The First Three Minutes
Meeting 3

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January 27, 2021

Meeting 3 – Expansion

- Announcements
- Discussion of II The Expansion of the Universe
- Redshift and its measurement
- Break
- Expansion of the Universe
  - Proper motion
  - Address distance, expansion
  - Cosmological principle
  - Galaxy surveys using redshift
  - The Hubble “Constant”

Announcements

- Notes, slides, etc. on website, tinyurl.com/firstthreeminutes
- Questions
  - Time and distance (remark on p. 41, second half tonight)
  - ”Infinite” Universe

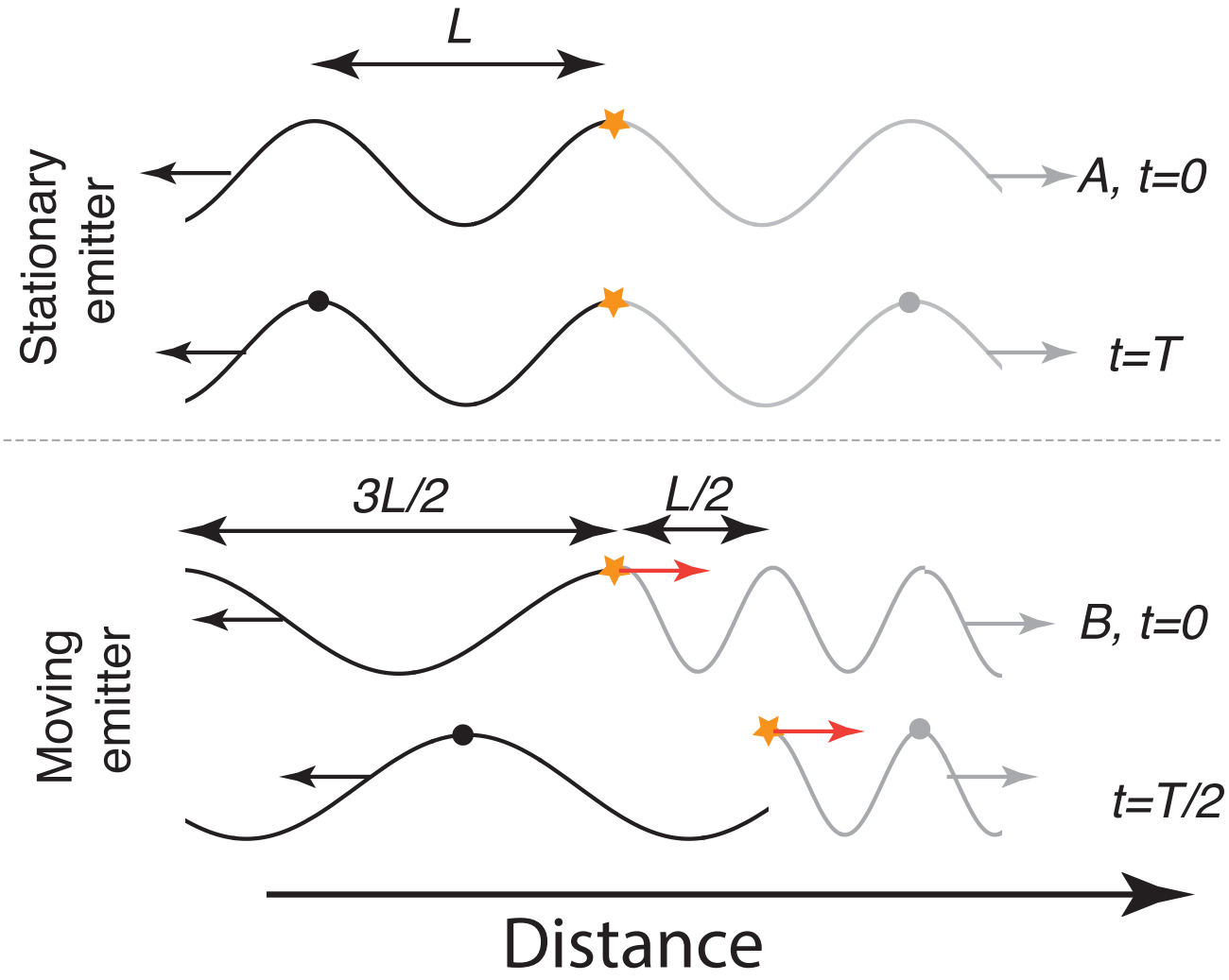
Redshift

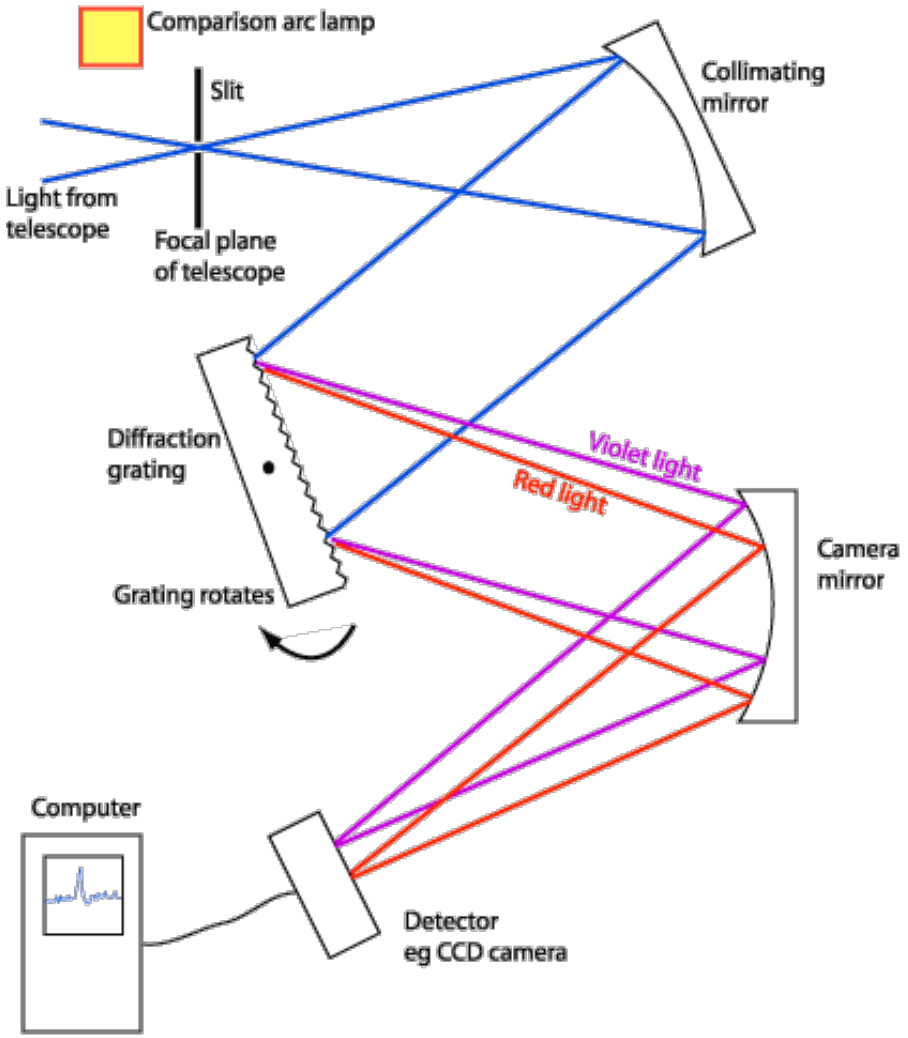
A moving emitter stretches light behind it, compresses light in front of it

