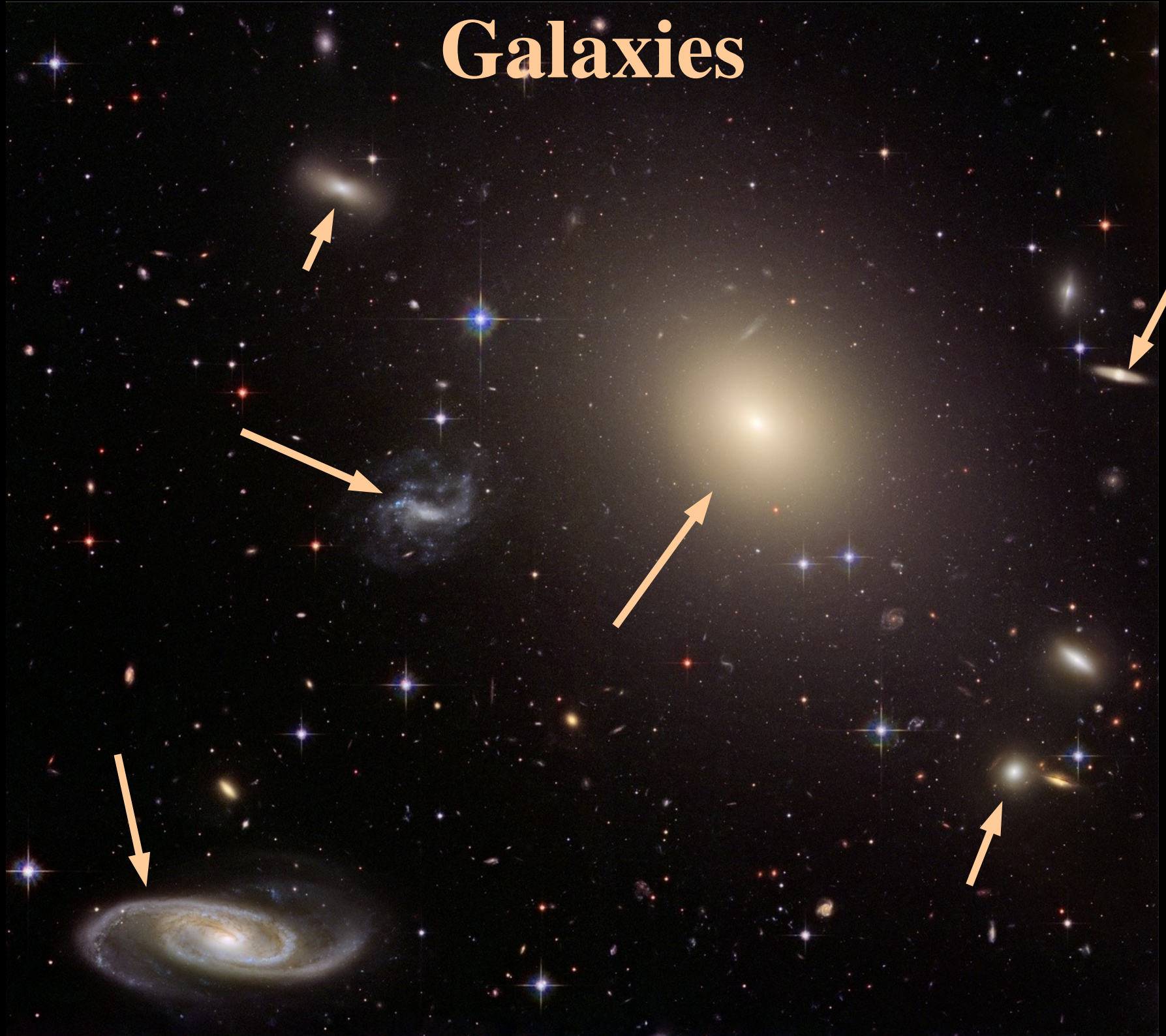
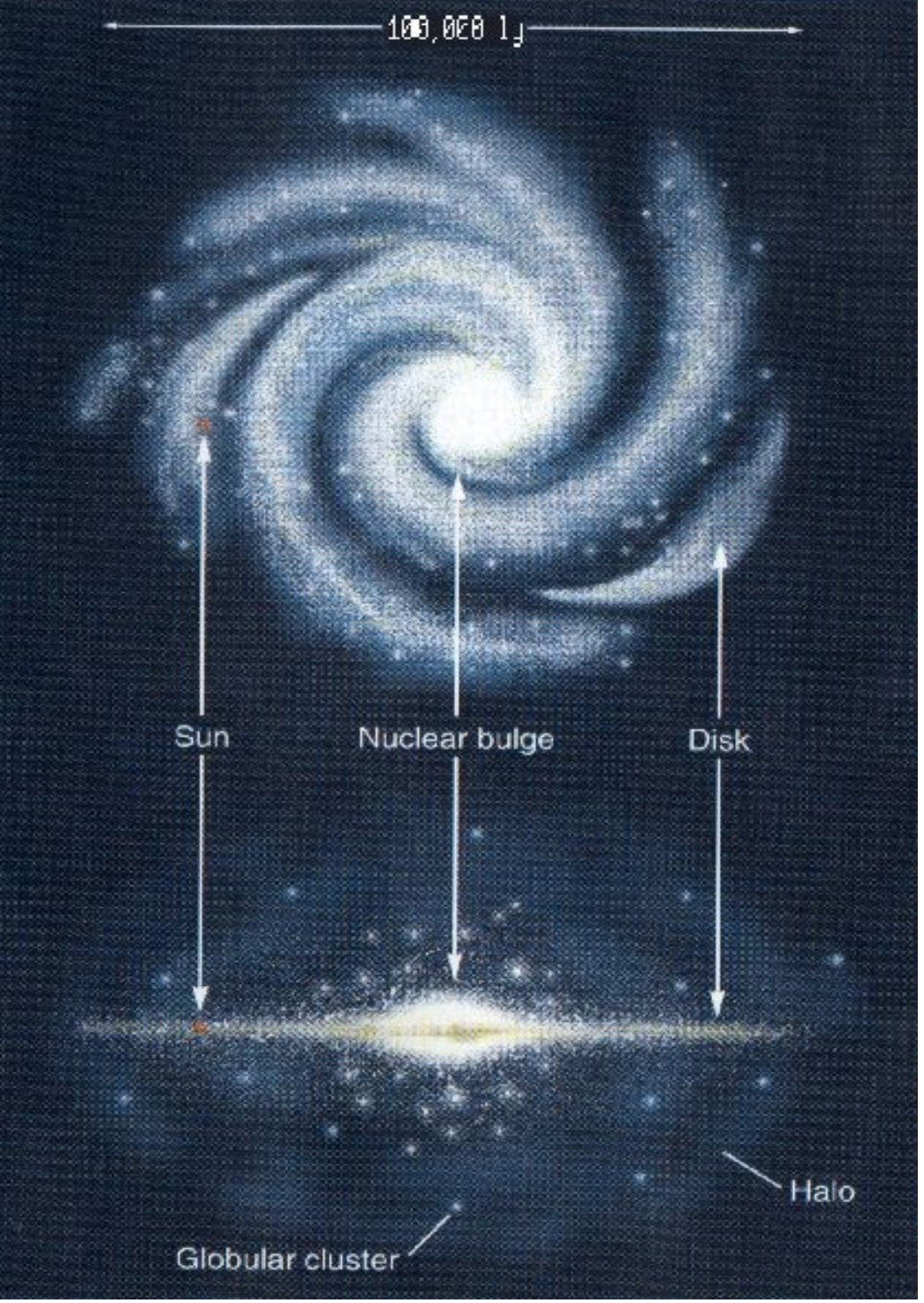
Galaxies





Spiral galaxies have 3 parts:

The Bulge (center): Old, Pop II stars which orbit randomly. Massive black hole.

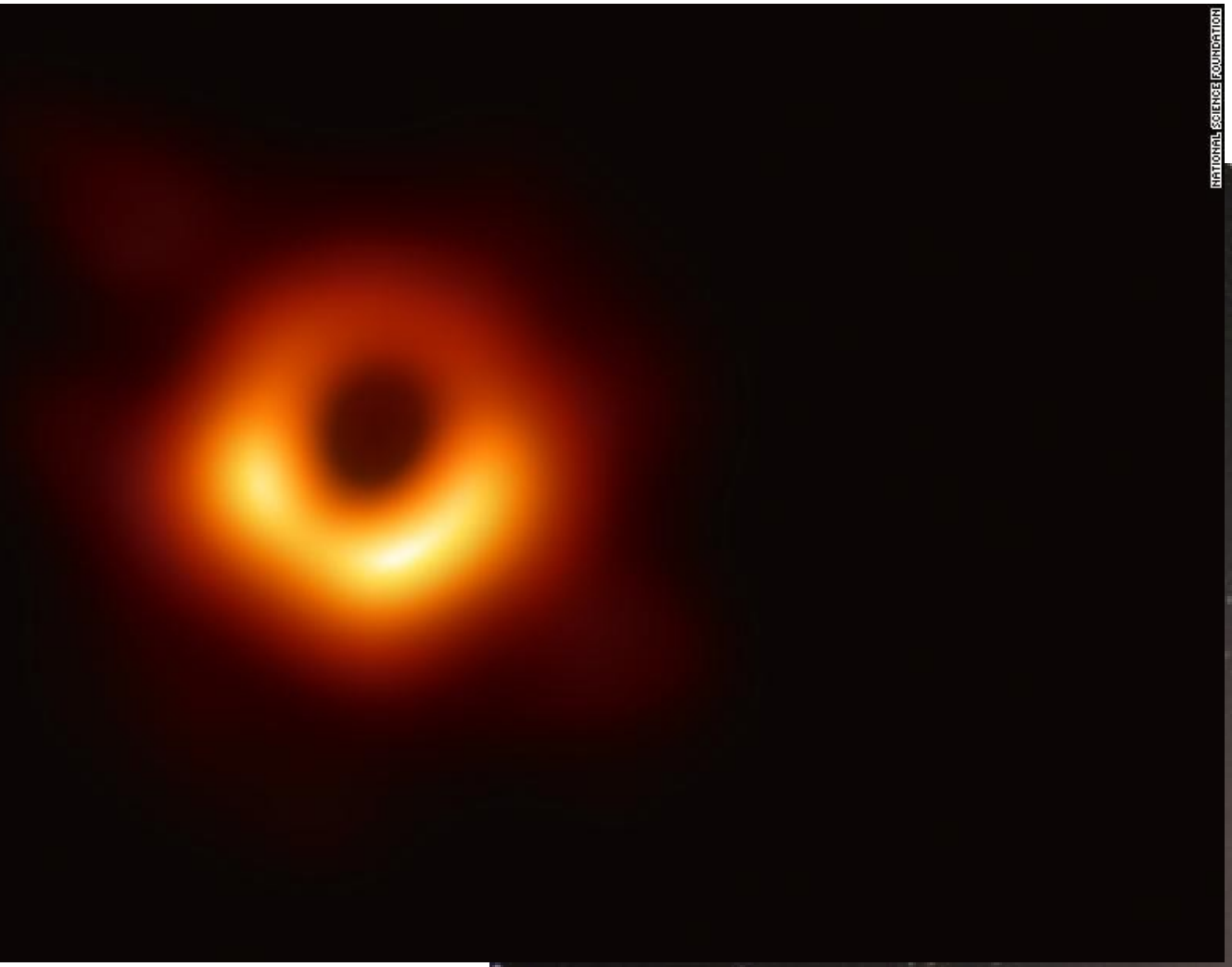
The Disk: Young, blue, Pop I stars which orbit uniformly. Gas/dust are here too.

