oscillations in the early universe.[14] Sound waves that propagate in the early universe, like spreading ripples in a pond, imprint a characteristic scale on the positions of galaxies relative to each other.[15]

Multi-object APO Radial Velocity Exoplanet Large-area Survey (MARVELS)

The Multi-object APO Radial Velocity Exoplanet Large-area Survey (MARVELS) will monitor the radial velocities of 11,000 bright stars, with the precision and cadence needed to detect gas giant planets that have orbital periods ranging from several hours to two years. This ground-based Doppler survey [] will use the SDSS telescope and new multi-object Doppler instruments to monitor radial velocities.[] It is one of four astronomical surveys conducted by SDSS-III, part of the Sloan Digital Sky Survey (SDSS).

The main goal of the project is to generate a large-scale, statistically well-defined sample of giant planets. It will search for gaseous planets that have orbital periods ranging from hours to 2 years, and are between 0.5 and 10 Jupiter masses. A total of 11,000 stars will be analyzed with 25-35 observations per star over an 18 month period. It is expected to detect between 150 and 200 new exoplanets, and will be able to study rare systems, such as planets with extreme eccentricity, and objects in the "brown dwarf desert".[][16]

The collected data will be used as a statistical sample for the theoretical comparison and discovery of rare systems.[17]

The project started in the fall of 2008, and will continue until spring 2014.[][18]

SEGUE-2

The original Sloan Extension for Galactic Understanding and Exploration (SEGUE-1) obtained spectra of nearly 240,000 stars of a range of spectral types. Building on this success, SEGUE-2 spectroscopically observed around 120,000 stars, focusing on the in situ stellar halo of the Galaxy, from distances of 10 to 60 kpc.

Combining SEGUE-1 and 2 reveals the complex kinematic and chemical substructure of the Galactic halo and disks, providing essential clues to the assembly and enrichment history of the Galaxy. In particular, the outer halo is expected to be dominated by late-time accretion events. SEGUE can help constrain existing models for the formation of the stellar halo and inform the next generation of high resolution simulations of Galaxy formation. In addition, SEGUE-1 and SEGUE-2 help uncover rare, chemically primitive stars that are fossils of the earliest generations of cosmic star formation.

It is an astronomical survey designed to map the outer reaches of the Milky Way with a spectra of 240,000 stars. This survey will double the sample size of SEGUE-1.[][19]

Data access

The survey makes the data releases available over the Internet. The **SkyServer** provides a range of interfaces to an underlying Microsoft SQL Server. Both spectra and images are available in this way, and interfaces are made very easy to use so that, for example, a full color image of any region of the sky covered by an SDSS data release can be obtained just by providing the coordinates. The data are available for non-commercial use only, without written permission. The SkyServer also provides a range of tutorials aimed at everyone from schoolchildren up to professional astronomers. The ninth major data release, DR9, released in July 2012,[] provides images, imaging catalogs, spectra, and redshifts via a variety of search interfaces.

The raw data (from before being processed into databases of objects) are also available through another Internet server, and through the NASA World Wind program.

Sky in Google Earth includes data from the SDSS, for those regions where such data are available. There are also KML plugins for SDSS photometry and spectroscopy layers,[20] allowing direct access to SkyServer data from within Google Sky.

The data is also available on Hayden Planetarium with a 3D visualizer.

Following from Technical Fellow Jim Gray's contribution on behalf of Microsoft Research with the SkyServer project, Microsoft's WorldWide Telescope makes use of SDSS and other data sources.[21]

MilkyWay@home also used SDSS's data for creating a highly accurate three dimensional model of the Milky Way galaxy

Results

Along with publications describing the survey itself, SDSS data have been used in publications over a huge range of astronomical topics. The SDSS website has a full list of these publications covering distant quasars at the limits of the observable universe,[22] the distribution of galaxies, the properties of stars in our own galaxy and also subjects such as dark matter and dark energy in the universe.

Maps

Based on the release of Data Release 9 a new 3D map of massive galaxies and distant black holes was published on August 8, 2012.[23]

References

[1] http://www.nyu.edu/about/news-publications/news/2012/08/08/new-3d-map-of-massive-galaxies-and-black-holes-offers-clues-to-dark-matter-dark-energy.html
[11] http://www.sdss3.org/surveys/
[12] http://www.astro.yale.edu/news/20100811-yale-joins-sloan-digital-sky-survey-collaboration

Further reading

- Ann K. Finkbeiner. *A Grand and Bold Thing: An Extraordinary New Map of the Universe Ushering In A New Era of Discovery* (2010), a journalistic history of the project

External links

- SDSS Homepage (http://www.sdss.org/)
- The SkyServer (http://cas.sdss.org/)
- SDSS imagery in NASA World Wind (http://www.worldwindcentral.com/wiki/SDSS)
- SDSS imagery in WikiSky (http://www.wikisky.org/?img_source=SDSS&ra=13.5&de=47.2&zoom=8)
- "More of the Universe" article in *symmetry* magazine (http://www.symmetrymagazine.org/cms/?pid=1000192)
- SEGUE Homepage (http://segue.uchicago.edu/)
- The Sloan Great Wall: Largest Known Structure? (http://apod.nasa.gov/apod/ap071107.html) on APOD (http://apod.nasa.gov)
- A Flight Through The Universe (http://apod.nasa.gov/apod/ap120813.html) on APOD (http://apod.nasa.gov)
- J-PAS is a new astronomical facility dedicated to mapping the observable Universe in 56 colors. (http://j-pas.org/)
- Sloan Digital Sky Survey Non-commercial use (http://cas.sdss.org/dr7/en/credits/datause.asp)

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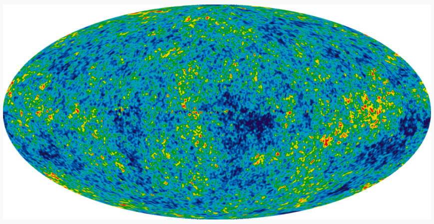
The 2dF Survey

(Two-degree-Field Galaxy Redshift Survey)

2dF Galaxy Redshift Survey

Part of a series on

Physical cosmology



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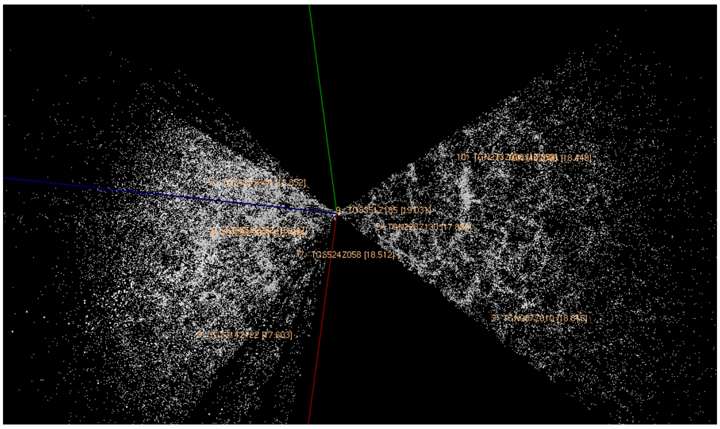


Rendering of the 2dFGRS data

In astronomy, the **2dF Galaxy Redshift Survey** (Two-degree-Field Galaxy Redshift Survey), **2dF** or **2dFGRS** is a redshift survey conducted by the Anglo-Australian Observatory (AAO) with the 3.9m Anglo-Australian Telescope between 1997 and 11 April 2002.[1] The data from this survey were made public on 30 June 2003. The survey determined the large-scale structure in one section of the local Universe. As of July 2009, it is the second largest redshift survey next to the Sloan Digital Sky Survey which began in 2000. Matthew Colless, Steve Maddox and John Peacock were in charge of the project.

Description

The 2dF survey covered an area of about 1500 square degrees, surveying regions in both the north and the south galactic poles.[2] The name derives from the fact that the survey instrument covers an area of approximately two square degrees.

The areas selected for observation were previously surveyed by the massive APM Galaxy Survey (on which Steve Maddox also worked).[2] The regions surveyed cover roughly 75 degrees of right ascension for both bands, and the declination of the North Polar band was about 7.5 degrees while the declination of the South Polar band was about 15 degrees. Hundreds of isolated two degree fields near the South Polar band were also surveyed (see this illustration [3], where black circles represent survey fields, and the red grid represents the earlier APM survey).

In total, the photometry of 382,323 objects were measured, which includes spectra for 245,591 objects, of which 232,155 were galaxies (221,414 with good quality spectra), 12,311 are stars, and 125 are quasi-stellar objects (quasars).[4] The survey necessitated 272 required nights of observation, spread over 5 years.

The survey was carried out with the 4 metre Anglo-Australian Telescope, with the **2dF instrument** installed at the primary focus permitting the observation of a field of 2 degrees per pointing. The instrument possesses a spectrograph equipped with two banks each of 200 optical fibres, permitting the simultaneous measurement of 400 spectra.

The limiting apparent magnitude of the survey is 19.5, covering objects with a redshift mostly within less than z=0.3 and a median redshift of 0.11. The volume of the Universe covered by the survey is approximately 10^8 h^{-1} Mpc^3, where h corresponds to the value of the Hubble constant, H_0, divided by 100. H_0 is approximately 70 km/s/Mpc. The largest redshift observed by the survey corresponds to a distance of 600 h^{-1} Mpc.

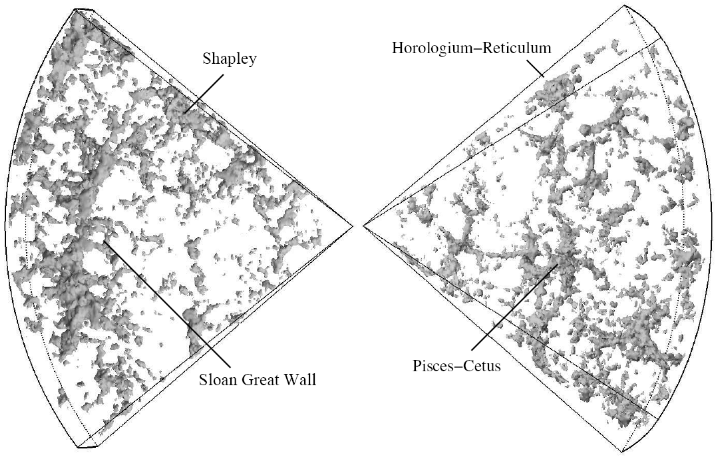
Survey Results

The principal results obtained for the field of cosmology by the 2dF survey are:

- The measurement of the density parameter of non-relativistic matter (baryonic matter plus dark matter plus massive neutrinos)
- The detection of Baryon acoustic oscillations, and as a consequence the relationship between the density of baryonic matter and dark matter
- Limits on the contribution of massive neutrinos to dark matter, putting a limit on the sum of the masses of the three families of neutrinos at 1.8 eV.

All these results are in agreement with the measurements of other experiments, notably those of WMAP. They confirm the standard cosmological model.

