Cosmology – Basic Facts

Basic Facts

Cosmology deals with answering the questions about the universe as a whole.

The main question is:

How did the universe evolve into what it is now?

For this, *four major facts* need to be taken into account:

The universe is:
- expanding,
- isotropic,
- and homogeneous.

The isotropy and homogeneity of the universe is called the *cosmological principle*.

Perhaps (for us) the most important fact is:

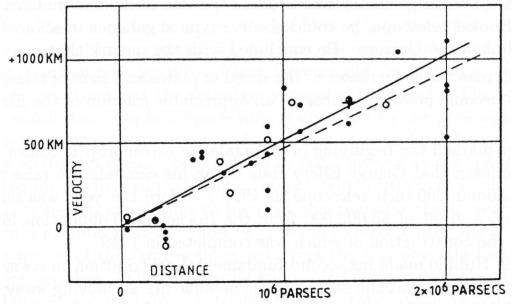
- The universe is habitable to humans.

i.e., the *anthropic principle*.

The one question cosmology does not attempt to answer is: How came the universe into being?

$\Longrightarrow$ Realm of theology!

Expansion, I



(Hubble, 1929, Fig. 1)

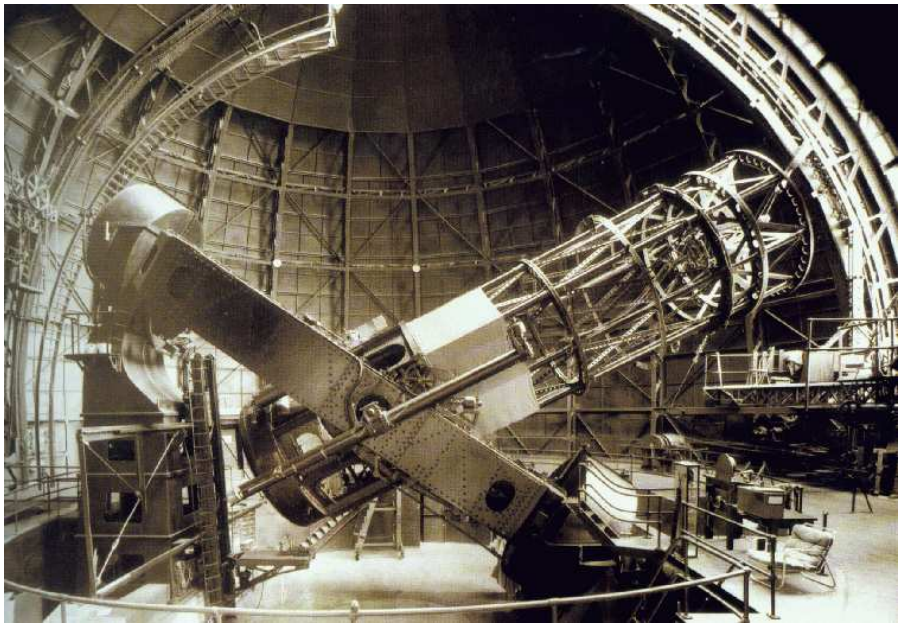
Hubble (1929): Velocity v (defined as $v/c := z = \Delta\lambda/\lambda$) for galaxy at distance r is

$$v(r) = H_0 r + v_X \cos\alpha\cos\delta + v_Y \sin\alpha\cos\delta + v_Z \sin\delta \quad (8.1)$$

