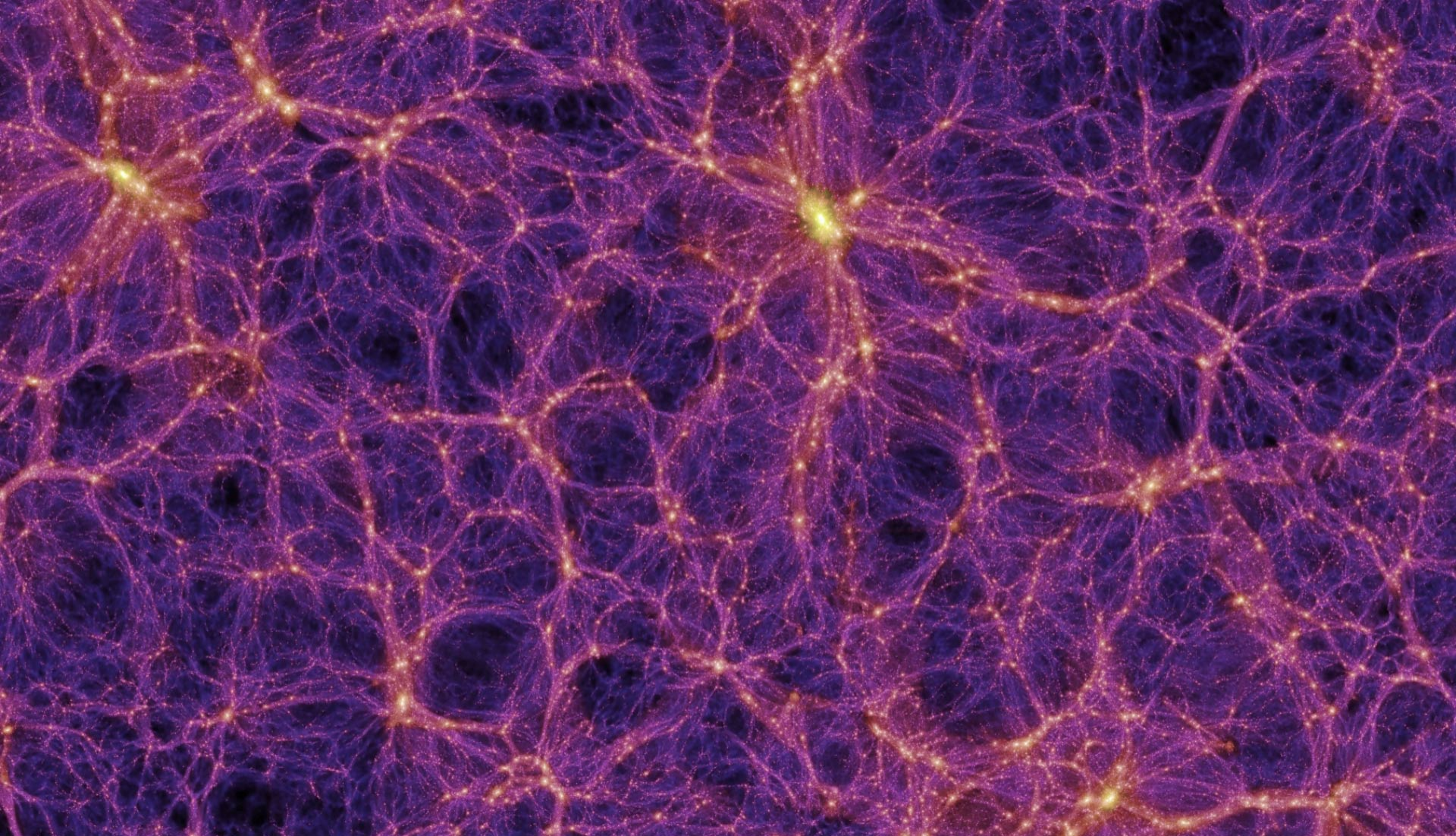


Phys 321: Lecture 12

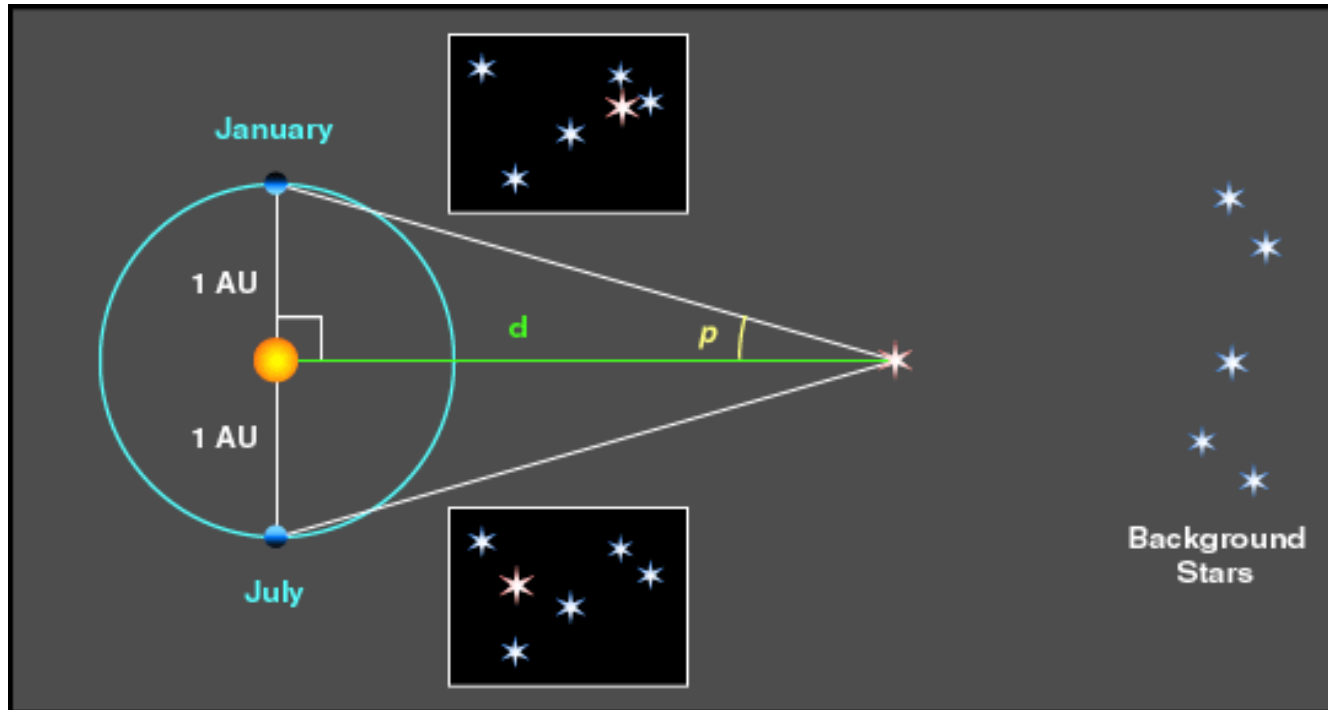
Large-Scale Structures



Outline

- 27.1 The Extragalactic Distance Scale
- 27.2 The Expansion of the Universe
- 27.3 Cluster of Galaxies

