Galaxies and the Universe

11/10 – Getting Distances

11/12 – The Zoo of Galaxies

11/14 – Time-travelling (without moving)

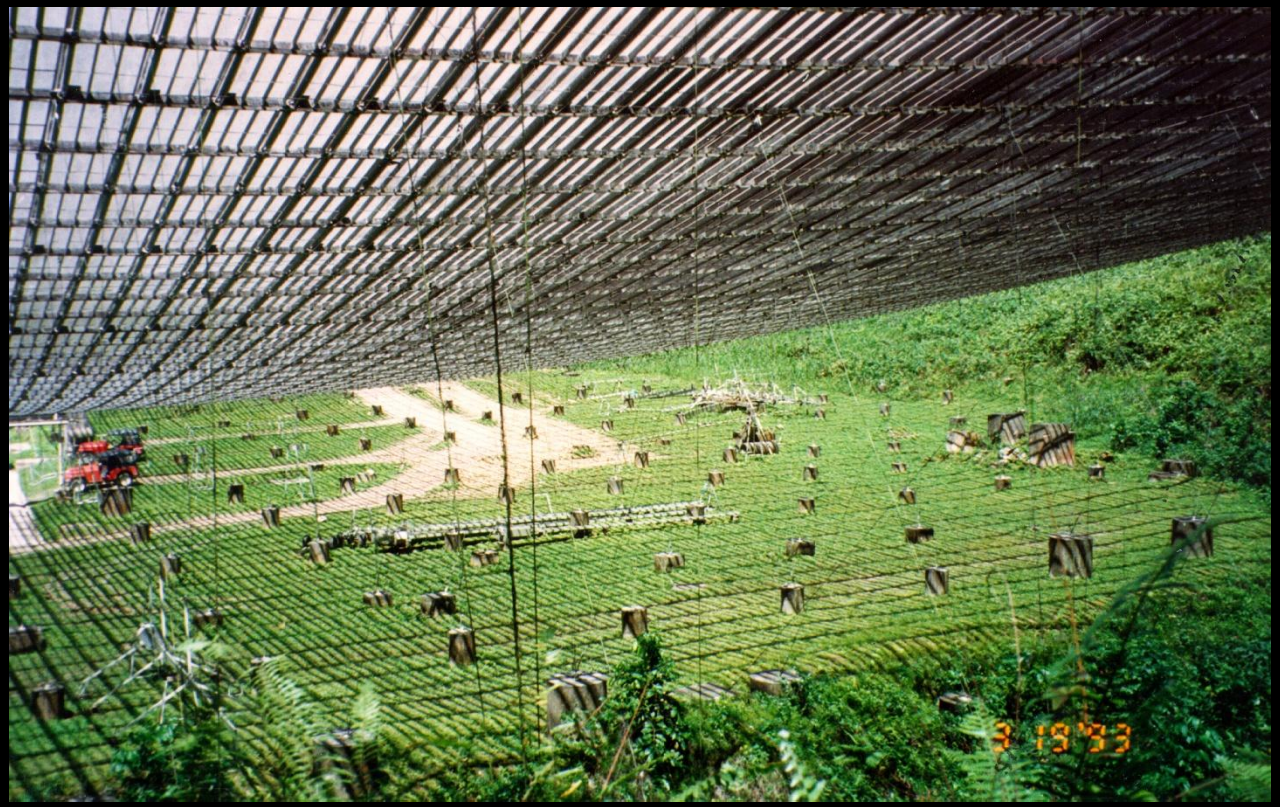
11/17 – The Expansion of the Universe

11/19 – Review for Midterm Exam 3

11/21 – Midterm Exam 3

Getting Distances

- The Sun is 1 AU (=150,000,000 km) away.
  - 1 AU is the definition, but how do we know it is 150,000,000 km?
  - Radar, and lasers. We can use radio dishes to bounce radio waves off the Sun and time how long it takes the signal to come back.

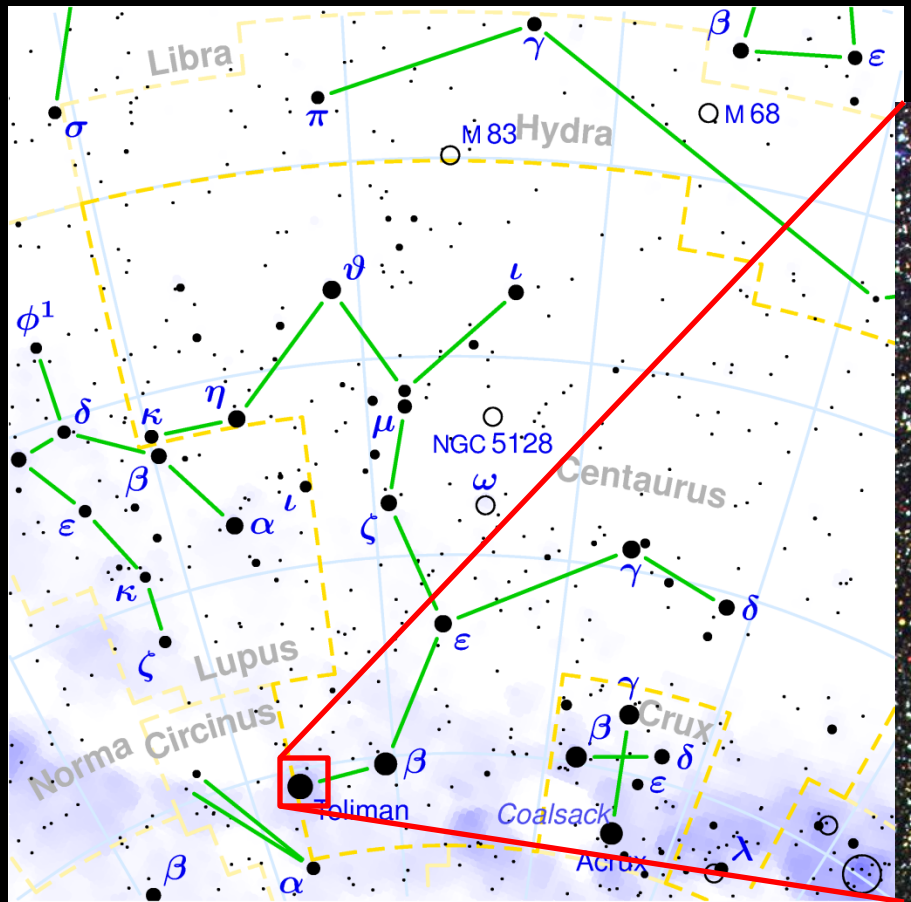

3 13'33

Getting Distances

- The Sun is 1 AU (=150,000,000 km) away.
  - 1 AU is the definition, but how do we know it is 150,000,000 km?
  - Radar, and lasers. We can use radio dishes to bounce radio waves off the Sun and time how long it takes the signal to come back – 1000 sec.
  - (500 sec. X 300,000 km/s = 150,000,000 km)
  - Can do this with the Moon also, and some planets.

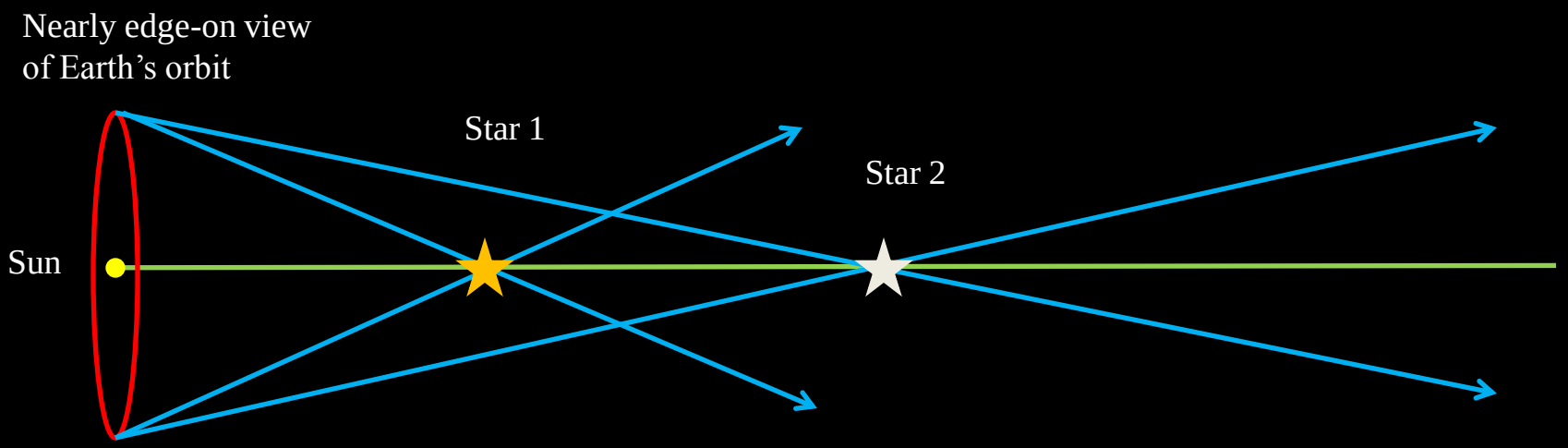
Getting Distances

- What about other stars?
  - Nearest one, Proxima Centauri, is 4.24 ly away.



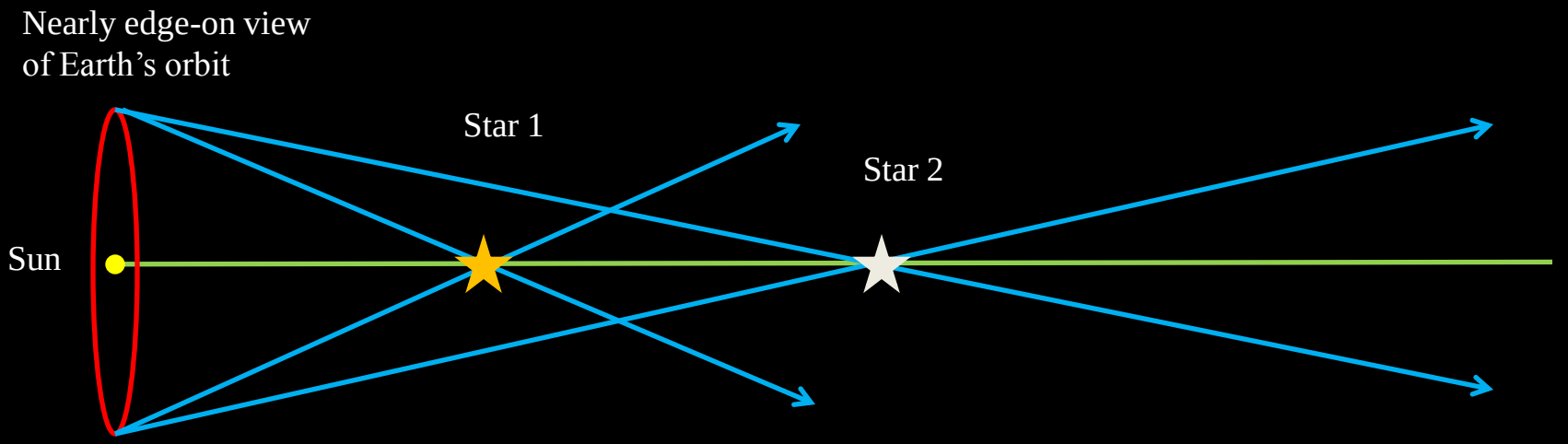
Getting Distances

- What about other stars?
  - Nearest one, Proxima Centauri, is 4.24 ly away.
  - Using radar, it would take us 2x4.24=8.48 years to measure the distance to this star! AACK!
  - Triangulate the distance…



Getting Distances

- What about other stars?
  - Half of the angle that the star appears to move is called the *parallax*.
  - A star that is twice as far away as another star has half the parallax angle. → No strange ``inverse-square'' stuff to remember like gravity and flux.