The 2dF survey also yields a unique view on our local cosmic environment. In the figure a 3-D reconstruction of the inner parts of the survey is shown, revealing an impressive view on the cosmic structures in the nearby universe. Several superclusters stand out, such as the Sloan Great Wall, one of the largest structures[5] in the universe known to date (see also Huge-LQG).



DTFE reconstruction of the inner parts of the 2dF Galaxy Redshift Survey.

Notes

[1] Final Status of Survey Observations (http://www2.aao.gov.au/~TDFgg/Public/Survey/Overview/sld013.htm)
[2] 2dFGRS – An Introduction (http://www2.aao.gov.au/~TDFgg/Public/Survey/description.html)
[3] http://www2.aao.gov.au/~TDFgg/Public/Survey/Overview/img009.GIF
[4] 2dFGRS Summary Statistics (http://www2.aao.gov.au/~TDFgg/Public/Survey/statusfinal.html)

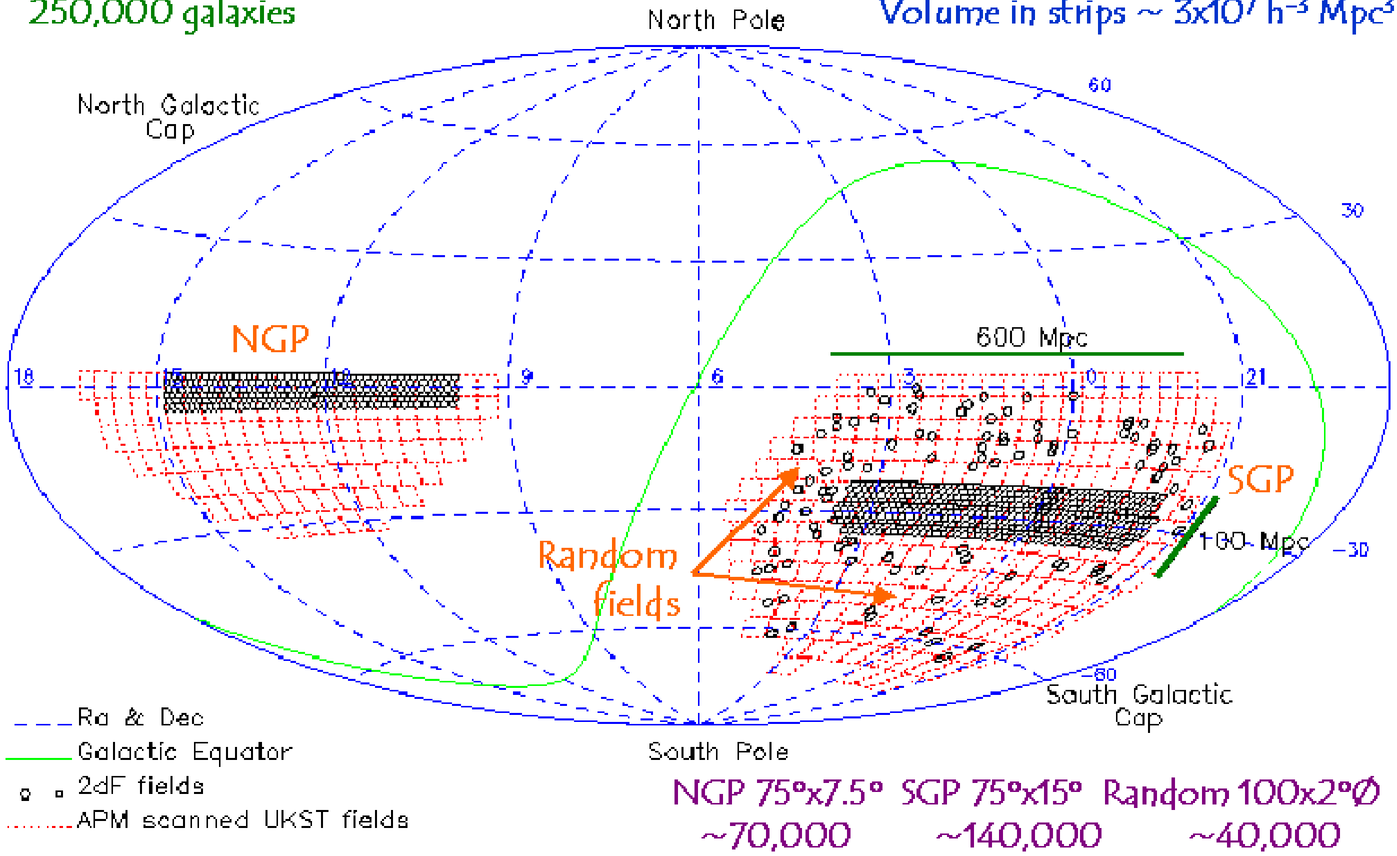
External links

- Official site (http://www2.aao.gov.au/2dFGRS/) of the 2dF Galaxy Redshift Survey
- *The 2dF Galaxy Redshift Survey: spectra and redshifts* (http://www2.aao.gov.au/2dFGRS/Public/Publications/colless_specz.pdf) – 2001 Royal Astronomical Society paper describing the survey
- Official site (http://www.aao.gov.au/2df/) of the Two Degree Field instrument system

2dFGRS survey design

~2000 sq.deg. to b_J=19.45
250,000 galaxies

Strips+random fields ~ $1x10^8$ h^{-3} Mpc^3
Volume in strips ~ $3x10^7$ h^{-3} Mpc^3



NGP 75°x7.5° SGP 75°x15° Random 100x2°Ø
~70,000 ~140,000 ~40,000

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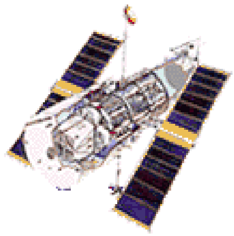
The GEMS Survey

(Galaxy Evolution From Morphology And SEDs)



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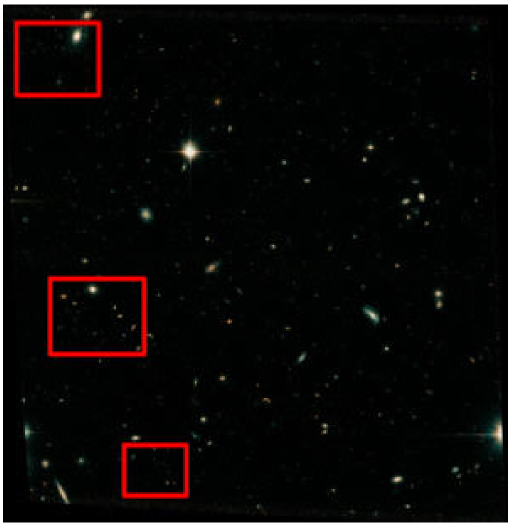
GEMS:
Galaxy Evolution From Morphology And SEDs

GEMS in a Nutshell:

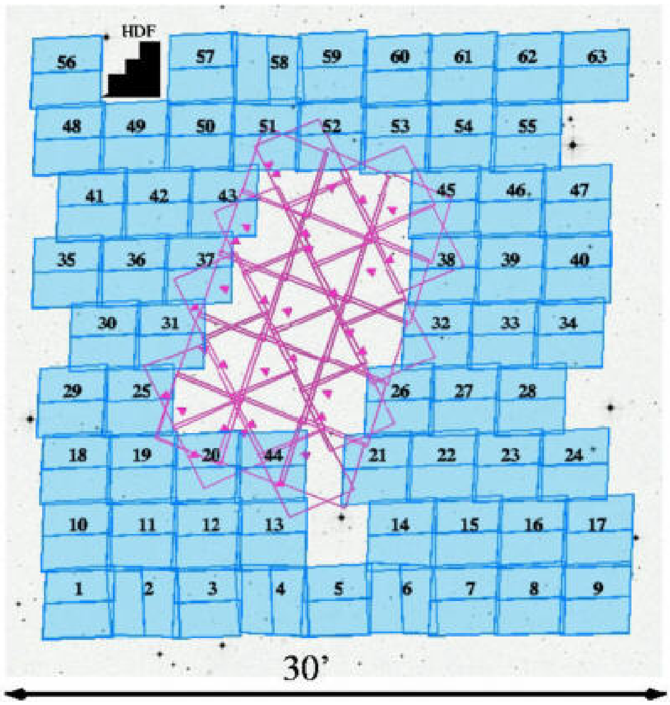
- largest contiguous field ever imaged with HST (900 arcmin^2)
- mosaic of 9x9 Advanced Camera for Surveys (ACS) pointings
- Field: Extended Chandra Deep Field South (E-CDFS)
- Filters: V (F606W) and z (F850LP)
- 10000 redshifts from COMBO-17 (galaxies down to R<24) in the range: 0.2<z<1.2
- SEDs from COMBO-17 in the range 3500 to 9250 Ångstroms

GEMS tile #58



(clicking on the red boxes displays the full-resolution version of that region; a larger (334kb) version of the total frame is available by clicking here)

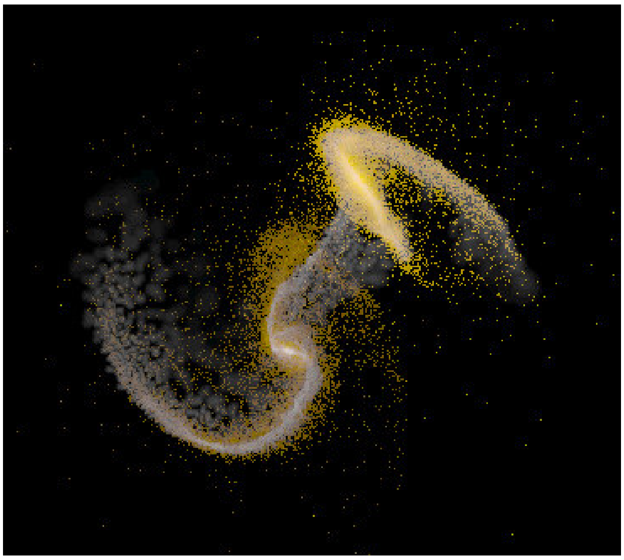
Simulation of a galaxy merger



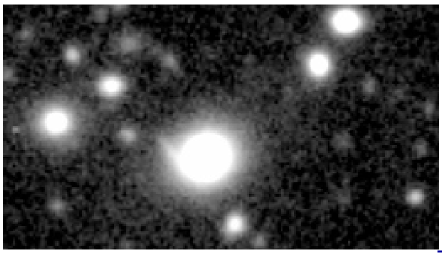
Science Questions:

- Why has star formation activity declined so dramatically sinze z~1:
  - changes in interaction and merger rate?
  - waning fuel supply?
  - shift of star-formation to progressively less massive systems?
- How did galactic discs and bulges form and evolve with time?
  - simple dimming of bulges?
  - radial growth of discs?
  - evolution of bars
- How did AGN host galaxies evolve over the last 10Gyrs?