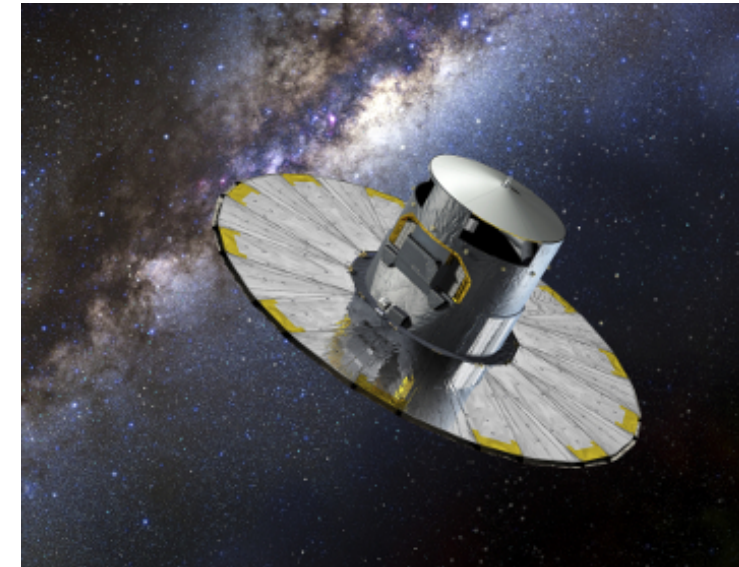
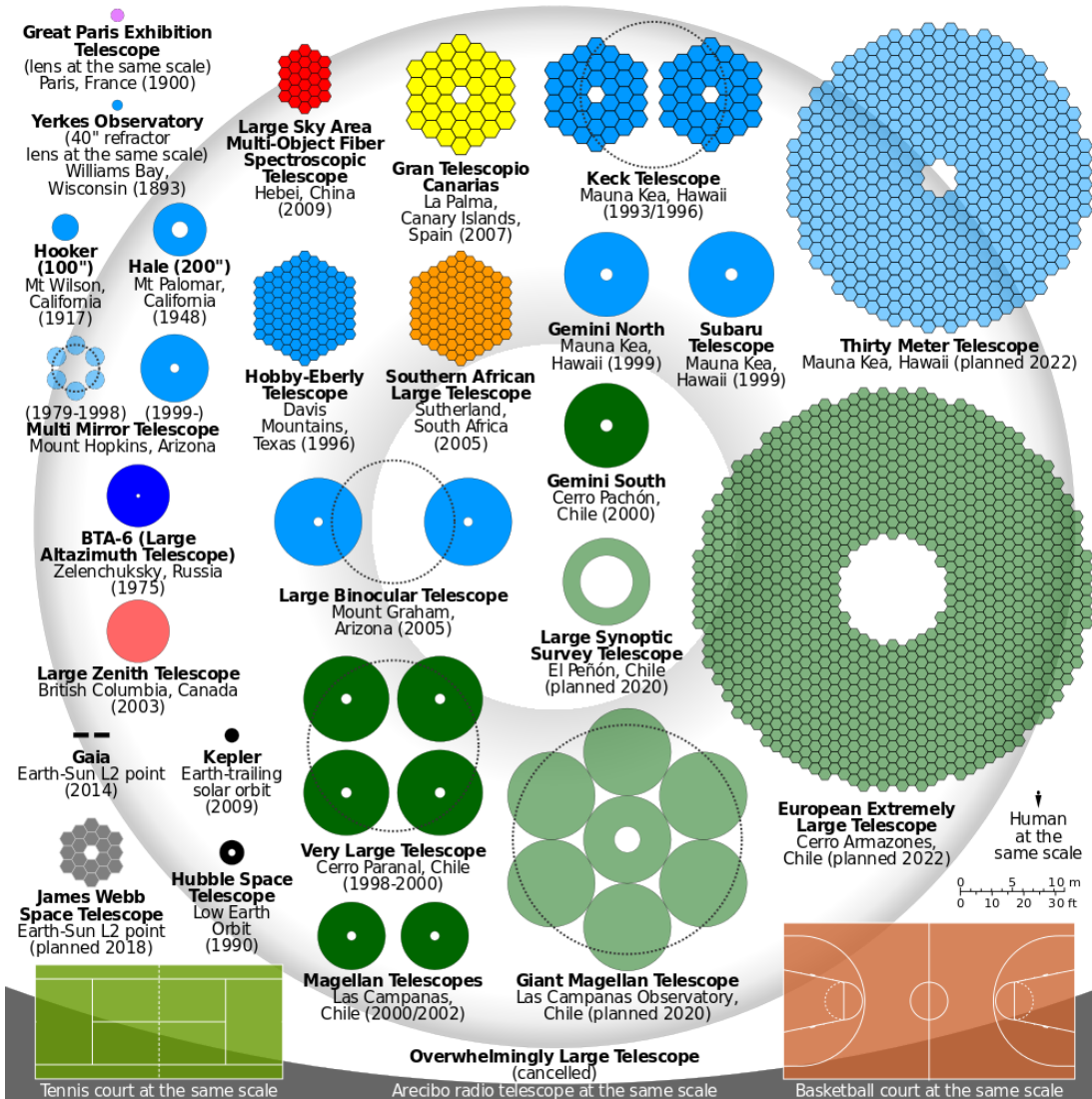
Parallax



$$d = \frac{1}{p''} \text{ pc.}$$

- 1 pc \approx 3.262 light year
- Measured parallax angle of 1'' gives a distance of 1 pc
- Smaller parallax angle \rightarrow larger distance

The Gaia Space Telescope



Gaia Data Release #2

→ HOW MANY STARS WILL THERE BE IN THE SECOND GAIA DATA RELEASE?



