Galaxy Classification

General Categories

Some Cautionary Notes

- Galaxies are *not* alike
  - For every general rule I give, one can find exceptions

- Classifying galaxies is difficult
  - They look different in different wavelengths
  - If the galaxy is moving, you have to correct for red-shift
  - Even experts often disagree on the classification

- There are different systems for classifying galaxies

- The original one, developed by Hubble, is the basis for most other systems

- I will use the Hubble - De Vaucouleurs system
  - An expansion on the original Hubble system

The Categories

Galaxies are classified by their appearance

- Unbarrred Spiral
  - Central roundish bulge plus disk
- Barred Spiral
  - Central elongated bulge plus disk
- Elliptical
  - Roundish or elongated bulge, no disk
- Irregular
  - No discernible shape
- Dwarf Spheroidal
  - Small, dim, and round

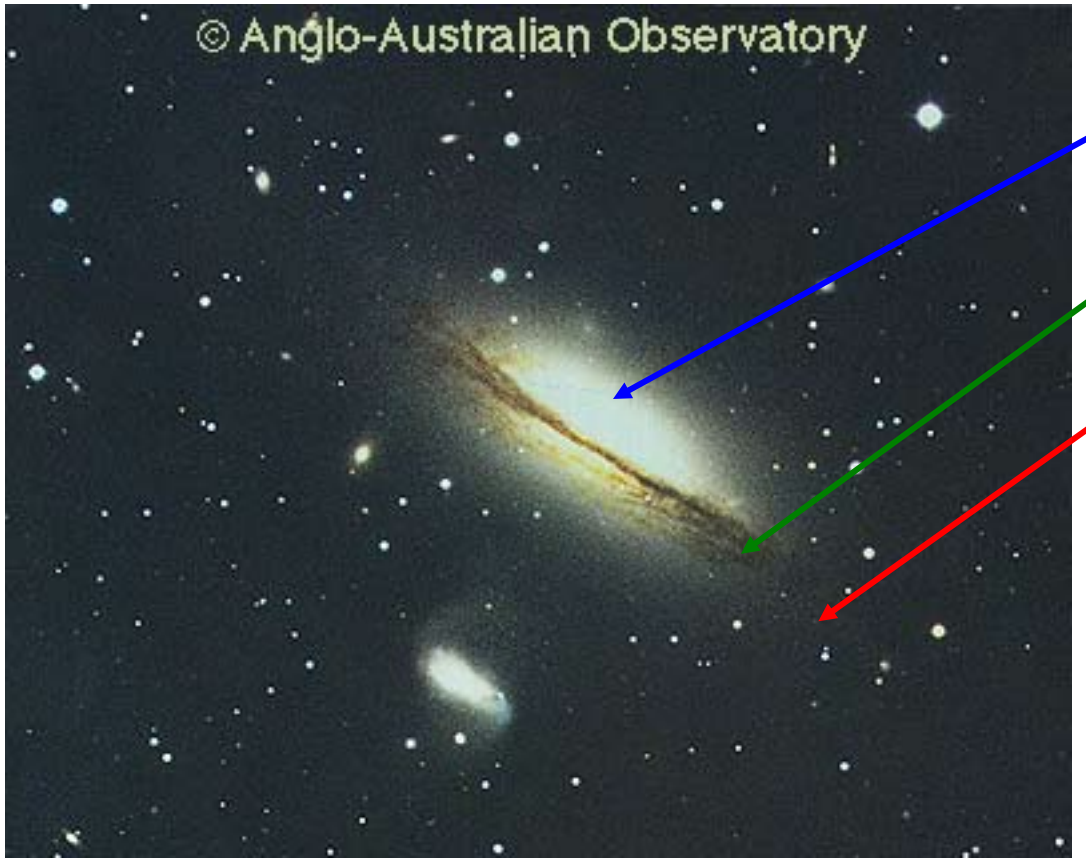
Unbarred Spiral Galaxies

General Description

- Denoted SA
- Pinwheel-like
  - Central bulge, spiral arms
  - Spiral arms, etc., signs of rotation
- Bulge is round
- Young and old stars, gas, dust
- 80% of large galaxies are Spirals (Barred or Unbarred)
- Sub-classified by amount of arms, and how tight or loose they are
  - SA0 - no distinguishable spiral arms
  - SAa, SAb, SAc, SAd - more spiral arms, and looser
  - SAm – no bulge, typically one distorted spiral arm

