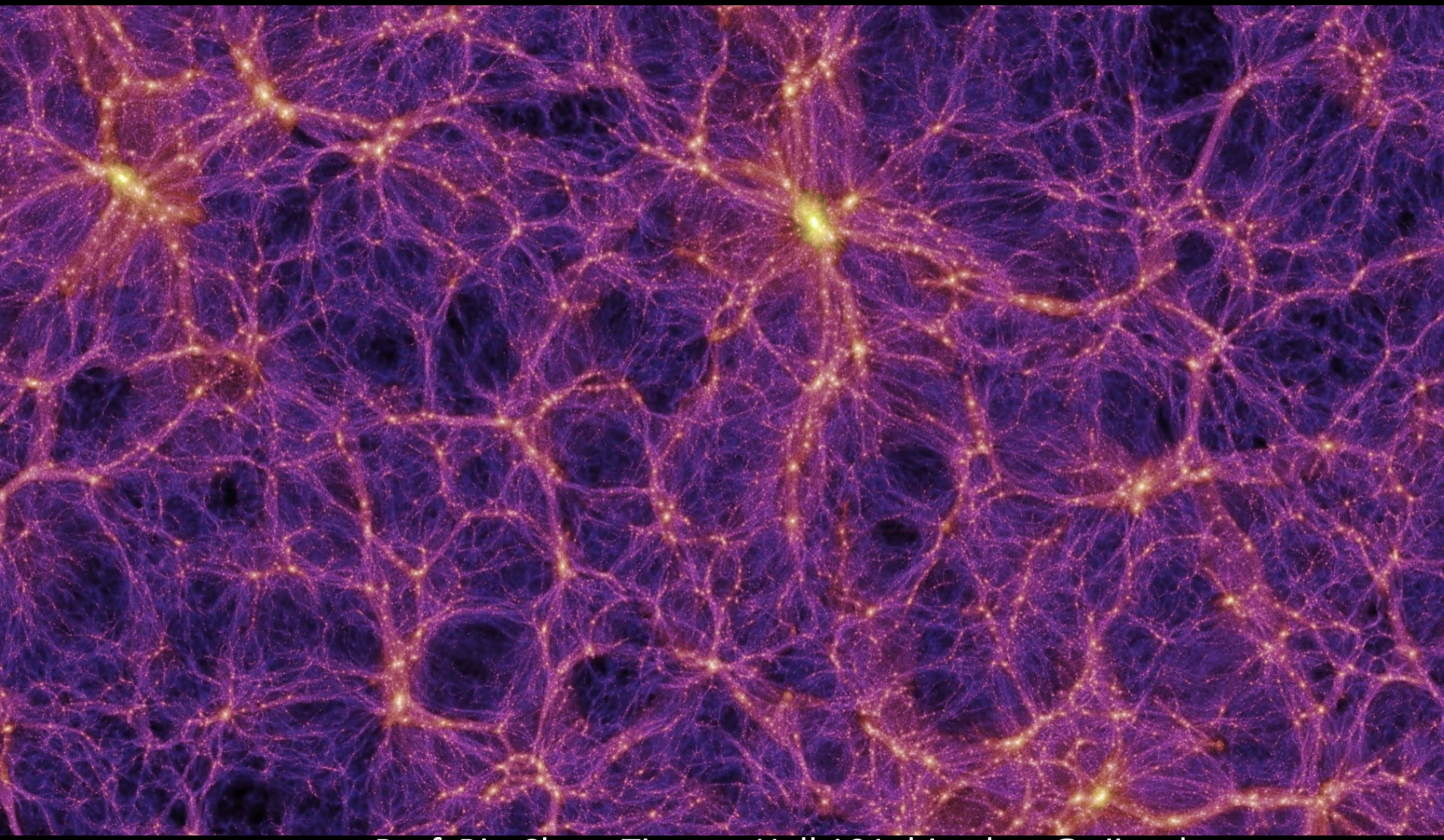
Phys 321: Lecture 12
Large-Scale Structures



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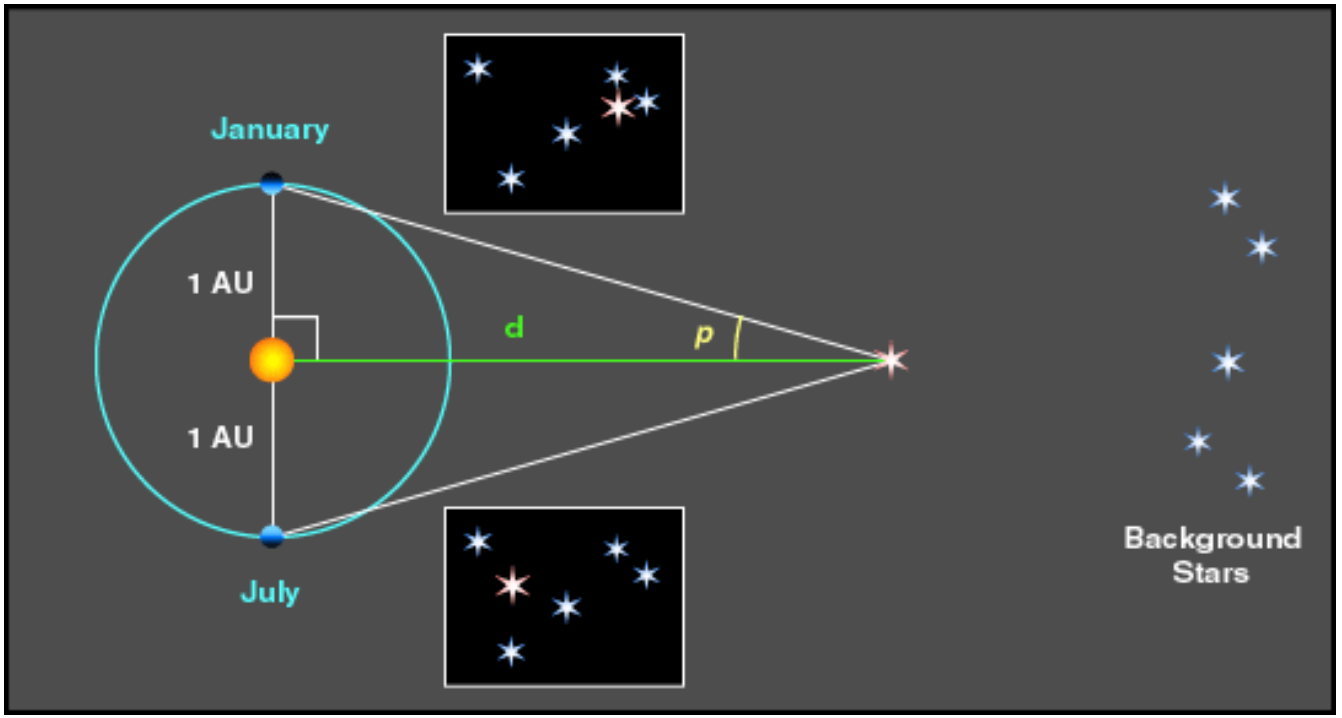
Outline

