



Universidad Nacional de Río Negro

Int Partículas, Astrofísica & Cosmología - 2021

- **Unidad** 03-Astrofísica, galaxias y Universo
- **Clase** UO3 CO2 - 12/16
- **Fecha** 20 Oct 2021
- **Cont** Gran Escala
- **Cátedra** Asorey





U3: Astrofísica, escalas grandes

4 encuentros, del 06/Oct al 27/Oct

- Relatividad General.
 - Introducción y conceptos básicos.
 - Solución de Schwarzschild.
 - Objetos compactos: enanas blancas, estrellas de neutrones y agujeros negros.
- Formación de estructuras
 - Galaxias: Modelos y formación. GalaxyZoo.
 - Galaxias de Núcleos activos. Clasificación.
 - Formación de estructuras. Corrimiento al rojo y el universo en expansión.
- Trabajo unidad → fecha máxima de entrega 12/Nov

Contenidos: un viaje en el tiempo y el espacio

HOW DID OUR UNIVERSE BEGIN?

Inflation
Some 13.8 billion years ago our entire visible universe was contained in an unimaginably hot, dense point, a billionth the size of a nuclear particle. Since then it has expanded—a lot—fighting gravity all the way.

Early building blocks
The universe expands, cools. In less than a nanosecond a massive energy field infuses space with particles that fill it with a soup of subatomic particles called quarks.

First nucleci
As the universe continues to cool, the light of hydrogen begins to arise. This light is as far back as our instruments can see.

First atoms, first light
Quarks clump into protons and neutrons, creating the building blocks of atomic nuclei. Perhaps dark matter forms.

The "dark ages"
For 300 million years this continues, with no light in sight. As electrons begin orbiting nuclei, creating atoms, the glow from their orbital motion is unveiled. This light is as far back as our instruments can see.

Gravity wins: first stars
Dense gas clouds collapse under their own gravity. Clumps of dark matter begin to form galaxies and stars. Fusion lights up the stars.

Antigravity wins
After being slowed for billions of years, dark energy accelerates again. The culprit: dark energy. Its nature: unclear.

Today
The universe continues to expand, becoming ever less dense. As a result, fewer new stars and galaxies are forming.

COSMIC QUESTIONS

In the 20th century the universe became a story—a scientific one. It had always been seen as static and eternal. Then astronomers observed other galaxies flying away from ours, and Einstein's general relativity theory implied space itself was expanding—which meant the universe had once been denser. What had seemed eternal now had a beginning and an end. But what beginning? What end? Those questions are still open.

WHAT IS OUR UNIVERSE MADE OF?

Stars, dust and gas—the stuff we can discern—make up less than 5 percent of the universe. Their gravity can't account for how galaxies hold together. Scientists figure about 24 percent of the universe is a mysterious dark matter—perhaps exotic particles formed right after inflation. The rest is dark energy, an unknown energy field or property of space that counters gravity, providing an explanation for observations that the expansion of space is accelerating.

The Universe

71.5%	Dark energy
24%	Dark matter
4%	Gas
0.5%	Planets and stars

WHAT IS THE SHAPE OF OUR UNIVERSE?

Einstein discovered that a star's gravity curves space around it. But is the whole universe curved? Might space close up on itself like a sphere or curve the other way, opening out like a saddle? By studying cosmic background radiation, scientists have found that the universe is poised between the two: just dense enough with just enough gravity to be almost perfectly flat, at least the part we can see. What lies beyond we can't know.

WHAT WILL IT END?

Which will win in the end, gravity or antigravity? Is the density of matter enough for gravity to halt or even reverse cosmic expansion, leading to a big crunch? It seems unlikely—especially given the power of dark energy, a kind of antigravity. Perhaps the acceleration in expansion caused by dark energy will trigger a big rip that shreds everything, from galaxies to atoms. If not, the universe may expand for hundreds of billions of years, long after all stars have died.

**Unidad 3
Astrofísica,
escalas grandes**

**Unidad 2
Astrofísica,
escalas medias**

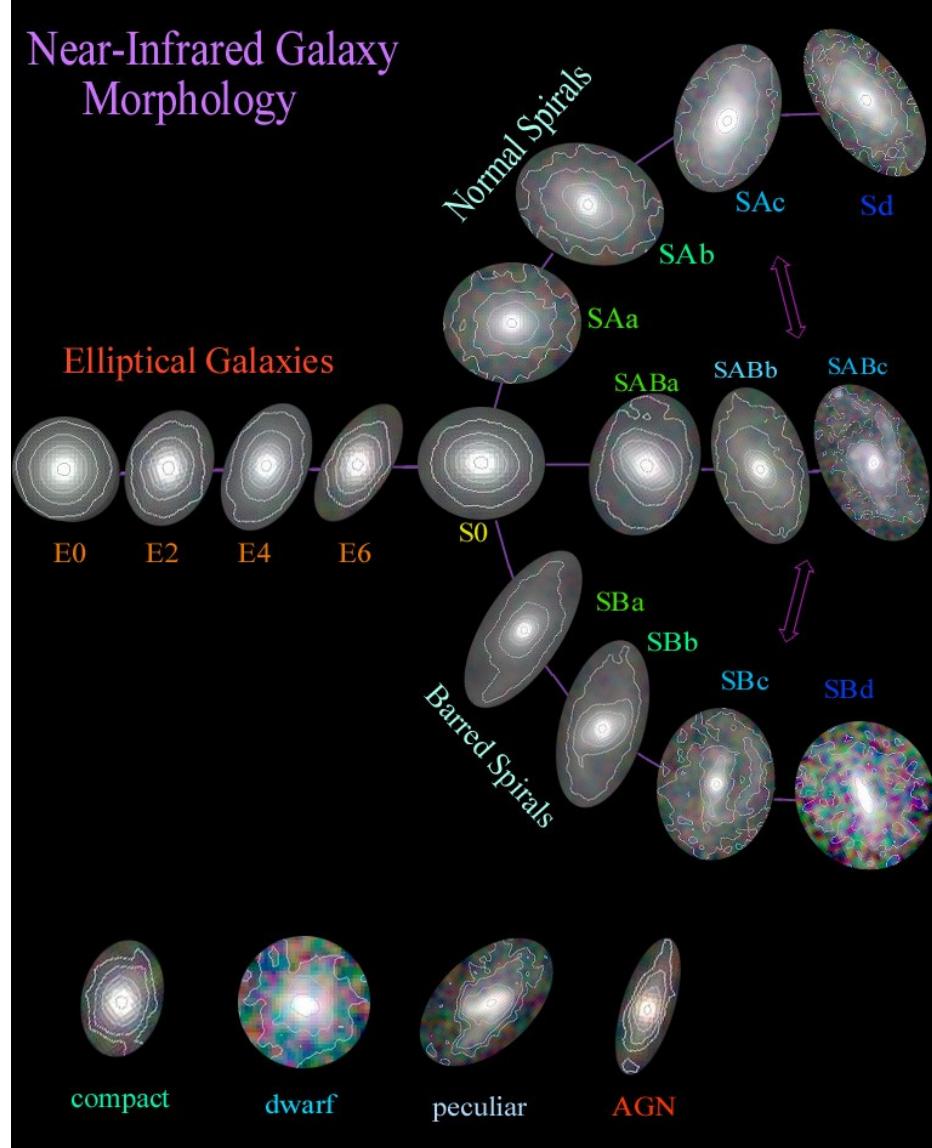
**Unidad 1
Partículas,
lo más pequeño**

Galaxias



- Una **galaxia** es un sistema autogravitante compuesto por:
 - Estrellas (Vía Láctea: 10^{11} estrellas)
 - Remanentes estelares
 - Un medio interestelar formado por gas y polvo...
 - Un agujero negro central (no en todas, pero...)
 - Materia oscura (no está confirmada, pero...)
- **Tamaños:**
 - Enanas (~1000 estrellas, 1000 pc)
 - Gigantes (100000 pc, 10^{14} estrellas)
- Están separadas por distancias ~Mpc (1 Mpc ~ $3,1 \times 10^{22}$ m)

Clasificación galáctica



Tipo	Fracción
Espirales	60%
Elípticas	13%
Lenticulares	22%
Irregulares	3%
Peculiares	1%

- **Ley de De Vaucouleurs**
Variación de la intensidad luminosa como función del radio

$$I(r) = I_0 e^{-\sqrt[4]{r/r_0}}$$

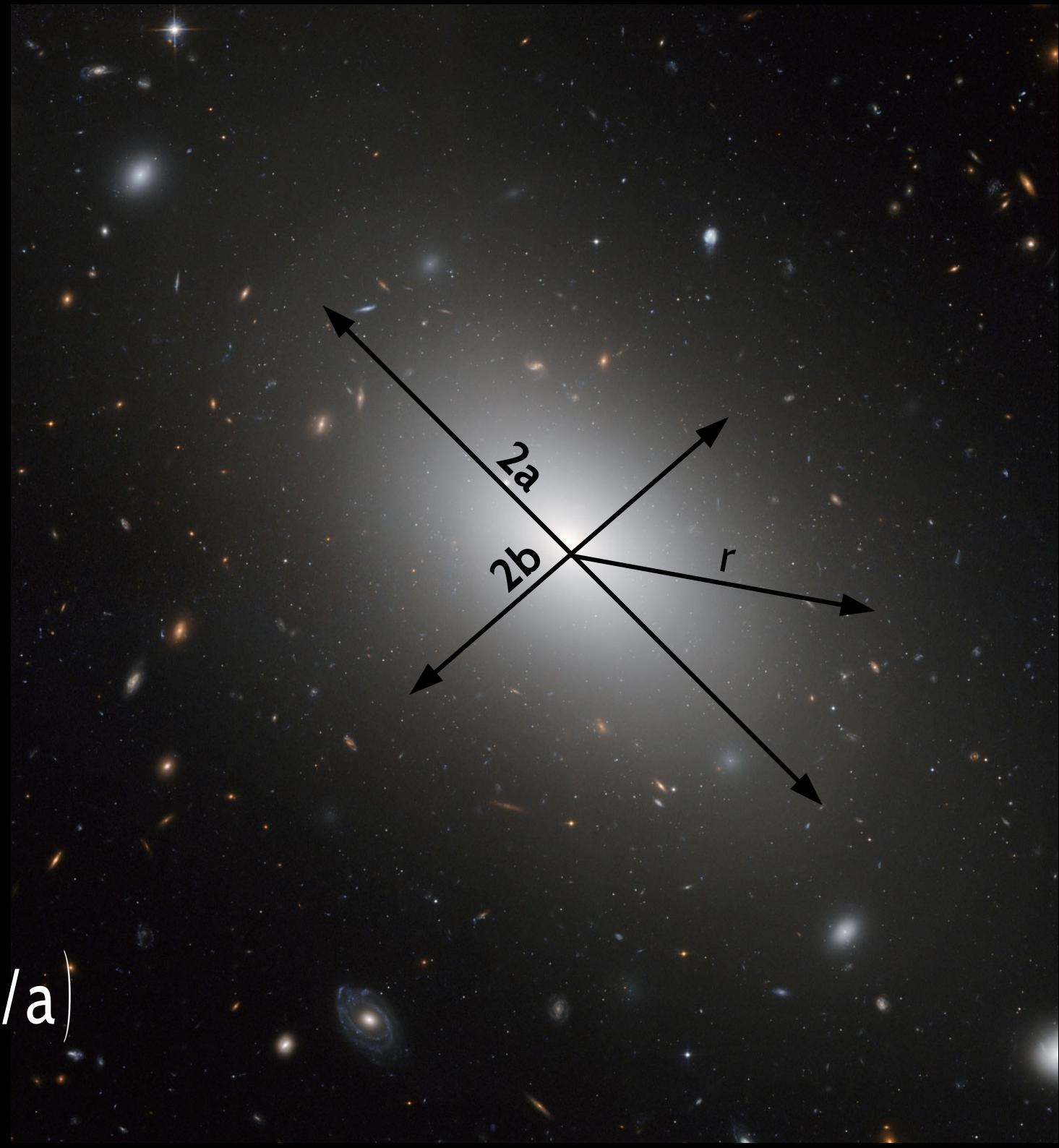
A dense field of galaxies of various shapes and colors against a dark background.

Galaxy Zoo

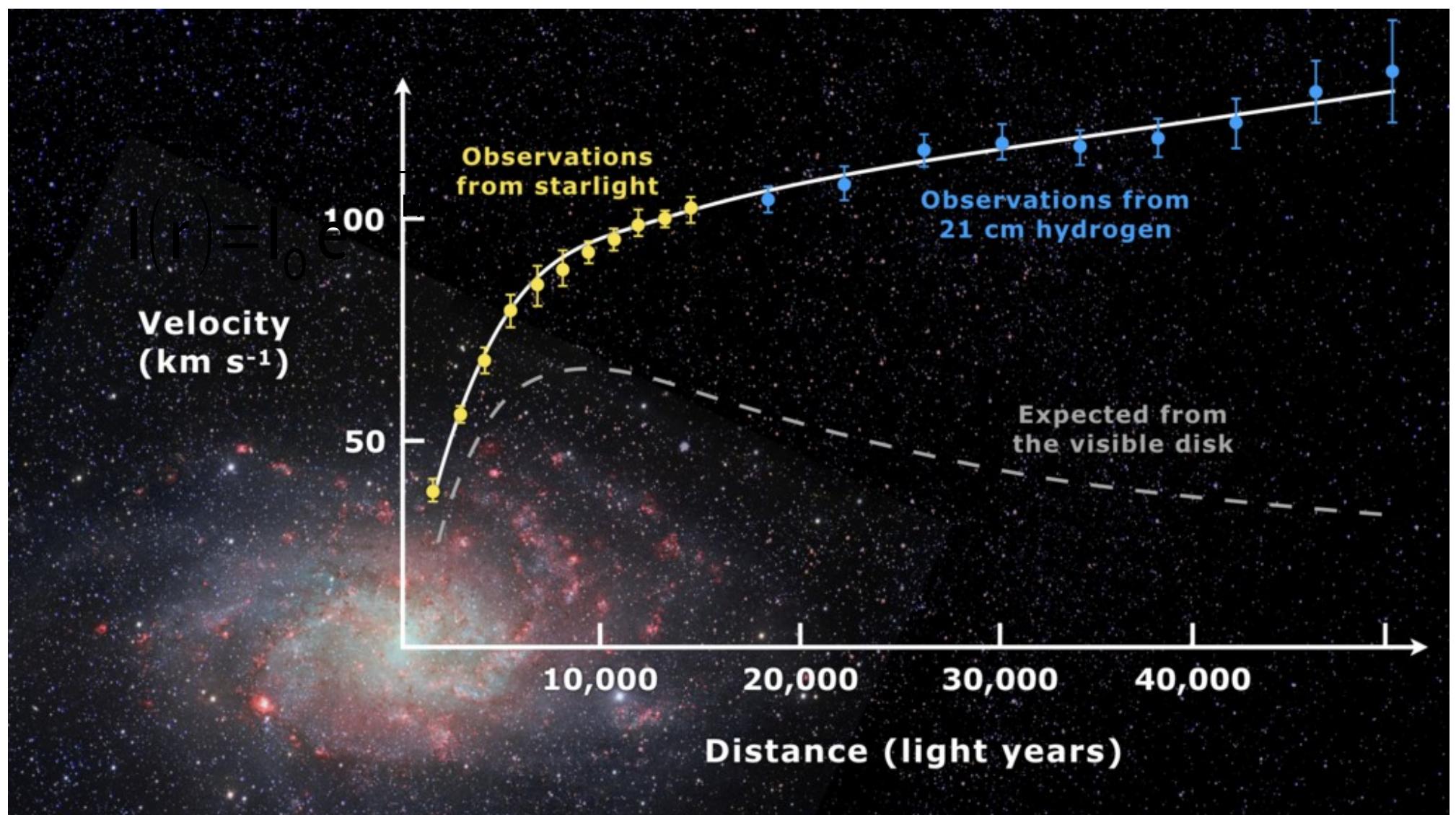
<http://www.galaxyzoo.org>

$$I(r) = I_0 e^{-\sqrt[4]{r/r_0}}$$

$$E_q \rightarrow E_q = 10(1 - b/a)$$



Curvas de rotación





Materia oscura (no visible)

- Consideremos, p. ej, $\alpha \sim 250 \text{ km/s}$ y $r \sim 50 \text{ kpc}$

$$M = \frac{(250 \text{ km/s})^2 50 \text{ kpc}}{G} \simeq 8 \times 10^{11} M_{\odot}$$

- Pero según Tully-Fisher, $M_{\text{vis}} \simeq 10^{10} M_{\odot}$

La masa galáctica es ~10-100 veces la masa observada

El tamaño galáctico es ~10-100 veces el radio observado

El “halo” de materia oscura

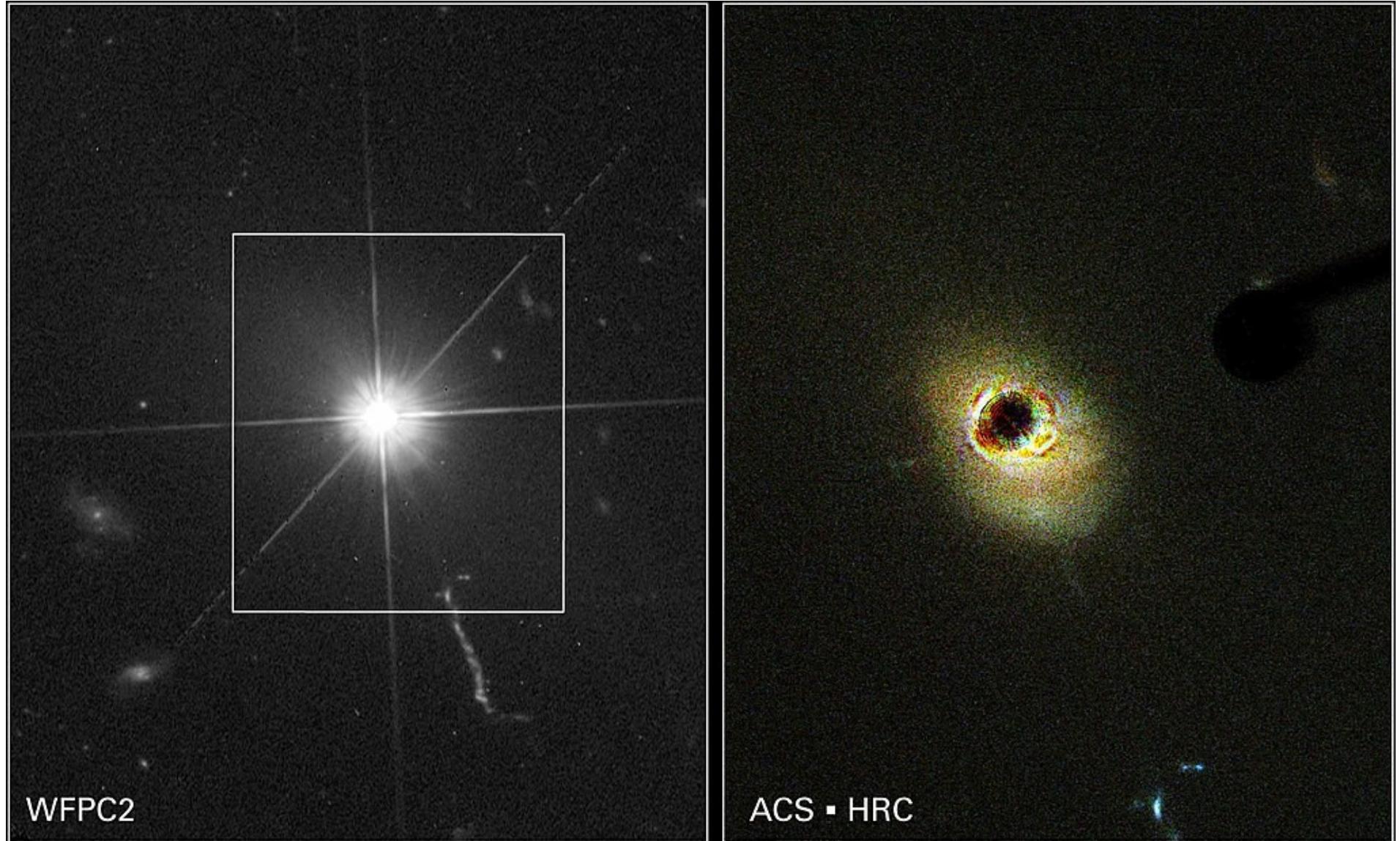


Galaxias de Núcleos Activos (AGN)

