Galaxies

1. Early Attempts to catalog and classify

1.1 Messier Catalog

A catalog of 110 astronomical objects - started in 1771

HST collection of images from the catalog

1.2 "The Great Debate"

26 April 1920

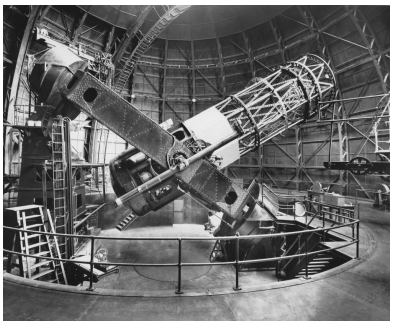
Smithsonian Museum of Natural History

Harlow Shapley's Position

All the distant nebula we could see where just small things located in the milky way. Essentially, the Milky way was the extent of the known universe.

Heber Curtis' Position

All the distant nebular were in fact other galaxies, like the milky way. "Island Universes" as Kant called them.



The 100 inch reflecting telescope at Mt. Wilson, near LA.

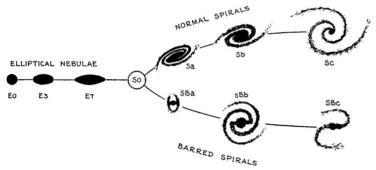
Courtesy of The Observatories of the Carnegie Institution for Science Collection at the Huntington Library, San Marino, Calif.

Hubble at the telescope

Edwin Hubble Papers/Courtesy of Huntington Library, San Marino, Calif.

Hubble - Andromeda

nasa



The Sequence of Nebula Types

Edwin Hubble The Realm of the Nebulae Dover Publications Inc. 1958

Hubble's first classification scheme was laid out around 1926. They were grouped in three main categories: ellipticals (E), spirals, and irregulars (Irr). Spirals could be normal: (S) or barred: (SB). Lenticulars were in between shapes. Hubble surmised that this arrangement also represented an evolution in time: elliptical galaxies would eventually become spirals... (we now know this is **not true**).

Ellipticity:

$$\epsilon \equiv 1 - \frac{\beta}{\alpha} \tag{1}$$

where α and β are the apparent major and minor axes of the galaxy.

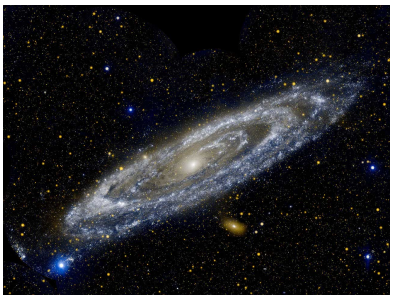
- Ellipticals that are nearly spherical are called E0
- Ellipticals might have ellipticity values of 0.7: E7

- Largest bulge/disk ratio, i.e. most prominent bulge: Sa
  - $L_{\text{bulge}}/L_{\text{disk}} \sim 0.3$
  - Spiral Arms tightly wound
  - Smooth distribution of stars
- Less obvious bulges: Sc
  - $L_{\text{bulge}}/L_{\text{disk}} \sim 0.05$
  - Loosely wound arms
  - Clumps of stars

