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:

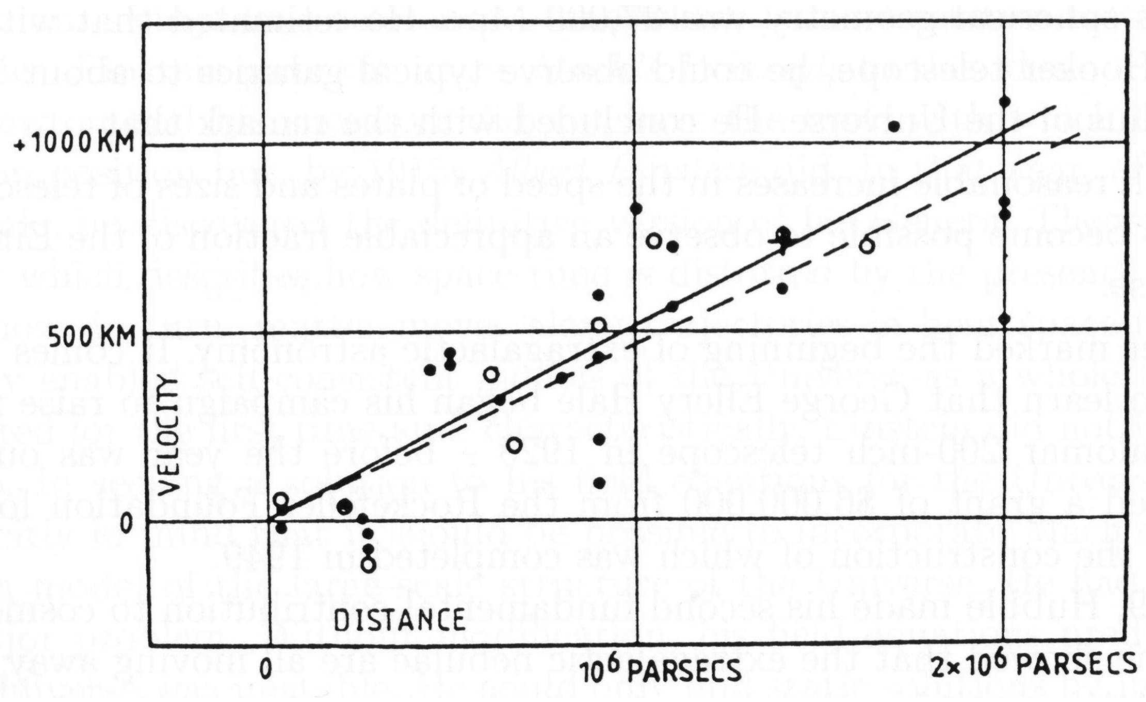
- The universe is habitable to humans.

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

$$v(r) = H_0 r + X\cos\alpha\cos\delta + Y\sin\alpha\cos\delta + Z\sin\delta \quad (3.1)$$

