Astronomy 120

Prof. Jeff Kenney   Class 11 June 11, 2018

midterm exam

- thurs june 14 morning? evening?
- fri june 15 morning? evening?
- sat june 16 morning? afternoon?
- sun june 17 morning? afternoon?

observing session

- tomorrow night, tues june 12 IF CLEAR
- 8pm-11pm
- complete observing “pre-assignment” before coming
- planetarium show 8-9pm
- observing & observing assignmen

main questions on Galaxies:

- How do galaxies form & evolve?

- Why do galaxies have such a variety of appearances?

Galaxy properties

Fundamental:

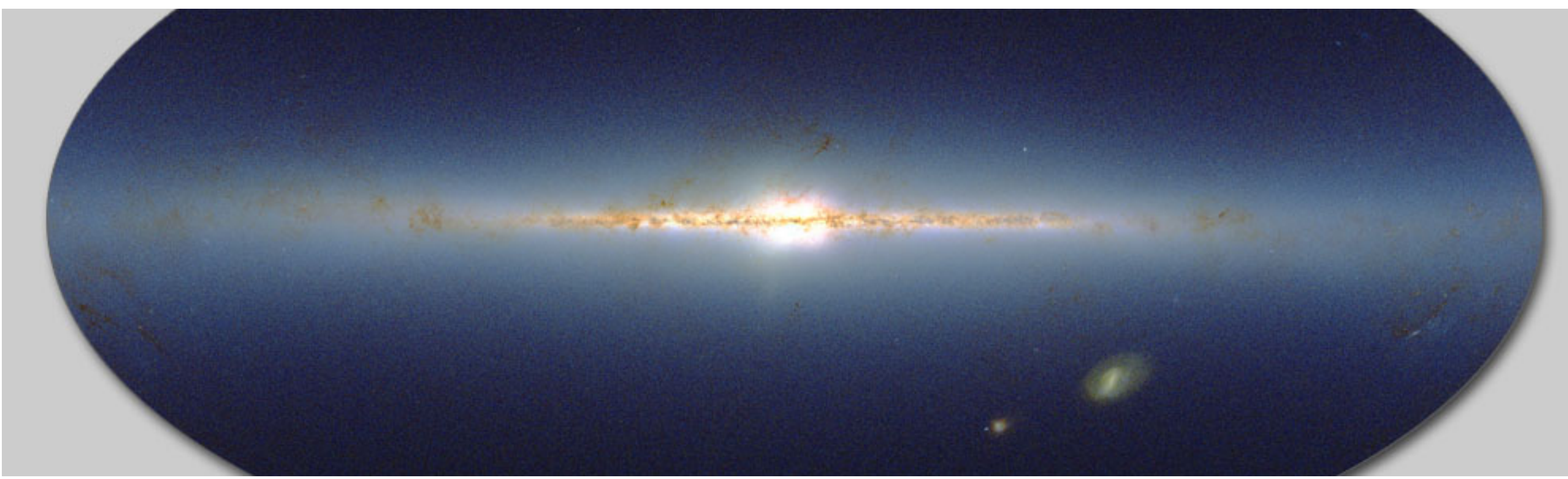
mass, spin (rotation), shape, gas content, ages of stars

Less fundamental:

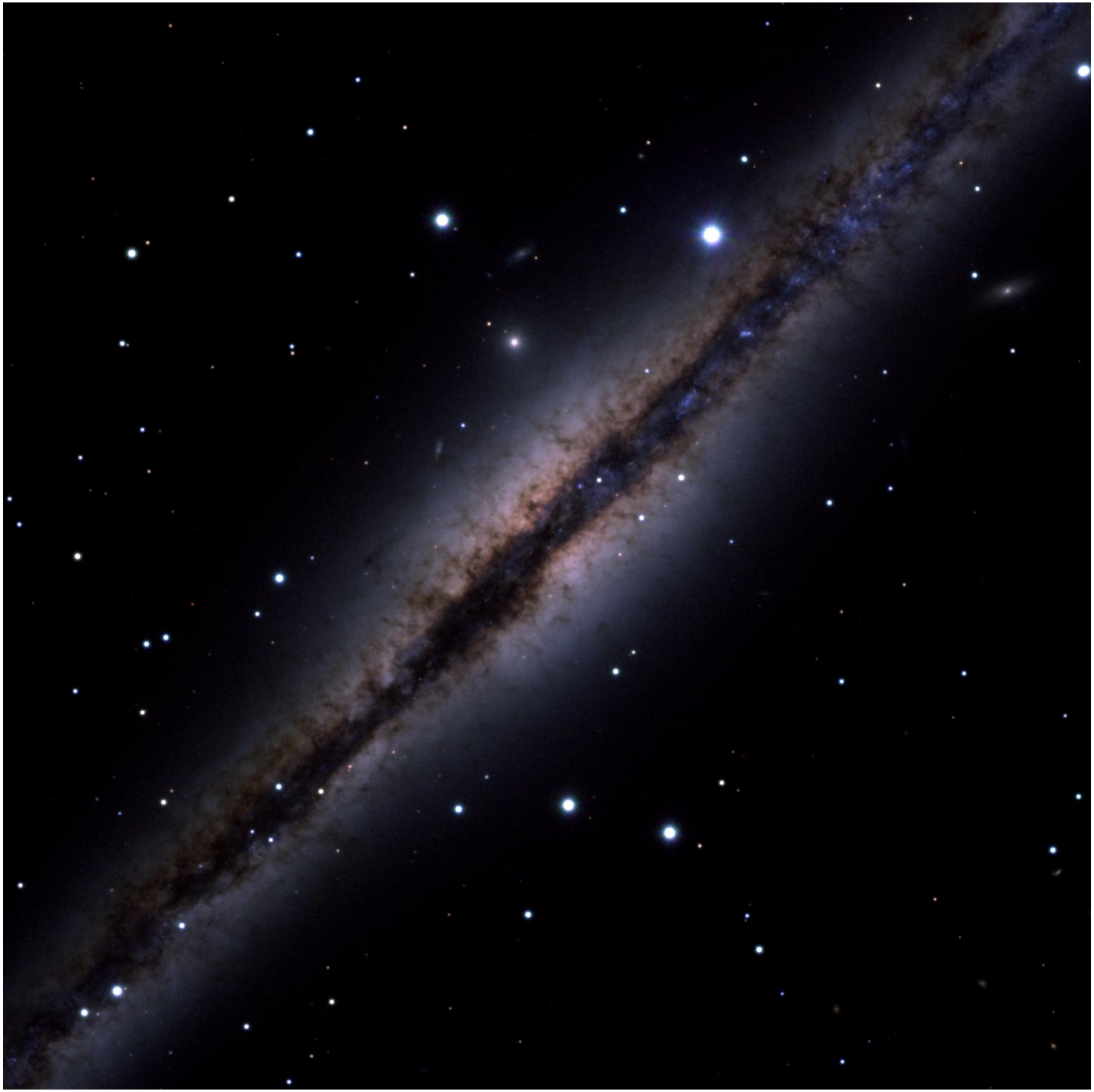
spiral arms, bars (but very interesting!)

Our Milky Way Galaxy, an Sb galaxy

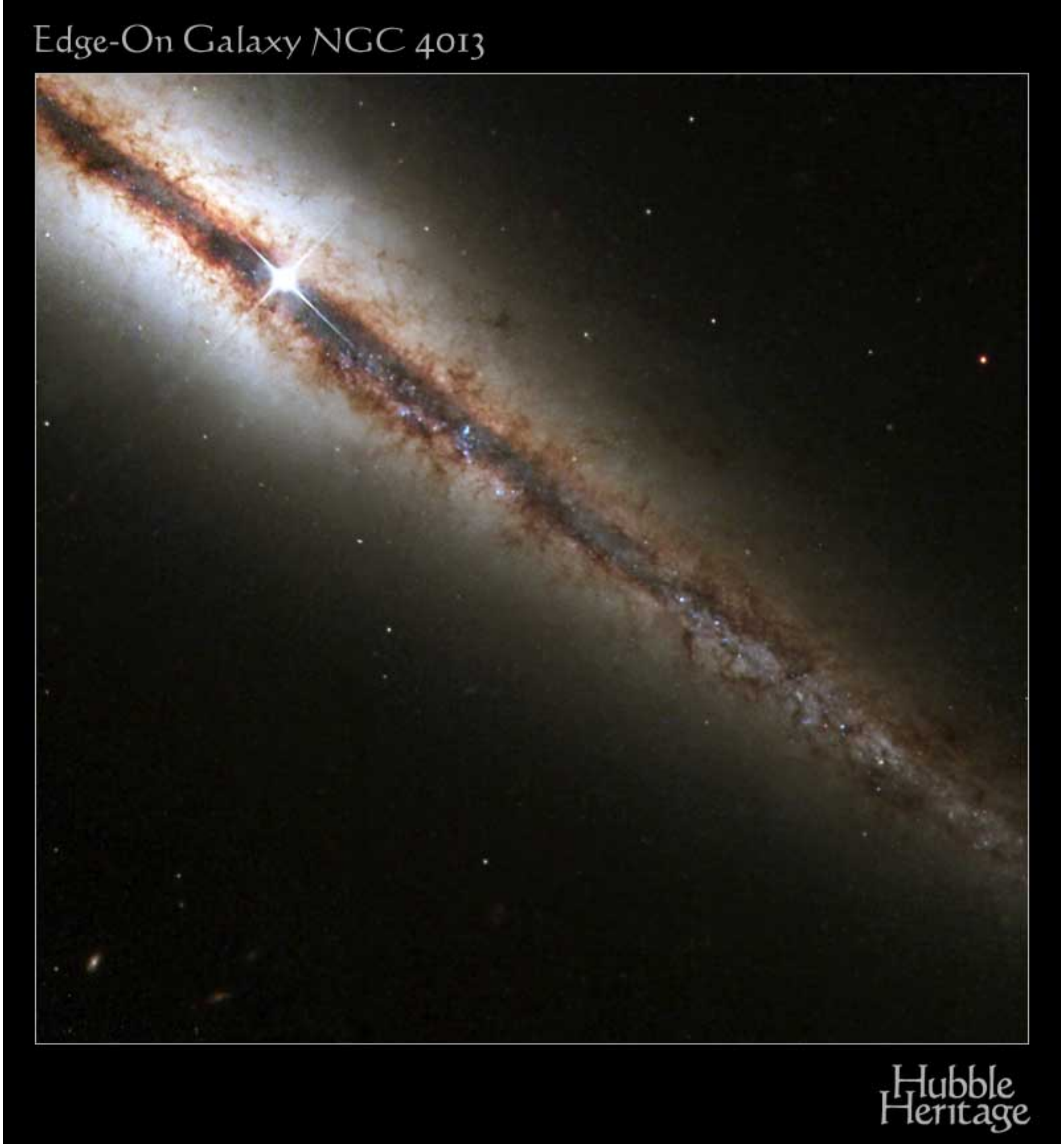
Milky way galaxy in optical (0.4 - 0.7μm)(B V R)



Milky way galaxy in infrared (1.2, 1.6, 2.2μm)(J H K)(2MASS)



NGC 891,
an Sc
galaxy
(edge-on)

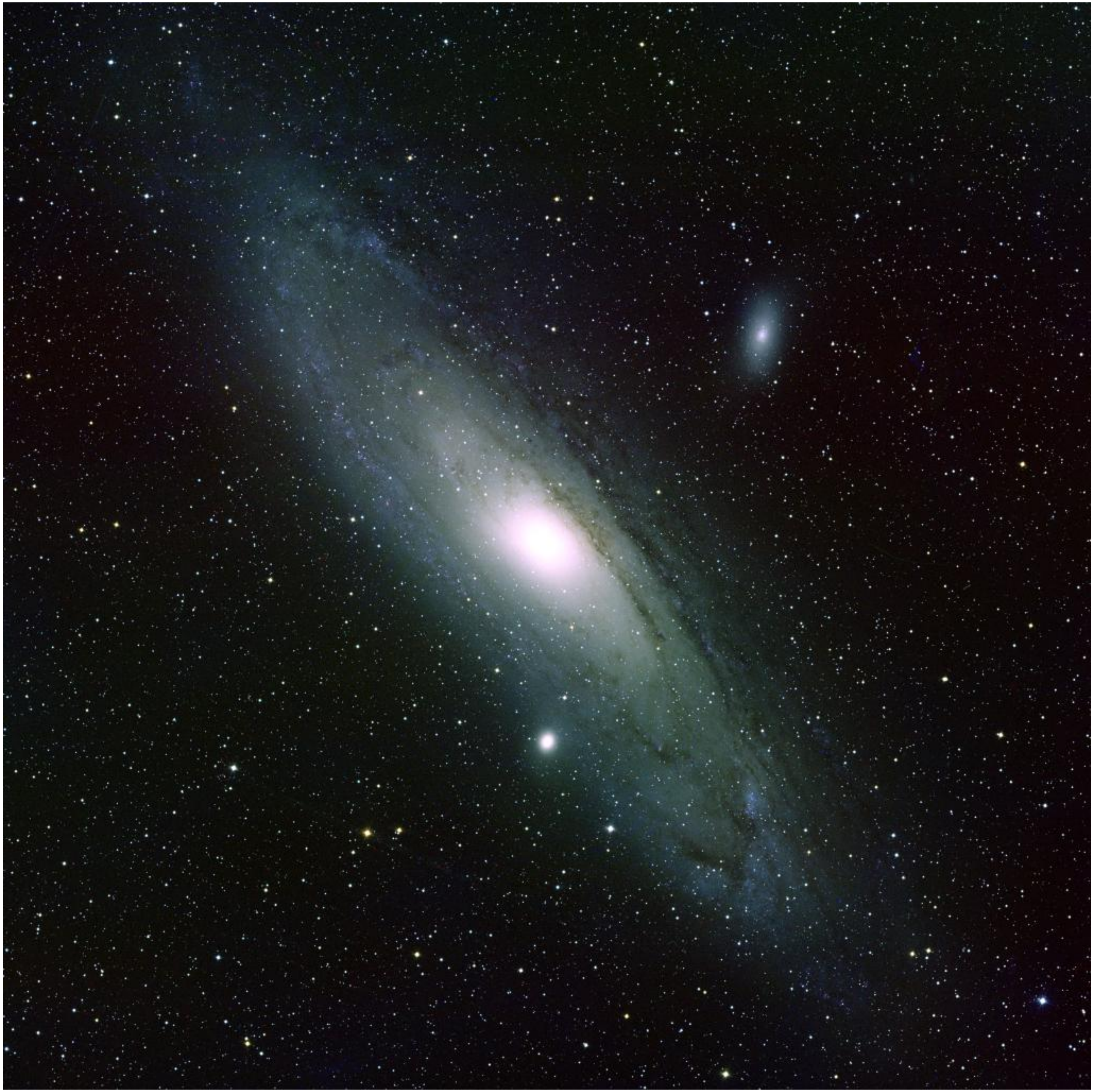


NGC 4013
an Sc spiral
(edge-on)

NGC 253, an Sc spiral – small bulge
(highly inclined but not quite edge-on)

NGC 3370, an Sc spiral (viewed at intermediate angle between edge-on and face-on)

M74, an Sc spiral (face-on)