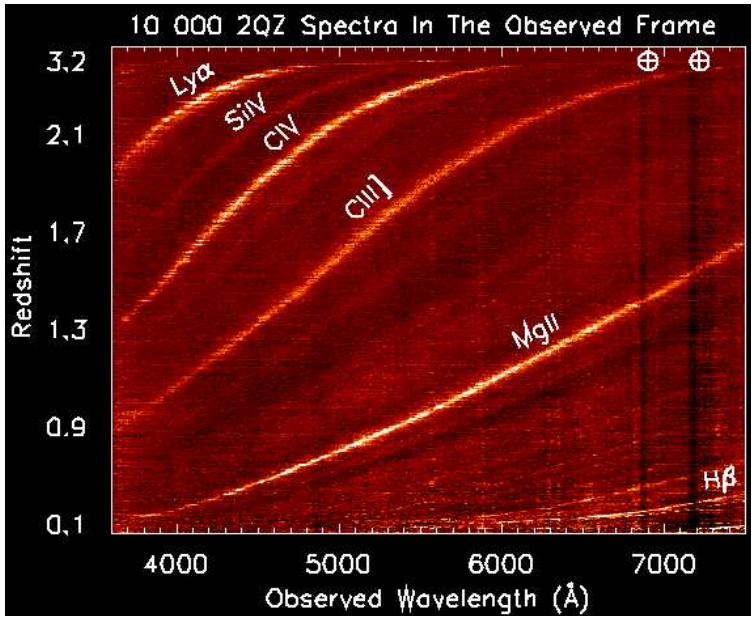
(v_X, v_Y, v_Z) velocity due to motion of solar system ($\sim$ 350 km s^{-1} towards $l = 264°$, $b = 48°$, Bennet et al., 1996)

H_0: "Hubble parameter"; *intrinsic* component of velocity due to *expansion* of the universe.

Old usage: "Hubble constant", but $H_0 \neq$ const. (cf. Eq. (9.49)).

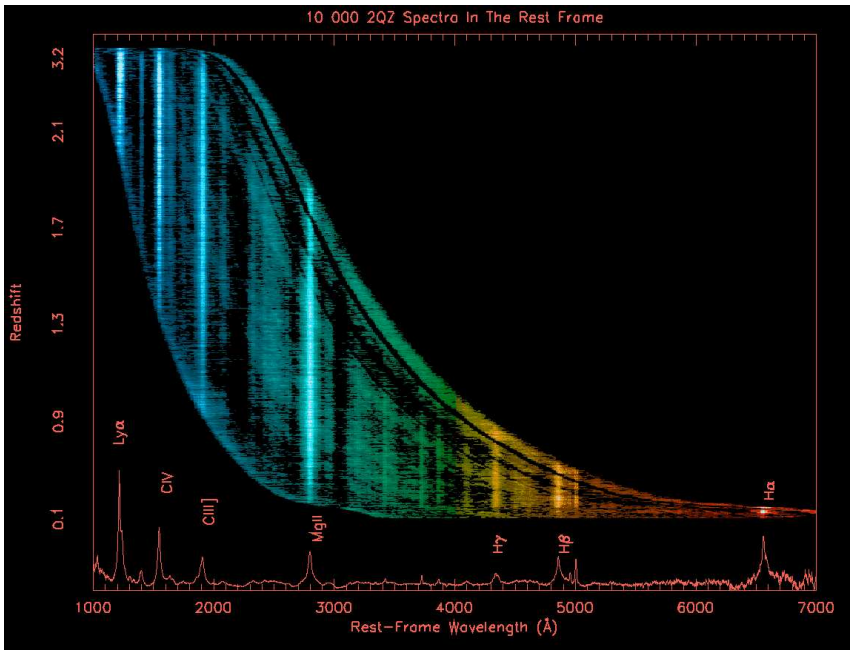


"Hubble's" 2.5 m (100-inch) telescope on Mt. Wilson
(Image: `http://sckim.kasi.re.kr/Images/hooker2_5m.gif`)

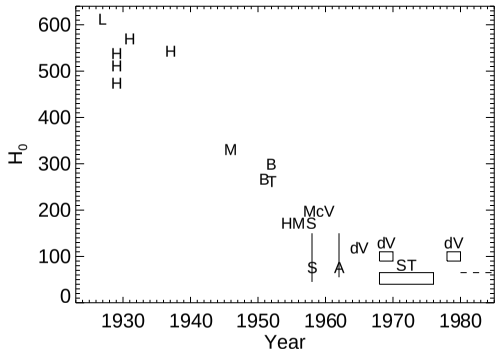


courtesy 2dF QSO Redshift survey

As a consequence of the cosmological redshift, for different z different parts of the spectrum of a distant source are visible.



