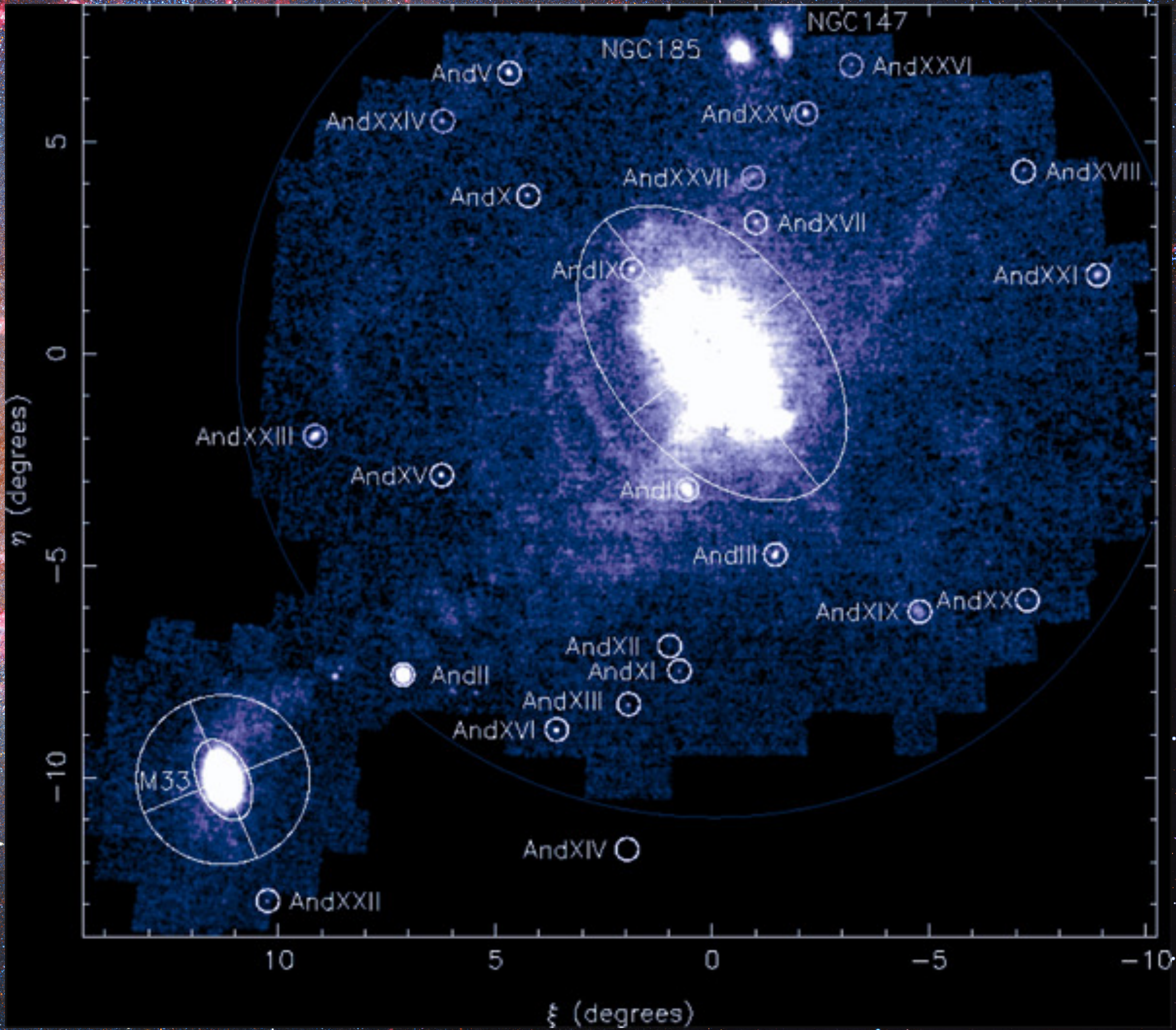
The Neighbors: Andromeda (M31)

comparable in size and mass to MW, maybe a bit bigger.

distance: 750 kpc
radial velocity: -200 km/s

The Neighbors: Triangulum (M33)

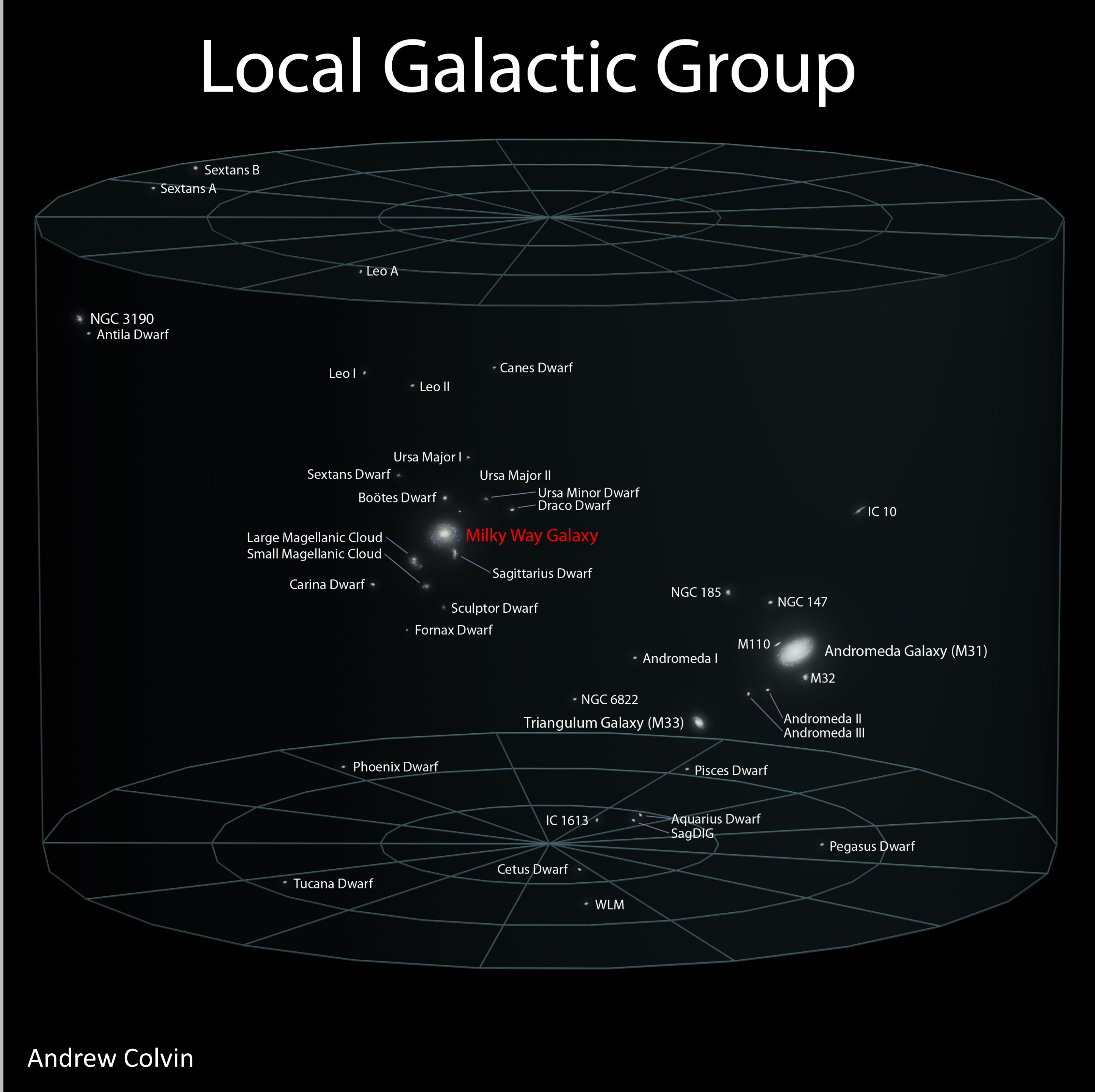
much smaller than MW/Andromeda
distance: 900 kpc
interacting with Andromeda

