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Extragalactic Astrophysics

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What is an Extragalactic Astrophysics Course?

What is an Extragalactic Astrophysics Course?

Semantic:

- Extra: outside; beyond. Via medieval Latin from Latin *extra* ‘outside’.

- Galaxy: a system of millions or billions of stars, together with gas and dust, held together by gravitational attraction. Late Middle English (originally referring to the Milky Way): via Old French from medieval Latin galaxia, from Greek *galaxias* (kuklos) ‘milky (vault)’, from gala, galakt- ‘milk’.

China: “Silver River”
Kalahari Desert: “Backbone of Night”

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What is an Extragalactic Astrophysics Course?

Semantic:

- Astro: relating to the stars or celestial objects. From Greek *astron* ‘star’.

- Physics: the branch of science concerned with the nature and properties of matter and energy. Late 15th century (denoting natural science in general, especially the Aristotelian system): plural of obsolete physic ‘physical (thing’), suggested by Latin physica, Greek phusika ‘natural things’ from phusis ‘nature’.

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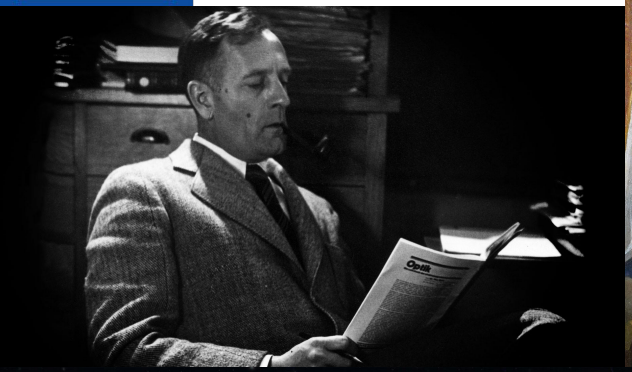

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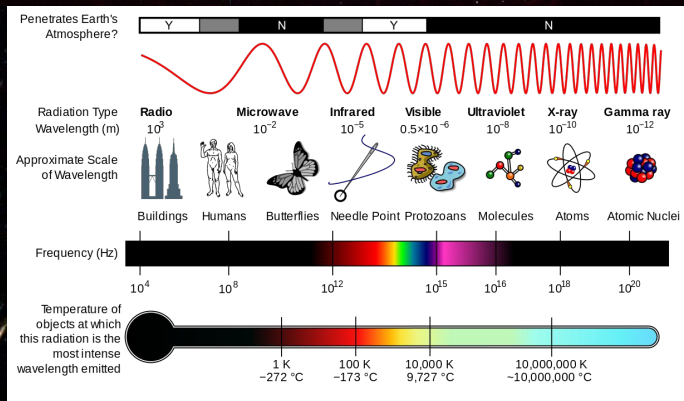

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Outline of the course

1. History
2. Review of the general concepts
3. Galaxies in our local Universe
4. Galaxies kinematics and scaling relations
5. Star formation
6. Interstellar Medium
7. Distances and redshift
8. High redshift Universe
9. Final remarks and open debate

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Suggestions

- Don’t panic!
- Be curious and ask questions
- If you take notes, be sure to be able to read the notes after
- Be focused during the lesson
- Each lesson will start with a briefing of the previous one: what you understood, what you have not understood, why lessons? Where will this bring?
- Stop me at any moment for comments or questions
- Don’t panic!

Evaluation Criteria

0.4 - Continuous Evaluation

0.6 - Final exam

Continuous Evaluation

The continuous evaluation is based on the work you do week after week:

0.15 = Written Assignments: Resolution of exercise (the procedure that is chosen to solve them)

0.15 = Practical Assignments: Laboratory activities

0.1 = Participation in the class

Final exam

The final exam is done at the end and consists of:

0.35 = a short presentation about a topic decided by the student

0.25 = fake proposal proposed to the students

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Doubts? Questions?

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1. History

Starting Point

Starting Point

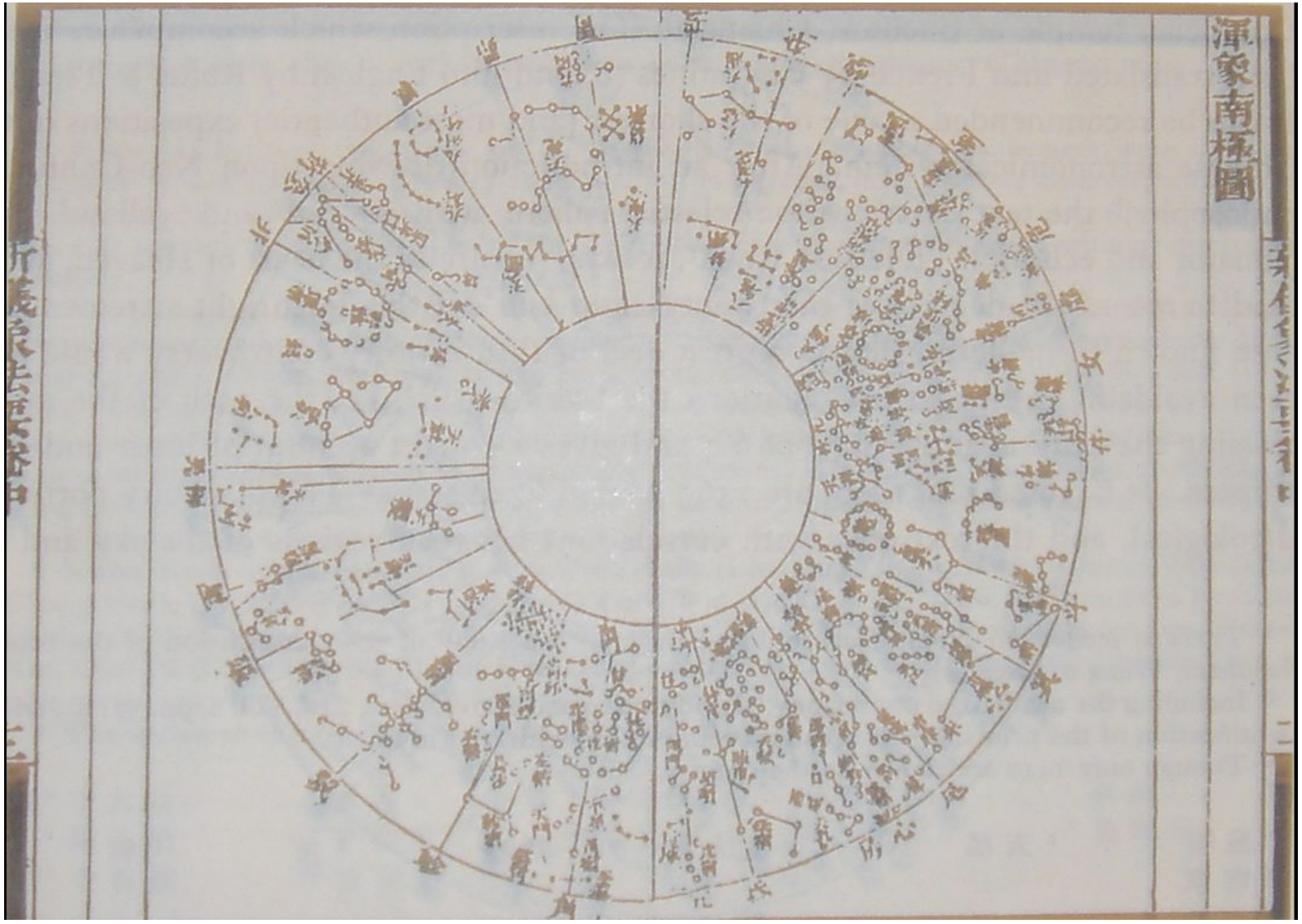
Humans have always been interested in the sky

Chichén Itzá (Messico)

Starting Point

Jantar Mantar (Jaipur)

Starting Point



Star map of Su Song (1020–1101) showing the south polar projection

Starting Point

Hans Lippershey: Dutch/German tradesperson who created and designed the first telescope, patented in 1608.
It magnify objects 3x closer than the naked eye.

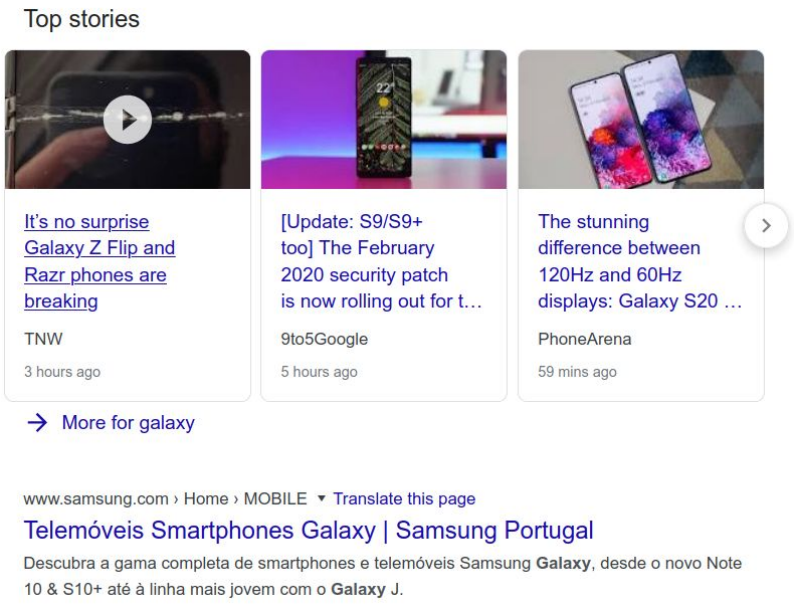
Starting Point

Galileo Galilei creates the field of astronomy leading to new discoveries about the solar system and Earth's place within the cosmos

What is a galaxy?

- According to Wikipedia, a galaxy is "*a gravitationally bound system of stars, stellar remnants, interstellar gas, dust, and dark matter.*
Galaxies range in size from dwarfs with just a few hundred million (10^8) stars to giants with one hundred trillion (10^{14}) stars, each orbiting its galaxy's centre of mass."

- According to Google Images:



What is a galaxy?

Galaxies are complex: general relativity, hydrodynamics, plasma physics, particle physics….

Investigation method peculiar because the lifetime of a galaxy is in the order of 10^{10} years, too large compared to our minuscule 10^{2} years.

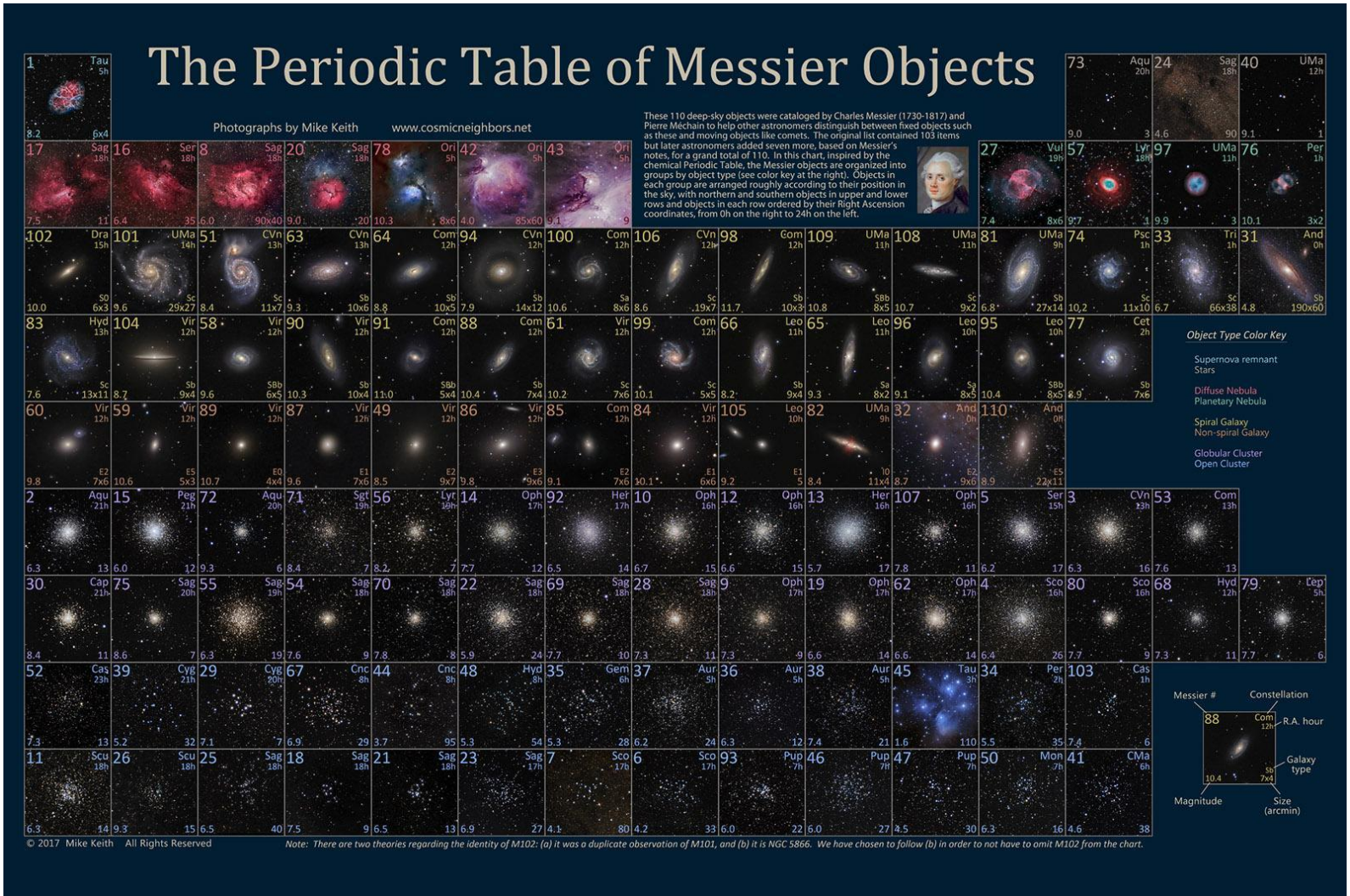
We use statistical methods to infer the properties and the evolution of galaxies, similarly to an alien taking a snapshot of the world now and infer from the picture the life phase of the human being.

