Arthur: You know, it’s at times like these, when I’m trapped in a Vogon airlock with a man from Betelgeuse, and about to die from asphyxiation in deep space that I really wished I’d listened to what my mother told me when I was young.

Ford: Why, what did she tell you?

Arthur: I don’t know, I didn’t listen.

The Hitchhiker’s Guide to the Galaxy

Group Project due on Friday.

Quizzes16, & 17 still to do.

Total pre-last-test points posted by May 1

On blackboard (total points column at the end)

NOTE: blackboard's "%" and "Total points" at the top will be incorrect but your individual grades and point total column I'm adding at the bottom should be correct.

Total in-class points: 690
Lab points: 230
Total Points: 920
A: 920-824, B:823-732, C:731-639

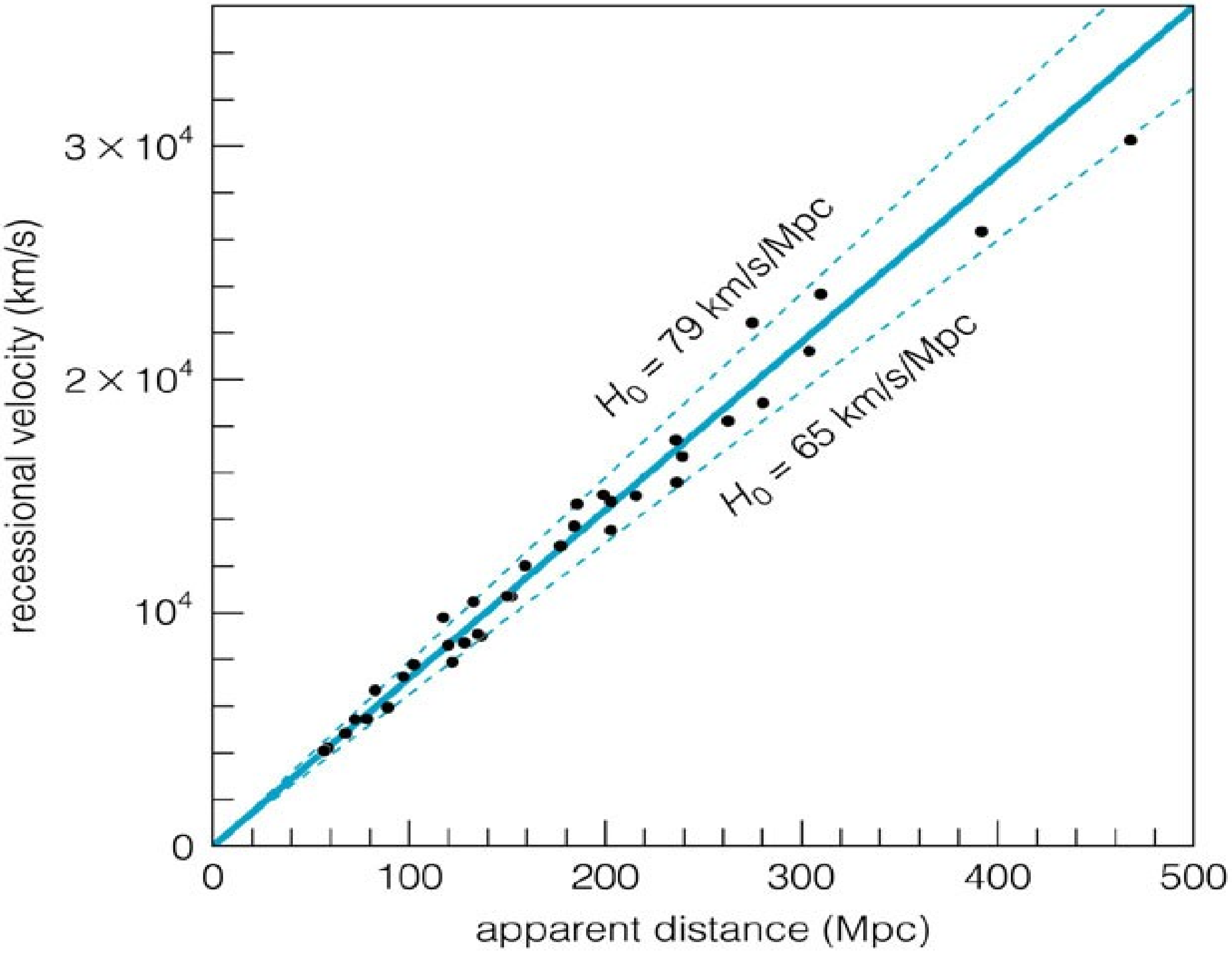
We will NOT MEET during our final time. I will be available on **zoom** during test time **(Wednesday, May 8 11am-1pm)**, in case you wish to take the test in a 'live' setting.

Test 3 and the Comprehensive Final will be on blackboard.

Tests will be timed: Test 3 has 60 minutes, Comprehensive Final has 120 minutes.

Tests will be available May 1 until May 8 @1pm

Expanding Universe



Distance indicator: $D = v/H_o$ using $H_o = 73.8$ km/s/Mpc

$H_o = 1/s$ or 1/timeAge of the Universe!

About 14 billion years.

Take-aways

*Our Universe began as an incredibly dense, bunch of energy, too hot for matter to exist

* Freaky expansion occurred early on to make our Universe *homogeneous and isotropic*.

* heavier particles (protons & neutrons) ‘froze’ out of the energy first, then the lighter ones (electrons)

*The Universe was hot enough to be a nuclear furnace, but deuterium prevented it early on. Then this furnace produced He (~23%).

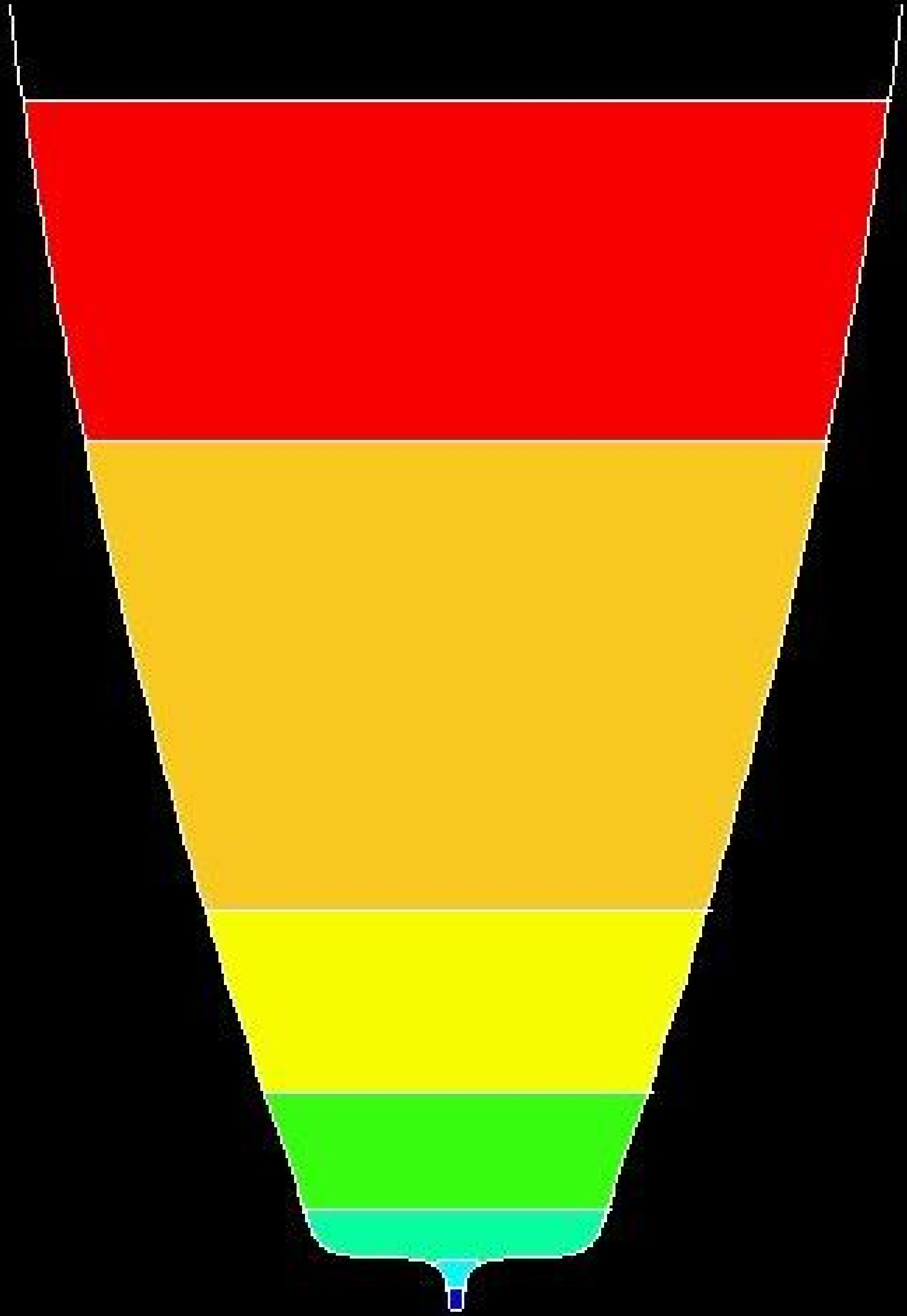
*The Universe became too cool to produce any particles or do fusion, but still very hot.