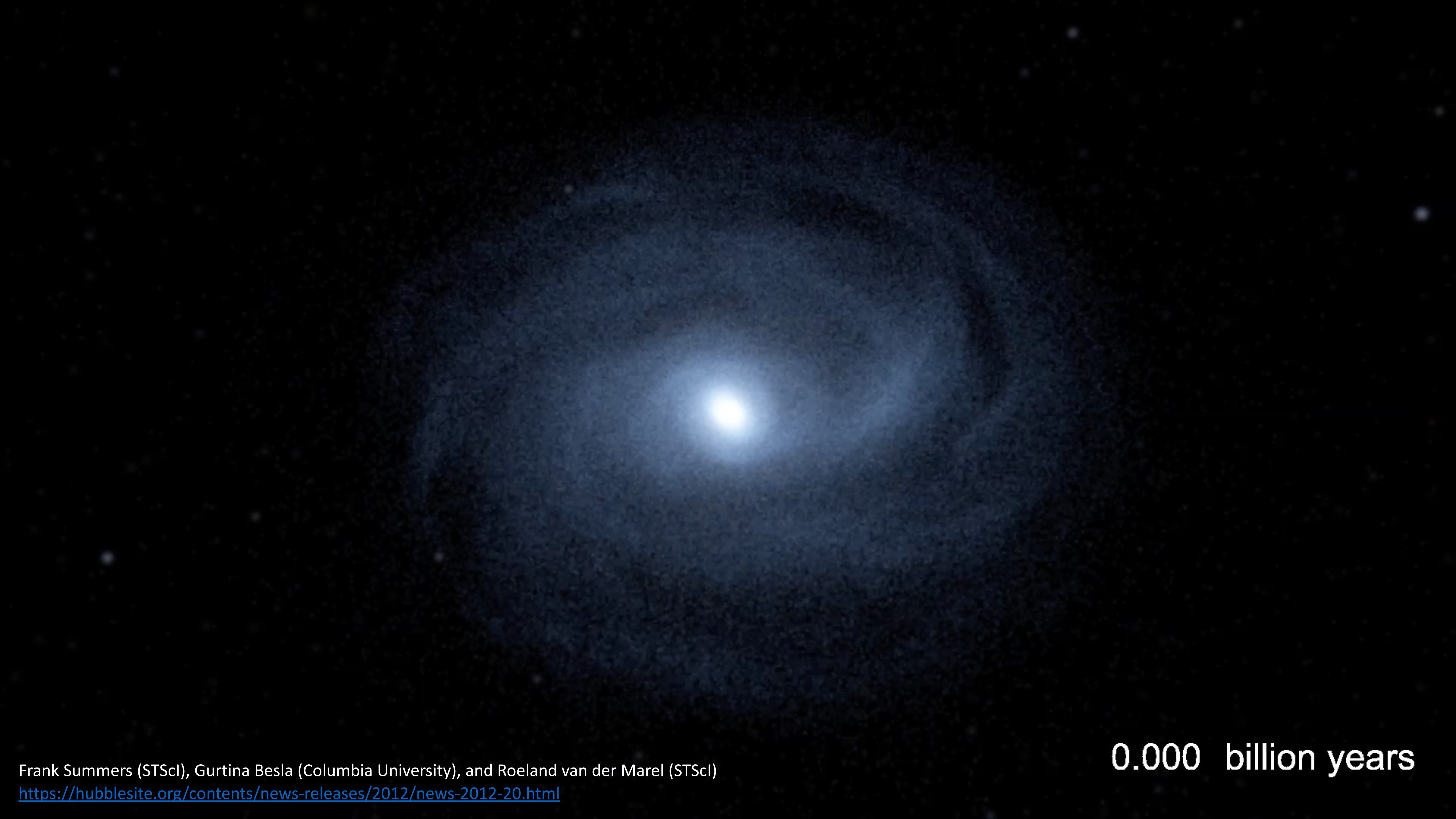


The Local Group

The Milky Way, Andromeda, and M33, plus their their satellite galaxies and a few rogue dwarfs all form the Local Group of galaxies.

Roughly 1 Mpc across.





Frank Summers (STScI), Gurtina Besla (Columbia University), and Roeland van der Marel (STScI)
https://hubblesite.org/contents/news-releases/2012/news-2012-20.html


The Future
Andromeda
Today


+ 2 billion years


+3.75 billion years


+3.85 billion years


+3.95 billion years


+4 billion years


+5 billion years


+7 billion years

Galaxies

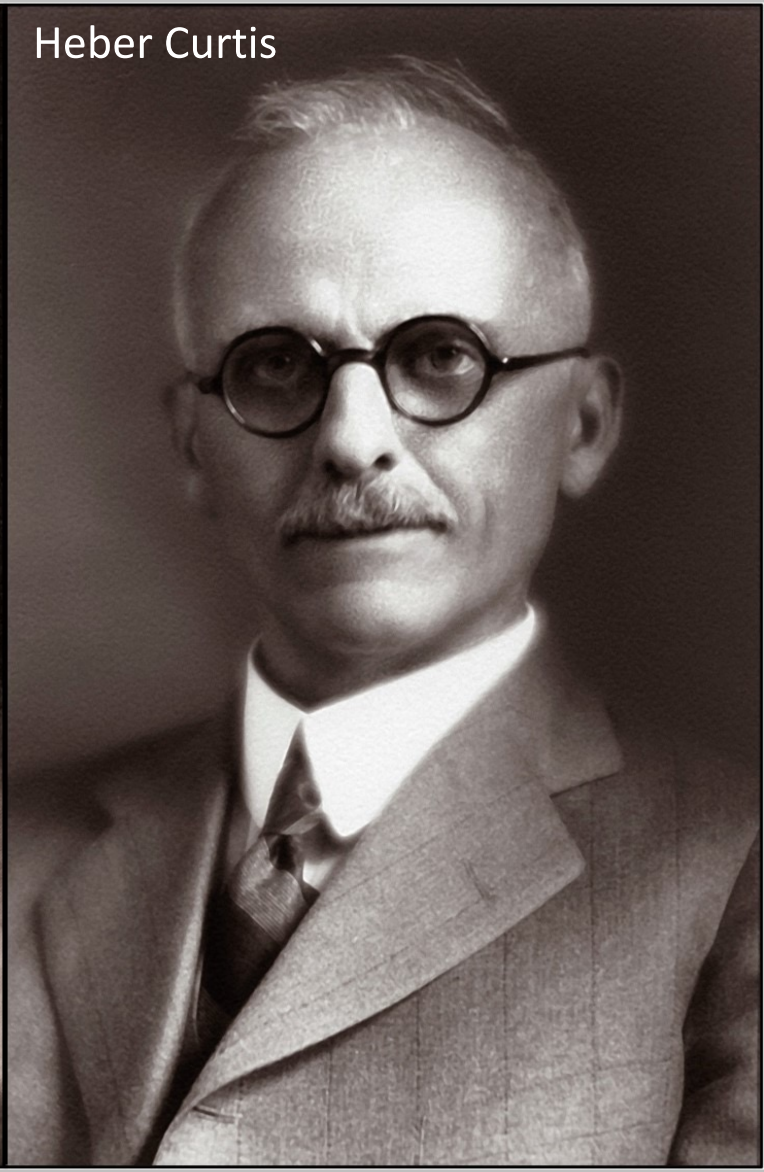
1920: The Shapley-Curtis Debate on the Nature of the Spiral Nebulae

During the early part of the twentieth century, there was much argument about the nature of the "spiral nebulae."

Some astronomers believed they were nearby objects, within our own Galaxy.

Others believed they were galaxies in their own right, very large and very distant.

The controversy led to the "Great Debate" in 1920 at the National Academy of Science in Washington, DC.



Harlow Shapley

The spiral nebulae are nearby objects inside the Milky Way Galaxy.

Argument 1: Novae

Novae had been seen in the Andromeda Nebula. Given Andromeda's angular size, if it was a galaxy as big as the Milky Way, it would be very distant and so those novae would have to be so much luminous than novae in the Milky Way to be seen at that distance.

Argument 2: The Rotation of M101

Adrian van Maanen had observed proper motion of stars in the outskirts of M101, and calculated that M101 rotated once every 85,000 years. If M101 was a distant galaxy, its stars would be moving faster than the speed of light!