Like Doppler shift for sound, but relativistic

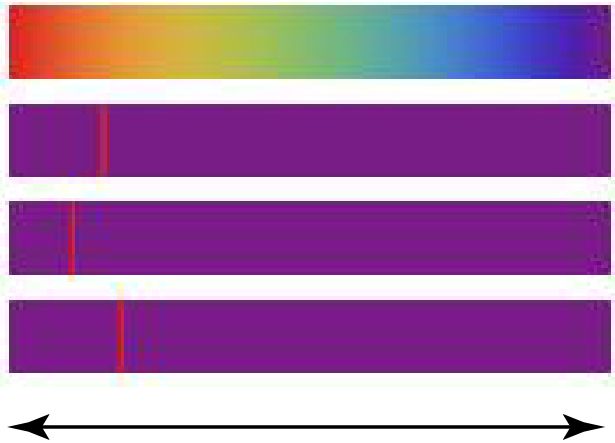
Measure wavelength from moving emitter (star) and compare with stationary emitter in lab

Exoplanets: measure 1 m/s





A Schematic Diagram of a Slit Spectrograph

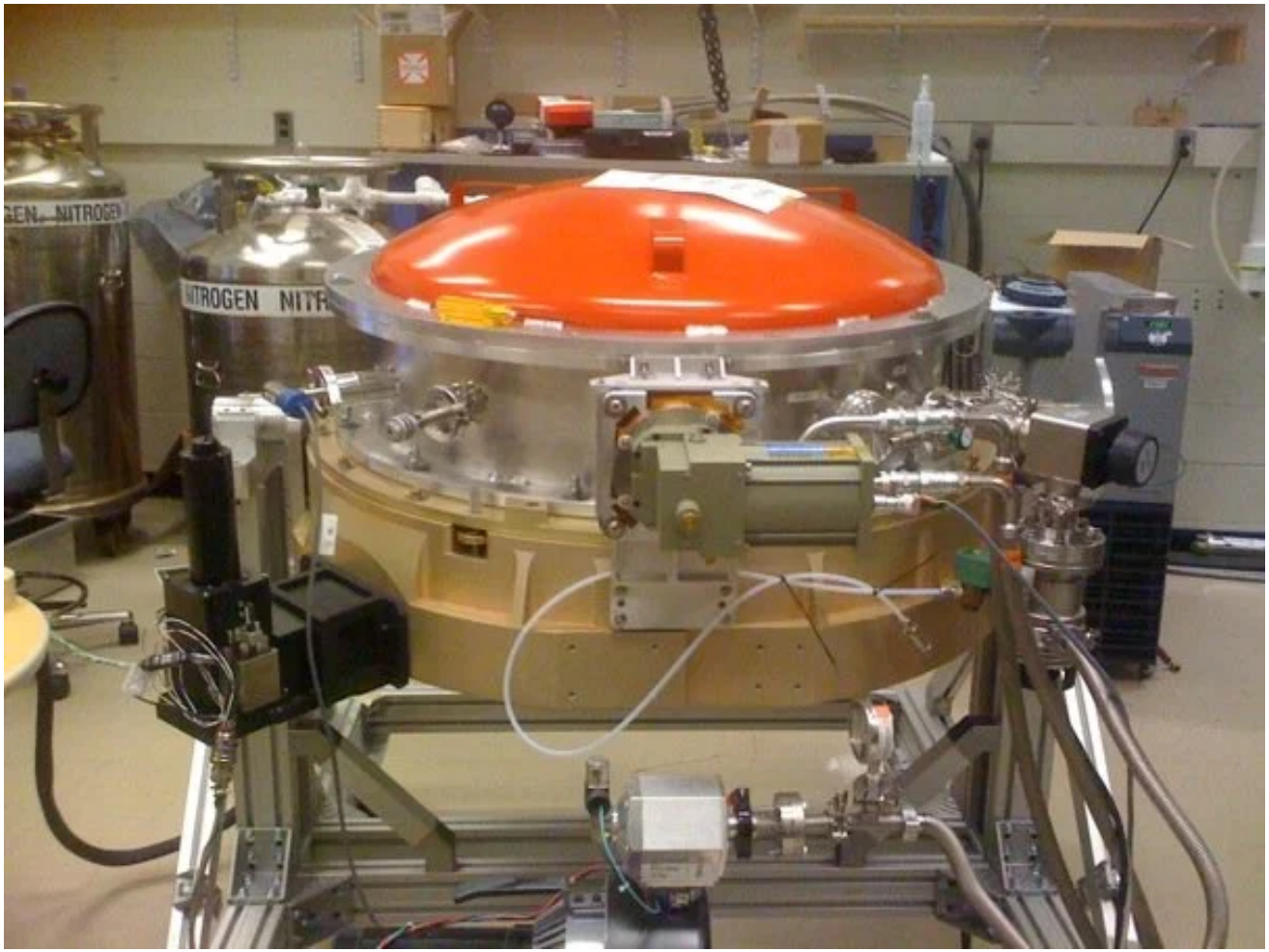


Measure line from an atomic transition (usually) with. Spectrograph

