Normal Matter :

- stuff made of protons, neutrons, and electrons (i.e. us, stars, hot X-ray gas in clusters, etc.)
- is the only stuff that emits *or absorbs* light.
- is only ~5% of the total energy density of the Universe

Dark Matter :

- holds galaxies and clusters together
- comprises ~25% of the total energy density of the Universe

Dark Energy :

- is driving the expansion of the Universe to accelerate
- has a *negative* gravitational effect
- comprises ~70% of the total energy density of the Universe

We have an equation for the expansion of the Universe (size as a function of time) that requires only the following parameters:

t_H The Hubble time, or expansion timescale; tells us the current expansion rate. (It is how old the Universe *would be* if the expansion rate had always been constant.)

Ω_M The fraction of the Universe's density that is currently in matter (normal + dark)

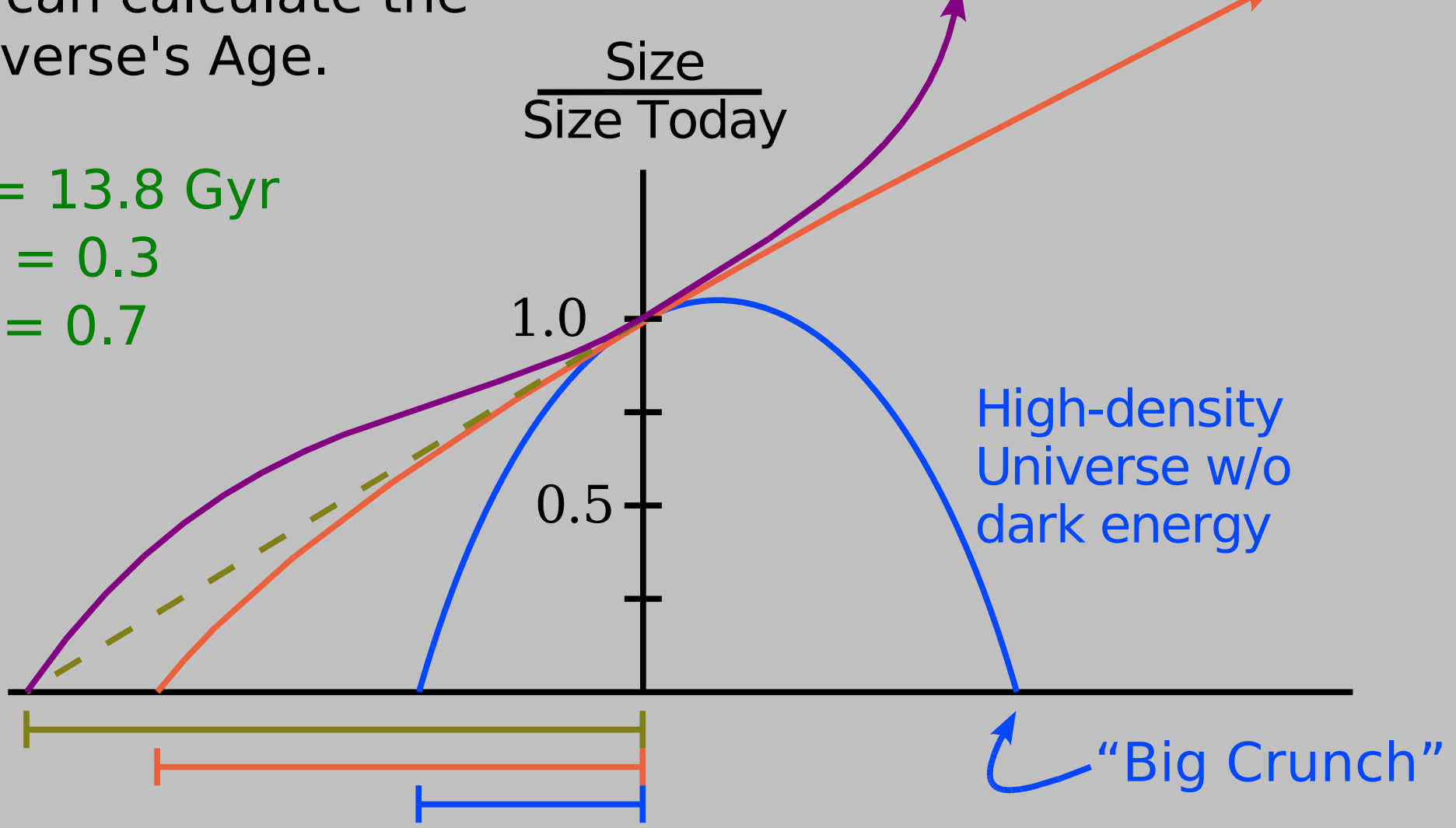
Ω_Λ The fraction of the Universe's density that is currently in dark energy