Jet en M87, una galaxia elíptica en Virgo A (Vir A)



Quasar (quasi stellar radio source) 3C 273 (https://en.wikipedia.org/wiki/3C_273)



Quasar



- Objeto puntual pero que presenta corrimientos al rojo muy grandes ($z > 1$)
 - Si $z = 1 \rightarrow d \sim 4000 \text{ Mpc}$.
 - $L \sim 10^{38} - 10^{41} \text{ W} (1 - 1000 L_{\text{VL}})$
 - Pero son puntuales \rightarrow pequeños $\rightarrow r \sim 10^{-3} \text{ pc}$
- Luego $GM \simeq \frac{L}{4\pi c} \rightarrow M \simeq \frac{L}{4\pi c G} \rightarrow 10^8 < M/M_{\odot} < 10^{10}$
- Radio de Schwarzschild

$$R_s = \frac{2GM}{c^2} \rightarrow 3 \times 10^{11} \text{ m} < R_s < 3 \times 10^{13} \text{ m}$$



Quasar emisión ~ 1 galaxia en un objeto muy pequeño

- Objeto puntual pero que presenta corrimientos al rojo muy grandes ($z > 1$)

- Si $z = 1 \rightarrow d \sim 4000 \text{ Mpc}$.
- $L \sim 10^{38} - 10^{41} \text{ W} \rightarrow 1 < L/L_{\text{VL}} < 1000$

- Pero son puntuales \rightarrow pequeños $\rightarrow r \sim 10^{-3} \text{ pc}$

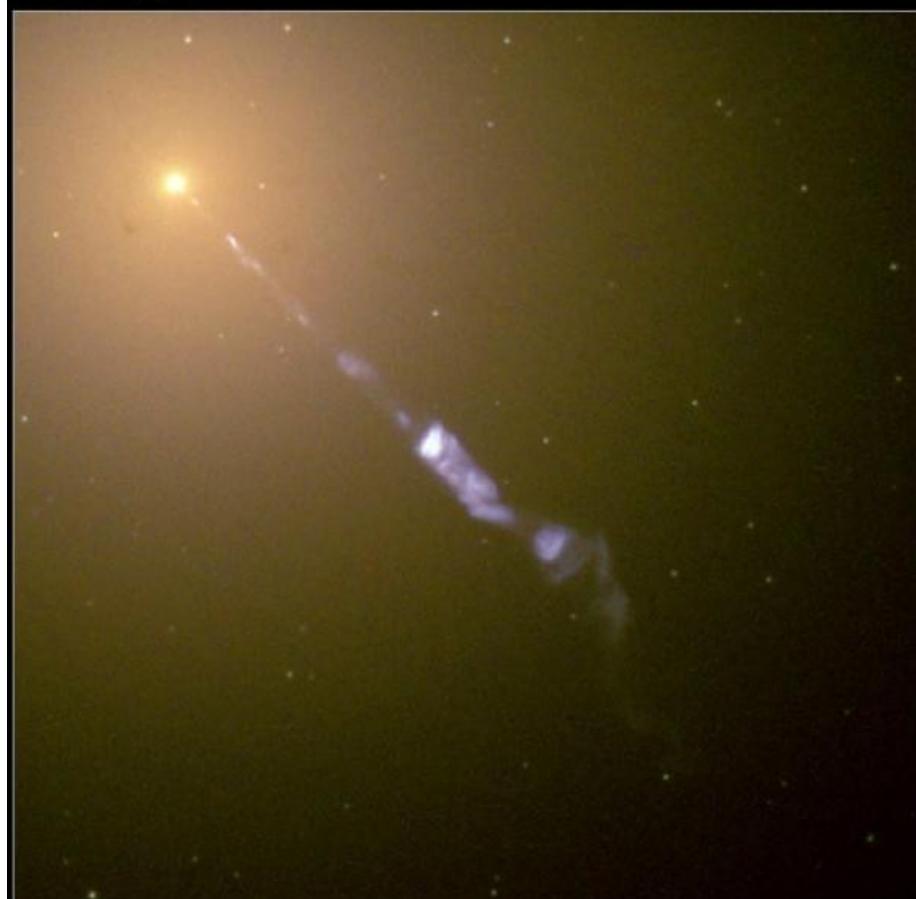
- Luego $GM \simeq \frac{L}{4\pi c} \rightarrow M \simeq \frac{L}{4\pi c G} \rightarrow 10^8 < M/M_{\odot} < 10^{10}$

- Radio de Schwarzschild

$$R_{\text{SCH}} = \frac{2GM}{c^2} \rightarrow 3 \times 10^{11} \text{ m} < R_{\text{SCH}} < 3 \times 10^{13} \text{ m} \rightarrow 2 \text{ UA} < R_{\text{SCH}} < 200 \text{ UA}$$

El chorro de M87 se origina a $5.5 R_{\text{SCH}}$ del centro

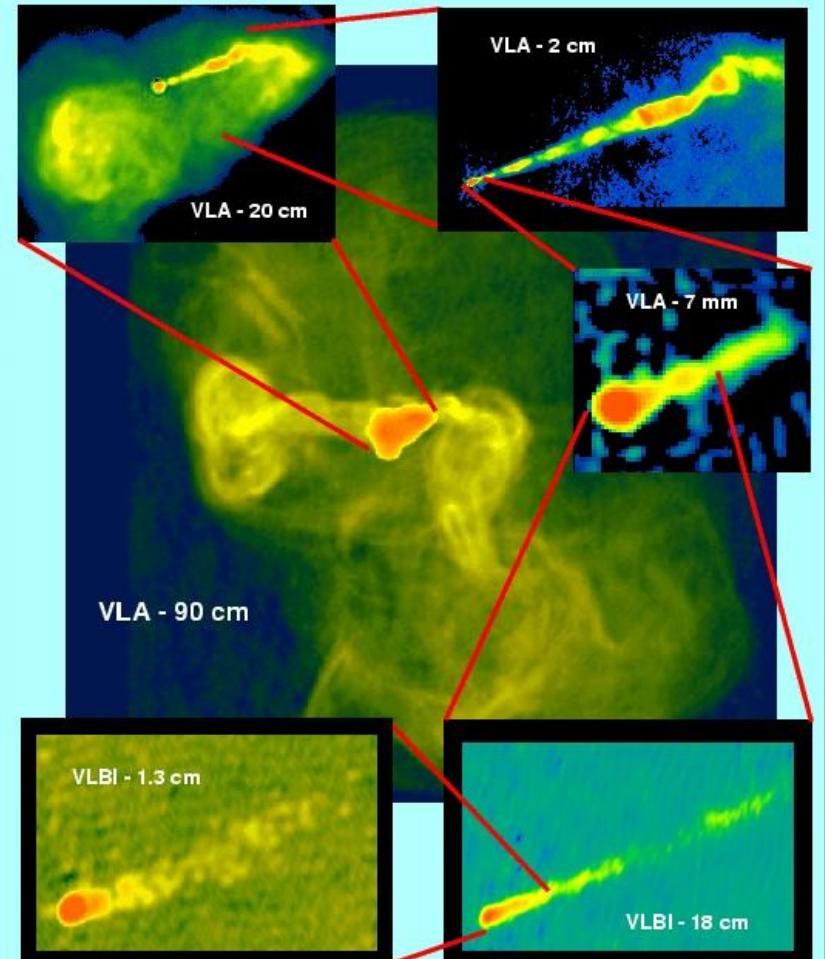
The M87 Jet



Hubble
Heritage

PRC00-20 • Space Telescope Science Institute • NASA and The Hubble Heritage Team (STScI/AURA)

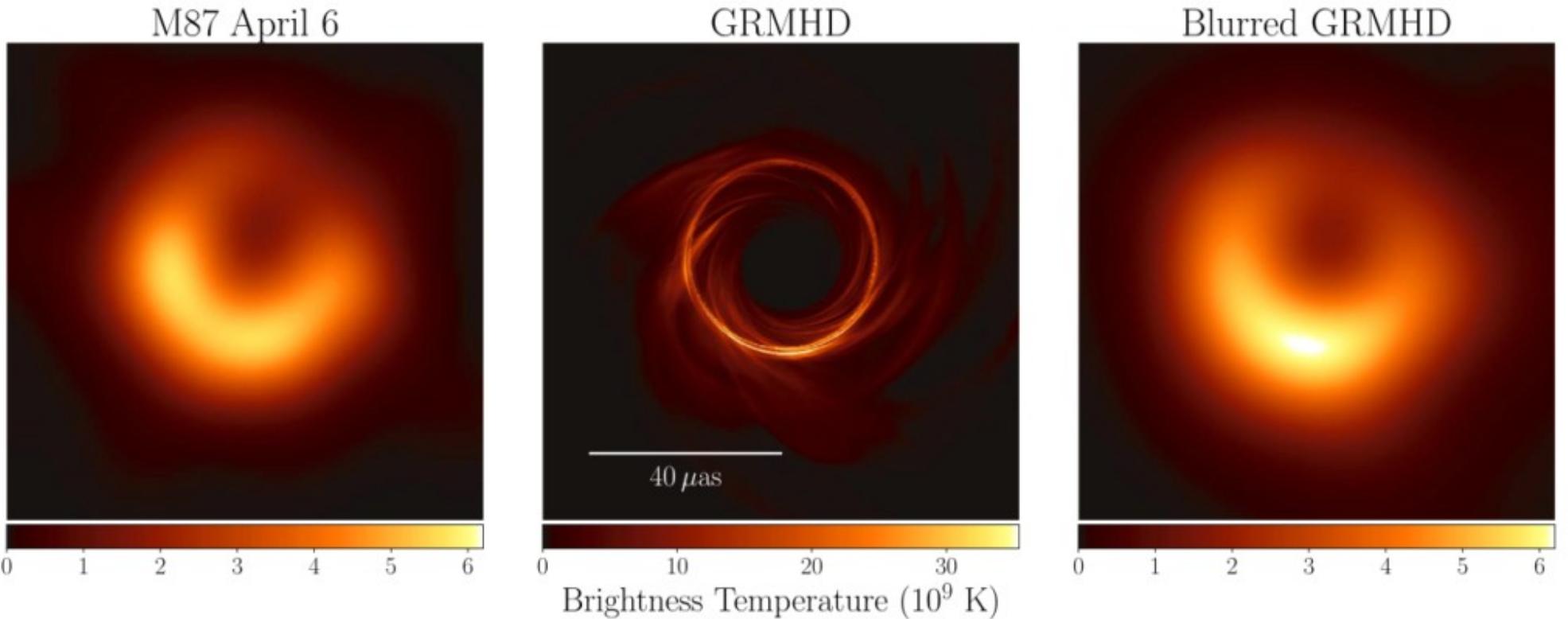
M87 -- From 200,000 Light-Years to 0.2 Light-Year



Credit: Frazer Owen (NRAO), John Biretta (STScI) and colleagues.
The National Radio Astronomy Observatory is a facility of the
National Science Foundation, operated under cooperative
agreement by Associated Universities, Inc.

El agujero negro en central en M87 → M87*

Agujero negro supermasivo → $M \sim 7 \times 10^9 M_\odot$



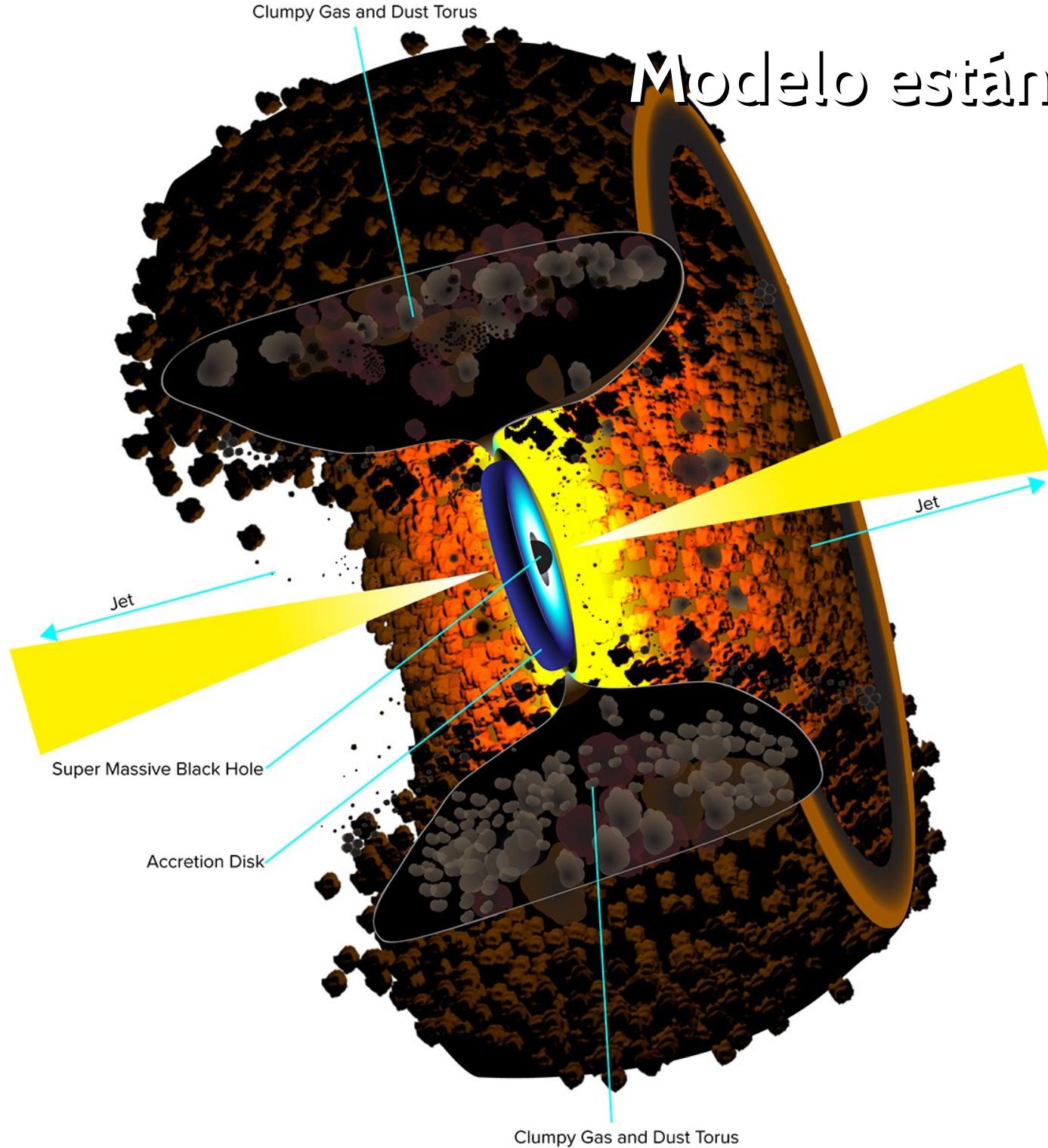
Galaxias de núcleos activos (NGC 5128 Cen A)

CenA* → $M \sim 5,5 \times 10^6 M_\odot$.



