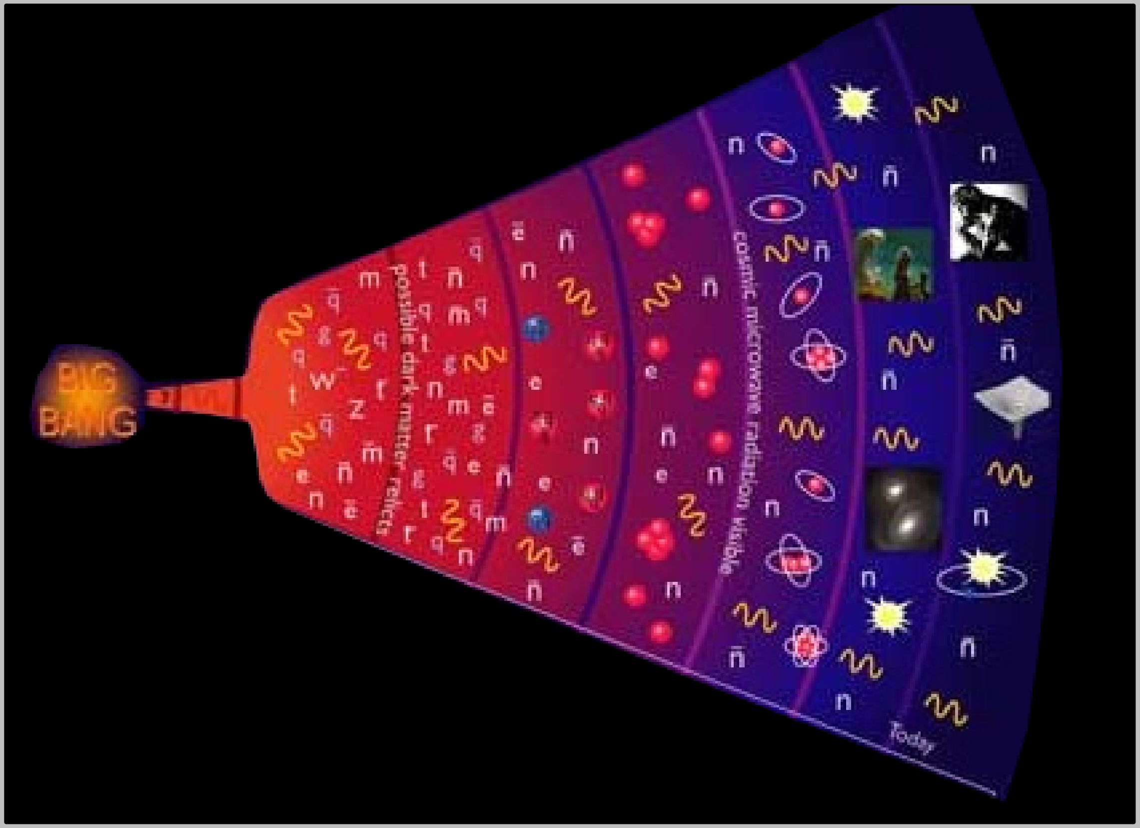
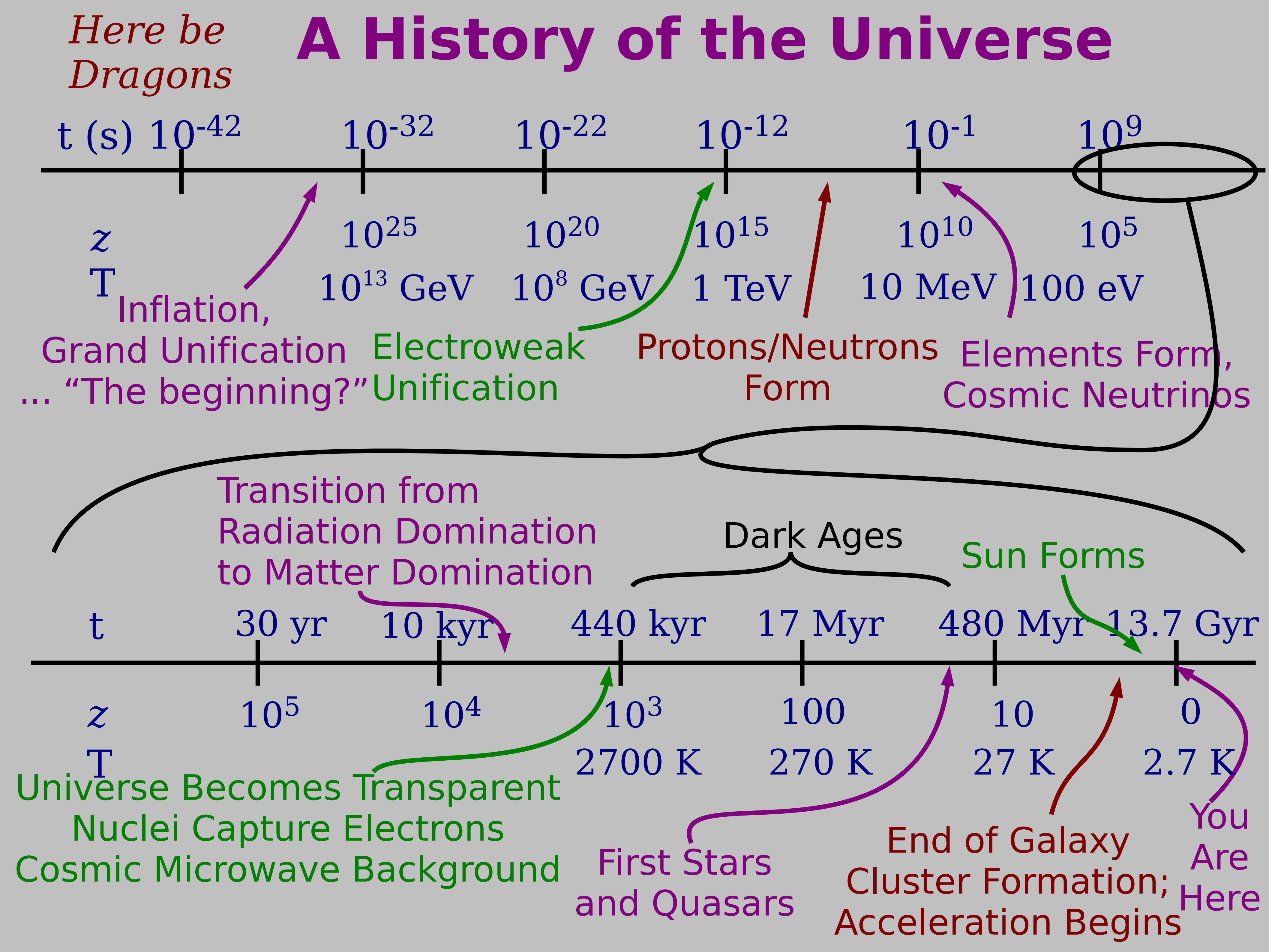
A History of the Universe