$$\frac{1}{R}\frac{dR}{dt} = \left(\frac{1}{t_H}\right)\sqrt{\Omega_M\left(\frac{R_0}{R}\right)^3 + \Omega_\Lambda}$$

You do not need to understand this equation!!!

Given t_H (Hubble Time), Ω_M (mass density), and Ω_Λ (dark energy density), we can calculate the Universe's Age.

$t_H = 13.8$ Gyr
$\Omega_M = 0.3$
$\Omega_\Lambda = 0.7$



Years in the Past ← t → Years from Today

(Drumroll please...)

The Age of the Universe:

13.7±0.2 billion years

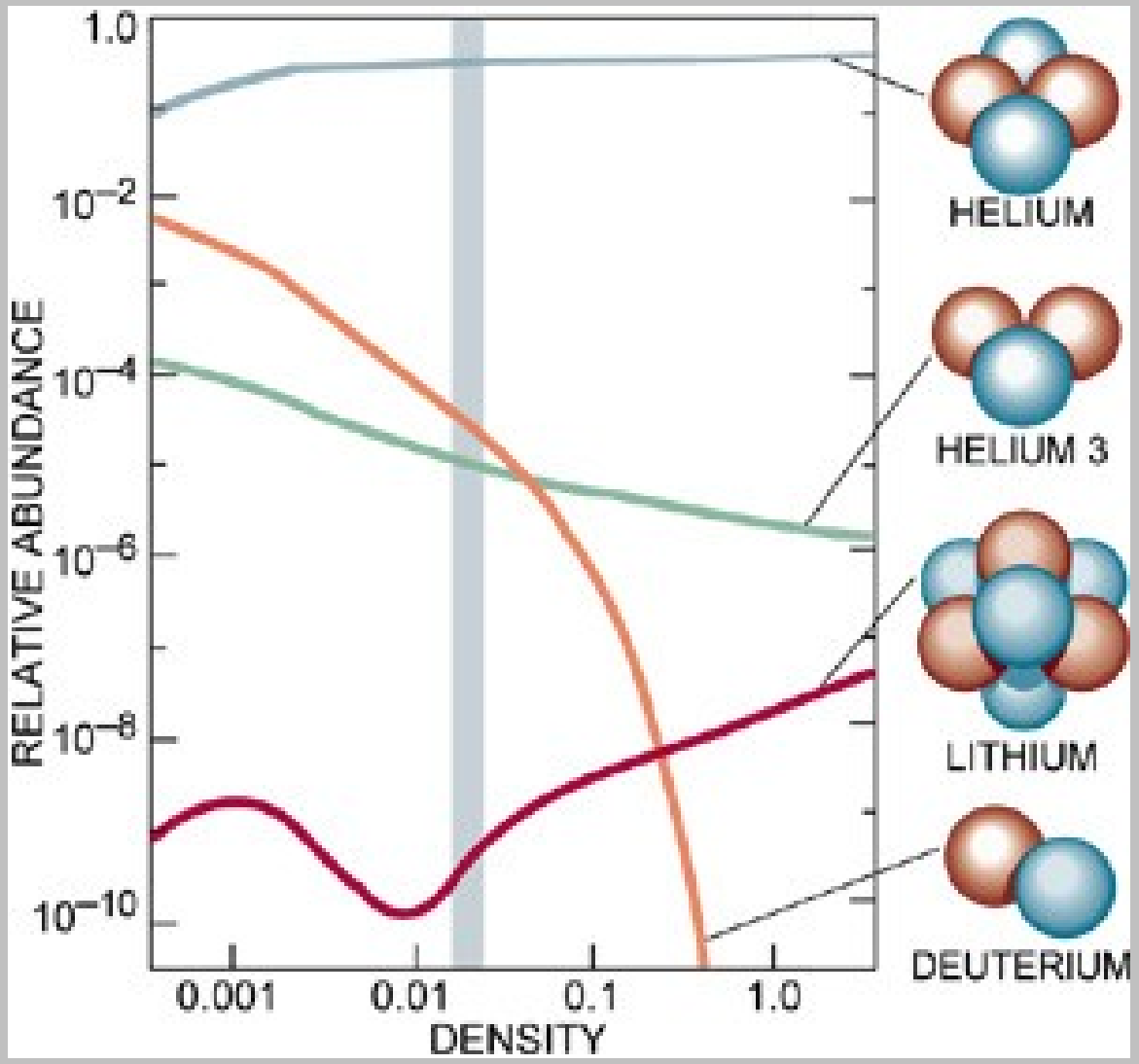
...but what is that since?