Luckily for us the speed of light is finite, and the Universe is very big, so galaxies at larger distances are observed in early phases of their life.

Towards the concept of galaxies

Milestones:

Nebulae: 1771-1784 - Messier catalog (M81, M31)



Towards the concept of galaxies

Milestones:

1771-1784 - Messier catalog (M81, M31)

1864 – General Catalog of Galaxies (1864, 5079 nebulae)

1888 – New General Catalog of Nebulae and Clusters of Stars (NGC), Index Catalog (IC)

Nature of nebular objects controversial:

1. Nebulae are objects within the MW
2. Nebulae are objects outside the MW

Towards the concept of galaxies

Milestones:

1912 – Vesto Sliper made spectrographic studies of the brightest spiral nebulae to study the chemistry of these objects…….surprisingly he found that object were red-shifted with a velocity above the escape velocity from the Milky Way

1917 – Heber Curtis found 11 more novae in the Andromeda nebula. They were 10 magnitudes fainter than the those occurred within our galaxy….so he estimated the distance of these objects well above the dimension of the Milky Way

EVERYTHING WAS READY FOR:

THE GREAT DEBATE

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The Great Debate

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Day: 26 April 1920

BAIRD AUDITORIUM SMITHSONIAN MUSEUM OF NATURAL HISTORY – WASHINGTON D.C.

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The Great Debate

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HARLOW SHAPLEY

Nashville, Missouri - 35 years

- He determined the distance of many globular clusters
- He realized for the first time that our galaxy was much larger than previously believed
- He does not think that there are object beyond the Milky Way

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The Great Debate

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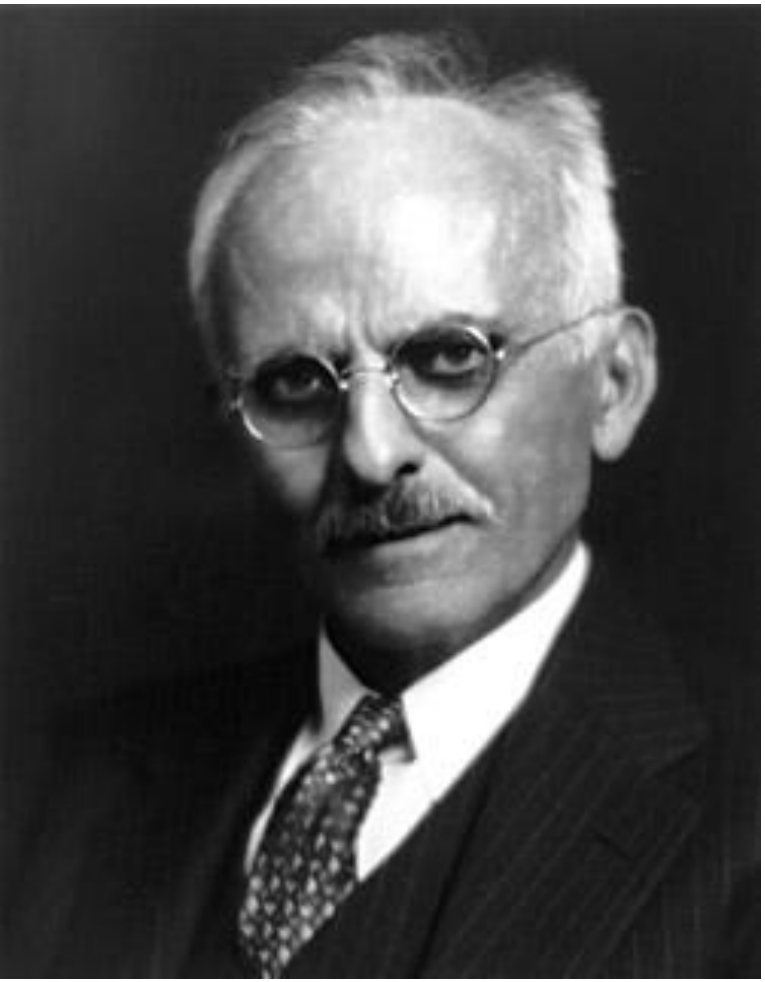

HEBER D. CURTIS

Muskegon, Michigan - 48 years

- He determined for the first time the polar jet from M87

- He invented a type of film plate comparator able to reduce the dimension of astronomical devices

- He thinks that there are objects beyond the Milky Way, Andromeda is an example.

From National Academy of Sciences,
Smithsonian Institution, Washington, D. C.
(Carl H. Butman, Representative).

For Release to Afternoon Papers,
Monday, April 26

for files

HOW MANY UNIVERSES ARE THERE?

This evening two California astronomers will discuss the Size of the Universe, and present their views as to whether or not there is only one or several universes, before the National Academy of Sciences, which is now in session in Washington.

In this public meeting, Dr. Harlow Shapley of the Mt. Wilson Solar Observatory, will discuss recently secured evidence pointing to the dimensions of our galaxy of stars, known popularly as the Milky Way, which he believes to be ten times greater than is held in the older theories concerning the dimensions and compositions of the Milky Way. In other words, he claims that it takes light about three hundred thousands of years to cross from one side to the other of the space occupied by the 3,000,000,000 stars of which our sun is the nearest one. He holds the spiral nebulae, those clam-shell-like cloudy luminous objects seen by great telescopes, to be inside our system.

Doctor Shapley's views will be followed by the discussion of Doctor Heber D. Curtis of the Lick Observatory, who will defend the older view that our Milky Way is approximately of the dimensions suggested by Newcomb, about 30,000 light-years in diameter, with the spiral nebulae regarded as very probably individual galaxies of "island universes", like ours. Thus there may be a million other universes each having 3,000,000,000 stars. Inhabitants of these numerous universes would see our Milky Way as a spiral nebula. The lectures of these two learned astronomers will be followed by a general discussion open to the auditors present who are interested in the development of this new advance in scientific research.

CHICAGO SCIENTIST WILL SPEAK

Professor A. A. Michelson, Vice-President of the Academy and one of the leading physicists of the world, will present a paper on new modifications of his famous invention, the interferometer, in connection with the experiments conducted at Mt. Wilson Observatory with the giant 100-inch telescope. By the aid of this invention astronomers are now able to study, with more accuracy, the distance between binary stars, a problem heretofore undertaken with great difficulty due to the fact of their close proximity. Dr. Michelson is the only American to receive the Swedish Nobel Prize, awarded to him for his research in physics.

NEW NATIONAL SCIENCE BUILDING

The President of the Academy, Dr. Charles D. Walcott, announced yesterday the plans of the society to erect a national headquarters in Washington at a cost of nearly a million and a half dollars. The fund was donated by the Carnegie Corporation of New York and the land purchased by friends of the Academy, for $185,000. The new building will be located in Potomac Park, a little north of the Lincoln Memorial building.

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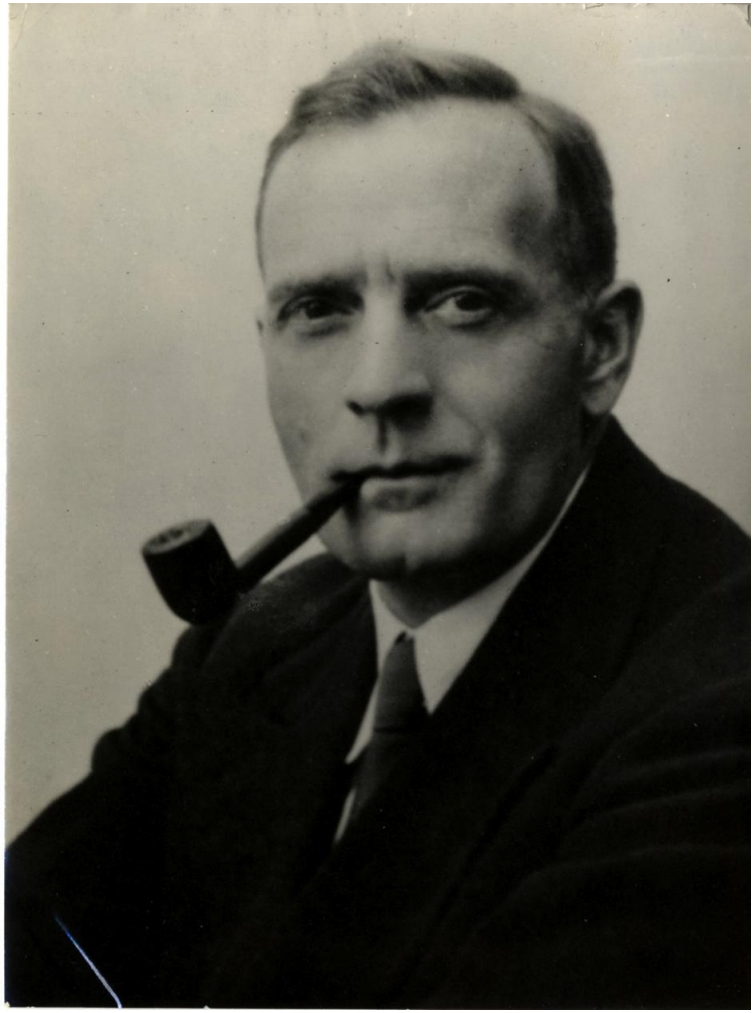
The Great Debate



EDWIN HUBBLE

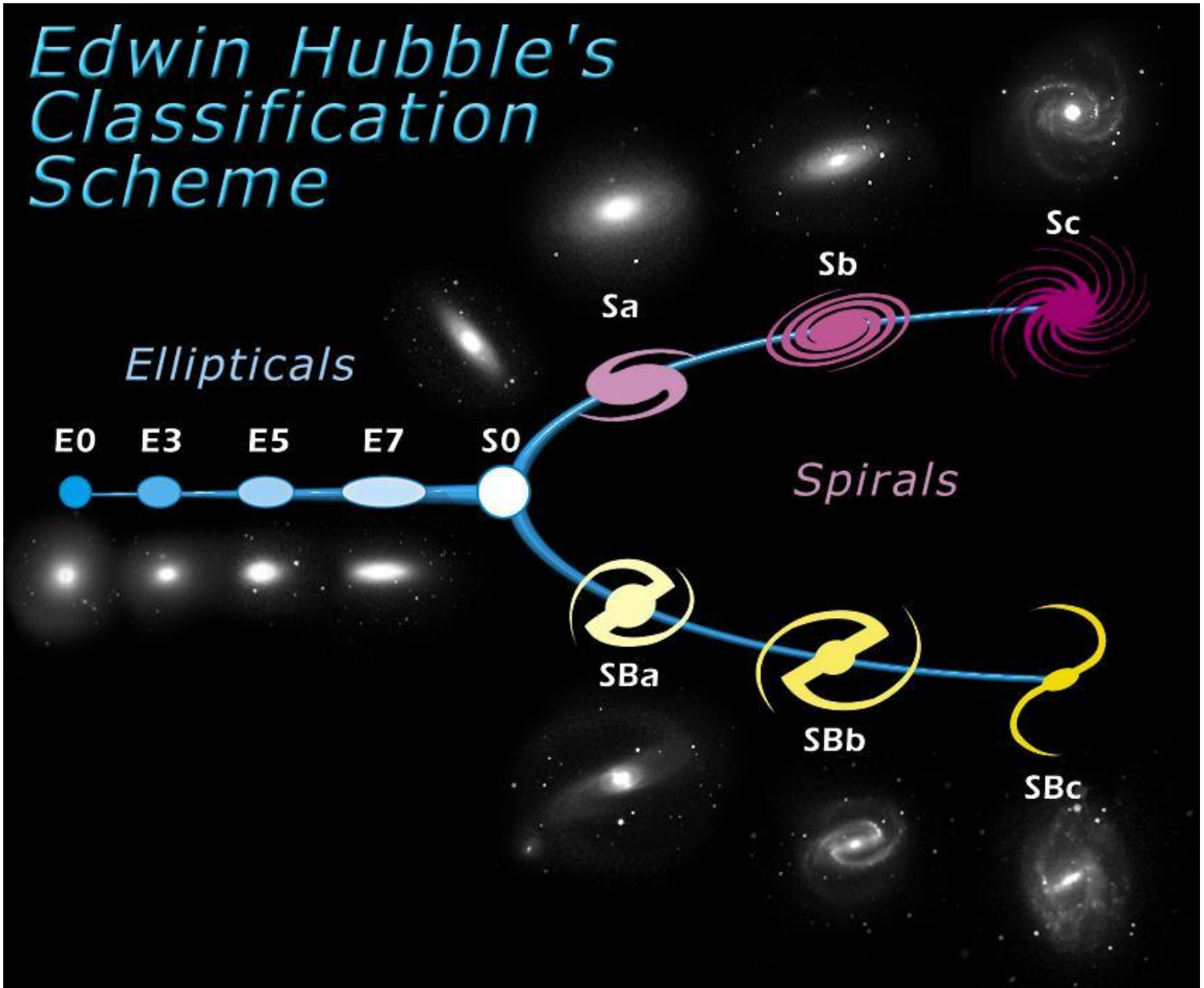
Marshfield, Missouri - 31 years (in 1920)