Expansion, V



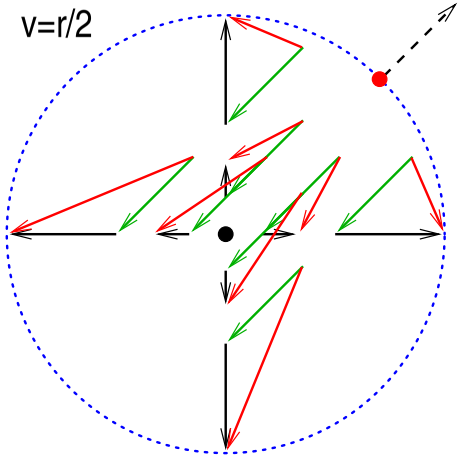
(after Trimble, 1997)

Currently accepted value:
$H_0 \sim 75\,\mathrm{km\,s^{-1}\,Mpc^{-1}}$.
The systematic uncertainty of H_0 is $\sim 10\,\mathrm{km^{-1}\,s^{-1}\,Mpc^{-1}}$.
Parameterize uncertainty in formulae by defining

$$H_0 = 100\,\mathrm{km\,s^{-1}\,Mpc^{-1}} \cdot h$$
$$H_0 = 75\,\mathrm{km\,s^{-1}\,Mpc^{-1}} \cdot h_{75} \quad (8.2)$$

Note: H_0^{-1} has units of time: $H_0^{-1} = 9.78\,\mathrm{Gyr}/h$: Hubble-Time;
for $h = 0.75$, the Hubble-Time is 13 Gyr.

Expansion, VI



Expansion law $\boldsymbol{v} = H_0\boldsymbol{r}$ is unchanged under rotation and translation: isomorphism.

Proof:

Rotation: Trivial.

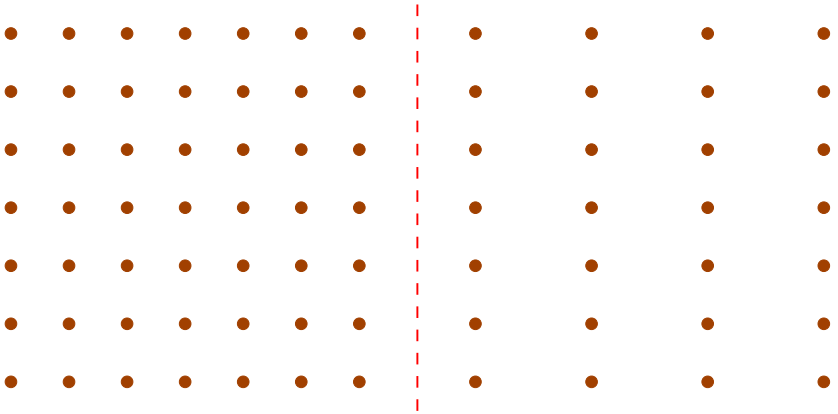
Translation: Observations from place with position $\boldsymbol{r}'$ and velocity $\boldsymbol{v}'$: Observed distance is $\boldsymbol{r}_\mathrm{o} = \boldsymbol{r} - \boldsymbol{r}'$, observed velocity is $\boldsymbol{v}_\mathrm{o} = \boldsymbol{v} - \boldsymbol{v}'$. Because of the Hubble law,

$$\boldsymbol{v}_\mathrm{o} = H_0\boldsymbol{r} - H_0\boldsymbol{r}' = H_0\,(\boldsymbol{r} - \boldsymbol{r}') = H_0\boldsymbol{r}_\mathrm{o}$$

This isomorphism is a direct consequence of the homogeneity of the universe.

Despite everything receding from us, we are not at the center of the universe $\Longrightarrow$ Copernicus principle still holds.

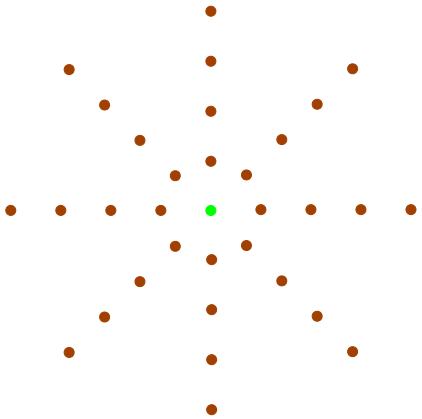
Homogeneity and Isotropy, I



after Silk (1997, p. 8).

