Left	Side	Left	Side	Right	Side	Right	Side
Last Name	First Name			Last Name	First Name		
LA		**LE**		**RA**		**RE**	
Smith	Jaihan	Green	Kailey	Oconnor	McKenna	Chabino	Conner
Hunt	Paige	Ehardt	Bella	Kolath	Caroline	Davis	Jackson
Holtgrewe	Emily	Brown	Tatianah	Stinnett	Nic	Gregory	Brinley
Gunalan	Purvez Vishnu	Ausler	Kiara	Hunt	Taylor	Shrimplin	Skylar
Barr	Abigail	Still	Martin	Adkins	Leo	White	Erin
LB		**LF**		**RB**		**RF**	
Tomczyk	Aaron	Swartz	Alicia	Morris	Riley	Petinaris	Joanna
Takeuchi	Fuka	Price	Elijah	Fernandez	Corey	Aleman	David
Lee	Tony	Davis	Samantha	Knight	Cassidy	Cherukumilli	Shan
Golovin	Anita	Pappageorge	Lauren	Coomes	Austin	Adams	Autumn
Byrum	Faith	Bayer	Caeden	Tlustos	Travis	McPike	Aiden
LC		**LG**		**RC**		**RG**	
Stiers	Alexis	Stirewalt	Robert	Mongillo	Hailie	Yoss	Aaron
Prater	Zane	Wood	Noelle	Shell	Brookelynn	Lambeth	Gabe
Devkota	Bishwash	Thompson	Natalie	Hunter	Kris	Bowe	Ava
Ayers	Carley	Desmond	Sarah	Govero	Brady	Beezley	Claire
Keeney	Alex	Schott	Connor	Tucker	Kali	Ashlin	Bradley
LD		**LH**		**RD**		**RH**	
Fernandez	Elizabeth	Czeschin	Kyle	Saucedo	Brithny	Bourcier	Savannah
Burdette	Lily	Brown	Quincy	McGeough	Natasha	McBurney	Sullivan
Ziff	Caitlin	Todd	Ana	DeMeyer	Lauren	Jones	Justice
Rosentreter	Riley	Evans	Hannah	Stringer	Jason	Sauceda	Emma
Quinn	Jamie			Ellis	Alexander	Pike	Alena

Group Project due on Friday, in class, hardcopy.

Total in-class points: 690
Lab points: 230
Total Course 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