*After ~300,000 years, the Universe cooled to become the dark skies we know now. Big Bang Theory ends here!

*Eventually stars, galaxies, planets, and people formed.

Gravity first: Universe is made of only energy.
Inflation: Still only energy
Quarks form
Protons/neutrons freeze out
Electrons freeze out: deuterium bottleneck
Nucleosynthesis begins
Nucleosynthesis ends H+He
Recombination: CMB

Stars form
Galaxies form
Our solar system forms
Humans evolve to question where the Universe came from.



The scientific principle

Big Bang theory predictions.

Big Bang predictions which have been observed

1) Expanding Universe

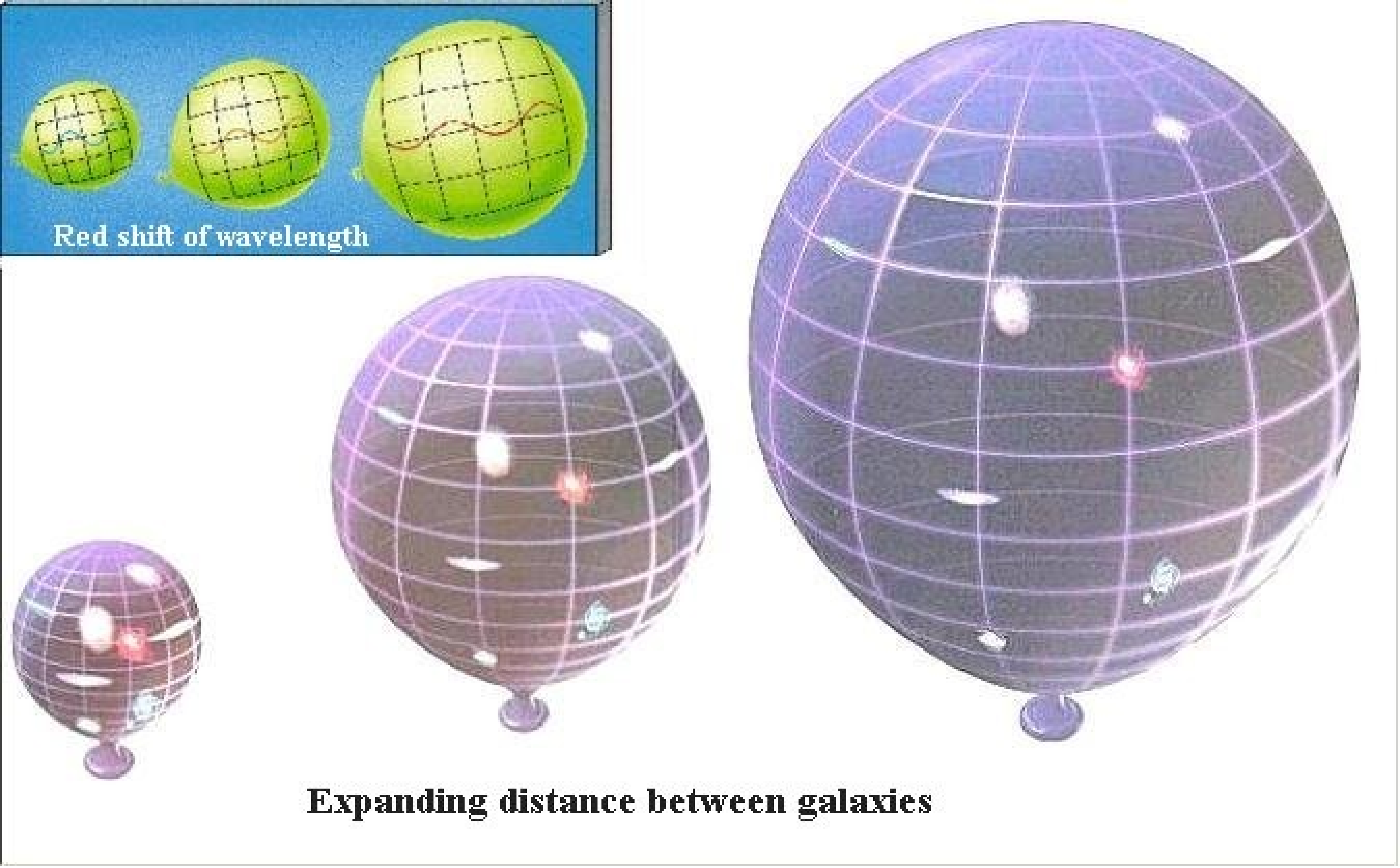
2) Nucleosynthesis: 75%H, 25% He, no ‘metals’ (Pop III stars)

Big Bang predictions #3

At recombination (when electrons and protons could stick together to form neutral atoms), the Universe became essentially transparent to light. The Universe fell below 3,000K, so photons now had less than 13.6 eV (the amount required to strip an electron from hydrogen).

From $E=hc/\lambda$ (with hc=1240 eV-nm) we get

λ=91.2nm. This is in the UV



Those photons would have had their wavelengths stretched by cosmic expansion.

Big Bang predictions #3

Recombination should have made cosmic radiation.

If we assume that the Universe is roughly as old as the oldest stars, and that it's been expanding at the speed of light for that time, we can determine how much the original UV (91.2nm) photons have stretched.

Big Bang predictions #3

In 1965, Robert Dicke and Jim Peebles at Princeton estimated that *if* the Big Bang model was correct, there should be many lingering photons, which they calculated would be cooled from 3,000K to about 3K. This would stretch the UV photons to microwave wavelengths.

They began to build a telescope to find them.