SA0

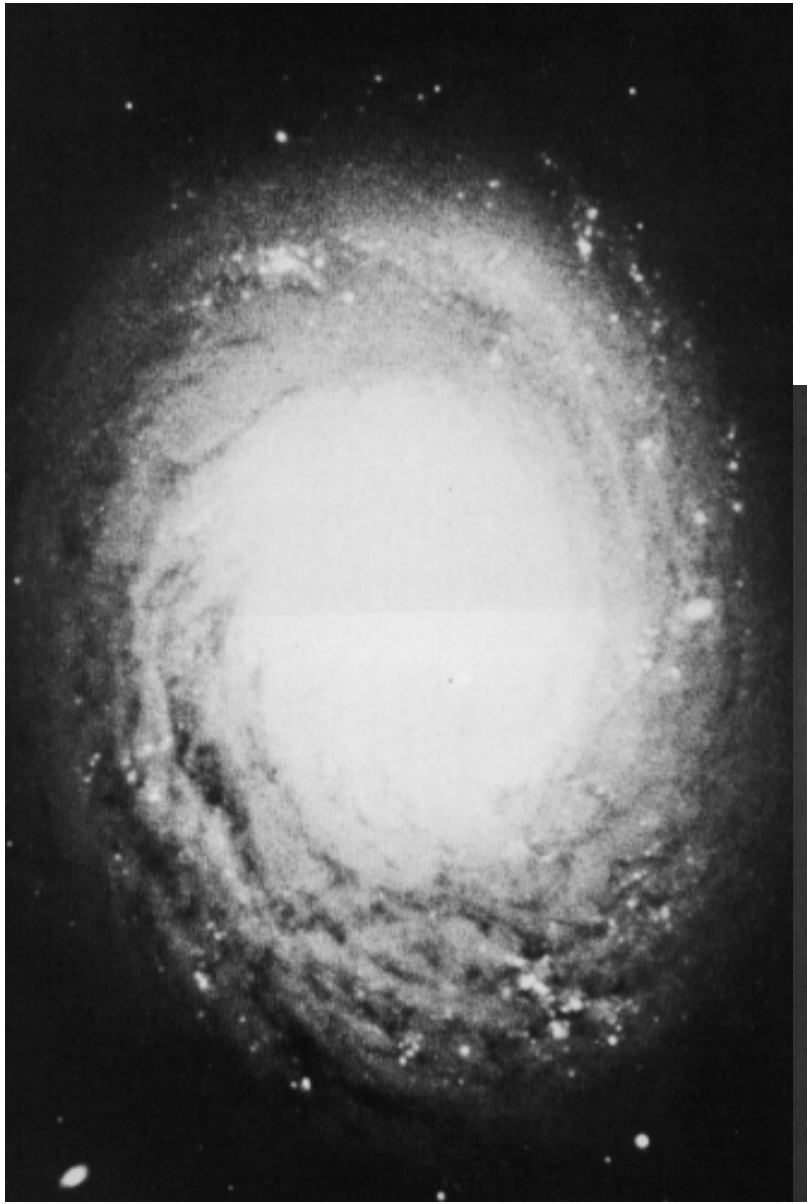
- Also called lenticular galaxies

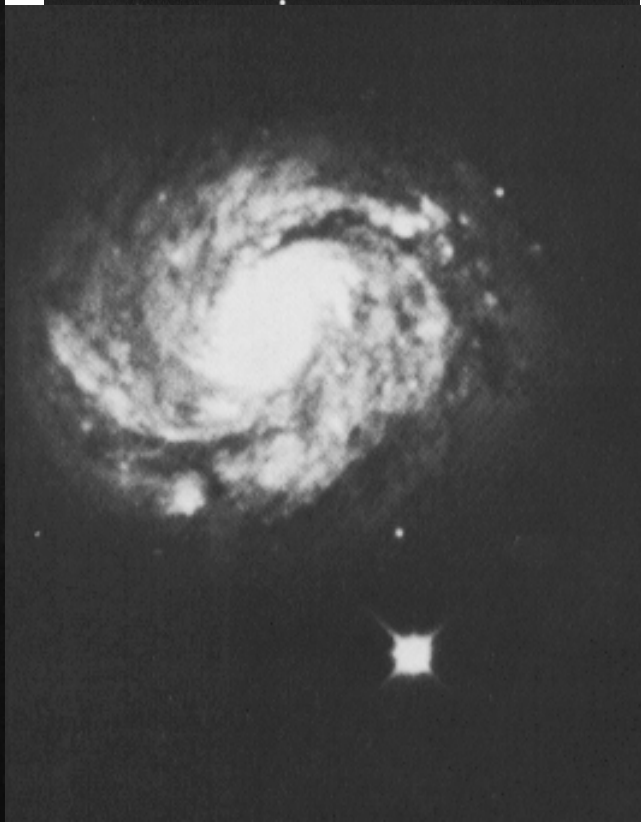


- Central Bulge
- Disk
- No Spiral arms

SAa

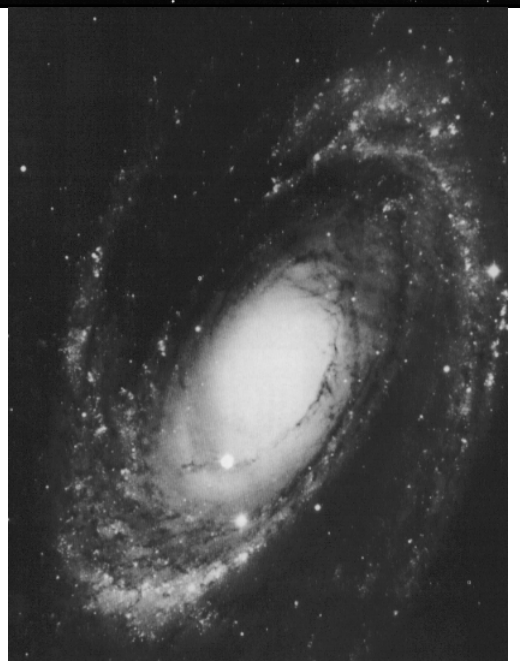
- Central Bulge
- Disk
- Tight spiral arms





SAb

- Central Bulge
- Disk
- Spiral arms



SAc

- Central Bulge
- Disk
- Loose spiral arms

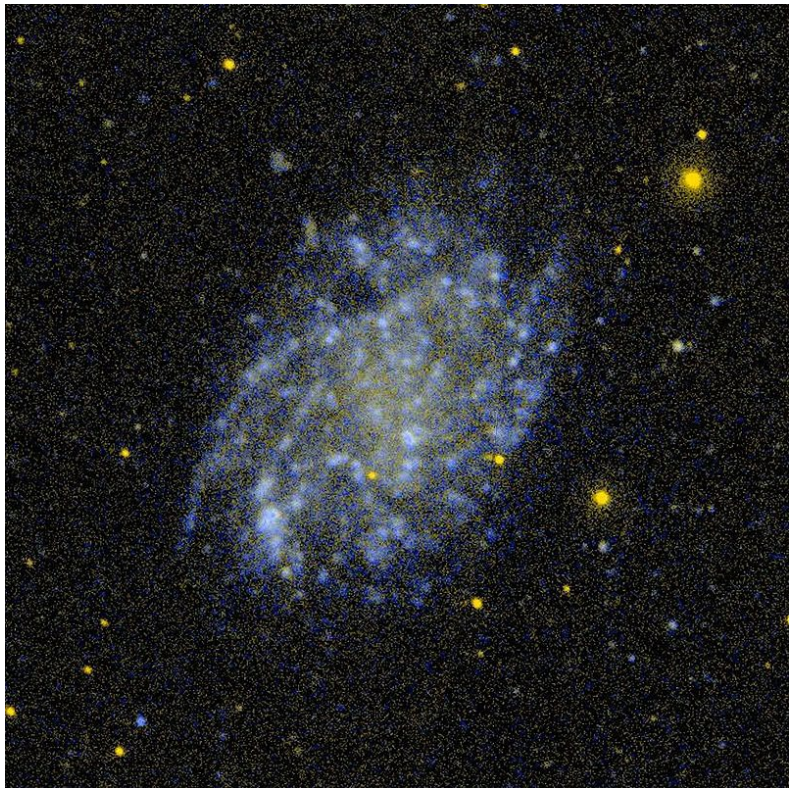
SAd

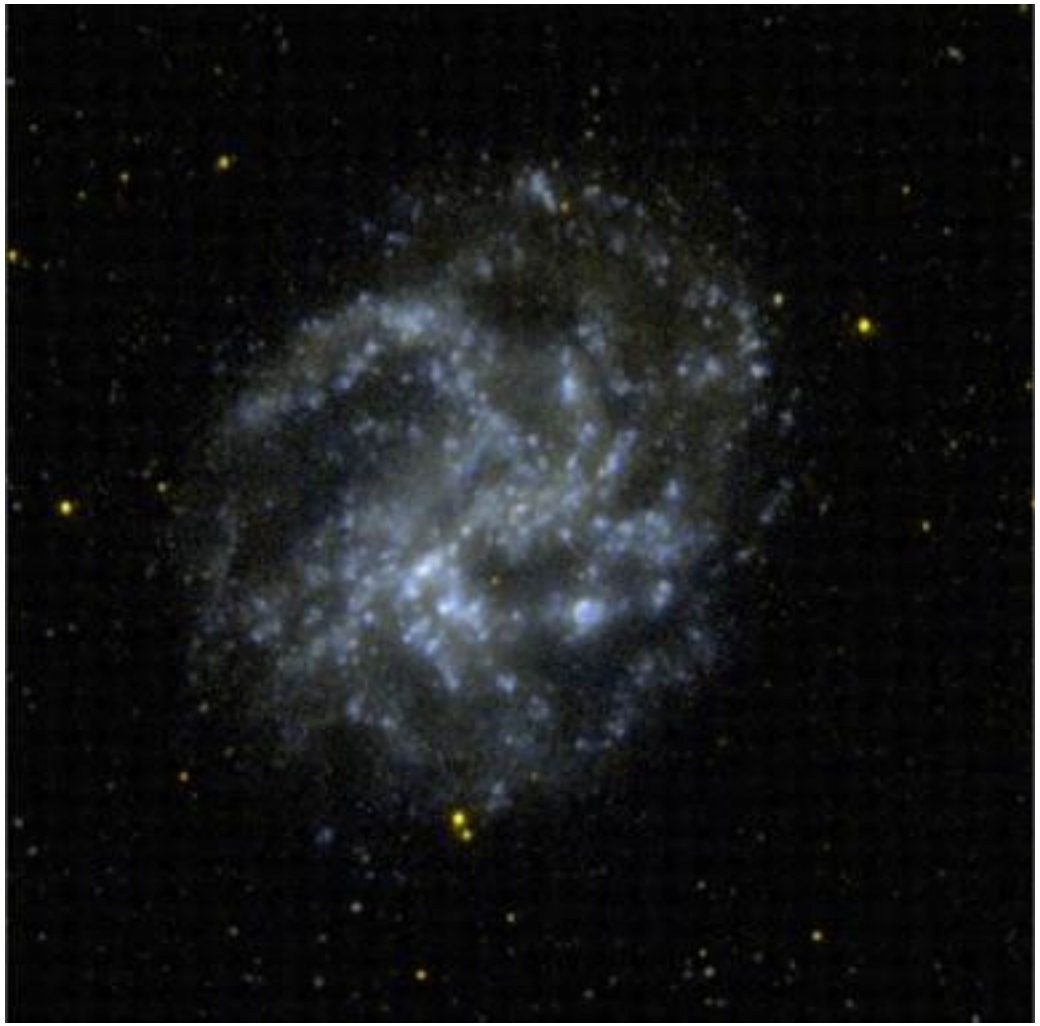
- Central Bulge
- Disk
- Very Loose Spiral arms
- Often, spiral arms are disconnected or broken

