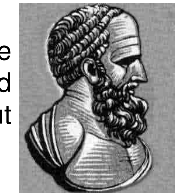
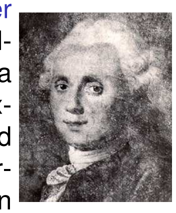
Sky surveys and deep fields of ground-based and space telescopes

• First systematic survey of all that is visible by the naked eye was performed by Hipparchus in the 2nd century BC. He drew up a catalog including about 850 stars.

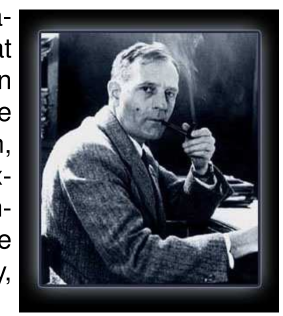


• After almost two thousand years, at the end of the 18th century, French astronomer Charles Messier published the first catalog including not stars but stellar clusters and nebulae. As we know know, about a third of these nebulae are extragalactic bodies – external galaxies. However, Messier was not interested in the dim fuzzy spots he discovered. He was primarily interested in comets and compiled this catalog in order to distinguish comets from fixed nebulae.



• William Herschel (1738-1822) was the first to formulate the problem of global sky surveys to study the structure and evolution of the world outside the solar system. To survey stars in the sky, he applied the original method of ”star gauging” (counting the number of stars in selected sky areas) and statistical data analysis. This allowed him to establish the general shape of our Galaxy and to estimate correctly its oblatness ($\sim$1/5). Another great merit of Herschel was the first systematic survey of faint nebulae and an attempt to establish regularities in their large-scale distribution. He discovered more than 2.5 thousand nebulae and star clusters, of which 80% are other galaxies. Herschel was first to attempt to estimate the size of dim nebulae and to measure their distance. His very approximate estimations gave rise to a picture of the Universe where the Milky Way is an ordinary stellar system of an infinite number of other galaxies.

• After E. Hubble (1889-1953) discovered the extragalactic nature of faint nebulae, it became clear that the Universe is much larger than had previously been thought. In order to study the large-scale structure of the Universe and to understand the nature, origin, and evolution of its principal ‘bricks’ - galaxies, extensive sets of extragalactic studies had to be compiled and analyzed. This work was started by Hubble himself, as well as by other astronomers (Shapley, Ames, Humason, Lundmark, Bok, etc.



During the entire subsequent history of the 20th century, the main achievements in sky surveys and deep studies of selected areas were due to 'technological' successes, such a the use of new big and specialized telescopes, increasingly sensitive photo emulsions, and then CCD matrices and computers, the elaboration of multi-object spectroscopy, etc. Each such a 'technological' step has led to ever deeper penetration into the Universe.

Main steps:

• *Mid 1980s:* First deep CCD surveys (Tyson 1988) revealed a large number of faint, blue galaxies in nearly confusion limited images.

• *Early 1990s:* (a) the development of multi-object spectrographs allows the first spectroscopic surveys of distant galaxies (Ellis et al., Lilly et al. 1995, 1996);
(b) central role of Hubble Space Telescope (HST) (resolved images of distant galaxies, morphological information).

• *Mid 1990s:* (a) spectroscopy with the Keck telescope (10 m collecting area) pushed the limit to two magnitude fainter;
(b) significant improvement in near-IR imaging;
(c) deep imaging in the millimetre wavelength with the SCUBA instrument.

• *Late-1990s:* (a) wide-field optical imaging;
(b) high-multiplexing spectroscopy (several handreds of spectra at once);
(c) 8 m class telescopes with active optics (VLT) (angular resolution of $0.''5$ or better).

• *On-going/upcoming:* (a) next generation of spectrographs + near-IR spectroscopy on 8–10 m class telescopes;
(b) integral-field spectrographs (x, y, λ information);
(c) adapting optics delivering diffraction-limited images ($\sim 0.''05$);
(d) ACS on HST (2001).

In the last 10-15 years, several international projects have been carried out that distinctively changed the aspect of modern astronomy. Observational data on the structure of our and other galaxies were increased by dozens and hundreds of times.
For the first time, it became possible to study the evolution of galaxies and their large-scale structure starting almost from the moment of their formation until now. There are statements that a 'golden age' of studies of galaxy formation and evolution has begun.

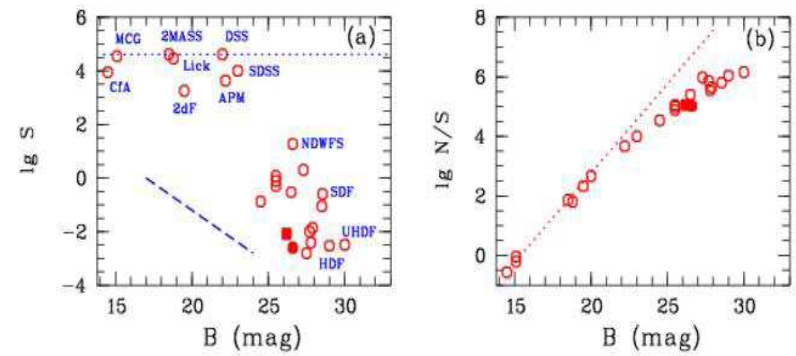
Sky surveys and so-called ‘deep fields’ represent different strategies for studying extraterrestrial objects.