The Halo: Globular clusters: orbit randomly, old Pop II stars.


All star forming regions are in the disk.

The black hole in the center of M87

6 billion solar masses



We are inside of the Milky Way, so how do we know what the galaxy is made of? How do we measure things?

Mass of the Milky Way

Method 1: Look at representative regions of the galaxy, count up the mass in stars, gas, and dust. Then extrapolate those regions to the rest of the galaxy.

Mass of the Milky Way

Method 2: Use stars at the edge of the galaxy to measure the mass of the galaxy.

Measure how fast those stars are orbiting, and it gives us the mass of the galaxy.

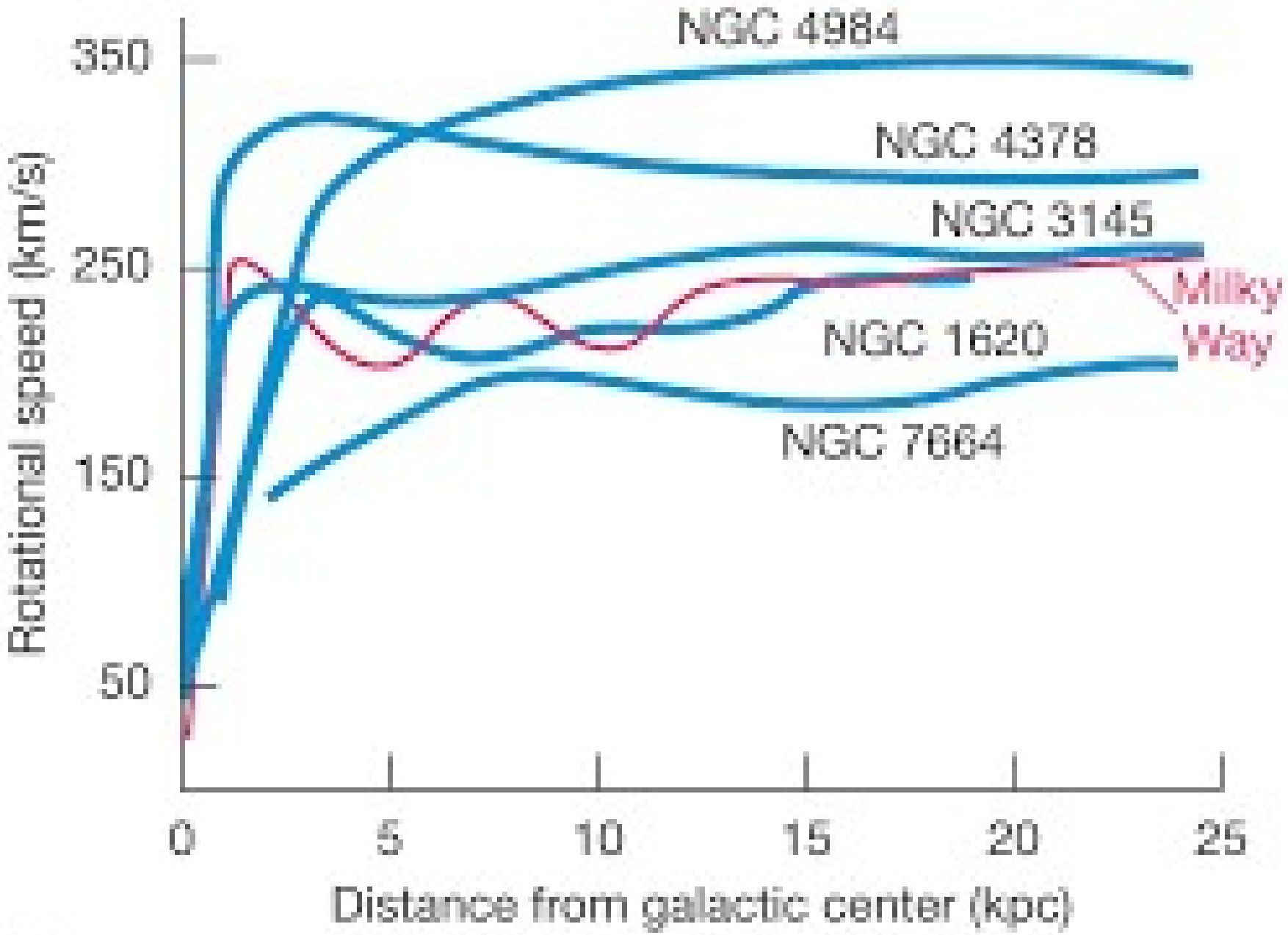
Using gravity, the total mass is 5_x10^{11} solar masses.

If you account for all the mass in stars and gas, you only get 5_x10^{10} solar masses.

Why are these numbers different? If we can measure this mass via orbits of stars, why can't we see it?

Dark Matter

We see this same thing in every galaxy.



As astronomers measure the rotation rate of galaxies (not just our own), and velocities of groups of galaxies, they realize that 90% of the Universe is Dark Matter.

So what is Dark Matter?

Criteria: We must not readily be able to “ see” it.

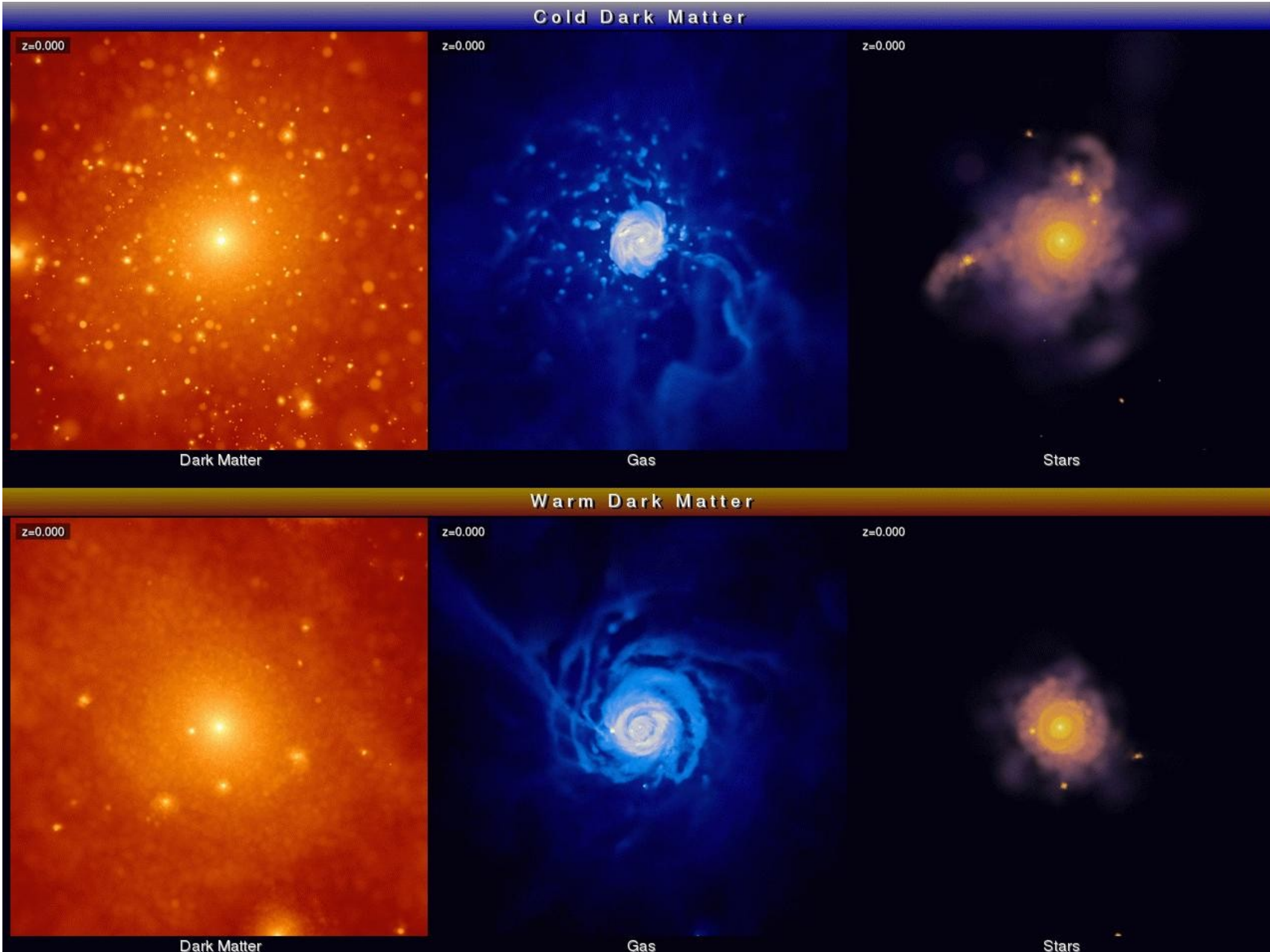
So What is Dark Matter?