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

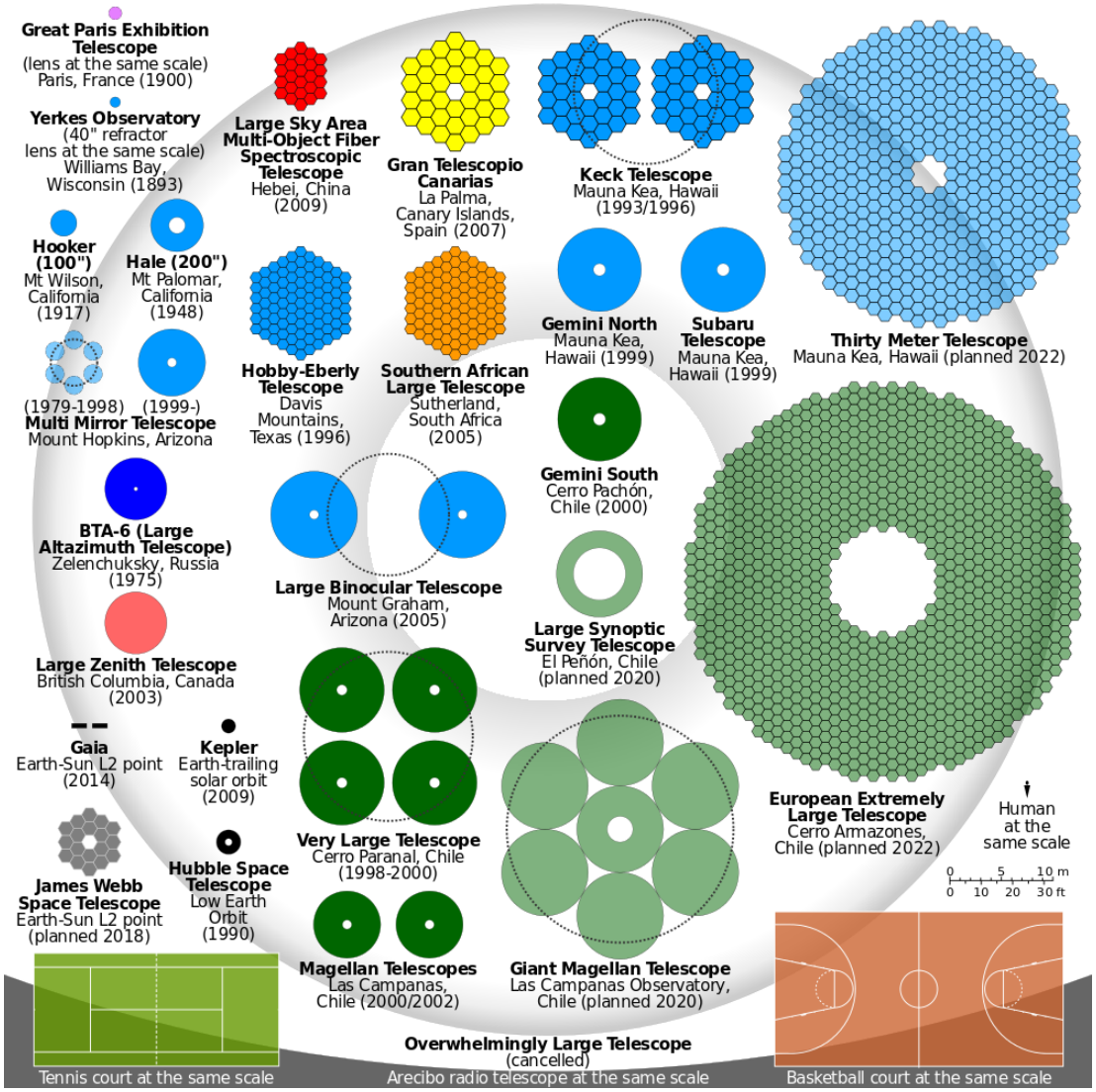
Parallax

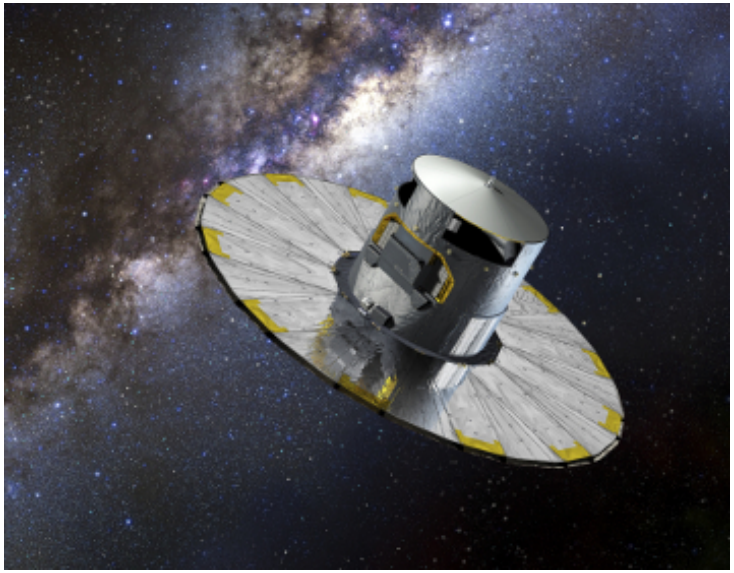


$$d = \frac{1}{p''} \text{ pc.}$$

- 1 pc ≈ 3.262 light year
- Measured parallax angle of 1” gives a distance of 1 pc
- Smaller parallax angle -> larger distance

