State of the Universe(s) 2014

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Science Resources at York

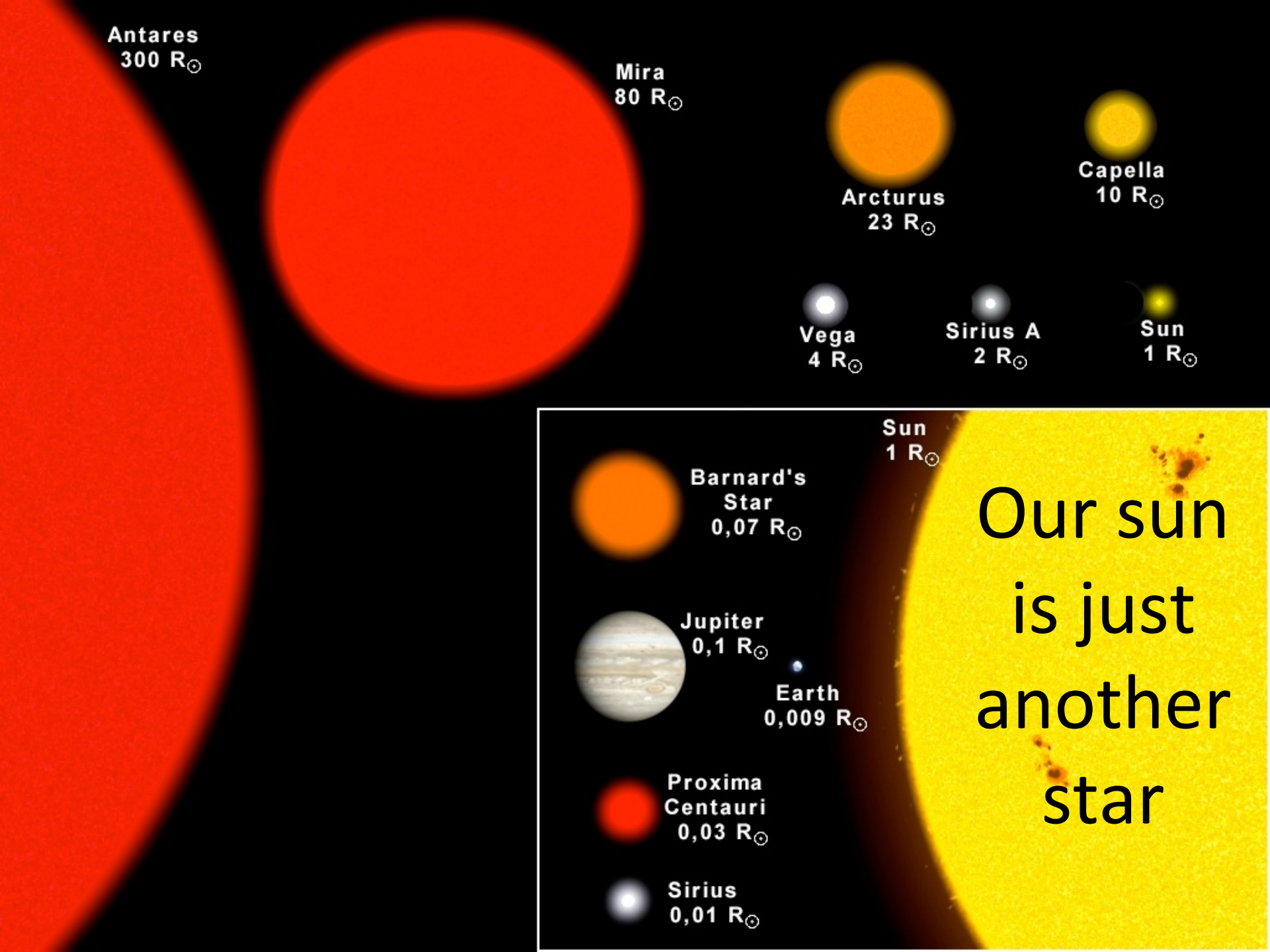
- Physics & Astronomy annual High School Teacher's Night: this year, a free screening of *Interstellar*! [email phasupd at yorku.ca if interested]

- http://science.yorku.ca/community-alumni/community-outreach/
- HELIX summer science institute for high schoolers
- SciX Science Explorations Camp
- Let's Talk Science, In-School Workshops, Speakers Bureau
- York Observatory
- this talk & others at: www.yorku.ca/phall/OUTREACH/

Outline

- Expanding Universe
- Balloon Universe Activity [PDF]
- The Big Bang
- Inflation
- Dark Matter and our Past
- Dark Energy and our Future
- Other Universes?

Expanding Universe


Antares
300 R⊙
Mira
80 R⊙
Arcturus
23 R⊙
Capella
10 R⊙
Vega
4 R⊙
Sirius A
2 R⊙
Sun
1 R⊙
Sun
1 R⊙
Barnard's
Star
0,07 R⊙
Jupiter
0,1 R⊙
Earth
0,009 R⊙
Proxima
Centauri
0,03 R⊙
Sirius
0,01 R⊙
Our sun
is just
another
star

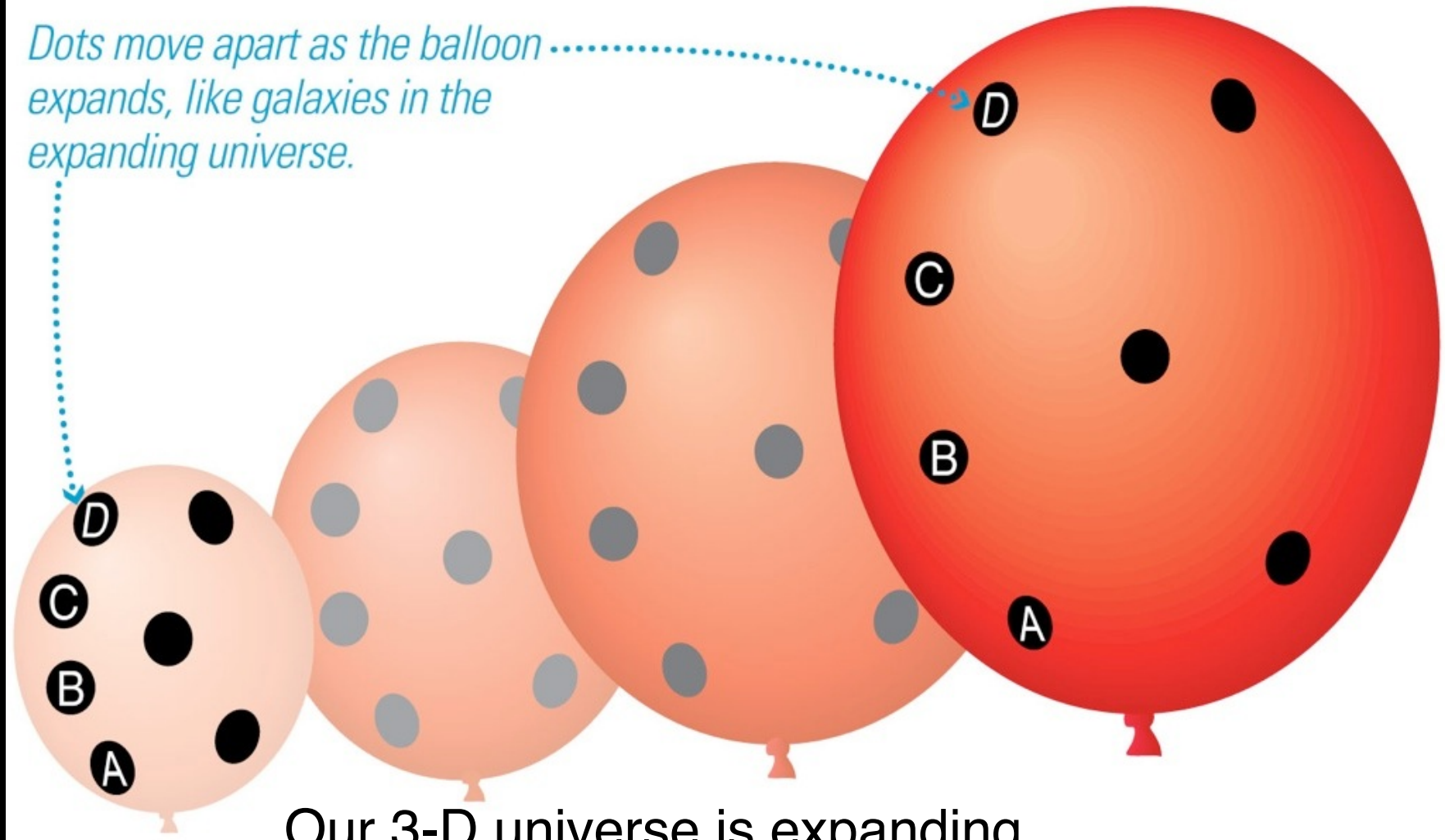
Stars group together to form galaxies

Galaxies are moving away from each other

- From our home galaxy, the Milky Way, we see almost all galaxies moving away from us.
- Galaxies are moving away from each other.
- (The only exceptions are galaxies so close to each other that the gravity between them is strong enough to keep them together.)
- The Milky Way is not at a special location in the universe; it is just another one of the billions of galaxies that are moving away from each other.

All galaxies move away from each other because *space itself* is expanding in time!

Animation credit: Michael Francis



Our 3-D universe is expanding like the 2-D SURFACE of a balloon, which doesn't have a centre or an edge... **neither does our universe!**

Our Universe

- Our universe has three space dimensions and one time dimension.

- As our universe ages, all points in three-dimensional space get farther away from each other; our universe is expanding through time.
- The start of time (the Big Bang) was when all points in this universe were infinitely close to each other.
- This universe has no edge or centre, only a beginning in time.

A Universe on the Surface of a Balloon

- A balloon universe has two space dimensions (the surface of the balloon) and one time dimension (running from the centre of the balloon outward).
- As the balloon universe ages, all points in its two-dimensional surface get farther away from each other: the balloon is expanding through time.
- The start of time (the Big Bang) was when all points in this universe were infinitely close to each other.
- This universe has no edge or centre, only a beginning in time.

Comparing Universes

Our Universe

- **3 space dimensions**
- 1 time dimension
- Space dimensions are expanding through time
- No edge or centre in space
- Big Bang is a point in time
- At that time, all locations in the universe were very close to each other

Balloon-Surface Universe

- **2 space dimensions**
- 1 time dimension
- Space dimensions are expanding through time
- No edge or centre in space
- Big Bang is a point in time
- At that time, all locations in the universe were very close to each other

Activity: A Balloon Universe

- Supplies:
- Balloons (normal party balloons work fine, though lighter colours are best)
- Confetti (holes from a paper punch work fine, though the lighter the confetti the better)
- Optional: markers, rulers

- Each balloon is a two-dimensional universe.
- The confetti pieces are galaxies in those universes.

Activity: A Balloon Universe

- Place confetti on desk, table, plate or shallow bowl.
- Inflate the balloon, and hold it closed.
- Rub balloon on hair about 10 times to build up static electricity.
- Roll balloon over confetti; confetti will stick.
- Gently deflate the balloon.
- Now inflate the balloon again and watch: confetti pieces stay the same size, but move farther apart, just like galaxies in our own universe.

