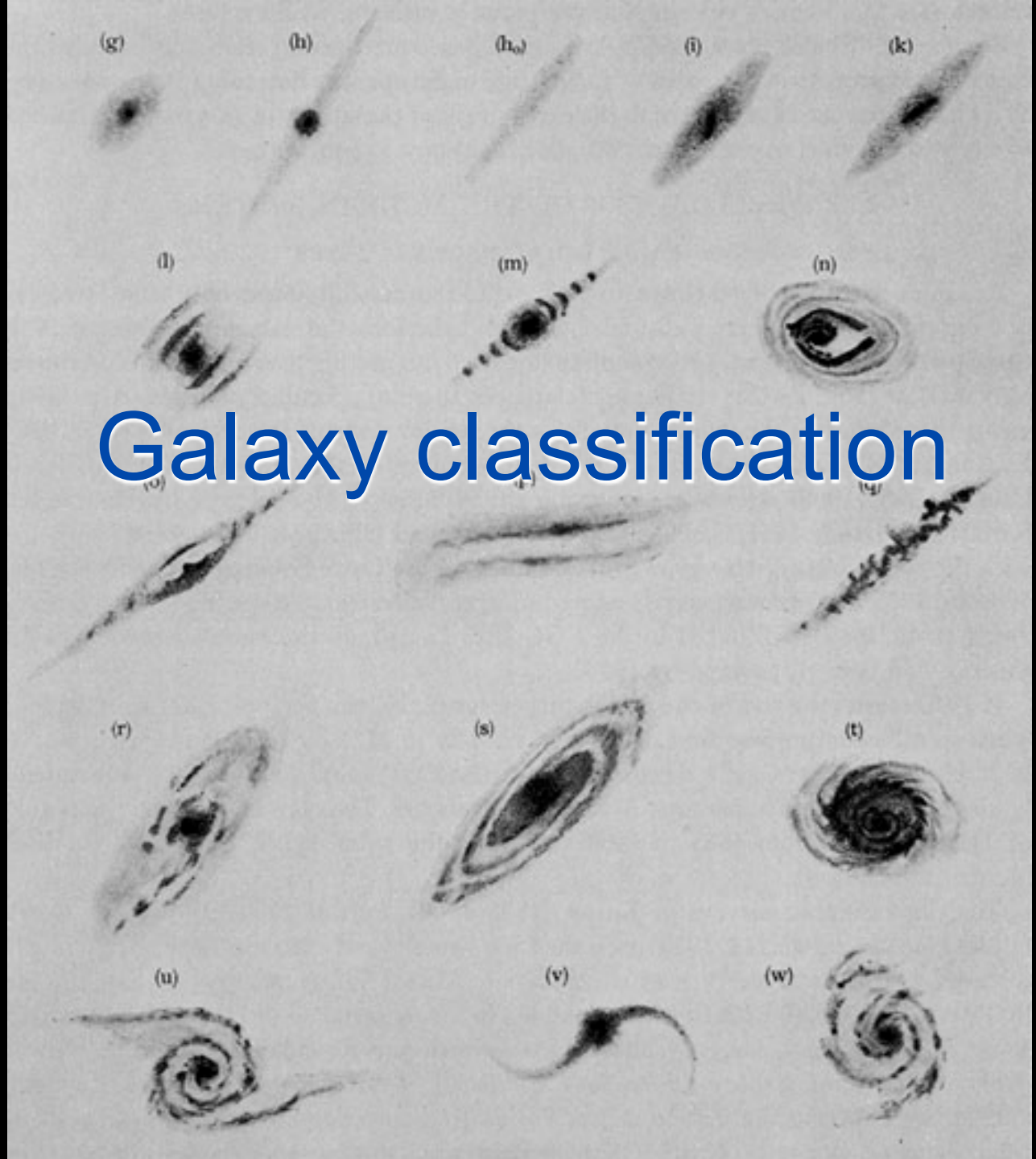
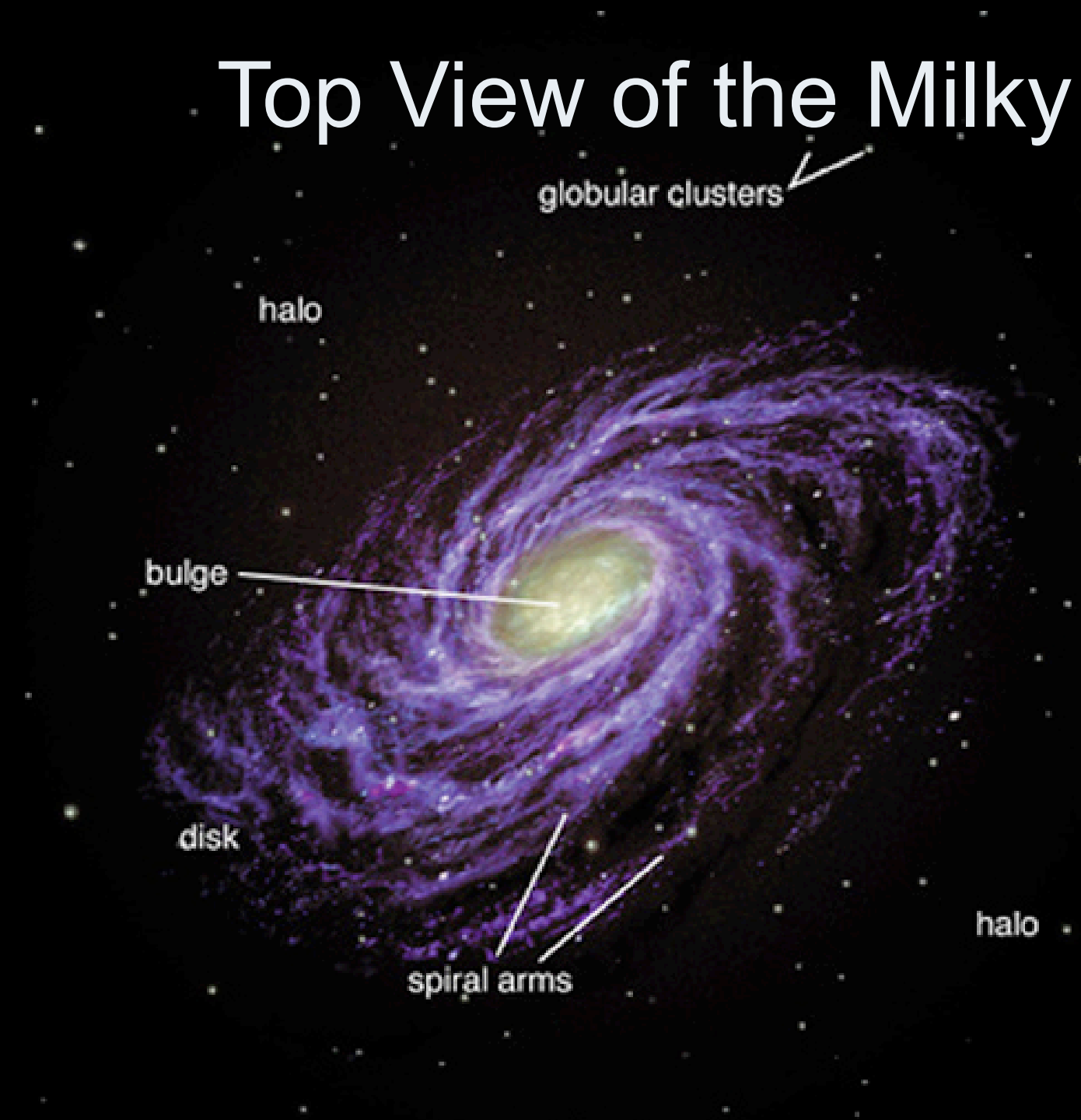


Galaxy classification

Questions of the Day

- What are elliptical, spiral, lenticular and dwarf galaxies?
- What is the Hubble sequence?
- What determines the colors of galaxies?

Top View of the Milky Way



- The MW is a "spiral" galaxy, or a "late type" galaxy.

The different components have different colors, motions, and chemical compositions → different origins!

Other Late Type Spiral Galaxies

- More disk than bulge (if any!).
- High current star formation.

These are also “late-type” galaxies. Apparent shape depends on orientation

Other Types: “Early type galaxies”

“Sombrero Galaxy”

- More bulge than disk.
- Low current star formation.

And even earlier type galaxies:



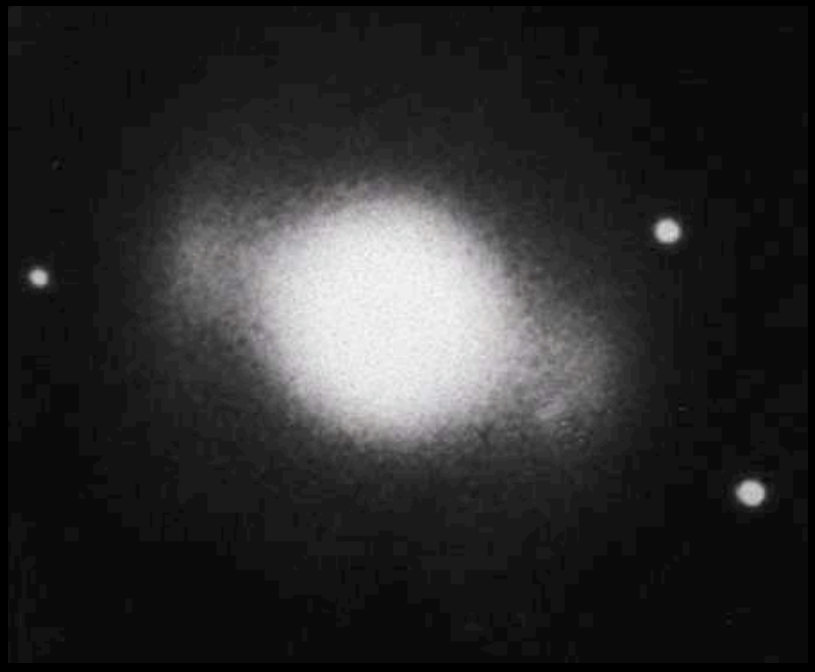
- **Elliptical Galaxies** (or just "ellipticals")
  - No disk! All bulge!
  - Very little gas
  - Probably old!

Have evolved to the point where no gas is left for making new stars!

"spheroidals"

And in between, “lenticulars”

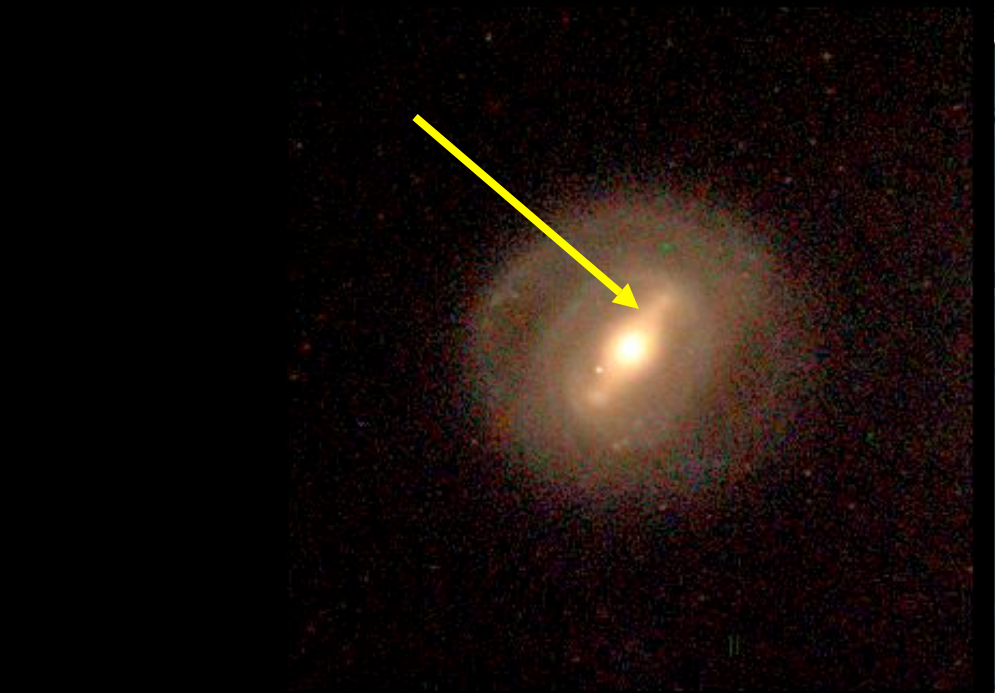
- Just a *hint* of a disk.
- Low current star formation.

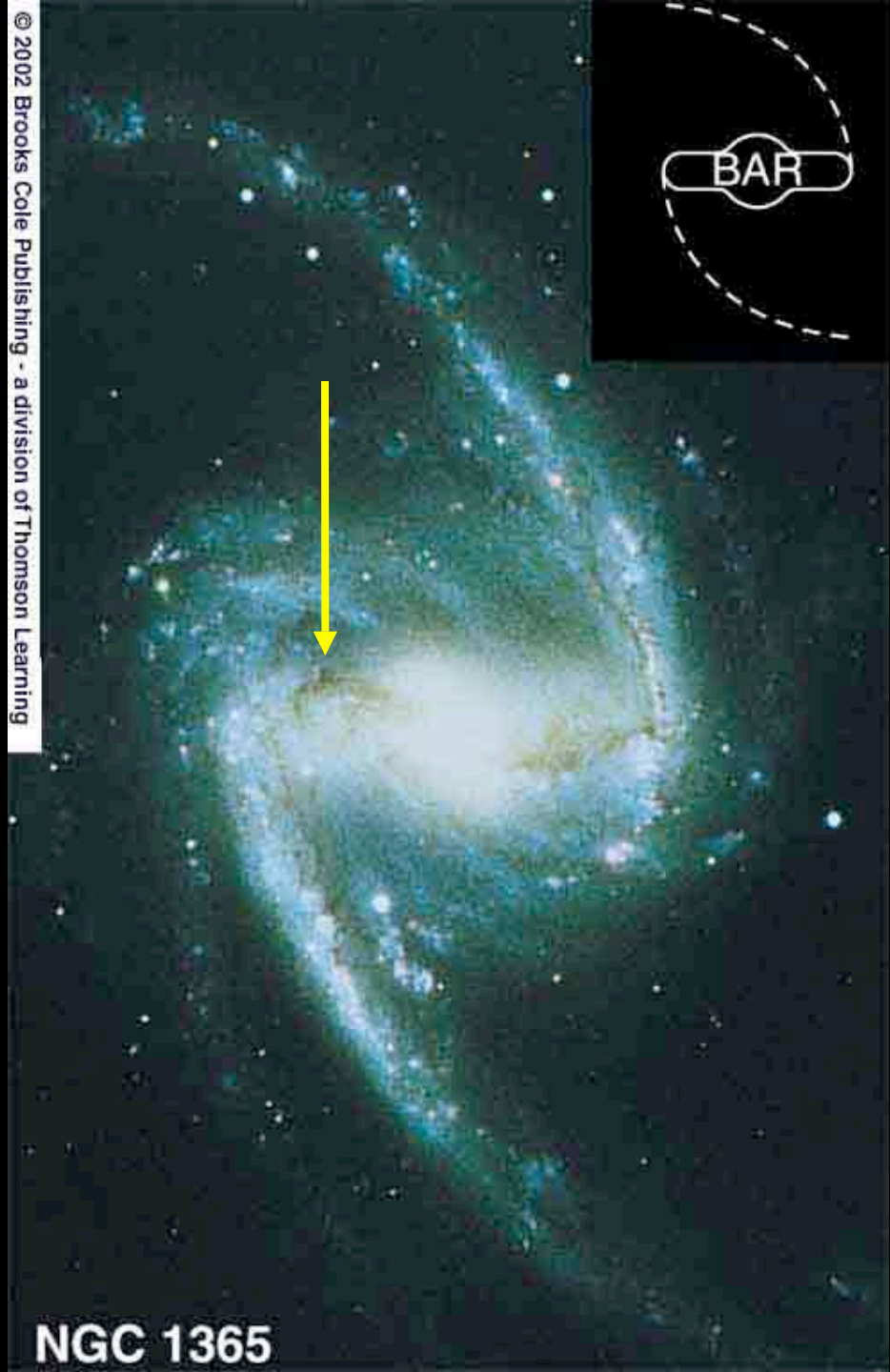


“S0” galaxies: Like ellipticals, but usually a bit flatter.

