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Our Universe

Plan of the talk

- In the first part I will start from Earth and show how it is placed with respect to the rest of the Universe
- In the second half I shall focus on theories of cosmogony, evolution and the future of our Universe

Distance Units

The average distance between the Sun and the Earth is called the Astronomical Unit

1 AU = 150 million km

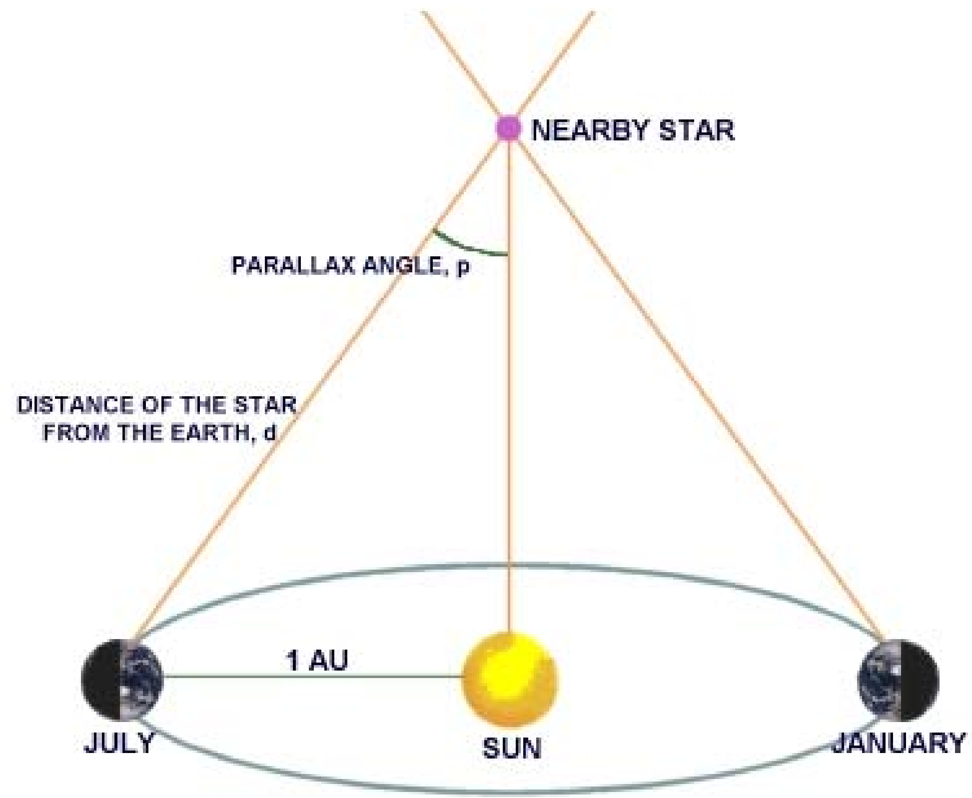
Distance to nearby stars can be measured by their parallax. A parallax of one arc second is defined as one parsec