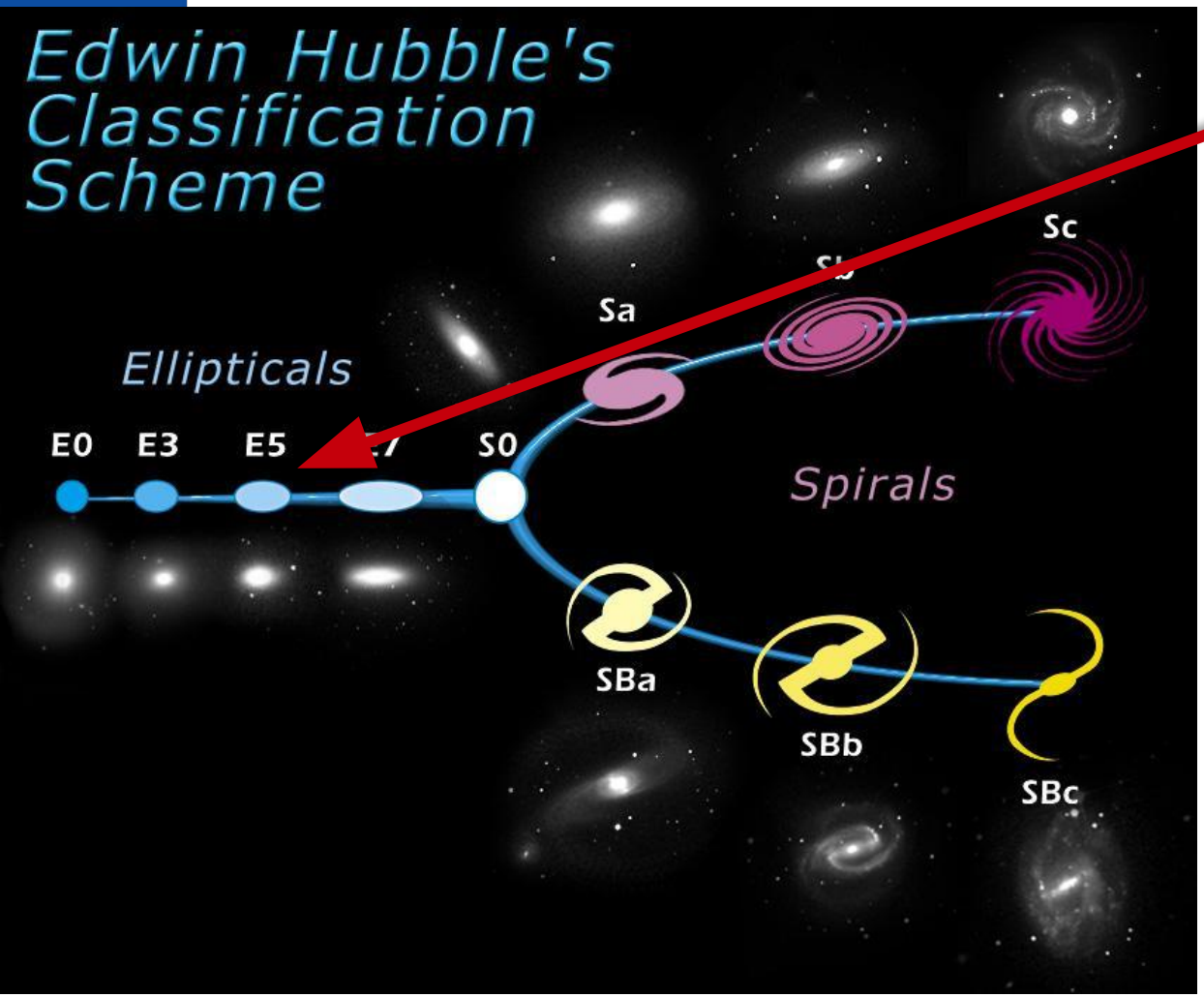
- Two years after the “Great Debate” he observed with the telescope of Mount Wilson different variable stars (Cepheid) in several spiral nebulae

- This proved that these nebulae were too far to be in the Milky Way

- He then provided a classification of the galaxies still used

Curiosity: he was a lawyer, coached the boy’s basketball team in New Albany (Indiana)

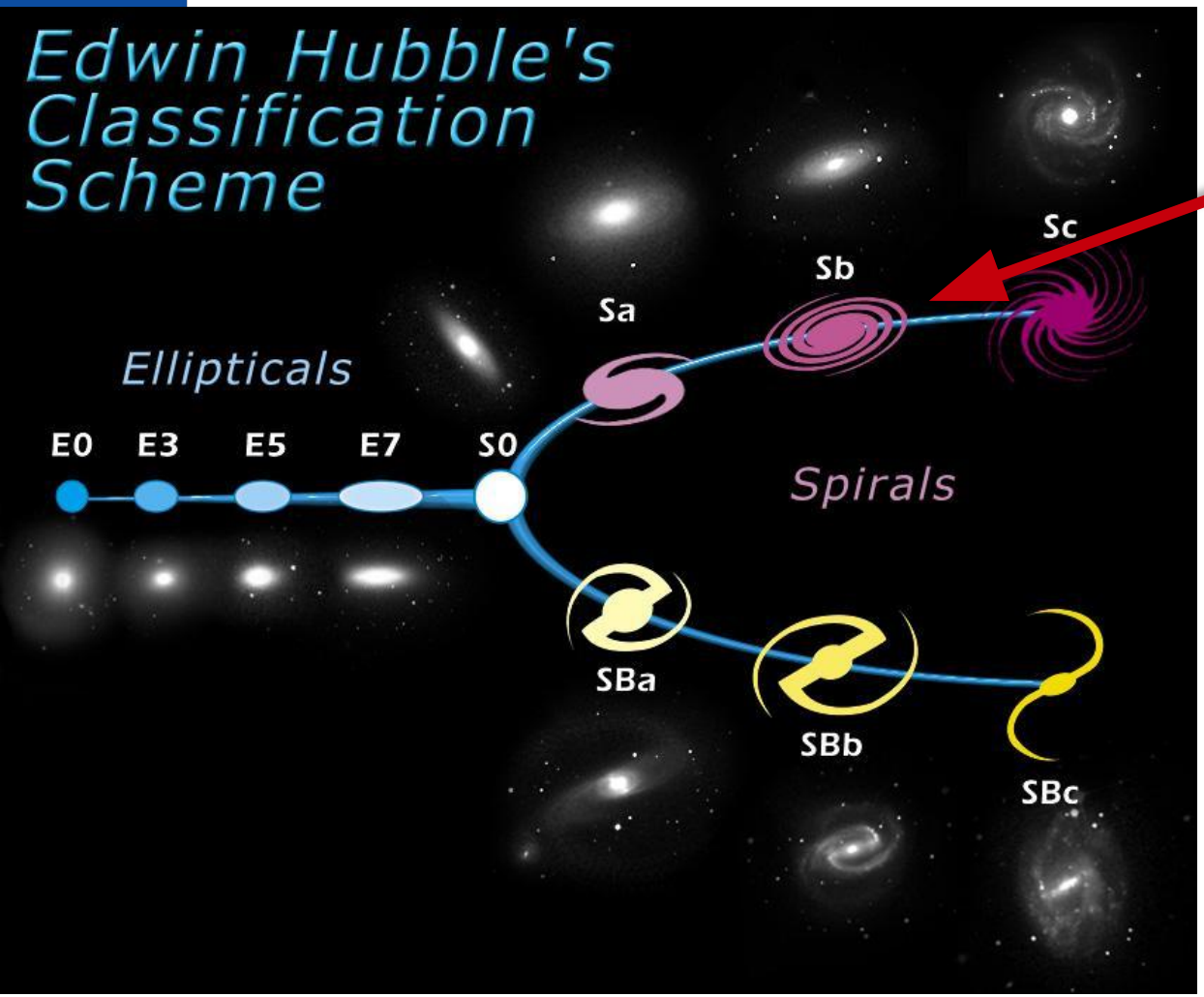

Edwin Hubble's Classification Scheme
Ellipticals
E0
E3
E5
E7
S0
Spirals
Sa
Sb
Sc
SBa
SBb
SBc



ELLIPTICALS

Billion of stars gathered in a roughly spheroidal volume.

Classified with the letter E followed by a number that indicates how much they are elliptical.



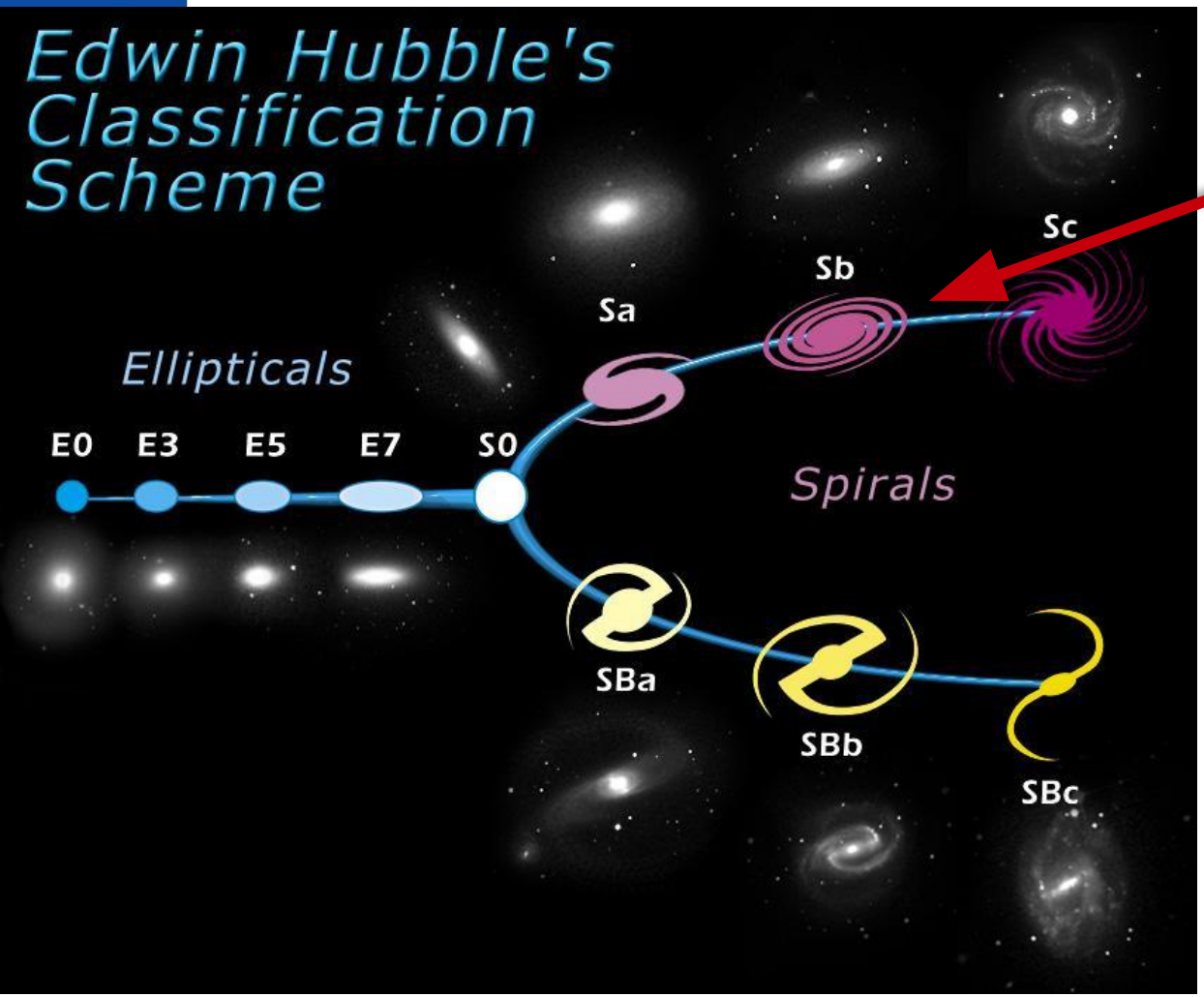
ELLIPTICALS
SPIRAL

A flattened disk with star-forming spiral structure and a central concentration of stars known as the BULGE.

Classified with S and a letter that defines the structure of the arms.

They are divided into two different families: normal spiral and barred spirals.

If they have a bar they are classified as SB.