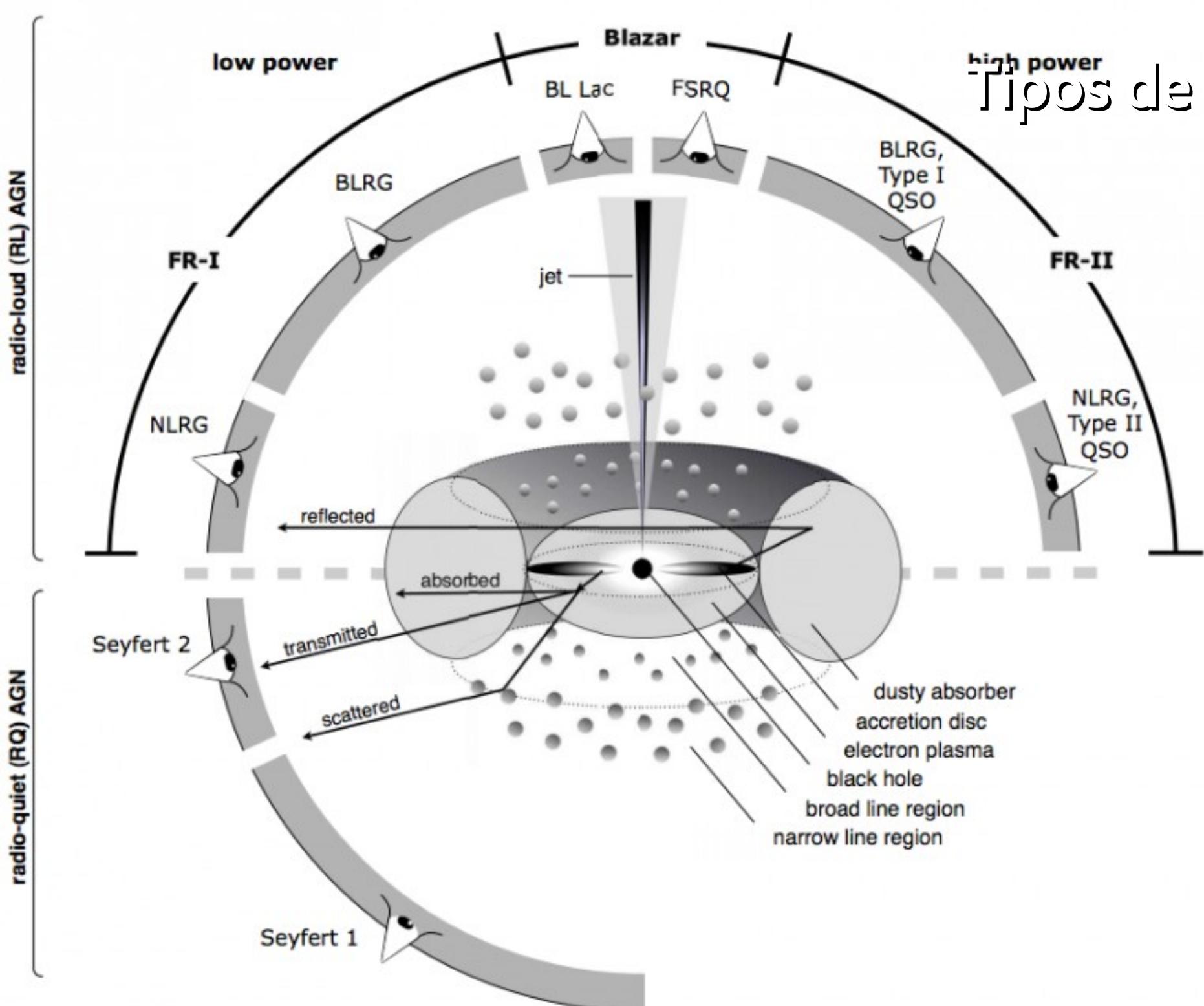


Modelo estándar de los AGN





Tipos de AGN



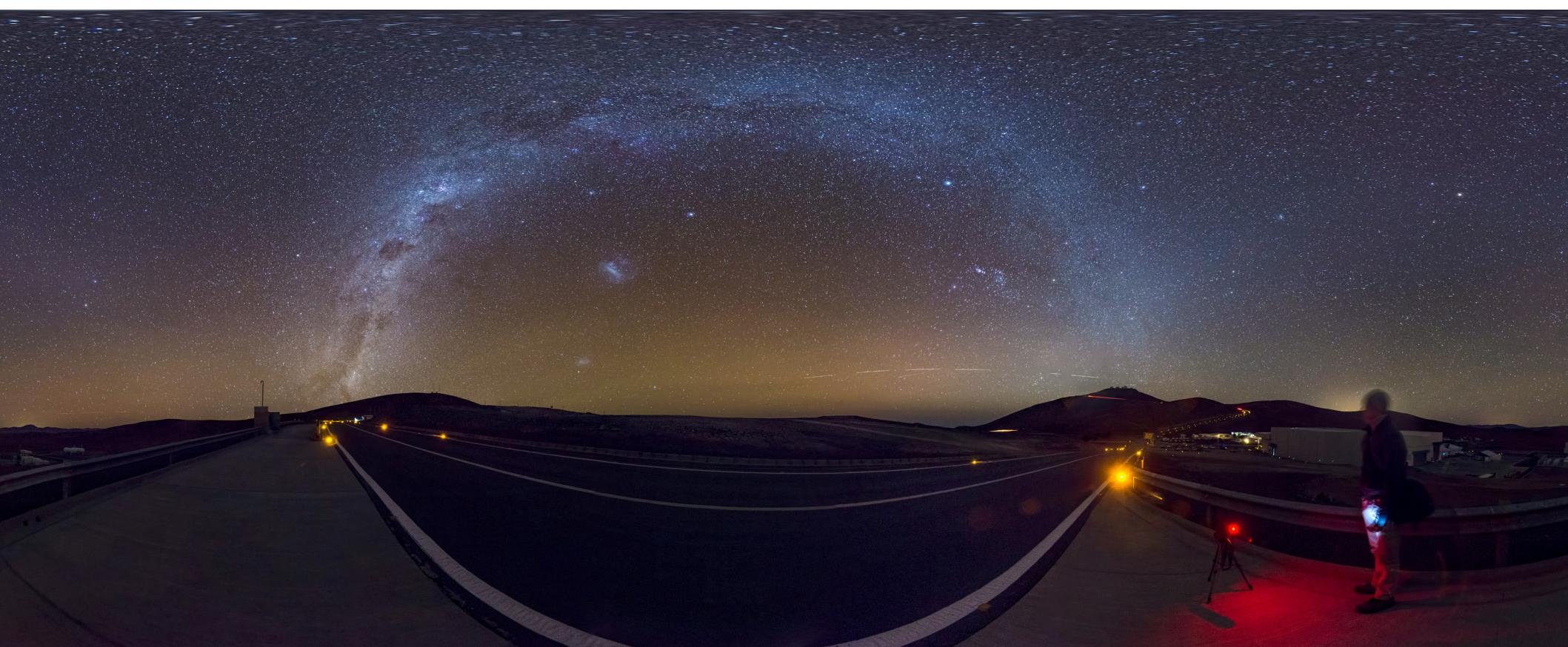
La Vía Láctea



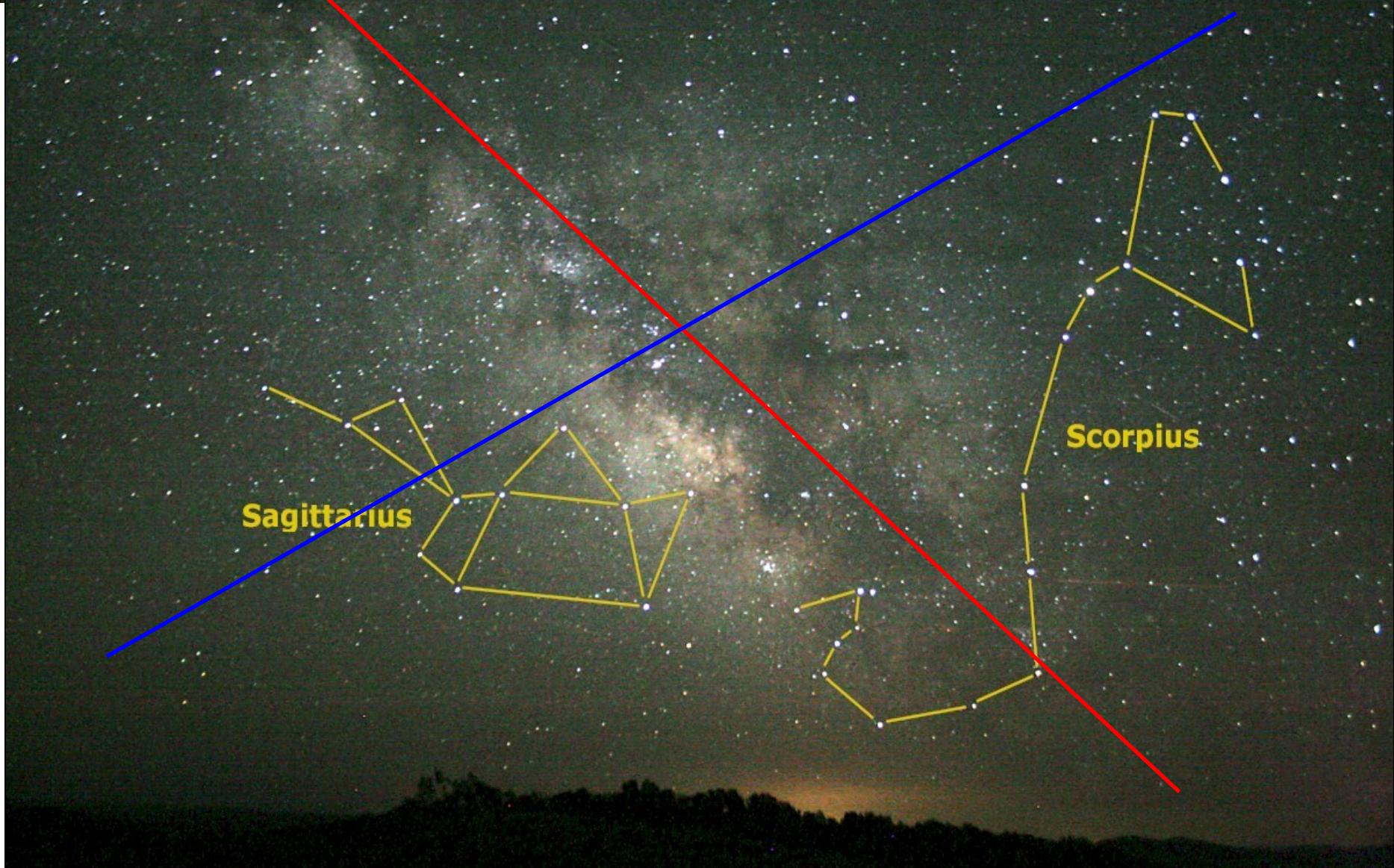




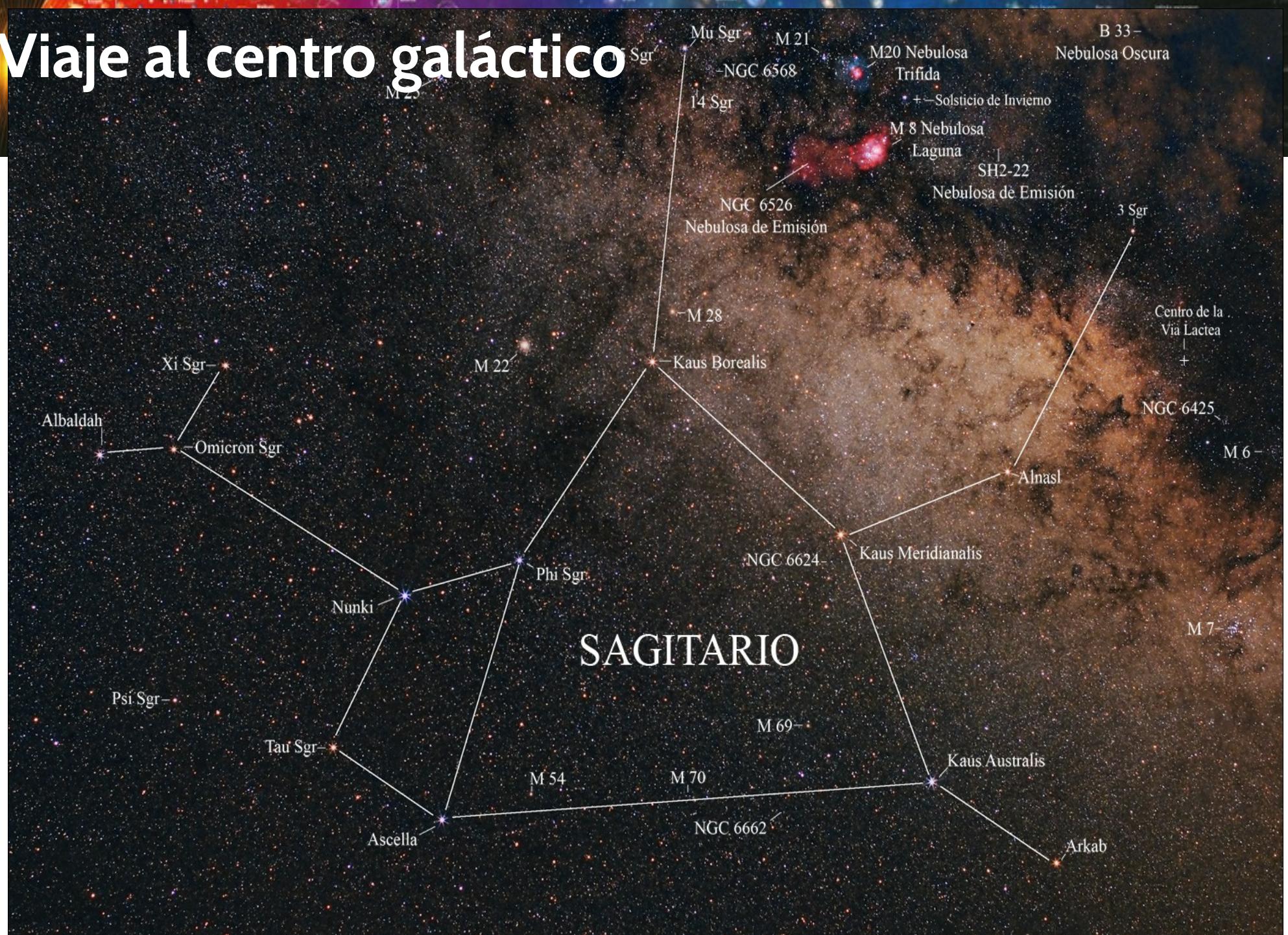
La Vía Láctea desde Cerro Paranal



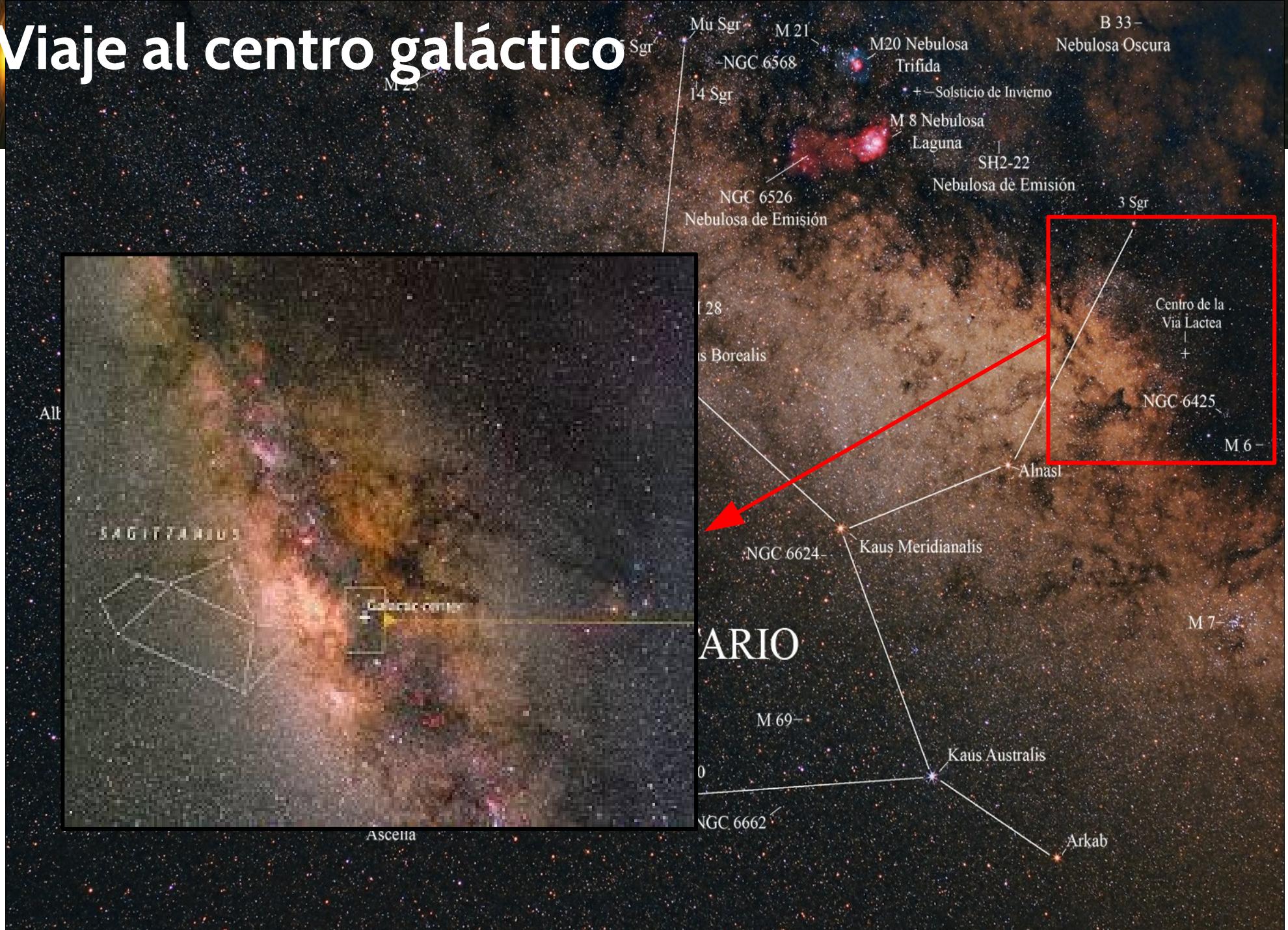
Inclinada $\sim 60^\circ$, respecto del Ecuador Celeste