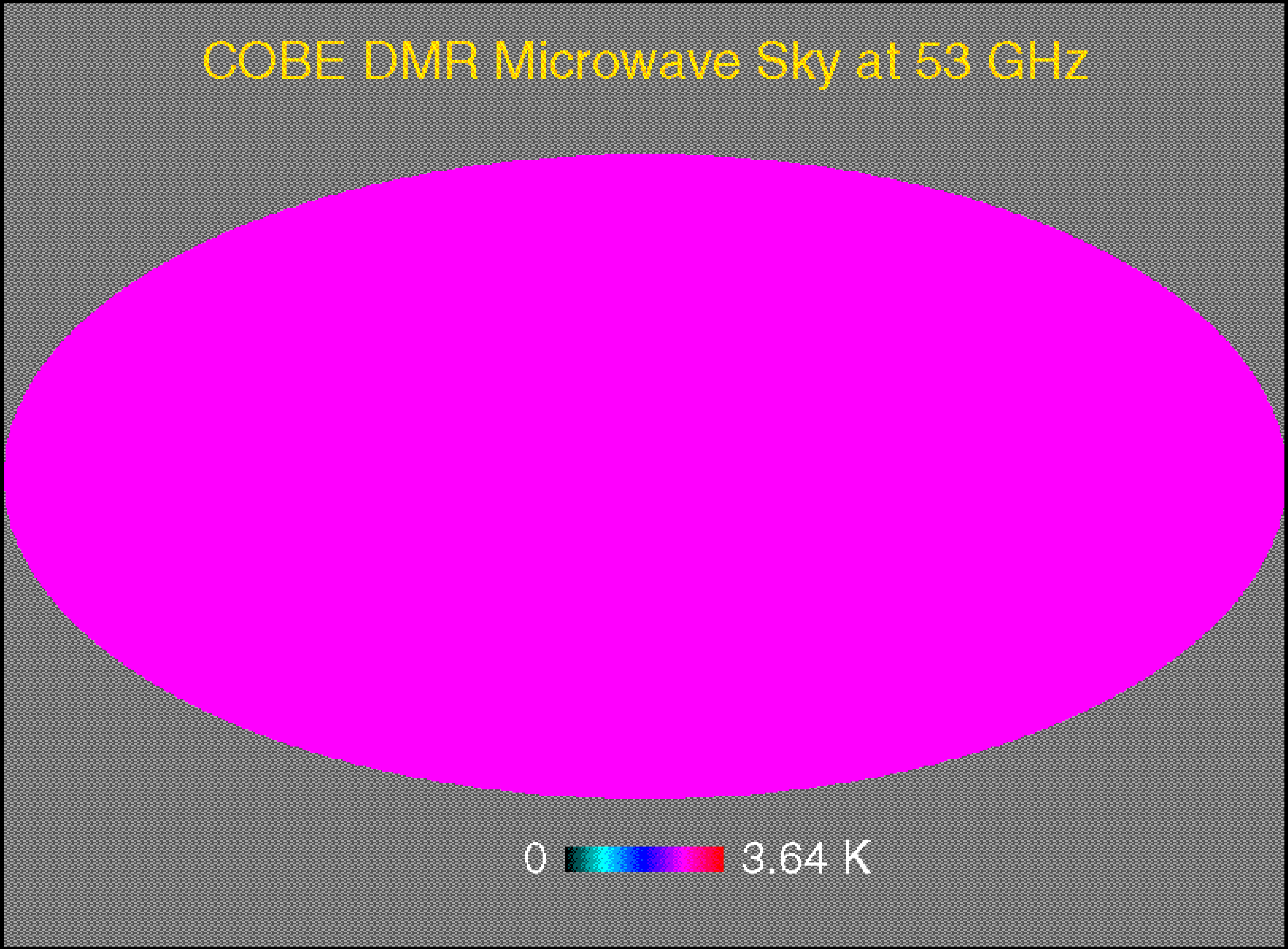
Big Bang predictions #3

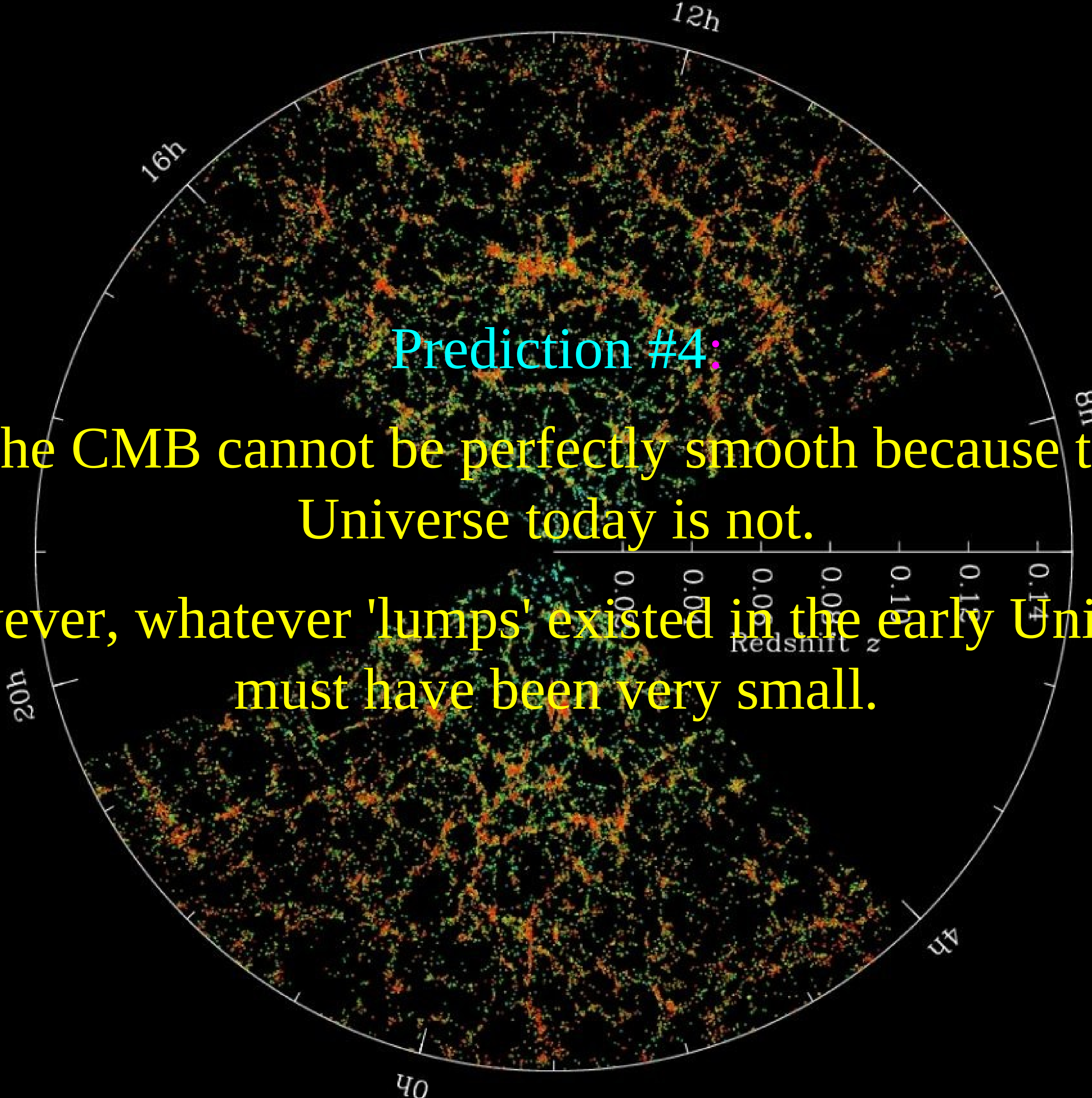
Unfortunately for Dicke and Peebles, such a telescope was already built at Bell labs, and two engineers, Arnio Penzias and Robert Wilson detected a "noise" at 2.7K.

They had discovered the radiation from recombination (of the Big Bang).

Penzias and Wilson won the Noble Prize; Dicke and Peebles did not.

The cosmic microwave background. A picture of the Universe when it first became transparent. It is impossible to take an earlier picture of the Universe (using photons).



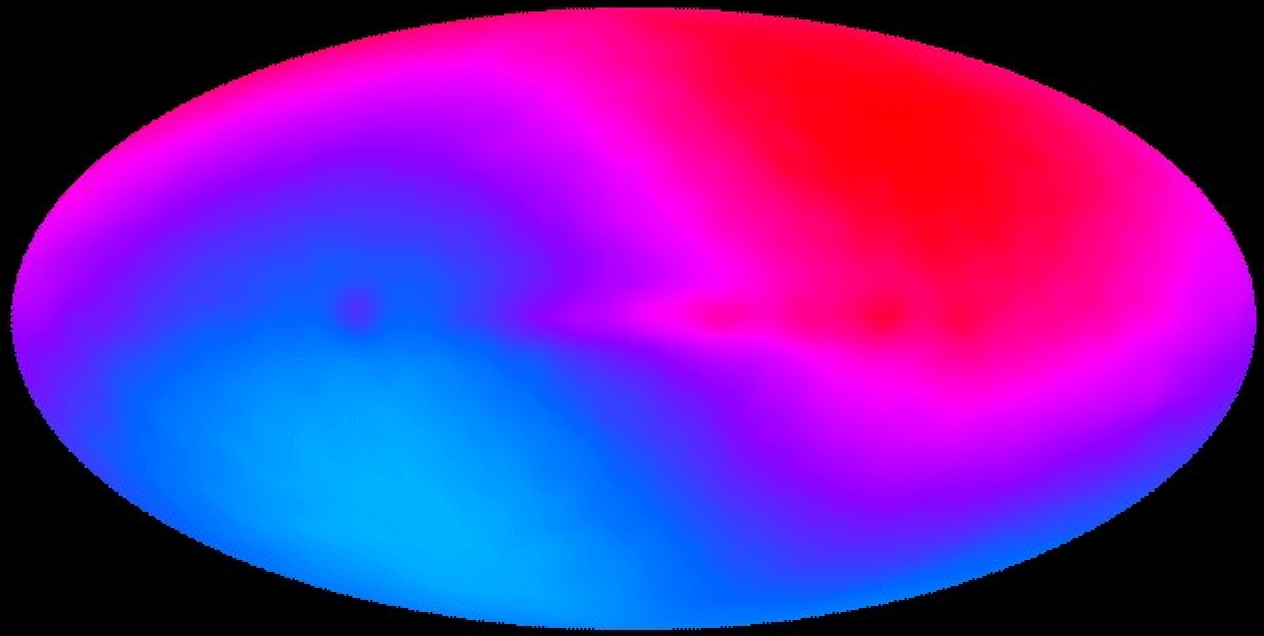


Prediction #4:

