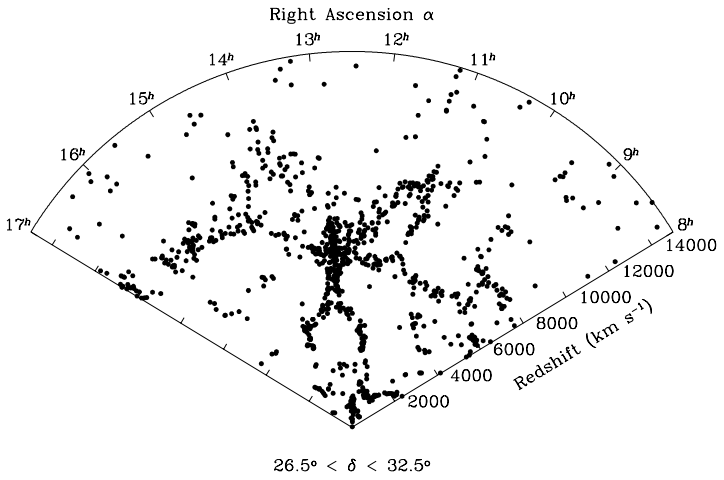
Large scale structure

Introduction



de Lapparent et al. (1986), limiting mag $m_B = 15.6$

Lumpy universe: spatial distribution of galaxies and greater structures.

Introduction

How do we study the structure of the Universe?

$\Longrightarrow$ We need distance information for many ($10^4 \ldots 10^7$) objects

$\Longrightarrow$ Large redshift surveys

Redshift survey: Survey of (patch of) sky determining galaxy z and position to predefined magnitude or z.

First larger survey: de Lapparent et al. (1986)

Classification:

1D-surveys: very deep exposures of small patch of sky, e.g. HST Deep Field, Lockman Hole Survey, Marano Field.

2D-surveys: cover long strip of sky, e.g., CfA-Survey ($1.5 \times 100^\circ$), 2dF-Survey ("2 degree Field"), 6dF-survey.

3D-surveys: cover part of the sky, e.g., Sloan Digital Sky Survey.

These surveys attempt to go to certain limit in z or m.

Other earlier approaches: use pre-existing galaxy catalogues (e.g., QDOT Survey [IRAS galaxies], APM survey,...). We will concentrate here on the larger surveys based on no other catalogue.

2D/3D Surveys

Future for Large Scale Structure: 2D and 3D Surveys observing large part of sky with dedicated instruments.

Currently largest surveys:

Las Campanas Redshift Survey (LCRS): 26418 redshifts in six $1.5 \times 80^\circ$ slices around NGP and SGP, out to $z = 0.2$.

CfA Redshift Survey: 30000 galaxies

APM: (Oxford University) $2 \sim 10^6$ galaxies, 10^7 stars around SGP, 10% of sky, through $B = 21$ mag.

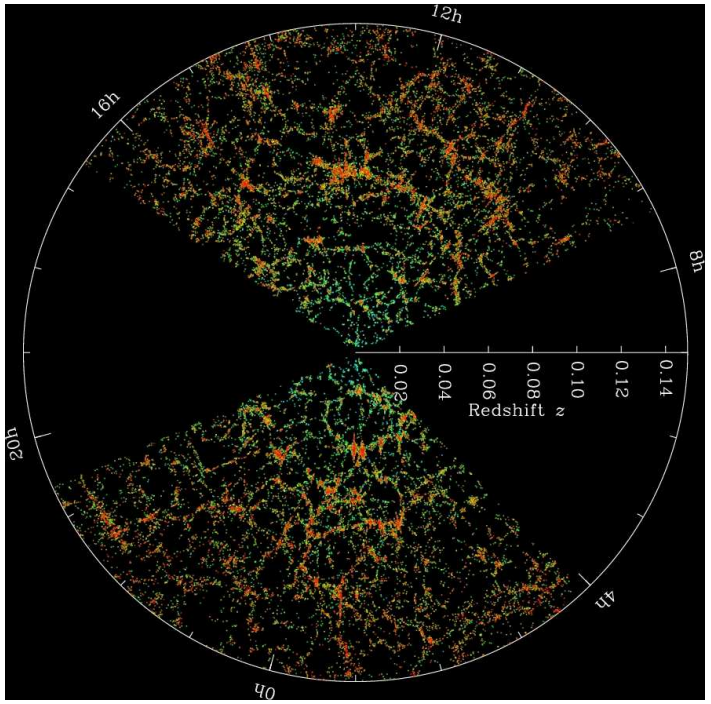
2MASS: IR Survey of complete sky (Mt. Hopkins/CTIO) completed 2000 October 25), 3 bands, $\sim 2 \times 10^6$ galaxies, accompanying redshift survey (8dF, CfA)