Approximate classification:

Sky surveys include projects performing photometric and/or spectral observations of a significant fraction of the sky (the total coverage $\geq 10^4$ sq. deg.). The effective depth of surveys is $z \sim 0.1$ or several hundred megaparsecs (Mpc). Modern sky surveys are carried out over several years by using, as a rule, middle-size specialized telescopes.

Deep fields relate to projects devoted to a detailed exploration of relatively small sky areas ($10^{-3} - 10^1$ sq. deg). Fields are much deeper ($z \geq 0.5$) compared to surveys and observations are performed with large telescopes. The typical exposures of a deep field are $10^{-3} - 10^{-1}$ year.

Characteristics of some modern observational projects



$N(\leq 30^m) \sim 1.5 \times 10^6$/sq. deg. (1 galaxy per $3'' \times 3''$),
$\sim 10^{11}$ galaxies ($B \leq 30^m$).

Selection of objects

There are basically three different selection methods:

• *Flux-limited selection.*
All the sources with a flux greater than a given threshold are included in the sample.

• *Color selection.*
The method accounts for not only the observed flux but also the color indices (SED). It is widely applied to find the most distant galaxies, because their spectra show a distinctive break near the Lyman limit (912Å).

• *Narrow-band filter selection.*
Selection of galaxies that show an excess when observed through a narrow-band filter, as compared to their broad-band flux. Emission line objects – e.g. starbursts, AGN.

POSS-I

Photographic surveys performed with Schmidt telescopes had a great impact on the development of astronomy. In the 1950s, a photographic survey of the sky available for observations from California ($\delta > -33^o$) was performed using the 1.2-m telescope of the Palomar Observatory.
Almost a thousand plates 6.^{o}5×6.^{o}5 each were obtained in the blue and red spectral bands. Copies of the Palomar sky survey (in the form of glass or printed copies of the plates) were spread over most astronomical institutes in the world and played a very important role in the development of all fields of astronomy, from solar system studies to remote galaxies and quasars.
Objects down to $B \sim 20^m$ can be distinguished in the Palomar prints, and the structure of tens of thousands of galaxies with $B \leq 15^m$ can be studied.

POSS-II

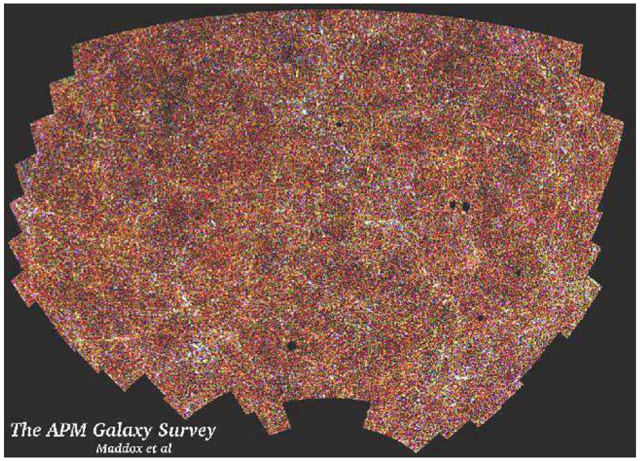
In the 1970s, the success of the Palomar survey stimulated carrying out similar surveys of the southern sky by the 1.2-m British Schmidt telescope (the Anglo–Australian Observatory (AAO), Australia) and the 1.0-m Schmidt telescope of the European Southern Observatory in Chile. Due to great progress in constructing telescopes and improving quality of photographic emulsions, the limiting apparent magnitude of these surveys (ESO/SERC) is by about $1.^m5$ smaller than in POSS-I. This, in turn, initiated, at the end of the 1980s, re-surveying the northern sky with the modified Palomar Schmidt telescope using improved emulsions, but this time with three filters, including the near infrared band centered on $\lambda_{eff} \approx$ 8500 Å. This survey was named POSS-II. The limiting magnitude in POSS-II for star-like objects is $B \approx 22.^m5$.

One photographic plate taken by a large Schmidt telescope can have $10^5 - 10^6$ images of stars and galaxies. This restricted earlier works by visual inspection of only small areas of the original plates. The effective reading of information from the Schmidt plates became possible only after high-speed measuring machines were designed that allowed image digitizing and subsequent computer processing. It is in this way that the first digital sky surveys APM and DSS appeared at the beginning of the 1990s.

The microdensitometer **APM** (Automatic Plate Measuring machine) in Cambridge, England, was used to scan 185 plates (the scan step was $0.''5$) obtained with the 1.2-m Schmidt telescope of the Anglo–Australian Observatory (Australia) near the southern galactic pole. The plates cover ~4300 sq. deg. on the sky. Around 20×10^6 objects with $B \leq 22^m$ were discovered on these plates. For each object, the coordinates, apparent magnitude, and a dozen other parameters characterizing the brightness distribution and shape were determined.

By analyzing photometric brightness profiles, the objects were classified to form a virtually complete sample of extragalactic objects containing $\sim2\times10^6$ galaxies with $B \leq 20.^m5$.