Measuring Angles

- When something moves on the sky, its motion is described by some angle.
- The common unit of measure for angles is degrees…
  - A full circle is 360 degrees…
  - A right angle is 90 degrees… (1/4 of a full circle)

Measuring Angles

- Parallax angles are very small, much smaller than a degree, so we subdivide degrees to get more useful units that give us relatable numbers.
  - $1/60^{th}$ of a degree is called an *arcminute*. [Just like $1/60^{th}$ of an hour is a minute…]
  - $1/60^{th}$ of an arcminute is an *arcsecond*. [Just like minutes and seconds…]
  - 60 arcminutes in a degree. 60x60=3600 arcseconds in a degree.

Measuring Angles

- The parallax angle for Proxima Centauri is 0.77 arcseconds (0.000214 degrees…).

- Everything else in the universe (except things in our Solar System) is farther away than Proxima Centauri.
- All of those things have a smaller parallax angle than Proxima Centauri.

The Parsec

- A parsec is a unit of distance [contrary to the use by certain Star Wars characters…sorry Han…]
- Definition: An object that has a parallax angle of 1 arcsecond is a parsec.
- This is about 31 trillion km. Or 3.26 ly.
- Proxima Centauri has a parallax of 0.77 arcseconds. So it is 1/0.77= 1.3 parsecs away.
- Sense of scale:
  - If you make a model where the distance between the Earth and the Sun (1 AU) is an inch, then one light-year is a mile. One parsec is 3.26 miles.
  - The size of our galaxy, the Milky Way, is about 100,000 ly across…. That's ~31 thousand parsecs [31 kiloparsecs].

Getting Distances

- With current technology, we can measure parallax angles down to 1/1000th arcsecond.
- So, this parallax method works for anything within 1000 parsec, or 1 kiloparsec.
- Most of the universe, and even most of our galaxy is beyond this. So how do we get distances to those things?

$$F = \frac{L}{4\pi r^2} \quad \Rightarrow \quad r = \sqrt{\frac{L}{4\pi F}}$$

Standard Candles

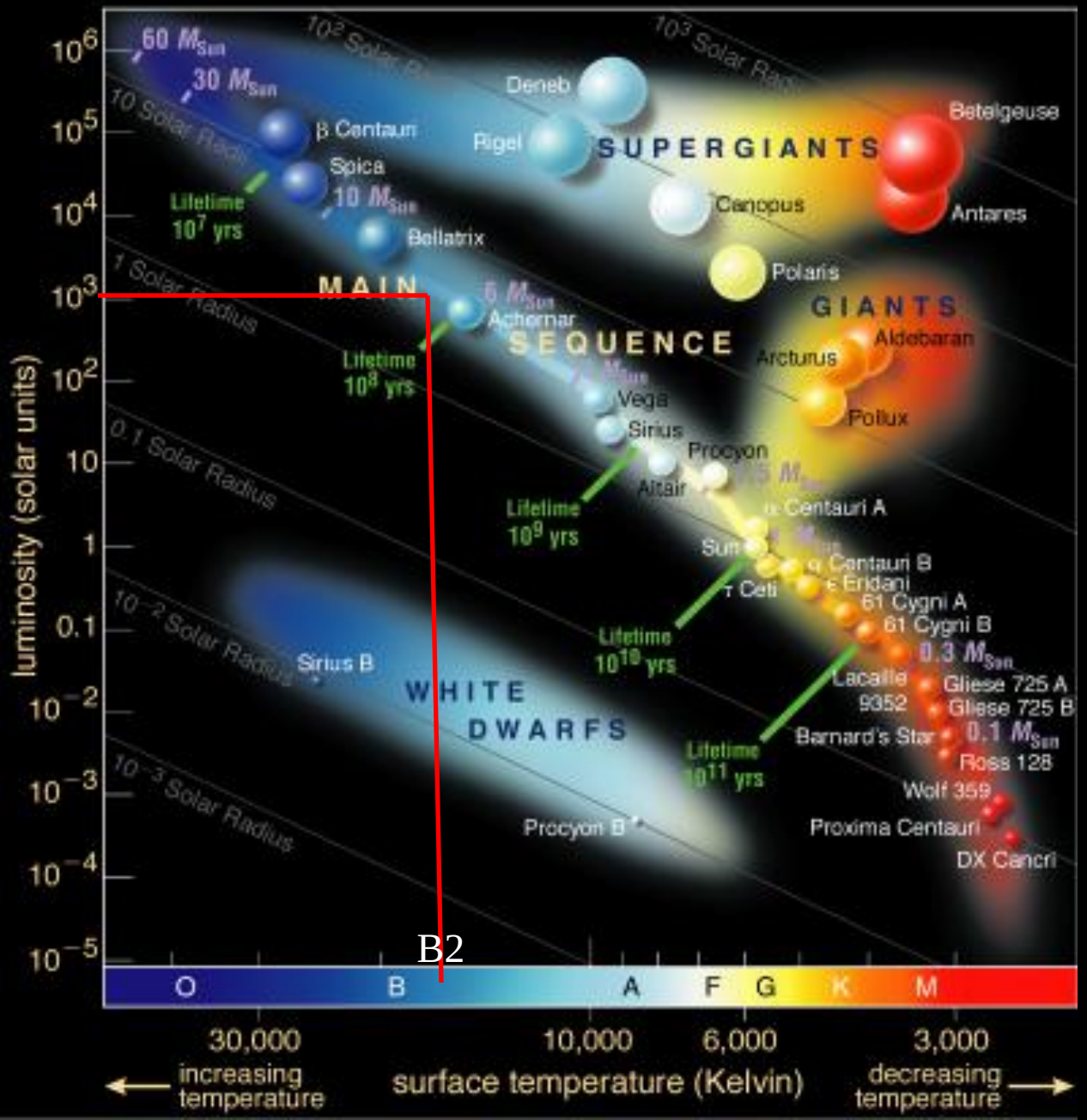
- You can get the distance to something if you know how much light we receive at Earth (the flux), and how much light it actually gives off (the luminosity).
- Standard candles are objects where some observed property allows one to infer the luminosity.
- Two examples:
  - Variable stars: stars that have an oscillating flux and the period of that oscillation gives us the average luminosity.
  - Type 1a Supernovae: the timescale for the light curve as it gets brighter and then slowly fades is related to how bright the supernova gets

Spectroscopic parallax

- Horrible traxoline…sigh…
- Take any star and assume that it is a main sequence star.
  - This is an ok assumption 90% of time…
- Measure its flux and use its spectrum to measure its temperature or spectral type [OBAFGKM].
- The temperatures and luminosities of MS stars are related…

Example: How far is Bellatrix?

- (A star in Orion)
- Observe:
  - App. Mag. = 1.64
  - Spectral Type: B2
- Infer luminosity 1000 Suns
  - Sun's Abs. Mag. = 4.83
  - Abs. Mag. is -2.67
- Difference between App. And Abs. Mag. is 4.31.
  - About a factor of 53 in brightness.
  - It appears 53 times fainter than if it would at 10 pc.
  - Distance is a factor of $\sqrt{53} = 7.28$ farther than 10 pc. → It is 72.8 pc away from us.
- (Distance from actual parallax is 75±5 pc.)



Lecture Tutorials

- Break up into groups of 2-3
  - NO MORE THAN THREE, NO SINGLES
- In your group, work through the following:
  - Parallax and Distance (pages 39-41)
  - Spectroscopic Parallax (pages 43-44)
  - Discuss the answers – don't be silent!
- MarkDan, Jacquelyn, and I will be roaming around if you need help…
- If your group finishes, check your answers with another group.
- If you are confident that your answers are correct, help another group that is struggling to find their own answers.

Think

Pair

Share!

To measure a star's parallax angle accurately, you should observe a star's location against background stars

A. On one night.
B. On two nights separated by one year.
C. On two nights separated by 6 months.
D. On many nights over the course of 6 months.
E. On many nights over the course of a year.

You observe two stars over the course of a year (or more) and find that both stars have measurable parallax angles. Star X has a parallax angle of 1 arcsecond. Star Y has a parallax angle of ½ an arcsecond. How do the distances to the two stars compare?

A. Star X is four times farther away than star Y.
B. Star X is twice as far away as star Y.
C. Star X is the same distance away as star Y.
D. Star X is half as far away as star Y.
E. Star X is one-fourth as far away as star Y.

- Quick survey about roof-top observing
- Deadline for submitting Semester Observing Projects – hard no later than Dec 1 in class.
  - THIS IS A HARD DEADLINE

The Zoo of Galaxies

11/14 – Time-travelling (without moving)

11/17 – The Expansion of the Universe

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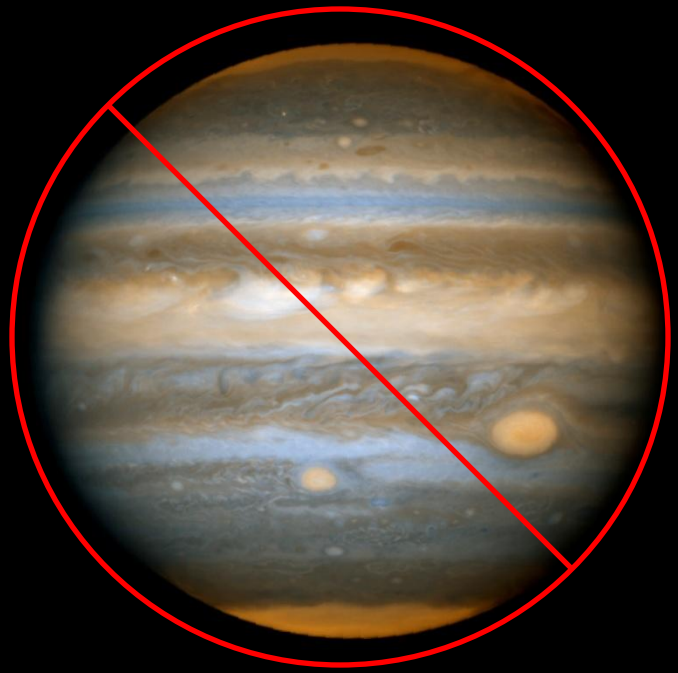
11/21 – Midterm Exam 3

What is a galaxy?