Heber Curtis

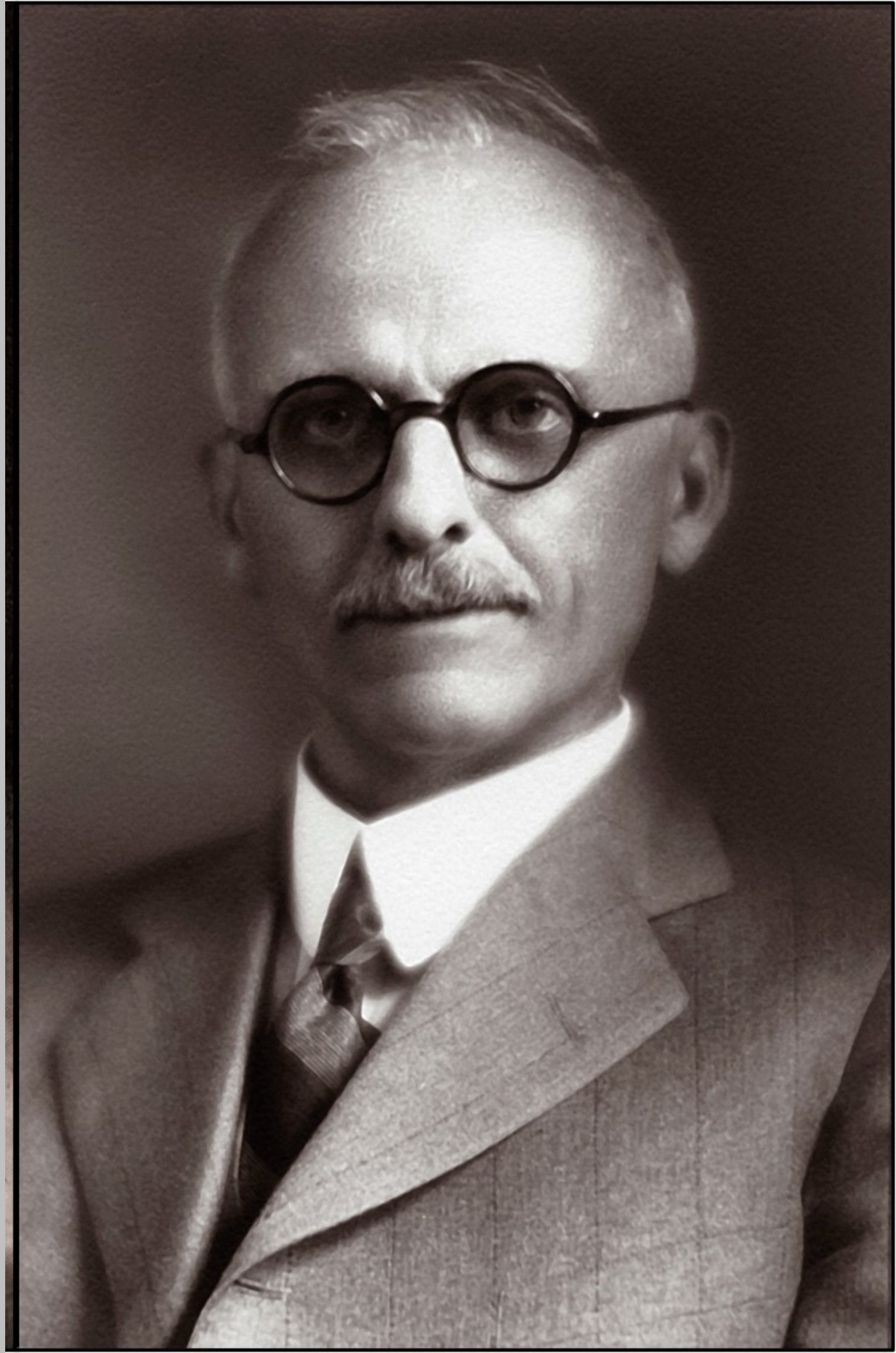
The spiral nebulae are distant galaxies similar to the Milky Way.

Argument 1: Novae

Novae in the Andromeda Nebula are very faint. If Andromeda was actually inside the Milky Way, those novae would be extremely underluminous compared to other Milky Way novae. *(Except for one really bright one....)*

Argument 2: Radial Velocities

Most spiral nebulae have radial velocities > 1000 km/s. No stars move this fast. If spiral nebulae move that fast, they wouldn’t be gravitationally bound to the Milky Way! And if they are moving that fast, we should see proper motion of the nebulae themselves, and we don’t! *(But why are they all moving away?)*



1920: The Shapley-Curtis Debate on the Nature of the Spiral Nebulae

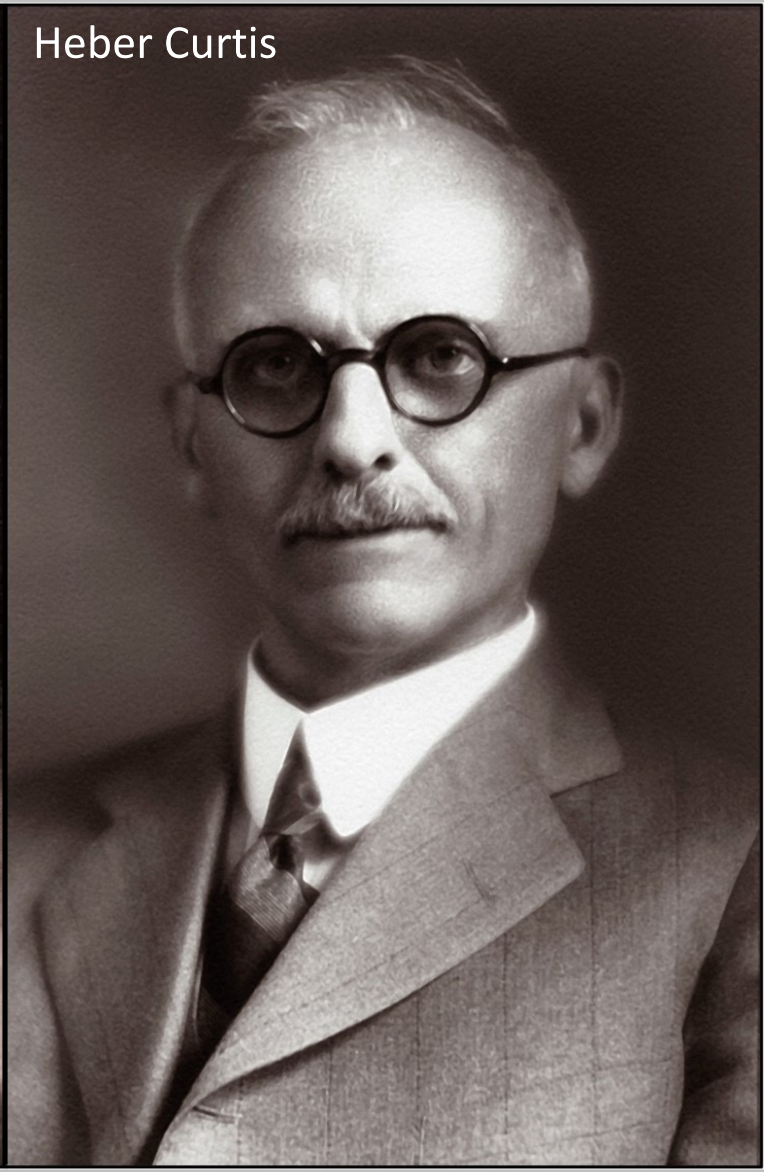
During the early part of the twentieth century, there was much argument about the nature of the "spiral nebulae."

Some astronomers believed they were nearby objects, within our own Galaxy.

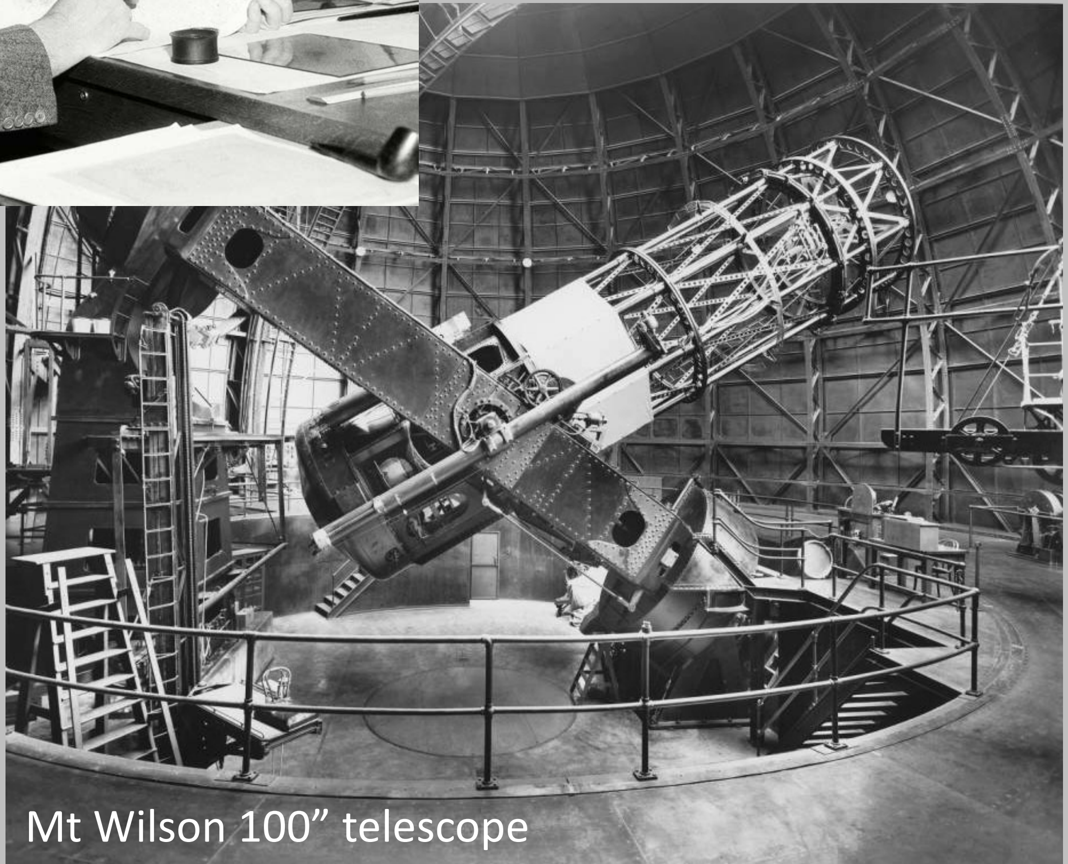
Others believed they were galaxies in their own right, very large and very distant.

