The Universe in 2009

Prof. Patrick Hall
Department of Physics and Astronomy
York University, Toronto, Ontario

Outline

- The Big Bang
- Our Past: Dark Matter & Structure Formation
- Our Future: Dark Energy

Steps to the Big Bang

- Here in the Milky Way, we see almost all galaxies moving away from us (Hubble's Law)
- Either we’re at the centre of the Universe…

...or galaxies are all moving away from each other, and the Milky Way is just another one of those galaxies.

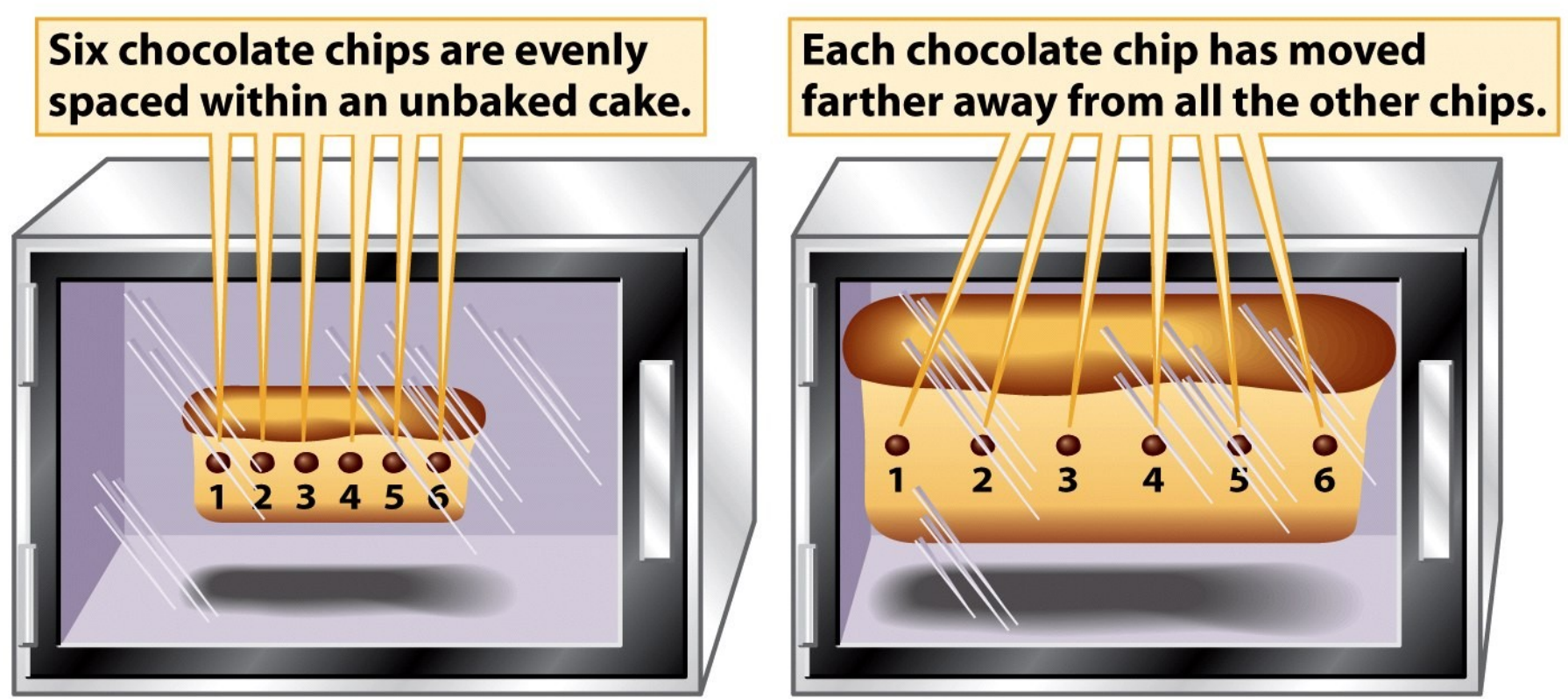
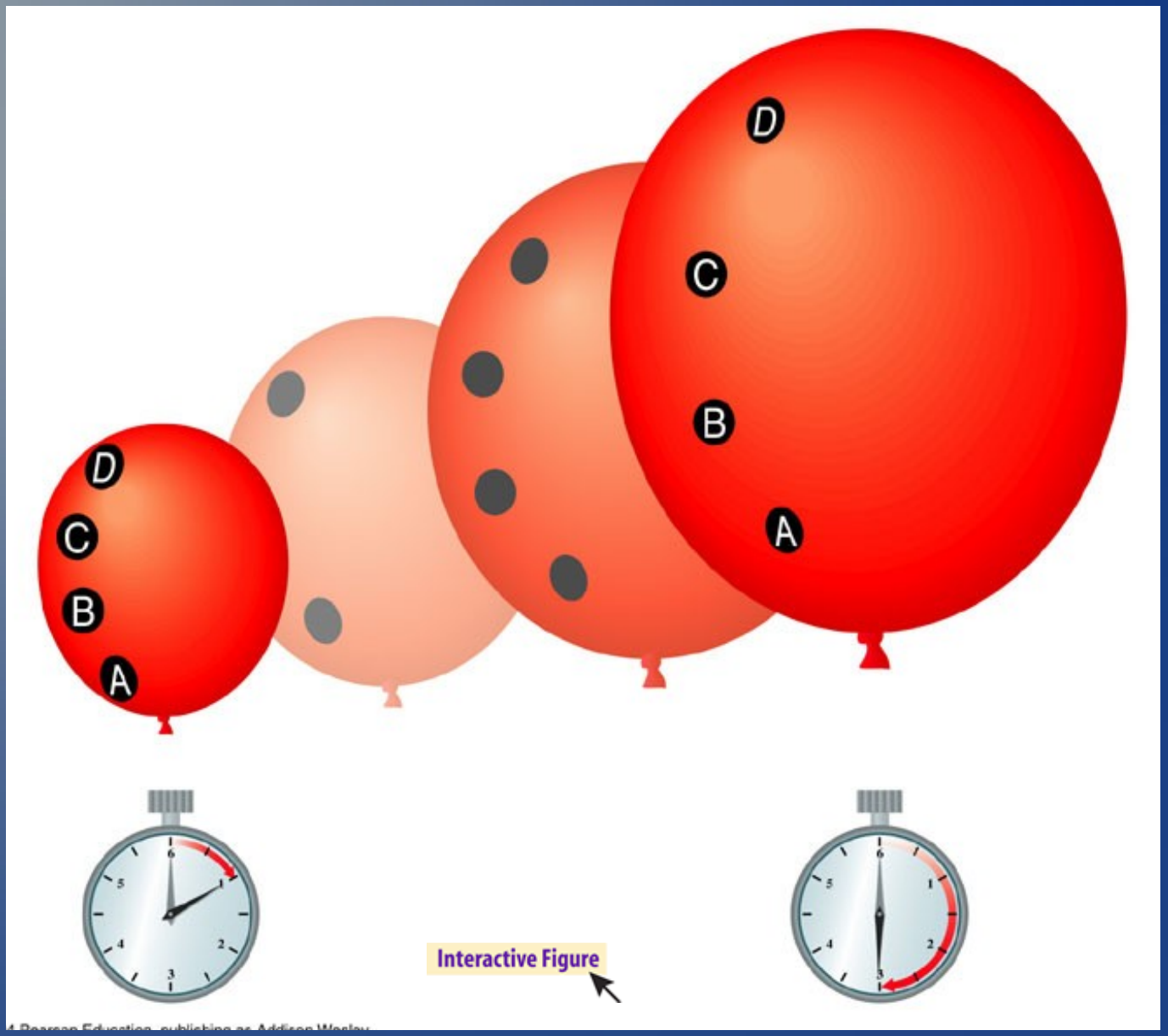