Dr. Rob Knop

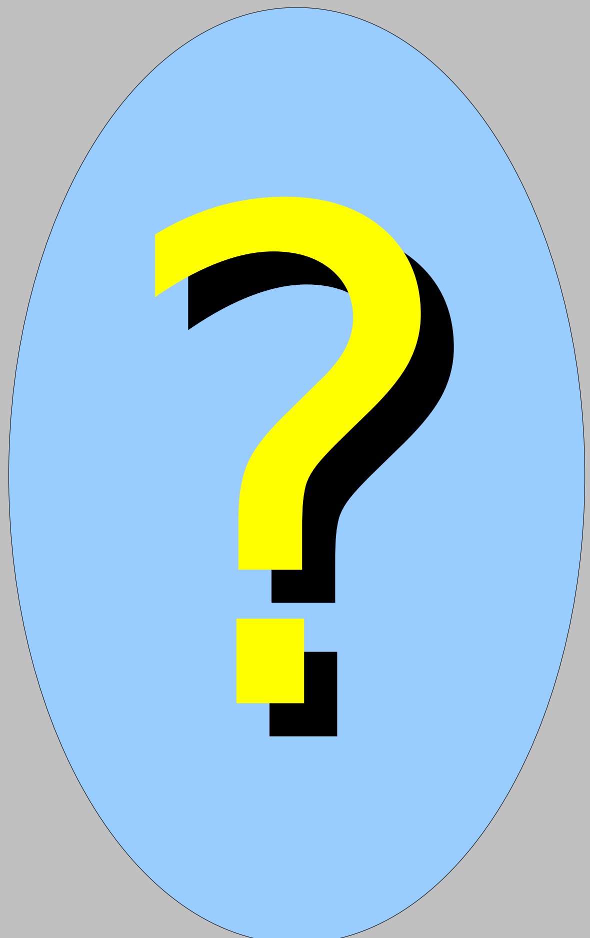
MICA (www.mica-vw.org)