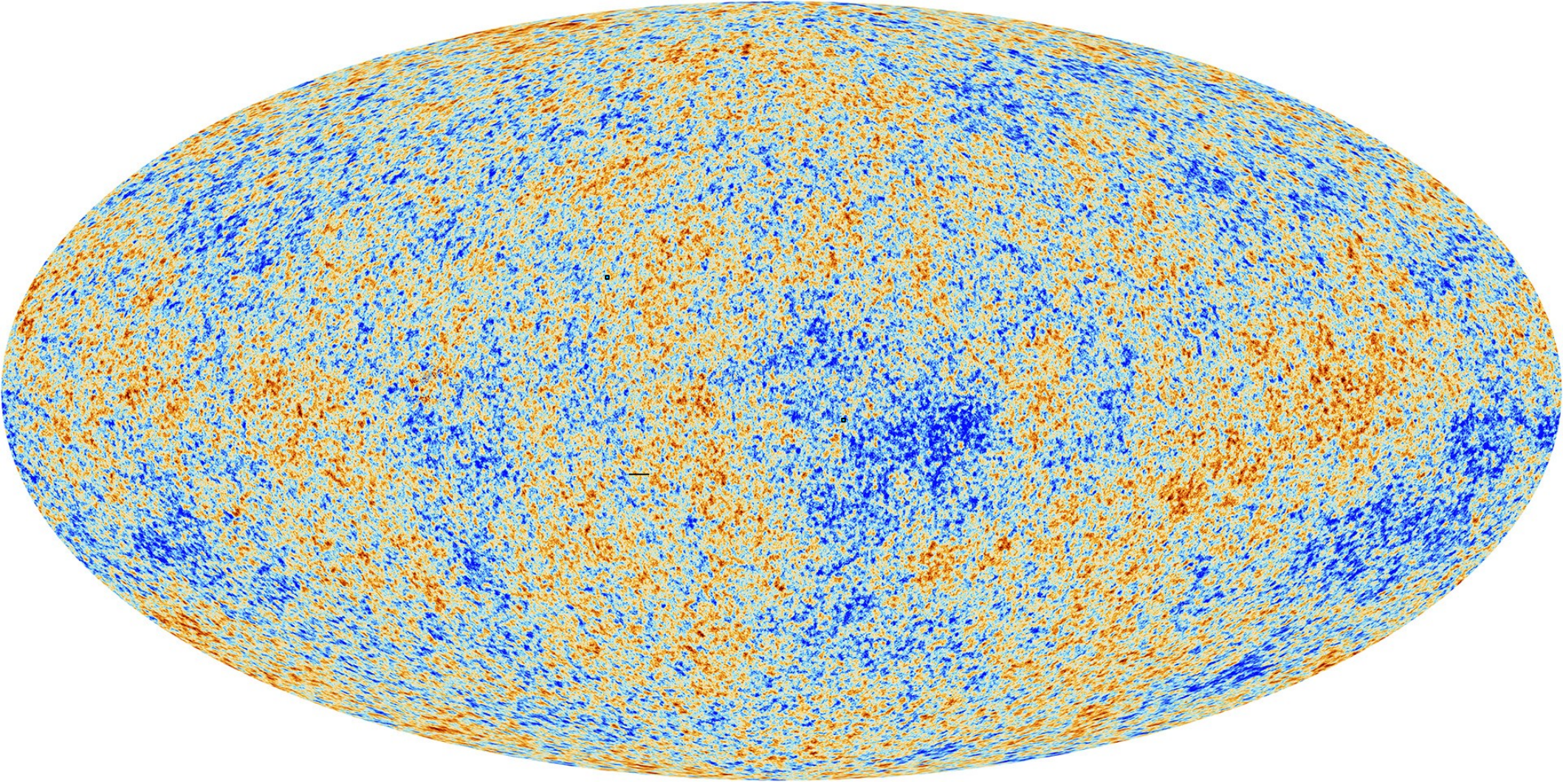
Big Bang predictions which have been observed

