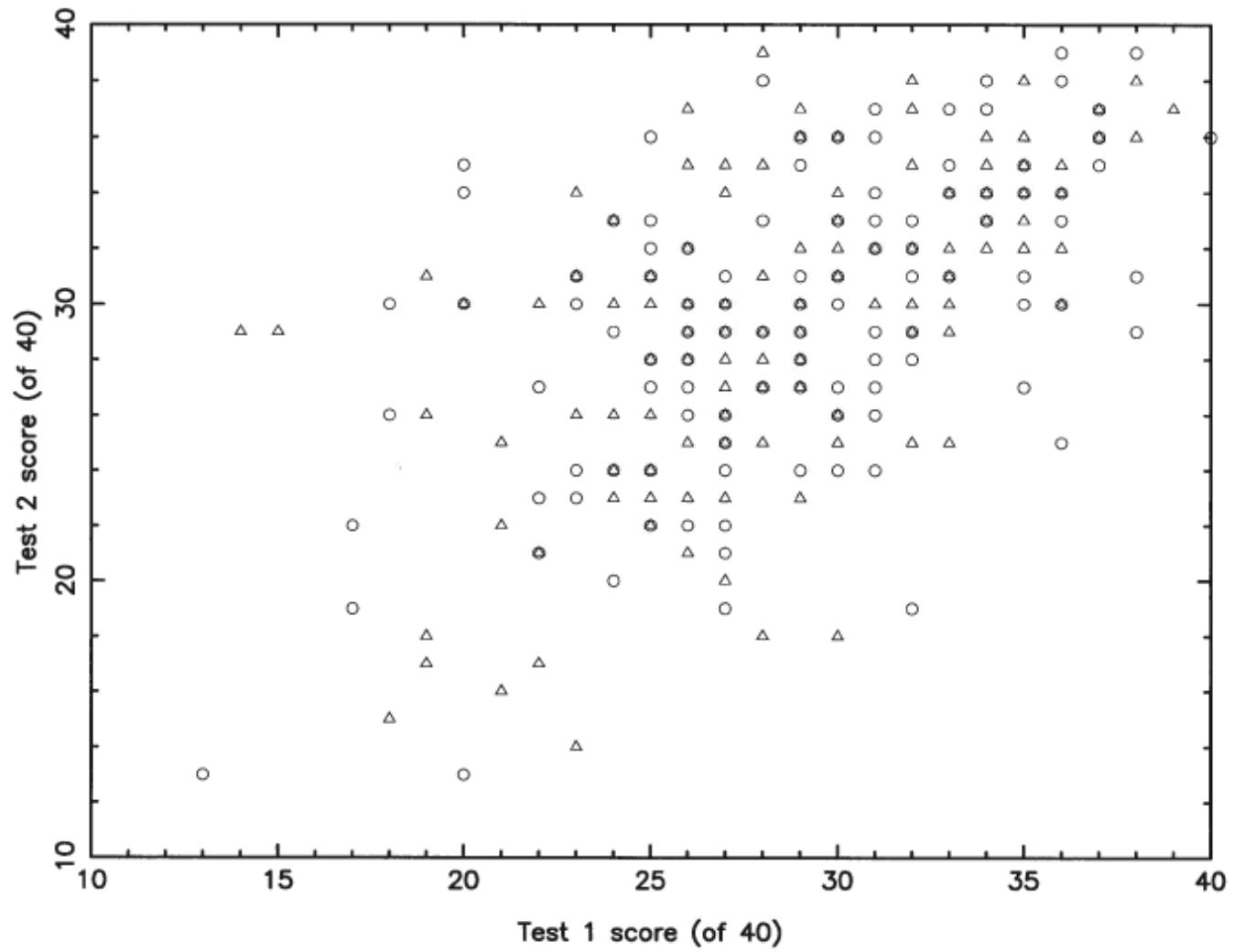


Galaxies

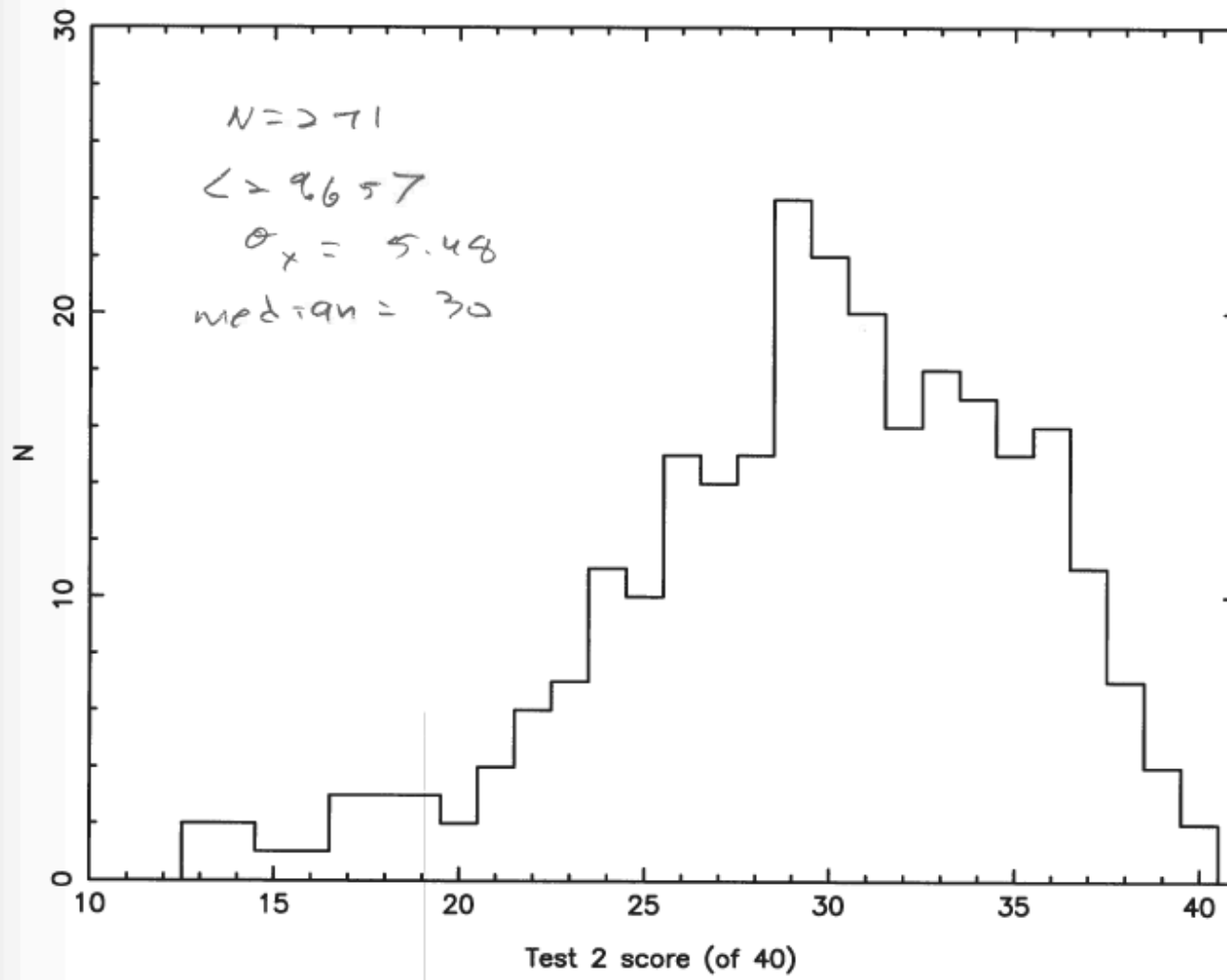


Visual-wavelength image

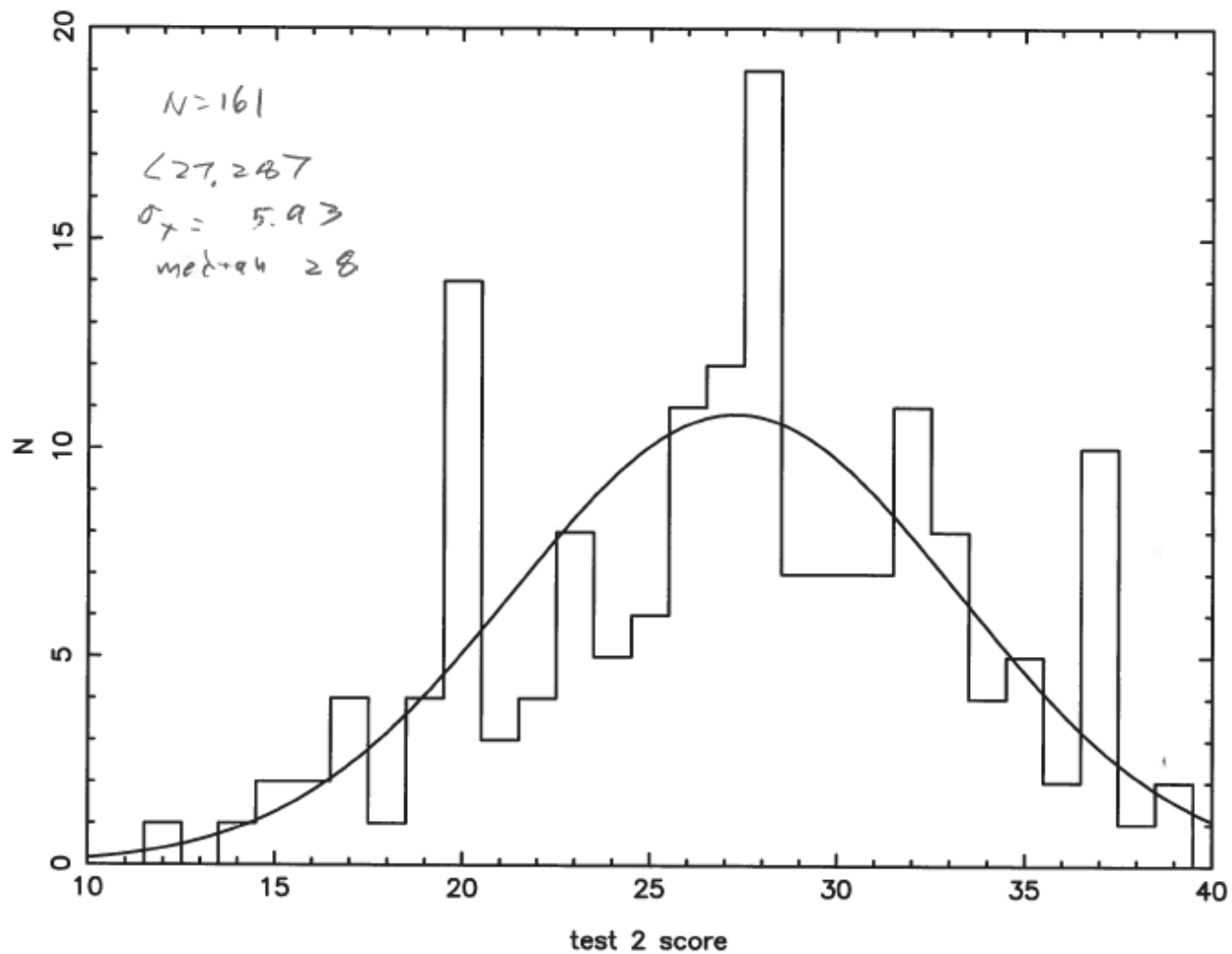
Fall 2020



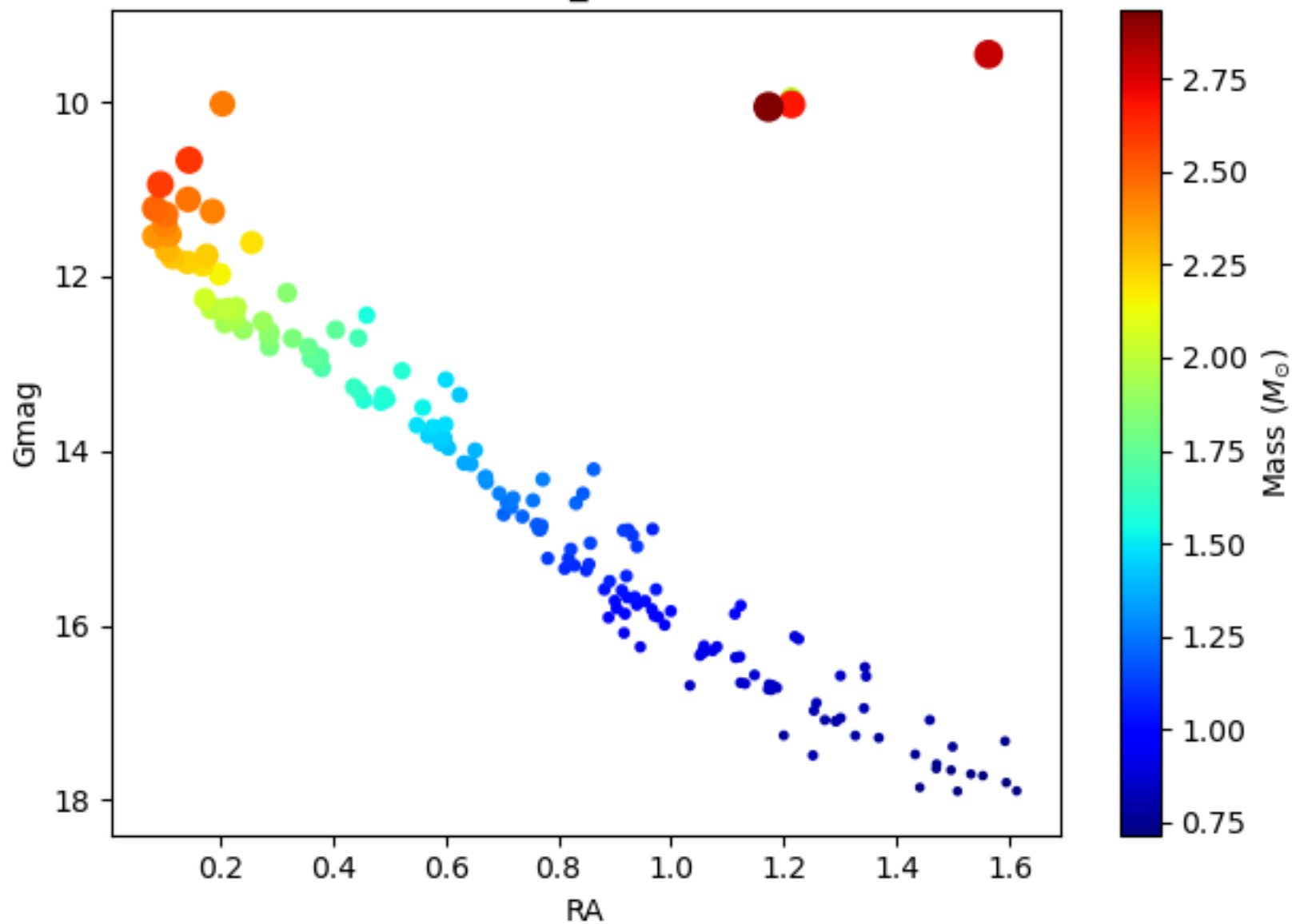
Fall 2020



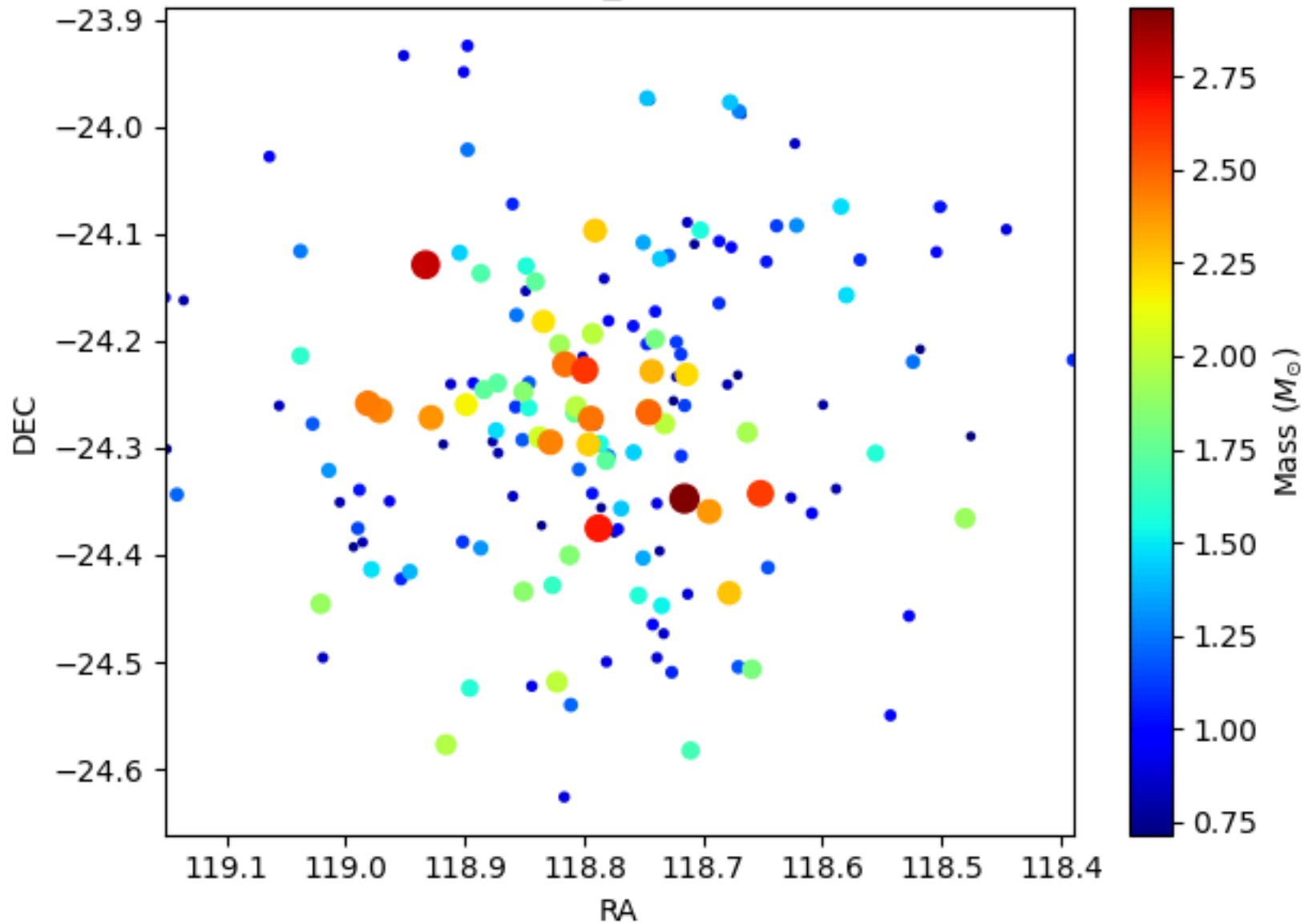
ASTR 101 fall 2019



NGC_2482



NGC_2482



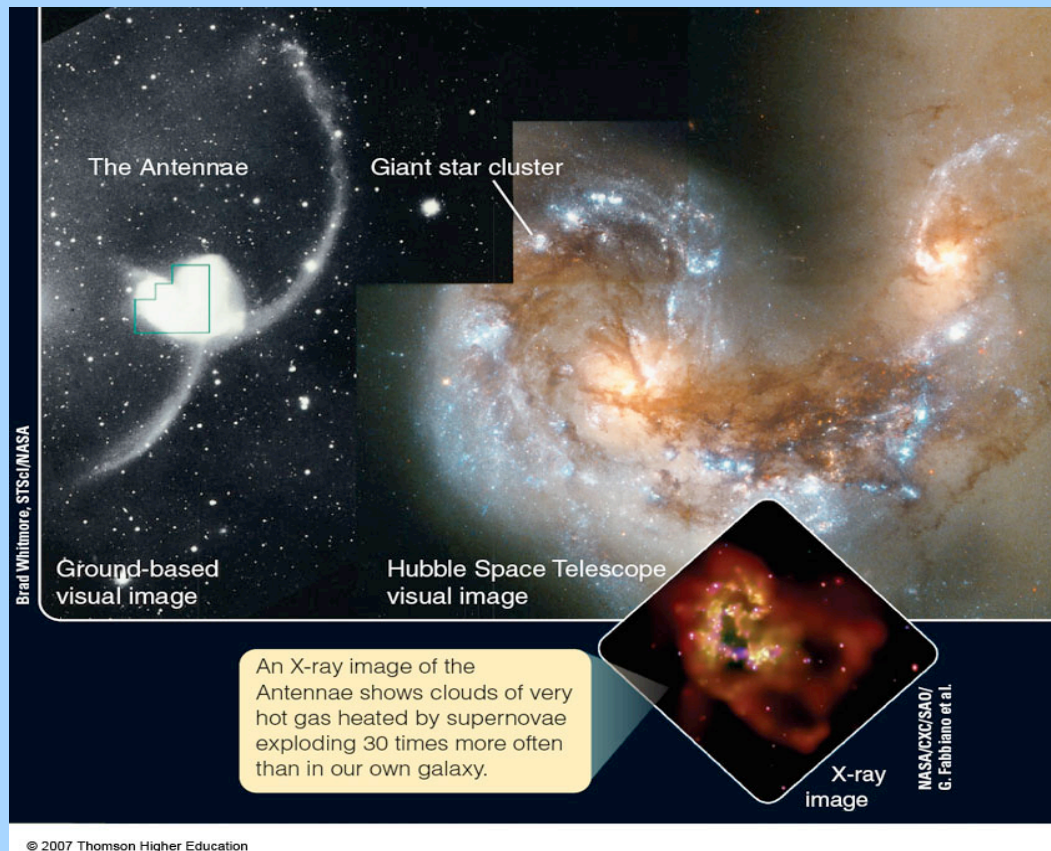
There are three basic types of galaxies:

Spirals

Ellipticals

Irregulars