The galaxy distribution of the APM survey over an area of $\sim 50^o \times 100^o$:



DSS (Digitized Sky Survey) is the first high-quality and freely available digitized image of *the entire sky* in the optical range. This survey stemmed from the Space Telescope Institute (STScI) project on creating a star catalog that can be used to precisely point the Hubble Space Telescope (HST) to a required object and guide it during observations. To compile such a catalog, the scanning of blue photographic plates of the POSS-I and SERC surveys was initiated. The scan step was $1.''7$. Soon, it was understood that the importance of the digitized images is far beyond the original purpose and it was decided to open them to the wider scientific community.

Free access to DSS-I was open through the web pages of STScI:

http://archive.stsci.edu/dss/

The **DSS-II** survey was the natural extension of DSS-I using data from POSS-II. The POSS-II plates of the northern sky, as well as the SERC plates and other surveys of the southern sky, were scanned with the step $1.''0$. Plates in three color bands were digitized, which allowed a comparison of sky areas in different spectral bands.

The total volume of DSS-II attains $\sim$5 TB and remote access to it is available, as a rule, through the same web pages as for DSS-I.

The surveys mentioned above were based on photographic observations and, naturally, suffer from all the standard short-comings of photo emulsions, such as low sensitivity, restricted dynamical range, and nonlinearity. Let's discuss truly digital projects, because CCD detectors are used to perform them.

2MASS (Two Micron All Sky Survey) is the result of the collaborative efforts of the University of Massachusetts and the Infrared Processing and Analysis Center at Caltech –

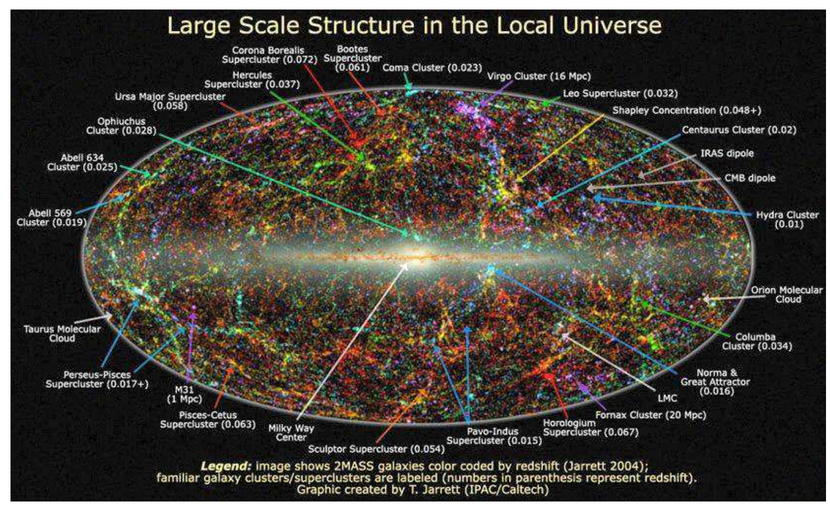
http://www.ipac.caltech.edu/2mass

2MASS is a purely photometric survey covering the whole sky in filters J (1.25 μm), H (1.65 μm), and K_s (2.17 μm). Observations were carried out from June 1997 to February 2001 with two robotic 1.3-m telescopes in Arizona, USA, and Chile. Each instrument was equipped with a three-channel camera imaging the sky simultaneously in the three spectral bands using 256$\times$256 IR CCD-detectors with the pixel size $2.''0$.

Calibrated images of any area of the sky in the J, H, and K_s-bands are available through several sites, for example,

http://irsa.ipac.caltech.edu

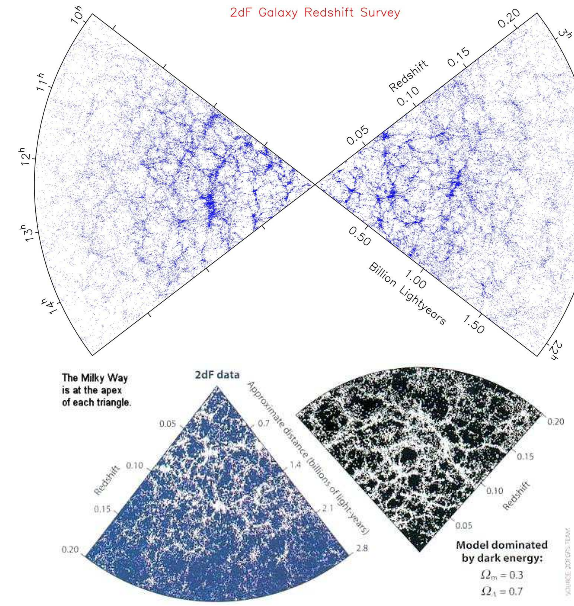
All sky distribution of the 2MASS galaxies ($> 10^6$):



The **2dF** (2 degree Field Galaxy Redshift Survey, or 2dFGRS) represents a spectroscopic survey of ∼5% (∼2000 sq. deg.) of the sky performed by British and Australian astronomers with the 3.9-m telescope of AAO.
Objects for this survey were sampled using the extended APM source catalog and included galaxies brighter than $B \approx 19.^m5$ near the North and South galactic poles. A specially designed multi-object spectrograph allowing simultaneously obtaining spectra of 400 objects within the 2° field of view was used. Observations included 272 nights in the period between 1997 and 2002.
The openly accessible results of the project

http://www.mso.anu.edu.au/2dFGRS

include: a photometric catalog of objects selected for spectroscopic studies; a spectroscopic catalog of 245,591 objects listing redshifts z and spectral types.