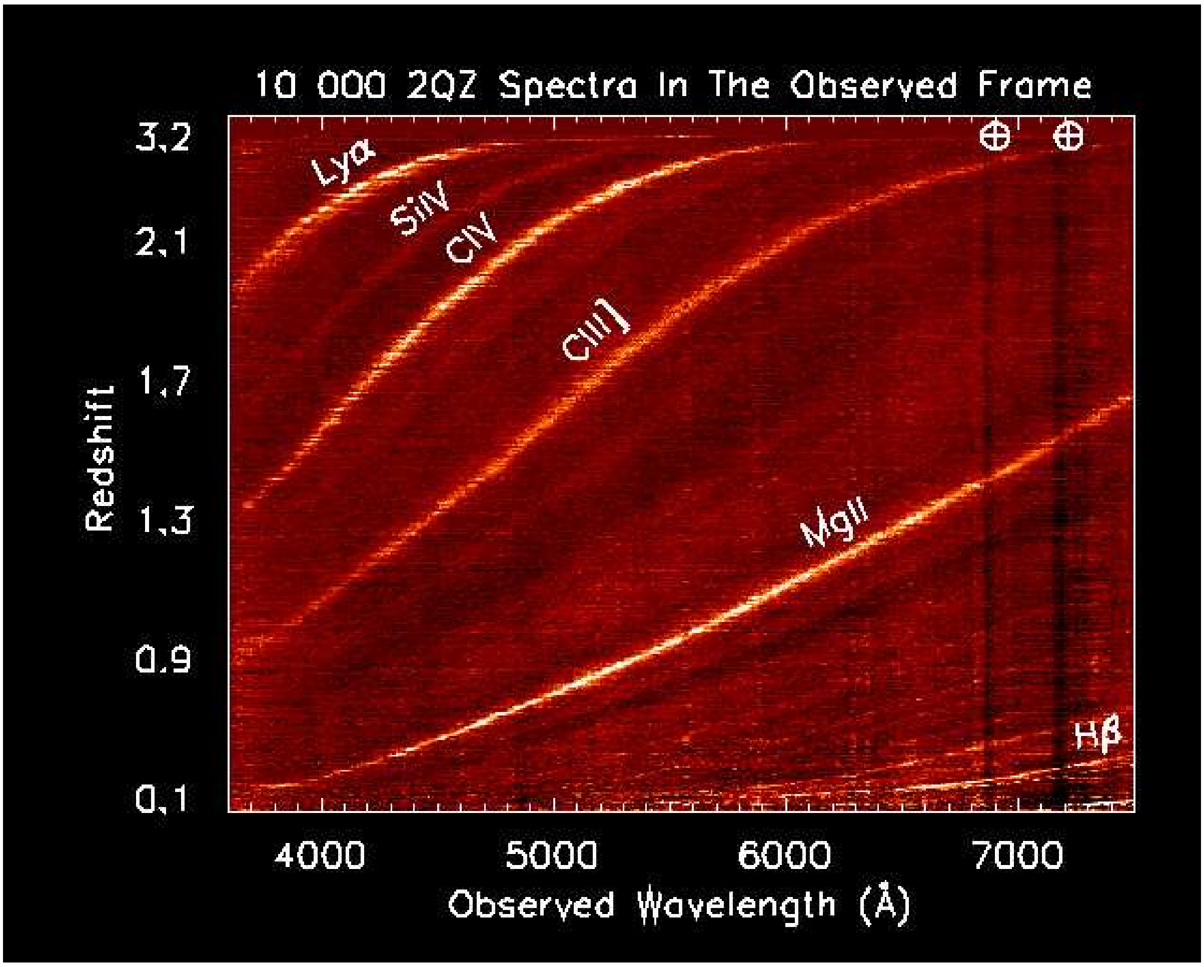
(X, Y, Z) velocity due to motion of solar system ($\sim$350 km/s towards $l = 264^\circ$, $b = 48^\circ$, Bennet et al., 1996)

H_0: *intrinsic* component of velocity due to *expansion* of the universe.

H_0: Hubble parameter

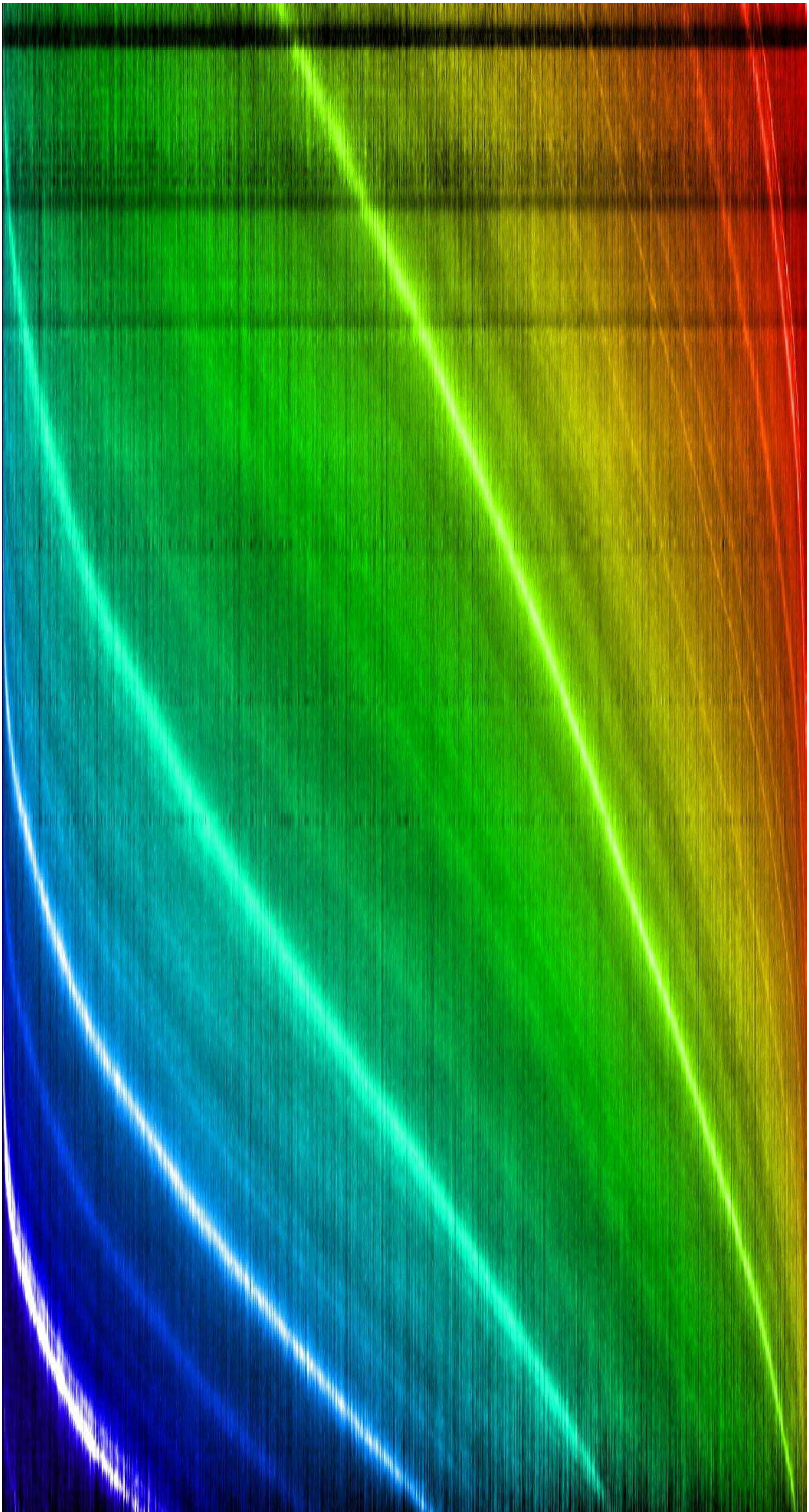
Old usage: "Hubble constant", but $H_0 \neq$ const. (cf. Eq. (4.38)).