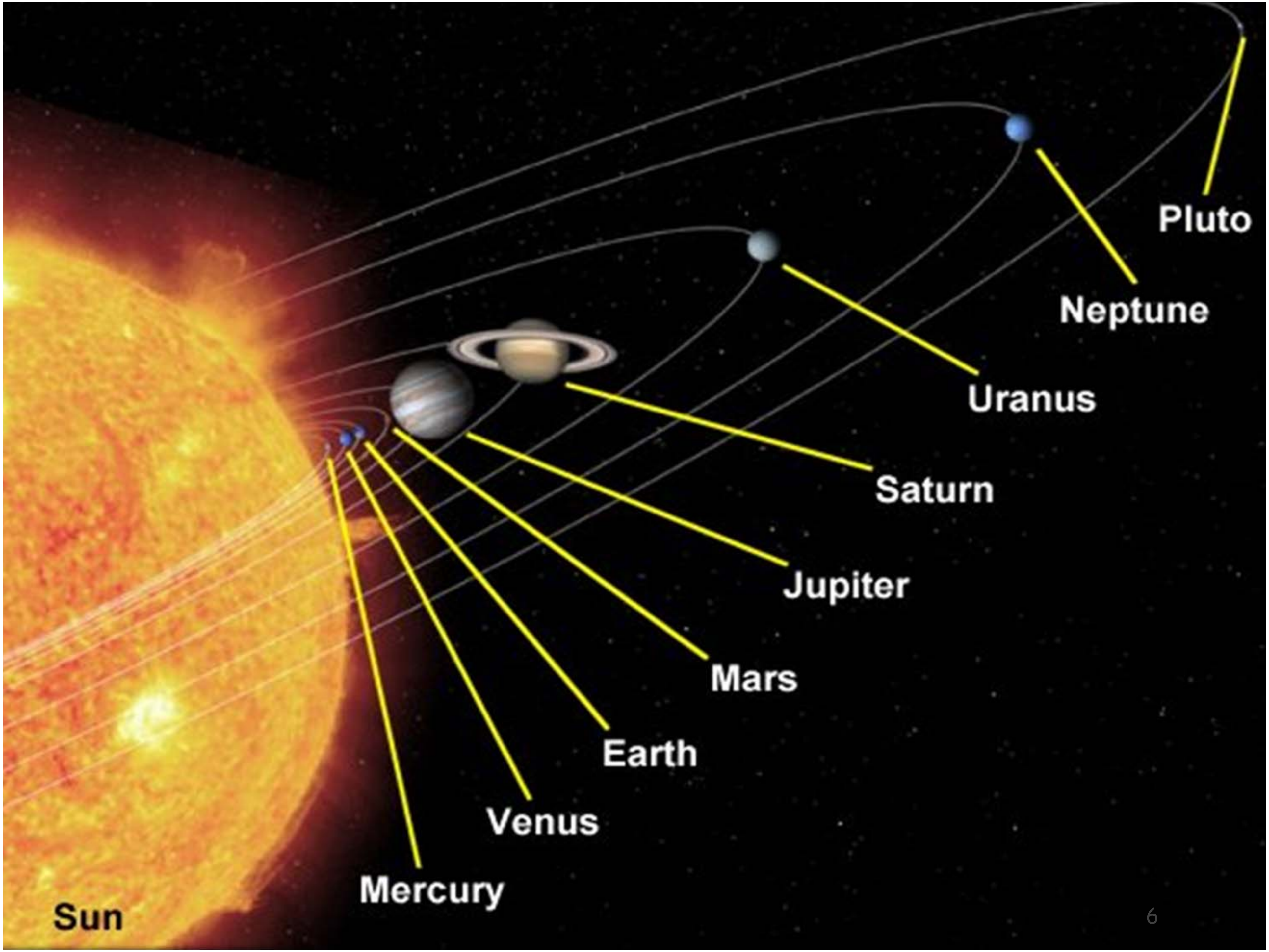
1 pc = 3.26 light years

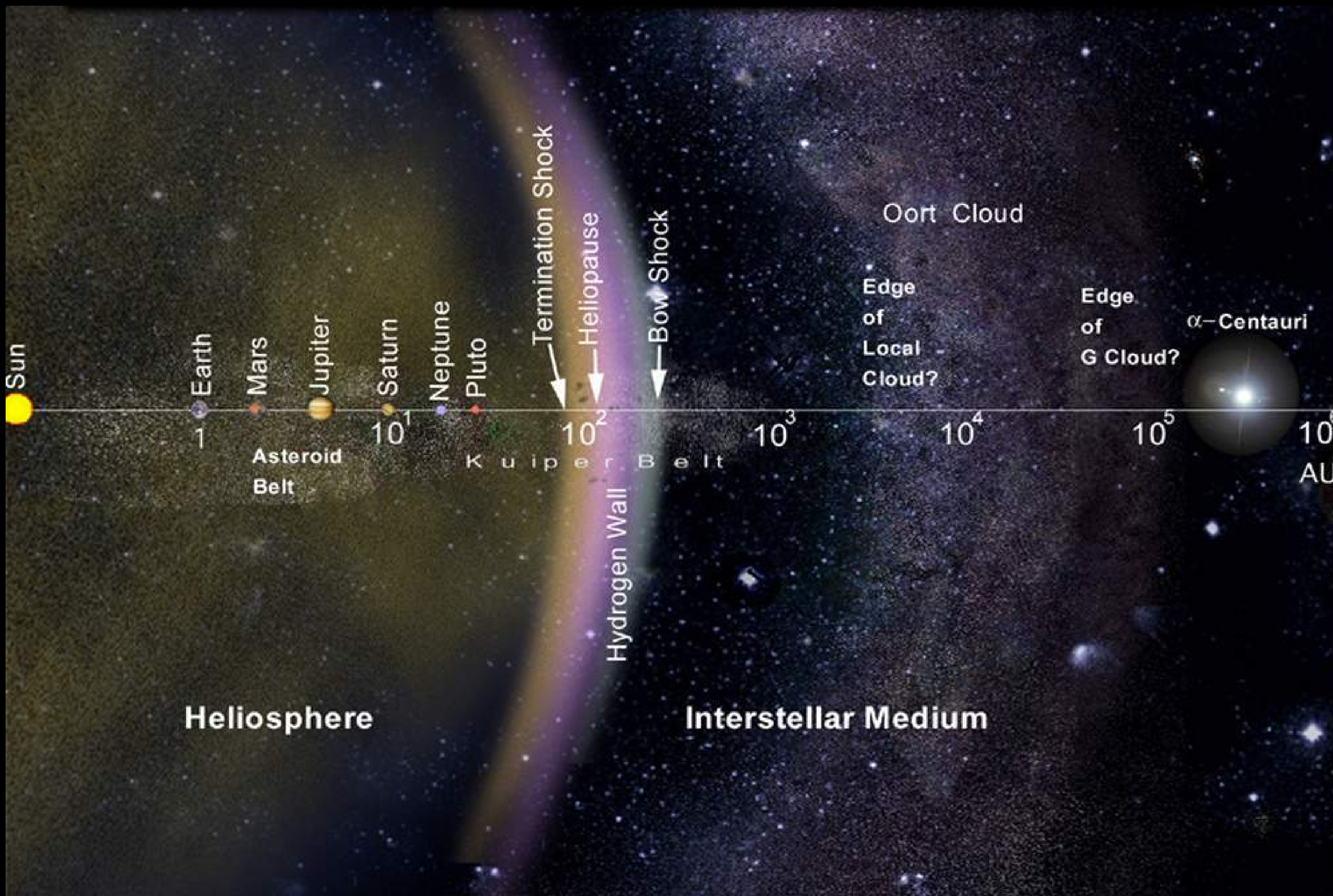
Or

31 trillion kilometers

Larger distances are often measured in mega parsecs or Mpc



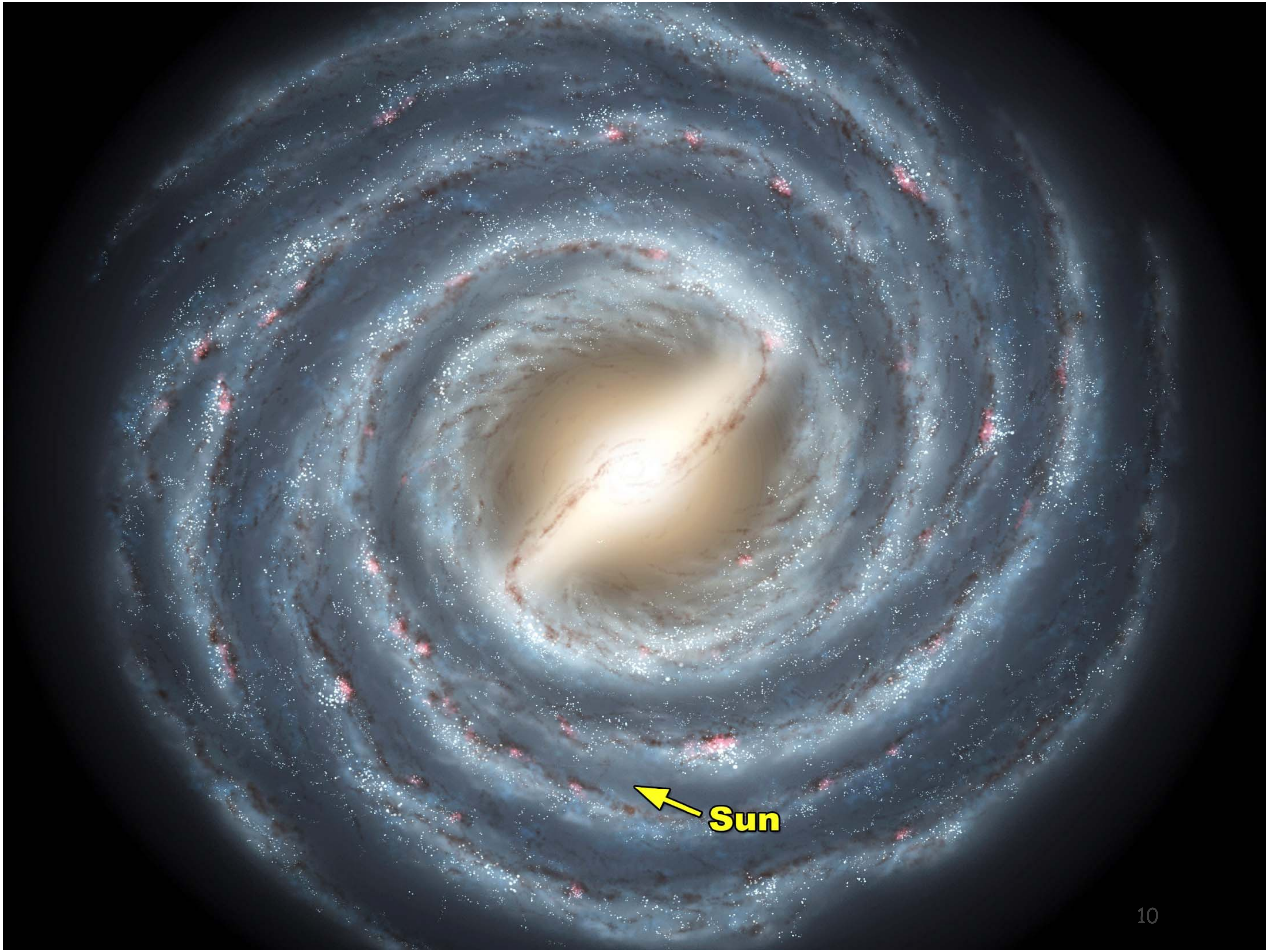

Pluto
Neptune
Uranus
Saturn
Jupiter
Mars
Earth
Venus
Mercury
Sun

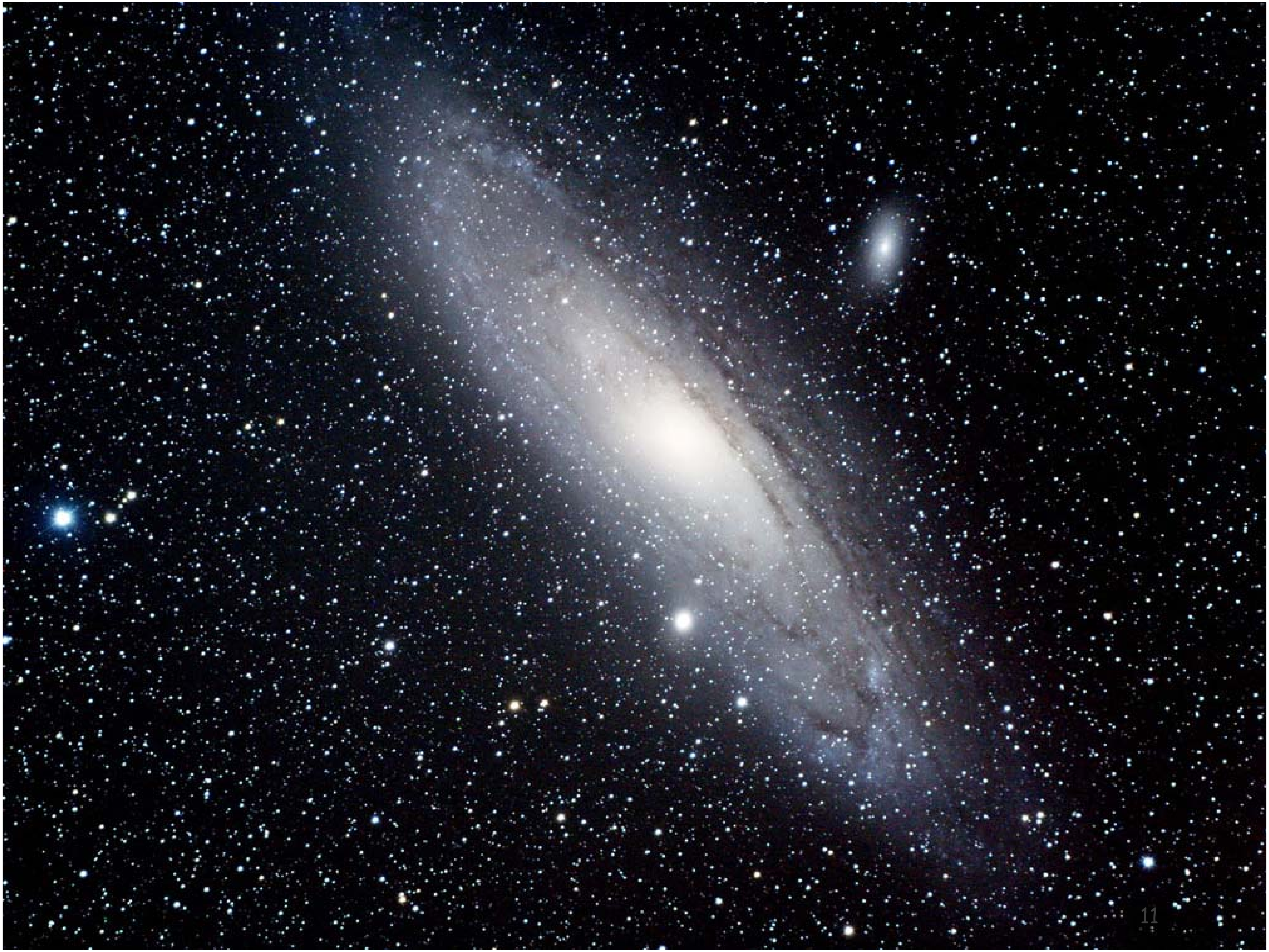


Sun
Earth
Mars
Jupiter
Saturn
Neptune
Pluto
Termination Shock
Heliopause
Bow Shock
Oort Cloud
Edge of Local Cloud?
Edge of G Cloud?
α−Centauri
1
10^1
10^2
10^3
10^4
10^5
10^6
AU
Asteroid Belt
Kuiper Belt
Hydrogen Wall
Heliosphere
Interstellar Medium

Solar system and the Galaxy

- Our Sun is a typical star (G4) and is about 10 pc away from the centre of our Galaxy
- Our Galaxy, also called the Milky Way, can be seen on a clear night as a faint band running through the constellation Sagittarius


Sun



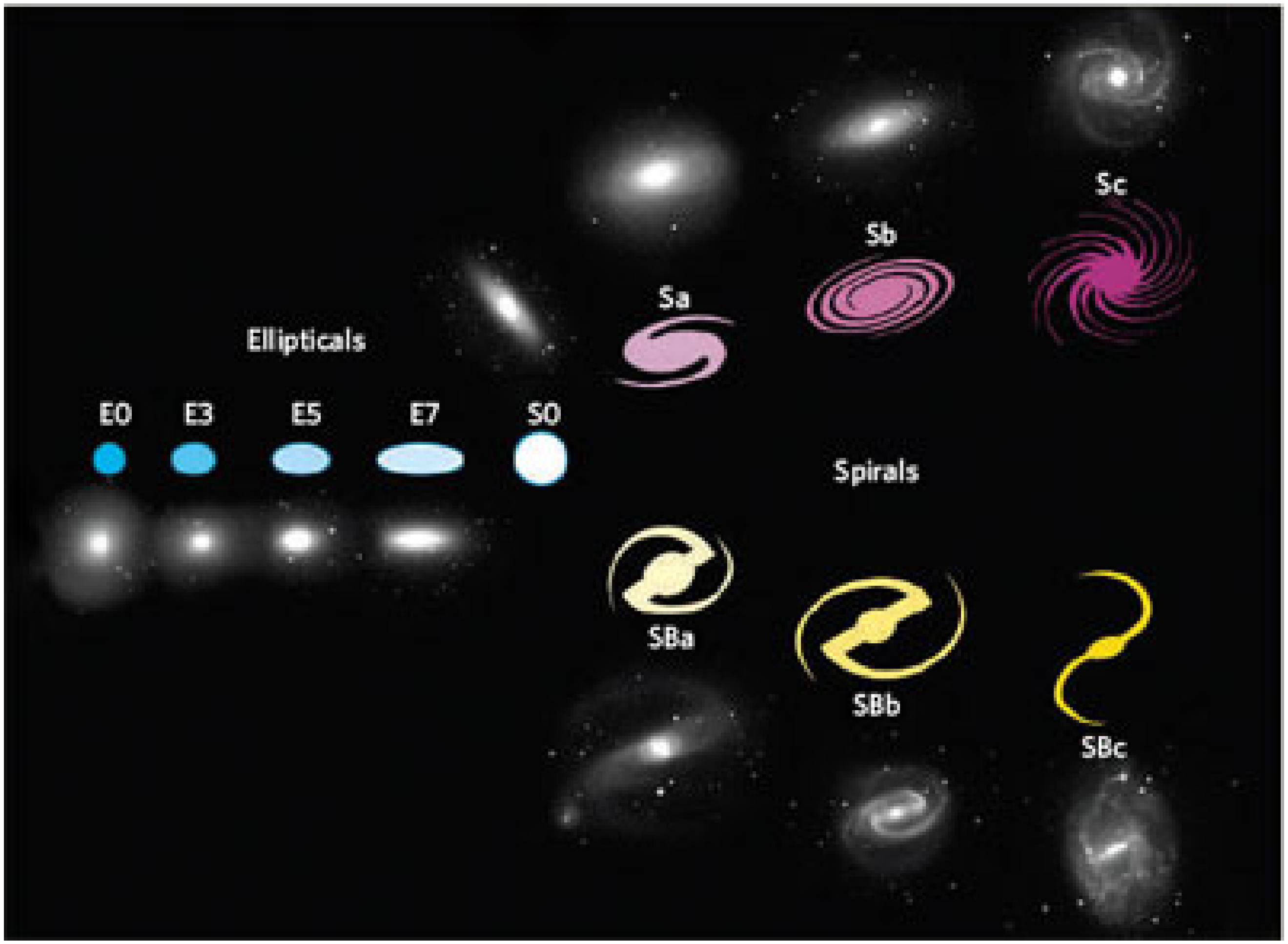
Galaxy Types

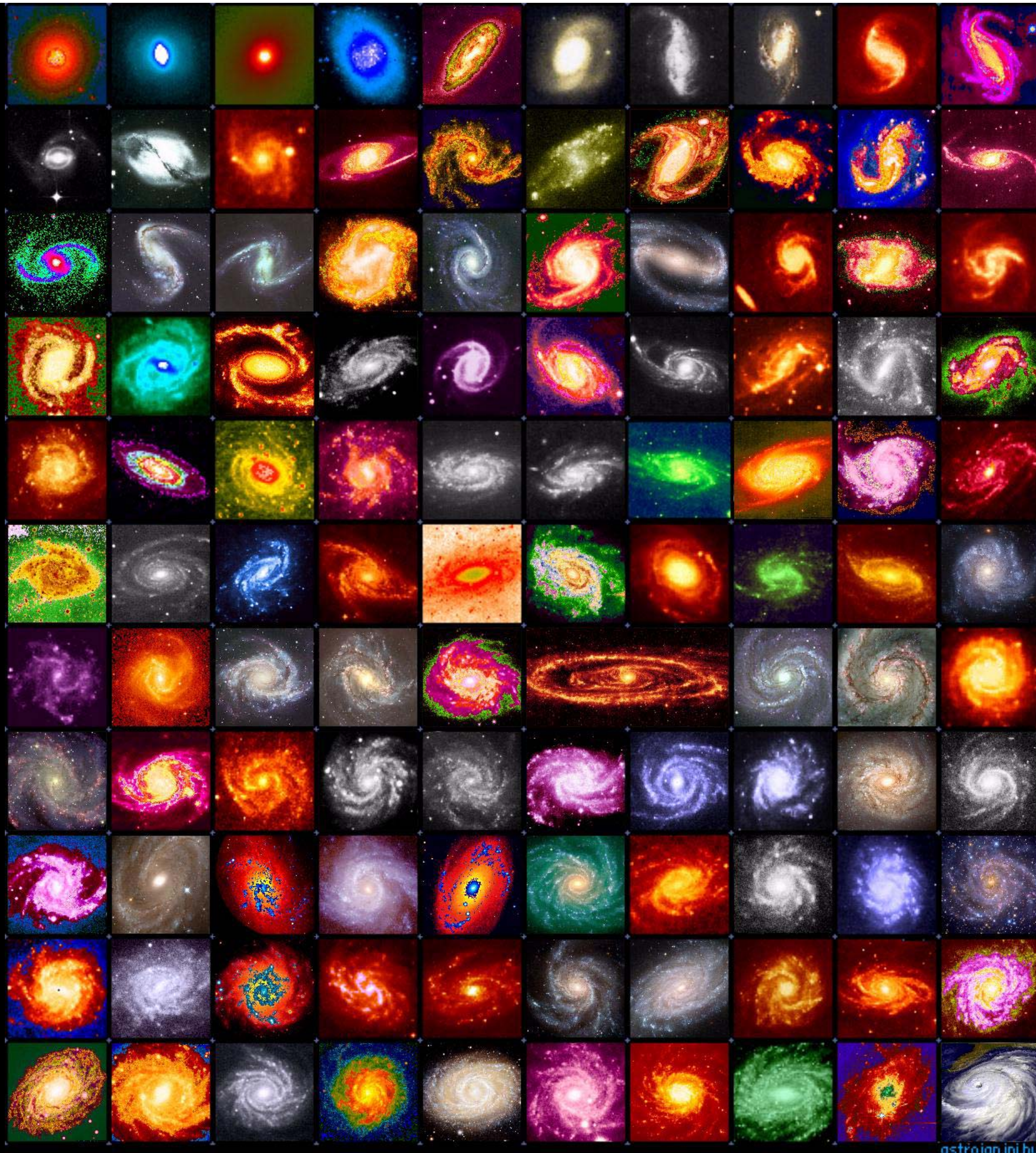
Galaxies come in various shapes and sizes, containing 10s of millions to 100 billion stars.