M31 or Andromeda Galaxy

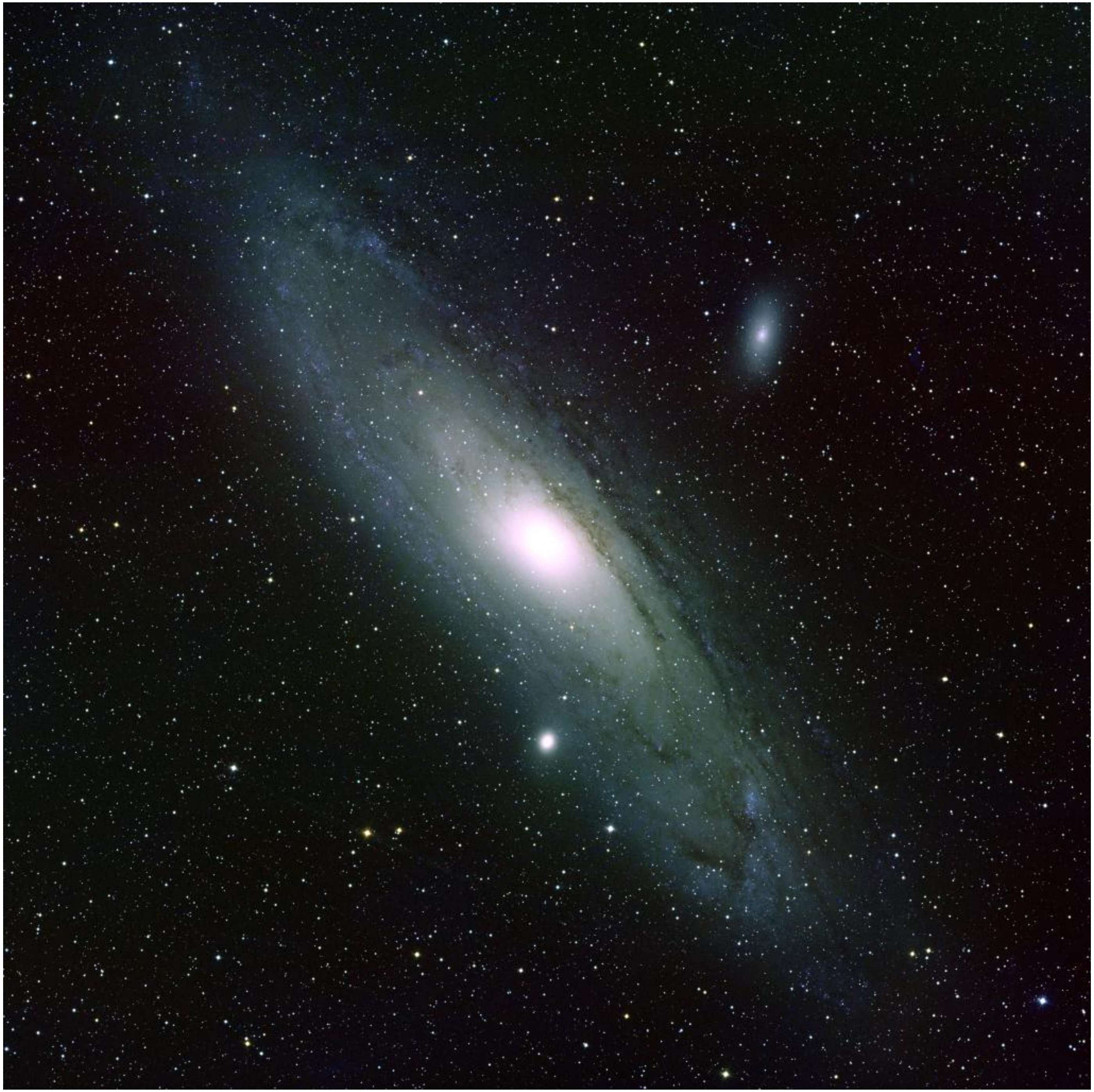
NGC 3370

What is main physical difference between M31 and NGC 3370?

A. M31 is more elongated
B. NGC 3370 has more prominent spiral arms
C. M31 is more massive
D. M31 is closer to Milky Way
E. M31 has bigger bulge

What is main physical difference between M31 and NGC 3370?

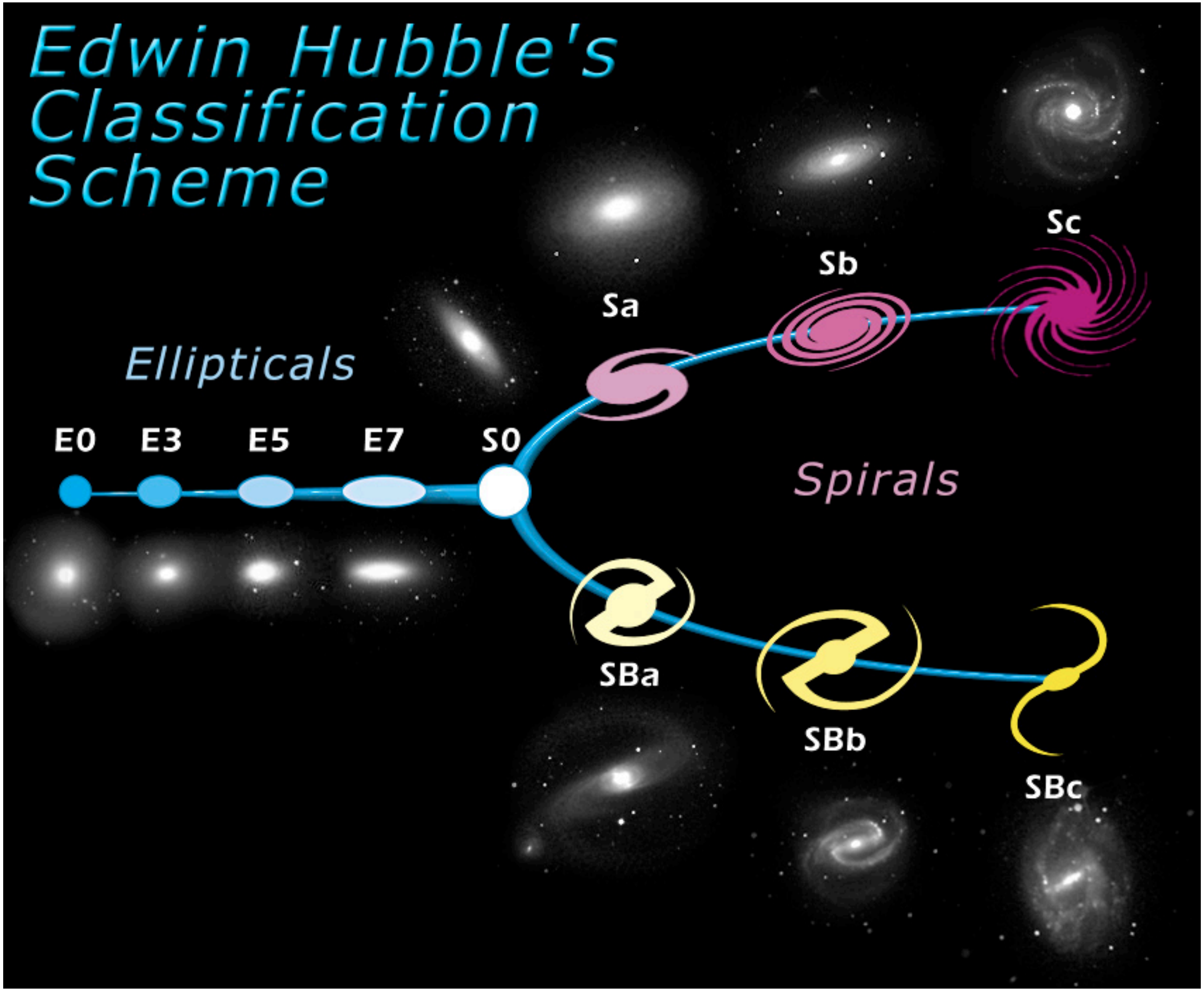
A. M31 is more elongated – appears to be more elongated, but this is due to different viewing angle, not different 3D shapes
B. NGC 3370 has more prominent spiral arms – true, moderately important (it has more gas & more star formation)
C. M31 is more massive – can’t tell from images, although mass is important property
D. M31 is closer to Milky Way – not a physical difference
E. M31 has bigger bulge – true, significant physical difference



M31 or Andromeda Galaxy

Sb spiral -- medium-sized bulge

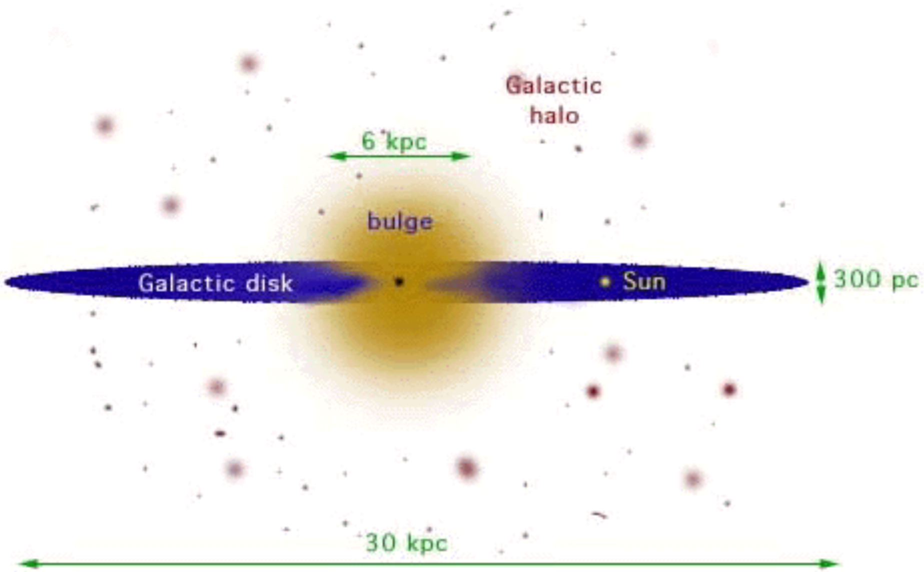
Sombrero Galaxy, Sa spiral – with large bulge


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

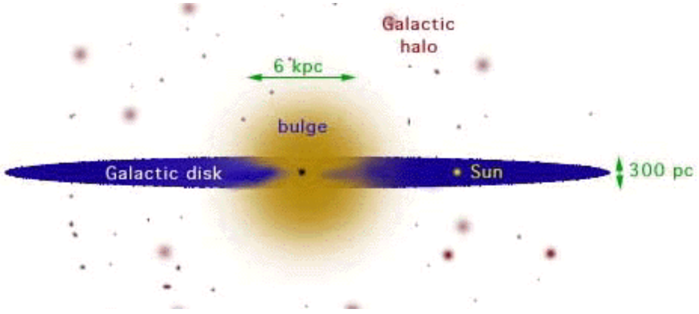
Spirals: contain disk & bulge

BULGE:

- not thin, extended in 3 directions
- Centrally concentrated
- Little or no gas & dust & star formation
- Like E galaxy in many ways



Spirals: contain disk & bulge



DISK:

- Thin
- Less centrally concentrated
- Contain gas + dust + star formation (& spiral arms)

Spirals: contain disk & bulge

BULGE:

- not thin, extended in 3 directions
- Centrally concentrated
- Little or no gas & dust & star formation
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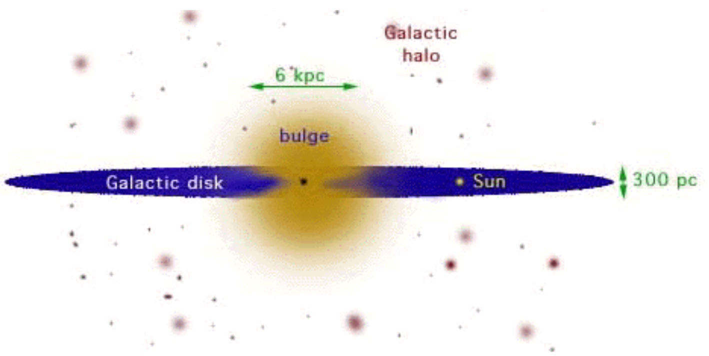
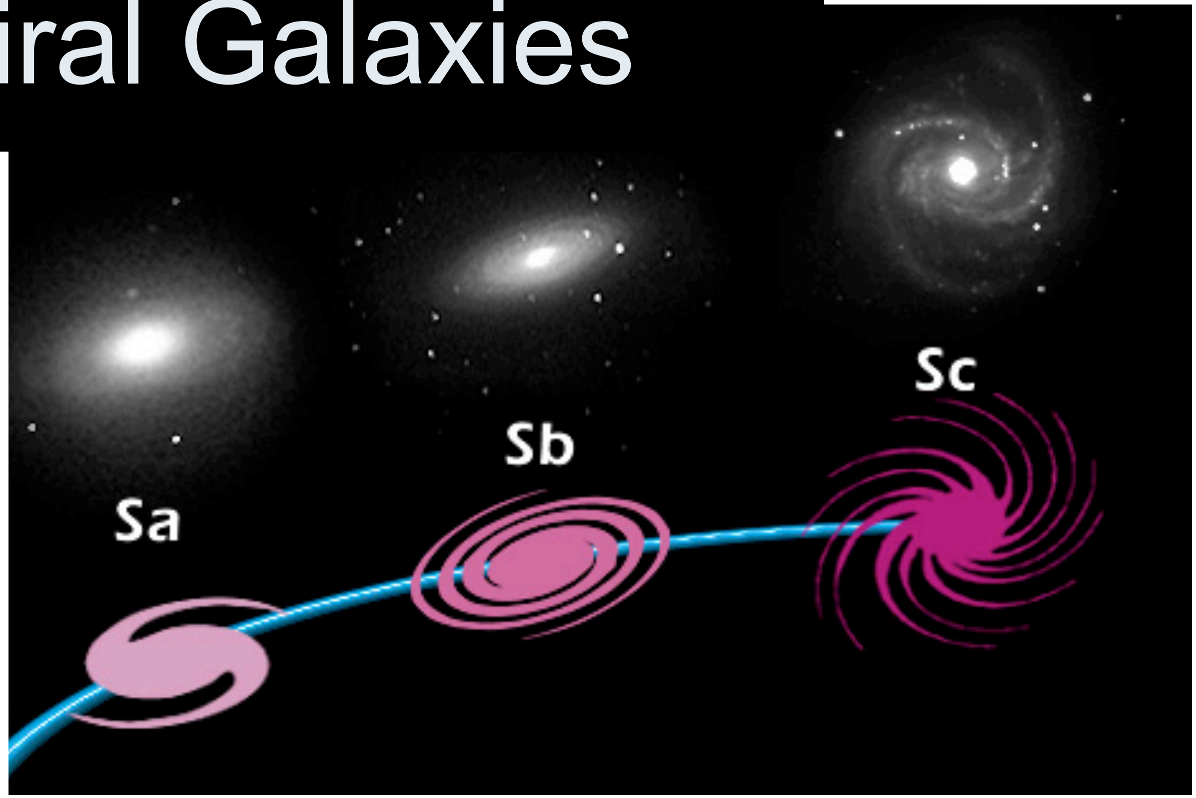


DISK

- Thin
- Less centrally concentrated
- Contain gas + dust + star formation (& spiral arms)