To make a long story short, elliptical galaxies are galaxies that have used up all their gas forming stars, or they have had their gas stripped away when they have collided with other galaxies.



Galaxy Interactions can stimulate the formation of spiral arms



In this computer model, two uniform disk galaxies pass near each other.



The small galaxy passes behind the larger galaxy so they do not actually collide.



Tidal forces deform the galaxies and trigger the formation of spiral arms.



The upper arm of the large galaxy passes in front of the small galaxy.

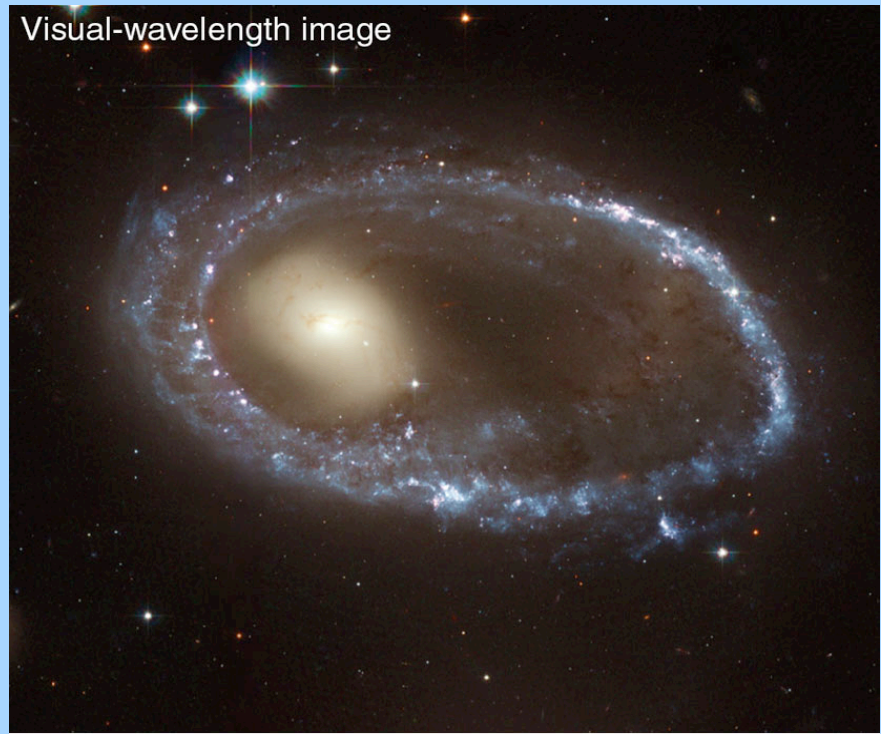
Alissa Bruehl

A photo of the well-known Whirlpool Galaxy resembles the computer model.

NOAO

Visual

Visual-wavelength image



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Ring galaxies are the result of high speed collisions of galaxies in which the smaller one passes through another galaxy almost perpendicular to its disk.