1) Expanding Universe

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

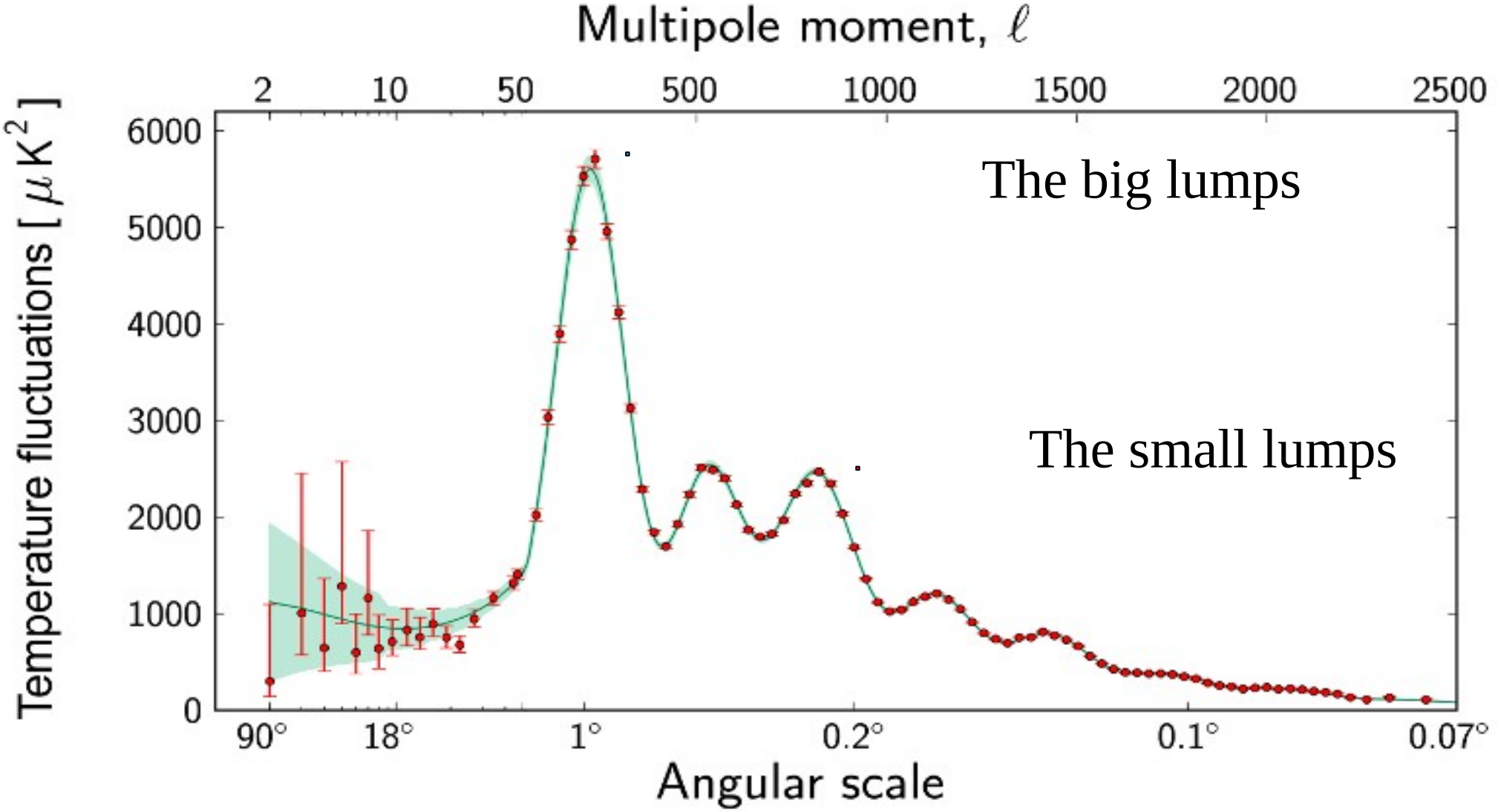
3) The cosmic microwave background (CMB). The ‘bang’ of the big bang which occurred at recombination.

4) Tiny variations in the CMB: to make galaxies & galaxy clusters.



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

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



So the current answer is our Universe is flat (in 4 dimensions).

Quiz 16: What did not exist prior to nucleosynthesis but did just after nucleosynthesis?