Tips for Best Visualization

- Make sure a few galaxies are visible to you as you blow up the balloon.
- **Focus on one galaxy**, and you will see other galaxies moving away from it.
- **Focus on a different galaxy**, and you will still see other galaxies moving away from it.
- Changing distances between confetti-galaxies can be measured on the balloons, with repeated tries. All distances will increase by the same factor.

Additional Activities with a Balloon Universe

- Draw a wave on the balloon:  …as the balloon expands, the wave stretches with it.
- In our expanding universe, light does the same thing: its wavelength increases with time.
- If a universe started contracting (shrinking):
- what would galaxies do?
- what would happen to the wavelength of light?
- Make predictions for the above, then slowly deflate the balloon and watch what happens.

The Big Bang

Lessons for our Universe

- In our experiment, we imagined that the 3rd space dimension was actually the time dimension.
- The balloon expands in time.
- At the beginning of time, all points in an ideal balloon universe were infinitely close to each other.
- We call that point in time the **Big Bang**.
- The Big Bang was a point in time, not in space.

The Big Bang Happened Everywhere

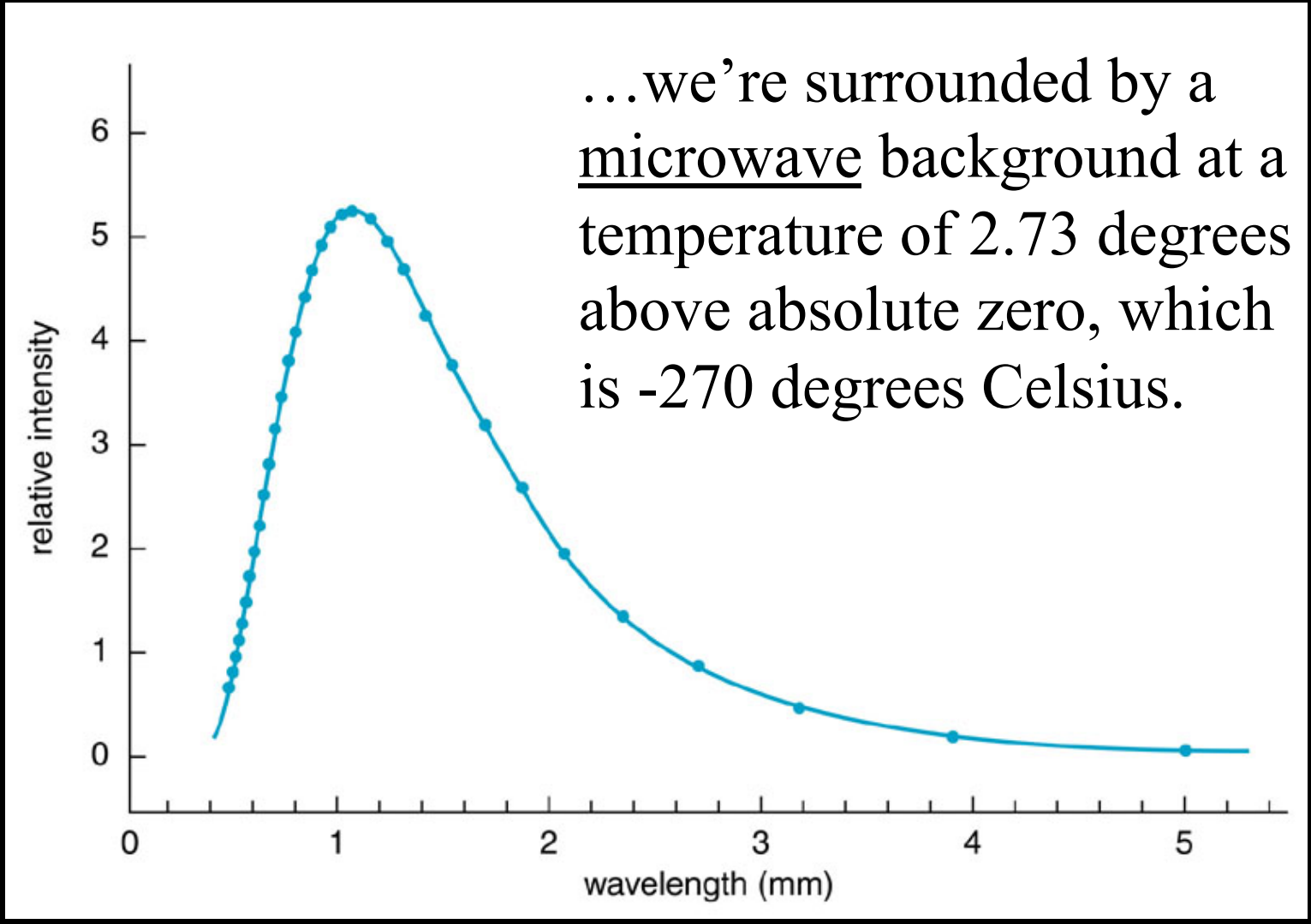
- You can't get to the centre of the Earth by driving around on the surface of the Earth.
- You must move in the 3rd dimension: down!

- All distant galaxies are moving away from each other, but you can't get to the event where they all started moving away from each other by flying around the universe.
- You must move in the 4th dimension: backwards in time! All the way back to the Big Bang.

Evidence for the Big Bang

- The universe cools down as it expands.
- Looking further and further back in time, the temperature of the universe goes up and up.
- The point in TIME where the universe's density and temperature appear to become infinite is called the **Big Bang**.

Since universe became transparent, expansion has cooled it from 3000 degrees Celsius to 3 degrees above absolute zero. Instead of 3000 degrees of heat surrounding us…



…we're surrounded by a microwave background at a temperature of 2.73 degrees above absolute zero, which is -270 degrees Celsius.

The Cosmic Microwave Background

- The Planck satellite, among others, has shown that our universe is about 13.8 billion years old.
- When our universe was about 380,000 years old, it was uniform in temperature to 1 part in 5,000.
- How flat would the Earth be if it was smooth to within 1 part in 5,000?
- The highest mountain would be 640 meters high, and the deepest ocean 640 meters deep.

The Cosmic Microwave Background

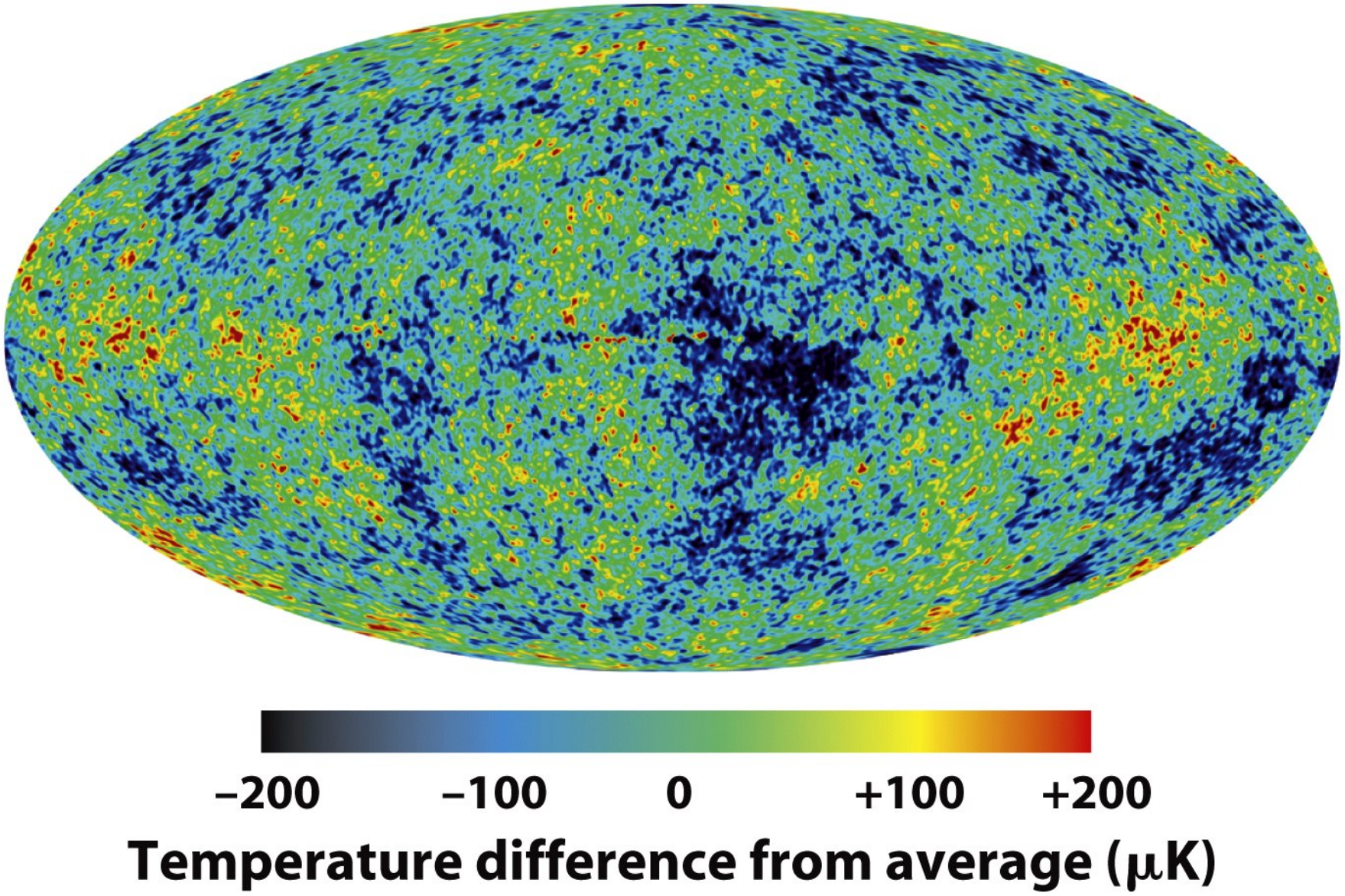
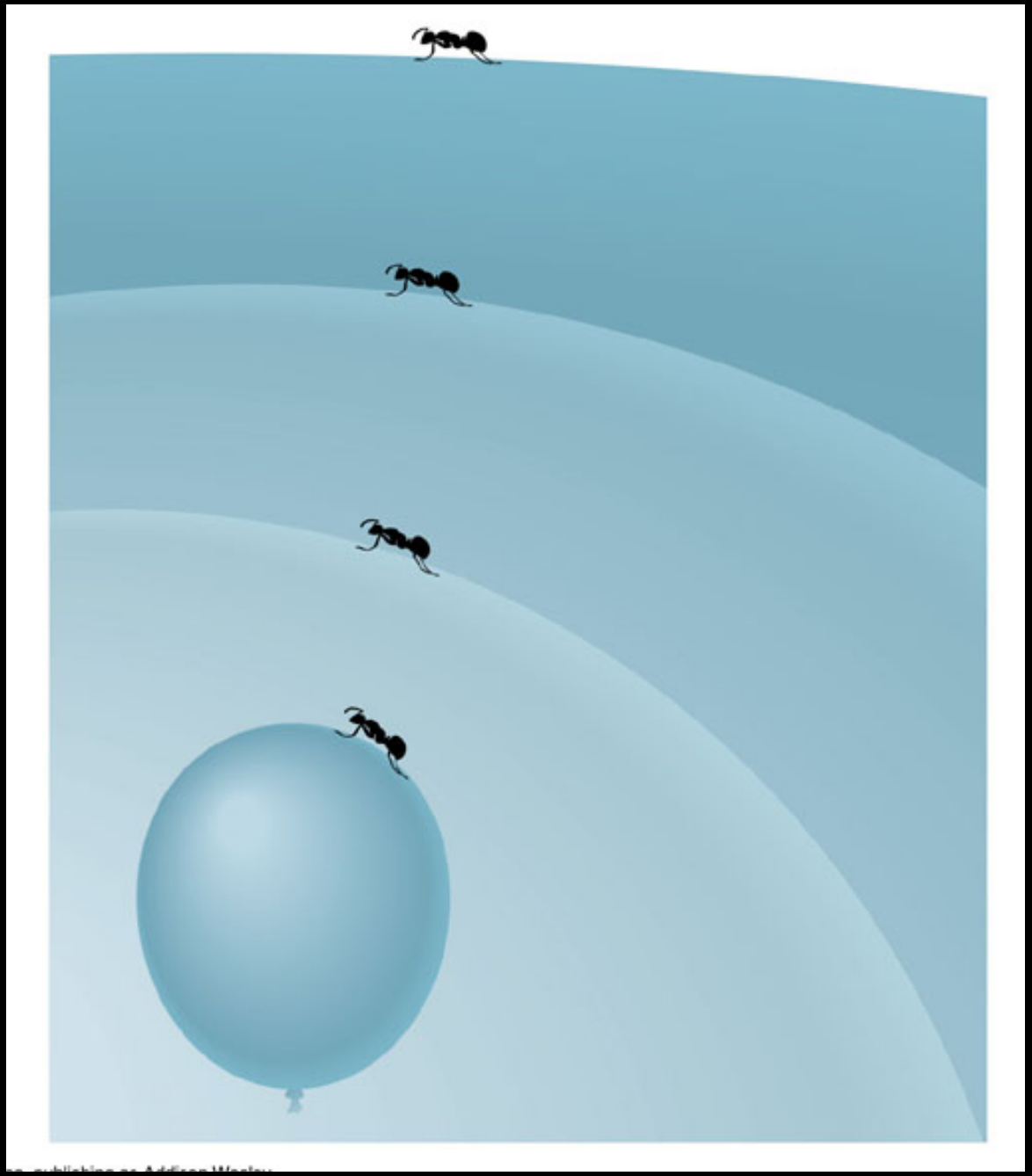