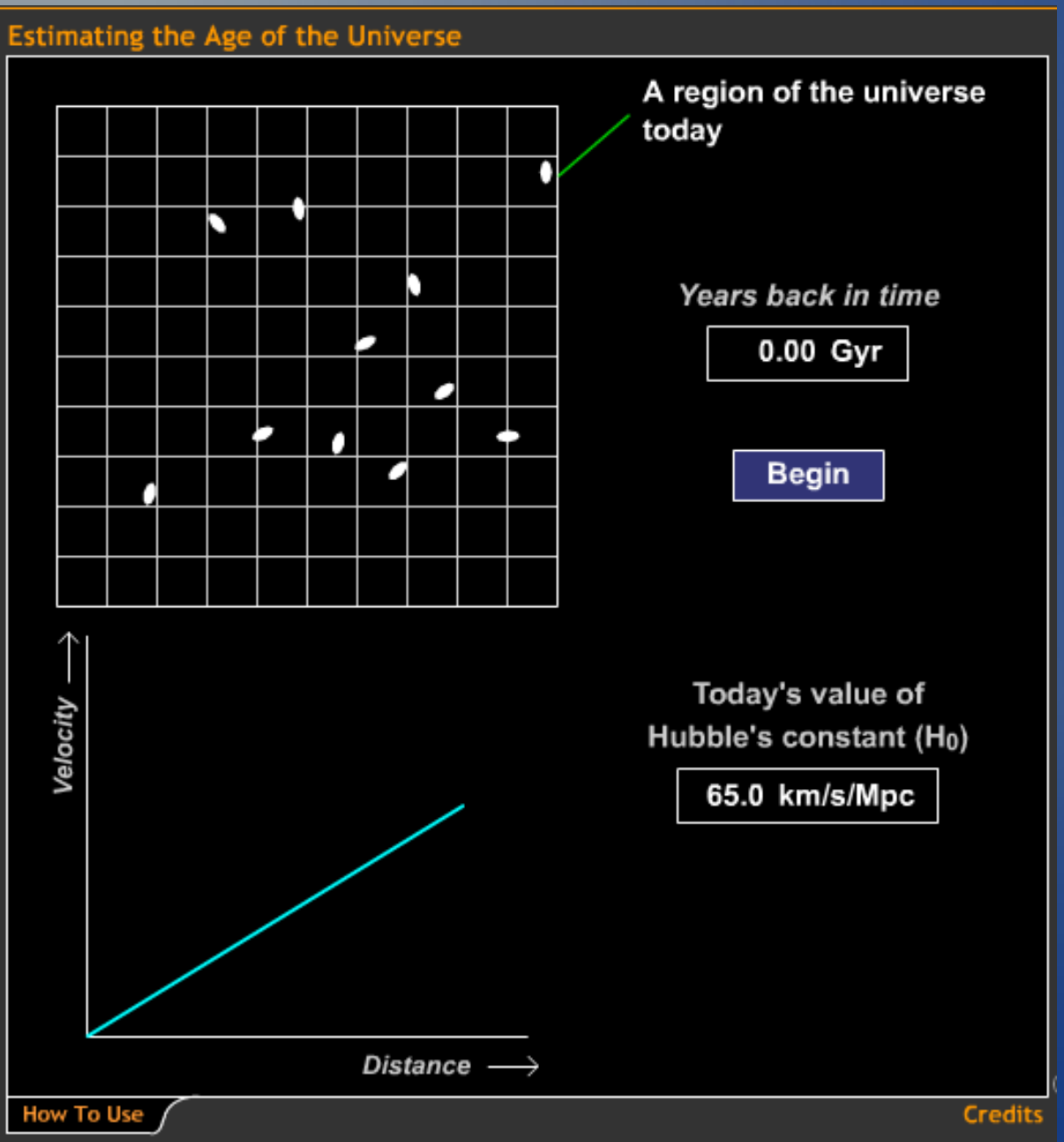
Figure 26-2
Universe, Eighth Edition



Surface of a balloon expands but has no center or edge

Steps to the Big Bang

- Here in the Milky Way, we see almost all galaxies moving away from us (Edwin Hubble)
- Either we're at the centre of the Universe…
- …or galaxies are all moving away from each other, and the Milky Way is just another one of those galaxies.
- Exceptions: galaxies very near to each other can orbit each other or crash into each other due to gravity.
- Galaxies all moving away from each other, so…



…the universe must have been much denser (and hotter) early in its history

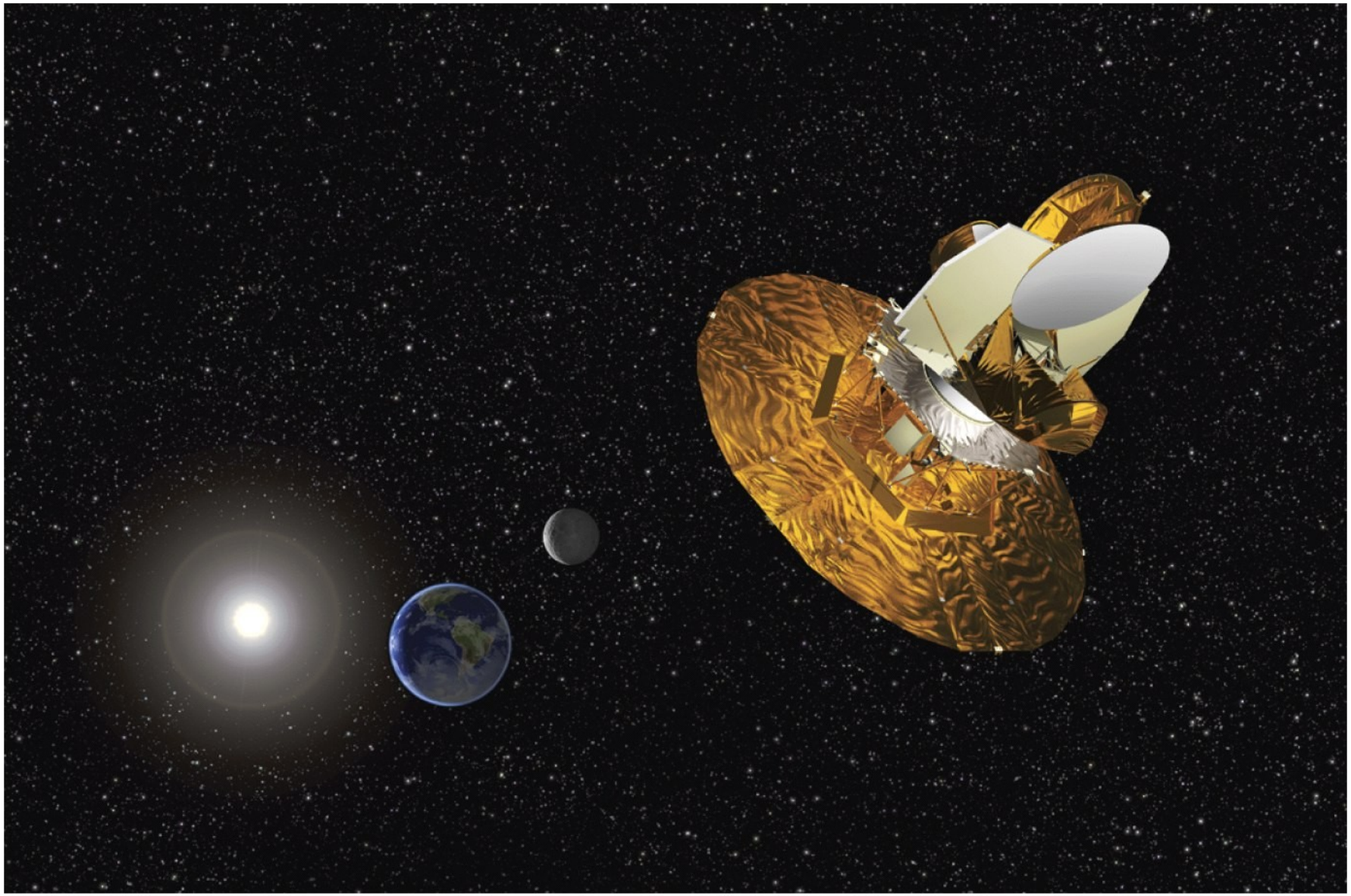
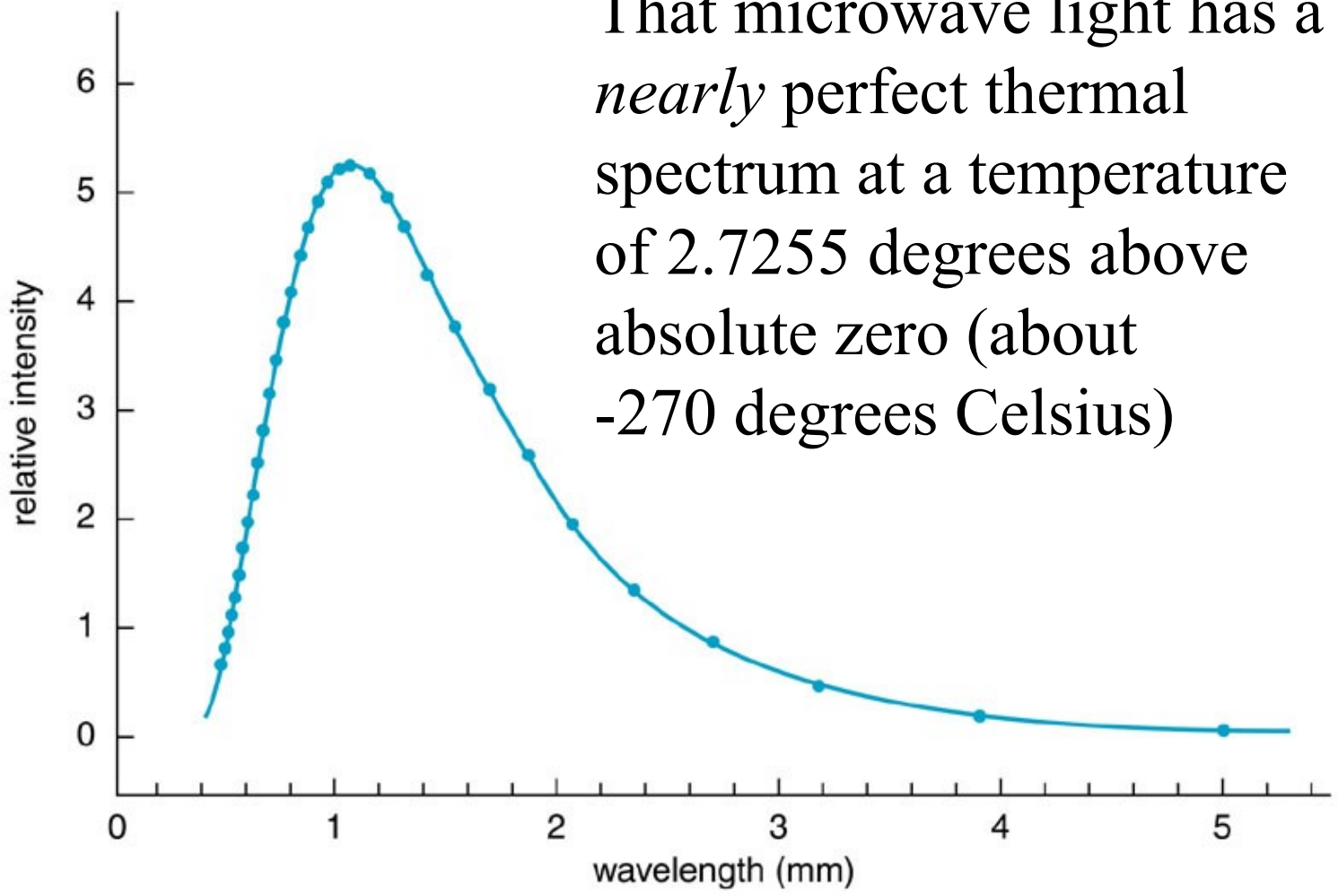
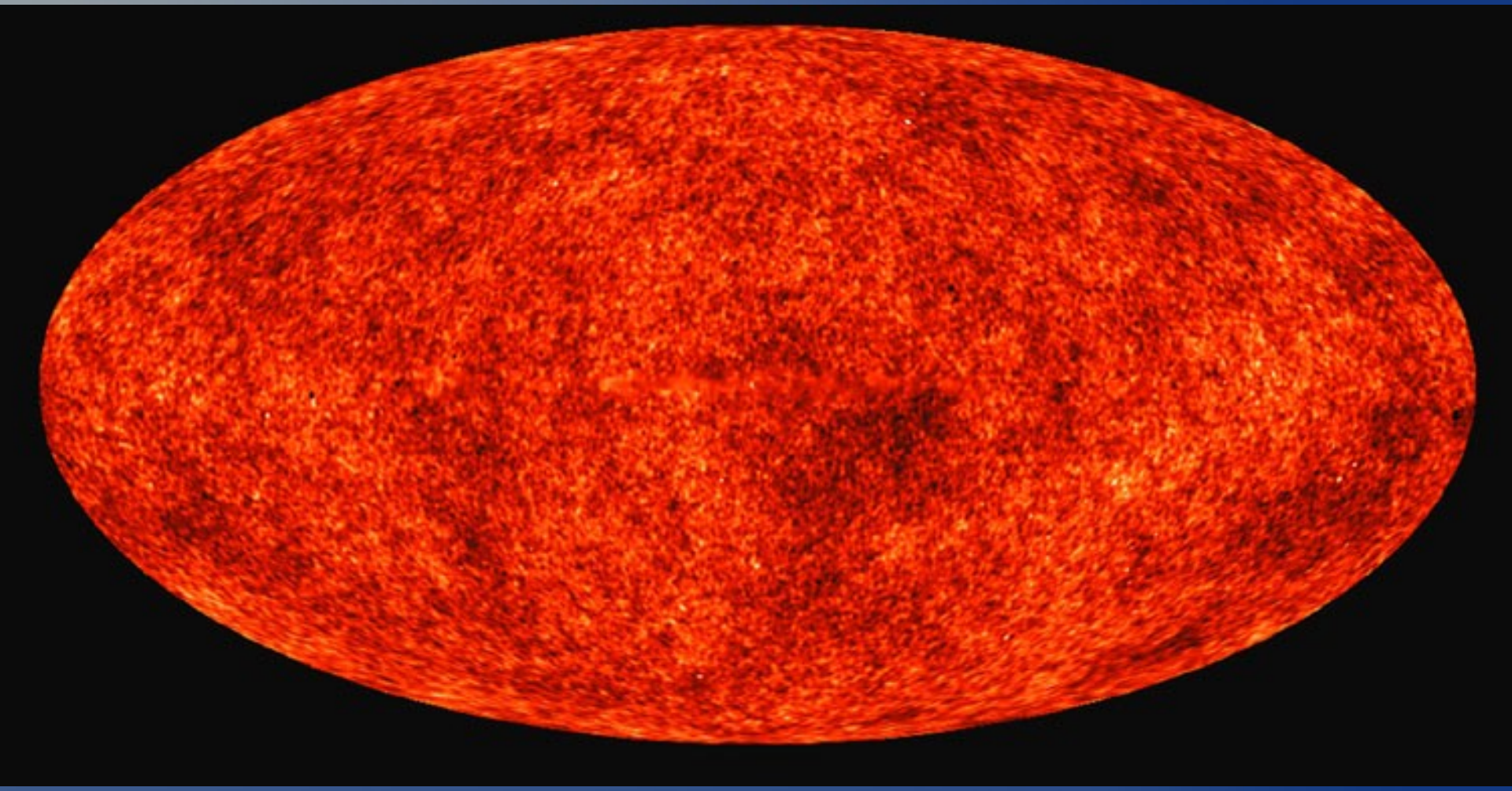