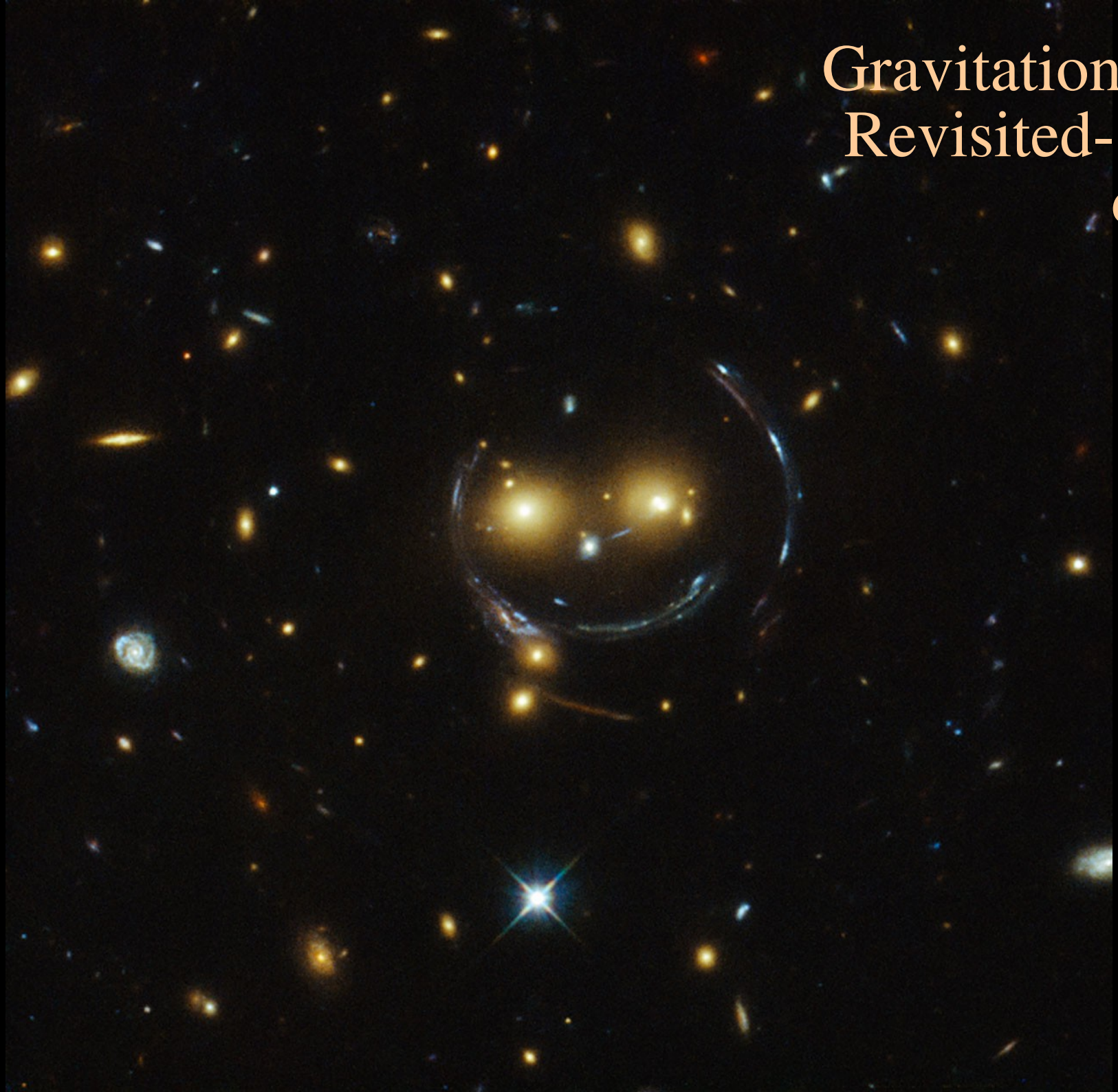
Easier to say what it is not!

- Gas- we would see a cold thermal spectrum.
- Dust- we would also see a cold thermal spectrum.
- Black holes- could detect in X-rays. Also, supernova leave gas behind.
- White dwarfs, brown dwarfs, planets- would require too many to make up the mass.
- Exotic known particles: Neutrinos with mass-limit on mass is too small to be helpful.

So What is Dark Matter?

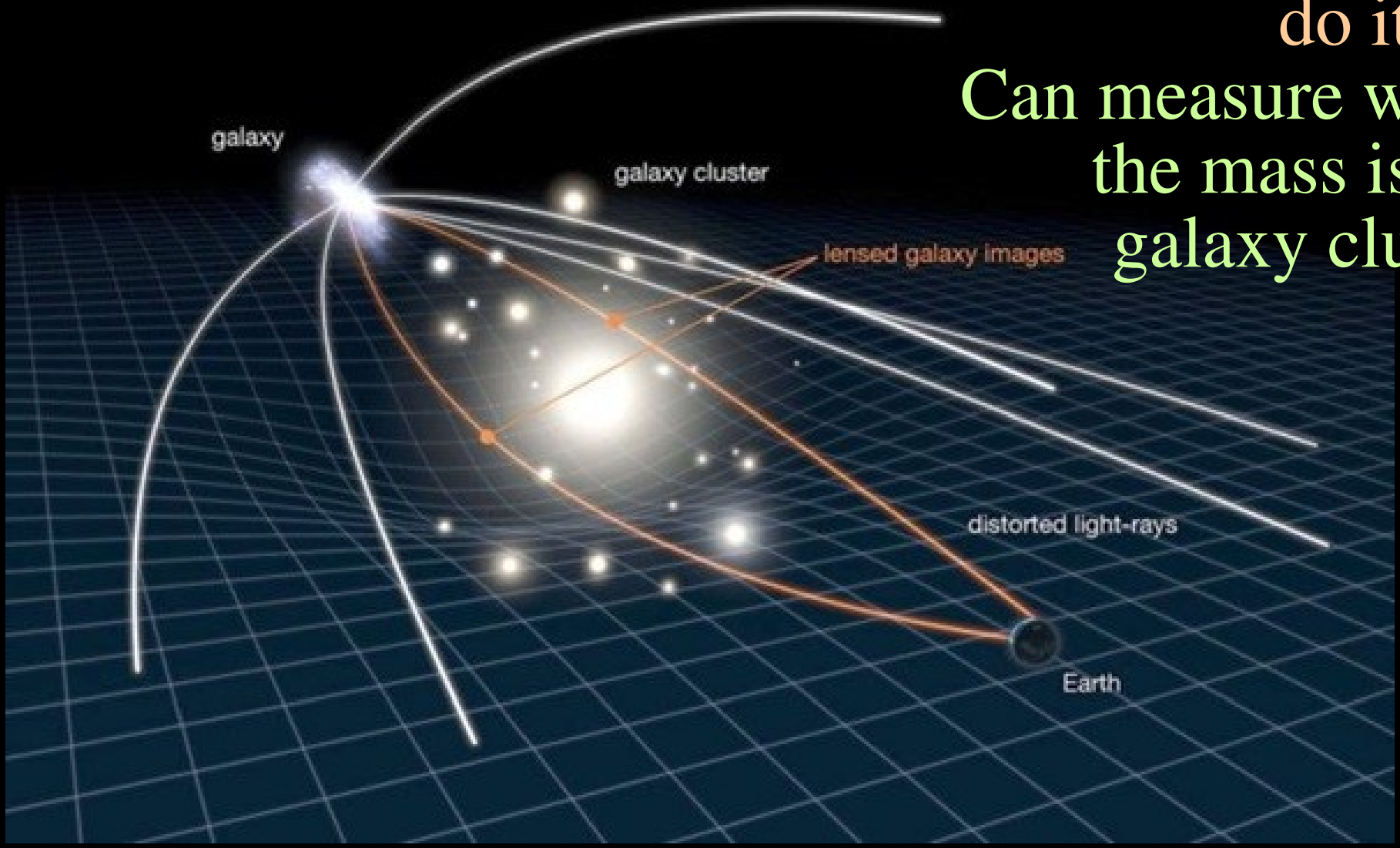
- Cold Dark Matter- massive (proton/neutron-sized) exotic particles which move slowly and each galaxy has 6-18 'lumps' of them, spread around.
- Hot Dark Matter- lighter (electron-sized) exotic particles which move quickly and each galaxy has one 'halo' of them.


Cold Dark Matter
z=0.000
z=0.000
z=0.000
Dark Matter
Gas
Stars
Warm Dark Matter
z=0.000
z=0.000
z=0.000
Dark Matter
Gas
Stars



Gravitational lenses
Revisited- galaxies
do it too.

Gravitational lenses
Revisited- galaxies
do it too.
Can measure where
the mass is in a
galaxy cluster.




Red is gas in galaxy,
blue is where the
(dark matter) mass is.


Red is gas in galaxy,
blue is where the
(dark matter) mass is.

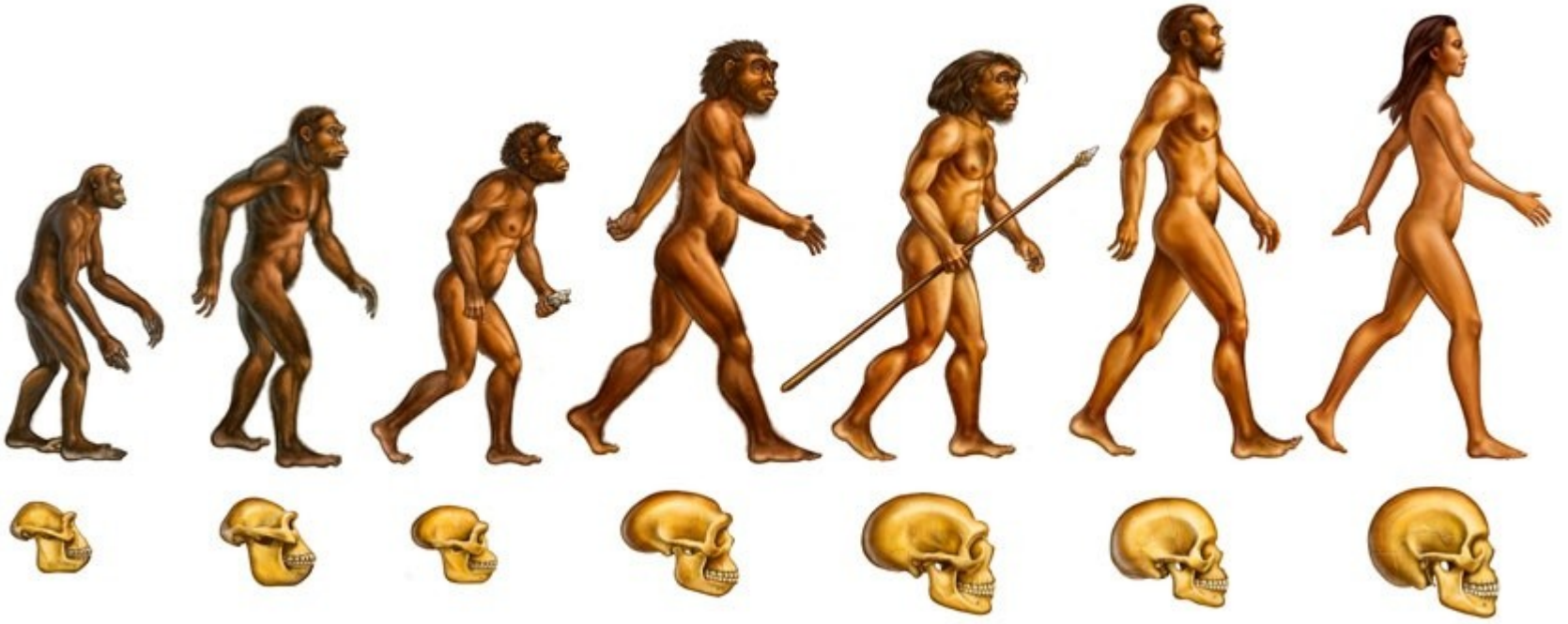
Consider this….
Our Sun, in the disk is a Pop I star. Before our Sun were Pop II stars, and before them…