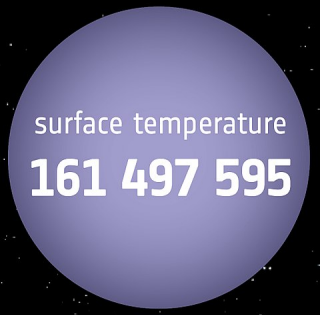
The Gaia Space Telescope





Gaia Data Release #2

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



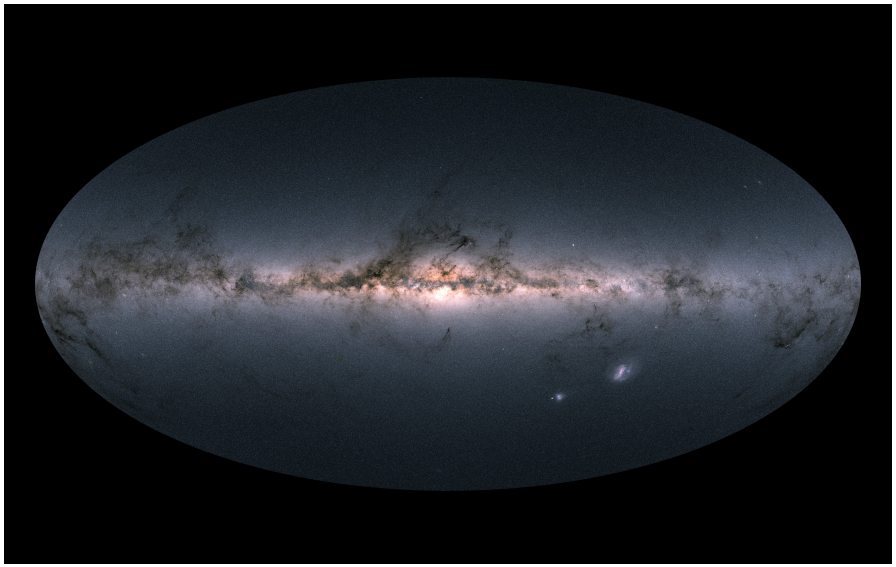
14 099
Solar System objects

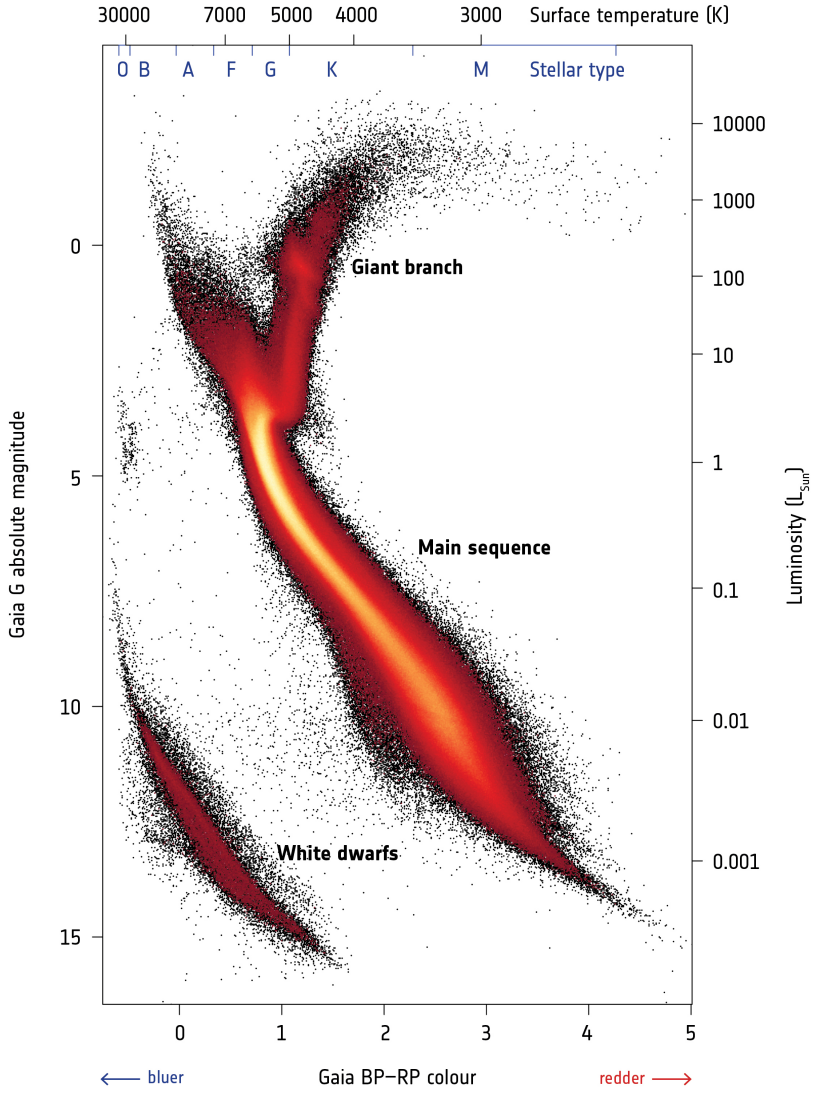
550 737
variable sources

The second data release of ESA's Gaia mission is scheduled for publication on 25 April 2018.