The **6dF** (6dF Galaxy Survey, or 6dFGS) represents a survey of redshifts and peculiar velocities of galaxies selected mainly from the 2MASS survey catalog.

The 1.2-m Schmidt telescope of the Anglo–Australian Observatory is used, equipped with a multi-object spectrograph simultaneously taking spectra of 150 objects inside the telescope's 6-degree field of view. Redshifts of around 150,000 galaxies are planned to be measured. The survey will cover almost the entire southern sky with $\delta < 0^o$ (the survey coverage is ≈17000 sq. deg.) and will give detailed information on the distribution of galaxies within the nearby $(z \approx 0.05)$ volume of the Universe. About half of the input galaxy sample is available now (89211 spectra)

http://www-wfau.roe.ac.uk/6dFGS

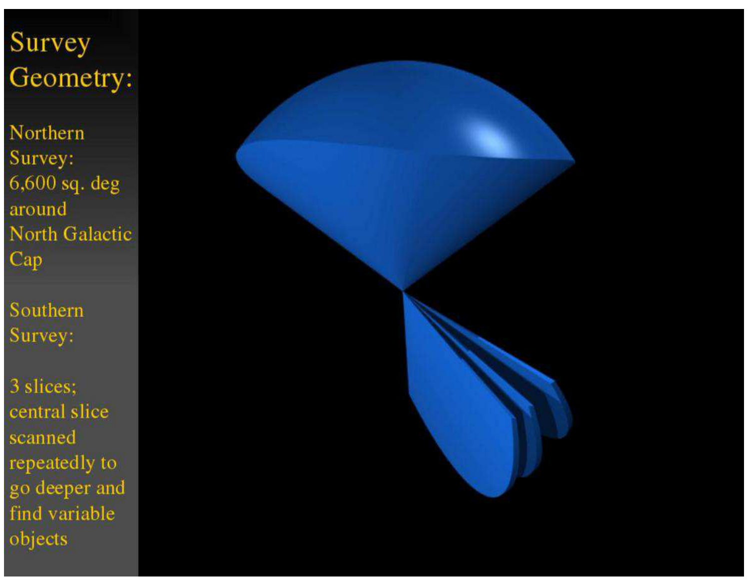
The principal goal of the 6dF is to study large-scale deviations in the velocity of galaxies from the homogeneous Hubble expansion. The distribution of such deviations provides the unique means to study mass distribution in the Universe independent of the assumptions that galaxies follow the true mass distribution.
For about 15,000 early-type galaxies evenly distributed over the southern sky, z-independent distances will be determined using the fundamental plane method. Then, by comparing these distances with those derived from the observed values of z, it will be possible to estimate the peculiar velocities of galaxies arising due to inhomogeneities in mass distribution. (In this way, the Great Attractor with the mass $\sim 5 \times 10^{16}$ M$_\odot$ in a relatively nearby region of the Universe was found).

The **SDSS** (Sloan Digital Sky Survey – **http://www.sdss.org**) is often referred to as one of the most grandiose astronomical projects in history. Starting at the end of the 1980s, it is being carried out by more than a hundred scientists from the USA, Japan, and some European countries.

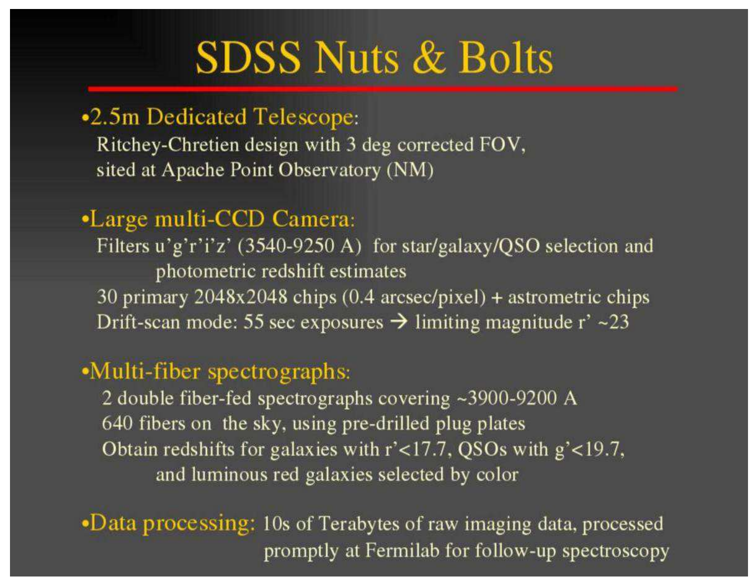
The purpose of the SDSS is to perform a photometric and spectral study of a quarter (≈10000 sq. deg.) of the sky. The survey covers one large area near the Northern Galactic Pole and three bands (with a total coverage of 740 sq. deg.) in the southern hemisphere. Observations are carried out with a specially designed 2.5-m telescope (the modified Ritchey–Chretien system, 3° field of view) in New Mexico (USA). The telescope is equipped with a CCD-camera and a couple of identical multi-object fiber-optic spectrographs to simultaneously take spectra of 640 objects.

