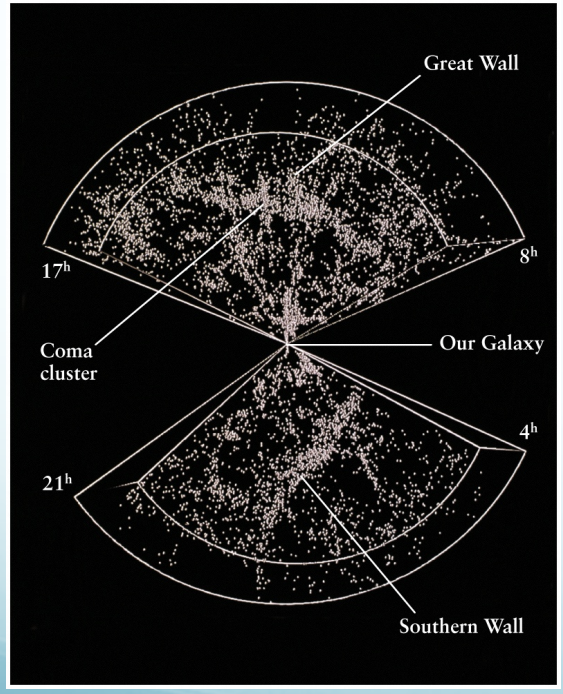
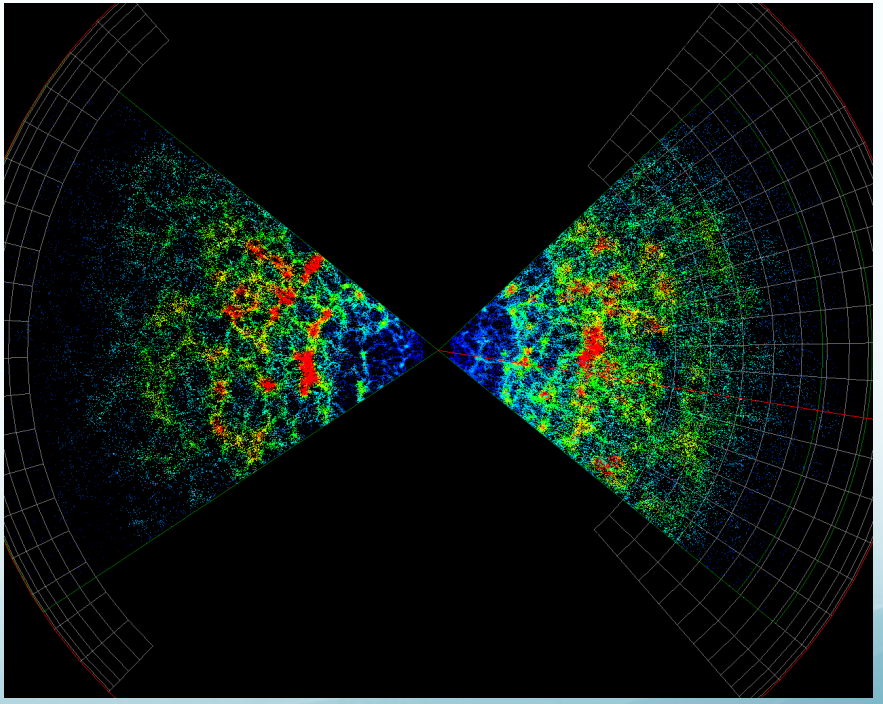
Lecture 3

Cosmology and the Age of the Universe

Large Scale Structure

- On the very largest scales, we find “superclusters”: clusters of clusters of galaxies.
- Filaments connecting thousands of galaxies, interconnected through the “cosmic web”, with
- Vast voids, where relatively few galaxies are found