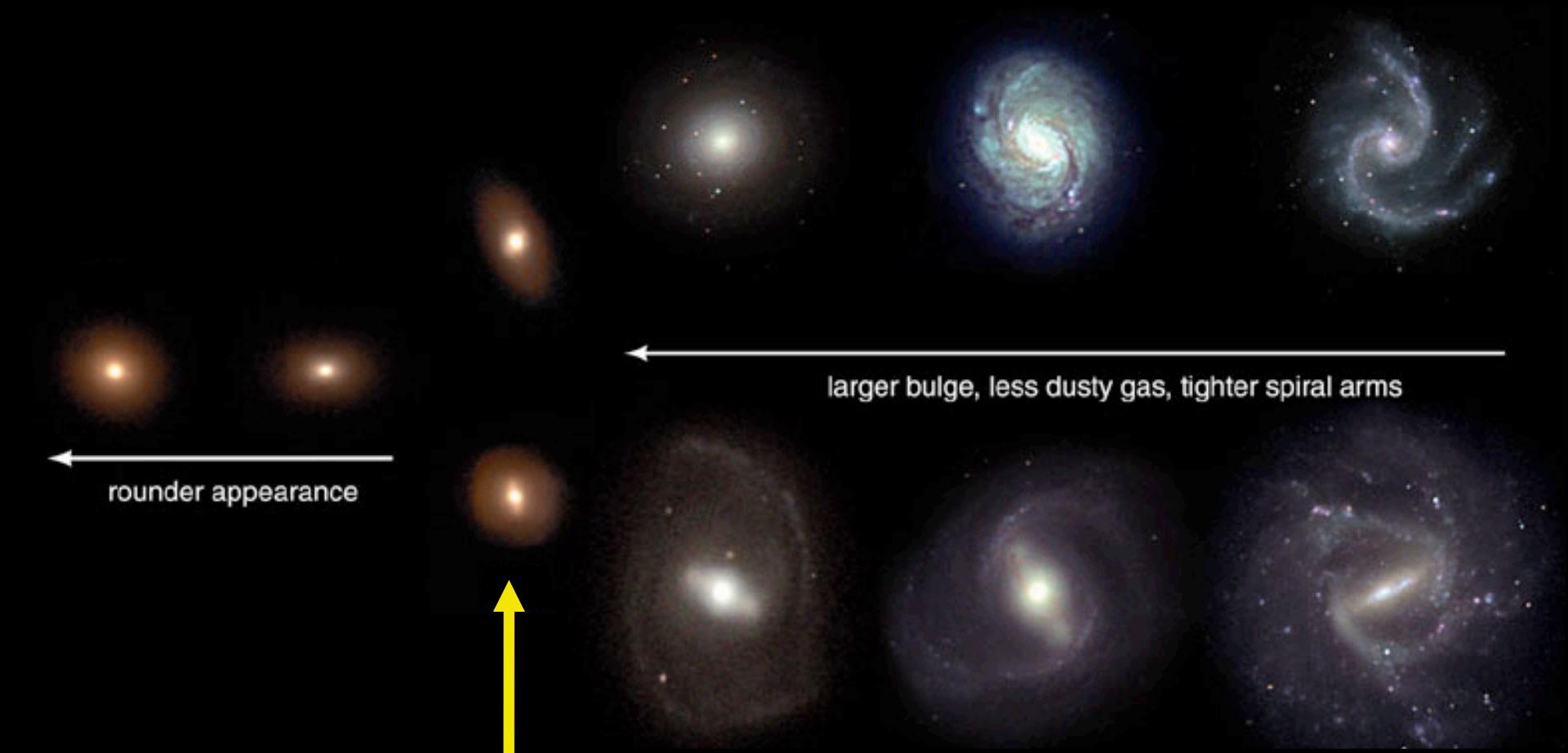
Many galaxies have "bars" – linear arrangements of stars

(The Milky Way has a bar!)

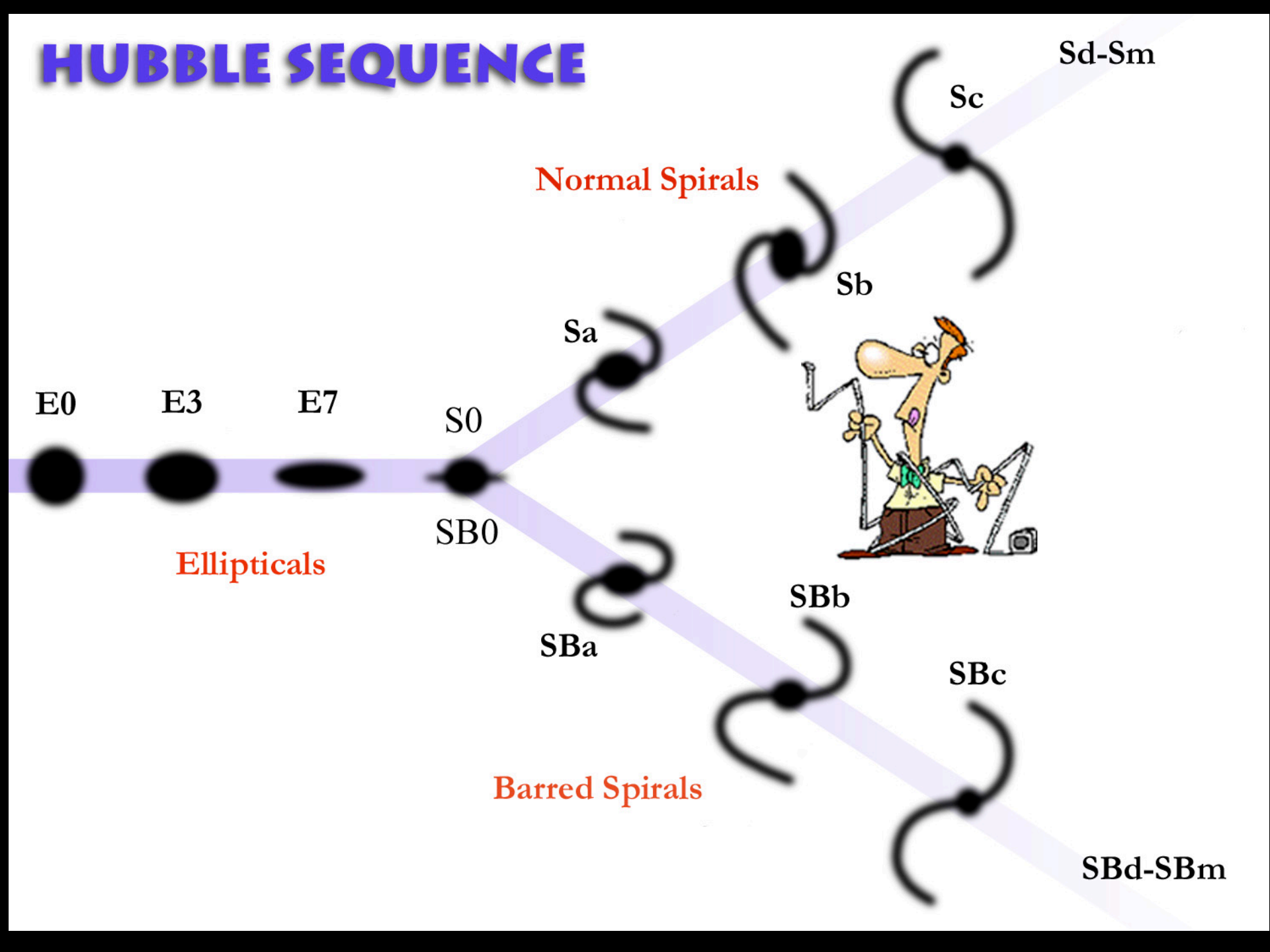




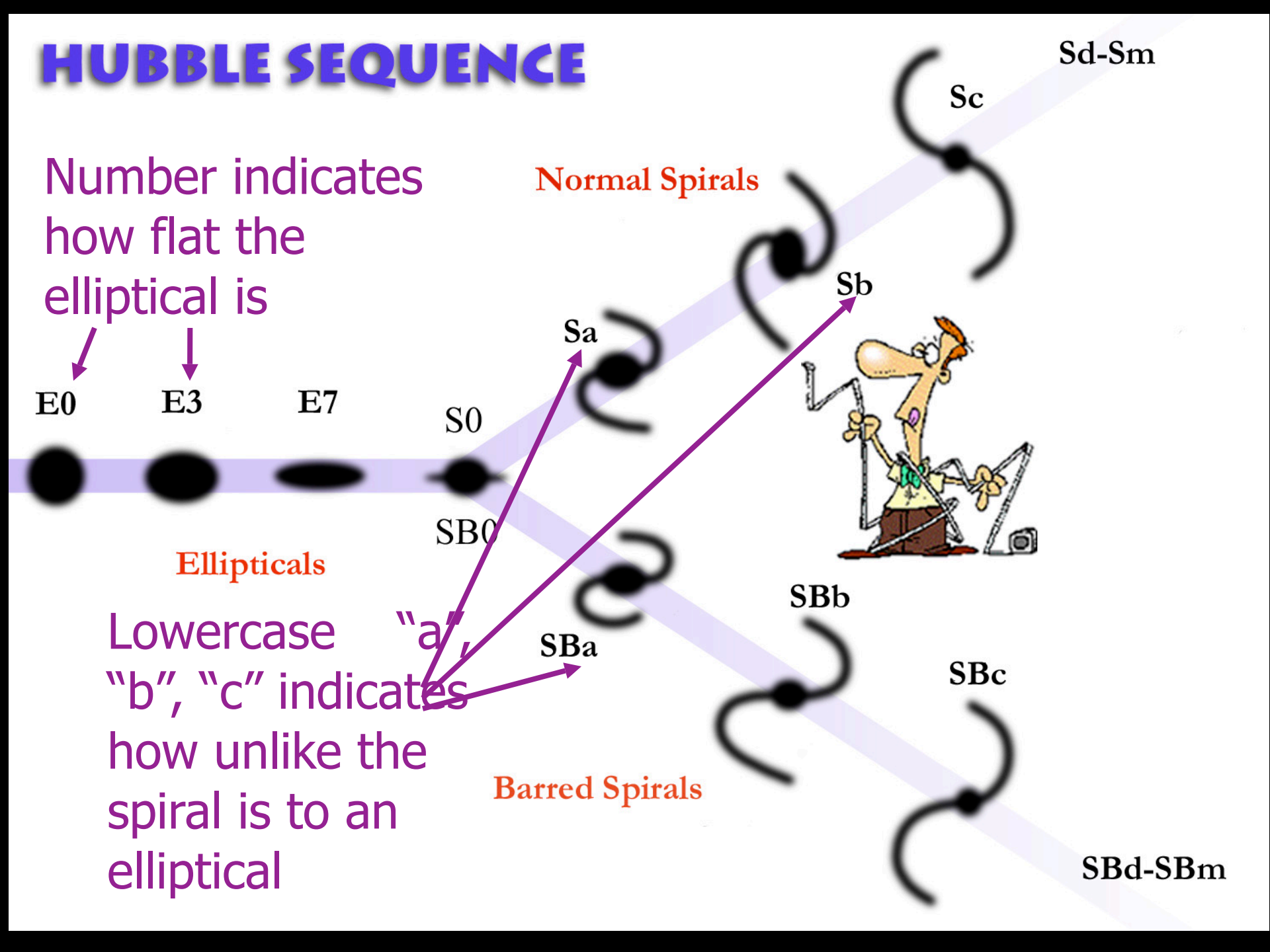
All of these different types of galaxy fit nicely into a sequence.

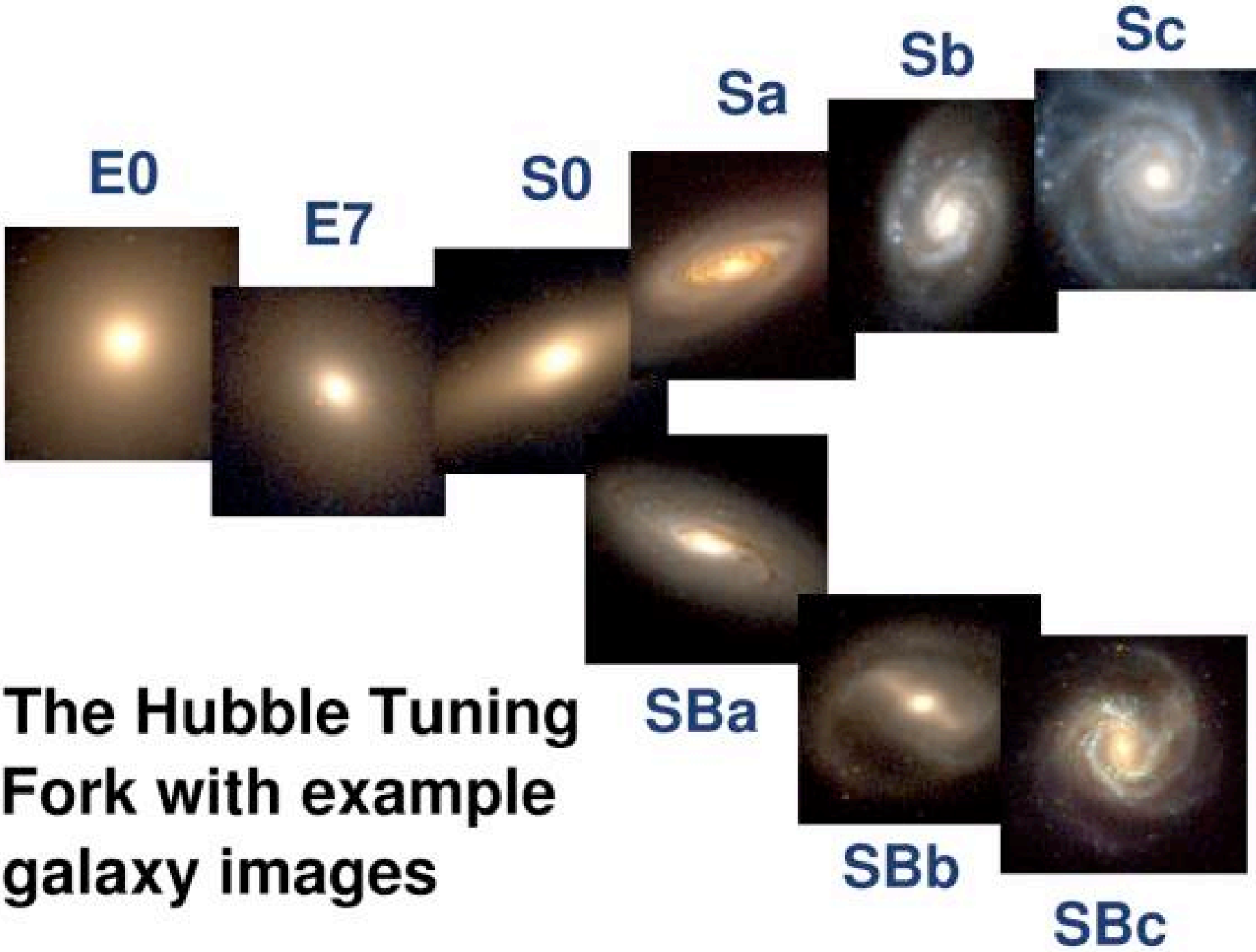


HUBBLE SEQUENCE



HUBBLE SEQUENCE





The Hubble Tuning Fork with example galaxy images

Things that vary along the Hubble Sequence:

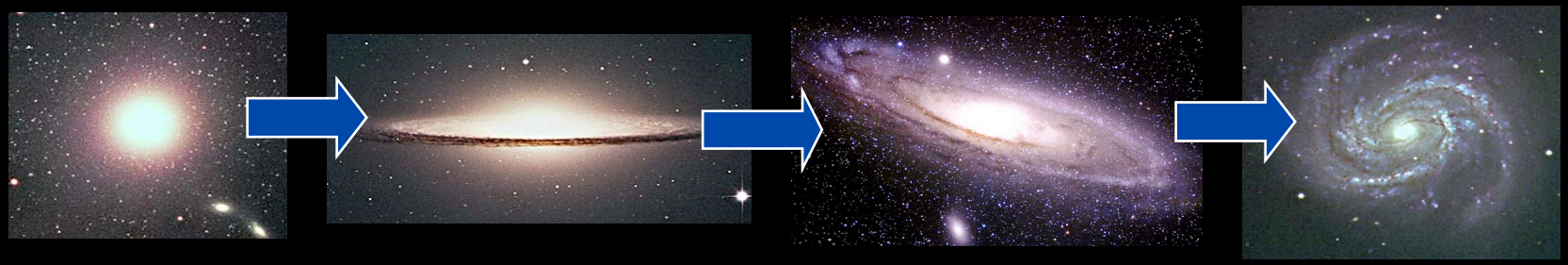
1. "Bulge-to-Disk Ratio"
2. Lumpiness of the spiral arms
3. How tightly the spiral arms are wound

E Sa Sb Sc

"early type" "late type"

Things that vary along the Hubble Sequence:

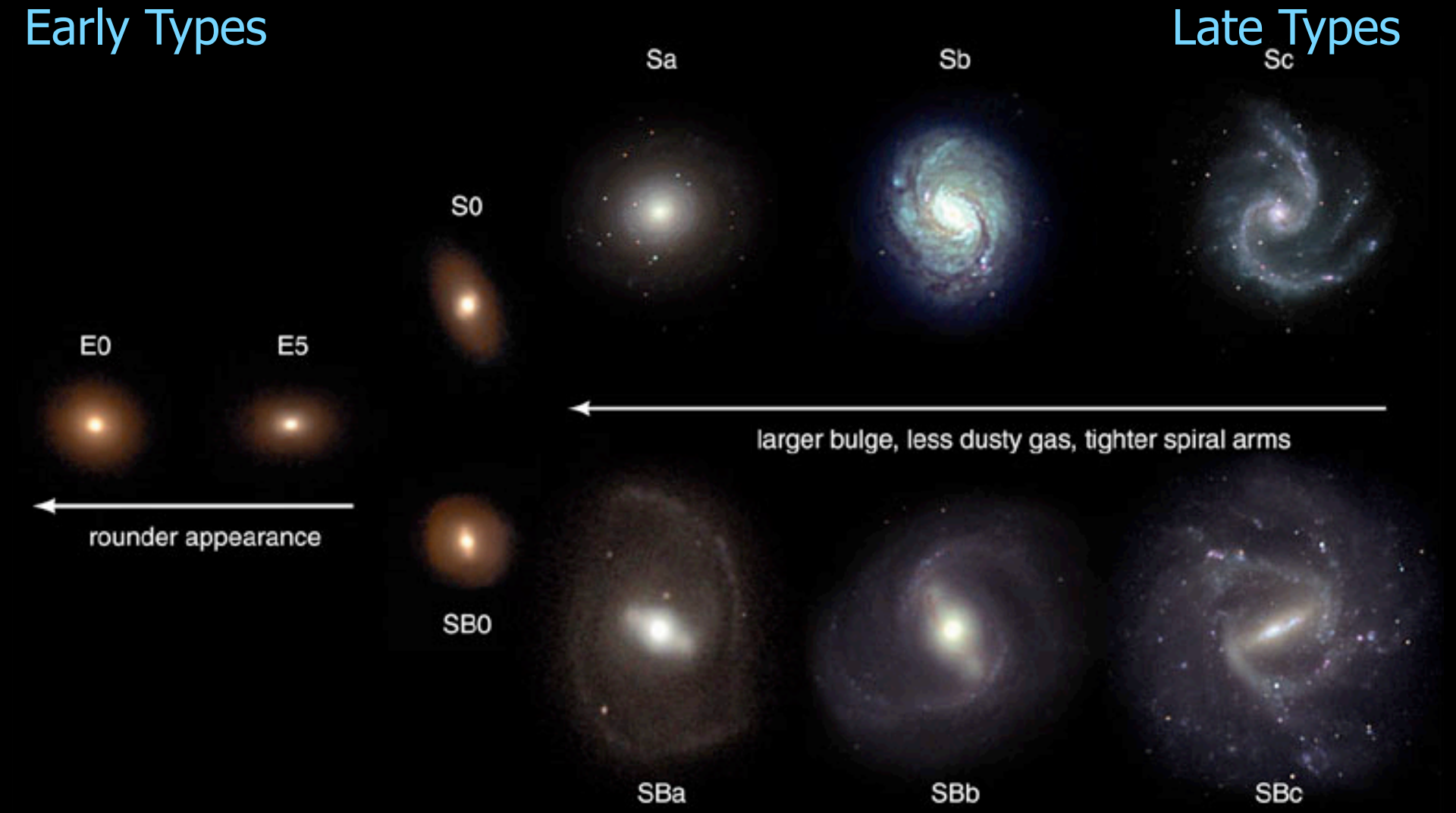
1. "Bulge-to-Disk Ratio"
2. Lumpiness of the spiral arms
3. How tightly the spiral arms are wound