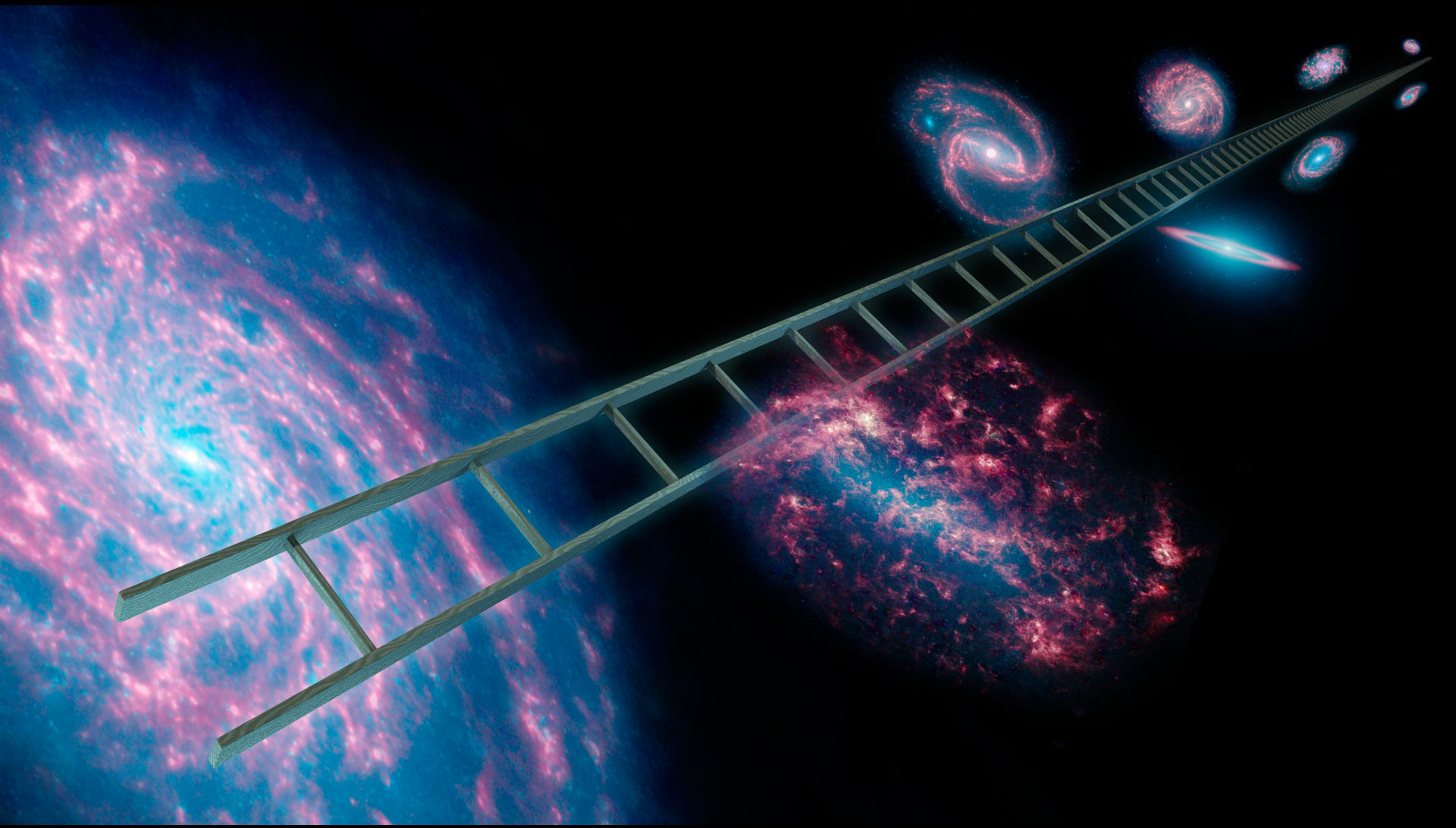
→ GAIA'S HERTZSPRUNG-RUSSELL DIAGRAM

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

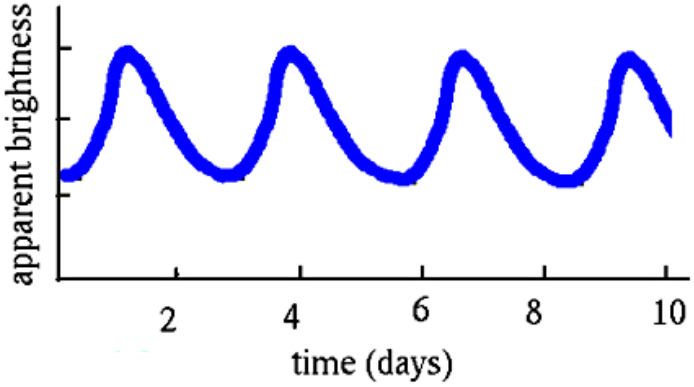




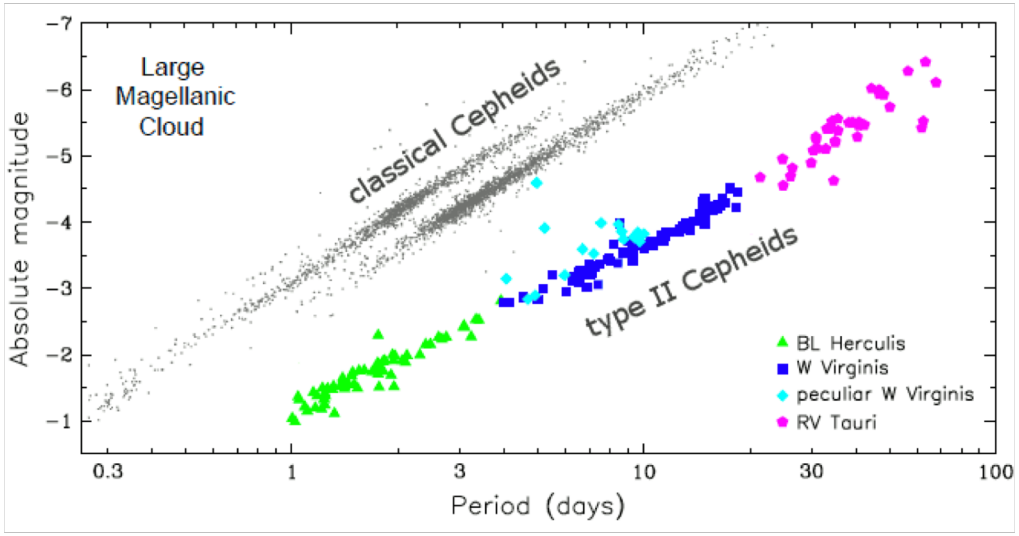
Climbing the Cosmic Distance Ladder



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