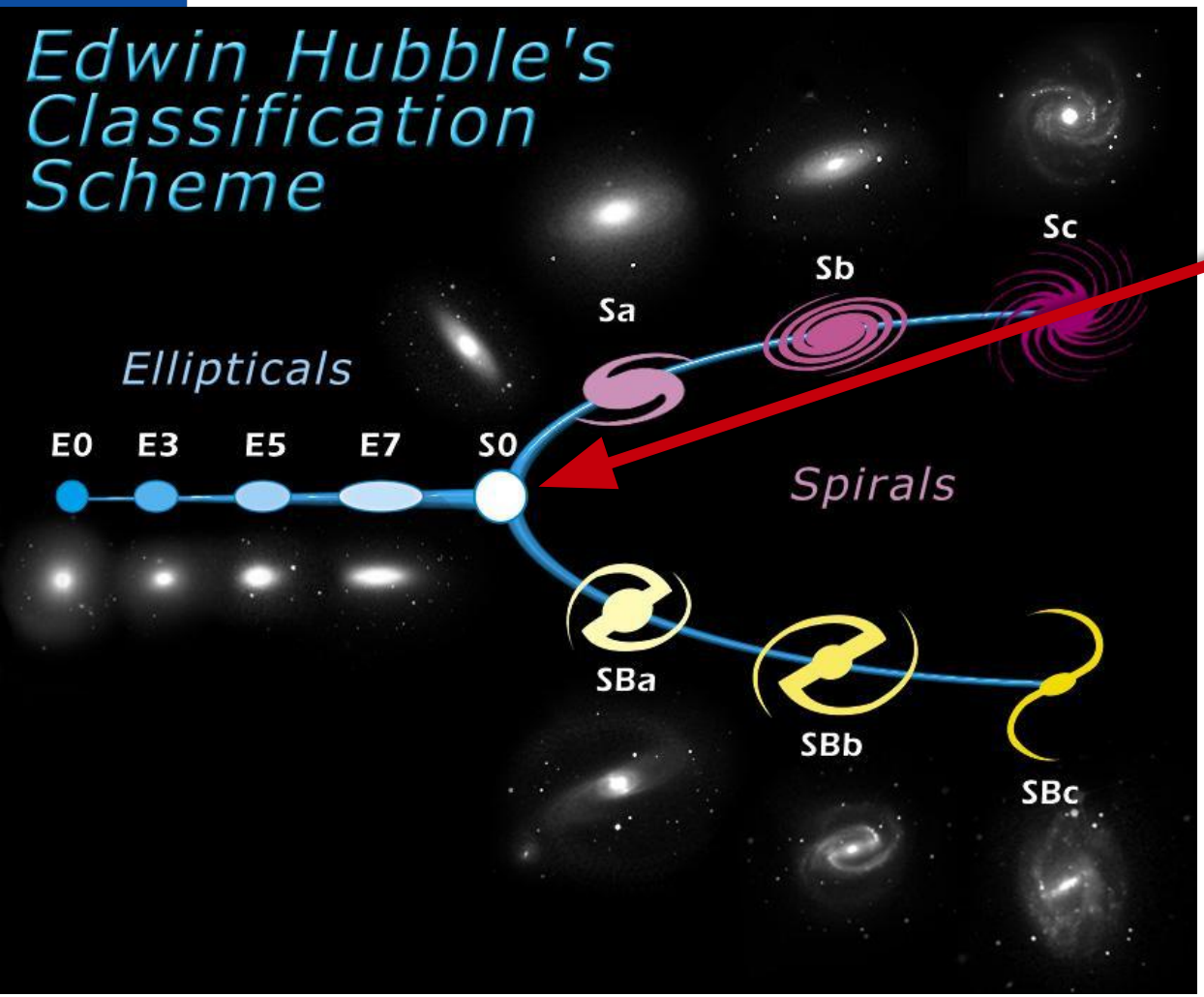
ELLIPTICALS
SPIRAL

Sa: strong bulge, undefined arms

Sb: intermediate

Sc: small bulge, well-defined arms

Sd: no bulge, sharps arms



ELLIPTICALS

SPIRAL

LENTICULAR

Intermediate.
Possible presence of bulges

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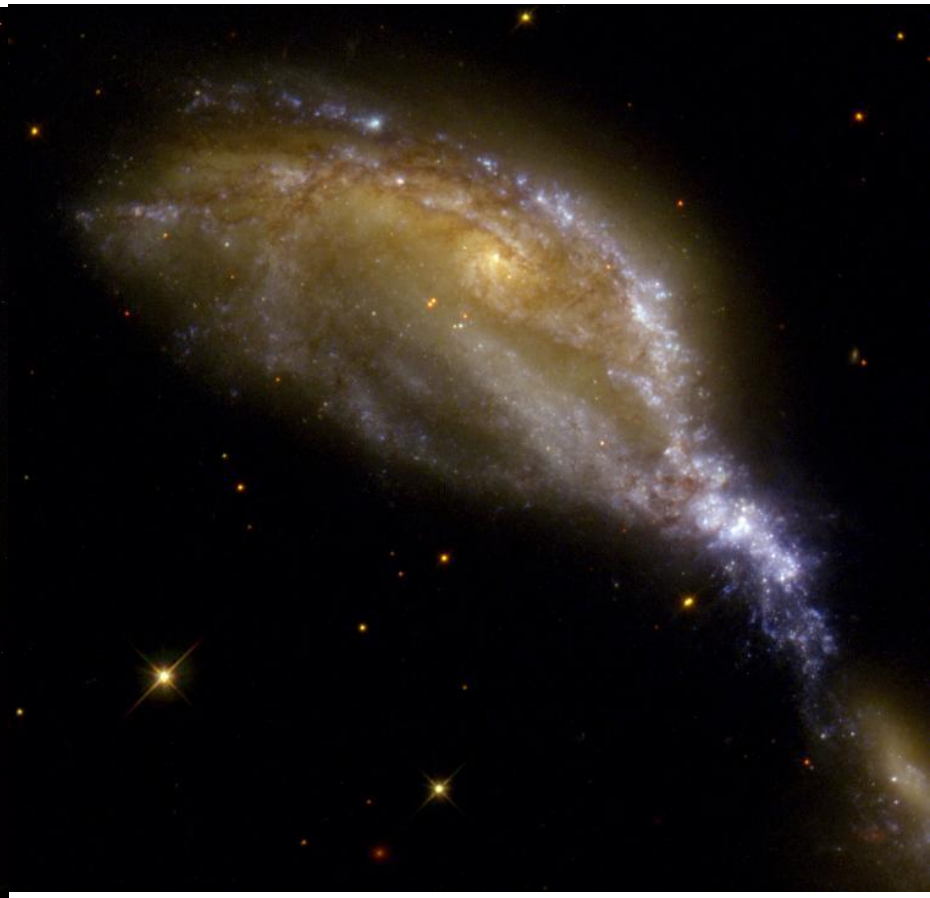
IRREGULAR

They are “strange”, with no obvious structure, they have bad manners and not an easy location in the well-defined Hubble classification....



Elliptical Galaxies

NGC1316

Composed mainly of old stars

- A small amount of interstellar matter (gas and dust)

- low star formation activity

- stars have in average a radial orbit different from the rotational motion of stars in spirals

- the general idea is that elliptical galaxies are the result of a past merging between different galaxies

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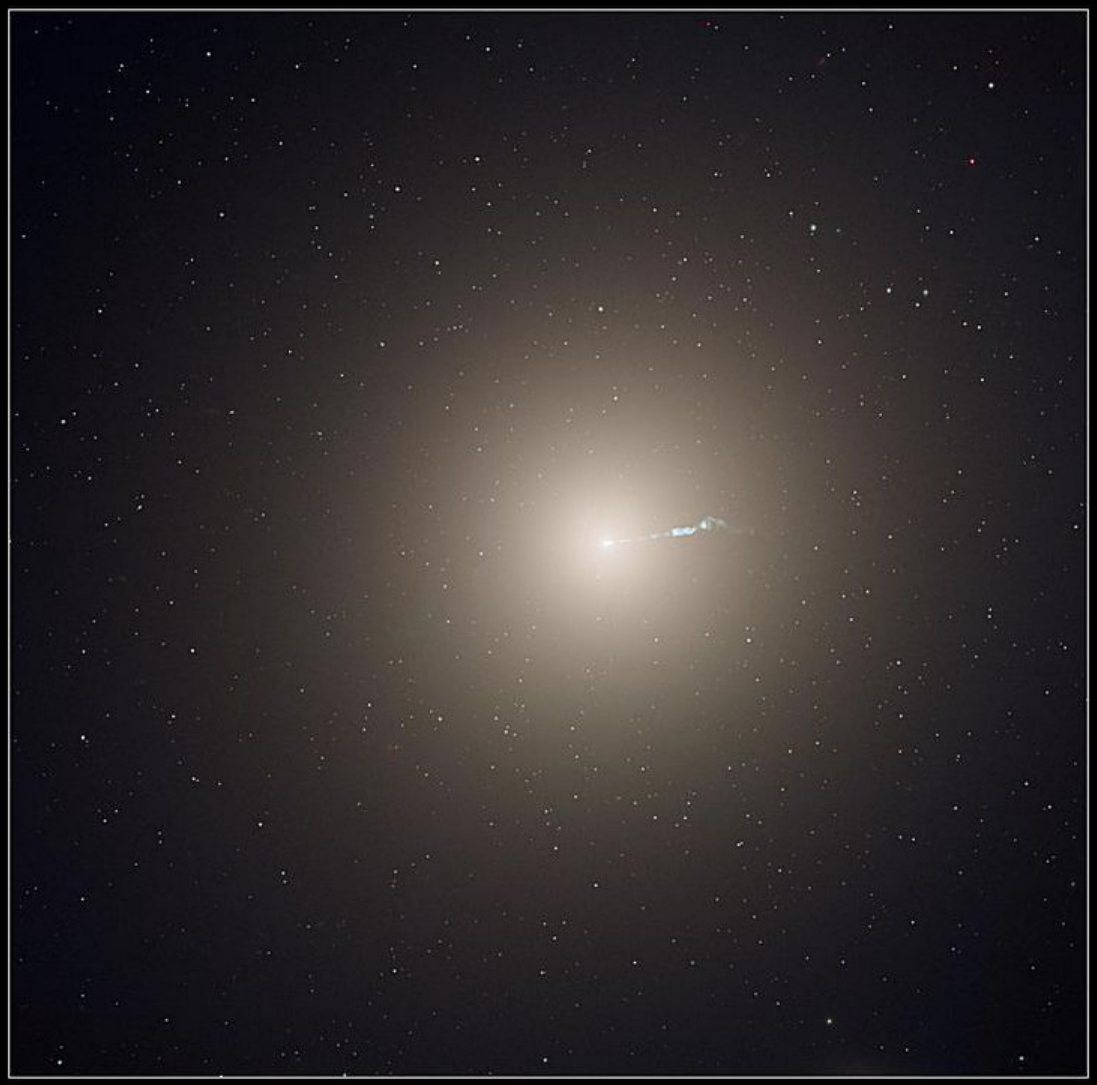

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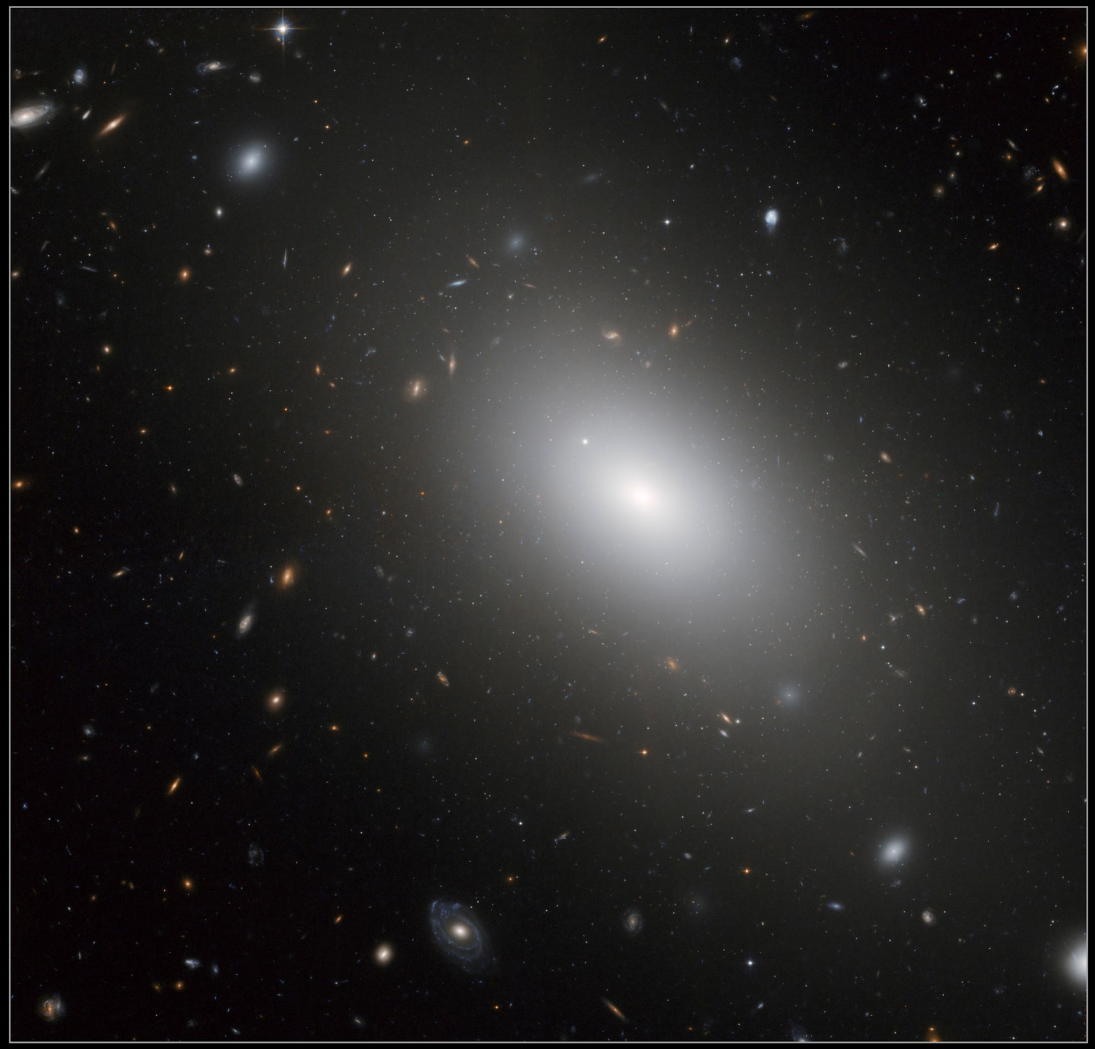
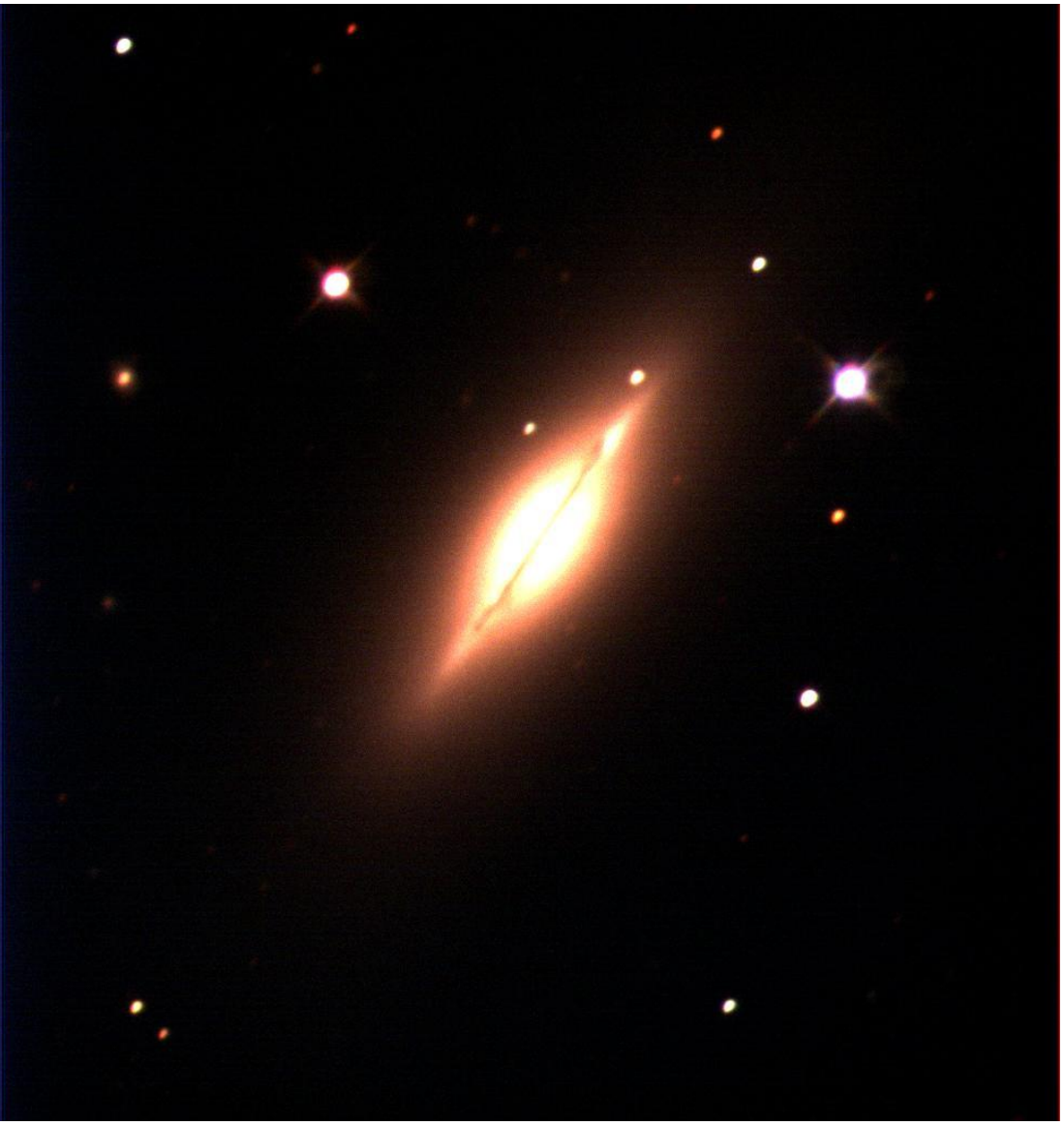
Elliptical Galaxy NGC 1132