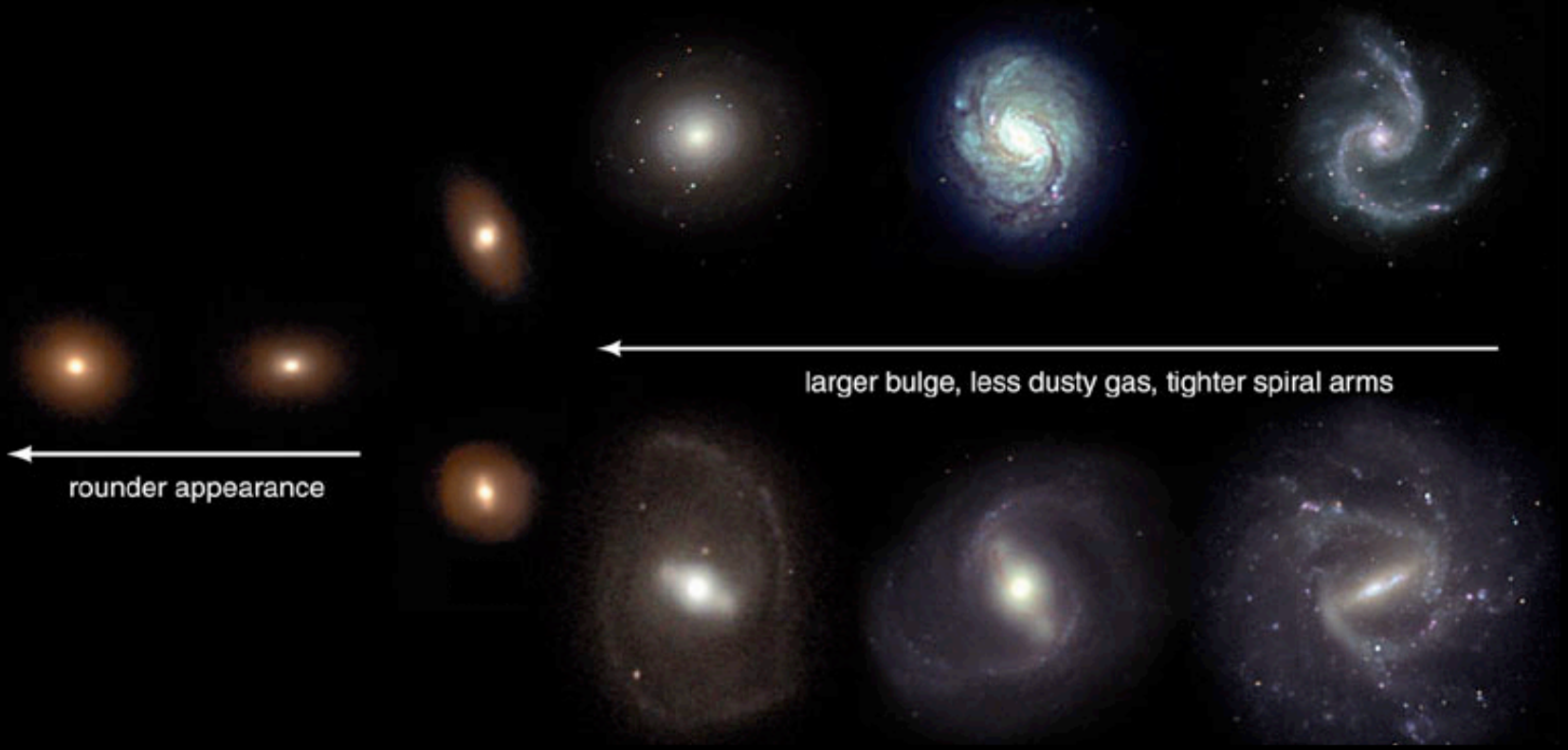
E Sa Sb Sc

Note: These are not exact trends! Galaxies are much more complex than stars!

1. "Bulge-to-Disk Ratio"
2. Lumpiness of the spiral arms
3. How tightly the spiral arms are wound



Varying amounts of bulge & disk components suggests different formation & evolution history!

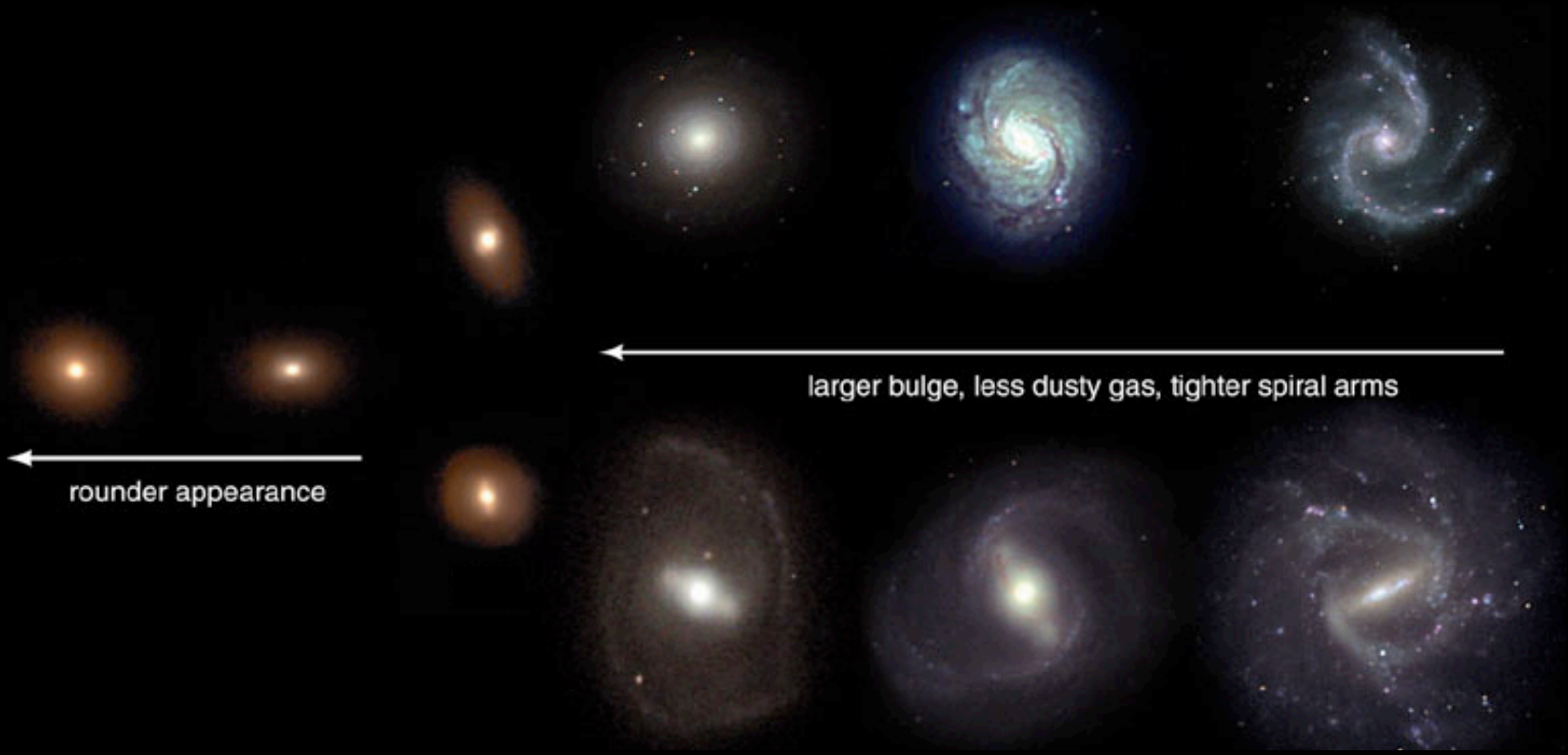


Which has a higher star formation rate?

A: Early-Type Ellipticals

B: Late-Type Spirals

Varying amounts of bulge & disk components suggests different formation & evolution history!

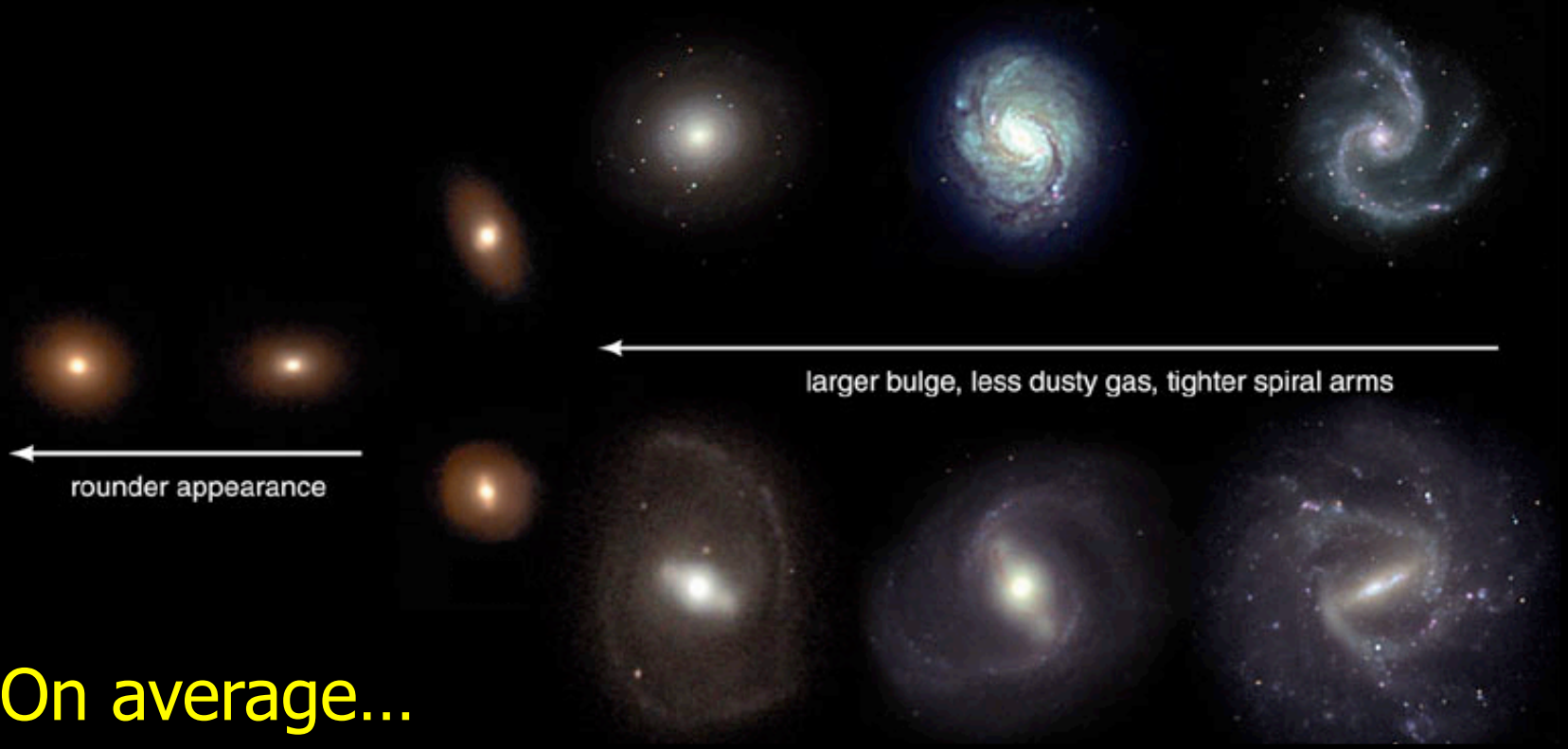


Which do you think has more gas?

A: Early-Type Ellipticals

B: Late-Type Spirals

Varying amounts of bulge & disk components suggests different formation & evolution history



On average…

- Older Stars
- Gas Poor
- More Massive

→

- On-going Star Formation
- Gas Rich
- Less Massive

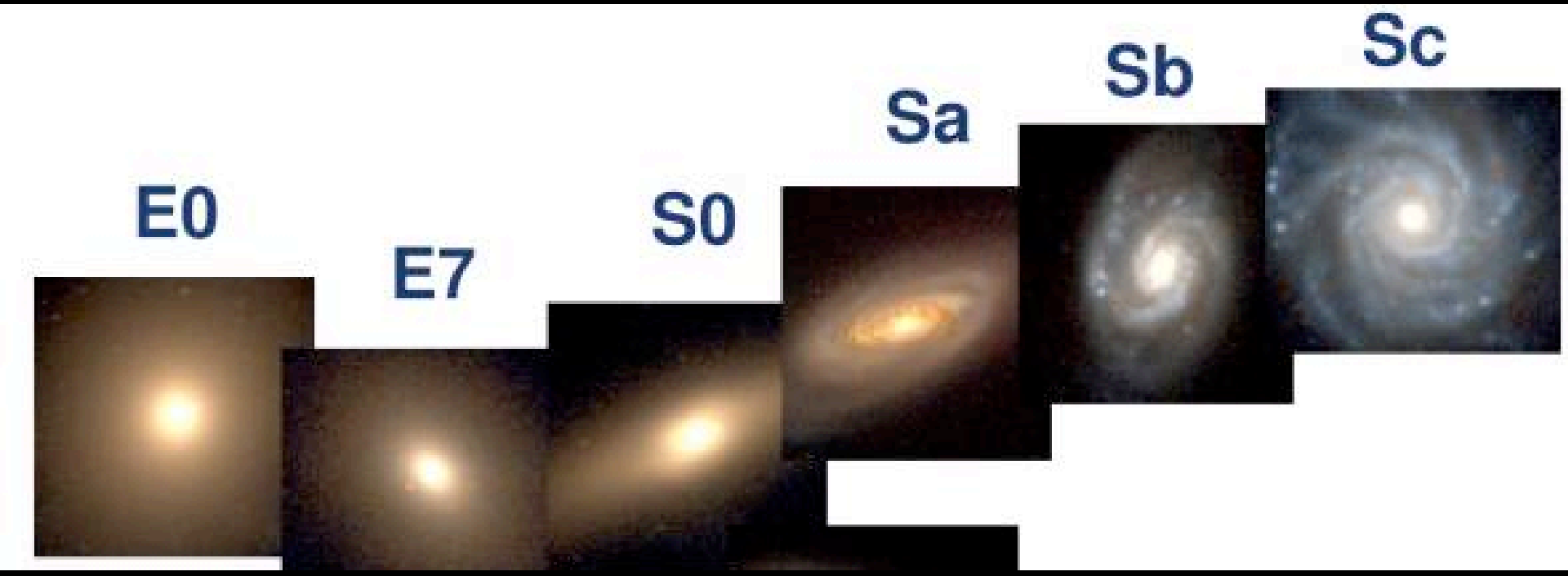
The "star formation history" varies along the Hubble sequence:

Late-type galaxies tend to have a much larger fraction of their normal matter in the form of gas.

They've used up less of their "fuel" for star formation.

The "star formation history" varies along the Hubble sequence:

The colors of late-type galaxies tend to be **bluer**.



Why do the *colors* of galaxies suggest that the stars in galaxies have different typical ages?

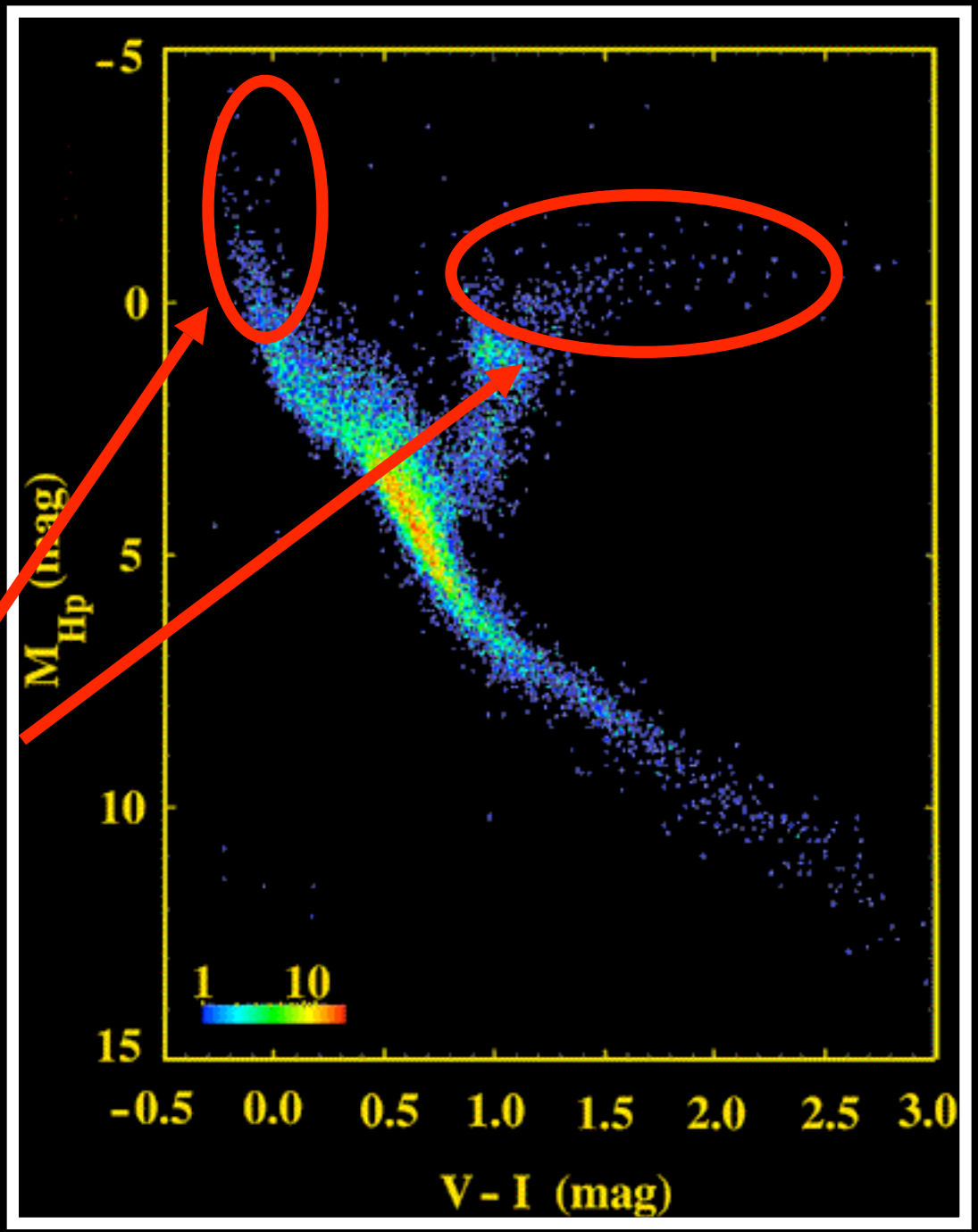
- First, what sets the colors of galaxies?