Second Life, 2010-05-22

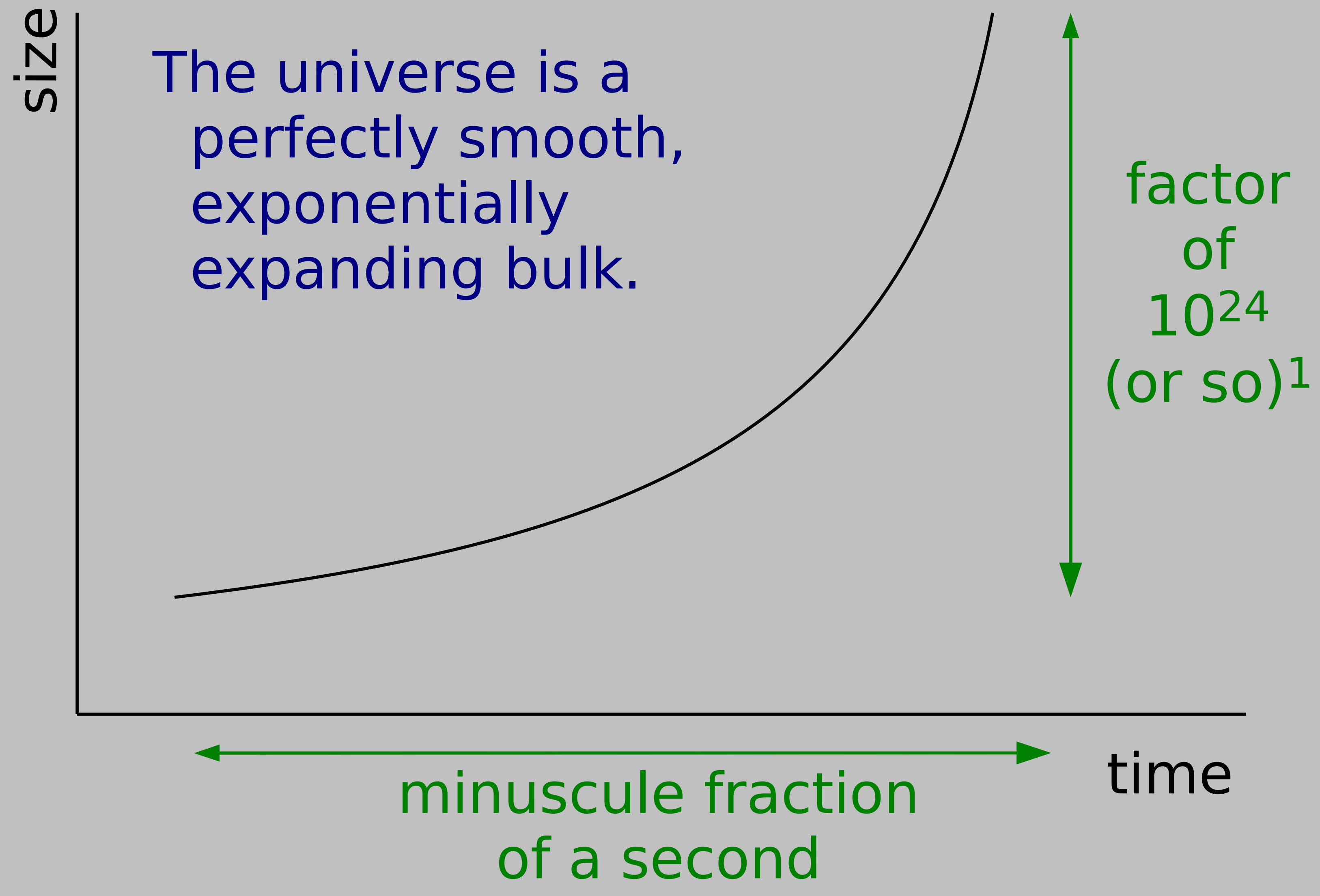


Here be Dragons
A History of the Universe
t (s) 10^-42 10^-32 10^-22 10^-12 10^-1 10^9
z 10^25 10^20 10^15 10^10 10^5
T 10^13 GeV 10^8 GeV 1 TeV 10 MeV 100 eV
Inflation, Grand Unification ... "The beginning?"
Electroweak Unification
Protons/Neutrons Form
Elements Form, Cosmic Neutrinos
Transition from Radiation Domination to Matter Domination
Dark Ages
Sun Forms
t 30 yr 10 kyr 440 kyr 17 Myr 480 Myr 13.7 Gyr
z 10^5 10^4 10^3 100 10 0
T 2700 K 270 K 27 K 2.7 K
Universe Becomes Transparent Nuclei Capture Electrons Cosmic Microwave Background
First Stars and Quasars
End of Galaxy Cluster Formation; Acceleration Begins
You Are Here

The Moment of Bang



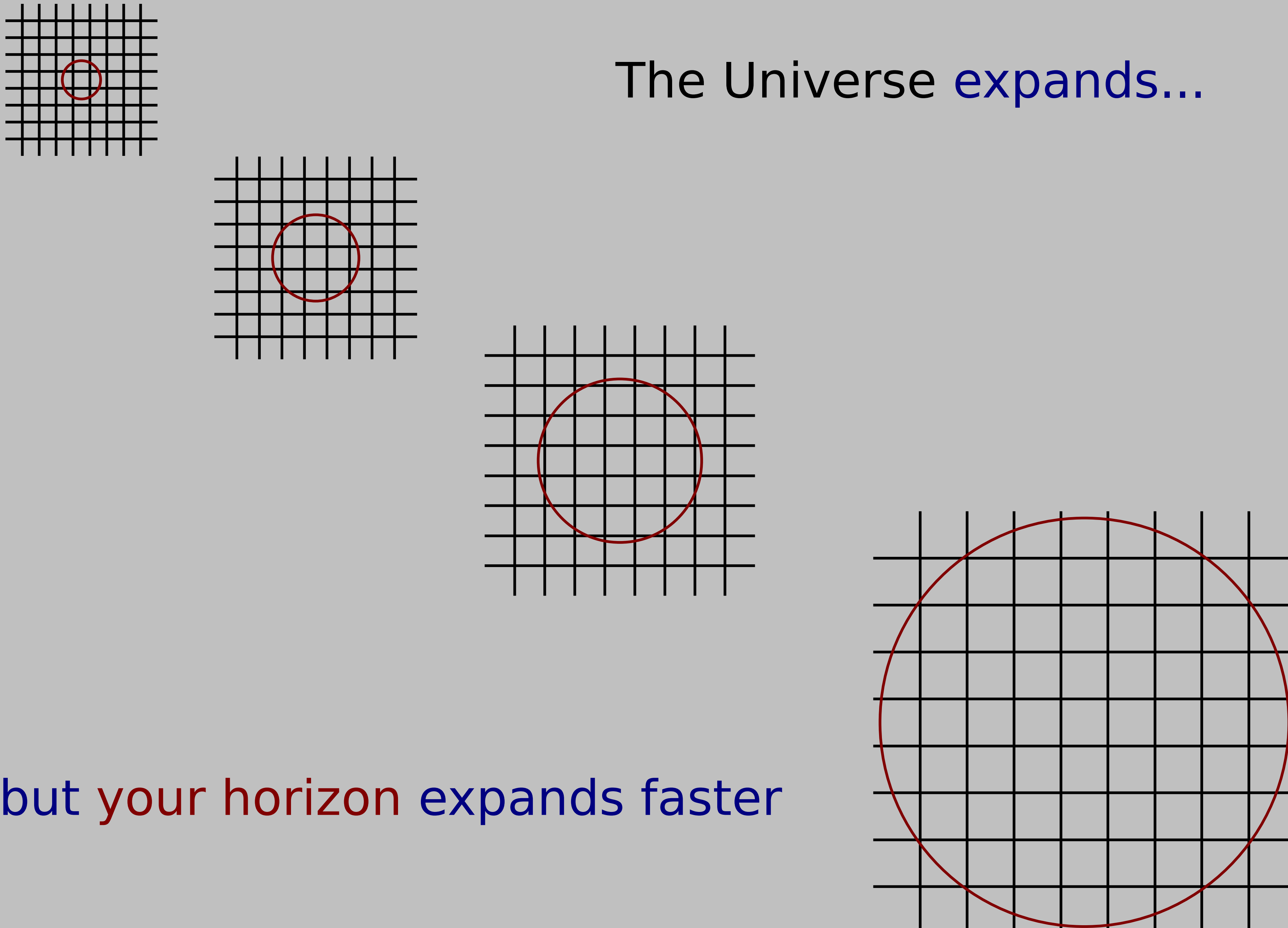
Inflation



1: Agulló *et al.*, 2009, PRL, 103, 061301

After Inflation...