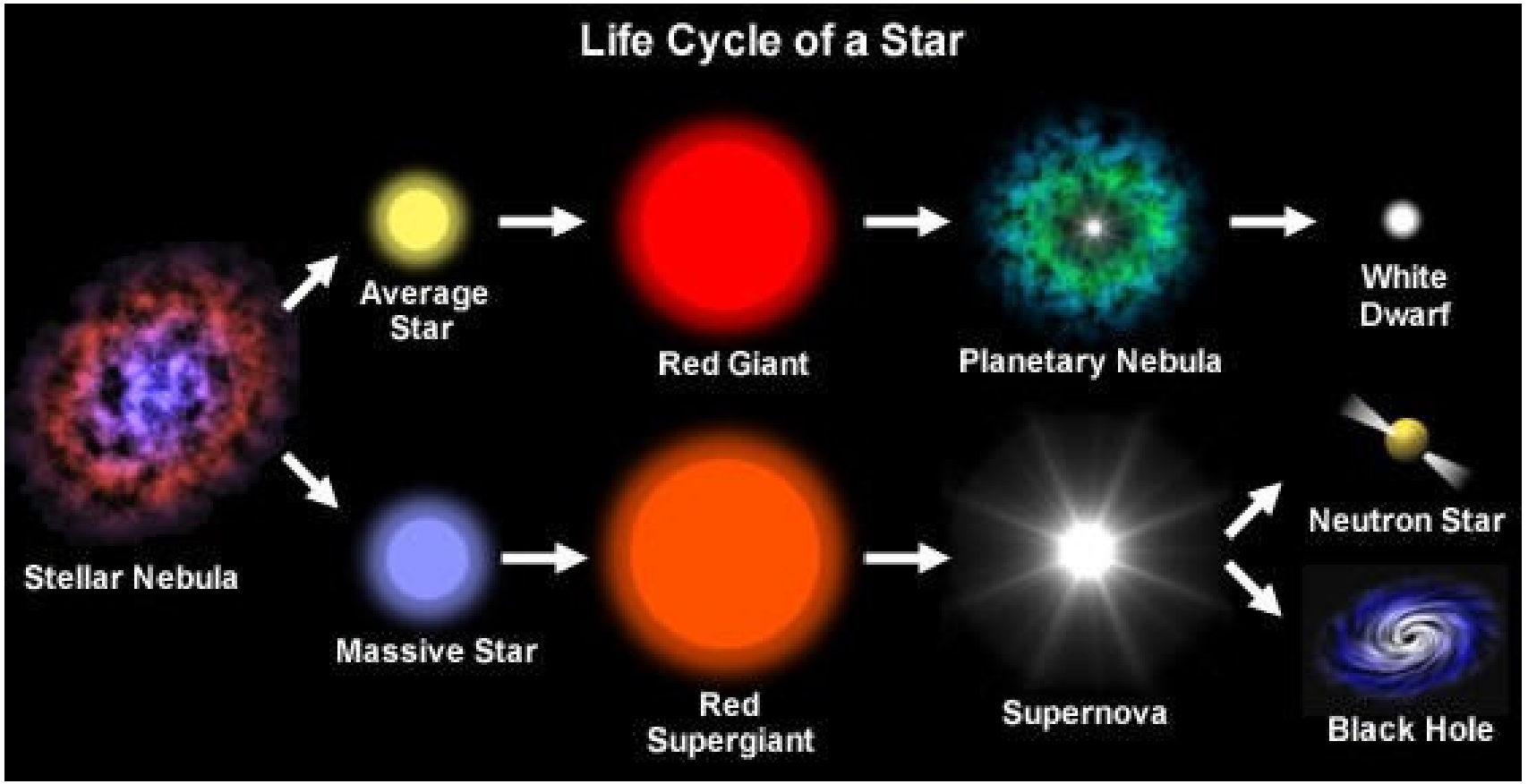
What would our galaxy have looked like when there were only Pop II stars? (Think about where those stars are located.)

Sketch our galaxy now and then.

Galaxy Formation

Why even worry about this?



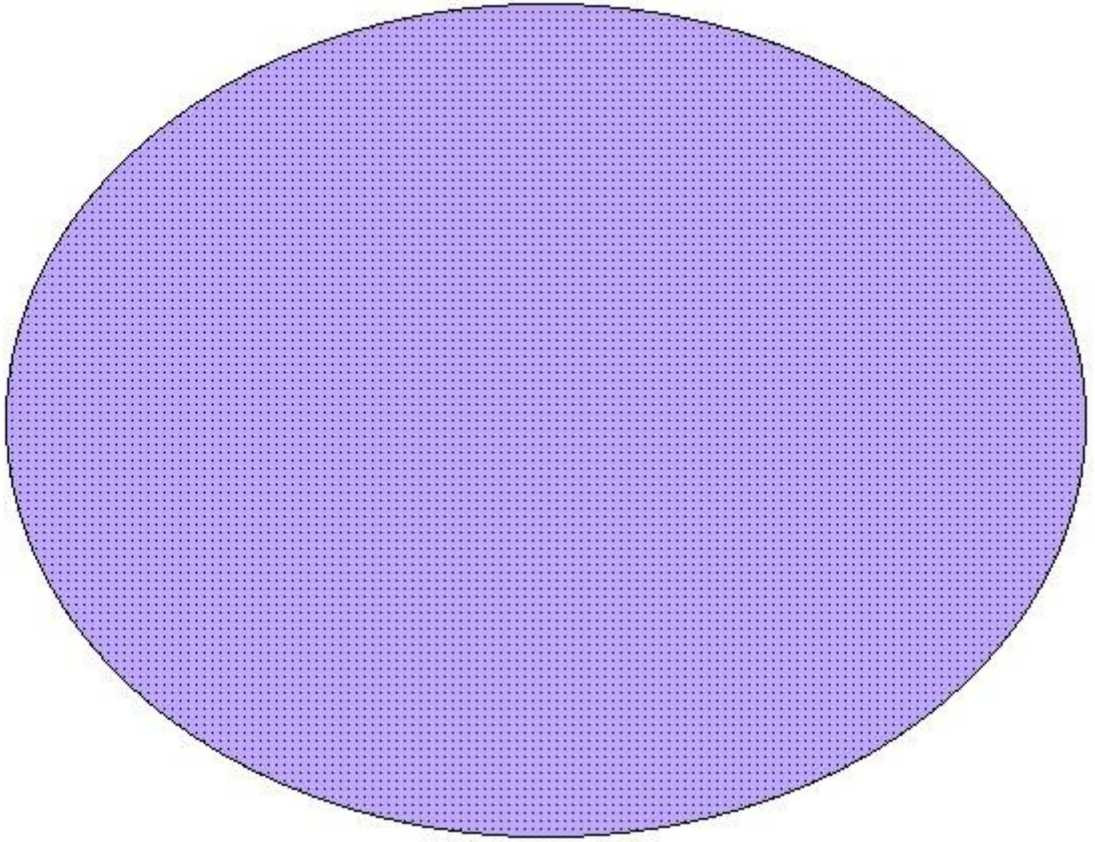

Life Cycle of a Star
Stellar Nebula
Average Star
Red Giant
Planetary Nebula
White Dwarf
Massive Star
Red Supergiant
Supernova
Neutron Star
Black Hole

Galaxy Formation

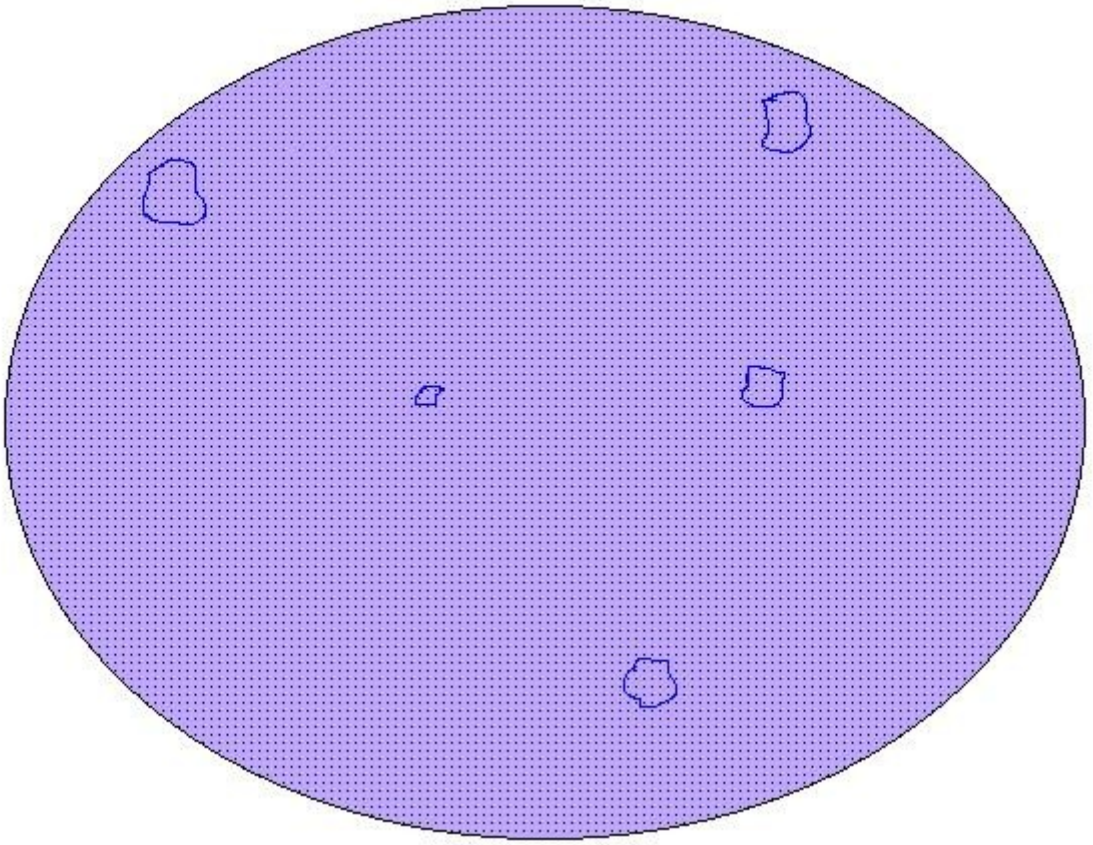
The clues

- Oldest stars are in the halo
- Next oldest stars in the bulge.
- Most gas and young stars in the disk.
- Halo and bulge stars have disorganized orbits
- Disk co-rotates.