Comparison of COMBO-17 and GEMS data



(animations are available by clicking on the image)



(for a larger version (330kb) click on the image)

GEMS has imaged an area of 900 square minutes of arc on the sky with the Advanced Camera for Surveys (ACS) on-board Hubble Space telescope. This contiguous field centred on the Chandra Deep Field South contains roughly 10000 galaxies down to a depth of 24th magnitude in the R-band. The central part was observed by the GOODS-project to an even fainter flux-limit, while GEMS mainly concentrates on the outer regions, the extended Chandra Deep Field South. For those 10000 objects redshifts in the range $0.2<z<1.2$ were determined in the COMBO-17 project, by means of low-resolution spectra using 17 medium band filters. Those spectra not only provide redshifts but also spectral energy distributions (SEDs) from 3500 to 9250 Ångstroms. The mosaic of 9 by 9 ACS pointings in the F606W and F850LP filters will allow us in combination with the known redshifts to construct a rest-frame B-band image of all target galaxies with resolutions < 0.1 arcseconds, corresponding to < 500 parsec in the object's rest-frame. This unique data set including SED and high resolution morphological information will let us determine the evolution of galaxy structure over the last half of cosmic history.

The Hubble Deep Field

Hubble Deep Field

Coordinates: $12^h 36^m 49.4^s$, +62° 12′ 58″ [1]

The **Hubble Deep Field** (HDF) is an image of a small region in the constellation Ursa Major, constructed from a series of observations by the Hubble Space Telescope. It covers an area 2.5 arcminutes across, about one 24-millionth of the whole sky, which is equivalent in angular size to a 65 mm tennis ball at a distance of 100 metres. The image was assembled from 342 separate exposures taken with the Space Telescope's Wide Field and Planetary Camera 2 over ten consecutive days between December 18 and December 28, 1995.

The Hubble Deep Field

The field is so small that only a few foreground stars in the Milky Way lie within it; thus, almost all of the 3,000 objects in the image are galaxies, some of which are among the youngest and most distant known. By revealing such large numbers of very young galaxies, the HDF has become a landmark image in the study of the early universe, with the associated scientific paper having received over 800 citations by the end of 2008.

Three years after the HDF observations were taken, a region in the south celestial hemisphere was imaged in a similar way and named the Hubble Deep Field South. The similarities between the two regions strengthened the belief that the universe is uniform over large scales and that the Earth occupies a typical region in the universe (the cosmological principle). A wider but shallower survey was also made as part of the Great Observatories Origins Deep Survey. In 2004 a deeper image, known as the Hubble Ultra-Deep Field (HUDF), was constructed from a total of eleven days of observations. The HUDF image was at the time the most sensitive astronomical image ever made at visible wavelengths, until the Hubble Extreme Deep Field (XDF) was released in 2012.[2]

Conception

The dramatic improvement in Hubble's imaging capabilities after corrective optics were installed encouraged attempts to obtain very deep images of distant galaxies.

One of the key aims of the astronomers who designed the Hubble Space Telescope was to use its high optical resolution to study distant galaxies to a level of detail that was not possible from the ground. Positioned above the atmosphere, Hubble avoids atmospheric airglow allowing it to take more sensitive visible and ultraviolet light images than can be obtained with seeing-limited ground-based telescopes (when good adaptive optics correction at visible wavelengths becomes possible, 10 m ground-based telescopes may become competitive). Although the telescope's mirror suffered from spherical aberration when the telescope was launched in 1990, it could still be used to take images of more distant galaxies than had previously been obtainable. Because light takes billions of years to reach Earth from very distant galaxies, we see them as they were billions of years ago; thus, extending the scope of such research to increasingly distant galaxies allows a better understanding of how they evolve.[3]

After the spherical aberration was corrected during Space Shuttle mission STS-61 in 1993,[4] the improved imaging capabilities of the telescope were used to study increasingly distant and faint galaxies. The Medium Deep Survey (MDS) used the Wide Field and Planetary Camera 2 (WFPC2) to take deep images of random fields while other instruments were being used for scheduled observations. At the same time, other dedicated programs focused on galaxies that were already known through ground-based observation. All of these studies revealed substantial differences between the properties of galaxies today and those that existed several billion years ago.[5]

Up to 10% of the HST's observation time is designated as Director's Discretionary (DD) Time, and is typically awarded to astronomers who wish to study unexpected transient phenomena, such as supernovae. Once Hubble's corrective optics were shown to be performing well, Robert Williams, the then-director of the Space Telescope Science Institute, decided to devote a substantial fraction of his DD time during 1995 to the study of distant galaxies. A special Institute Advisory Committee recommended that the WFPC2 be used to image a "typical" patch of sky at a high galactic latitude, using several optical filters. A working group was set up to develop and implement the project.[6]

Target selection

The HDF is at the centre of this image of one degree of sky. The Moon as seen from Earth would fill roughly one quarter of this image.

The field selected for the observations needed to fulfill several criteria. It had to be at a high galactic latitude, because dust and obscuring matter in the plane of the Milky Way's disc prevents observations of distant galaxies at low galactic latitudes. The target field had to avoid known bright sources of visible light (such as foreground stars), and infrared, ultraviolet and X-ray emissions, to facilitate later studies at many wavelengths of the objects in the deep field, and also needed to be in a region with a low background infrared 'cirrus', the diffuse, wispy infrared emission believed to be caused by warm dust grains in cool clouds of hydrogen gas (H I regions).[6]

These criteria restricted the field of potential target areas. It was decided that the target should be in Hubble's 'continuous viewing zones' (CVZs)—the areas of sky which are not occulted by the Earth or the moon during Hubble's orbit.[6] The working group decided to concentrate on the northern CVZ, so that northern-hemisphere telescopes such as the Keck telescopes, the Kitt Peak National Observatory telescopes and the Very Large Array (VLA) could conduct follow-up observations.[]

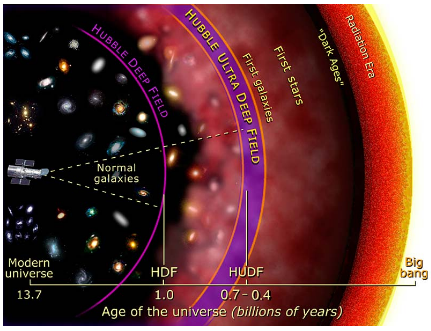
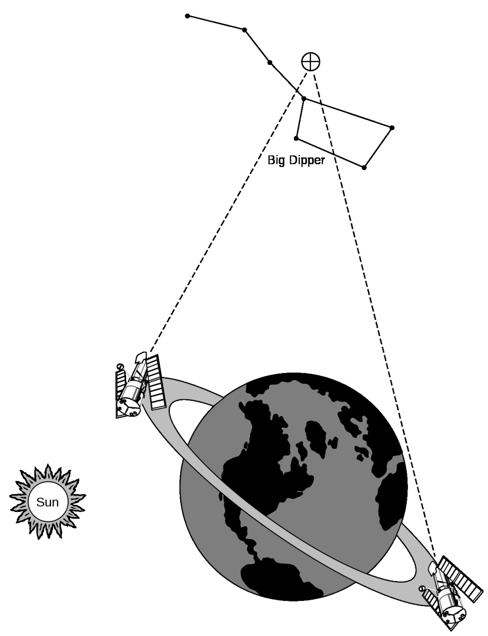


Diagram illustrating comparative sampling distance of the HDF and the 2004 Hubble Ultra-Deep Field

Twenty fields satisfying these criteria were initially identified, from which three optimal candidate fields were selected, all within the constellation of Ursa Major. Radio snapshot observations with the VLA ruled out one of these fields because it contained a bright radio source, and the final decision between the other two was made on the basis of the availability of guide stars near the field: Hubble observations normally require a pair of nearby stars on which the telescope's Fine Guidance Sensors can lock during an exposure, but given the importance of the HDF observations, the working group required a second set of back-up guide stars. The field that was eventually selected is located at a right ascension of $12^h\ 36^m\ 49.4^s$ and a declination of +62° 12′ 58″;[6][] in area it is a mere 5.3 square arcminutes.[7] This is approximately 1/28,000,000 of the total area of the sky.[]

Observations



The HDF was located in Hubble's northern Continuous Viewing Zone, as shown by this diagram.

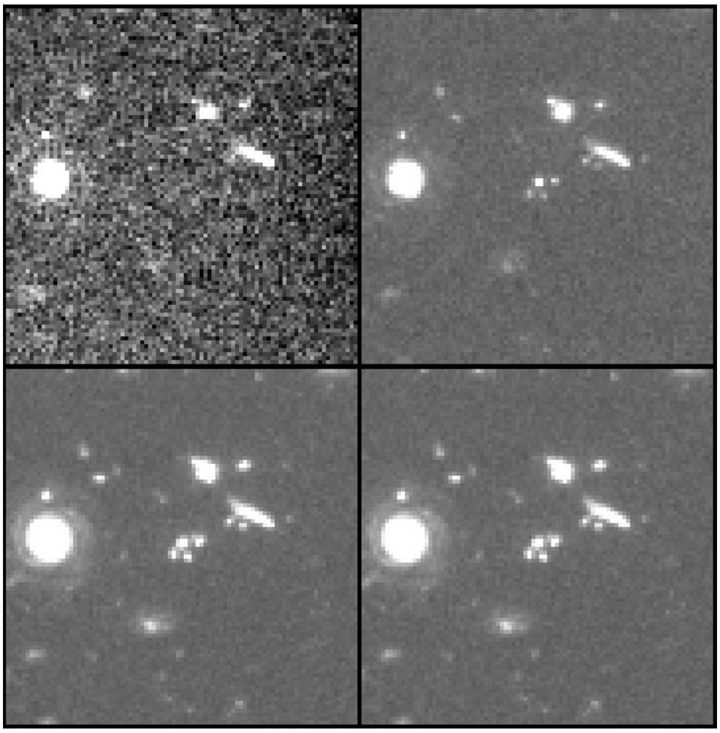
Once a field had been selected, an observing strategy had to be developed. An important decision was to determine which filters the observations would use; WFPC2 is equipped with forty-eight filters, including narrowband filters isolating particular emission lines of astrophysical interest, and broadband filters useful for the study of the colours of stars and galaxies. The choice of filters to be used for the HDF depended on the 'throughput' of each filter—the total proportion of light that it allows through—and the spectral coverage available. Filters with bandpasses overlapping as little as possible were desirable.[6]

In the end, four broadband filters were chosen, centred at wavelengths of 300 nm (near-ultraviolet), 450 nm (blue light), 606 nm (red light) and 814 nm (near-infrared). Because the quantum efficiency of Hubble's detectors is quite low at 300 nm, the noise in observations at this wavelength is primarily due to CCD noise rather than sky background; thus, these observations could be conducted at times when high background noise would have harmed the efficiency of observations in other passbands.[6]