The controversy led to the Great Debate in 1920 at the National Academy of Science in Washington, DC.

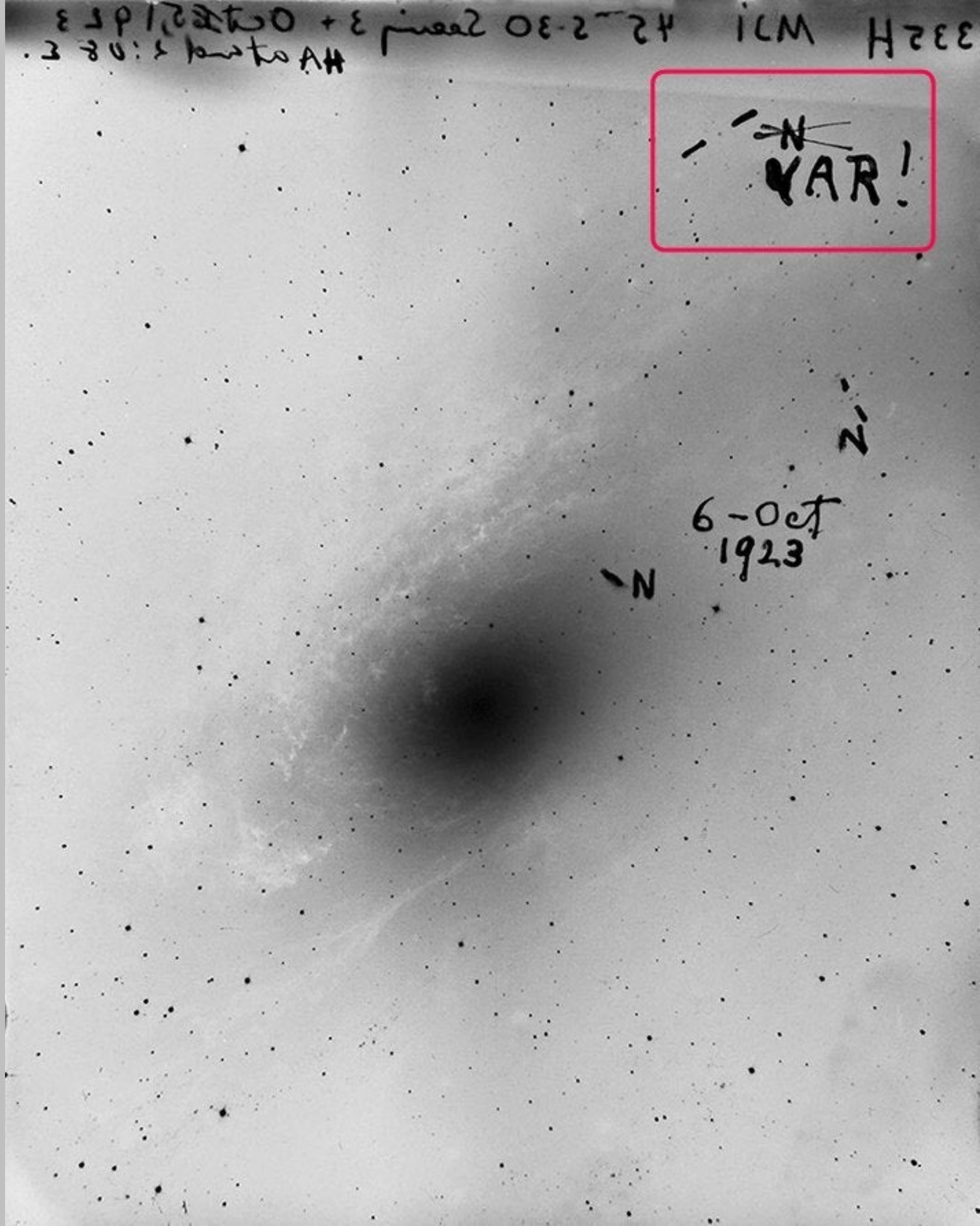
Neither side won.



1923: Edwin Hubble finds variable stars in Andromeda



Mt Wilson 100” telescope

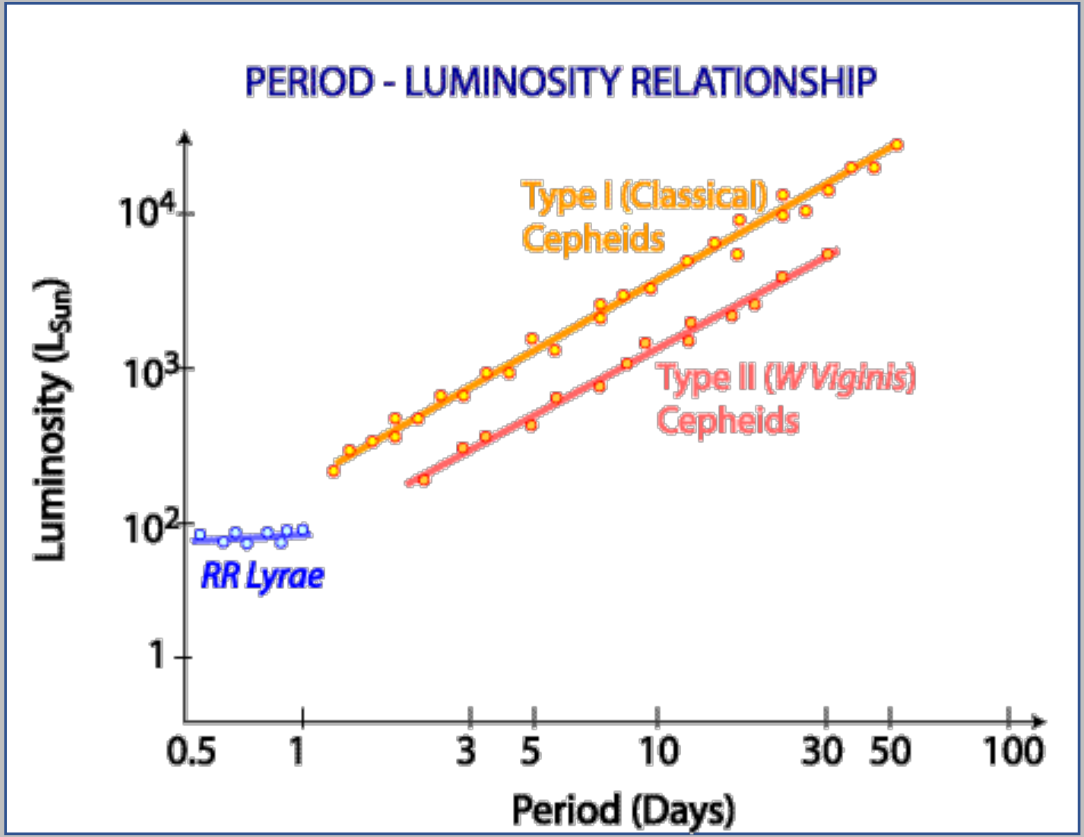


Hubble's Distance to Andromeda

Hubble uses the Cepheid period-luminosity relationship to calculate the distance to Andromeda.

Distance: 285 kpc. Not part of the Milky Way!

Our whole view of the Universe changes.



And actually Hubble got the distance wrong! He was using a P-L relationship calibrated on fainter, metal-poor Cepheids (W Virginis stars), but he was looking at regular Cepheids.

Since he thought his variable were intrinsically faint, he got a distance that is erroneously small. The actual distance to Andromeda is 780 pc.

Harlow Shapley

The spiral nebulae are nearby objects inside the Milky Way Galaxy.

Argument 1: Novae

Novae had been seen in the Andromeda Nebula. Given Andromeda's angular size, if it was a galaxy as big as the Milky Way, it would be very distant and so those novae would have to be so much luminous than novae in the Milky Way to be seen at that distance.

*Mistake: Shapley had overestimated the Milky Way's size, and thus overestimated Andromeda's distance if it was that big. A too-distant Andromeda **would** need overly-luminous novae. But it's **not** that far away.*

Argument 2: The Rotation of M101

Adrian van Maanen had observed proper motion of stars in the outskirts of M101, and calculated that M101 rotated once every 85,000 years. If M101 was a distant galaxy, its stars would be moving faster than the speed of light!

*Mistake: van Maanen's observations were **wrong**.*

Heber Curtis

The spiral nebulae are distant galaxies similar to the Milky Way.