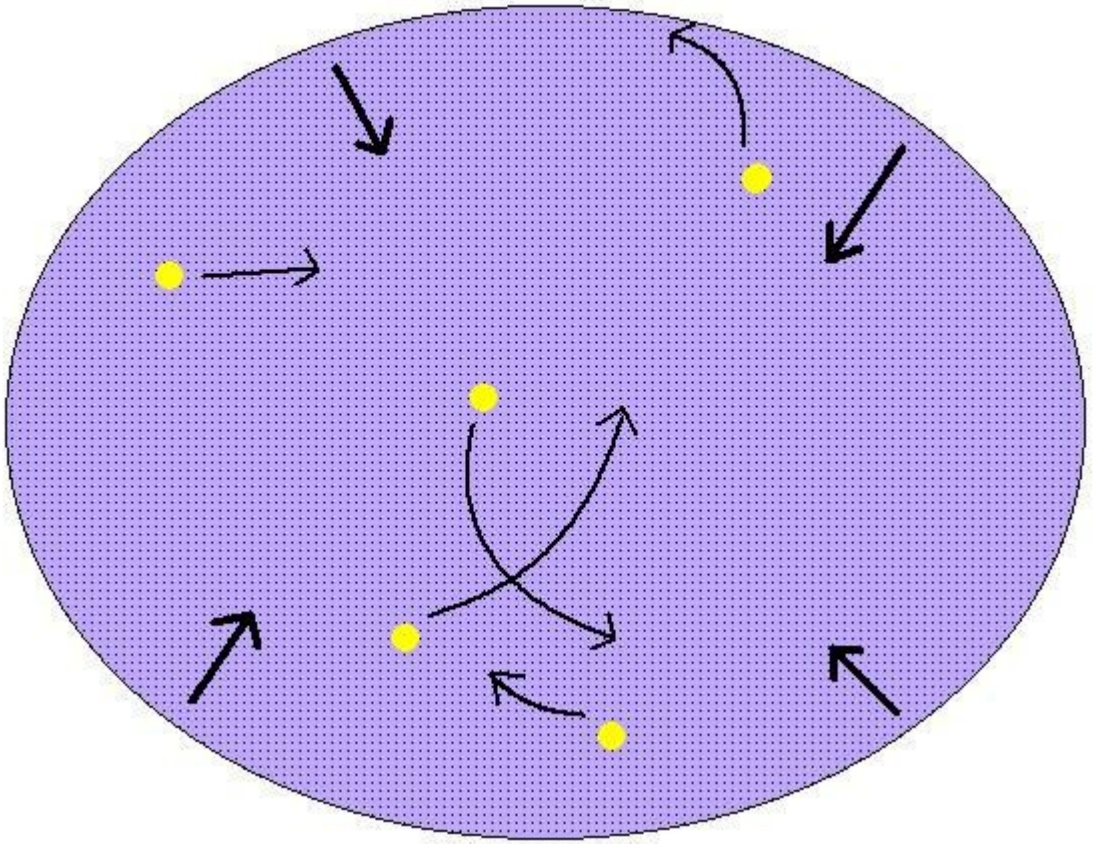
Galaxy starts out as an enormous ball of gas.
This ball of gas either already had, or during this stage will have Pop III stars.



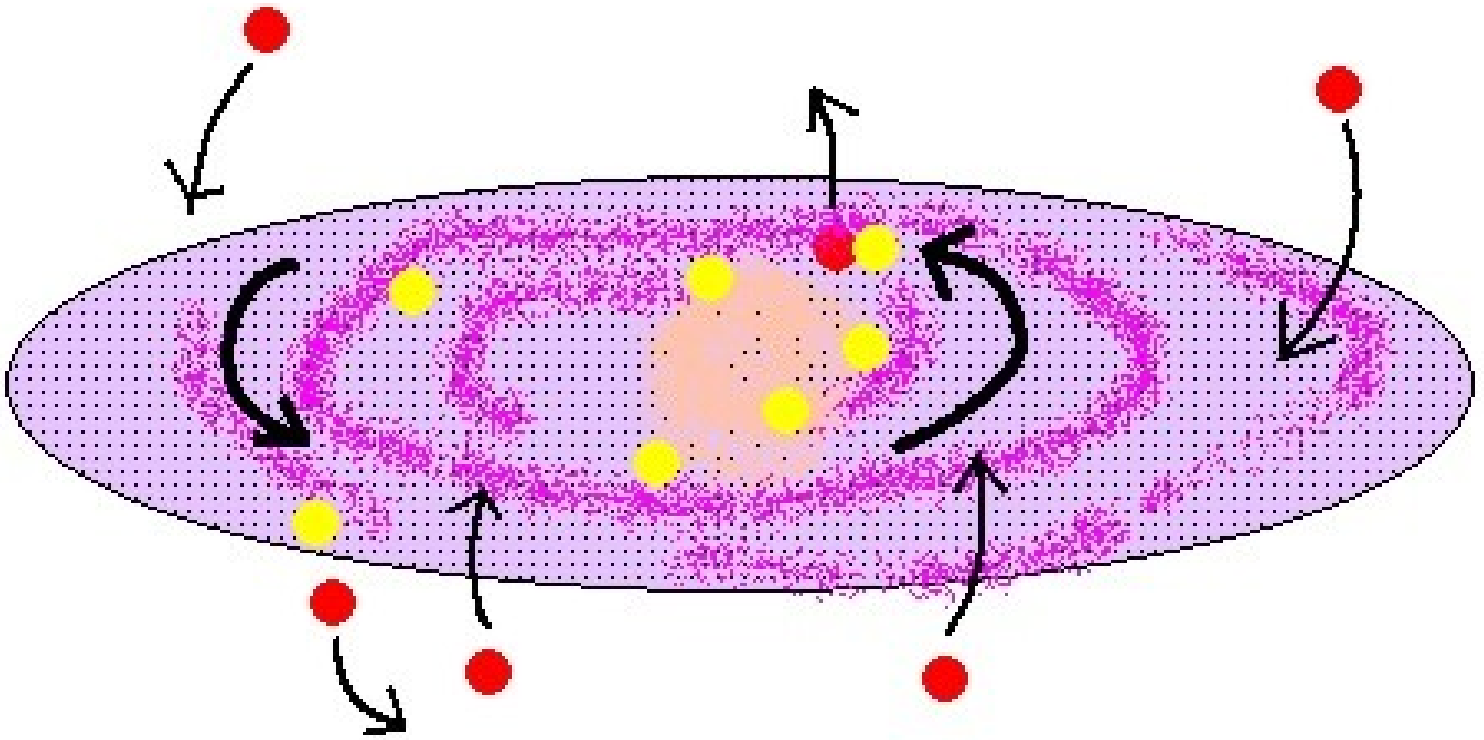
Some regions inside this ball of gas start to contract.



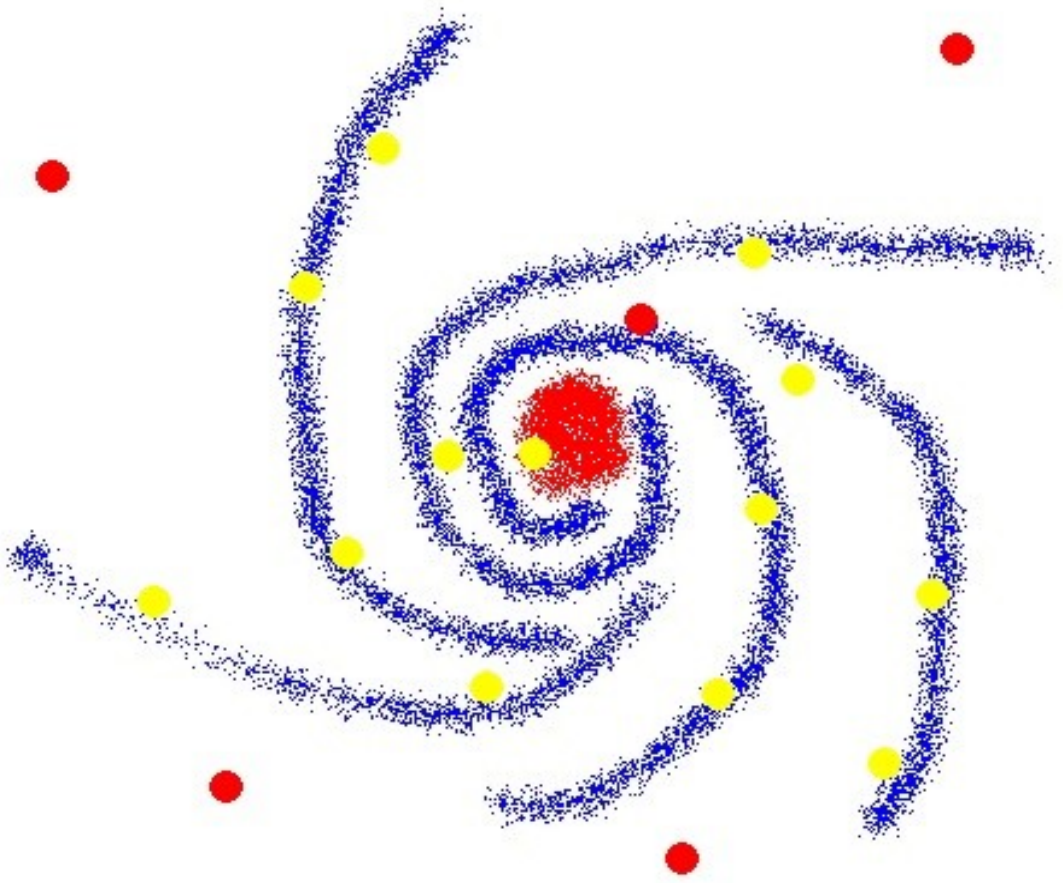
The first bits of cloud to contract have now formed globular clusters (Pop II stars).
Now the whole ball of gas begins to contract. The center compresses first, forming stars there.