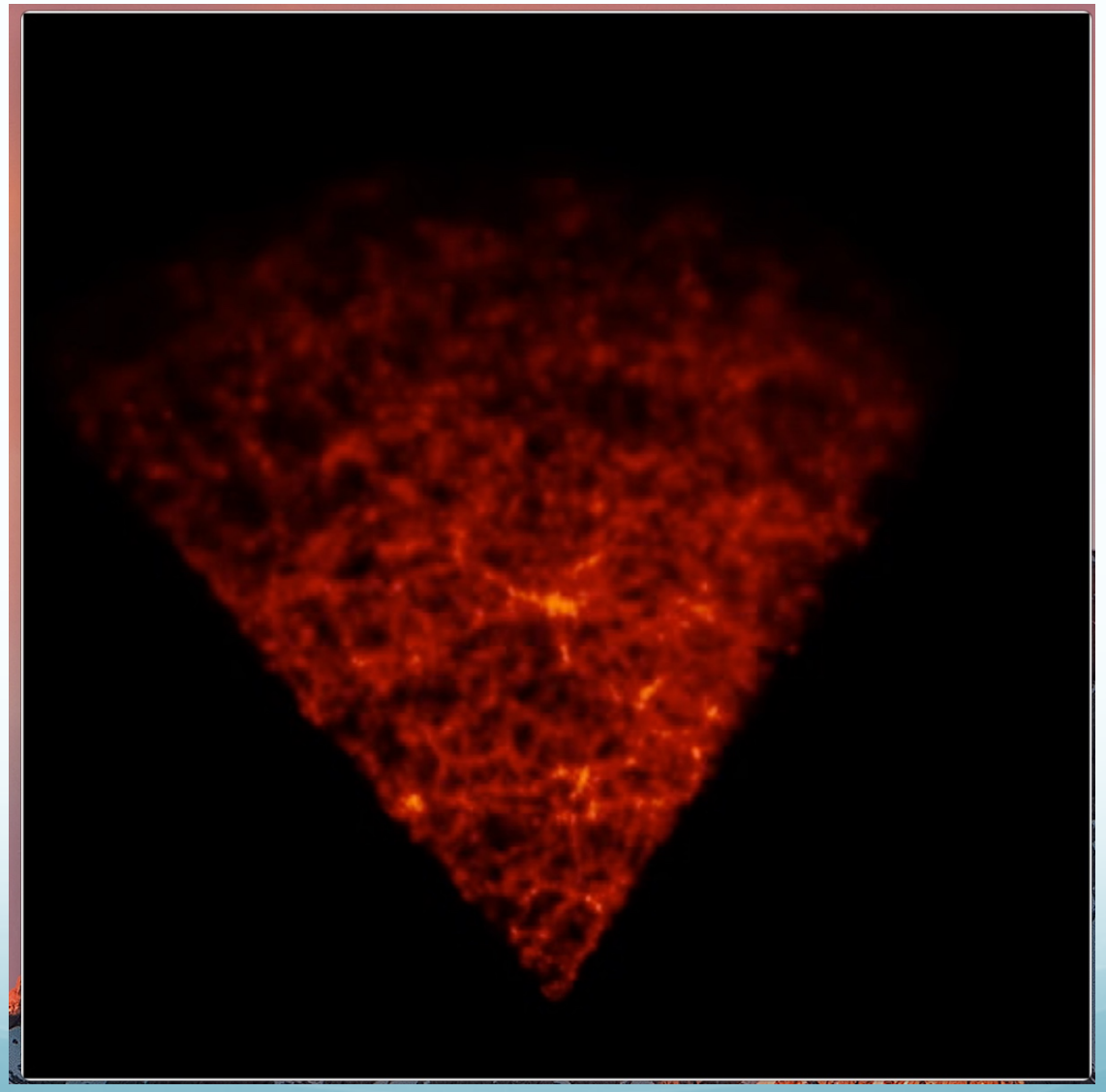




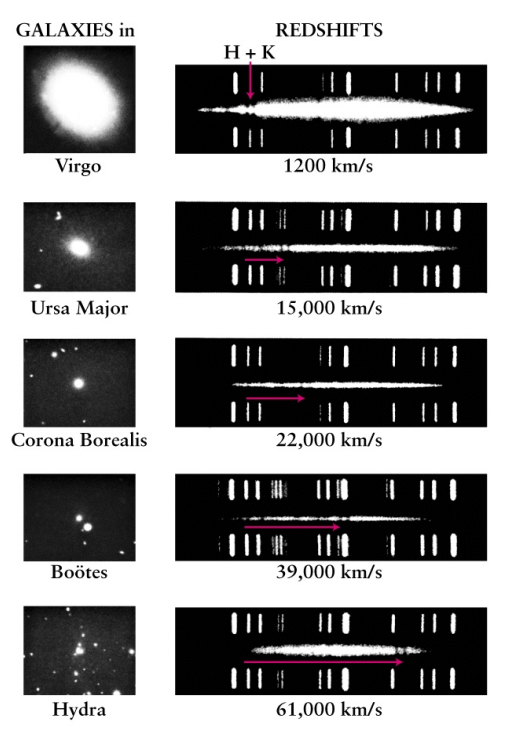
2dF Galaxy Redshift Survey

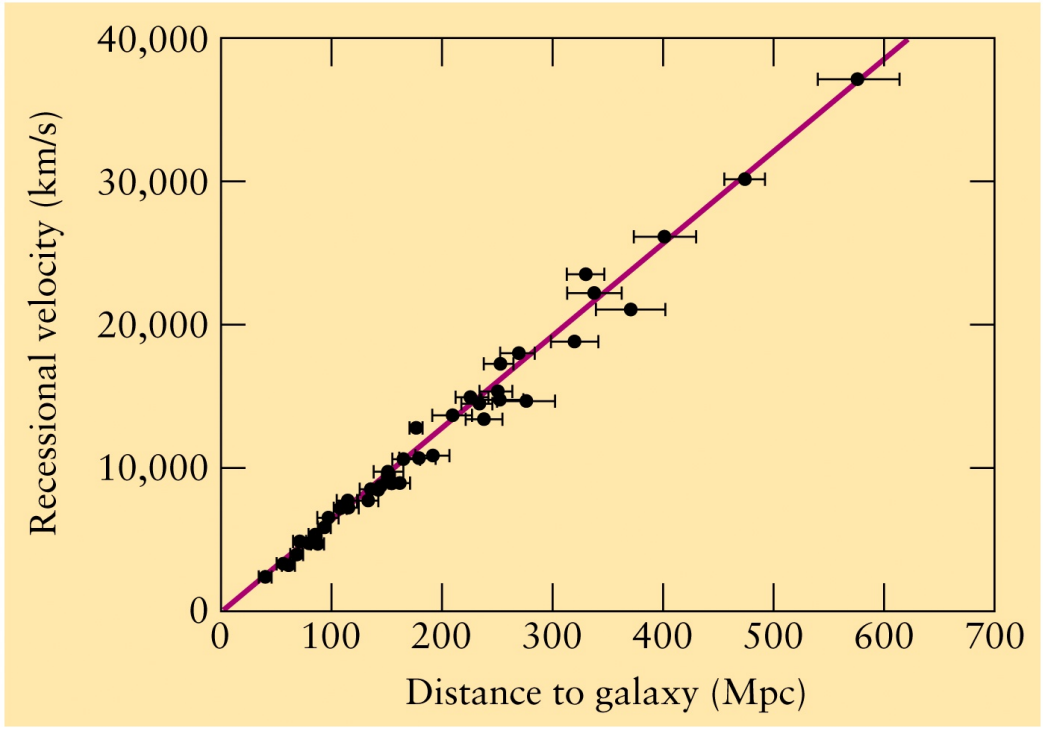
Large Scale Structure

Mapped via the Cosmological Redshift!



Hubble's Experiment
The Expansion of the Universe





- Estimated distances to bright galaxies
- Measured their velocities using the Doppler Shift
- Discovered a linear relation between speed and distance

Hubble's Law

- Hubble found two remarkable results:
  - Apart from a few nearby galaxies, all were receding
  - The more distant the galaxy, the faster it is moving away
- Found a linear relation between distance and speed

$$v = H_0 D, \text{ with } H_0 = 73 \text{ km/s/Mpc}$$

$$\text{or equivalently } H_0 = 2.4 \times 10^{-18} \text{ s}^{-1}$$

  - Note: Hubble actually obtained $H_0 \sim 500$ km/s/Mpc
- The result is now known as "Hubble's Law" for the expansion of the Universe.

The Hubble-Lemaitre Law

"Un Universe homogeneous de masses constant et de rayon croissant rendant de la Vitesse radiate des nébuleuses extra-galactiques"

[A homogeneous Universe of constant mass and growing radius accounting for the radial velocity of extragalactic nebulae]

Lemaitre, 1927 (two years before Hubble)

In 2019 the International Astronomical Union decided to recognise the contribution of Belgian Astronomer George Lemaitre to formulating our understanding of the expansion of the universe by renaming Hubble's law.