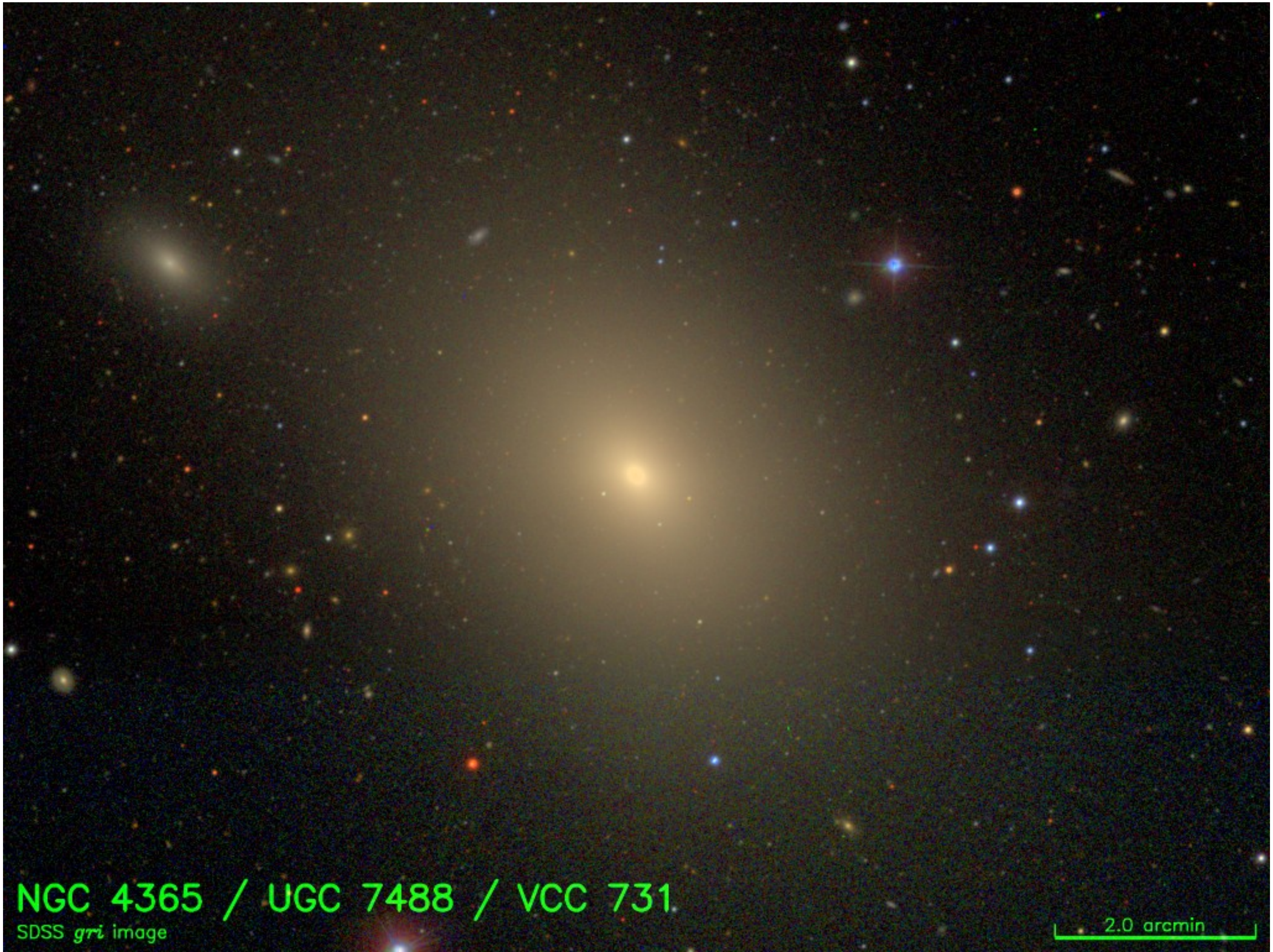
Spirals subclassified by Bulge/Disk ratio:
Sa's have larger bulges relative to their disks than Sc's

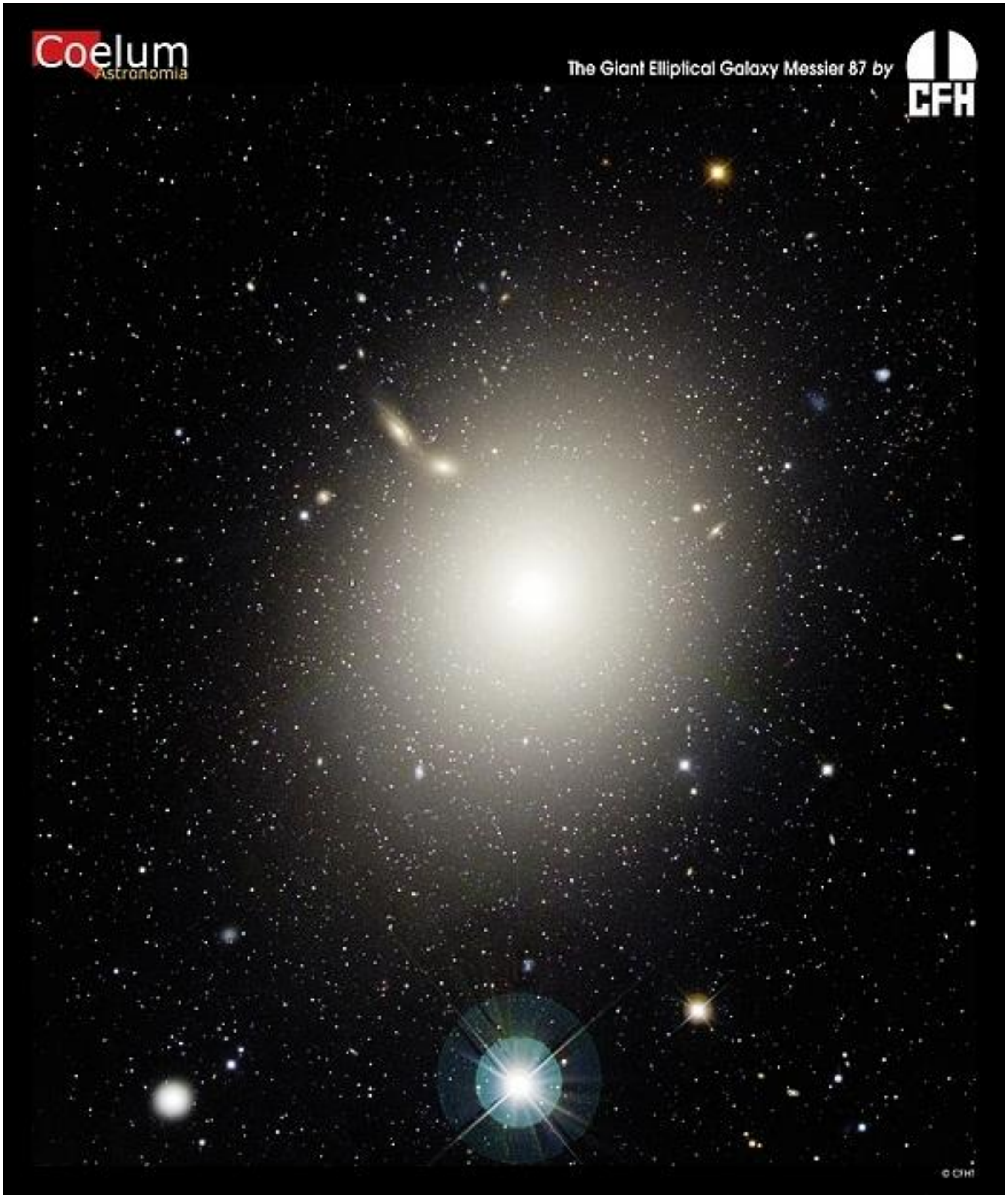
Spiral Galaxies



	bulge-to-disk ratio	spiral arms	star formation
Sa	large	tight	less
Sc	small	open	more

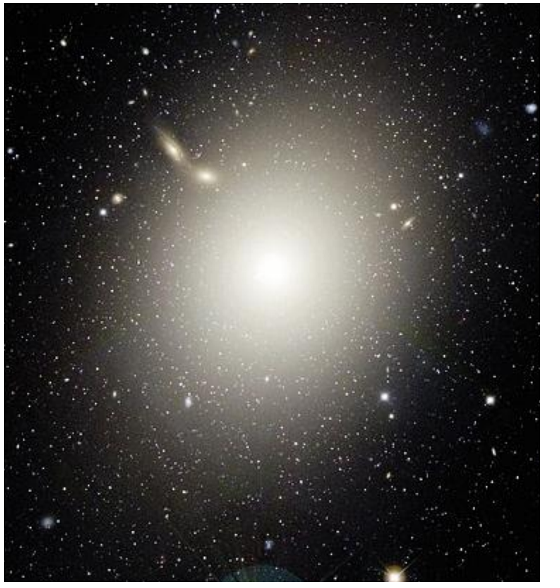
NGC 4365, an Elliptical





M87,
an Elliptical

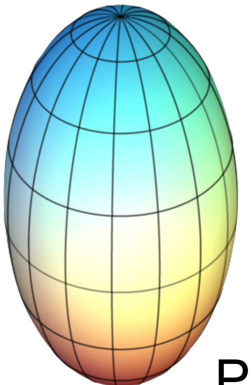
Ellipticals (E)



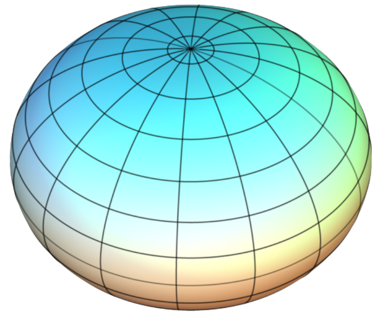
Shape:

- in projection: some round, most elliptical with maximum axial ratio 3:1
- in 3D: some oblate spheroids, some squashed footballs (triaxial ellipsoids)