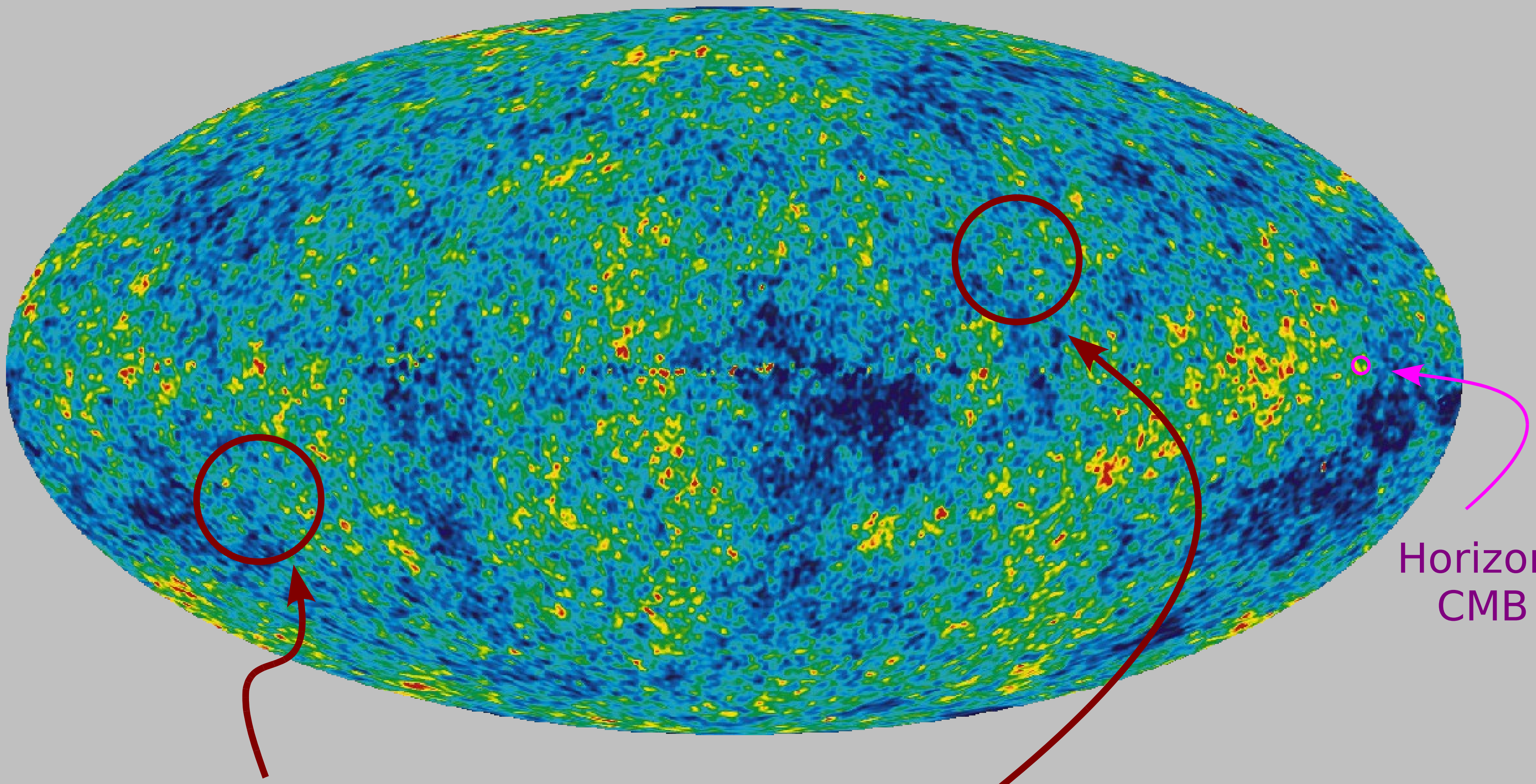
The Universe expands...



...but your horizon expands faster

The "Horizon" Problem

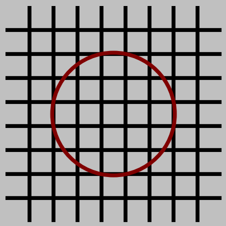
The Cosmic Microwave Background, emitted a few hundred thousand years after the big bang, is smooth to one part in 10,000...