Diffraction grating or a slit splits light into colors

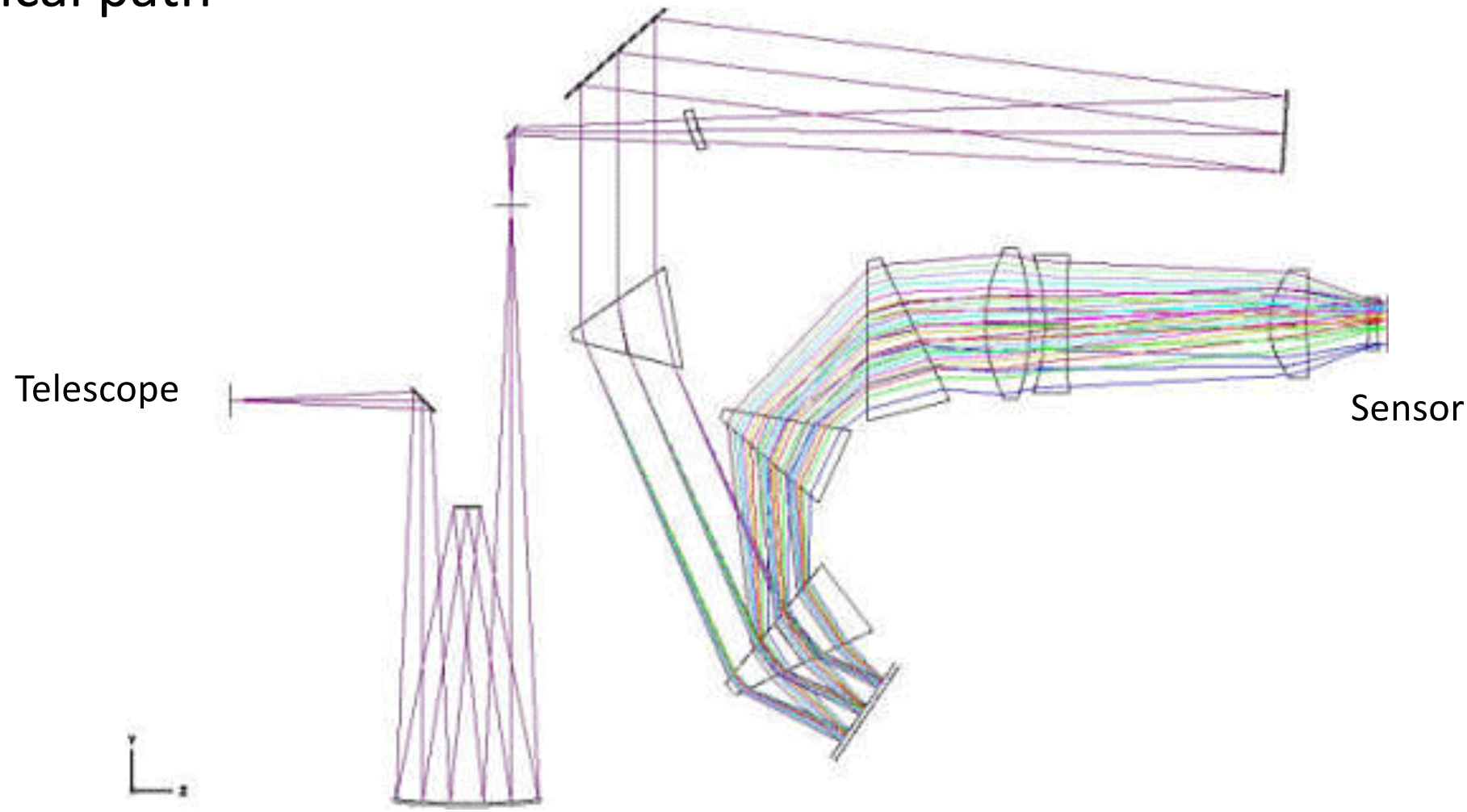
Need to block off light except from source

Folded Port Infrared Echellete (FIRE)



Magellan 8 m telescope in Chile

Optical path



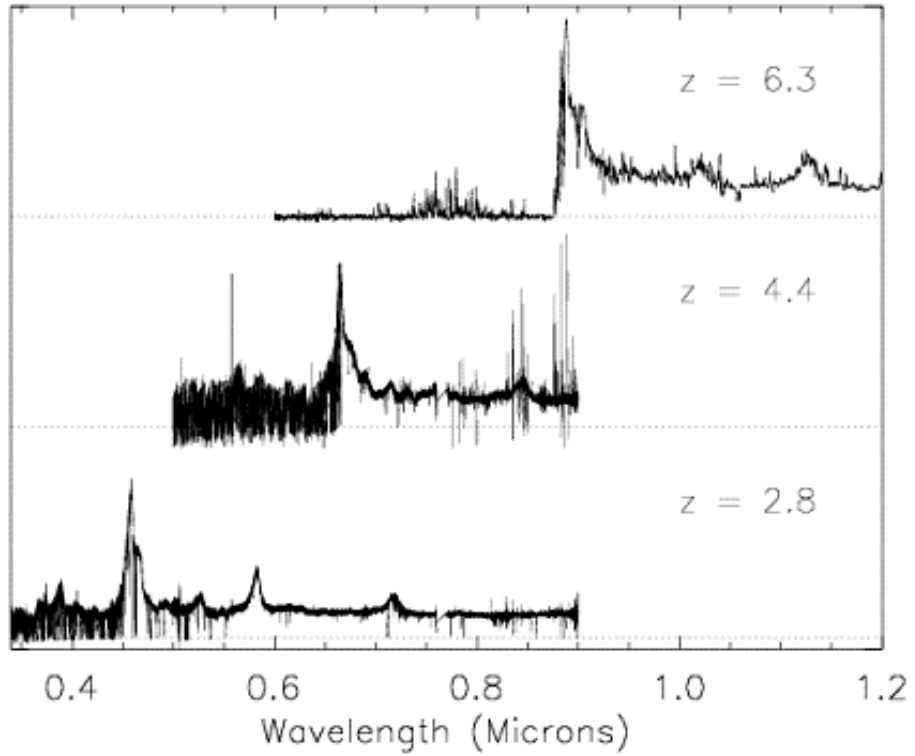
Example: Folded port Infrared Echellette (FIRE) – Rob Simcoe, Magellan Telescope