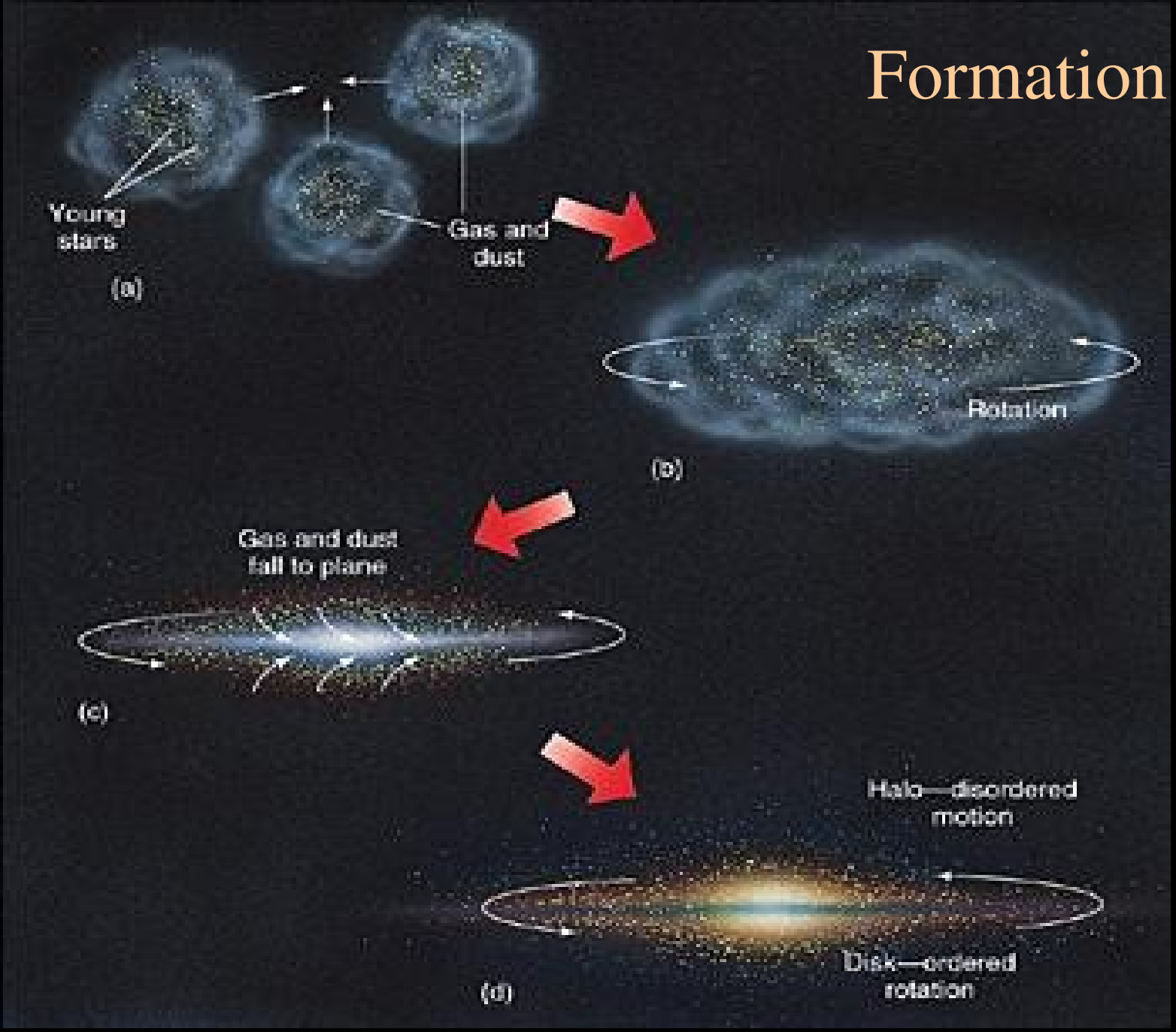
Massive stars in the globular clusters supernova, enriching the gas in the disk. The first stars (now Pop I) form in the disk.



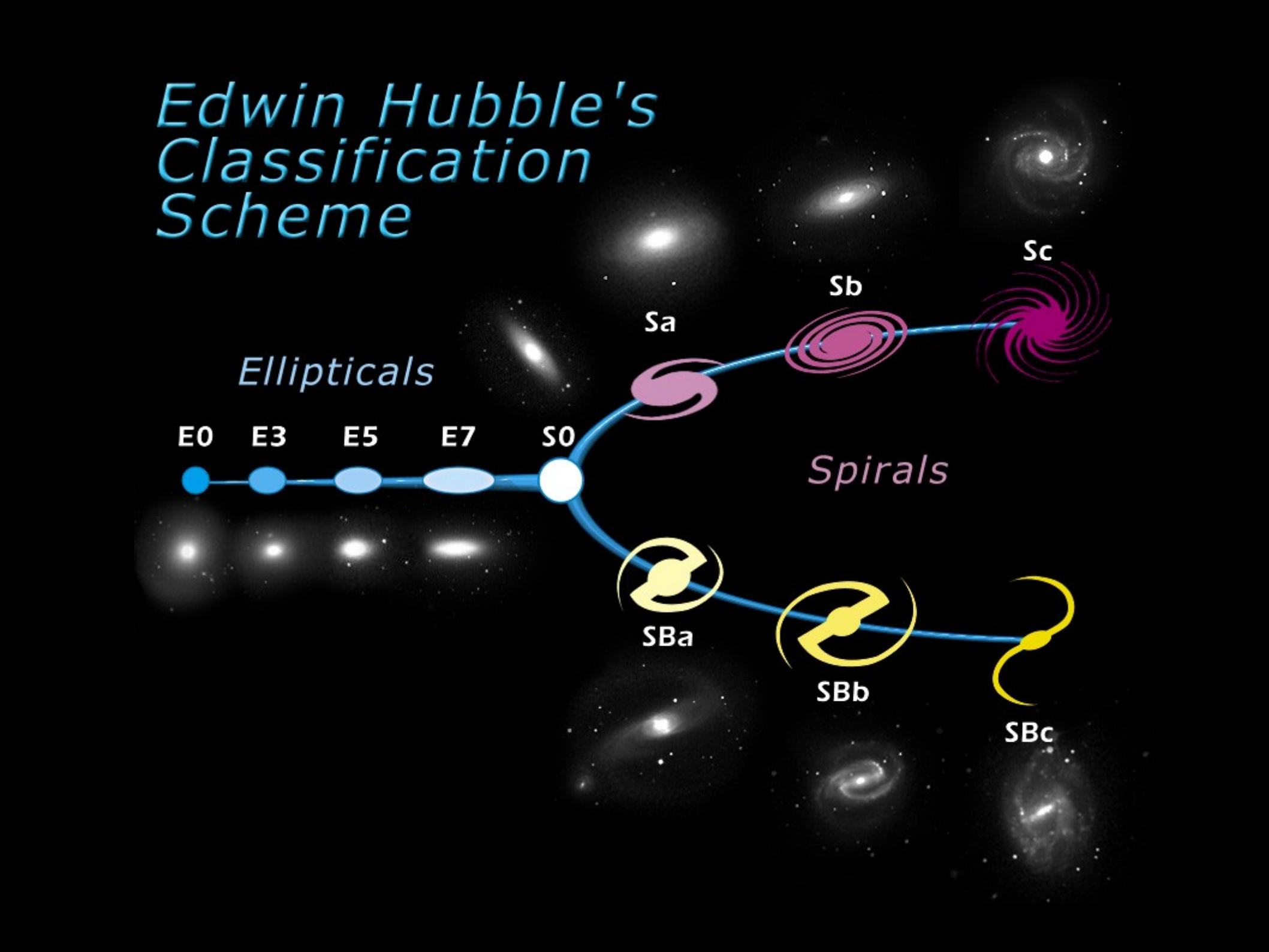
The spiral galaxy has now formed.
Supernova in the disk continue to enrich
the gas for generations of stars to come.



Formation


Young stars
Gas and dust
(a)
Rotation
(b)
Gas and dust fall to plane
(c)
Halo—disordered motion
Disk—ordered rotation
(d)


But not all galaxies are spiral


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

Elliptical Galaxies

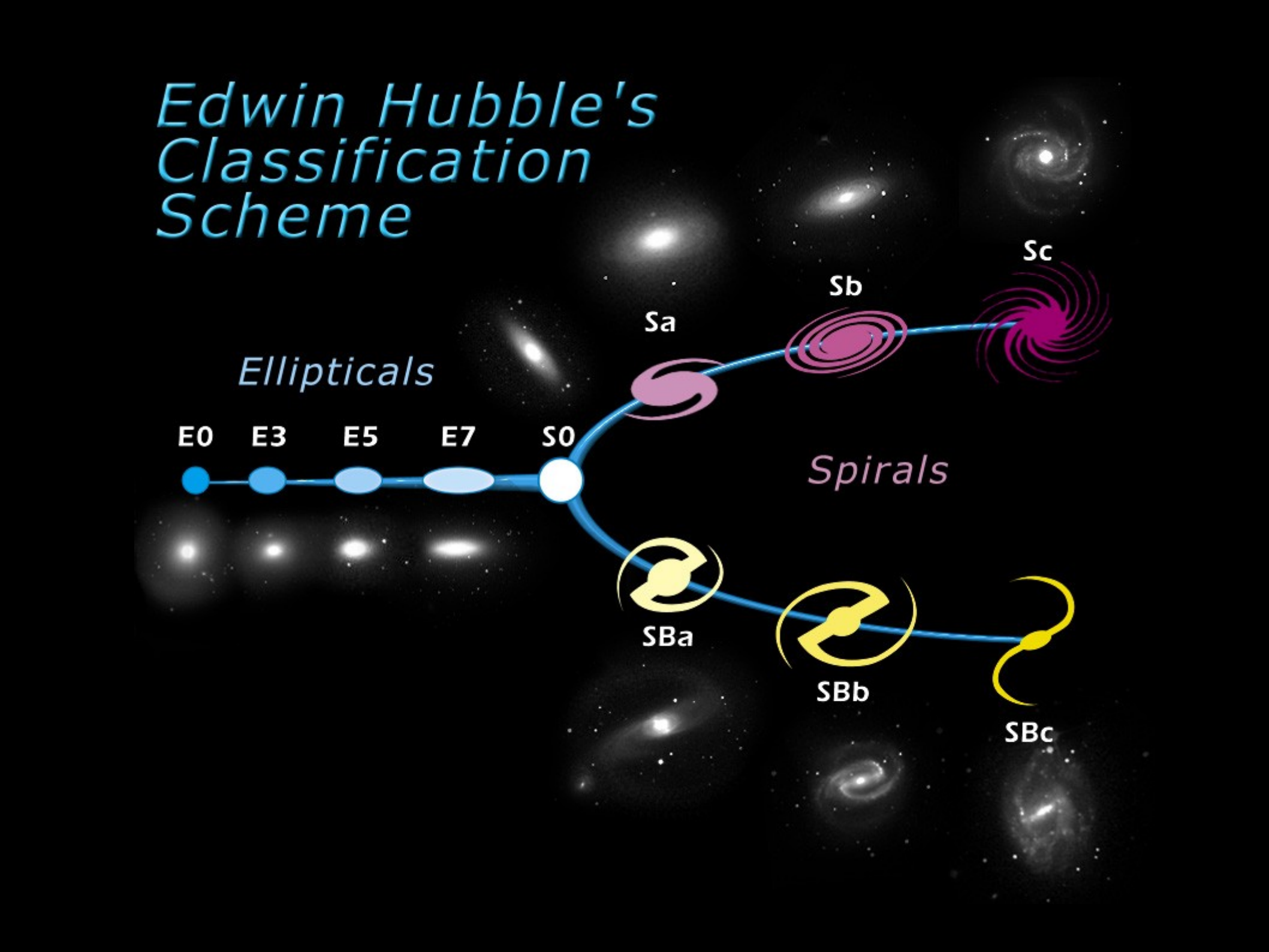
Elliptical are round, with no disk. They are essentially like the bulge of a spiral galaxy, but possibly quite a bit larger (though they come in all sizes). They contain Pop II stars, which orbit in random directions.
Elliptical galaxies have little dust and are red.