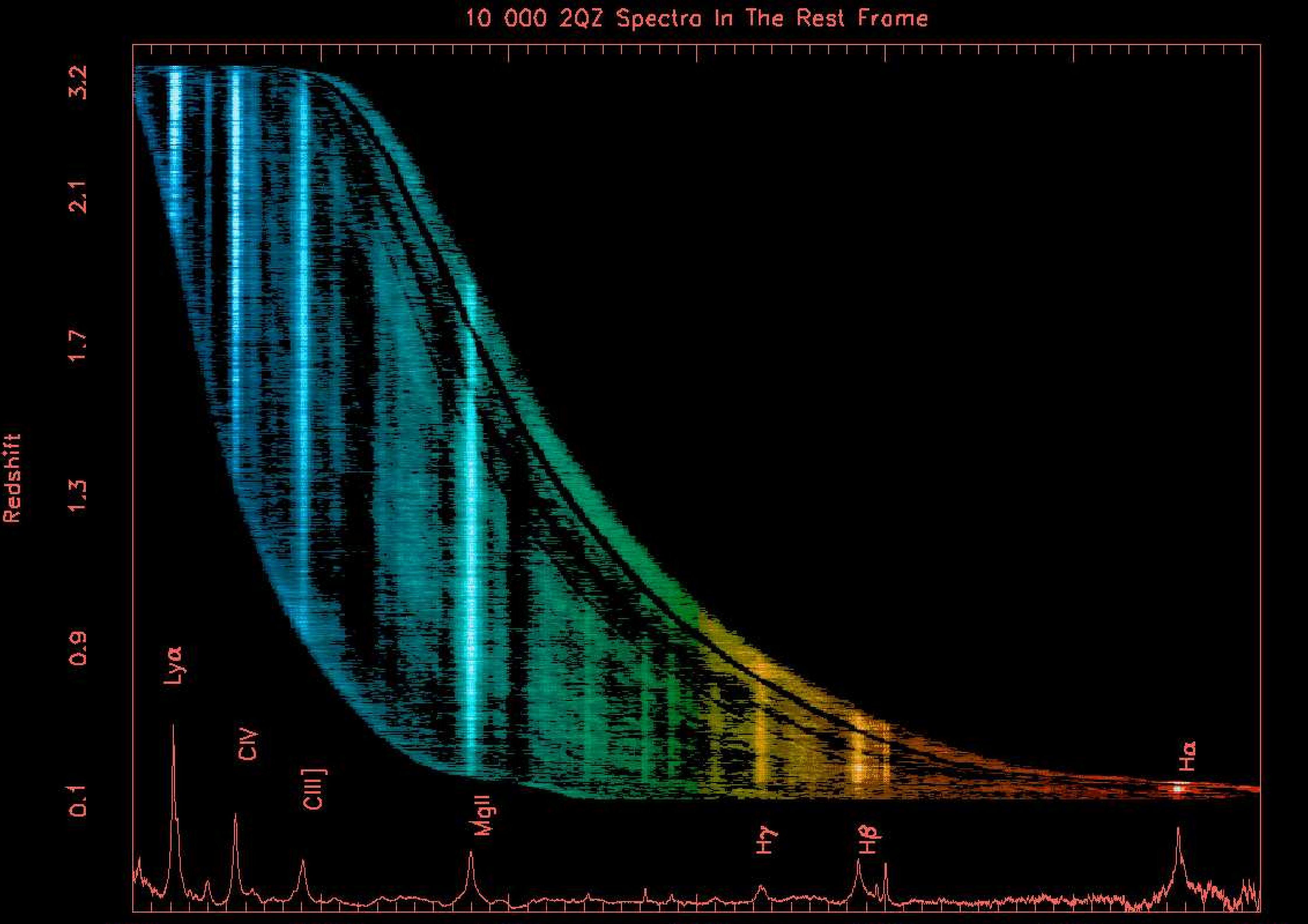
Expansion, II



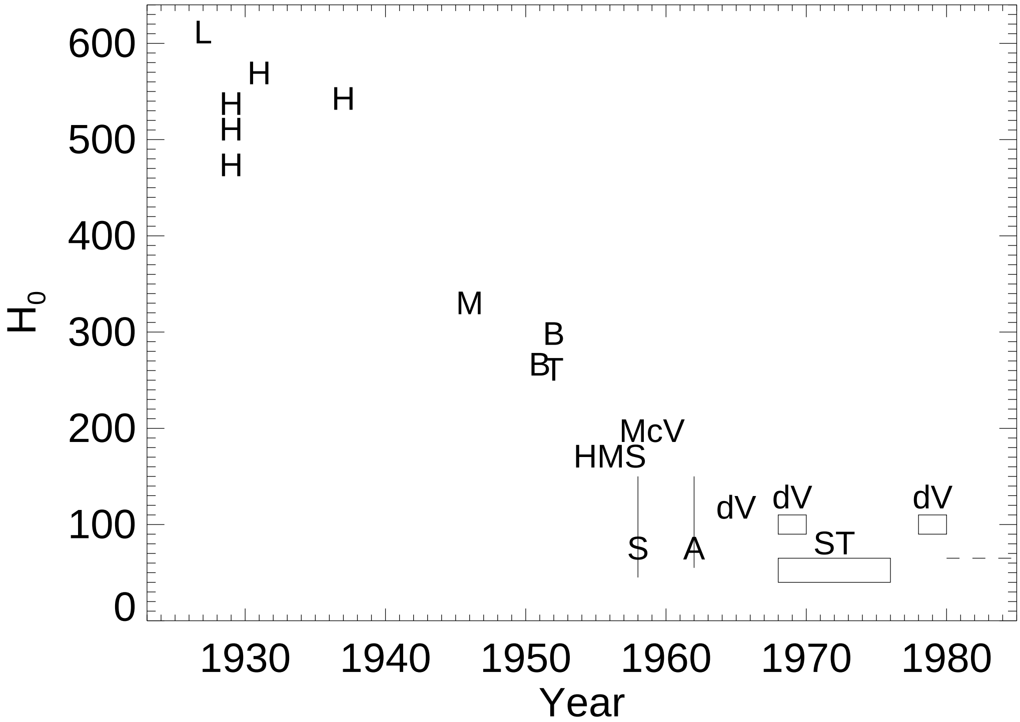
courtesy 2dF QSO Redshift survey

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




10 000 2QZ Spectra In The Rest Frame
Redshift
3.2
2.1