Spectra from quasars at different redshifts

Same spectral features

z is fractional change in wavelength

z	v/c	
1.	0.6	
2.8	0.87	
4.4	0.93	
6.3	0.96	
10	0.98	First stars

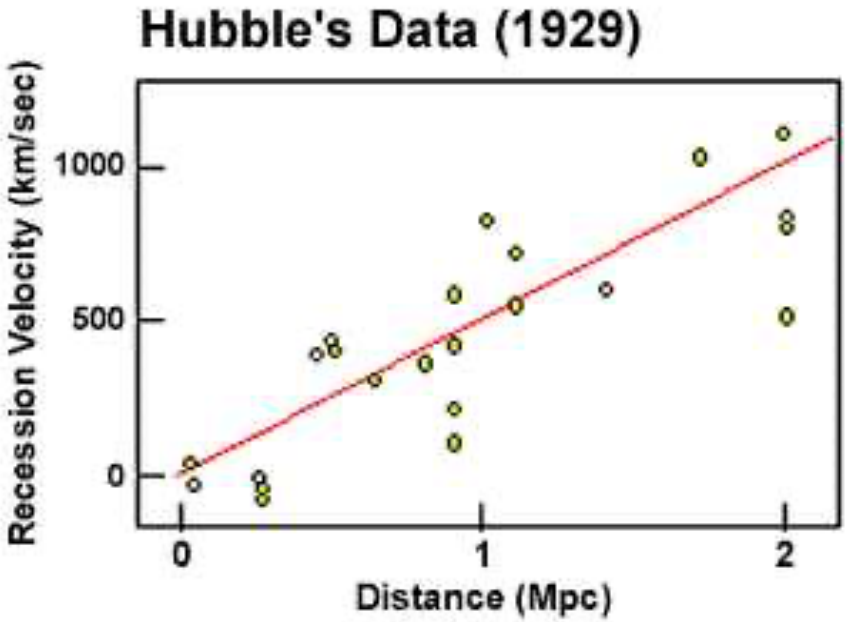


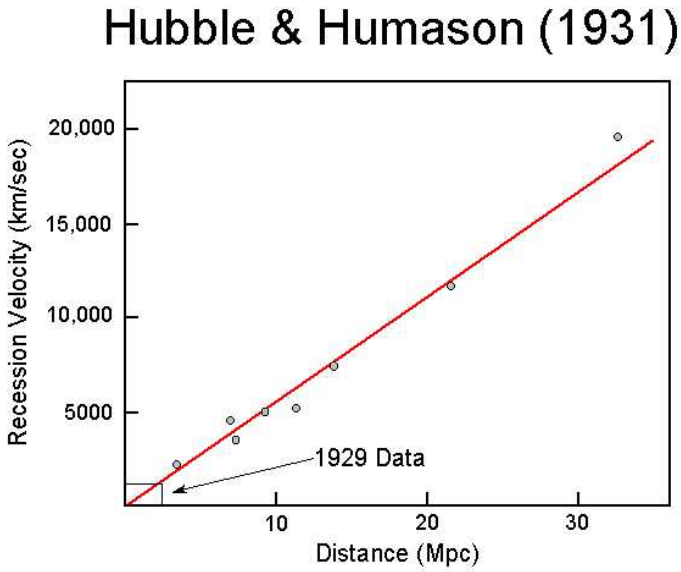
Violet

Red

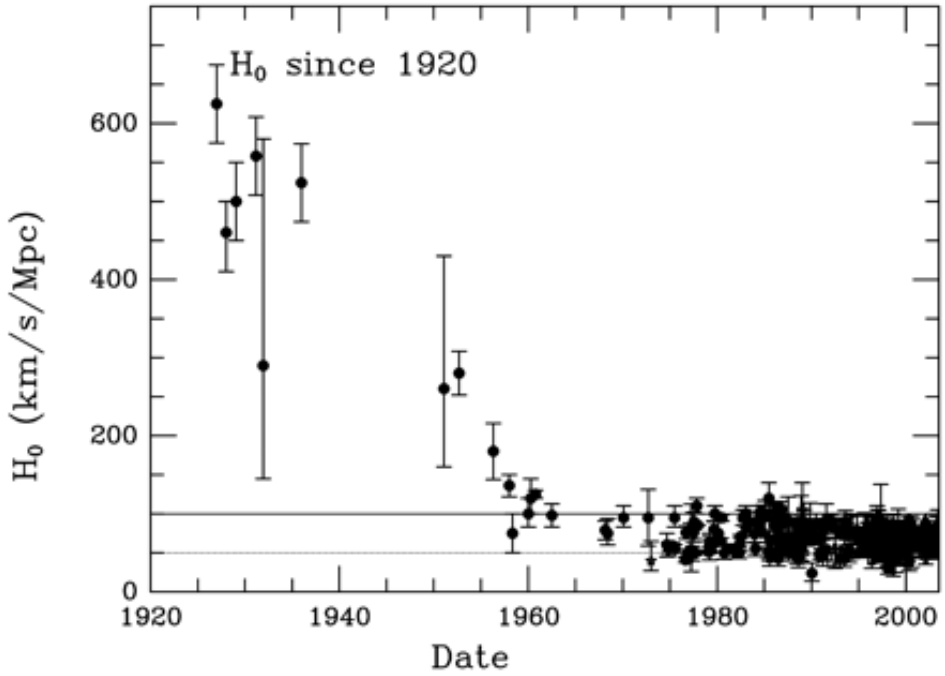
Wavelength at source 0.123 um

Hubble Data


Hubble's Data (1929)
Recession Velocity (km/sec)
1000
500
0
0
1
2
Distance (Mpc)