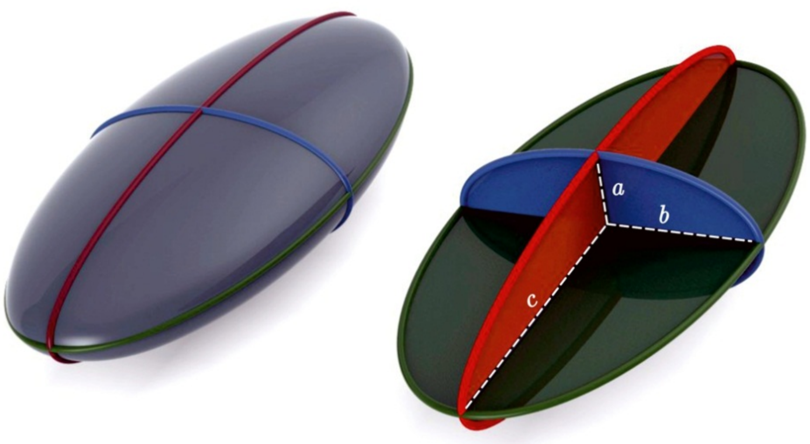
Possible 3D shapes of ellipticals



Prolate spheroid a=b<c
Hard to make these
Probably no E's like this

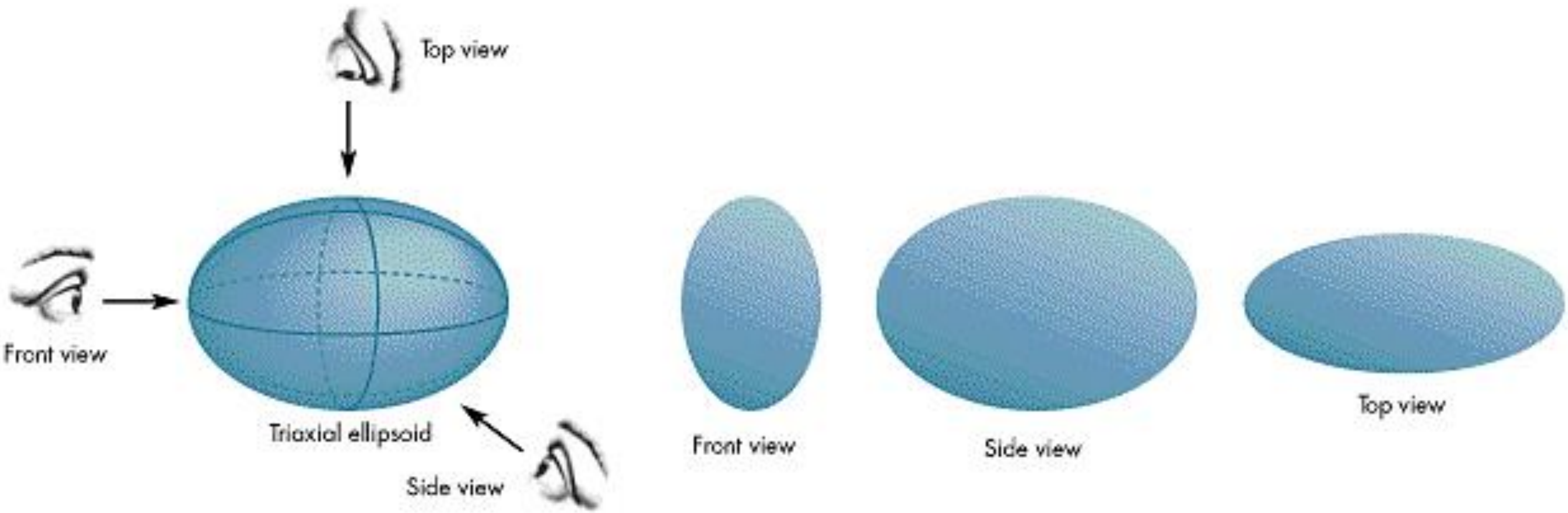


Oblate spheroid a=b>c
Can be flattened by rotatio
Some E's like this



Triaxial ellipsoid a<b<c
No rotational symmetry
Some E's like this

Triaxial ellipsoids



Triaxial ellipsoid $a<b<c$

No rotational symmetry

Projected 2D shape not circular from (almost) any angle

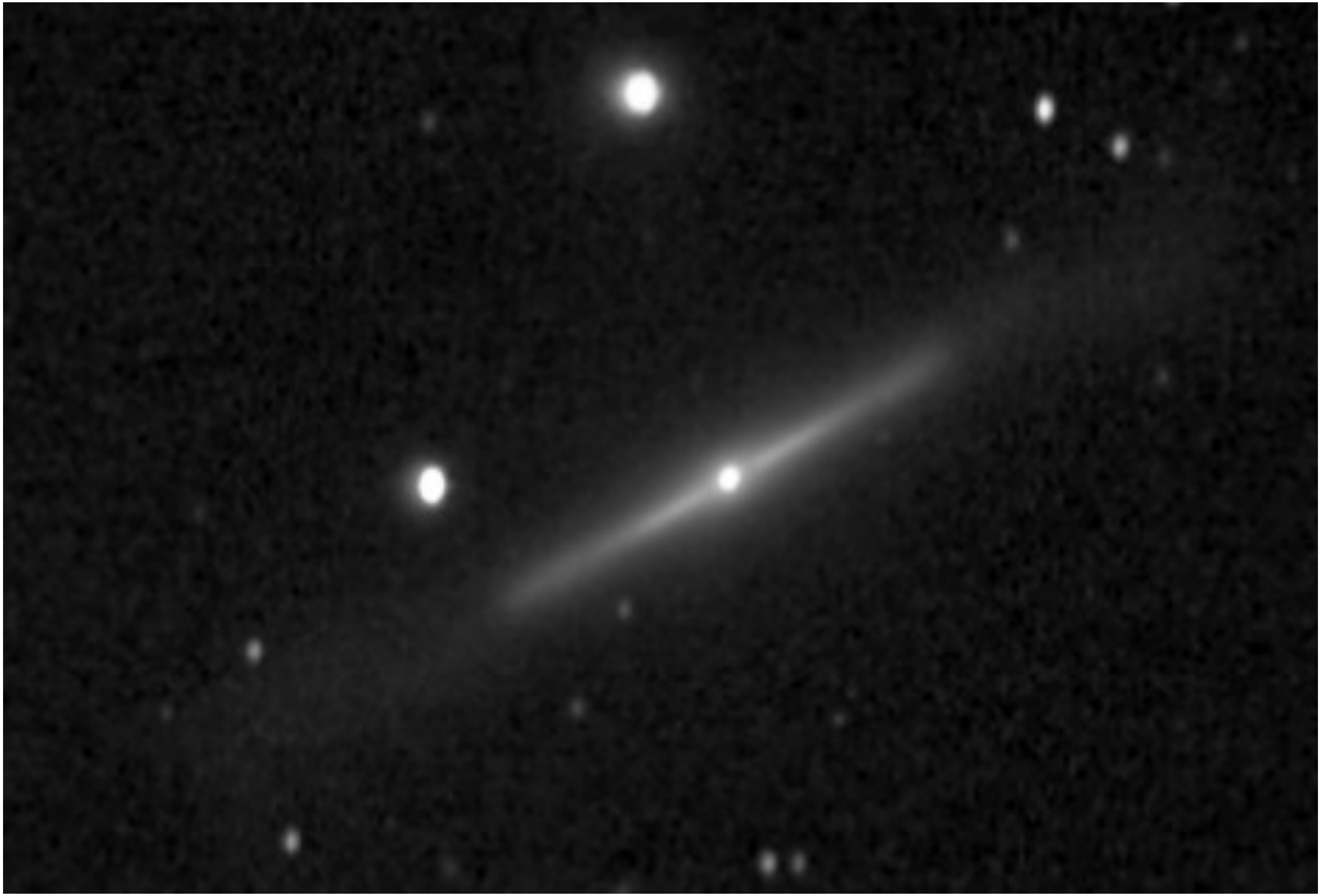
Ellipticals (E)

Shape:

- in projection: some round, most elliptical with maximum axial ratio 3:1
- in 3D: some oblate spheroids, some squashed footballs (triaxial ellipsoids)

Smooth, featureless appearance →

no young stars or (much) dust or cold gas



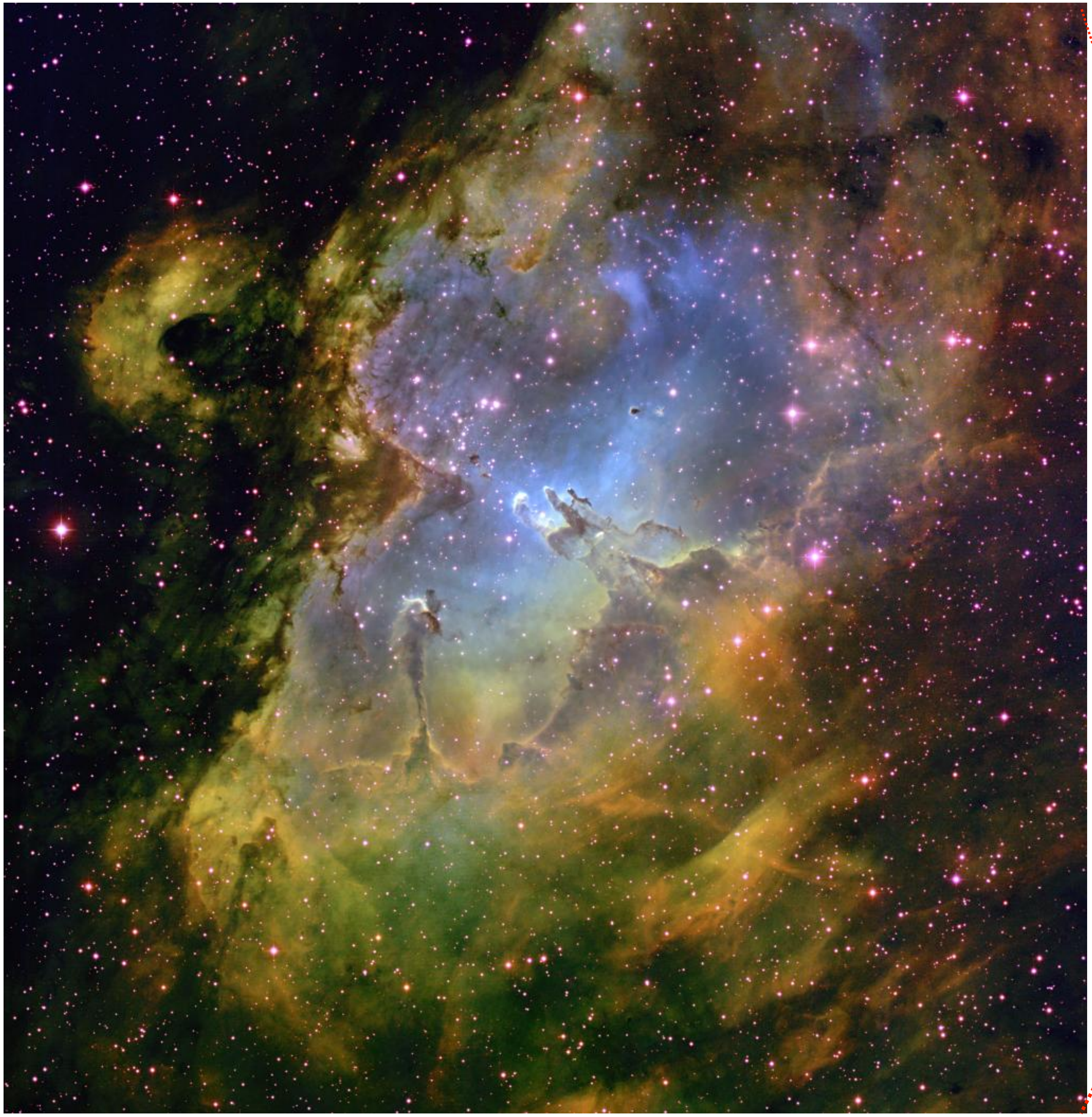
NGC 4762, an S0 galaxy (edge-on)

NGC 891, edge on Sc spiral

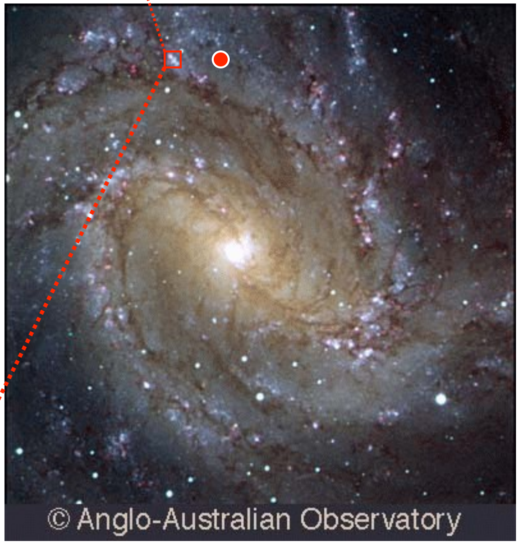
Eagle Nebula

(in Milky Way)

Cloud of Gas & Dust which is forming stars

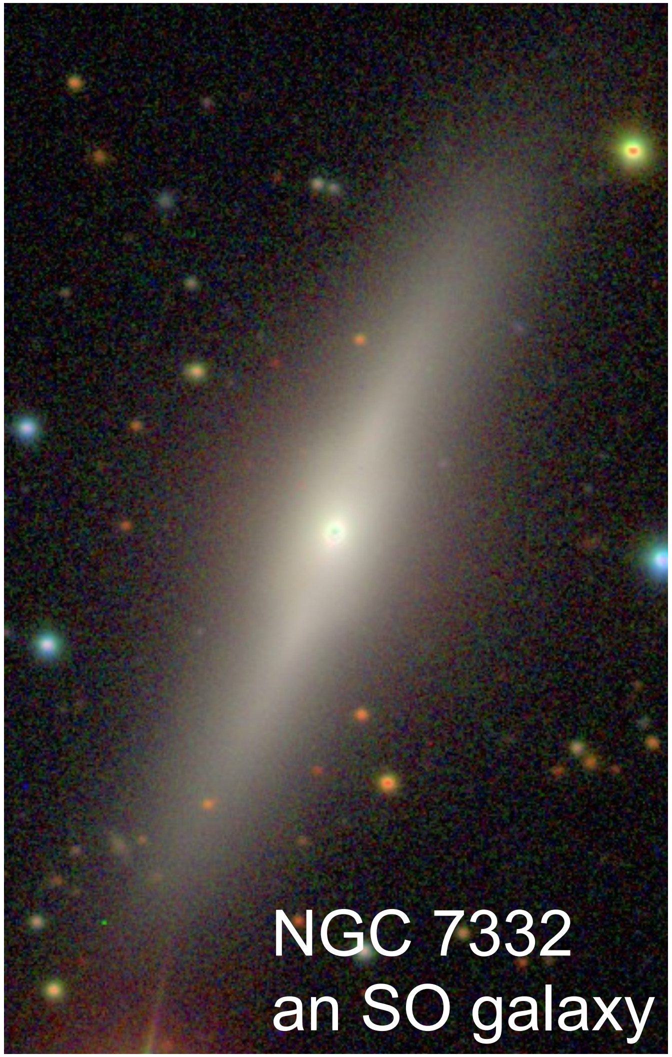


M83 Spiral Galaxy

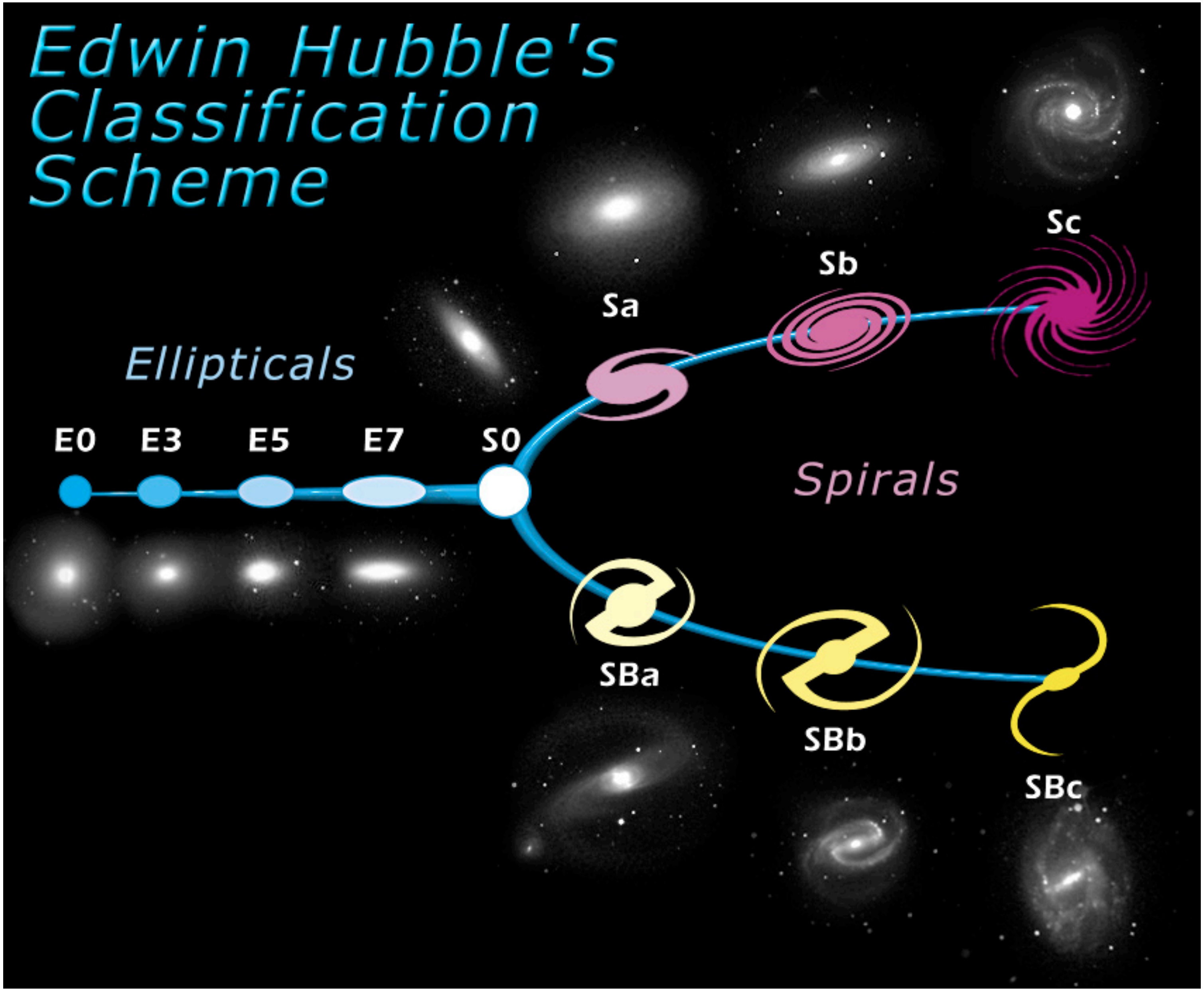


Lenticulars (S0's)

- Contain disks & bulges, like spirals
- But unlike spirals, disks have no gas & dust & star formation (or spiral structure)
- Like dead or inactive spirals