Evidence of galactic cannibalism: Giant elliptical galaxies in rich clusters sometimes have multiple nuclei, thought to be the densest parts of smaller galaxies that have been absorbed and only partly digested.

Multiple nuclei

Michael J. West

Visual false-color image

In which type of galaxy are we *least* likely to find stars being formed at the present epoch?

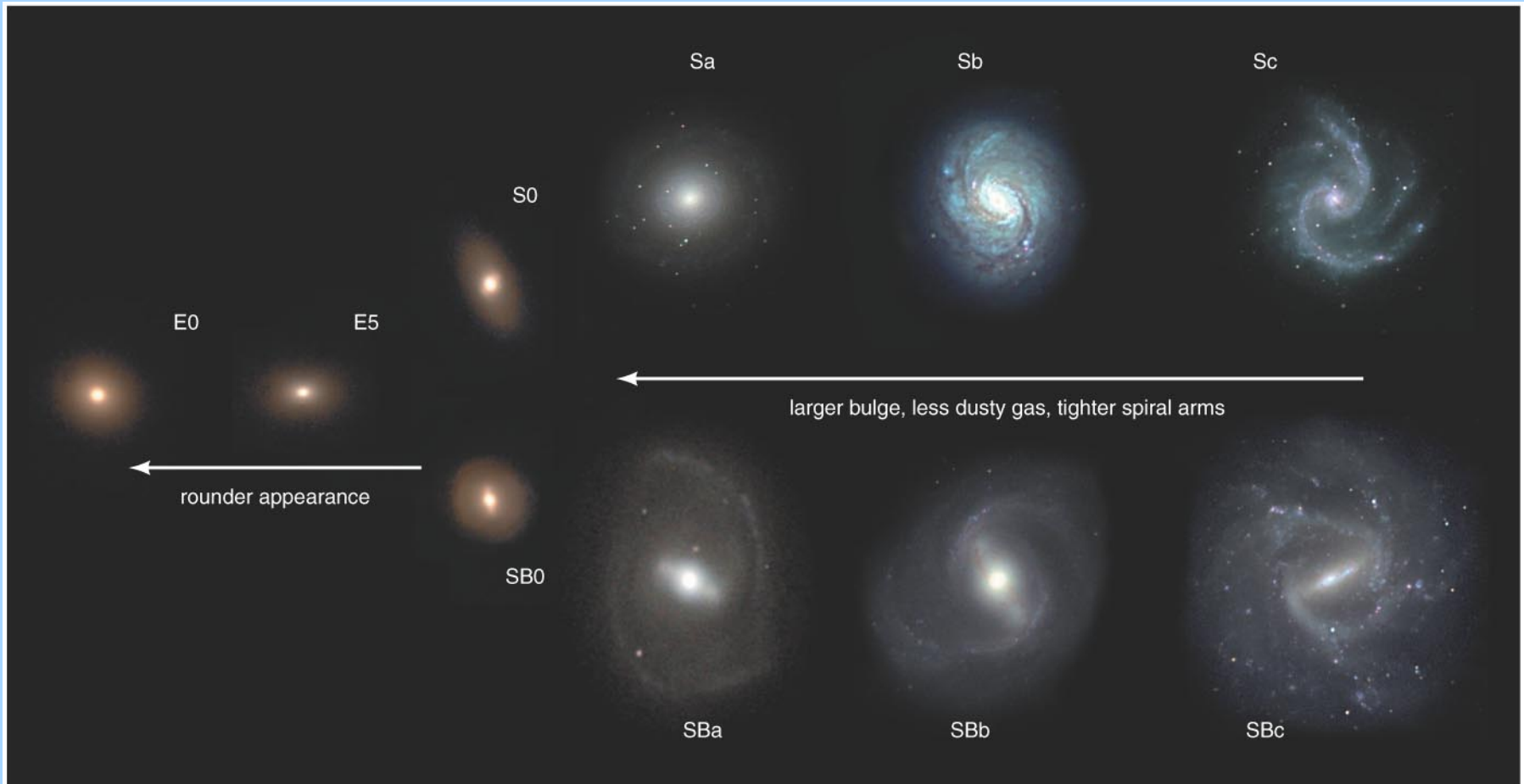
- a. spiral galaxy
- b. barred spiral galaxy
- c. elliptical galaxy
- d. irregular galaxy