Between December 18 and December 28, 1995—during which time Hubble orbited the Earth about 150 times—342 images of the target area in the chosen filters were taken. The total exposure times at each wavelength were 42.7 hours (300 nm), 33.5 hours (450 nm), 30.3 hours (606 nm) and 34.3 hours (814 nm), divided into 342 individual exposures to prevent significant damage to individual images by cosmic rays, which cause bright streaks to appear when they strike CCD detectors. A further 10 Hubble orbits were used to make short exposures of flanking fields to aid follow-up observations by other instruments.[6]

Data processing

The production of a final combined image at each wavelength was a complex process. Bright pixels caused by cosmic ray impacts during exposures were removed by comparing exposures of equal length taken one after the other, and identifying pixels that were affected by cosmic rays in one exposure but not the other. Trails of space debris and artificial satellites were present in the original images, and were carefully removed.[6]



A section of the HDF about 14 arcseconds across in each of the four wavelengths used to construct the final version: 300 nm (top left), 450 nm (top right), 606 nm (bottom left) and 814 nm (bottom right)

Scattered light from the Earth was evident in about a quarter of the data frames, creating a visible "X" pattern on the images. This was removed by taking an image affected by scattered light, aligning it with an unaffected image, and subtracting the unaffected image from the affected one. The resulting image was smoothed, and could then be subtracted from the bright frame. This procedure removed almost all of the scattered light from the affected images.[6]

Once the 342 individual images were cleaned of cosmic-ray hits and corrected for scattered light, they had to be combined. Scientists involved in the HDF observations pioneered a technique called 'drizzling', in which the pointing of the telescope was varied minutely between sets of exposures. Each pixel on the WFPC2 CCD chips recorded an area of sky 0.09 arcseconds across, but by changing the direction in which the telescope was pointing by less than that between exposures, the resulting images were combined using sophisticated image-processing techniques to yield a final angular resolution better than this value. The HDF images produced at each wavelength had final pixel sizes of 0.03985 arcseconds.[6]

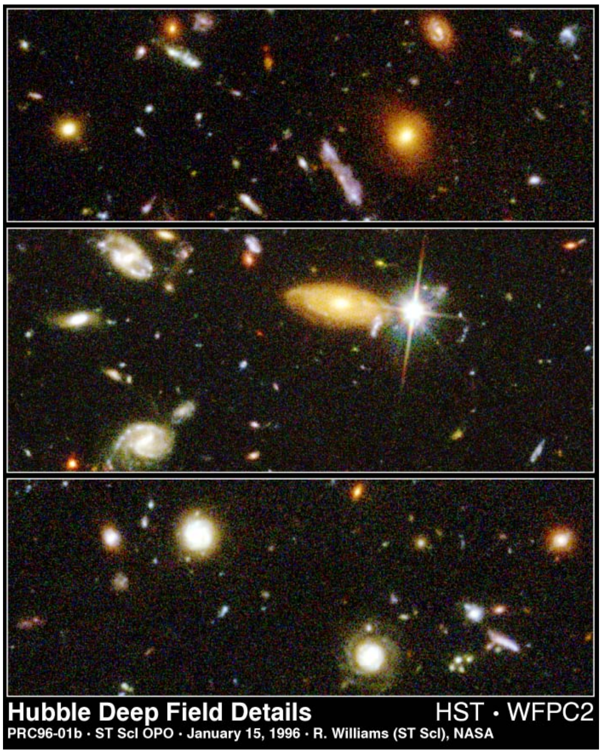
The data processing yielded four monochrome images (at 300 nm, 450 nm, 606 nm and 814 nm), one at each wavelength.[8] One image was designated as red (814 nm), the second as green (606 nm) and the third as blue (450 nm), and the three images were combined to give a colour image.[] Because the wavelengths at which the images were taken do not correspond to the wavelengths of red, green and blue light, the colours in the final image only give an approximate representation of the actual colours of the galaxies in the image; the choice of filters for the HDF (and the majority of Hubble images) was primarily designed to maximize the scientific utility of the observations rather than to create colours corresponding to what the human eye would actually perceive.[8]

Contents of the Deep Field

The final images were released at a meeting of the American Astronomical Society in January 1996,[9] and revealed a plethora of distant, faint galaxies. About 3,000 distinct galaxies could be identified in the images,[10] with both irregular and spiral galaxies clearly visible, although some galaxies in the field are only a few pixels across. In all, the HDF is thought to contain fewer than twenty galactic foreground stars; by far the majority of objects in the field are distant galaxies.[11]

There are about fifty blue point-like objects in the HDF. Many seem to be associated with nearby galaxies, which together form chains and arcs: these are likely to be regions of intense star formation. Others may be distant quasars. Astronomers initially ruled out the possibility that some of the point-like objects are white dwarfs, because they are too blue to be consistent with theories of white dwarf evolution prevalent at the time. However, more recent work has found that many white dwarfs become bluer as they age, lending support to the idea that the HDF might contain white dwarfs.[12]

Scientific results



Details from the HDF illustrate the wide variety of galaxy shapes, sizes and colours found in the distant universe.

The HDF data provided extremely rich material for cosmologists to analyse and as of late 2008, the associated scientific paper for the image has received over 800 citations.[] One of the most fundamental findings was the discovery of large numbers of galaxies with high redshift values.

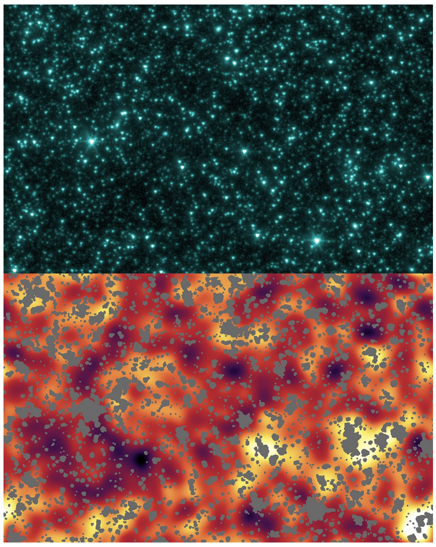
As the universe expands, more distant objects recede from the Earth faster, in what is called the Hubble Flow. The light from very distant galaxies is significantly affected by the cosmological redshift. While quasars with high redshifts were known, very few galaxies with redshifts greater than one were known before the HDF images were produced.[9] The HDF, however, contained many galaxies with redshifts as high as six, corresponding to distances of about 12 billion light-years. Due to redshift the most distant objects in the HDF (Lyman-break galaxies) are not actually visible in the Hubble images; they can only be detected in images of the HDF taken at longer wavelengths by ground-based telescopes.[13]

The HDF galaxies contained a considerably larger proportion of disturbed and irregular galaxies than the local universe;[9] galaxy collisions and mergers were more common in the young universe as it was much smaller than today. It is believed that giant elliptical galaxies form when spirals and irregular galaxies collide.

The wealth of galaxies at different stages of their evolution also allowed astronomers to estimate the variation in the rate of star formation over the lifetime of the universe. While estimates of the redshifts of HDF galaxies are somewhat crude, astronomers believe that star formation was occurring at its maximum rate 8–10 billion years ago, and has decreased by a factor of about 10 since then.[14]

Another important result from the HDF was the very small number of foreground stars present. For years astronomers had been puzzling over the nature of dark matter, mass which seems to be undetectable but which observations implied made up about 90% of the mass of the universe.[15] One theory was that dark matter might consist of Massive Astrophysical Compact Halo Objects (MACHOs)—faint but massive objects such as red dwarfs and planets in the outer regions of galaxies.[16] The HDF showed, however, that there were not significant numbers of red dwarfs in the outer parts of our galaxy.[9][11]

Multifrequency followup


The HDF imaged by the Spitzer Space Telescope. The top segment shows the foreground objects in the field; the bottom shows the background with the foreground objects removed.

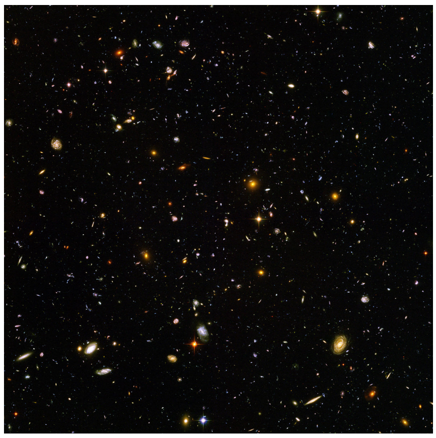
Very-high redshift objects (Lyman-break galaxies) cannot be seen in visible light and generally are detected in infrared or submillimetre wavelength surveys of the HDF instead.[13] Observations with the Infrared Space Observatory (ISO) indicated infrared emission from 13 galaxies visible in the optical images, attributed to large quantities of dust associated with intense star formation.[17] Infrared observations have also been made with the Spitzer Space Telescope.[18] Submillimeter observations of the field have been made with SCUBA on the James Clerk Maxwell Telescope, initially detecting 5 sources, although with very low resolution.[10] Observations have also been made with the Subaru telescope in Hawaii.[]

X-ray observations by the Chandra X-ray Observatory revealed six sources in the HDF, which were found to correspond to three elliptical galaxies: one spiral galaxy, one active galactic nucleus and one extremely red object, thought to be a distant galaxy containing a large amount of dust absorbing its blue light emissions.[19]

Ground-based radio images taken using the VLA revealed seven radio sources in the HDF, all of which correspond to galaxies visible in the optical images.[20] The field has also been surveyed with the Westerbork Synthesis Radio Telescope and the MERLIN array of radio telescopes at 1.4 GHz;[21][22] the combination of VLA and MERLIN maps made at wavelengths of 3.5 and 20 cm have located 16 radio sources in the HDF-N field, with many more in the flanking fields.[10] Radio images of some individual sources in the field have been made with the European VLBI Network at 1.6 GHz with a higher resolution than the Hubble maps.[23]

Subsequent HST observations


The Hubble Deep Field South looks very similar to the original HDF, demonstrating the cosmological principle.


The Hubble Ultra-Deep Field further corroborates this.