- "… a massive, gravitationally bound system consisting of stars, an interstellar medium of gas and dust, and dark matter."
- One of these pictures is of a galaxy. Which is it?



What are the relative sizes of these two things?

Things that make Rajib's brain hurt

"UA HAD ROLE IN FINDING GALAXIES
Its heat imager aboard Spitzer yields excitement"

By Anne Minard

ARIZONA DAILY STAR- (Like the Boomerang)

"The discovery announced this week of 31 new galaxies in the outermost reaches of the solar system has Tucson written all over it. NASA's Spitzer Space Telescope used a heat-sensing imager developed at the University of Arizona to peer into the constellation Bootes……."

Things that make Rajib’s brain hurt

Taken from CNN.com article, April 25, 2007 on the discovery of an extra-solar planet of nearly Earth mass:

There's still a lot that is unknown about the new planet, which could be deemed inhospitable to life once more is learned about it. ***But as galaxies go, it's practically a neighbor****. At only 120 trillion miles away, the red dwarf star that this planet circles is one of the 100 closest to Earth.*

Things that make Rajib's brain hurt

"The Great Planet Debate" Quiz

Professional astronomers sometimes aren't much better…

"IRAS galaxies are all chocolate chip flavored rather than vanilla flavored as heretofore supposed. This no doubt accounts for their diversity and appeal."

Vader & Simon

AJ 94, 865 (1987)

"...preliminary estimates indicate that the alcoholic content of this cloud (Sgr B2), if purged of all impurities and condensed, would yield approximately 10^{28} fifths at 200 proof. This exceeds the total amount of all of man's fermentation efforts since the beginning of recorded history."

Zuckerman et al.,

ApJ Letters 196, L99, March 1975

http://www.astr.ua.edu/keel/sayings.html

Morphologies of Galaxies

- For “large” galaxies, there are two basic shapes that we see

Some spirals have very clean arms

M51, AKA the Whirlpool Galaxy: A “Grand Design” Spiral

Other spirals don’t…

M33, AKA the Pinwheel Galaxy:
A “Flocculent” Spiral

Some have bars…

NGC 1365, AKA… uh… George: A Barred Spiral

Some are seen edge-on…

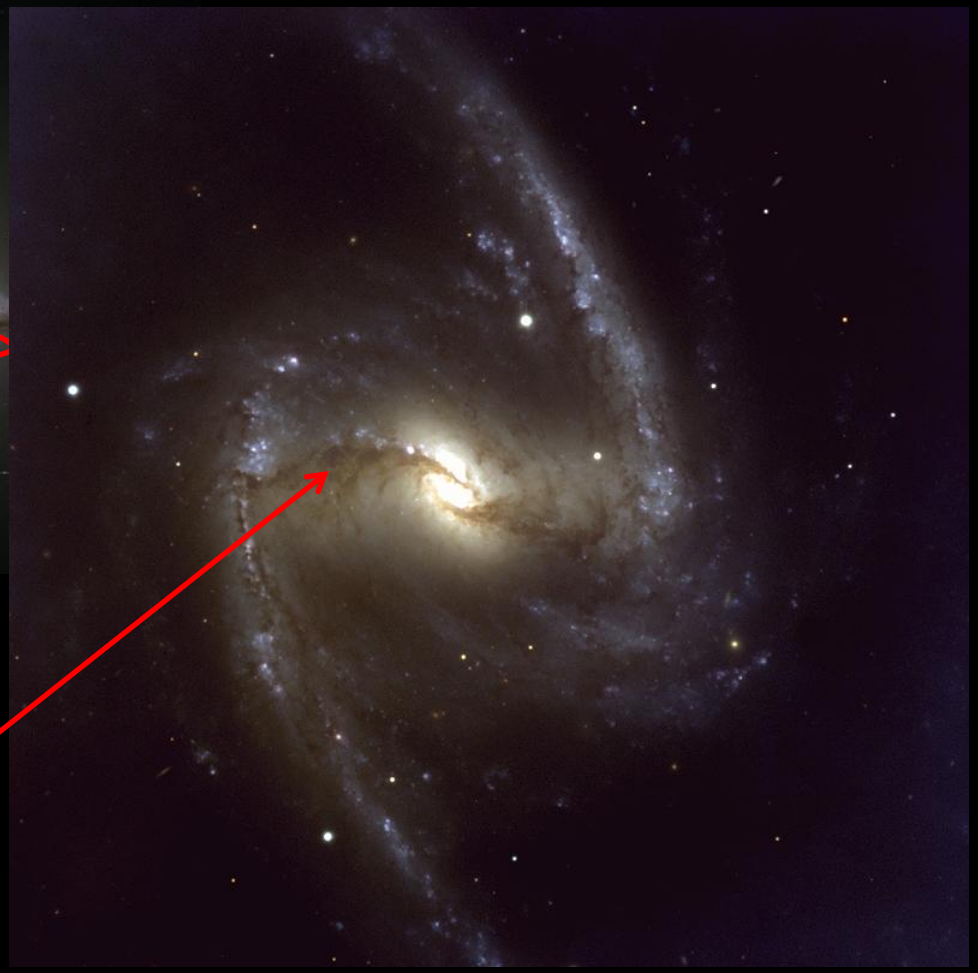
M104, AKA The Sombrero Galaxy: An edge-on spiral

Colors of Galaxies

- Galaxies get their light from all of their stars
- Red galaxies have lots of red stars (both giants and main sequence).
- Blue galaxies have both blue and red main sequence… but probably not a lot of red giants yet.
  - Blue MS are much more luminous than red MS so a population with both would appear mostly blue.

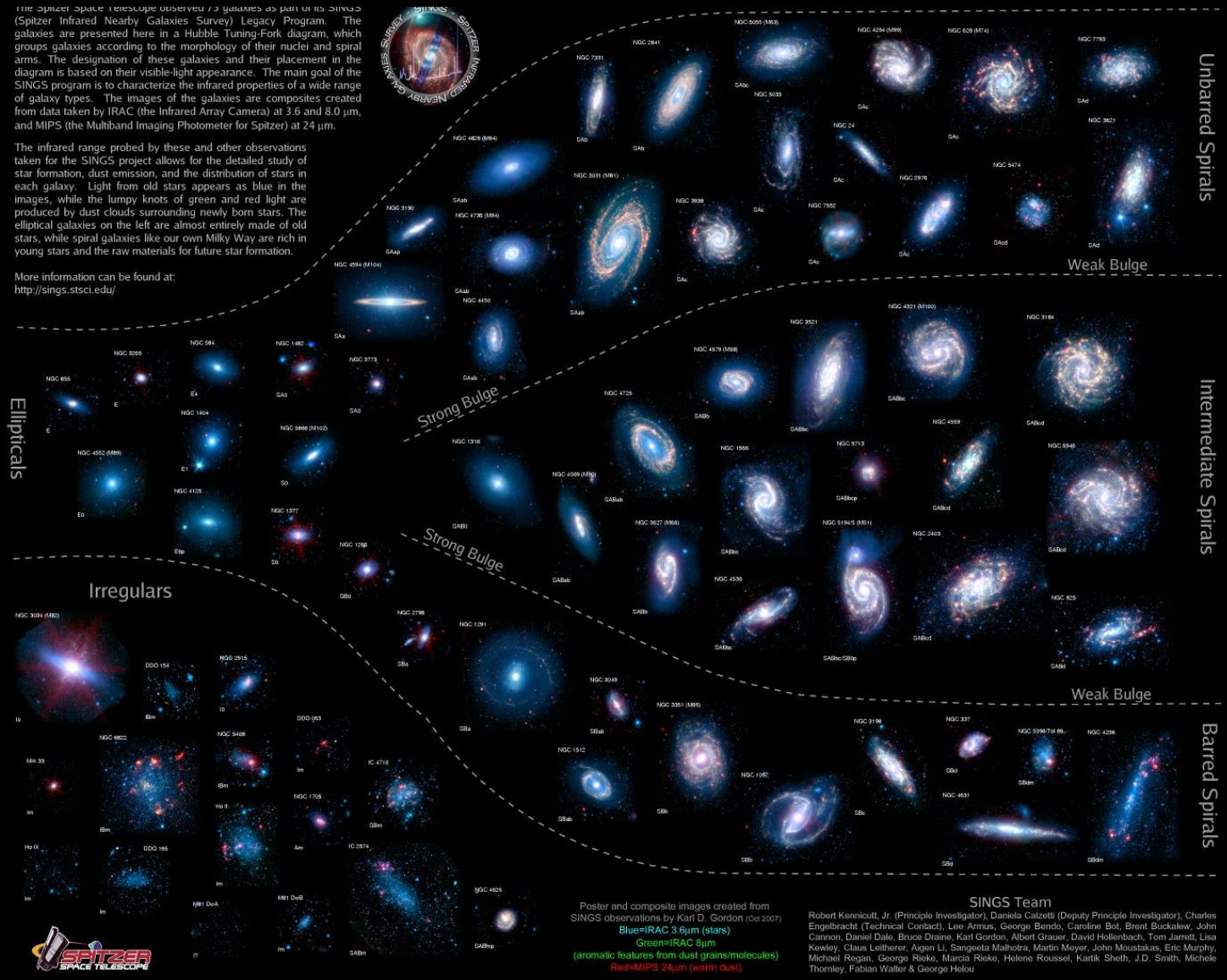
- Stars form where there is gas… (and where there is gas, stars form)
  - A red stellar population implies that stars have not formed recently. The blue MS stars have aged into red giants and white dwarfs (too dim, perhaps, to contribute to the overall color).