A) Stars

B) Planets

C) Helium

D) Carbon

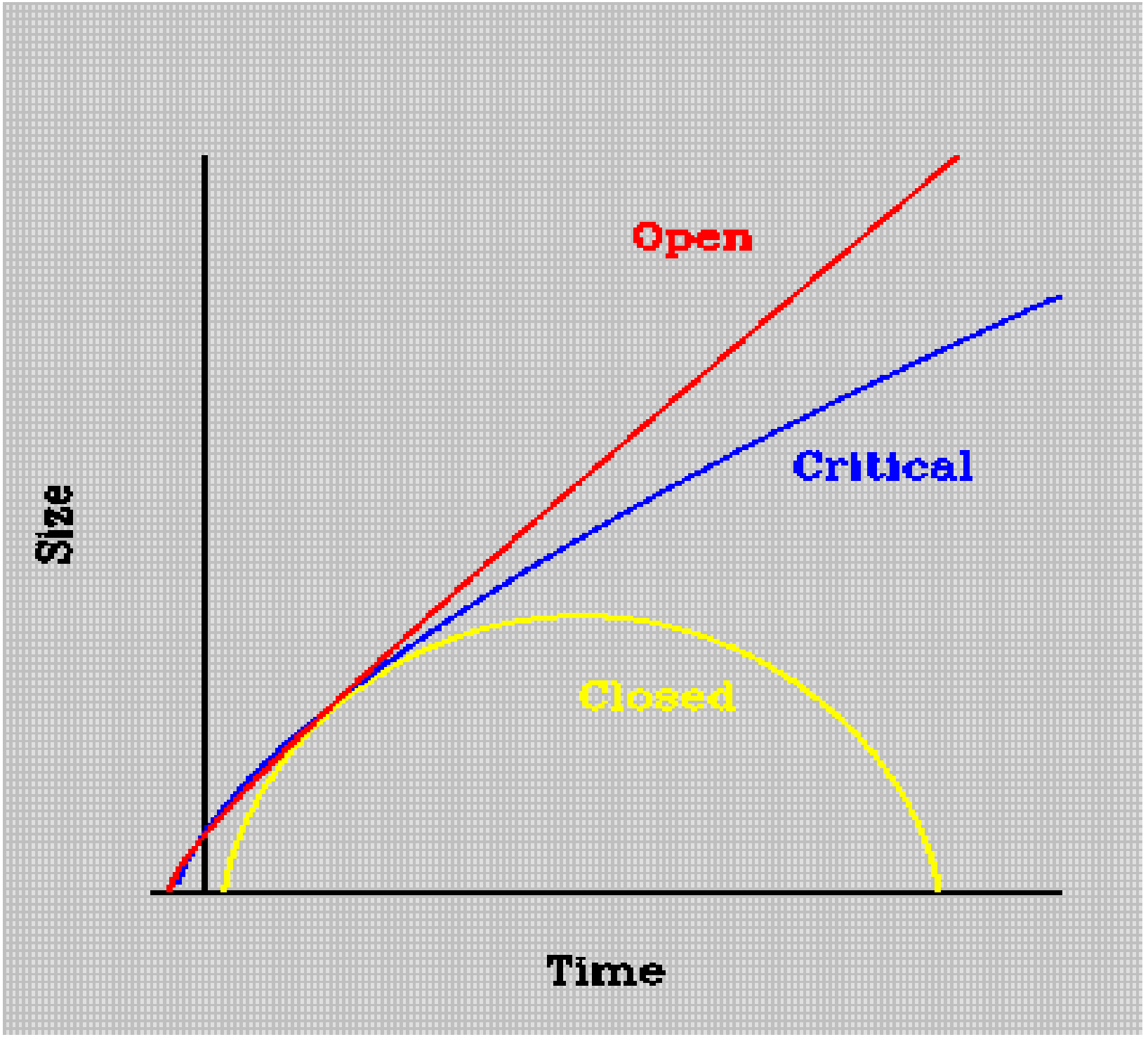
E) Galaxies

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?

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.

$\rho_{crit} = 10^{-29}$ g/cc

(1 proton in a box 46 cm wide)