Argument 1: Novae

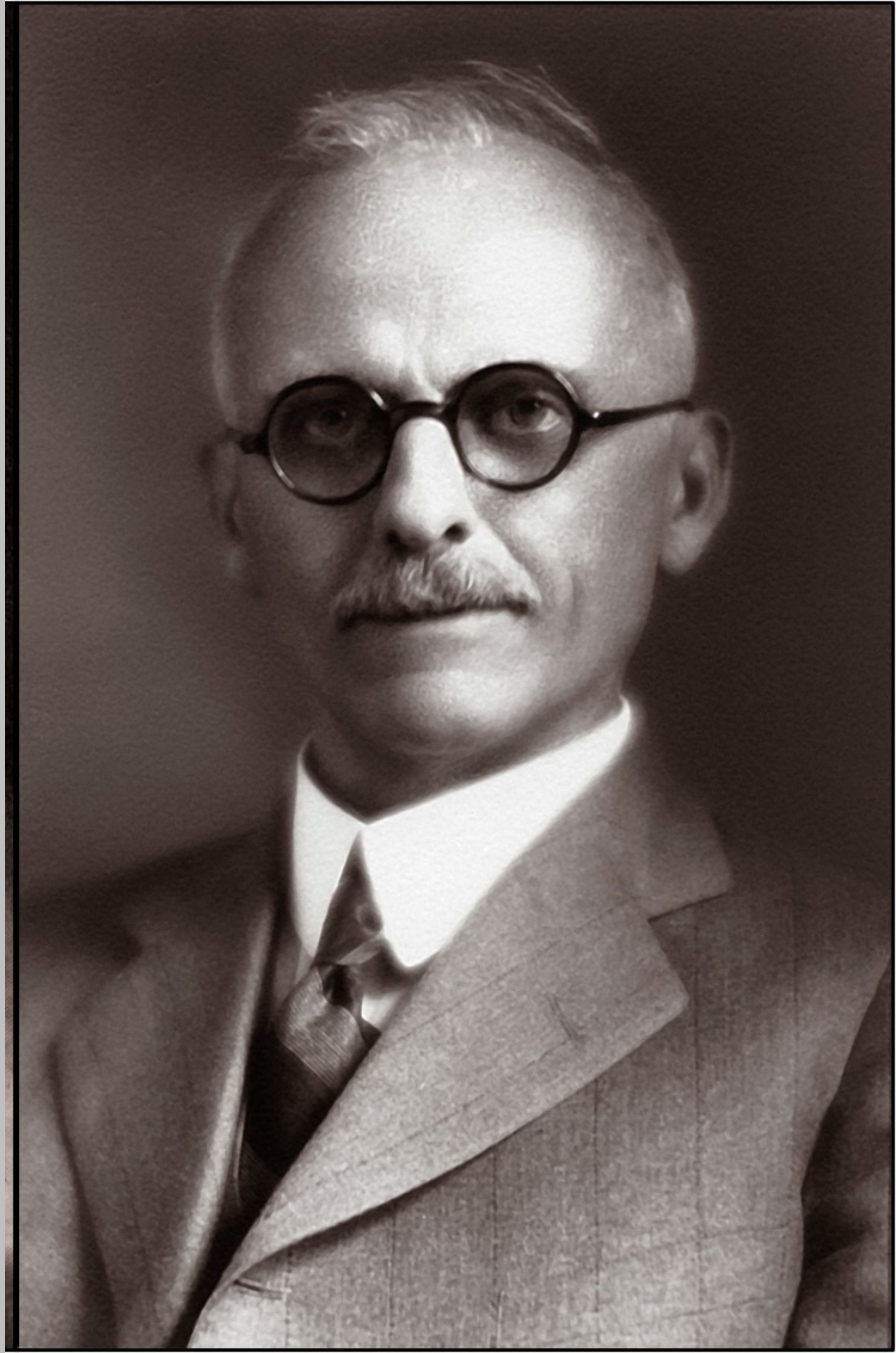
Novae in the Andromeda Nebula are very faint. If Andromeda was actually inside the Milky Way, those novae would be extremely underluminous compared to other Milky Way novae. *(Except for one really bright one....)*

*The really bright one was actually a **supernova**.*

Argument 2: Radial Velocities

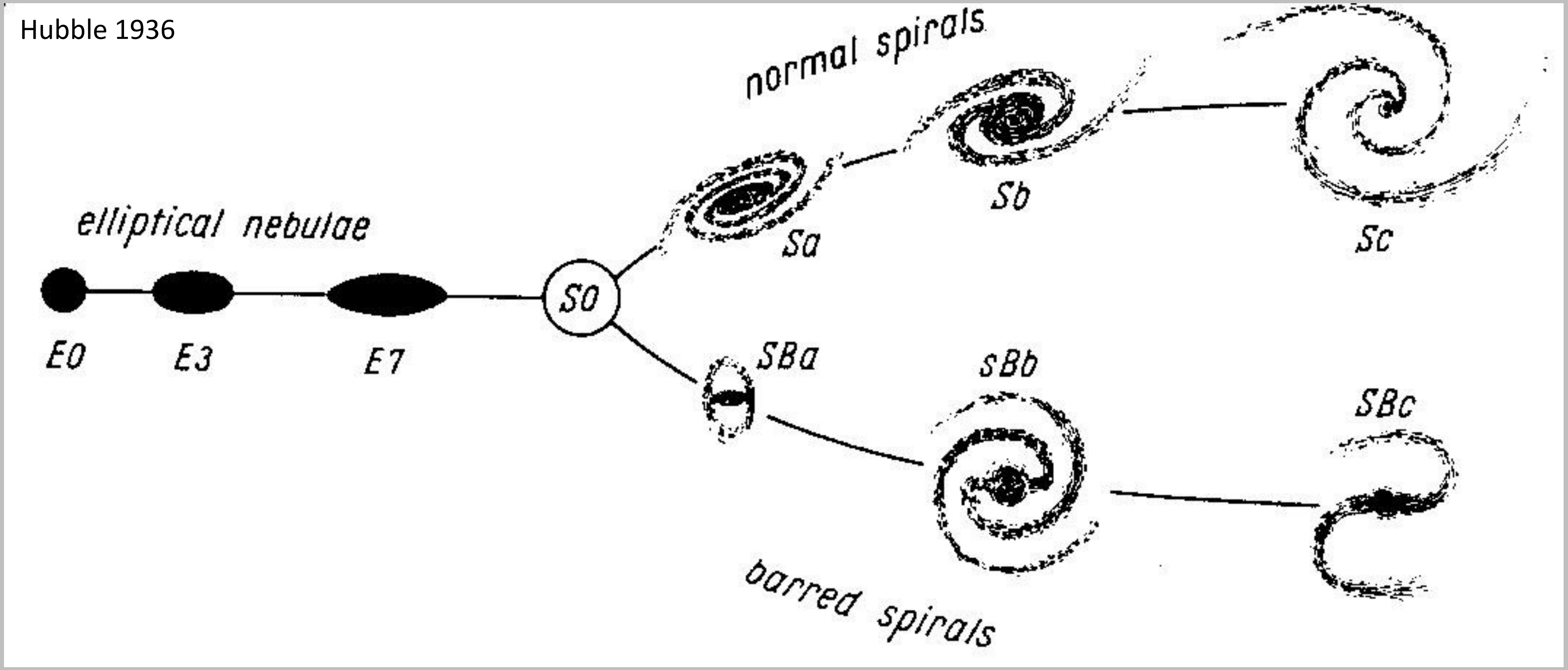
Most spiral nebulae have radial velocities > 1000 km/s. No stars move this fast. If spiral nebulae move that fast, they wouldn't be gravitationally bound to the Milky Way! And if they are moving that fast, we should see proper motion of the nebulae themselves, and we don't! *(But why are they all moving away?)*

***Nobody** could explain why the nebulae were all moving away.*



Galaxies: Types and Properties

Hubble Sequence (“The Tuning Fork”): The most basic of classification schemes: visual morphology.