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

SAm

- Classified by Hubble as irregular galaxies
- They have just a bulge and typically one spiral arm
- Probably a spiral galaxy disturbed by collision with a larger galaxy





Spiral Galaxy Structure

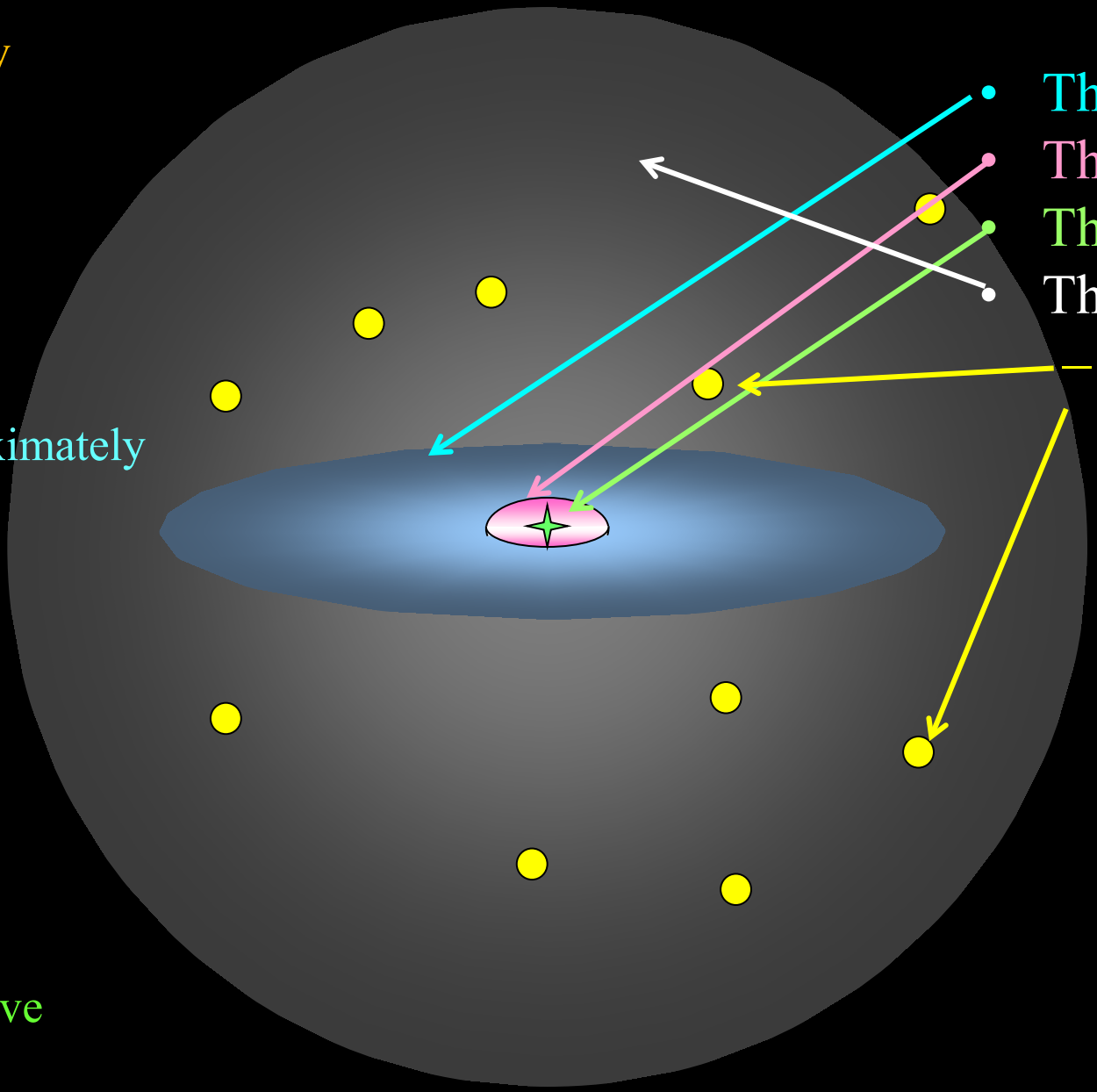
Overall, very similar to Milky Way

- Disk contains
  - Gas
  - Dust
  - Young and old stars
  - Open clusters
- Stars in the disk orbit in approximately circular orbits

- The bulge contains older stars
- Orbits much more random

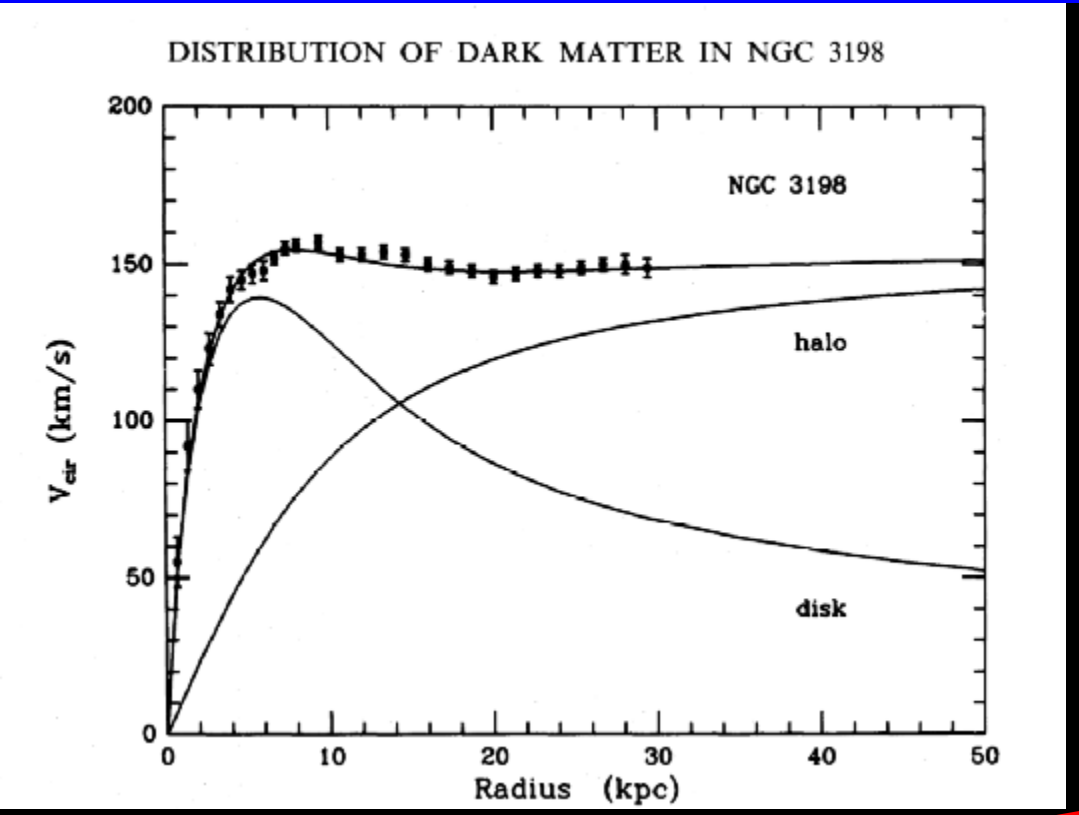
- The halo contains oldest stars and globular clusters
- Orbits completely random

