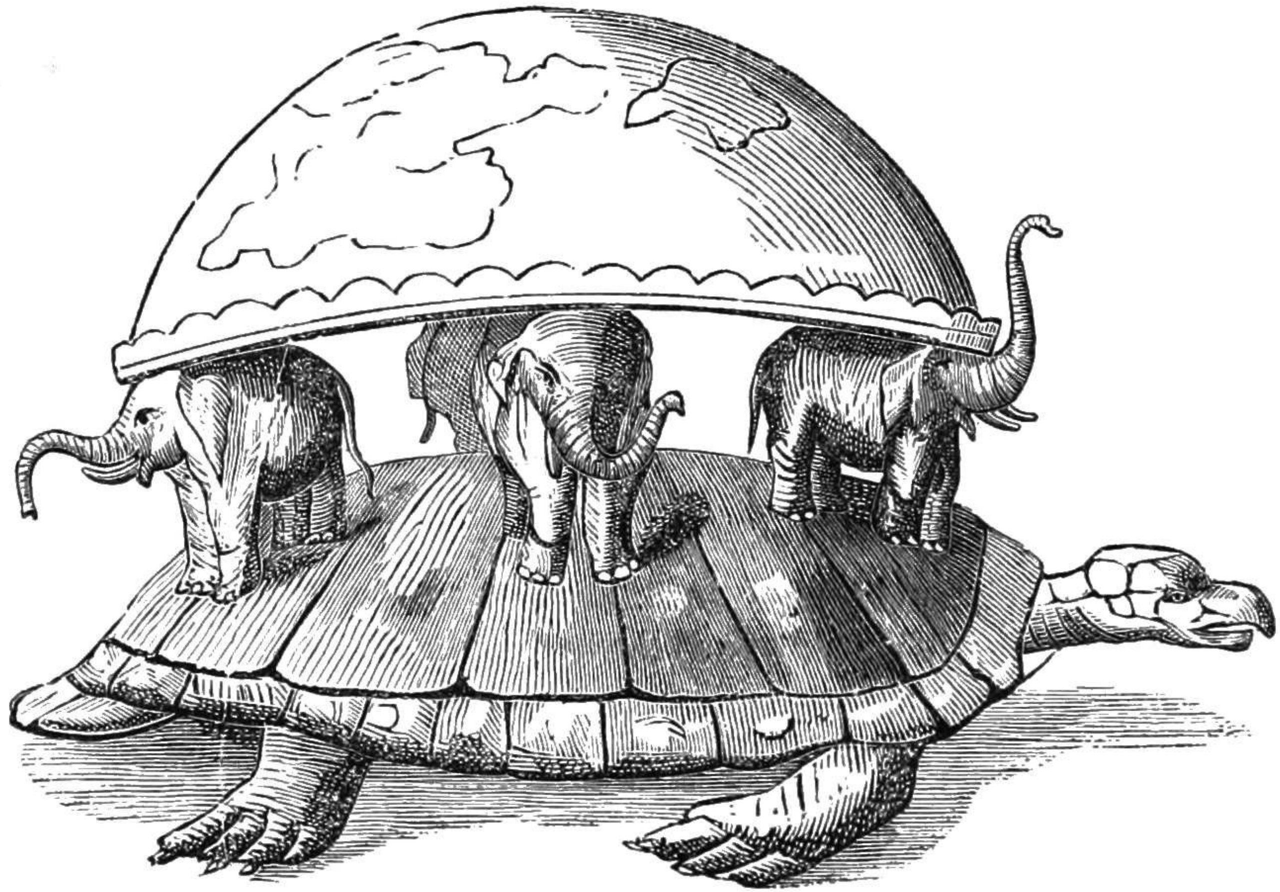
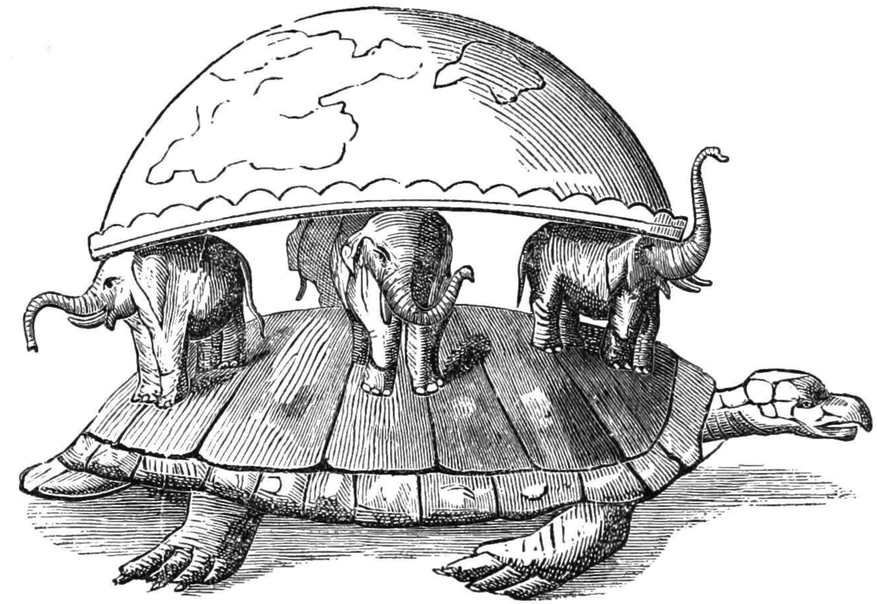
Cosmologia



What is Cosmology



Cosmos= Universe, Order, beauty

-logy= study

Study of the Universe as a whole

Aim at getting an understanding of:

-its origin

-its structure and composition

(where do galaxies, stars, planets, people come from?)