E1 E5

Elliptical Galaxies

How can you tell a face-on E5 from a side-view E1?

E1 E5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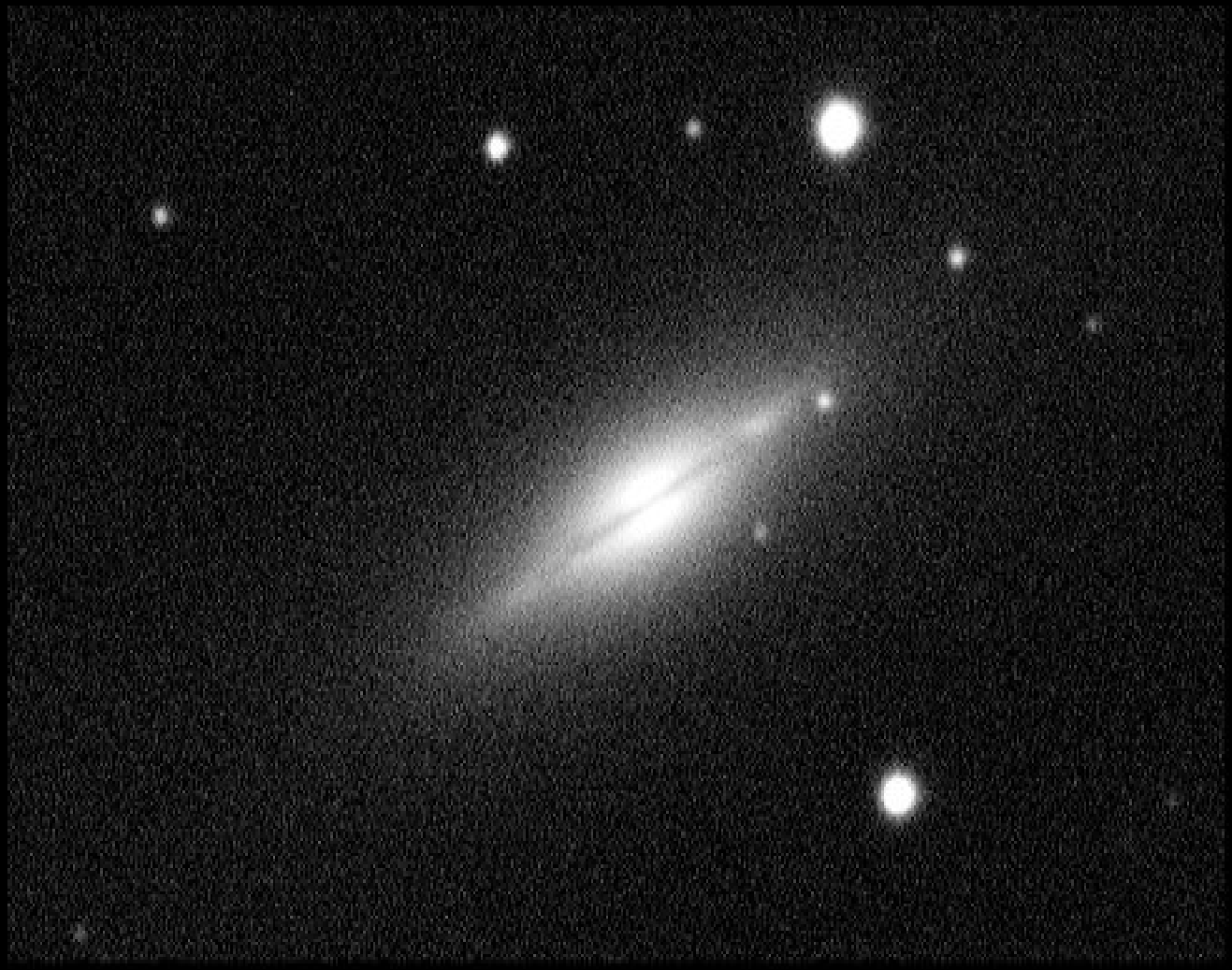
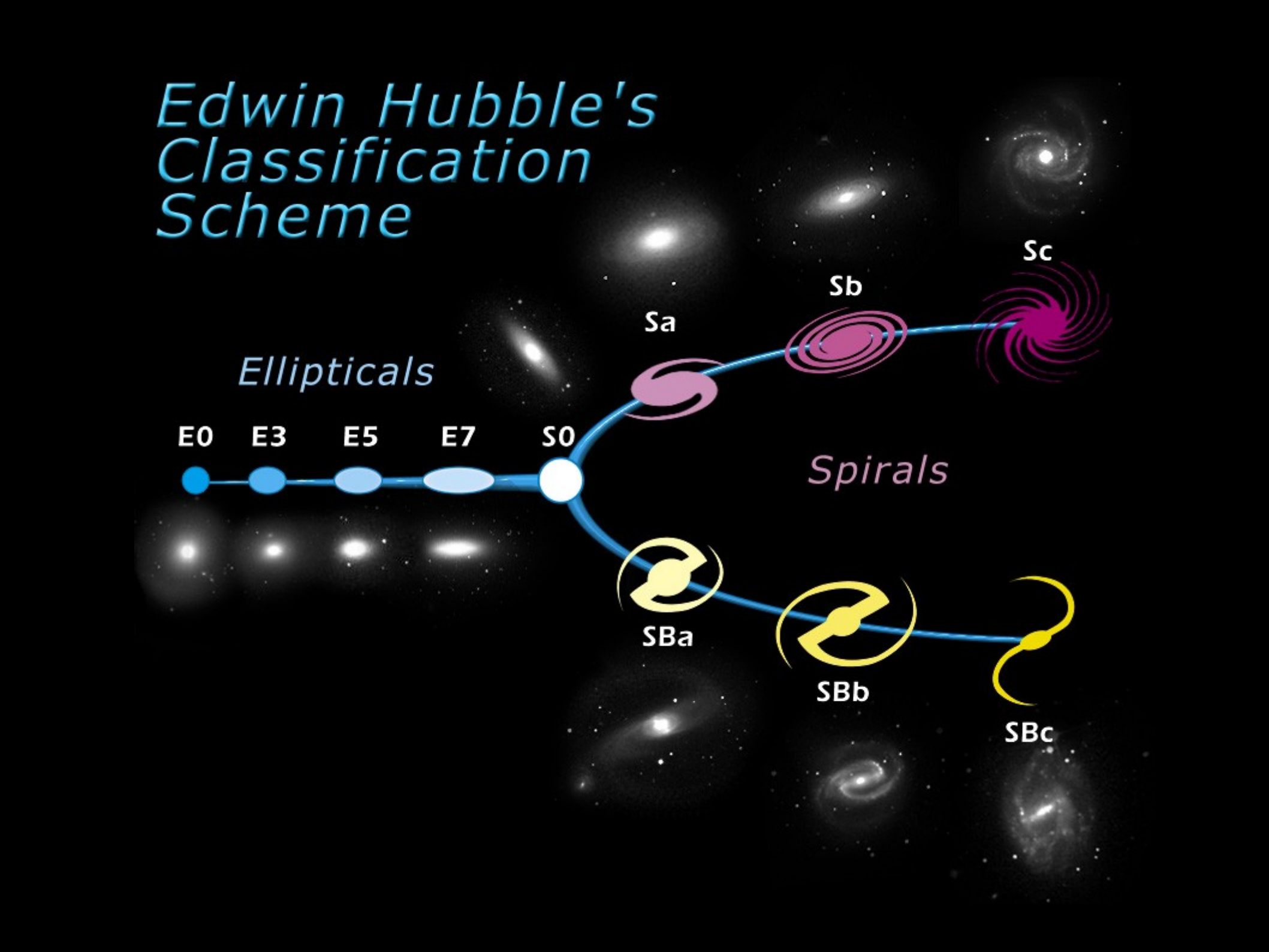
SBc

S0 galaxies

S0 galaxies are mostly bulge, but also have a small disk.

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Sb
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SBc

Spiral Galaxies:

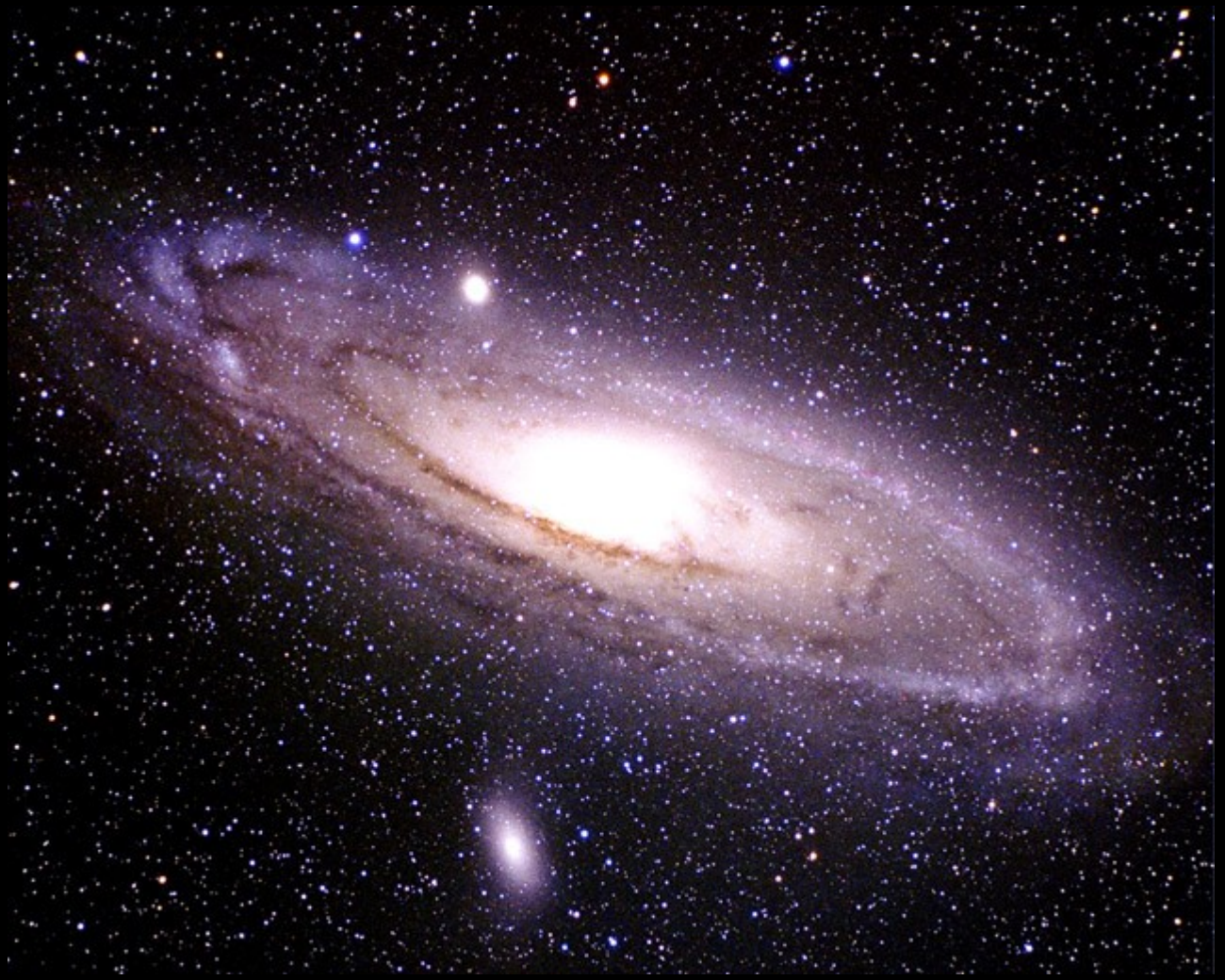
Spiral galaxies fall into 2 main categories:
Those with bars and those without bars.

Sa

This is an Sa galaxy: Big bulge, disk with spiral arms.

Sb

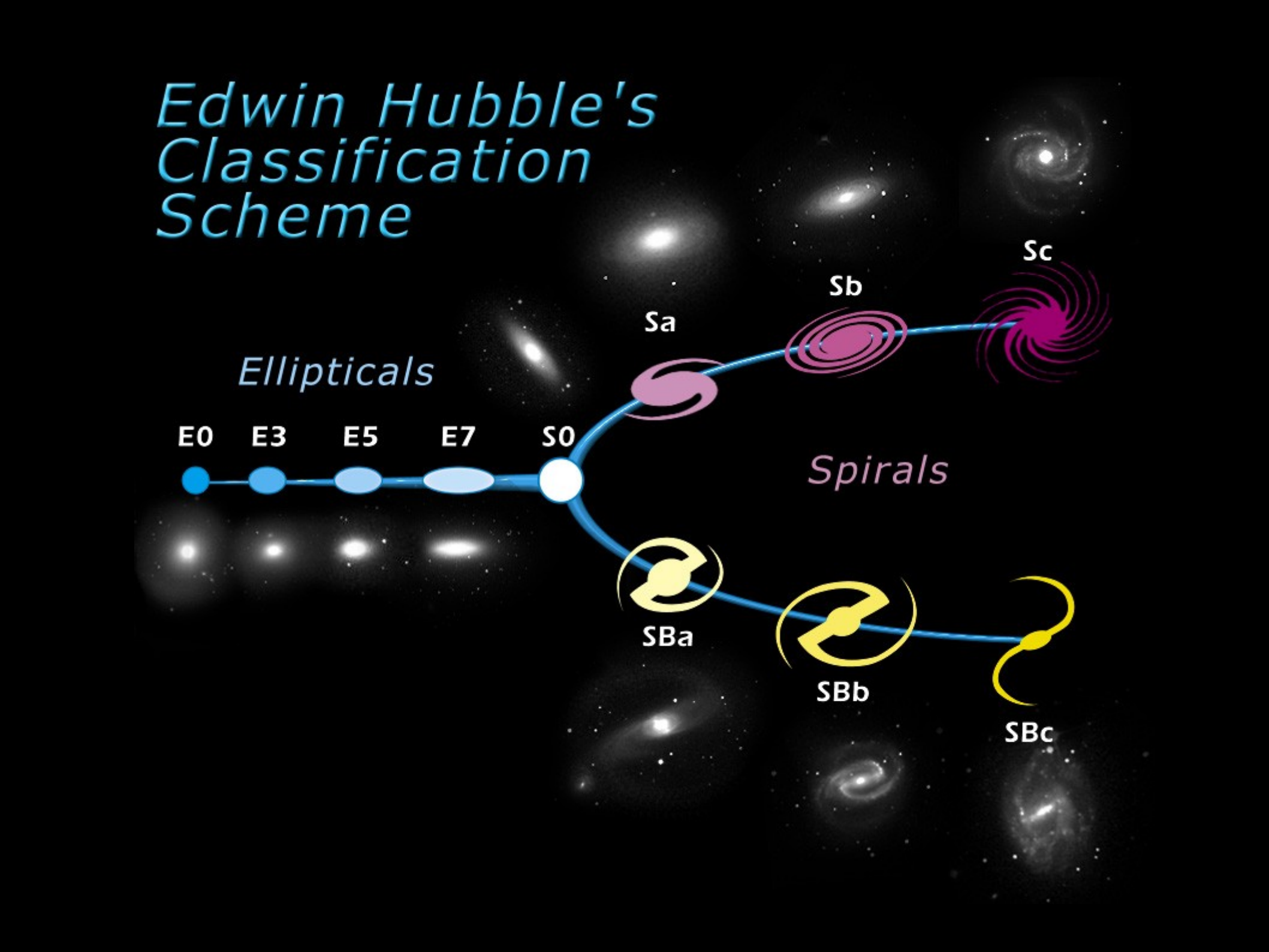
The bulge is smaller, the disk is relatively larger.



M33 © IAC/RGO/Malin
Photo from Isaac Newton Telescope plates by David Malin

Sc

Sc galaxies have the smallest bulges compared to their disks. Also, the spiral arms are not wrapped as tightly.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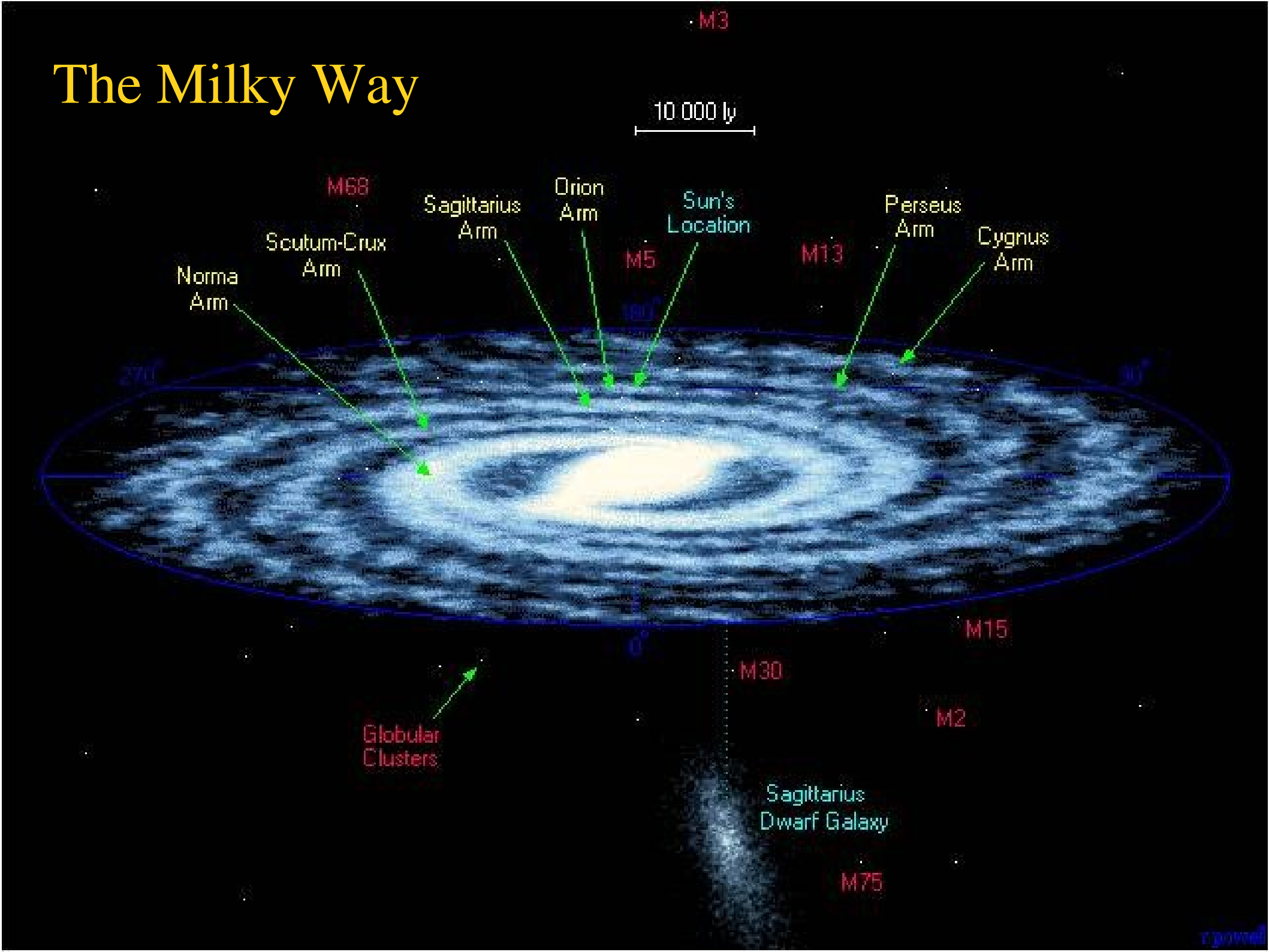
Barred spirals are the same as spirals, but with a bar.

The Milky Way



Irregular galaxies:
These are not on the Hubble tuning fork. They do not have a disk, nor are they elliptical.
They tend to be young, gas-rich and contain Pop I stars.

Take-aways

Our galaxy is a barred spiral galaxy, but that is just one type among several.

Galaxies are characterized by their appearance: elliptical, spiral, barred spiral, or the in-between S0 type. There are also irregular galaxies which don't fit on the tuning fork diagram.

Appearance is based on orbits of stars (elliptical=random, disk=organized) and amount of gas.