(edge-on)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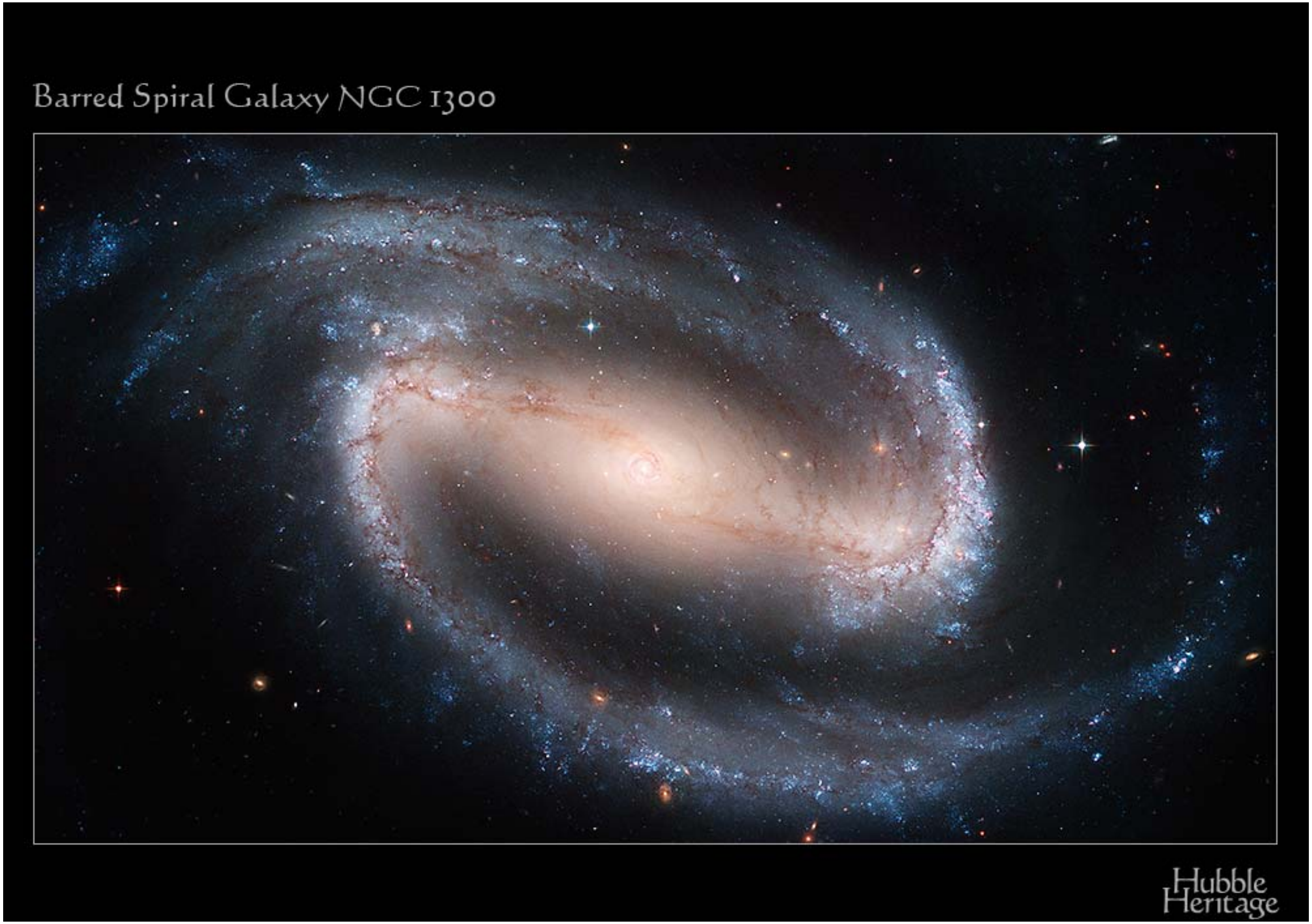
M109 -- Barred Sb galaxy

(similar to the Milky Way; & viewed at intermediate angle)



NGC 1300, a Barred Sb

Bars

- Linear stellar feature of uniform brightness centered on nucleus
- Stellar orbits become elongated and aligned to make bar

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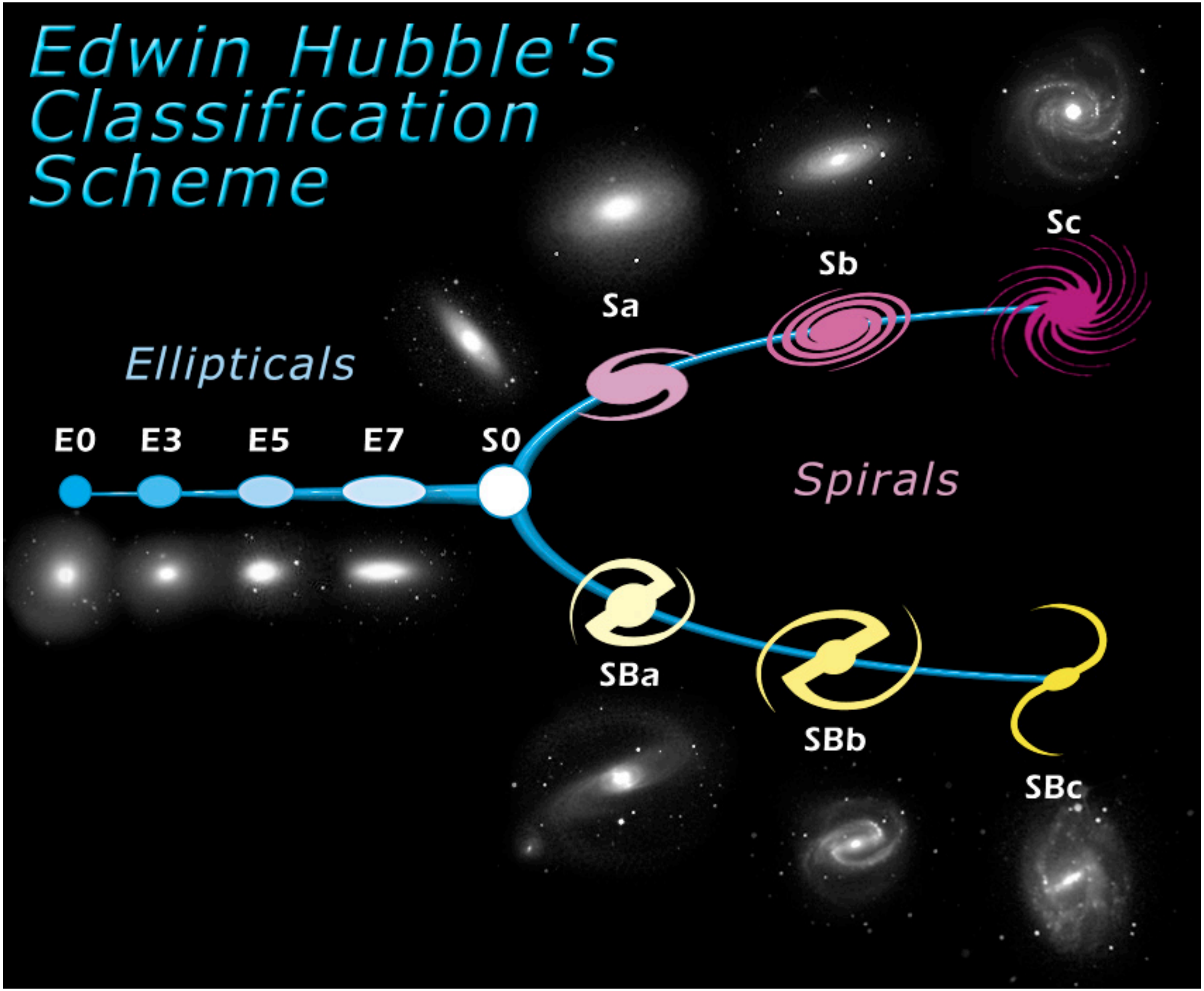
- Something that happens in some disks, can be caused by interaction with another galaxy
- May not be permanent feature of galaxy

Bars

- Linear stellar feature of uniform brightness centered on nucleus
- Stellar orbits become elongated and aligned to make bar
- Something that happens in some disks, can be caused by interaction with another galaxy
- May not be permanent feature of galaxy
- About ½ of spirals and S0's have bars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Limitations of Hubble Classification Scheme

apparent ellipticity of Ellipticals – depends on viewing angle – not true shape; also true shape not so fundamental

3 different criteria for subclassifying spirals unsatisfactory -- parameters not perfectly correlated (uncorrelated in some galaxies)

bars – not all or nothing, there is continuum of bar strengths. also bars not that fundamental – they come & go

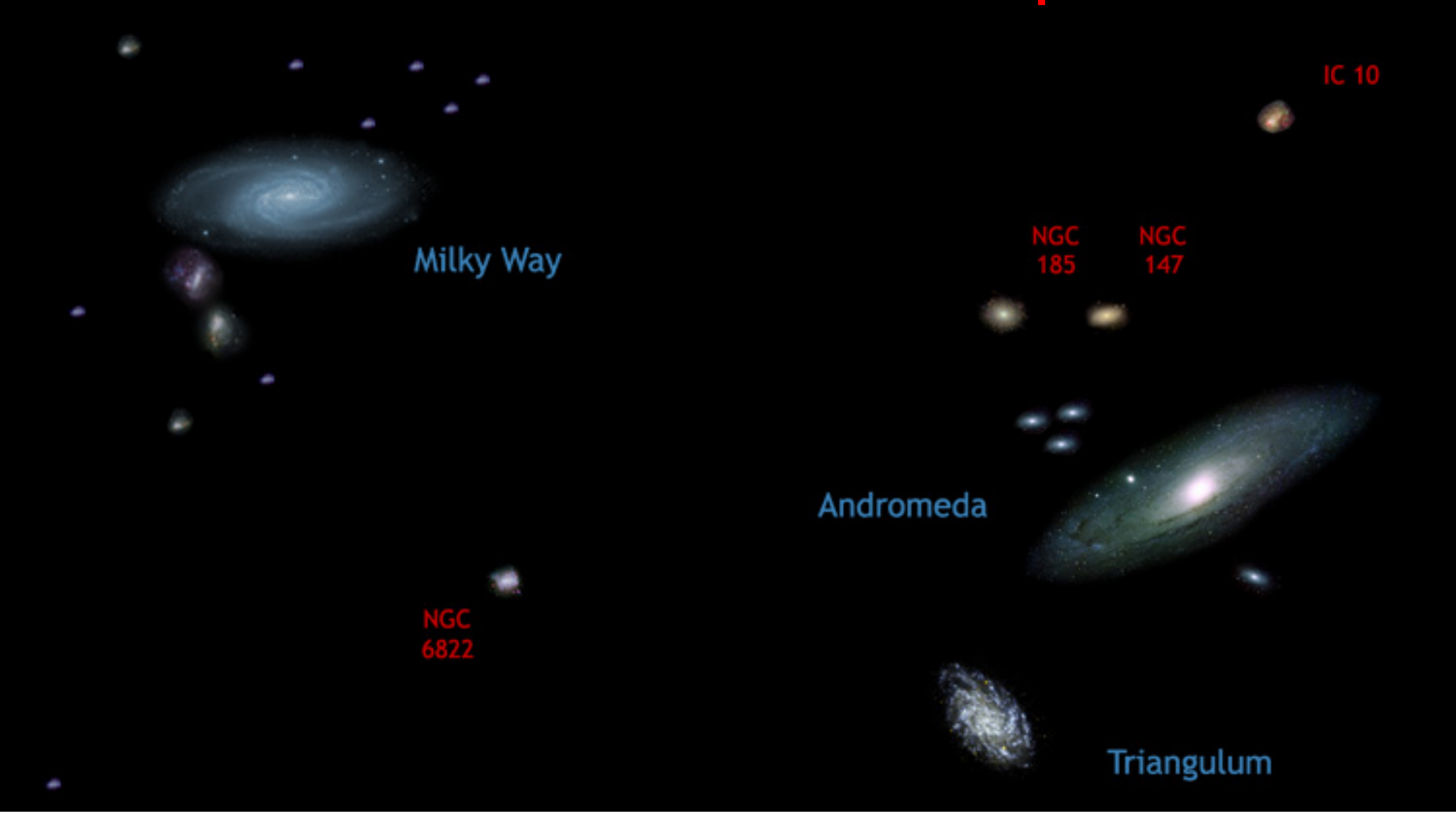
relation between E's, S0's, spirals not so simple

Limitations of Hubble Classification Scheme

Hubble scheme omits most of galaxies in the universe!

- small galaxies
- interacting & starburst galaxies -> galaxies in interesting evolutionary phases
- low surface brightness galaxies
- most massive galaxies in universe – cDs – large E's in some clusters

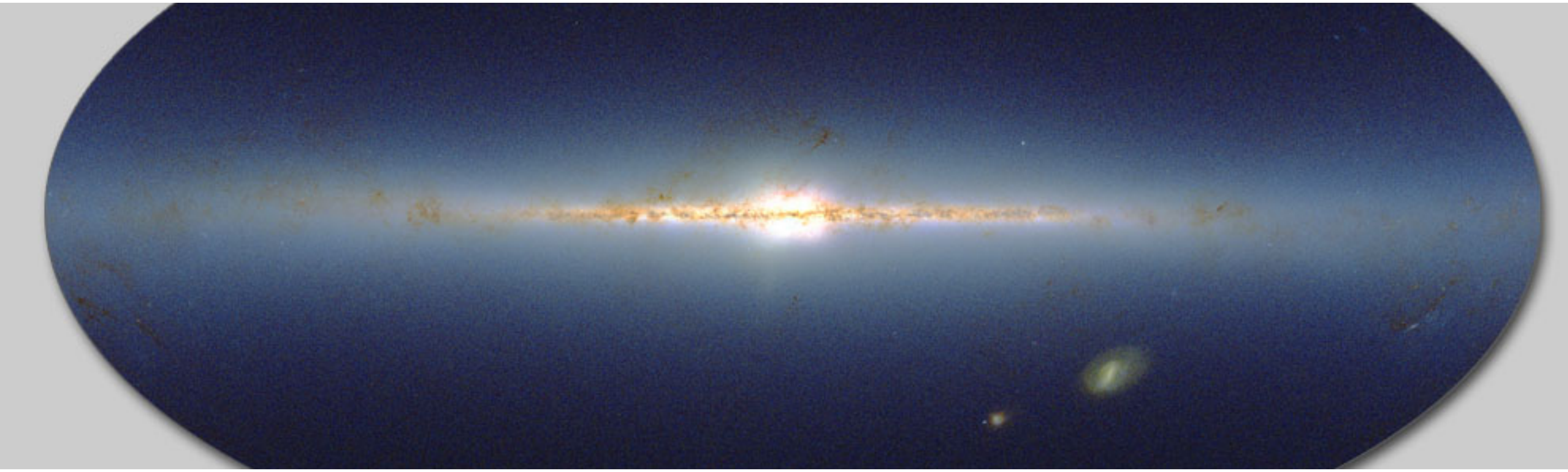
The Local Group



~3 large galaxies, ~40+ small galaxies (currently known)
stellar mass varies by factor of ~10^5

Our Milky Way Galaxy, an Sb galaxy

Milky way galaxy in optical (0.4 - 0.7μm)(B V R)



Milky way galaxy in infrared (1.2, 1.6, 2.2μm)(J H K)(2MASS)

Stellar mass 1-2X that of Milky Way
Classified as Sb spiral (b-> moderate-size bulge)