-its evolution

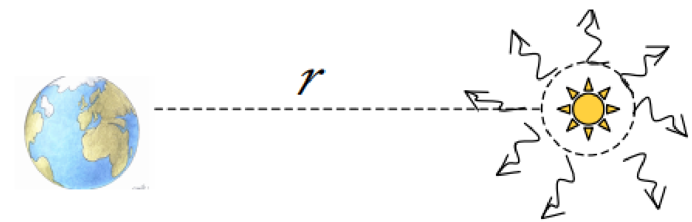
-its fate

-Observational Cosmology & Inference!

Olbers' Paradox (1826): The night sky is dark!

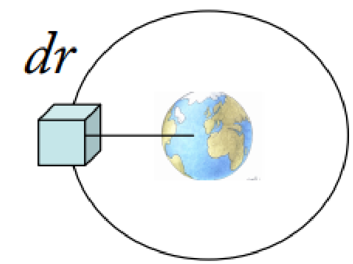
How bright would the night sky be if the distribution of stars was infinite?

Flux from a star $$f = \frac{L}{4\pi r^2}$$



Intensity of radiation form a shell of stars per sterradiant $$dJ = \frac{L}{4\pi r^2} n r^2 dr$$

Density, for simplicity assume constant



If the Universe is infinite: $$J = \int_{r=0}^{r=\infty} dJ = \frac{nL}{4\pi} \int_0^{\infty} = \infty$$

Olbers' Paradox (1826):
The night sky is dark!

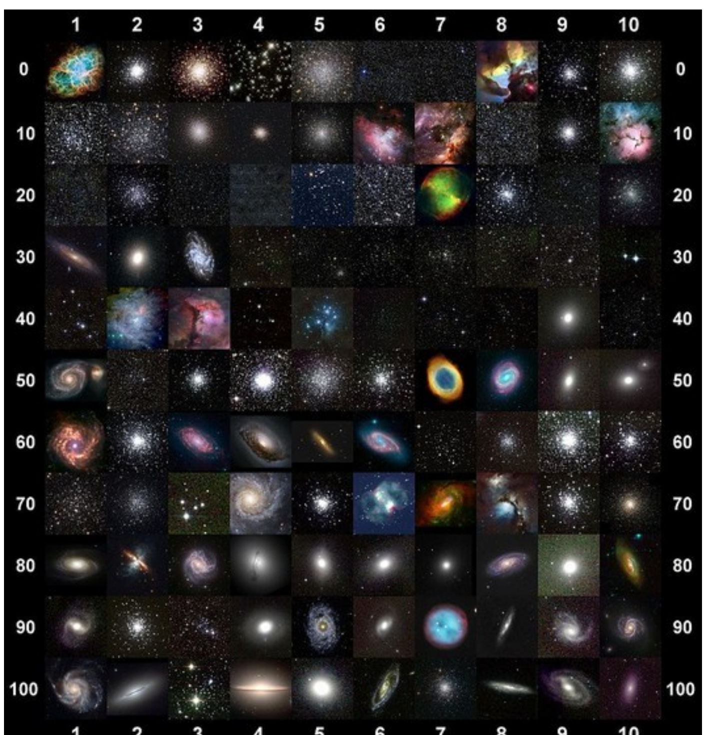
Possible solutions of Olbers' Paradox:

1) Distant stars are hidden by opaque material as dust clouds (This doesn't work in the long run. Those clouds would heat up and we would see them).
2) The Universe has finite size (Or stars occupy only a finite volume.)
3) The Universe has finite age (Or stars have existed for a finite time.)

Either the Universe is not INFINITE or the Universe is not STATIC.