Dust in Galaxies

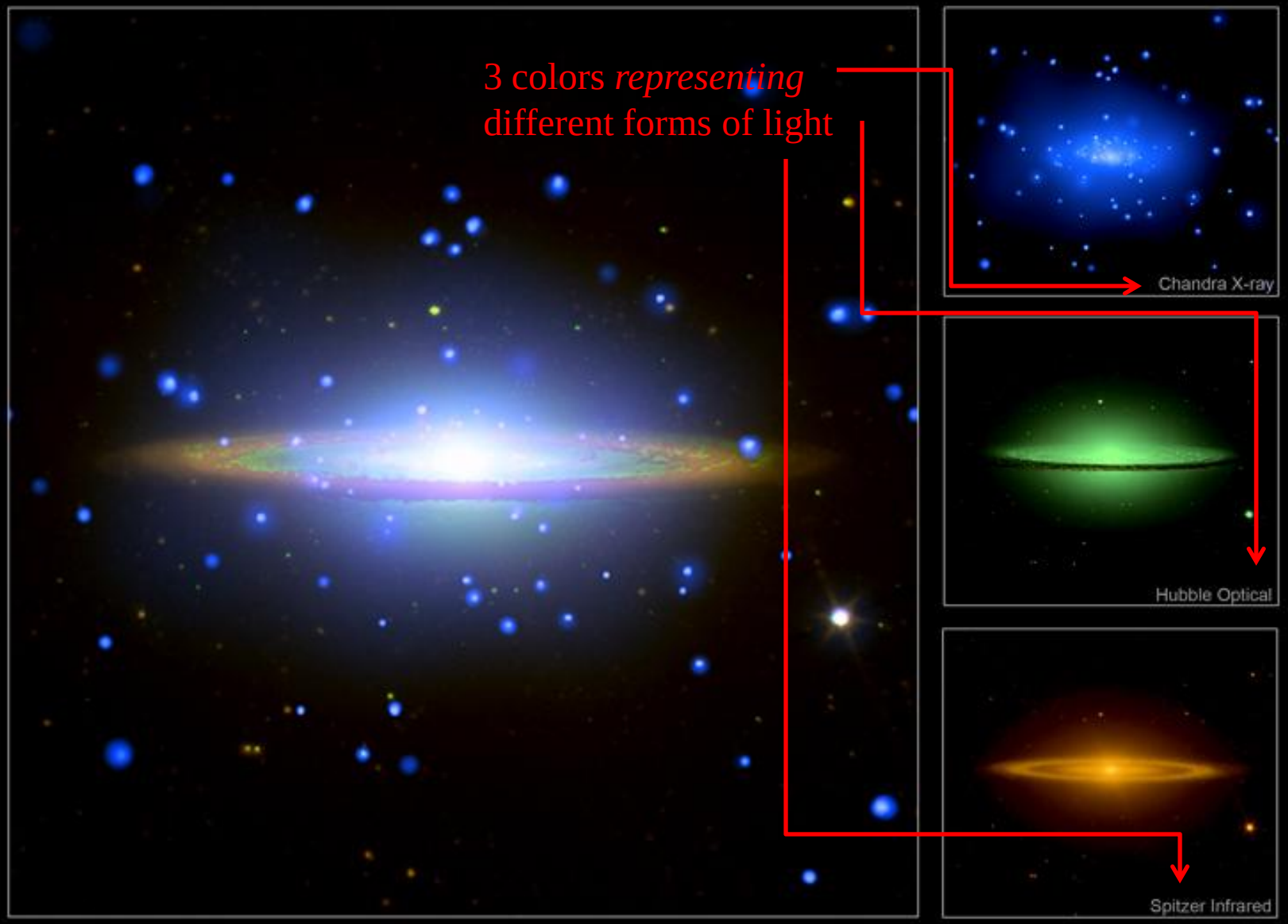


Dust blocks (visible) light.

The Hubble Tuning Fork



Nowadays, make sure to read the fine print….



Nowadays, make sure to read the fine print….

Dust blocks visible light,
but shines in the infrared!

Nowadays, make sure to read the fine print….

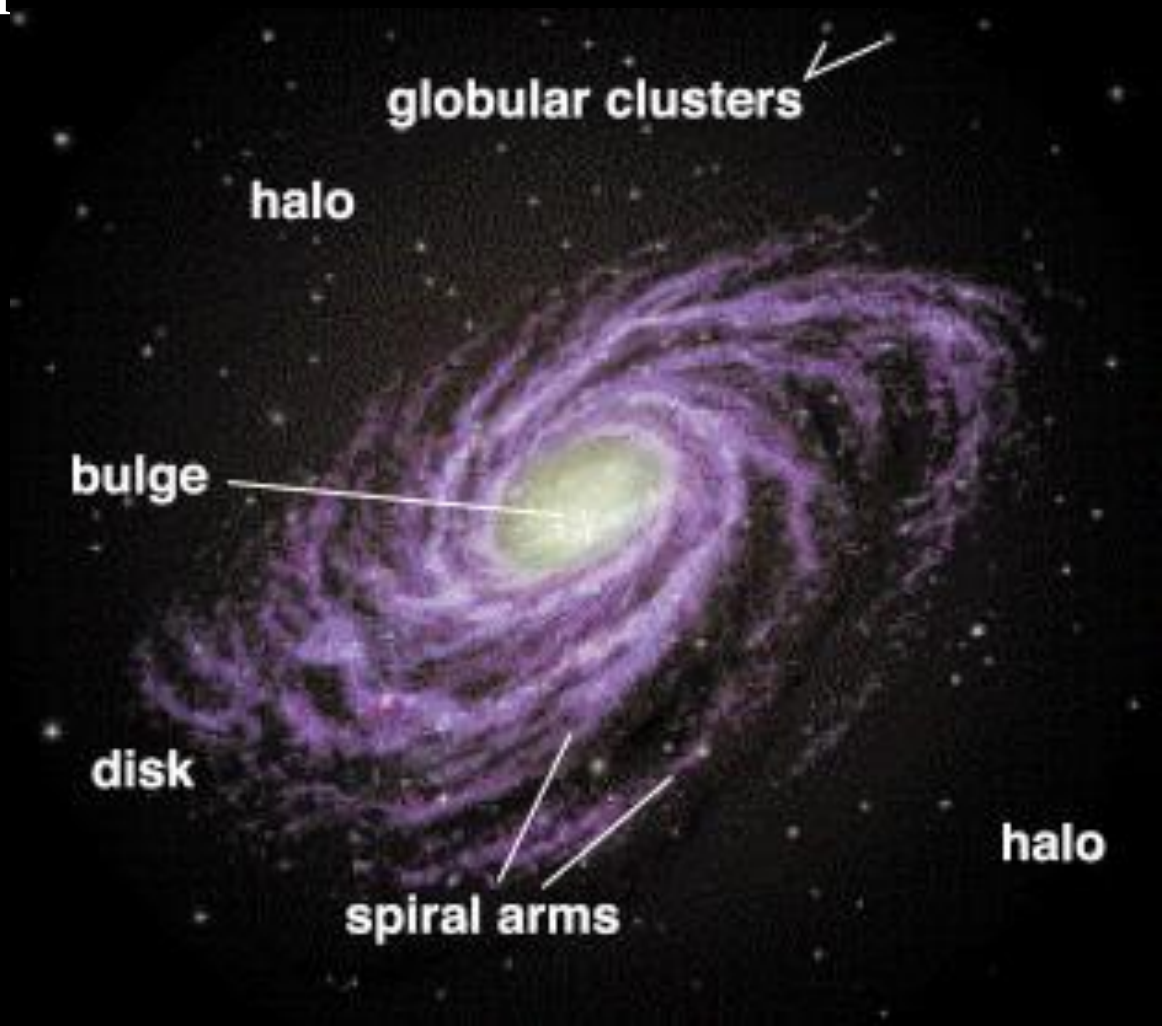
Nowadays, make sure to read the fine print….

Our Milky Way Galaxy

- What kind of galaxy are we in?

Our Milky Way Galaxy

- Components of a spiral galaxy



Lecture Tutorials

- Break up into groups of 2-3
  - NO MORE THAN THREE, NO SINGLES
- In your group, work through the following:
  - Galaxy Classification (pages 127-130)
  - Discuss the answers – don't be silent!
- MarkDan, Jacquelyn, and I will be roaming around if you need help…
- If your group finishes, check your answers with another group.
- If you are confident that your answers are correct, help another group that is struggling to find their own answers.

Think

Pair

Share!

A galaxy that appears to be populated by mostly red stars, likely:

A. never had blue stars in the galaxy.
B. had blue stars that are not present anymore but were at one time long ago.
C. has been around long enough for blue stars to all evolve into the red main sequence stars we see.
D. never contained enough gas to have blue stars develop.
E. has blue stars that are being blocked by dust

Why are the arms of spiral galaxies typically blue in color?

A. They are usually moving toward us and are Doppler Shifted to blue wavelengths.
B. The gas and dust in the arms filter out all but the blue light from stars in the arms.
C. Stars are forming in the spiral arms so there are high mass, hot, blue stars in the arms.
D. Almost all the stars are in the arms of the disk of the galaxy and their light makes the arms appear blue.

Travelling through time without even moving

11/17 – The Expansion of the Universe

11/19 – Review for Midterm Exam 3

11/21 – Midterm Exam 3

The speed of light…

- …is very very very large…
  - 299792.458 km/s (there's nothing faster in spite of the efforts of certain people on the highway)
- … but it is not infinite.
- It takes time for light to travel from one place (like a star or stars in a galaxy) to another place (like here).
- How long?
  - Distance = velocity times time
  - Time = distance/velocity

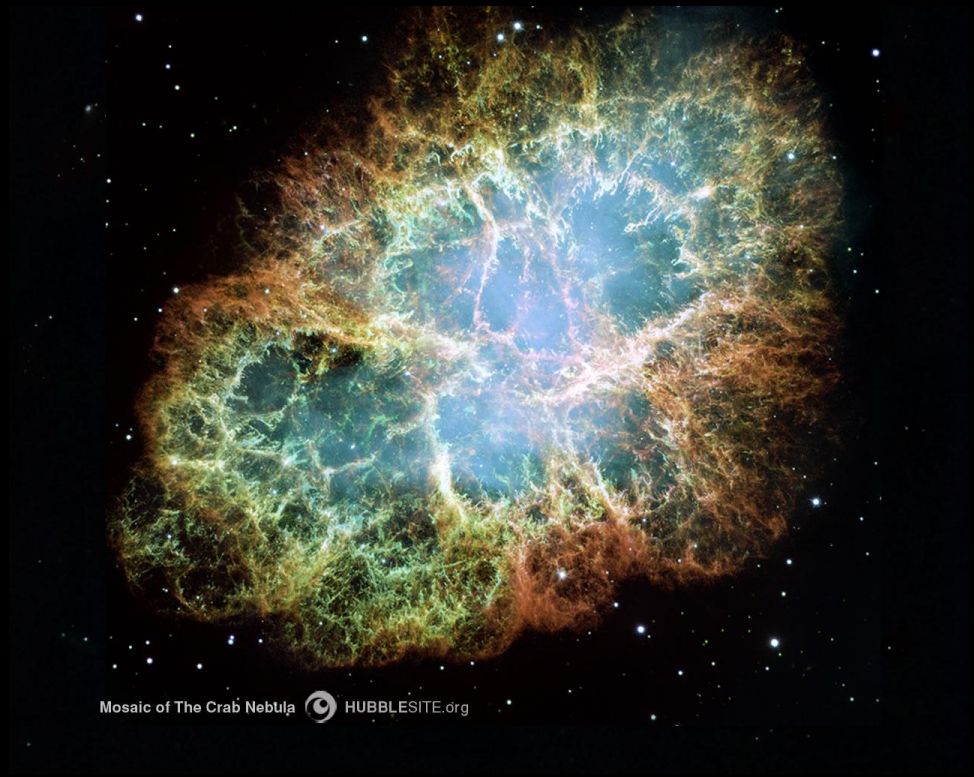
A light-year is…

- … a distance.
  - The distance light travels in one year…
  - Distance = velocity x time
    = 299,792.458 km/s x 31,556,926 s =
    9,460,528,436,448 km
- It is NOT a time even though there is the word "year" in it… but we can use it to easily figure out light travel times.
- Proxima Centauri is 4.24 ly away. It takes 4.24 years for light to travel to us… hmmm…