Note that homogeneity does not imply isotropy!

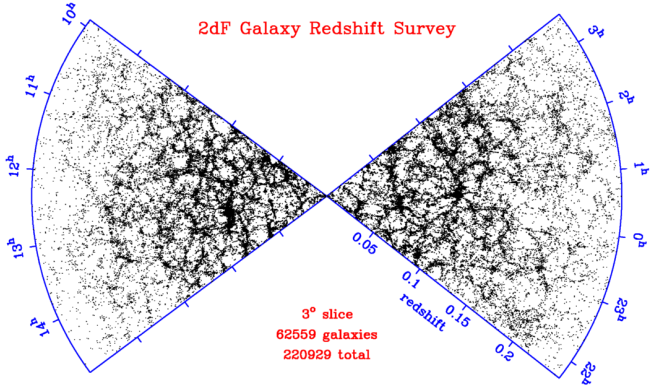
Homogeneity and Isotropy, II



Neither does isotropy *around one point* imply homogeneity!

$\Longrightarrow$ *Both* assumptions need to be tested.

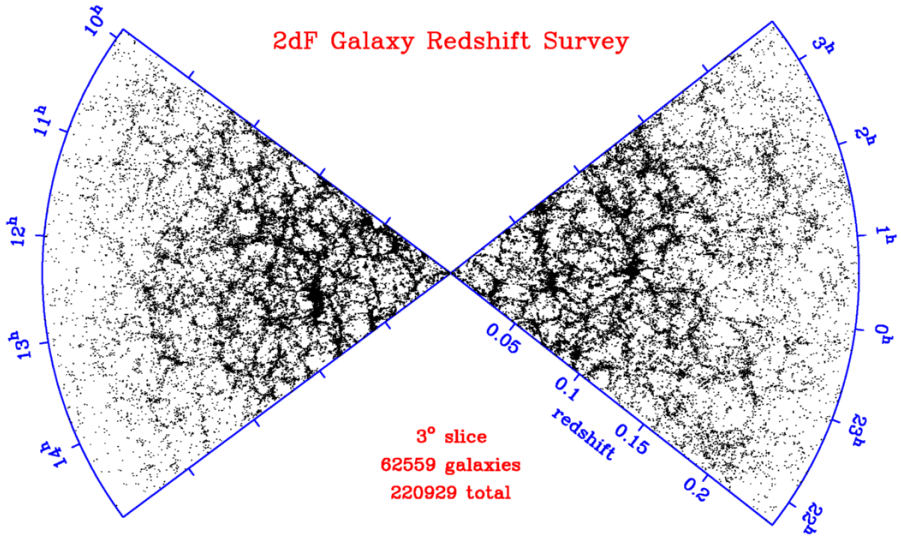
Homogeneity, I



2dF Survey, ∼220000 galaxies total

The universe is homogeneous $\Longleftrightarrow$ The universe looks the same everywhere in space

Testable by observing spatial distribution of galaxies.