La Via Lattea

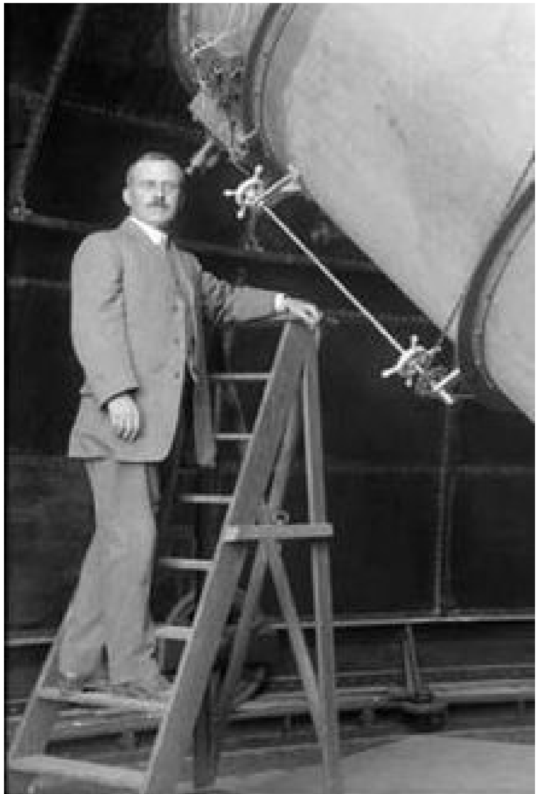
- Pioniere dell'astronomia (radiazione infrarossa, Urano)
- 1786: Classificazione del catalogo di oggetti diffusi di Messier (nebulose)
- 1800: Determinazione della forma della Via Lattea dalla distribuzione di stelle fisse: forma / disco
- (Approssimazione: tutte le stelle hanno la stessa luminosità assoluta.)



Wilhelm Herschel (1738 – 1822)

La Via Lattea e la sua “nebbia”

- 1915 „Big Galaxy“-Ipotesi: Via Lattea sola galassia e "nebbia" all'interno della Via Lattea (H. Shapley)
- 1920 „Universo Isola“-Ipotesi (H.D. Curtis): Via Lattea una delle tante galassie
- **Modello Universo Isola confermato da E. Hubble (1923)**



Hubble's law

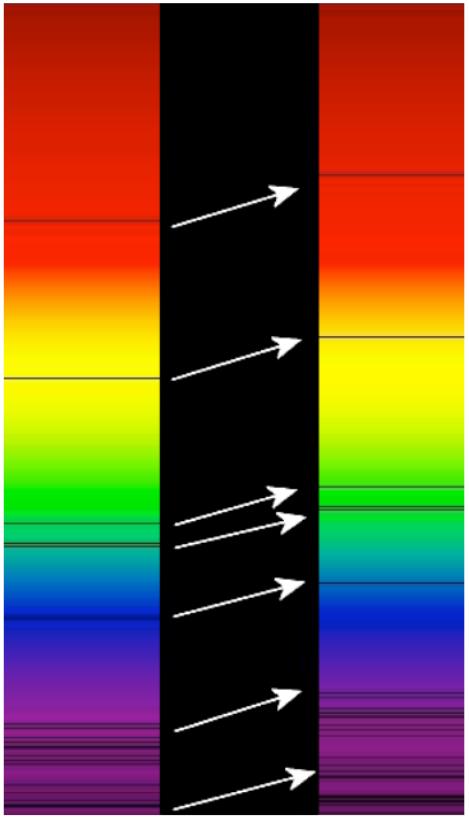
- 1912 - 1920s: Vesto Slipher finds most galaxies (nebulae) are redshifted

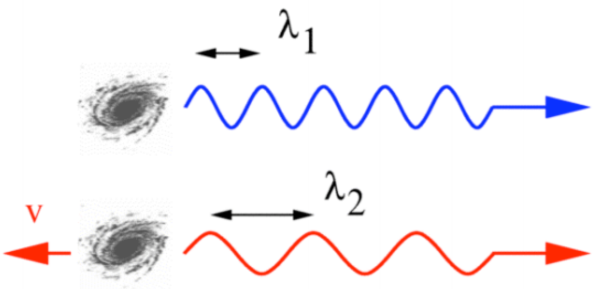
$$z = \frac{\lambda_{\rm obsv} - \lambda_{\rm emit}}{\lambda_{\rm emit}} \quad \text{or} \quad 1 + z = \frac{\lambda_{\rm obsv}}{\lambda_{\rm emit}}$$

In relativity:

$$1 + z = \gamma\left(1 + \frac{v_{\parallel}}{c}\right)$$

$$z \approx \frac{v_{\parallel}}{c}$$ For small velocity

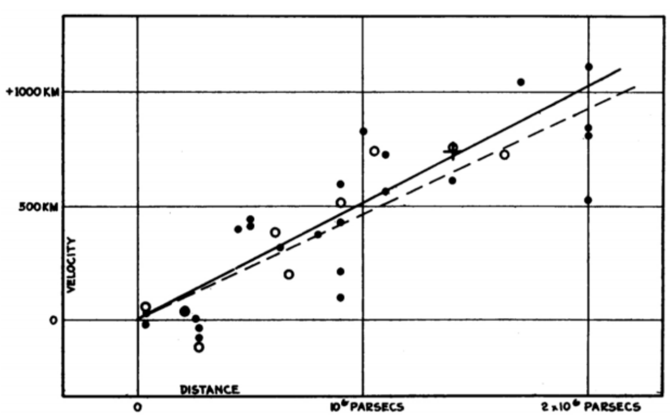




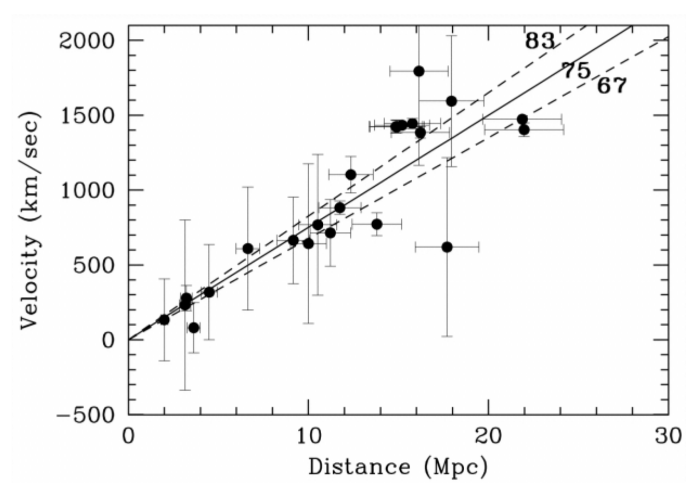
Hubble's law

- Until mid 20s was not clear that our Galaxy was the not the whole Universe
- 1929: Hubble shows that galaxies have a measured redshift proportional to estimated distance
- Edwin Hubble estimates galaxy distances using Cepheid variable stars.

  36 redshifts (positive velocity), 5 blueshifts (negative velocity): "The great preponderance of positive (receding) velocities is very striking"