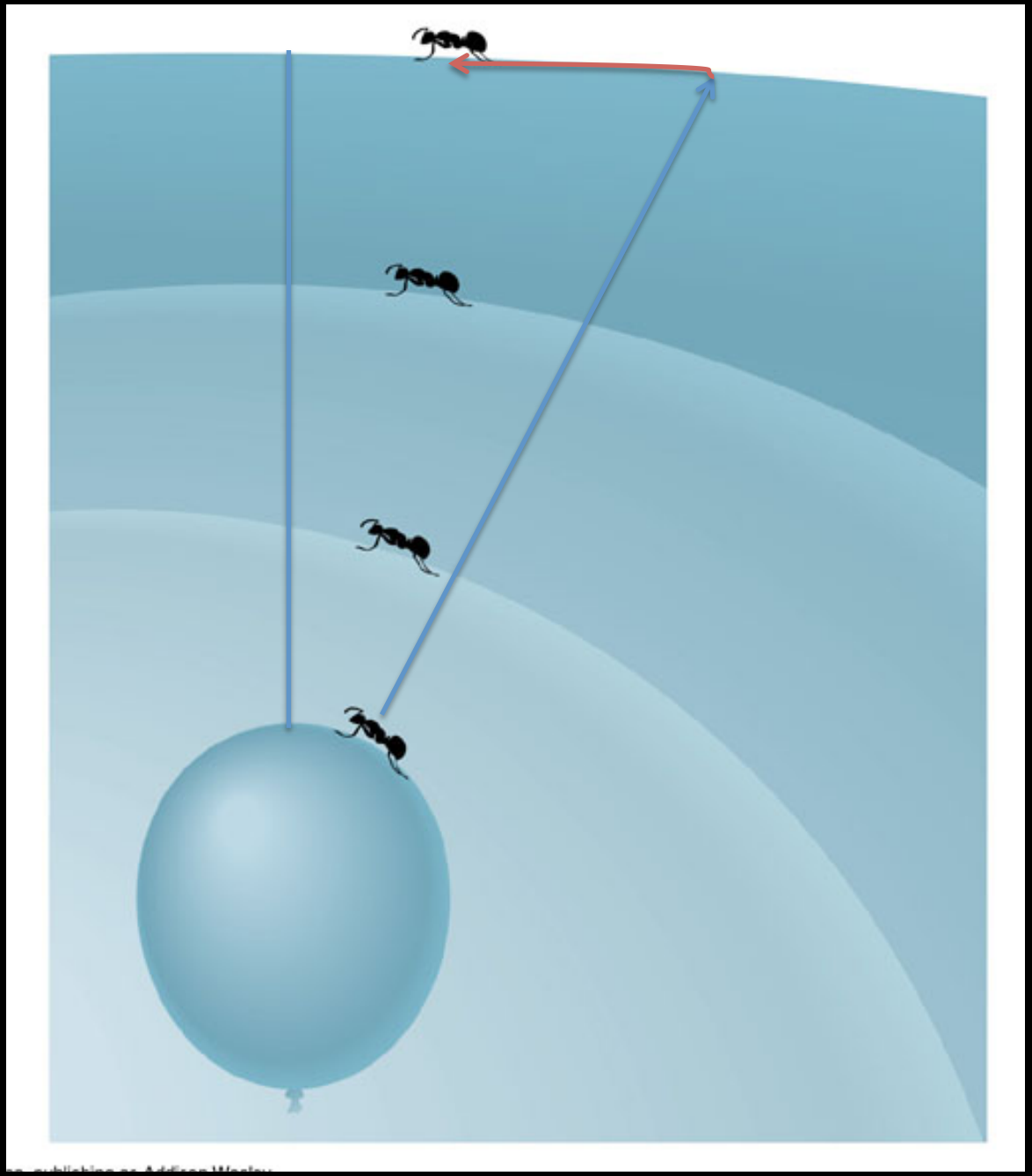
Figure 26-14
Universe, Eighth Edition

Inflation

- Our universe was created with an unstable form of energy.
- Right after the Big Bang, that potential energy became kinetic energy (energy of motion).
- What started moving? The universe started expanding, extremely fast, and we call that **inflation**.

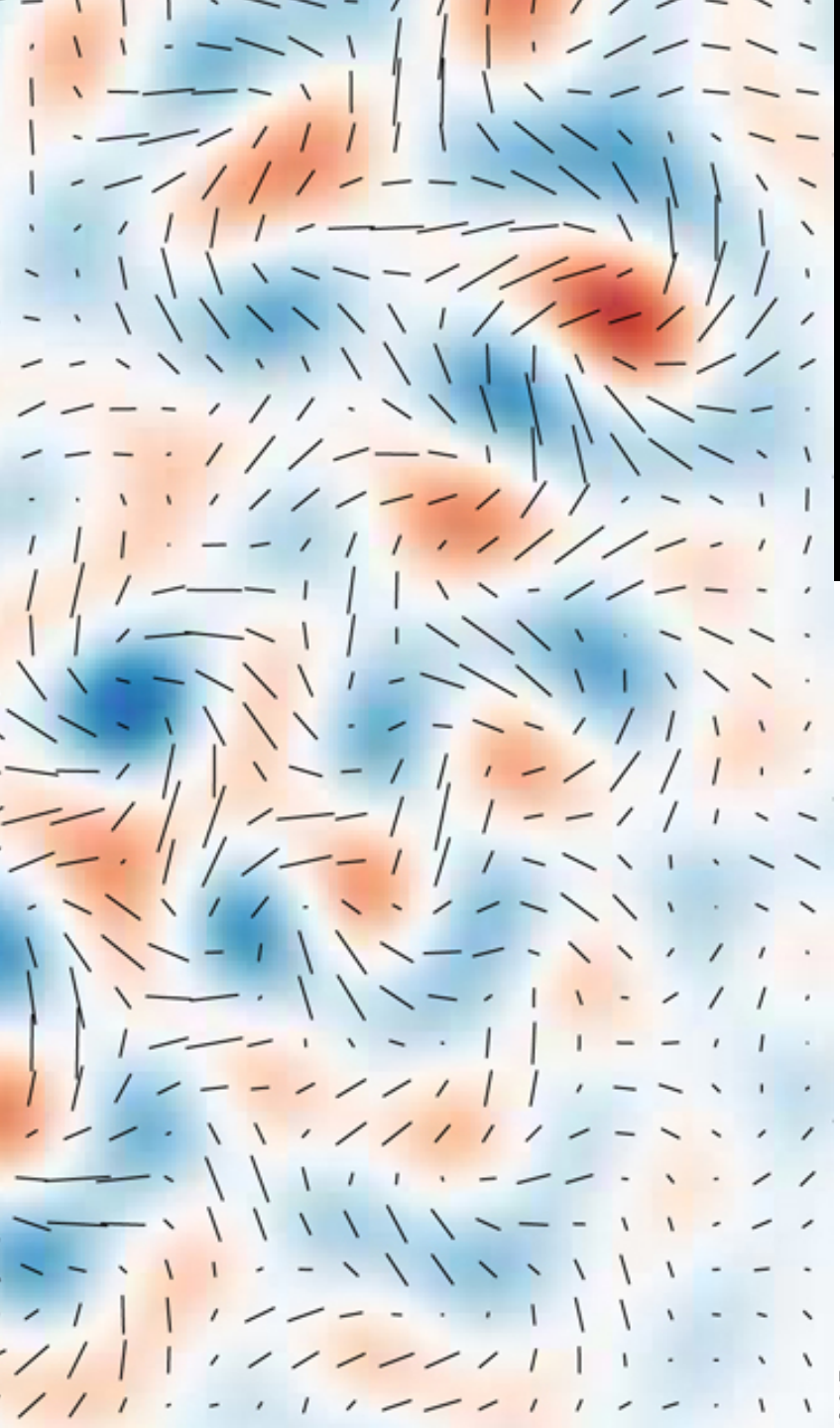


Inflation of a universe flattens it out, like the inflation of a balloon – however the universe started out, it will end up almost exactly flat.



Inflation can expand the universe faster than the speed of light, the same way you can blow up a balloon faster than an ant can walk on the balloon.

Lightspeed is the speed limit for information to travel, not for space itself to expand.



The BICEP2 experiment may have detected inflation using polarization (left) of the microwave background (below). But it's more likely they were misled by dust.