1.3 Spiral: Andromeda

M31 - Andromeda

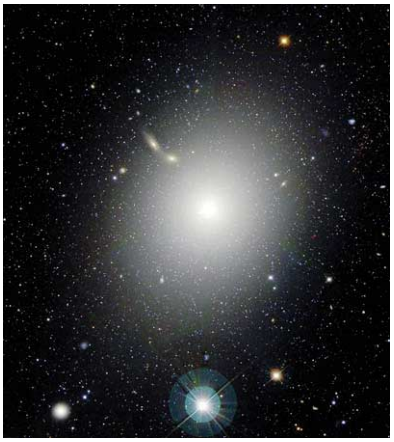
Closest major galaxy



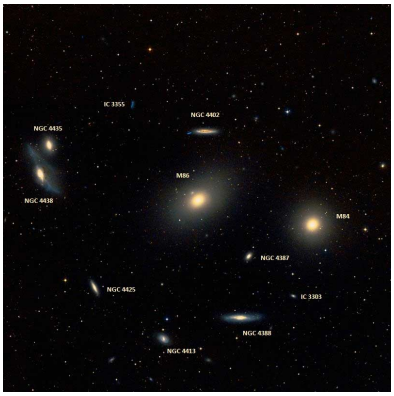
2.5 million light-years

We have a meeting in about 4.5 billion years

1.4 Ellipticals



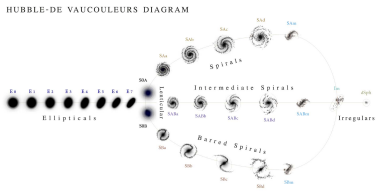
M87 Virgo a



M84 and M86

Messier 87 (also known as Virgo A or NGC 4486, and generally abbreviated to M87) is a supergiant elliptical galaxy in the constellation Virgo. One of the most massive galaxies in the local universe, it is notable for its large population of globular clusters—M87 contains about 12,000 compared to the 150–200 orbiting the Milky Way

2. Updates to the scheme



The Hubble - de Vaucouleurs system

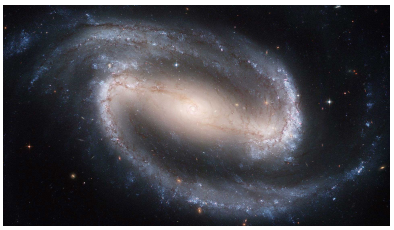
By Antonio Ciccolella / M. De Leo - https://en.wikipedia.org/wiki/File:Hubble-Vaucouleurs.png, CC BY 3.0, https://commons.wikimedia.org/w/index.php?curid=50260841

Hubble's system has been refined over the years.

1. Spirals with no bars: SA
2. Spirals with some hints of a bar: SAB
3. Strongly Barred spirals: SB

The final scheme for non-barred spiral galaxies looks like: E0, E1, ... E7, $S0_1$, $S0_2$, $S0_3$, Sa, Sab, Sb, Sbc, Sc, Scd, Sd, Sm, Im, Ir

2.5 NGC1300



NGC1300 is an example of a barred galaxy.

By NASA, ESA, and The Hubble Heritage Team STScI/AURA) - http://hubblesite.org/newscenter/archive/releases/2005/01/image/ahttp://www.spacetelescope.org/images/opo0501a/ ([cdn.spacetelescope.org/archives/images/screen/opo0501a.jpg direct link]), Public Domain, https://commons.wikimedia.org/w/index.php?curid=119211

2.6 Grand Design Spiral

A 'grand design' spiral has well defined arms.

Messier 100 is a grand design spiral

The Whirlpool Galaxy (Spiral Galaxy M51, NGC 5194), a classic spiral galaxy located in the Canes Venatici constellation, and its companion NGC 5195.

https://esahubble.org/images/heic0506a/

2.7 Flocculent spiral galaxy

Flocculent ("having or resembling tufts of wool.") spirals don't have well defined arms

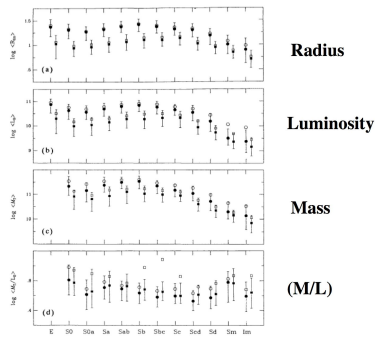
About 30% of spirals are like this.

NGC_4414

- Disks: generally metal rich stars and ISM, nearly circular orbits with little random motion, spiral patterns
  - Thin disks: younger, star forming, dynamically very cold
  - Thick disks: older, passive, slower rotation and more random motions
- Bulge: metal poor to super-metal-rich stars, high stellar densities, mostly random motion – similar to ellipticals
- Bar: present in ~ 50 % of disk galaxies, mostly older stars, some random motions and a ~ solid body rotation?
- Nucleus: central (< 10pc) region of very high mass density, massive black hole or starburst or nuclear star cluster
- Stellar halo: very low density (few % of the total light), metal poor stars, globular clusters, low density hot gas, little or no rotation
- Dark halo: dominates mass (and gravitational potential) outside a few kpc, probably triaxial ellipsoids, radial profile ~ singular isothermal sphere, DM nature unknown