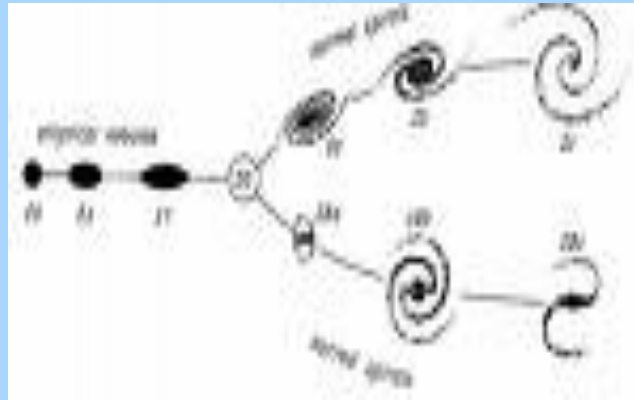
Galaxies range widely in size and mass

■ **Table 16-1** | **The Properties of Galaxies***

	Elliptical	Spiral	Irregular
Mass	0.0001–50	0.005–2	<0.0005–0.15
Diameter	0.01–5	0.2–1.5	0.05–0.25
Luminosity	0.00005–5	0.005–10	0.00005–0.1

*In units of the mass, diameter, and luminosity of the Milky Way.





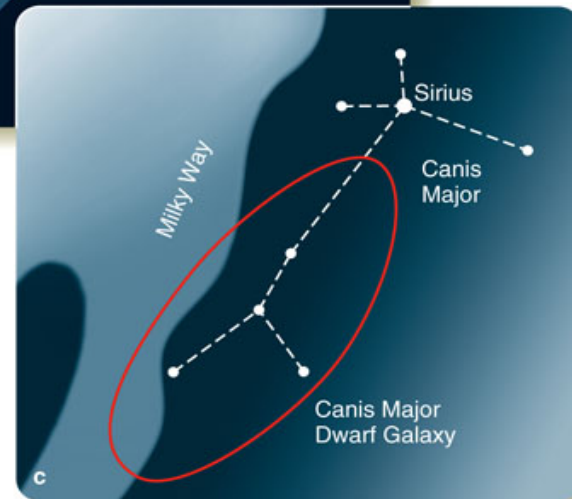
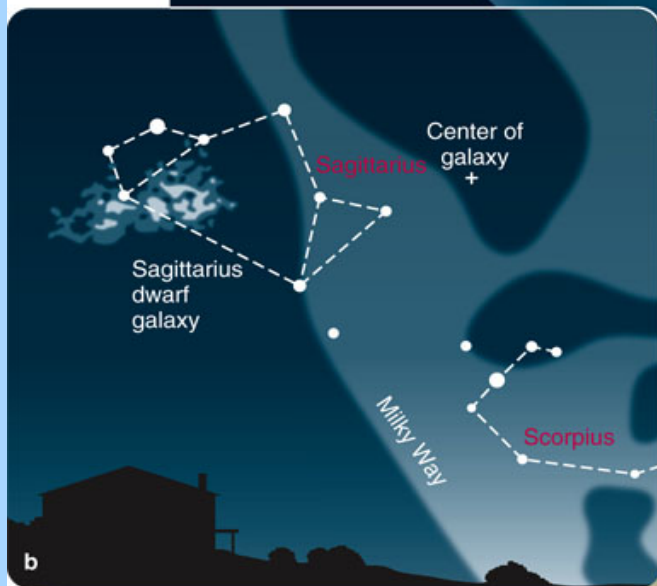
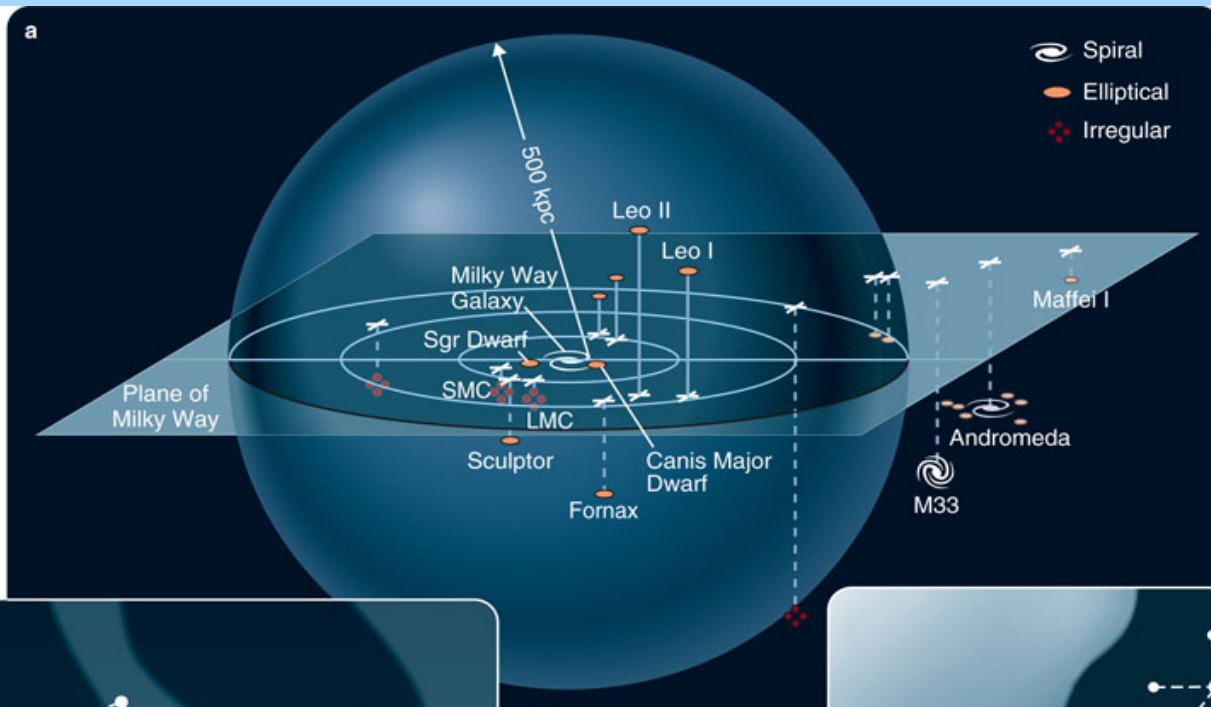
Edwin Hubble devised this classification scheme for galaxies.