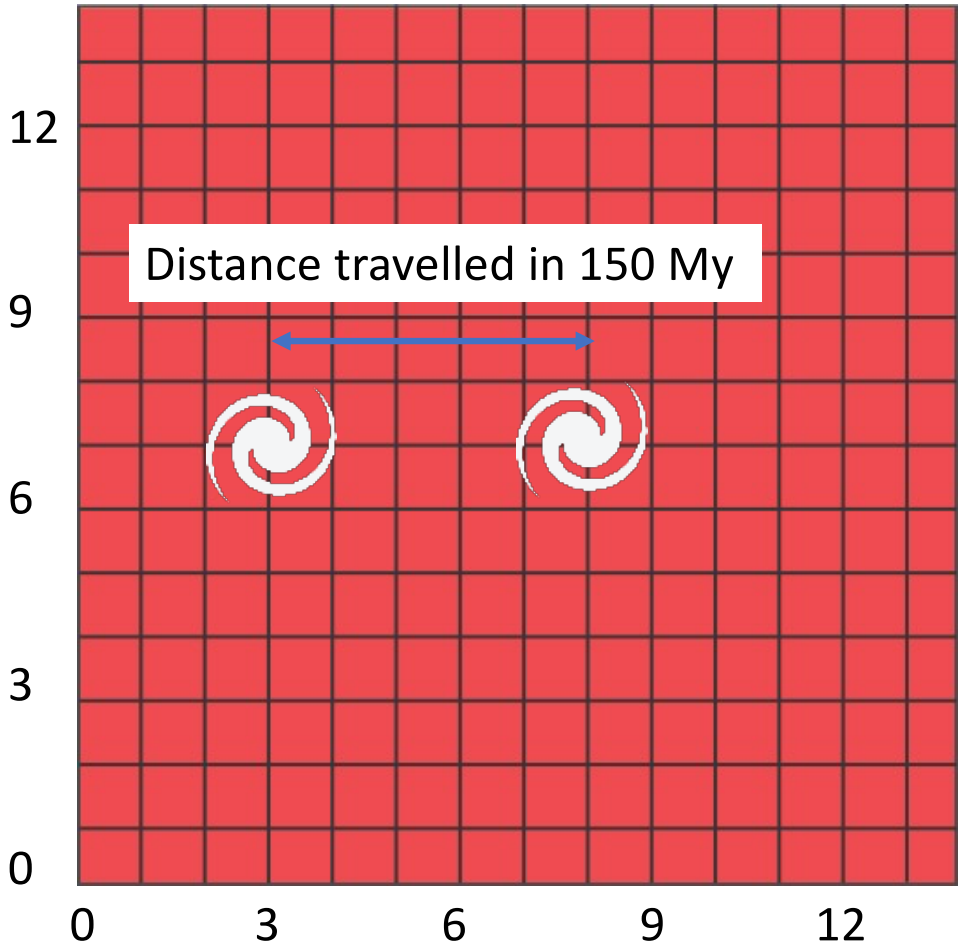

Hubble & Humason (1931)
Recession Velocity (km/sec)
20,000
15,000
10,000
5000
1929 Data
10
20
30
Distance (Mpc)

Hubble “Constant”



5 m Break

Proper motion



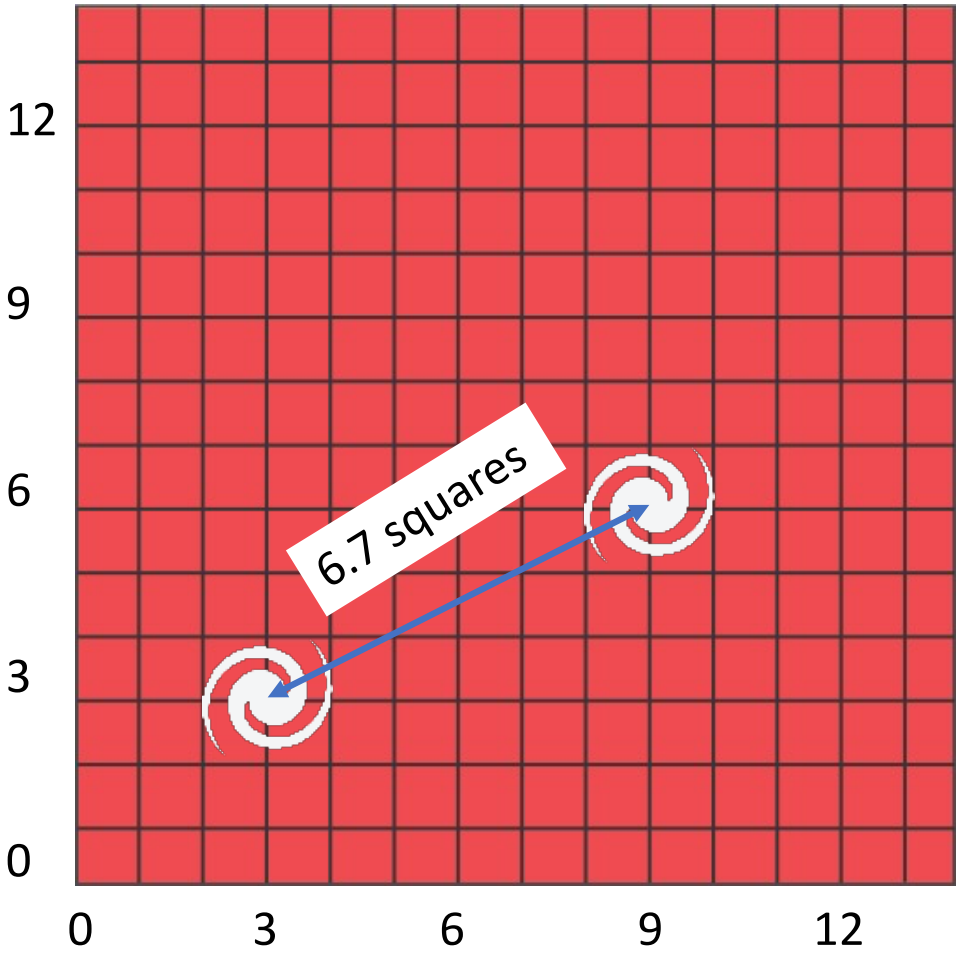
Each square is 100,000 ly on a side (about the size of a galaxy)

The galaxy has a speed of 1,000 km/s.

After 150 My, the galaxy will have travelled 500,000 ly, or 5 squares

Capisce?