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

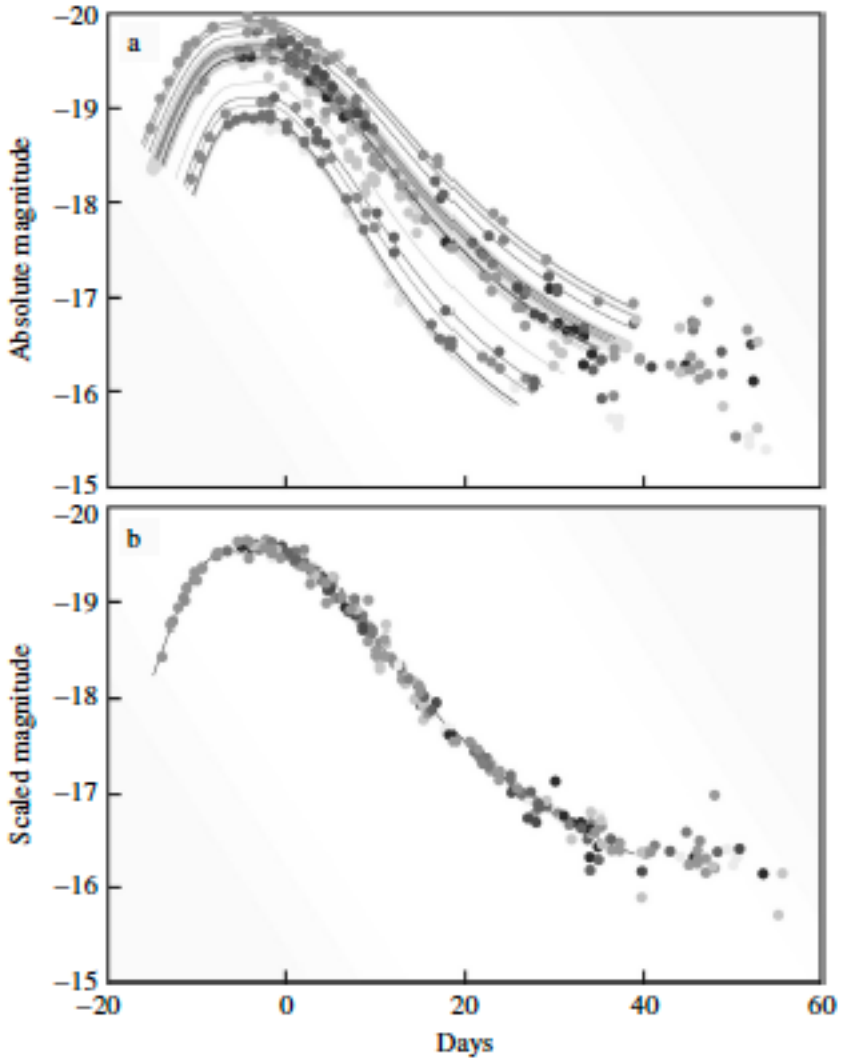
Type Ia Supernovae

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

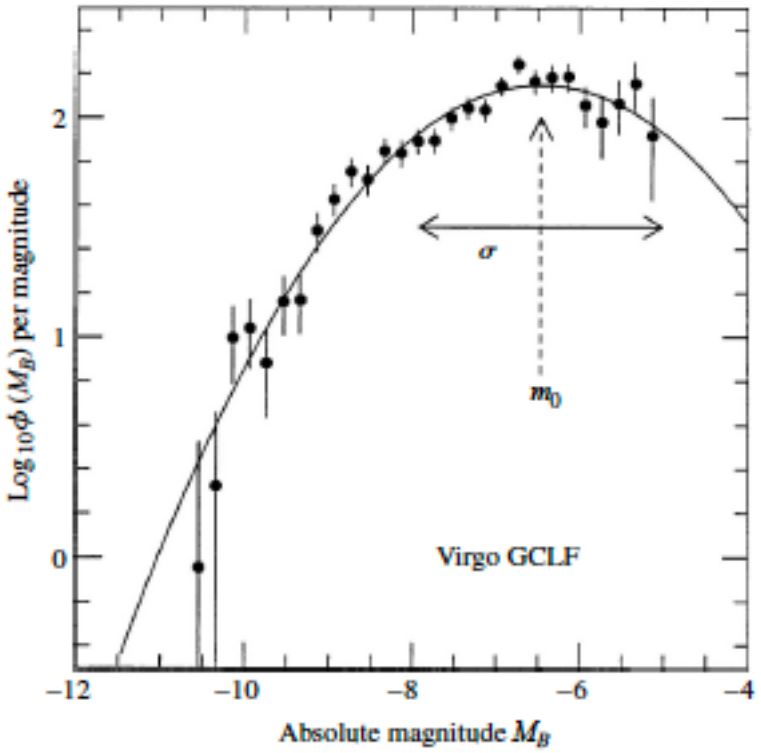
$$M_{SNIa} \approx -19.3 \pm 0.03$$

For Novae

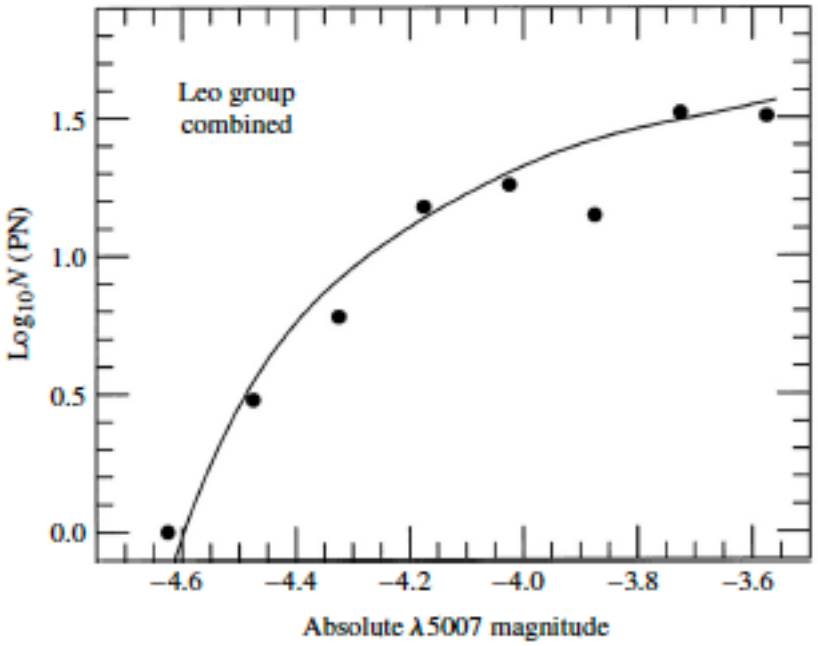
$$M_V^{\max} = -9.96 - 2.31 \log_{10} \dot{m}$$