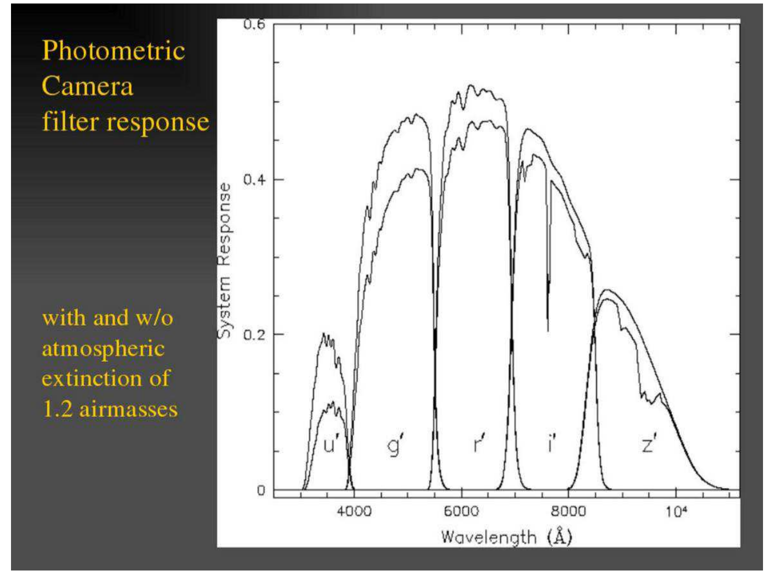
Sky surveys
SDSS

Sky surveys
SDSS



Sky surveys
SDSS





Over eight years of operations (**SDSS-I, 2000-2005**; **SDSS-II, 2005-2008**), it obtained deep, multi-color images covering more than a quarter of the sky and created 3-dimensional maps containing more than 930,000 galaxies and more than 120,000 quasars.

The seventh data release of the SDSS (december 2008):
– includes 11663 deg^2 of imaging data,
– five-band photometry for 357 million distinct objects,
– over 1.6 million spectra in total, including 930,000 galaxies, 120,000 quasars, and 460,000 stars.

Building on the legacy of the Sloan Digital Sky Survey (SDSS) and SDSS-II, the SDSS-III Collaboration will carry out a program of four surveys on three scientific themes:

- Dark energy and cosmological parameters
- The structure, dynamics, and chemical evolution of the Milky Way
- The architecture of planetary systems

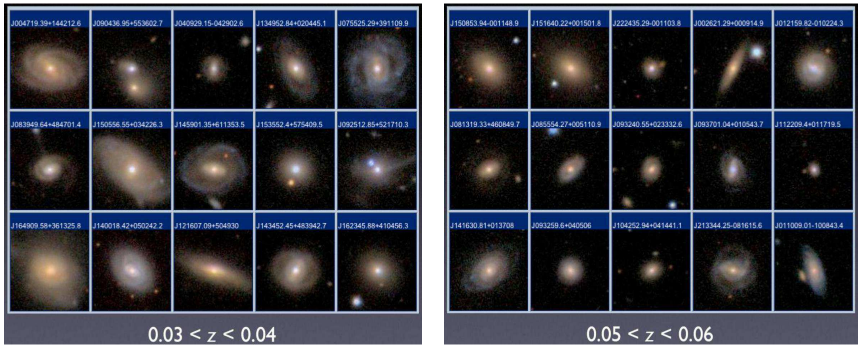

The SDSS's 2.5-meter telescope at Apache Point Observatory

Over the next six years (2008-2014), these four surveys will exploit the unique wide-field spectroscopic capability of the Apache Point Observatory's 2.5-meter telescope. The surveys are:

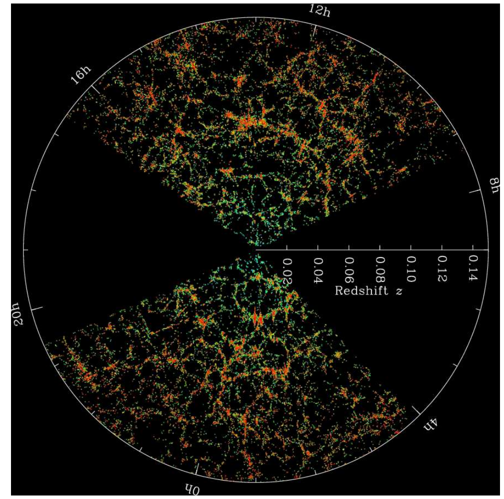
- BOSS will measure the cosmic distance scale via clustering in the large-scale galaxy distribution and the Lyman-α forest
- SEGUE-2 will map the structure, kinematics, and chemical evolution of the outer Milky Way disk and halo
- APOGEE will use high-resolution infrared spectroscopy to see through the dust to the inner Galaxy
- MARVELS will probe the population of giant planets via radial velocity monitoring of 11,000 stars

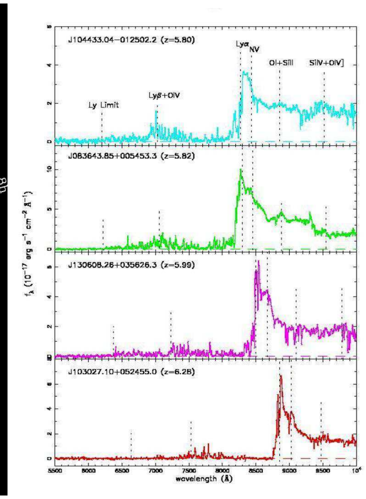
Sky surveys
SDSS

Several results:



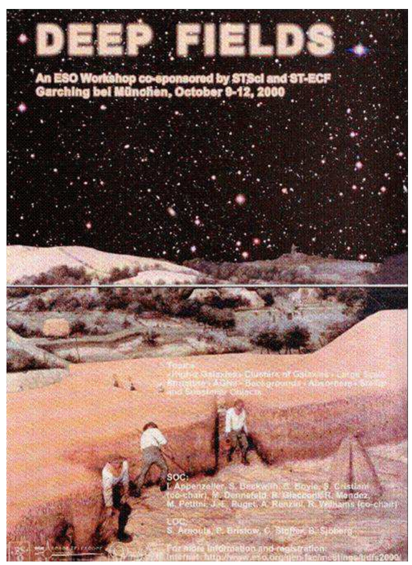
Sky surveys
SDSS





Deep fields

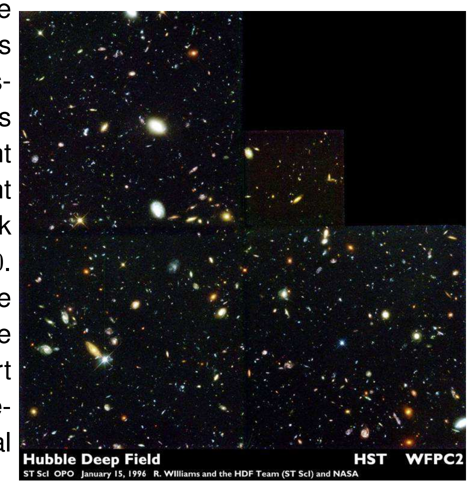
Let's discuss several remarkable projects to study relatively small ultra-deep areas – the deep fields.



Deep fields
HDFs

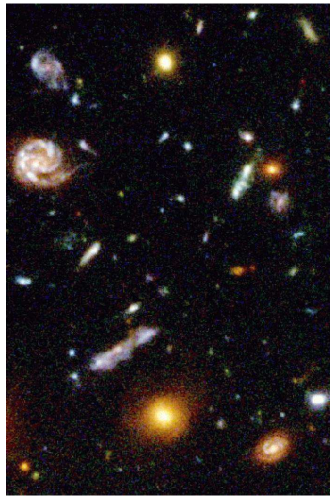
HDF-N

Observations with the HST (the diameter of the main mirror is 2.4 m, the Ritchey–Chretien system) in the first half of the 1990s demonstrated that this instrument resolves the structure of distant galaxies and these galaxies look different than those at $z \approx 0$. The idea emerged to use some free time at the discretion of the STScI director (at that time, Robert Williams) to obtain an unprecedented deep image of one typical area at high galactic latitudes.



Observations of this northern area (**HDF-N**) were carried out in December 1995 with the WFPC-2 (Wide-Field Planetary Camera 2) in four broadband filters centered on 3000 Å (filter F300W), 4500 Å (F450W), 6060 Å (F606W), and 8140 Å (F814W). From fifty to a hundred individual frames were taken, with each frame being taken at a slightly displaced position of the telescope.

The HDF-N covers about 5.3 sq. min. (pixel size is $0.''04 \times 0.''04$), and the field has a non-rectangular shape. The total exposure time in each filter amounted to one to almost two days. The HDF-N was later observed in the near IR bands.

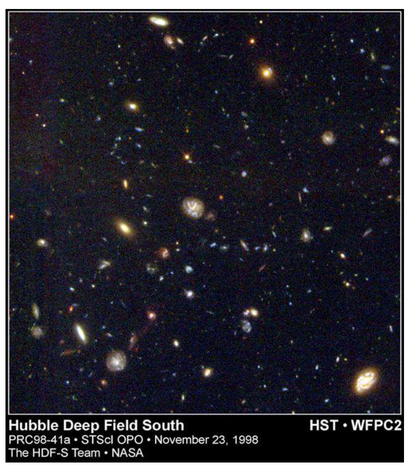


In mid-January of 1996, immediately after primary data processing, the deep field images were open to access through the STScI web-pages
http://www.stsci.edu/ftp/science/hdf/hdf.html

In addition to original images, this site provides a detailed description of observations, their processing, and calibration. It turned out that in the HDF-N, one can detect galaxies as faint as $B \sim 29^m$. Depending on the selection criteria, up to 2000–3000 galaxies in this field can be discovered (for comparison, only several dozen stars of our Galaxy were found).