Most of the large galaxies are shaped like a spiral or are elliptical.

The elliptical galaxies contain little or no net sense of rotation

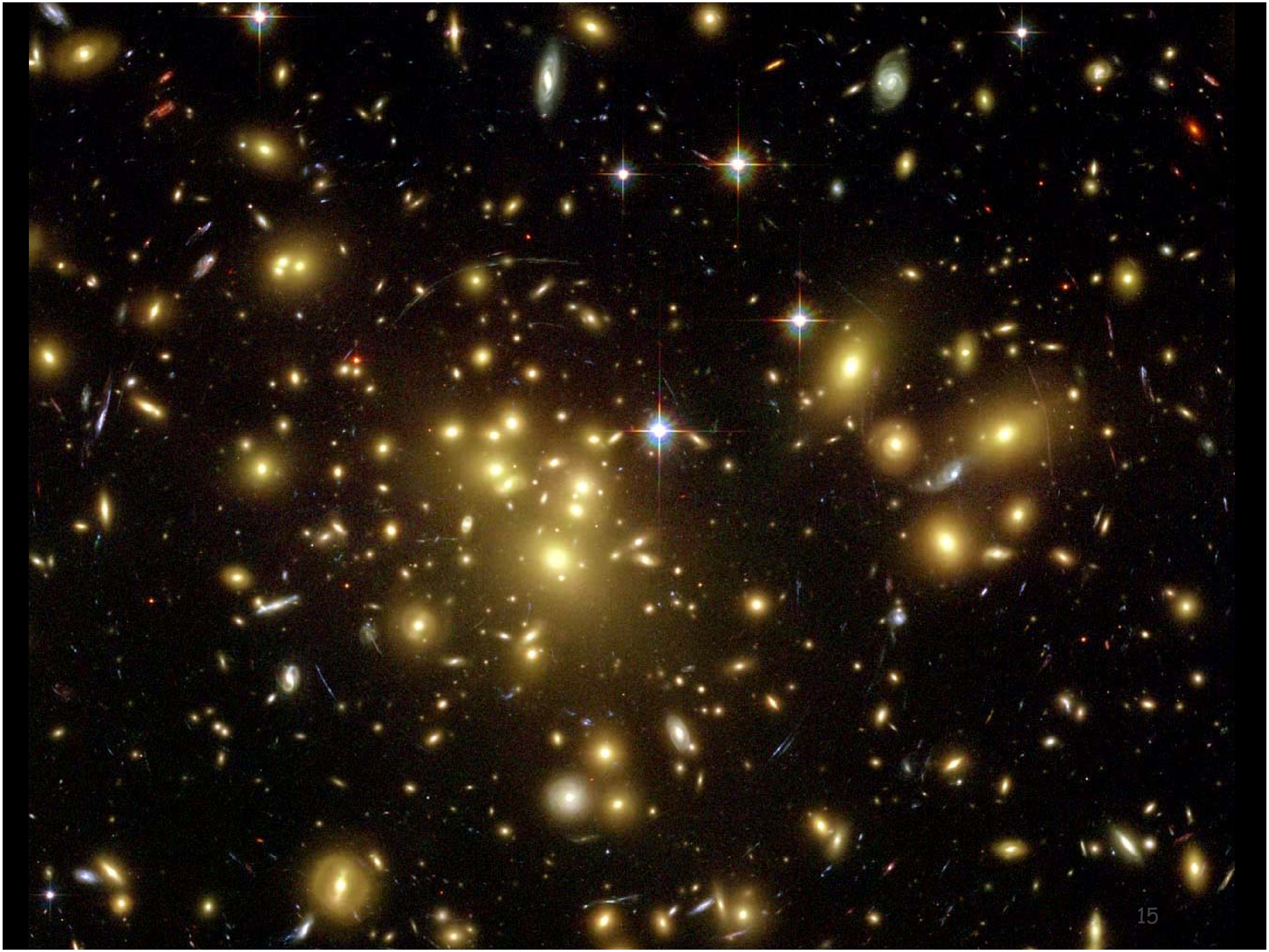
Spiral galaxies possess net angular momentum and rotate around their centers.