Why do we believe the Big Bang Theory?

- Expansion of the Universe – if it's expanding now, in the past it was more dense; far in the past, it was a lot more dense
- The Cosmic Microwave Background – the “afterglow of creation”
- Successful prediction of the primordial abundances of Helium, Deuterium, Lithium

...as well as detailed matches between observation and calculations for all of the above, and for the formation of structure.

Big Bang Nucleosynthesis



The Big Bang made:

- 90% Hydrogen
- 10% Helium
- trace amounts of Deuterium, Lithium, Beryllium.

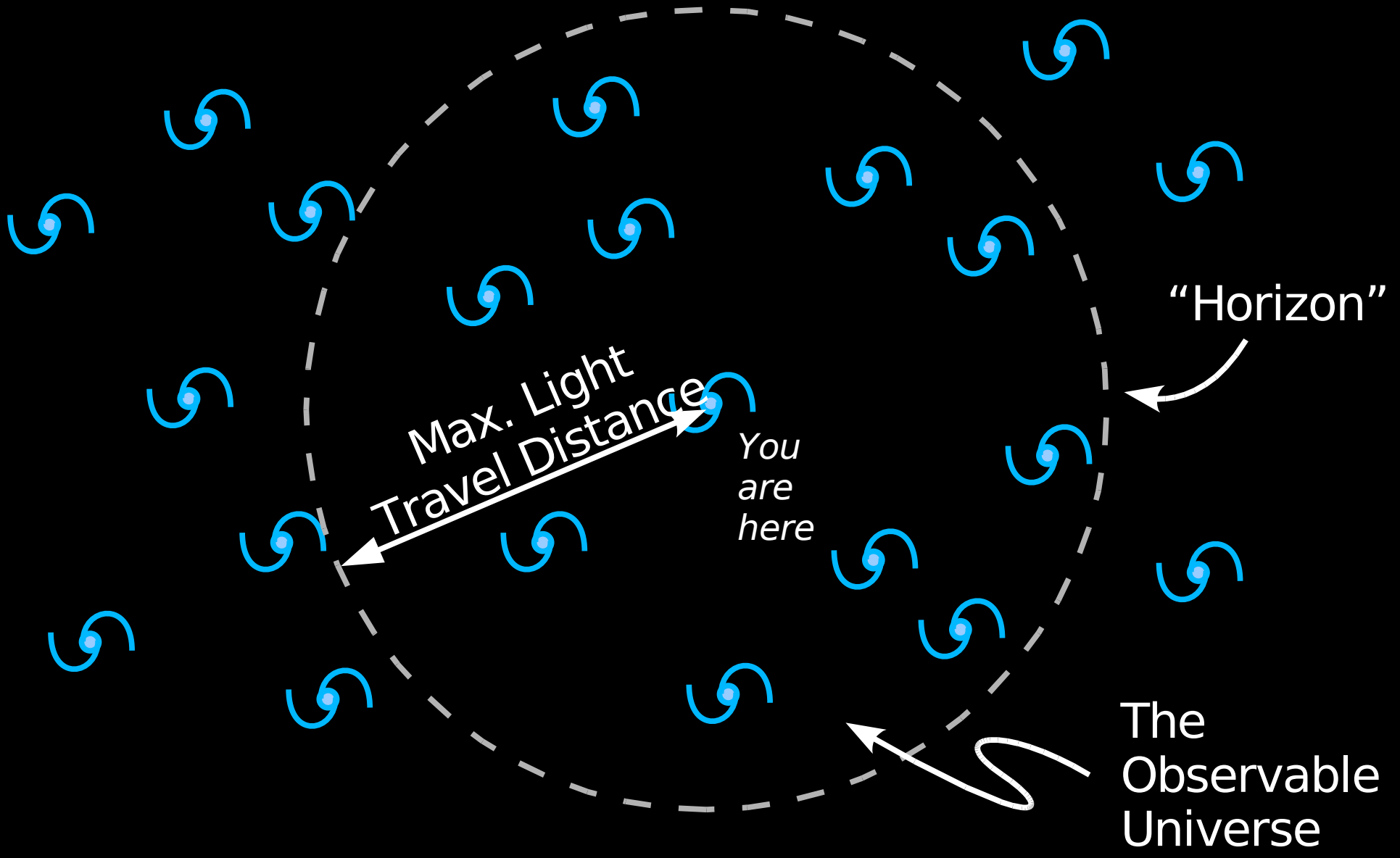
Everything else was made in stars and supernovae!!!