1.7
1.3
0.9
0.1
Lyα
CIV
CIII]
MgII
Hγ
Hβ
Hα

Expansion, V



(after Trimble, 1997)

Currently accepted value: $H_0 \approx 75\,\mathrm{km/s/Mpc}$.

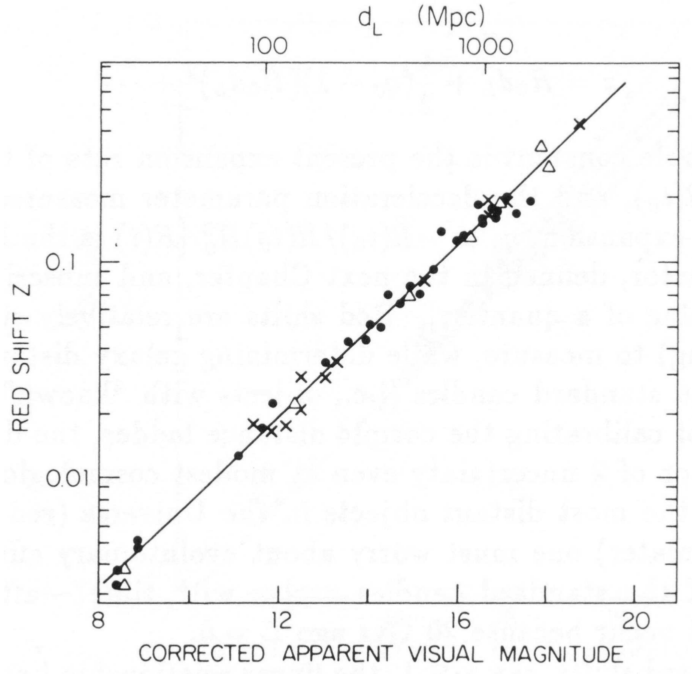
The systematic uncertainty of H_0 is 10...20 km/s/Mpc