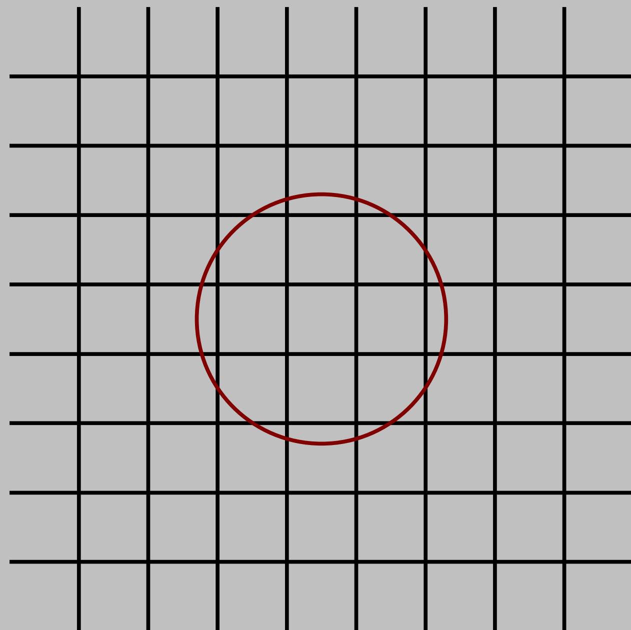


Horizon size at CMB emission

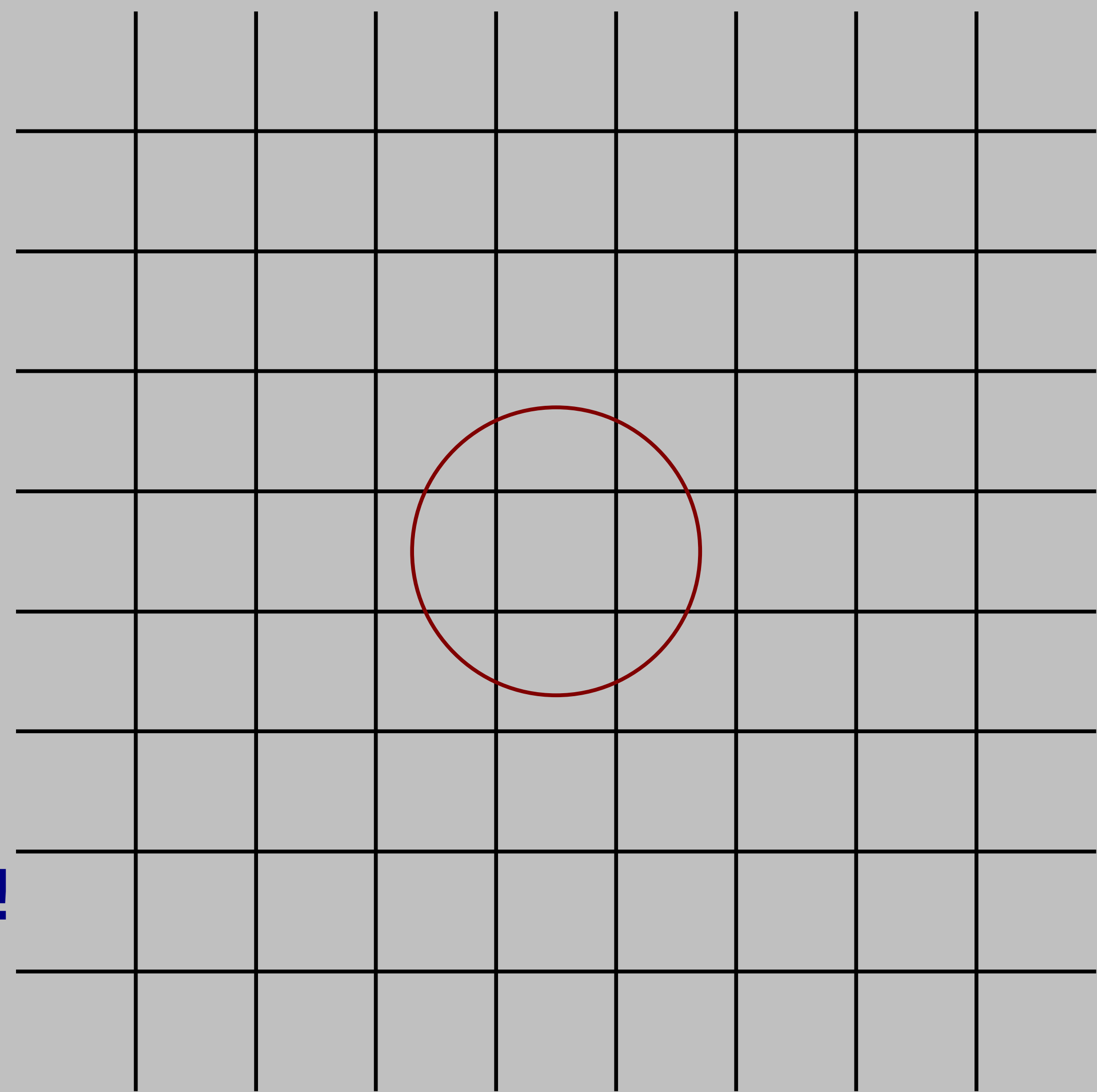
...but this part of the sky and this part of the sky were way outside each other's horizon!

During Inflation



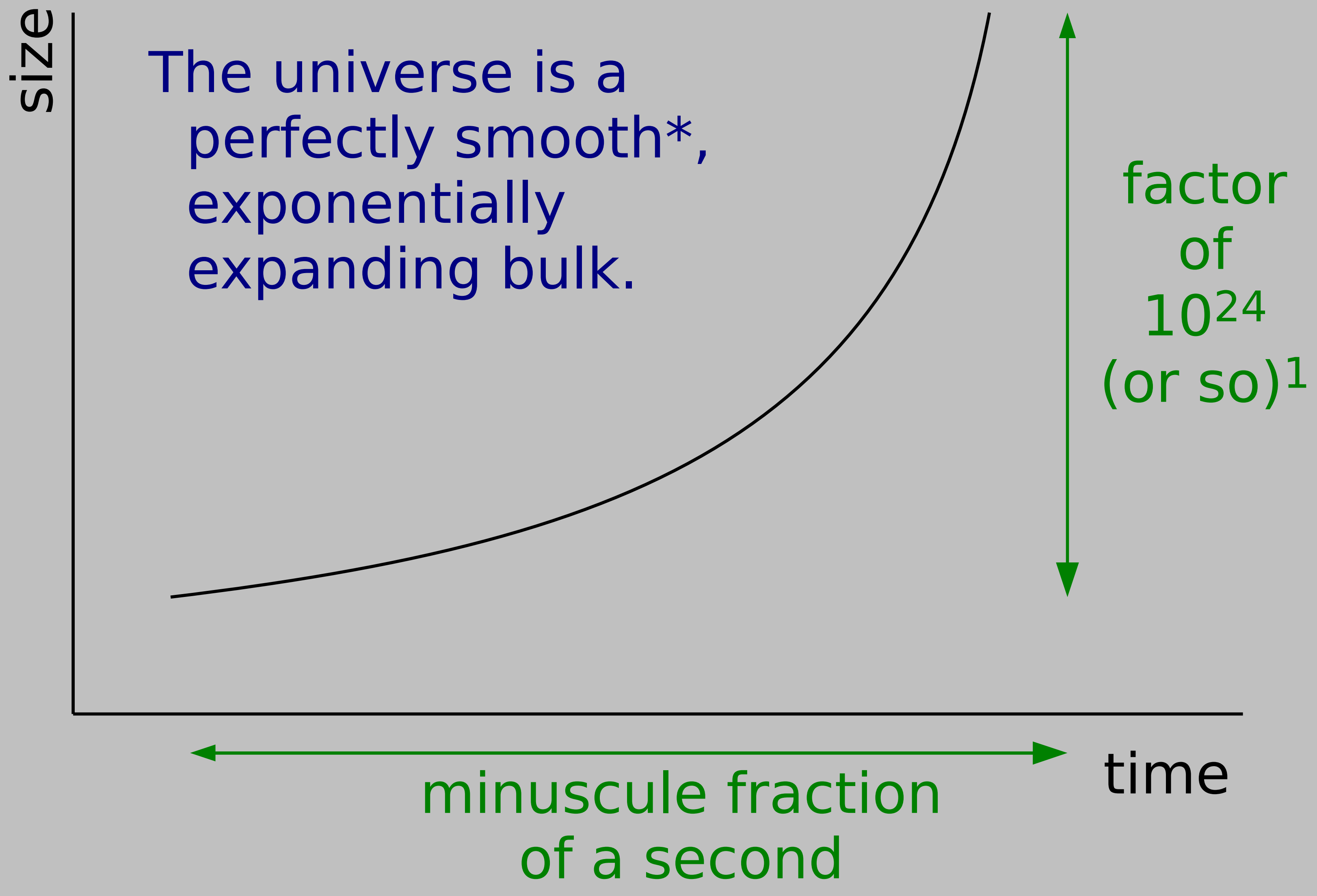


The Universe expands...