Hubble Heritage

NASA, ESA, and the Hubble Heritage (STScI/AURA)-ESA/Hubble Collaboration
Hubble Space Telescope ACS • STScI-PRC08-07

Lenticular Galaxies



M102

Intermediate between elliptical and spiral

- Composed mainly of old stars

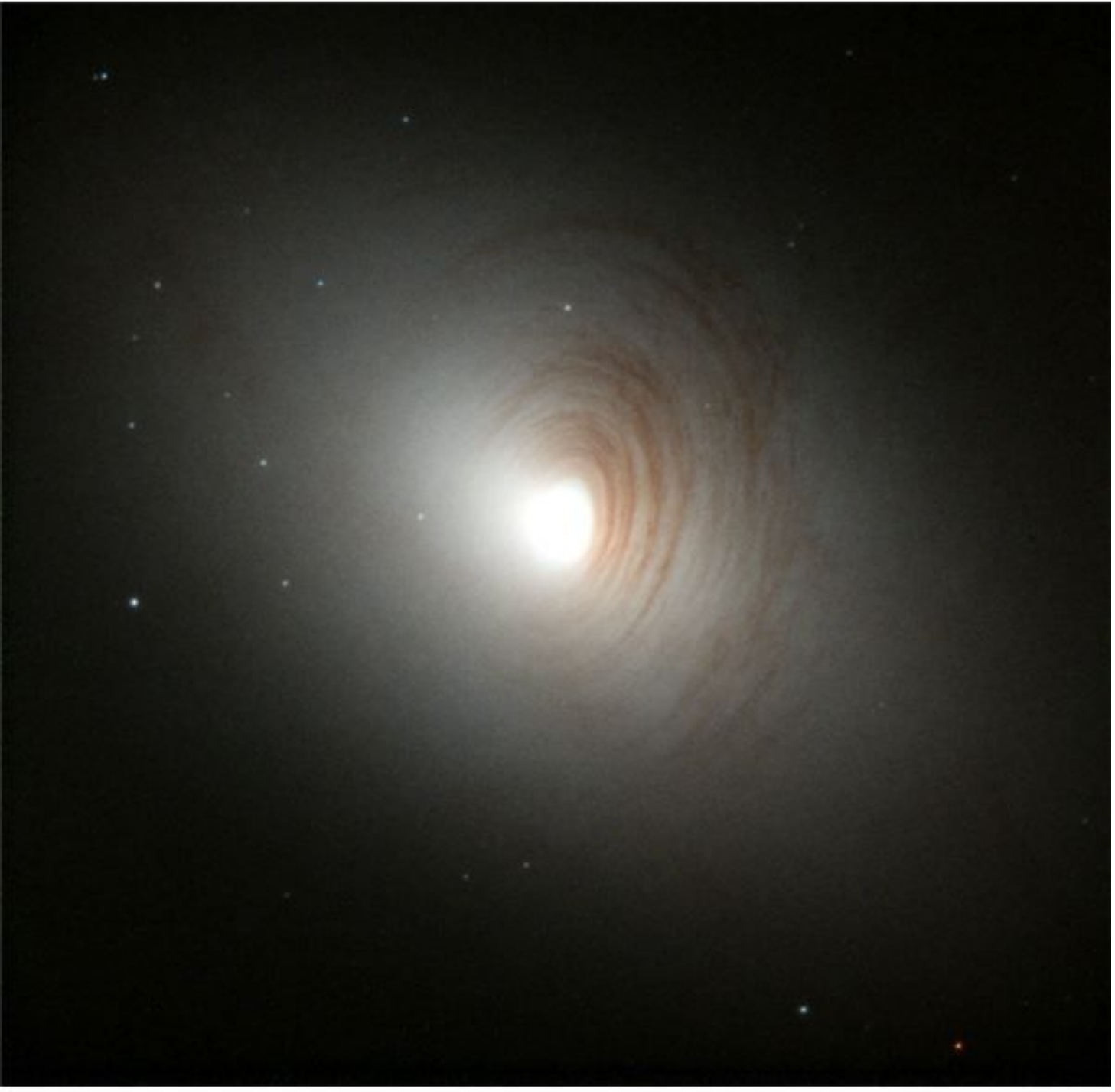
- A small amount of interstellar matter (gas and dust) but if they have disk structure they can retain a significant fraction of dust

- Low star formation activity

2 formation scenarios:

1: faded spiral: a spiral galaxy that consumed all of its gas for the star formation

2: merging: a spiral after a merging with another galaxy lost its arms.



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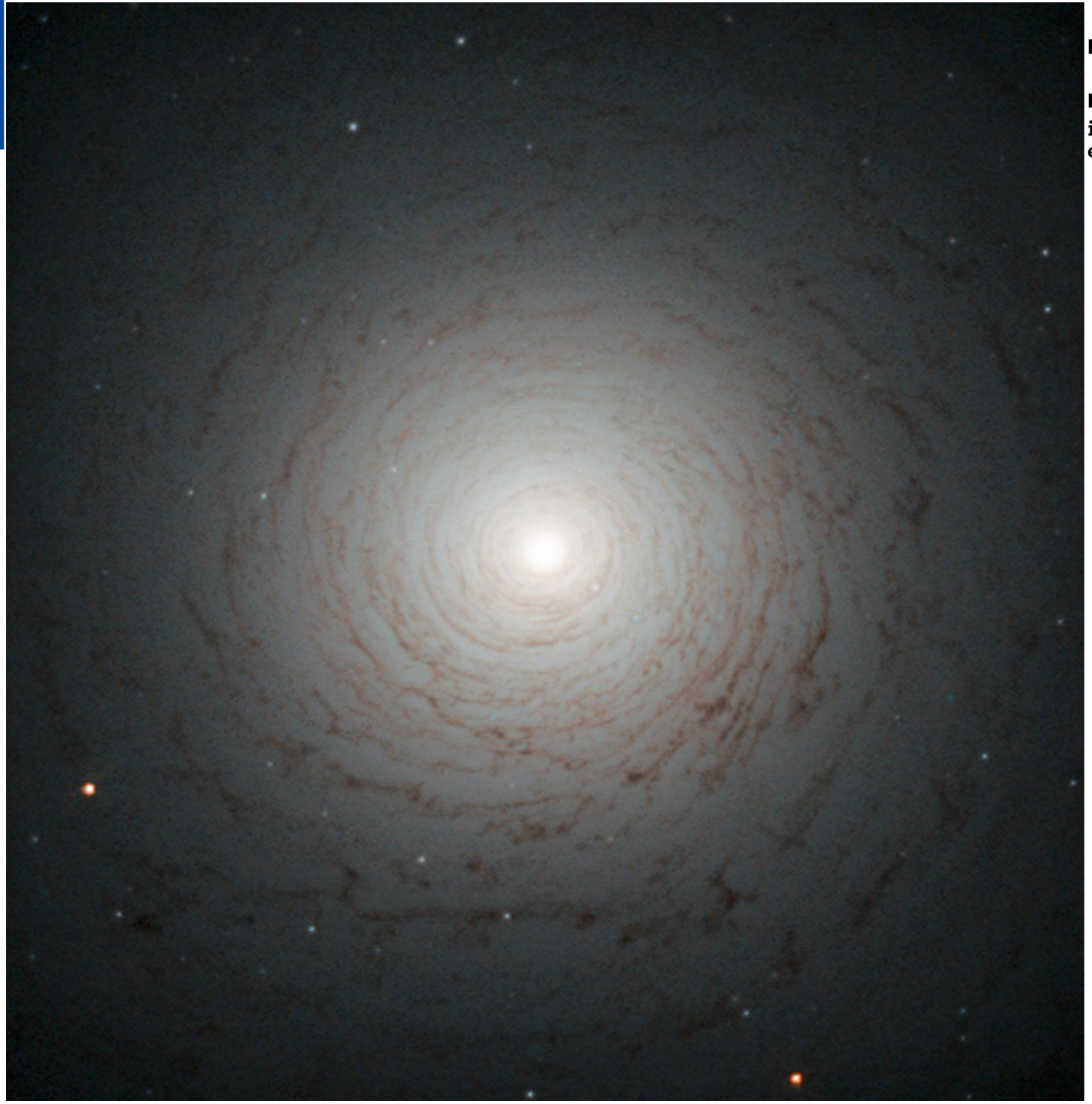

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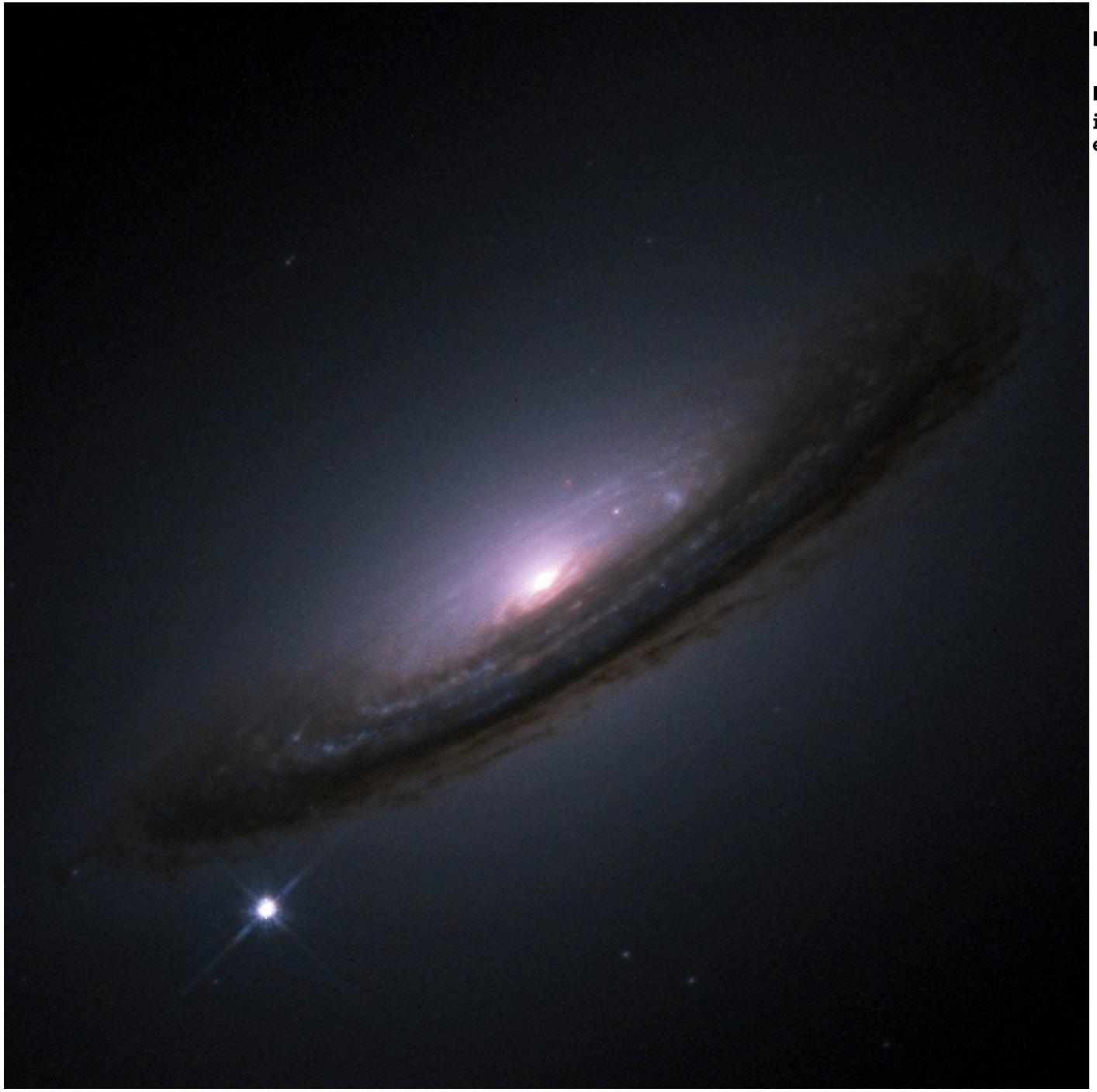

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Spiral Galaxies

ESO243-49

M74

They are formed of:

- a central concentration of stars known as the bulge

- a flat, rotating disk containing stars gas and dust

In the spiral arms inhabit a strong activity of star formation

The bulge population is variable, depending on the type of spiral that we are considering:

a) in the spirals with tight spiral arms (Sa) the bulge is populated by old red stars.

b) in the spirals with more opened bar (Sb) the bulge has a younger population.