Proxima Cen is 4.24 ly away…

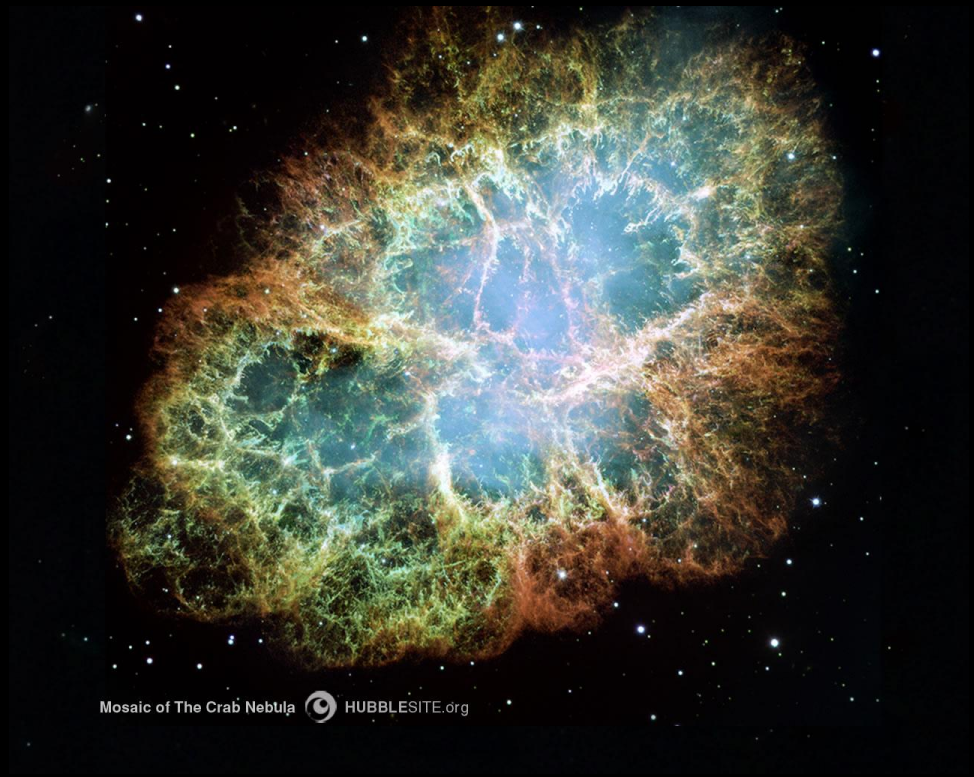
This is how Proxima Centauri looked 4.24 years before this picture was taken!

1054



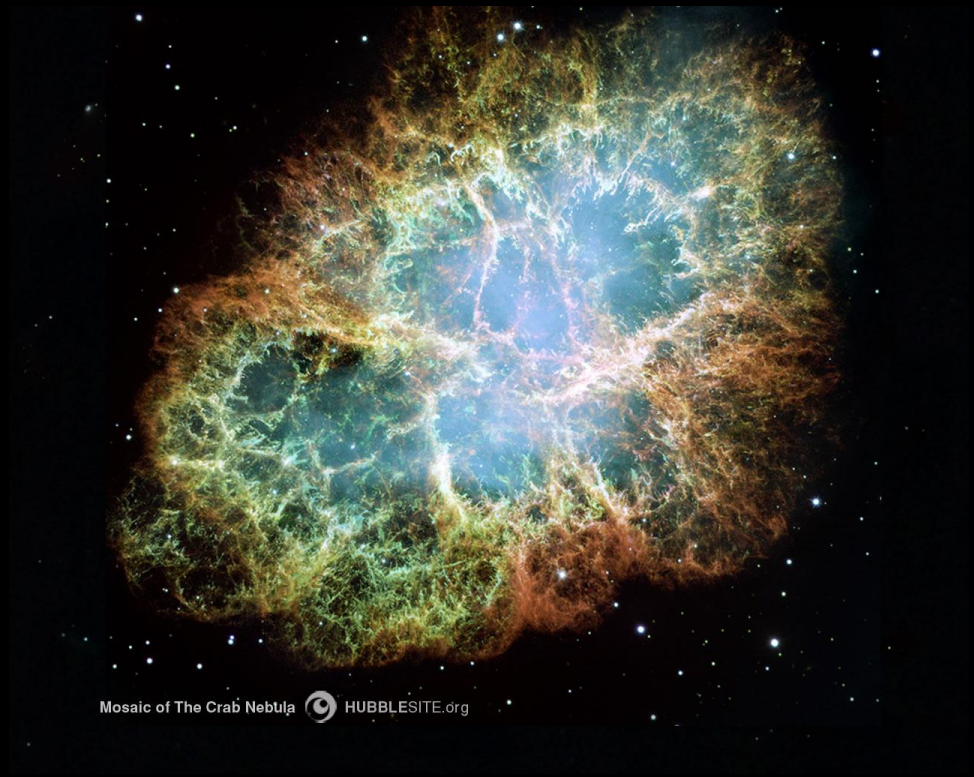
- Chinese and Arab astronomers reported seeing a star in the constellation Taurus go supernova.
- The explosion was bright enough to be seen during broad daylight!

1054



- What we see now is known as the Crab Nebula.
- But did the explosion actually happen 954 years ago? (2008-1054=954)

1054



- Distance measurements place the remnant of this explosion at 65,000 light years away.
- The explosion happened 65,000 years before we actually saw it!
- Does your brain hurt yet?

February 23, 1987

- Astronomers (first in Chile, then) around the world witness the explosion of a star in the Large Magellanic Cloud
- The Large Magellanic Cloud is a dinky little galaxy that is in orbit around our own galaxy.
  - It is one of three objects that we can see in the sky that is not part of our own Galaxy!

February 23, 1987

- The Large Magellanic Cloud is about 168,000 light years away.
- Humans saw the star that created the Crab Nebula explode first.
- Did that explosion actually happen first, or did this one?
- Does your brain hurt now?

Travelling through time (without moving)

- The farther a star is, the more time it takes for the light it emits to get to us.
- So, we have to take care in making conclusions about different objects using the light that gets to us at the same time…

Travelling through time (without moving)

- Suppose we go out tonight, and we look at two stars in the sky.
- One looks like a red giant, one looks like a blue main sequence star.
- Which one *appears* older?
- Which one is *actually* older?

The Andromeda Galaxy

- M31 is 700 kiloparsecs away
  - 2,282,000 light years

• When we look at more and more distant galaxies, we see snap shots of what things looked like at younger and younger stages in the evolution of our universe.

The Andromeda Galaxy

- M31 is 700 kiloparsecs away
  - 2,282,000 light years

• Astronomers use this simple fact to travel back in time… without ever having to leave home (or dome).

Lecture Tutorials

- Break up into groups of 2-3
  - NO MORE THAN THREE, NO SINGLES
- In your group, work through the following:
  - Looking at Distant Objects (pages 131-132)
  - Discuss the answers – don't be silent!
- MarkDan, Jacquelyn, and I will be roaming around if you need help…
- If your group finishes, check your answers with another group.
- If you are confident that your answers are correct, help another group that is struggling to find their own answers.