position & brightness on the sky

1 692 919 135

surface temperature

161 497 595

red colour

1 383 551 713

blue colour

1 381 964 755

parallax and proper motion

1 331 909 727

radius & luminosity

76 956 778

amount of dust along
the line of sight

87 733 672

radial velocity

7 224 631

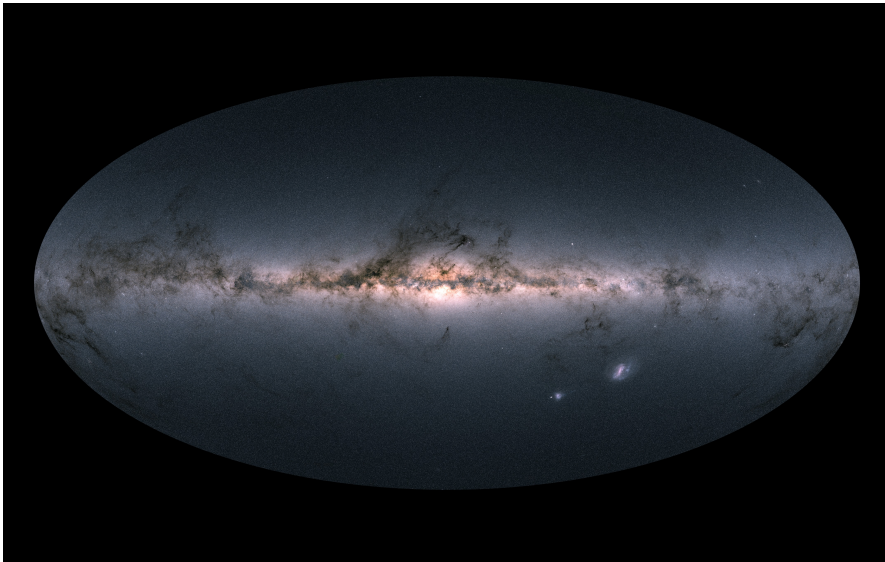
14 099

Solar System
objects

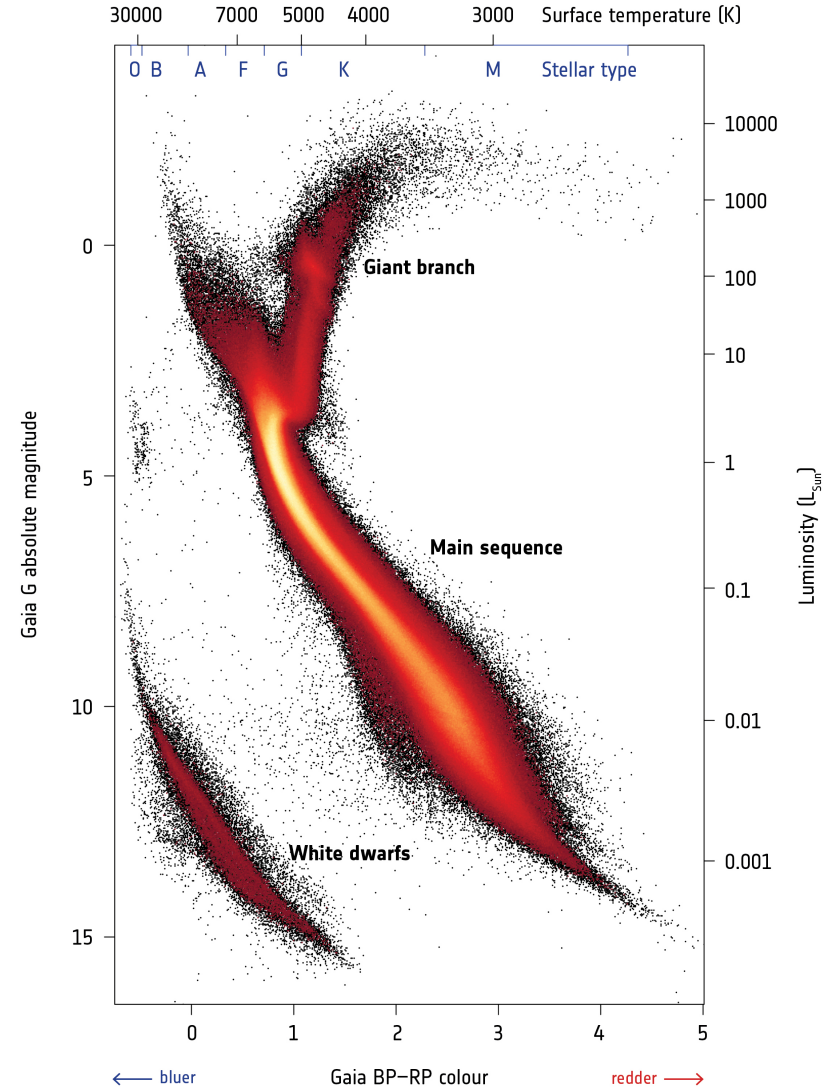
550 737

variable sources

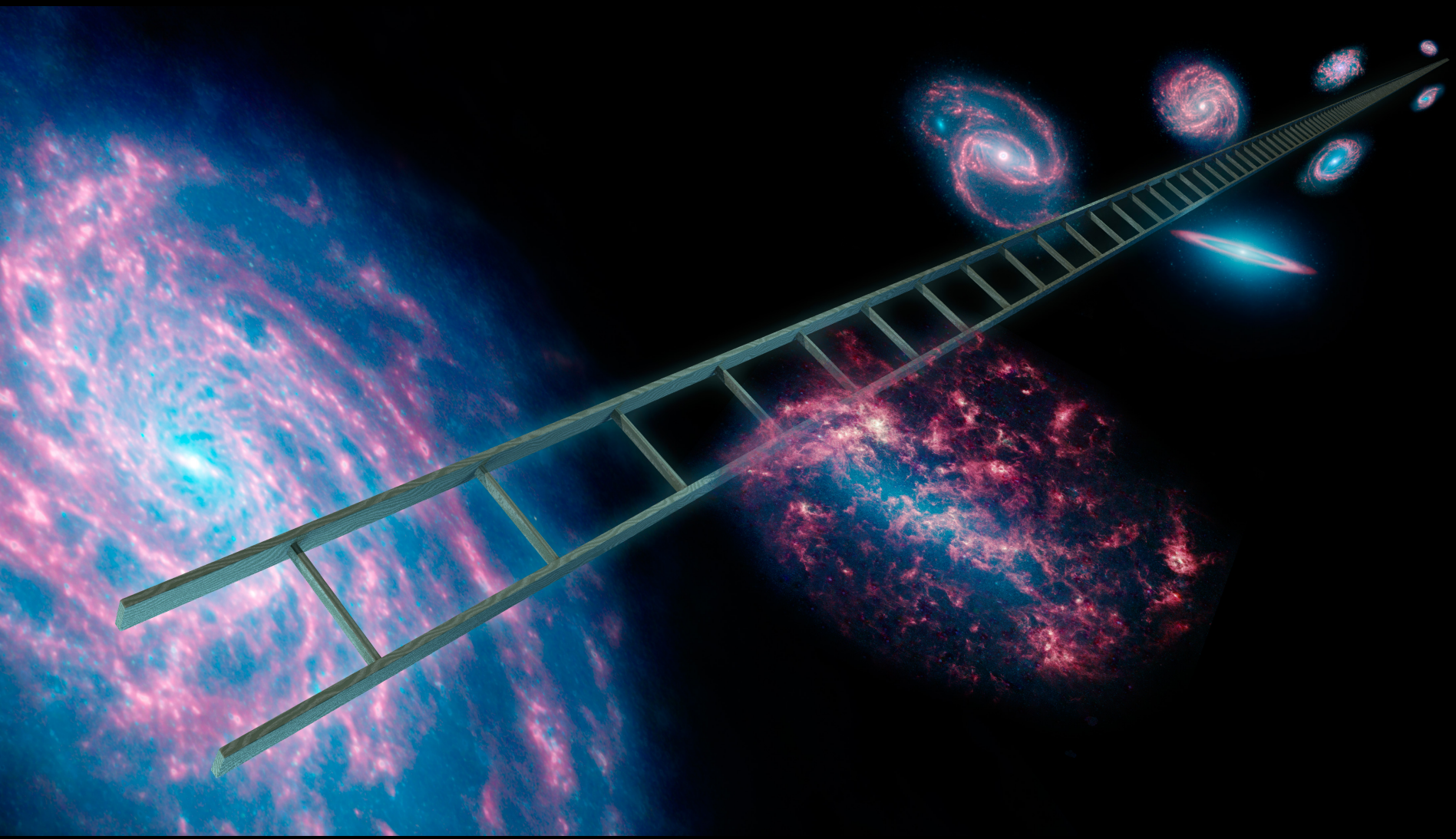
Even Gaia can only go up to ~50 kpc — Galactic scale. How about further distances?