$\Longrightarrow$ parameterize uncertainty in formulae by defining

$$
\begin{aligned}
H_0 &= 100\,\mathrm{km}/\mathrm{s}/\mathrm{Mpc} \cdot h \\
H_0 &= 75\,\mathrm{km}/\mathrm{s}/\mathrm{Mpc} \cdot h_{75}
\end{aligned}
\tag{3.2}
$$

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 13.2 Gyr

Expansion, VI



For standard candles, i.e., objects where the absolute luminosity L is known, the Hubble law can be written using observed quantities only:

Euclidean space $\Longrightarrow$ observed flux

$$f = \frac{L}{4\pi d_{\mathrm{L}}^2} \quad \Longleftrightarrow \quad d_{\mathrm{L}} = \left(\frac{L}{4\pi f}\right)^{1/2} \tag{3.3}$$

where d_{L} is the luminosity distance.
Using the Hubble law eq. (3.1)

$$H_0 d_{\mathrm{L}} = cz \quad \Longrightarrow \quad z \propto H_0 \left(\frac{L}{4\pi f}\right)^{1/2} \tag{3.4}$$

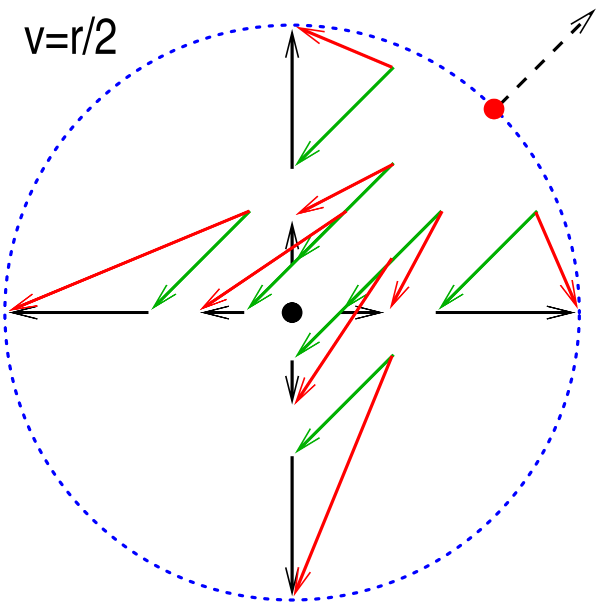
Since *magnitudes* are defined via $m \propto -2.5 \log f$:

$$\log z \propto \log H_0 + \frac{1}{2}(\log L - \log f) \tag{3.5}$$

$$\Longrightarrow \log z = a + b(m - M) \tag{3.6}$$

($m - M$: distance modulus)

Expansion, VII



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

Proof:

Rotation: Trivial.

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

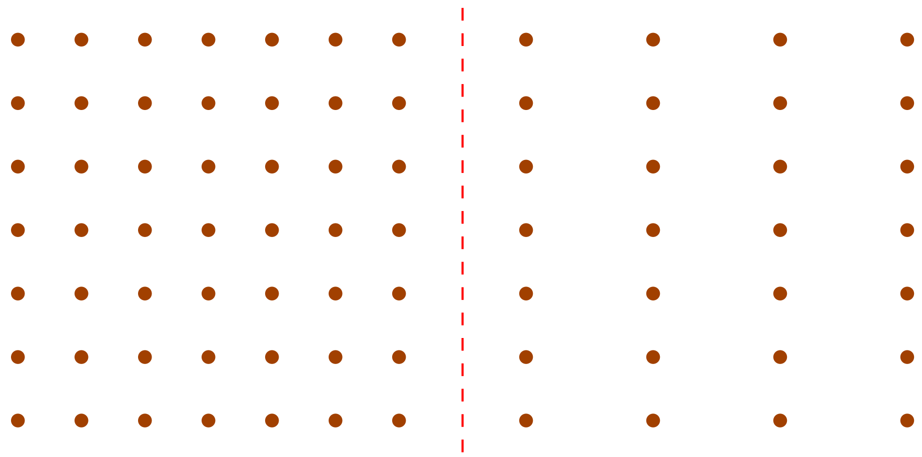
$$\mathbf{v}_\mathrm{o} = H_0\mathbf{r} - H_0\mathbf{r}' = H_0\left(\mathbf{r} - \mathbf{r}'\right) = H_0\mathbf{r}_\mathrm{o}$$

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.