Viaje al centro galáctico



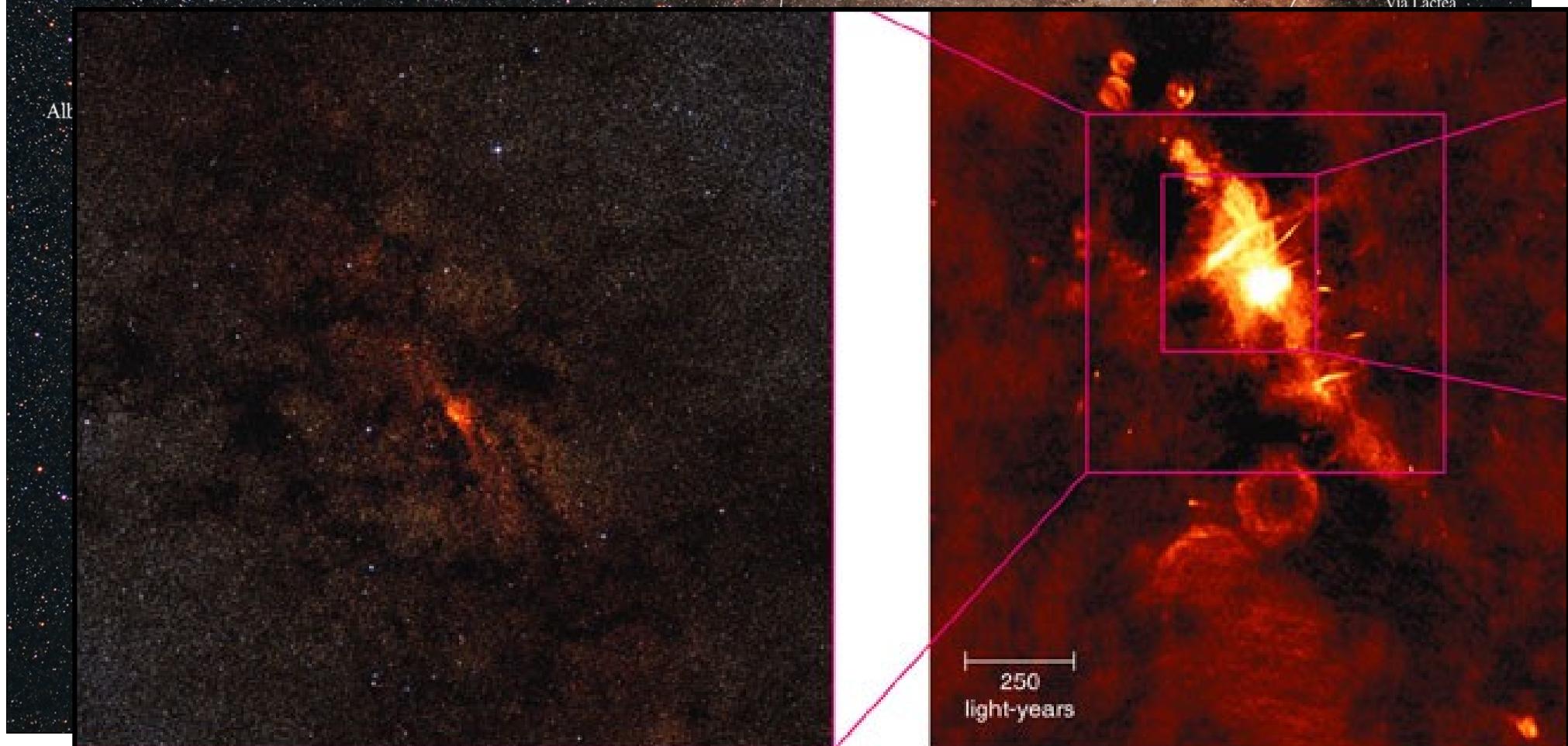
Viaje al centro galáctico



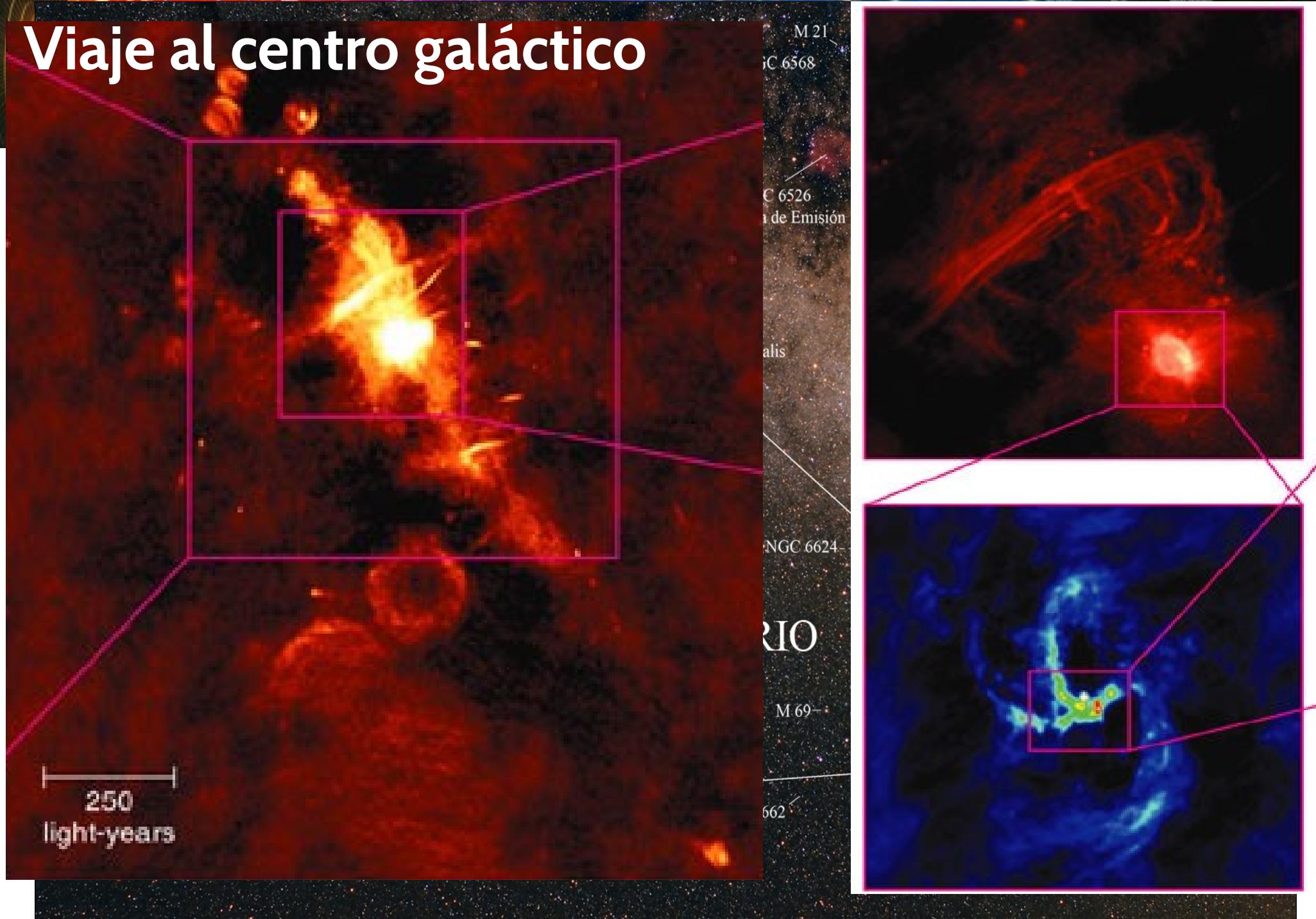
Viaje al centro galáctico



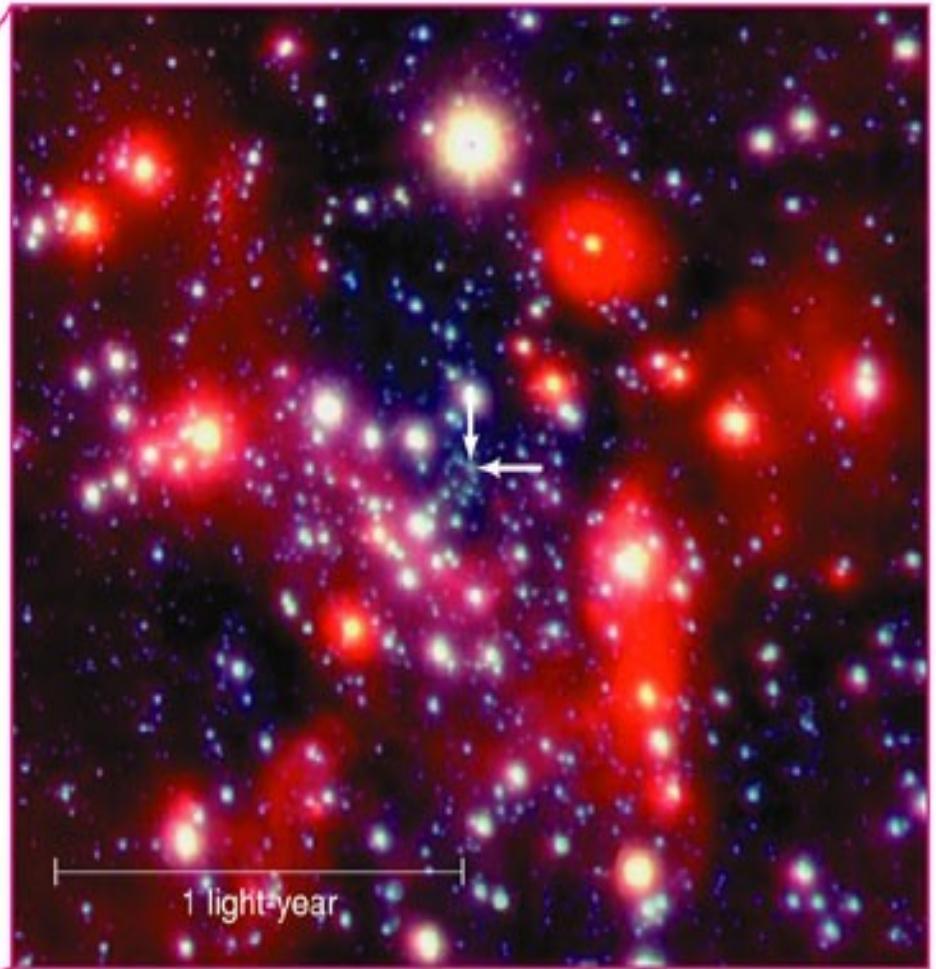
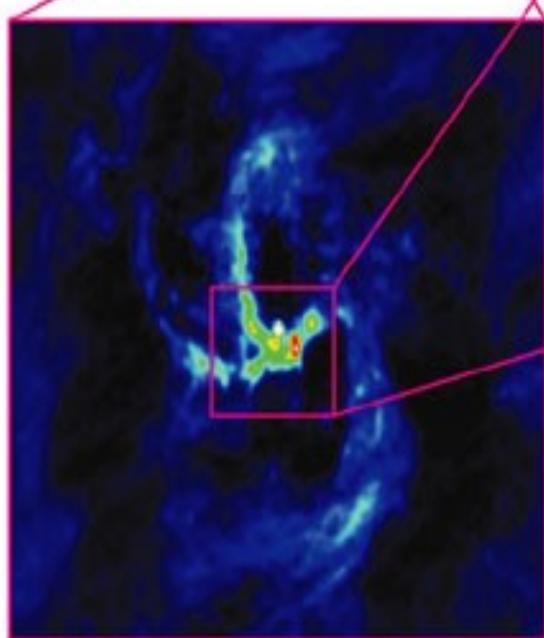
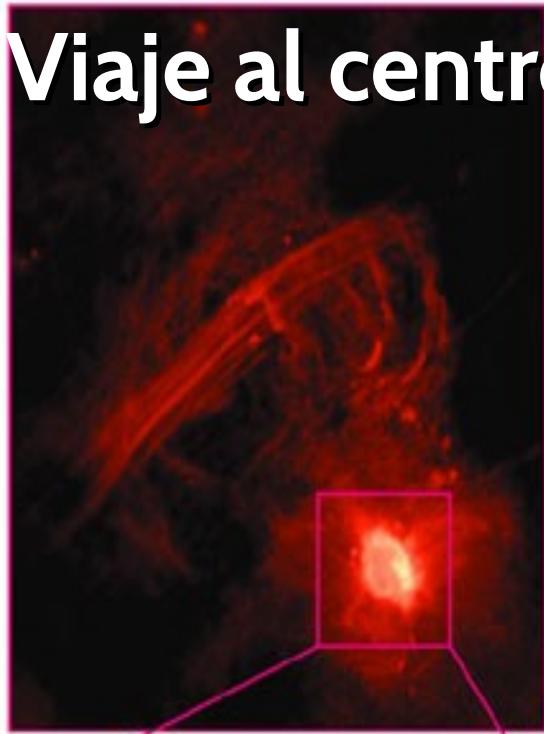
Viaje al centro galáctico



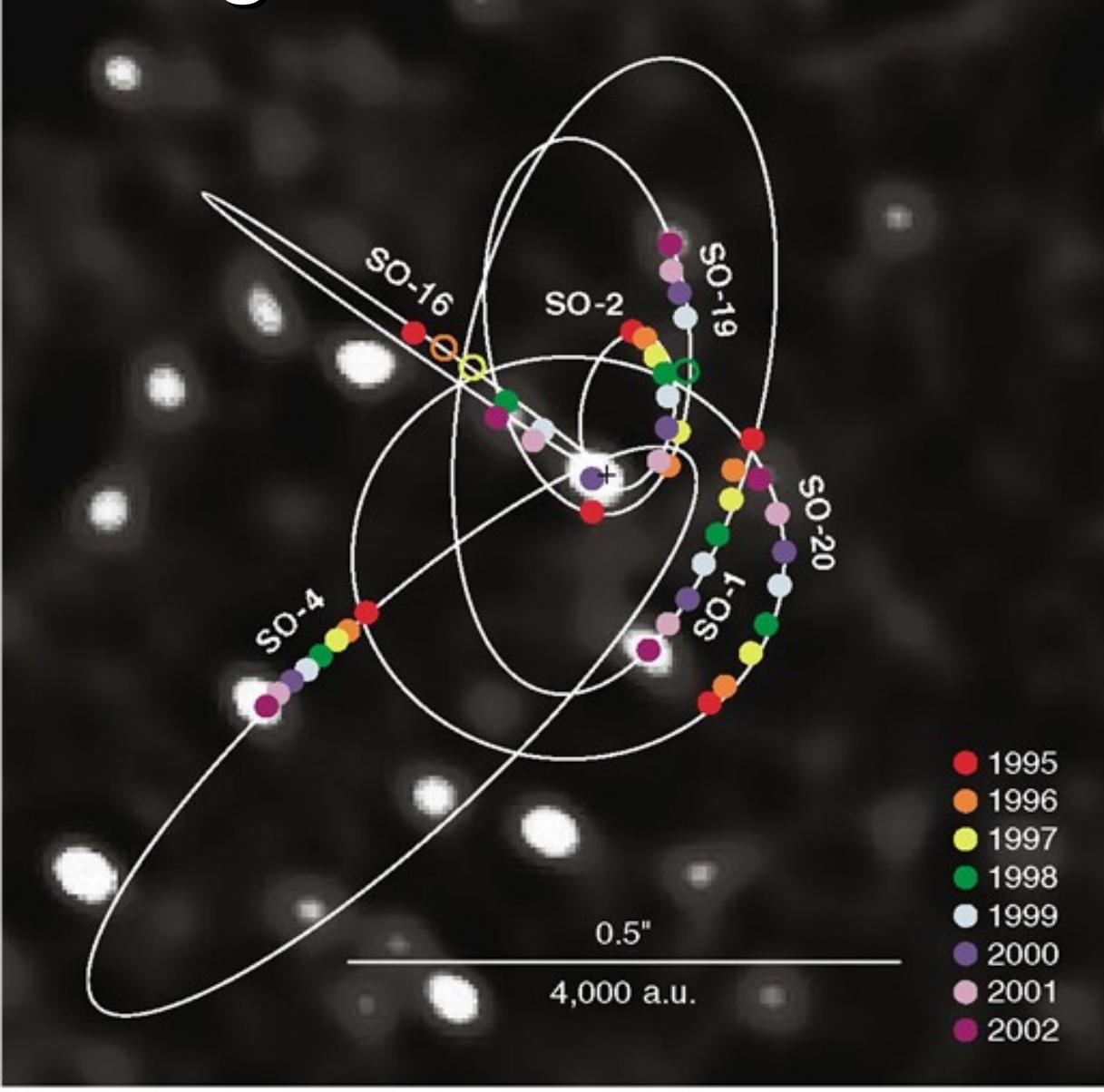
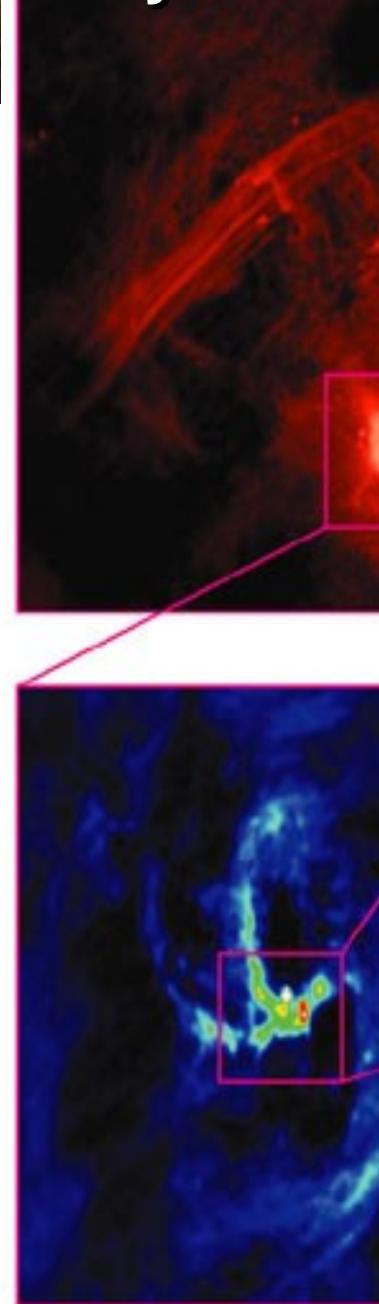
Viaje al centro galáctico



Viaje al centro galáctico



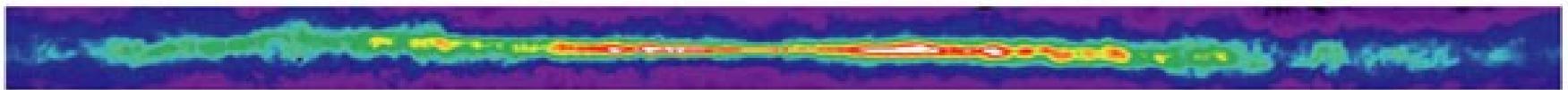
Viaje al centro galáctico



<https://www.youtube.com/watch?v=duoHtJpo4GY>

El agujero negro central

Observations with the VLT



a 21-cm radio emission from atomic hydrogen gas.



b Radio emission from carbon monoxide reveals molecular clouds.



c Infrared (60–100 μm) emission from interstellar dust.



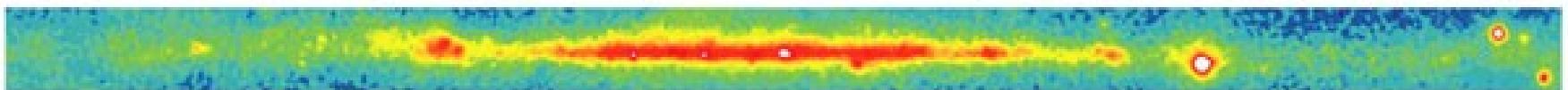
d Infrared (1–4 μm) emission from stars that penetrates most interstellar material.



e Visible light emitted by stars is scattered and absorbed by dust.