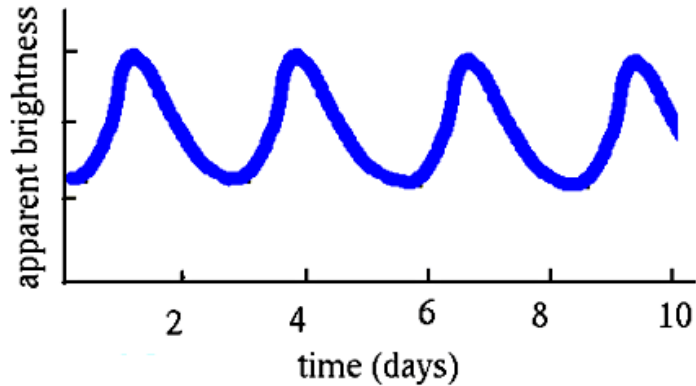
→ GAIA'S HERTZSPRUNG-RUSSELL DIAGRAM



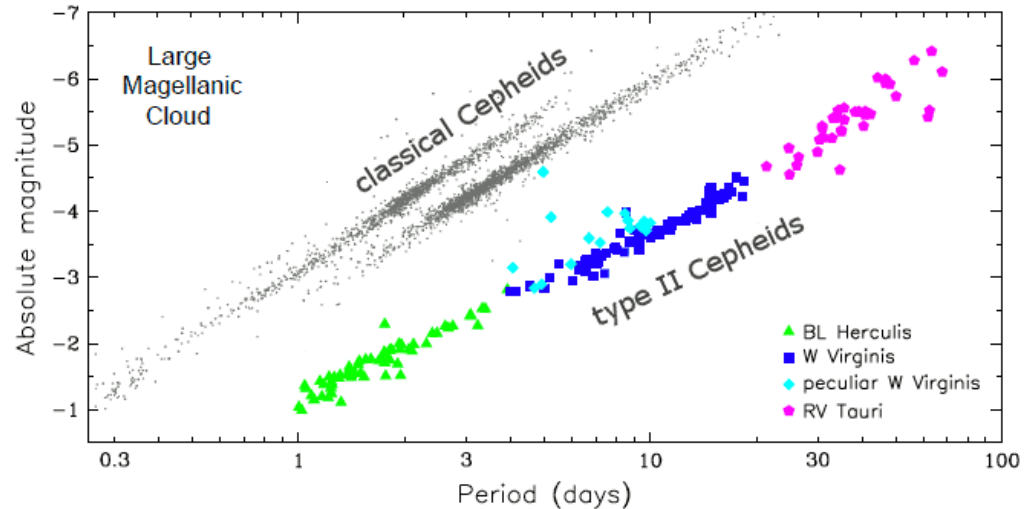
Climbing the Cosmic Distance Ladder



Cepheid variables



- For a class of variable stars, there is a tight relationship in **absolute magnitude** and **periods**
- Can be used as a **standard candle**



$$M_{\text{Cepheids}} \approx -1 \text{ to } -7$$

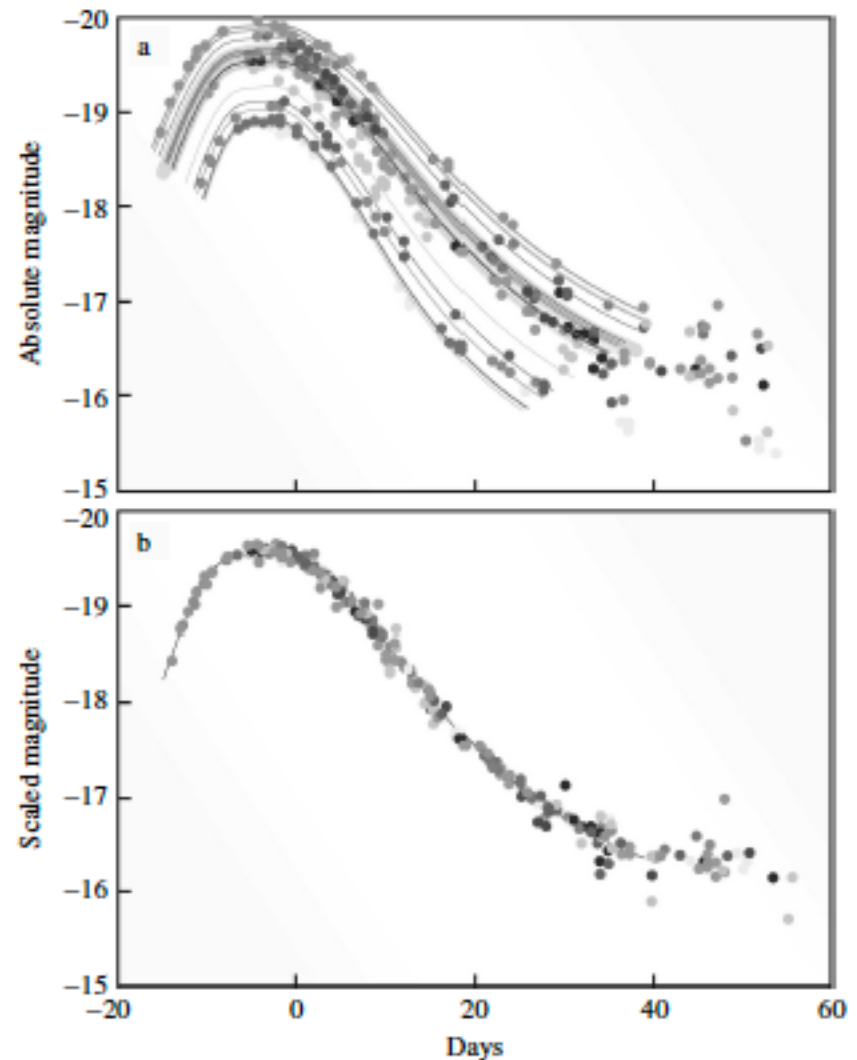
Type Ia Supernovae

- Type Ia Supernovae has a well-determined absolute magnitude at maximum light, can be used as a **standard candle** at greater distances
- An inverse correlation between **maximum brightness** and the **rate of decline of its light curve**