Ellipticals: EN

$$N = 10\left(1 - \frac{b}{a}\right)$$

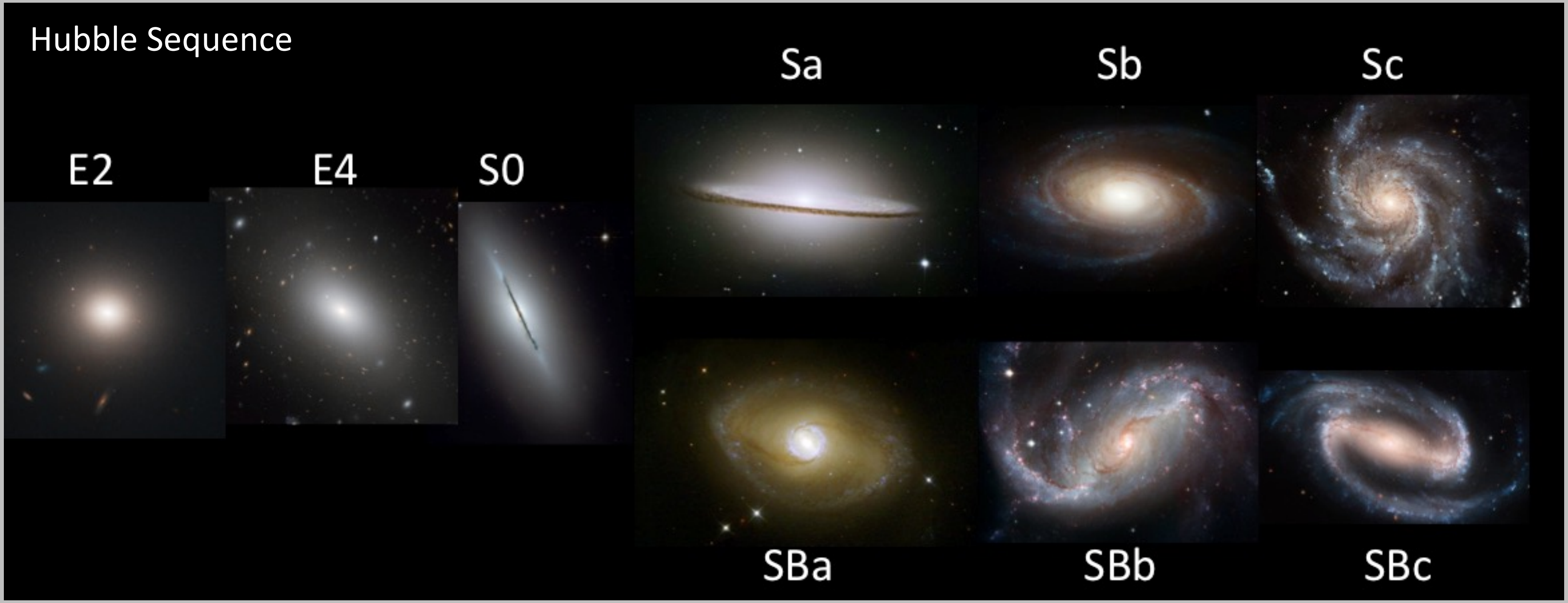
S0 (“Lenticulars”)
transitional type
disky but smooth

Spirals: Sa,Sb,Sc
tightness of spiral
prominence of bulge

Barred Spirals: SBa, SBb, SBc
presence of central bar
otherwise like Spiral

Galaxies: Types and Properties

Hubble Sequence ("The Tuning Fork"): The most basic of classification schemes: visual morphology.



Extensions to the Hubble Sequence:

Sd
(diffuse spiral)

Sm
(irregular spiral)

Irr
(very irregular)

Ellipticals: EN

$$N = 10\left(1 - \frac{b}{a}\right)$$

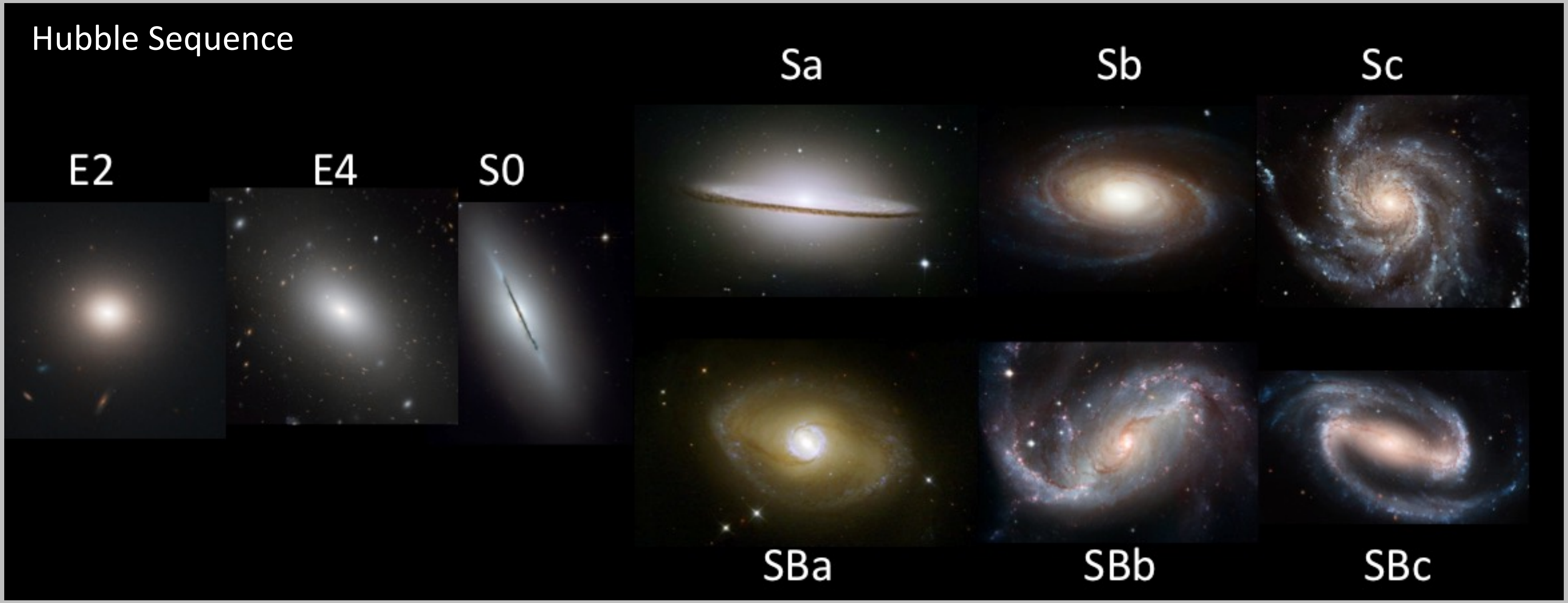
S0 ("Lenticulars")
transitional type
disky but smooth

Spirals: Sa,Sb,Sc
tightness of spiral
prominence of bulge

Barred Spirals: SBa, SBb, SBc
presence of central bar
otherwise like Spiral

Galaxies: Types and Properties

Hubble Sequence ("The Tuning Fork"): The most basic of classification schemes: visual morphology.



Extensions to the Hubble Sequence:

Sd
(diffuse spiral)

Sm
(irregular spiral)

Irr
(very irregular)

"Early" → "Late"

Important: *The nomenclature of "Early" and "Late" type galaxies is historical and misleading. Galaxies do not evolve from early to late types, and early types did not necessarily form before late types!*

Galaxy Properties (a thumbnail sketch)

Milky Way *(very rough numbers)*:

- Radial scale length: $h \approx 3$ kpc
- Blue luminosity: $L_B \approx 1.5 \times 10^{10} L_\odot$
- Absolute B magnitude: $M_B \approx -20.7$
- Total mass: $\mathcal{M}_B \approx 10^{12} \mathcal{M}_\odot$

Spiral Galaxies

- About ¾ of big galaxies are spiral galaxies.
- Scale lengths from from < 1 kpc (dwarfs) to > 10 kpc.
- Absolute magnitudes range from –16 to –23 (a factor of 1000 in luminosity!)
- Masses range from 10^9 – few x 10^{12} $M_\odot$

On this scale, the Milky Way is a large spiral galaxy, but not the most extreme.

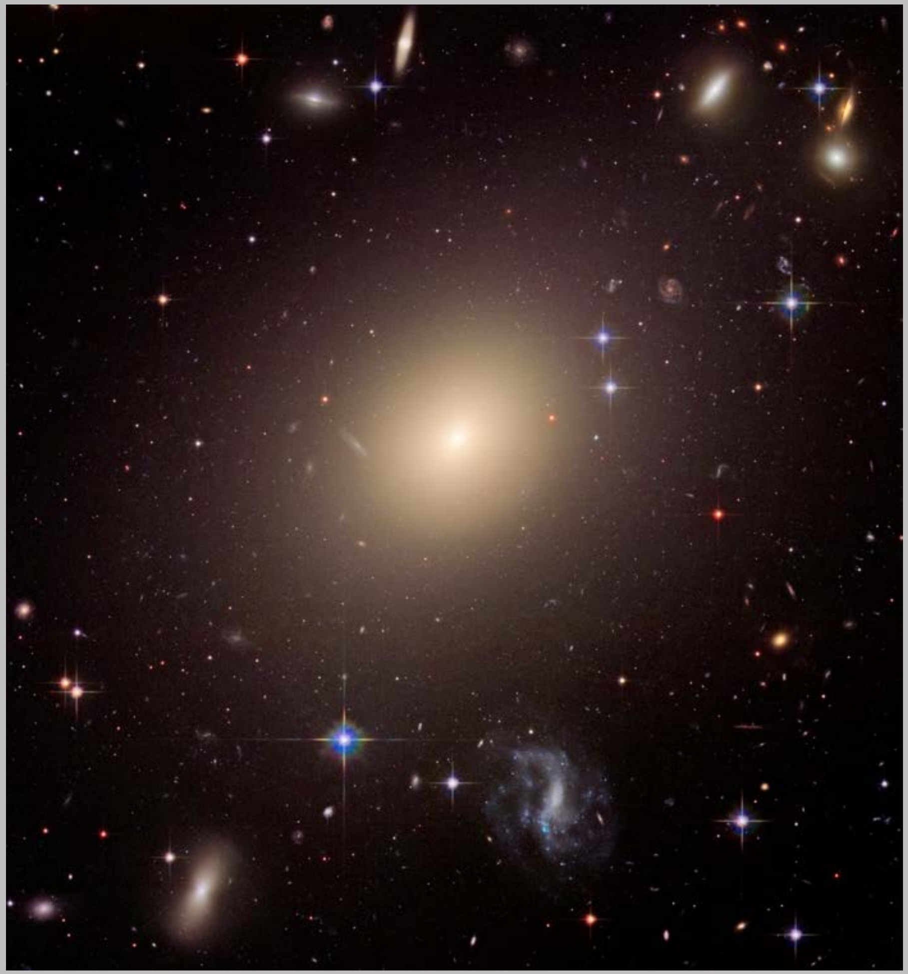
Galaxy Properties (a thumbnail sketch)