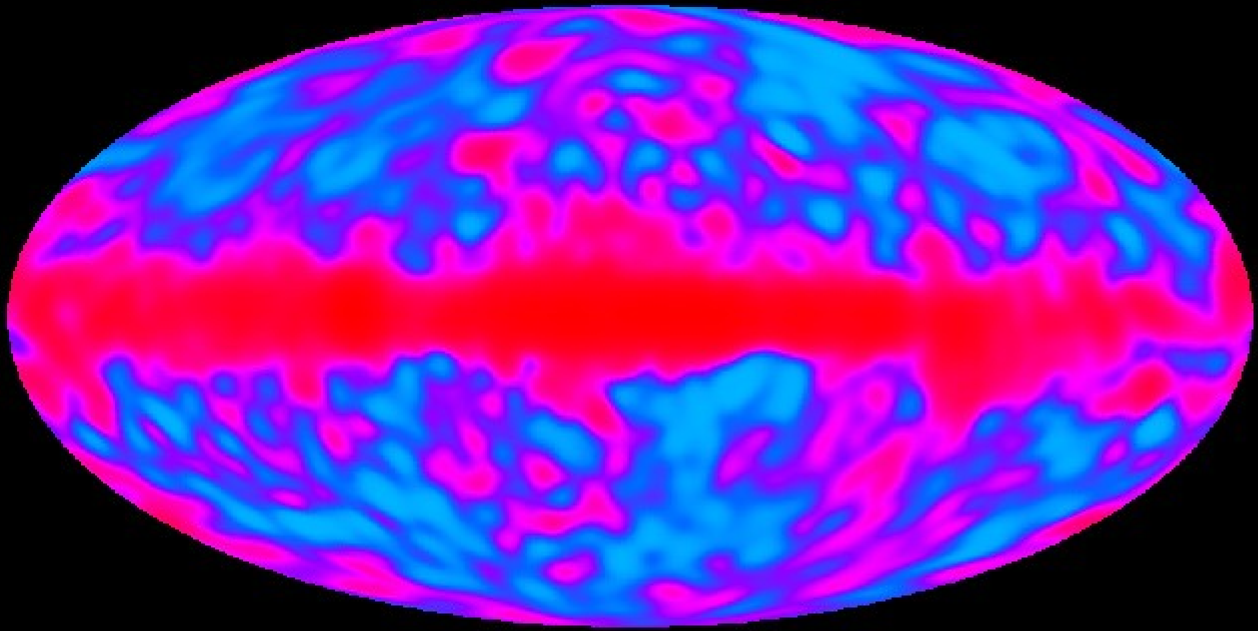
The CMB cannot be perfectly smooth because the Universe today is not.

However, whatever 'lumps' existed in the early Universe must have been very small.

These variations are caused by the motion of our galaxy (600 km/s) towards the Virgo cluster. In front of us, it's blueshifted, behind us, redshifted.

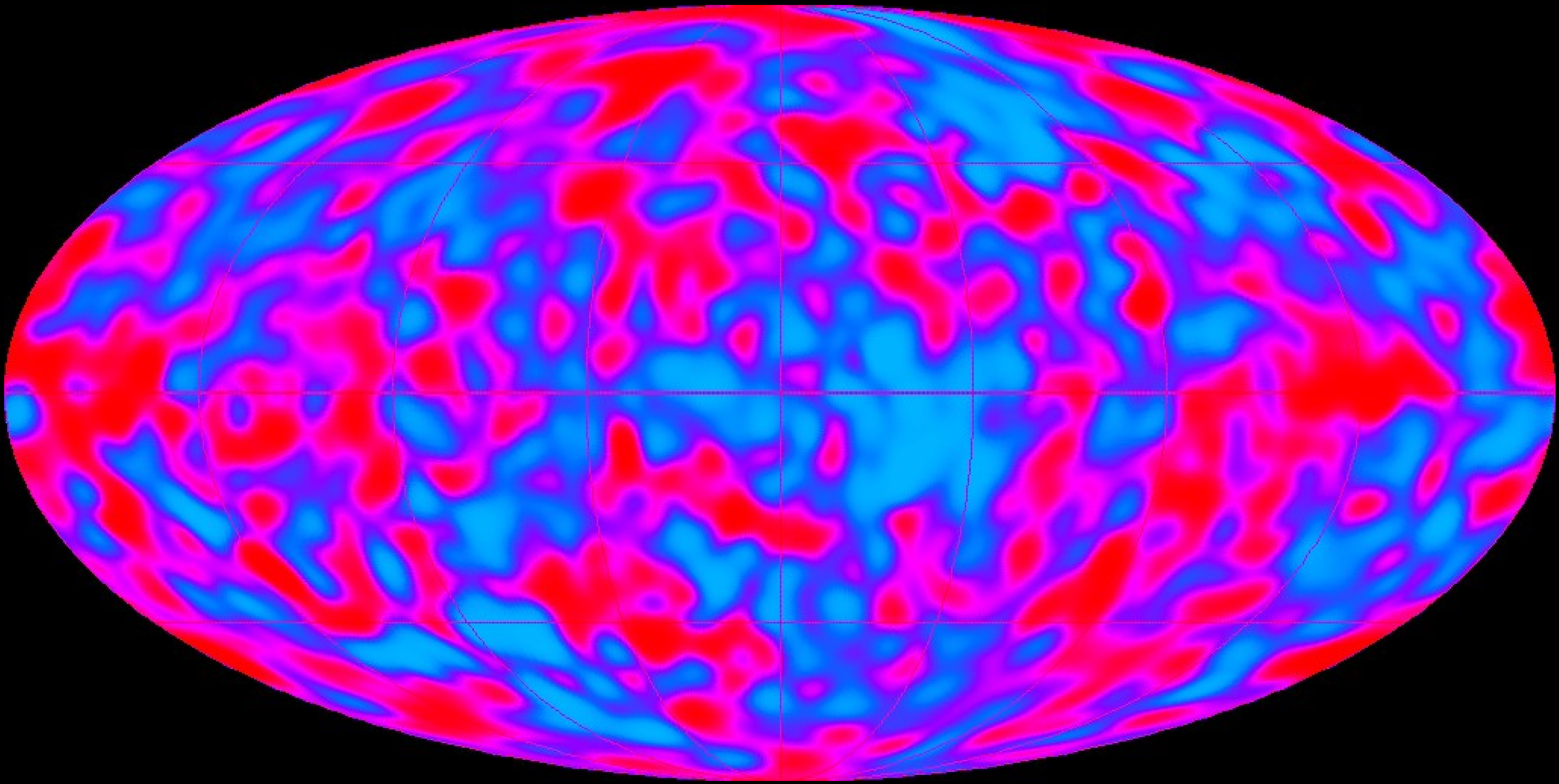


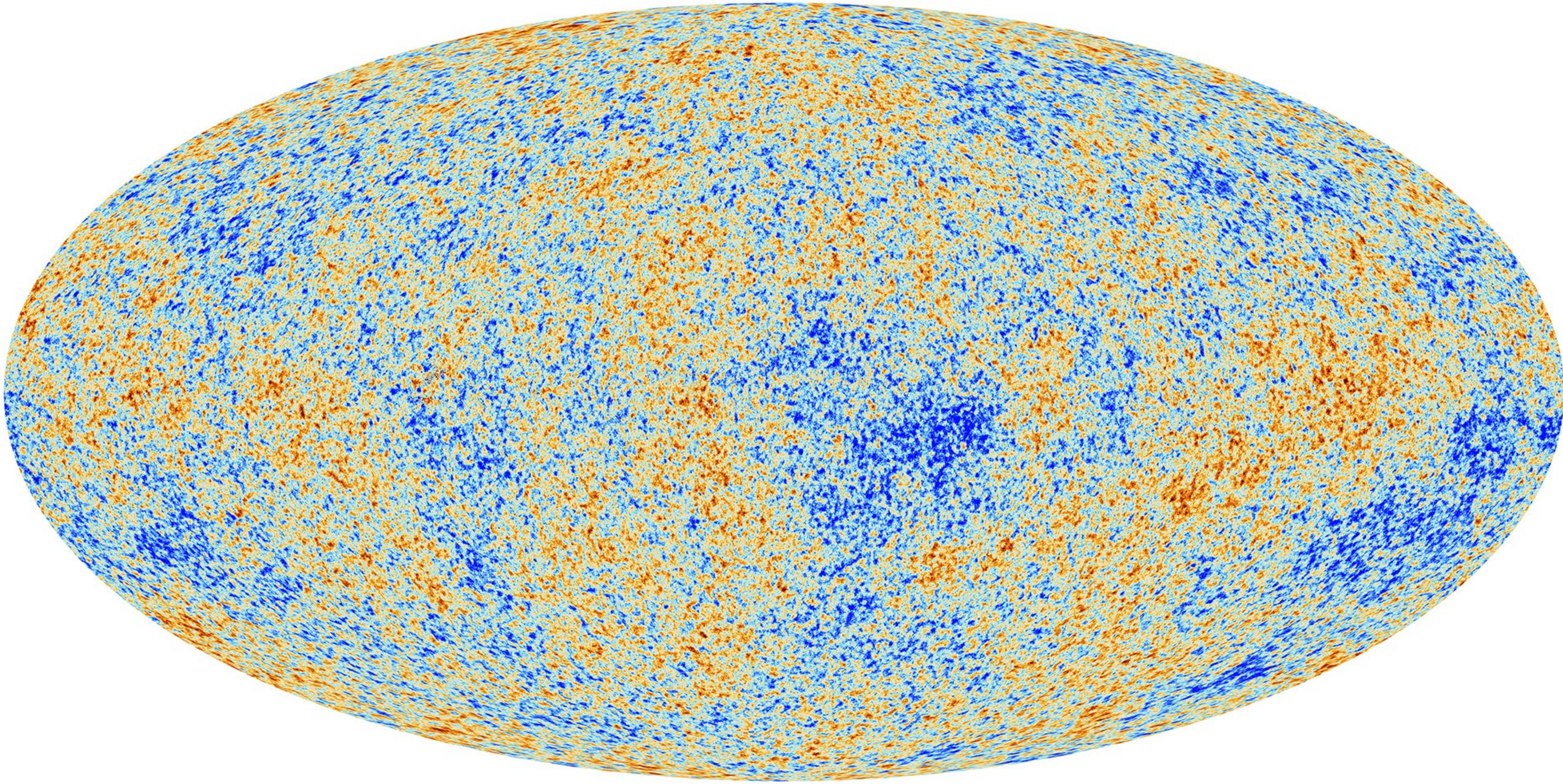
Once we correct for our motion in the Universe, this is the updated picture.