STARS!

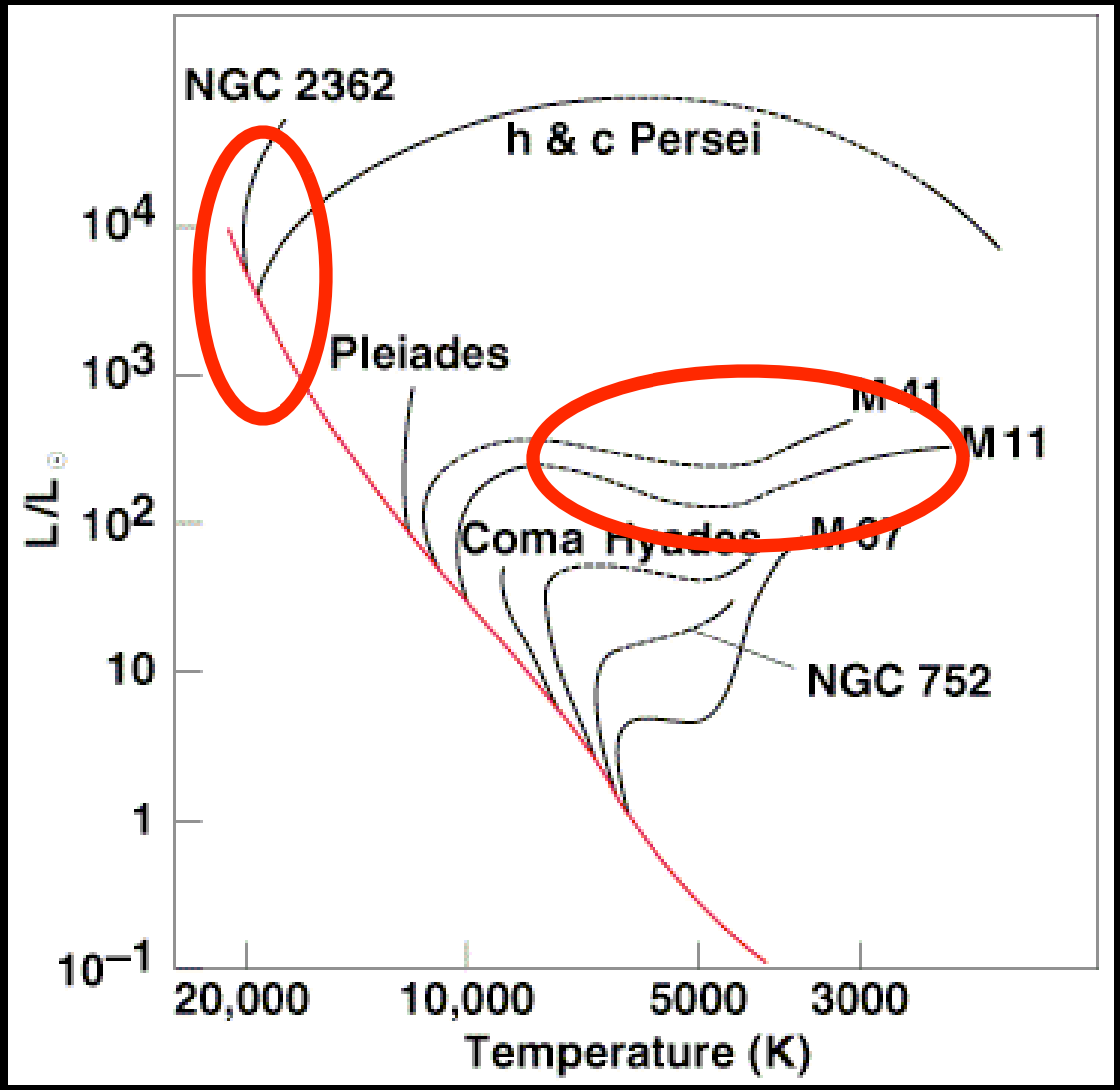
Reddening from dust, and light emitted by HII regions have only a secondary effect on color

The color of the brightest stars pretty much sets the **color** of the galaxy.

These stars tend to be young massive main sequence stars, or red giants.

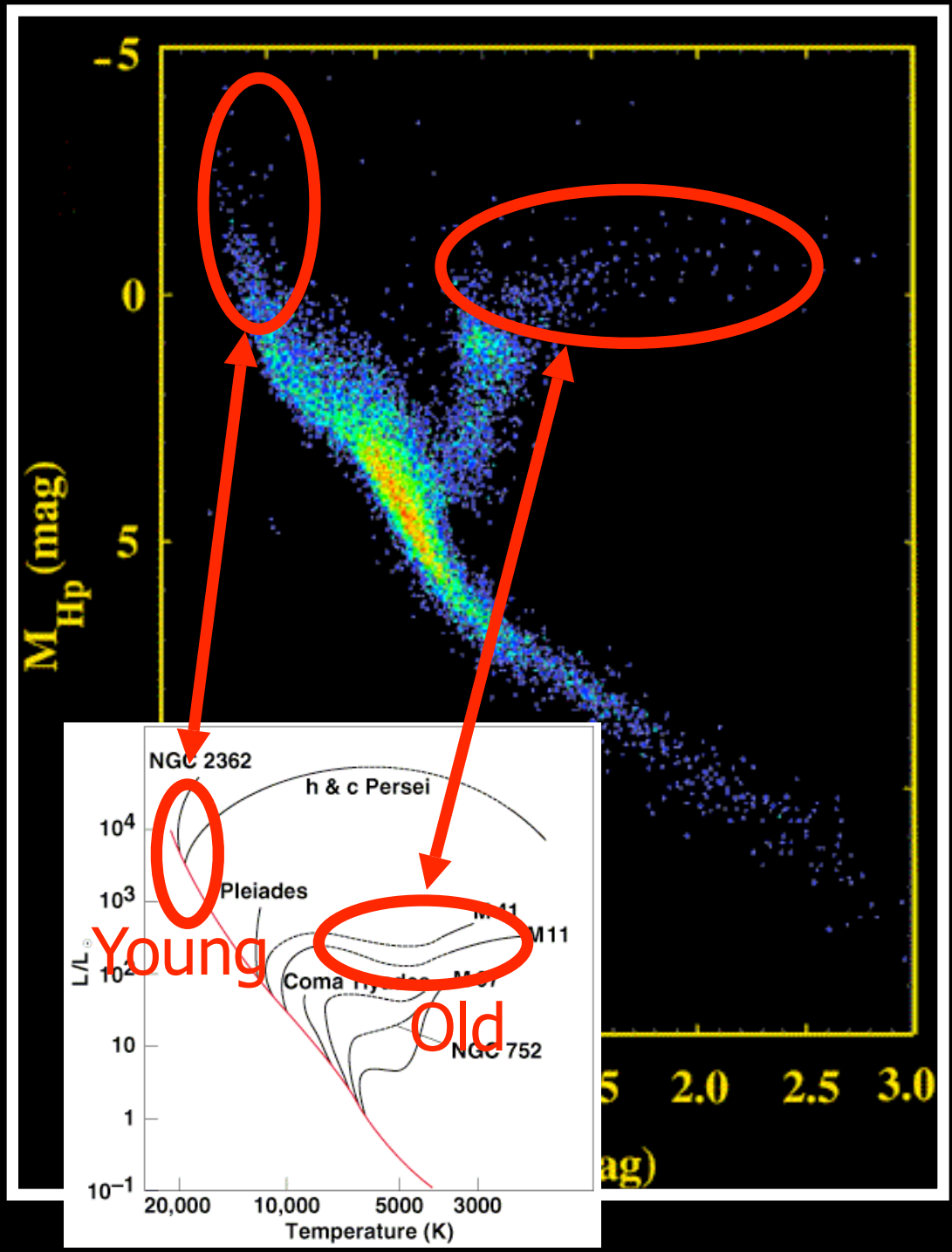


Star clusters of different ages have different fractions of these bright red and blue stars



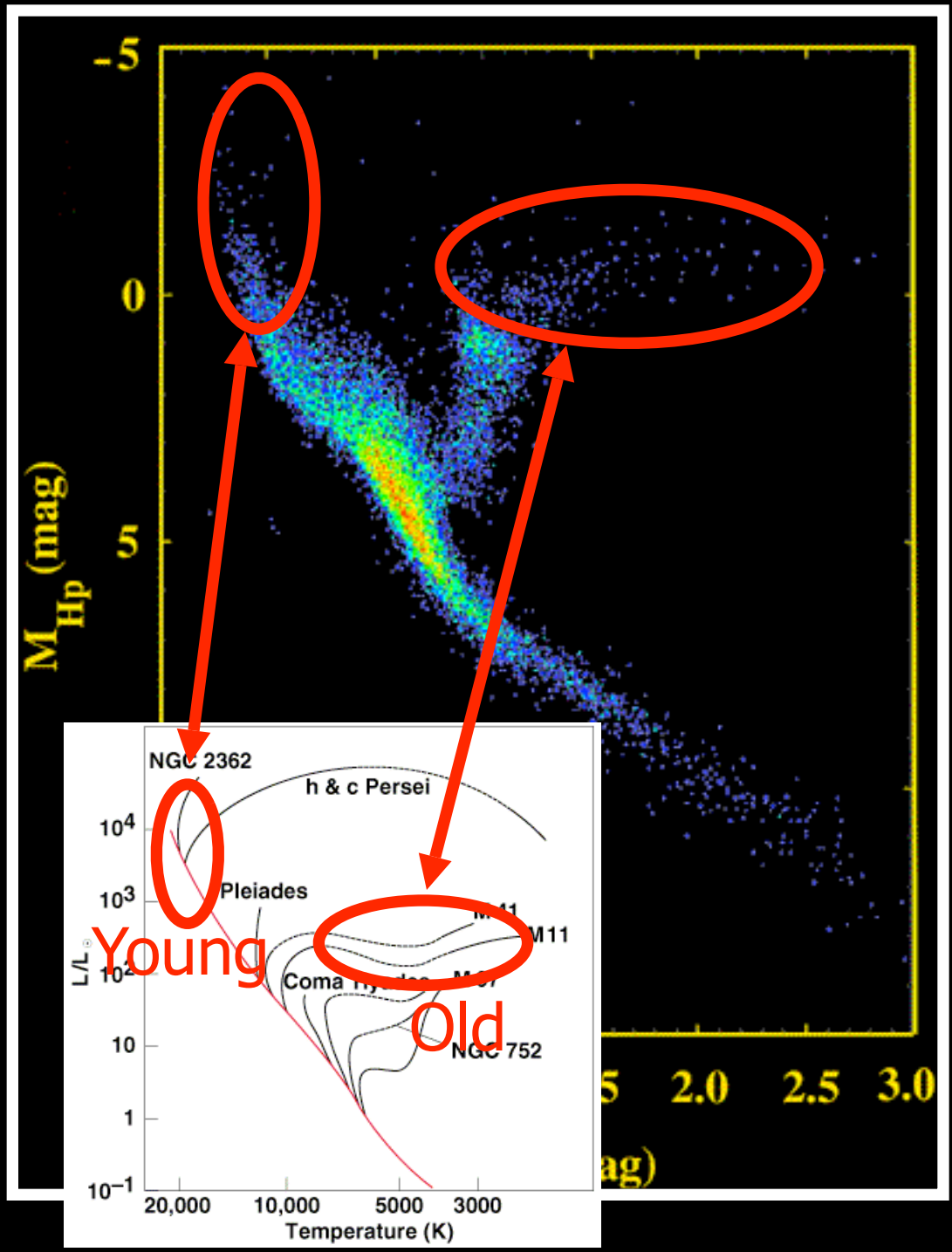
Galaxies have more complex stellar populations than single clusters.

They have a mix of stars formed at different times.



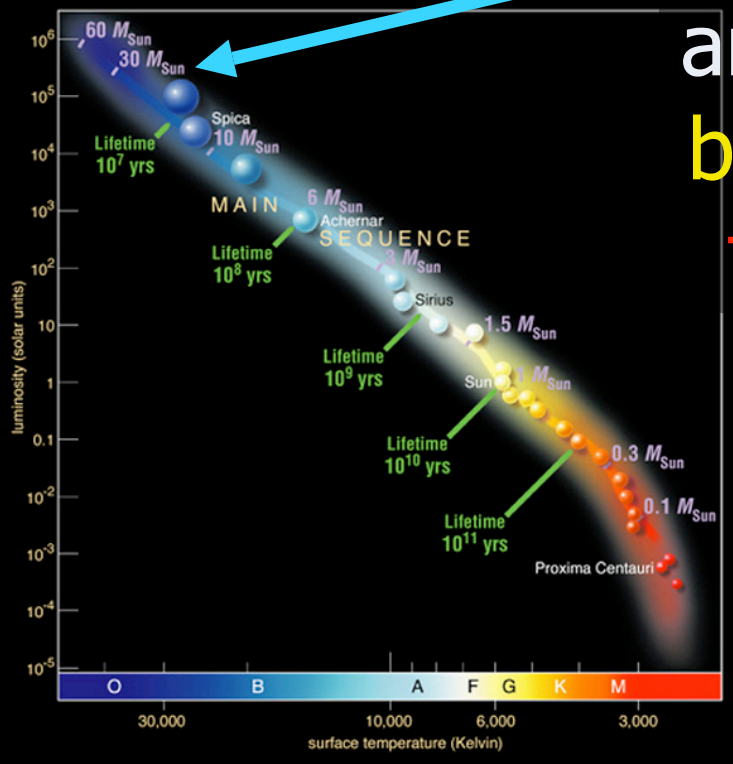
Galaxies with more recent star formation have a larger fraction of young main sequence stars.

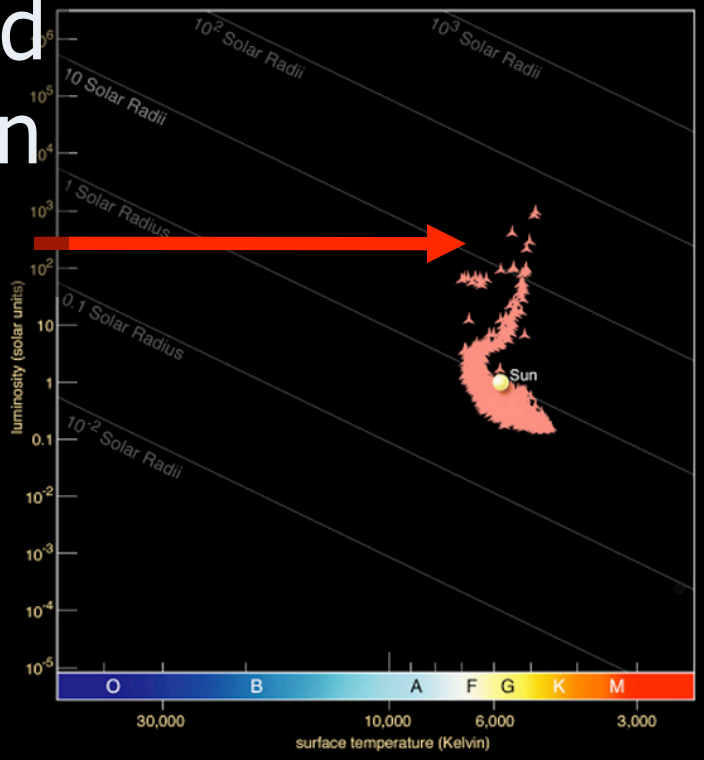
Galaxies with no young stars have red giants as their brightest stars.