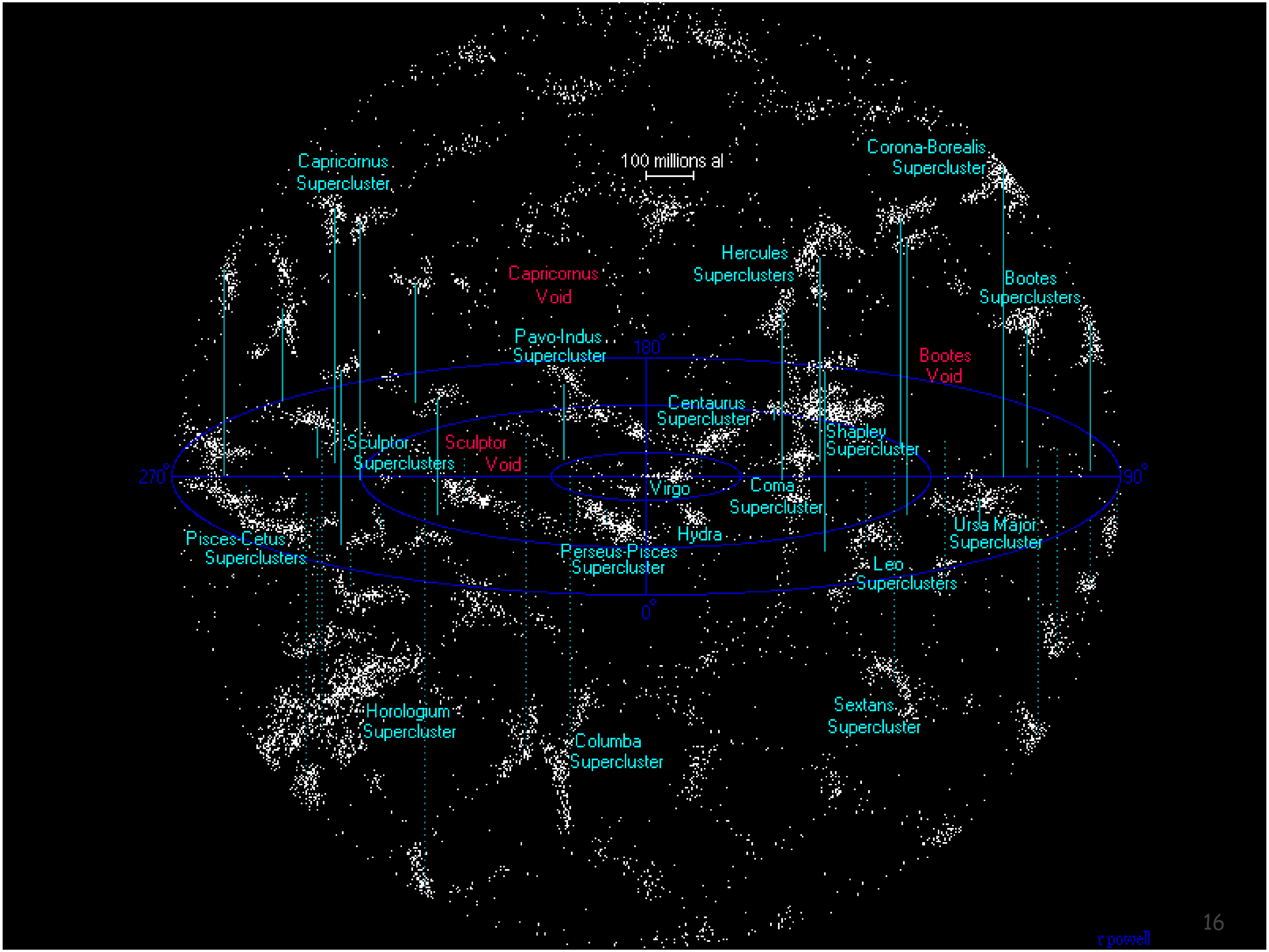


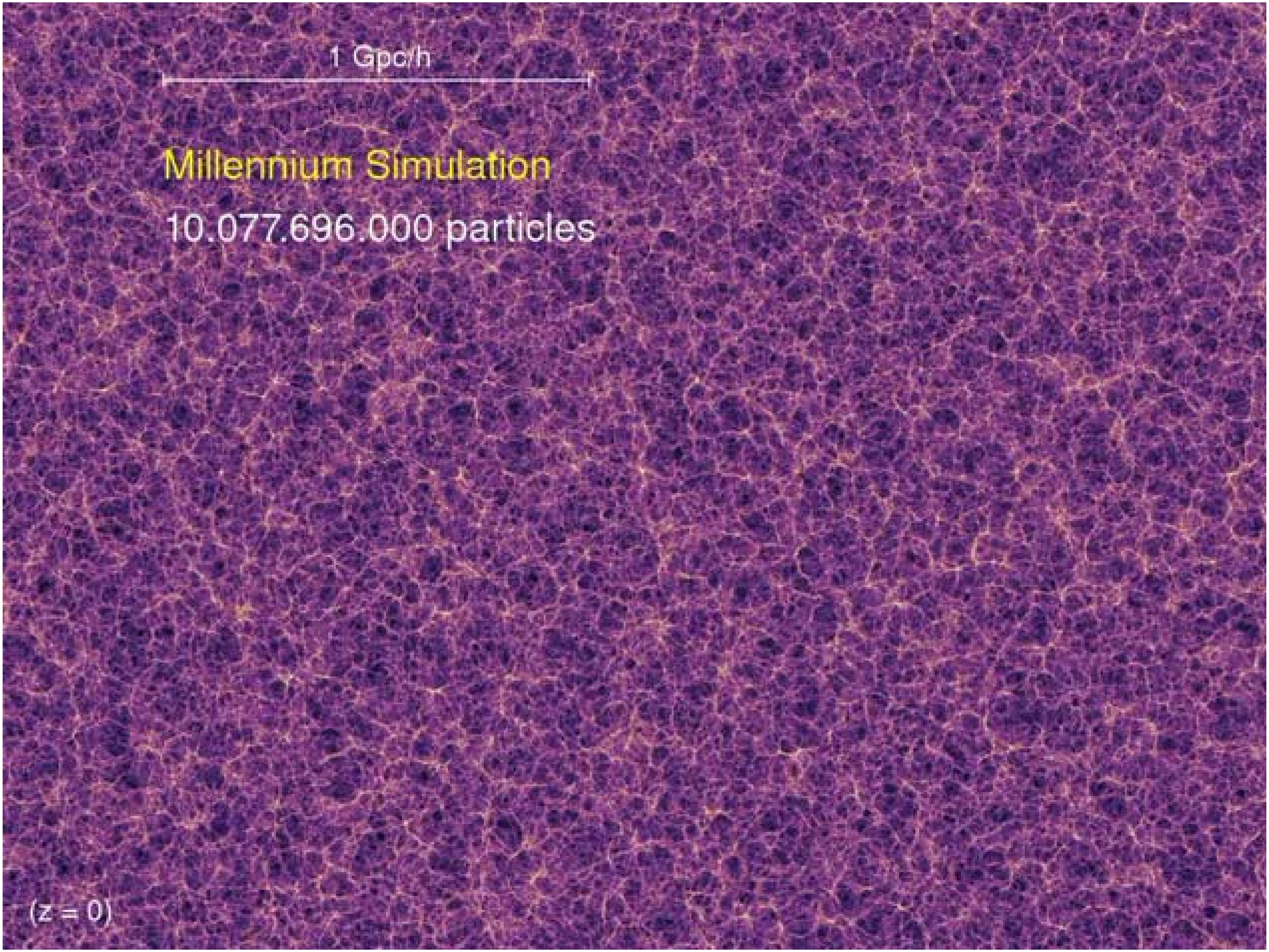

astrojan.ini.hu

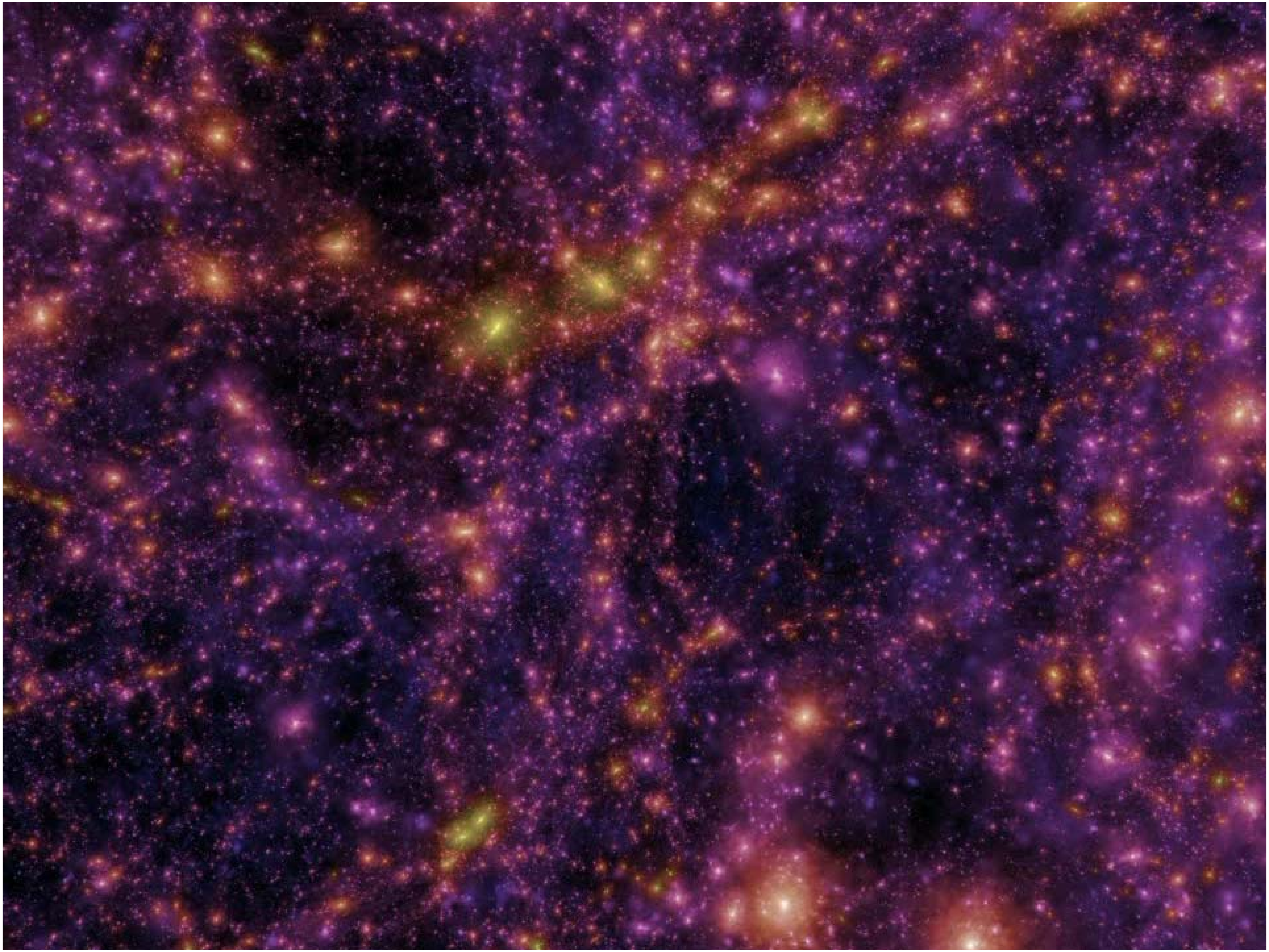
Larger agglomerations

- Galaxies are gravitationally bound systems
- On still larger scale we find that galaxies are organized in local groups and clusters
- On still larger scales the clusters are organized in the form of super clusters that are only weekly bound by gravity and are still evolving




100 millions al
Capricornus Supercluster
Corona-Borealis Supercluster
Hercules Superclusters
Capricornus Void
Bootes Superclusters
Pavo-Indus Supercluster
180°
Bootes Void
Centaurus Supercluster
Shapley Supercluster
Sculptor Superclusters
Sculptor Void
270°
Virgo
Coma Supercluster
90°
Ursa Major Supercluster
Hydra
Pisces-Cetus Superclusters
Perseus-Pisces Supercluster
Leo Superclusters
0°
Horologium Supercluster
Columba Supercluster
Sextans Supercluster
c powell


1 Gpc/h
Millennium Simulation
10.077.696.000 particles
(z = 0)

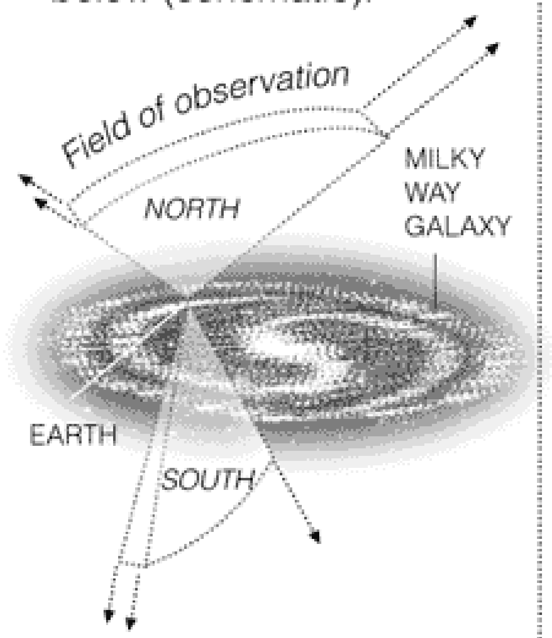


The Geography of the Universe on the Grandest Scale

An international team of astronomers has measured the distances to more than 100,000 galaxies, allowing them to construct the largest, most detailed map of a large section of the universe near our galaxy.

THE OBSERVATIONS

The directions of the two survey regions are shown below (schematic).

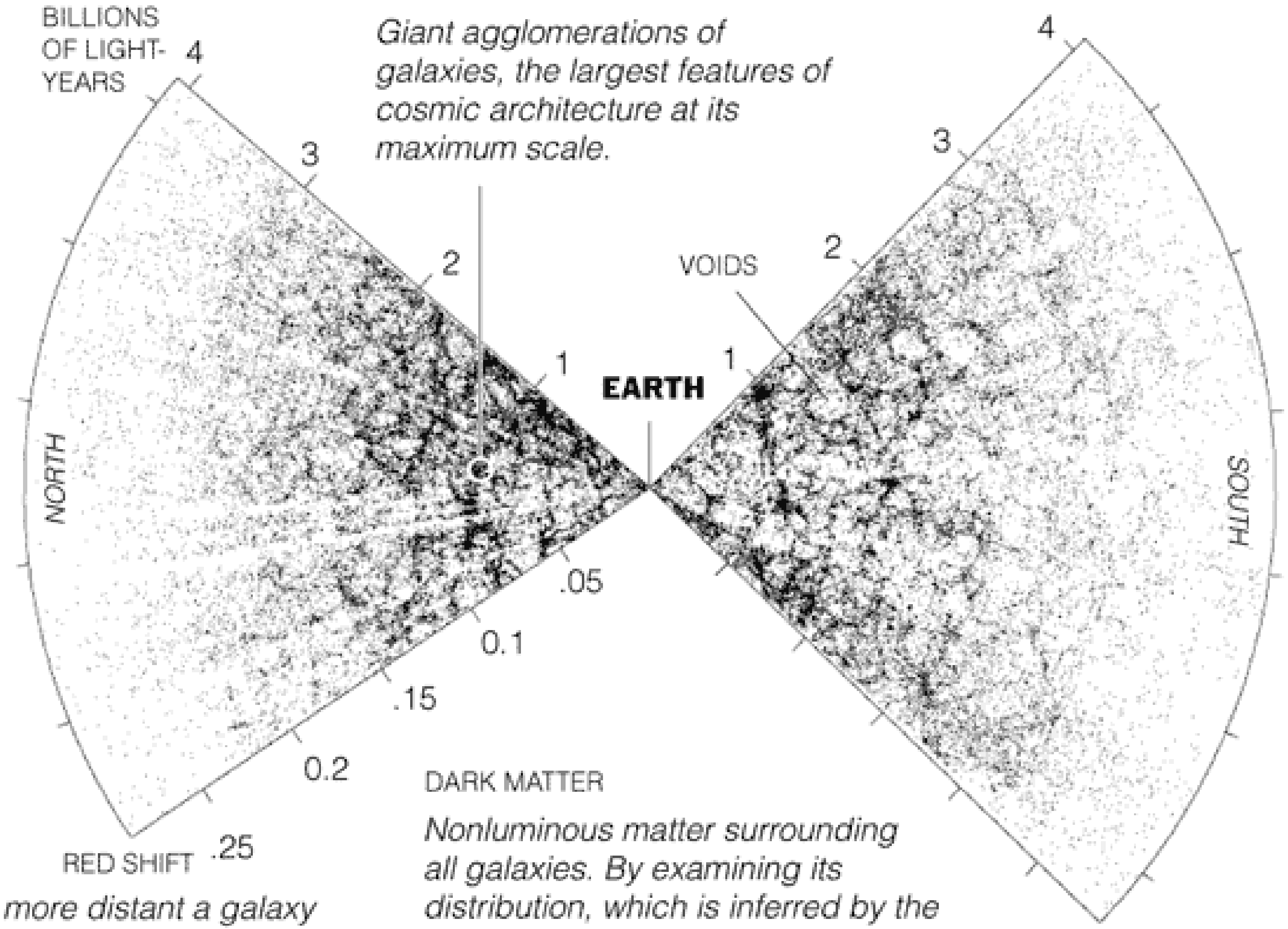


Survey regions extend outward for billions of light-years.

Sources: Dr. Robert Smith, The Australian National University; 2-Degree Field Galaxy Redshift Survey.

THE MAP

Each dot below is a galaxy, and the team eventually plans to locate 250,000.



The more distant a galaxy the more its light shifts to the red end of the spectrum.

DARK MATTER

Nonluminous matter surrounding all galaxies. By examining its distribution, which is inferred by the patterns of galaxies, astronomers can estimate the amount of mass in the universe.

The New York Times/Map courtesy of Peder Norberg, Dr. Shaun Cole, University of Durh

Grand Design

Evolution and History

1915 Einstein publishes the general theory of relativity and introduces a cosmological constant term to find a static solution

1922 Alexander Friedman finds an expanding solution using the general theory of relativity

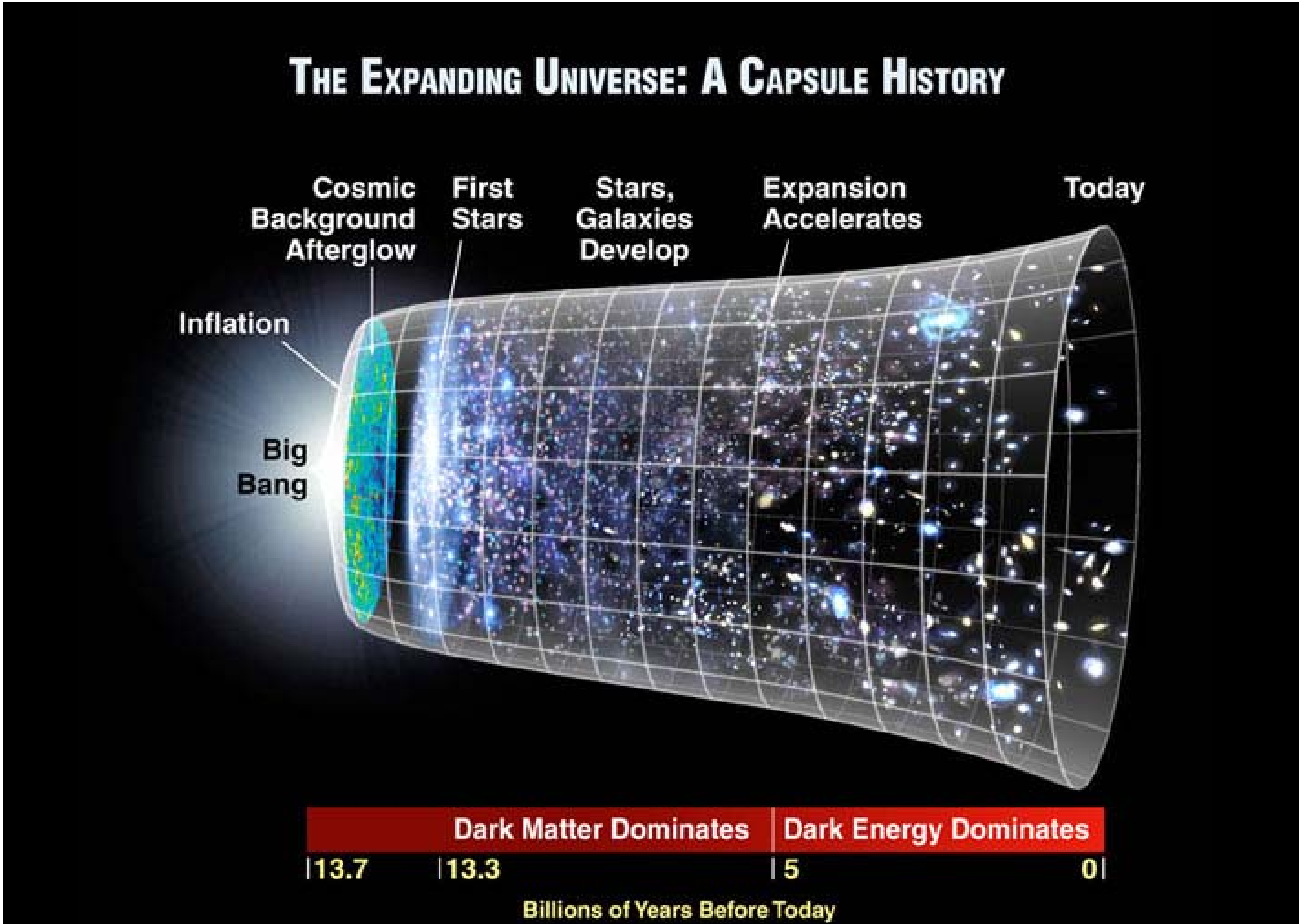
1927 Lemaitre predicts that the Universe must have started small, expanding outwards