Sloan Digital Sky Survey (SDSS): dedicated 2000 October 5, Apache Point Obs., NM, 25% of whole sky, $\sim 10^8$ objects, now in Google Earth

And many more (e.g., Keck, ESO, LSST,...).

SDSS 2.5 m telescope at Apache Point Observatory

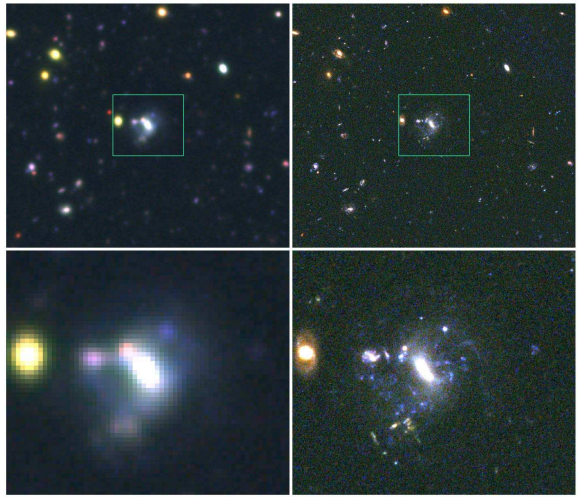
courtesy SDSS



Galaxy distribution from the SDSS

1D Surveys

Ground: Subaru (8m) Space: *HST* (2.4m)



To go deep one needs to go to space

Hubble Space Telescope

STScI

Hubble Space Telescope

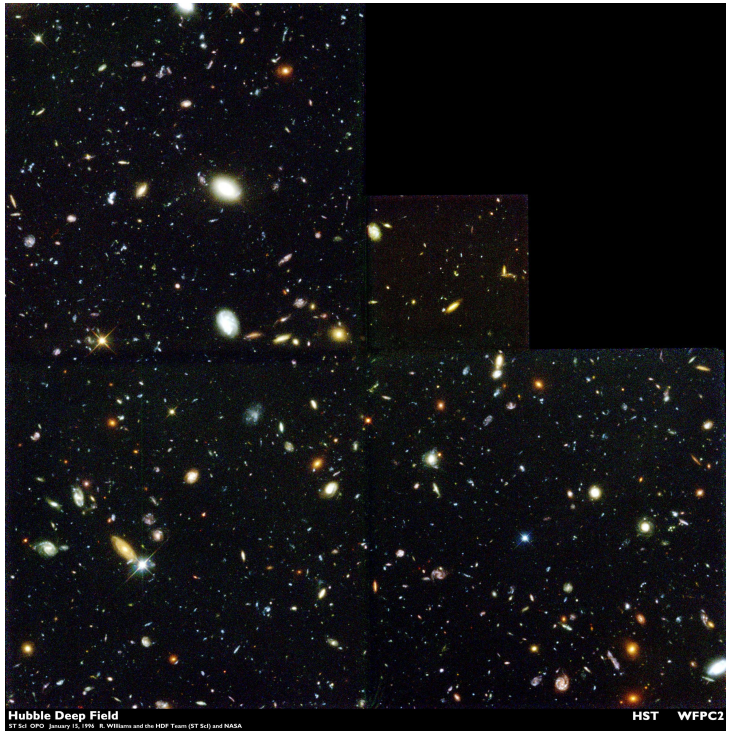
The Hubble Space Telescope has a large set of instruments well suited for cosmological observations:

Current HST Instruments :