Galaxies that are forming stars are **BLUER** and **BRIGHTER**

These stars are bluer and brighter than these stars





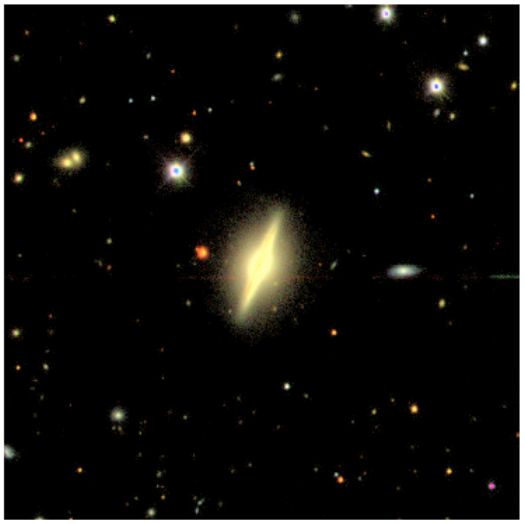
Young

Old

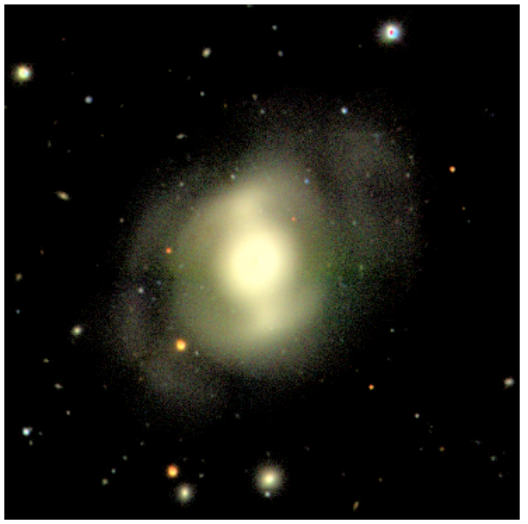
Early-Type Galaxies

from the Sloan Digital Sky Survey (SDSS)

NGC 4418: S0



NGC 3042: S0



NGC 936: SB0

NGC 2618: Sa

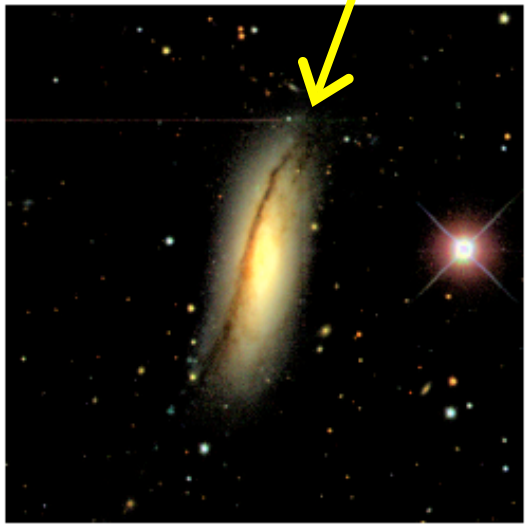
NGC 6010: Sa

NGC 2555: SBa

Late-Type Galaxies From SDSS

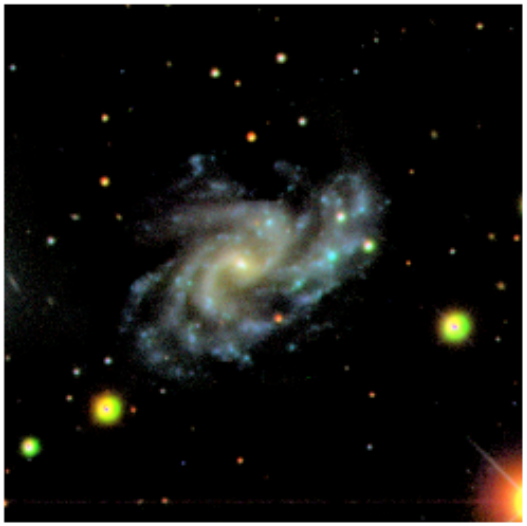
(red because of dust)

NGC 4030: Sb



NGC 5719: Sb

Z 1042.6+0023: SBb

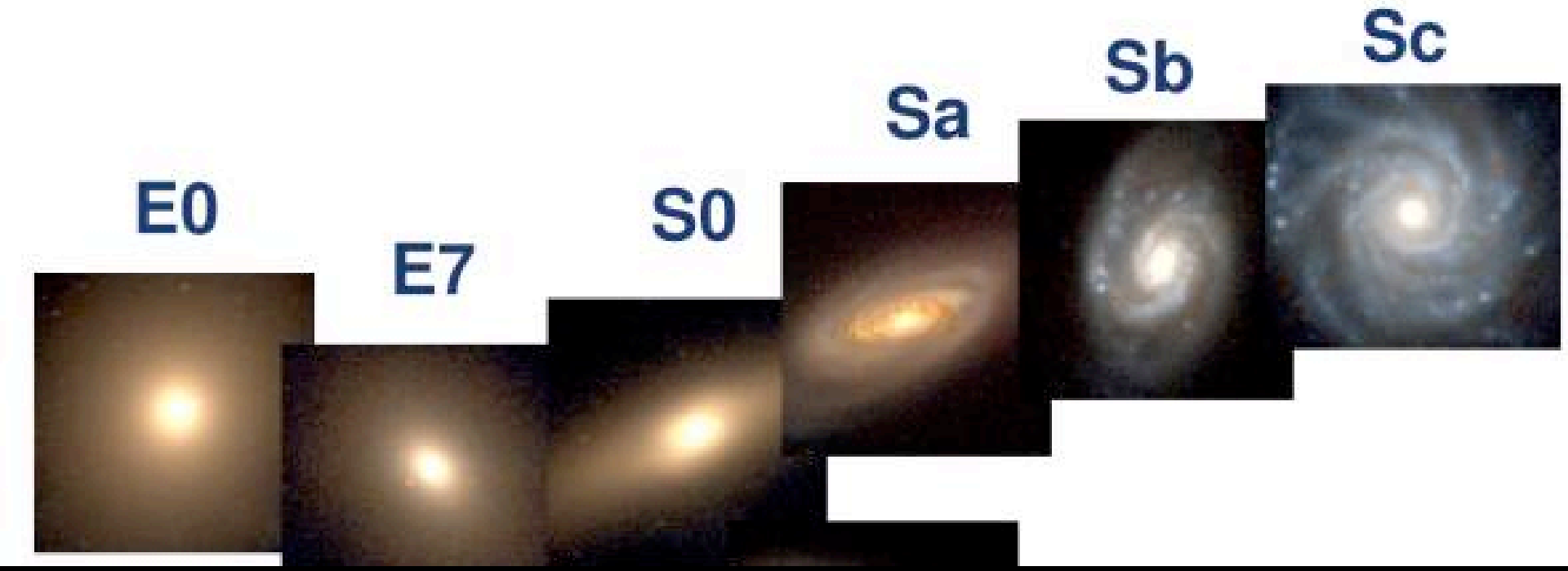


NGC 5584: Sc

NGC 5496: Sc

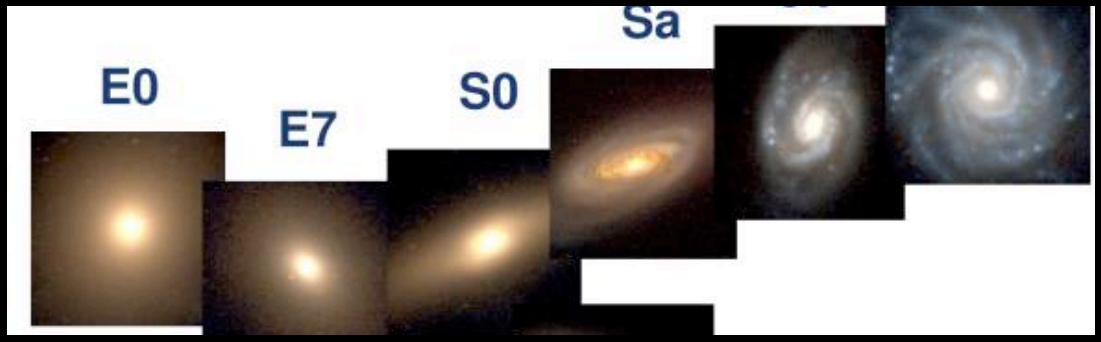
NGC 5334: SBc

Early Types tend to be redder than Late Types



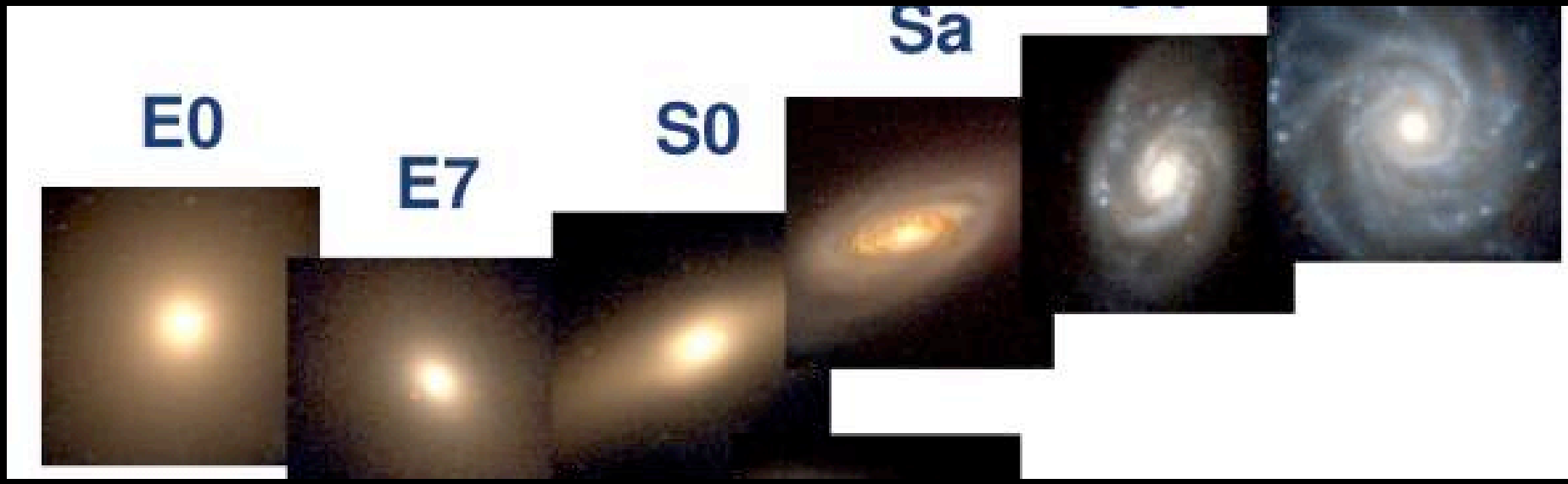
- "Early-Type"
- More Massive
- Gas Poor
- Older Stars

- "Late-Type"
- Less Massive
- Gas Rich
- On-going Star Formation



- Early-type galaxies turned almost all of their gas into stars, very ***quickly***, very **early** in their lives!

- Late-type galaxies turn gas into stars ***slowly***, and have lots of gas left today. They're forming lots of stars at the present day, at **late** times.

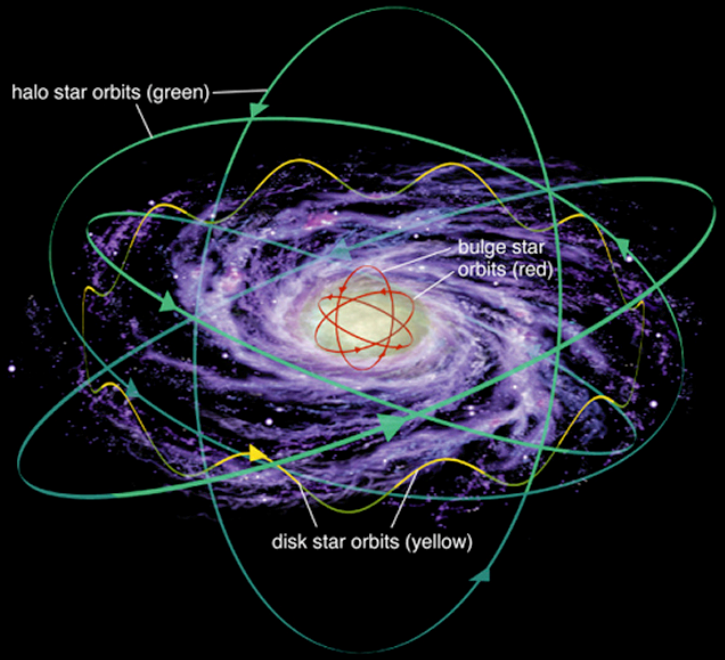


– What did an elliptical look like billions of years ago?

– What will a late-type spiral look like in billions of years from now?

What do the shapes of galaxies tell us?

Stars preserve motion, so *motion reveals history*



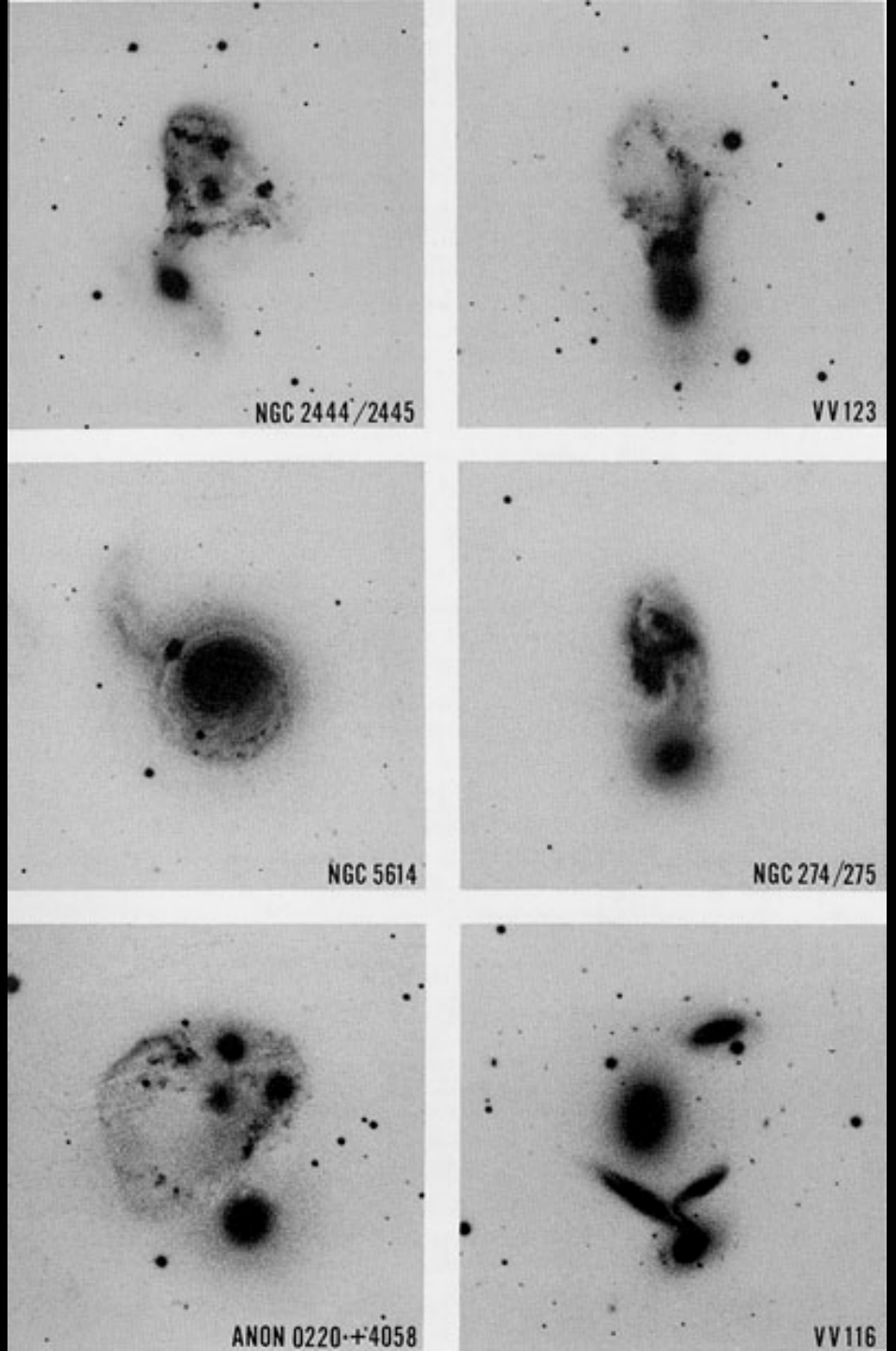
- Disk → ROTATION
  - Made from gas with high angular momentum
- Stellar halo, bulge → RANDOM ORBITS
  - Made from many different blobs of gas & stars

Smooth collapse of rotating gas
= **DISKS**

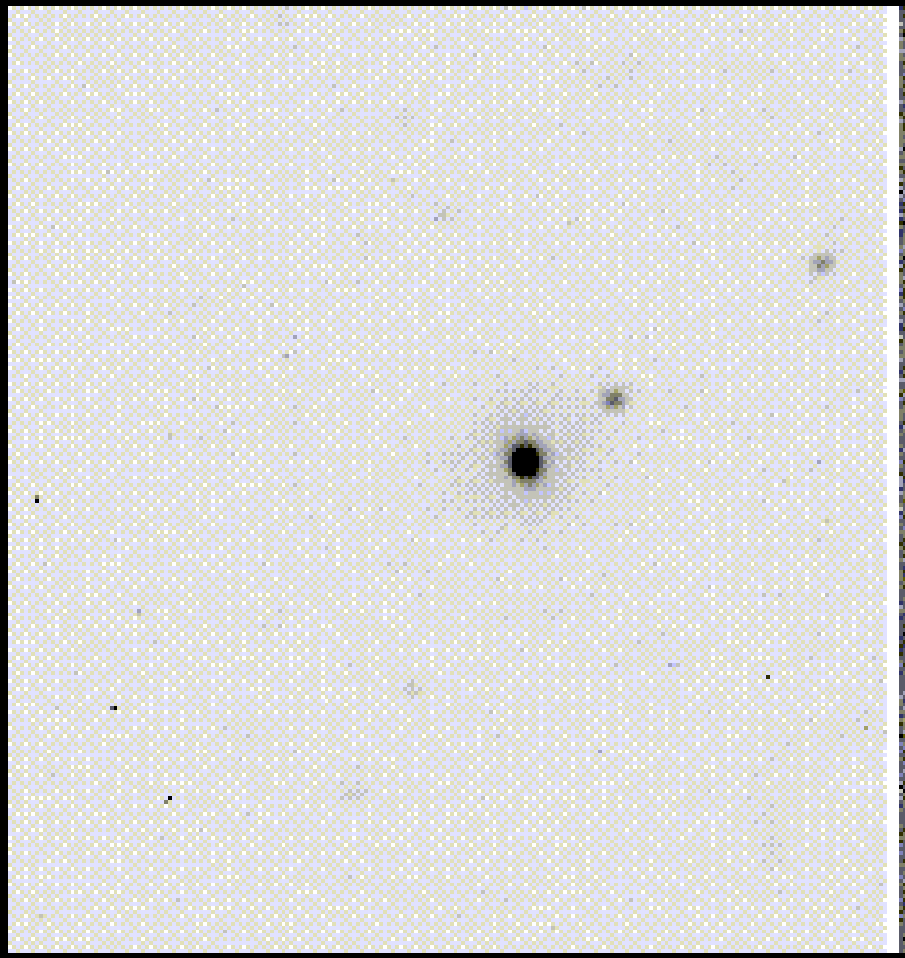
Messy merging of large blobs
= **SPHEROIDS**
(bulges, ellipticals, stellar & dark matter halos)