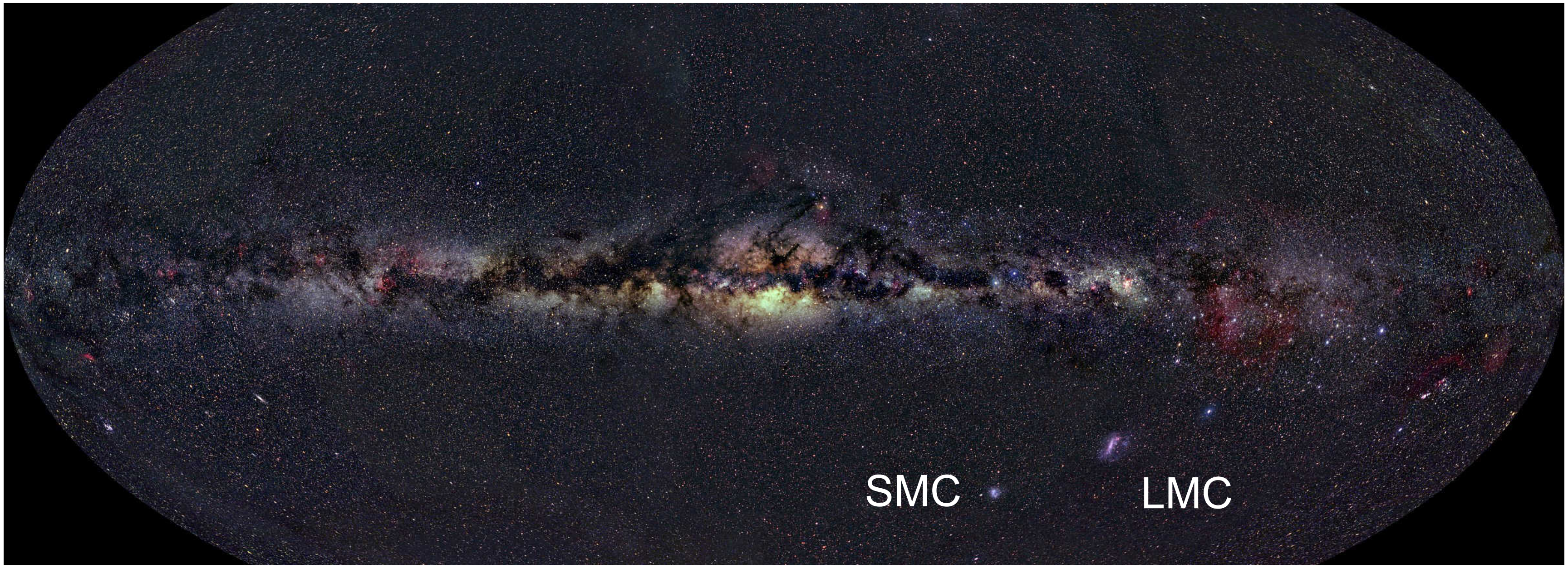
M33 – spiral companion of M31

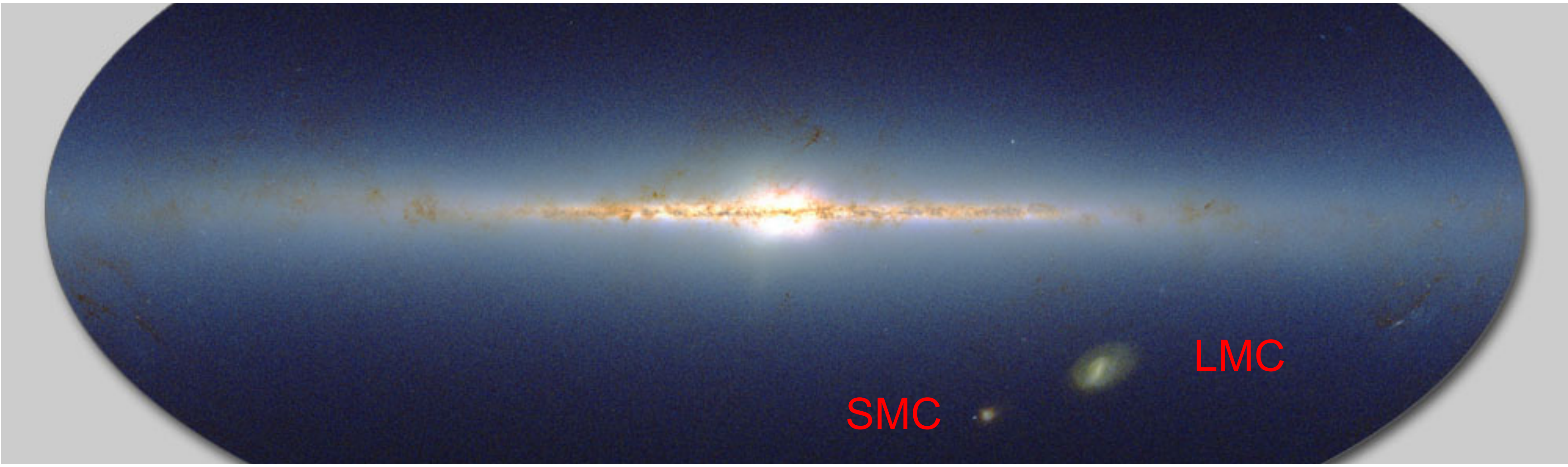
- Stellar mass ~1/3 that of Milky Way
- Classified as Sc spiral (c → small bulge)

Large Magellanic Cloud

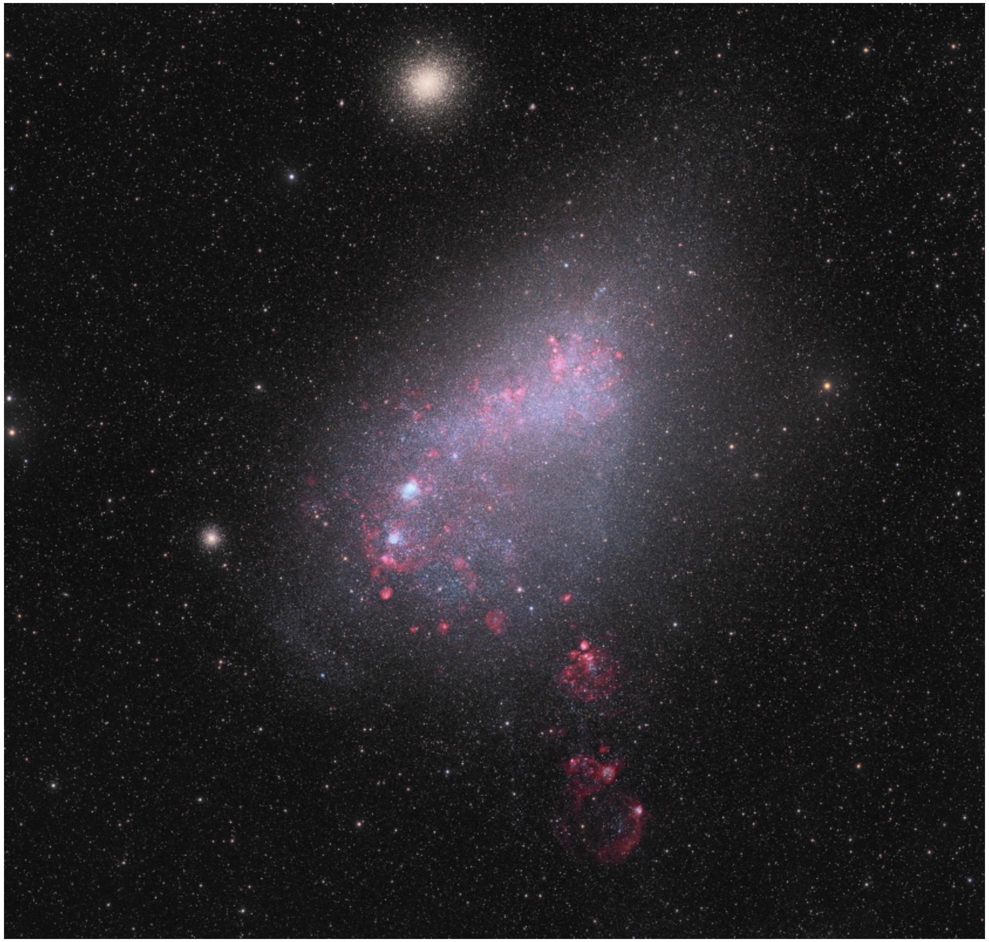
- Stellar mass ~1/10 that of Milky Way
- Classified as *magellanic irregular galaxy* or *large dwarf irregular galaxy*

Milky way galaxy in optical (0.4 - 0.7μm)(B V R)



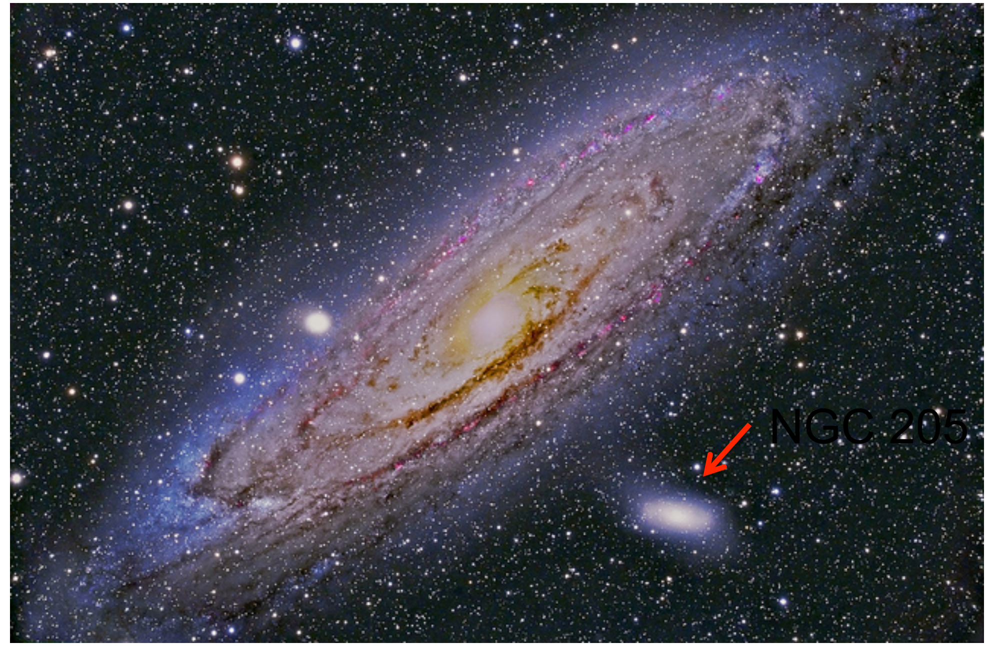


Milky way galaxy in infrared (1.2, 1.6, 2.2μm)(J H K)(2MASS)



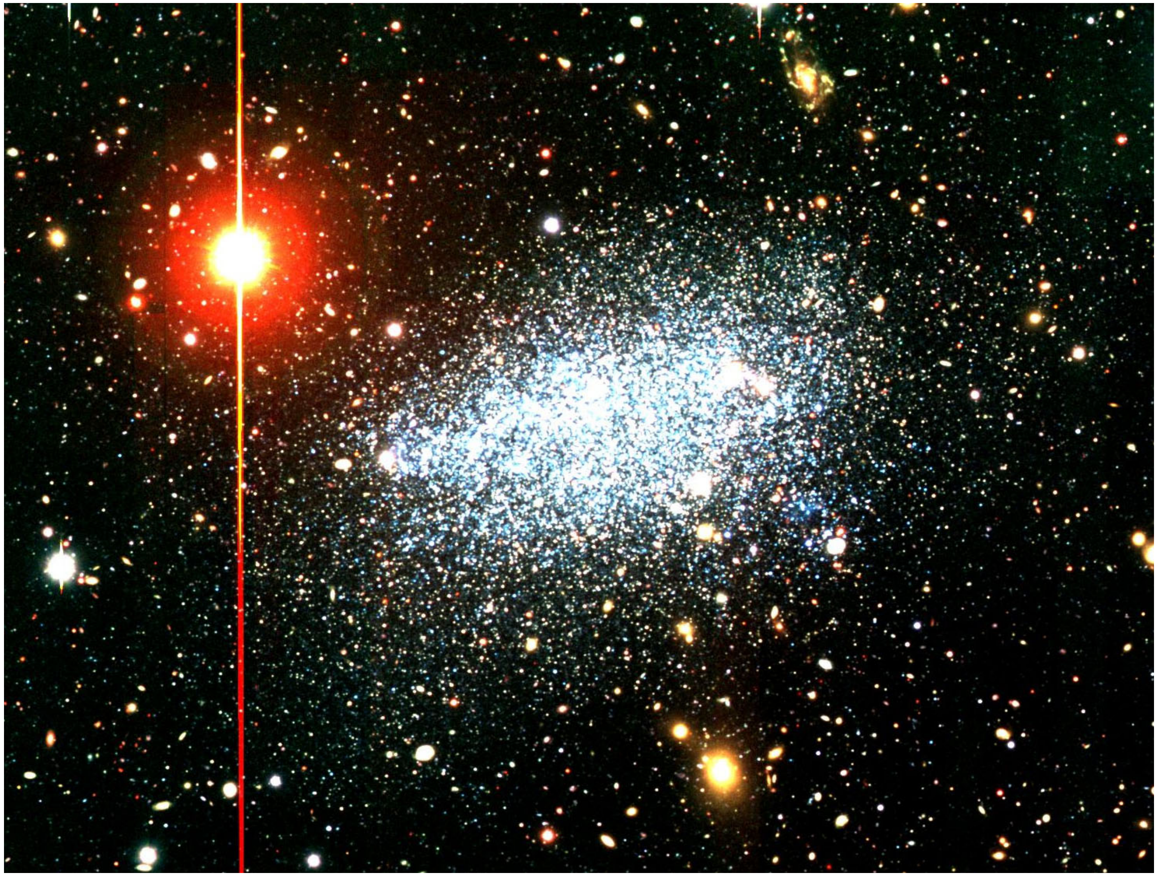
Small Magellanic Cloud

- Stellar mass ~1/30 that of Milky Way
- Classified as *dwarf irregular*



NGC 205, companion of M31

- Stellar mass ~1/30 that of Milky Way
- Classified as *Dwarf elliptical* (dE)
- Similar to SMC, BUT very little gas & dust & no ongoing star formation
- Ongoing gravitational interaction with M31 (tidal tails)



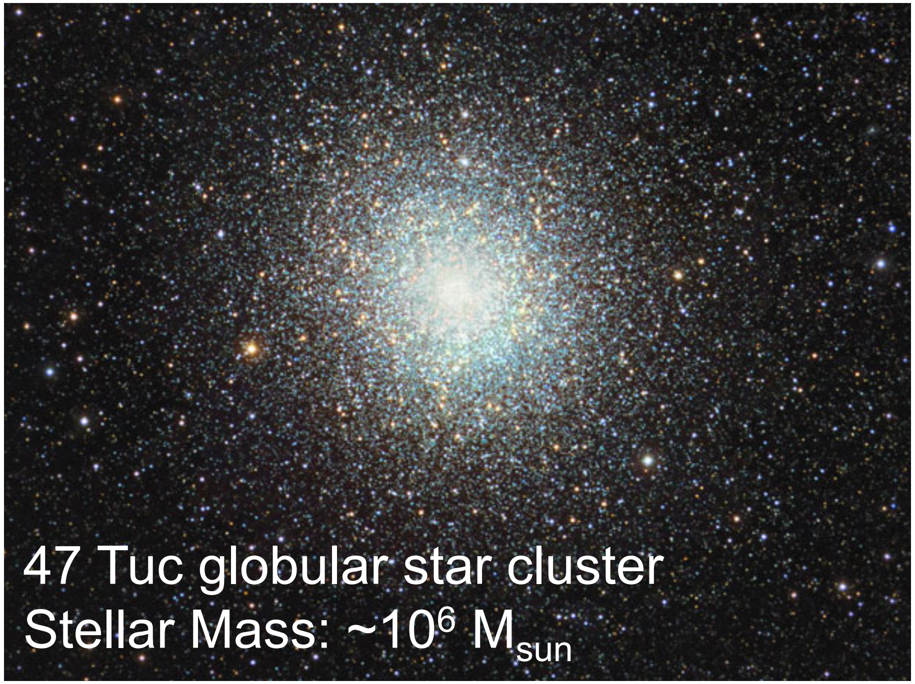
Leo A

- Stellar mass ~1/3000 that of Milky Way
- Classified as *dwarf irregular*
- has gas & dust & ongoing star formation