”Address” of a galaxy in the universe



Galaxy 1: Location 3,3

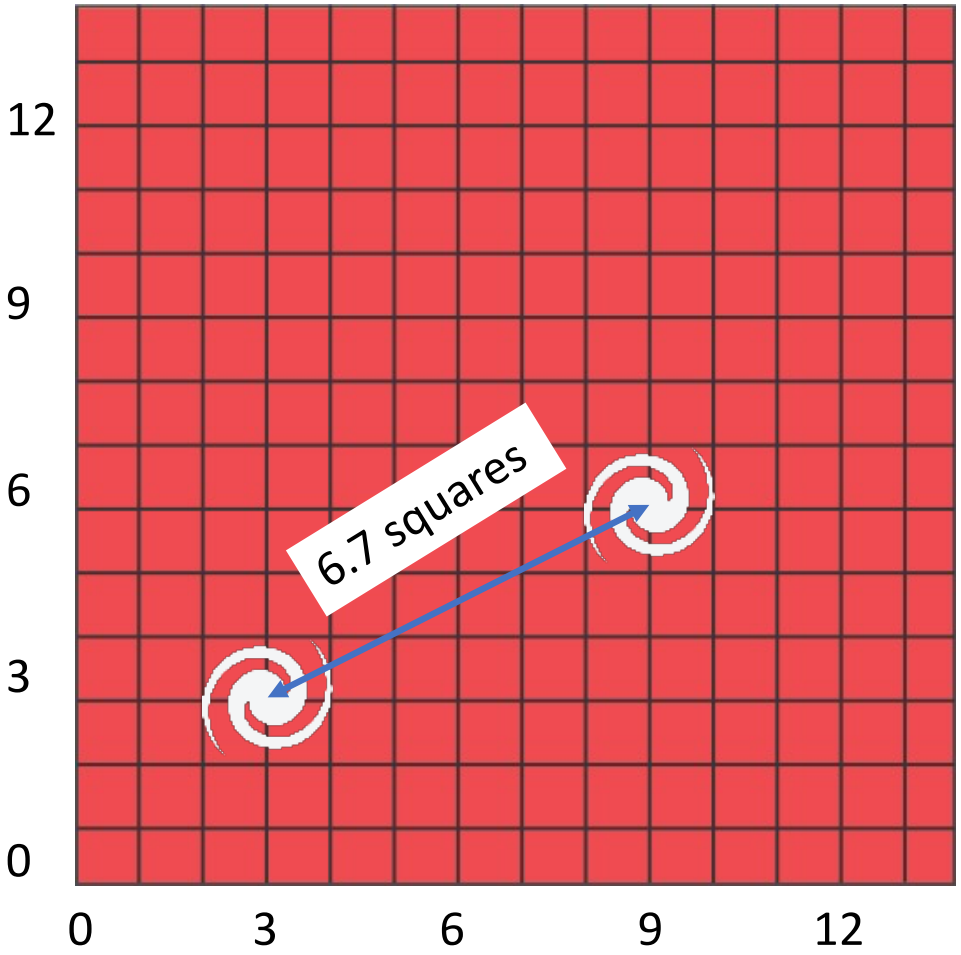
Galaxy 2: Location 9,6

Galaxies are 6.7 squares apart

Call this the “Address Distance”

Each square has size of 2 Mly, galaxies are 13.4 Mly apart, “proper distance”

The square size is changing with time

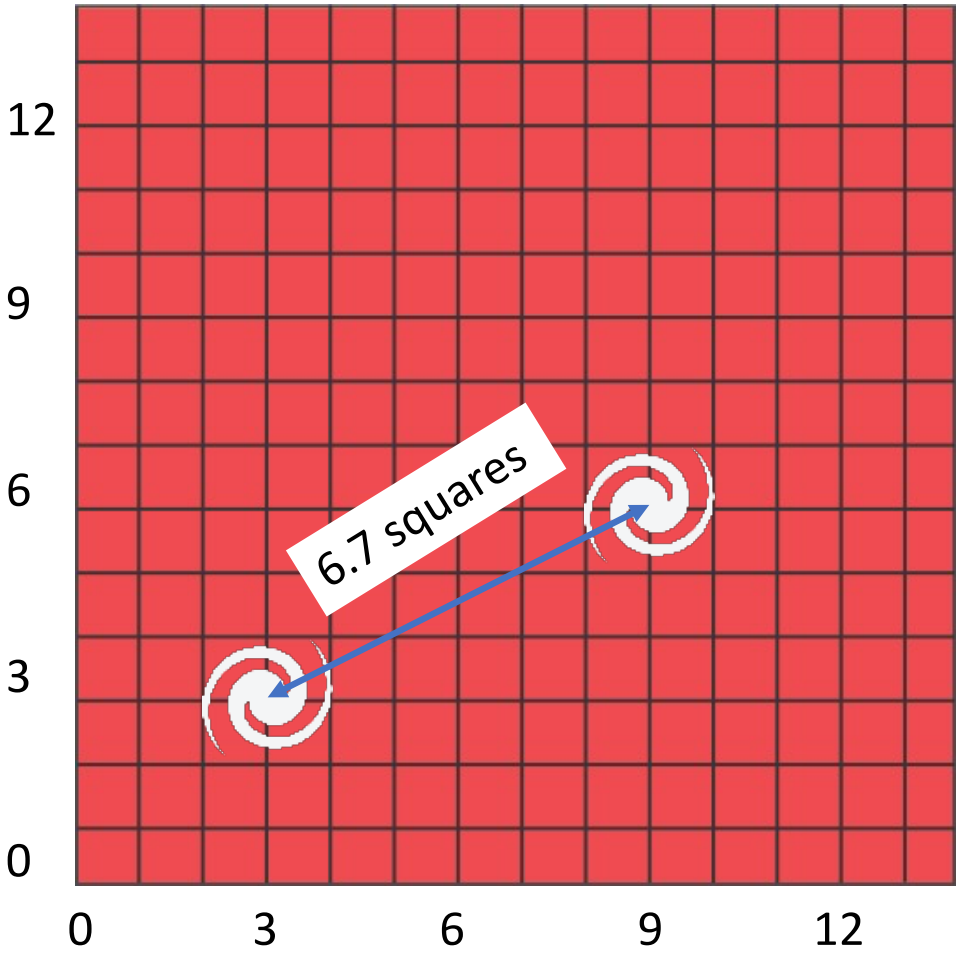


Expansion: each square is growing as time passes

This means the galaxies move apart.