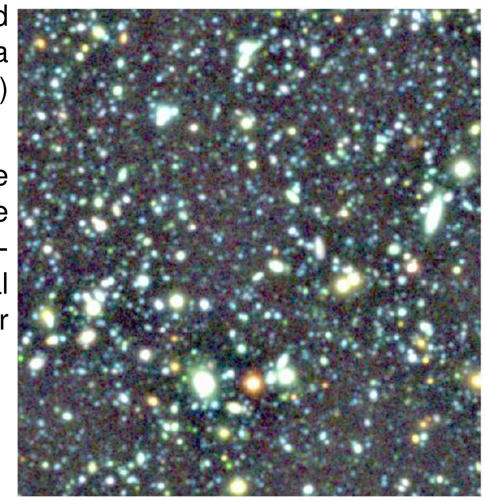
HDF-S

The success of the HDF-N stimulated carrying out an analogous project in the southern hemisphere. Observations of the southern area (located in the Tucanus constellation) were carried out in October 1998. The **HDF-S** project has two important differences from the HDF-N: a remote quasar with $z = 2.24$ falls within this field and several instruments are simultaneously used.
As in the case of the HDF-N, completely reduced observations of this field were open to access at the end of November 1998 –
http://www.stsci.edu/ftp/science/hdfs.html



The main goal of the Japanese project Subaru Deep Field (**SDF**) is to select and study a large sample of distant $(z > 4)$ galaxies.

Since 1999, the Japanese Subaru (Pleiades) telescope has been carrying out multi-color photometric and spectral observations of an area near the north galactic pole.



http://step.mtk.nao.ac.jp/sdf/project/

The Subaru Deep Field (SDF) project

--- A very deep multi-color imaging survey ---

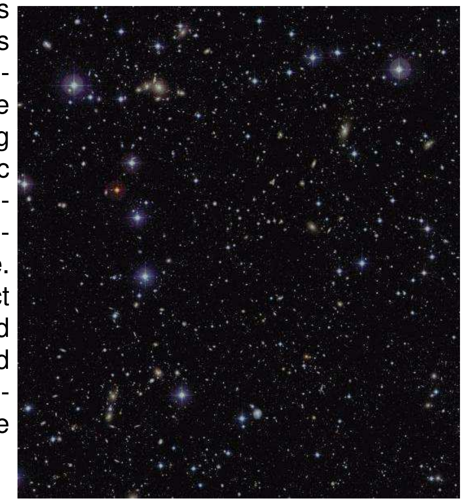
Field Center	R.A. (J2000.0)	**13h 24m 38s.9**
	Decl. (J2000.0)	**27d 29' 25".9**
	--- Near the North Galactic Pole (NGP): b=82.6d ---	
Survey Area		**30' x 37' (dR.A. x dDecl.)**
Telescope		**Subaru**
Detector		**Suprime-Cam**

Filter	Limiting magnitude(*)	Integration time	Number of cataloged sources
	(AB mag)	(hr)	
B	28.45	9.9	214708
V	27.74	5.7	198441
R_C	27.80	10.0	209452
i'	27.43	13.4	198556
z'	26.62	8.4	187622
NB816	26.63	10.0	195344
NB921	26.54	15.0	197338

(*) The limiting magnitude is 3 sigma, measured with a 2" diameter aperture on the sky.

COMBO-17 (Classifying Objects by Medium-Band Observations in 17 filters) represents a multi-color photometric survey of five $\sim 0.^\circ 5 \times 0.^\circ 5$ areas (including the CDF-S, the south galactic pole, and the Abell 901/902 supercluster) obtained with the 2.2-m MPG/ESO telescope in Chile. The main feature of this project is that observations were carried out with 17 filters (five broadband – U, B, V, R, I , and 12 medium-band) covering the spectral range 3500–9300 Å.

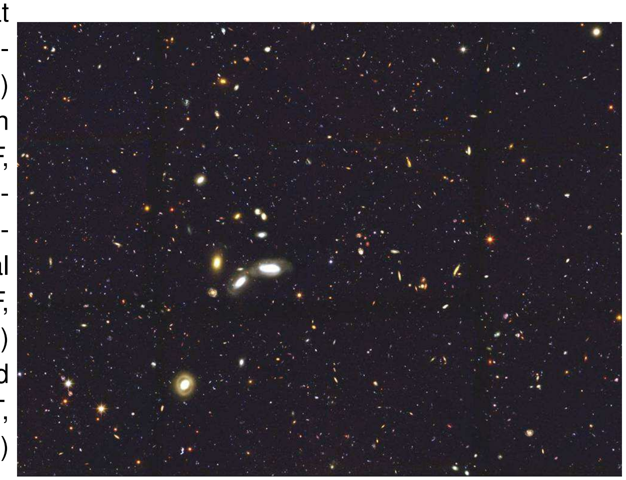
http://www.mpia.de/COMBO/



Such a detailed photometry allows constructing a kind of low-resolution spectrum of each object, which can be used both to spectrally classify and to evaluate the redshift of each object with a relatively good accuracy ($\sigma_z \approx 0.03$).

The relatively small depth of COMBO-17 ($B \approx 25.5$), therefore, is compensated by the large coverage, as well as by the possibility of estimating the type and z of an object without additional spectral observations. These advantages of COMBO-17 make it a convenient tool to study galaxies using the weak gravitational lensing method.

The **GOODS** (Great Observatories Origins Deep Survey) is a new-generation project after the HDF, combining deep multi-wavelength observations from several space (HDF, SIRTF, CXO, XMM-Newton) and ground-based (ESO VLT, ESO NTT, KPNO 4-m, etc.) telescopes.