The Expansion of the Universe

11/19 – Review for Midterm Exam 3

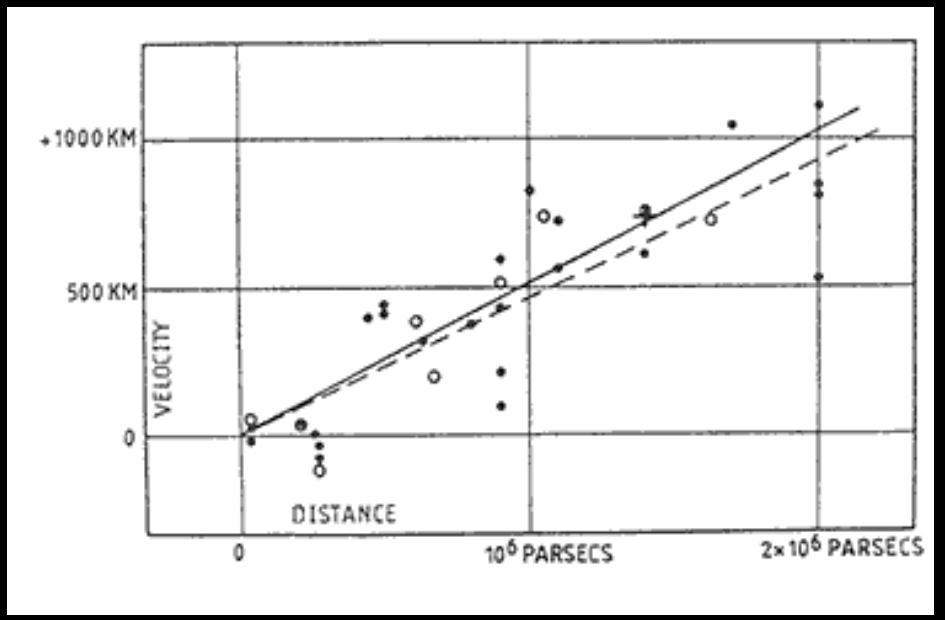
11/21 – Midterm Exam 3

Review of three concepts…

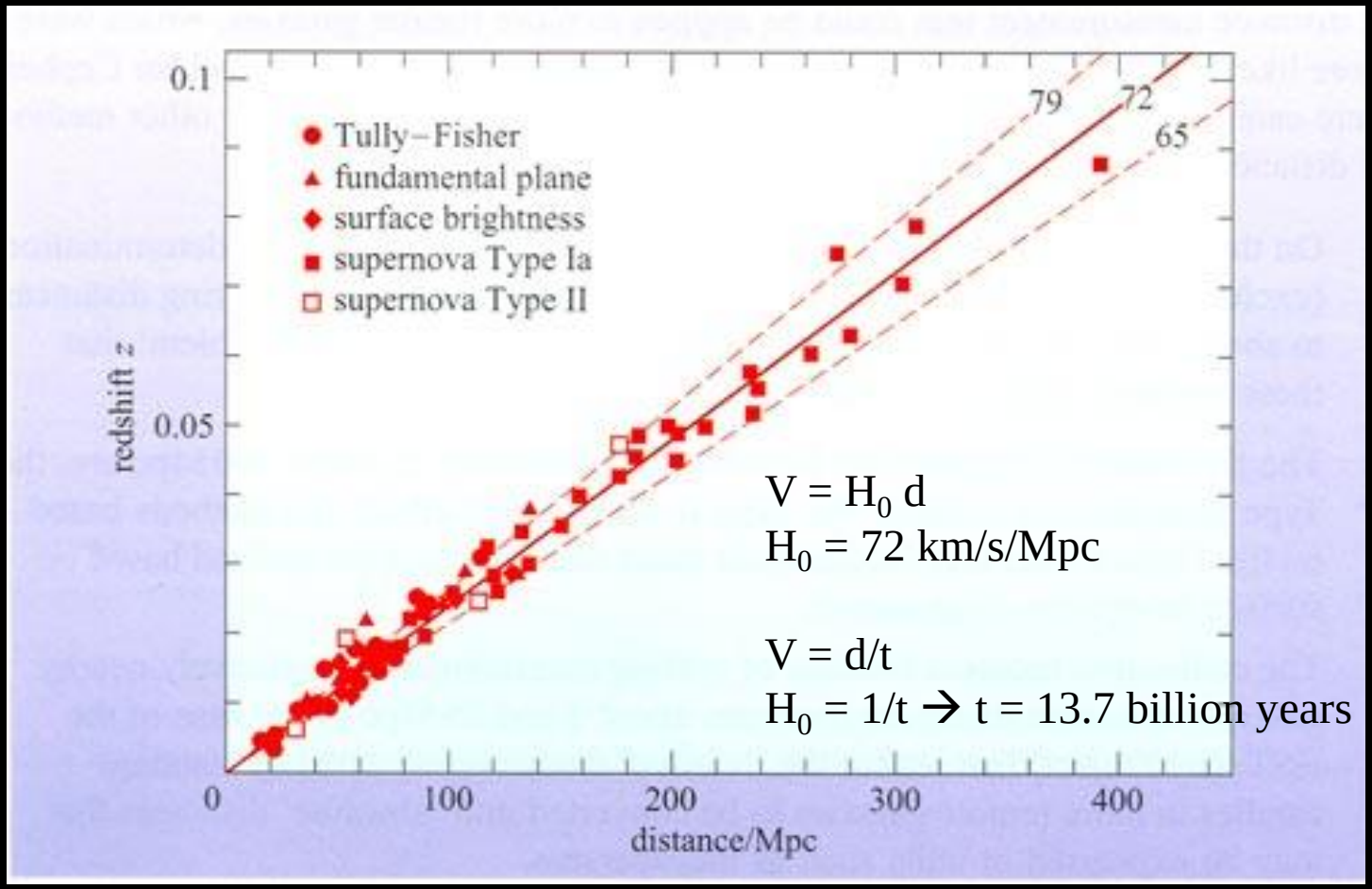
- Redshift
  - Objects that are moving away from us have absorption or emission lines that are redshifted. The size of the shifting is called *redshift*. (In normal interpretation, redshift is a measure of speed → Doppler Shift)
- Distance - we can measure distances to objects using
  - Radar from "very close" objects, like the Sun
  - Parallax angle for objects with about 1000 parsecs
  - The relation between apparent and absolute brightness is we have a means of gauging the absolute brightness from other means.
    - Standard Candles
    - Flux ~ Luminosity/(distance)^2
- Velocity = distance/time

Expansion of the Universe

- A curious things happened at the beginning of the last century…
- Hubble measured the distances to galaxies using a type of variable star called a Cephied, and plotted those distances against the *redshifts* of those galaxies (as measured by Vesto Slipher).



A More Modern Hubble Law…

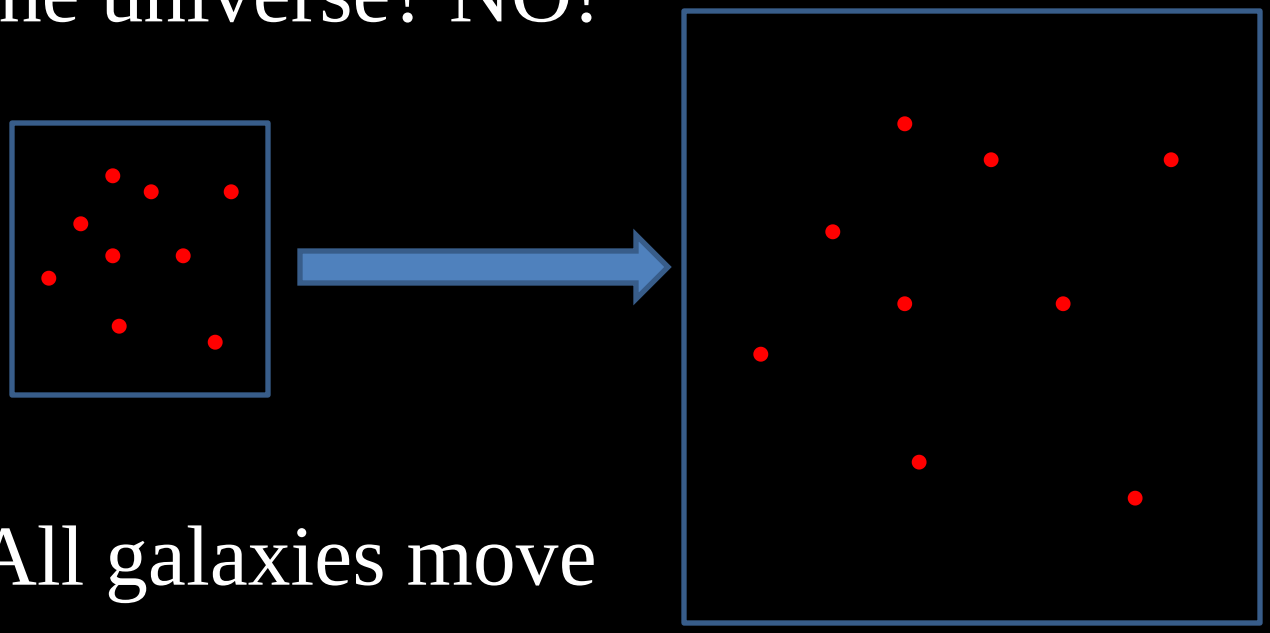


Hubble Law: More distant galaxies have larger redshifts.

As distance to a galaxy increases, its velocity away from us also increases.

Expansion of the Universe

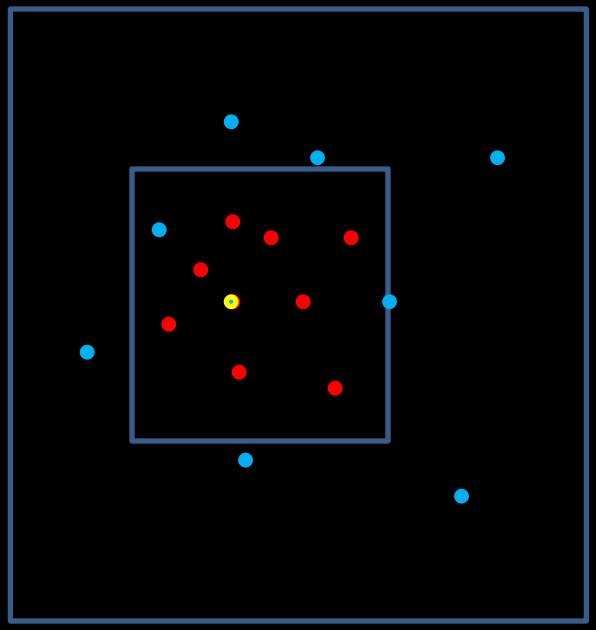
- So, if galaxies are (almost) all moving away from us, does that mean we are the center of the universe? NO!



- All galaxies move away from each other.

Expansion of the Universe

- So, if galaxies are (almost) all moving away from us, does that mean we are the center of the universe? NO!



Expansion of the Universe

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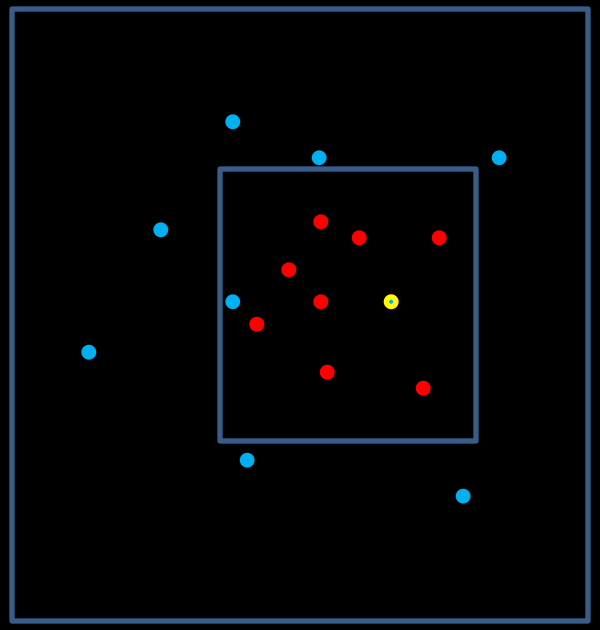


Expansion of the Universe

- Is the redshift measured an indication of actual velocity? Not necessarily…
- Einstein's explanation was that space *itself* expands, carrying galaxies with it…
- As space expands, light that is travelling through space also expands…
  - The wavelength gets longer the more the light travels.
  - *Cosmological* Redshift, not Doppler Shift

Expansion of the Universe

- Do Rajib, stars, and galaxies expand as the Universe expands?
  - Stars and galaxies are held together by gravity, which counteracts that expansion. So, NO.
  - Rajib… well, maybe some, but that probably has more to do with the wall of Fanta than with the expansion of the Universe.