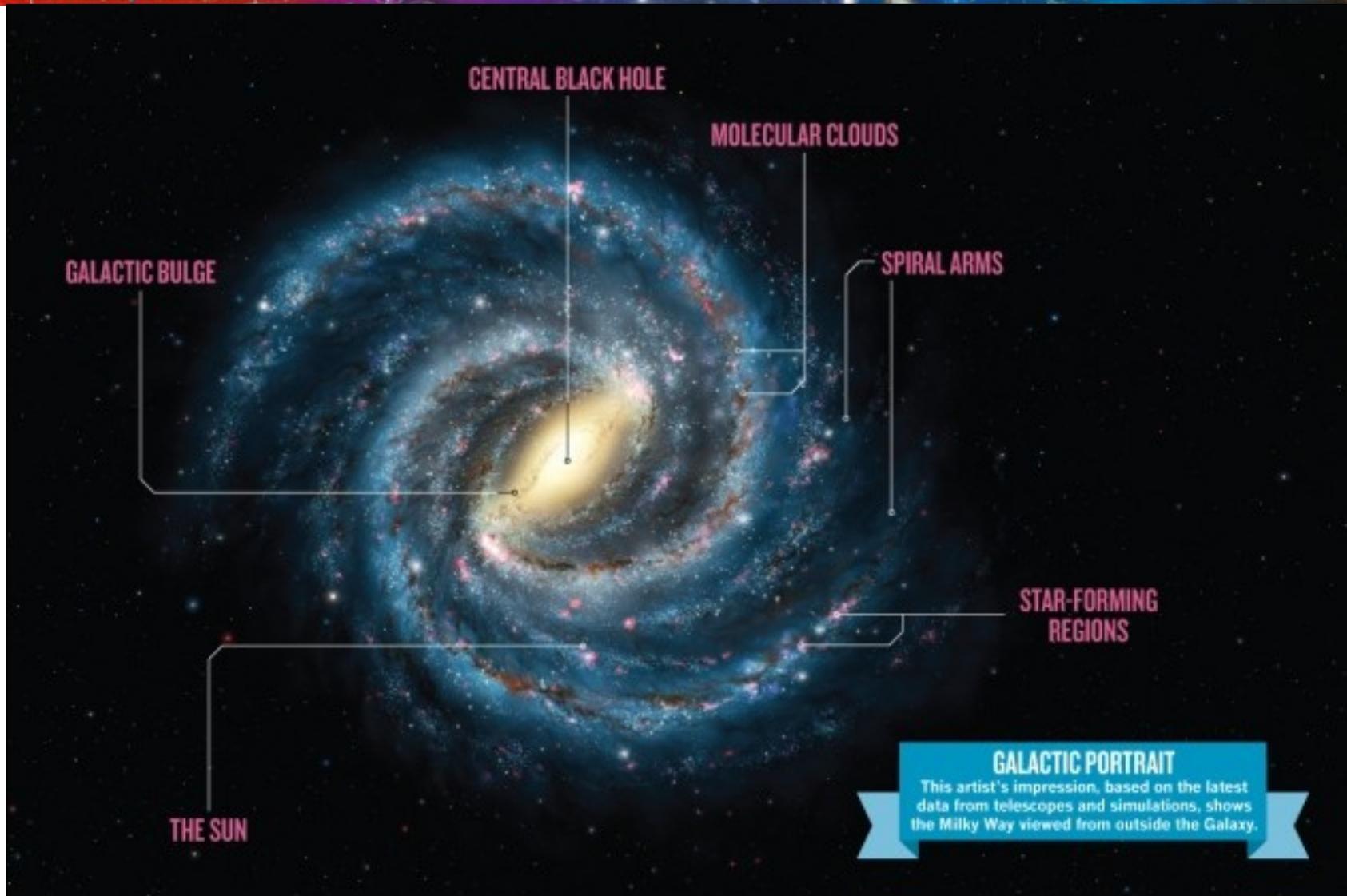


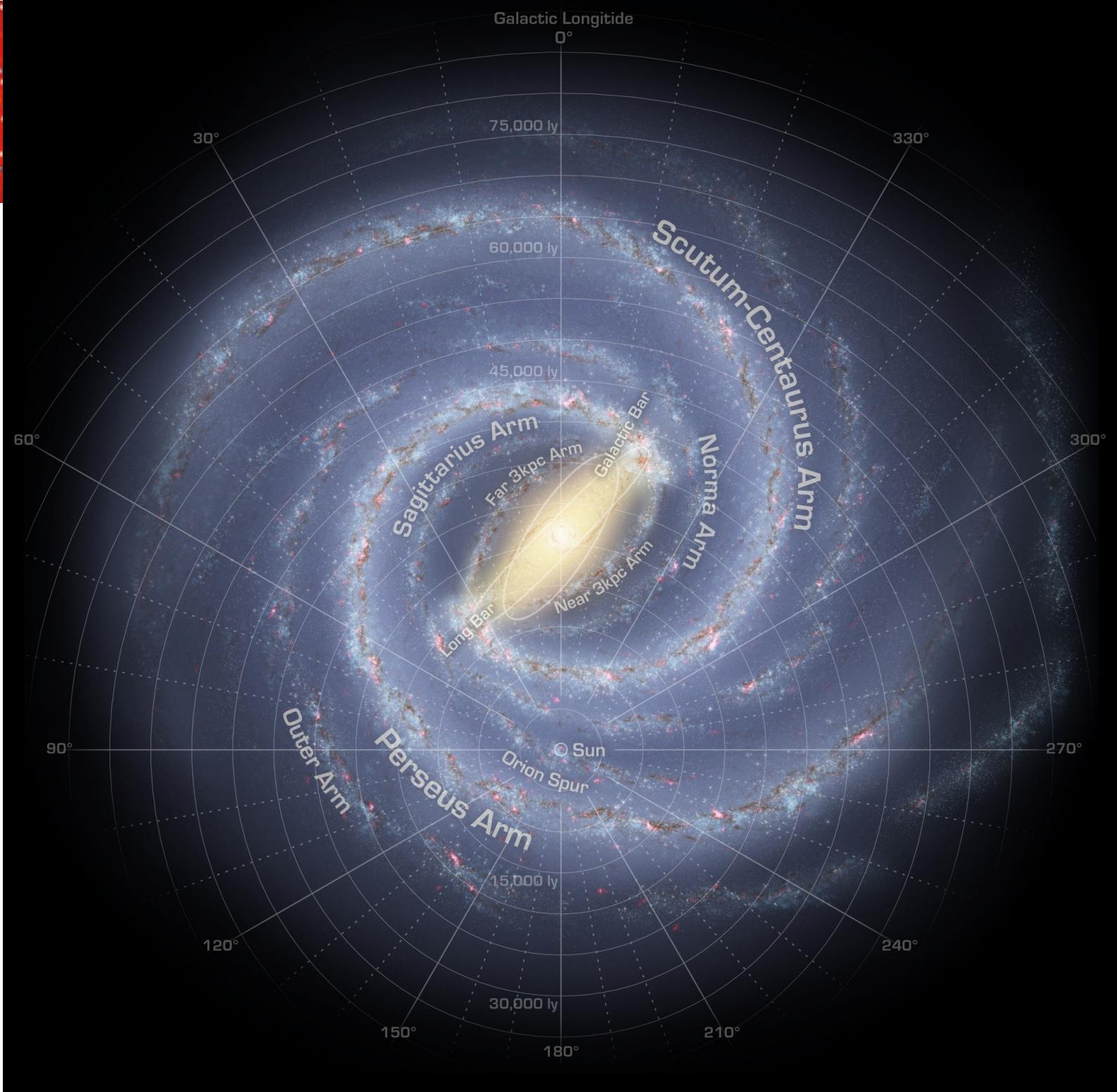
f X-ray emission from hot gas bubbles (diffuse blobs) and X-ray binaries (pointlike sources).

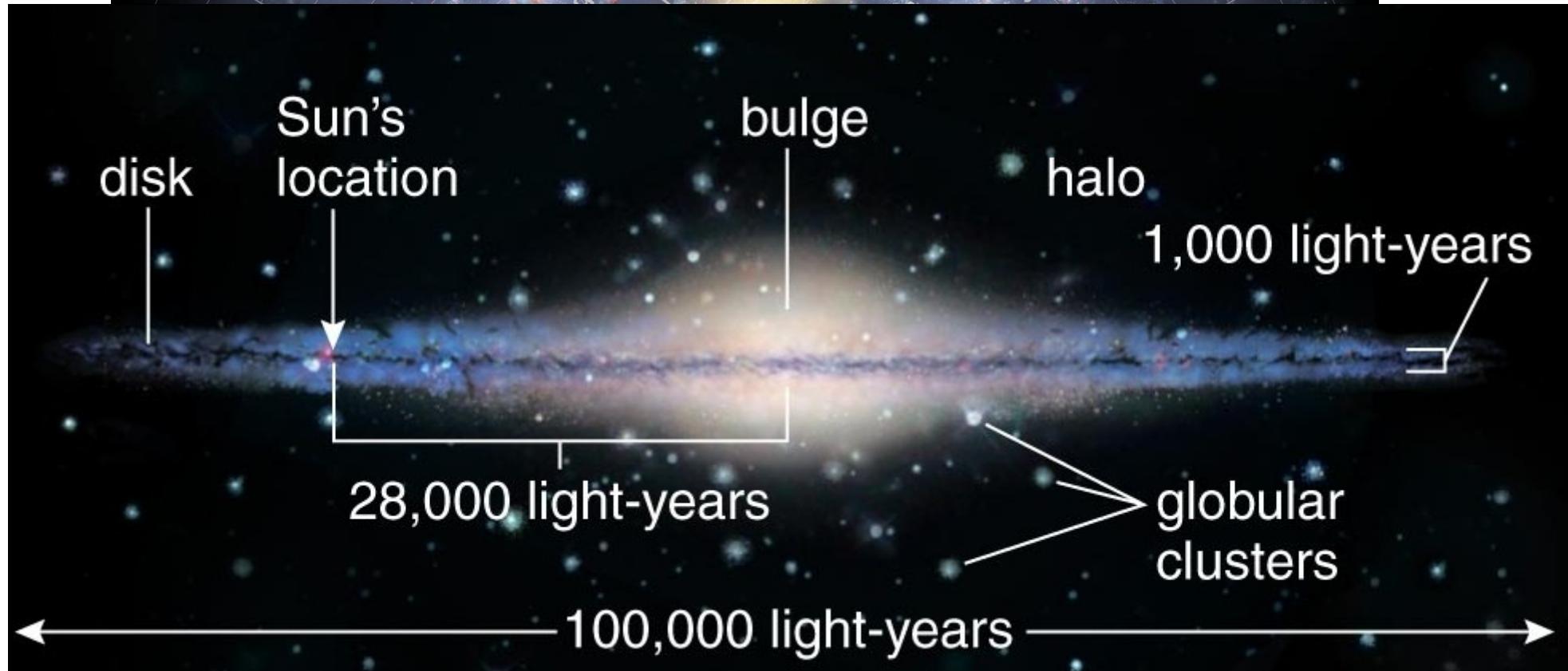
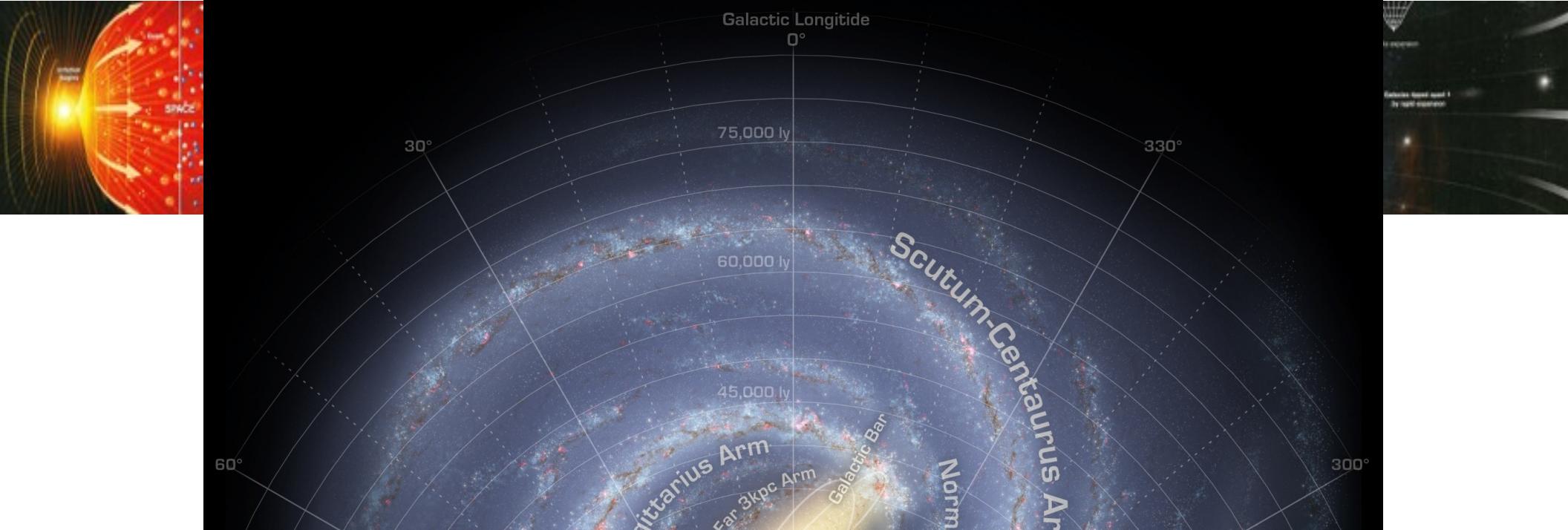


g Gamma-ray emission from collisions of cosmic rays with atomic nuclei in interstellar clouds.

http://en.wikipedia.org/wiki/File:Infrared-visible_light_comparison_of_VISTA's_gigapixel_view_of_the_centre_of_the_Milky_Way.ogv

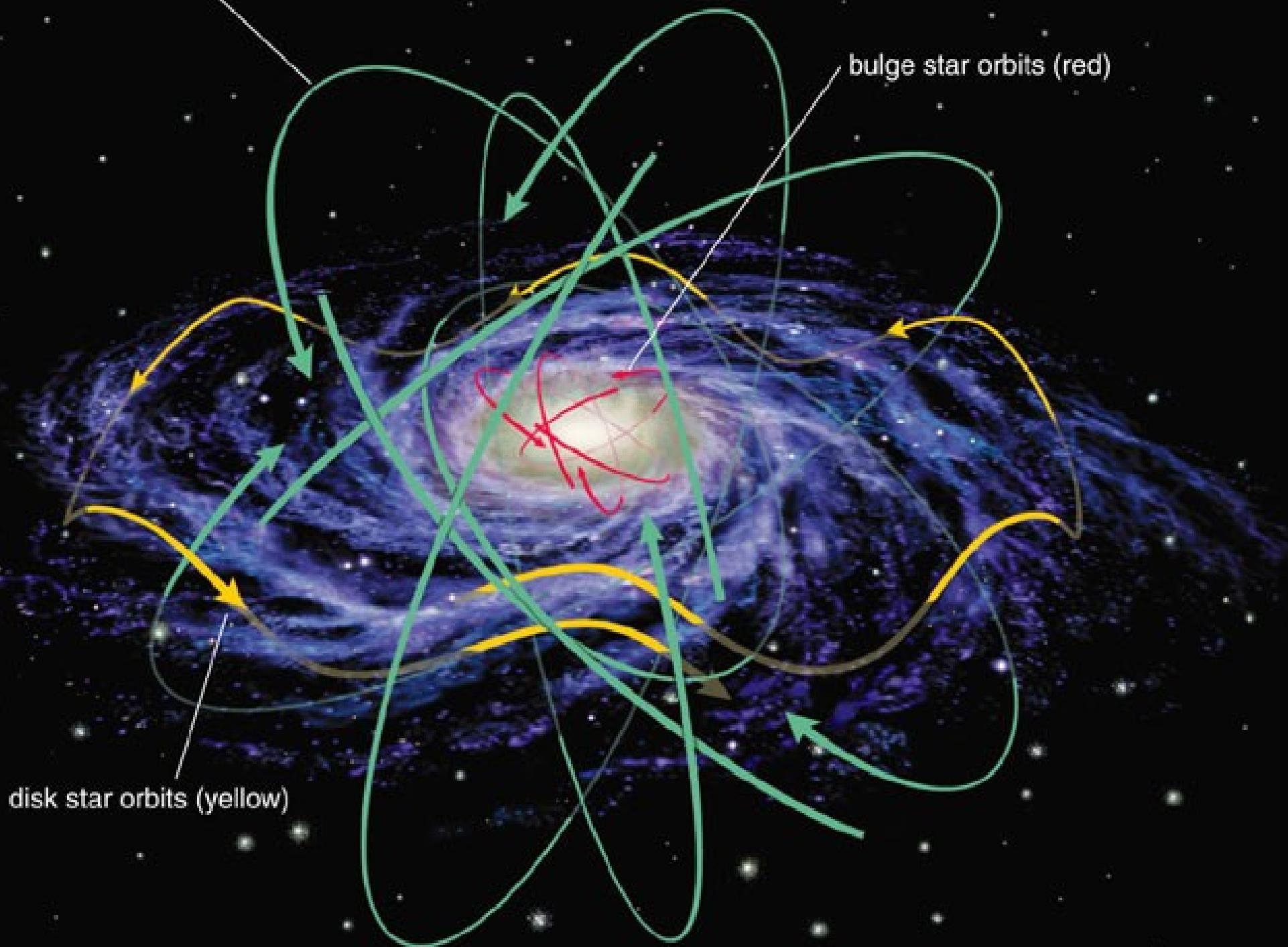






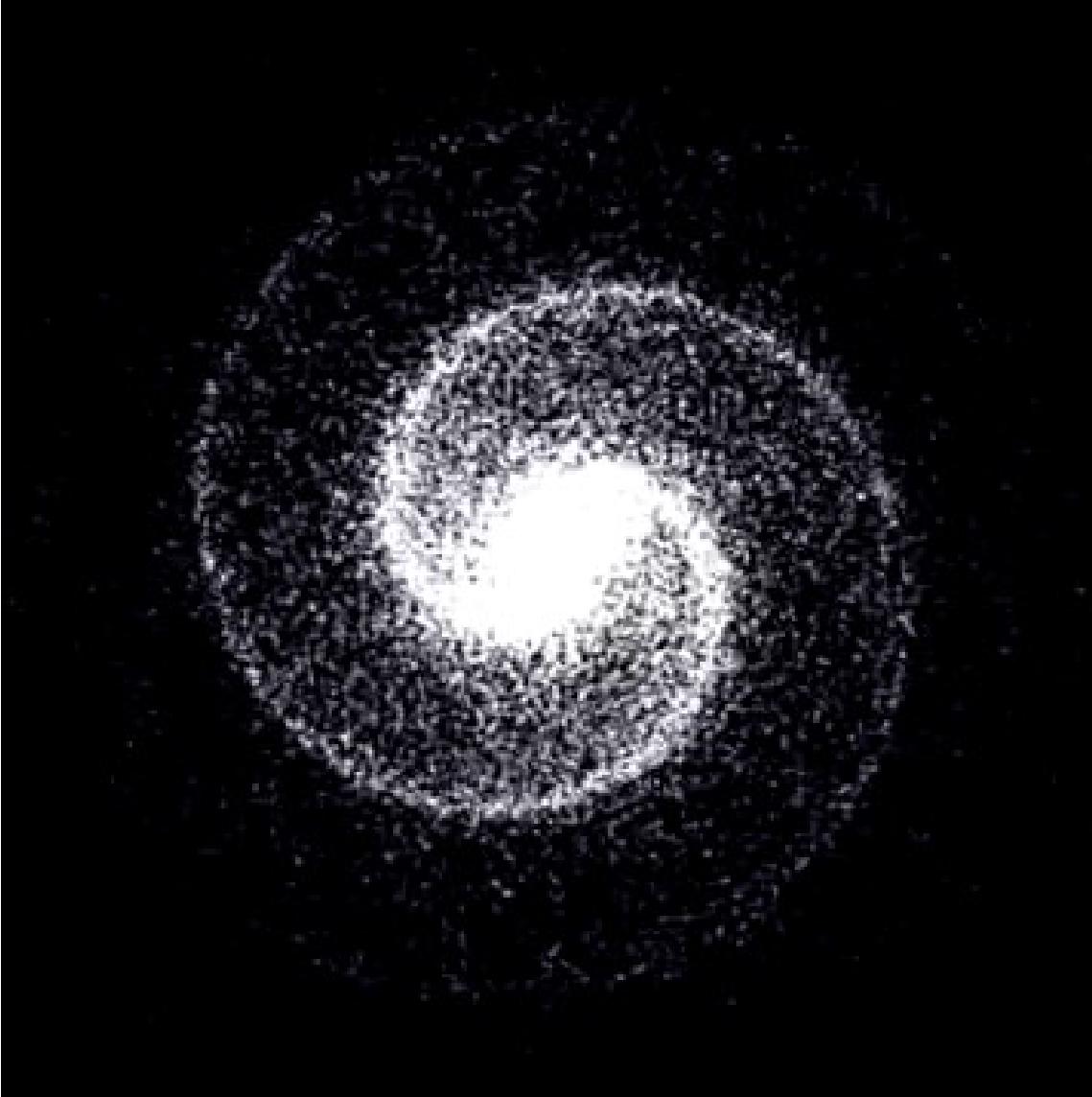
halo star orbits (green)

bulge star orbits (red)



• disk star orbits (yellow)

Brazos espirales → atracción entre vecinos



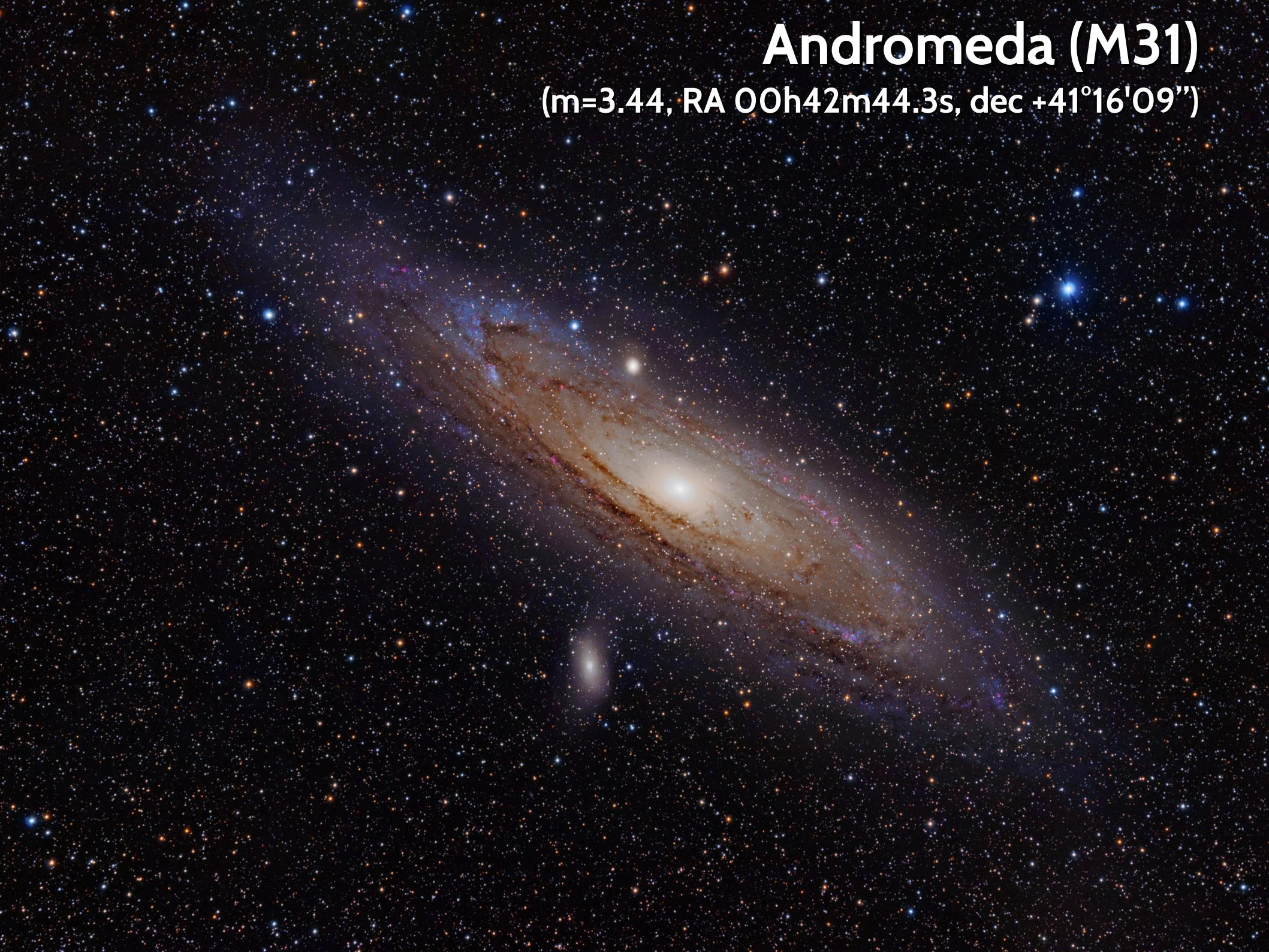


Si Andrómeda fuera más brillante...