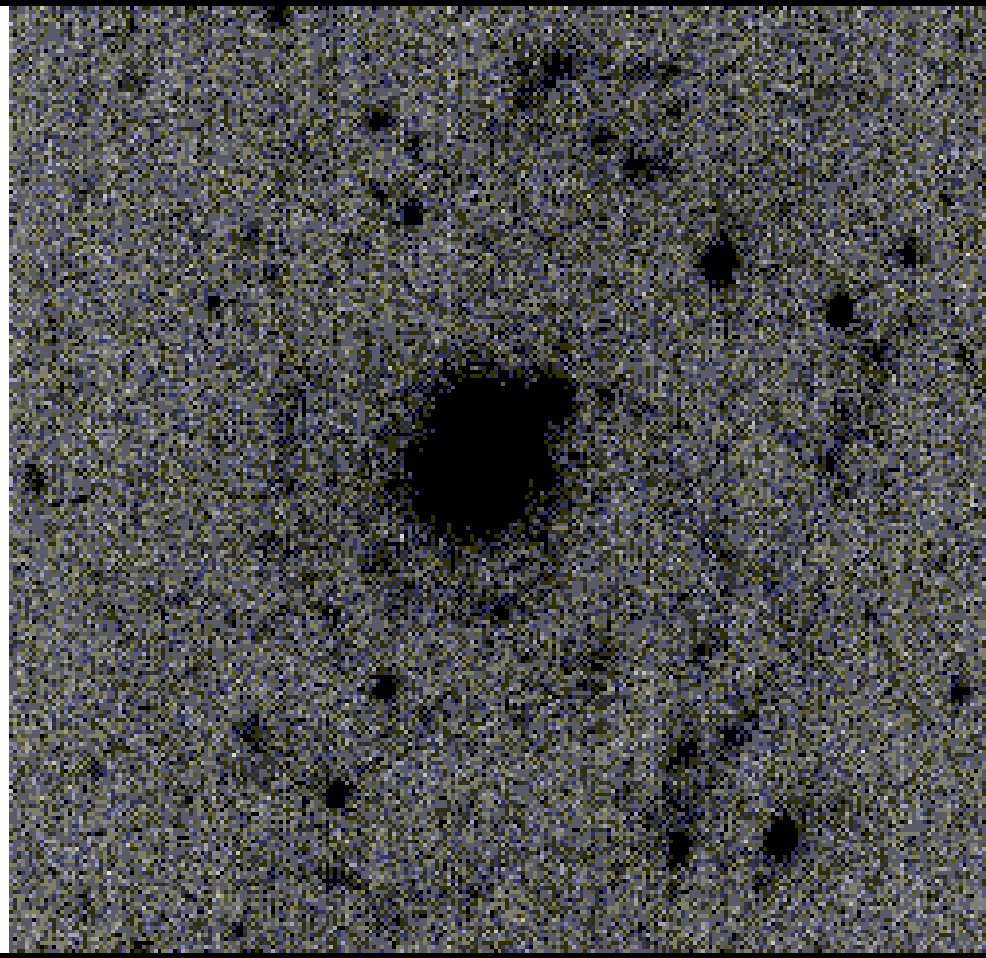
THESE PROCESSES ARE ONGOING!

Galaxies that do not fit into the extended Hubble system - ’Peculiar’ galaxies



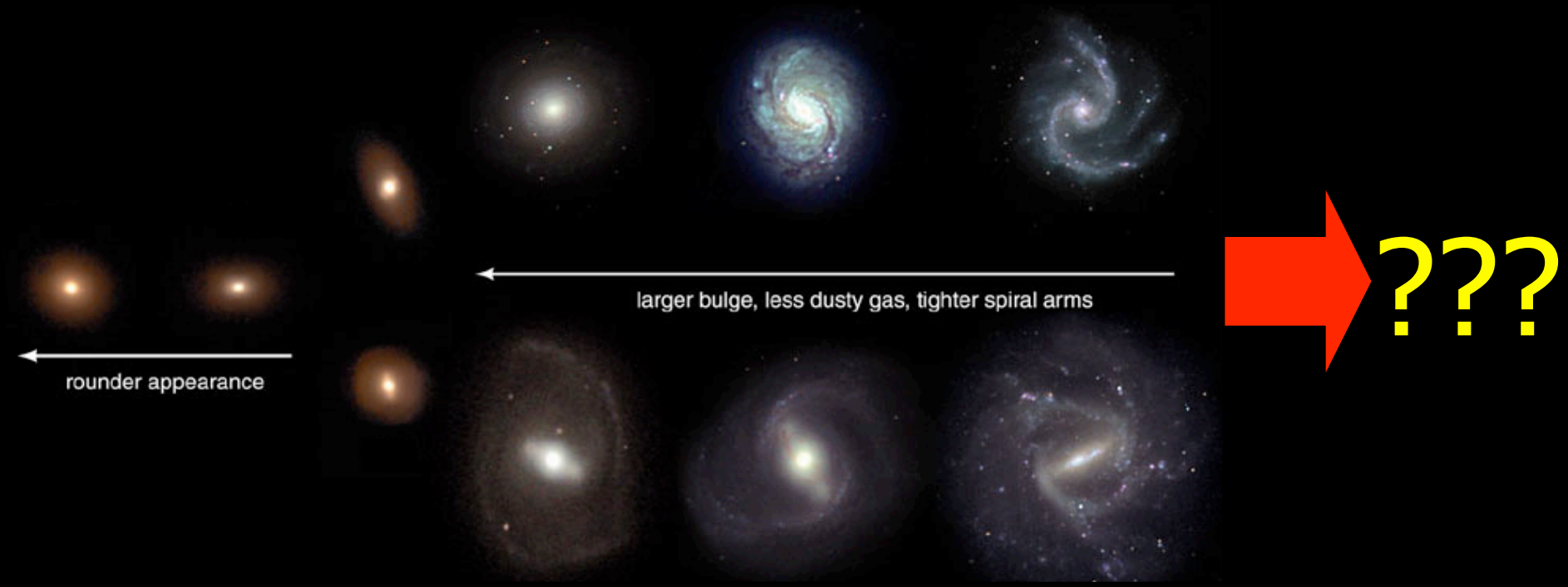
Malin I



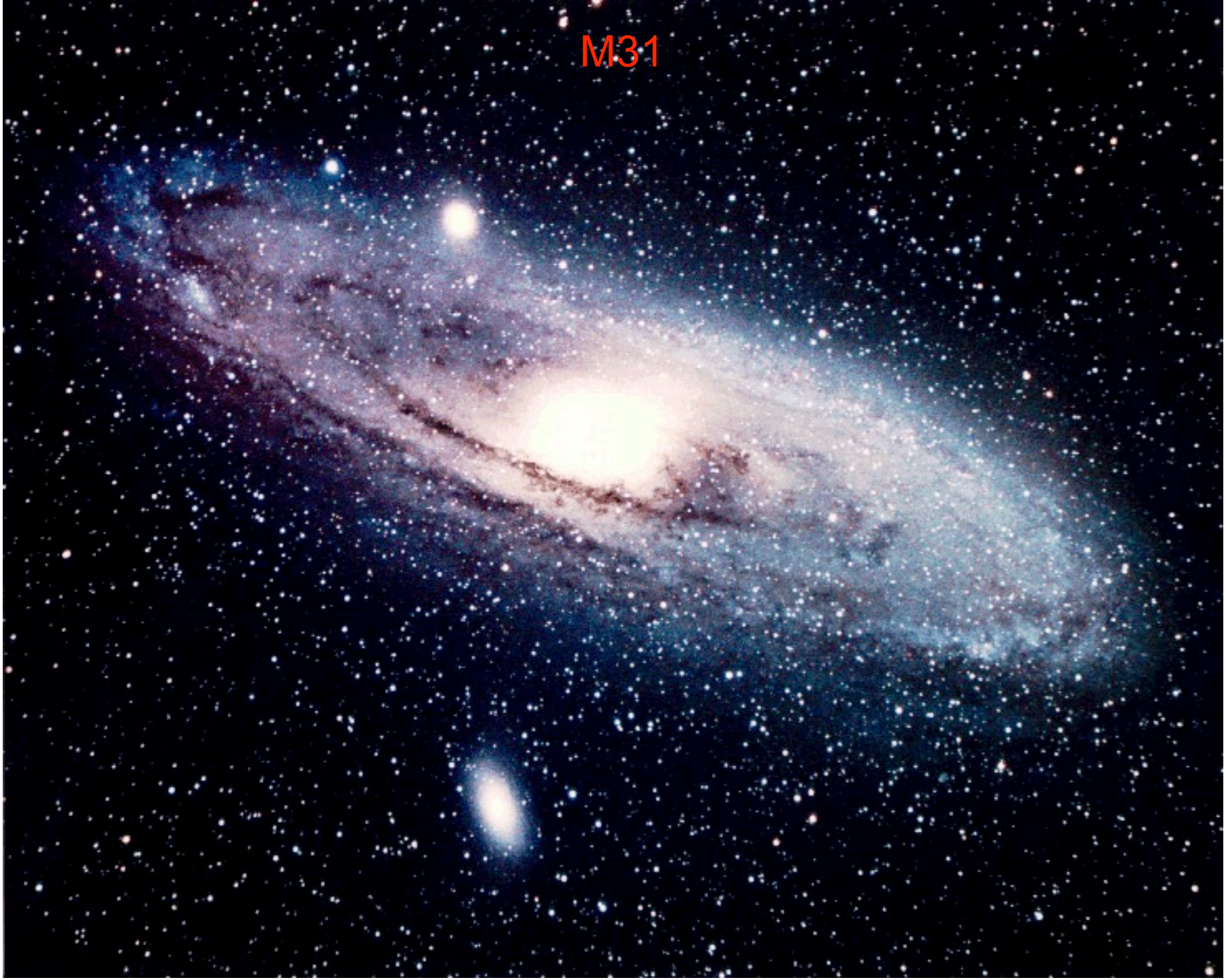


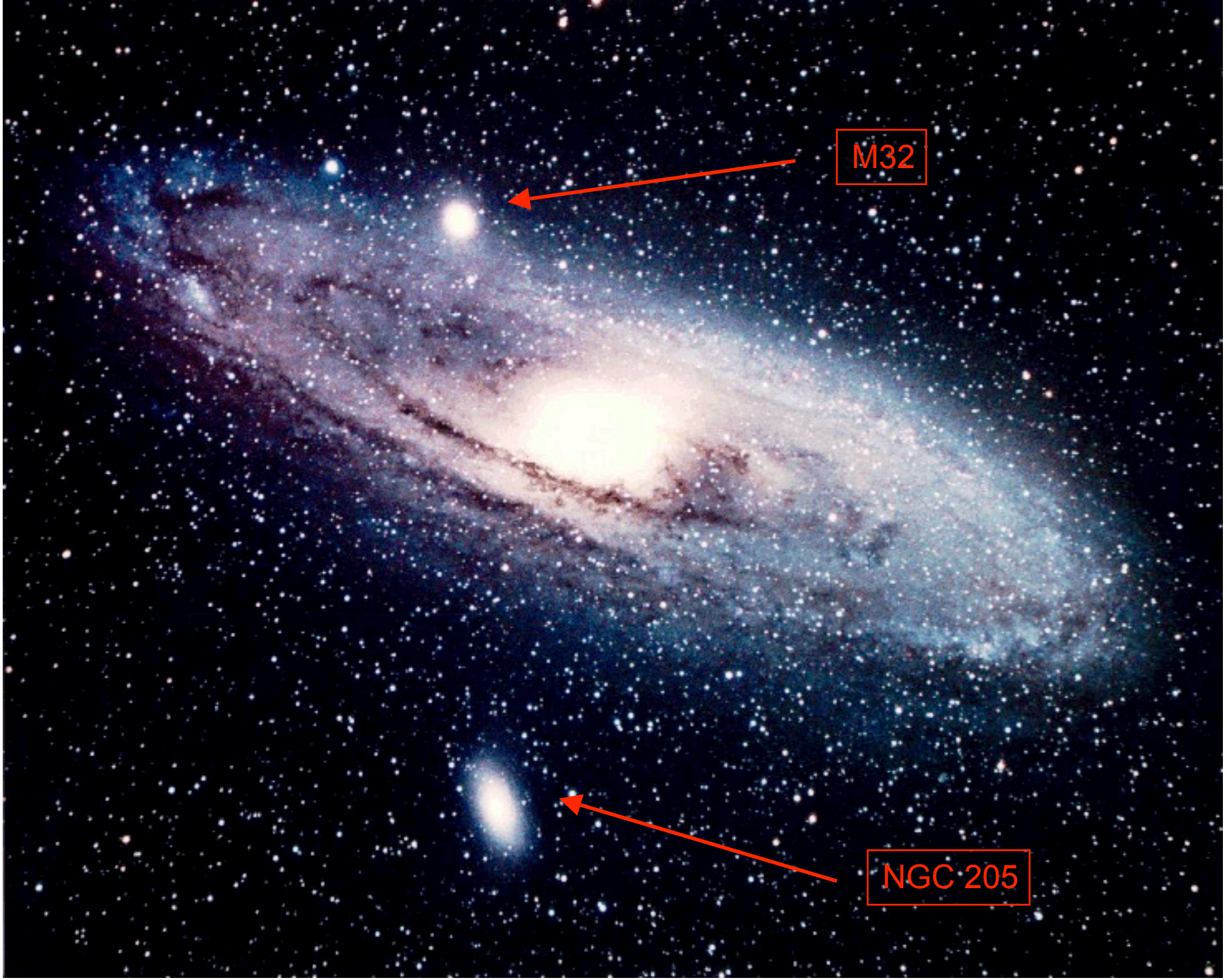
Low surface brightness galaxy - LSBG

There are galaxies beyond the Hubble Sequence that continue this trend.

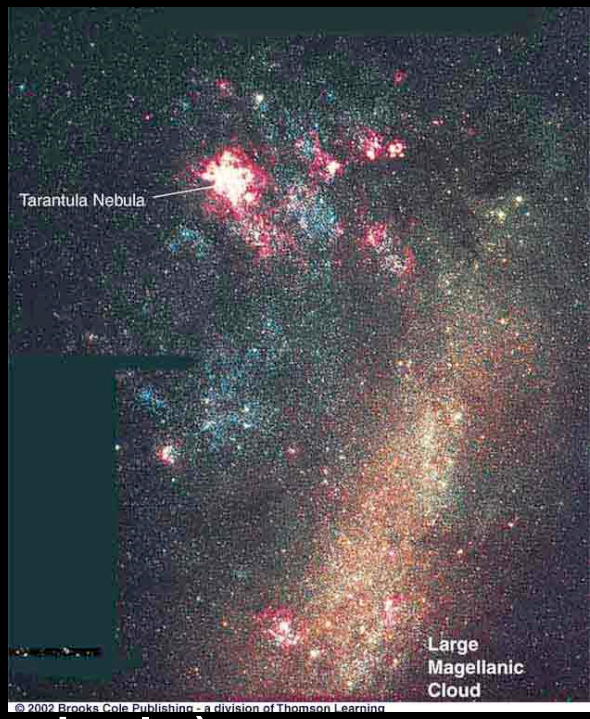


"Dwarf" or "Irregular" Galaxies


M31


M32
NGC 205

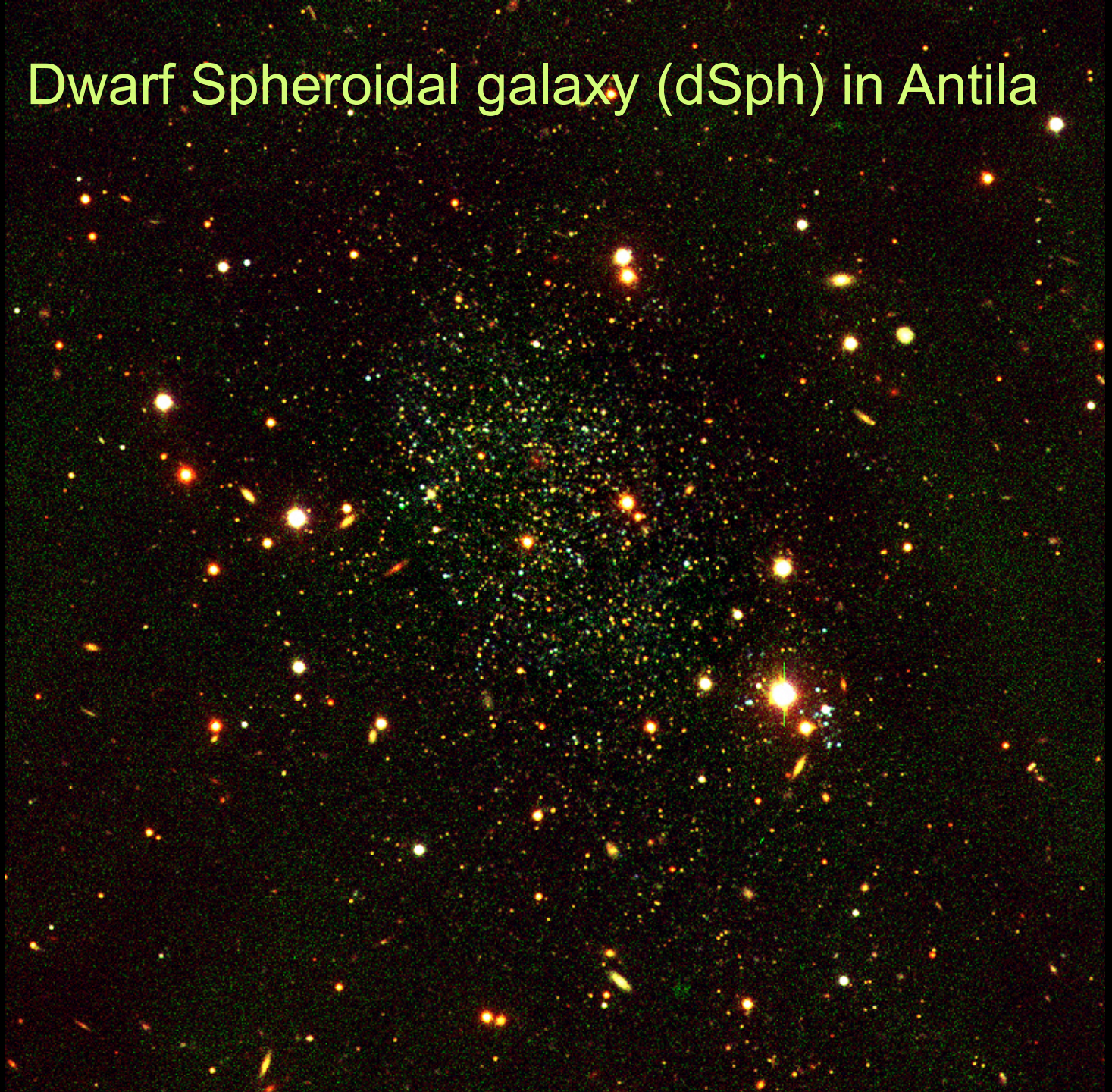
"Dwarf" or "Irregular" galaxies tend to have more chaotic appearances…