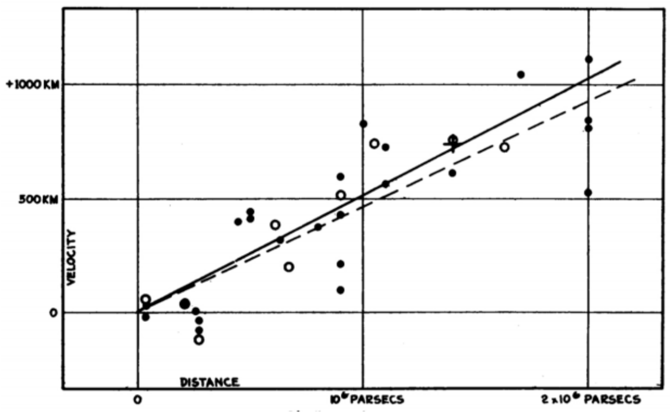


Hubble 1929

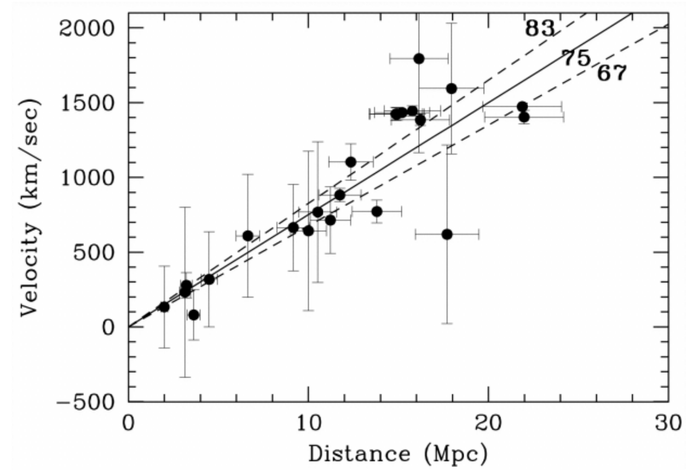


Freedman et al. 2001

Hubble's law



Hubble 1929



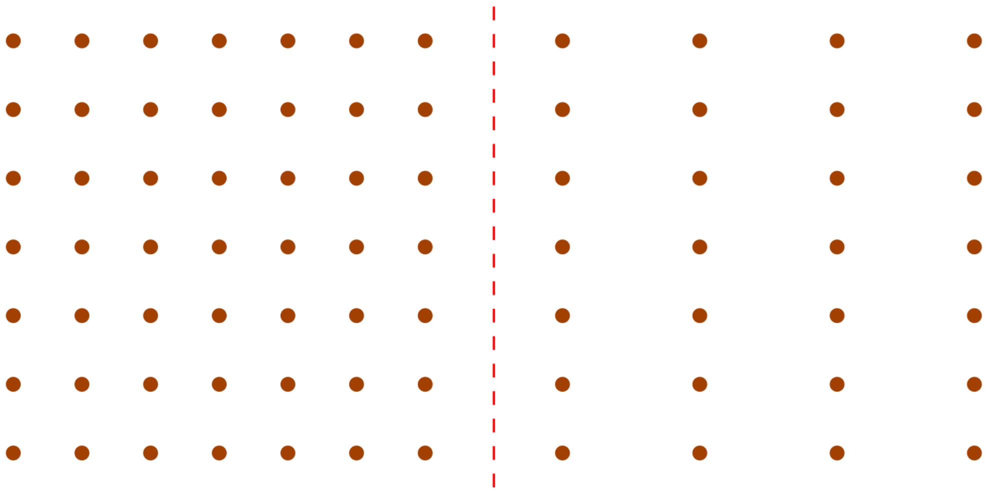
Freedman et al. 2001

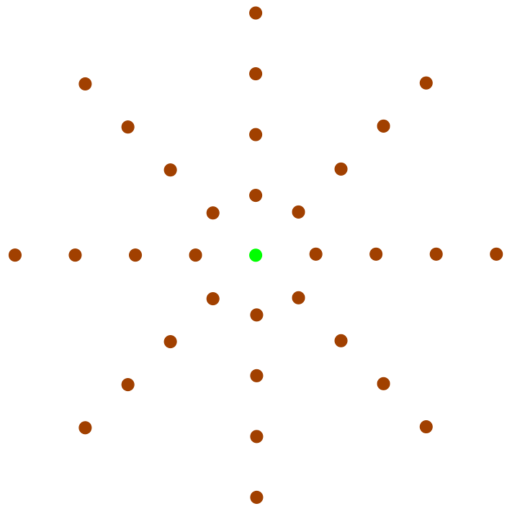
$$cz = H_0 r$$

- H_0 = 'Hubble constant' ≈ 70 km s^{-1} Mpc^{-1}
- $1/H_0$ = 'Hubble time' ≈ 14.4 Gyr
- c/H_0 = 'Hubble distance' ≈ 4400 Mpc

Hubble’s law

- Consistent with homogeneous, isotropic expansion

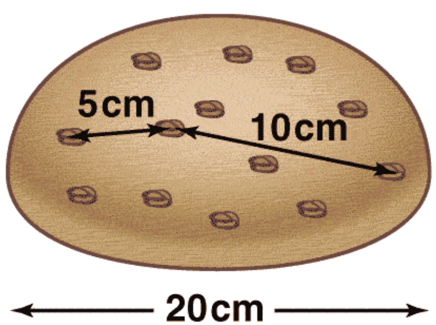




- Homogeneity does not imply isotropy
- Isotropy around one point does not imply homogeneity
- Both assumptions need to be tested

Hubble’s law

- Consistent with homogeneous, isotropic expansion



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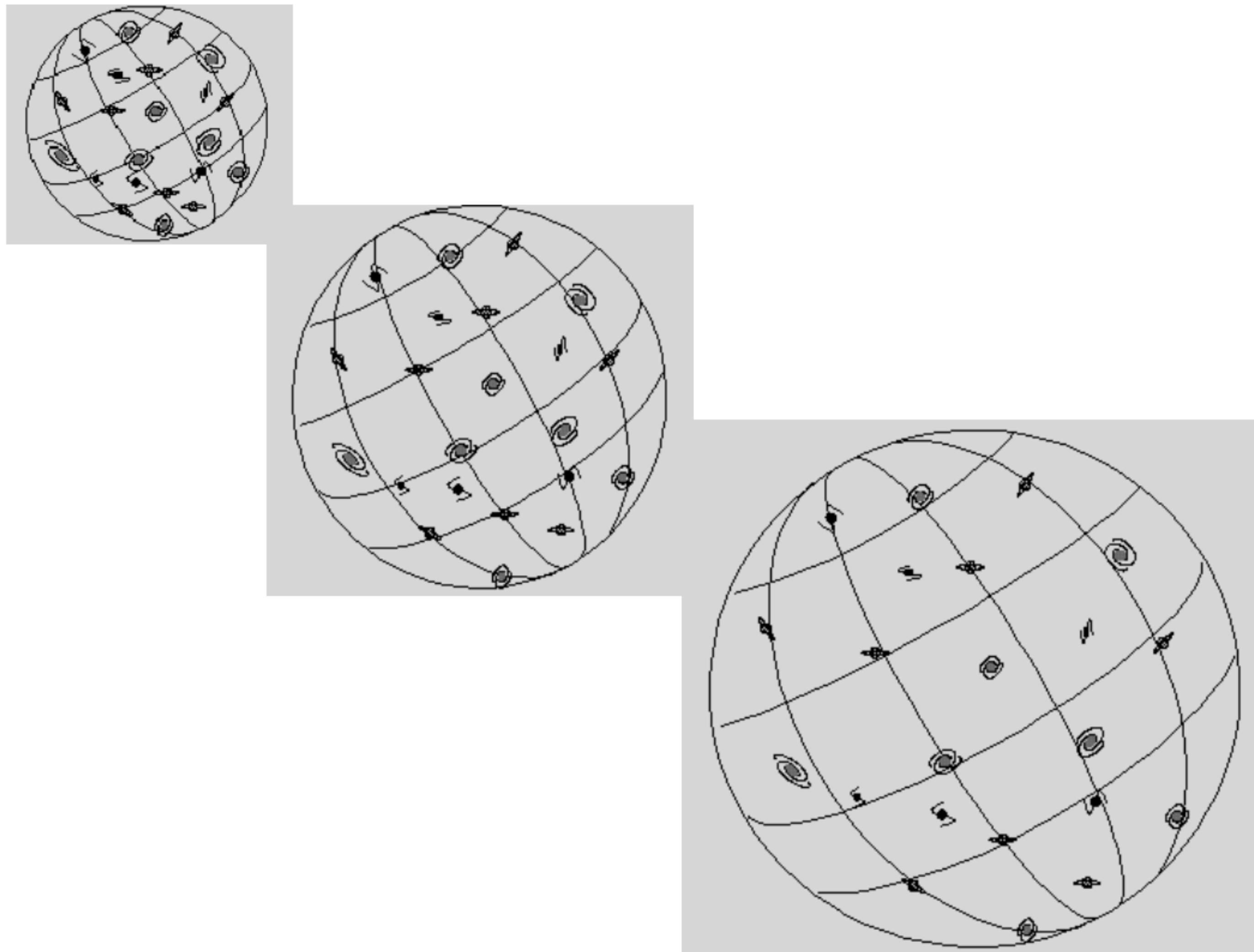