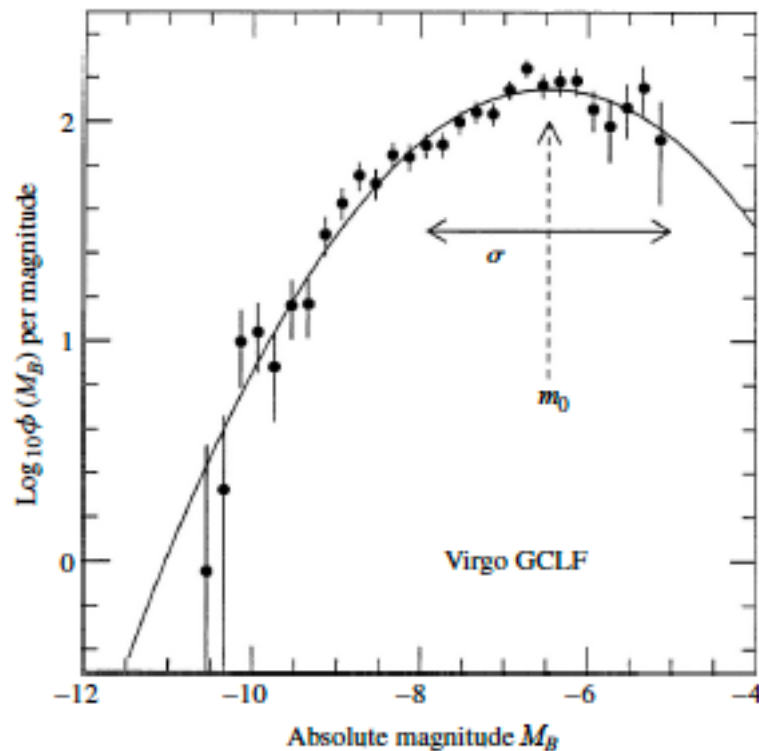
$$M_{SNIa} \approx -19.3 \pm 0.03$$

For Novae

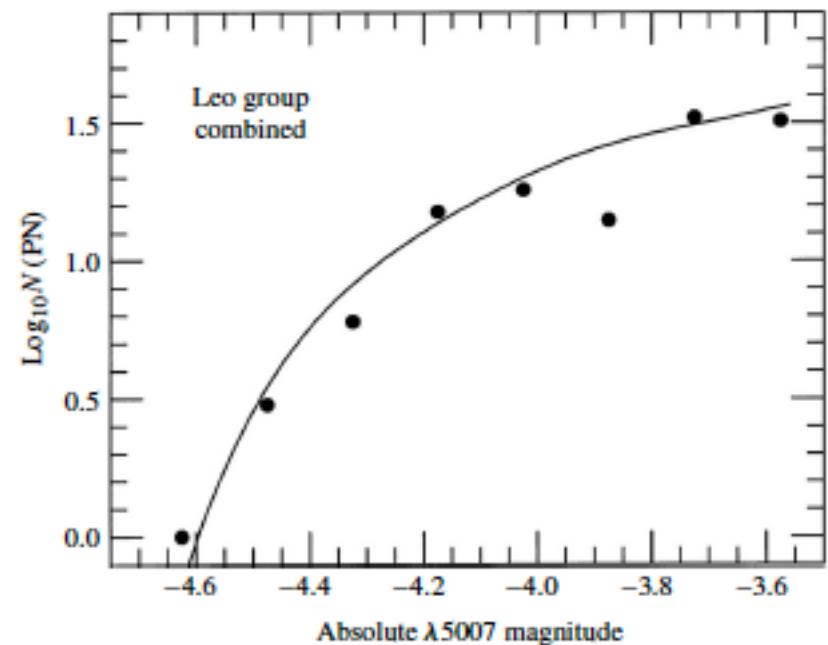
$$M_V^{\max} = -9.96 - 2.31 \log_{10} \dot{m}$$