- Most (all?) galaxies seem to have black holes in their centers

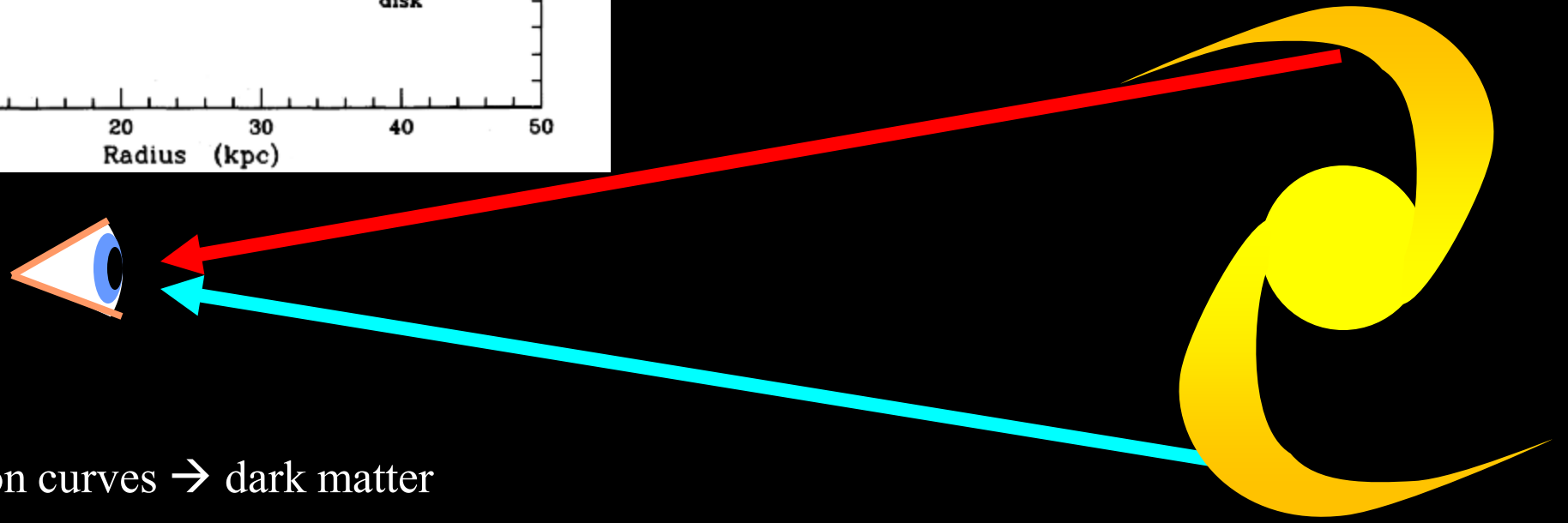


- The disk
- The bulge
- The nucleus
- The halo
  - Globular clusters

Dark Matter in Spiral Galaxies



- Spirals Rotate
- Rotation measured by Doppler shift
- Mass, again, not concentrated in the center
- 85% of mass is dark matter



- Flat rotation curves → dark matter

Barred Spiral Galaxies

General Description

- Denoted SB

- It is now believed that most spiral galaxies have at least some bar

- Pinwheel-like
  - Central bulge, spiral arms
  - Spiral arms, etc., signs of rotation

- Bulge is straight - barred

- Young and old stars, gas, dust
- 80% of large galaxies are spirals or barred spirals

- Sub-classified by amount of arms, and how tight or loose they are
  - SB0 - no distinguishable spiral arms
  - SBa, SBb, SBc, SBd - more spiral arms, and looser
  - SBm – no bulge, typically one distorted spiral arm

SB0

- Also called lenticular galaxy
- Central Bulge
- Disk
- No Spiral arms

SBa

- Central barred bulge
- Disk
- Tight spiral arms

SBb

- Central Bar
- Disk
- Spiral arms
- This is approximately galaxy type of the Milky Way

SBc

- Central Bar
- Disk
- Looser spiral arms

SBd

- Central Bar
- Disk
- Very loose spiral arms
- Often the arms are partially disconnected

SBm

- Classified by Hubble as irregular galaxies
- They have just a bulge and typically one spiral arm
  - Coming off of a bar-shaped central region
- Probably a barred spiral galaxy disturbed by collision with a larger galaxy

Intermediates

- The amount of barring and the amount of spiral arms are continuous variables
- As we have gotten better at classifying, it becomes useful to have categories between these
- Between the spirals (SA) and the barred spirals (SB) are the intermediate spirals
  - Denoted SAB
- Between each of the categories a through d, there are intermediate
  - Denoted by using both letters, like bc
- For example, a SABcd galaxy would have
  - Some barring, but not as much as an SB galaxy
  - Looser arms than an SABc, but tighter than SABd

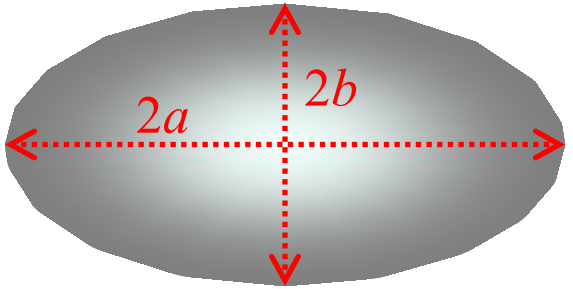
Barred Versus Unbarred Spirals

- It is not obvious what causes bars to form
- Numerical simulations indicate that over time, instability causes bars to form
- *Probably* bars are a sign that a galaxy has "matured"
- Over time, most (all?) unbarred spiral galaxies become barred spirals
- Process takes a couple Gyr
  - Age of universe < 14 Gyr
- Over long times, bars may also become unstable
  - May cause barred galaxies to return to unbarred (?)

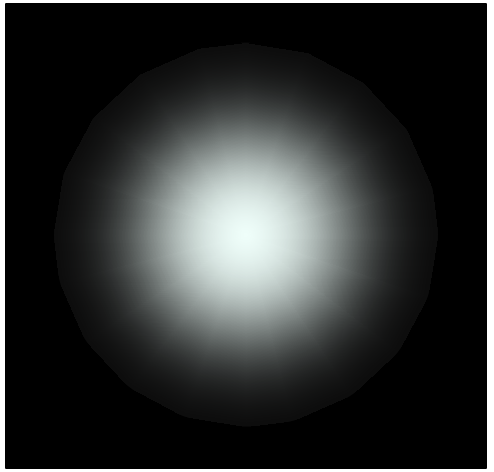
Elliptical Galaxies

Categorization

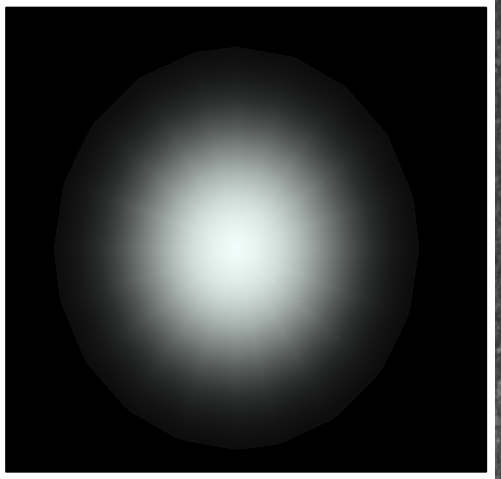
- Look like a sphere or a flattened sphere
- Little gas and dust
- Mostly old stars
- Classified by how round they look
  - E0 looks circular
  - E7 is very elongated
- There is a relatively objective way to classify them
  - Measure their long and short axes
  - Formula for the number is $e = 10\left(1 - \frac{b}{a}\right)$
- Elliptical galaxies have the largest range of masses
  - Dwarf ellipticals are the smallest
    - Add the letter d in front, so it might be a dE2 galaxy
  - Giant ellipticals are the largest