An HDF counterpart in the southern celestial hemisphere was created in 1998: the HDF-South.[24] Created using a similar observing strategy,[24] the HDF-S was very similar in appearance to the original HDF.[25] This supports the cosmological principle that at its largest scale the universe is homogeneous. The HDF-S survey used the Space Telescope Imaging Spectrograph (STIS) and the Near Infrared Camera and Multi-Object Spectrometer (NICMOS) instruments installed on the HST in 1997; the Hubble Deep Field has since been re-observed several times using WFPC2, as well as by the NICMOS and STIS instruments.[7][10] Several supernova events were detected by comparing the first and second epoch observations of the HDF-N.[10]

A wider survey, but less sensitive, was carried out as part of the Great Observatories Origins Deep Survey; a section of this was then observed for longer to create the Hubble Ultra-Deep Field, which was the most sensitive optical deep field image for years[26] until the Hubble Extreme Deep Field was completed in 2012.[27] Images from the Extreme Deep Field, or XDF, were released on 26 September 2012 to a number of media agencies. Images released in the XDF show galaxies which are now believed to have formed in the first 500 million years following the Big Bang.[28][29]

Notes and references

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[2] http://timesofindia.indiatimes.com/home/science/New-extreme-Hubble-telescope-shows-deepest-view-yet-of-night-sky/articleshow/16554731.cms

[3] Ferguson et al. (1999), p.84

[4] Trauger et al. (1994)

[5] Abraham et al. (1996)

[6] Williams et al. (1996)

[7] Ferguson (2000a)

[8] Ferguson et al. (1999), p.88

[10] Ferguson et al. (2000b)

[11] Flynn et al. (1996)

[12] Hansen (1998)

[13] Ferguson et al. (1999), p.105

[14] Connolly et al. (1997)

[15] Trimble (1987)

[16] Alcock et al. (1992)

[17] Rowan-Robinson et al. (1997)

[19] Hornschemeier et al. (2000)

[20] Kellerman et al. (1998)

[21] Garratt et al. (2000)

[23] Garrett et al. (2001)

[24] Williams et al. (2000)

[25] Casertano et al. (2000)

[26] Beckwith et al. (2006)

[28] Hubble Site News Center (http://hubblesite.org/newscenter/archive/releases/2012/37/image/a/)

[29] Astronomers Release Deepest View of the Night Sky (http://www.guardian.co.uk/science/2012/sep/26/hubble-astronomers-deepest-view-night-sky|Hubble)

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External links

- "The Hubble Deep Field" (http://www.stsci.edu/ftp/science/hdf/hdf.html). STScI. Main Hubble Deep Field website.
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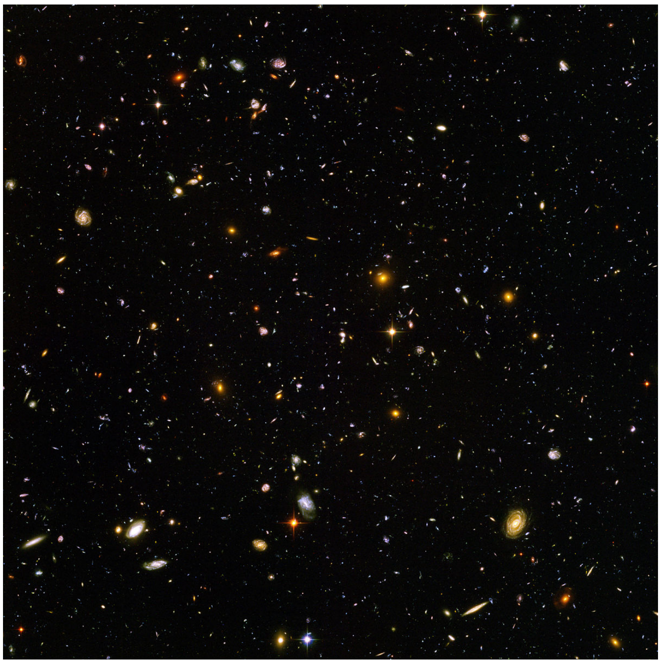
The Hubble
Ultra-Deep Field

Hubble Ultra-Deep Field

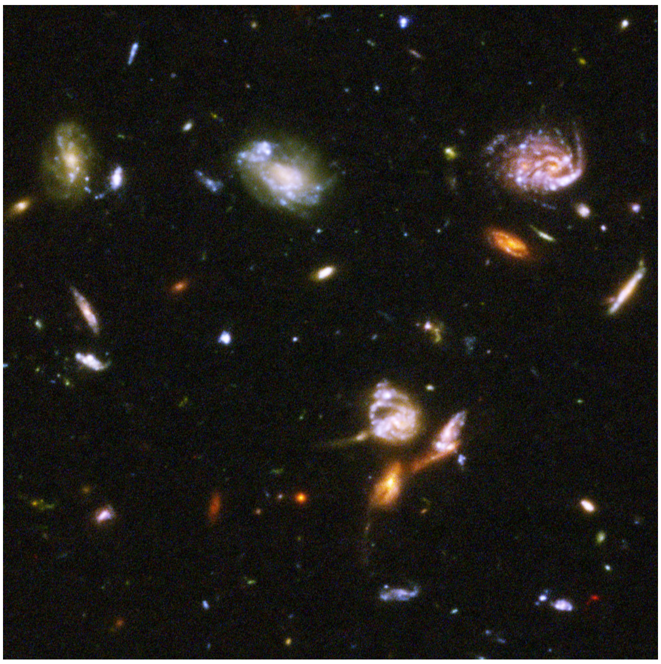
Coordinates: $3^{h}\ 32^{m}\ 39.0^{s}$, −27° 47′ 29.1″ [1]

The **Hubble Ultra-Deep Field** (**HUDF**) is an image of a small region of space in the constellation Fornax, composited from Hubble Space Telescope data accumulated over a period from September 24, 2003, through to January 16, 2004. Looking back approximately 13 billion years (between 400 and 800 million years after the Big Bang) it will be used to search for galaxies that existed at that time. The HUDF image was taken in a section of the sky with a low density of bright stars in the near-field, allowing much better viewing of dimmer, more distant objects. The image contains an estimated 10,000 galaxies. In August and September 2009, the Hubble's Deep Field was expanded using the infrared channel of the recently attached Wide Field Camera 3 (WFC3). When combined with existing HUDF data, astronomers were able to identify a new list of potentially very distant galaxies.[]



This high-resolution image of the HUDF includes galaxies of various ages, sizes, shapes, and colors. The smallest, reddest galaxies, of which there are approximately 10,000, are some of the most distant galaxies to have been imaged by an optical telescope, probably existing shortly after the Big Bang.

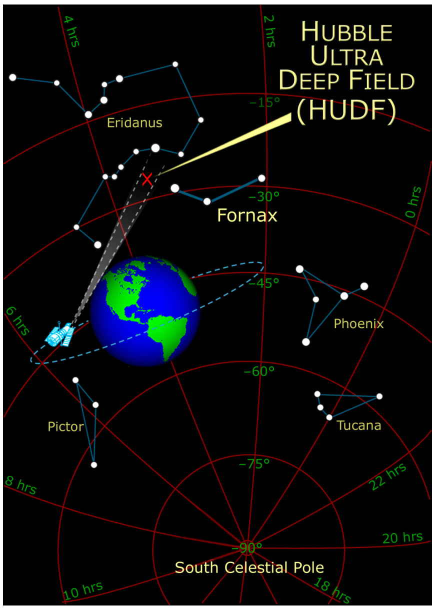
Located southwest of Orion in the southern-hemisphere constellation Fornax, the image is a bit over 3 arcminutes across.[2] This is just one-tenth of the diameter of the full Moon as viewed from Earth, smaller than a 1 mm by 1 mm square of paper held at 1 meter away, and equal to roughly one thirteen-millionth of the total area of the sky. The image is oriented so that the upper left corner points toward north (−46.4°) on the celestial sphere.



Zoom on the upper middle-left part of the Hubble Ultra-Deep Field

On September 25, 2012, NASA released a further refined version of the Ultra-Deep Field dubbed the eXtreme Deep Field (XDF). The XDF reveals galaxies that span back 13.2 billion years in time, revealing a galaxy theorized to be formed only 450 million years after the big bang event.[]

Planning



Location of the Hubble Ultra-Deep Field on the sky

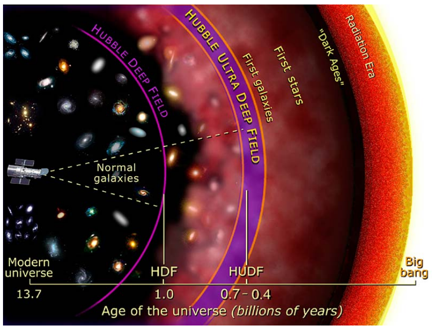


Diagram illustrating comparative sampling distance of the HUDF and the earlier Hubble Deep Field.

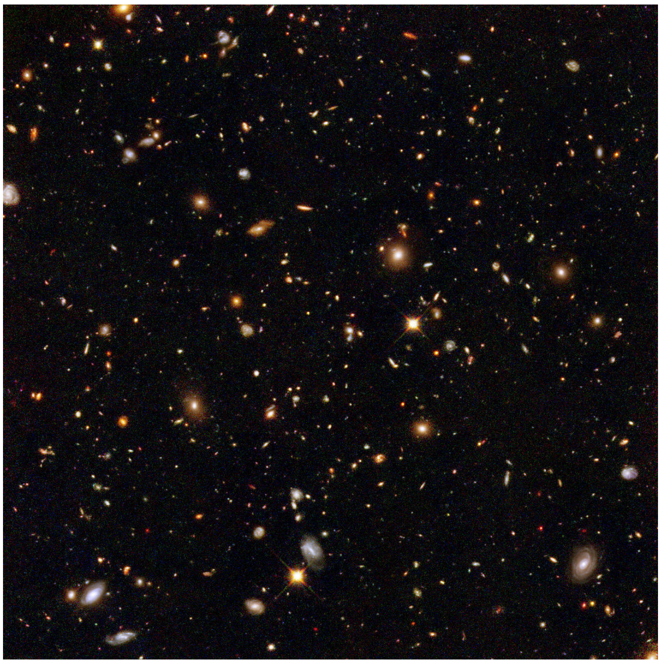
In the years since the original Hubble Deep Field, the Hubble Deep Field South and the GOODS sample were analyzed, providing increased statistics at the high redshifts probed by the HDF. When the Advanced Camera for Surveys (ACS) detector was installed on the HST, it was realized that an ultra-deep field could observe galaxy formation out to even higher redshifts than had currently been observed, as well as providing more information about galaxy formation at intermediate redshifts (z~2).[] A workshop on how to best carry out surveys with the ACS was held at STScI in late 2002. At the workshop Massimo Stiavelli advocated an Ultra Deep Field as a way to study the objects responsible for the reionization of the Universe.[] Following the workshop, the STScI Director Steven Beckwith decided to devote 400 orbits of Director's Discretionary time to the UDF and appointed Stiavelli as the lead of the Home Team implementing the observations.