Ellipticals were classified on the basis of their ellipticity, E0 for the roundest ones, E7 for the most elliptical ones.

Spirals were classified by the tightness of the spiral arms, and whether or not the galaxy had a central bar.

Our Galaxy is a large spiral galaxy, which is part of the Local Group of galaxies.

Our Galaxy has a number of satellite galaxies that are gravitationally bound to it, the largest of which are the Large and Small Magellanic Clouds.



Some galaxy clusters contain only 20 galaxies. Others contain more than 1000 galaxies, such as the Virgo cluster and the Coma cluster.



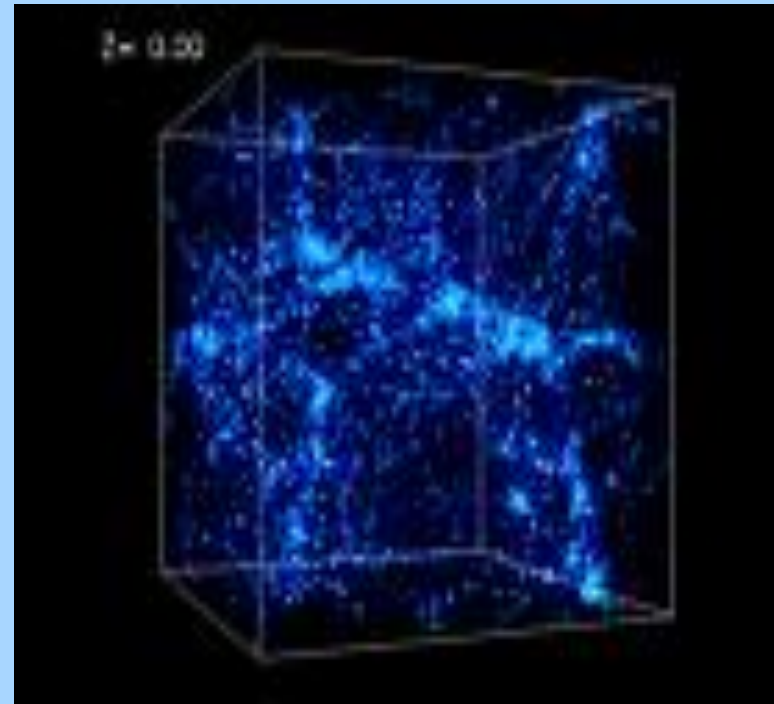
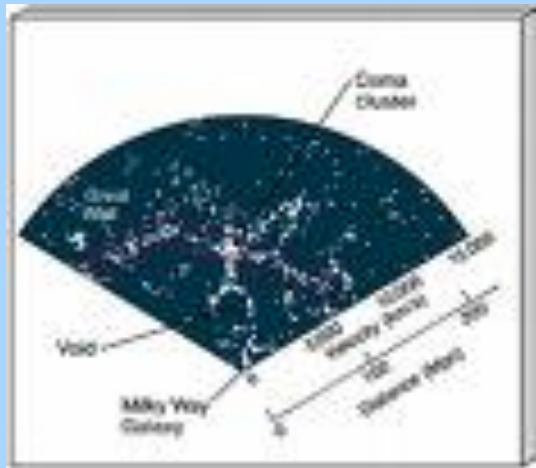
In two papers in 1933 and 1937 the Swiss-American astronomer Fritz Zwicky (1898-1974) discovered that the Coma cluster must contain much more mass than could be identified in stars and gas. He attributed this to some form of mysterious **dark matter**. Other astronomers ignored these findings until the 1970's when Vera Rubin found evidence for dark matter in many individual galaxies.



Zwicky



Rubin



There are clusters of clusters of galaxies too. Studies of the large scale structure of the universe show that the the universe is a cosmic-wide web of connections, with individual galaxies as the building blocks.

V. M. Slipher (1875-1969) was an astronomer who worked at Lowell Observatory in Flagstaff, Arizona. In 1909 he began studying the spectrum of the Andromeda Nebula. He found that that object was approaching us at a speed of 300 km/sec. This was the largest Doppler shift measured.



Radial velocities of nebulae measured by Slipher:

NGC	velocity (km/sec)
221	-300
224	-300
598	~zero
1023	+200 roughly
1068	+1100
3031	+ small
3115	+400 roughly
3627	+500
4565	+1000
4594	+1100
4736	+200 roughly
4826	+ small
5194	+ small
5866	+600
7331	+300 roughly

We can compare these velocities with a three other velocities:

orbital speed of the Earth around the Sun ~ 30 km/sec

orbital speed of Sun around center of Galaxy ~ 220 km/sec

Escape speed from our Galaxy is

$$(V_{\text{esc}})^2 = 2 G M_{\text{Gal}} / r_{\text{Gal}}$$

With a mass of the Galaxy of 1.5×10^{12} solar masses and a radius of 25,000 parsecs, the escape speed is about ~ 720 km/sec.

In 1914 Slipher delivered a paper on the radial velocities of 15 spiral nebulae. Some had Doppler shifts of 1100 km/sec. Astronomers who heard his speech did not know what to make of it, but they knew it would prove to be significant. They gave him a standing ovation.