Andromeda (M31)

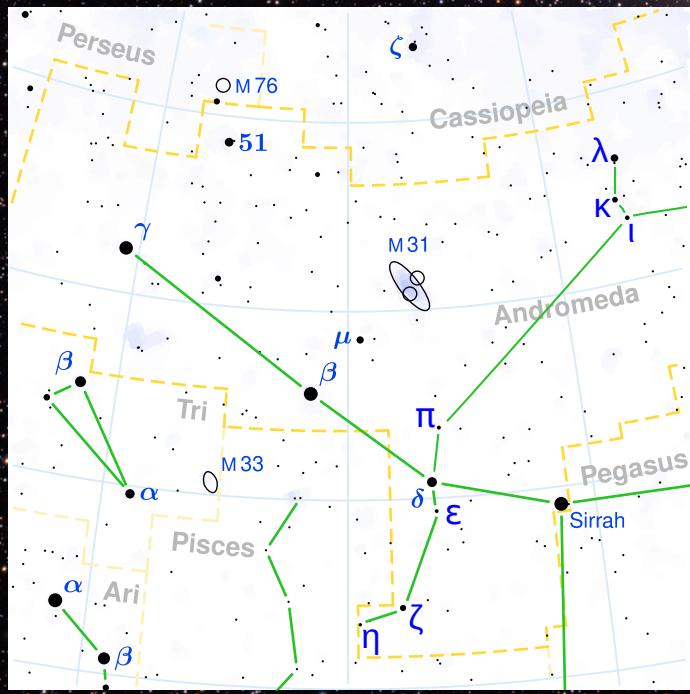
(m=3.44, RA 00h42m44.3s, dec +41°16'09")



Andromeda (M31)

(m=3.44, RA 00h42m44.3s, dec +41°16'09")

- Ubicada a 780 kpc
- Visible con binoculares (noches sin luna y oscuras a simple vista como una mancha borrosa)
- Es la galaxia más masiva del Grupo Local: $1.5 \times 10^{12} M_s$





Un viaje hacia los confines del Universo...



La Vía Láctea

- No dejen de ver este video:

<https://www.youtube.com/watch?v=Z3xkHmC-KQE>

- Con música de Nigel Stanford,

<https://open.spotify.com/artist/4JybOl1PTSn1VxNmiFxSf4?si=uDF9LHL3Q1iZX18T2nkmKA>

- un viejo conocido de Física II B (Ondas), en

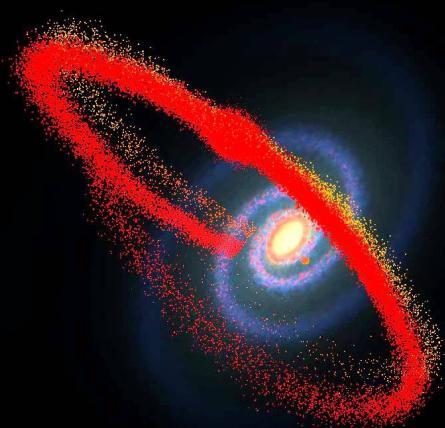
<https://www.youtube.com/watch?v=Q3oltpVa9fs>

Los satélites de la Vía Láctea

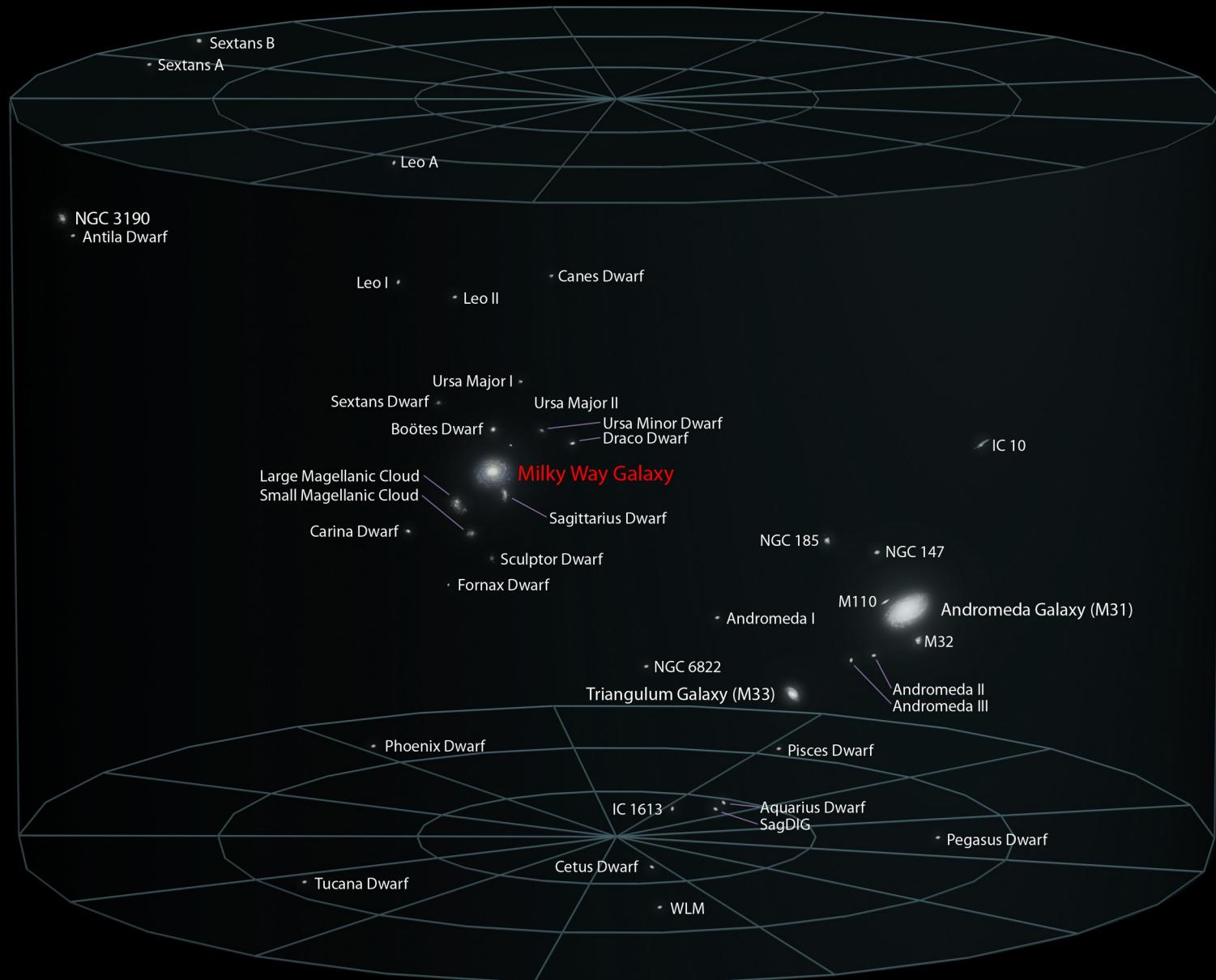


Los satélites de la Vía Láctea

- Subgrupo de la Vía Láctea
 - ~25 galaxias pequeñas unidas gravitatoriamente a la Vía Láctea
 - Nubes de Magallanes son visibles a simple vista, aunque aún no se sabe si son satélites de la Vía Láctea (2006)
 - Galaxia Enana sub-esférica de Sagitario es el mayor satélite conocido

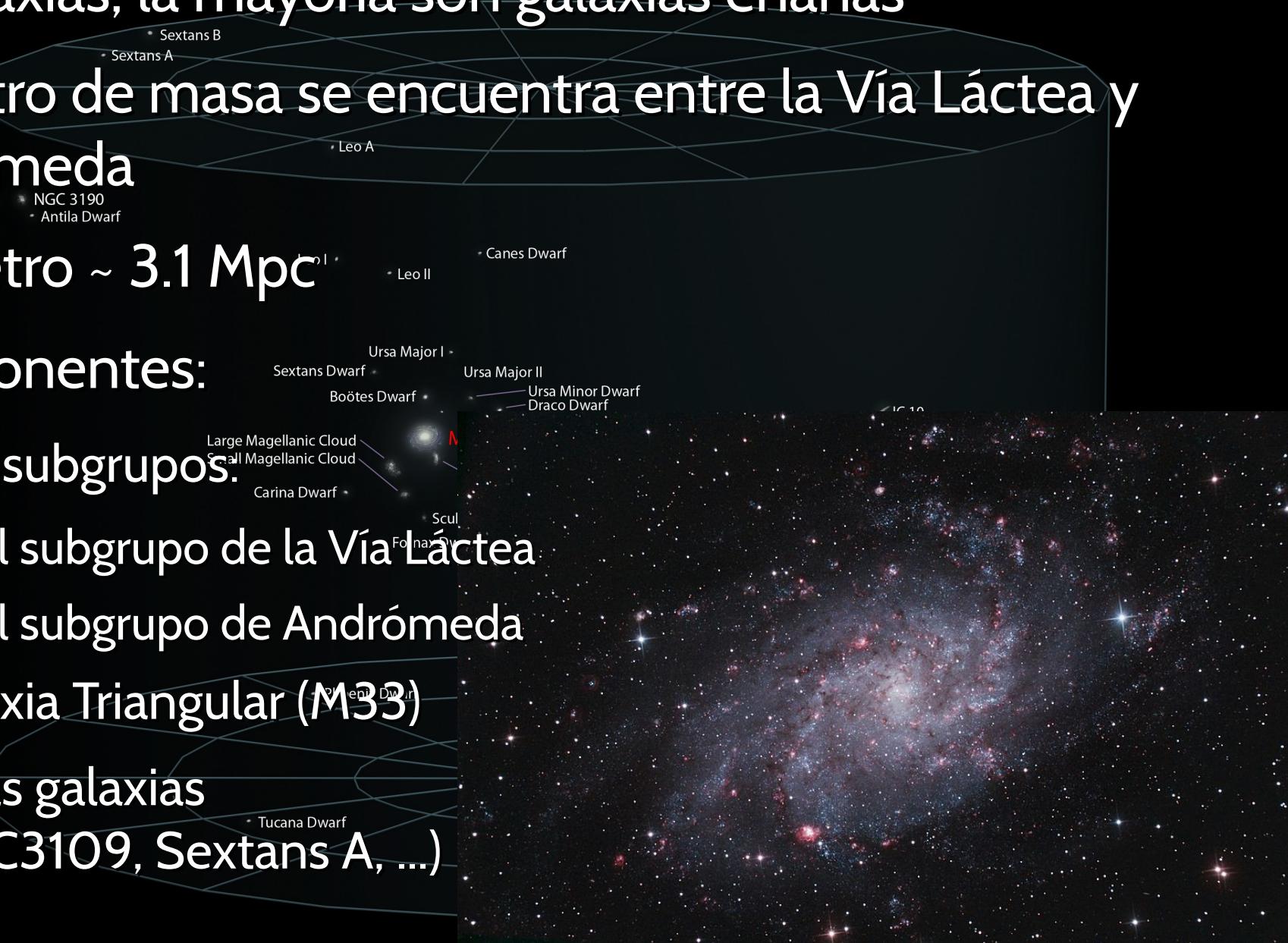


Grupo Local



Grupo Local

- 54 galaxias, la mayoría son galaxias enanas
- El centro de masa se encuentra entre la Vía Láctea y Andrómeda
- Diámetro ~ 3.1 Mpc
- Componentes:
 - Dos subgrupos:
 - El subgrupo de la Vía Láctea
 - El subgrupo de Andrómeda
 - Galaxia Triangular (M33)
 - Otras galaxias (NGC3109, Sextans A, ...)



Supercúmulo de Virgo (o Local)



Supercúmulo de Virgo

Virgo Cluster

M66

- Concentración de galaxias que incluyen al Cúmulo de Virgo y al Grupo Local

35,000,000 ly

Leo I

- Hay millones de supercúmulos como este en el Universo

- 100 grupos de galaxias en 33 Mpc

Local Group

- $\sim 10^{15} M_s$ y $\sim 3 \times 10^{12} L_s$. Se desplaza a ~ 600 km/s hacia el Cúmulo de Norma (Abel3627 → Gran Atractor)

40,000,000 ly

Draco Group

SGY

Coma

Supercúmulo de Laniakea (2014)