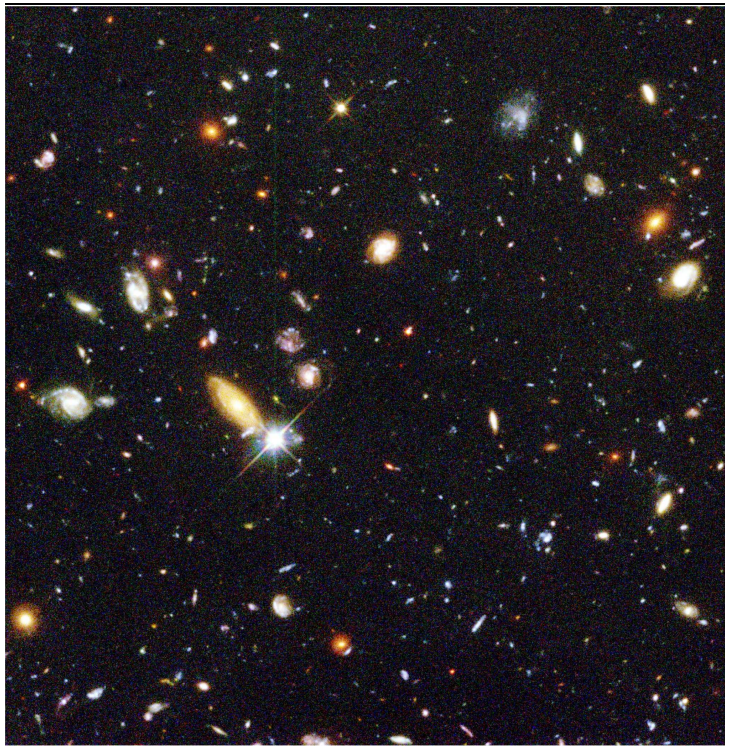
- ACS: Advanced Camera for Surveys (03.2002–)
- COS: Cosmic Origins Spectrograph (06.2009–)
- FGS: The Fine Guidance Sensors
- NICMOS: Near Infrared Camera and Multi Object Spectrometer (02.1997–)
- STIS: Space Telescope Imaging Spectrograph (02.1997–)
- WFC3: Wide Field Camera 3 (06.2009–)

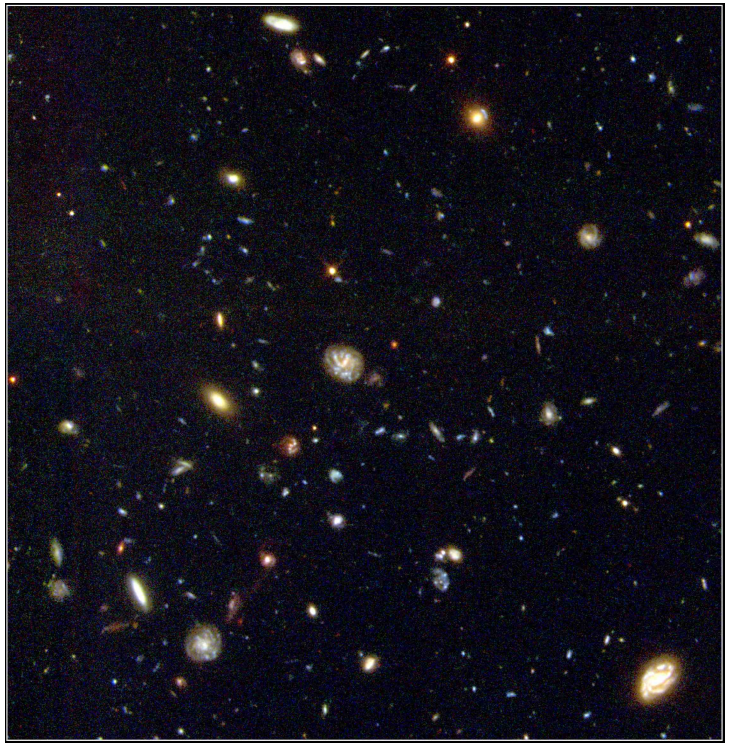
Former Generation Instruments :