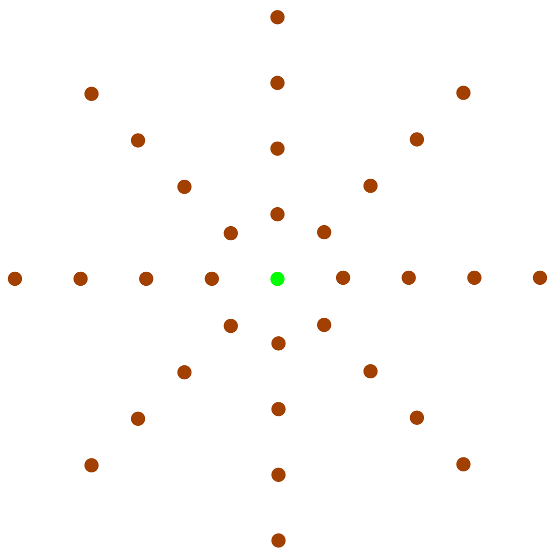
Copernicus principle: We are not at a special place in the universe in time or space.

Homogeneity and Isotropy



after Silk (1997, p. 8).

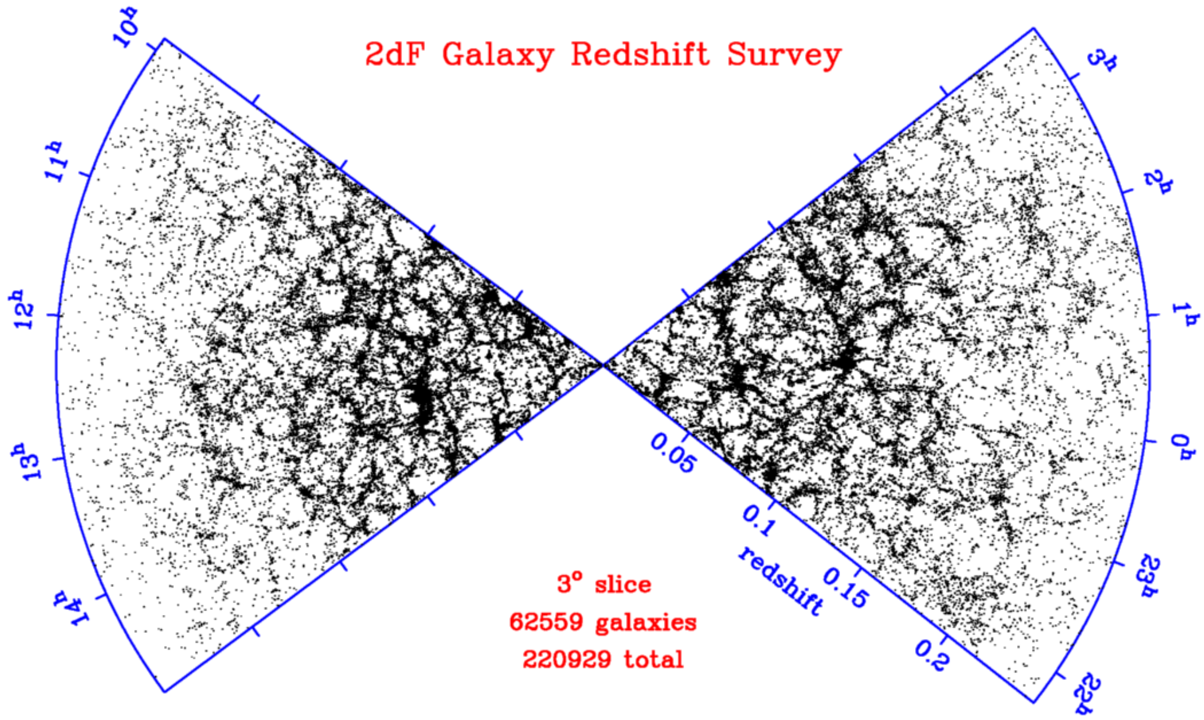
Note that homogeneity does not imply isotropy!



Neither does isotropy *around one point* imply homogeneity!