...*faster* than your horizon!!!

Inflation



1: Agulló *et al.*, 2009, PRL, 103, 061301

*Quantum Fluctuations

Heisenberg's Uncertainty Principle:

$$\Delta x \, \Delta p \geq \frac{\hbar}{2}$$

$$\Delta E \, \Delta t \geq \frac{\hbar}{2}$$

Inflation takes small-scale quantum fluctuations, and blows them up outside of the horizon, freezing them in.

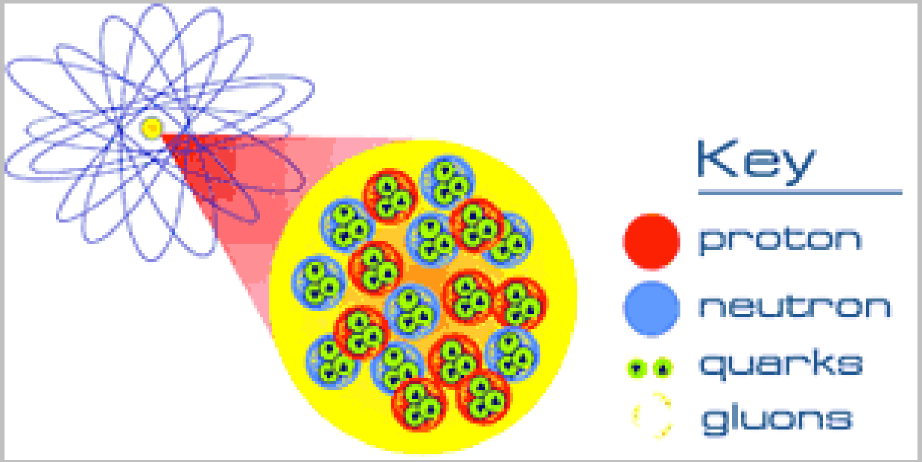
These tiny density fluctuations form the seed for all the structure in the Universe today.

“The Beginning”

Since we don't *really* know what happened at the moment of bang, or even if there *was* a “moment of bang”, from now on when I say “the beginning”, I mean the end of inflation.

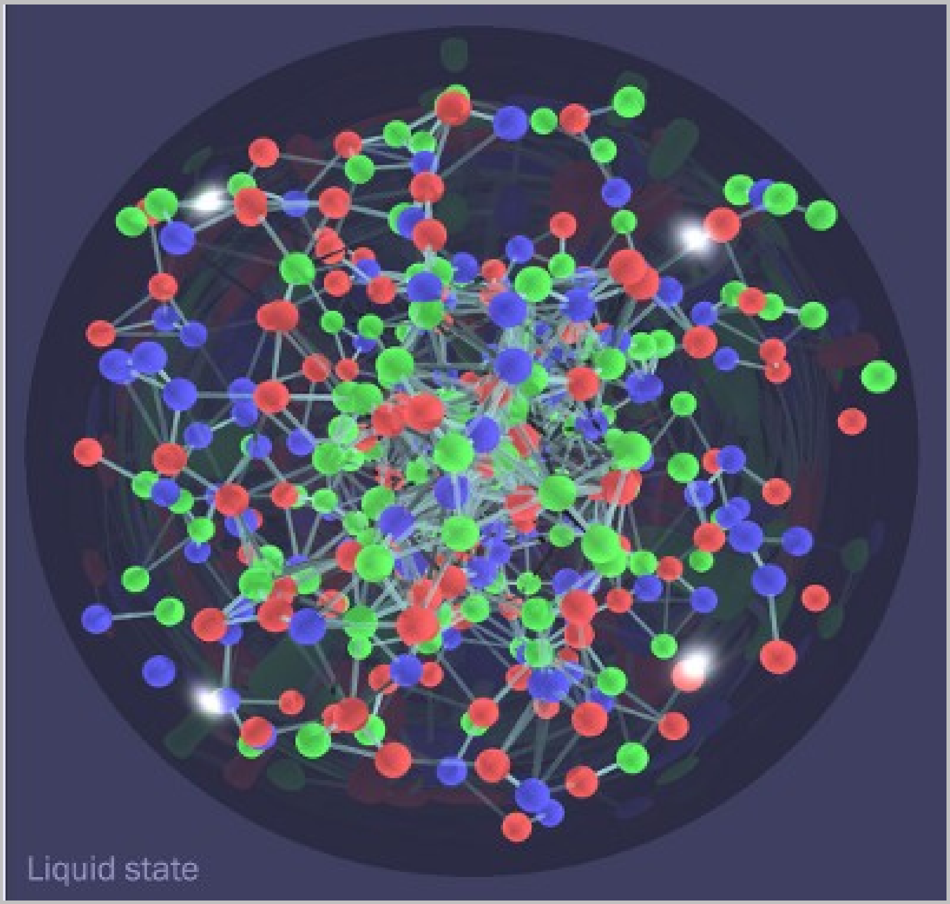
Until 1/1,000,000th of a second after the beginning...

The Universe is a **quark-gluon plasma**



Look inside an atom...