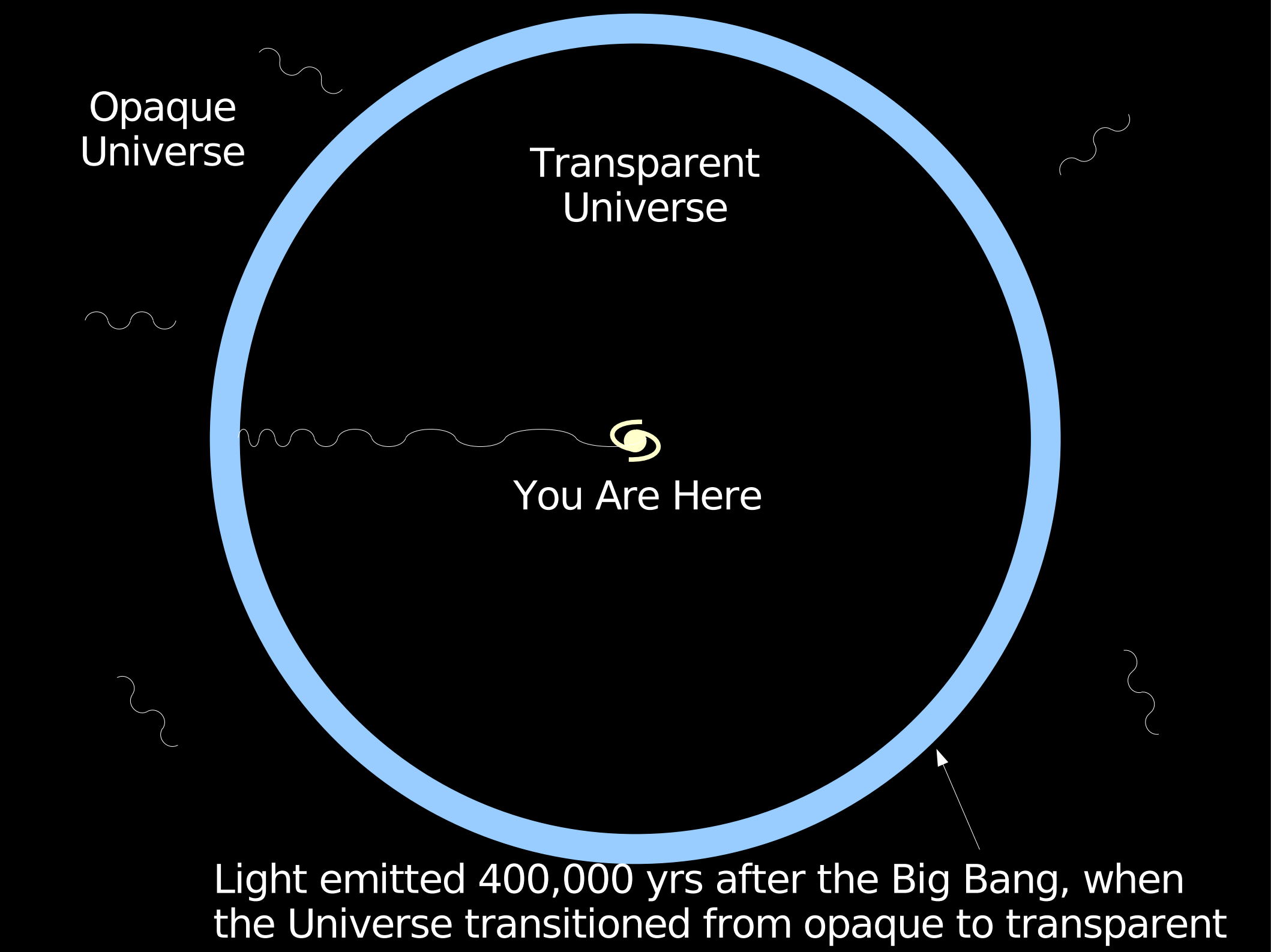
Big Bang predictions match observed primordial abundances.