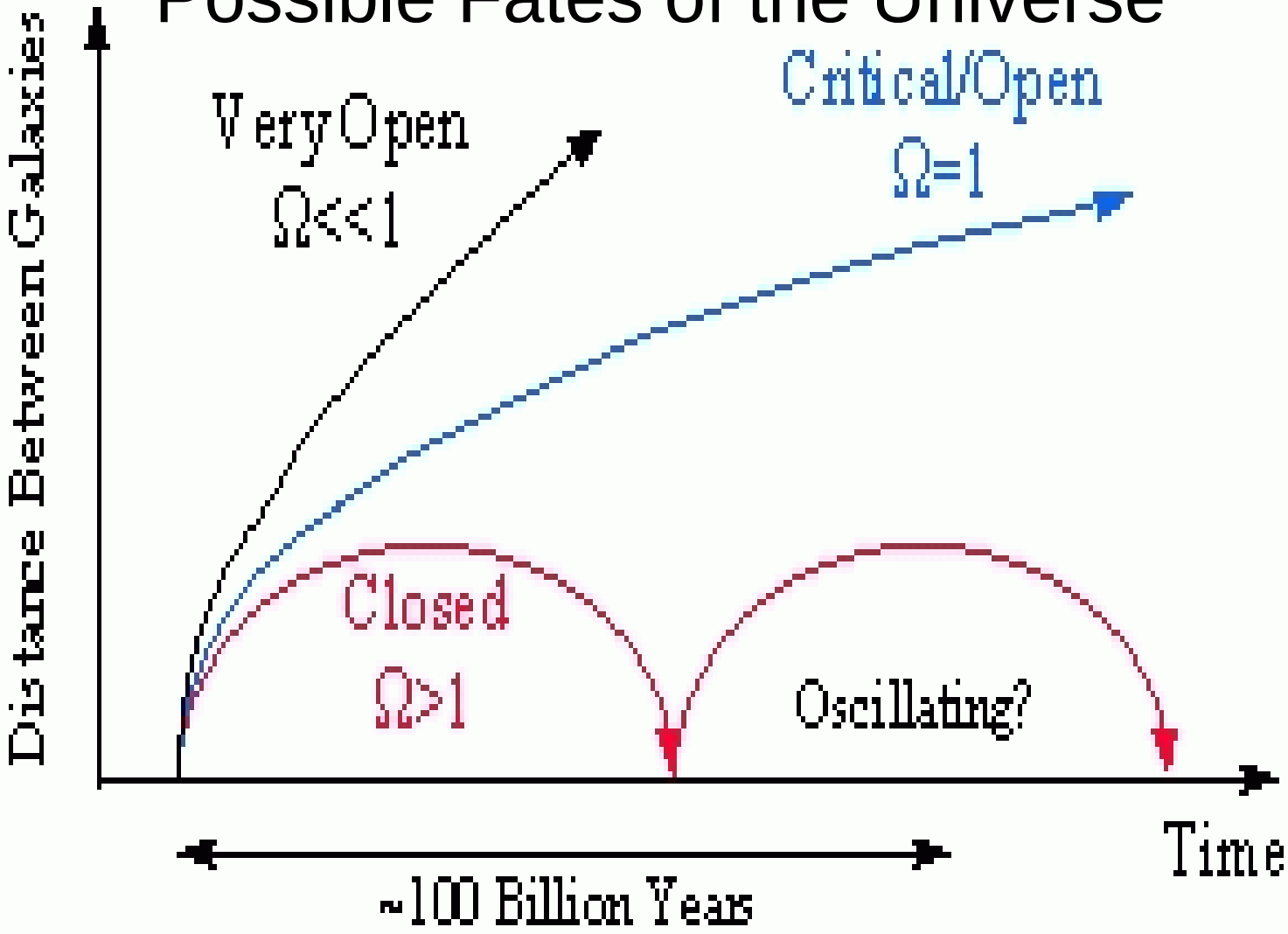
0.00000000000000000000000001 g/cc

New Term

$$\otimes = \rho_{crit}$$

That is, $\otimes$ 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.

Closed, open, or critical?

Now that we know the 'magic number,' how can we tell if we have enough mass to close the Universe?

Total it up!!!

What if we could 'see' to the edge of the Universe?

We would be able to 'count' the total mass in that direction. (Making assumptions!)

Then include all of the sky and we're in business.

This image was taken with the Hubble Space Telescope. The exposure time was 11.3 days in the constellation of Fornax.

Almost everything in this picture is a galaxy. Initially, the claim was there would be nothing else to see in this direction: they had seen to the edge of the Universe

We now know that is not true, but it is unlikely to be far off.

Calculating the Density of the Universe!

1) Count the number of galaxies in the image.
2) Multiply by the number of images it would take to cover the entire sky.

This gives the total number of galaxies in the Universe.

That estimate is about 100 Billion galaxies in total in our Universe!

Calculating the Density of the Universe!

1) Count the number of galaxies in the image.
2) Multiply by the number of images it would take to cover the entire sky.

This gives the total number of galaxies in the Universe (about 100 Billion!)

3) Multiply by the average mass of a galaxy.

This gives the total mass of the Universe.

Calculating the Density of the Universe!

1) Count the number of galaxies in the image.
2) Multiply by the number of images it would take to cover the entire sky.

This gives the total number of galaxies in the Universe (about 100 Billion!)

3) Multiply by the average mass of a galaxy.

This gives the total mass of the Universe.

4) Divide by the volume of the Universe (assume a size based on its age).

This gives the density of the Universe.

Calculating the Density of the Universe!

1) Count the number of galaxies in the image.
2) Multiply by the number of images it would take to cover the entire sky.

This gives the total number of galaxies in the Universe (about 100 Billion!)

3) Multiply by the average mass of a galaxy.

This gives the total mass of the Universe.

4) Divide by the volume of the Universe (assume a size based on its age).

This gives the density of the Universe.

5) Divide by the critical density to find out if it's open, closed, or critical.

Density of the Universe!

From the Hubble deep fields:

Ω=0.26!

According to this calculation, the Universe will

e x p a n d f o r e v e r