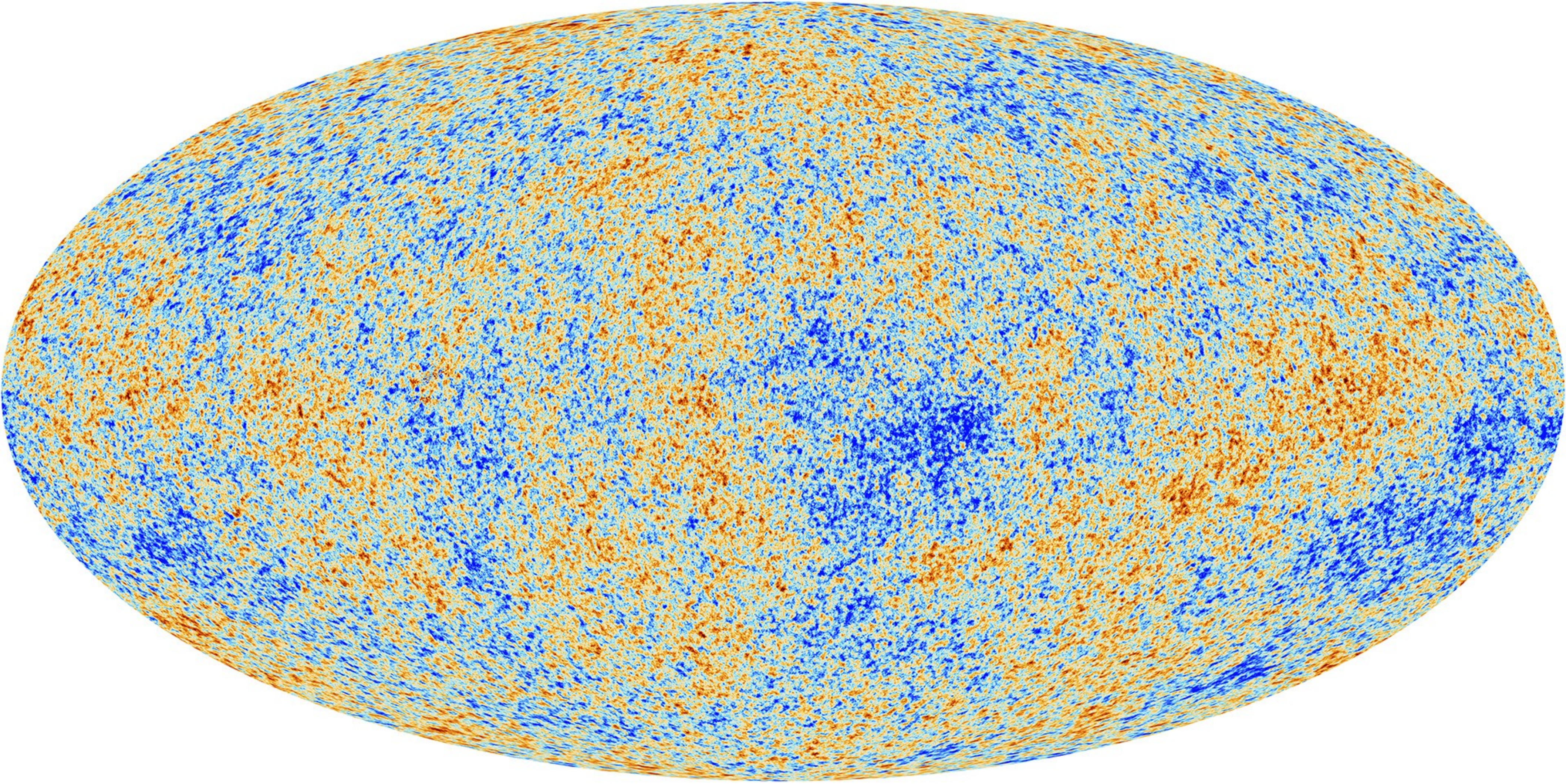
The red strip through the middle is emission by our own galaxy.

Here's a more modern picture.. There are tiny fluctuations in the microwave background at 1 part in 100,000.





Our best picture of the CMB so far.



Notice the 2 different sizes.
These will be important later on.

Big Bang Predictions: which have been observed

- The Universe is expanding: as seen by galaxies moving away from each other.
- Nucleosynthesis: The fraction of H/He and the evolution of 'metals' in stars indicates He was made during the big bang. The Universe could only make a certain amount of material other than H.
- Cosmic microwave background: The resounding echo of the Big Bang.
- Fluctuations in the cosmic microwave background: necessary to form galaxies and clusters of galaxies.

Big Bang Theory

These (and other) predictions make the Big Bang theory the predominant theory for the formation of our Universe. However, it is not the only theory, and it may not end up being the correct theory.

Time to do homework 4

Take out your homework and put other items away please.

Do not talk or share answers.

Question 1: What are the characteristics of stars in the bulge of a spiral galaxy?

A) Pop I, organized orbits.
B) Pop I, random orbits
C) Pop II, organized orbits
D) Pop II, random orbits.

Question 2: What of galaxy is in the picture?

A) Elliptical.

B) Spiral

C) Irregular

D) None of the above.

Question 3: What of galaxy is in the picture?

A) Elliptical.

B) Spiral

C) Irregular

D) None of the above.

Question 4: What of galaxy is in the picture?

A) Elliptical.

B) Spiral

C) Irregular

D) None of the above.

Question 5: What of galaxy is in the picture?

A) Elliptical.

B) Spiral

C) Irregular

D) None of the above.

Question 6: What of galaxy is in the picture?

A) Elliptical.

B) Spiral

C) Irregular

D) None of the above.

Question 7: What of galaxy is in the picture?

A) Elliptical.

B) Spiral

C) Irregular

D) None of the above.

Question 8: The planet HD149026b is 77pc from us. What year did the light we see today leave that planet??

A) 1947 (77 yrs ago)
B) 1774 (250 yrs ago)
C) 2047 BC (4071 yrs ago)
D) 2024

Question 9: What is the distance to a galaxy moving at 250,000 km/s?

A) 74 Mpc
B) 247 Mpc
C) 3,400 Mpc
D) 9,200 Mpc

Question 10: What is the consequence of running the Hubble expansion backwards?

A) The Big Bang (one place, one time)

B) The Earth gets older.

C) Stars get more ‘metals’.

D) Local groups of galaxies fall into clusters.

E) Nothing. The Universe stays the same.

Question 11: What is the distance to a galaxy moving at 6,500 km/s?