Spiral Galaxies

NORMAL **BARRED**

NGC6744 **NGC1097**

The bar is thought to be the result of a density wave radiating from the centre of the galaxy whose effects reshape the orbits of the inner stars.

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Spiral Galaxies

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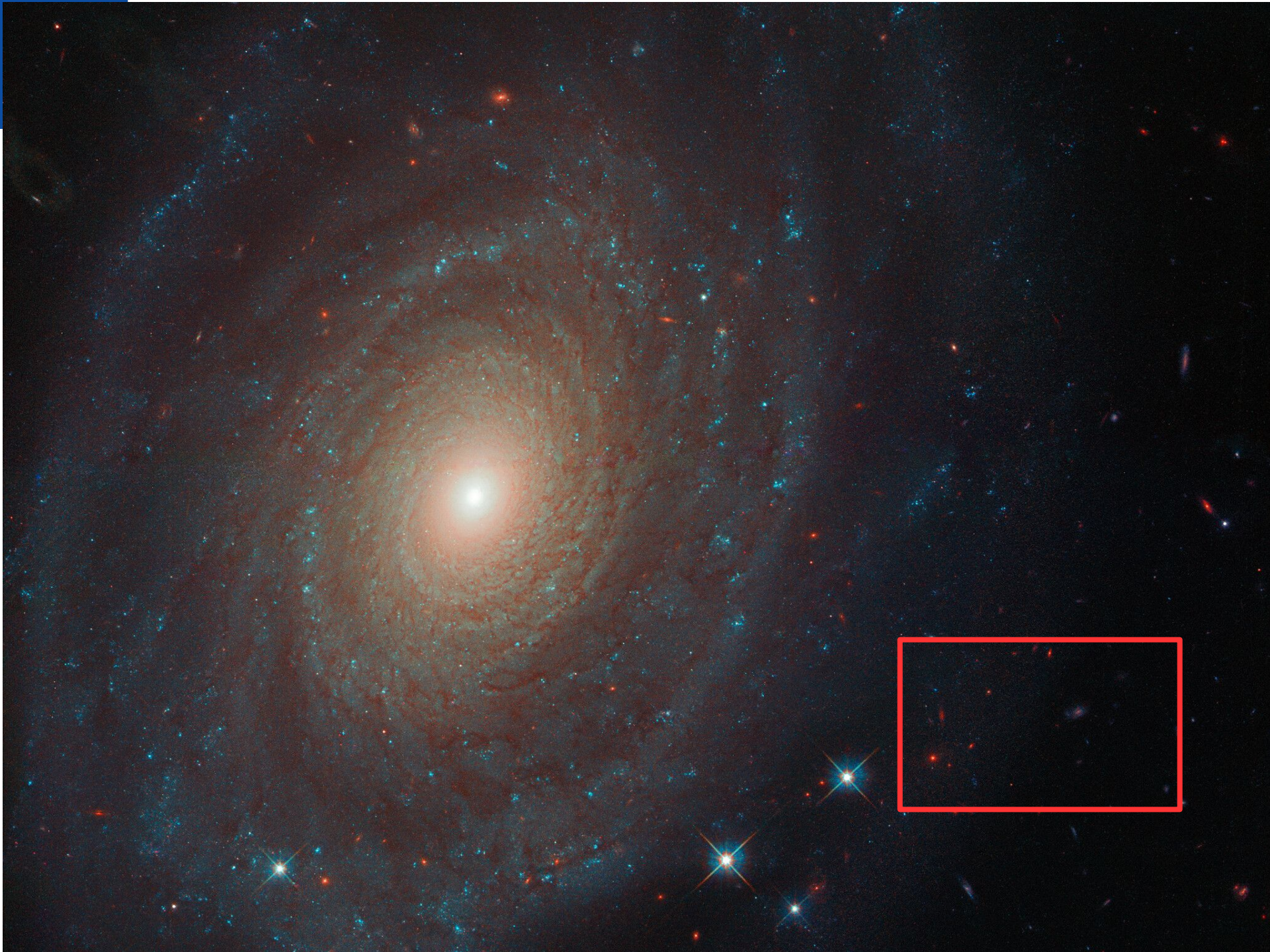
Spiral Galaxy NGC 2841

Hubble Heritage

NASA, ESA, and the Hubble Heritage (STScI/AURA)-ESA/Hubble Collaboration • Hubble Space Telescope • WFC3/UVIS • STScI-PRC11-06



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Spiral Galaxies

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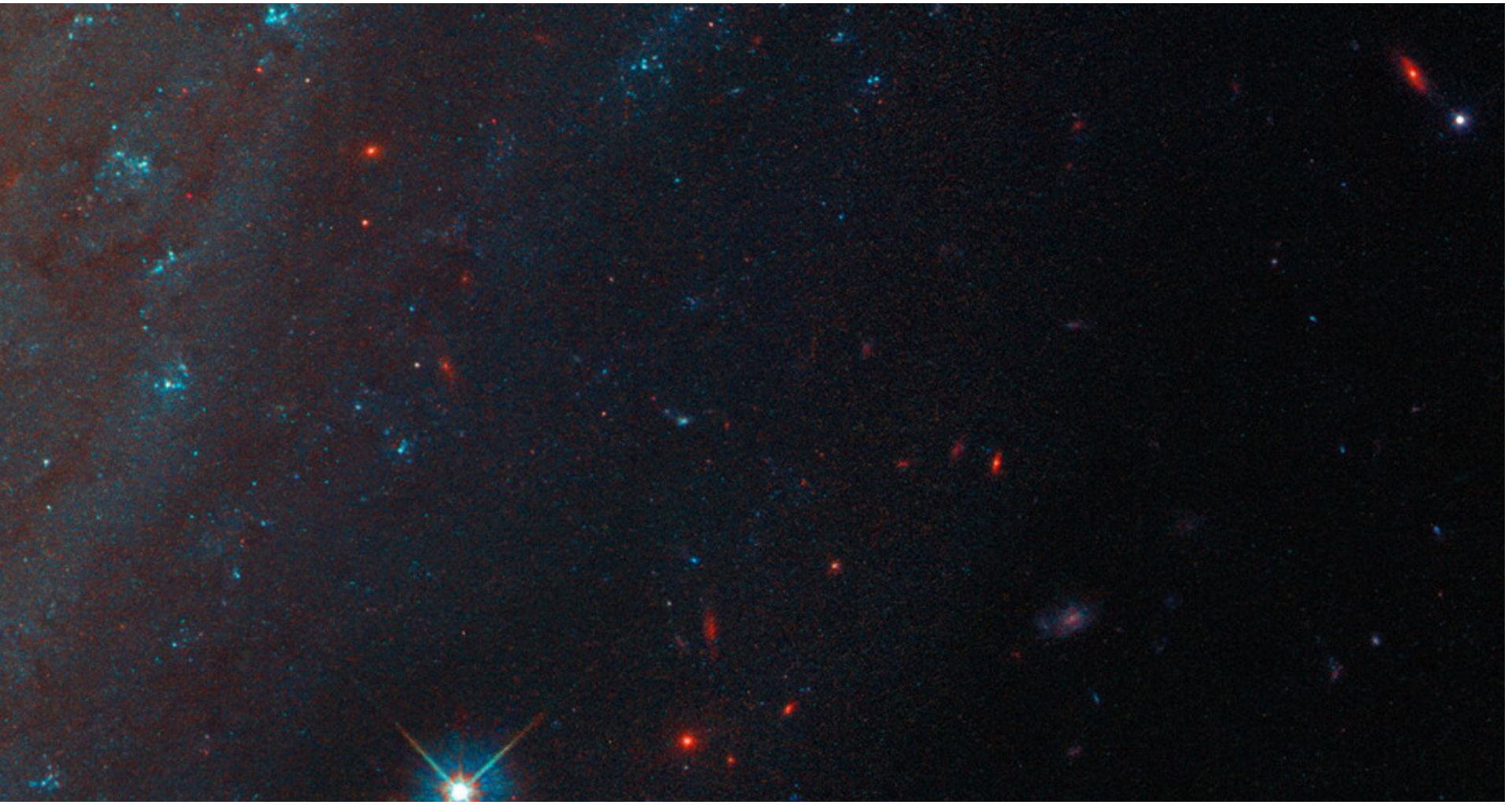

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A fly-through of GAMA

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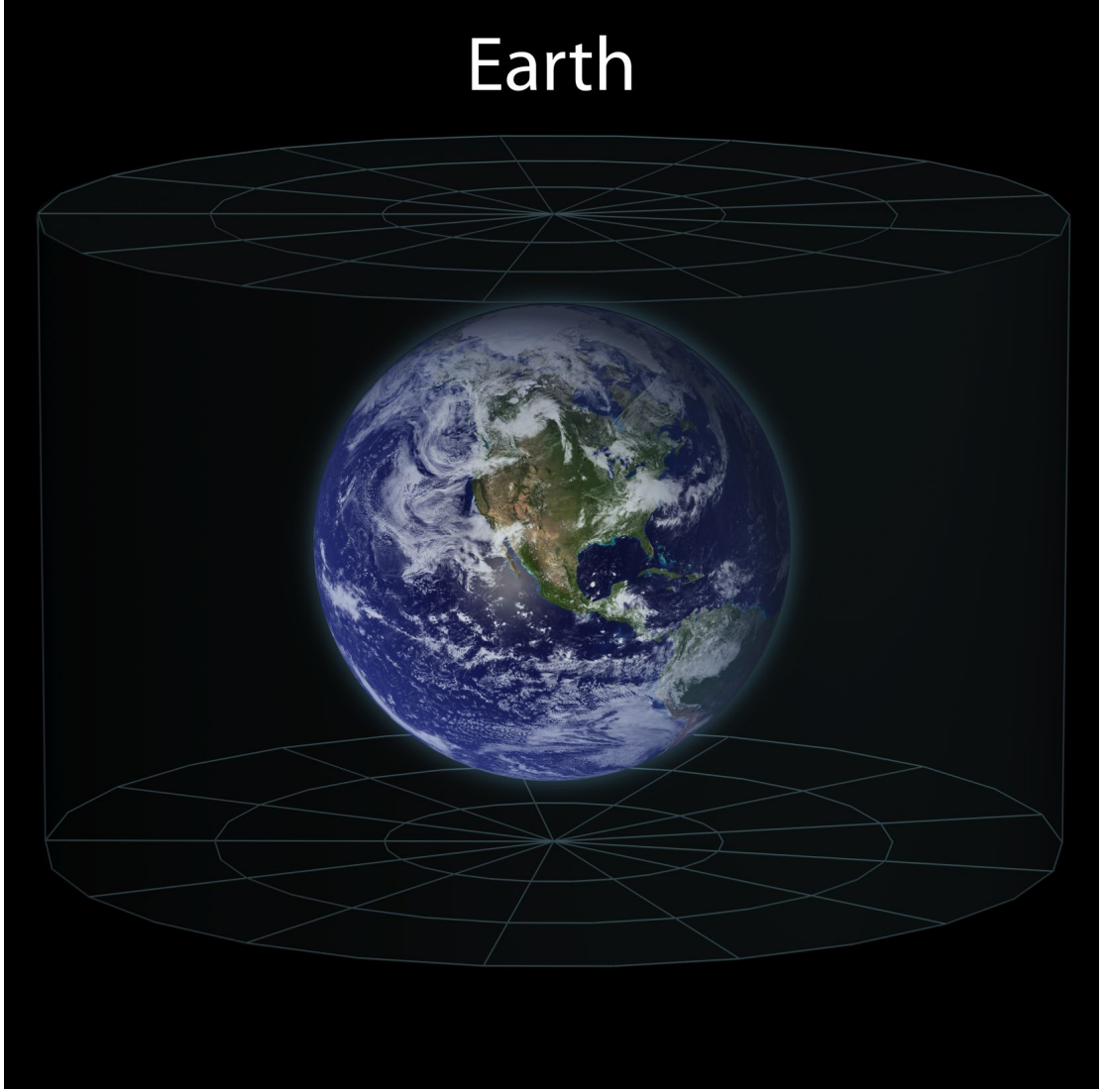
The Galaxy and Mass Assembly catalogue is a map of the Universe in 3D. This simulated flythrough shows the real positions and images of the galaxies.