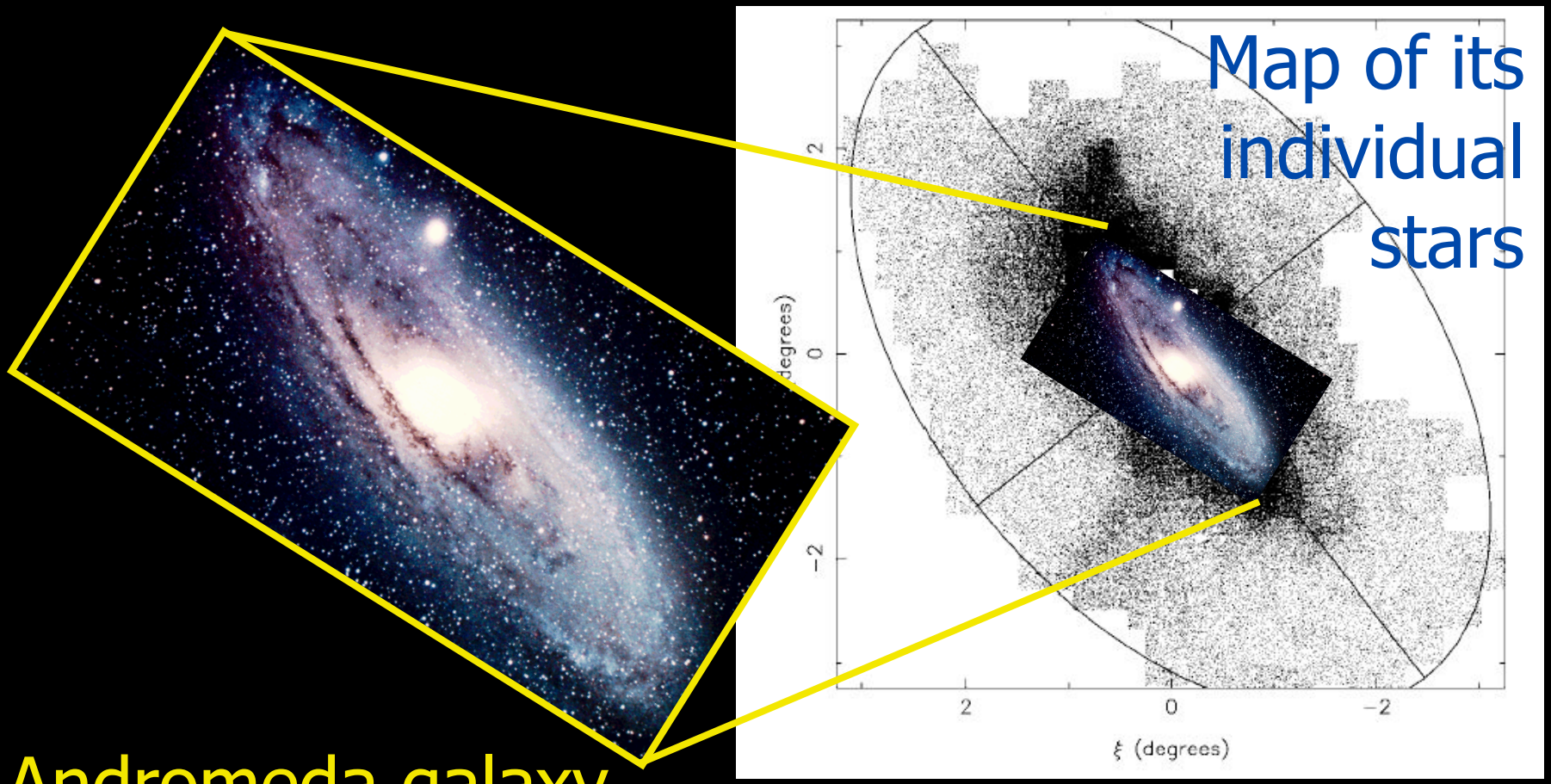
- Low mass (10^7-10^9 stars, vs 10^{10} for spirals)
- High star formation rates (usually)
- No obvious bulge or spiral patterns.
- Most numerous type of galaxy in the Universe!

Dwarf galaxies from the Sloan Digital Sky Survey.

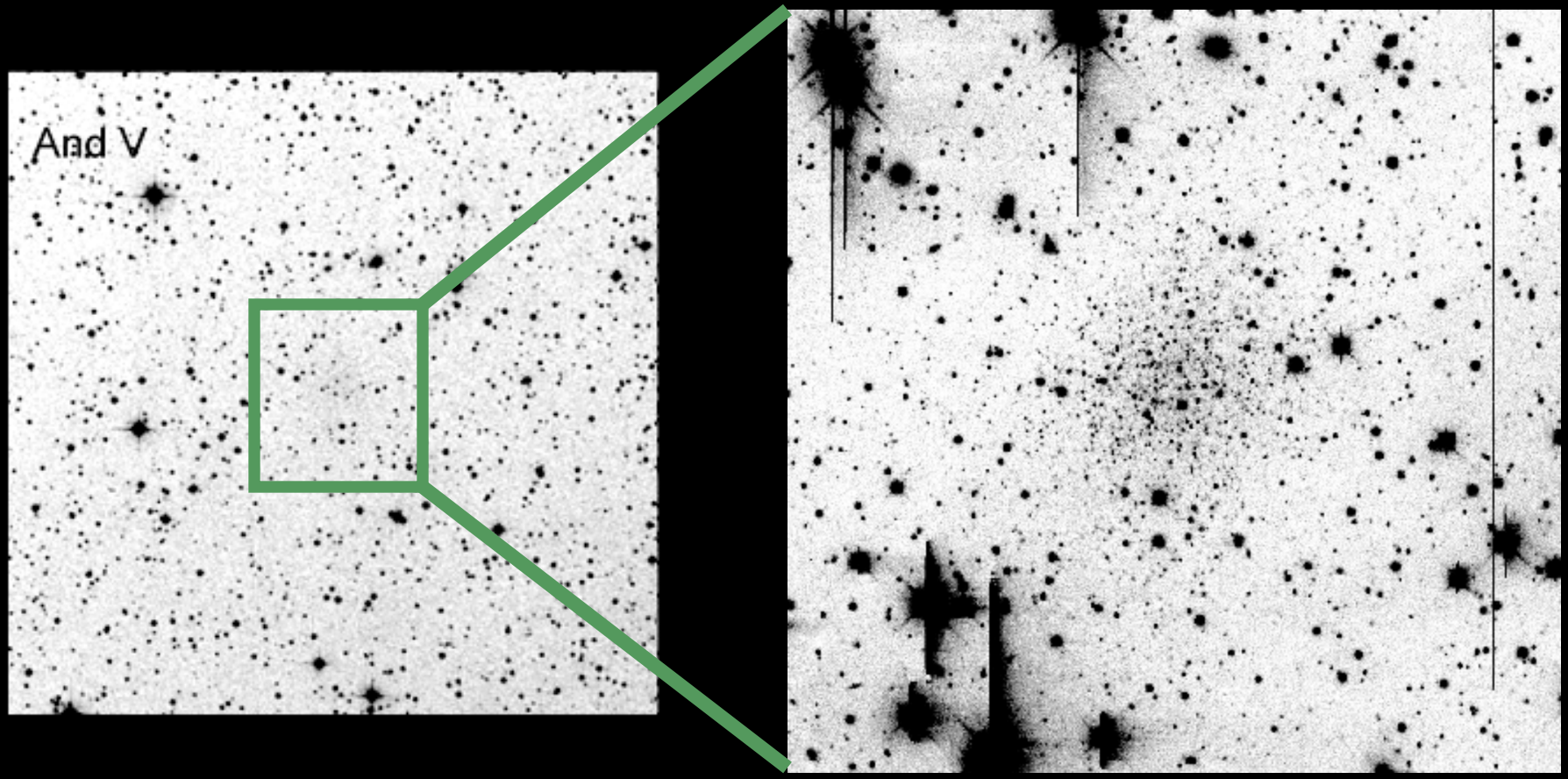
Dwarf Spheroidal galaxy (dSph) in Antila



- Dwarf galaxies are the most numerous type of galaxy in the universe.
- Most giant galaxies are probably made up of merged dwarf galaxies!



A Good Dwarf Galaxy is Hard to Find



They're faint and low contrast against the night sky

The standard broadband photometric system

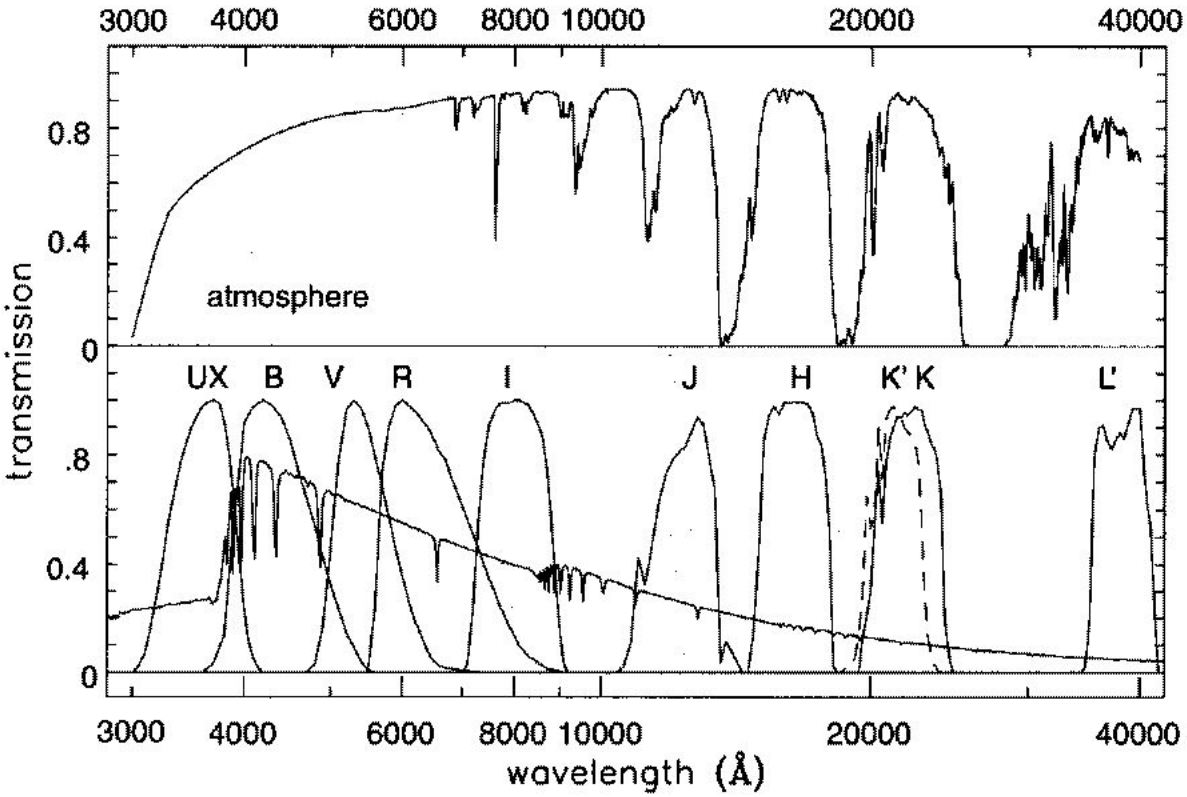
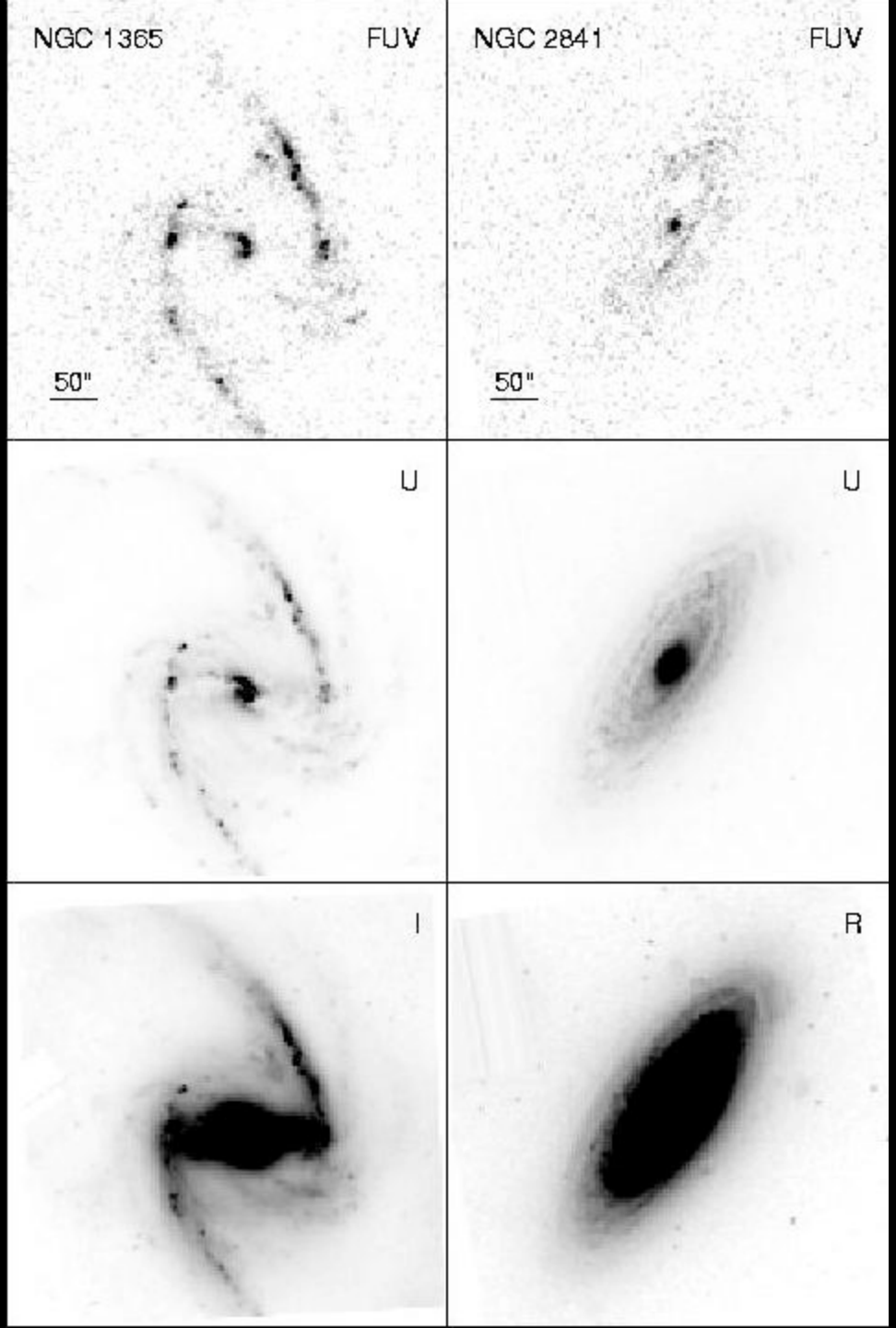
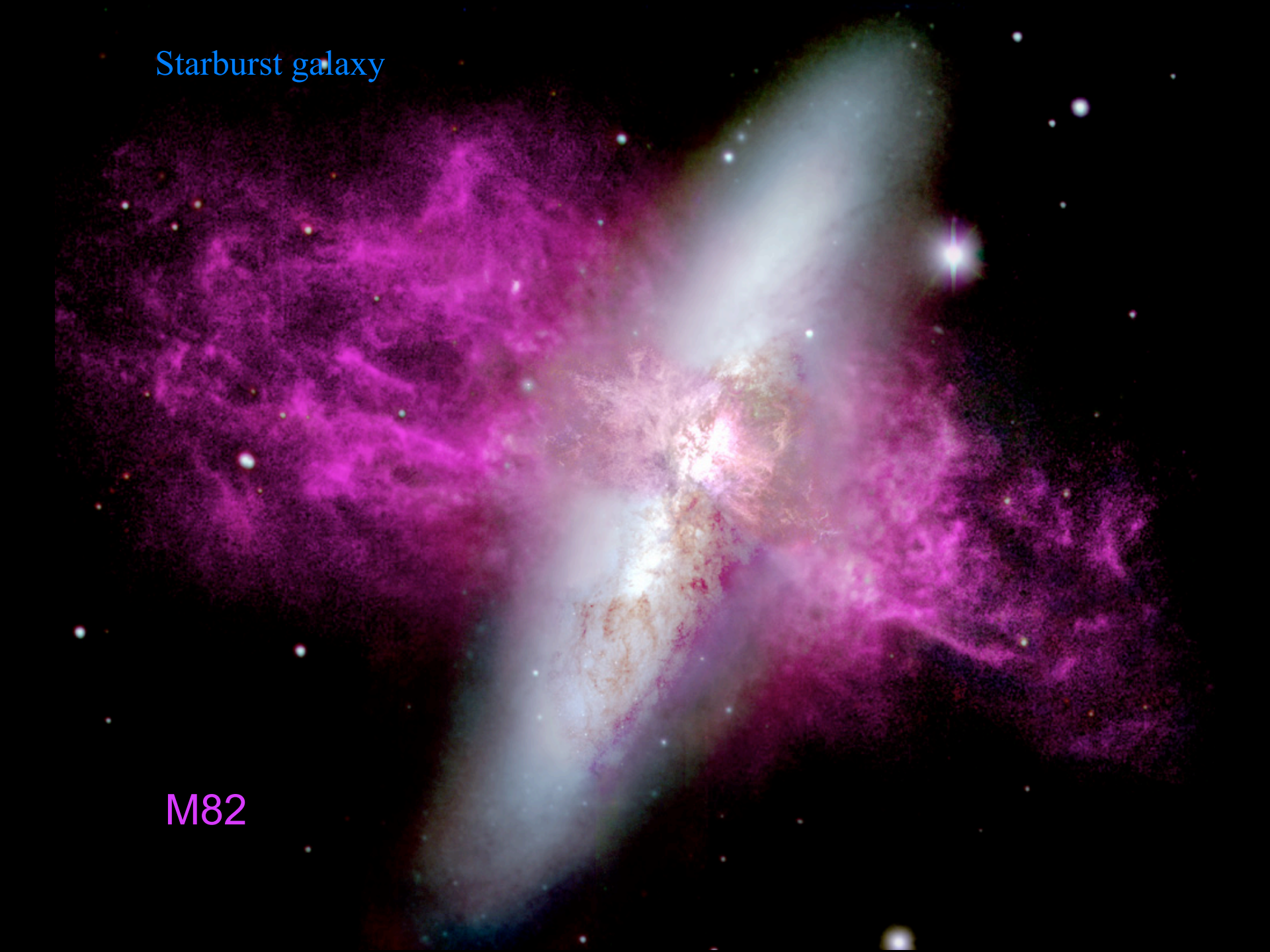