1929 Edwin Hubble observationally shows that all galaxies recede away from us with their velocity proportional to their distance

1946 George Gamow , Robert Dicke and Hermann Bondi predict the presence of a background radiation produced shortly after the beginning

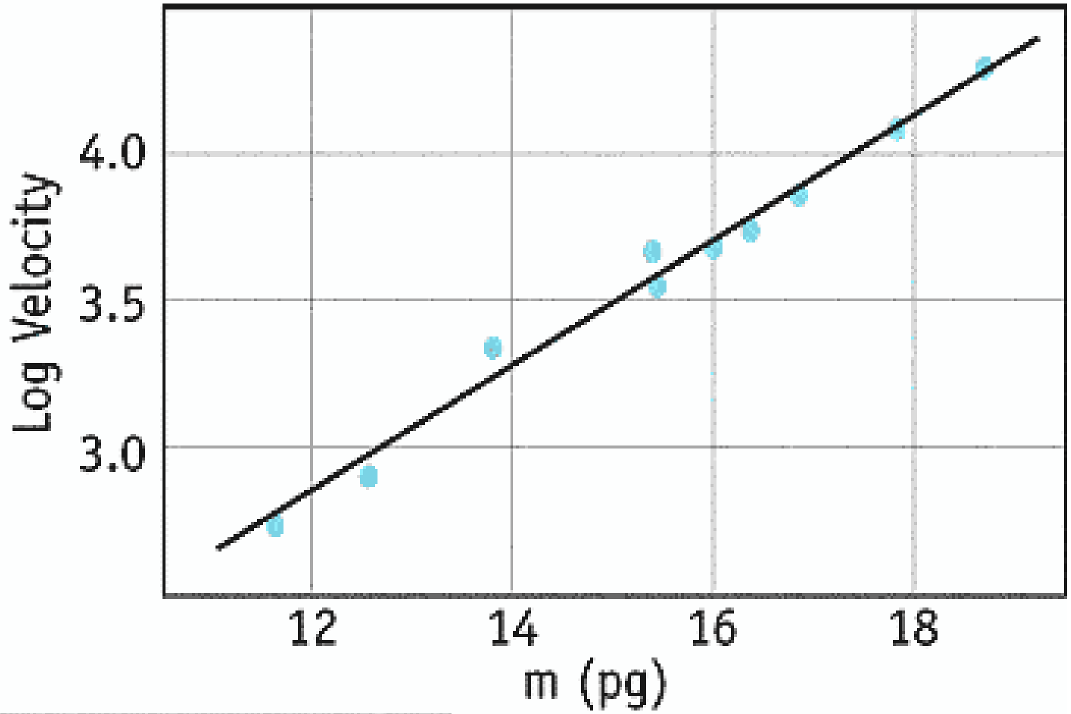
1948 Fred Hoyle and Thomas Gold publish the Steady State theory, Hoyle mockingly calls the universe starting from a singular state as Big Bang

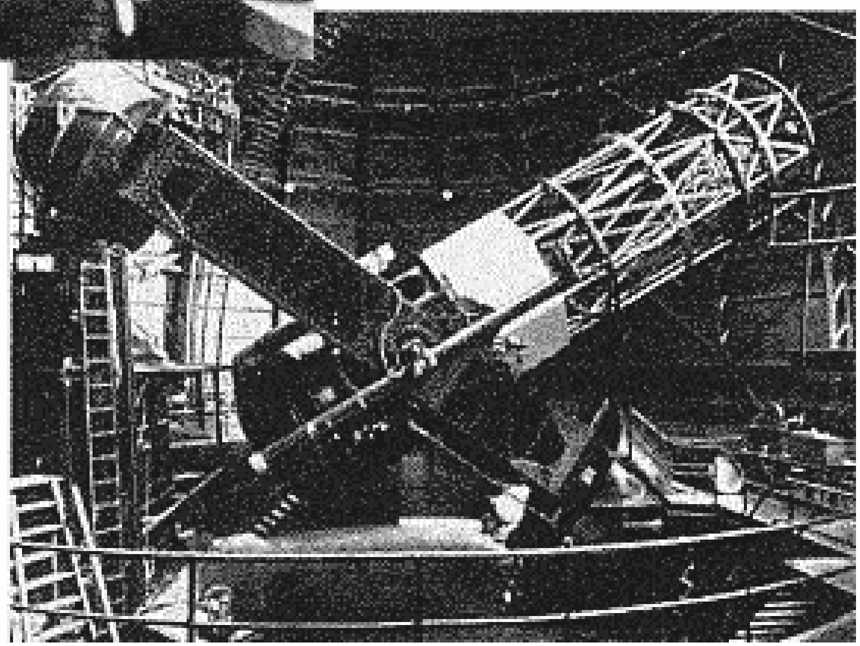
1965 Penzias and Wilson serendipitously discover the relic radiation, known as the Cosmic Microwave Background radiation, thus proving Gamow's ideas



THE EXPANDING UNIVERSE: A CAPSULE HISTORY
Cosmic Background Afterglow
First Stars
Stars, Galaxies Develop
Expansion Accelerates
Today
Inflation
Big Bang
Dark Matter Dominates
Dark Energy Dominates
13.7
13.3
5
0
Billions of Years Before Today

Edwin Hubble





Mt. Wilson
100 Inch
Telescope

Friedman Robertson Walker Universe

$$ds^2 = c^2 dt^2 - a^2(t)\left[\frac{dr^2}{1-kr^2} + r^2\left(d\phi^2 + d\theta^2 \sin^2\theta\right)\right]$$

The scale factor a(t) can be thought as distance between two points

K controls the overall geometry of the universe
K=0 implies a spatially flat geometry
K=1 implies a closed sphere like geometry
K=-1 implies an open saddle like geometry

Hubble's Law

Here is a derivation of Hubble's law

However, it works only for small distances!

For large distances light takes a long time to reach us and the scale factor changes during this time, thus a local approximation cannot be used

$$d = a(t)r$$

$$\dot{d} = \dot{a}(t)r = \frac{\dot{a}}{a}d$$

$$v = Hd$$

$$H_0 = \left(\frac{\dot{a}}{a}\right)_0$$

Redshift and Scale Factor

Hubble law manifests as a change
In frequency *f* of light

This derivation shows how the redshift *z* and the scale factor
Are related

Derivation is valid only for small distances but the result is exact

$$v = H_0 d = \left(\frac{\dot{a}}{a}\right)_0 d = \left(\frac{\dot{a}}{a}\right)_0 c\Delta t$$

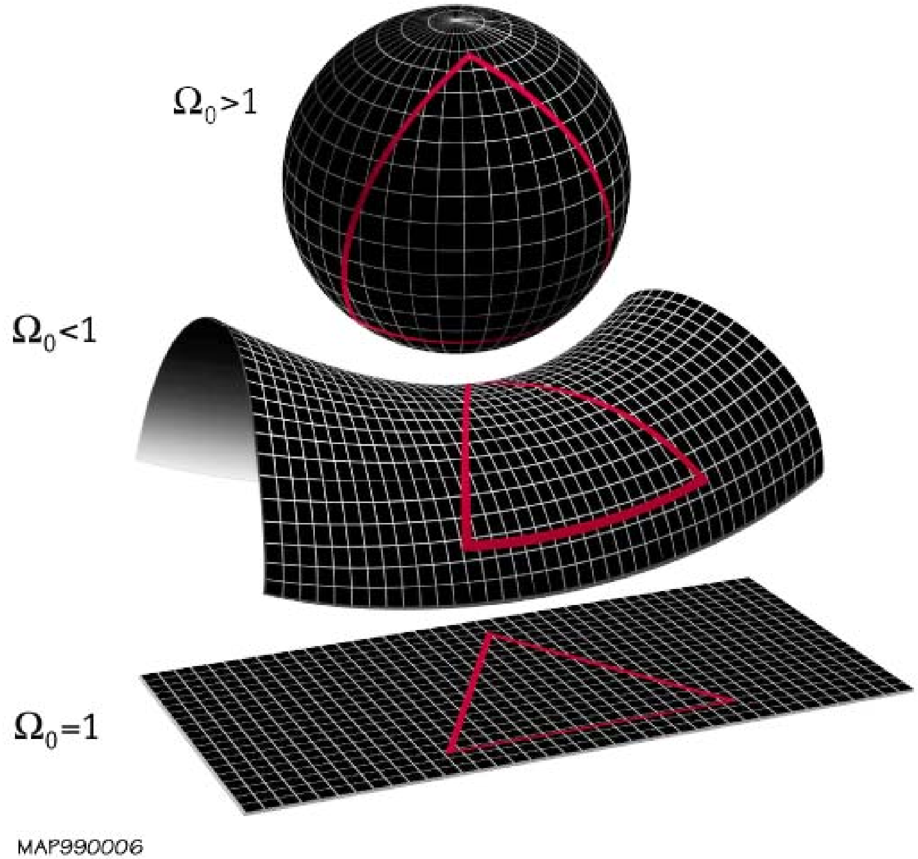
$$\frac{v}{c} = \frac{\Delta a}{a} = \frac{a_0}{a} - 1$$

$$\frac{f_0}{f} = 1 + \frac{v}{c} = \frac{a_0}{a} = 1 + z$$

Curvature

The curvature of the Universe depends on the total amount of matter present in the Universe
And is controlled by a critical density

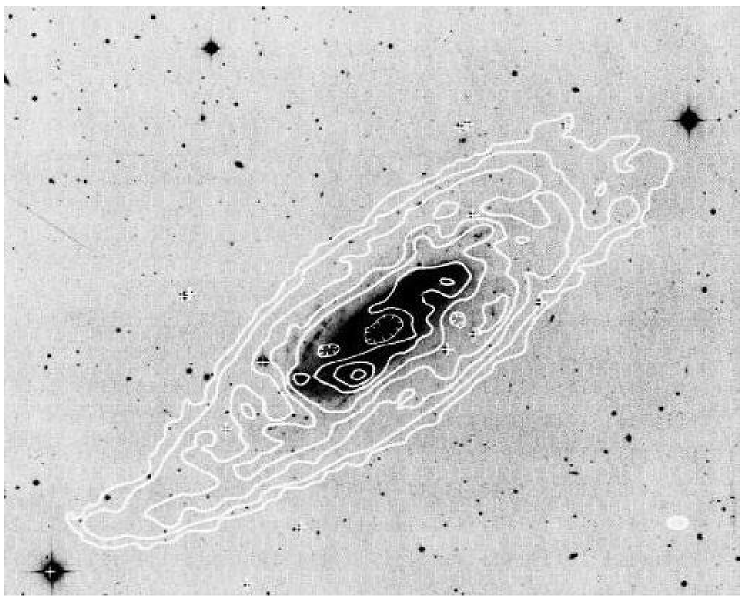
$$= 10^{-30}\,\mathrm{g\ cm}^{-3}$$

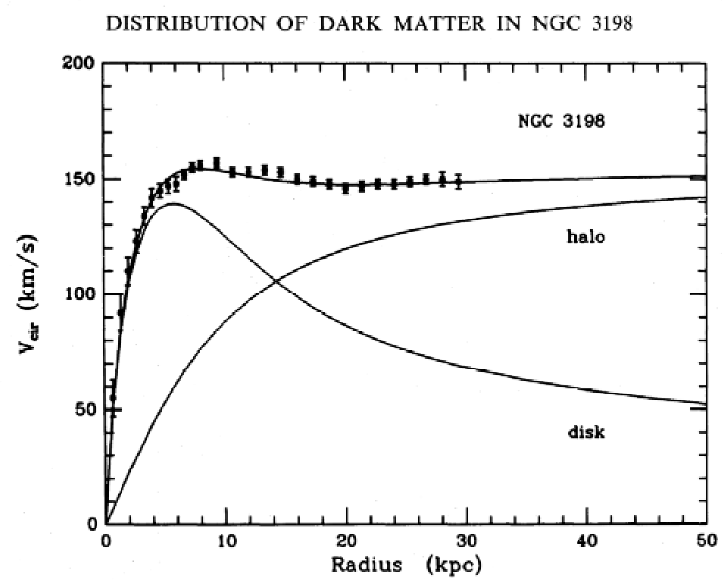


How Much Matter Is there in the Universe?

1. Newton's law of gravity for circular orbits: $v_c^2 = GM / r$
2. Doing the same for velocity dispersion in the hot galaxy clusters
3. Gravitational lensing by galaxies and galaxy clusters
4. Geometrical tests, such as Luminosity distance test and angular diameter distance test

Rotation Curve of NGC 3198





What Do We Learn From This?

- This shows that much of the matter in the universe is dark this is known as *Dark Matter*
- However, this cannot be completely baryonic
- There are stringent constraints on how much dark matter can be there from Big Bang nucleosynthesis argument, which shows that only 2% of total density can be baryonic!
- Structure formation in the universe will be adversely affected if all of this matter is baryonic since it has pressure and resists gravitational collapse when it is hot
- Observations of galaxies and clusters show that matter is concentrated at the centre
- Direct searches for dark baryonic objects, such as brown dwarfs, black holes and others find very little of it

So what is Dark matter?