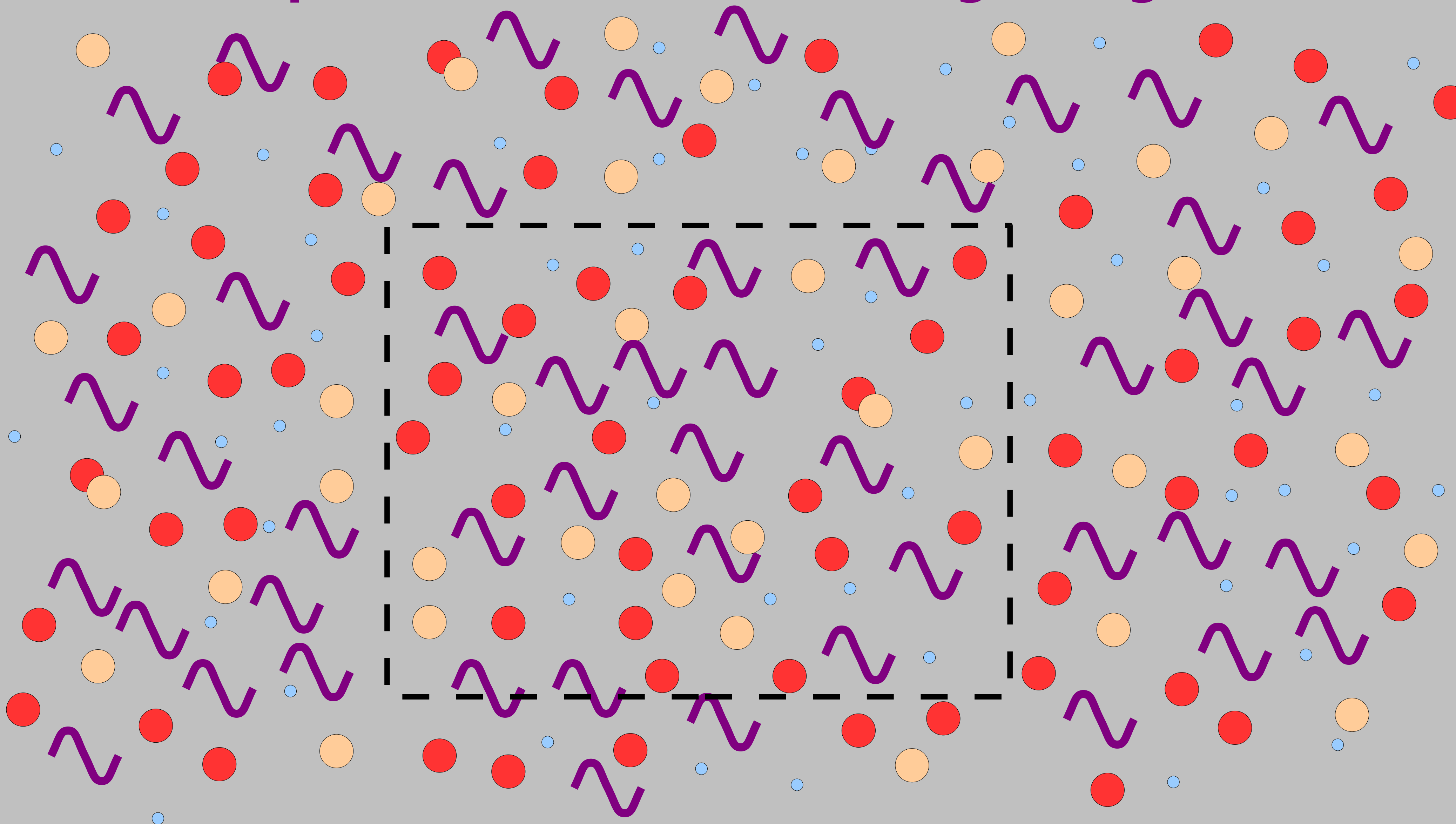
...early on, quarks aren't confined



The quark-gluon liquid observed at RHIC ($T \sim 4 \times 10^{12}$K, ~300MeV)