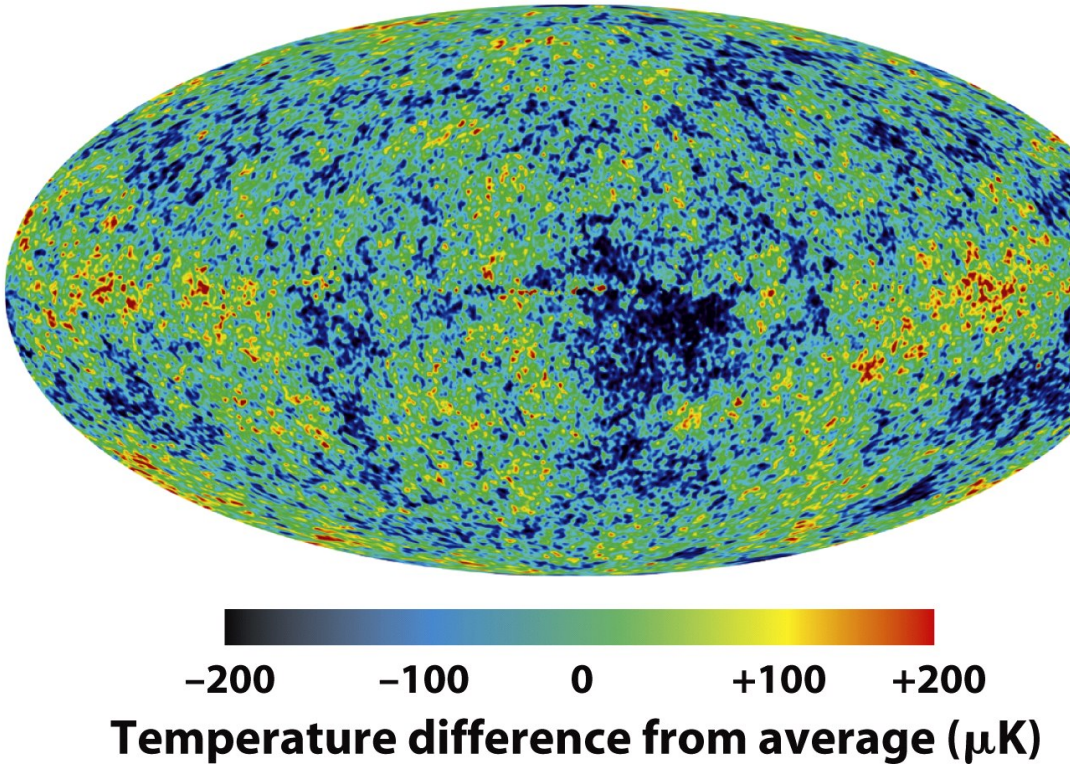
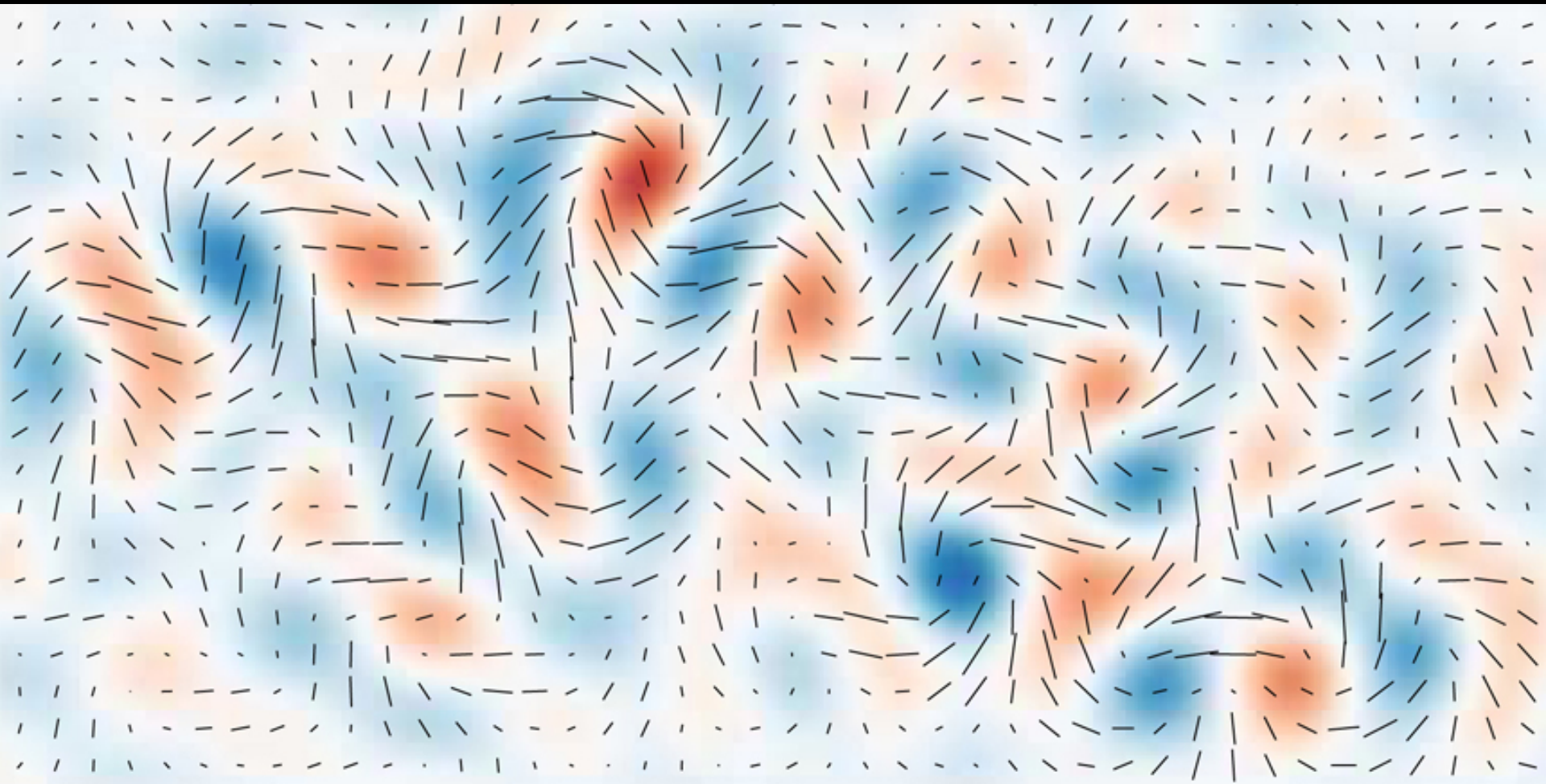


Figure 26-14
Universe, Eighth Edition

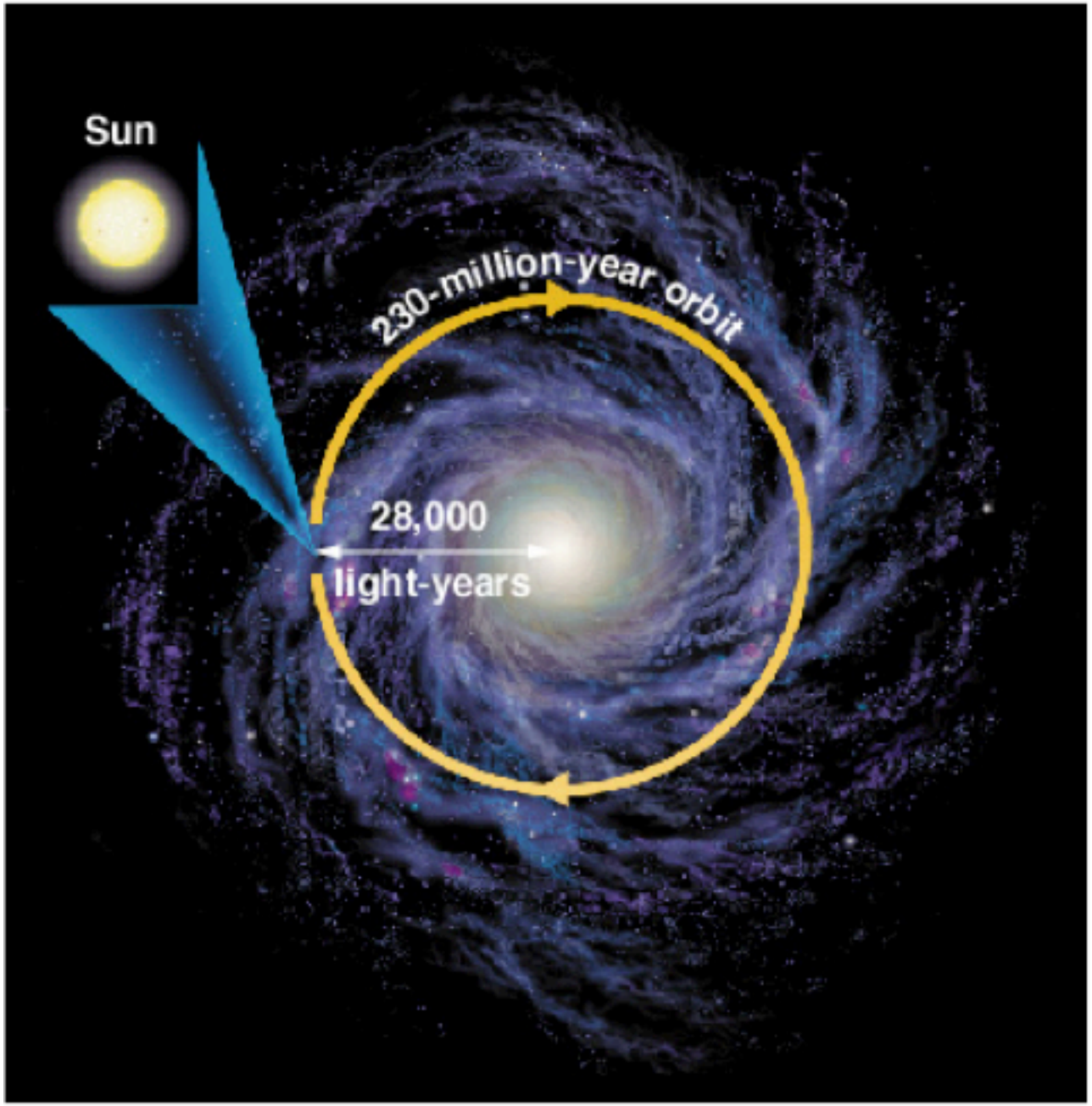
Light can scatter off dust and become polarized in a similar way to the predictions of inflation.