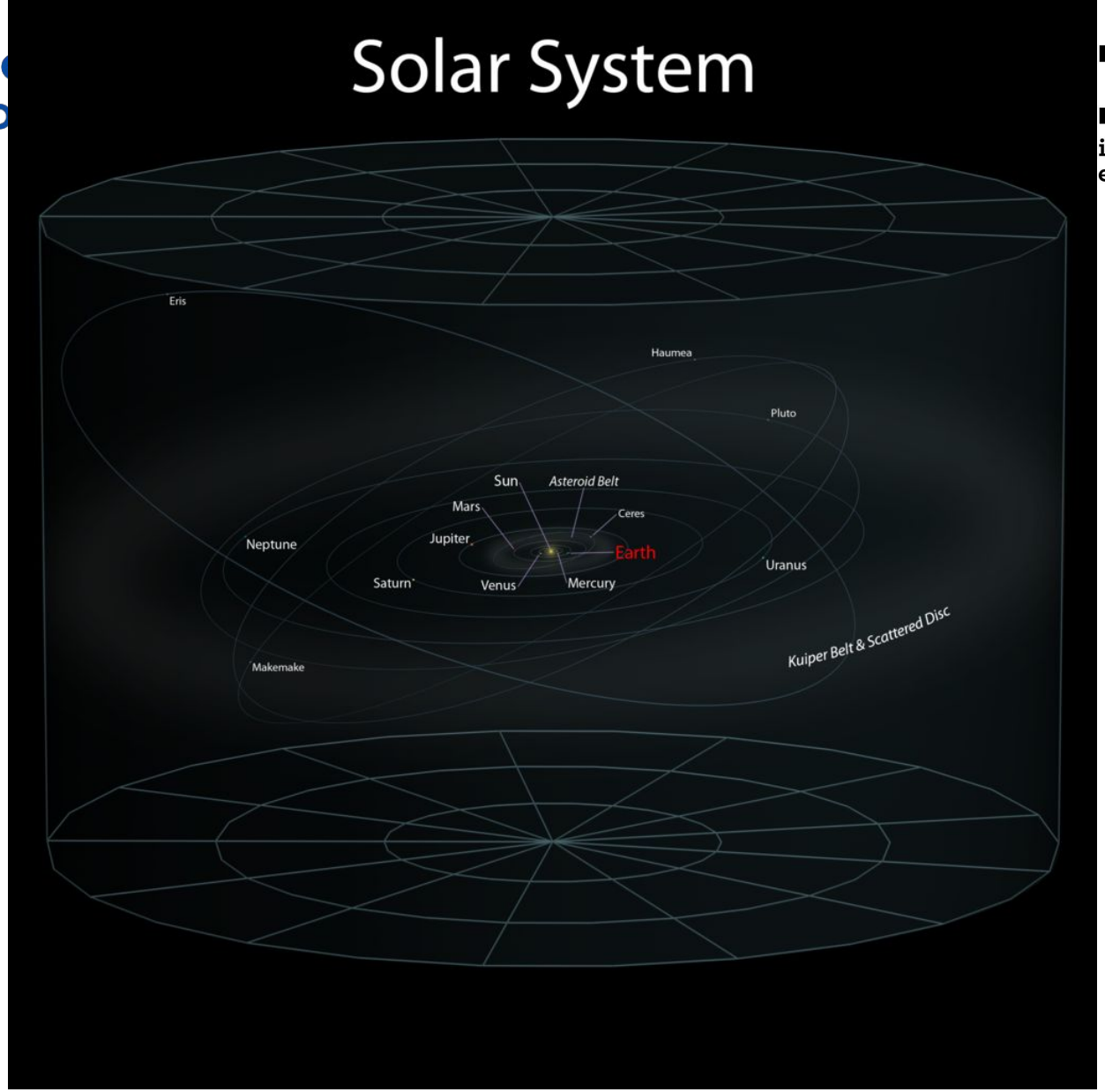
Where are we?

Some useful units:

- Speed of light = 3×10^5 km/s
- Seconds in 1 day = 8.64×10^4 s
- 1 light year = distance traveled by light in 1 year
- 1 ly = $9.46\ 10^{12}$ km
- 1 Solar Mass = 2×10^{30} kg
- 1 Solar Luminosity = 3.8×10^{26} W = 3.8×10^{33} erg/s
- 1 pc = 3.08×10^{13} km = 3.26 ly



- Radius: 6 371 km
- Circumference: 40 075 km = 0.13 s at the speed of light
- Moons distance: 384 400 km = 1.28 s at *c*



- Dist Sun: 1.49 x 10^6 km = 8 minutes at *c*
- Dist Pluto: 5.9 x 10^9 km = 5.5h at *c* = 0.0006 ly

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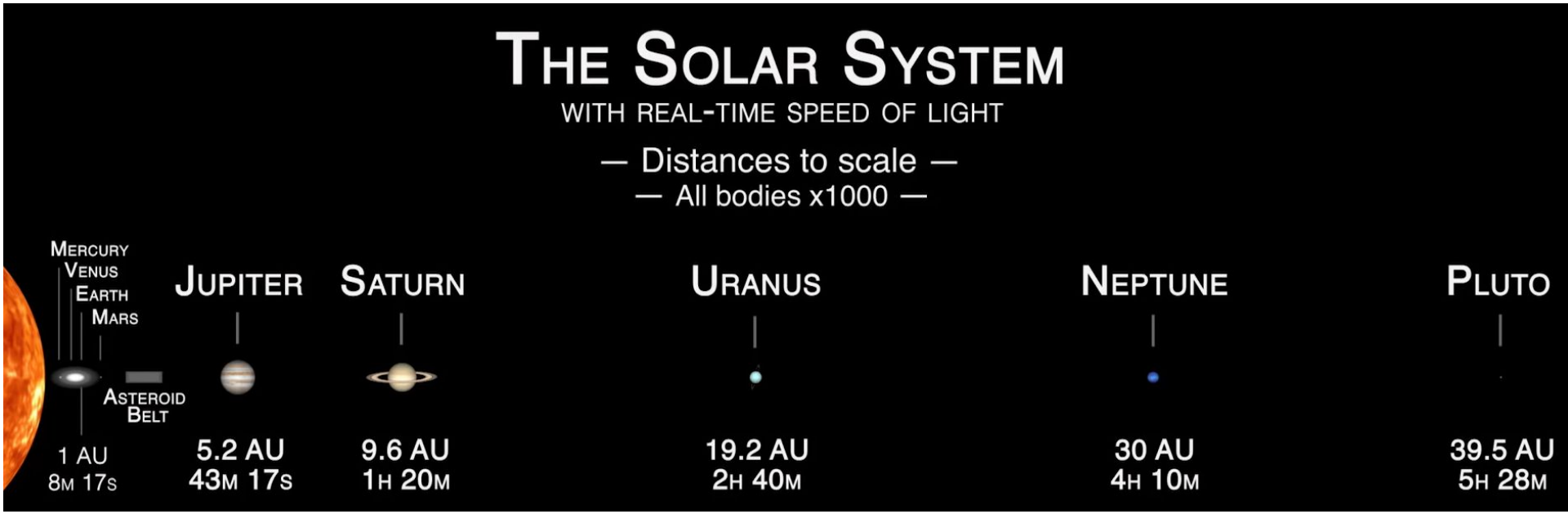

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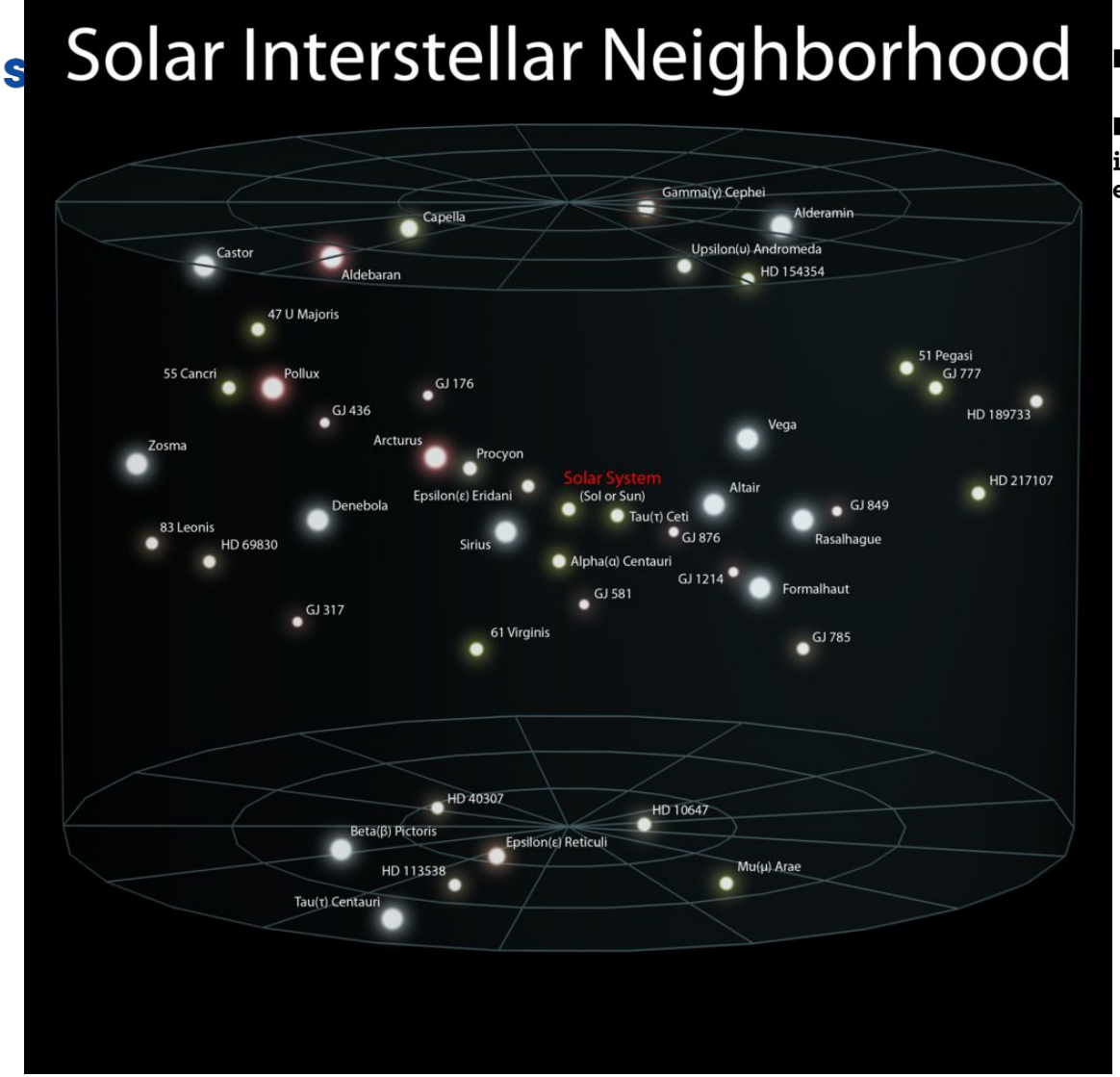

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The Local Interstellar Cloud (LIC) is the interstellar cloud roughly 30 light-years (9.2 pc) across through which the Solar System is moving.