Know one really knows

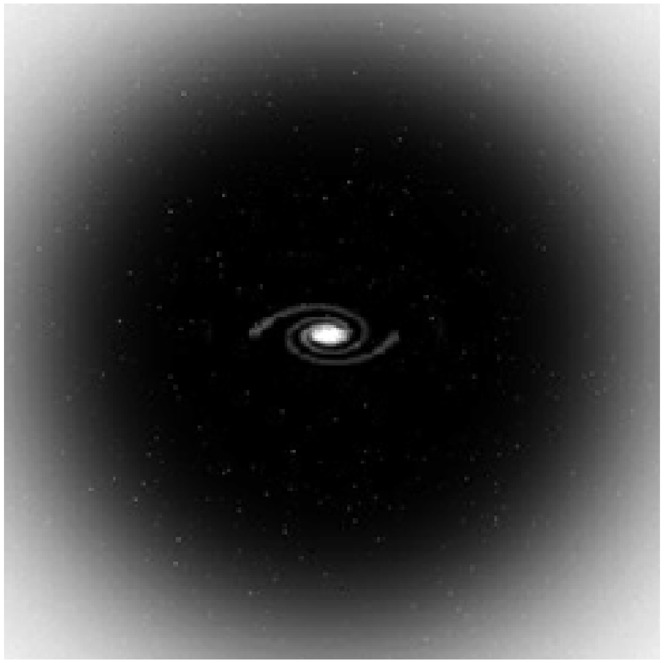
Possible candidates are WIMPs: Weakly Interacting Massive Particles

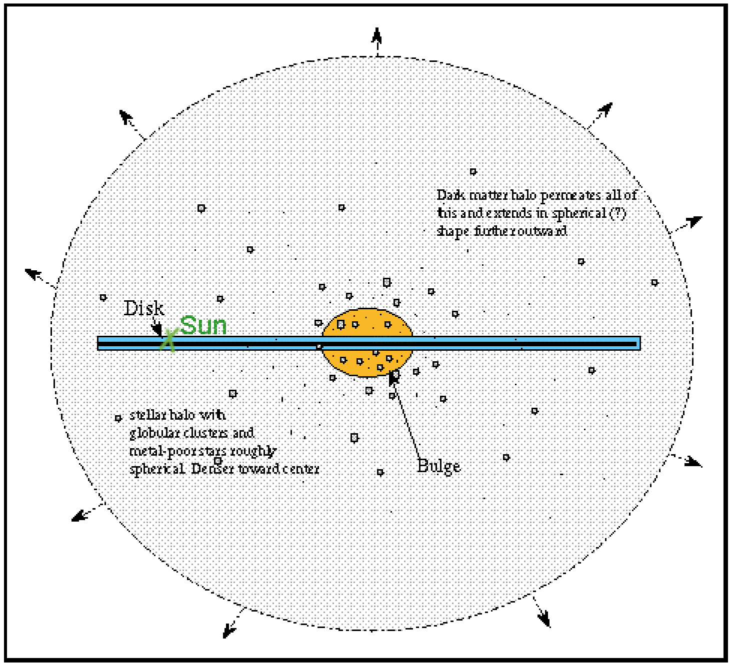
Massive neutrinos? – almost certainly no

Could something be wrong with our understanding of gravity?