Figure 26-13
Universe, Eighth Edition

Expansion of universe has redshifted the light and heat from the early, hot universe to ~1000 times longer wavelength: *microwaves*



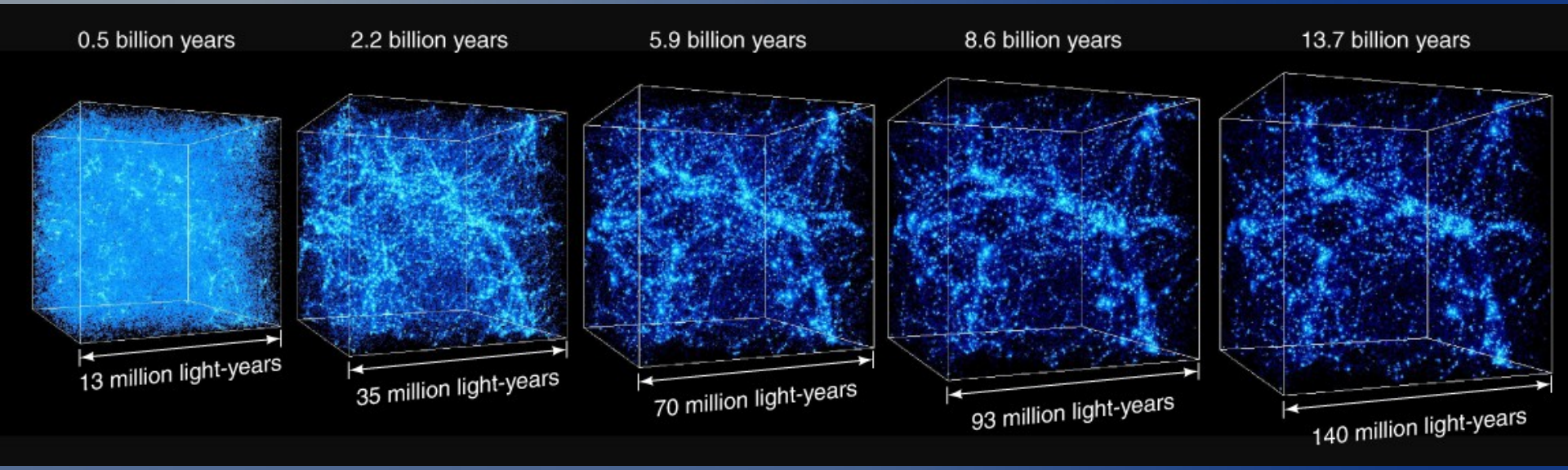
That microwave light has a *nearly* perfect thermal spectrum at a temperature of 2.7255 degrees above absolute zero (about -270 degrees Celsius)



Imperfections in the cosmic background = the seeds of galaxies. Remember that every point on this map of the microwave sky represents light that travelled 13.7 billion light years to reach us…