Centaurus

Virgo

Pisces Perseus

Pavo Indus

Вы здесь

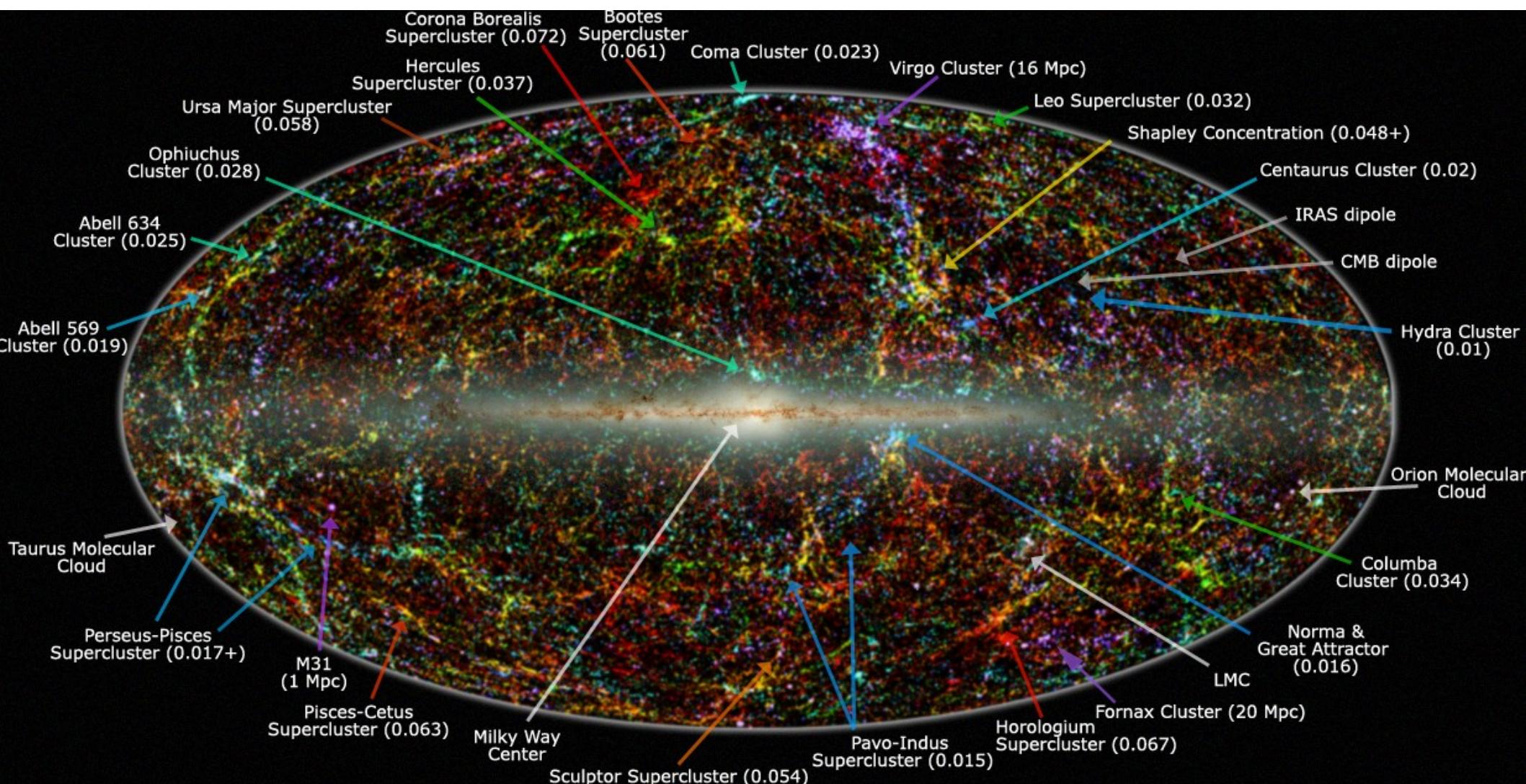
NGC 315

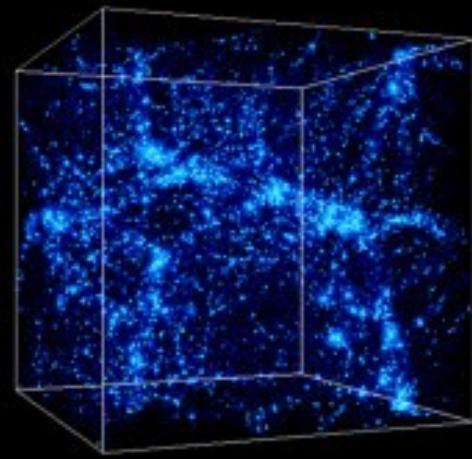
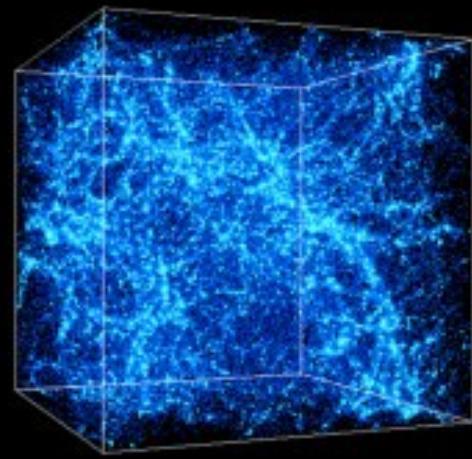
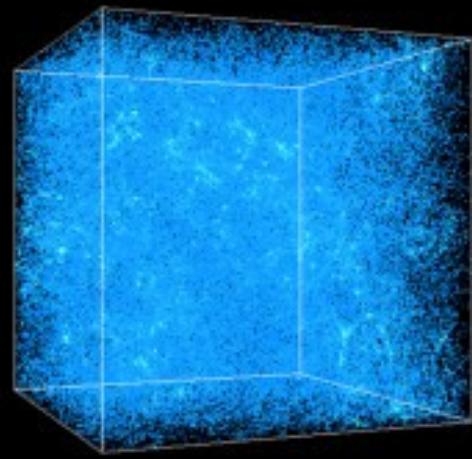
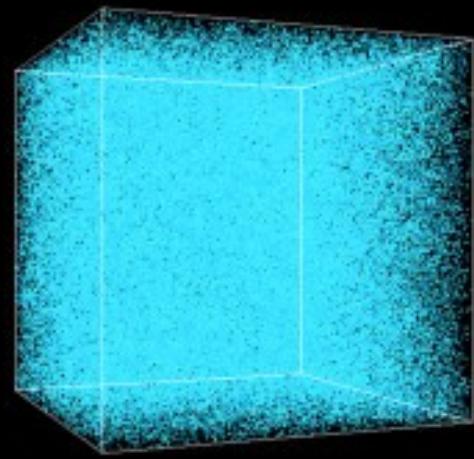
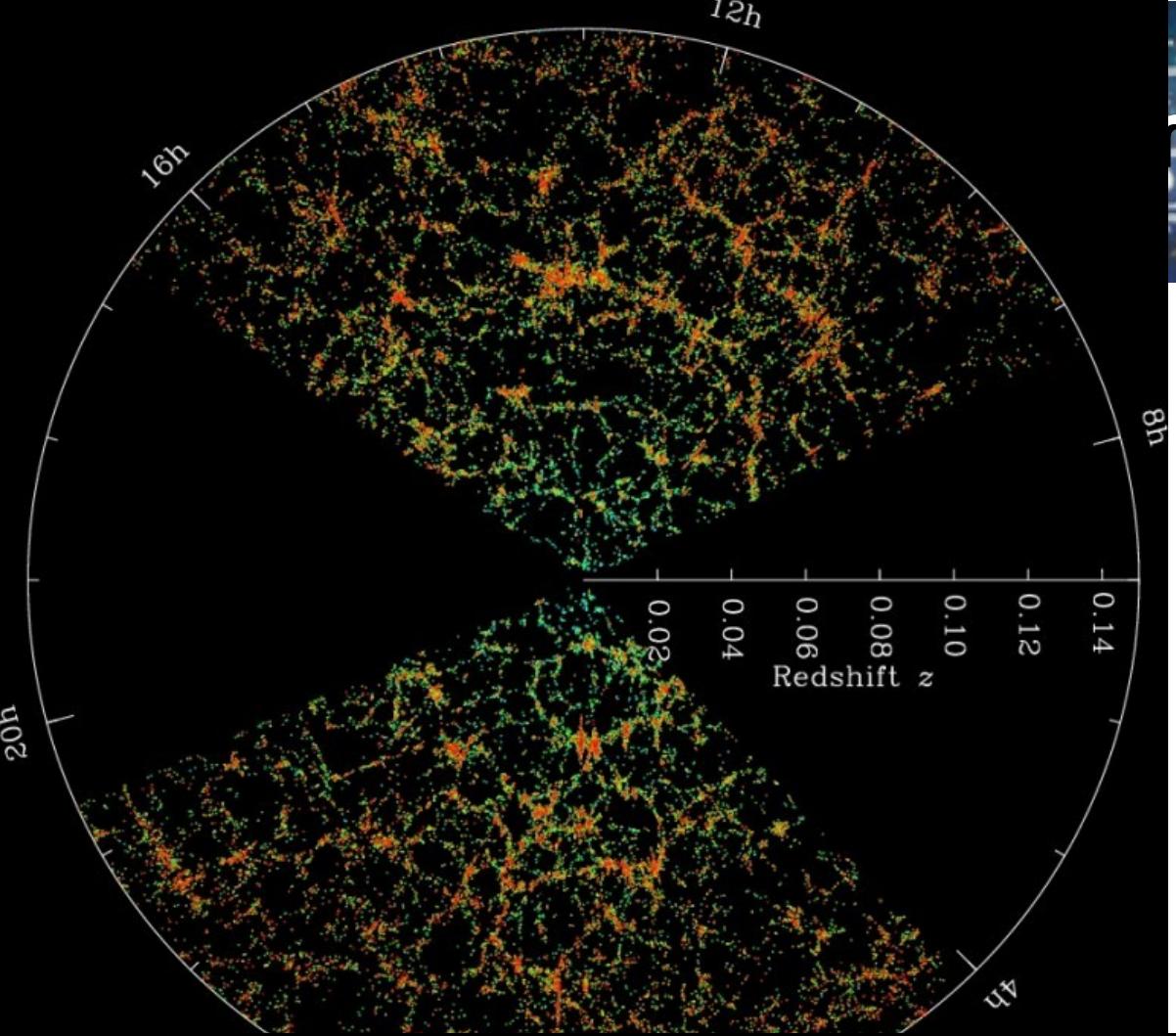
SGX

Supercúmulo de Laniakea (2014)

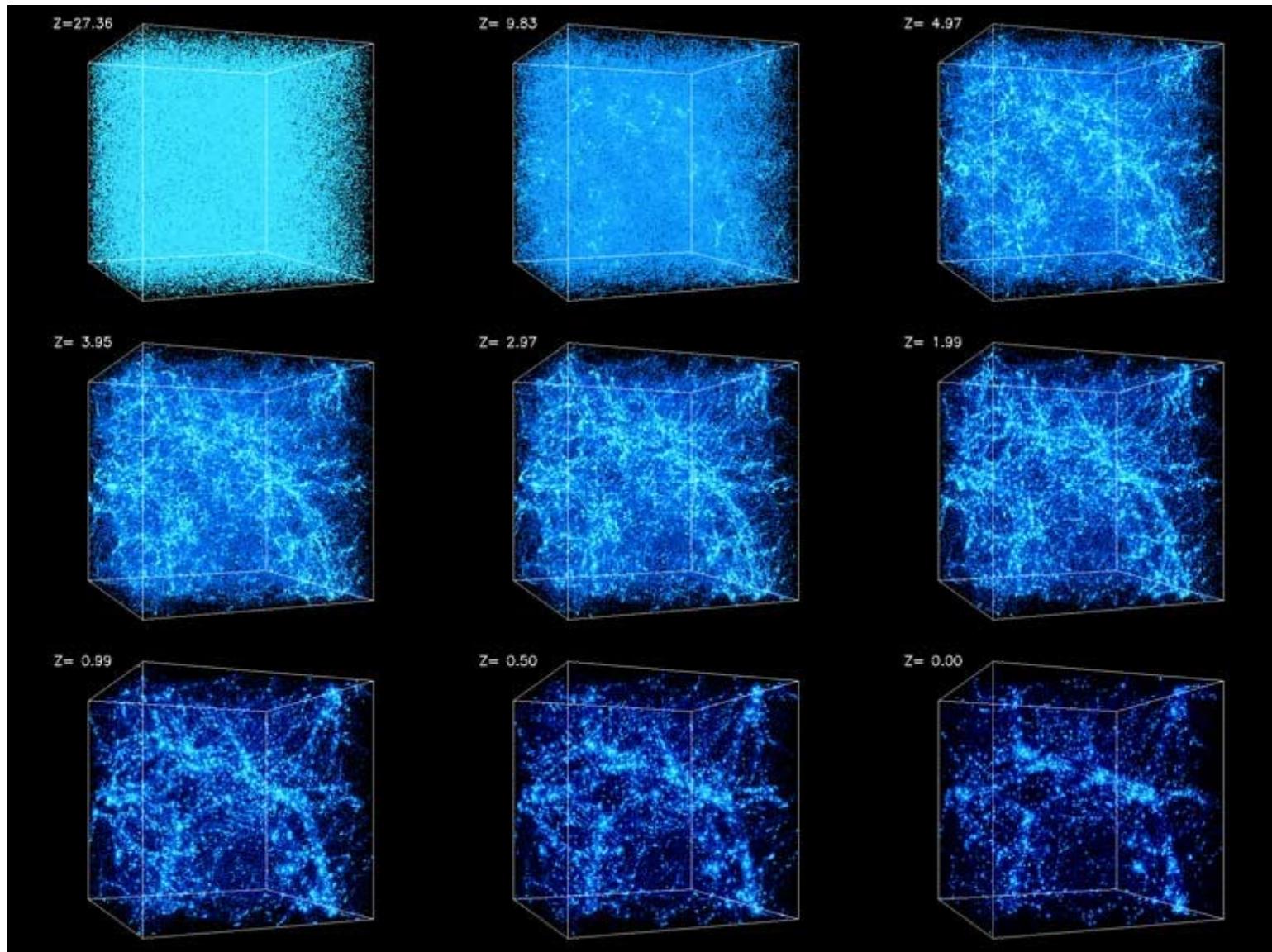
- Entre 300 y 500 cúmulos de galaxias
- 100000 galaxias en 160 Mpc
- $\sim 10^{17} M_s$ y $\sim 5 \times 10^{14} L$.
 - Supercúmulo de Virgo
 - Supercúmulo Hydra-Centauro (incluye el Gran Atractor)
 - Supercúmulo Pavo-Indus
 - Supercúmulos vecinos:
 - Shapley, Hercules, Coma, Perso-Piscis 