Dark Matter & Our Past

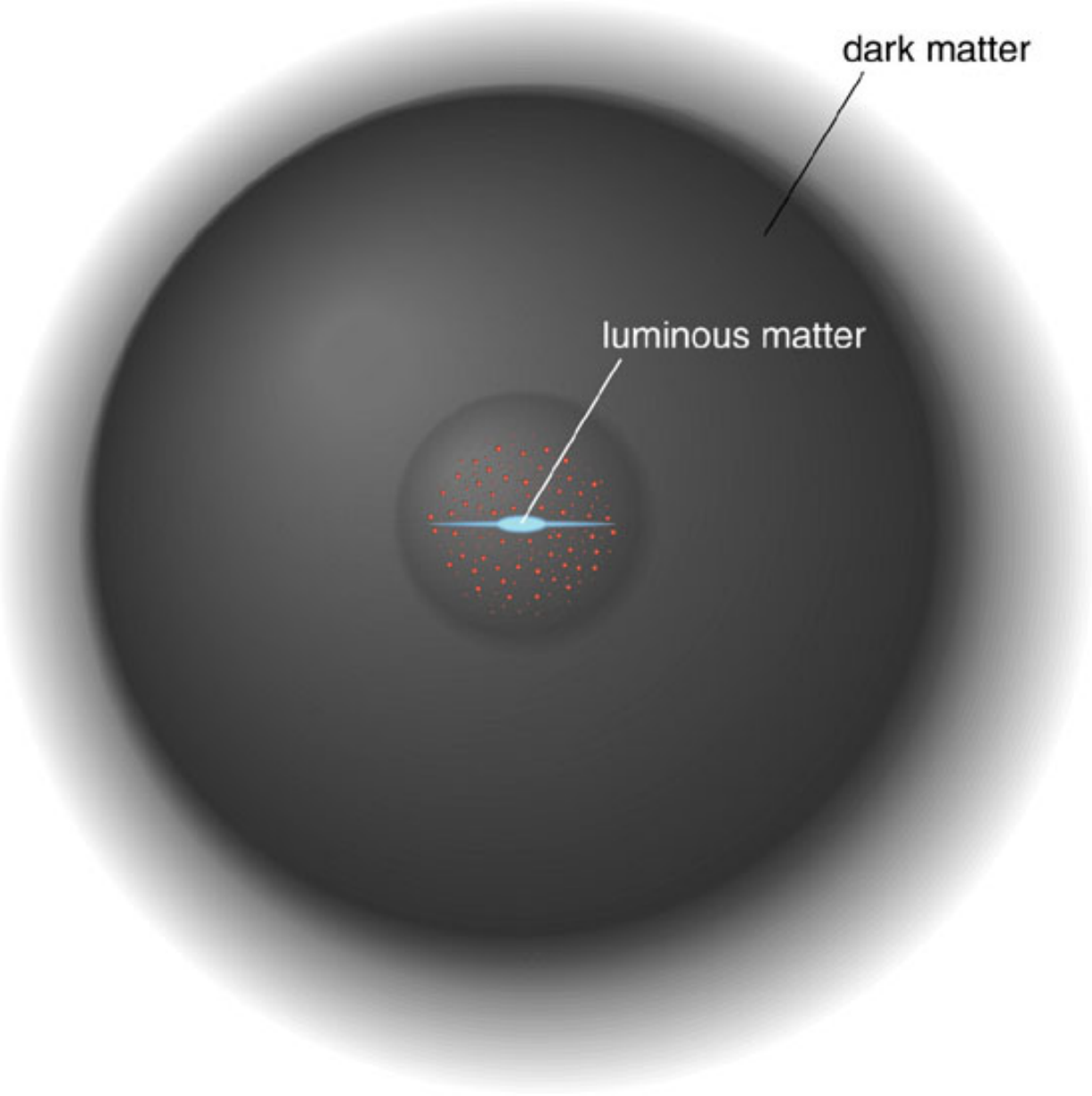
Dark Matter

- Dark matter: if you can't see it, how do you know it's there?



Gravity! The Sun's speed tells us the mass within the Sun's orbit is 100 billion times the Sun's mass (that's like $100 compared to all Canadian money!)

That's much more than the mass of all the stars that we can see in the Milky Way.



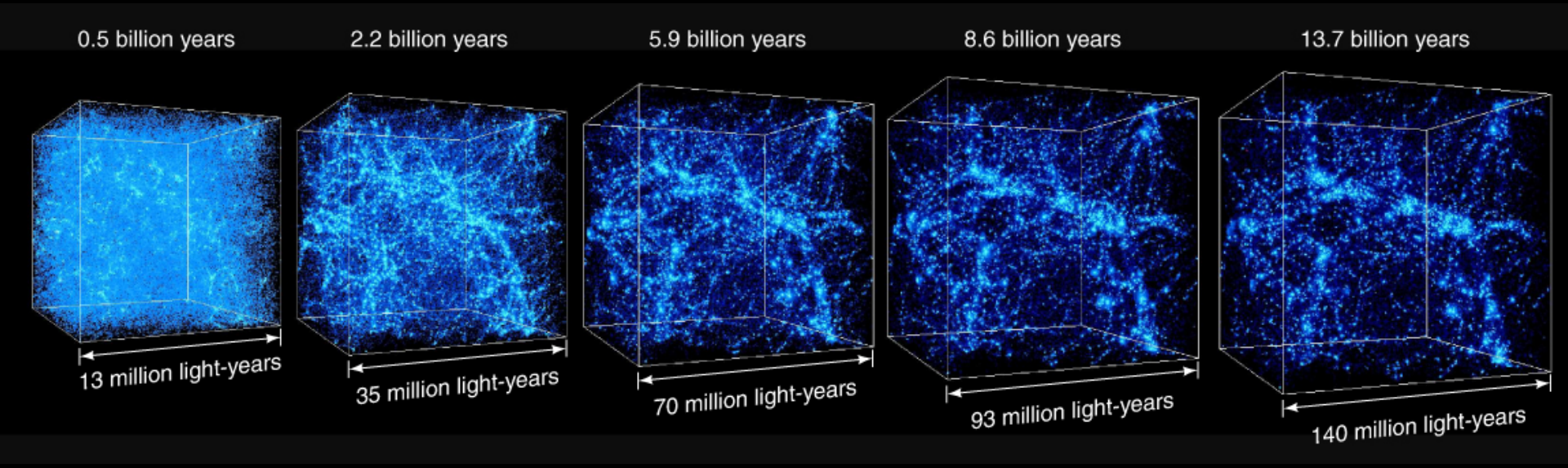
So the stars we see in each galaxy must lie deep in the heart of a large cloud of dark matter.

Dark Matter

- Dark matter: if you can't see it, how do you know it's there?
- Gravity!
- Use an analogy: we can't see air, but we can see it affect leaves or water by its motion.
- We can't see dark matter, but we can see it affect galaxies by its gravity.
- The gravity of dark matter changed our young, nearly-uniform universe into one full of lumps of matter we call galaxies.

Time in billions of years

0.5 2.2 5.9 8.6 13.8



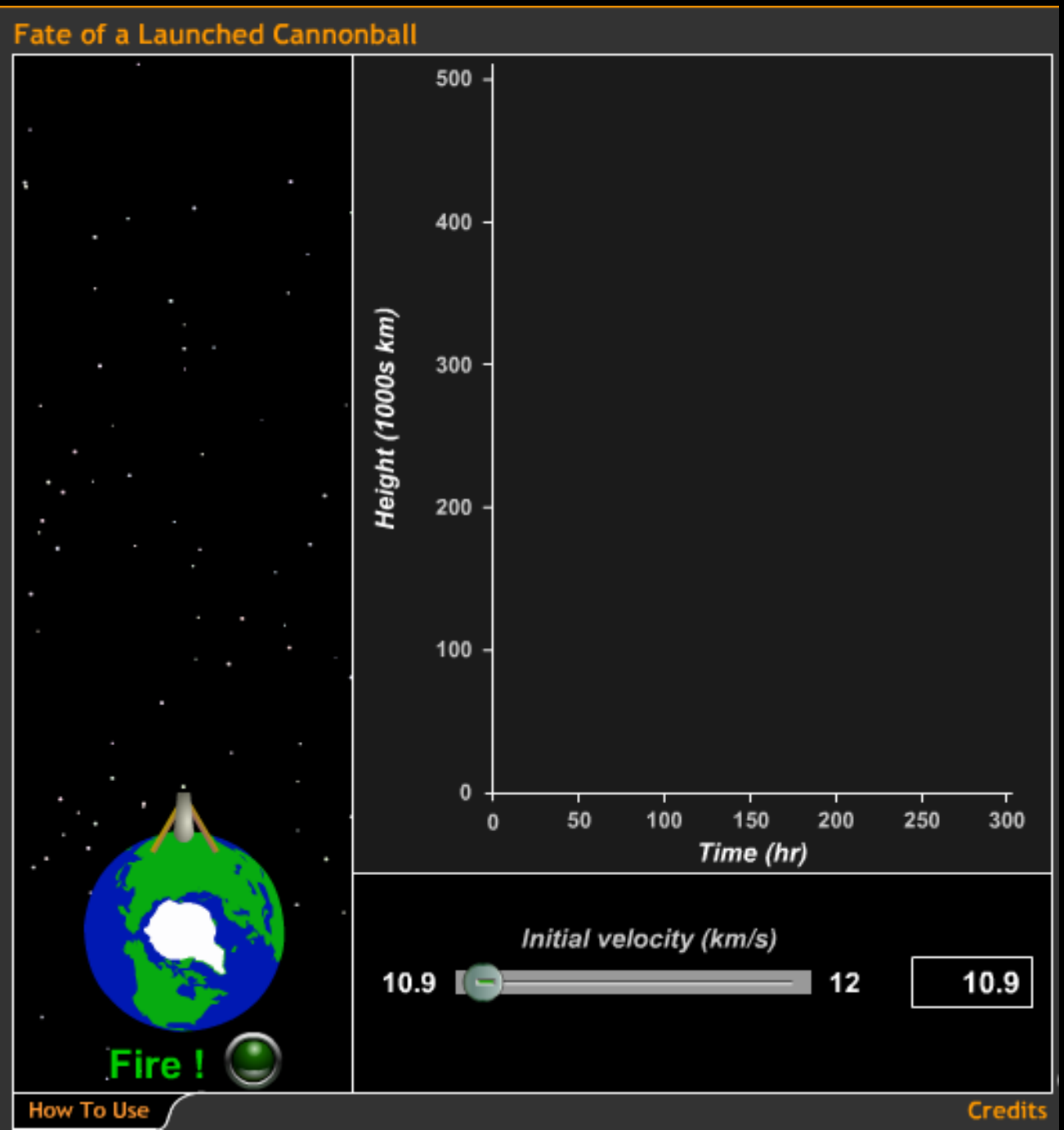
13 35 70 93 140

Size of expanding box in millions of lt-yrs

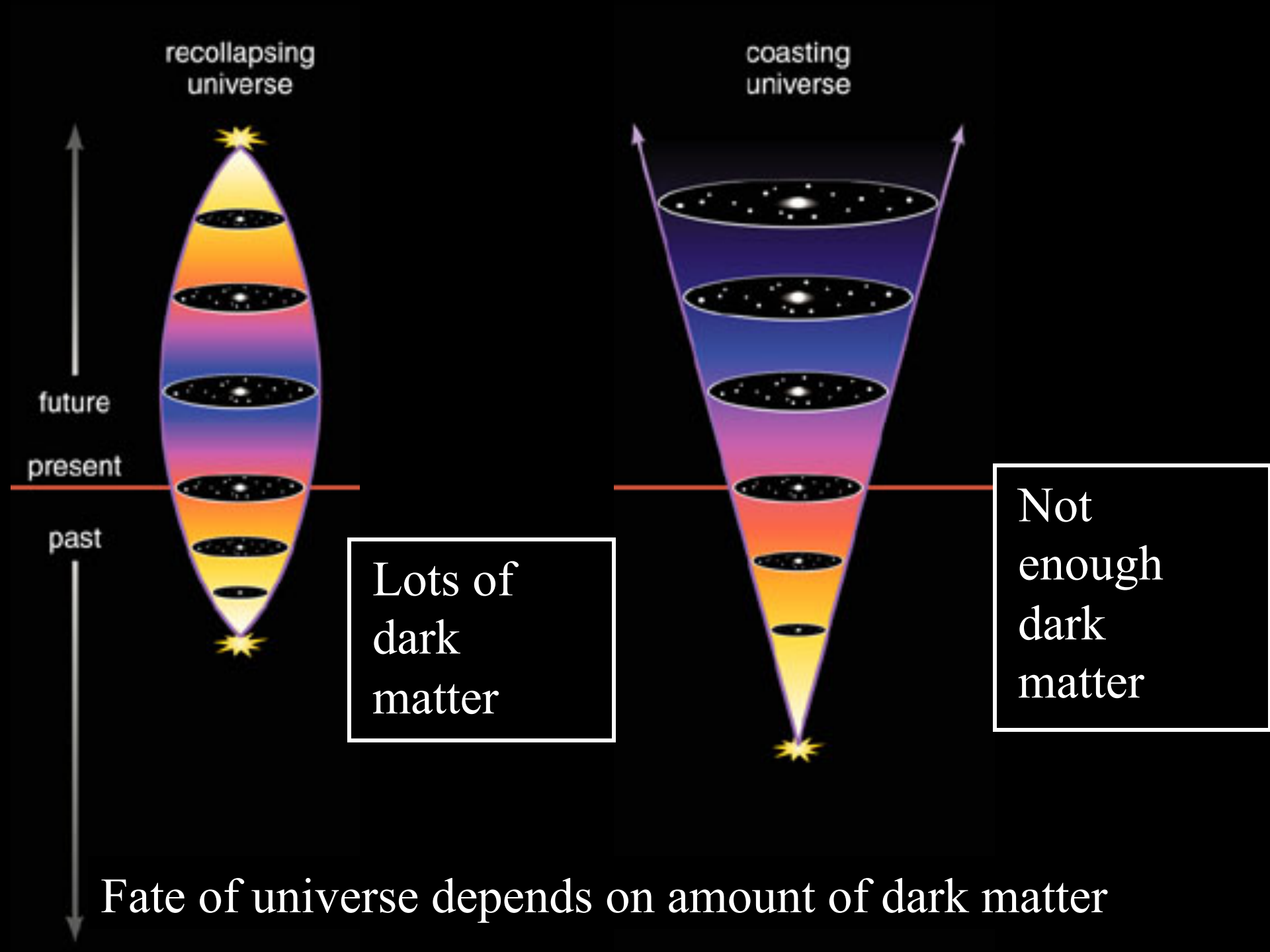
Models show that gravity of dark matter pulls mass into denser regions – universe grows lumpier with time