Secondary Distance Indicators: Luminosity Functions I

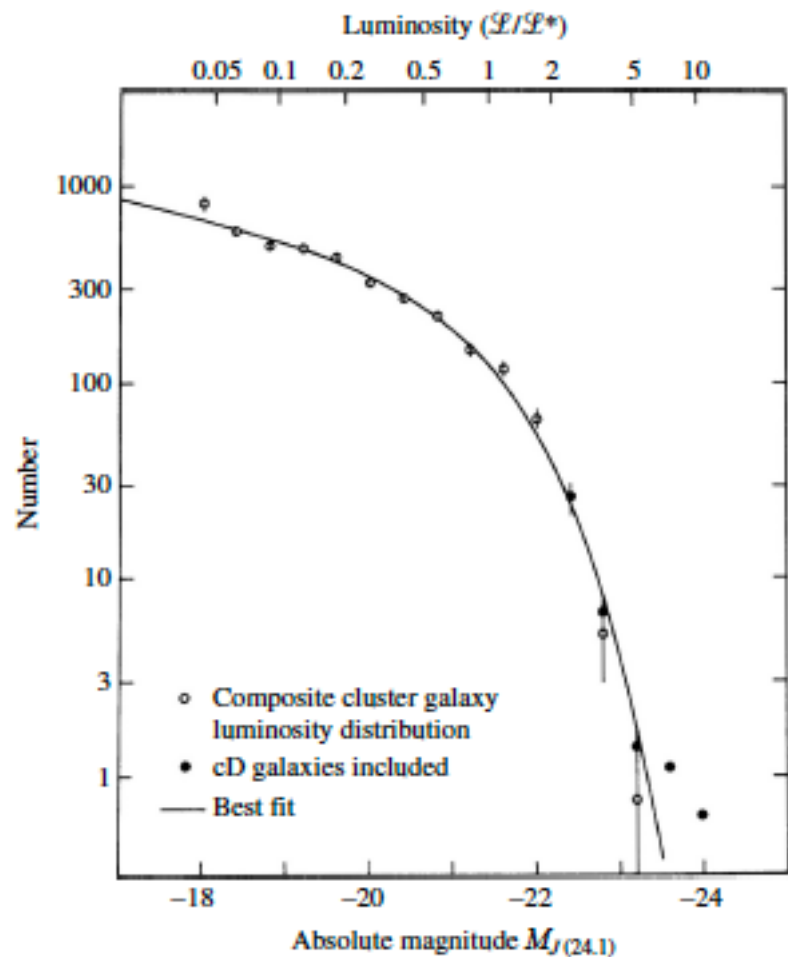


Globular Cluster Luminosity Function



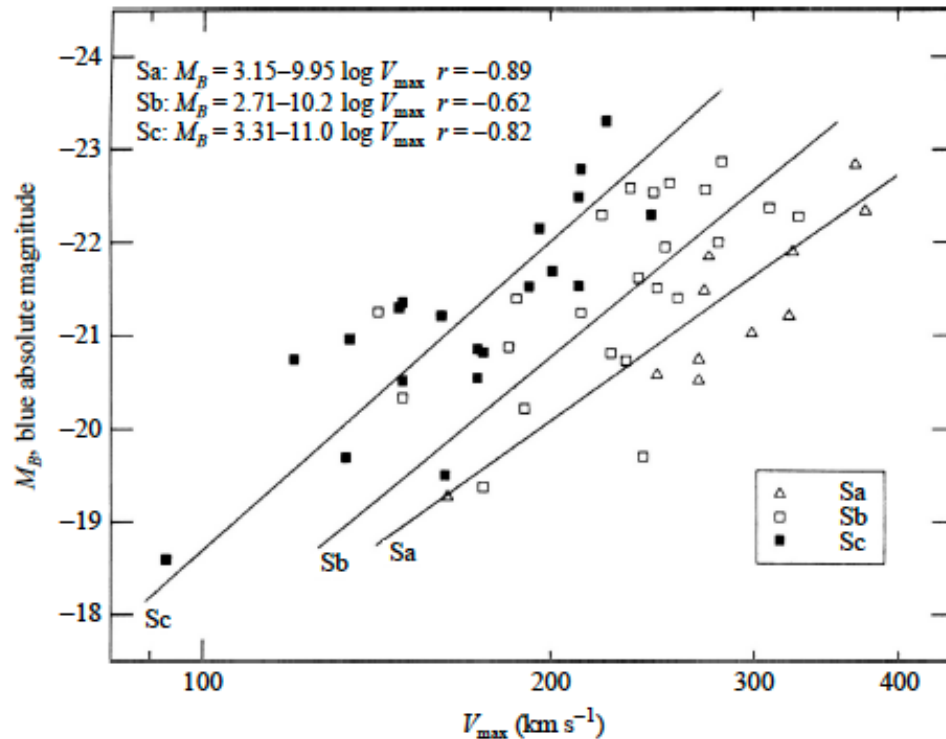
Planetary Nebula Luminosity Function

Secondary Distance Indicators: Luminosity Functions II

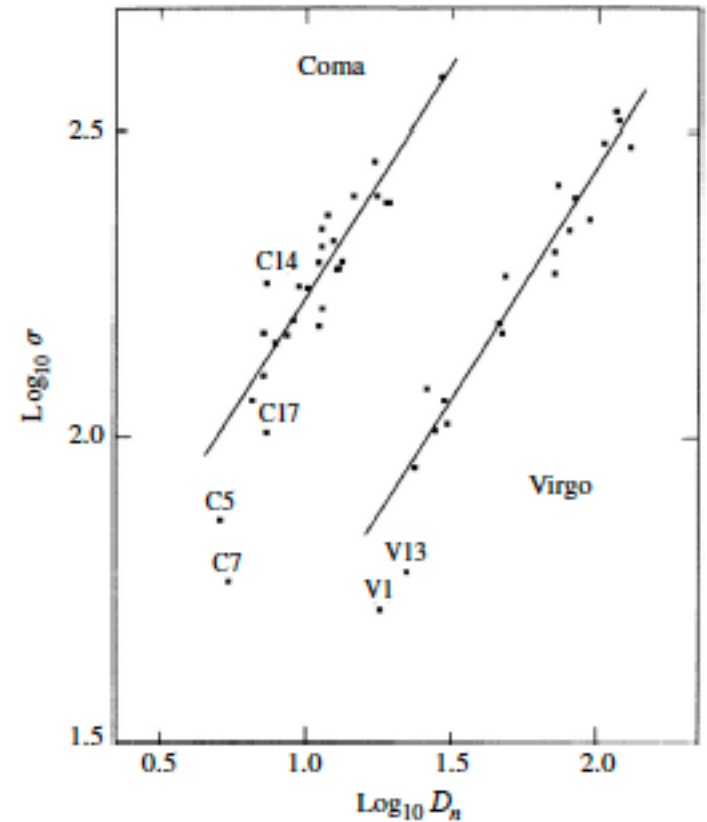


Luminosity function
of Galaxy Clusters

Secondary Distance Indicators: Galactic Kinematics



Tully-Fisher Relation for spirals

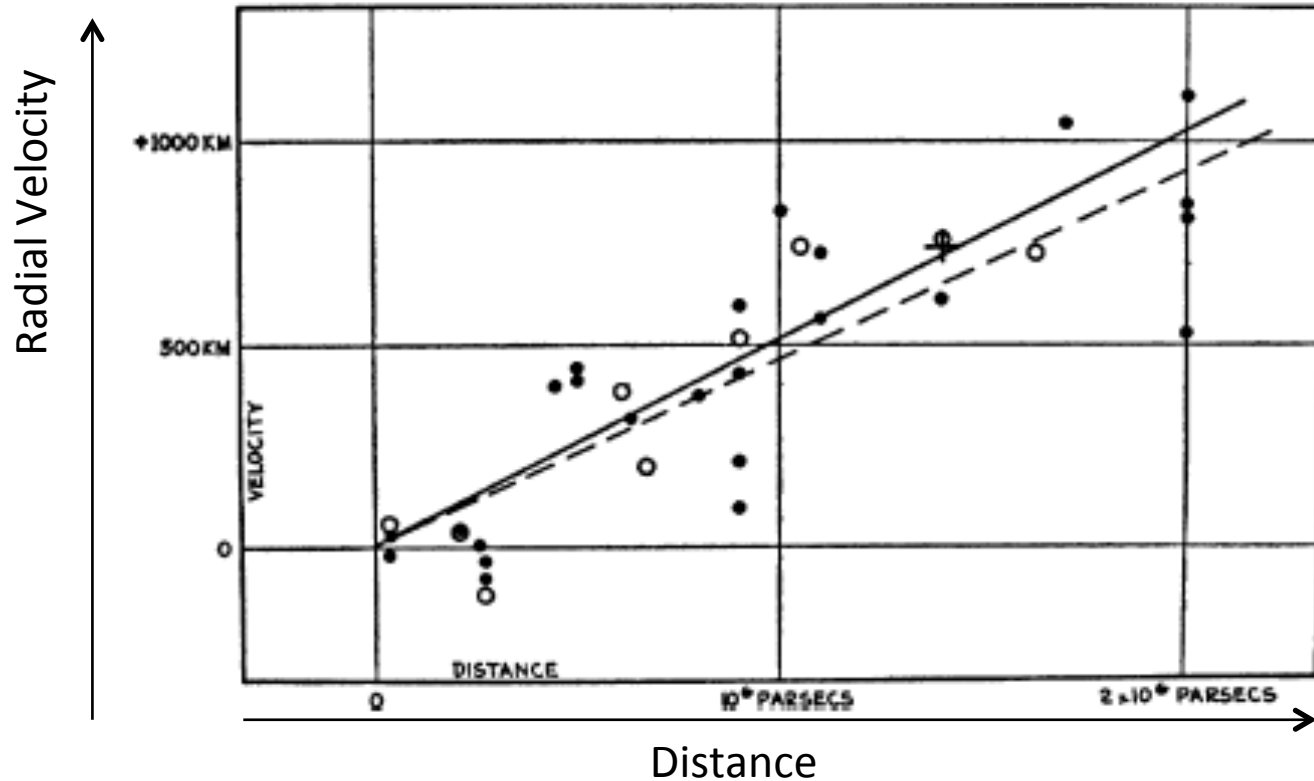


D- σ relation for ellipticals
(modified version of the Faber-Jackson relation but tighter)

Distance Indicators: A Summary

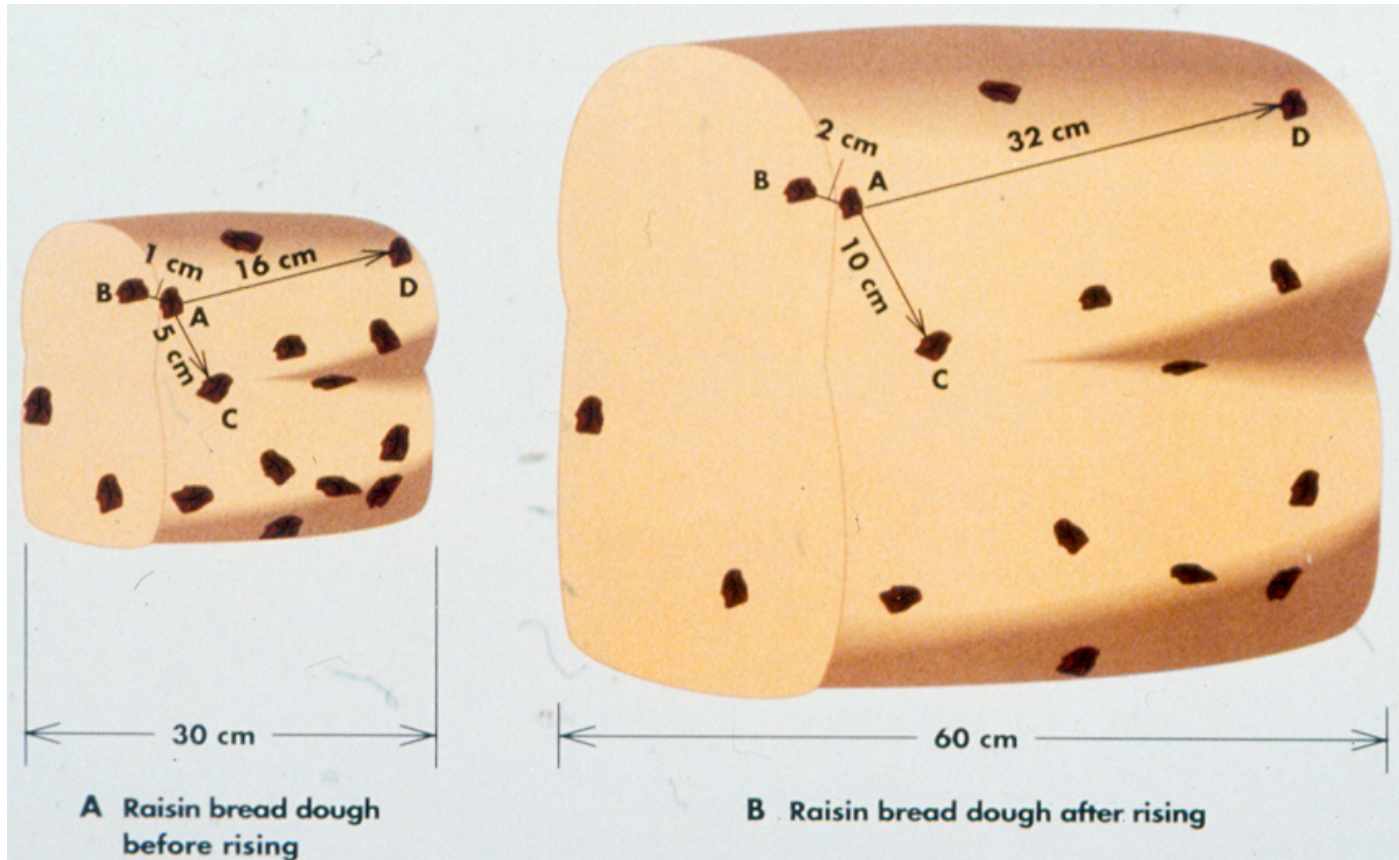
Method	Uncertainty for Single Galaxy (mag)	Distance to Virgo Cluster (Mpc)	Range (Mpc)
Cepheids	0.16	15 – 25	29
Novae	0.4	21.1 ± 3.9	20
Planetary nebula luminosity function	0.3	15.4 ± 1.1	50
Globular cluster luminosity function	0.4	18.8 ± 3.8	50
Surface brightness fluctuations	0.3	15.9 ± 0.9	50
Tully–Fisher relation	0.4	15.8 ± 1.5	> 100
D – σ relation	0.5	16.8 ± 2.4	> 100
Type Ia supernovae	0.10	19.4 ± 5.0	> 1000