Hubble's law and Big Bang

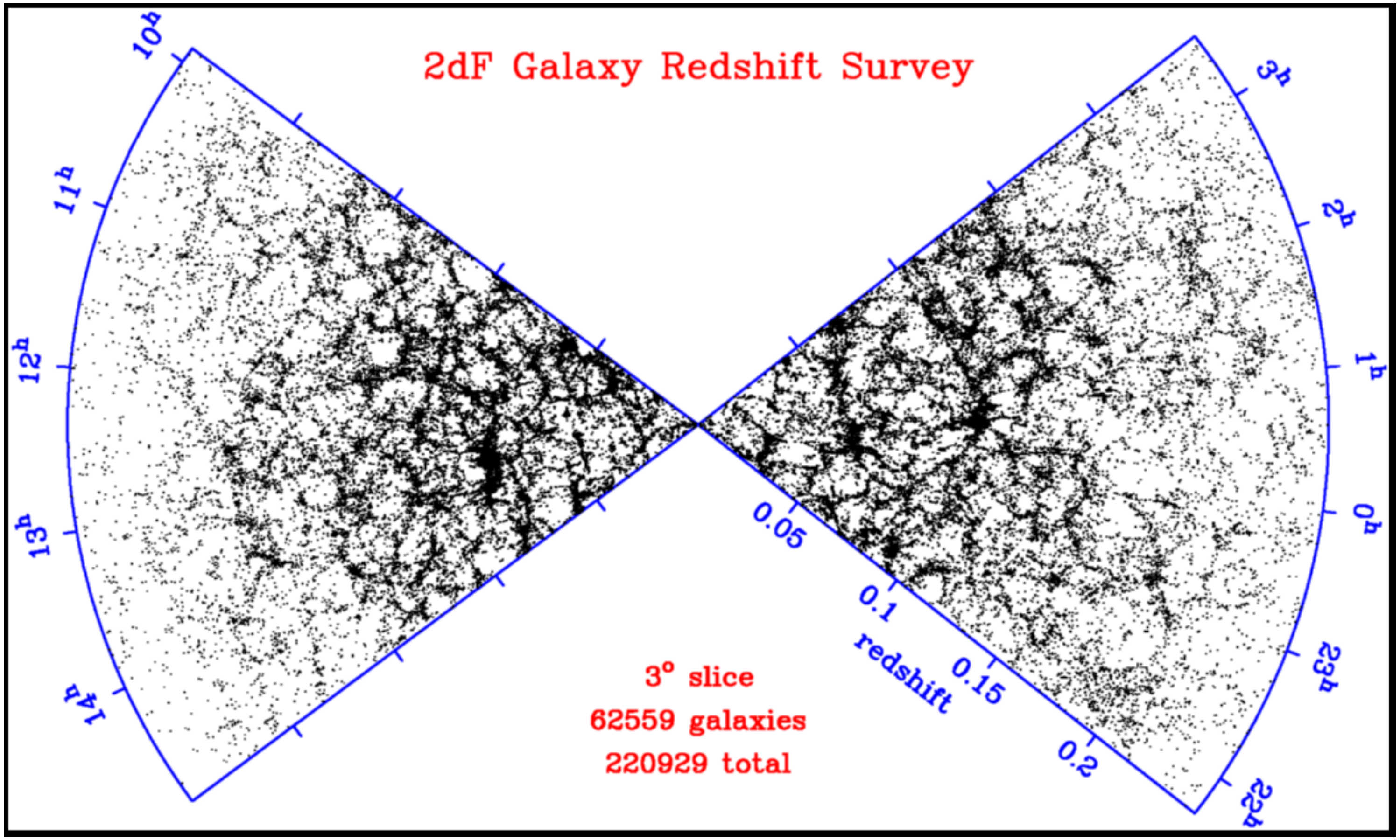
Hubble's law is consistent with a Big Bang model, but does not require it

Hot Big Bang	**Steady State** (Bondi, Gold, & Hoyle 1948)
Cosmological principle: universe is spatially homogeneous & isotropic (on large scales), but changes with time, becoming cooler & less dense.	***Perfect*** cosmological principle: universe is spatially homogeneous & isotropic (on large scales), and its global properties are constant with time.

Observational Evidences

The universe is homogeneous:

Each volume is about like every other volume: Large volumes of the sky in different directions, 100's of Mpc in size, look about the same.