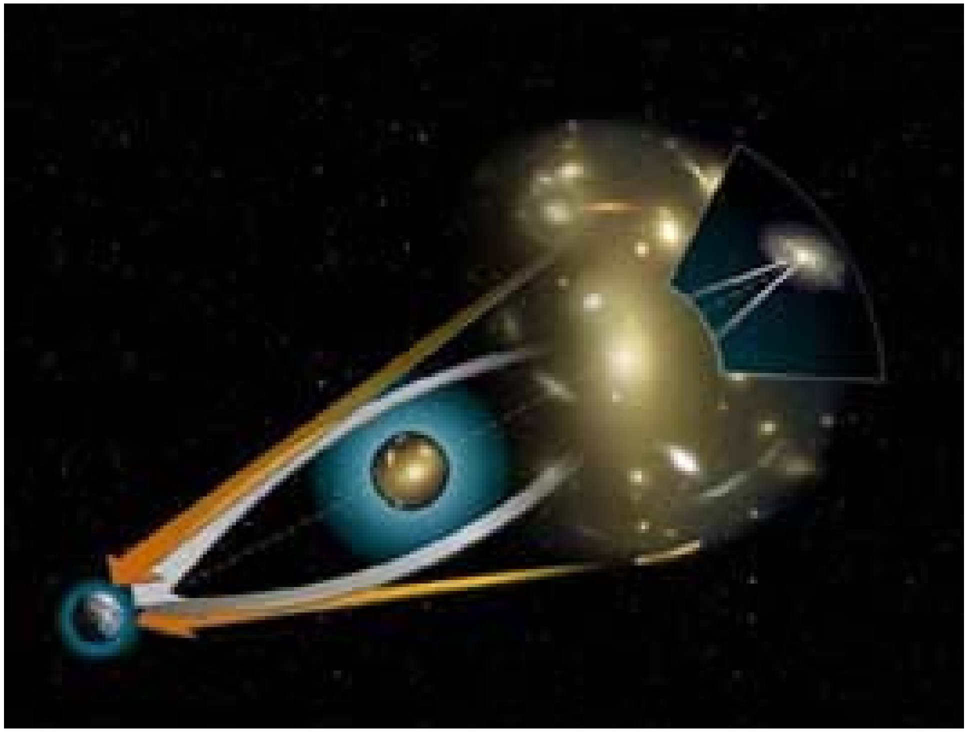
Search continues…

Current Picture of a Galaxy

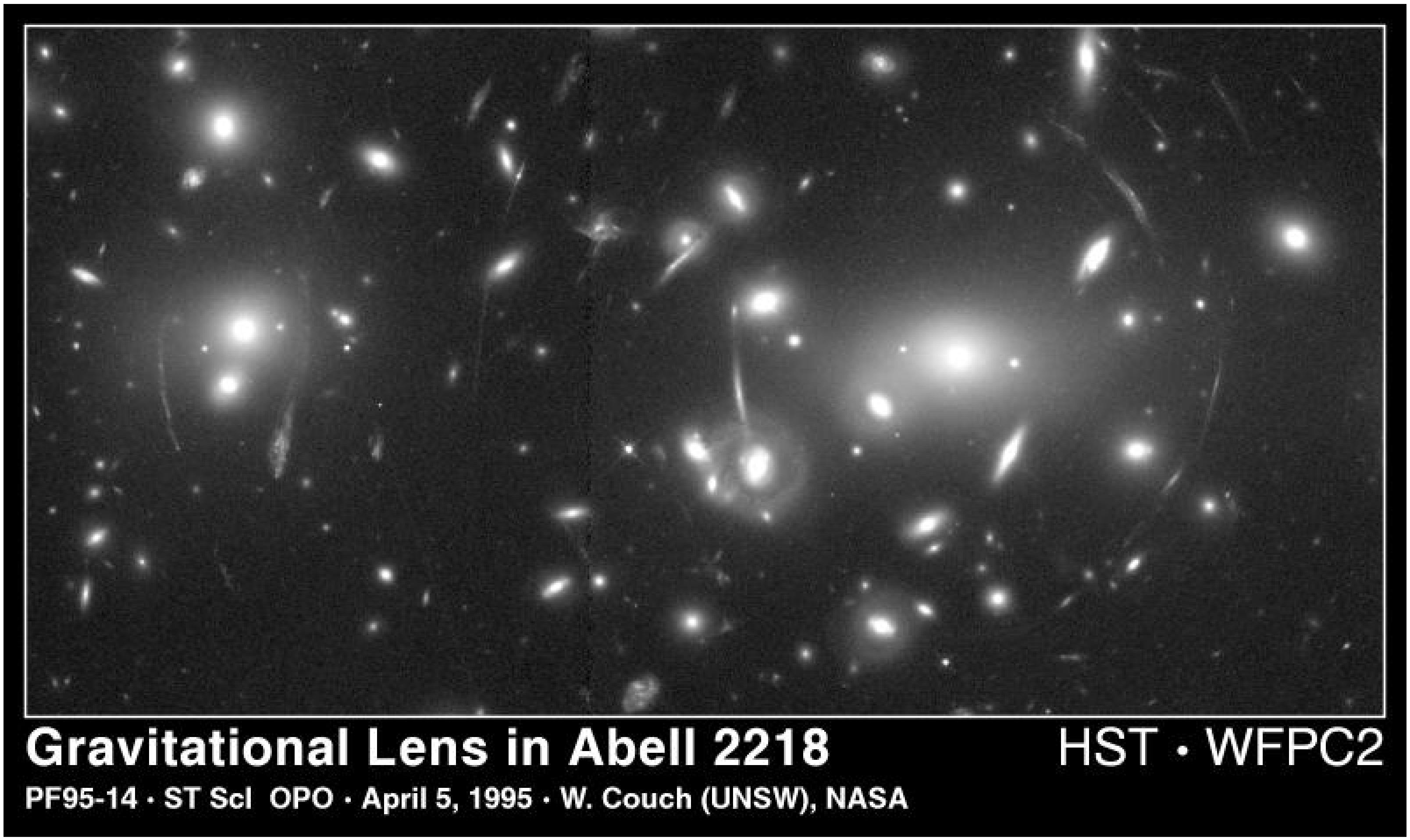




Evidence From Gravitational Lensing



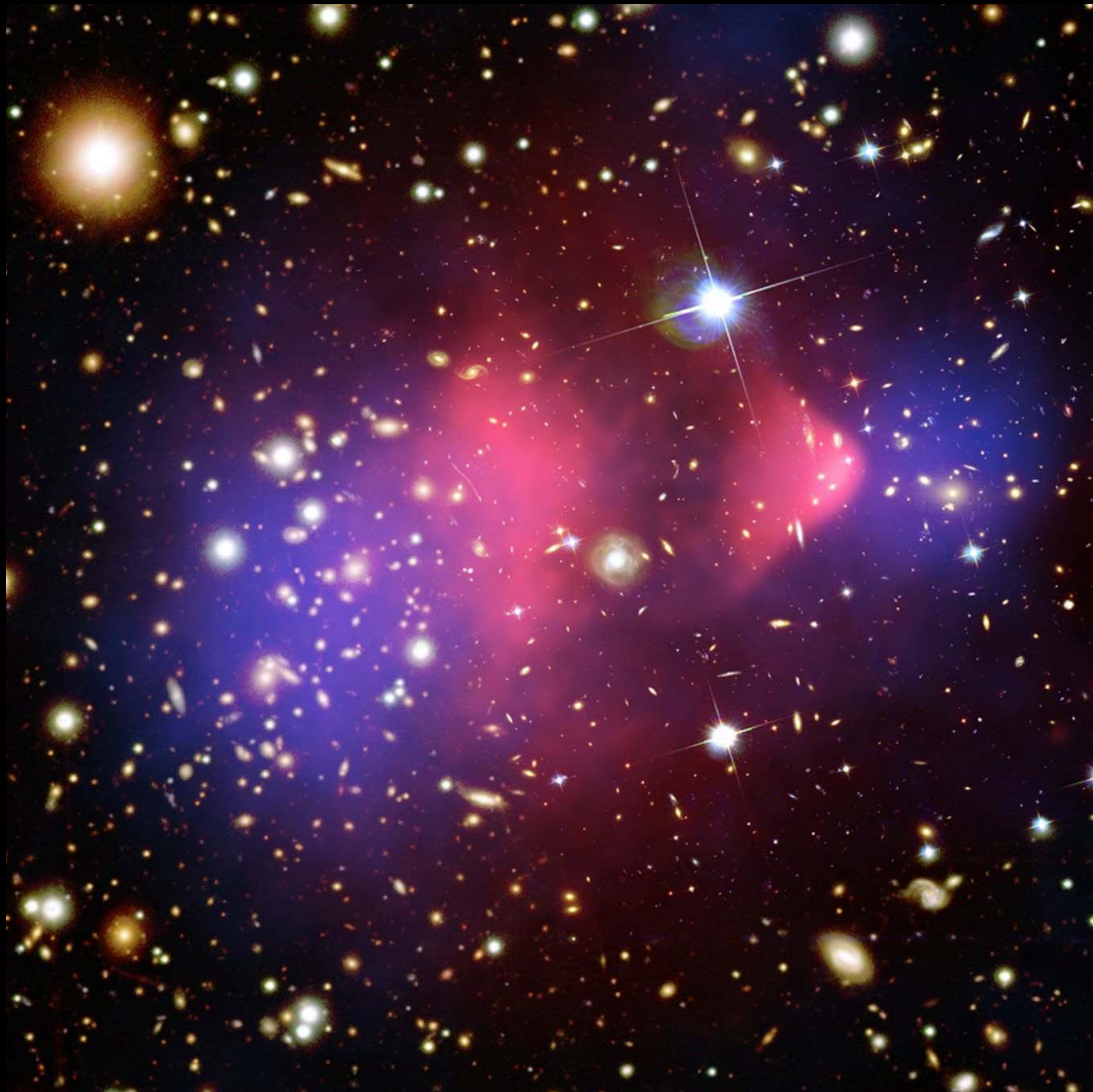
The Case of A2218



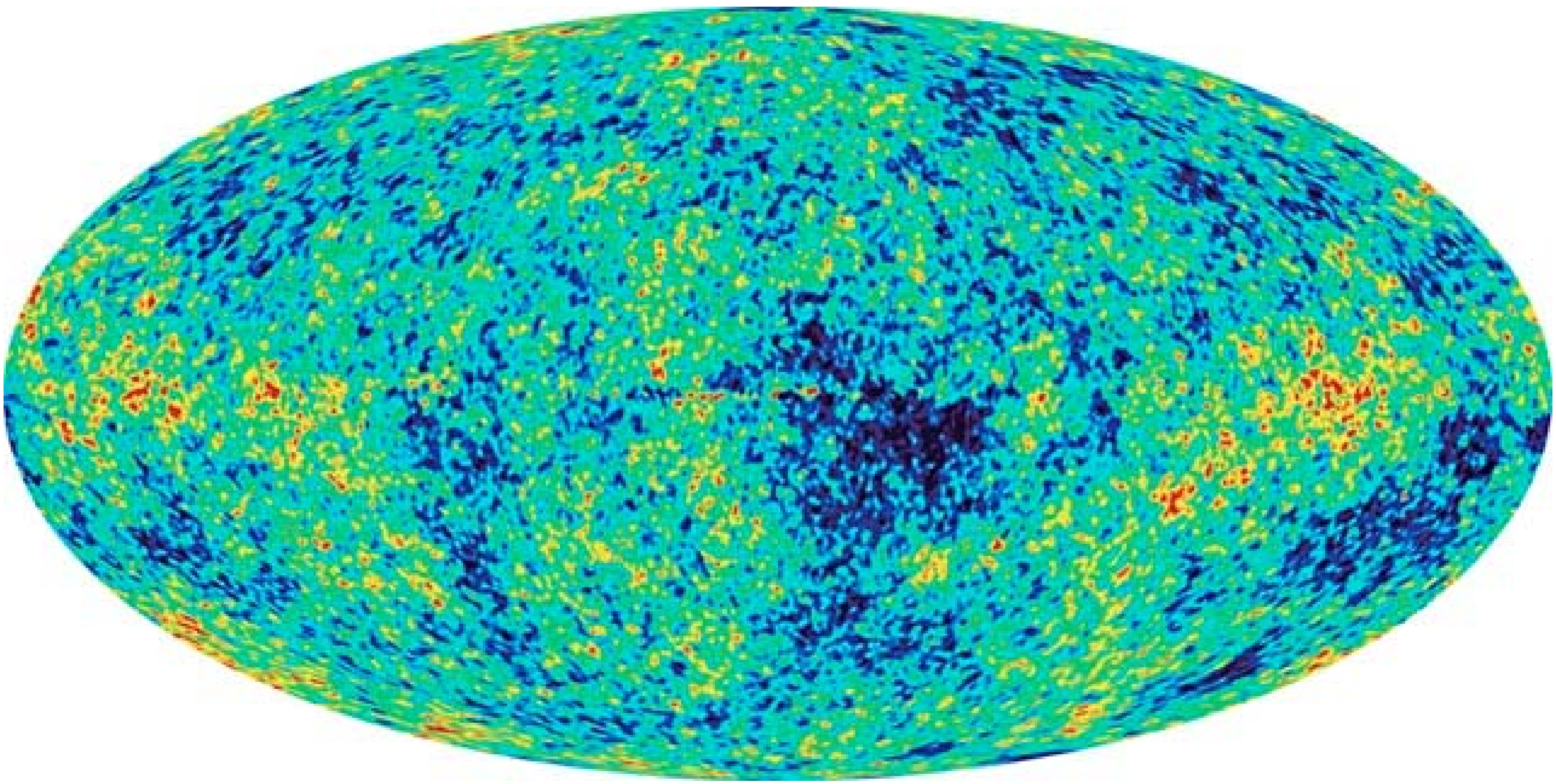
Total Matter Budget in the Universe

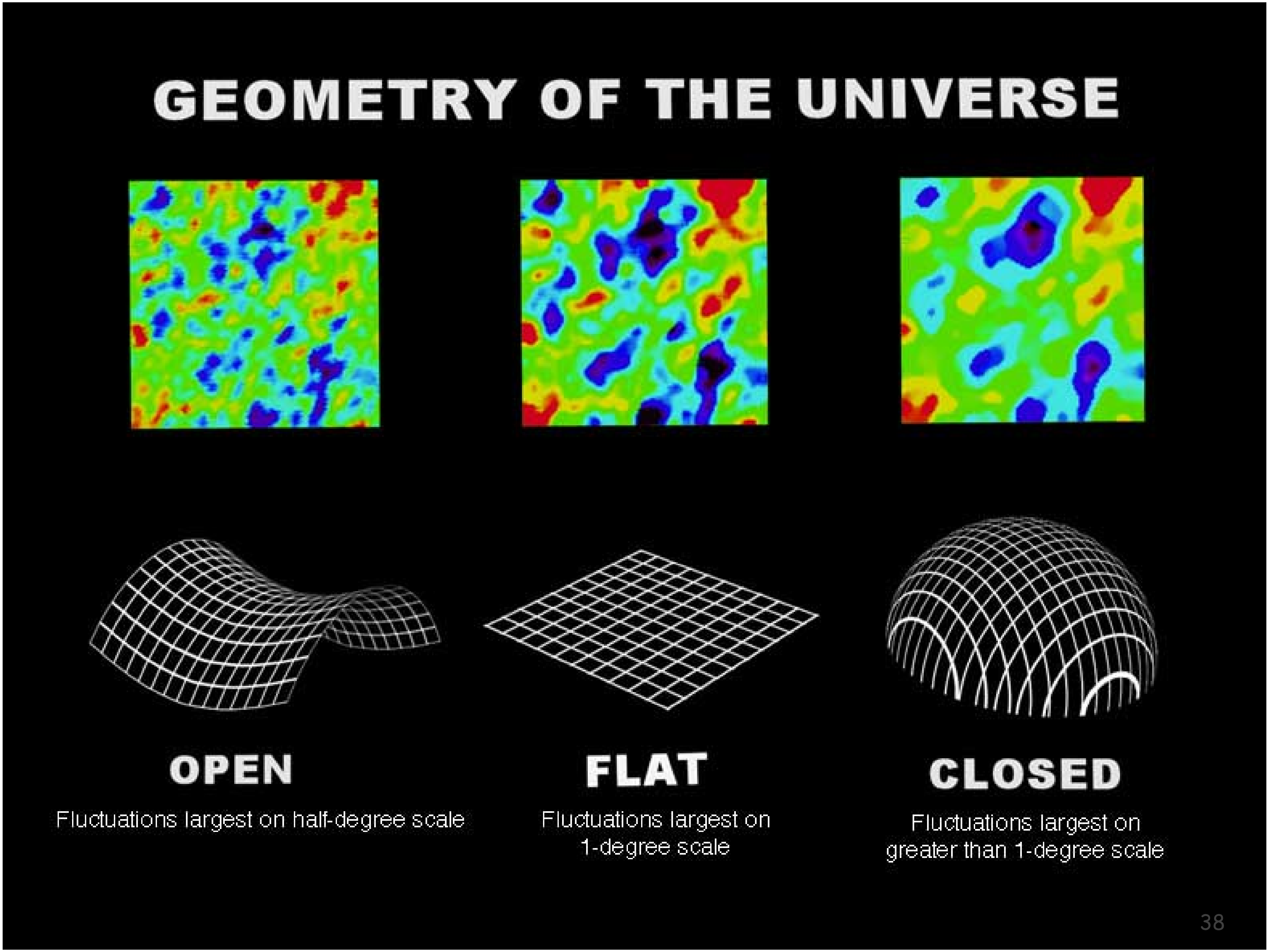
All the methods mentioned so far tell us the total amount of matter
In the universe – baryonic and the exotic Dark matter is not more
Than 30 per cent of the amount needed to make the critical density

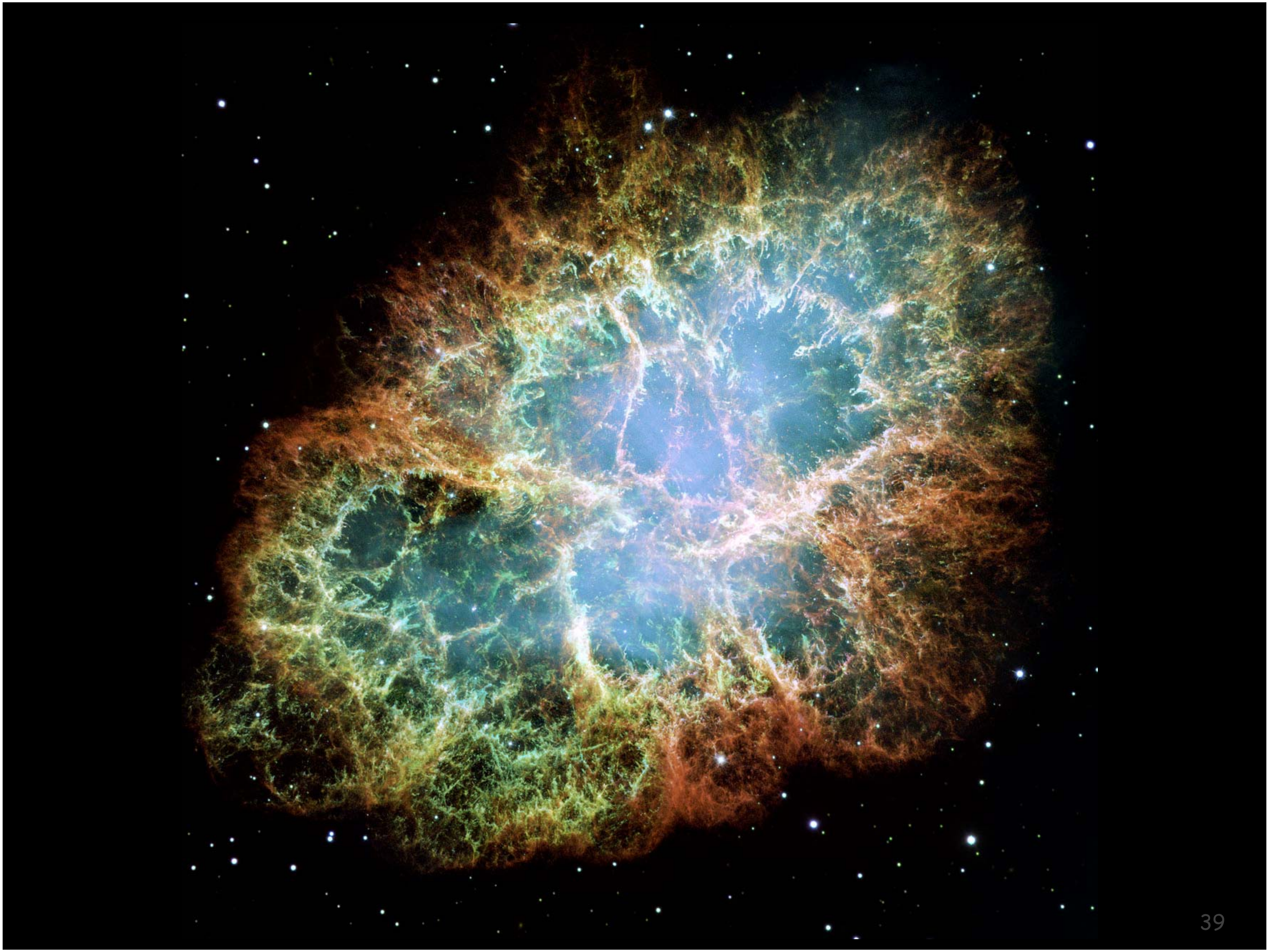
Is there any direct evidence for dark matter?