Time in billions of years

0.5 2.2 5.9 8.6 13.7



13 35 70 93 140

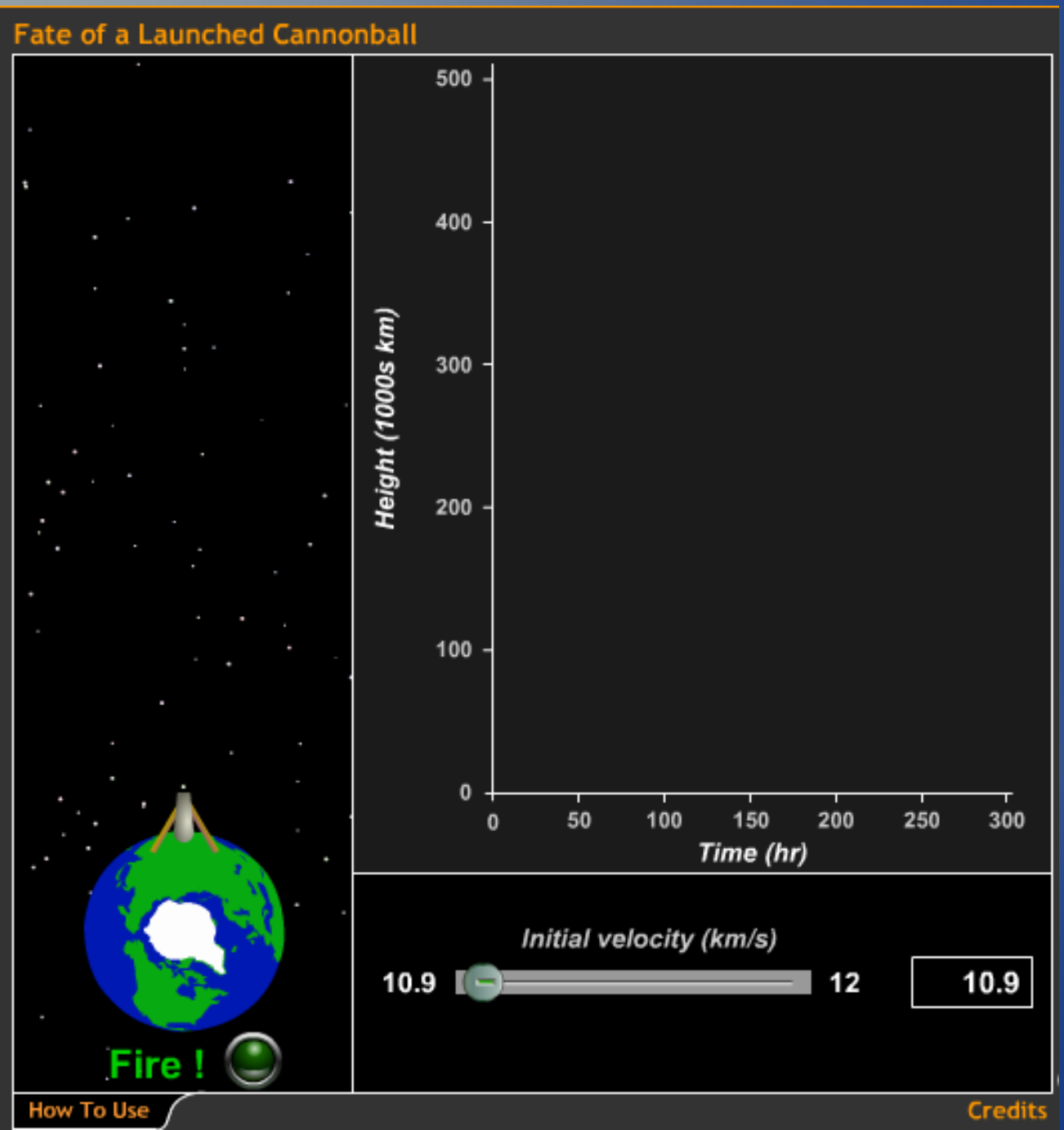
Size of expanding box in millions of light-years

Gravity pulls mass towards denser-than-average regions – the universe grows lumpier with time. However, there's too little luminous mass in the universe to explain its lumpiness. There must be **dark matter** we're detecting only via gravity.

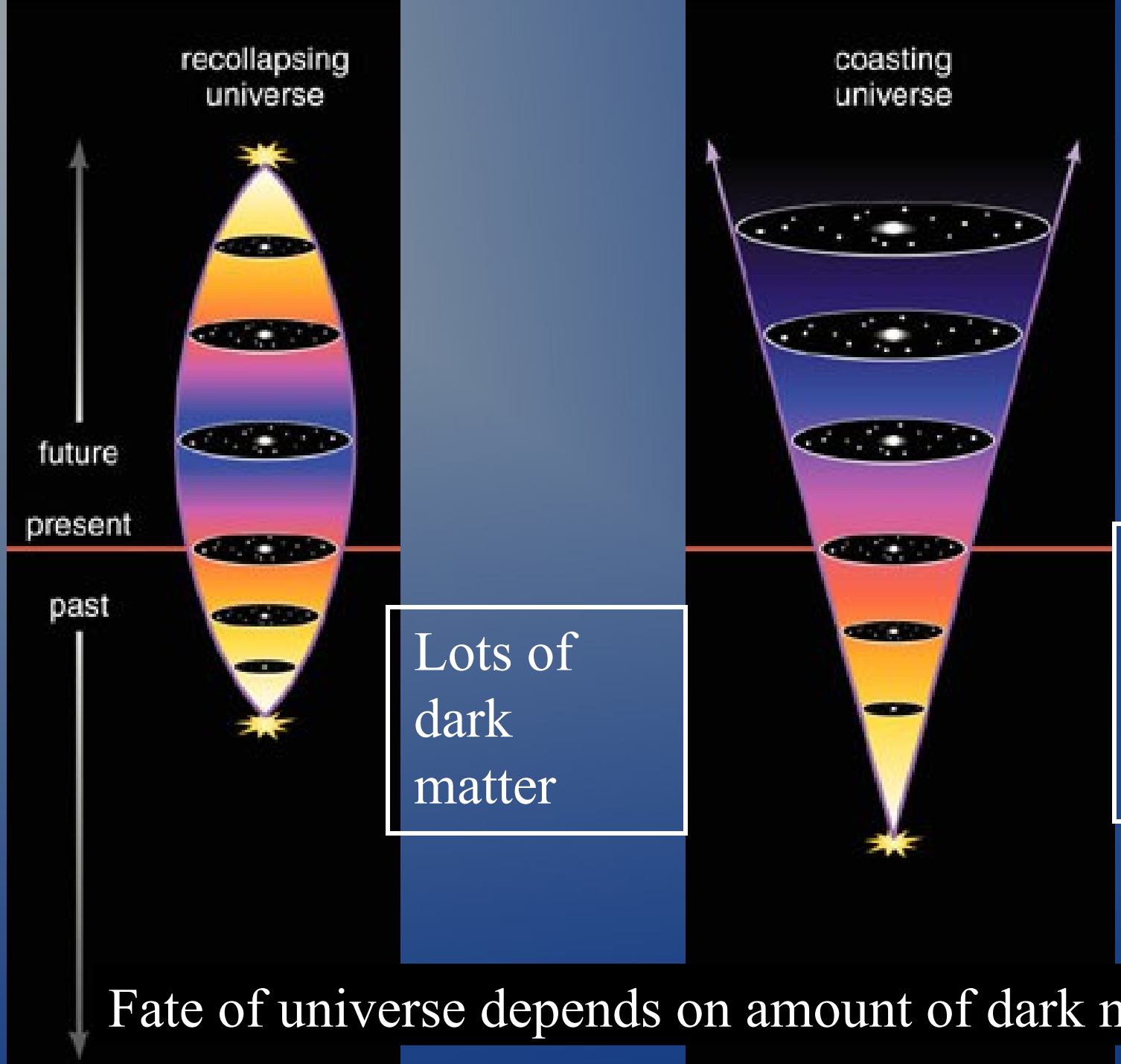
The story so far

- Big Bang about 13.7 billion years ago
- Universe expanding ever since
- Galaxies forming via the pull of gravity from some normal matter, but mostly dark matter
- Stars forming in those galaxies
- Planets forming around those stars
- Life evolving on at least one planet!

Will the universe continue expanding forever?