See Astronotes blog article (search for Lemaitre):
http://www.armaghplanet.com/blog/

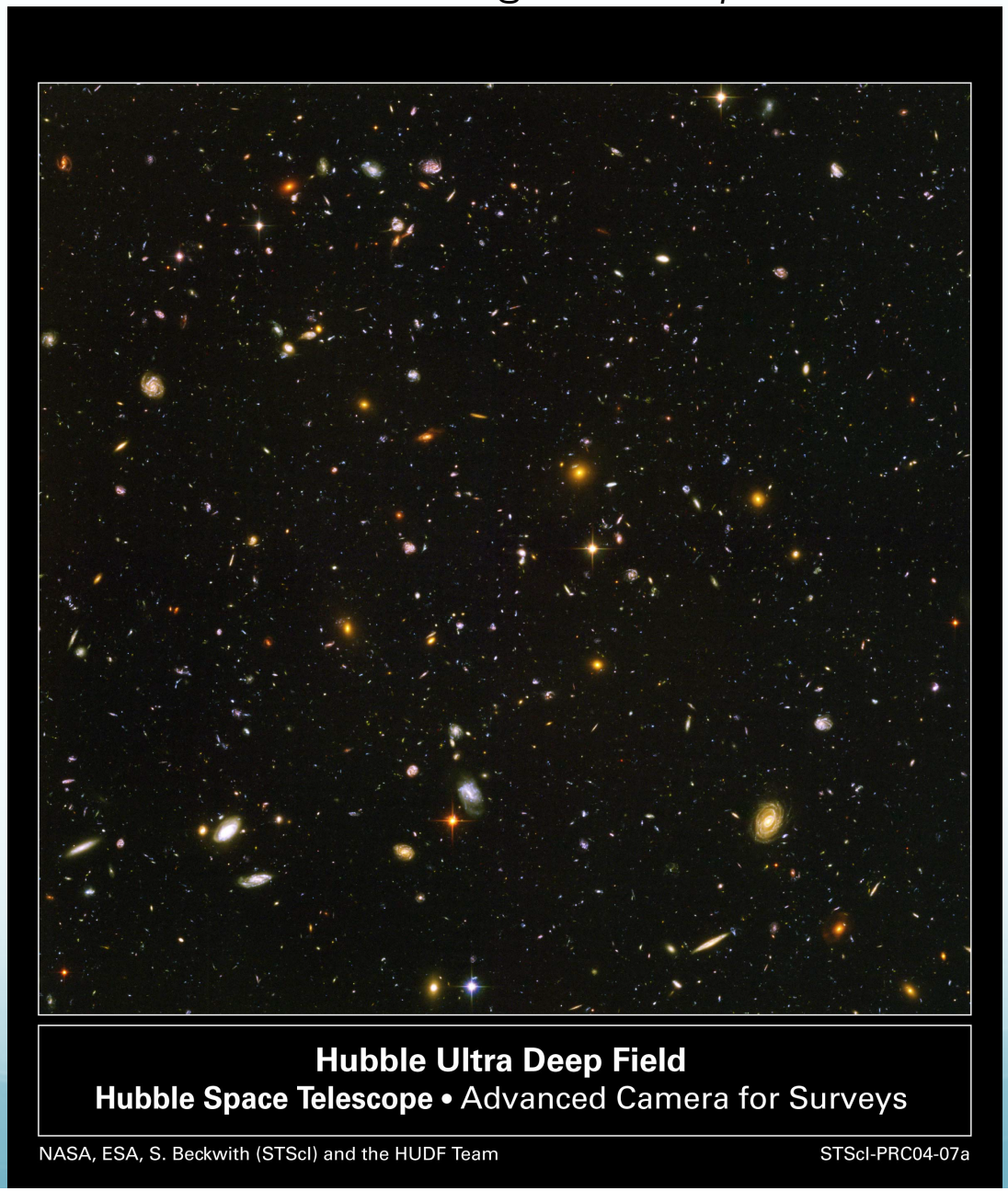
The Age of the Universe

- Suppose that rate of expansion of the Universe is constant
  - i.e. H_0 really is a constant
- Then at some distant time in the past all galaxies were "together"
  - i.e. the Universe had a beginning!
    - The "Big Bang"
- Suppose this happened a time T ago.
  - Distance away from us for a galaxy is given by $D=vT$
  - Since $v=H_0D$ then $vT=D=H_0DT$
  - So that $1=H_0T$
- Thus, the age of Universe is given by $T=1/H_0$
  - Exercise: show T = 1.3 x 10^{10} years = 13 billion years
    - *Note: this only strictly applies for uniform expansion, but it turns out to be remarkably close to the best estimates made today.*

The Hubble Deep Field

Galaxies as far as the largest telescopes can see!