Leo I

- Stellar mass ~1/3000 that of Milky Way
- Classified as *dwarf spheroidal* (lower mass version of dwarf elliptical)
- has NO gas & dust & ongoing star formation

Globular cluster vs. Dwarf spheroidal galaxy



Number of stars:	Generally fewer	Generally more *BUT OVERLAP*
Concentration & size:	compact, small extent	diffuse, large extent
Star formation history:	Single episode	Multiple episodes
Dark matter concentration:	NO	YES

Dwarf spheroidal galaxy vs. globular cluster

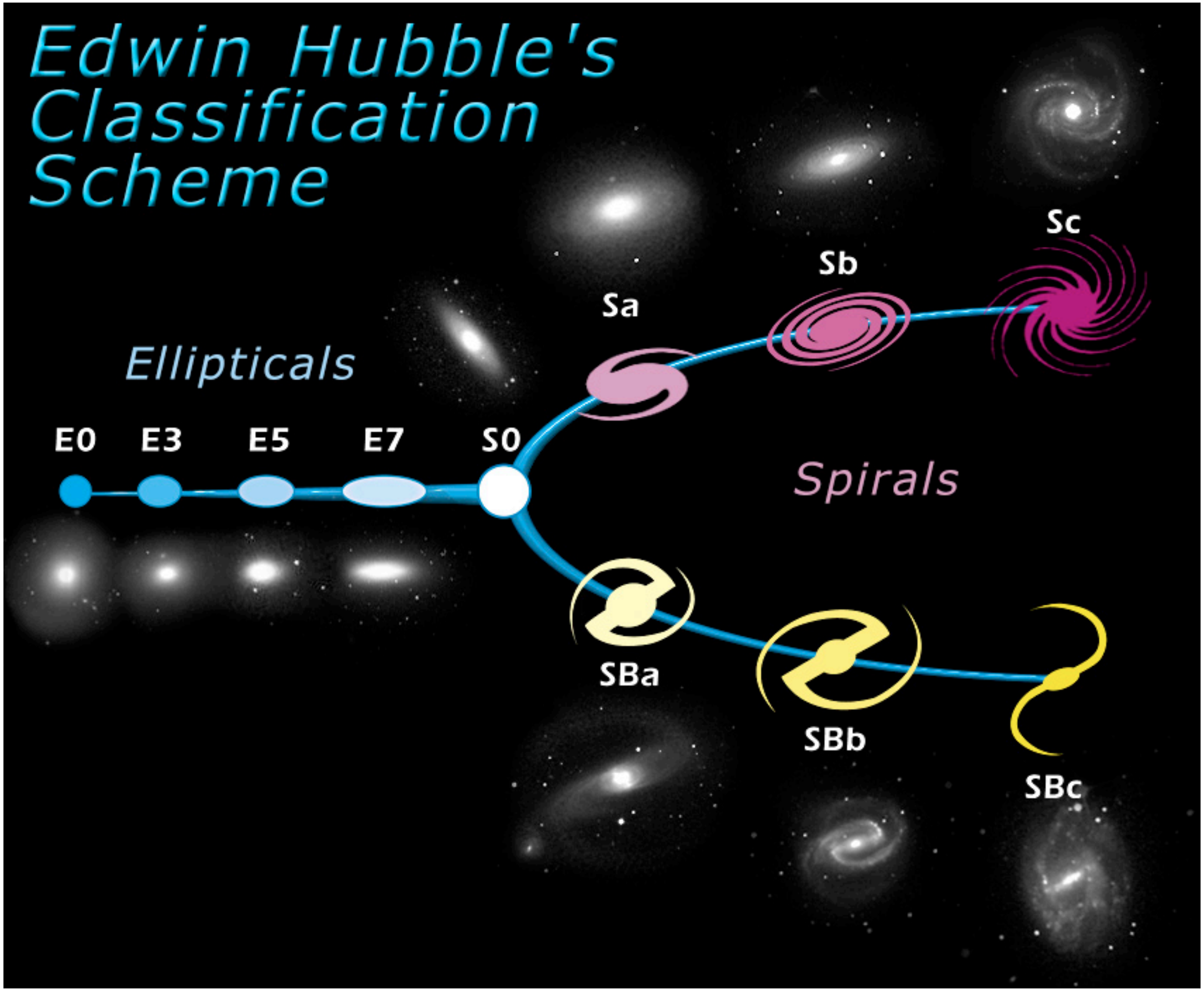
to
~correct
scale

47 Tuc
globular star cluster
Stellar Mass: ~10^6 M_{sun}

Leo I dwarf spheroidal galax
Stellar mass: ~10^7 M_{sun}

Small Galaxies

- Dominant type of galaxy in universe by number (but not by mass)
- Both dwarf elliptical & dwarf irregular types
- Dwarf irregulars (like Magellanic Clouds) are essentially low mass versions of spiral galaxies, i.e., disk systems which lack symmetry and spiral structure due to small mass
- Most dwarfs are orbiting companions to larger galaxies
- Building blocks for larger galaxies



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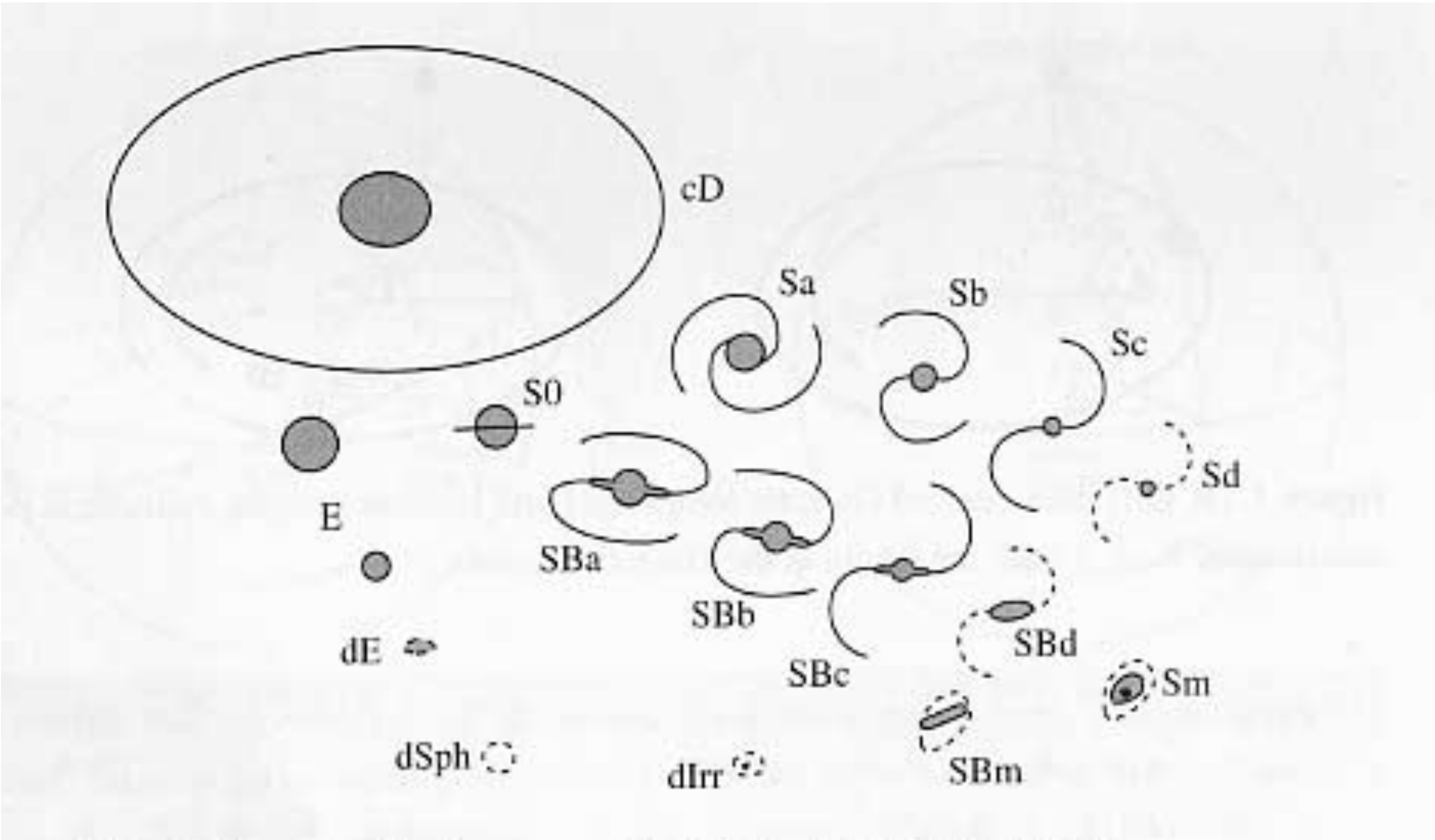
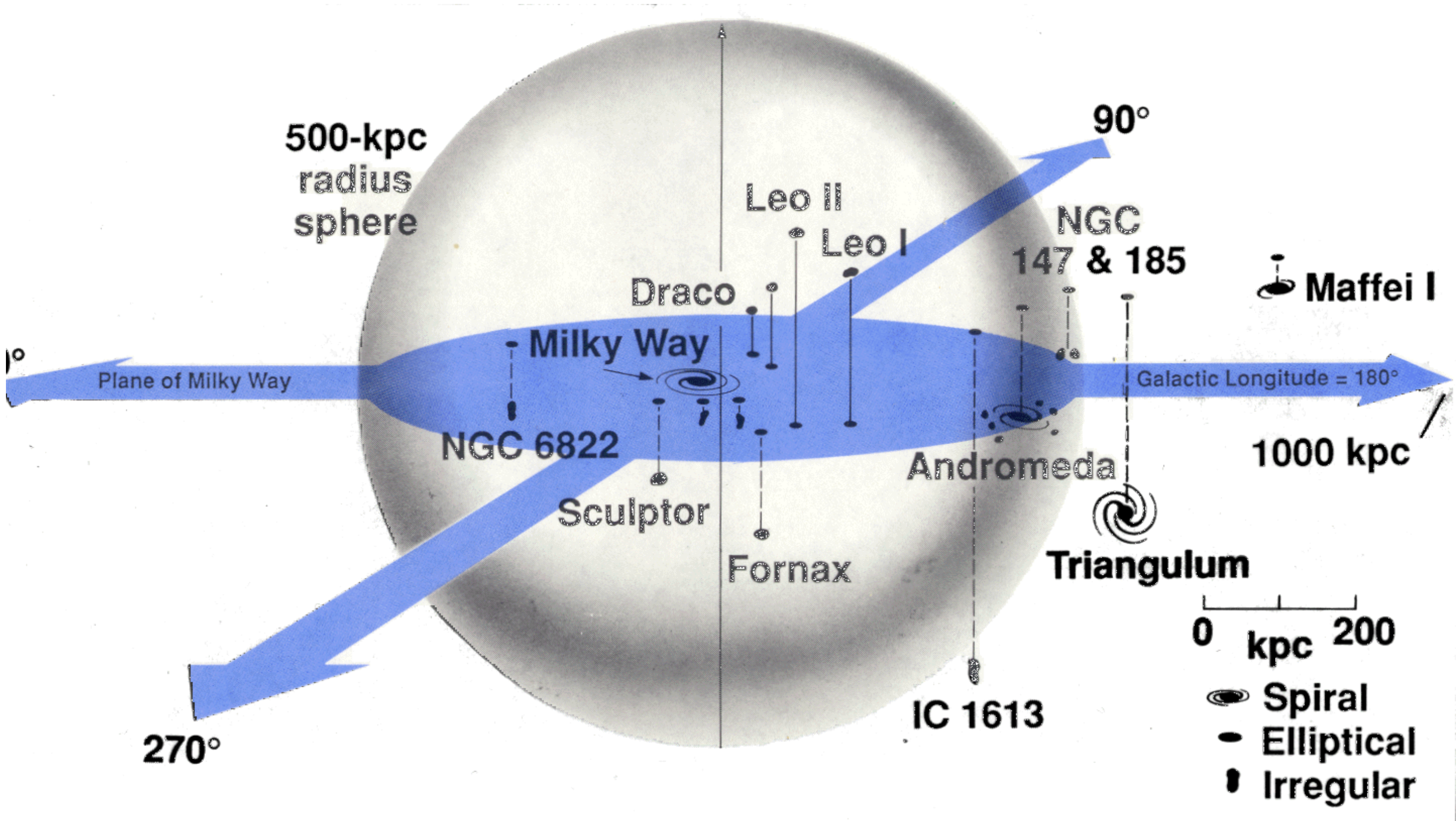
Galaxy classification: a modified form of Hubble's scheme

Mass



← Average age of stars

3D distribution of galaxies in The Local Group



Most small galaxies are satellite companions to large galaxies

Galaxies somewhat concentrated toward a plane,
not randomly distributed within 3D volume

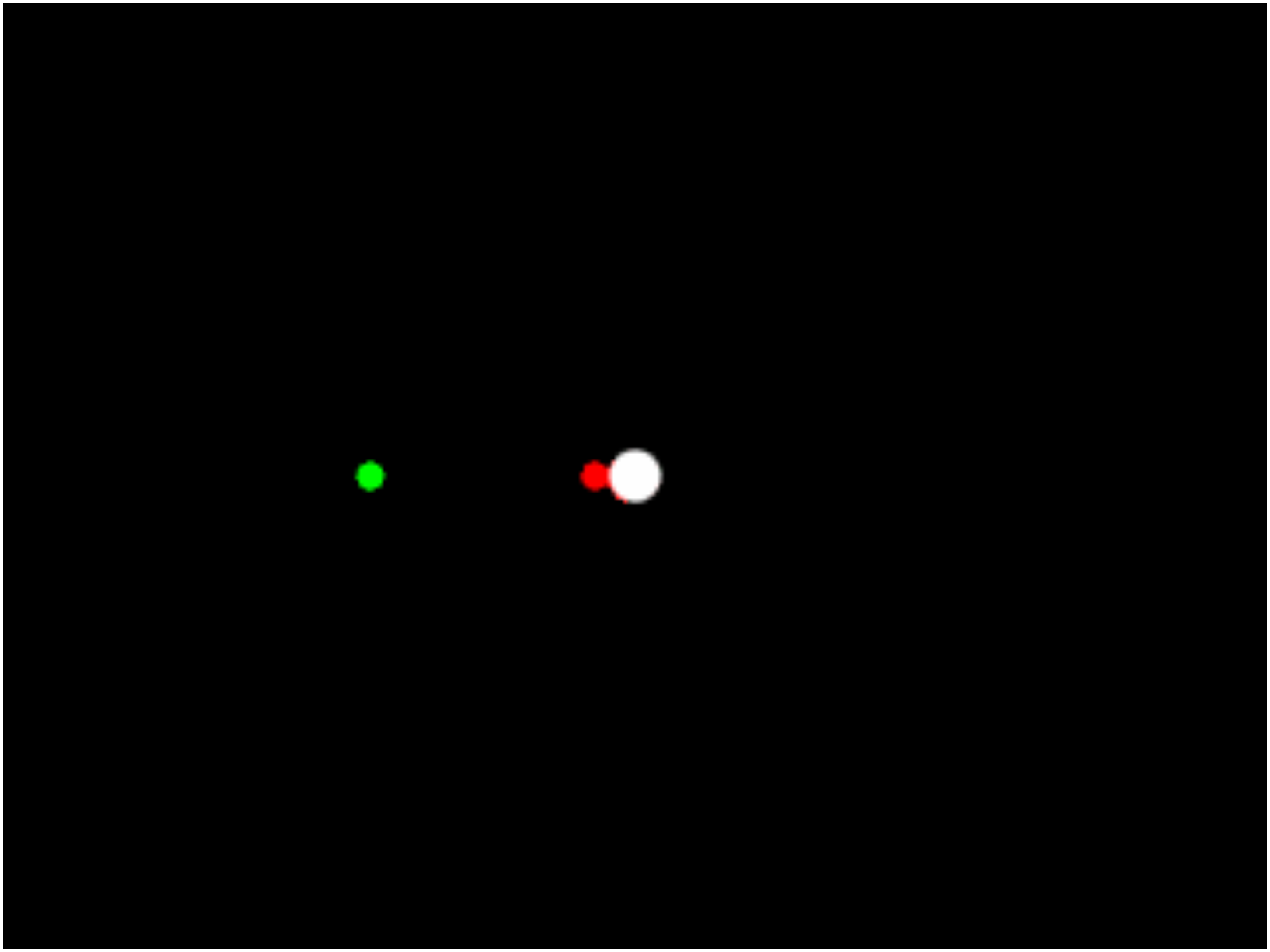
Compared to the present day Milky Way, the galaxy 3 billion years ago would have had