Dark Energy & Our Future

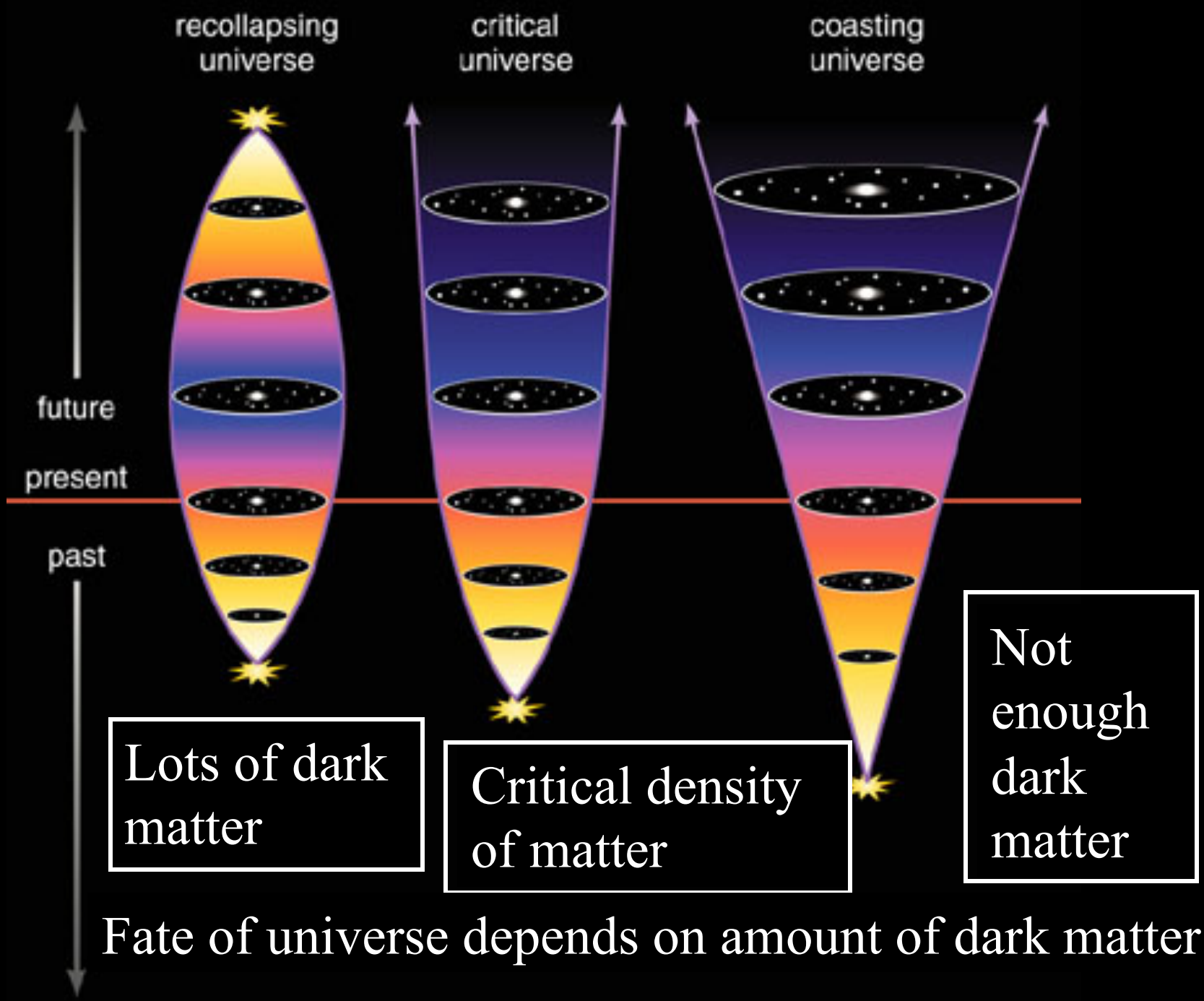
Will the universe continue expanding forever?



Is the universe moving fast enough to resist its own gravitational pull?

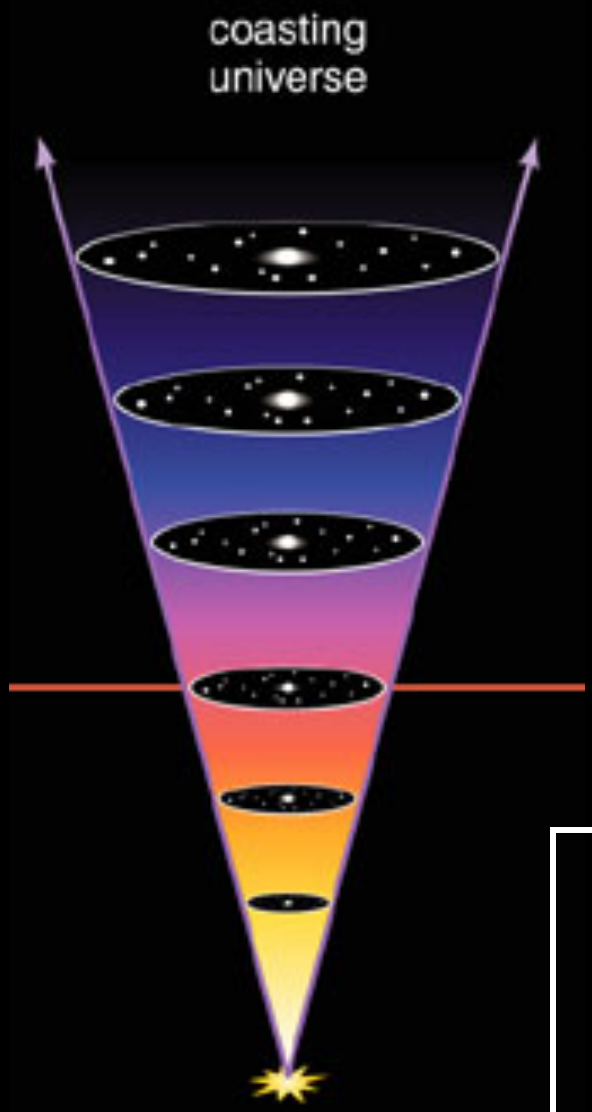


Fate of universe depends on amount of dark matter



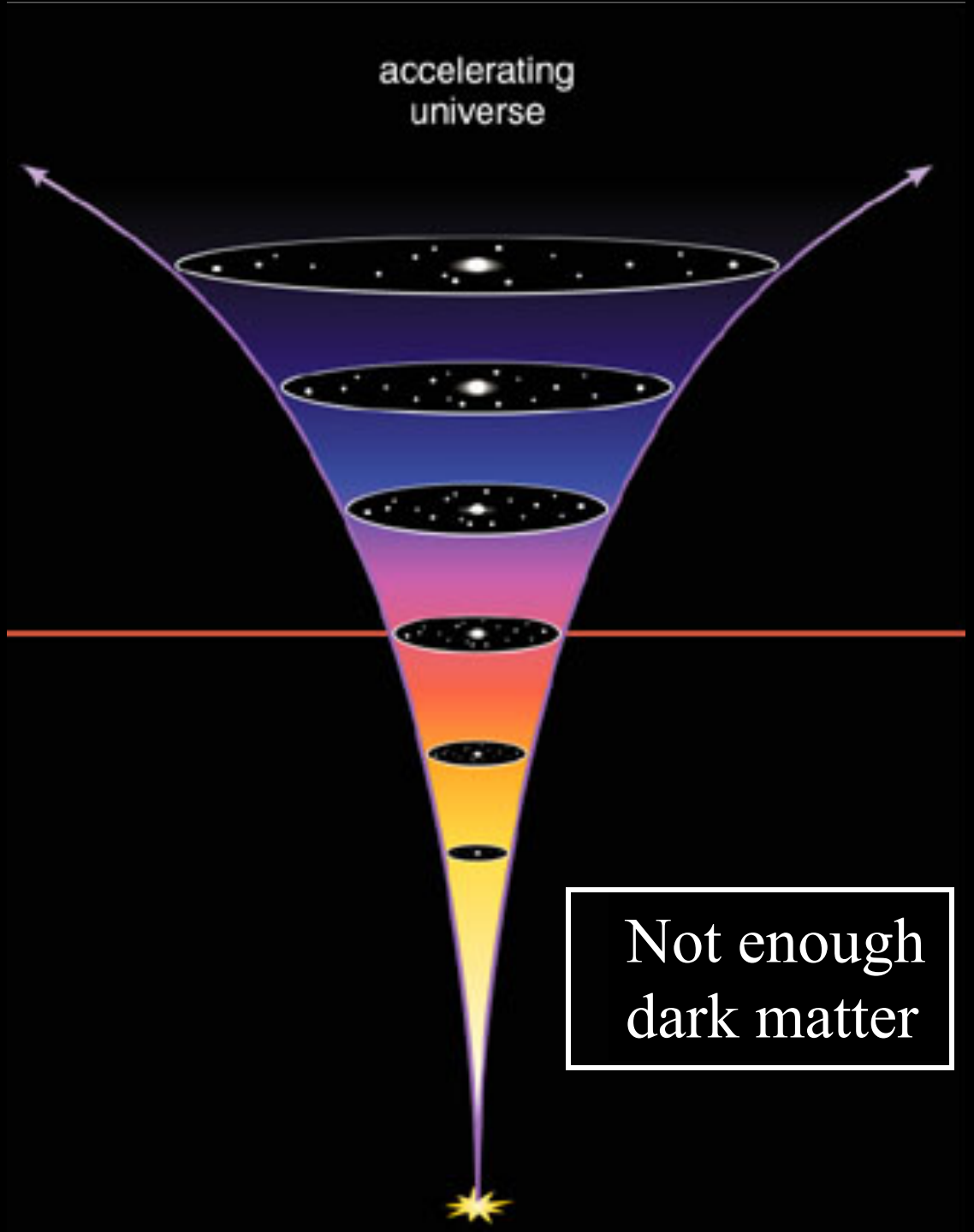
Fate of universe depends on amount of dark matter