The Cosmic Microwave Background (CMB)

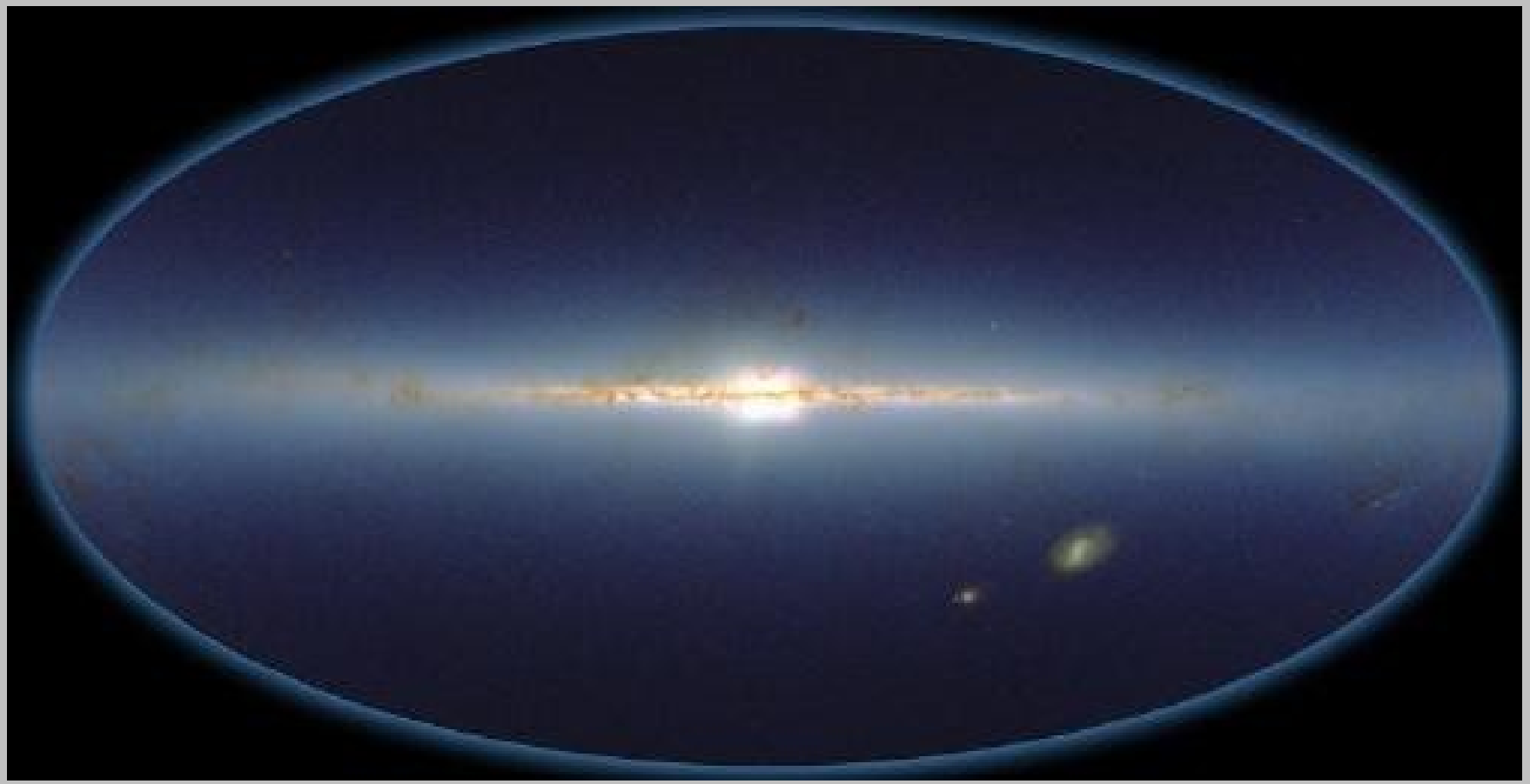
- Emitted ~400,000 years after the Big Bang
- The Universe was a plasma at 3,000 K
- Since then the Universe has expanded $\gtrsim 1000\times$
- Temperature of the light goes down as all of the light is redshifted
- Temperature observed today : 2.7 K
  (Discovered by Penzias & Wilson in 1963)
- Tiny fluctuations in the CMB (one part in 10,000) are small regions of overdensity that grew into the galaxy clusters we see today!!