Expansion of the Universe

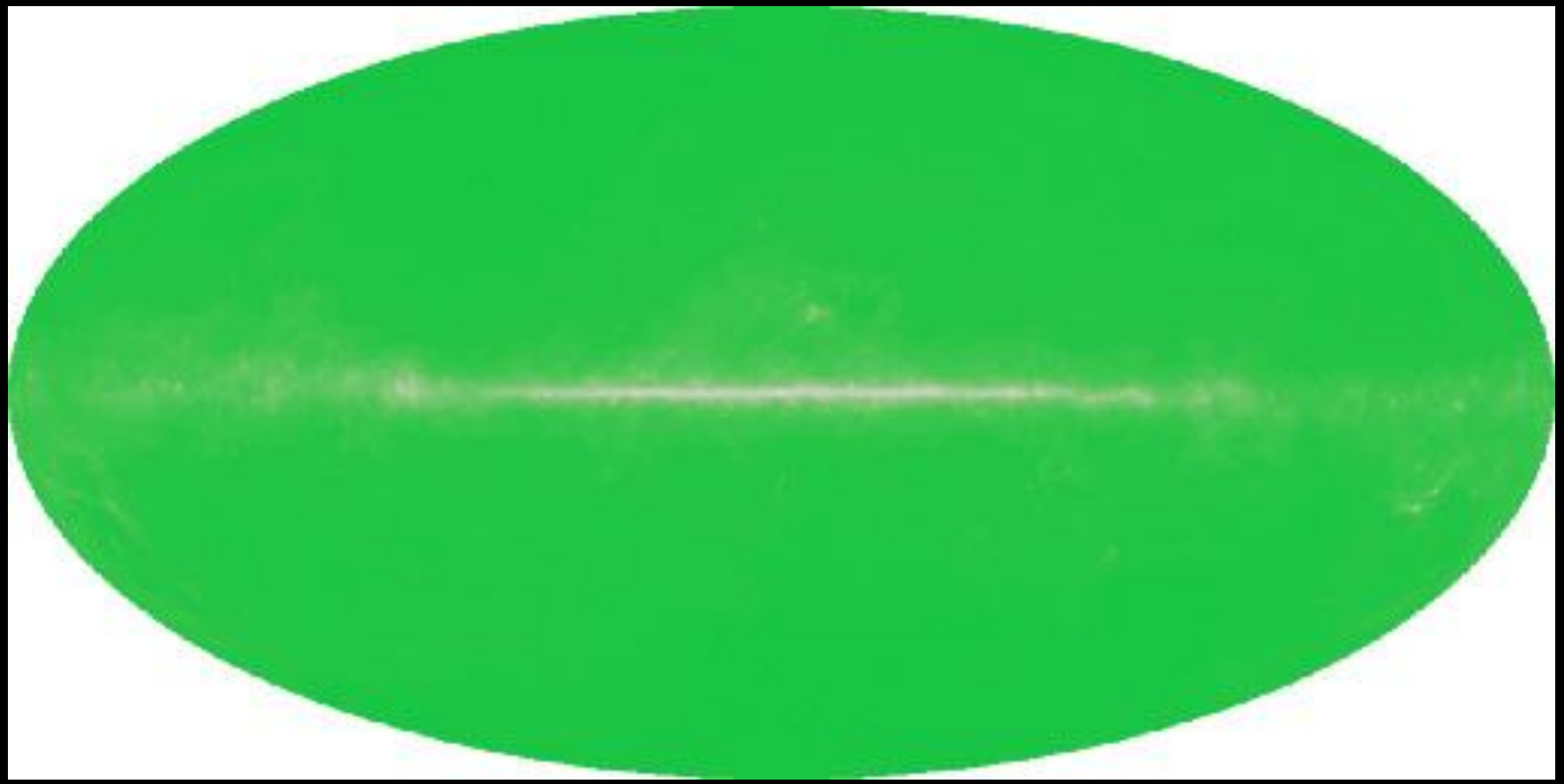
- If we turn back time, what happens?
  - Galaxies and us are all coming toward each other. At some point in the past, all the matter in the Universe was on top of each other…
  - This is what is thought of as the beginning of the Universe.
    - The Big Bang Theory… (no, not the tv sitcom)
    - Was it an actual explosion? Not really, no.

The Big Bang Theory

- The theory posits that space started out as a miniscule point, from which the expansion started.
- The matter in the Universe was all compressed into this point. It was very hot, very dense
  - What does a hot, dense source do?
  - Radiate a continuous spectrum, specifically blackbody radiation. → A prediction!
  - The Universe has expanded quite a bit since the beginning, and so has the light. Big Bang theory predicted that we should see blackbody radiation from the beginning of the Universe (well, 400,000 years afterwards) in the microwave.

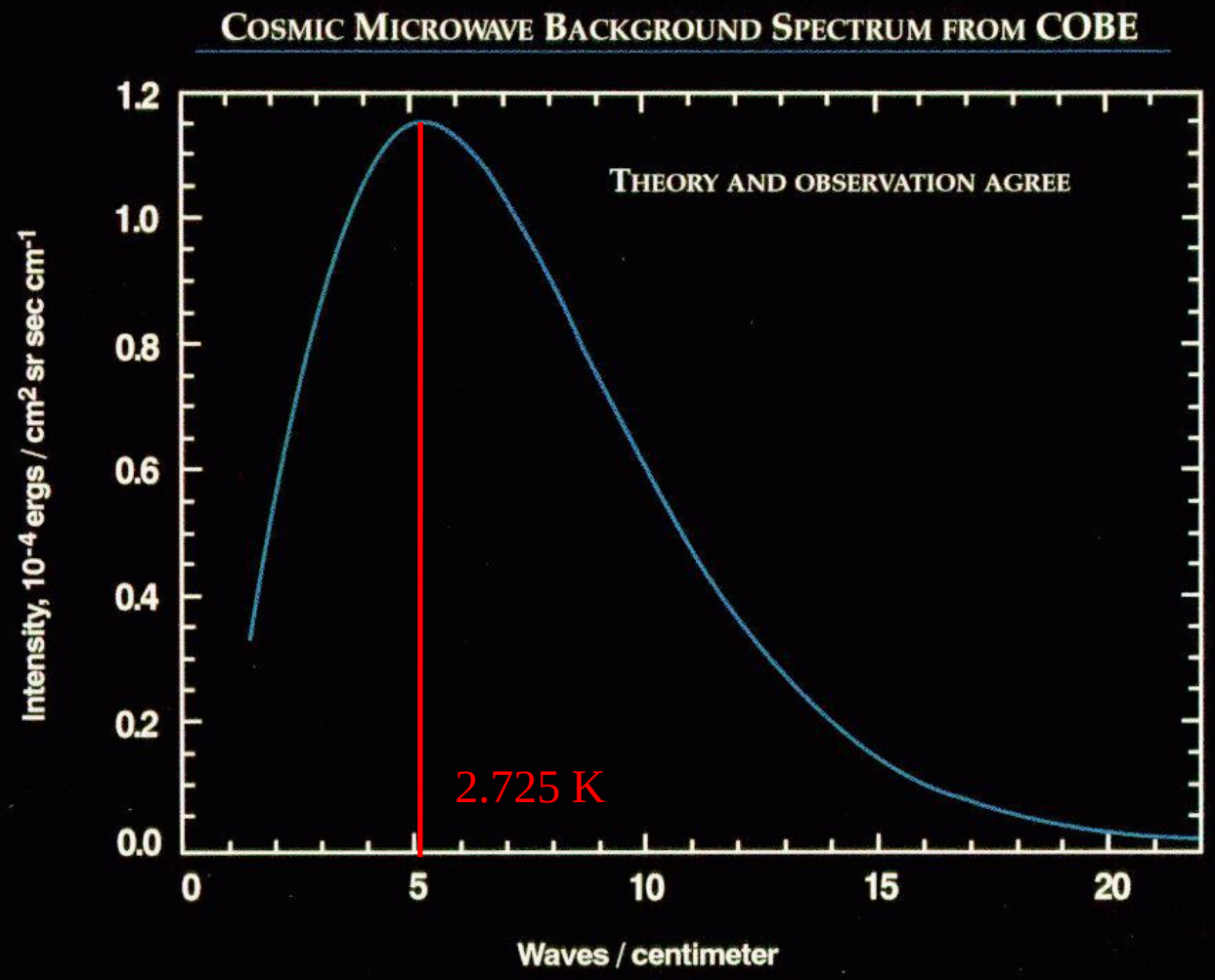
The Big Bang Theory

The sky view in microwave light…



The Big Bang Theory

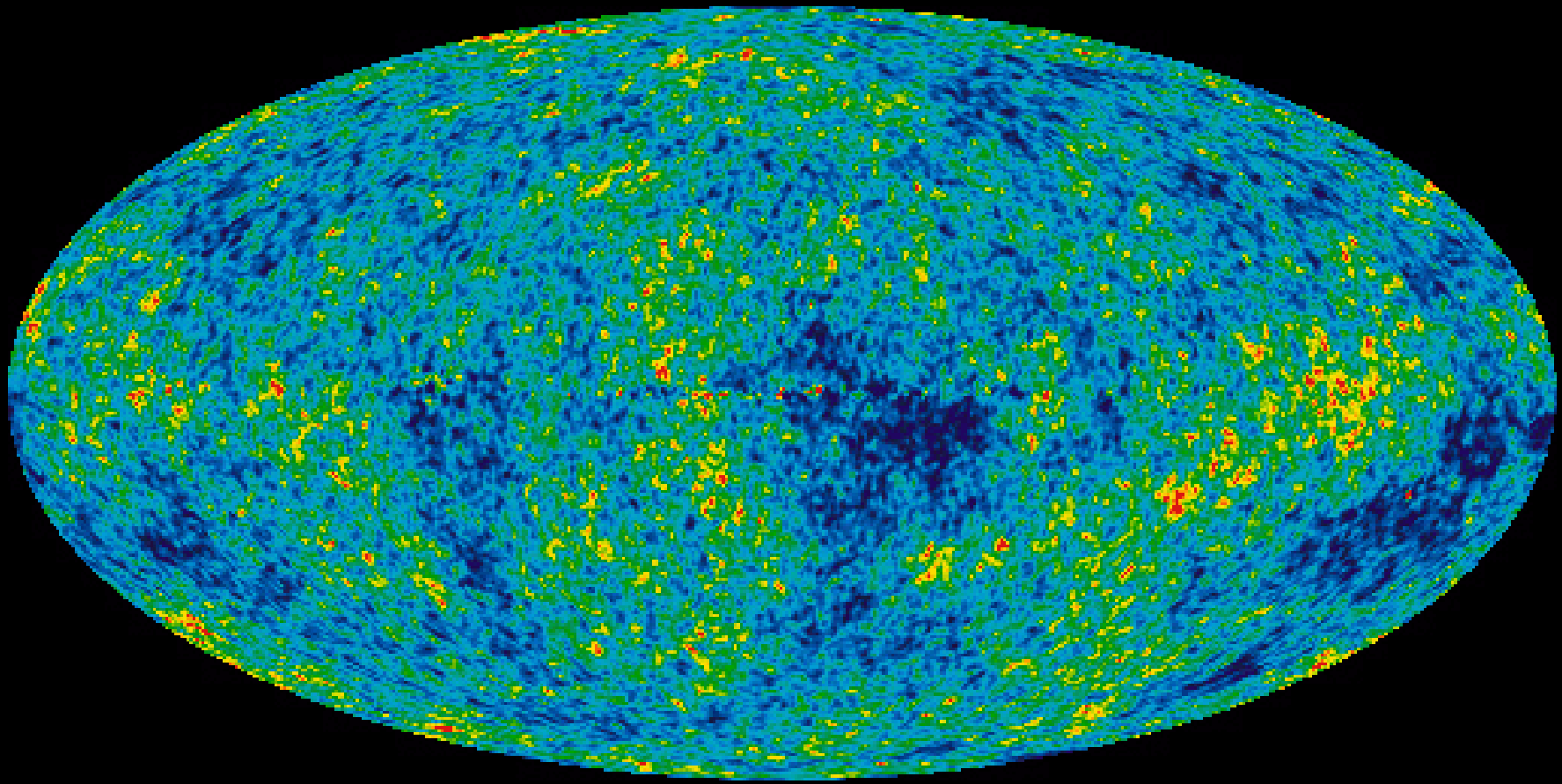
Data from the COsmic Background Explorer in April 1992