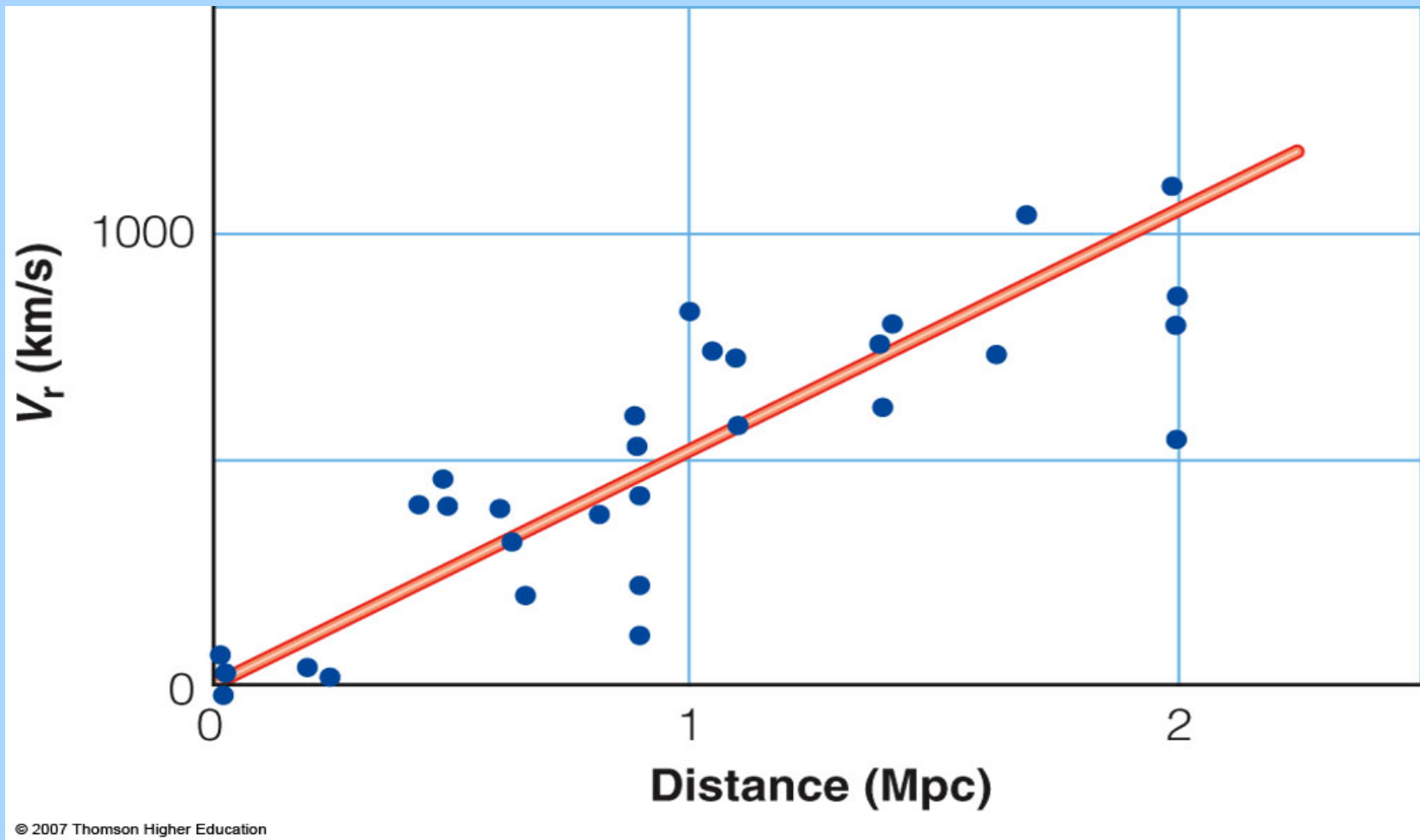
Slipher had at his disposal only the 24-inch refractor at Lowell Observatory. In 1917 a much larger telescope was inaugurated – the 100-inch telescope at Mount Wilson, California. Observations with the 100-inch soon proved that the nebulae studied by Slipher were “island universes” -- other galaxies like our Milky Way.

Edwin Hubble (1889-1953) was one of the most important astronomers of the first half of the 20th century.

In 1924, using observations of Cepheid variables in the Andromeda Nebula, he proved that it was a giant spiral galaxy like the Milky Way Galaxy.

In 1929 he discovered the expansion of the universe.





Hubble's 1929 diagram showing the radial velocities of galaxies vs. their distances. Note that the slope is about 500 km/sec/Mpc.

Hubble used as a “standard candle” the brightest stars he could detect in the galaxies he photographed. He assumed that they had absolute magnitudes comparable to the brightest supergiants in our Galaxy.

However, it turned out that some of Hubble's bright “stars” in other galaxies were groups of stars, so he was using the wrong absolute magnitudes. That is why the slope in his velocity-distance diagram is not correct.

By 1931 Hubble and Humason had determined distance to galaxies as far as 30 million parsecs, whose radial velocities were as large as 20,000 km/sec: 7 percent of the speed of light.

What we know as **Hubble's Law** relates the velocity of recession of galaxies with their distances:

$$V = H_0 d$$

V is the velocity in km/sec. d is the distance in millions of parsecs (Megaparsecs). H_0 is known as the **Hubble constant**. It has units of km/sec/Mpc.

Let the Hubble constant be 72 km/sec/Mpc . Say there is a galaxy at a distance of 111 Megaparsecs . at what velocity is it receding from us?

- A. 800 km/sec
- B. 4000 km/sec
- C. 8000 km/sec
- D. 111 km/sec

Say a galaxy's radial velocity is 8000 km/sec. At what fraction of the speed of light is it receding from us?

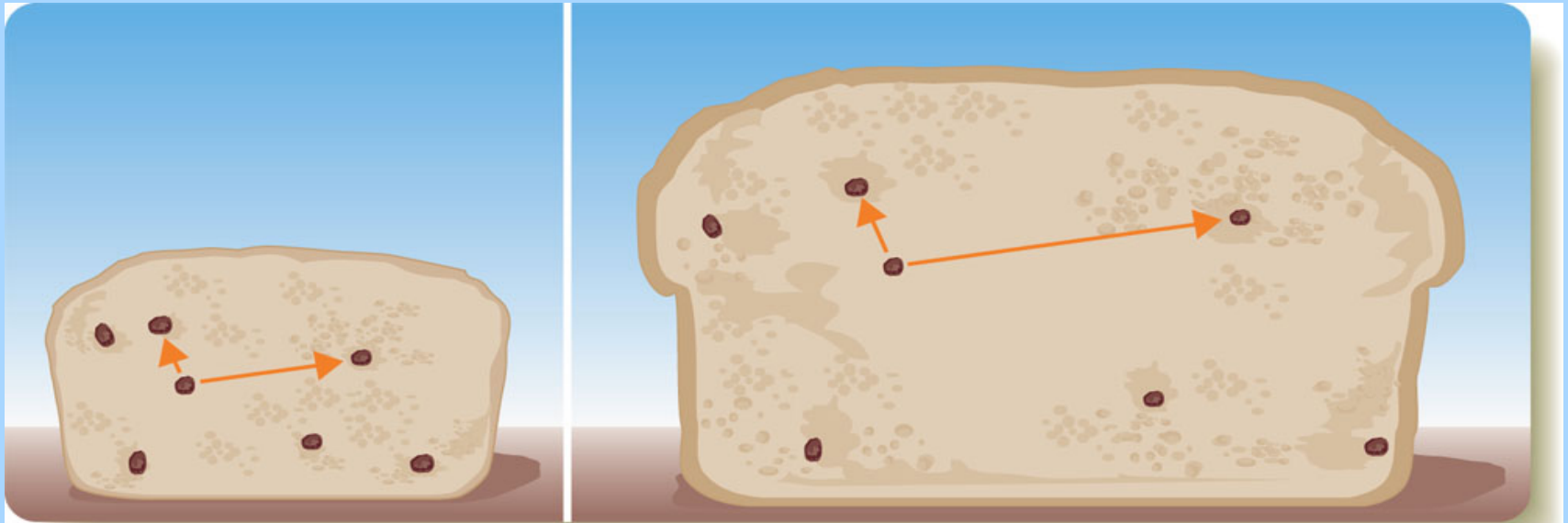
- A. 0.027
- B. 0.27
- C. 0.60
- D. 0.80