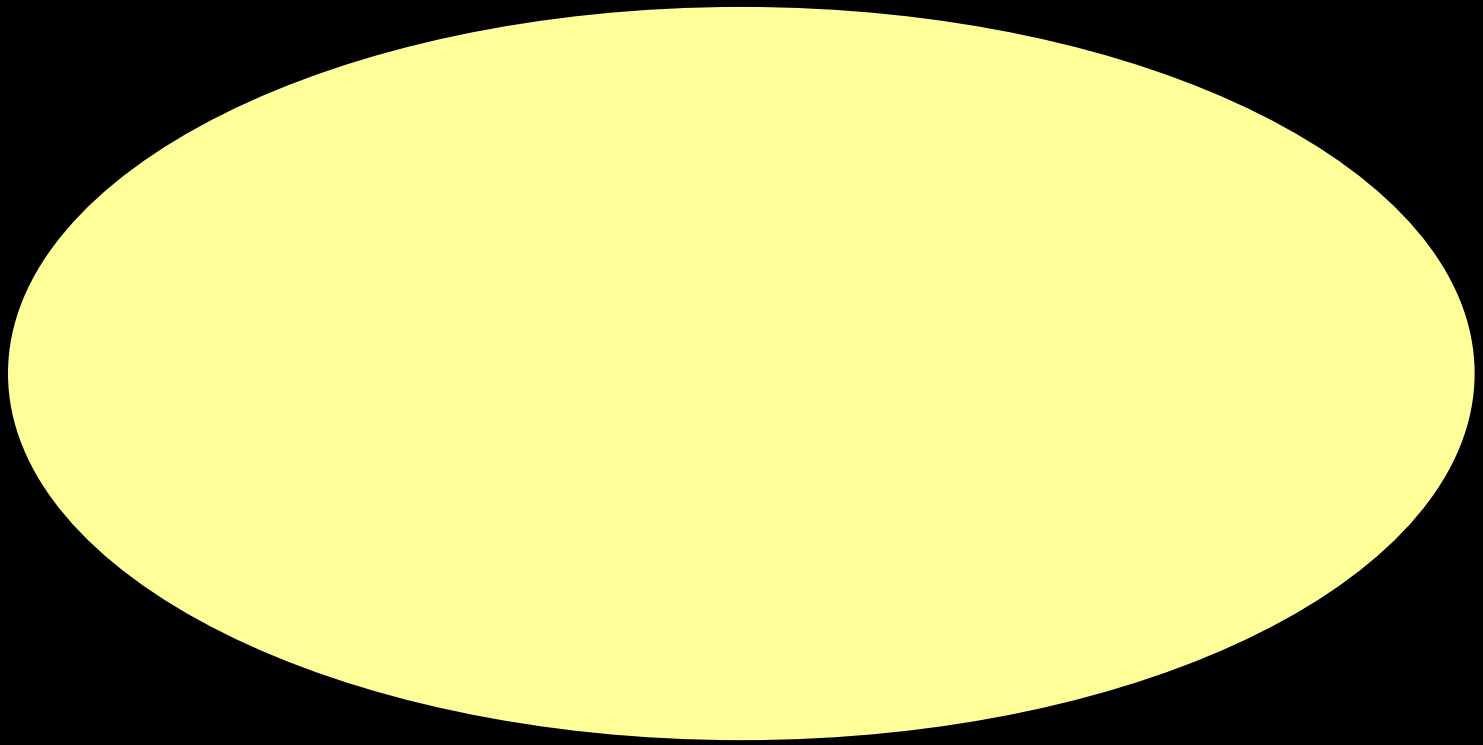
Even if the Universe is infinite, the *Observable Universe* is finite