Each square doubles in size after 26 Gy

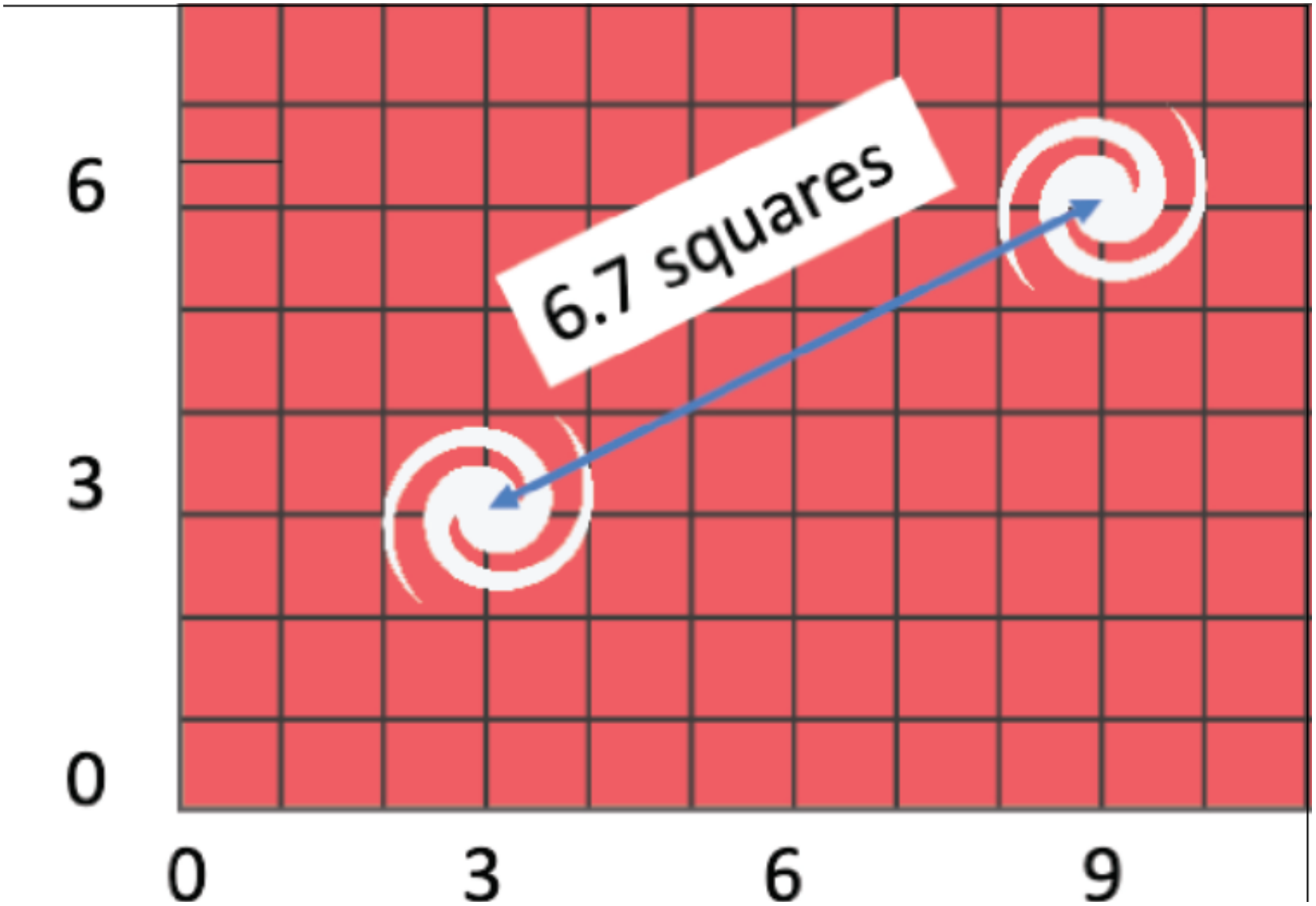
Galaxies appear to be moving apart



The proper distance is proportional to the square size…

…the square size is increasing with time…

…galaxies appear to be moving apart at 337 km/s – origin of redshift



After 25 Gy,

Address distance is still 6.7 squares

Each square is now 4 Mly

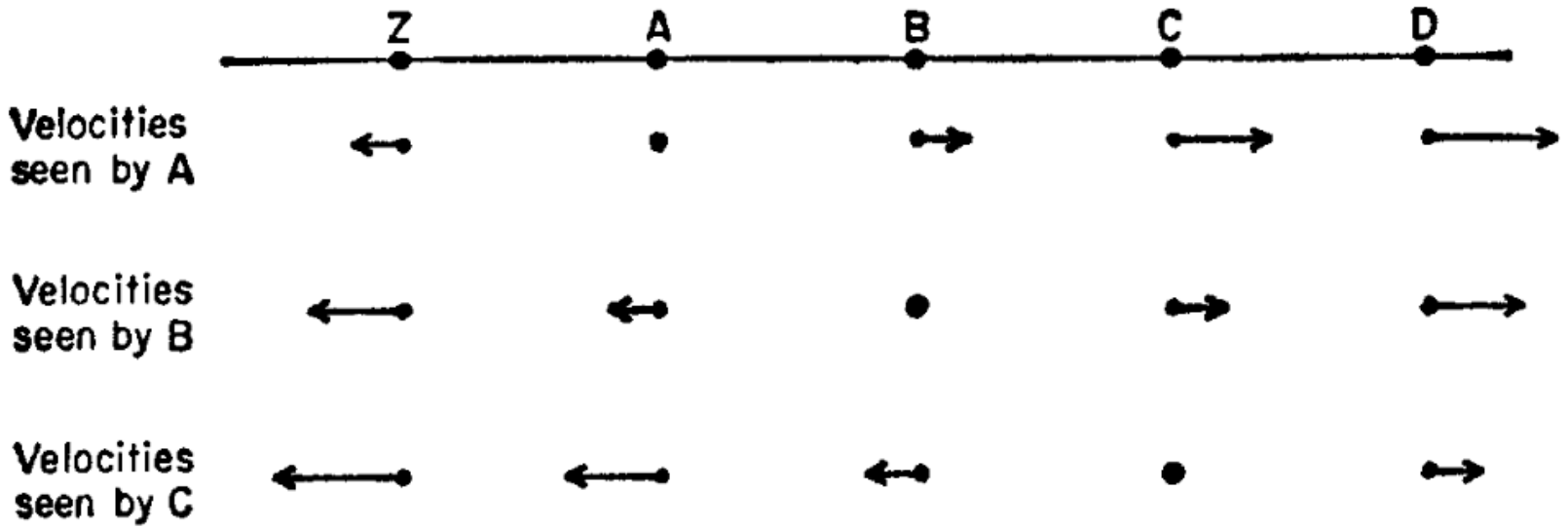
Galaxies are 26.8 Mly apart

Hubble Law

The expansion of the universe moves all galaxies away from each other at a speed proportional to the distance between them.