We are looking back in time and viewing the history of the Universe!

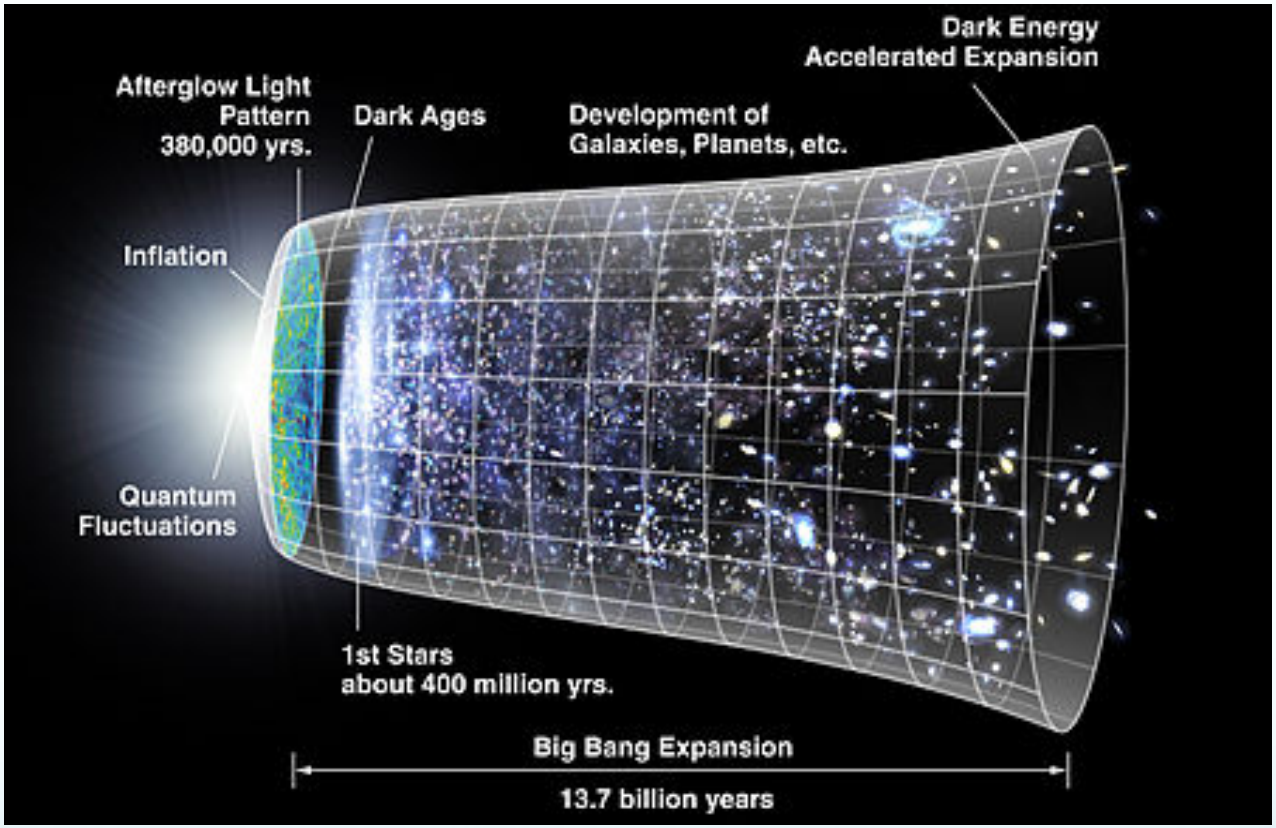


Hubble Ultra Deep Field
Hubble Space Telescope • Advanced Camera for Surveys

NASA, ESA, S. Beckwith (STScI) and the HUDF Team

STScI-PRC04-07a

The Universe is Accelerating?!



The latest measurements show that the rate of expansion is in fact increasing;
i.e. the Universe is accelerating!

Driven by a currently unknown "Dark Energy". What is it??!!

The Hypercube and the Hill of Infinity