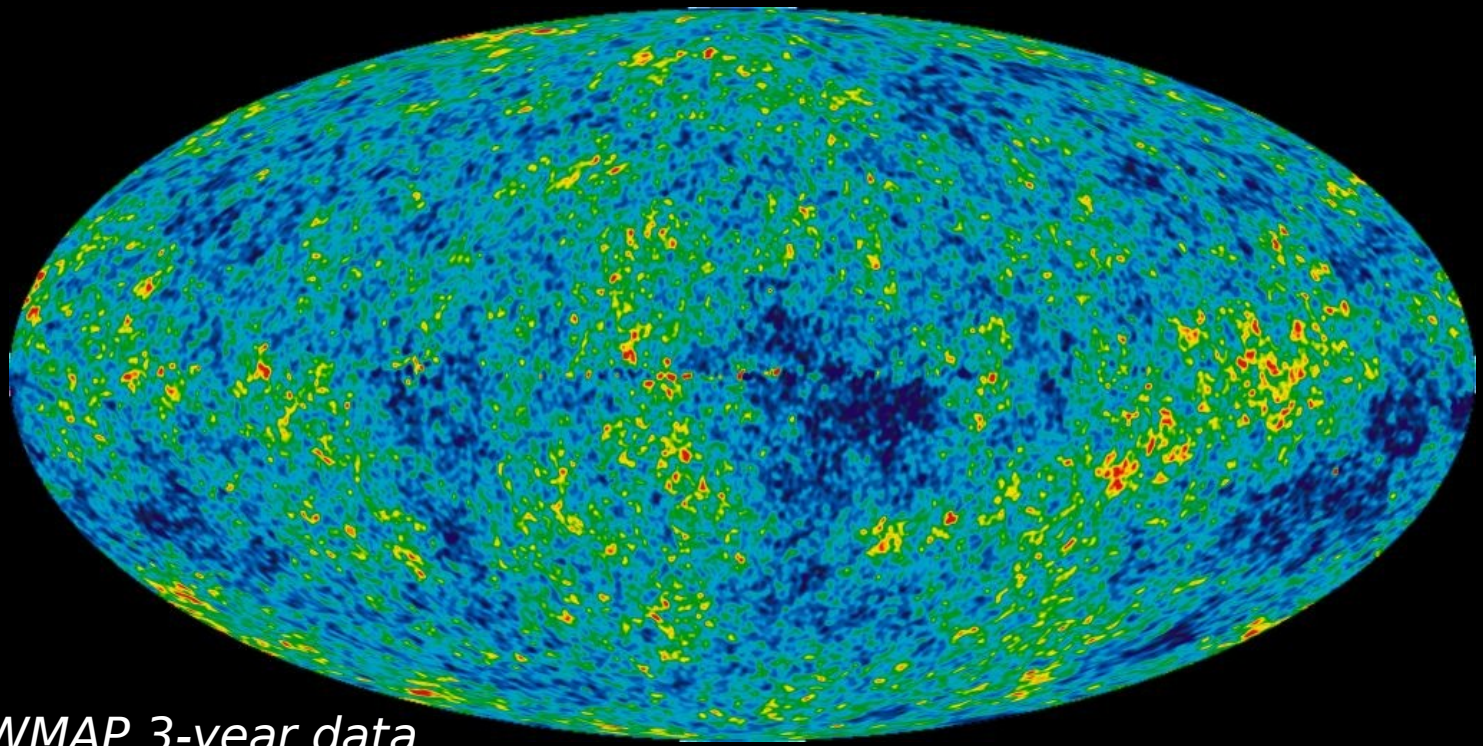

Opaque
Universe
Transparent
Universe
You Are Here
Light emitted 400,000 yrs after the Big Bang, when
the Universe transitioned from opaque to transparent

All-Sky Map (near-infrared from 2MASS) showing the Milky Way





All-sky map : the CMB (uniform temperature of 2.7 K)