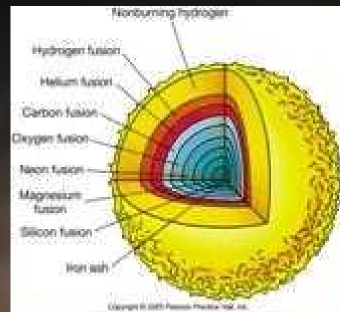
Relic Radiation



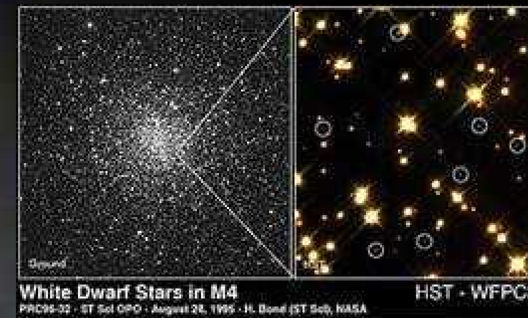

GEOMETRY OF THE UNIVERSE
OPEN
Fluctuations largest on half-degree scale
FLAT
Fluctuations largest on
1-degree scale
CLOSED
Fluctuations largest on
greater than 1-degree scale
38



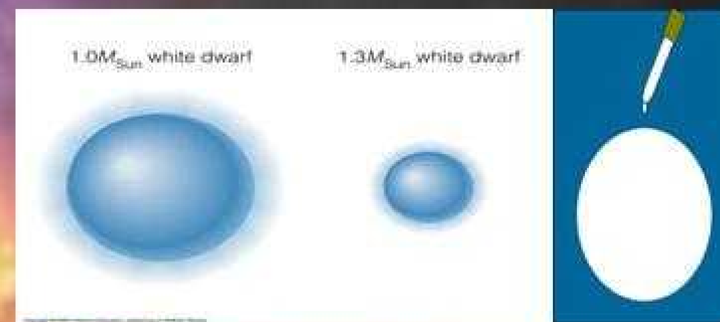
Science as a Life time mission



Black Hole

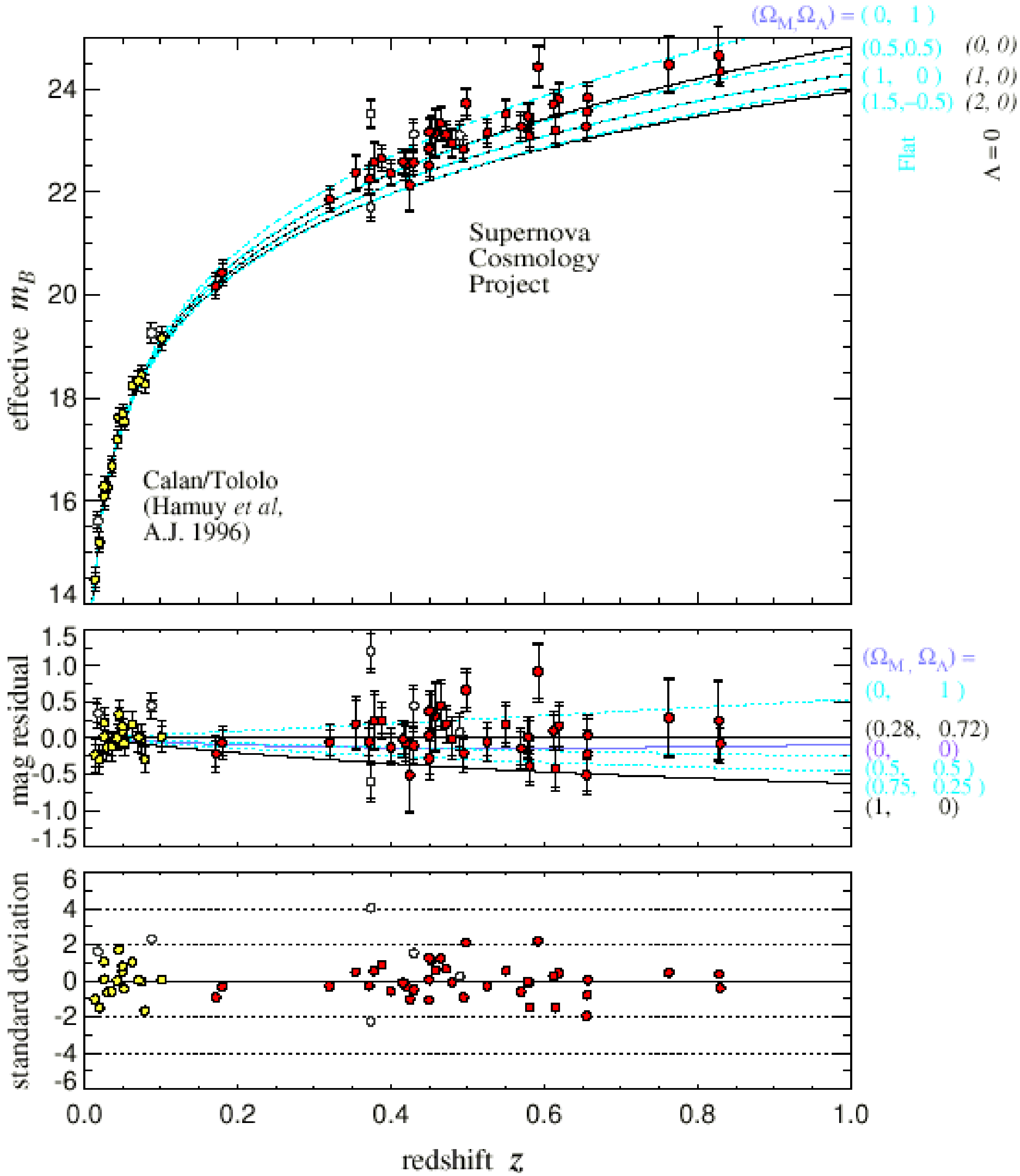


White dwarf stars



The radii of white dwarfs DECREASE with INCREASING mass because of the increasing strength of gravity.

When the mass exceeds 1.4 M, electron degeneracy is no longer strong enough to resist the pull of gravity and the white dwarf abruptly collapses into a neutron star. (animation by G. Rieke) 1.4 M is called the **Chandrasekar limit** in honor of the astronomer who first explained the nature of white dwarfs (and won the Nobel prize for his work).



(ΩM,ΩΛ) = (0, 1)
(0.5,0.5) (0, 0)
(1, 0) (1, 0)
(1.5,–0.5) (2, 0)
Flat
Λ = 0
Supernova
Cosmology
Project
Calan/Tololo
(Hamuy et al,
A.J. 1996)
effective mB
mag residual
(ΩM , ΩΛ) =
(0, 1)
(0.28, 0.72)
(0, 0)
(0.5, 0.5)
(0.75, 0.25)
(1, 0)
standard deviation
redshift z

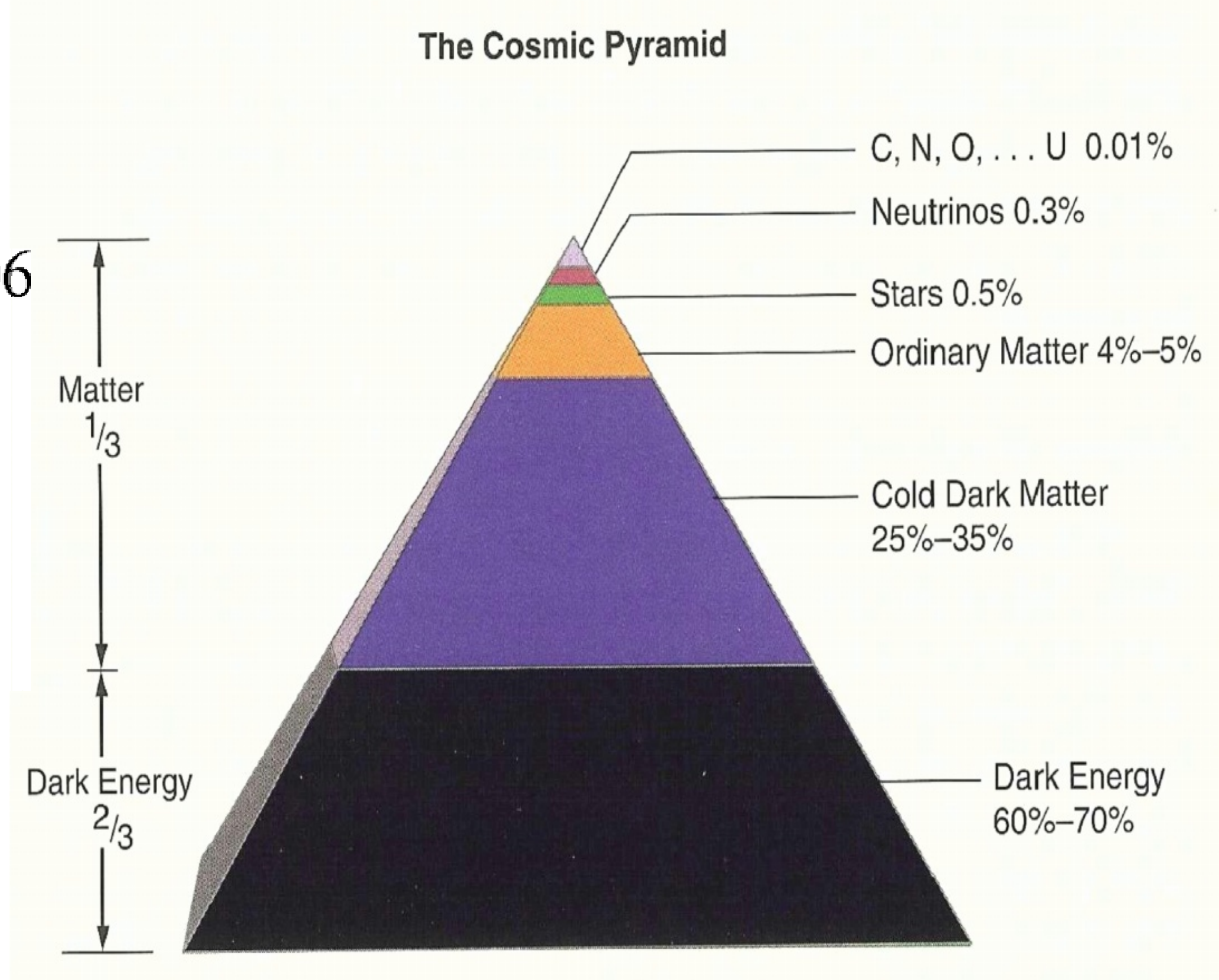
Contents of the Universe

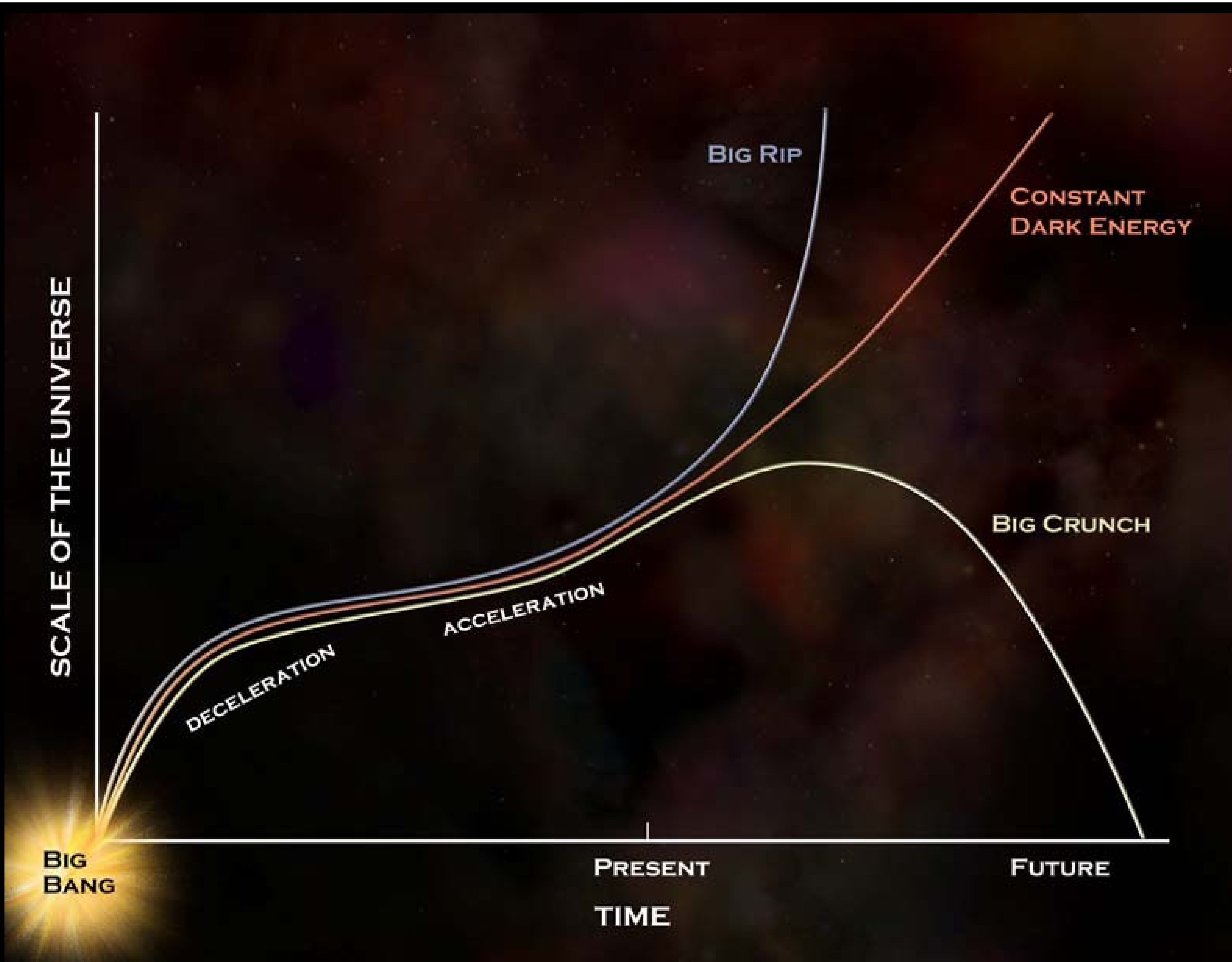
$$\Omega_{baryon} = 0.047 \pm 0.006$$

$$\Omega_{matter} = 0.29 \pm 0.07$$

$$k = 0 \quad (\Lambda CDM)$$

$$\Omega_{tot} = 1.00 \pm 0.02$$




Big Rip
Constant
Dark Energy
Big Crunch
Scale of the Universe
Deceleration
Acceleration
Big
Bang
Present
Future
Time

Thank you for your attention!