Unlike the Deep Fields, the HUDF does not lie in Hubble's Continuous Viewing Zone (CVZ). The earlier observations, using the Wide Field and Planetary Camera 2 (WFPC2) camera, were able to take advantage of the increased observing time on these zones by using wavelengths with higher noise to observe at times when earthshine contaminated the observations; however ACS does not observe at these wavelengths, so the advantage was reduced.[]

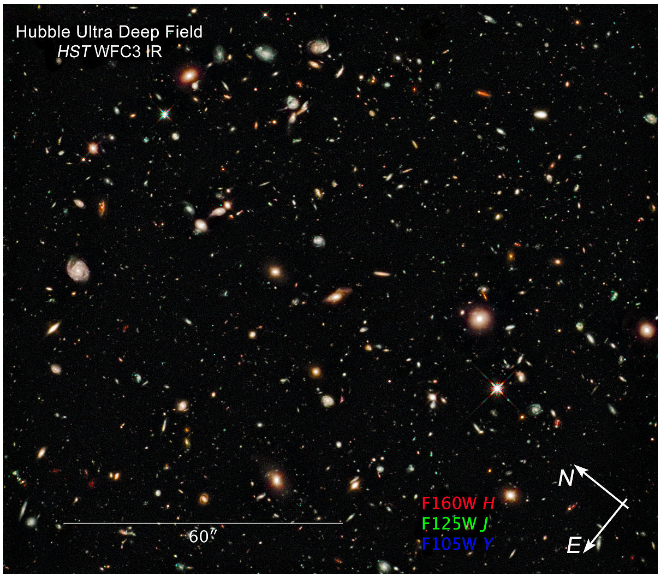
As with the earlier fields, this one was required to contain very little emission from our galaxy, with little Zodiacal dust. The field was also required to be in a range of declinations such that it could be observed both by southern hemisphere instruments, such as the Atacama Large Millimeter Array, and northern hemisphere ones, such as those located on Hawaii. It was ultimately decided to observe a section of the Chandra Deep Field South, due to existing deep X-ray observations from Chandra X-ray Observatory and two interesting objects already observed in the GOODS sample at the same location: a redshift 5.8 galaxy and a supernova. The coordinates of the field are right ascension $3^h\ 32^m\ 39.0^s$, declination -27° 47′ 29.1″ (J2000). The field is 200 arcseconds to a side, with a total area of 11 square arcminutes,[] and lies in the constellation of Fornax.[]

Observations

Four filters were used on the ACS, centered on 435, 606, 775 and 850 nm, with exposure times set to give equal sensitivity in all filters. These wavelength ranges match those used by the GOODS sample, allowing direct comparison between the two. As with the Deep Fields, the HUDF used Directors Discretionary Time. In order to get the best resolution possible, the observations were dithered by pointing the telescope at slightly different positions for each exposure—a process trialled with the Hubble Deep Field—so that the final image has a higher resolution than the pixels on their own would normally allow.[]


HUDF with NICMOS infrared data. Slightly different framing

The observations were done in two sessions, from September 23 to October 28, 2003, and December 4, 2003, to January 15, 2004. The total exposure time is just under 1 million seconds, from 400 orbits, with a typical exposure time of 1200 seconds.[] In total, 800 ACS exposures were taken over the course of 11.3 days, 2 every orbit, and NICMOS observed for 4.5 days. All the individual ACS exposures were processed and combined by Anton Koekemoer [3] into a single set of scientifically useful images, each with a total exposure time ranging from 134,900 seconds to 347,100 seconds. To observe the whole sky to the same sensitivity, the HST would need to observe continuously for a million years.[]



WFC3 infrared data from part of the field (with labels)

Observations made of the HUDF with ACS.[]

Camera	Filter	Wavelength	Total exposure time	Exposures
ACS	F435W	435 nm	134,900 s (56 orbits)	116
ACS	F606W	606 nm	135,300 s (56 orbits)	116
ACS	F775W	775 nm	347,100 s (144 orbits)	288
ACS	F850LP	850 nm	346,600 s (144 orbits)	288

The sensitivity of the ACS limits its capability of detecting galaxies at high redshift to about 6. The deep NICMOS fields obtained in parallel to the ACS images could in principle be used to detect galaxies at redshift 7 or higher but they were lacking visible band images of similar depth. These are necessary to identify high redshift objects as they should not be seen in the visible bands. In order to obtain deep visible exposures on top of the NICMOS parallel fields a follow-up program, HUDF05, was approved and granted 204 orbits to observe the two parallel fields GO-10632 [4]). The orientation of the HST was chosen so that further NICMOS parallel images would fall on top of the main UDF field.

After the installation of WFC3 on Hubble in 2009, the HUDF09 programme (GO-11563 [5]) devoted 192 orbits to observations of three fields, including HUDF, using the newly available F105W, F125W and F160W infra-red filters (which correspond to the Y, J and H bands):[6]

Observations made of the HUDF with WFC3

Camera	Filter	Wavelength	Exposure time
WFC3	F105W	1050 nm ± 150	16 orbits, 14 usable
WFC3	F125W	1250 nm ± 150	16 orbits
WFC3	F160W	1600 nm ± 150	28 orbits

Contents

The HUDF used to be the deepest image of the universe ever taken and it will be used to search for galaxies that existed between 400 and 800 million years after the Big Bang (redshifts between 7 and 12).[] The furthest object located as of 2011 was UDFj-39546284 at a time of 600 million years after the Big Bang.[7][8] The red dwarf UDF 2457 at distance of 59,000 light-years is the furthest star resolved by the HUDF.[] The star near the center of the field is USNO-A2.0 0600-01400432 with apparent magnitude of 18.95.[]


Spiral galaxy UDF 423 (visible-light)

The field imaged by the ACS contains over 10,000 objects, the majority of which are galaxies, many at redshifts greater than 3, and some that probably have redshifts between 6 and 7.[] The NICMOS measurements may have discovered galaxies at redshifts up to 12.[]

Scientific results

- High rates of star formation during the very early stages of galaxy formation, under a billion years after the Big Bang.[]
- Improved characterization of the distribution of galaxies, their numbers, sizes and luminosities at different epochs, allowing investigation into the evolution of galaxies.[]
- Confirmation that galaxies at high redshifts are smaller and less symmetrical than ones at lower redshifts, showing the rapid evolution of galaxies in the first couple of billion years after the Big Bang.[]

Successor

The Hubble eXtreme Deep Field (XDF) is an image of a small part of space in the center of the Hubble Ultra Deep Field within the constellation Fornax, showing the deepest optical view in space. Released on September 25, 2012, it took 10 years to compile the images and shows galaxies from 13.2 billion years ago. The exposure time was two million seconds, or approximately 23 days. The faintest galaxies are one ten-billionth the brightness of what the human eye can see. The red galaxies are the remnants of galaxies after major collisions during their elderly years. Many of the smaller galaxies are very young galaxies that eventually became the major galaxies, like the Milky Way and other galaxies in our galactic neighborhood. The Hubble eXtreme Deep Field, or XDF, adds another 5,500 galaxies to Hubble's 2003 and 2004 view into a tiny patch of the farthest universe.

References

[1] http://www.wikisky.org/?ra=3.5441666666667&de=-27.791416666667&zoom=12&show_grid=1&show_constellation_lines=1&show_constellation_boundaries=1&show_const_names=1&show_galaxies=1&img_source=IMG_all
[2] http://www.pbs.org/deepspace/hubble/index.html#science
[3] http://www.stsci.edu/~koekemoer
[4] http://www.stsci.edu/cgi-bin/get-proposal-info?id=10632&observatory=HST
[5] http://www.stsci.edu/cgi-bin/get-proposal-info?id=11563&observatory=HST

External links

- NASA site with animations (http://www.nasa.gov/vision/universe/starsgalaxies/hubble_UDF.html)
- Exploring galaxy formation in the early universe (http://hubblesite.org/newscenter/newsdesk/archive/releases/2005/28/full/) - How did the first galaxies get so large so quickly?
- Scalable interactive UDF with 10,000 galaxies mapped. Wikisky.org (http://www.wikisky.org/?img_source=IMG_all&zoom=13&ra=3.54417&de=-27.7914)

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The Hubble Extreme Deep Field

Hubble Extreme Deep Field

The **Hubble eXtreme Deep Field** (**XDF**) is an image of a small part of space in the center of the Hubble Ultra Deep Field within the constellation Fornax, showing the deepest optical view in space.[][]

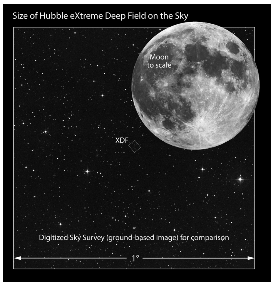
Hubble Extreme Deep Field

Video (02:42) about how the Hubble eXtreme Deep Field image was made.

Released on September 25, 2012, the *XDF* image compiled 10 years of previous images and shows galaxies from 13.2 billion years ago. The exposure time was two million seconds, or approximately 23 days. The faintest galaxies are one ten-billionth the brightness of what the human eye can see. Many of the smaller galaxies are very young galaxies that eventually became the major galaxies, like the Milky Way and other galaxies in our galactic neighborhood.[]

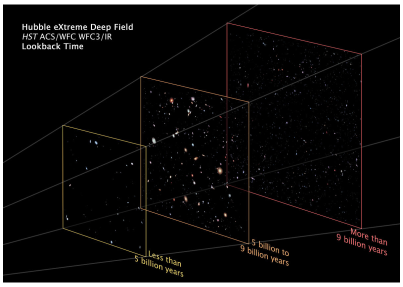
The Hubble eXtreme Deep Field, or *XDF*, adds another 5,500 galaxies to those discovered in the Hubble Ultra-Deep Field.[1]

eXtreme Deep Field



XDF size compared to the size of the moon - several thousand galaxies, each consisting of billions of stars, are in this small view.

XDF (2012) view - each light speck is a galaxy - some of these are as old as 13.2 billion years[] - the observable universe is estimated to contain 200 billion galaxies.



XDF image shows mature galaxies in the foreground plane - nearly mature galaxies from 5 to 9 billion years ago - protogalaxies beyond 9 billion years.

References

External links

Media related to Galaxy at Wikimedia Commons Media related to Universe at Wikimedia Commons

- XDF Project (http://xdf.ucolick.org/xdf.html)

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The Cosmos Evolution Survey

Cosmic Evolution Survey

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COSMOS Overview
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Publications
Search

COSMOS Project Summary

COSMOS is an HST Treasury Project to survey a 2 square degree equatorial field with the Advanced Camera for Surveys (ACS). It is the largest survey that HST has ever done, utilizing 10% (640 orbits) of its observing time over the course of two years (HST Cycles 12 and 13). The project also incorporates major commitments from other observatories around the world, including the VLA radio telescope, ESO's VLT in Chile, ESA's XMM X-ray satellite, and Japan's 8-meter Subaru telescope in Hawaii. The COSMOS collaboration involves almost 100 scientists in a dozen countries.

Members of the COSMOS Collaboration

The primary goal of COSMOS is to study the relationship between large scale structure (LSS) in the universe and the formation of galaxies, dark matter, and nuclear activity in galaxies. This includes a careful analysis of the dependence of galaxy evolution on environment. The wide field of coverage of COSMOS will sample a larger range of LSS than any previous HST survey.