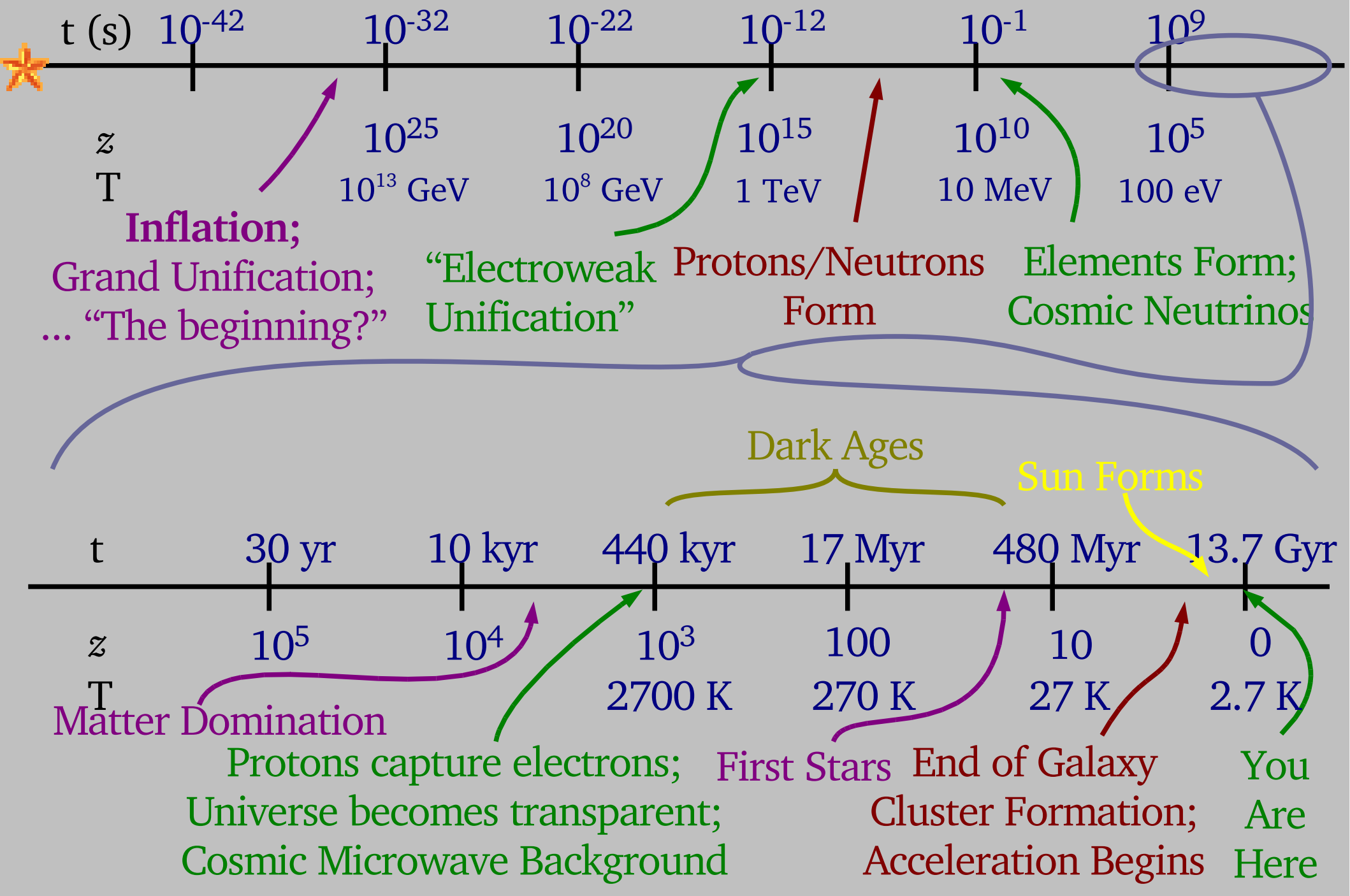


Variations around the uniform temp.: 1 part in 10^5

WMAP 3-year data

Here be Dragons

A History of the Universe



What the Big Bang Theory really is:

- Based on General Relativity, with input from other physics (e.g. plasma physics, nuclear physics)
- Basic overview: the Universe today evolved and expanded from a very hot, very dense state. (Picture is quite solid back to the time of the formation of the elements.)

What the modern Big Bang Theory tells us nothing about:

- The moment of the “Bang” itself (!!!!)

The time of the “classical Big Bang” comes from pure General Relativity. But, before 10^{-42}ish seconds after that, our Physics breaks down, and at the moment we can't say much.