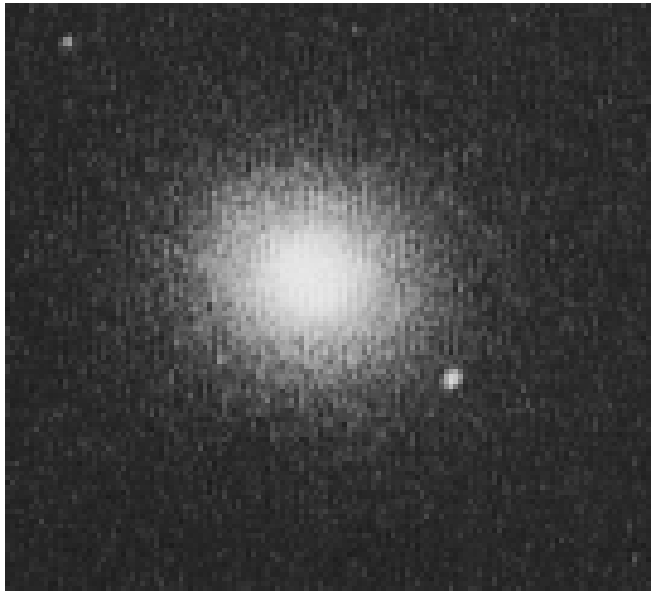
E0

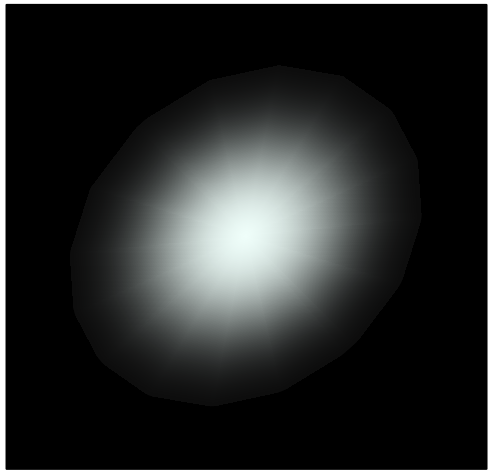


E1

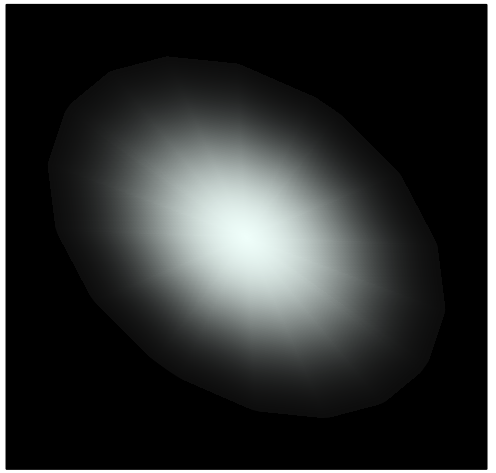


E2

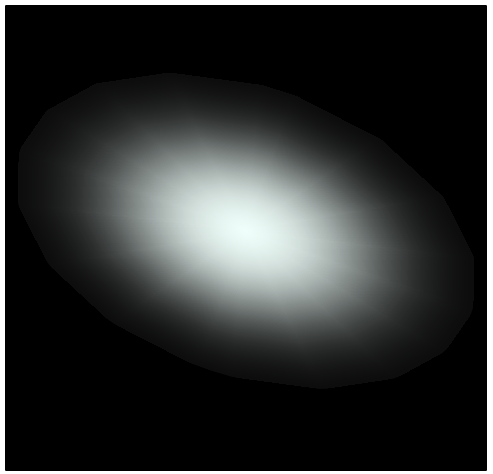


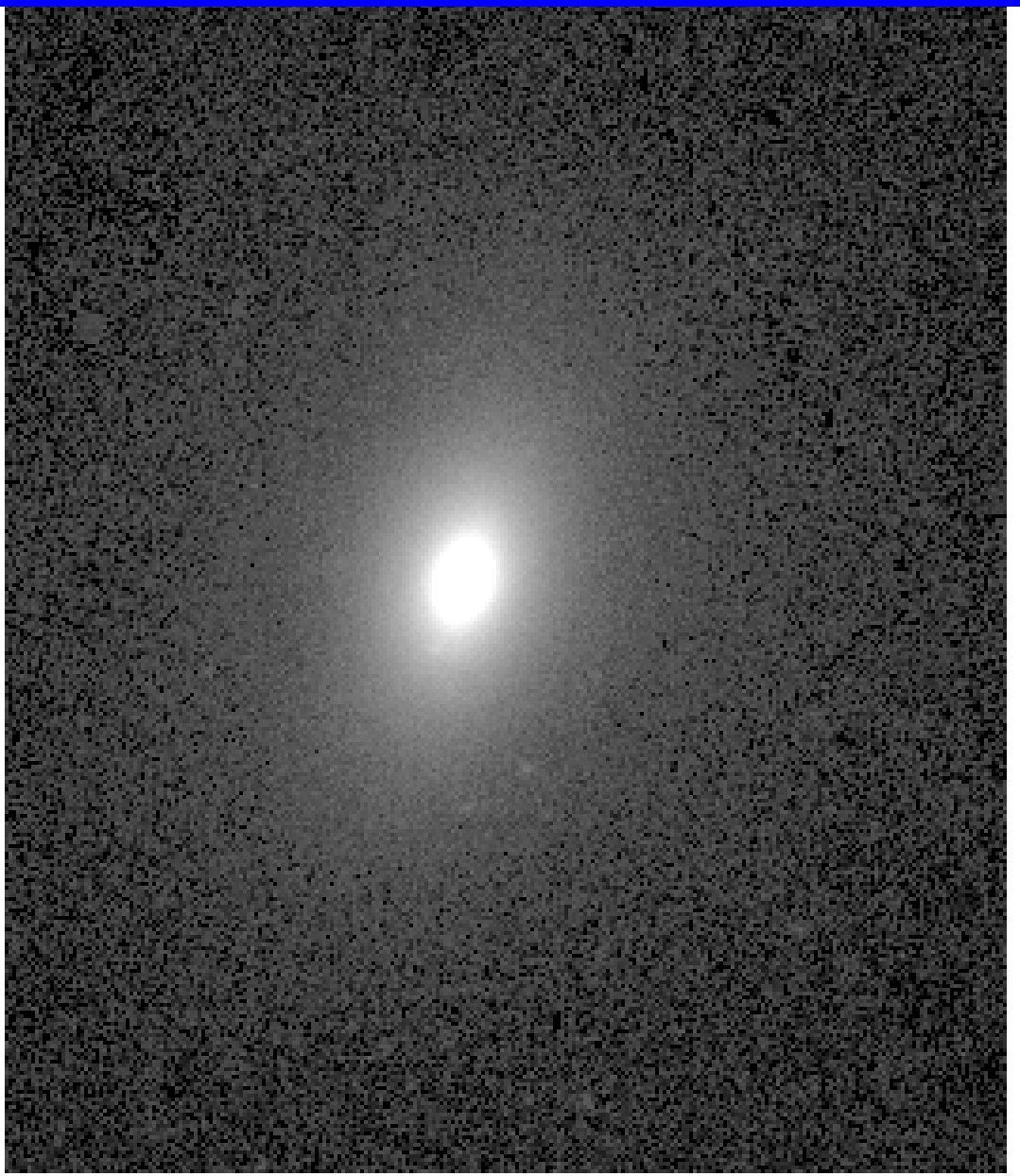


E3

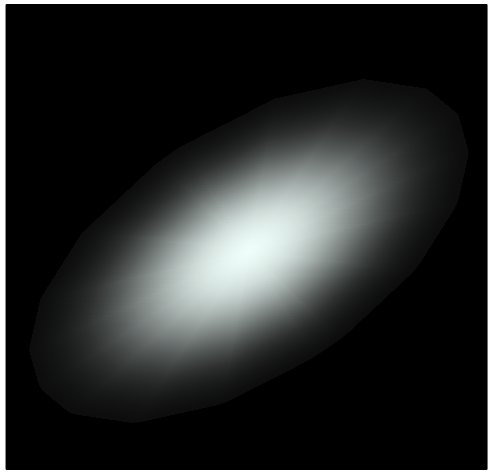


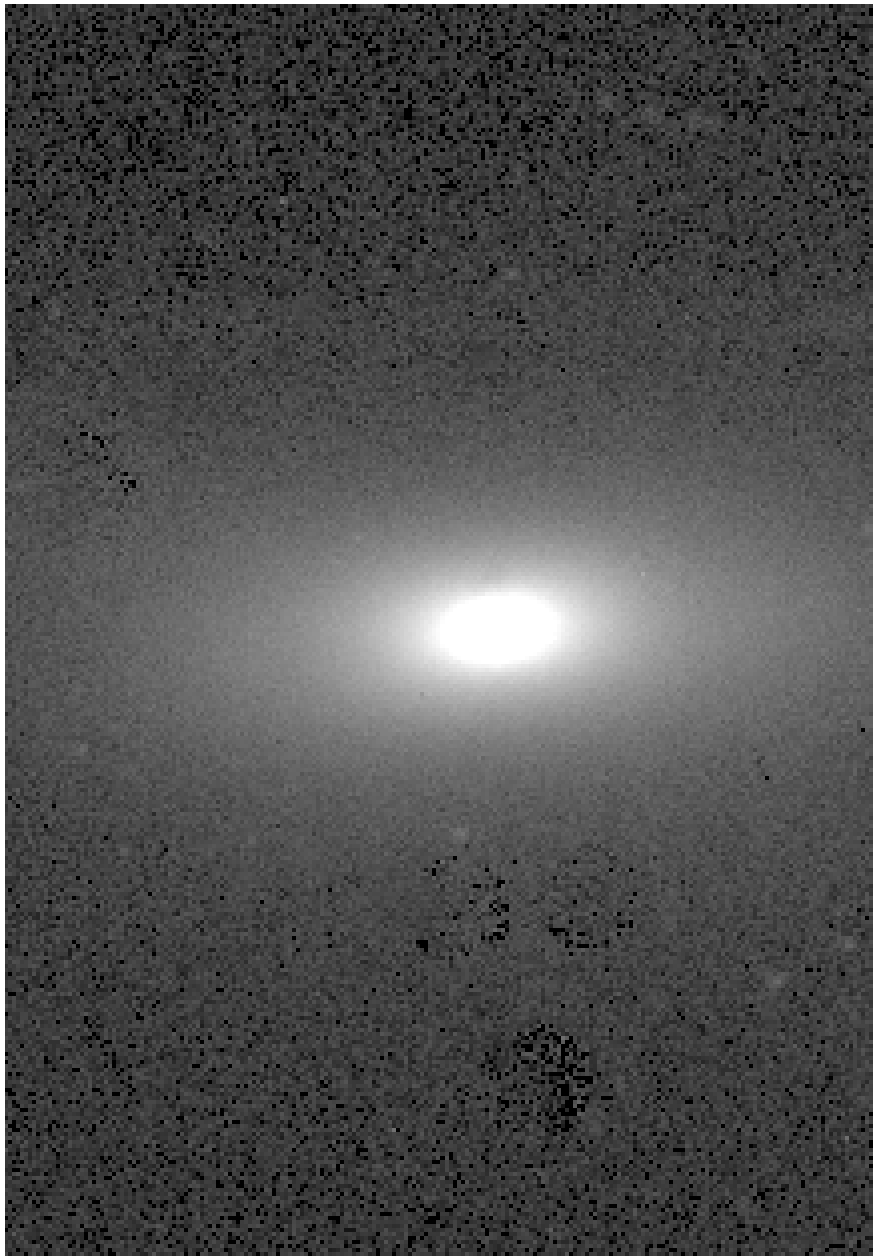
E4



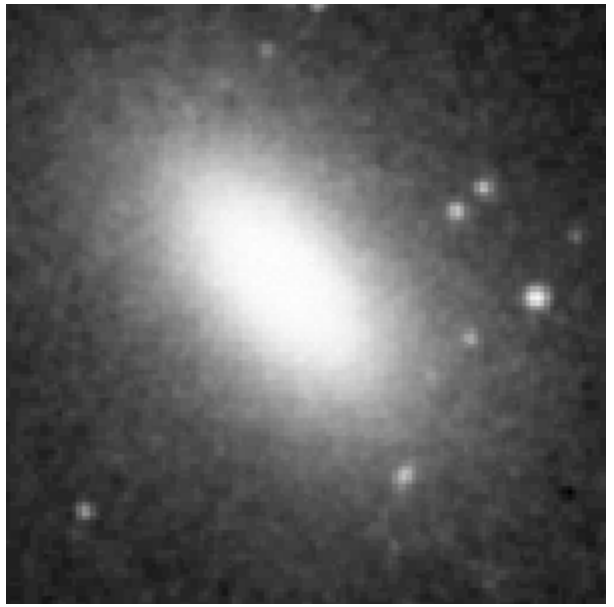


E5

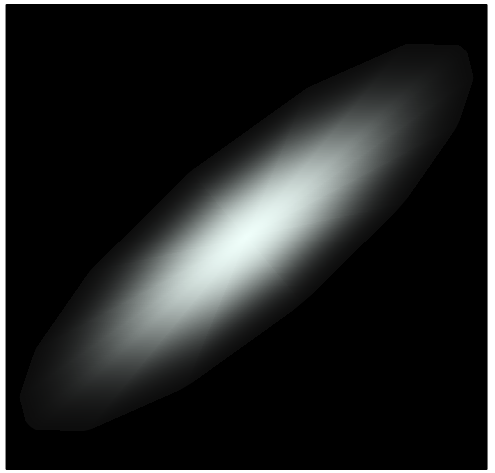




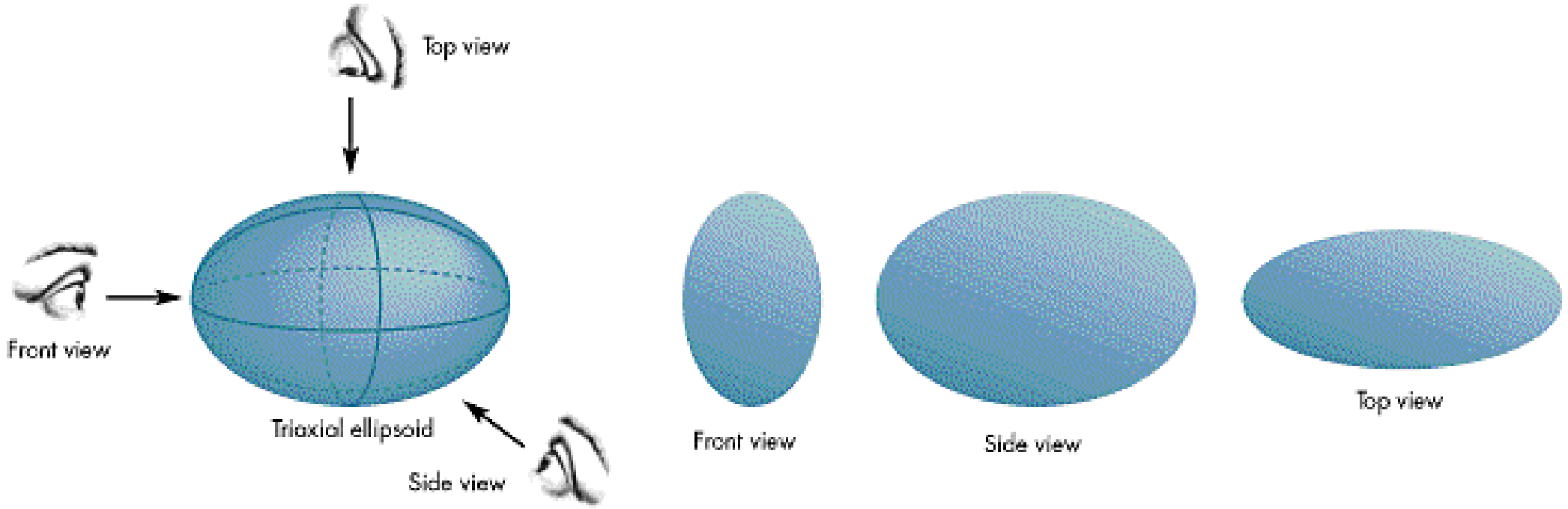
E6



E7



Elliptical Galaxy Shapes

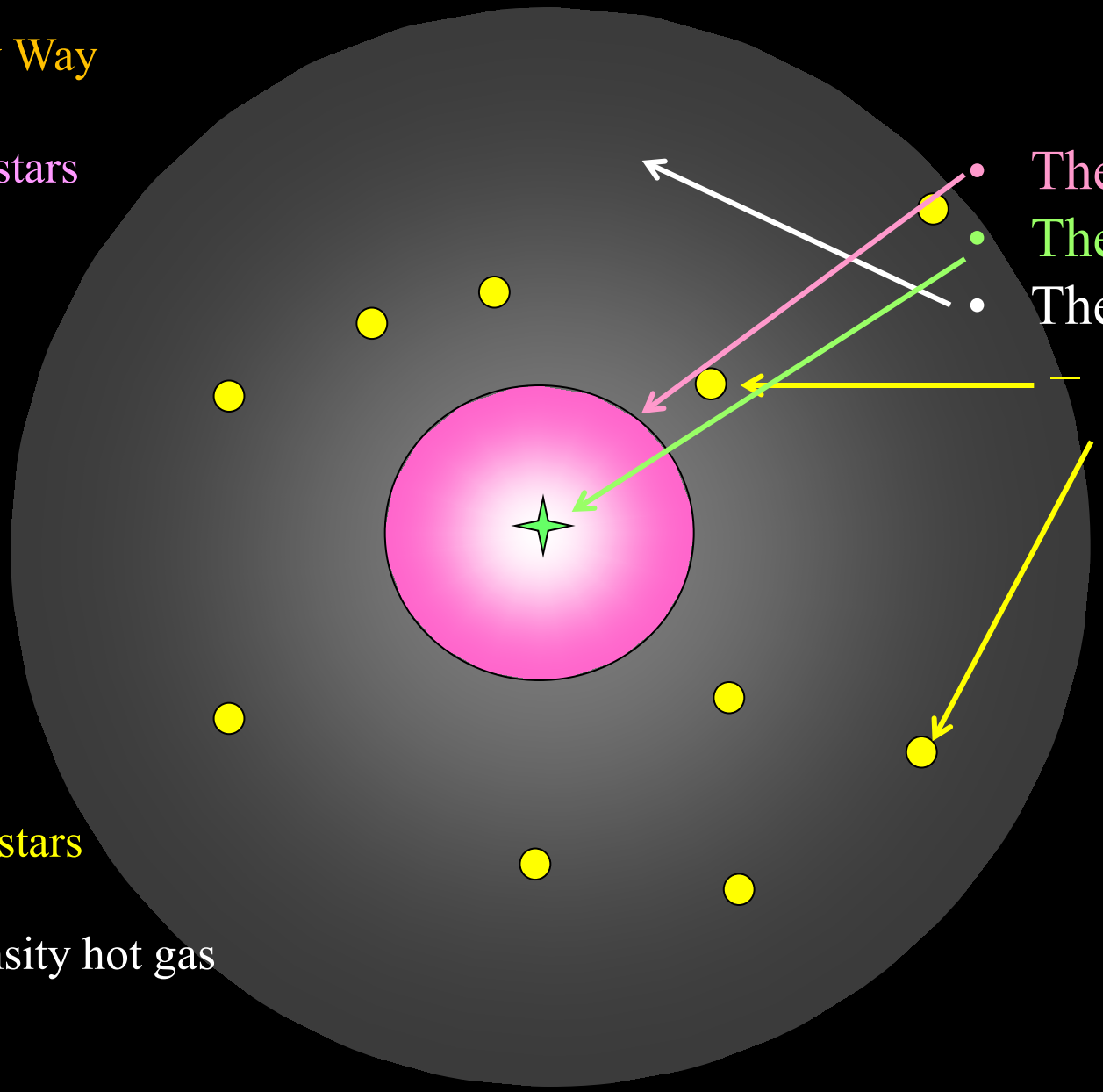


- Appearance may depend on angle of view
- Amount of flattening probably has to do with rotation
- Beyond E7, galaxy probably becomes unstable

Elliptical Galaxy Structure

Rather different from the Milky Way

- Typically contains only old stars
- Star orbits can be
  - Completely random, or
  - Have a bias so there is net angular momentum of the galaxy