- FOC: The Faint Object Camera (04.1990–03.2002)
- FOS: The Faint Object Spectrograph (04.1990–02.1997)
- GHRS: The Goddard High Resolution Spectrograph (04.1990–02.1997)
- HSP: The High Speed Photometer (04.1990–10.1993)
- WF/PC-1: Wide Field Planetary Camera 1 (04.1990–10.1993)
- WFPC2 The Wide Field Planetary Camera 2 (12.1993–06.2009)

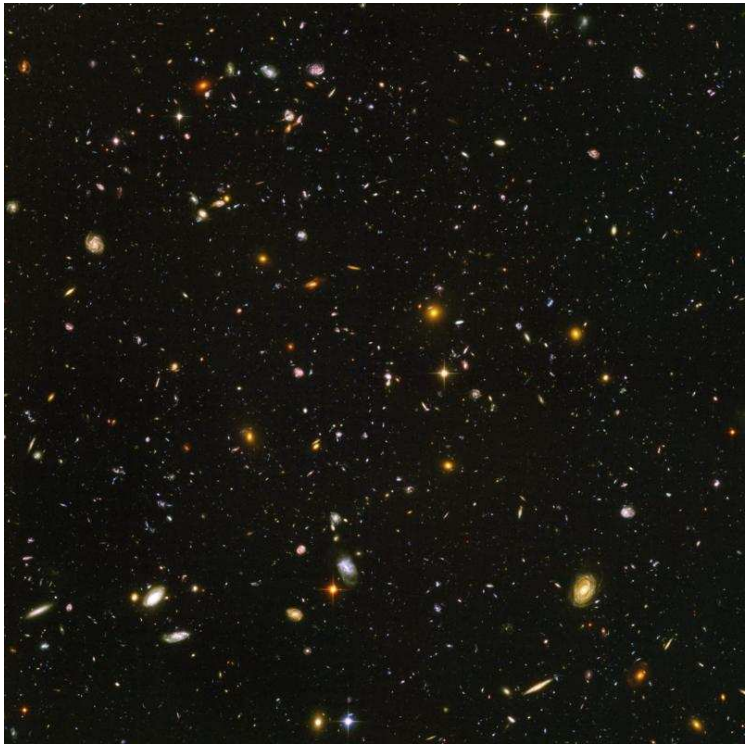


1995 December: Hubble Deep Field:
$\sim$ 150 ksec/Filter for four HST Filters
Many galaxies with weird shapes $\Longrightarrow$ protogalaxies!
Redshifts: $z \in [0.5, 5.3]$
(Fernández-Soto et al., 1999)