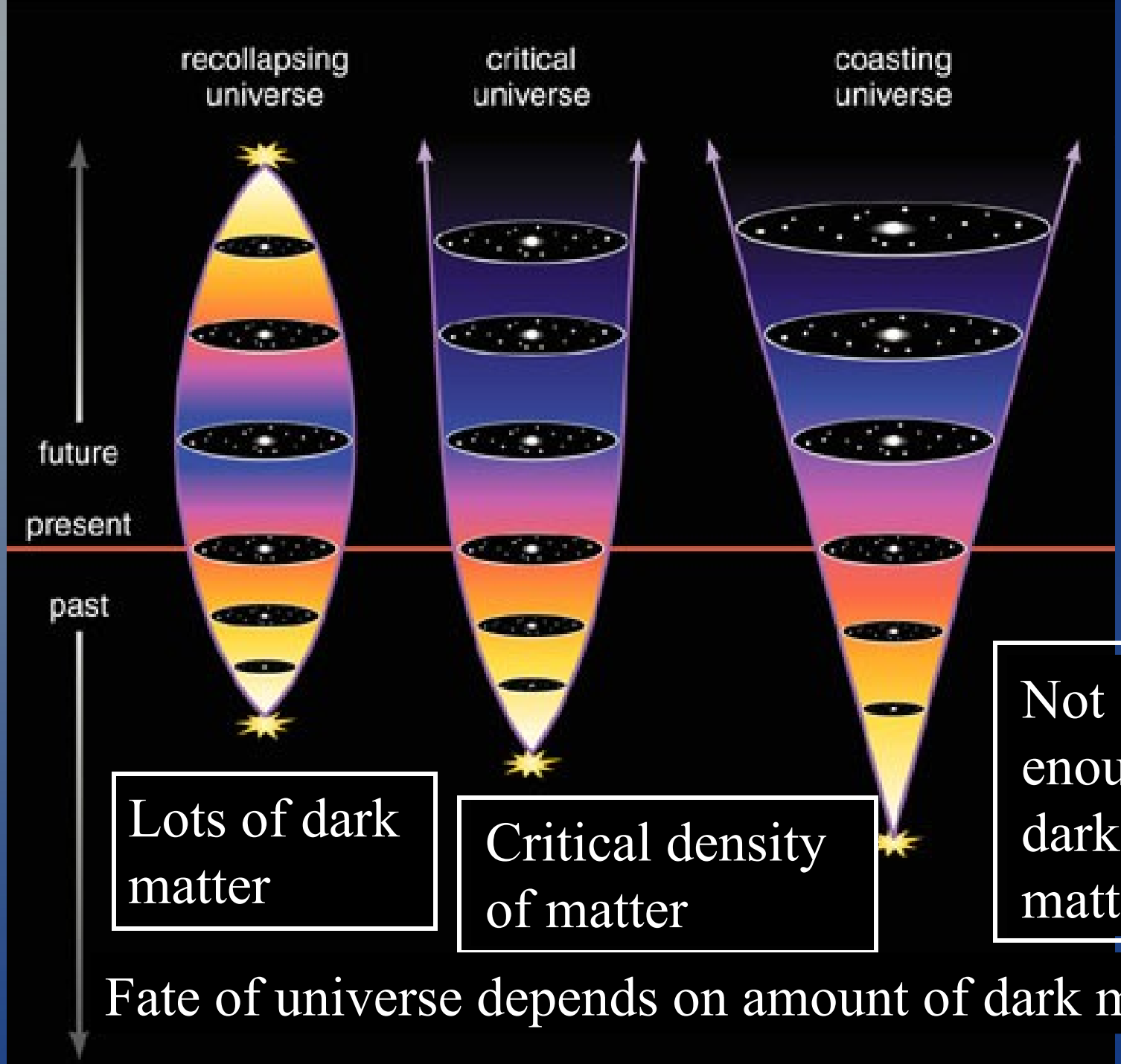
Does the universe have enough kinetic energy to escape its own gravitational pull?



Lots of dark matter

Not enough dark matter

Fate of universe depends on amount of dark matter



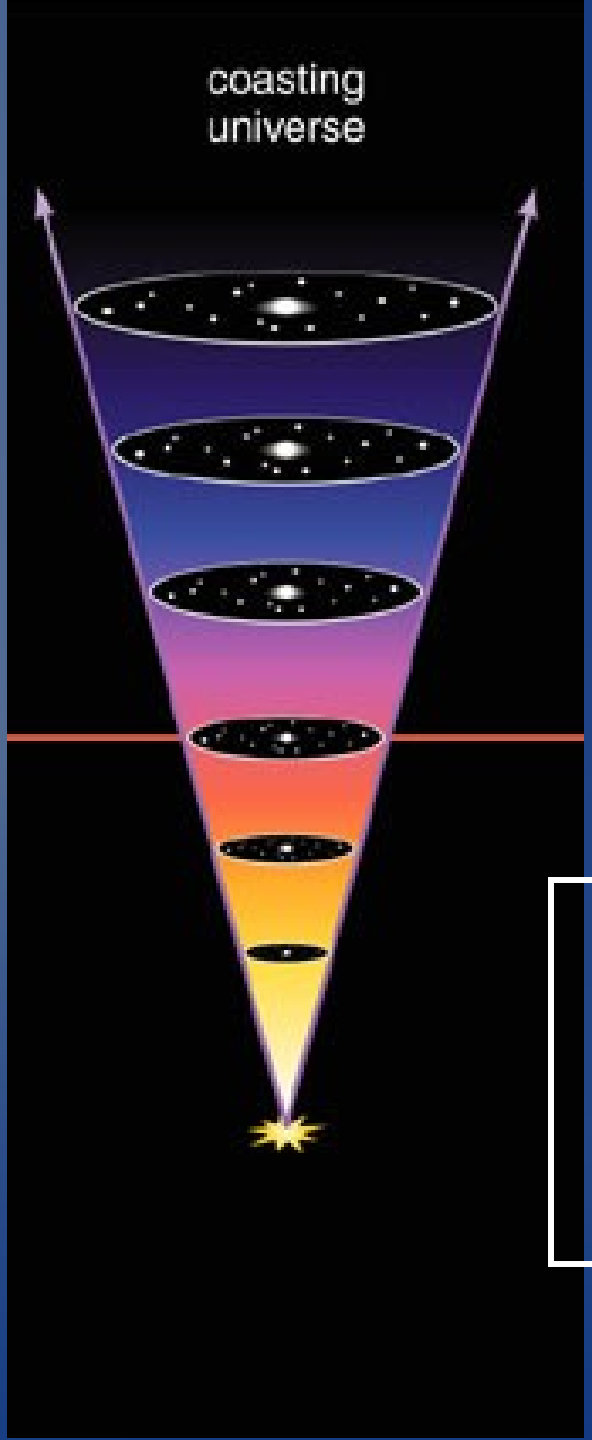
Lots of dark matter

Critical density of matter

Not enough dark matter

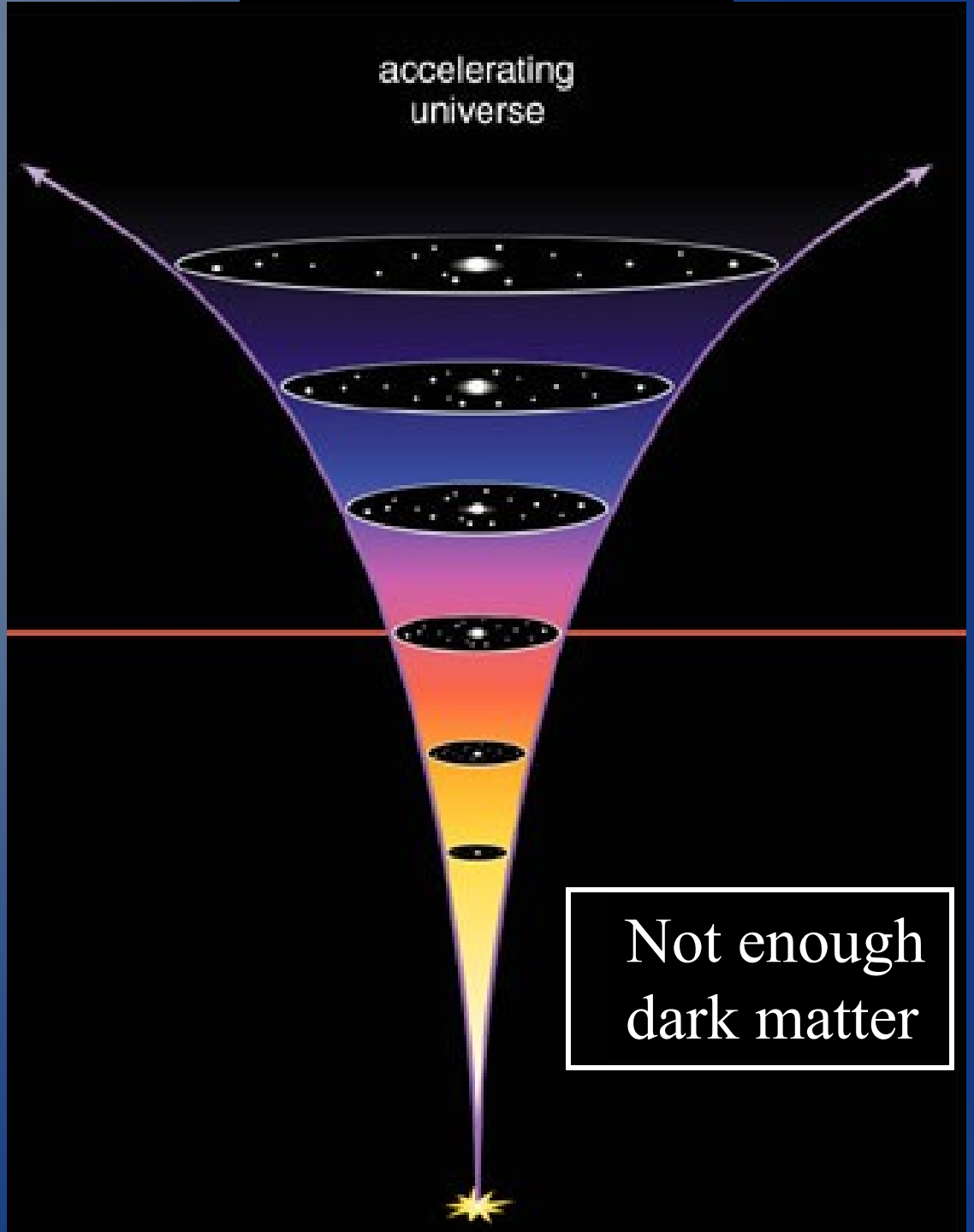
Fate of universe depends on amount of dark matter