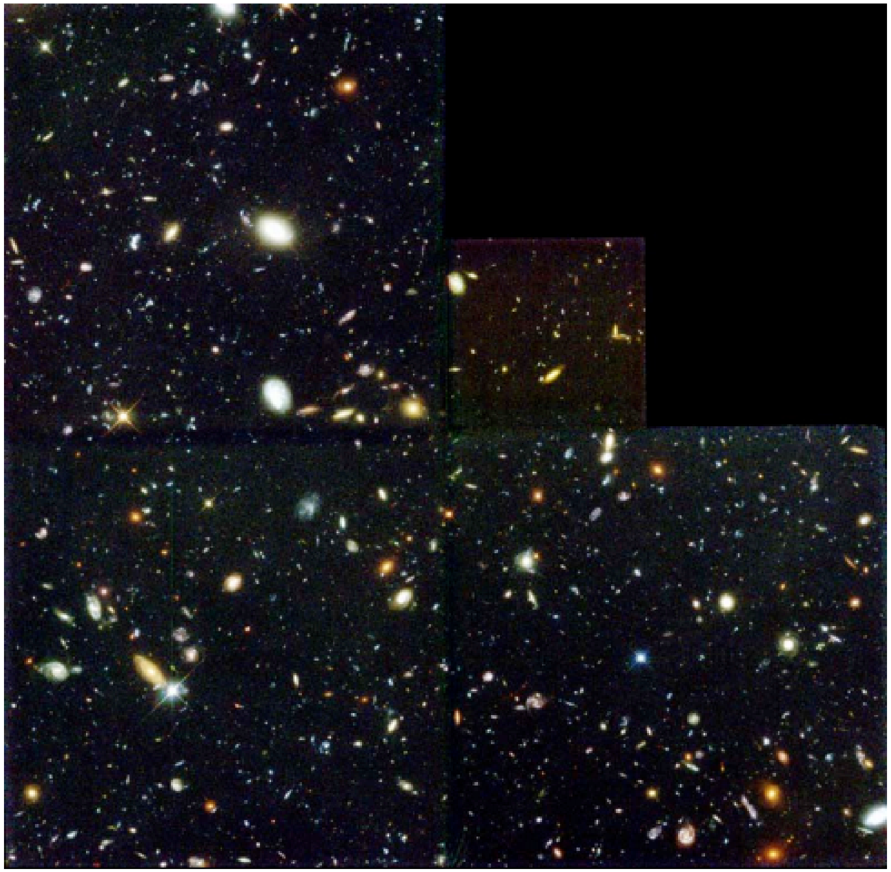


Observational Evidences

The universe is homogeneous:

it looks the same in every direction

HDF-North

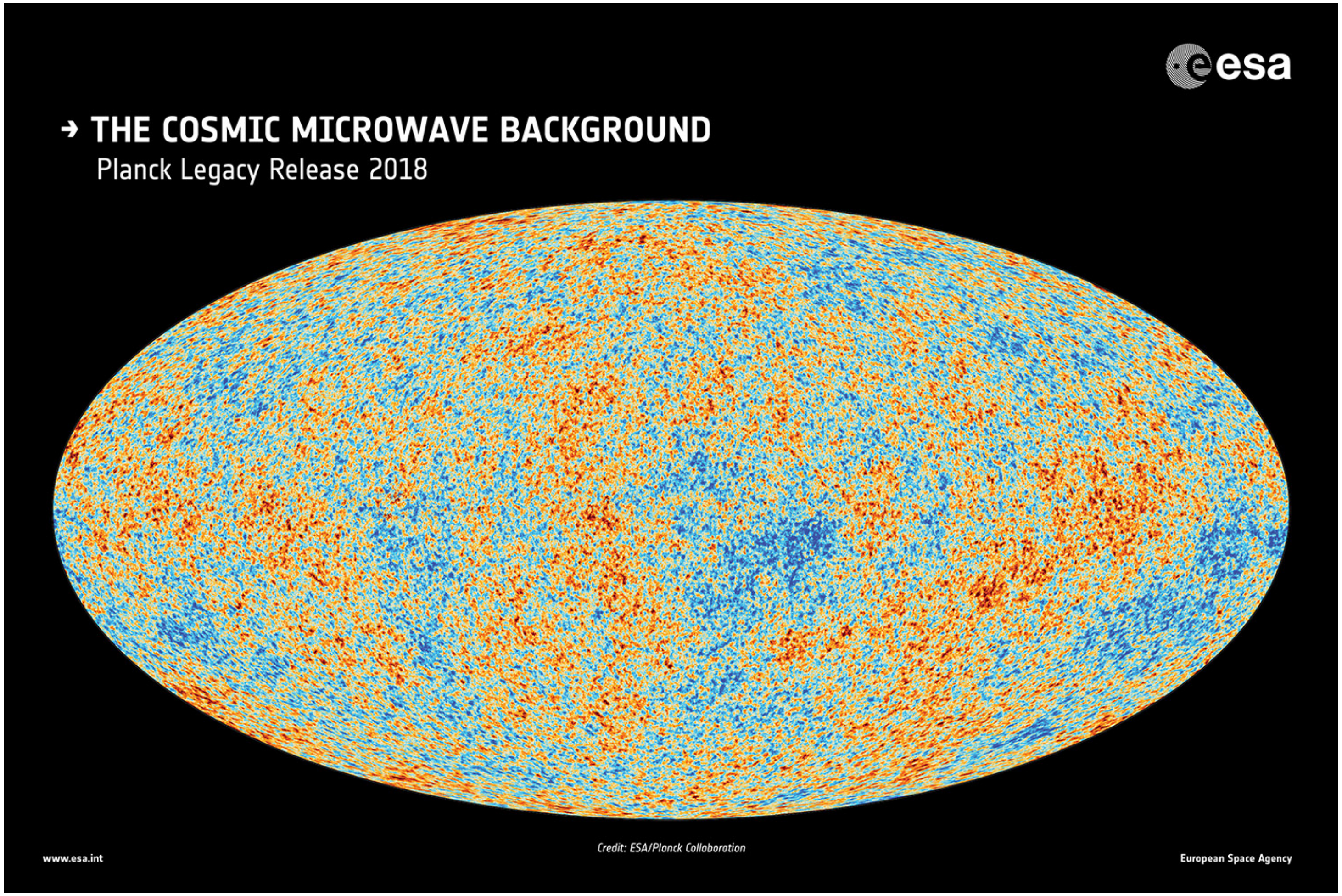


HDF-South

Observational Evidences

The universe is homogeneous:

it looks the same in every direction



Observational Evidences

The universe contains a cosmic microwave background (CMB) Penzias & Wilson, 1965:

- CMB is very well fitted by a blackbody spectrum

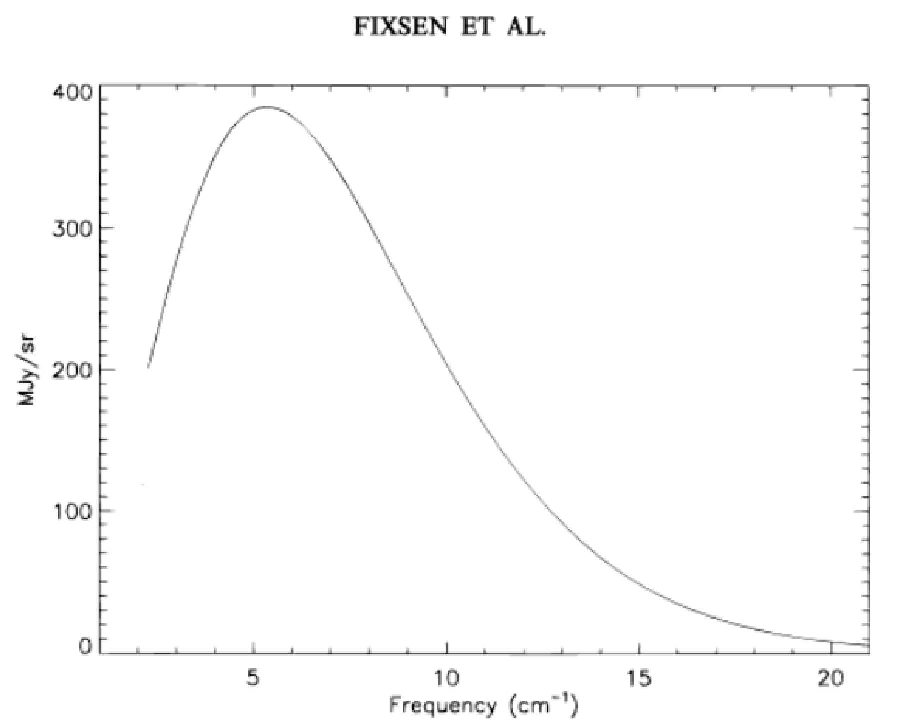


FIG. 4.—Uniform spectrum and fit to Planck blackbody (T). Uncertainties are a small fraction of the line thickness.

$$n(\nu)d\nu = \frac{8\pi}{c^3}\frac{\nu^2 d\nu}{\exp(h\nu / kT) - 1}$$

$$T_0 = 2.7255 \pm 0.0006\,\mathrm{K}$$

Observational Evidences

Blackbody spectra are produced by opaque objects:

- CMB tells us that the early universe was opaque.
- Baryonic matter (protons, neutrons, & electrons) was ionized.
- Rate at which photons scattered from free electrons was greater than the expansion rate of the universe ($\Gamma > H$).
- Equivalently: mean free path for photons was shorter than the Hubble distance ($c/\Gamma < c/H$).

Universe was opaque. Now it is transparent:

- Violation of the perfect cosmological principle

Cosmological Principle

The Universe is homogeneous & isotropic only on large scales today (>100 Mpc).

In the past, the Universe was more nearly homogeneous & isotropic:

- There is no preferred location (i.e., a centre) in the universe; and our own Milky Way (and Sun and, Earth) is not in any particularly special place.

Expansion of a homogeneous & isotropic universe is described by the Freedman-Robertson-Walker metric and the Friedmann equation.