Milky Way *(very rough numbers)*:

- Radial scale length: $h \approx 3$ kpc
- Blue luminosity: $L_B \approx 1.5{\times}10^{10} L_\odot$
- Absolute B magnitude: $M_B \approx -20.7$
- Total mass: $\mathcal{M}_B \approx 10^{12} \mathcal{M}_\odot$

Elliptical Galaxies

- About 10−20% of big galaxies are ellipticals, except in galaxy clusters where ellipticals dominate.
- Ellipticals have a wide range of properties:
  - Normal ellipticals
  - cD galaxies: massive E's at the center of a galaxy cluster
  - dE's: dwarf ellipticals
- Size is measured by the effective radius (r_e), which is the radius containing half the total light. Sometimes called the half-light radius.
- Sizes: r_e ranges from < 1 kpc (dE's) to 10s of kpc (cD's)
- Absolute magnitudes: −10 to −25 (a factor of a million in luminosity!)
- Masses range from 10^7 – few x 10^{13} $M_\odot$

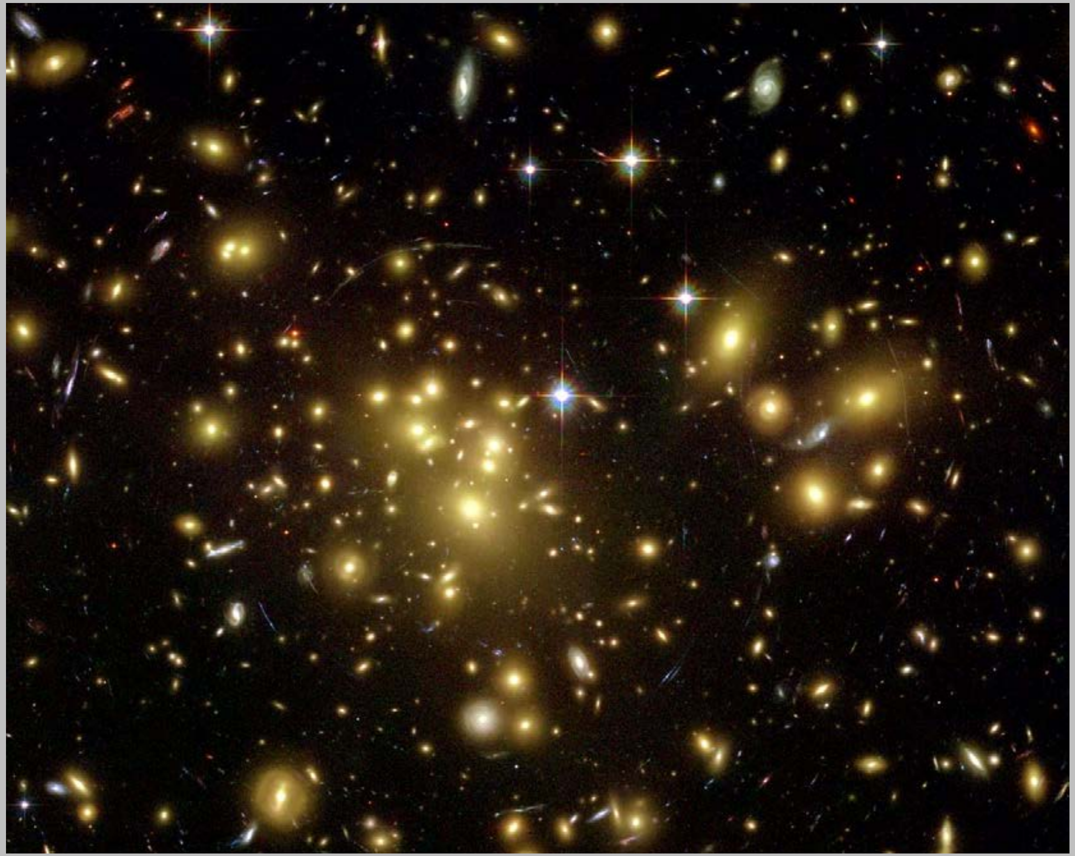


Galaxies: Morphology-Density Relationship

In the local universe, the fraction of galaxy types is a strong function of local environment.

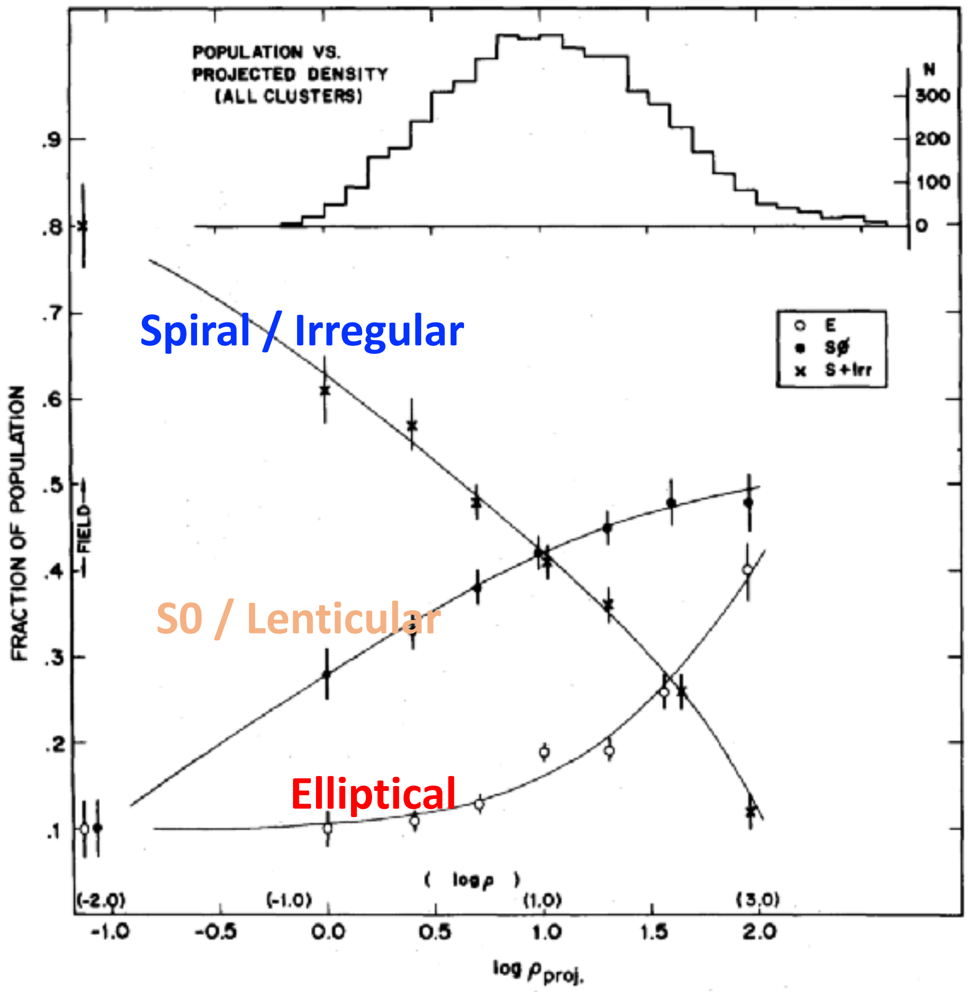
Spirals/Irregulars dominate the in the field environment.

S0's and E's dominate in galaxy clusters.