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



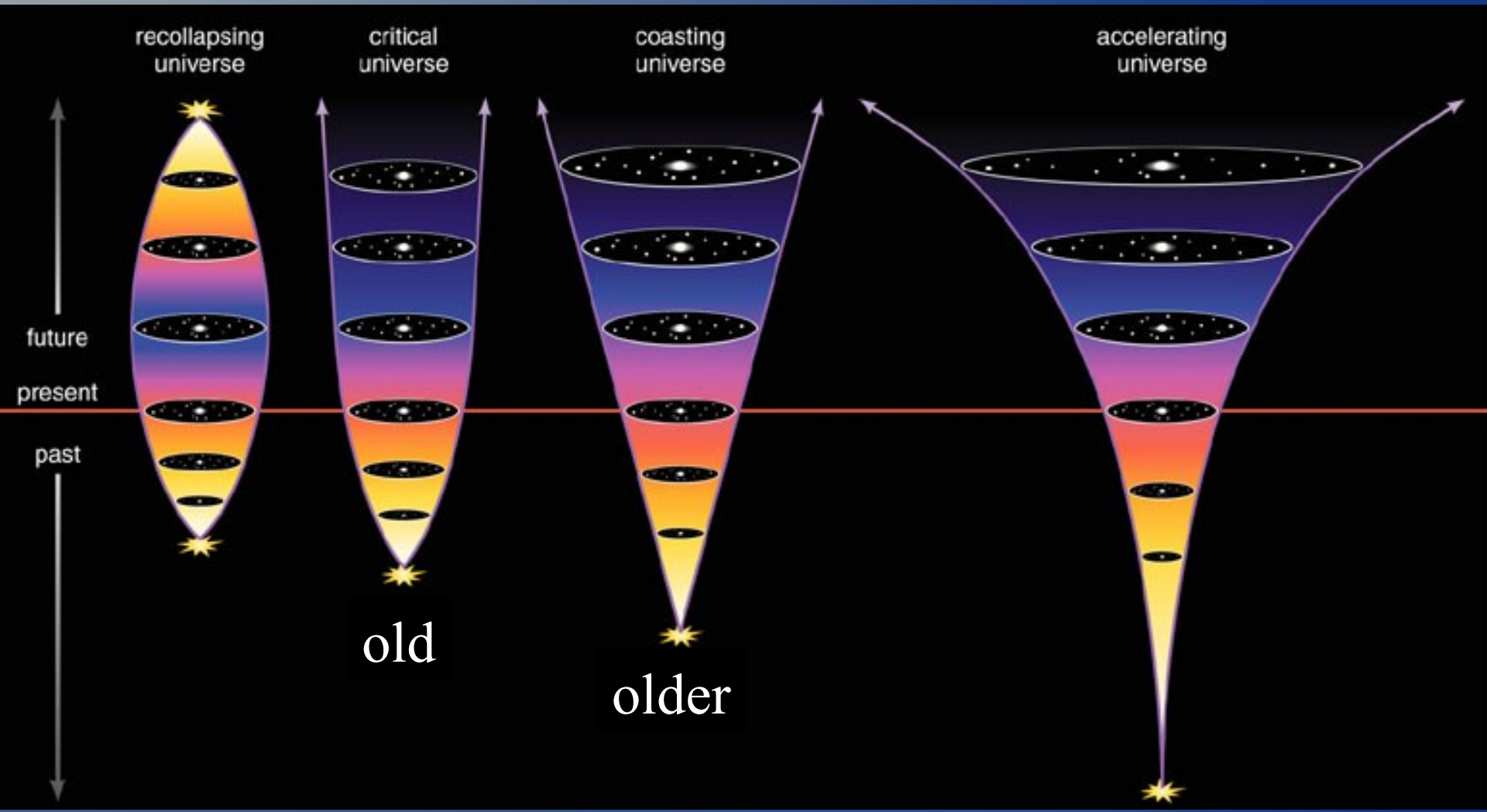
Not enough dark matter

But expansion is speeding up!



Dark Energy!

Not enough dark matter



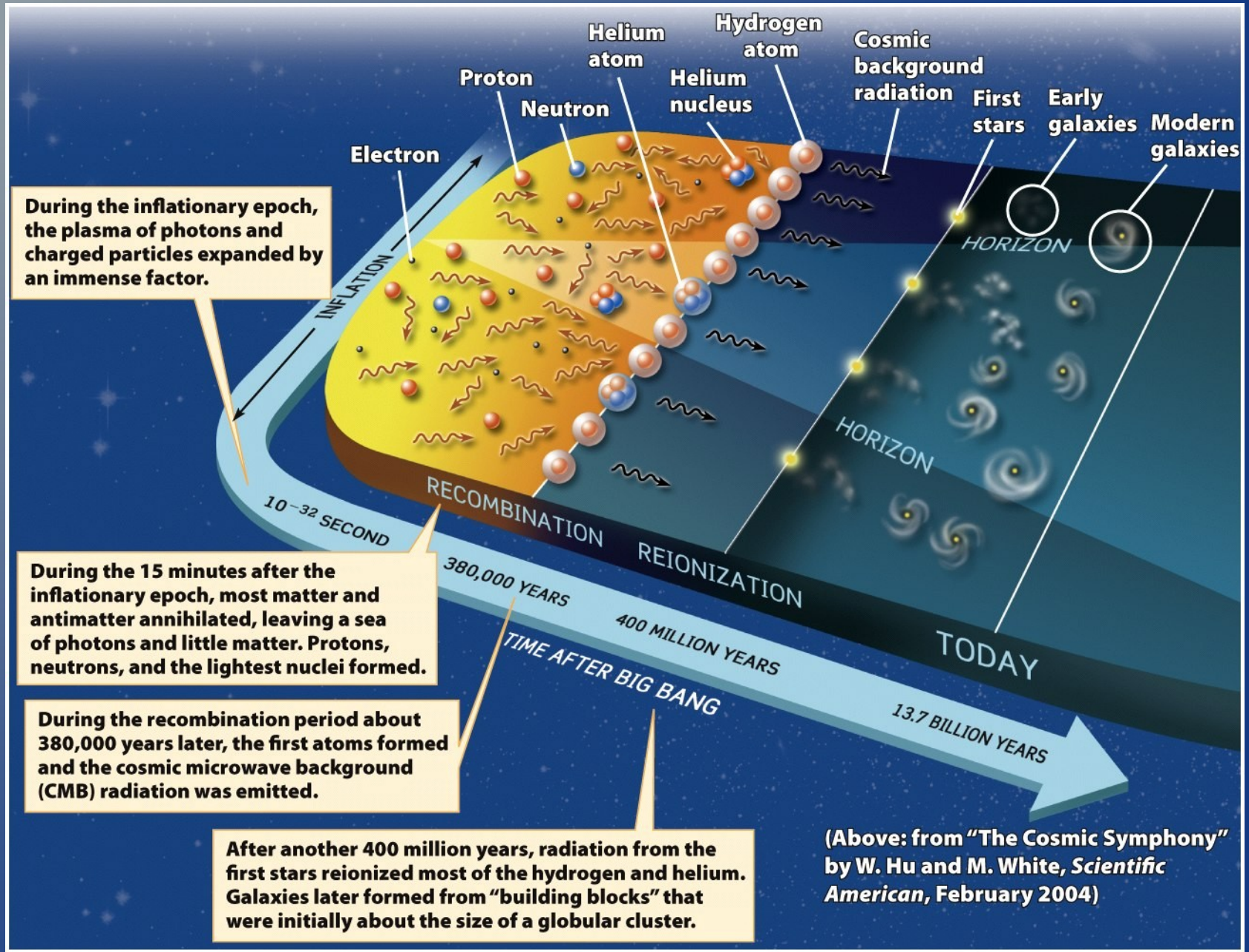
Estimated age of universe
depends on dark matter & dark energy

Dark Energy

- We can measure how fast our universe is expanding today (Hubble's Law), and how much dark matter slows the expansion
- We can measure how old the universe is (ages of the oldest stars, for example)
- The above measurements lead to the conclusion that the expansion of our universe is accelerating
- Our universe must be dominated by dark energy (= whatever causes the acceleration)