A) 88 Mly

B) 287 Mly

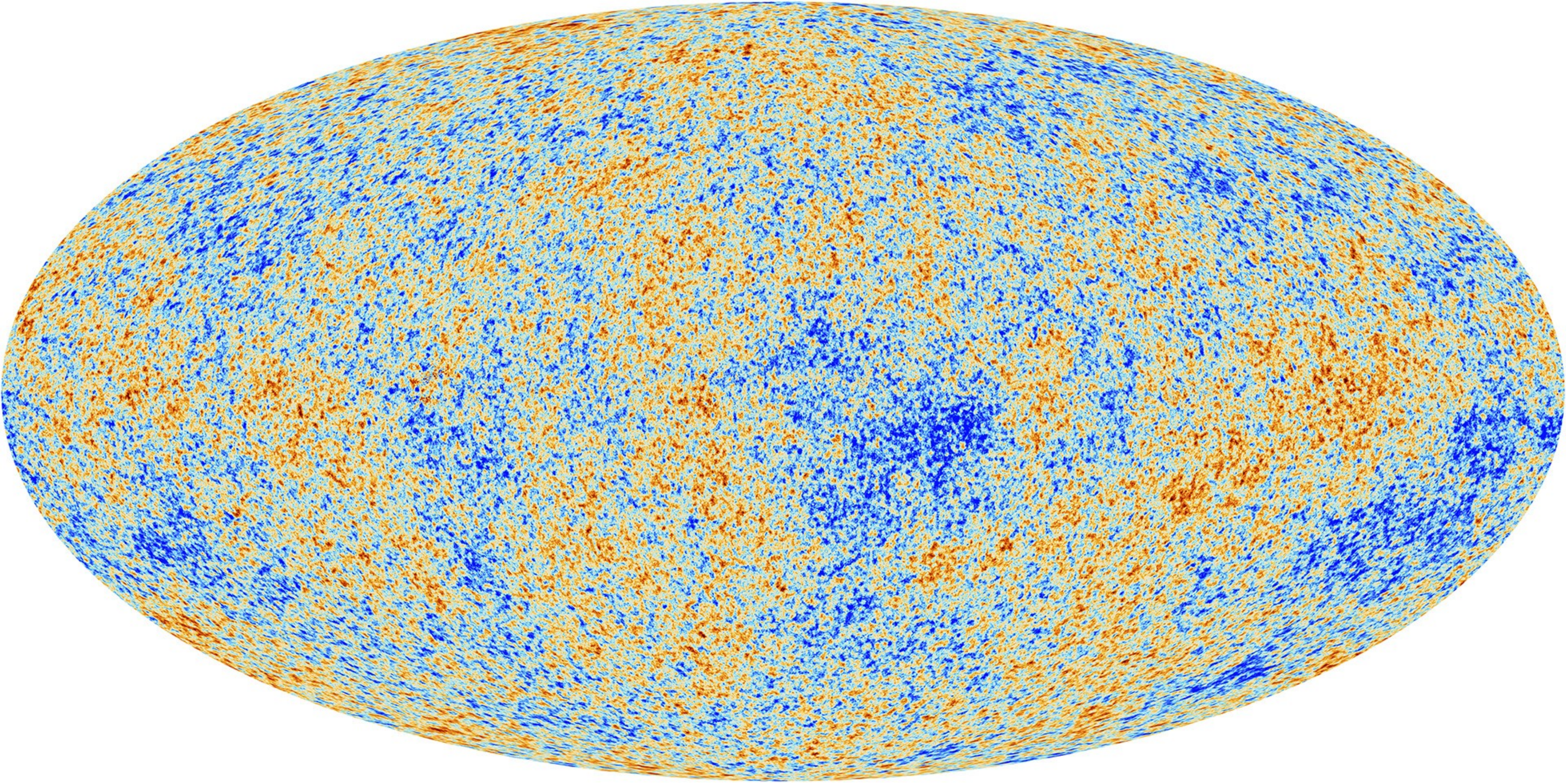
C) 3,400 Mly

D) 9,200 Mly

Turn in your paper copy. Be sure your name (first and last) are on it and your row letter.

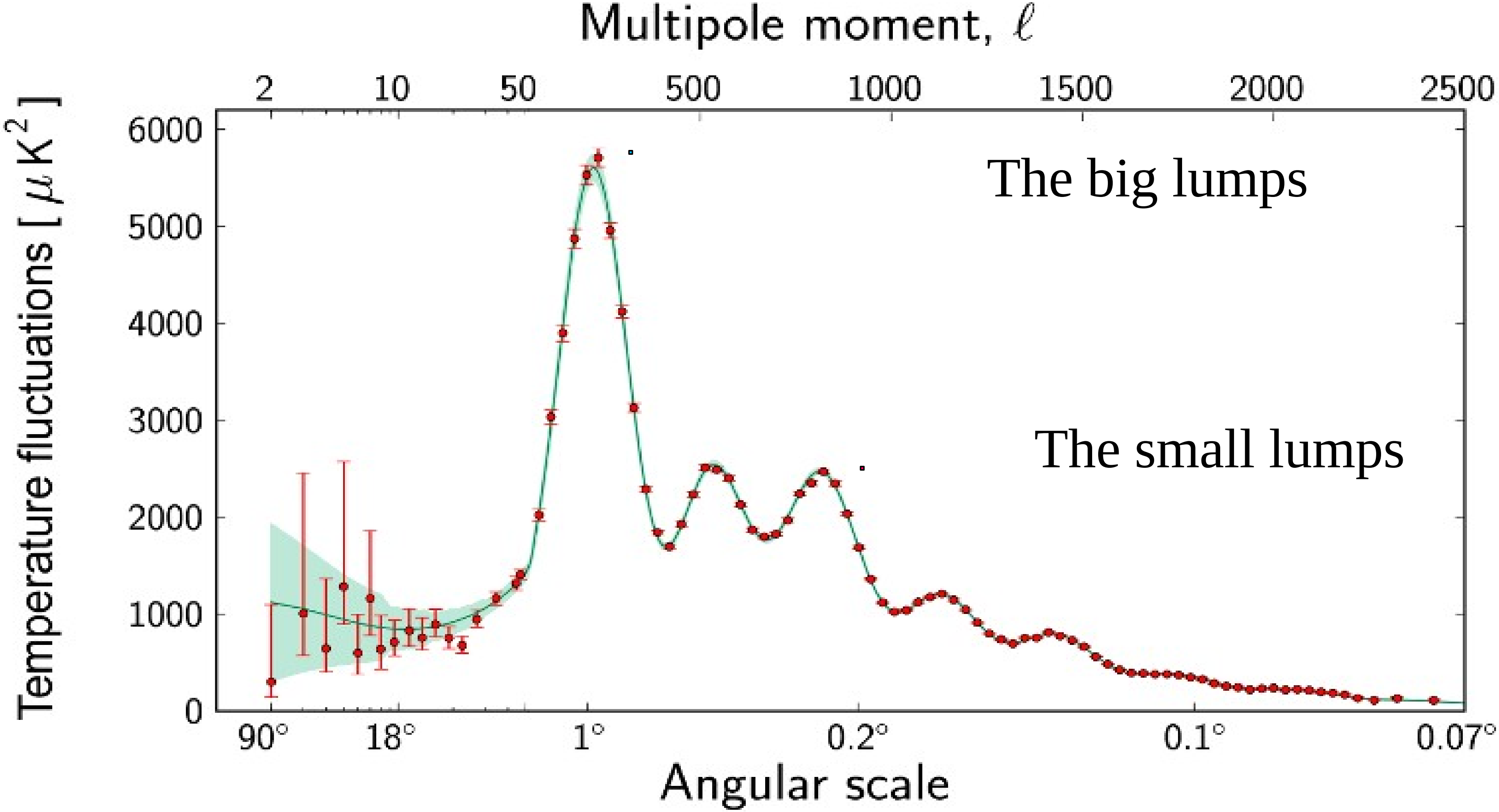
They will be passed back and solutions posted next Monday.

Pass it to your right, please.



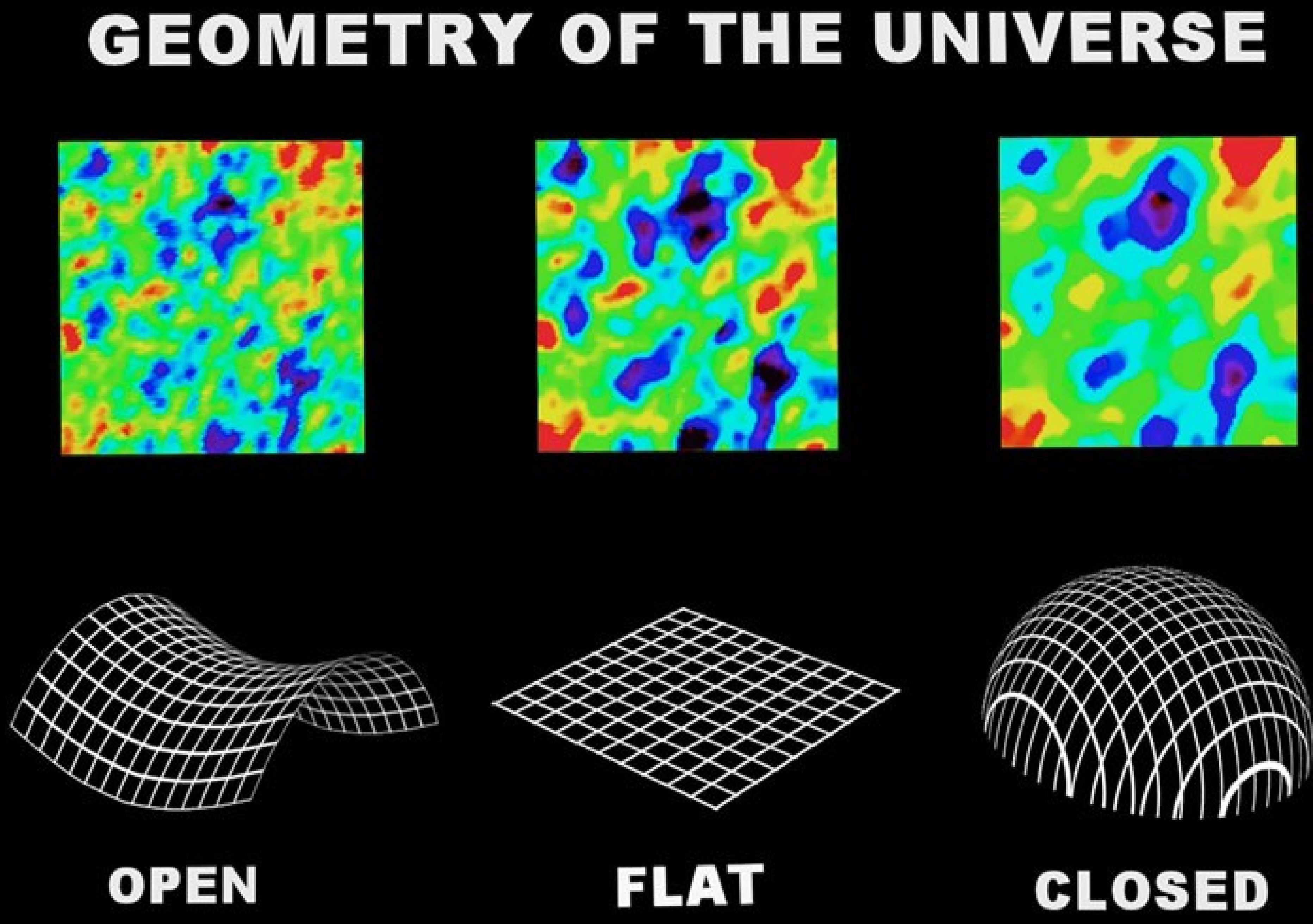
Notice the 2 different sizes.
These will be important later on.