Secondary Distance Indicators: Luminosity Functions I

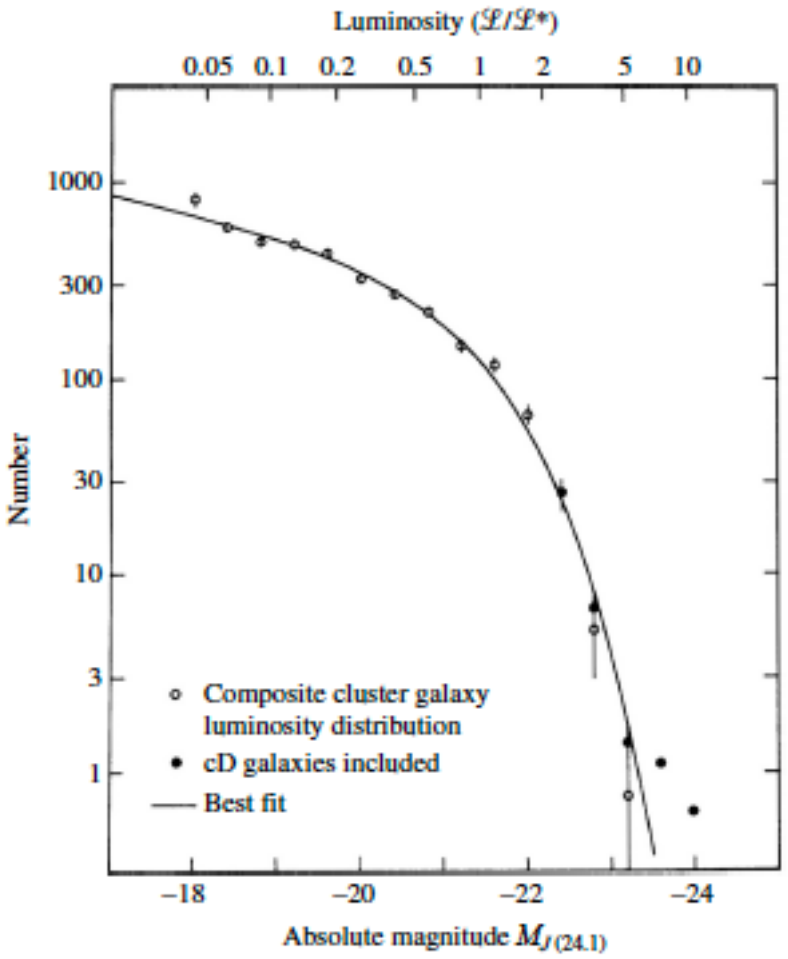


Globular Cluster Luminosity Function



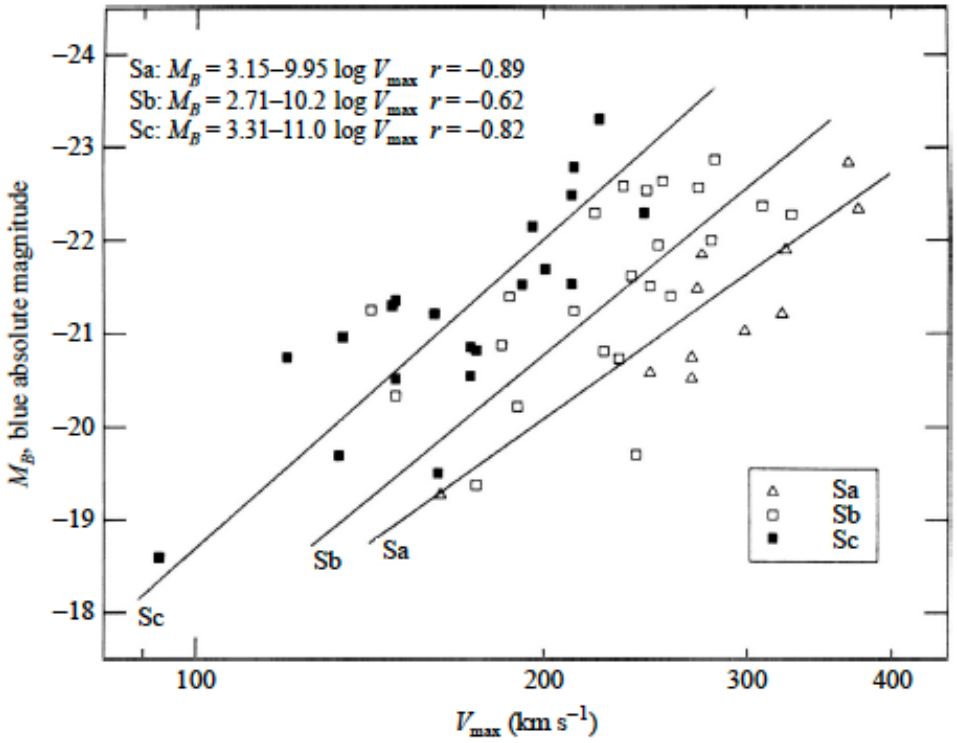
Planetary Nebula Luminosity Function

Secondary Distance Indicators: Luminosity Functions II

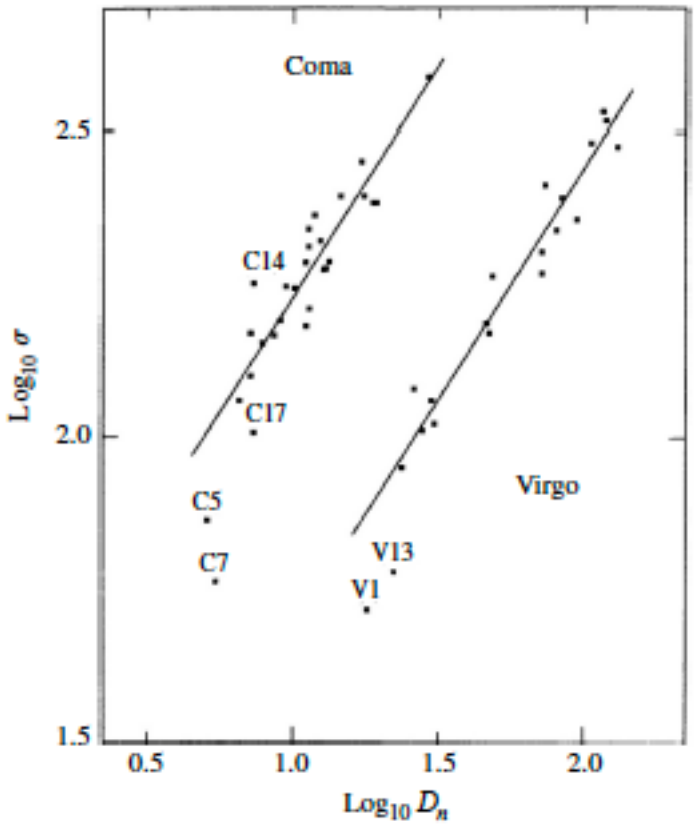


Luminosity function of Galaxy Clusters

Secondary Distance Indicators: Galactic Kinematics



Tully-Fisher Relation for spirals

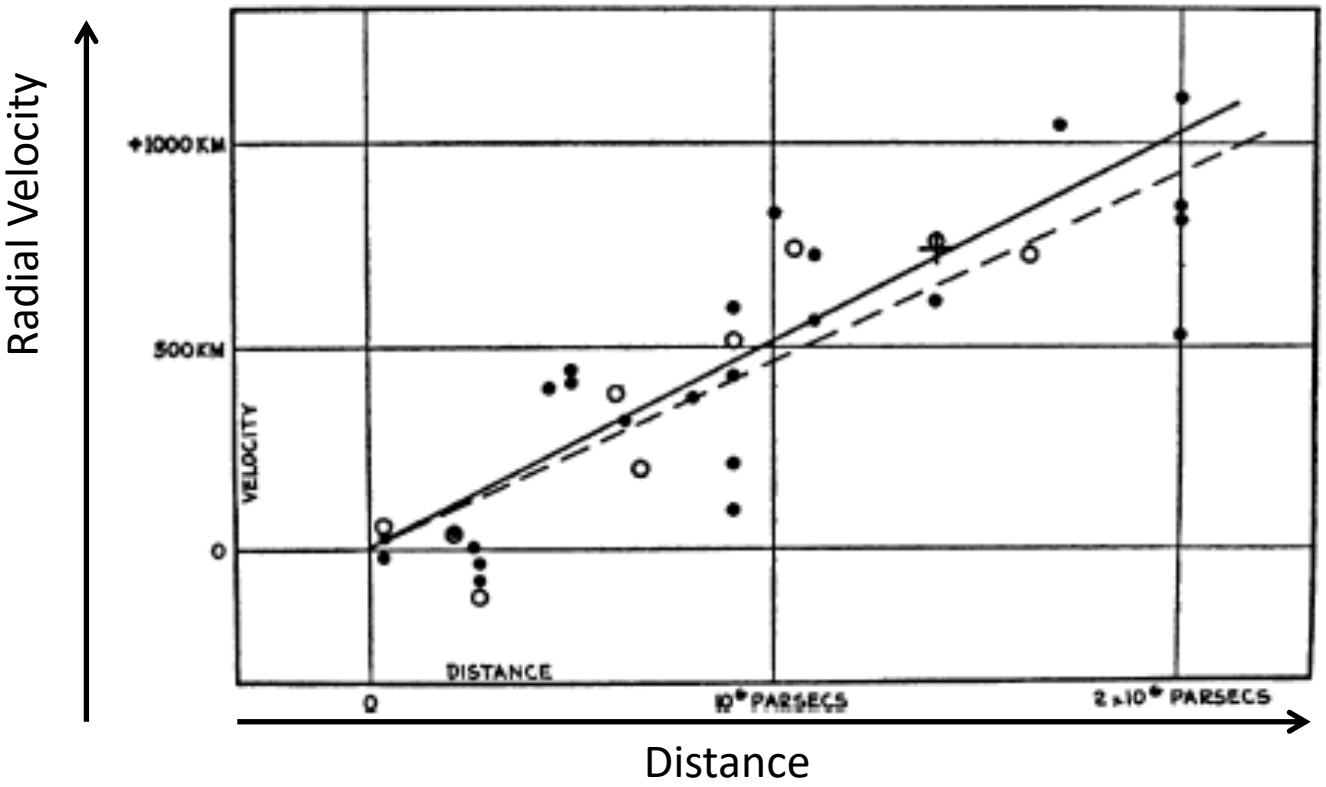


D-σ relation for ellipticals (modified version of the Faber-Jackson relation but tighter)