The constant of proportionality is called the Hubble constant, H_o=22.5 km/s/Mly – a galaxy 1 Mly from Earth moves away from the Earth at 22.5 km/s

This picture holds for every point in the visible universe



An stationary observer at A, B, or C will each see all the other galaxies receding.

Motion of Galaxies in the Universe

1. Each galaxy has a fixed address in the visible universe. The fixed addresses do not change with time.
2. Galaxies may move *through* space in the usual fashion – Proper motion.
3. The universe is expanding – the size of each square is changing with time – carrying the galaxies with it. This is called the Hubble Flow. Increase in square size with time proportional to the Hubble constant

Distances

$1/H_o$=13.6 Gy, the age of the universe. The address distance to the start of the universe is 13.6 Gly.

BUT – when we see it, the light from the Big Bang has traveled 47 Gly, the longer distance comes from the expansion of the universe that took place *while the light was travelling to us.*

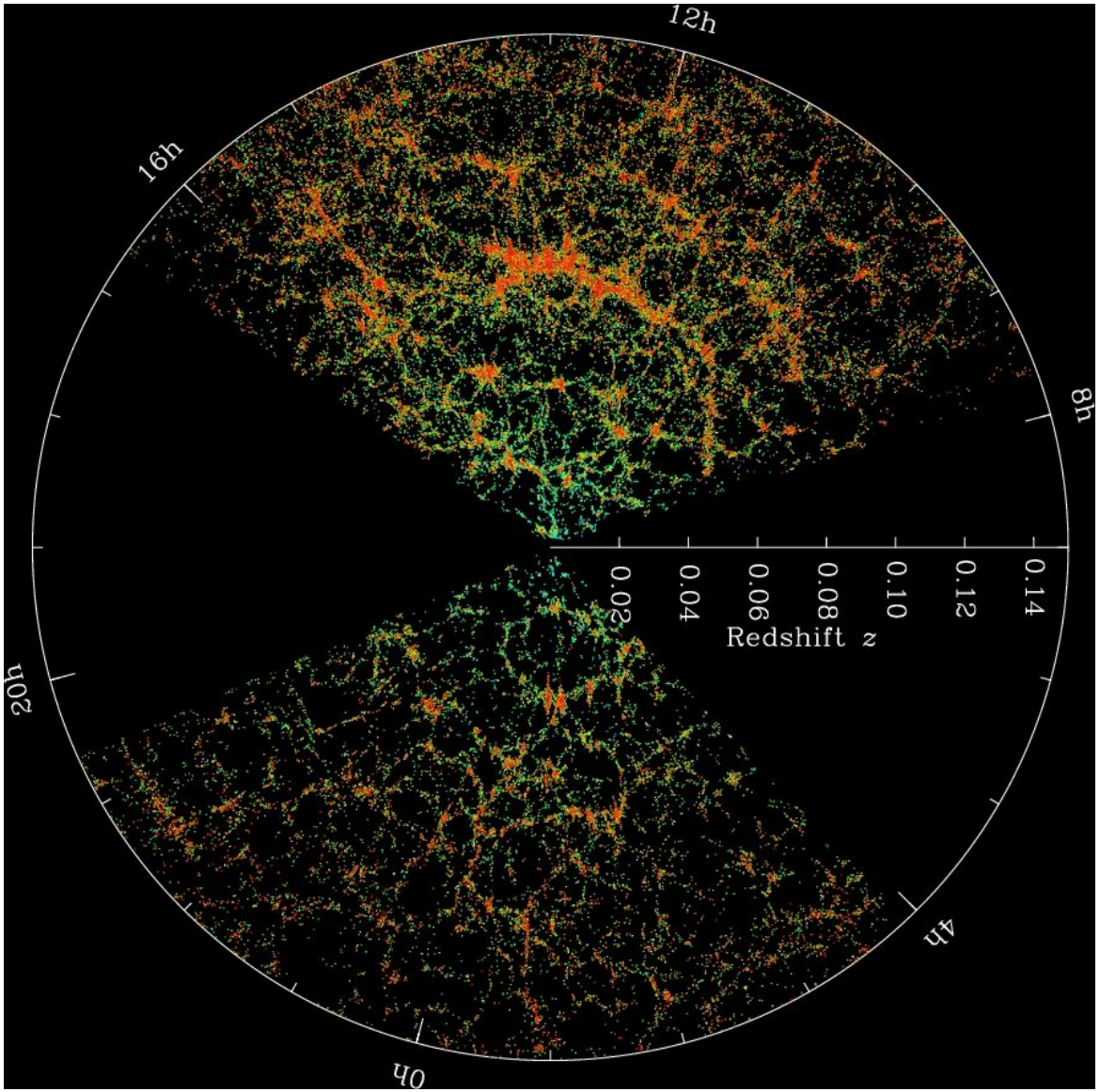
From Hubble Law, the emitter at the start of the universe recedes at the speed of light – nothing beyond can reach us…. …yet.

Weinberg, p. 41, third paragraph:

on us - it is beyond the horizon. If the universe is now 10,000 million years old, the horizon is now at a distance of 30,000 million light years. But when the universe was a few minutes

The horizon distance is how far the light has travelled to reach us.

The actual value is 41,500 Mly – Weinberg did not know about dark energy.



SDSS – Sloan Digital Sky Survey

Automated telescope on Apache Peak

Hubble “Constant”