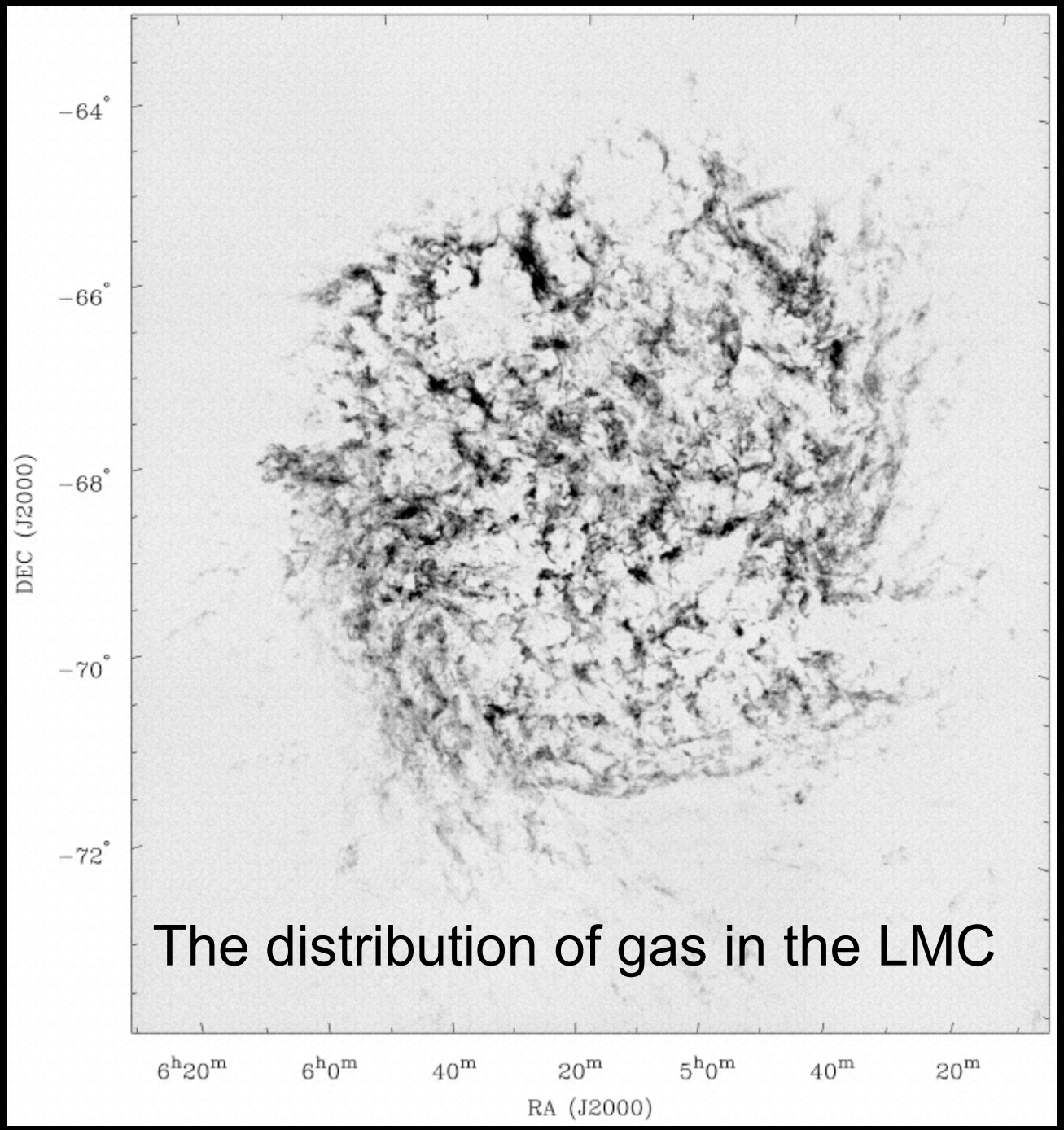
Figure 1.7 Above, atmospheric transmission in the optical and near-infrared. Below, flux F_λ of a model A0 star, with transmission curves $\mathcal{T}(\lambda)$ for standard filters from Bessell, PASP 102, 1181; 1990. UX is a version of the U filter that takes account of atmospheric absorption. For $JHK'KL'$, $\mathcal{T}(\lambda)$ is for transmission through the atmosphere and subsequently through the filter.

The morphology is depending on the frequency window used at the observations



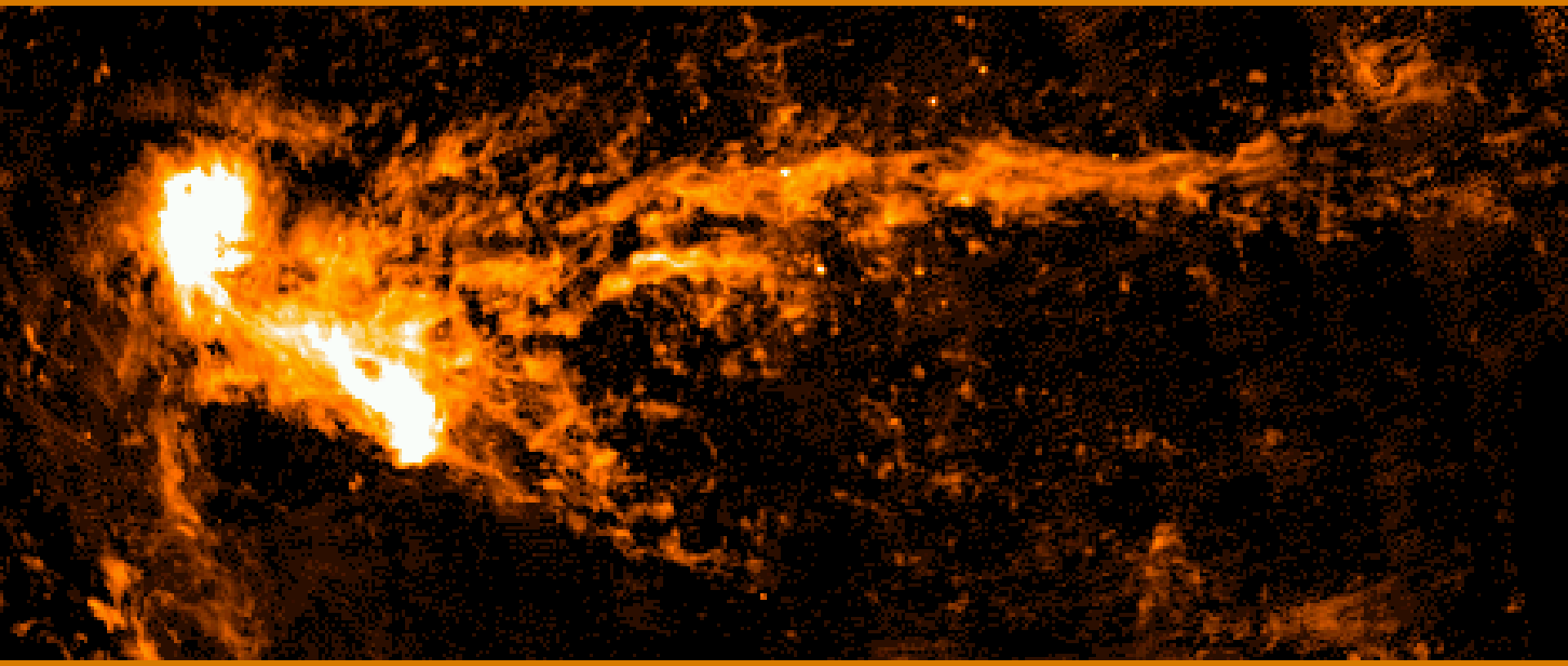

Starburst galaxy
M82


The Large Magellanic Cloud (LMC)
© Anglo-Australian Observatory/Royal Observatory, Edinburgh.



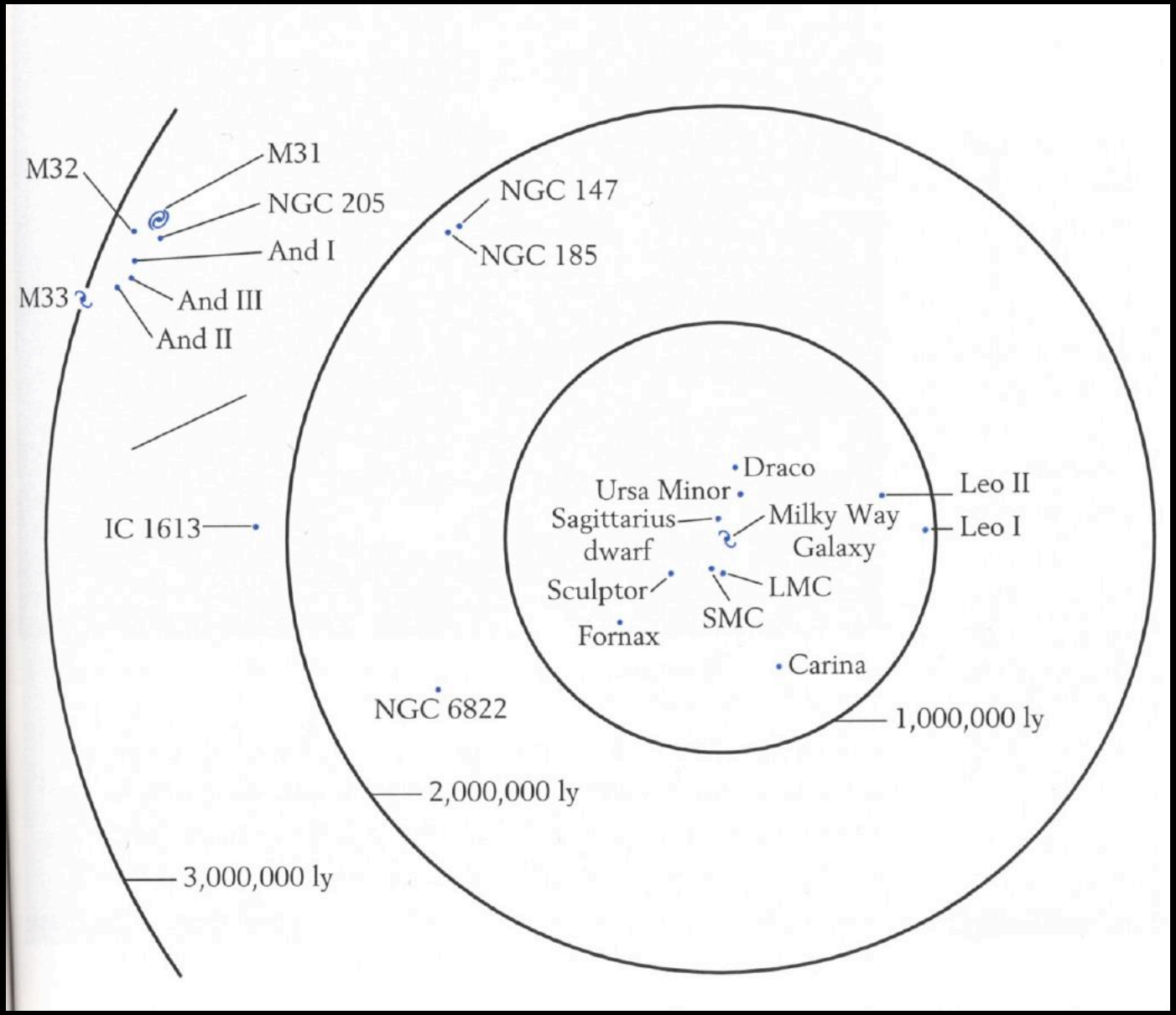
The distribution of gas in the LMC

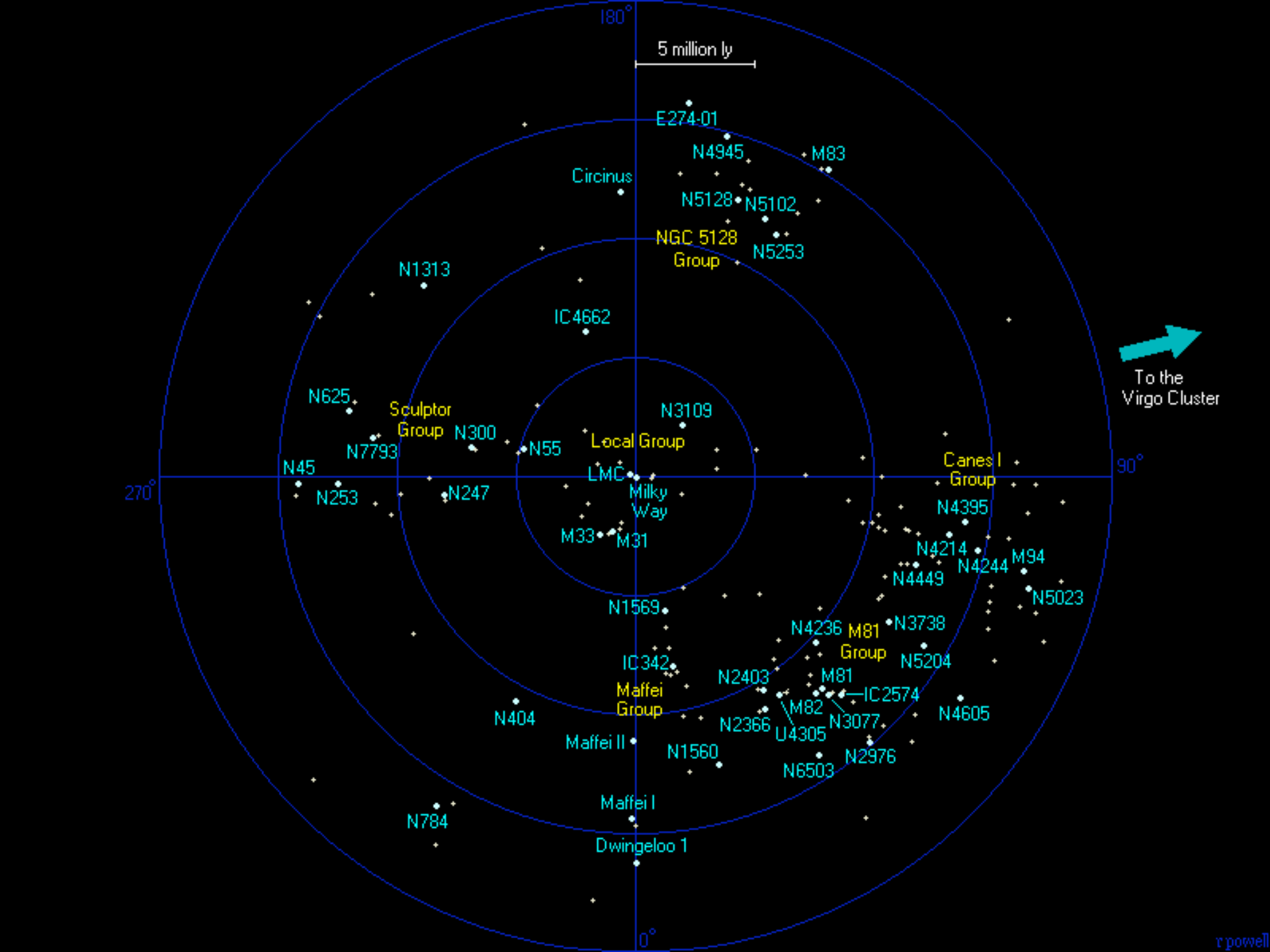
The magellenic stream
(gas distribution)



The Local Group

- 36 known and probable galaxy members
- Radius ~1200 kpc
- 3 spirals: M31, Milky Way, and M33.
  - 90% of light.
- Two more massive galaxies:
  - the irregular Large Magellanic Cloud
  - the small elliptical galaxy M32
- All other galaxies in the Local Group are dwarf galaxies


M32
M31
NGC 205
And I
M33
And III
And II
IC 1613
NGC 147
NGC 185
Draco
Ursa Minor
Leo II
Sagittarius
dwarf
Milky Way
Galaxy
Leo I
Sculptor
LMC
SMC
Fornax
Carina
NGC 6822
1,000,000 ly
2,000,000 ly
3,000,000 ly


180°
5 million ly
E274-01
N4945
M83
Circinus
N5128
N5102
NGC 5128
Group
N5253
N1313
IC4662
To the
Virgo Cluster
N625
Sculptor
Group
N3109
N300
N7793
N55
Local Group
N45
LMC
Canes I
Group
270°
90°
N253
N247
Milky
Way
N4395
M33
M31
N4214
N4244
M94
N4449
N5023
N1569
N4236
M81
N3738
Group
IC342
N5204
N2403
M81
Maffei
Group
IC2574
N404
M82
N4605
N2366
U4305
N3077
Maffei II
N1560
N6503
N2976
Maffei I
N784
Dwingeloo 1
0°
rpowell