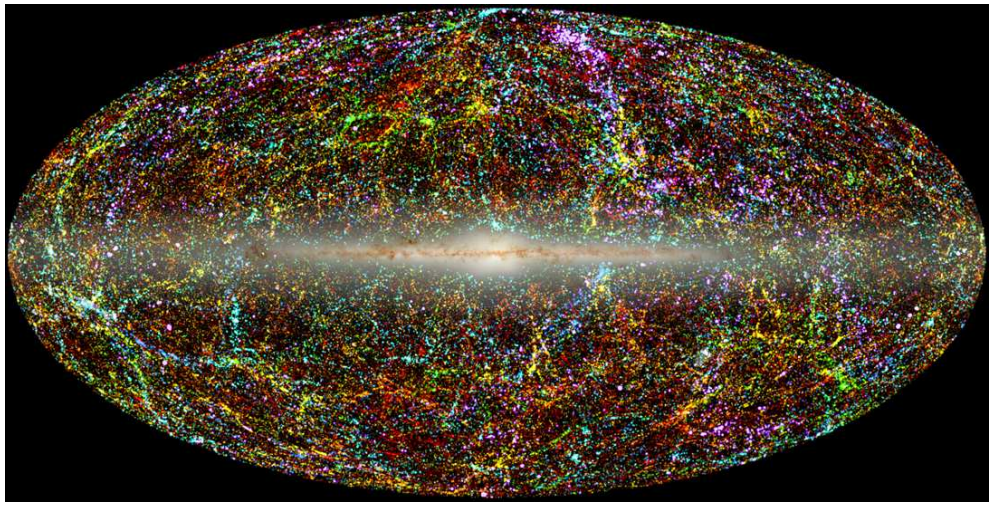


2dF Survey, ∼220000 galaxies total

On scales $\gg$100 Mpc the universe looks indeed the same.

Below that: structure.

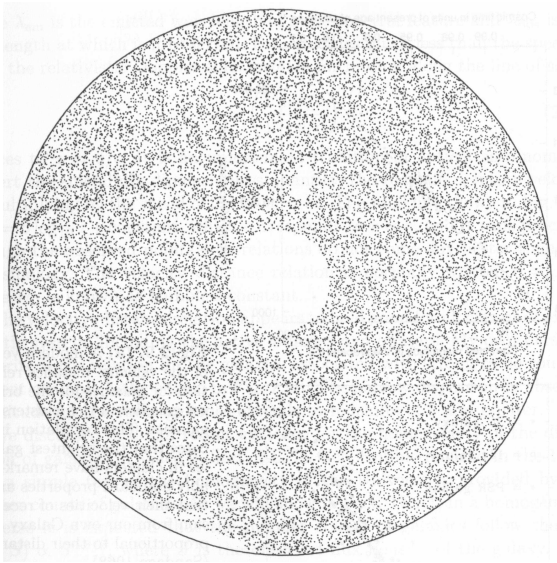
Structures seen are galaxy clusters (gravitationally bound) and superclusters (larger structures, not [yet] gravitationally bound).



(Jarrett, 2004, Fig. 1)

Distribution of Galaxy redshifts in the 2MASS galaxy catalogue
(color code: blue - $z < 0.01$; green - $0.01 < z < 0.04$; red - $0.04 < z < 0.1$)

Isotropy

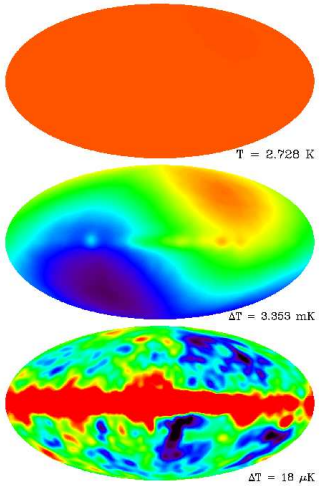


The universe is isotropic
$\Longleftrightarrow$ The universe looks the same in all directions
Radio galaxies are mainly quasars
$\Longrightarrow$ Sample large space volume ($z \gtrsim 1$)
$\Longrightarrow$ Clear isotropy.

Peebles (1993): Distribution of 31000 objects at λ =6 cm from the Greenbank Catalogue.

Anisotropy in the image: galactic plane, exclusion region around Cyg A, Cas A, and the north celestial pole.

Isotropy



Best evidence for isotropy: Intensity of 3 K Cosmic Microwave Background (CMB) radiation.

First: dipole anisotropy due to motion of Sun (see slide 8–3), after subtraction: $\Delta T/T \lesssim 10^{-4}$ on scales from $10''$ to 180°.

At level of 10^{-5}: structure in CMB due to structure of surface of last scattering of the CMB photons, i.e., structure at the time when Hydrogen recombined.

Bennet, C. L., et al., 1996, ApJ, 464, L1

Hubble, E. P., 1929, 15, 168

Jarrett, T., 2004, Proc. Astron. Soc. Aust., 21, 396

Peebles, P. J. E., 1993, Principles of Physical Cosmology, (Princeton: Princeton Univ. Press)

Silk, J., 1997, A Short History of the Universe, Scientific American Library 53, (New York: W. H. Freeman)

Trimble, V., 1997, Space Sci. Rev., 79, 793