Amount of dark matter is ~25% of the critical density suggesting fate is eternal expansion



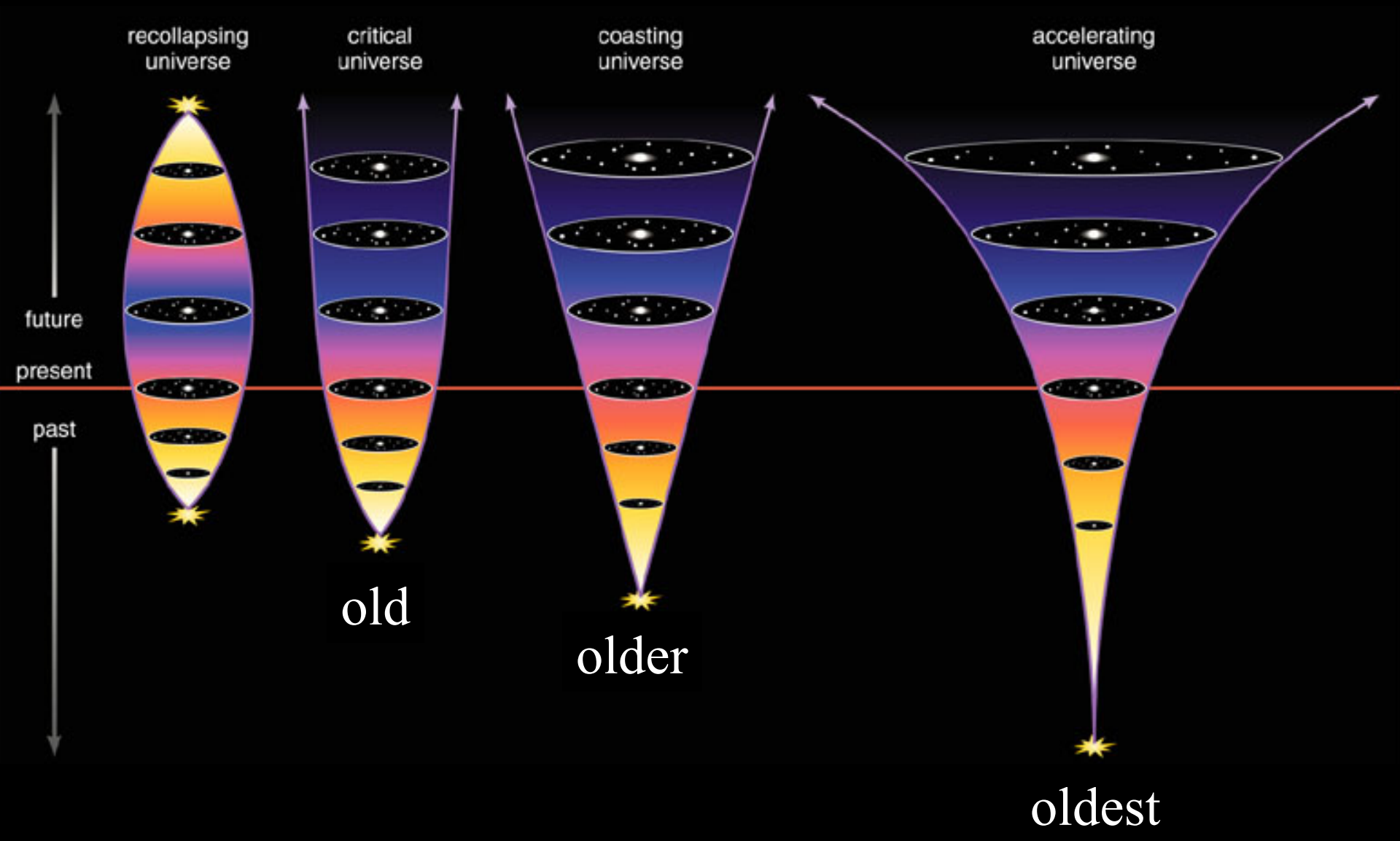
Not enough dark matter

But expansion appears to be speeding up!



Dark Energy?

Not enough dark matter

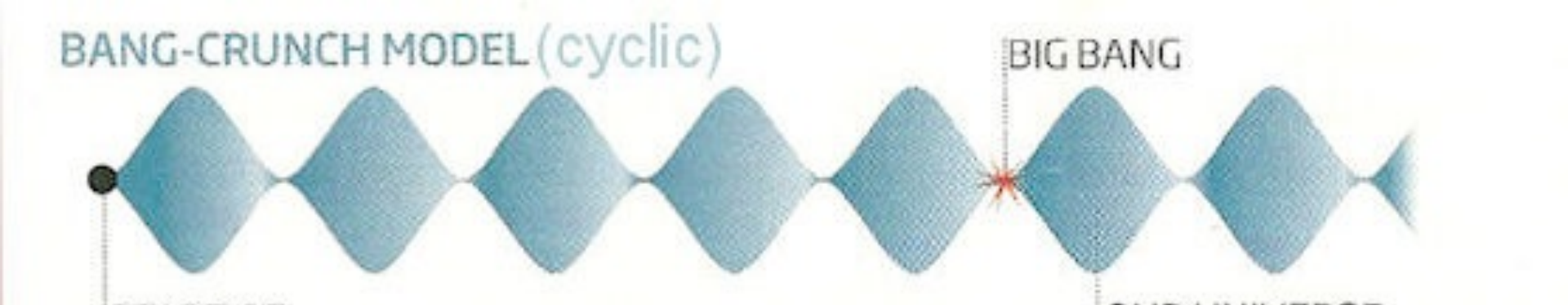


Estimated age depends on dark matter and dark energy

Other Universes?

Before the Big Bang?

- How did the early universe get so hot and dense?
- Maybe it was just born in the Big Bang with enough energy to be hot and dense.
- Or maybe it existed before the Big Bang, and gravity collapsed it to a hot, dense state, in a Big Crunch that led to a Big Bang that was really a Big Bounce:

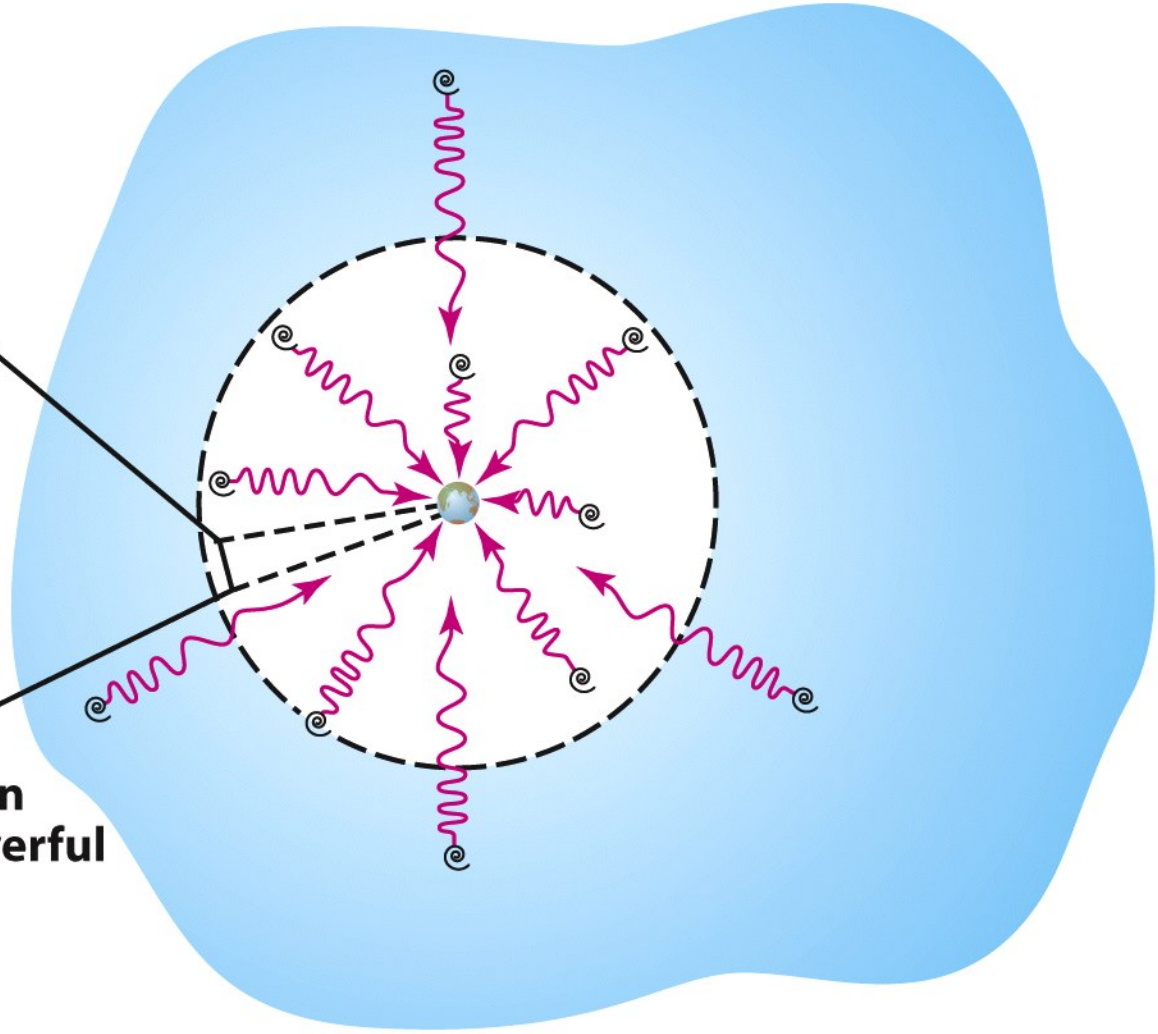


A universe launched with a Big Bang will look different

than a universe launched with a Big Bounce (gravity waves)

Our Observable Universe

- Our observable universe is centered on us: we observe light from everything that was within about 13.8 billion light-years of our current location when the universe became transparent.
- Next year, we'll see light from everything that was within about 13.8 billion +1 light-years.
- [*A circle around a galaxy on a balloon represents that galaxy's observable universe at some time.*]
- Our universe is bigger than our observable universe:



All of the objects that we can see with even the most powerful telescopes lie within our observable universe.