COSMOS will detect:

- over 2 million objects with $I_{AB} > 27$ mag
- over 35,000 Lyman Break Galaxies (LBGs)
- extremely red galaxies out to z ~ 5

The COSMOS field is equatorial, for easy access to telescopes in both hemispheres:

RA (J2000) = 10:00:28.6
DEC (J2000) = +02:12:21.0

Status of COSMOS: July 1, 2005

COSMOS has completed all of its HST observations. This includes two years of observations with the ACS, WFPC2, and NICMOS instruments. Currently the first cycle of observations are available through the COSMOS Archive. Additional observations, such as the Subaru optical, VLA radio, and XMM X-ray surveys of the field have also been completed. Those data will be released over the next several months. Object catalogs are also being produced, and spectral observations of

objects in the field are ongoing.

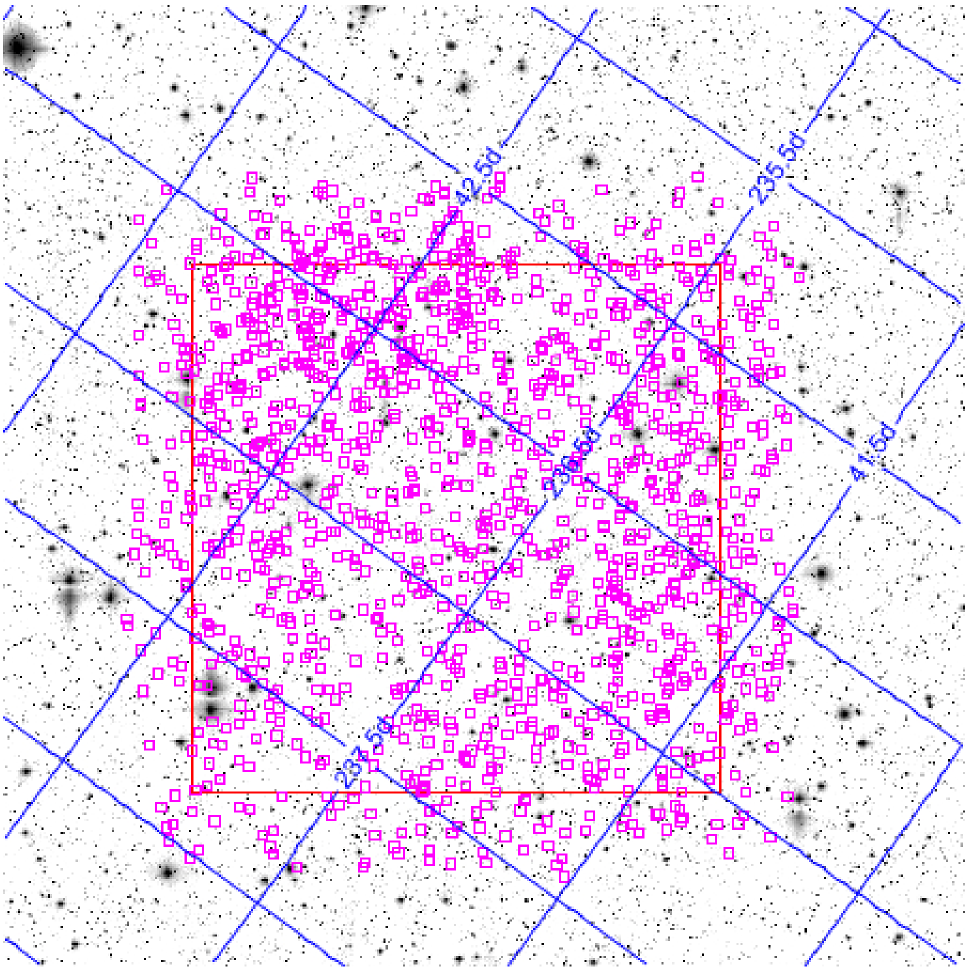
The COSMOS collaboration is currently concentrating on producing the first batch of scientific papers on the survey. These papers should appear in print at the same time as the COSMOS special session at the January, 2006 AAS Meeting in Washington, D.C. Stay tuned to these web pages for future updates!

COSMOS Archive

The COSMOS Archive serves data taken for the **Cosmic Evolution Survey** (COSMOS) project, using IRSA's general search service, Atlas. **COSMOS** is an astronomical survey designed to probe the formation and evolution of galaxies as a function of cosmic time (redshift) and large scale structural environment. The survey covers a 2 square degree equatorial field with imaging by most of the major space-based telescopes (Hubble, Spitzer, GALEX, XMM, Chandra) and a number of large ground based telescopes (Subaru, VLA, ESO-VLT, UKIRT, NOAO, CFHT, and others). Over 2 million galaxies are detected, spanning 75% of the age of the universe. The COSMOS survey involves almost 100 scientists in a dozen countries. The Spitzer observations of the COSMOS field (S-COSMOS Legacy Project) have been integrated into the COSMOS archive. S-COSMOS images are incorporated in the search results using the form below. The COSMOS and S-COSMOS **photometry catalogs** can be accessed using IRSA's General Catalog Search Service, **Gator**.

[**Description of available datasets**]

[**Image Search** | **Cutouts** | **Gator Catalog Search** | **Images** | **Spectra** | **Catalogs**]



You can get a close-up map of a region by clicking on any area on the above image, or by typing a coordinate below.

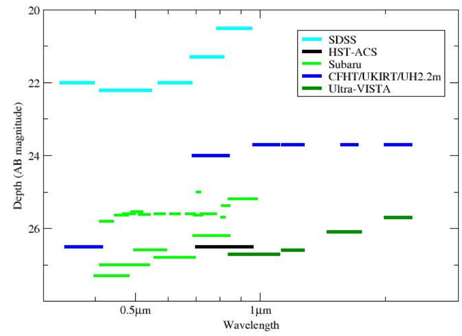
- Background greyscale image is a mosaic of COSMOS SDSS 'i' band data, and is used to visualize the COSMOS area of interest
- The red box shows the COSMOS area of interest. Image coverage outside this area is incomplete.
- The magenta squares show the 1332 Magellan spectra sources in the field.

COSMOS Home
COSMOS Overview
Astronomer's Site
Technical Details
HST
Spitzer
VLA
Subaru
GALEX
IR/optical/UV
X-Ray
Spectroscopy
Sub-millimeter
Team Site (Private)
Data Products
Publications
Search

COSMOS Observations: Infrared, Optical, and Ultraviolet

In additon to the major COSMOS S-Cam optical observing program underway at the Subaru Telescope, IR/Optical/UV large imaging surveys of the entire COSMOS field are ongoing at several telescopes in both hemispheres.

Significant amounts of time have been allocated to COSMOS on the Subaru Telescope with Suprime-Cam, CFHT with Mega-Prime and WIRCAM, UKIRT with WFCAM, the UH2.2m with ULBCAM, the KPNO 4m with Flamingos, and the Blanco 4m with ISPI. The filter information and tranmission curves can be found at http://www.astro.caltech.edu/~capak/cosmos/filters/index.html.



This plot shows the final 5 sigma depth for all existing data and the expected 5 sigma depth for the Ultra-VISTA survey. The depths quoted are the measured flux in a 3 arc-second aperture with the exception of ACS which uses a 0.15 arc second aperture. The Ultra-VISTA data will only cover a 1x1.5 degree region in the center of the field with half of the data going 0.5 magnitudes deeper.

- Subaru Suprime-Cam (PI: Y. Taniguchi): Broad band (100nm) imaging in Bj, g+, Vj, r+, i+ and z+ bands, Intermediate band (30nm) imaging centered at 427nm, 464nm, 484nm, 505nm, 527nm, 574nm, 624nm, 679nm, 709nm, 738nm, 767nm, and 827nm, and Narrow band (12nm) imaging centered at 711nm and 815nm.
- CFHT Megaprime (PI D. Sanders (u*) and O. LeFevre (i*)): 30h of u* imaging spread over 4 pointings covering 2 square degrees, and 5h of i* data spread over 3.2 square degrees. In addition, the central 0.9 square degrees was covered by CFHT-LS in u*,g*,r*,i*,z*
- CFHT WIRCAM (PI D. Sanders, C. Willot, J-P. Kneib): ~120h of Ks band imaging over 2 square degrees, with an additional 60h of H band allocated and 60h more planned.
- UKIRT WFCAM (PI D. Sanders): ~12 nights of J band and ~5 nights of Y band imaging covering 2 square degrees.

- UH2.2m ULBCAM (PI D. Sanders): ~45 nights of J band imaging covering 2 square degrees.
- KPNO 4m and Blanco 4m (PI B. Mobasher): 19 nights of Ks band imaging
- Starting in the spring of 2009 the Ultra-VISTA project will image the central 1 x 1.5 degrees of the COSMOS field to unprecedented 5 depths of >25.5 AB magnitude in Y, J, H, K over a five year period.

Updated June 2008.

Cosmic Evolution Survey

COSMOS

- COSMOS Home
- COSMOS Overview
- Astronomer's Site
- Technical Details
  - HST
  - Spitzer
  - VLA
  - Subaru
  - GALEX
  - IR/Optical/UV
  - X-Ray
  - Spectroscopy
  - Sub-millimeter
- Team Site (Private)
- Data Products
- Publications
- Search

COSMOS Observations: VLA

Major radio continuum surveys of the COSMOS field with the VLA are largely complete:

- VLA-COSMOS Large Project
  - 264 hours to cover the entire 2 square degree field at 20 cm (1.4 GHz, 75 MHz bandwidth) with a resolution of ~1.7" and sensitivity of ~8 microJy (1sigma)
  - Two part survey:
    1. 240 hours VLA A-array, 23 pointings at 10 hours per pointing
    2. 24 hours VLA C-array
  - Data products:
    1. flux calibrated image with absolute astrometry over the full COSMOS field
    2. a (parametric) source catalog (positions fluxes, sizes) of nearly 5,000 radio sources.
  - Goals:
    - the secure identification of dust-obscured galaxies
    - the evolution of the FIR/radio correlation for star forming galaxies
    - the evolution of low luminosity radio AGN to high redshift
    - setting the absolute astrometry for the entire COSMOS field
  - Team: E. Schinnerer (PI, MPIA) + 12 others
- VLA-COSMOS Pilot Project
  - 10 hour pilot continuum survey with VLA A-array (Aug'03) at 1.4 GHz (bandwidth 75 MHz) covering the inner ~0.84 square degrees of the COSMOS field; (Schinnerer et al. 2004, AJ 128, 1974)
  - Sources: 246 sources detected, ~20 clearly extended. Sensitivity 25-100 microJy/beam
  - Data products (available from the COSMOS archive):
    1. flux calibrated image with absolute astrometry
    2. a (parametric) source catalog (positions, fluxes, sizes)
  - Team: E. Schinnerer (PI, NRAO/MPIA) + 9 others

Additional information on the VLA observations can be found on the VLA-COSMOS website.

- COSMOS Home
- COSMOS Overview
- Astronomer's Site
- Technical Details
- HST
- Spitzer
- VLA
- Subaru
- GALEX
- IR/Optical/UV
- X-Ray
- Spectroscopy
- Sub-millimeter
- Team Site (Private)
- Data Products
- Publications
- Search

COSMOS Observations: X-Ray

Imaging in the X-Ray domain allows the detection of Active Galaxy Nuclei and clusters of galaxies. Together with the ACS HST and spectroscopic data, the role of environment and galaxy morphology in the evolution of AGN activity will be measured.