- Probably, the more rotation there is, the more flattened the shape is
- No gas and dust, so no new stars
- Halo often contains low-density hot gas



- The visible part
- The nucleus
- The halo
  - Globular clusters

Elliptical Halos

- Elliptical galaxies don't have thick clouds, but they do have diffuse, hot gas
- These gasses emit X-rays
- Gravity vs. pressure – they expand to make a giant sphere
- Amount of gravity tells us 85% of the mass of the galaxy is dark matter in the halo

Dwarf Ellipticals

- Some elliptical galaxies are much smaller than typical galaxies
  - Denoted dE, for dwarf ellipticals
  - There are typically no spiral galaxies of this size
- These galaxies probably originally had gas, but all gas has since been consumed
- These may have been the first galaxies ever formed
  - Other galaxies formed primarily from mergers of dwarf ellipticals

Giant Ellipticals

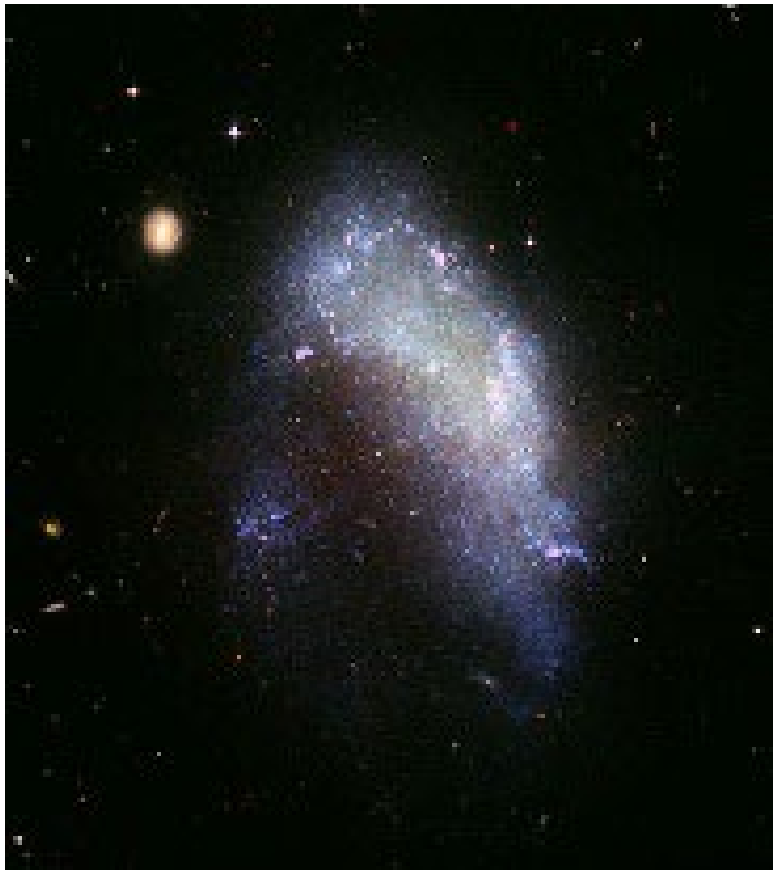
- The largest galaxies tend to be elliptical galaxies
  - Still denoted by E
  - There are typically no spiral galaxies this large
- They tend to be more round
- They galaxies often have low densities of stars
  - They are therefore “low surface brightness galaxies”
  - Denoted D in the Yerkes classification system
- The largest of these are called cD or Central Dominant galaxies
- Usually at the center of a cluster of galaxies
- Often contain multiple nuclei
  - Multiple giant black holes
- Probably formed from the merger of many smaller galaxies

Other Types of Galaxies

Irregular Galaxies

Irregular galaxies don't fit in well with the others

- *Some* of them look a little like spiral galaxies
- Gas, dust, young and old stars
- Like a galactic disk, no spirals, a mess
- Probably caused by disruptive collisions
- Classified as Im