Figure 26-5
Universe, Eighth Edition

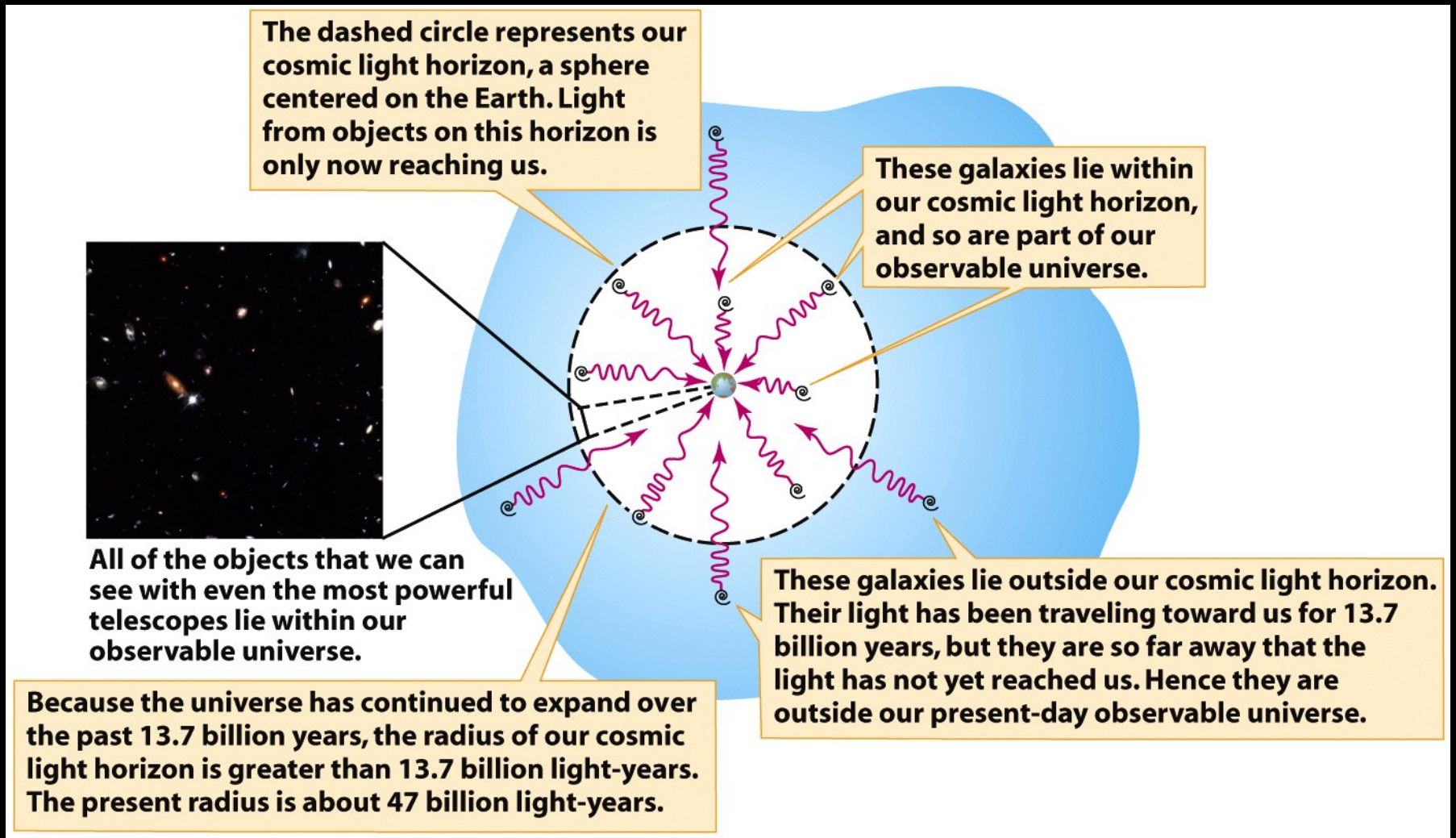
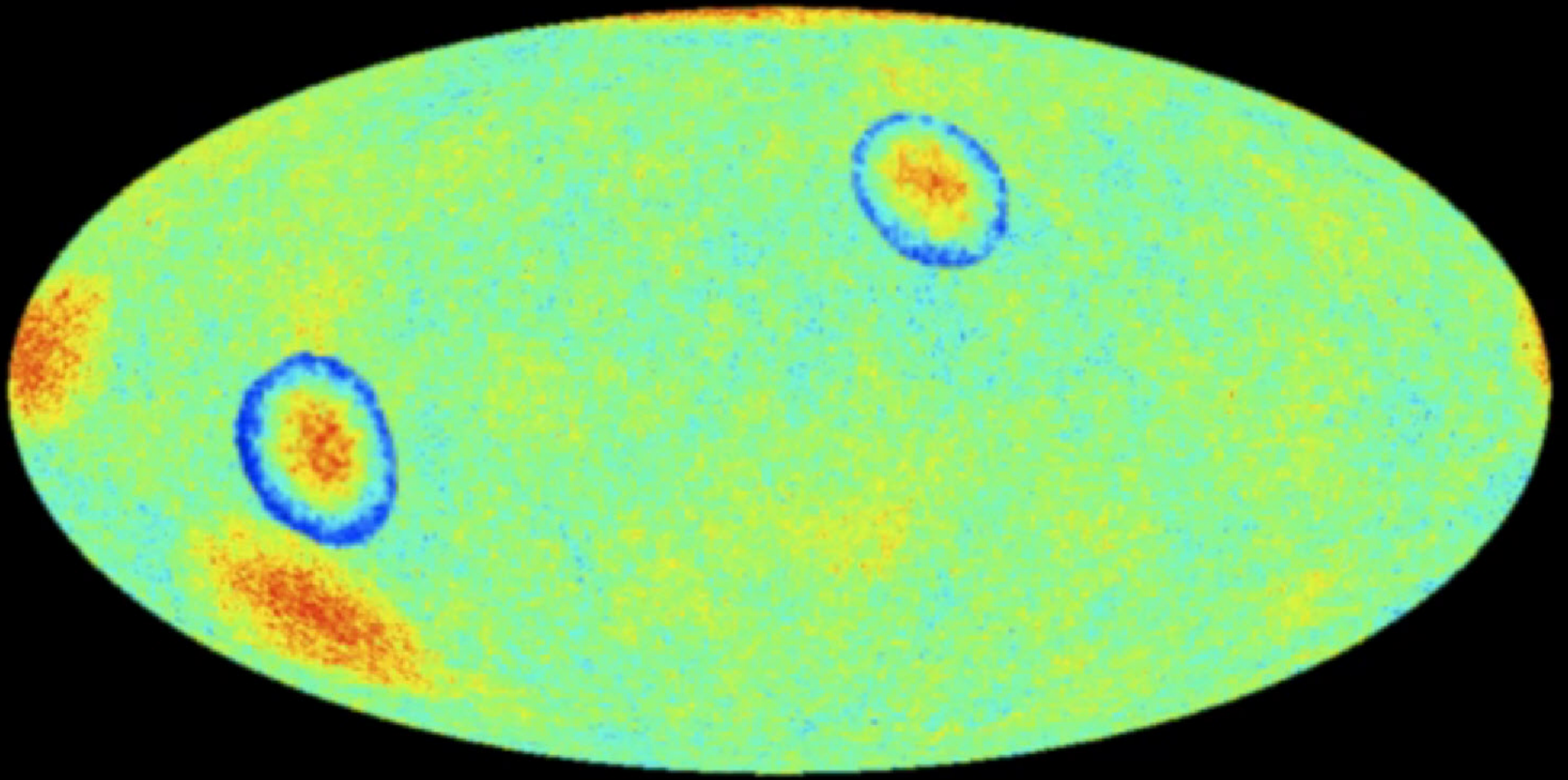


Figure 26-5
Universe, Eighth Edition

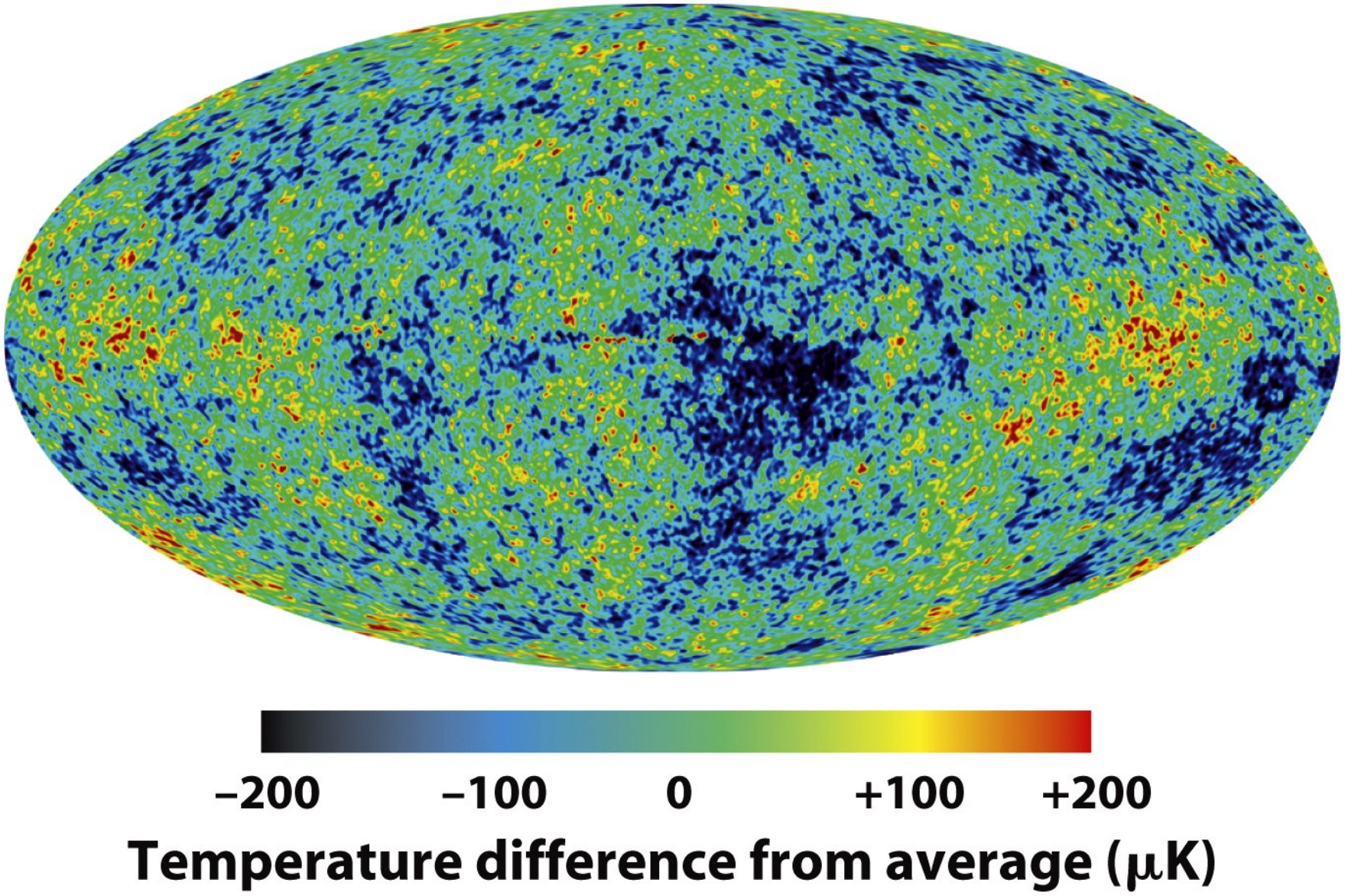
Our Universe

- Inflation might result in many universes.
- If two balloon universes collide, the resulting universe is the outer surface of both balloons. You can draw a line from one balloon to the other, but you might notice the resulting distortion in geometry at the boundary between.
- If you live in a 3-D universe that's a result of a collision, that universe's Big Bang was nonuniform in space, and you might see the resulting distortion in the cosmic microwave background.
- Work by Prof. Matt Johnson (York and Perimeter).

Collisions with other universes would create circular distortions on the cosmic microwave background



No evidence for our universe colliding with another…



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