Distance Indicators: A Summary

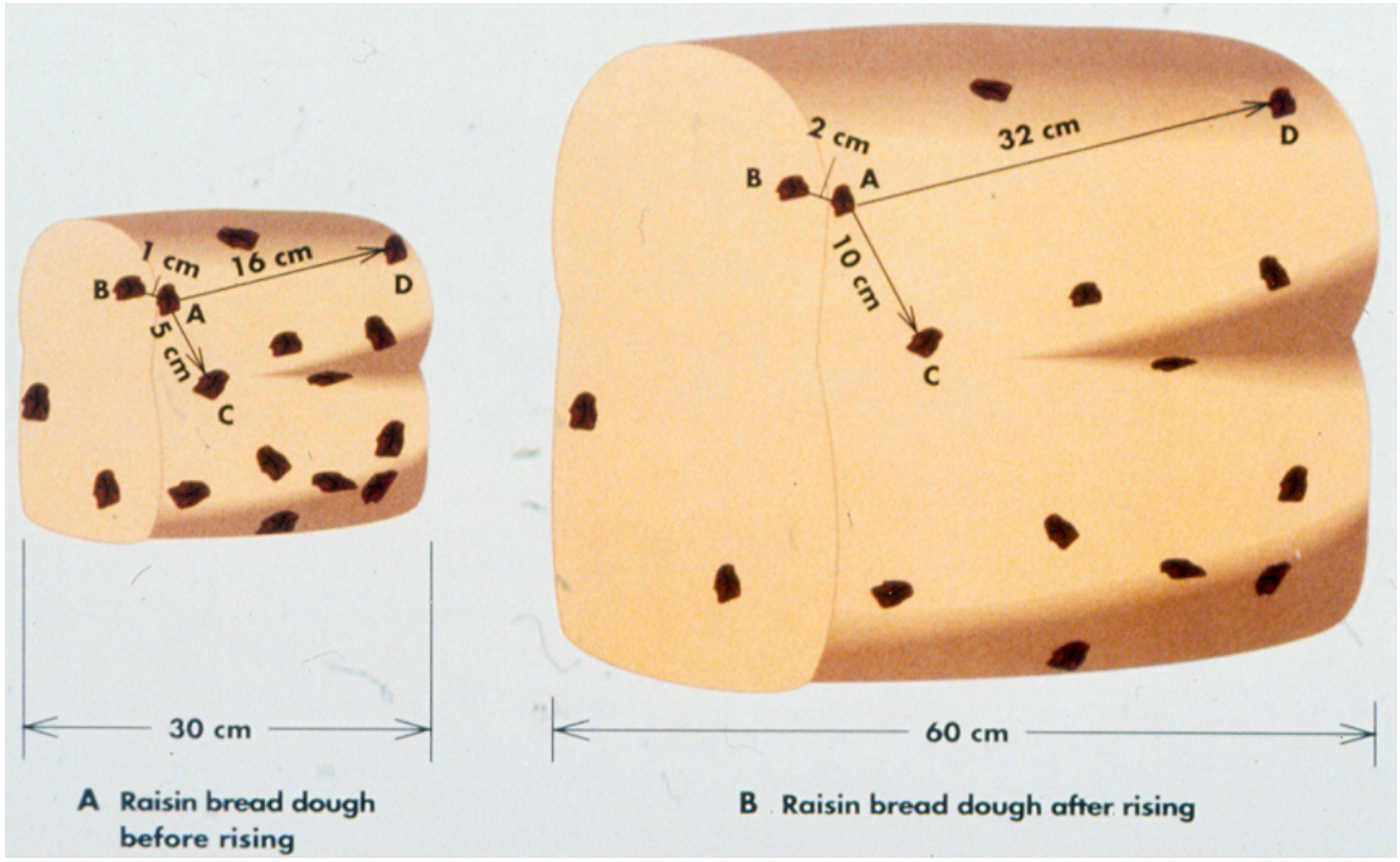
Method	Uncertainty for Single Galaxy (mag)	Distance to Virgo Cluster (Mpc)	Range (Mpc)
Cepheids	0.16	15 – 25	29
Novae	0.4	21.1 ± 3.9	20
Planetary nebula luminosity function	0.3	15.4 ± 1.1	50
Globular cluster luminosity function	0.4	18.8 ± 3.8	50
Surface brightness fluctuations	0.3	15.9 ± 0.9	50
Tully–Fisher 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