Say a galaxy is receding from us at 2.7 percent the speed of light. In the lab we would observe the hydrogen alpha line at 656.3 nm. At what wavelength would we observe this line a spectrum of this galaxy?

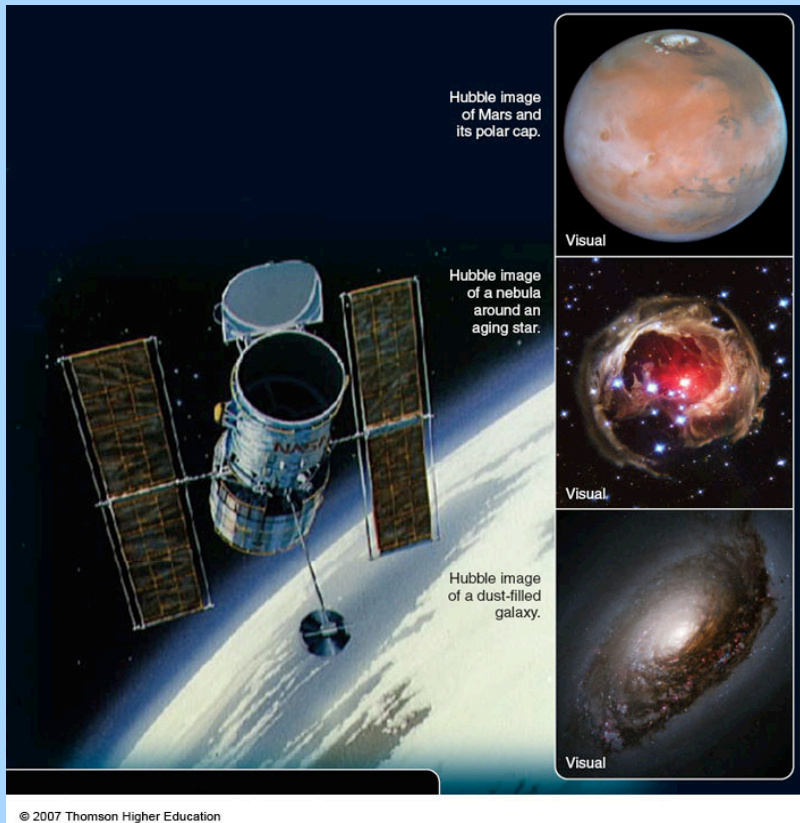
- A. 2.7% of 656.3 nm
- B. 2.7% less than 656.3 nm
- C. 2.7% more than 656.3 nm
- D. It depends on the Hubble constant.

A few of the nearby galaxies are approaching us.
But almost *all* the galaxies have redshifted spectra --
they are receding from us at a speed that is
proportional to distance.

The linear velocity-distance relationship implies that the universe is expanding. Furthermore, no matter where you are in the universe, you would observe the nearest galaxies to be receding at the smallest velocities, and the more distant galaxies would recede with velocities proportional to distance.



The standard modern value of the Hubble constant is 72 ± 8 km/sec/Mpc (Freedman et al. 2001). This was made from observations of Cepheids in nearby galaxies using the Hubble Space Telescope.



This value of H_0 also required observations of Type Ia supernovae, which are excellent standard candles.

What's the fastest speed you can go? The speed of light, of course. So, using Hubble's Law, how far would galaxies be if they were receding from us at the speed of light?

$$V(\text{km/sec}) = 72 (\text{km/sec/Mpc}) d (\text{Mpc})$$

Set $V = \text{speed of light} = 300,000 \text{ km/sec}$. Then $d = 4167 \text{ Mpc}$. Since each parsec = 3.26 light-years, that's a distance of 13.58 billion lt-yrs.

Since those hypothetical galaxies have been sending us their light from 13.58 billion lt-yrs away, that light must be 13.58 billion years old. We are looking back in time 13.58 billion years.

Another way of looking at this is just to consider the Hubble constant:

$$H_0 = 72 \text{ km/sec/Mpc}$$

The Hubble constant is measured in some units of distance per unit time, divided by some other unit of distance. In other words, it has units of 1/time. So, let us consider a different constant:

$$1/H_0 = (1/72) (\# \text{ km in a Mpc}) \times \text{sec}$$

This will have the units of time. In fact, we call $1/H_0$ the *Hubble time*.

One parsec = 206,265 AU times 149.6 million km/AU =
 3.086×10^{13} km.

One Megaparsec = one million parsecs, so 1 Mpc =
 3.086×10^{19} km.

Therefore,

$$1/H_0 = (1/72) \times 3.086 \times 10^{19} = 4.286 \times 10^{17} \text{ sec.}$$

That's a lot of seconds. Since 1 year $\sim 3.1557 \times 10^7$ sec,
it follows that $1/H_0 \sim 13.58$ billion years, exactly what
we got from Hubble's Law and the speed of light.

Since the value of the Hubble constant always has some uncertainty associated with it, it is convenient to redefine the Hubble time as follows:

$$T_H = 9.778 / (H_0/100)$$

If $H_0 = 72$ km/sec/Mpc, the Hubble time is 13.58 billion years.

The bottom line is that from an investigation of the *rate* of expansion of the universe, you directly get an estimate of the *age* of the universe.

Why is the Hubble time only an *estimate* of the age of the universe? Partly, because we don't know the Hubble constant with great accuracy.

Also, it turns out that one must consider the mean mass density of the universe. If the universe had just the right amount of matter to halt the general expansion, the age of the universe would be $2/3$ of the Hubble time. Why is it smaller? Because the sum total of all the gravitational attraction of all the galaxies should be slowing down the expansion of the universe. This was our strong expectation until 1998 when two groups of astronomers discovered that the universe was actually accelerating in its expansion.

The Milky Way galaxy

- a. is expanding in accord with Hubble's Law
- b. is contracting because of the black hole in its center
- c. is a gravitationally bound entity and is neither expanding nor contracting
- d. goes through cycles of expansion and contraction