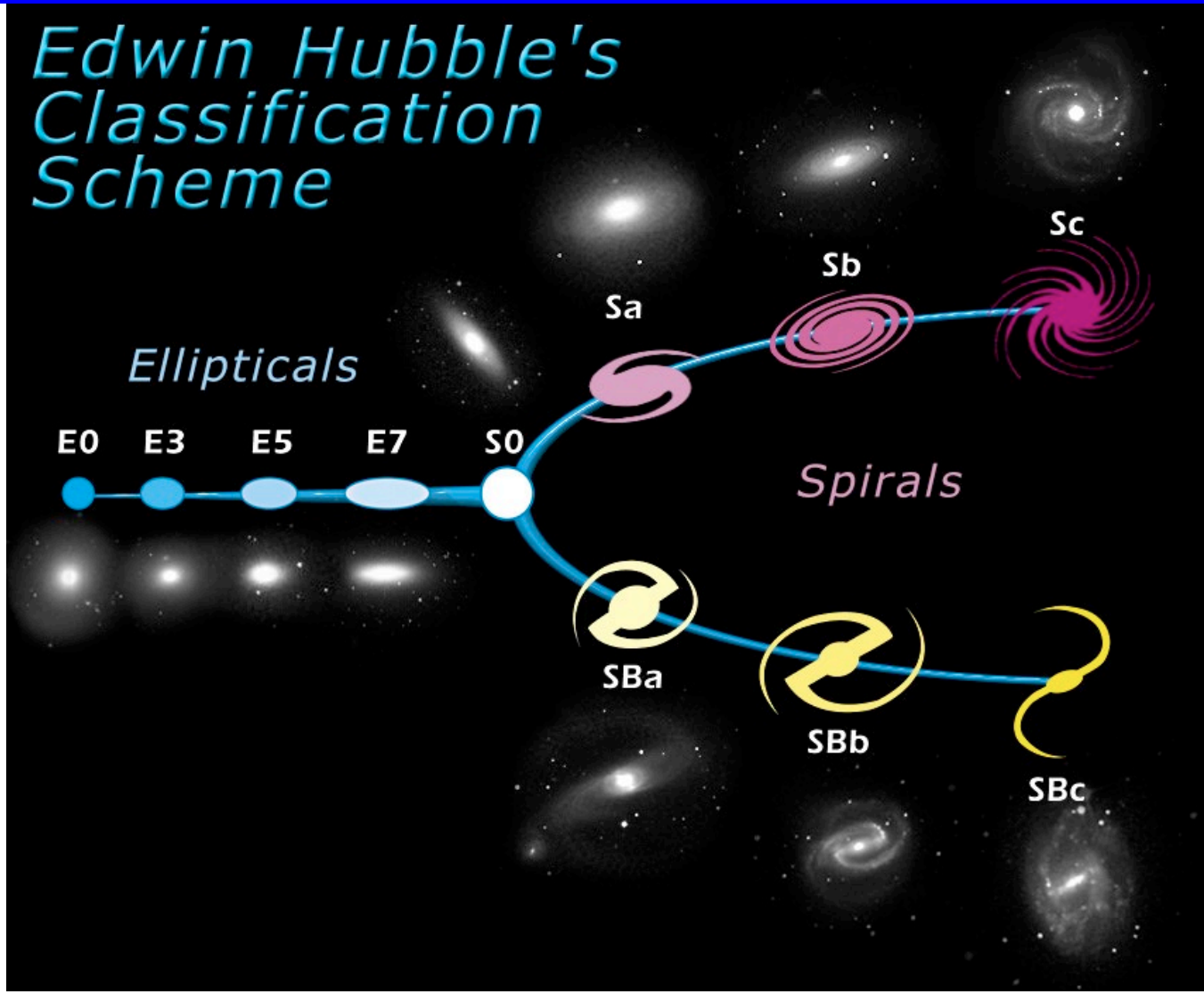
Dwarf Spheroidal Galaxies

- Much lower mass than typical galaxies
- Stars are spread out – low density
- Mass of stars insufficient to hold them together
- Strong indication they are mostly dark matter, not much else
- Difficult to see beyond nearby galaxies
- Denoted dSph

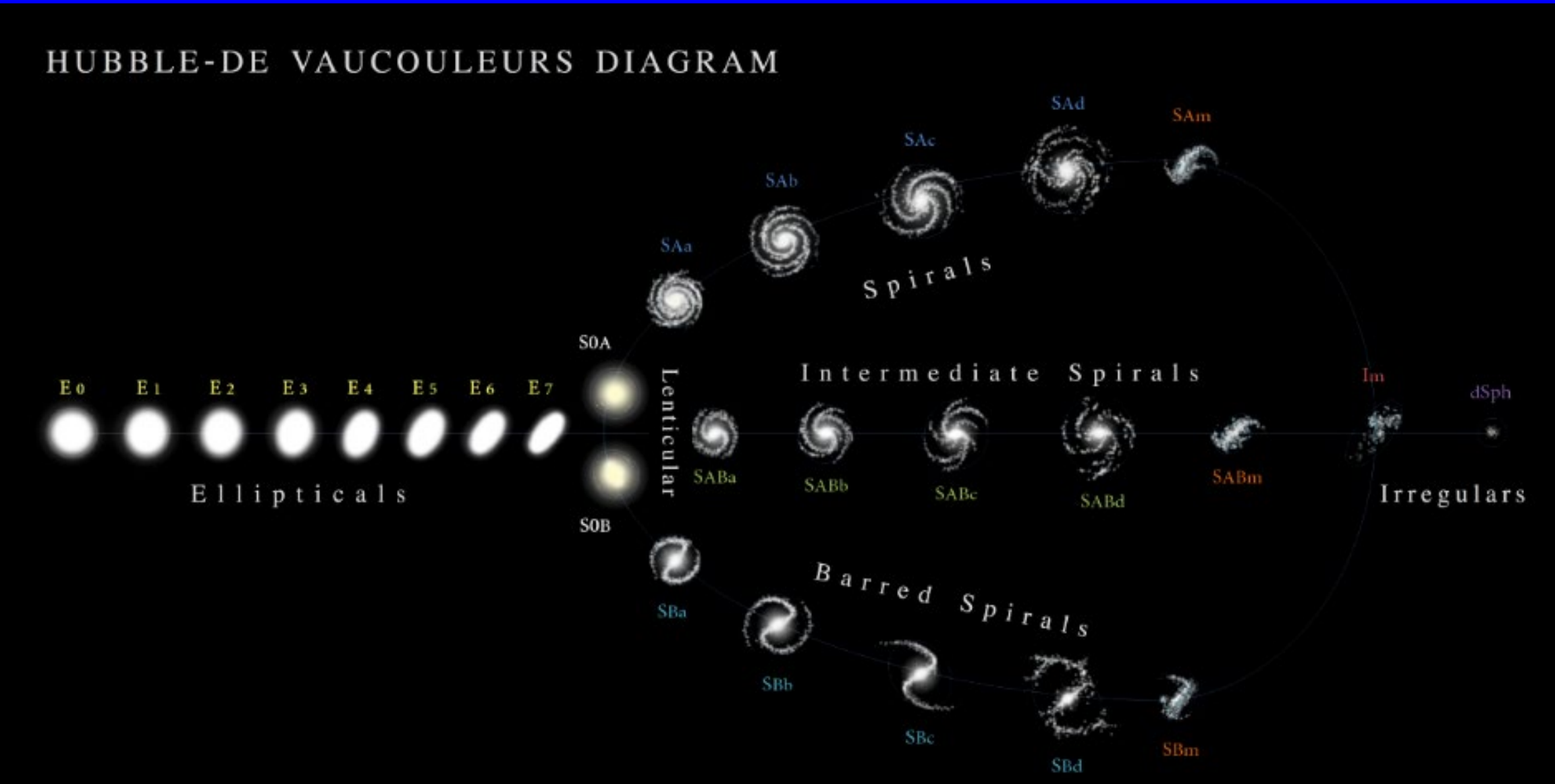
Putting it All Together

The Original Tuning Fork

- Original Hubble classification had a two-pronged system that described how these go together
  - Because he didn't have intermediate bars (SAB)
- With the De Vaucouleurs system, it is now a three pronged fork
- And the "tines" have gotten longer



The Updated Tuning Fork



Differences - Spirals vs. Ellipticals

- Spirals have disks and spiral structure
- Spirals have dust/gas/young stars in the disk
- Ellipticals have hot gas spread out through a large halo

Can we explain these differences?

Hot Gas Vs. Cool Gas

- Hot gas has low density
  - Atoms cool off by colliding and radiating light
    - But at low density, collisions are rare
  - Low density gas cools slowly
    - Will not cool off in age of universe

- Hot gas has pressure:
  - Gravity vs. pressure = sphere
  - An elliptical galaxy

- Cool gas has high density
  - High density gas collides more often
    - And then can radiated that energy
  - Can cool off further in short time

- Cool gas has little pressure, but still has rotation
  - Gravity vs. rotation = disk
  - A spiral (or barred spiral) galaxy

What Determines Galaxy Type?

- If we have a source of cool gas:
  - Gas will form a disk
  - Disk will form stars
  - There will be young stars

- If all gas is hot:
  - Gas remains in a giant halo, no disk
  - No star formation
  - No young stars

- Conclusion: If you have a source of cool gas, you get a spiral or barred spiral, otherwise get elliptical