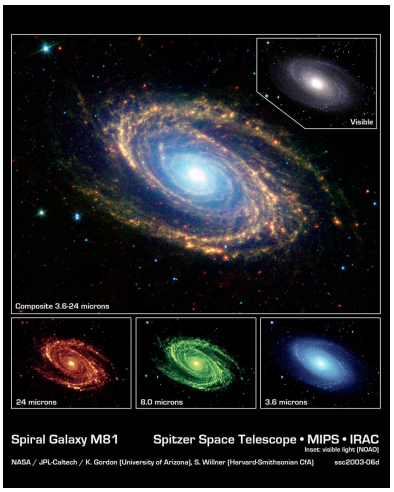
A largely successful classification scheme.

Although it was still rather qualitative based on just 'how they looked'.



Some parameters don't correlate much with galaxy type.

M-81 in different wavelengths



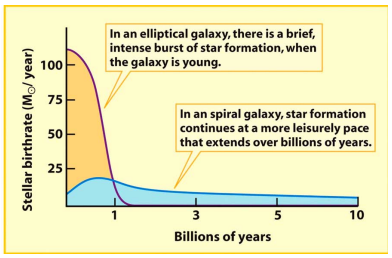
Messier Object 81 in different wavelengths

NASA/JPL-Caltech/K. Gordon (University of Arizona) & S. Willner (Harvard-Smithsonian Center for Astrophysics), N.A. Sharp (NOAO/AURA/NSF)

M81 in Multiple Wavelengths

NASA, ESA, and G. Bacon (STScI)

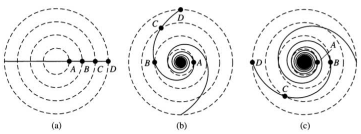
3. Star formation



Ellipticals and early type spirals formed most of their stars early on (used up their gas, have older/redder stars)

Late type spirals have substantial on-going star-formation, didn't form as many stars early-on (and thus lots of gas left)

4. Spiral Origins

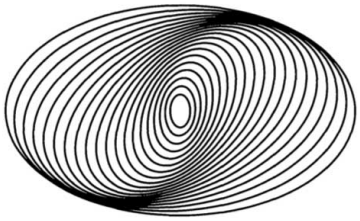


Stars closer to the center will take less time to go around. Over time, the arms will become 'tightly wound' and not observable spirals.

This will take not a lot of time ~ a few billion years. So, if this were the mechanism for getting spirals, then it we shouldn't see spirals in the current universe. But we do.

4.8 Density Wave Theory

The orbits in the galaxy are elliptical, but slightly rotated. This causes regions of differing densities.



Higher density means higher gravitational force.

Objects (such as gas clouds) will be attracted to these regions and will drift towards them.

The spiral appearance is thought to be a result of density waves rotating through the galaxy.

Spirals

Spiral arms are waves of compression that move around the galaxy and trigger star formation

Star formation will occur where the gas clouds are compressed

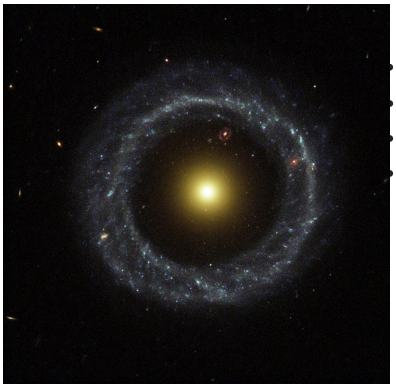
Simulations Here.

5. Ellipticals

Hubble originally thought there was not much going on elliptical galaxies. They just seems less complex.

Turns out that's not really the case. They are full of interesting features.

6. What's out there?



Other types:

- Rings
- Lenticular
- Irregulars
- Dwarf Galaxies

about 10^{11} galaxies in the visible universe - maybe more.

Over billions of years, galaxies interact.

Hoag's object: a ring galaxy

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Galaxy-Zoo