Deep fields
GOODS

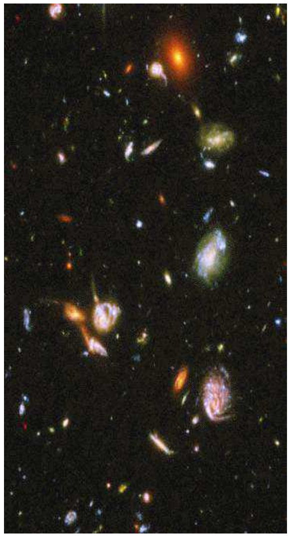
Observations have been carried out in two areas ~160 sq. min. The fields were observed with the HST by the Advanced Camera for Surveys (ACS) installed in 2002 in four broad-band filters F435W (B), F606W (V), F775W (i), and F850LP (z) Observations in V, i, and z were carried out during five periods delayed by 40–50 days. (Such an observational strategy was adopted to facilitate searches for distant 'cosmological' supernovae. As a result, more than 40 supernovae were discovered by the GOODS, with six SN Ia's at $z > 1.25$.)

The limiting magnitude of extended objects in these fields is by $0.^m5$–$0.^m8$ worse than in the previous HST deep fields, but the total coverage of the GOODS is 30 times larger than that of the HDF-N and HDF-S taken together. The original HST frames and reduced images are available through the web pages of the GOODS project: **http://www.stsci.edu/science/goods**

Deep fields
HUDF

The Hubble Ultra Deep Field (**HUDF**) is the deepest optical imaging of a patch of the sky ever made. The authors of the project believe it will remain such in the next several years and, consequently, this field will long remain the main source of information on the most distant objects in the Universe.

The coordinates of the HUDF are $\alpha(2000) = 3^h32^m39^s.0$ and $\delta(2000) = -27^\circ47'29.''1$. The observations were carried out by the HST from Sept 2003 till Jan 2004 with a wide-field camera ACS with the same four filters as the GOODS observations. The field coverage is relatively small: 11.5 $\square'$.



Deep fields
HUDF

More than a hundred individual images were taken in the B and V filters (total exposure time ~40^h). Observations in the i and z bands include almost 300 frames (total exposure time ~100^h with each filter).

The final calibrated HUDF images with the step 0.″03 (the image size with each filter is 430 Mb) and the catalog of discovered objects can be found on the web page of the project: **http://www.stsci.edu/hst/udf**

The HUDF is by about one magnitude deeper than the HDF. In this field, around 10,000 galaxies up to $B \sim 30^m$ (!) were discovered.

To improve the impact of the ACS data, the central part of the HUDF was also observed by the HST with the NICMOS (Near-Infrared Camera and Multi-Object Spectrometer) with filters F110W (J) and F160W (H).

Deep fields
Other projects

- The **LCRS** (Las Campanas Redshift Survey) is a spectroscopic survey of ~2600 galaxies with the 2.5-m telescope of the Las Campanas observatory (Chile). The survey covers about 700 sq. deg. and consists of six extended patches $1.^o5 \times 80^o$ each.
- The **CNOC2** (Canadian Network for Observational Cosmology) is a survey covering ~1.5 sq. deg. of the sky with the 3.6-m CFHT telescope. The survey is aimed at determining redshifts for ~6000 galaxies with the apparent magnitude $R \leq 21.^m5$ and providing multicolor photometry for ~40,000 galaxies with $R \leq 23^m$.
- The **DEEP2** (Deep Extragalactic Evolutionary Probe 2) is a spectroscopic survey covering ~3.5 sq. deg. of the sky with a multi-object spectrograph on the 10-m Keck-II telescope. Redshifts for ~60,000 remote ($z > 0.7$) galaxies will be measured.

- The **MUNICS** (Munich Near-Infrared Cluster Survey) represents a photometric and spectroscopic study of several thousand galaxies with $K \leq 19.^m5$ within several areas with the total coverage ~1 sq. deg. The photometry was obtained with the 2.2-m and 3.5-m telescopes of the Calar Alto observatory (Spain). The Hobbey-Eberly (9.2-m, USA) and ESO-VLT telescopes were also used for spectral observations.
- The **VVDS** (VIMOS-VLT Deep Survey) is a photometric and spectroscopic survey of ~100,000 galaxies within several deep fields covering ~ 16 sq. deg. with the VIsible Multi-Object Spectrograph (VIMOS) on the ESO VLT telescope.

Deep fields
Other projects

- The **GEMS** (Galaxy Evolution from Morphologies and SEDs) represents the largest ($\sim 28' \times 28'$) image obtained up to the present time with the Hubble Space Telescope. The field was observed with two filters (F606W and F850LP). The integrated image represents a mosaic from about 60 WFC ACS fields. The GEMS field is centered on the CDF-S and includes the GOODS field. The size and location of GEMS are almost identical to the COMBO-17. The GEMS data allow the study of the structure and morphology of ~10,000 galaxies.
- The **OACDF** (Capodimonte Deep Field) is a multi-color (9 color bands) photometric survey of ~50,000 galaxies within a ~0.5 sq. deg. field with the ESO/MPG 2.2-m telescope.

Deep fields
Other projects

- The **COSMOS** (Cosmological Evolution Survey) 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.

Site: **http://cosmos.astro.caltech.edu**

Deep fields
Other projects

The primary goal of COSMOS is to study the relationship between large scale structure 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 $I > 27^m$
– over 35,000 Lyman Break Galaxies (LBGs)
– extremely red galaxies out to $z \sim 5$