The Universe in 2009

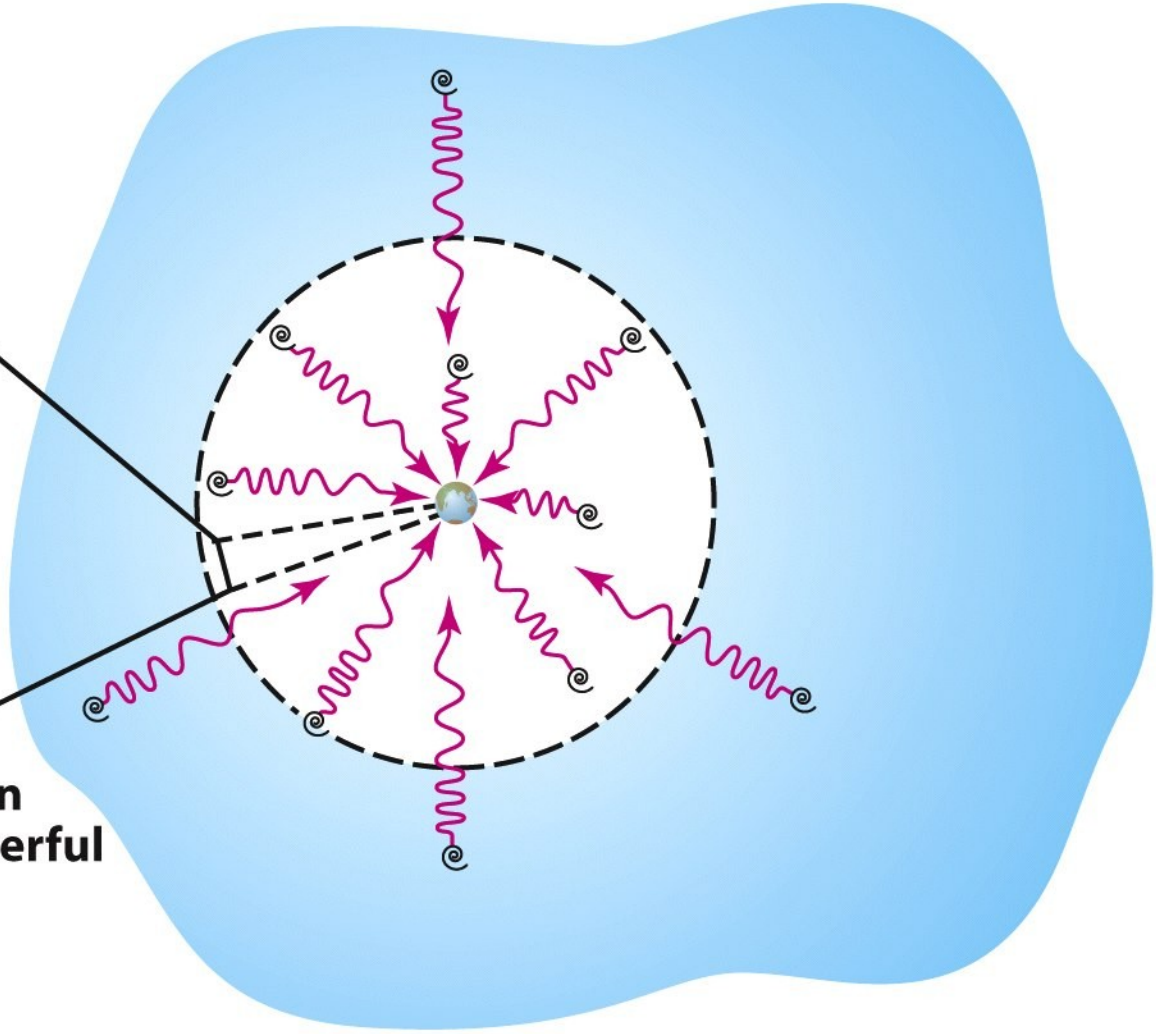
- We know the Universe's age (13.7 billion years)
- We know that since the Big Bang, the gravity of dark matter has pulled all kinds of matter into galaxies (and galaxy groups, clusters, etc.).
- We don't know what most dark matter is. It's not just neutrinos. If it is a supersymmetric particle, it could be detected soon by the LHC.
- We know that the universe is expanding, and that the expansion is accelerating: dark energy.
- We don't know much at all about dark energy!



Cosmic Connections 27a
Universe, Eighth Edition

The Big Bang and our Universe

- The Big Bang was a point in time, not in space
- The physical universe has no centre or edge
- The observable universe is centred on us: we observe light from everything that was within 13.7 billion light years of our current location when the universe became transparent. Next year, we'll see 1 light-year farther away.

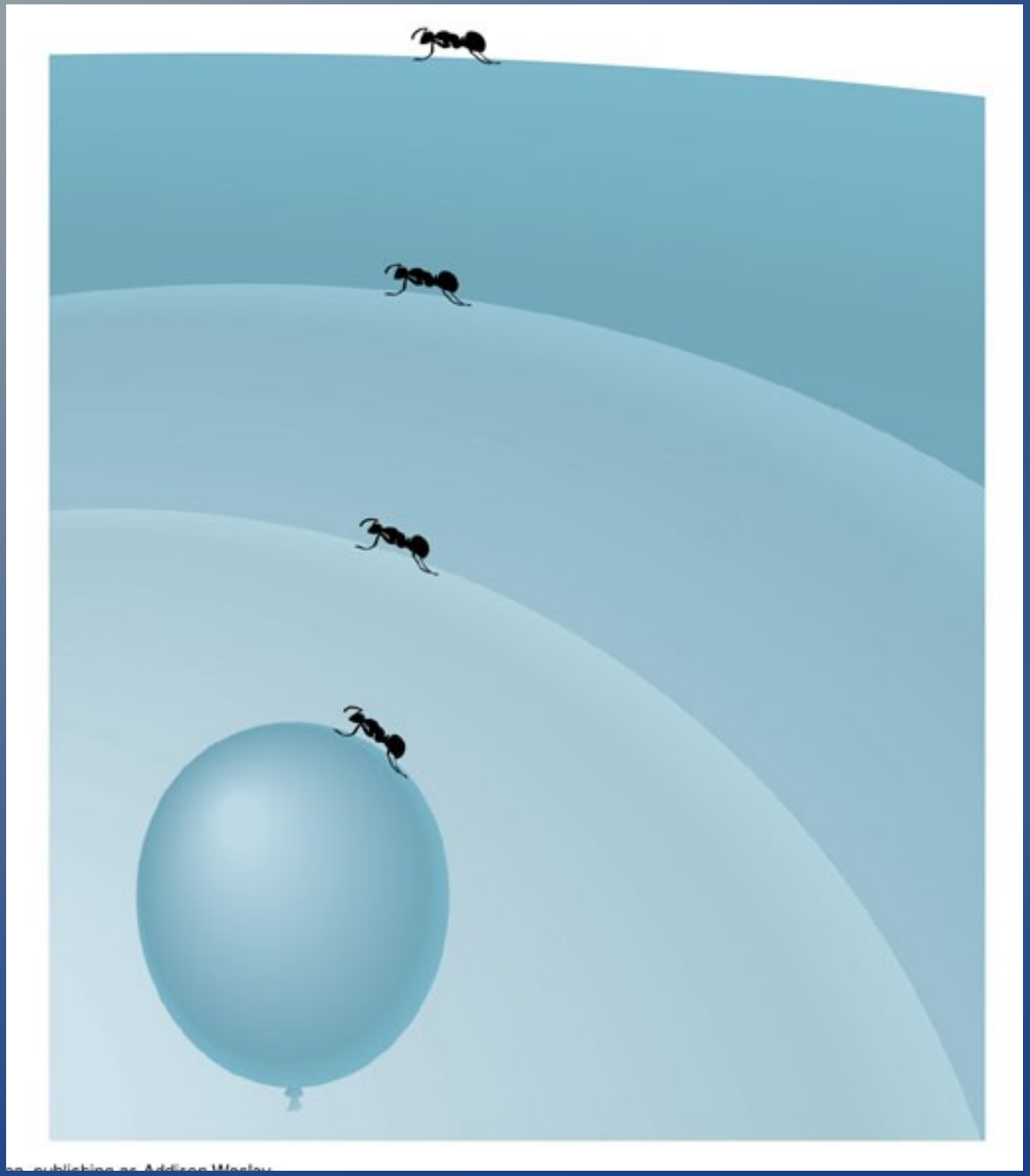


All of the objects that we can see with even the most powerful telescopes lie within our observable universe.

Figure 26-5
Universe, Eighth Edition

The Big Bang and our Universe

- The Big Bang was a point in time, not in space
- The physical universe has no centre or edge
- The observable universe is centred on us: we observe light from everything that was within 13.7 billion light years of our current location when the universe became transparent. Next year, we'll see 1 light-year farther away.
- *The ultimate zero-sum game? The universe's positive mass-energy plus its negative potential energy (three kinds: gravitational, electroweak, strong-force) can sum to zero.*



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

(Could there be island universes in a long, thin balloon?)