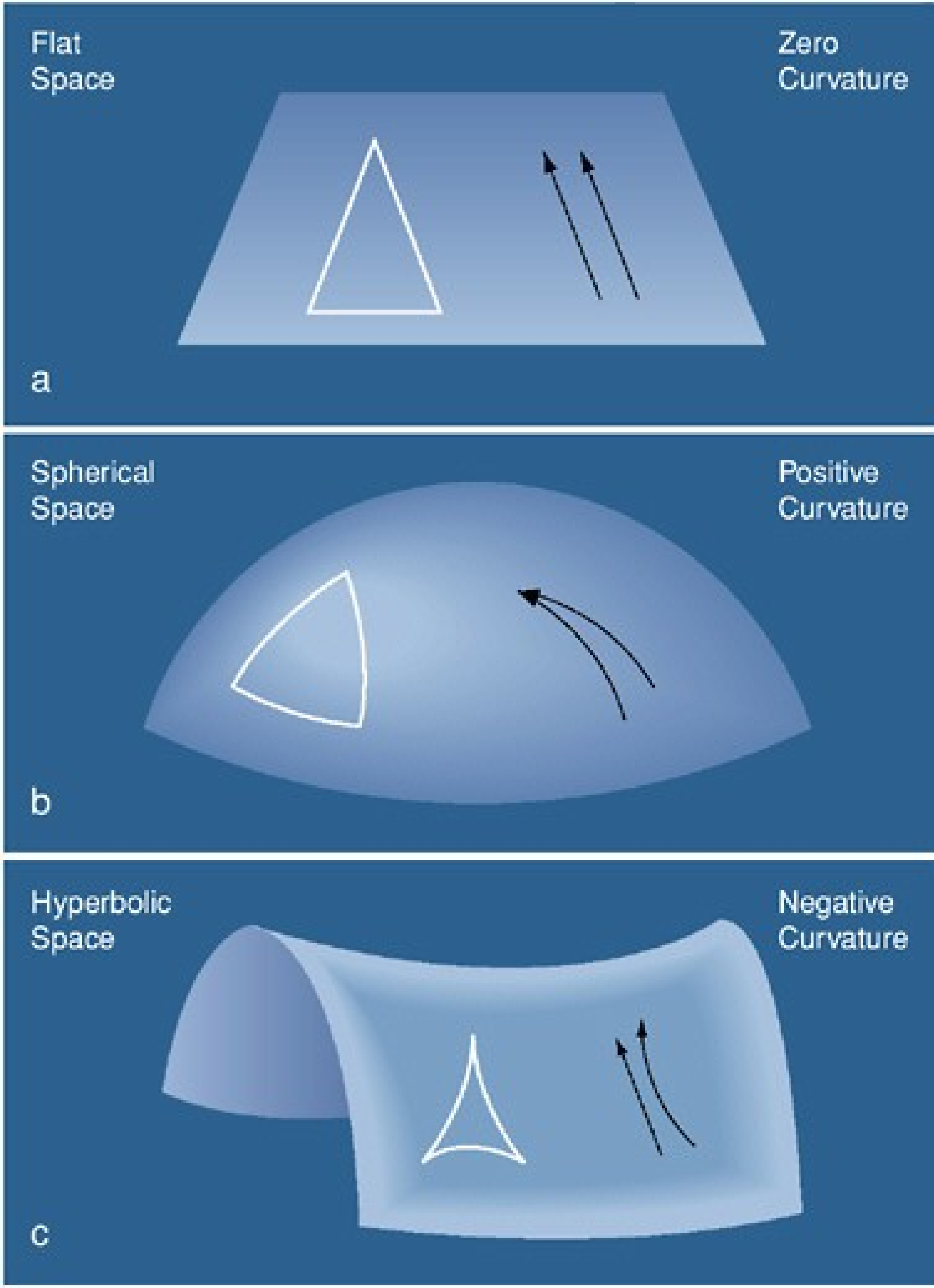
Lump sizes in the CMB. The extra lumps tell us about the Universe

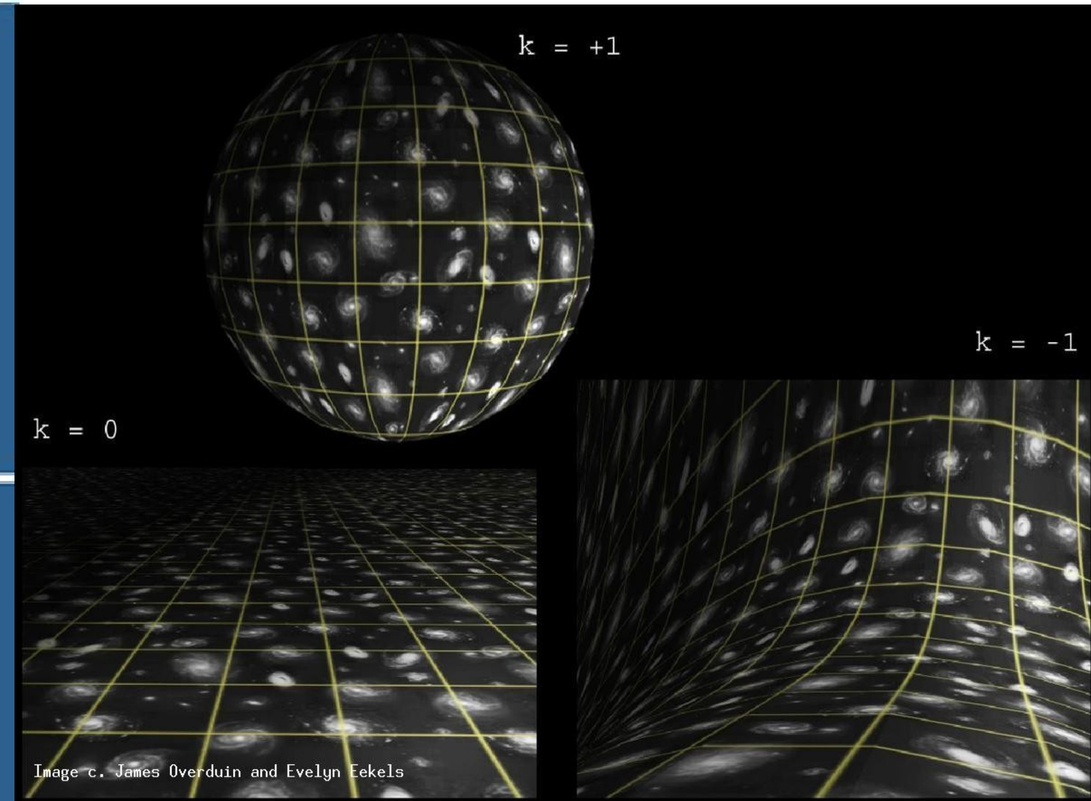


The shape of our Universe

From fluctuations in the CMB, we can also model the shape of our Universe.


GEOMETRY OF THE UNIVERSE
OPEN
FLAT
CLOSED


Flat Space
Zero Curvature
a
Spherical Space
Positive Curvature
b
Hyperbolic Space
Negative Curvature
c


k = +1
k = -1
k = 0
Image c. James Overduin and Evelyn Eekels

So the current answer is flat.