The Big Bang Theory

- How far did this light travel?
  - We found from the Hubble law that the light has been travelling 13.7 billion years.
  - The Universe is 13.7 billion years old (plus 400,000 years).
  - The farthest that any light could have travelled is 13.7 billion light years. → *cosmic horizon*
- Are there things beyond our cosmic horizon?
  - Sure. The cosmic horizon is not a physical edge to the universe. It just represents how far we can see.

The Big Bang Theory



If we subtract the Milky Way, and then also subtract the average temperature, we find this map, which shows deviations in temperature of about 10^{-5} K.

Lecture Tutorials

- Break up into groups of 2-3
  - NO MORE THAN THREE, NO SINGLES
- In your group, work through the following:
  - Expansion of the Universe (pages 133-134)
  - Discuss the answers – don't be silent!
- MarkDan, Jacquelyn, and I will be roaming around if you need help…
- If your group finishes, check your answers with another group.
- If you are confident that your answers are correct, help another group that is struggling to find their own answers.

Think

Pair

Share!

According to modern ideas and observations, what is said about the location of the center of the universe?

A. Earth is at the center.

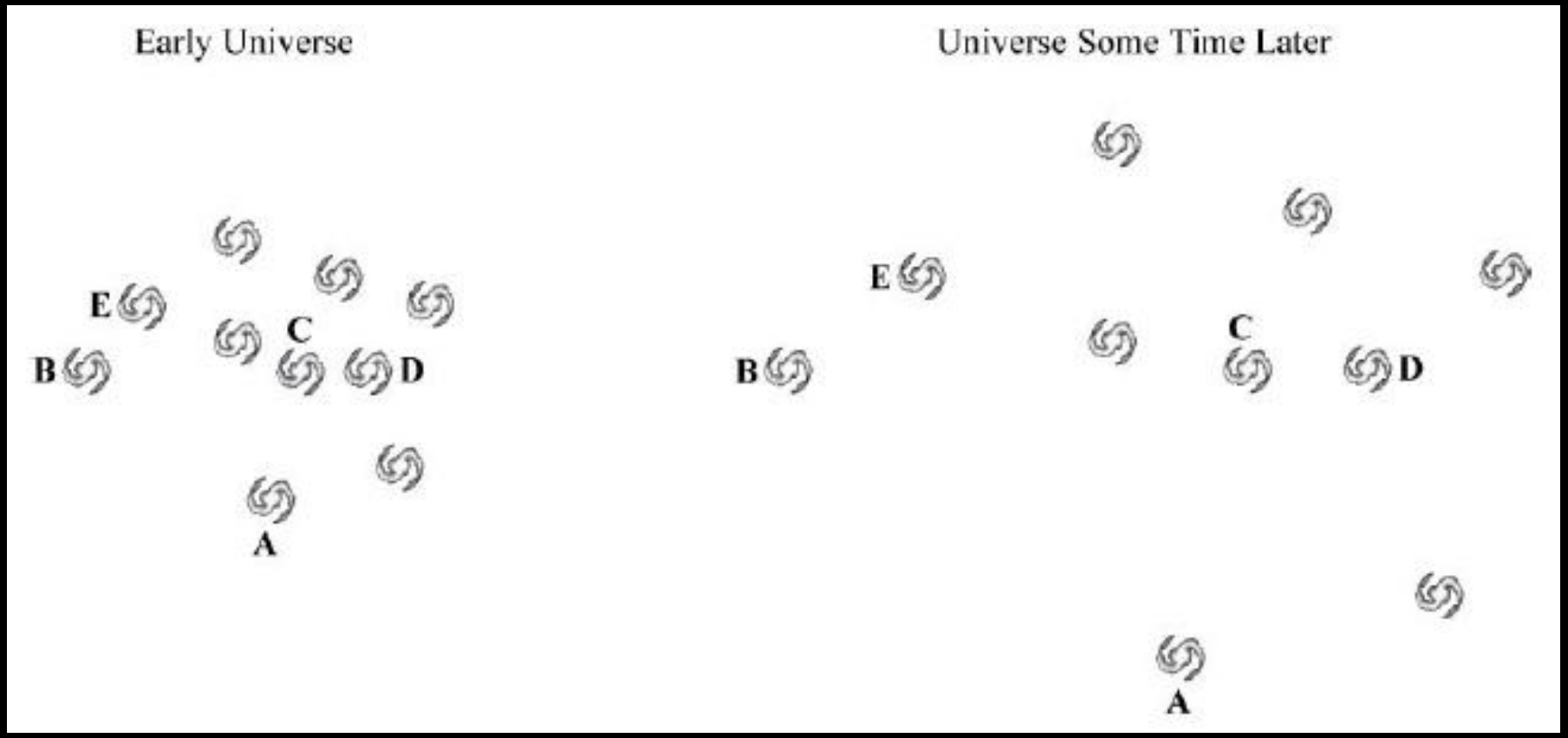
B. The Sun is at the center.

C. The Milky Way galaxy is at the center.

D. The Universe does not have a center.

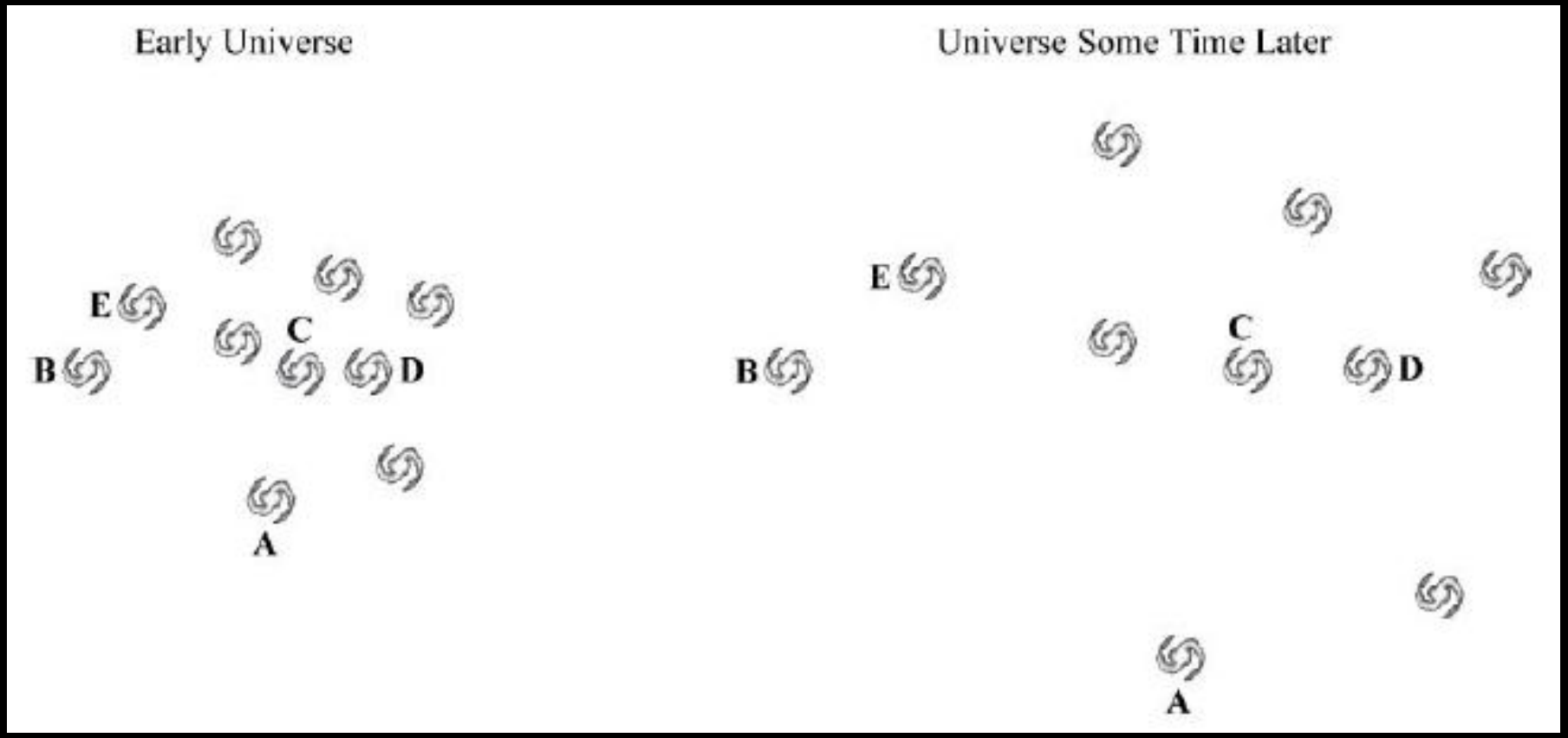
If our Universe is expanding, what are the implications for the separation between two stars within our galaxy?

A. The two stars are moving farther apart.
B. The two stars are moving closer together.
C. The distance between the two stars is unaffected.



For an observer in Galaxy B, which of the following rankings lists the speeds (from fastest to slowest) at which Galaxies C, D, and E would be moving away?

A. E>C>D
B. D>E>C
C. C>D>E
D. D>C>E



Galaxy E is located

A. at the center of the Universe
B. at the edge of the Universe
C. at a position that depends on the observer's home galaxy
D. none of the above.