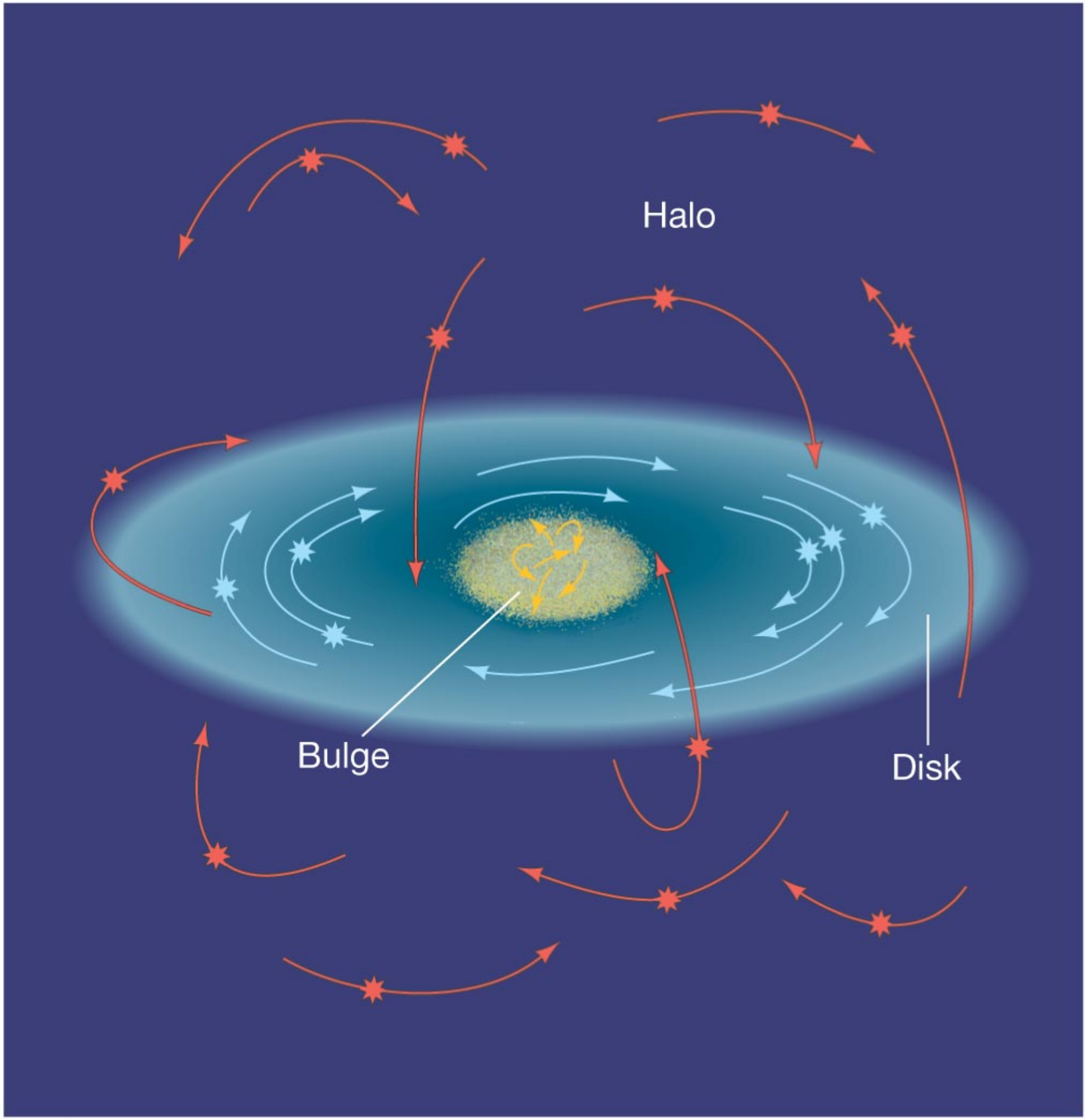
A. More stars in the halo
B. More gas in the disk
C. More stars in the disk
D. More stars in the bulge
E. More time alone

Most stars in a disk

A. Stay inside spiral arms
B. Travel in radial (in & out) orbits in the disk plane
C. Have random orbits and spend most time in the disk
D. Travel in nearly circular orbits close to the disk plane
E. Have about the same age

circular vs. elongated (radial) orbits



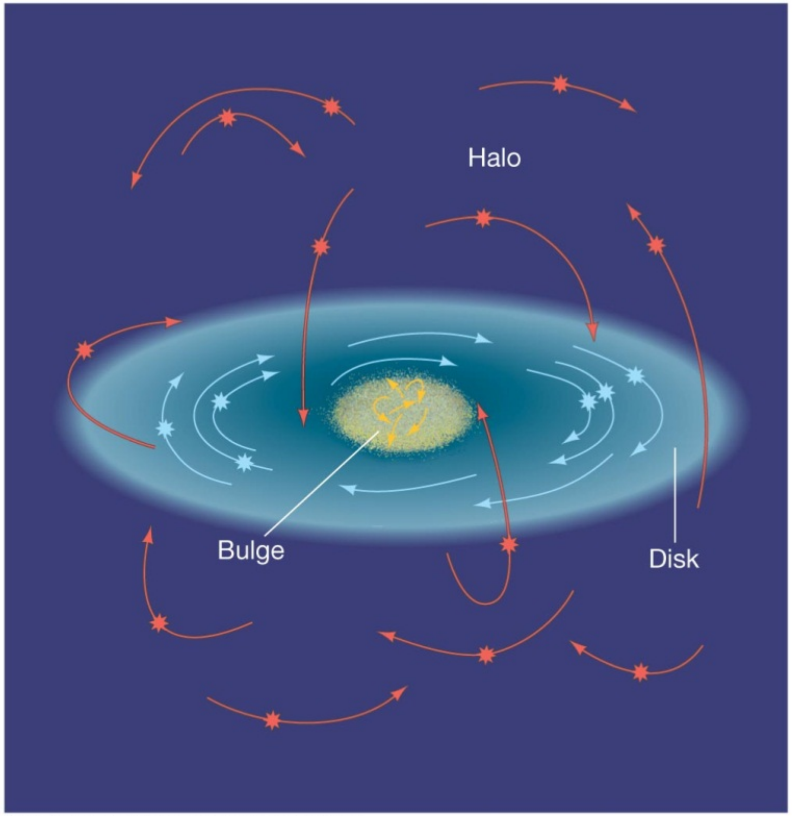


Stellar motions in disk, bulge, halo

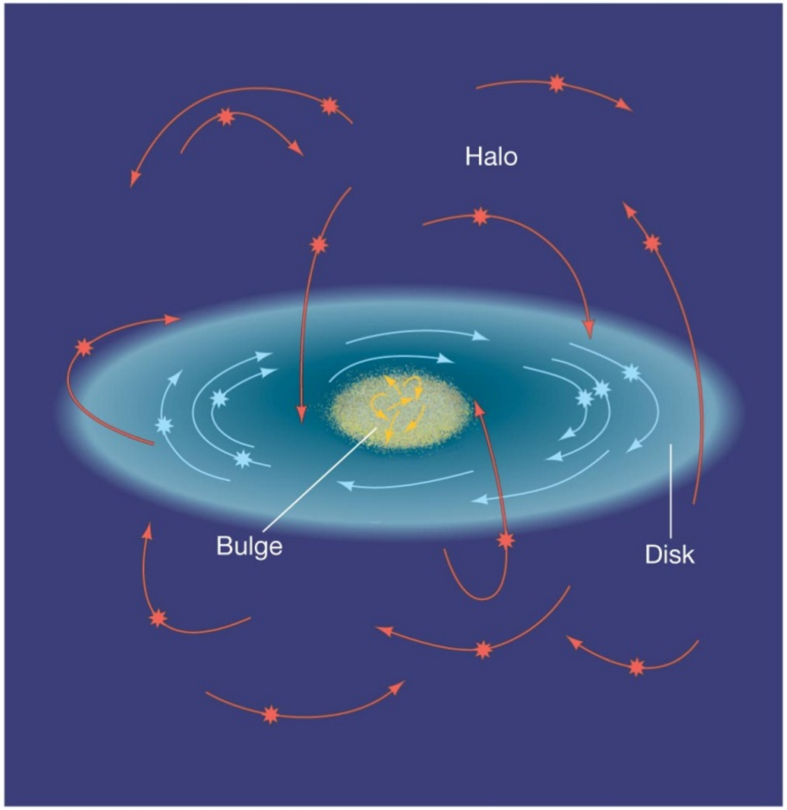
Stellar motions in disk, bulge, halo

Disk:

- stars orbit center
- nearly circular orbits
- same direction,
- all close to same plane



Stellar motions in disk, bulge, halo



Disk:

- stars orbit center
- nearly circular orbits
- same direction,
- all close to same plane

Bulge & Halo:

- stars orbit center
- many orbits highly elongated (radial)
- in all directions
- not confined to 1 plane


Spiral galaxy
M83

Dust + blue stars in spiral arms of M83

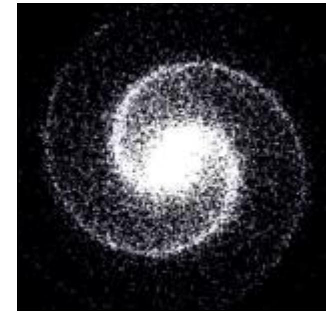
Spiral arms

Spiral-shaped regions of enhanced density and enhanced star formation

Two effects make Spiral arms

1. "traffic jams" of stars & gas in arms
2. Star formation triggered in arms

Two effects make Spiral arms



. "traffic jams" of stars & gas in arms

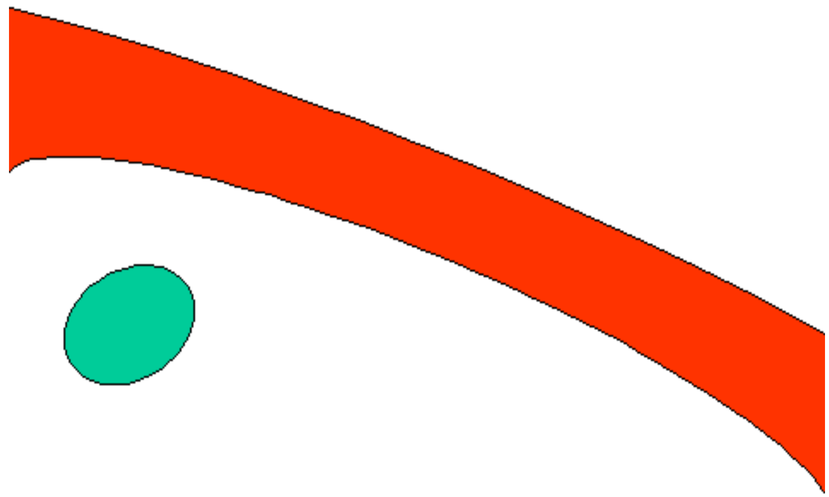
•Stars in arms now DON'T STAY in arm, they pass through arm

•Arm is region of extra mass & density → extra gravity in arm causes stars to slow down

•a wave caused by disturbance to disk → arms are ***"density waves"***

Two effects make Spiral arms

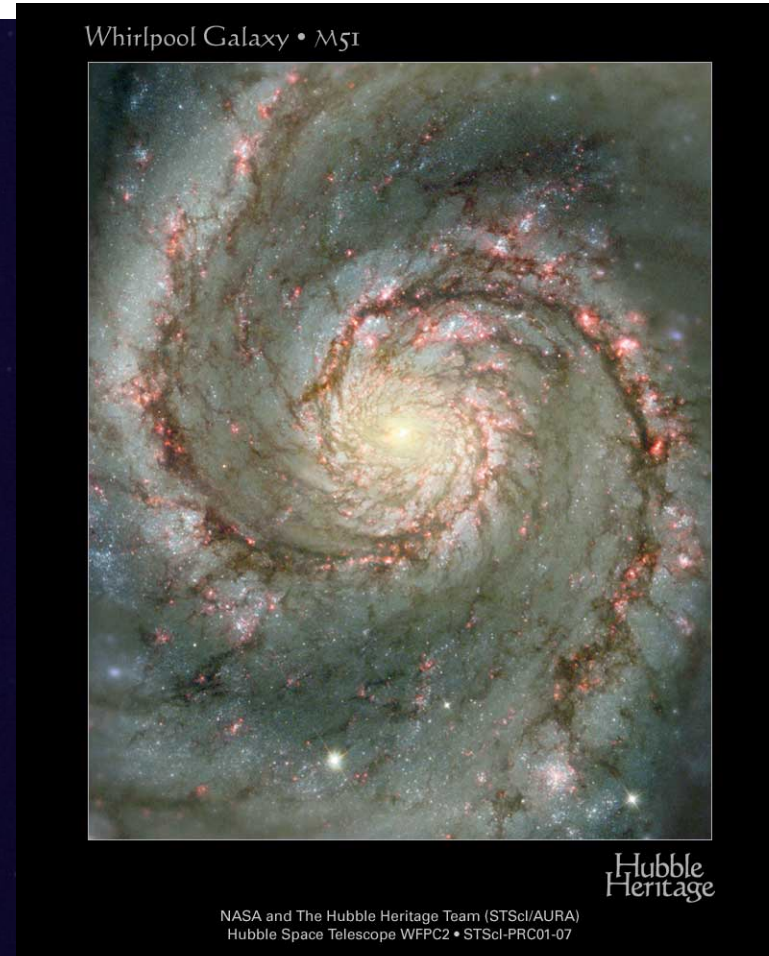
Star formation triggered in arms



Gas cloud compressed when it enters density wave, triggering star formation.

The most massive young stars are blue and very luminous, AND they explode as Supernovae shortly after they form, before they get far from spiral arm.

So luminous massive stars seen near arm, not between arms.



M51 an Sc spiral

interacting with another galaxy;
interaction makes strong spiral arms