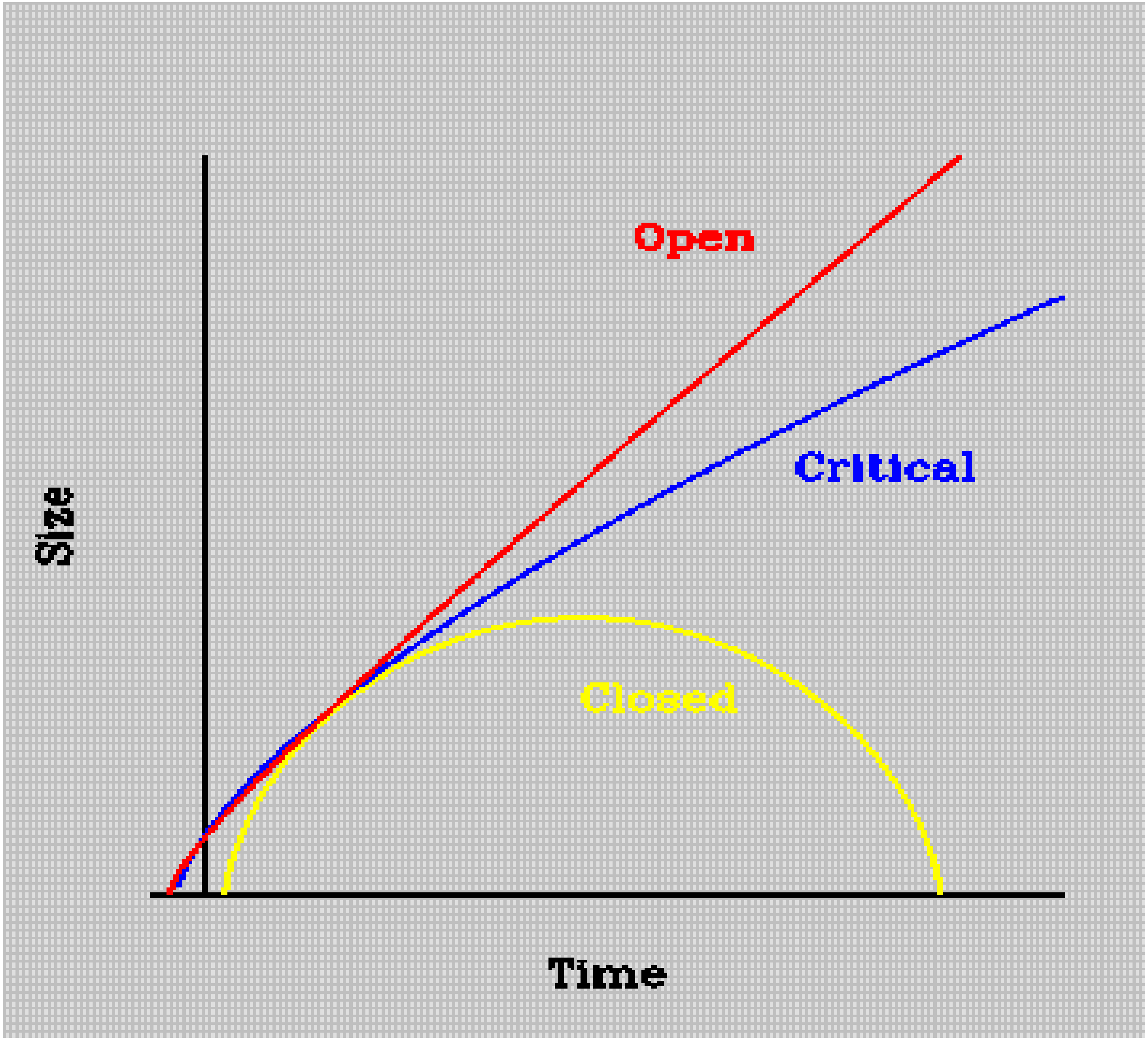
This answer depends on models, which use other evidence too, which I will show later.

The future of our Universe

Evidence strongly suggests the Universe began with the Big Bang,
it is currently expanding,
what about the future?

3 possible fates of our Universe.

- Continues to expand forever.
- Gravity stops the expansion and the Universe collapsing back down into the "Big Crunch" sometimes called the “gnab gib”.
- Gravity exactly balances the expansion- the critical case.


Open
Critical
Closed
Size
Time

How do we know which case is correct?

What force(s) will decide?

How do we know which case is correct?

Determine how fast galaxies are moving away from each other. Determine how much force would be required to stop them. Put enough mass into the Universe such that gravity can provide that force.

How do we know which case is correct?

This gives you an amount of mass needed to stop expansion. Spread that mass out over the size of the Universe (what we think it is now) and you get the critical density.

✈$_{crit}=10^{-29}$g/cc

(1 proton in a box 46 cm wide)

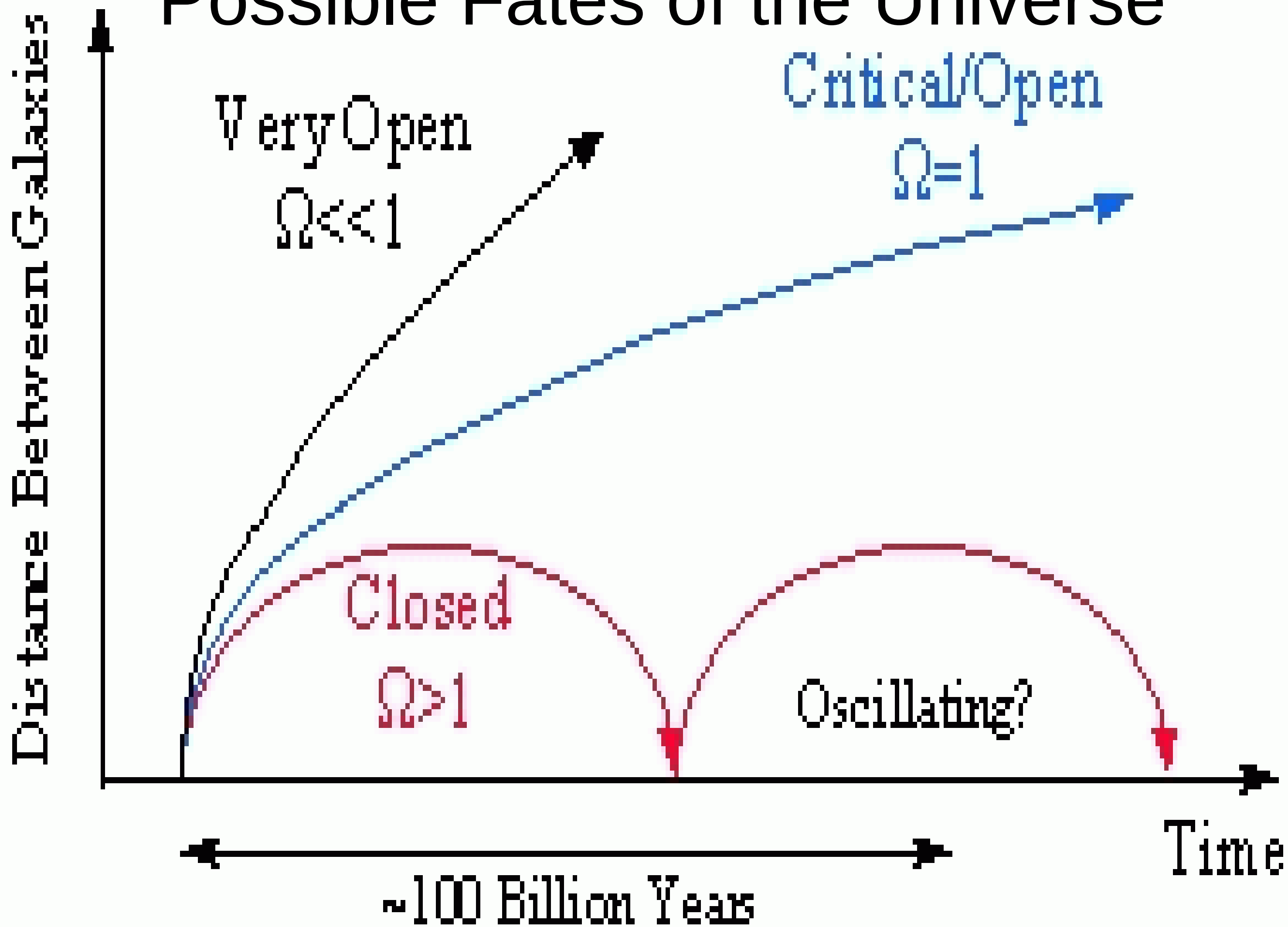
0.0000000000000000000000000000001 g/cc

New Term

⊗ = ✈🖶✈$_{crit}$

That is, ⊗ is a measure of whether there is enough matter to close the Universe.

Possible Fates of the Universe



$\Omega = \rho/\rho_{crit}$ = the actual density over the critical density.