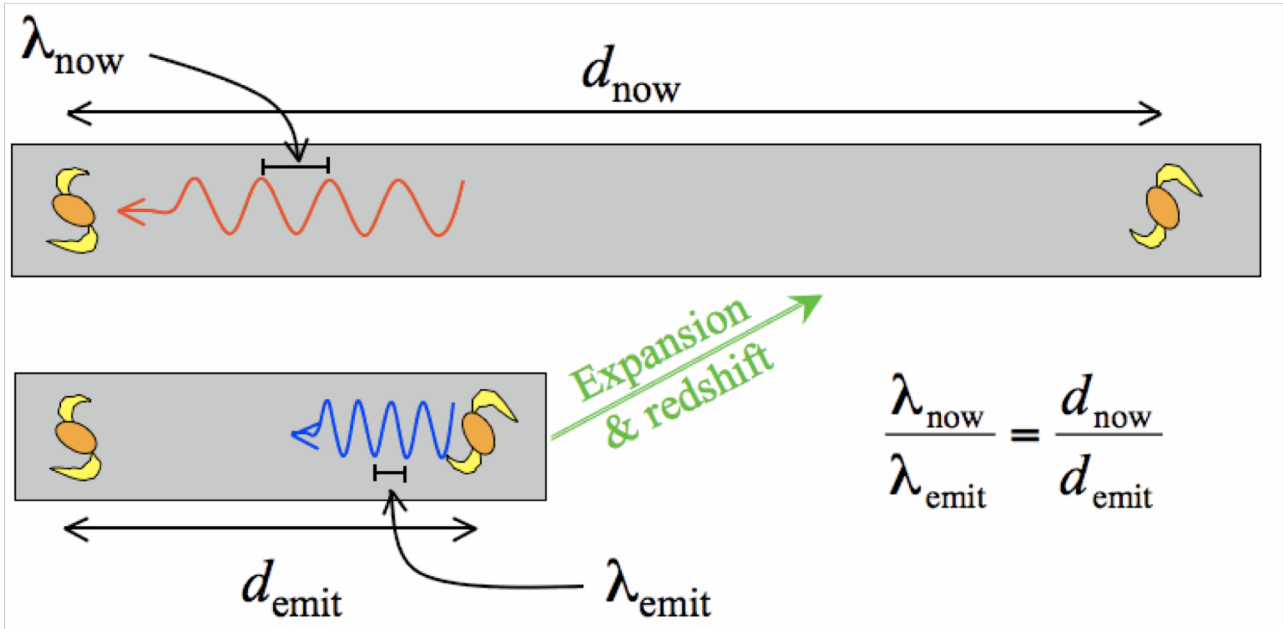
$$v = H_0 d$$

The Expansion of Space



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

The Cosmological Redshift



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

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

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

$$d = v\, t_H = H_0 d\, t_H$$

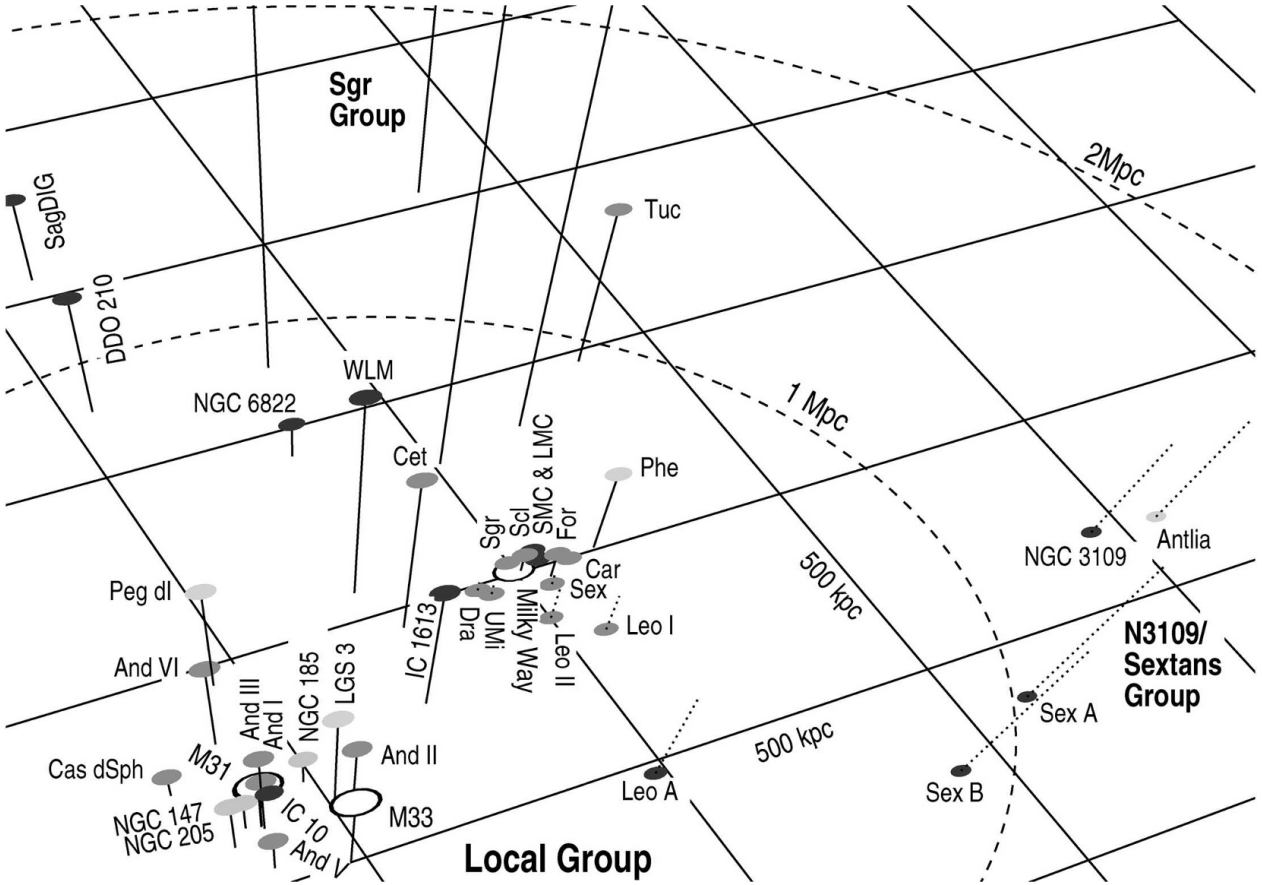
and so the **Hubble time** is

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

Using WMAP values,

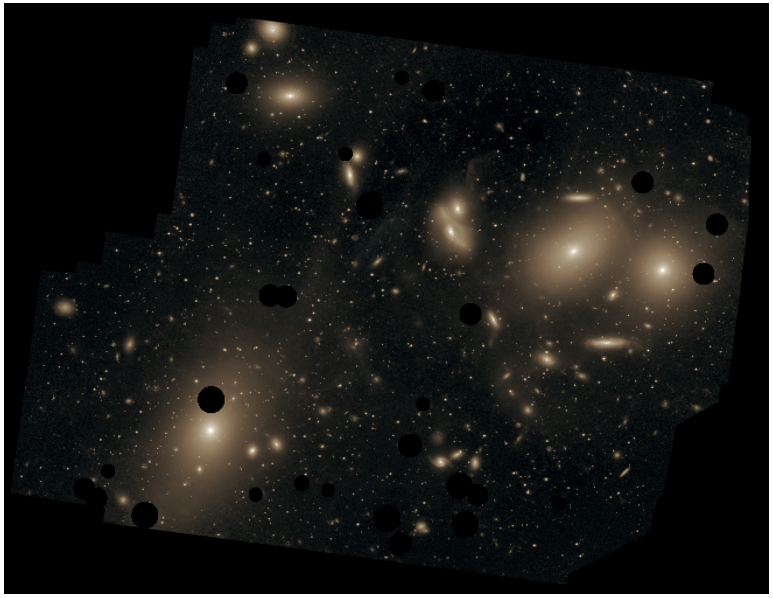
$$t_H = 4.35 \times 10^{17}\ \mathrm{s} = 1.38 \times 10^{10}\ \mathrm{yr}.$$

The Local Group

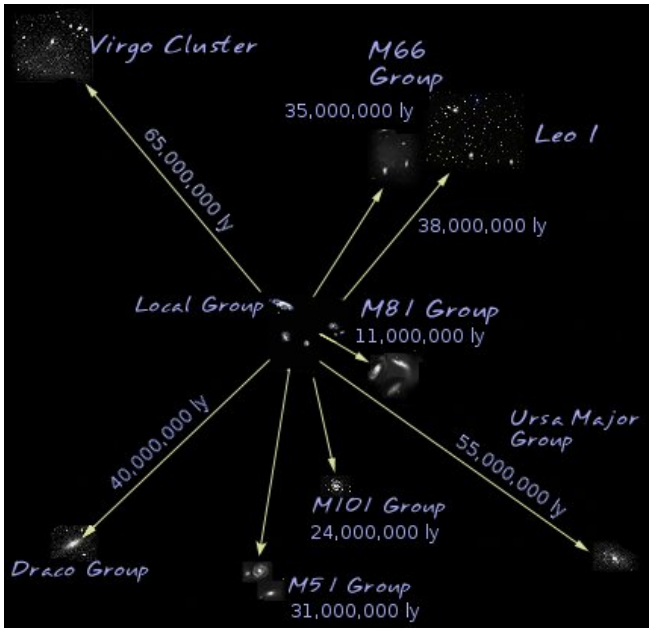


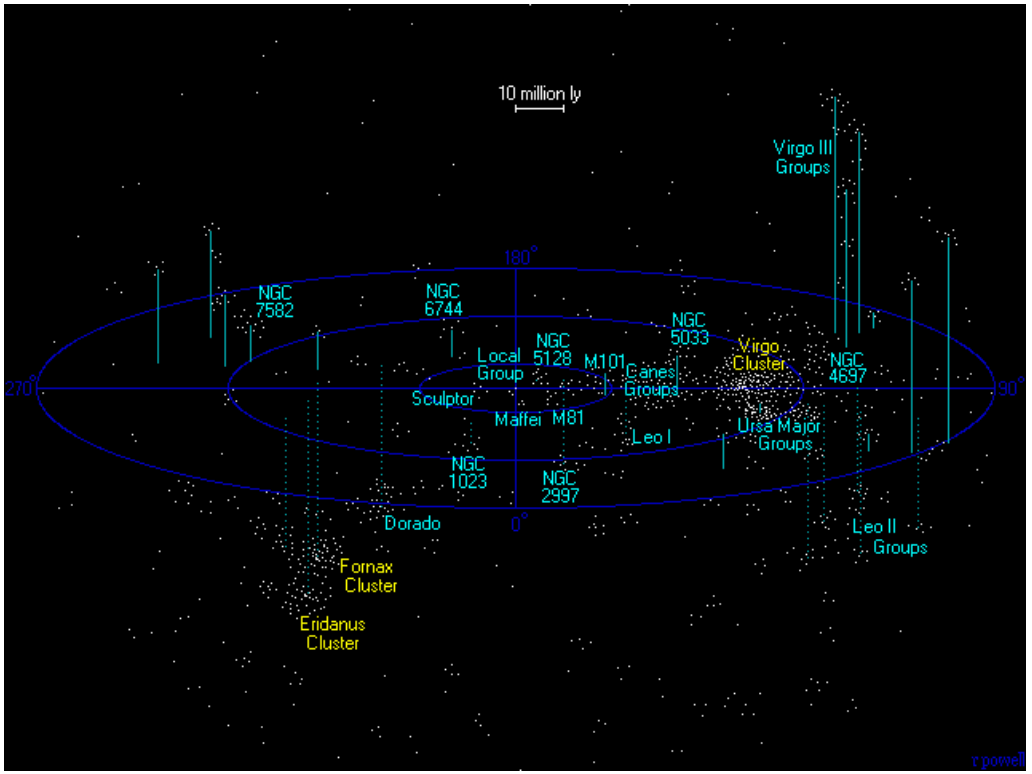
Virgo Cluster

- 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