Hubble's Law of Universal Expansion



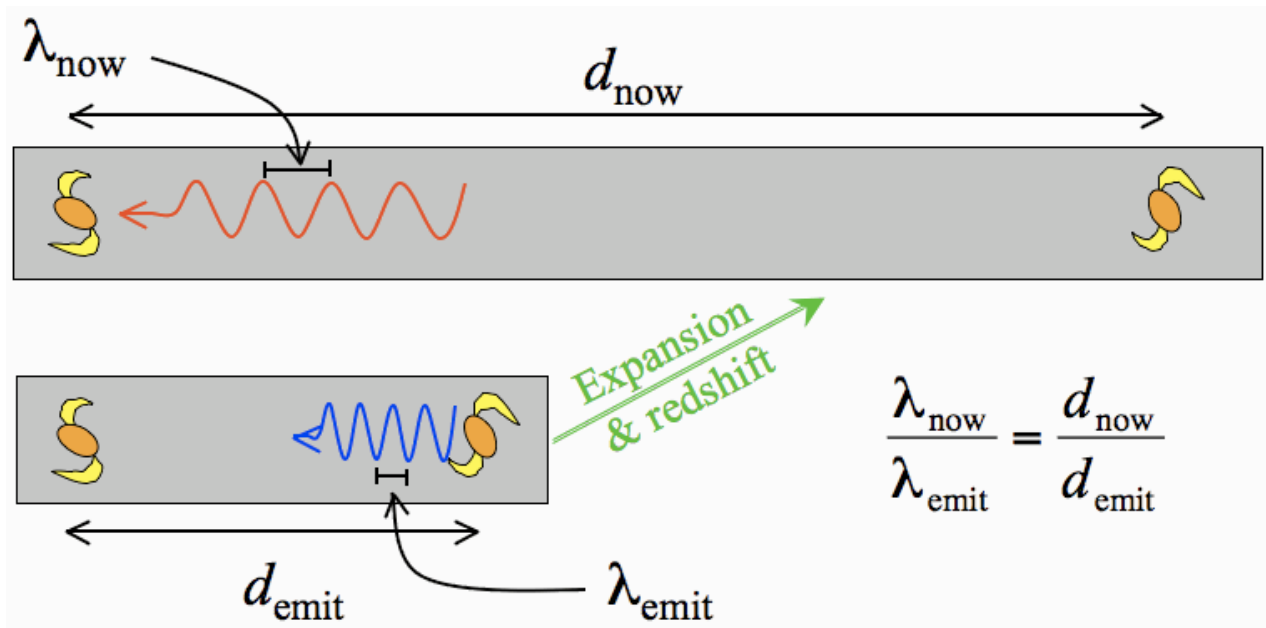
$$v = H_0 d$$

The Expansion of Space



The **larger** the distance, the **faster** it expands!

The Cosmological Redshift



$$\frac{\lambda_{\text{now}}}{\lambda_{\text{emit}}} = \frac{d_{\text{now}}}{d_{\text{emit}}}$$

$$Z = \frac{\lambda_{\text{now}} - \lambda_{\text{rest}}}{\lambda_{\text{rest}}}$$

The cosmological redshift

The Cosmological Distance

Non-relativistic

$$d = \frac{cz}{H_0}$$

Relativistic

$$d \simeq \frac{c}{H_0} \frac{(z+1)^2 - 1}{(z+1)^2 + 1}$$

Hubble's Constant

$$H_0 = 100h \text{ km s}^{-1} \text{ Mpc}^{-1}.$$

$$[h]_{\text{WMAP}} = 0.71^{+0.04}_{-0.03}.$$

In conventional units:

$$H_0 = 3.24 \times 10^{-18} h \text{ s}^{-1}$$

$$[H_0]_{\text{WMAP}} = 2.30 \times 10^{-18} \text{ s}^{-1}.$$

The Hubble Time

Assuming the expansion remains to have a constant velocity

$$d = v t_H = H_0 d t_H$$

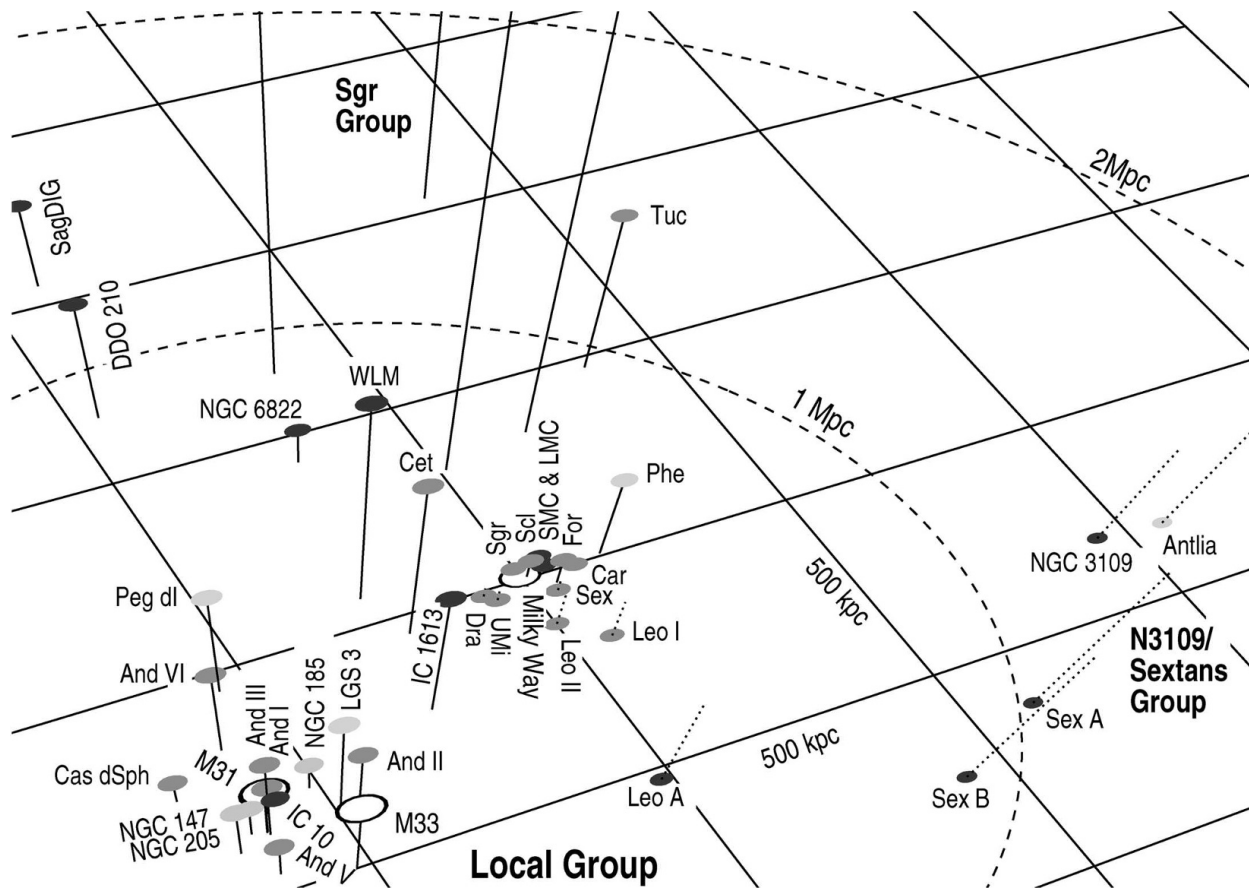
and so the **Hubble time** is

$$t_H \equiv \frac{1}{H_0} = 3.09 \times 10^{17} h^{-1} \text{ s} = 9.78 \times 10^9 h^{-1} \text{ yr.}$$

Using WMAP values,

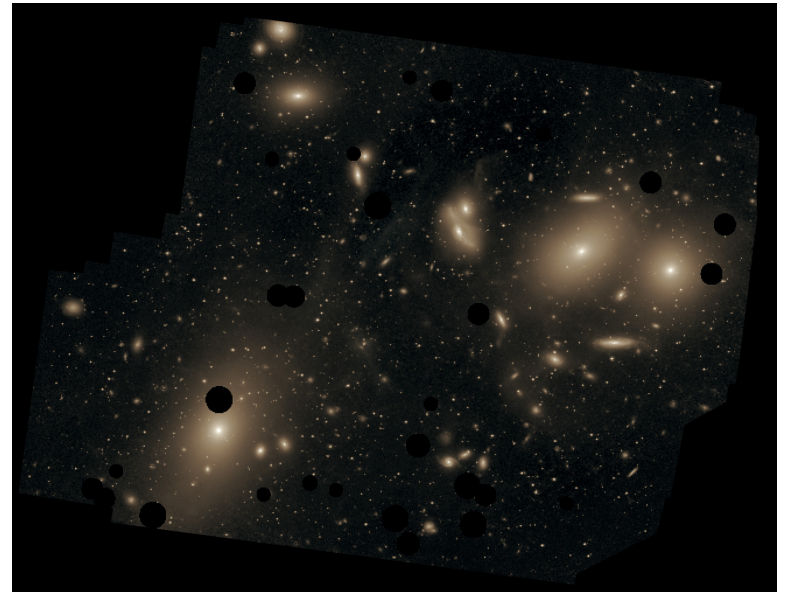
$$t_H = 4.35 \times 10^{17} \text{ s} = 1.38 \times 10^{10} \text{ yr.}$$

The Local Group

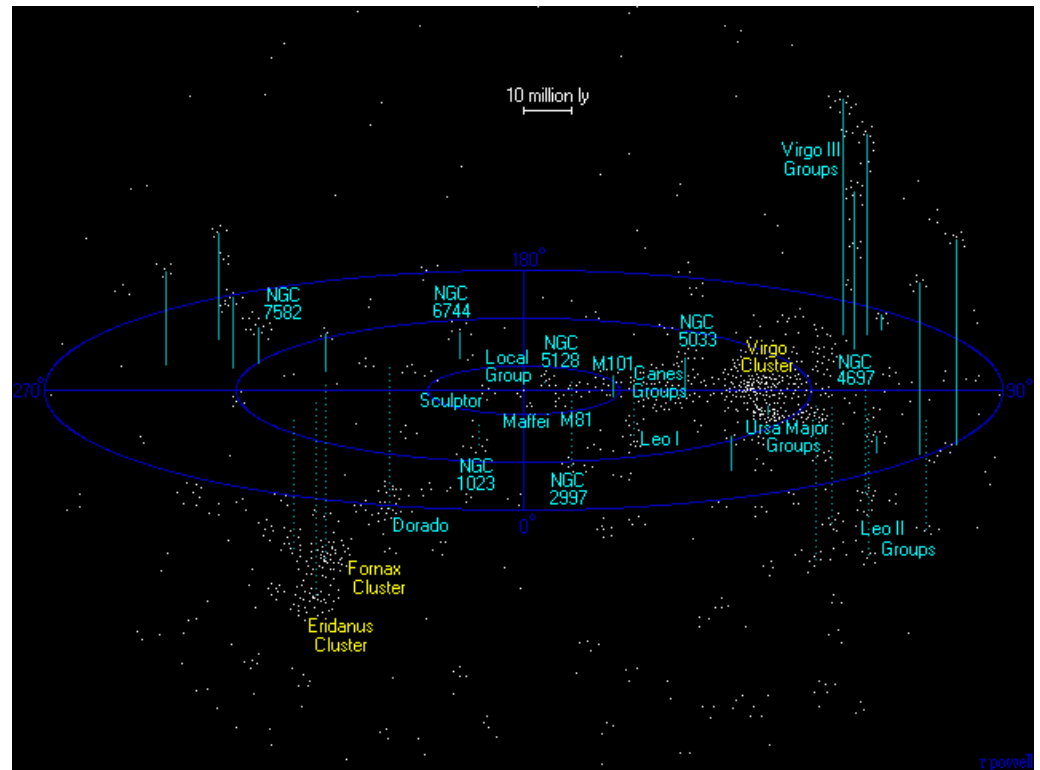
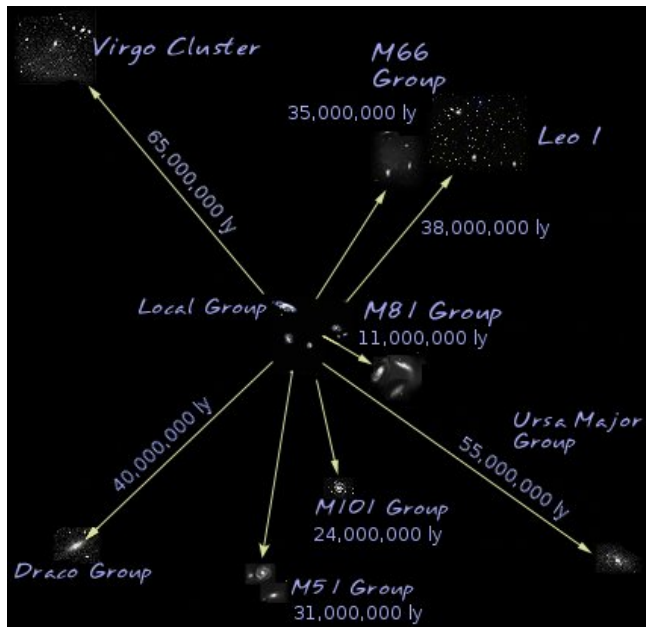


Virgo Cluster

- The Milky Way is part of the Local Group which is part of the Virgo Cluster
- Located in the direction of constellation Virgo
- 1300 galaxies in this group



Local Supercluster



Structures on the Largest Scales