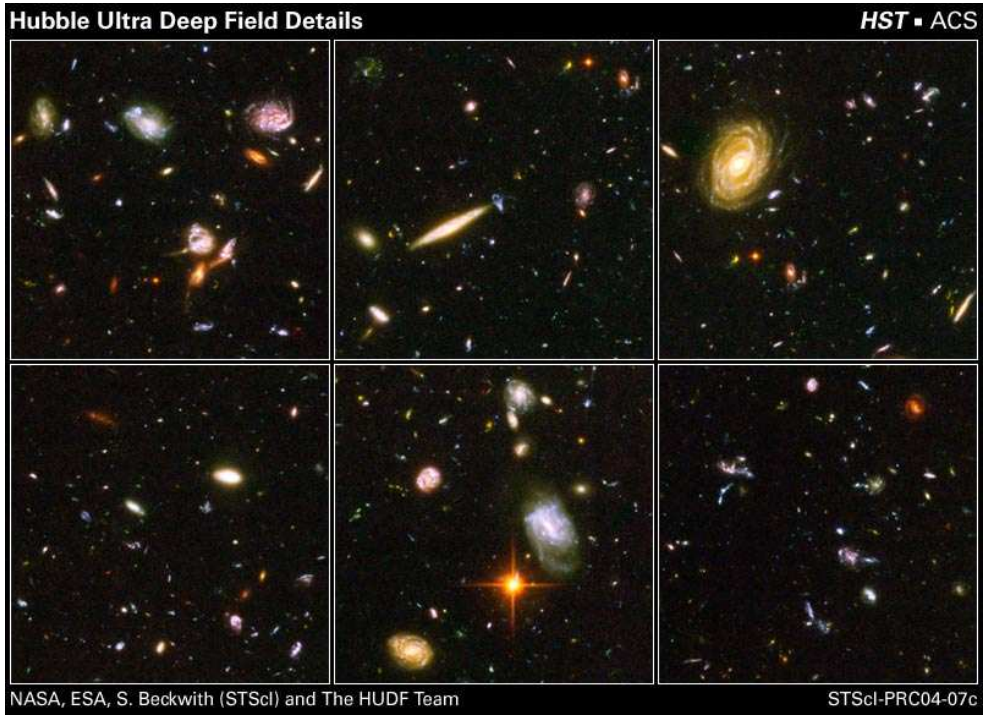


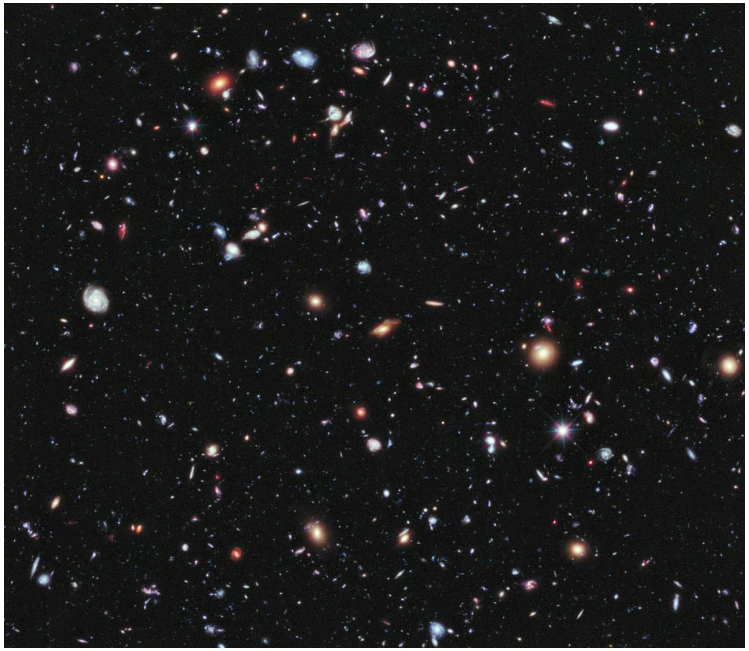


1998: Hubble Deep Field South, 10 d of total observing time!

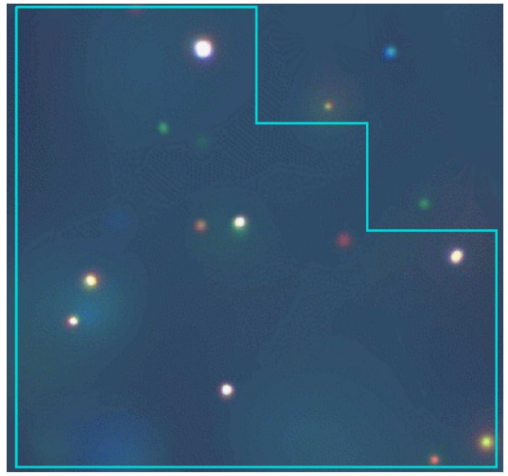


2004: Hubble Ultra Deep Field, 1 Msec long exposure of field in Fornax. Uses updated HST with Advanced Camera for Surveys (ACS) and Near Infrared Camera and Multi-Object Spectrometer (NICMOS); diameter: $3'$ ($2\times$ older HDF)
Limiting magnitude: 30 mag, $\sim$10000 galaxies visible, up to $z \gtrsim 7$
IR reveals many reddened objects





2012: Hubble Extreme Deep Field, combined HST exposures in the area of the HUDF, total of up to 2 Msec.
Limiting magnitude: 30.15. . . 30.25 mag, +5500 galaxies relative to HUDF
candidate record z$\sim$11.9 object



HST

Chandra

Chandra/HST Image of Hubble Deep Field North; 500 ksec

Joint multi-wavelength campaigns allow the measurement of broad-band spectra of sources in the early universe!