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

Homogeneity



2dF Survey, ∼220000 galaxies total

The universe is homogeneous ⟺ The universe looks the same everywhere in space

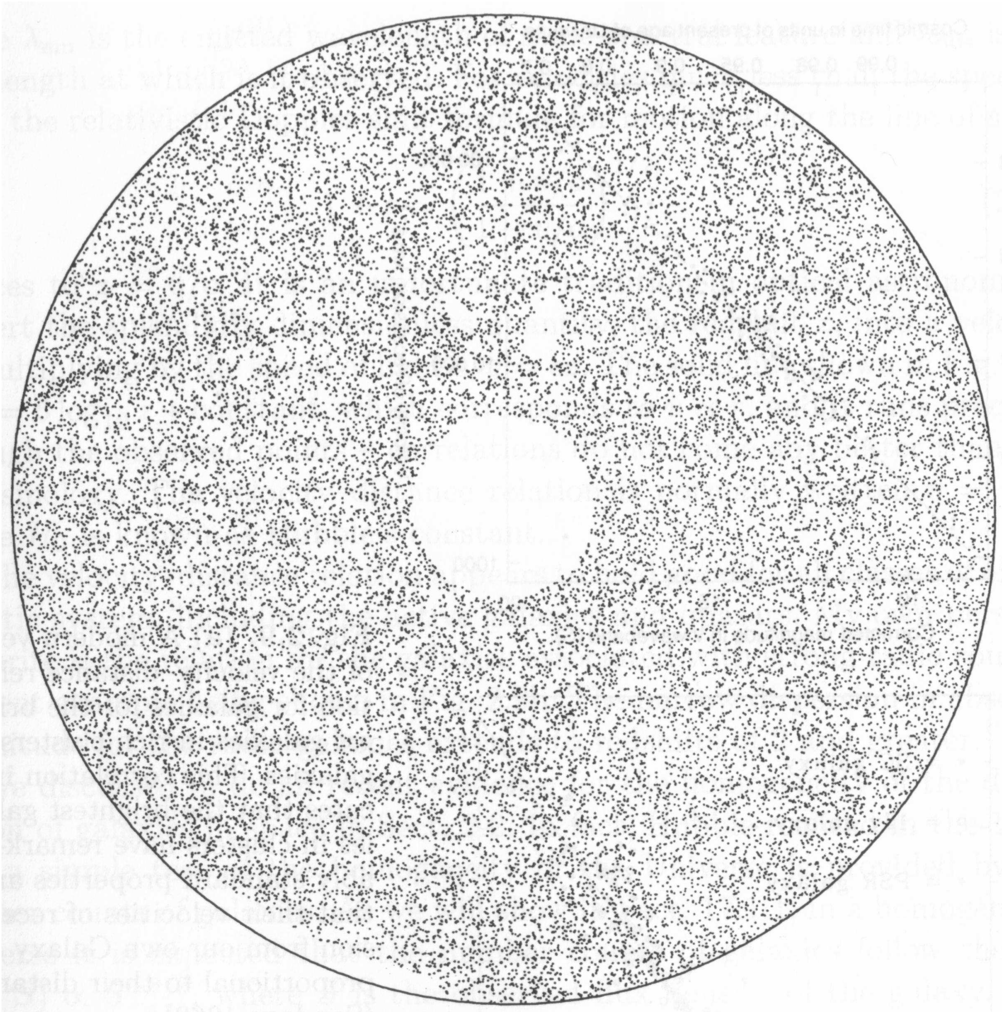
Testable by observing spatial distribution of galaxies.

On scales ≫ 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).

Isotropy



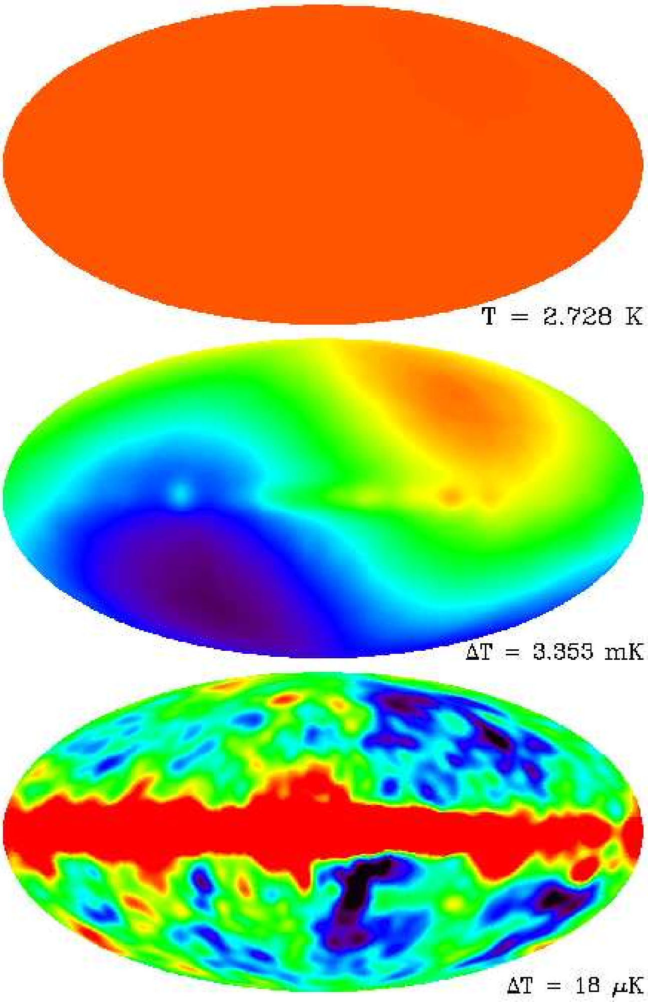
Peebles (1993): Distribution of 31000 objects at $\lambda = 6$ cm from the Greenbank Catalogue.