- XMM/Newton

  We have so far secured 1.4 megaseconds of observing time with XMM/Newton in the AO3 and AO4 observing cycles. With the XMM data, we shall probe for the first time the 3D clustering as a function of redshift in the X-ray band and detect sufficient numbers of AGN to probe the accretion history at high redshift.

  Additional information on the XMM campaign can be found on the XMM-COSMOS website.

- Chandra

  The Chandra COSMOS Survey (C-COSMOS) covers the central area of the COSMOS field to $\sim 2\times10^{-16}$ cgs (0.5-2 keV) with a series of 36 heavily overlapped ACIS-I 50 ksec pointings, giving a total exposure of 200 ksec over ~0.8 sq. deg. A catalog of 1760 X-ray sources has been produced, compared with about 200 in the combined Chandra Deep Surveys, CDF-N and -S. This flux range will include many starburst dominated galaxies as well as AGNs. Thanks to the large and deep COSMOS data set a multi-wavelength ID program has yielded counterparts to 95% of the C-COSMOS X-ray sources, whose properties we have begun to study.

  Updated June 2008.

Cosmic Evolution Survey

C O S M O S

COSMOS Home
COSMOS Overview
Astronomer's Site
Technical Details
HST
Spitzer
VLA
Subaru
GALEX
IR/Optical/UV
X-Ray
Spectroscopy
Sub-millimeter
Team Site (Private)
Data Products
Publications
Search

COSMOS Observations: Spectroscopy

Major optical spectroscopy surveys for COSMOS are on-going:

- zCOSMOS
  - 540 hr on the ESO VLT using the VIMOS spectrograph
  - Two part survey:
    1. 25,000 galaxies at $0.3 < z < 1.0$ with $IAB < 22.5$
    2. 12,500 star-forming galaxies color selected for $1.4 < z < 2.5$
  - Goals:
    - redshift survey to identify and characterize environment
    - accurate census galaxy populations
    - targetted AGN & X-ray sources
  - Team: S. Lilly (PI) + 25 others
- Magellan COSMOS
  - 12 nights Spring 05 with IMACS spectrograph
  - 3000 galaxies sampling:
    1. passively-evolving galaxies at $1.4 < z < 2.5$
    2. high redshift galaxies and AGN
  - Team PIs: C. Impey (Az), P. McCarthy (Carnegie), M. Elvis (CfA) and J. Huchra (CfA) + others
- Other Spectroscopy
  - Keck DEIMOS and LRIS:
    3 nights - Evolution of the Fundamental Plane , N. Scoville (PI) + 5 others
  - Galileo DOLORES and NICS:
    5 nights - Opt/IR Spect. of XBONG and EROs AGN , A. Comastri (PI) + 10 others

The Great Observatories Origins Deep Survey (GOODS)

Great Observatories Origins Deep Survey

The **Great Observatories Origins Deep Survey** or **GOODS** is an astronomical survey combining deep observations from three of NASAs Great Observatories: the Hubble Space Telescope, the Spitzer Space Telescope and the Chandra X-ray Observatory along with data from other space-based telescopes, such as XMM Newton, and some of the worlds most powerful ground-based telescopes. GOODS is intended to enable astronomers to study the formation and evolution of galaxies in the distant (and hence early) universe.

GOODS Field (Hubble component)

GOODS consists of optical and near-infrared imaging taken with the Advanced Camera for Surveys on the Hubble Space Telescope, the Very Large Telescope and the 4-m telescope at Kitt Peak National Observatory; infrared data from the Spitzer Space Telescope. These are added to pre-existing x-ray data from the Chandra X-ray Observatory and ESAs XMM-Newton. two fields of 10' by 16'; one centered on the Hubble Deep Field North (12h 36m 55s, +62° 14m 15s) and the other on the Chandra Deep Field South (3h 32m 30s, -27° 48m 20s). The two GOODS fields are the most data-rich areas of the sky in terms of depth and wavelength coverage.

Instruments

GOODS consists of data from the following space-based observatories:

- The Hubble Space Telescope (optical imaging with the Advanced Camera for Surveys)
- The Spitzer Space Telescope (infrared imaging)
- The Chandra X-Ray Observatory (X-ray)
- XMM-Newton (an X-ray telescope belonging to the European Space Agency)
- The Herschel Space Observatory (an infrared telescope belonging to the ESA)

Composite image of the GOODS-South field, result of a deep survey using two of the four giant 8.2-metre telescopes composing ESO's Very Large Telescope.

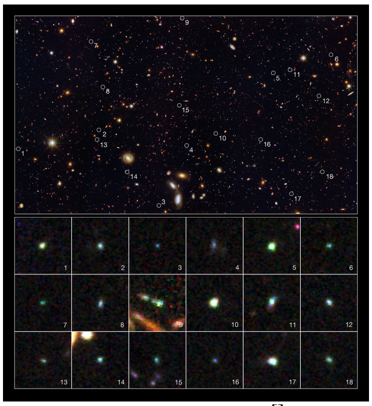
Hubble Space Telescope images

GOODs used the Hubble Space Telescope's Advanced Camera for Surveys with four filters, centered at 435, 606, 775 and 850 nm. The resulting map covers 30 times the area of the Hubble Deep Field to a photometric magnitude less sensitivity, and has enough resolution to allow the study of 1 kpc-scale objects at redshifts up to 6, and provides photometric redshifts for over 60,000 galaxies within the field, providing an excellent sample for studying bright galaxies at high redshifts.[]

Herschel

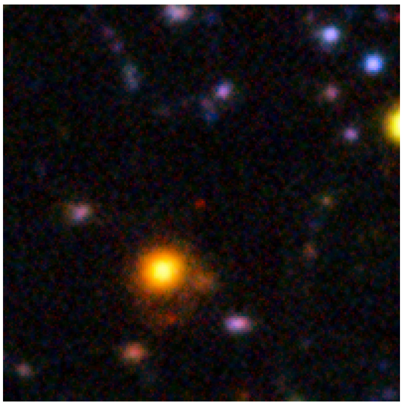
In May 2010, scientists announced that the infrared data from the Herschel Space Observatory was joining the GOODS dataset, after initial analysis of data using Herschel's PACS and SPIRE instruments. In October 2009, Herschel observed the GOODS-North field, and in January 2010 the GOODS-South field. In so doing, Herschel identified sources for the Cosmic Infrared Background.[1]

Gallery



GOODS South Field.[]

Galaxy NTTDF-474 is one of five that have been used to chart the timeline of the reionisation of the Universe.[2] Image taken by ESO's Very Large Telescope.



Galaxy NTTDF-6345 is one of five that have been used to chart the timeline of the reionisation of the Universe. UNIQ-ref-2-bdb6f1c280ad27ff-QINU Image taken by ESO's Very Large Telescope.

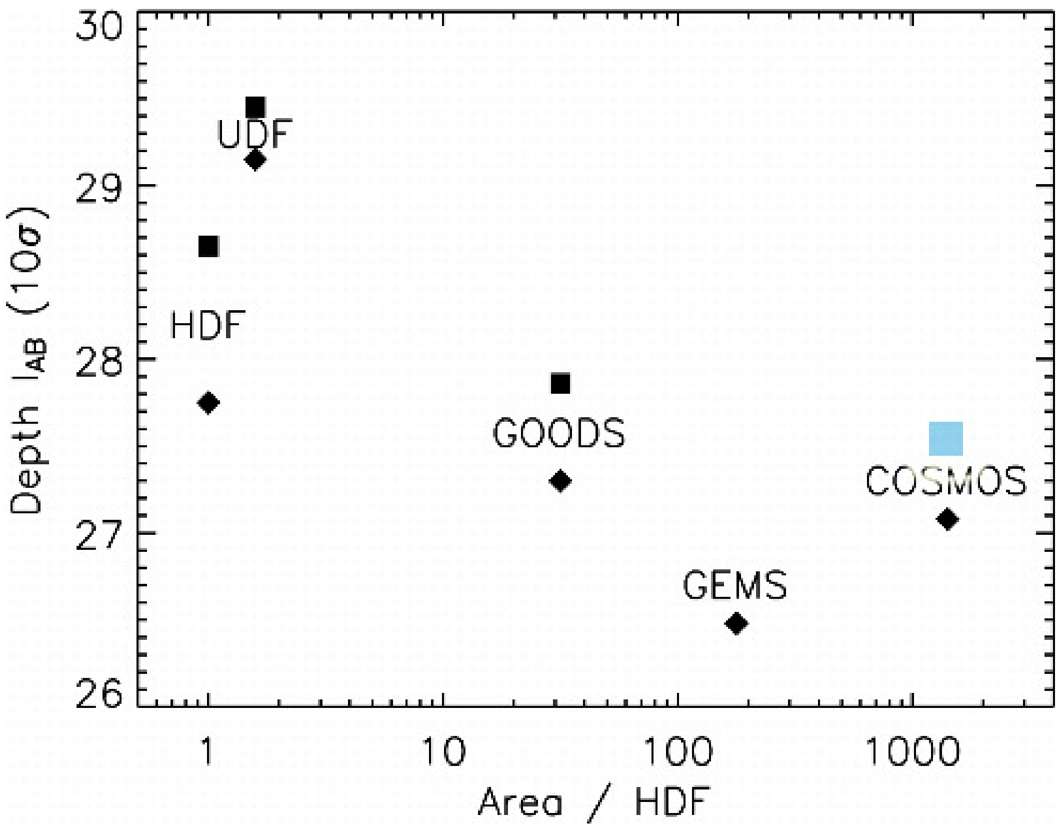
References

[1] Herschel Reveals Galaxies In The GOODS Fields In A Brand New Light (http://www.spacedaily.com/reports/Herschel_Reveals_Galaxies_In_The_Goods_Fields_In_A_Brand_New_Light_999.html), spacedaily.com, 12 May 2009, accessed 13 May 2009

[2] Herschel Reveals Galaxies In The GOODS Fields In A Brand New Light (http://www.spacedaily.com/reports/Herschel_Reveals_Galaxies_In_The_Goods_Fields_In_A_Brand_New_Light_999.html), spacedaily.com, 12 May 2009, accessed 13 May 2009

External links

- GOODS Homepage (http://www.stsci.edu/science/goods/)
- NASA Image of the Day Gallery January 7, 2010 - History Revealed (http://www.nasa.gov/multimedia/imagegallery/image_1558.html) - More than 12 billion years of cosmic history are shown in this panoramic, full-color view of thousands of galaxies.
- ESOcast 21: The Great Observatories Origins Deep Survey (GOODS) (http://www.eso.org/public/videos/esocast21/).



30
29
28
27
26
Depth I_AB (10σ)
UDF
HDF
GOODS
COSMOS
GEMS
1
10
100
1000
Area / HDF

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