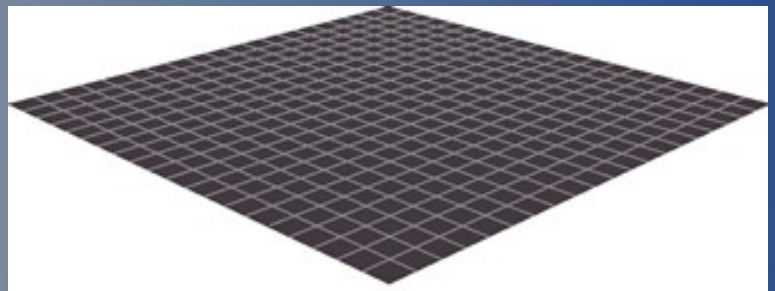
Thinking about our universe

- Our three-dimensional universe appears very close to flat (1 part in 50 at the moment), as well as infinite (infinite in all spatial directions)
- Inflation predicts our universe is very close to flat (probably at the level of 1 part in 100,000)
- If the universe is that flat, for all intents and purposes it is exactly flat, and we may never know whether our universe started out exactly flat or curved (positively or negatively)
- *(2-dimensional analogies: zero curvature = infinite piece of paper; positive curvature = like a balloon; negative curvature = like a Pringle)*

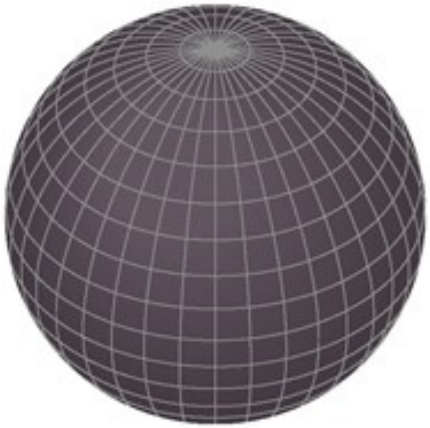
Density = Critical

Density > Critical

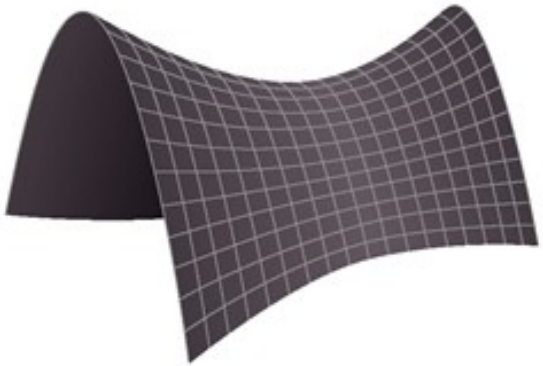
Density < Critical



flat (critical) geometry

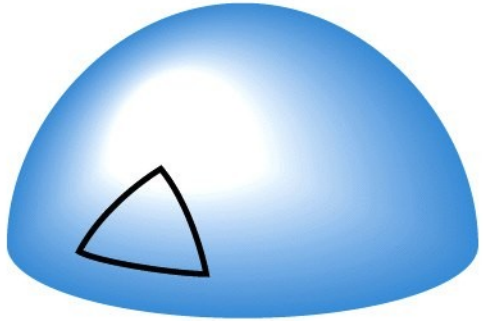


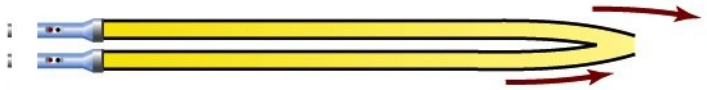
spherical (closed) geometry



saddle-shaped (open) geometry

Overall geometry of the universe is closely related to total density of matter & energy

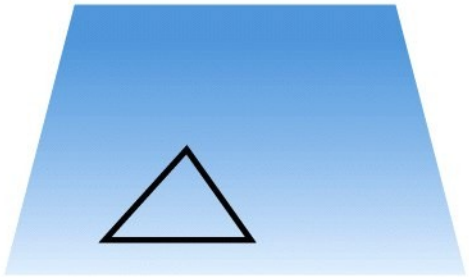


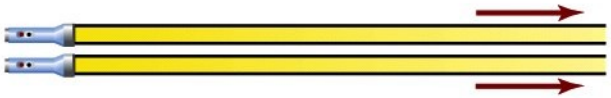


Parallel light beams converge

(a) Spherical space

$\rho_0 > \rho_c$, $\Omega_0 > 1$

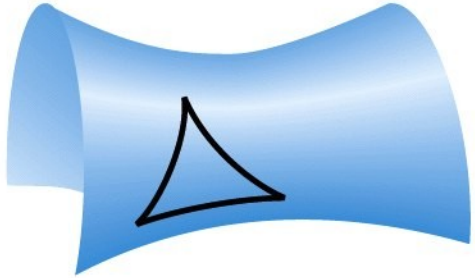


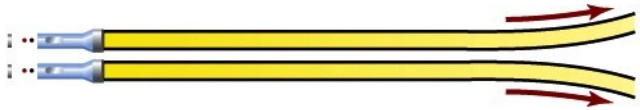


Parallel light beams remain parallel

(b) Flat space

$\rho_0 = \rho_c$, $\Omega_0 = 1$



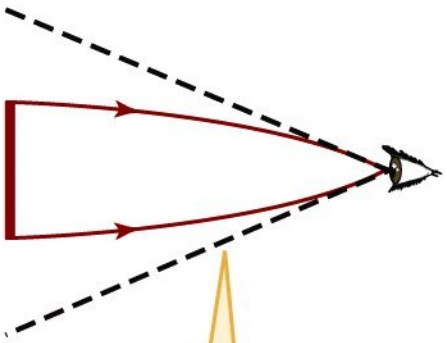


Parallel light beams diverge

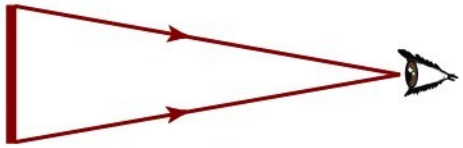
(c) Hyperbolic space

$\rho_0 < \rho_c$, $\Omega_0 < 1$

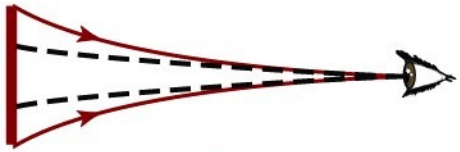
Figure 26-15
Universe, Eighth Edition



If the universe is closed, light rays from opposite sides of a hot spot bend toward each other …

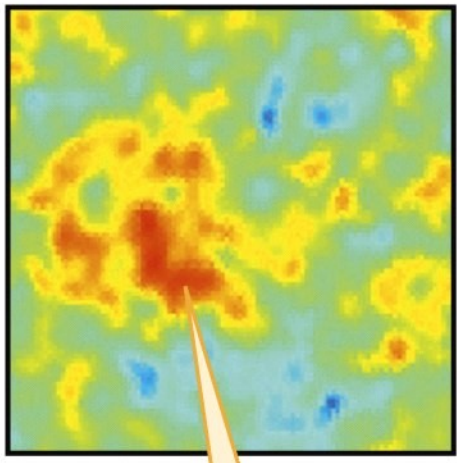


If the universe is flat, light rays from opposite sides of a hot spot do not bend at all …



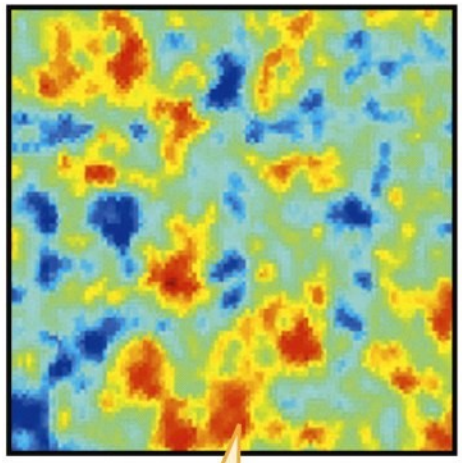
If the universe is open, light rays from opposite sides of a hot spot bend away from each other …

(a)



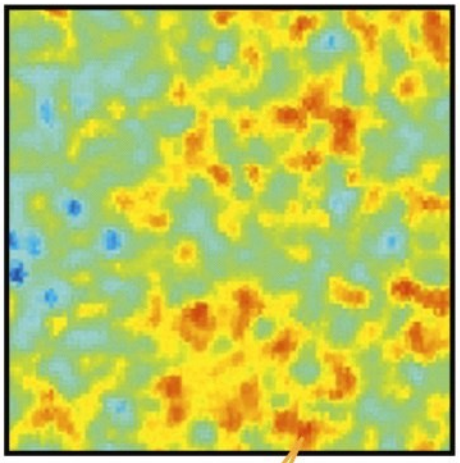
… and as a result, the hot spot appears to us to be larger than it actually is.

(b)



… and so the hot spot appears to us with its true size.

(c)



… and as a result, the hot spot appears to us to be smaller than it actually is.

Figure 26-16
Universe, Eighth Edition