Closest Star: Proxima Centauri = 4.22 ly = 1.3 pc

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Diameter = 46-61 kpc

D = 1.5-2.0 x 10^3 ly

# of stars = 1-4 x 10^{11}

Mass ~ 1 x 10^{12} M_o

Our neighbours

LMC

Diameter: 14 000 ly = 4.3 kpc

Distance: 163 000 ly = 50 kpc

Mass ~ 10^{10} M_o

SMC

Diameter: 7000 ly = 2.1 kpc

Distance: 200 000 ly = 60 kpc

Mass ~ 7 x 10^9 M_o

Our neighbours

M33

Distance: 2.73 x 10^6 ly = 840 kpc

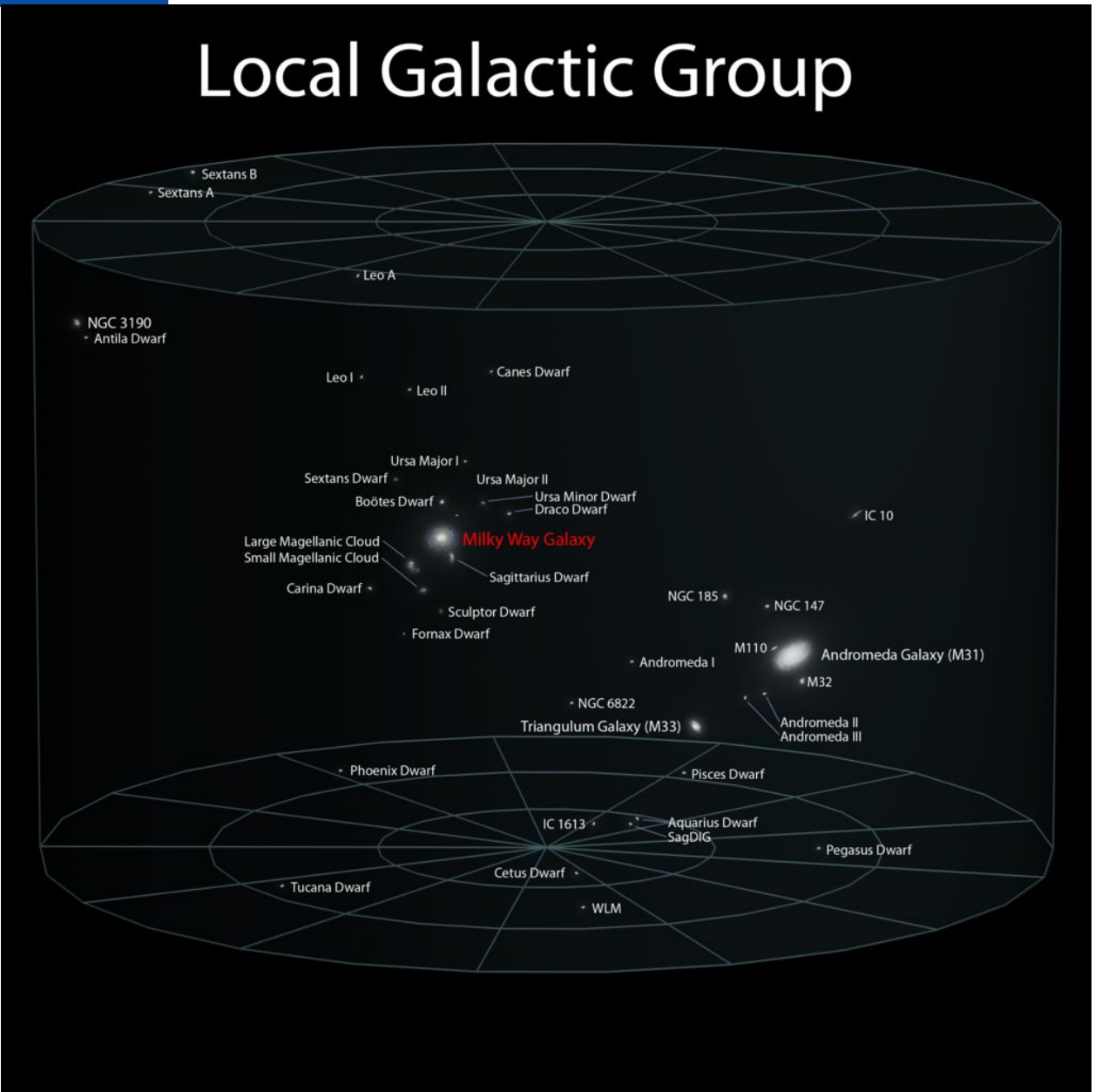
Mass ~ 10^{10} M_o

M31

Distance: 2.5 x 10^6 ly = 778 kpc

Mass ~ 1.5 x 10^{12} M_o

Local Galactic Group



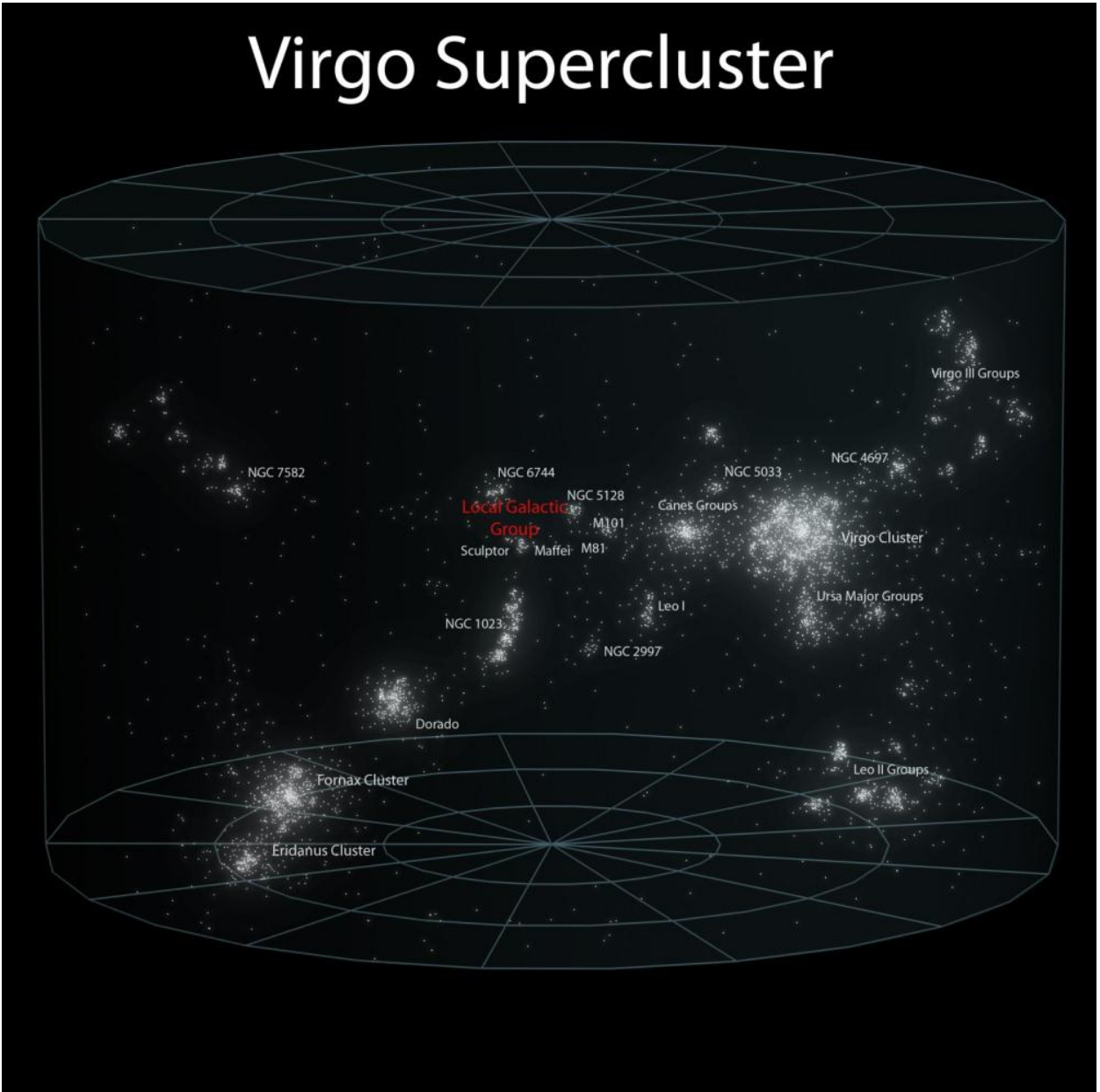
MW belongs to this group of galaxies, moving within a region of ~ 3 Mpc

2 clusters: Milky Way and its satellites on one hand, and the Andromeda Galaxy and its satellites on the other.

The two clusters are separated by about 0.8 Mpc and move towards one another with a velocity of 123 km/s.

Total members estimated in 54, most of them being dwarf galaxies.

Virgo SuperCluster

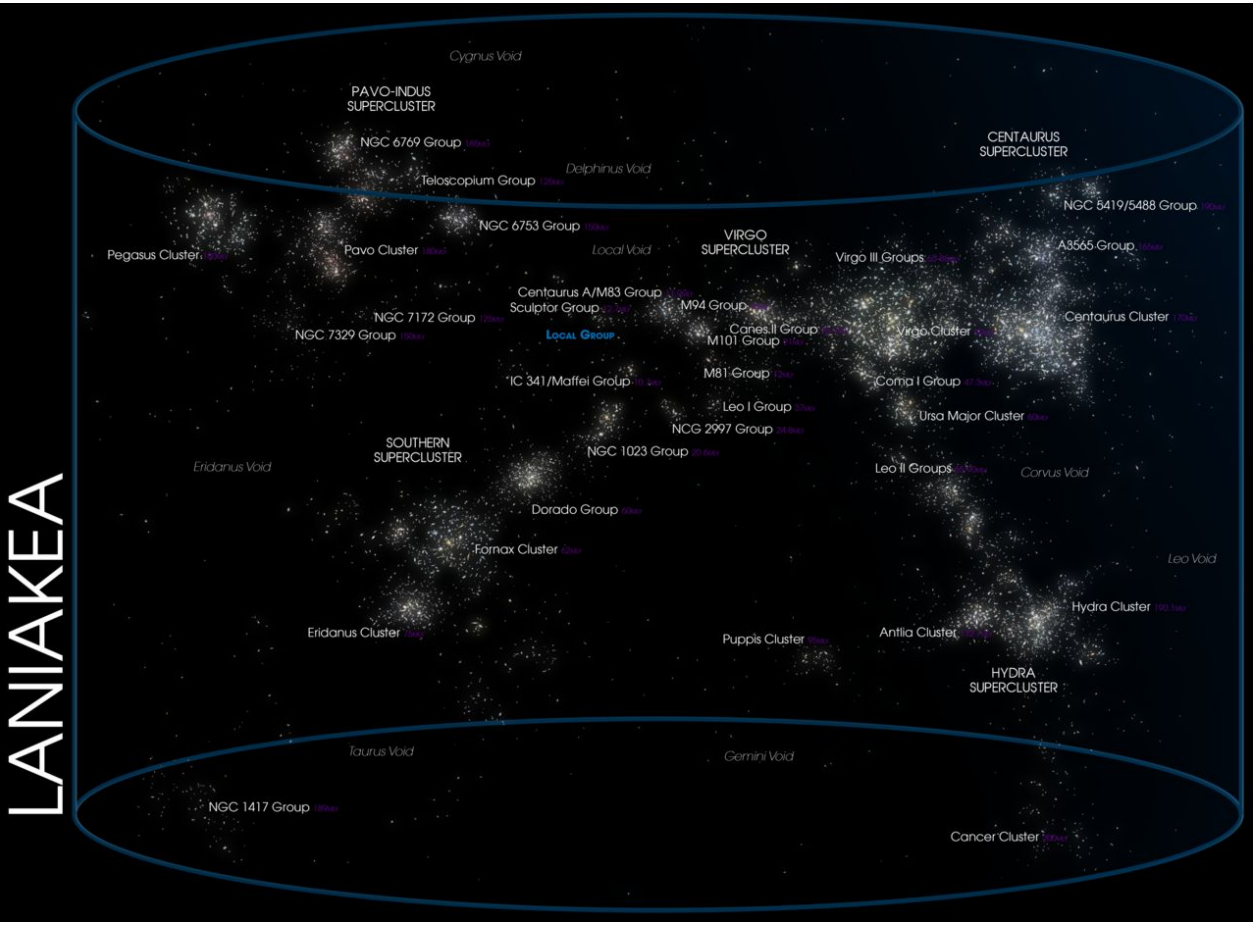


A mass concentration of galaxies containing the Virgo Cluster (~17 Mpc) and Local Group.

100 galaxy groups and clusters are located within a diameter of 33 Mpc. The Virgo SC is one of about 10 million superclusters in the observable universe and is in the Pisces–Cetus Supercluster Complex, a galaxy filament.

A 2014 study indicates that the Virgo Supercluster is only a lobe of an even greater Supercluster, Laniakea

Laniakea



Laniakea: Hawaiian for open skies or immense heaven

Members: 100,000

Major Axis: 160 Mpc

Distance: 77 Mpc

Follow-up studies suggest that the Local Supercluster is not gravitationally bound; it will disperse rather than continue to maintain itself as an overdensity relative to surrounding areas.

The most massive galaxy clusters are Virgo, Hydra, Centaurus, Abell 3565, Abell 3574, Abell 3521, Fornax, Eridanus and Norma

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Local Supercluster

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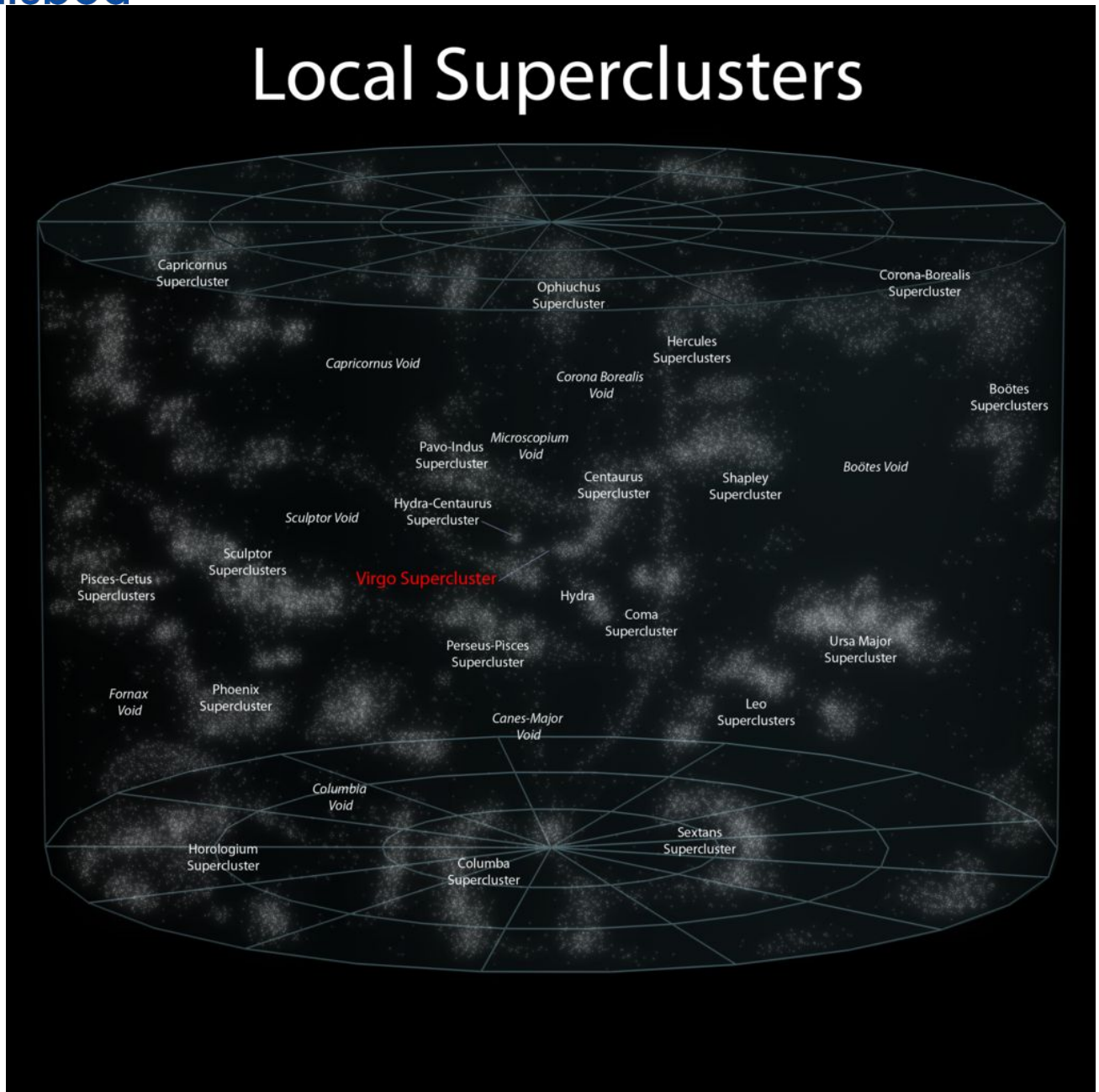

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Virtual Supercluster

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Map 1507-2014

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What did we learn?

1. Development of astrophysics at the beginning ot the 19th century: towards the concept of “galaxy”
2. Large scale structure (group, cluster, supercluster)

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This is the End

(my only friend, cit.)