El Universo a las escalas más grandes

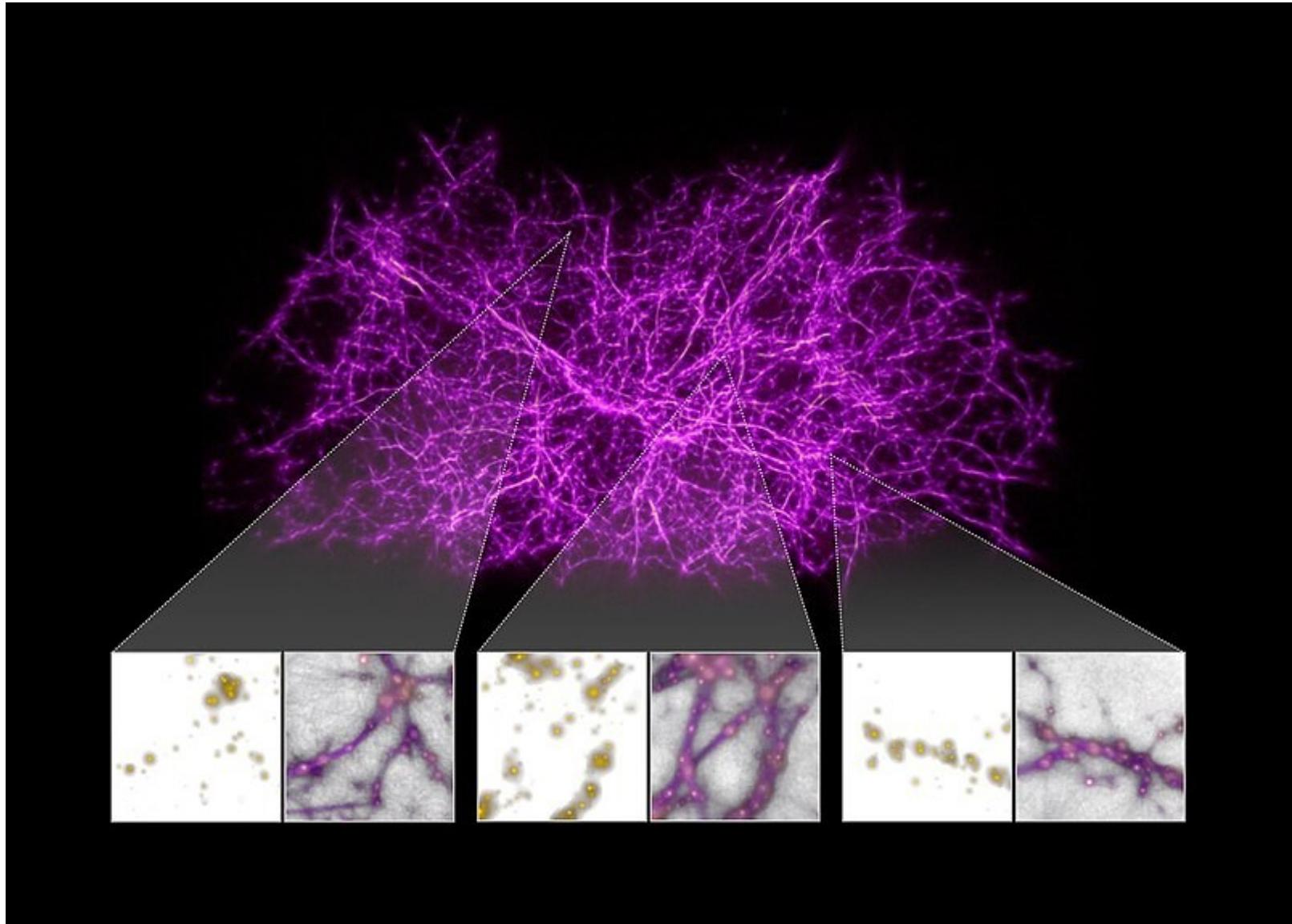


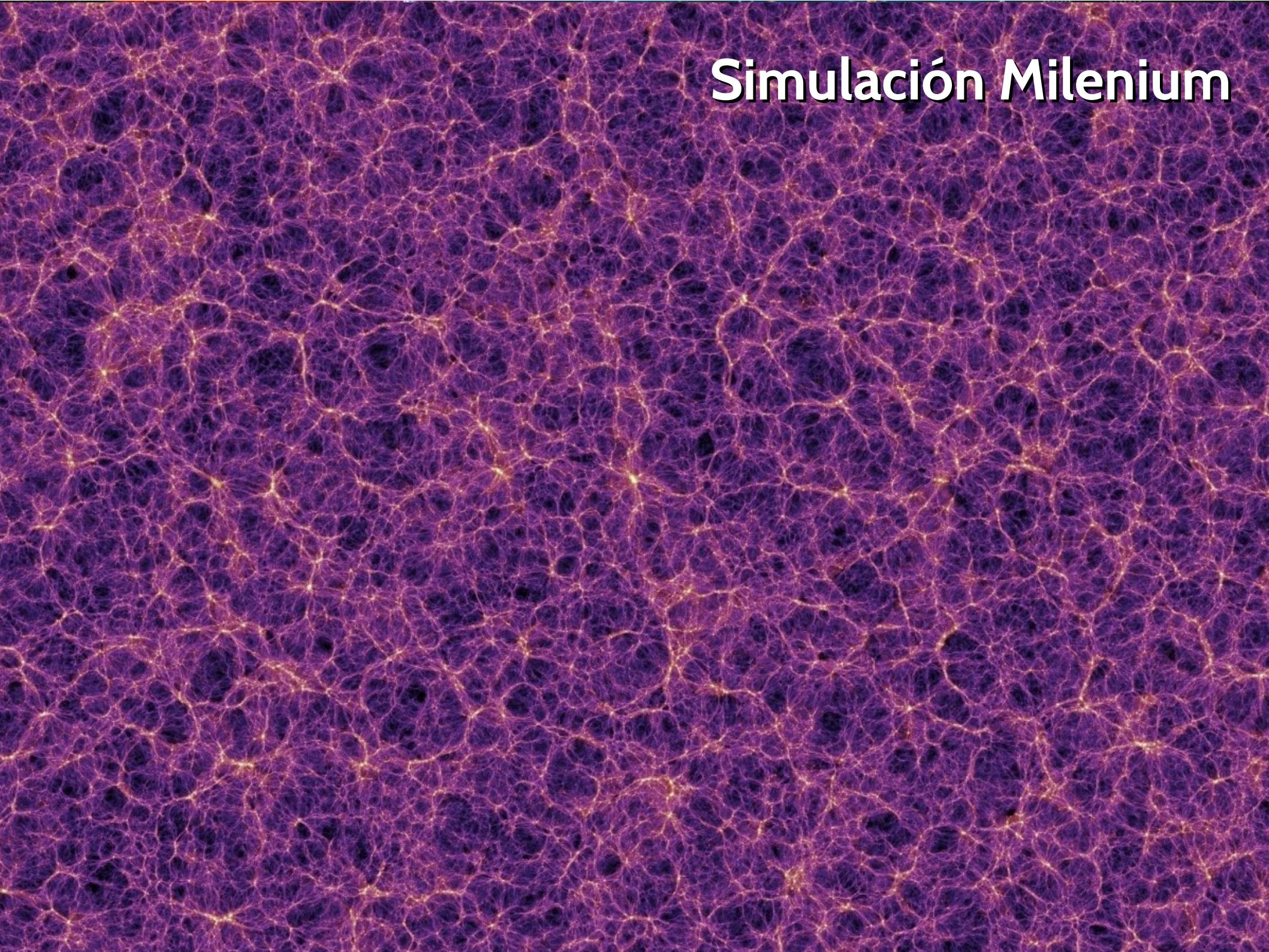


Simulaciones



Simulaciones de formación de estructuras



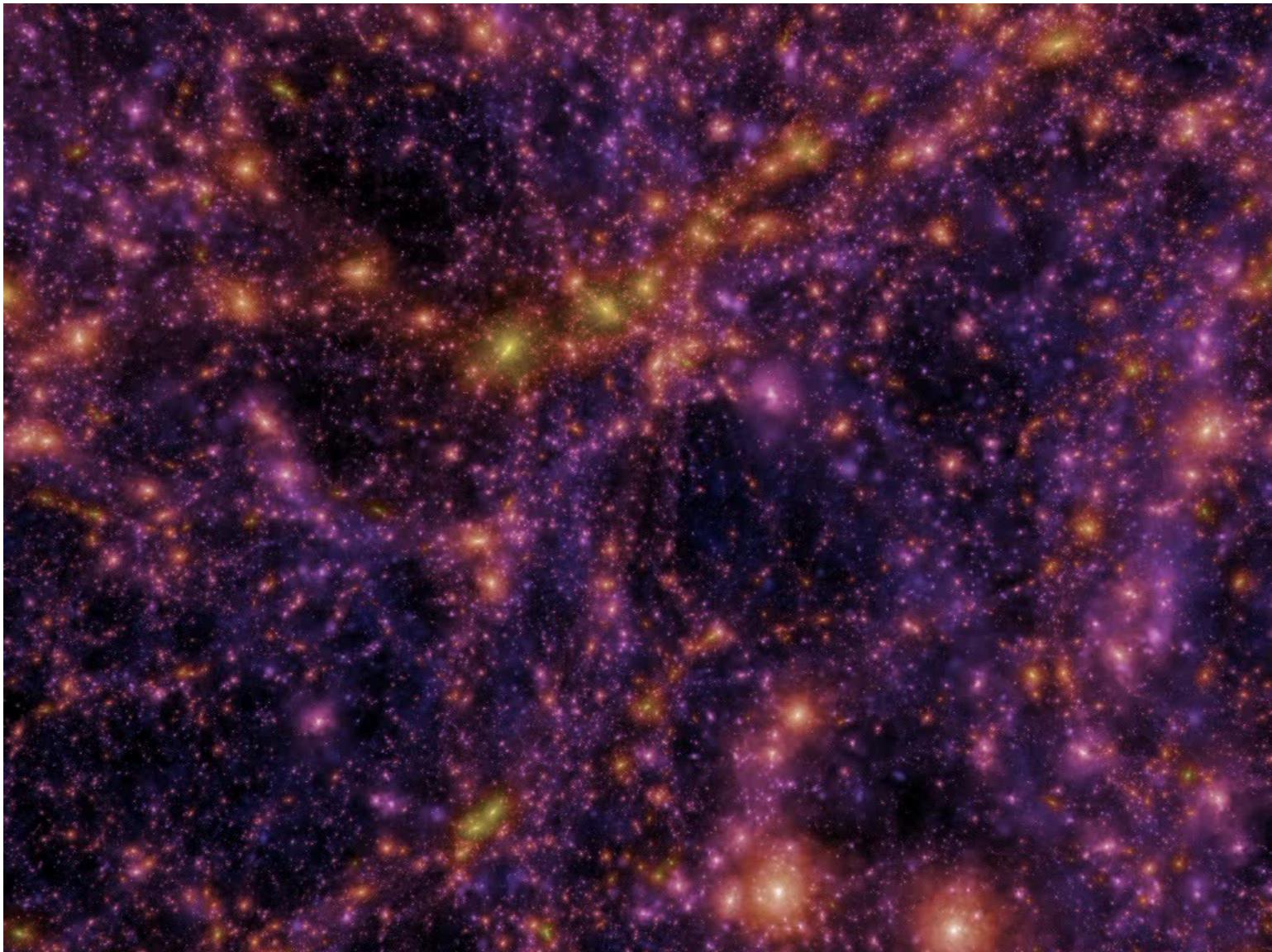


Simulación Milenium

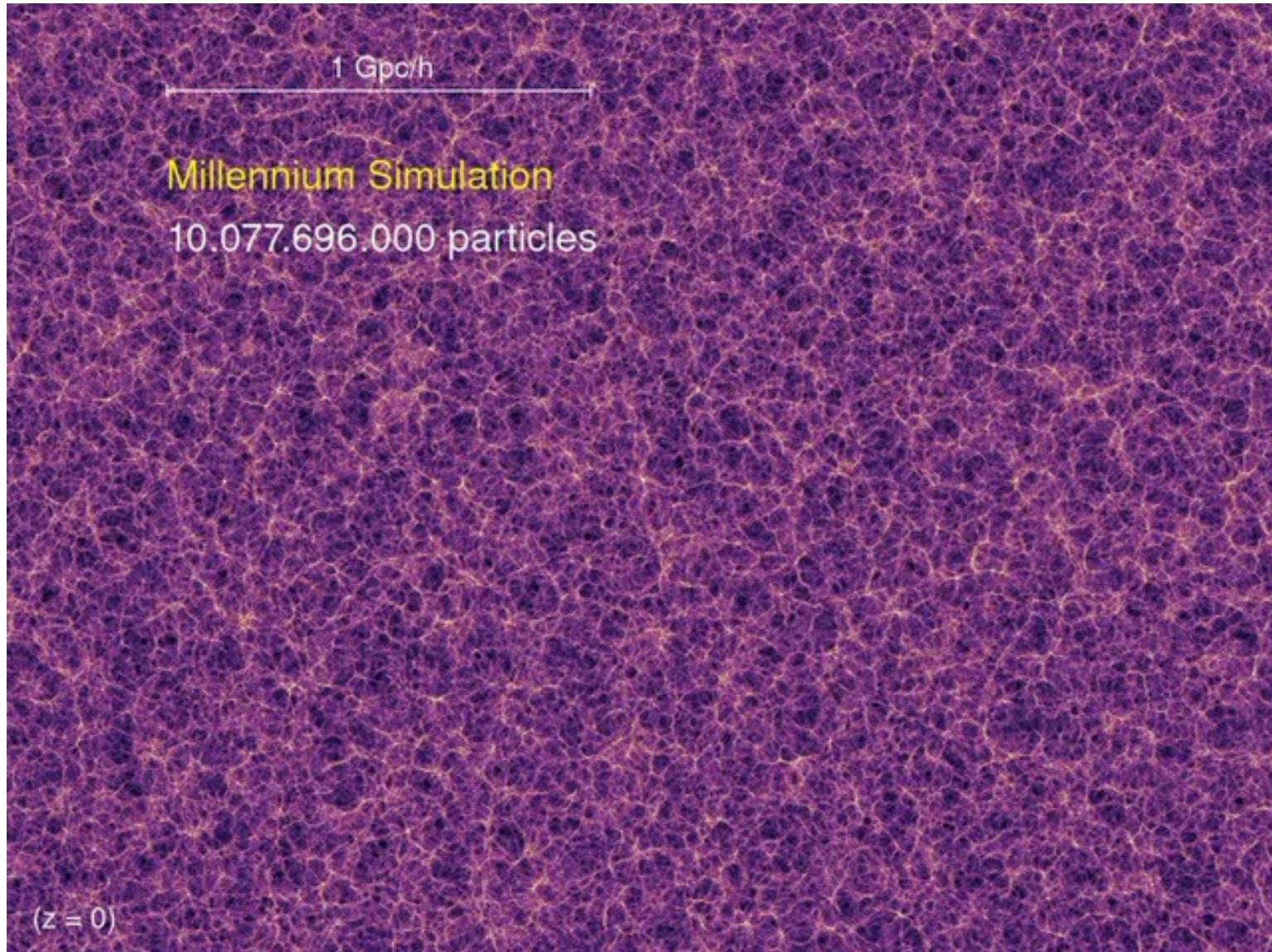
Simulación Milenium



Resultados

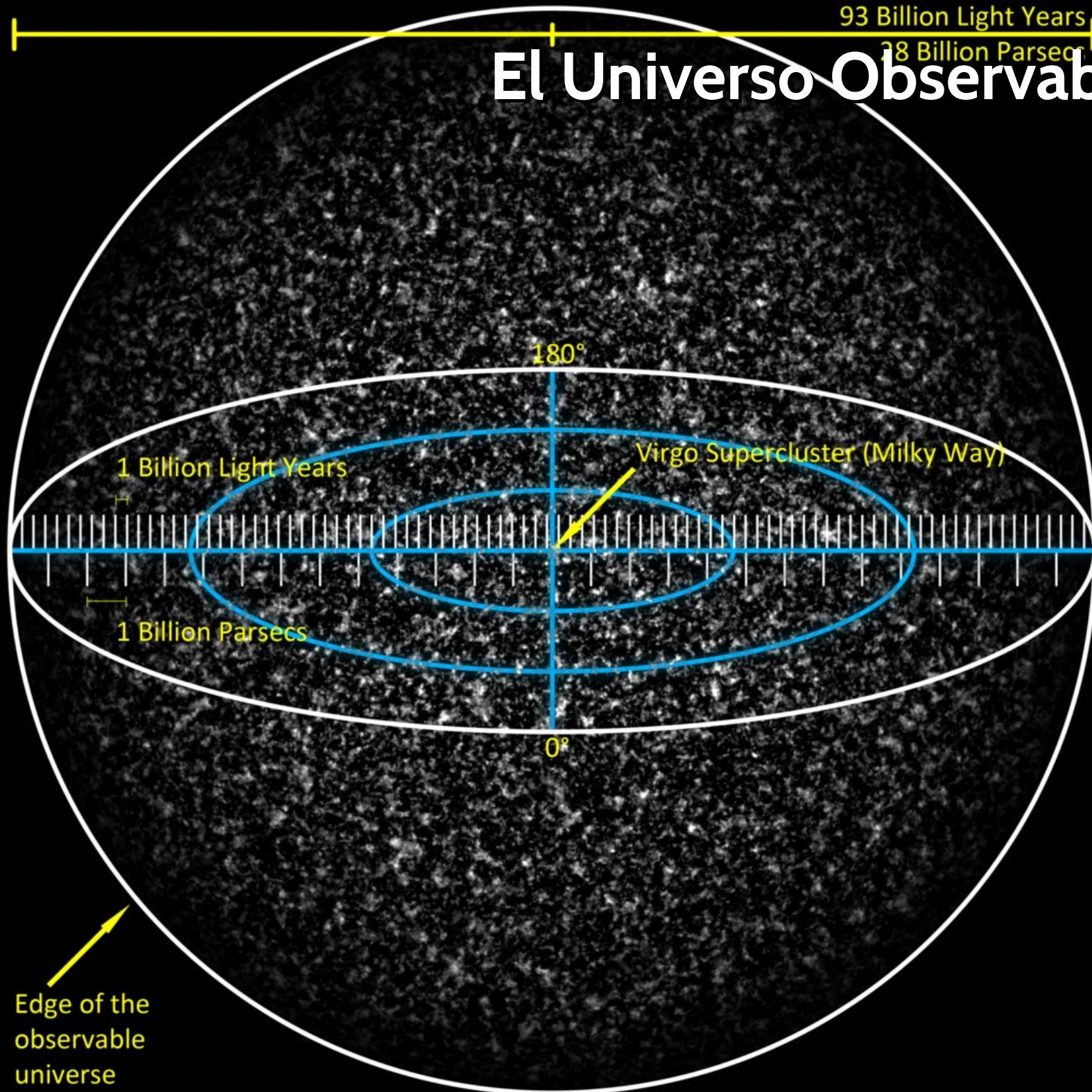


Zoom



93 Billion Light Years
28 Billion Parsecs

El Universo Observable





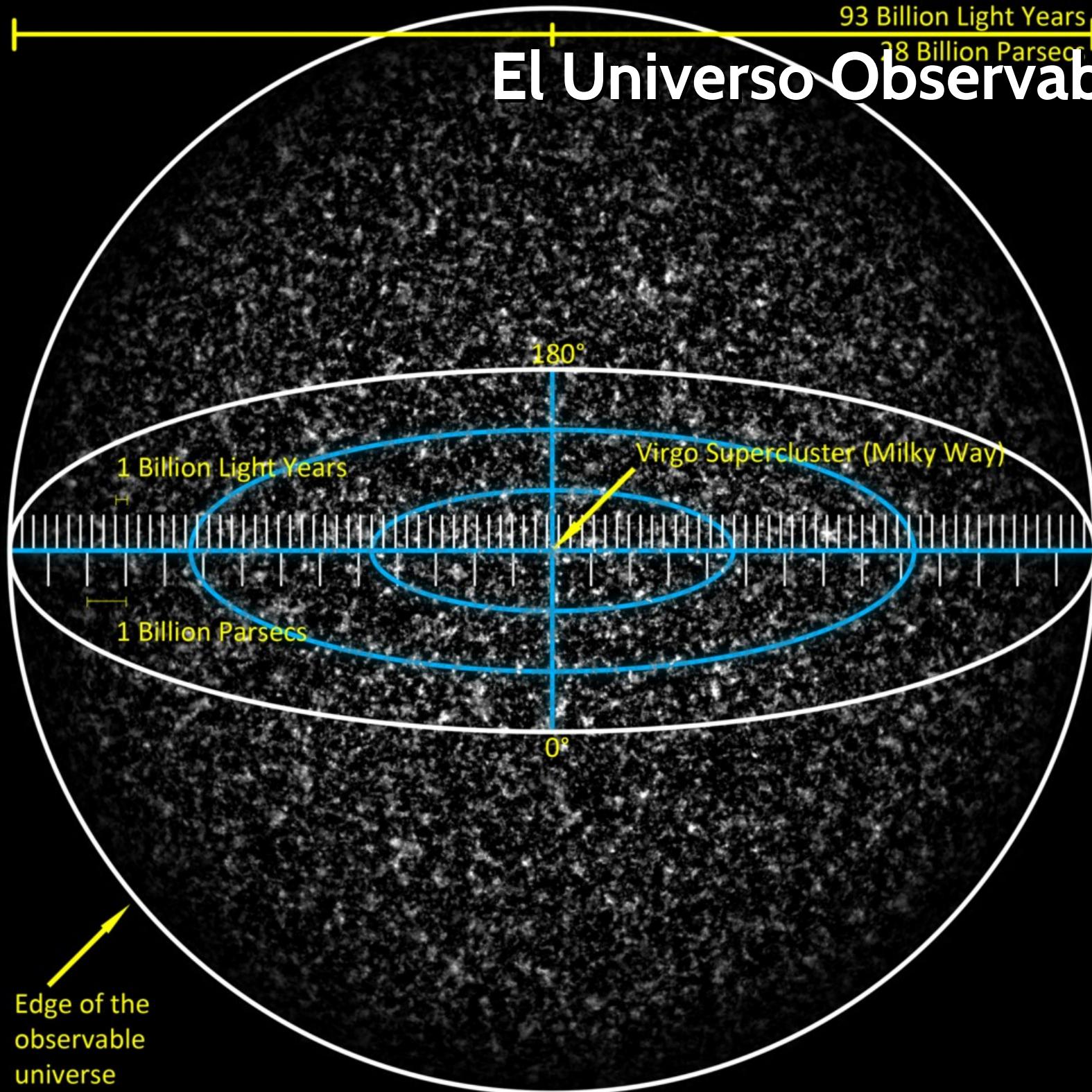
Alto, ¿Qué significa “observable”?

- **Universo observable** → $r \sim 46.5$ mil millones años luz
 - Es una esfera centrada en la Tierra que contiene a todos los objetos que pueden ser vistos desde la Tierra ahora.
 - La luz emitida por estos objetos ha tenido tiempo suficiente para alcanzar a la Tierra
 - Edad del Universo: 1.37×10^{10} años → El Universo observable NO tiene 13.7×10^9 a.l. → universo en expansión (volveremos)
- **Radio de Hubble** → es la distancia que viaja la luz en un tiempo igual al tiempo de Hubble

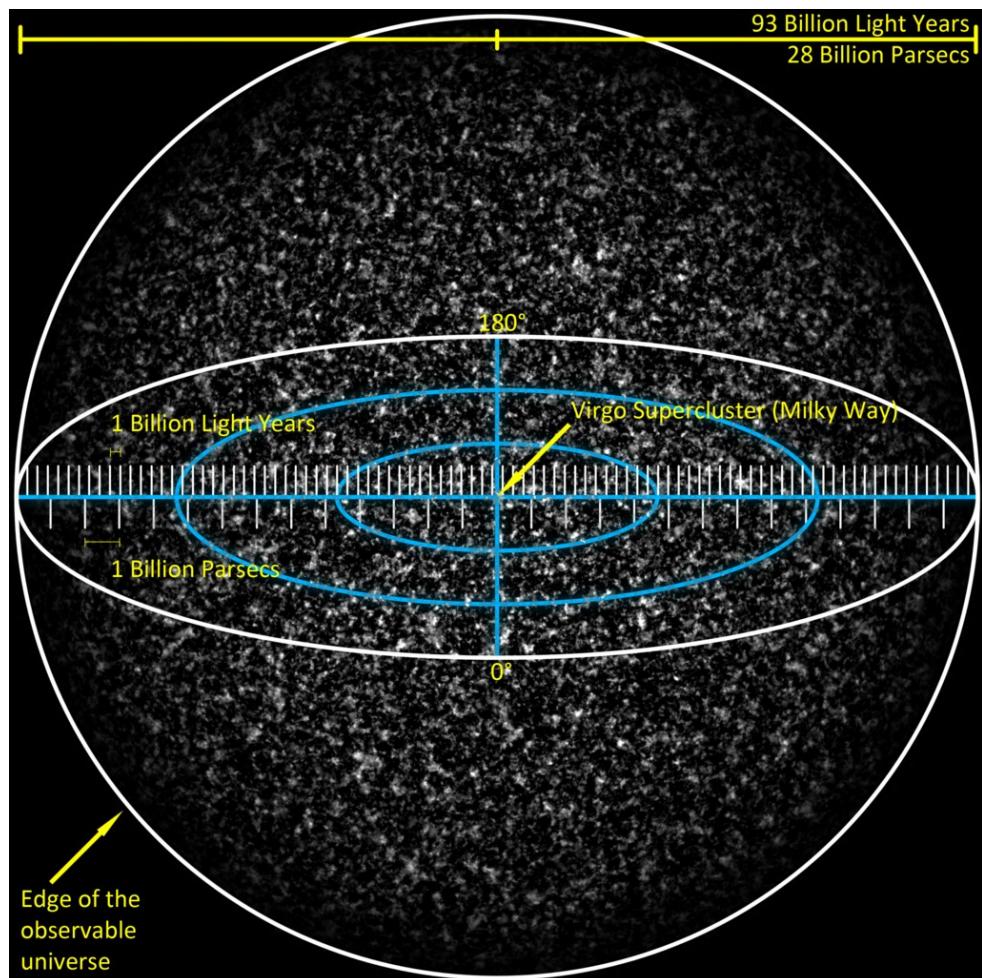
$$r_{H_0} = ct_{H_0} = \frac{c}{H_0} \simeq 1.37 \times 10^{10} \text{ años luz}$$

93 Billion Light Years
28 Billion Parsecs

El Universo Observable



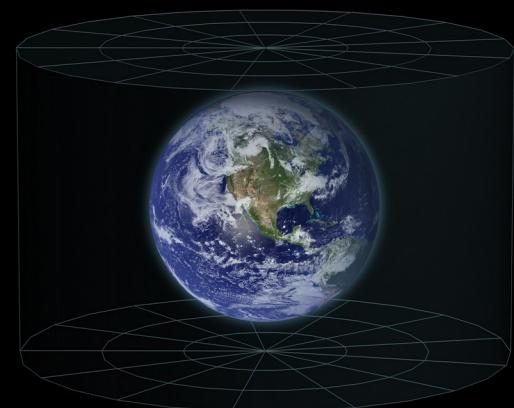
¿Cómo se distribuye?



- ¡¡¡A las escalas más grandes el Universo es isótropo y homogéneo!!!
- *parejito dirían por ahí...*
- Esto tiene consecuencias observaciones que veremos en la próxima unidad

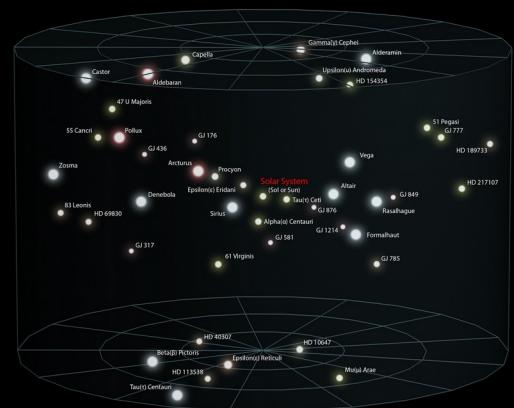
El Universo Observable

Earth

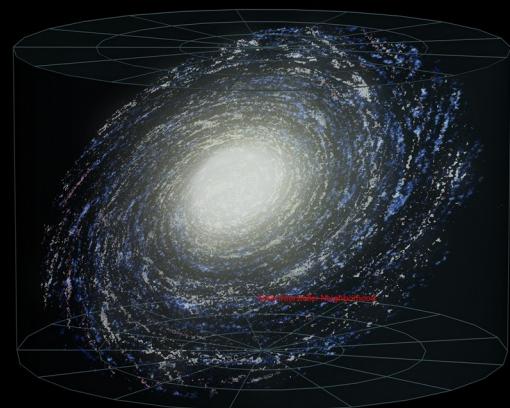


Solar System

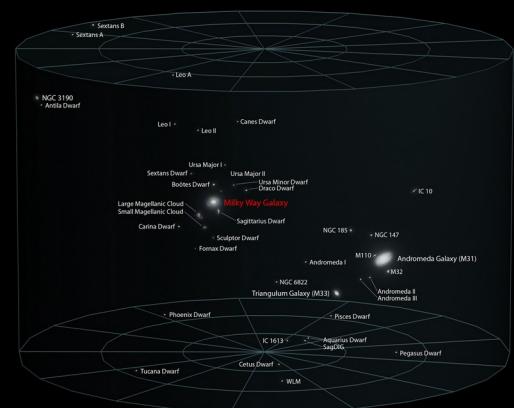
Solar Interstellar Neighborhood



Milky Way Galaxy

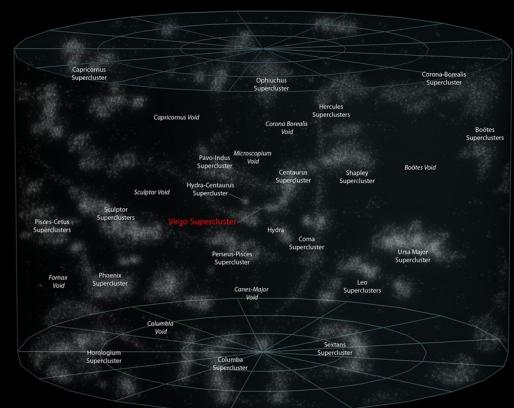


Local Galactic Group



Virgo Supercluster

Local Superclusters



Observable Universe