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.

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

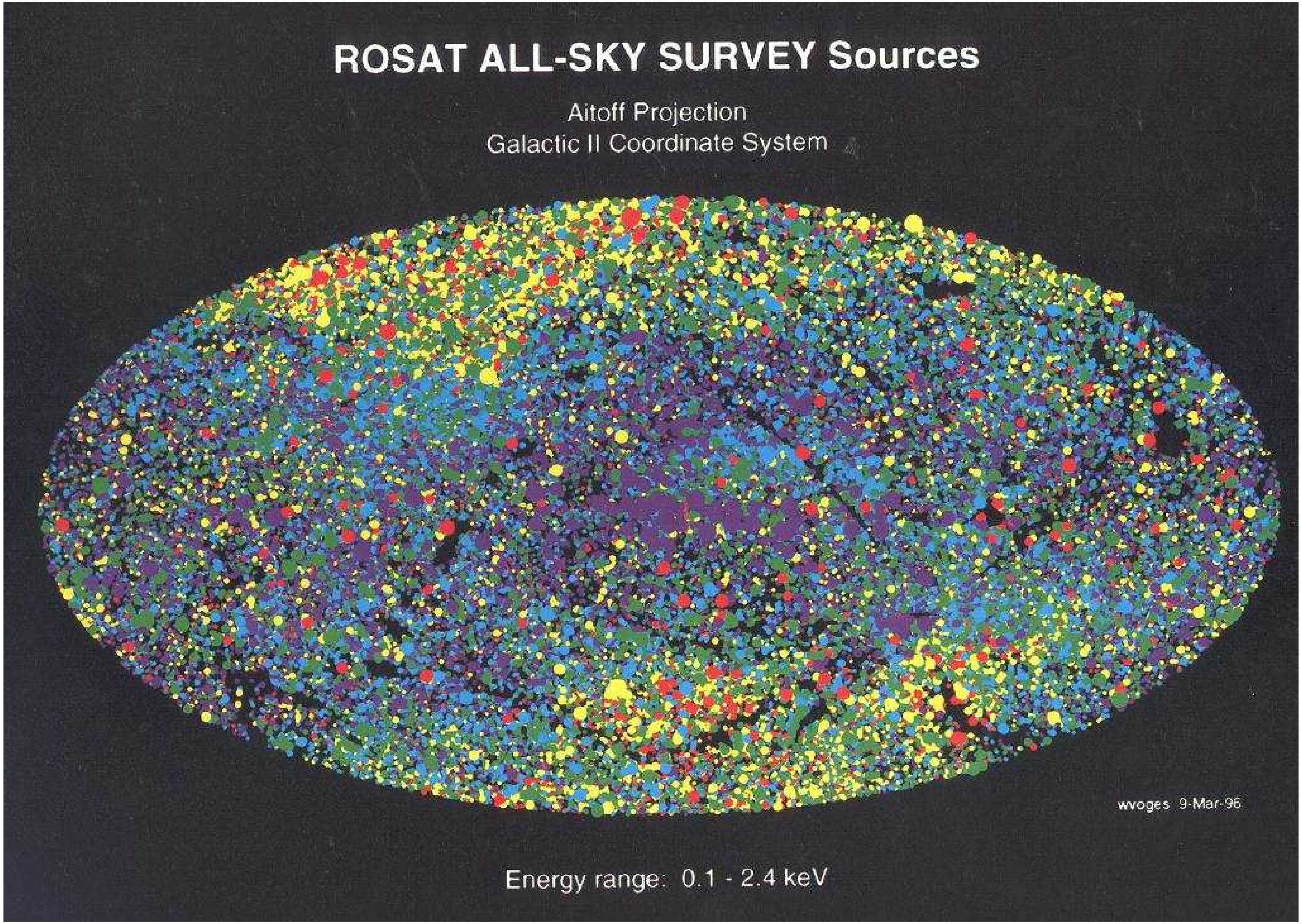
Isotropy



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

First: dipole anisotropy due to motion of sun (see slide 3–3), after subtraction $\Longrightarrow \Delta T/T \lesssim 10^{-4}$ 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.



Also clear isotropy from X-ray source counts as seen in the ROSAT All Sky Survey (0.1. . . 2 keV), which mainly traces distribution of Active Galactic Nuclei (AGN) ("X-ray Background").

Bibliography

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