Dressler 1980

Galaxy Population Fraction



Projected Number Density of Galaxies
log(# per Mpc^2)

Galaxies: Luminosities

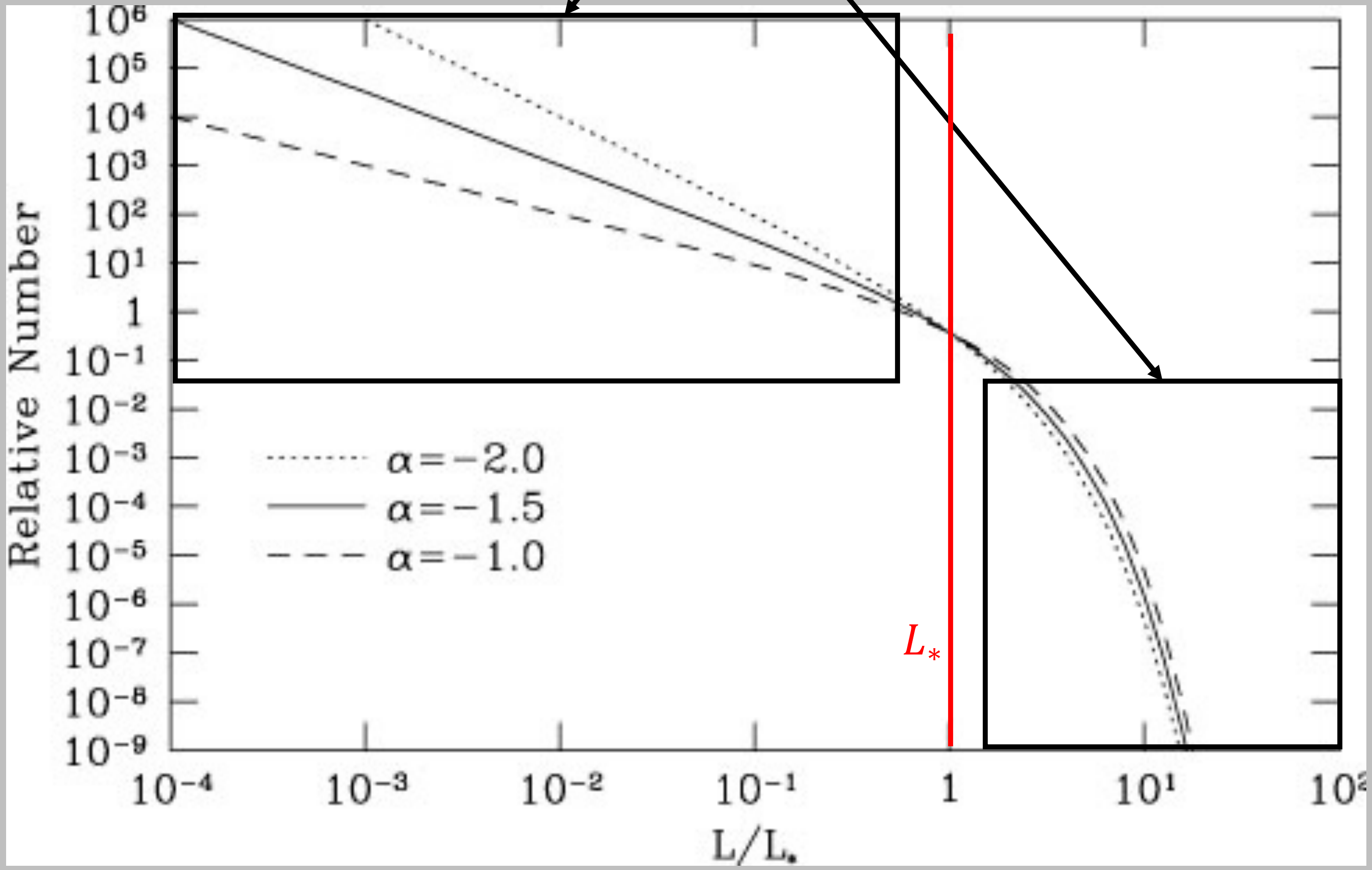
Luminosity function: number of galaxies (per unit volume) in a luminosity range L ⇒ L + dL

Common parameterization is the **Schechter Function**: $$\Phi(L)dL = \Phi_*\left(\frac{L}{L_*}\right)^{\alpha} e^{(-L/L_*)} dL$$

$\mathbf{\Phi}_*$: overall density (units = #/Mpc^3)

L_*: characteristic luminosity, the “knee” of the luminosity function

α: faint end power law slope

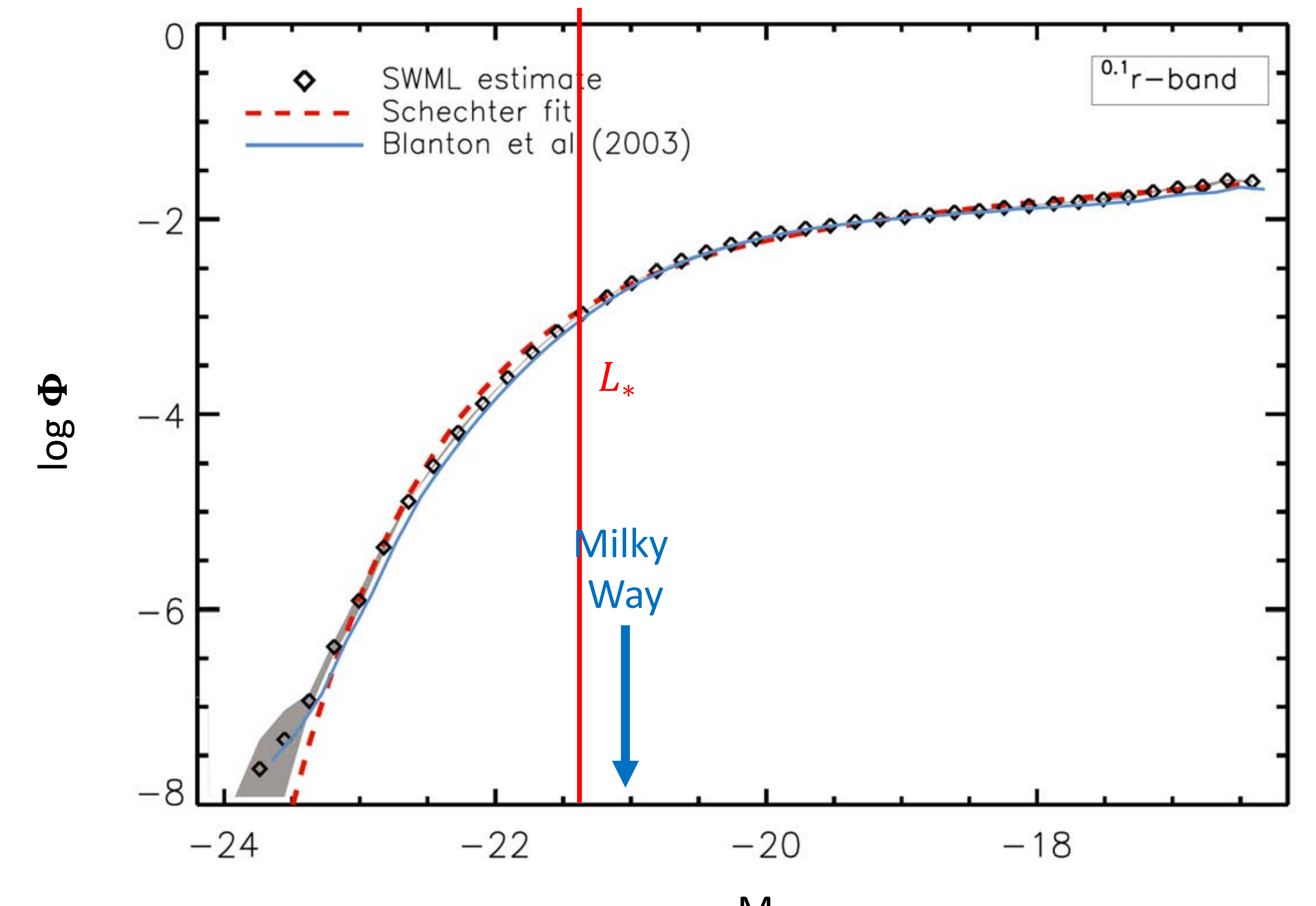


Galaxies: Luminosities (expressed as absolute magnitudes)

$$\Phi(M)dM = \Phi_0 10^{-0.4(\alpha+1)M} e^{-10^{0.4(M_* - M)}} dM$$

Galaxy luminosity function from Sloan Digital Sky Survey:

$$M_* = -21.4$$
$$\alpha = -1.26$$



Montero-Dorta & Prada 09

⟸ Luminosity Increases

Galaxy luminosity function: Very strong dependence on galaxy type and environment

These are schematic LFs, not real

Inside big galaxy clusters:

- E/S0 dominate
- faint end mostly red things

In groups and field:

- Spirals dominate
- faint end mostly blue things