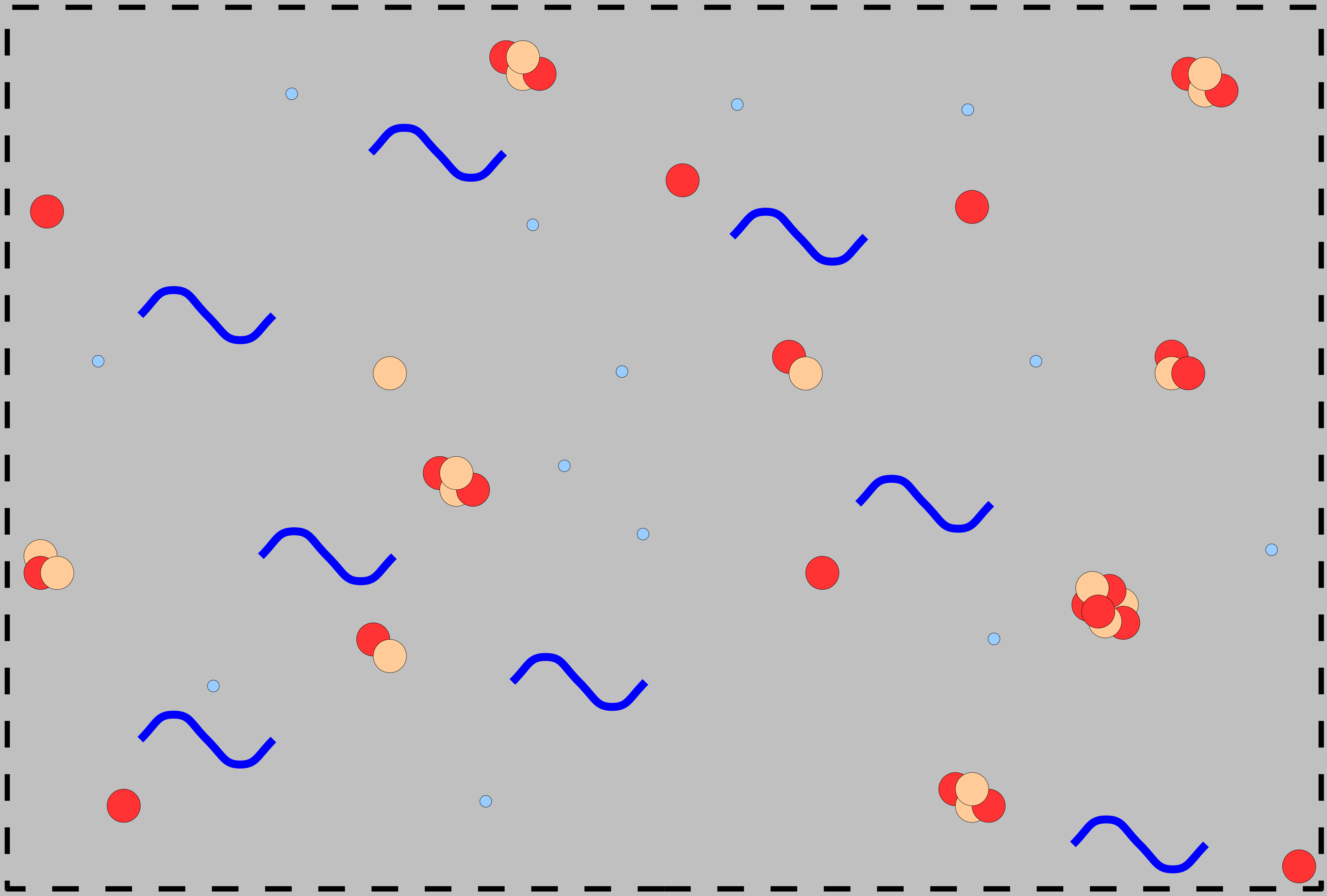
http://www.bnl.gov/rhic/

1 μs to 20min after the beginning...



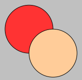
The Universe is a soup of dark matter, plus protons, neutrons, electrons, positrons, and photons.

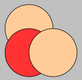
20 minutes after the big bang:

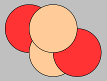


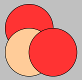
When the Big Bang is done making elements, what is left?

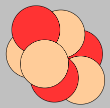
 Hydrogen : 75% (by mass)

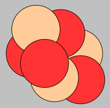
 Deuterium : tiny

 Tritium : tiny

 Helium : 25% (by mass)

 Helium-3 : tiny

 Lithium : tiny

 Beryllium : tiny

...AND THAT'S IT!!!

That's what the Big Bang theory predicts... ...is there data to support it?

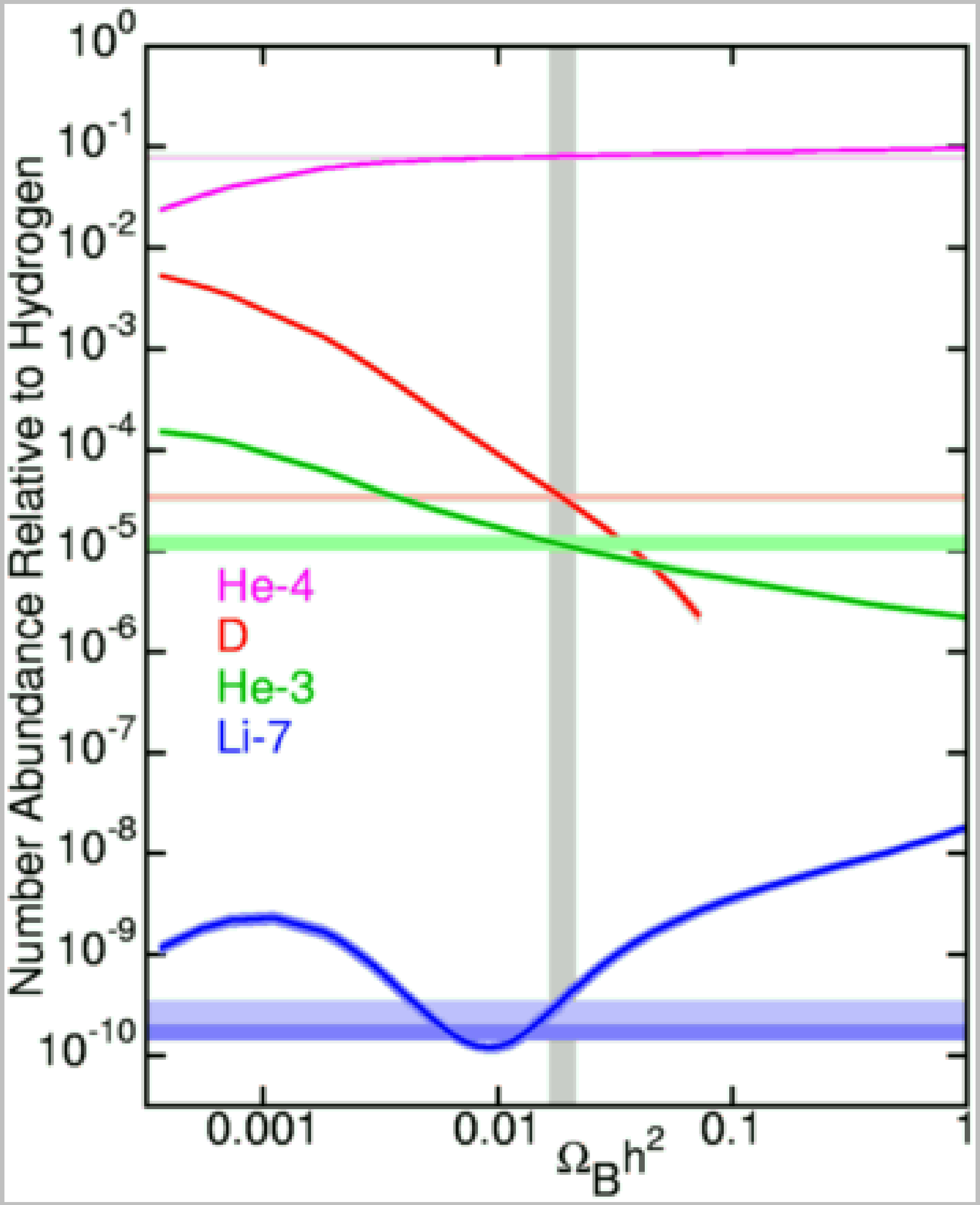
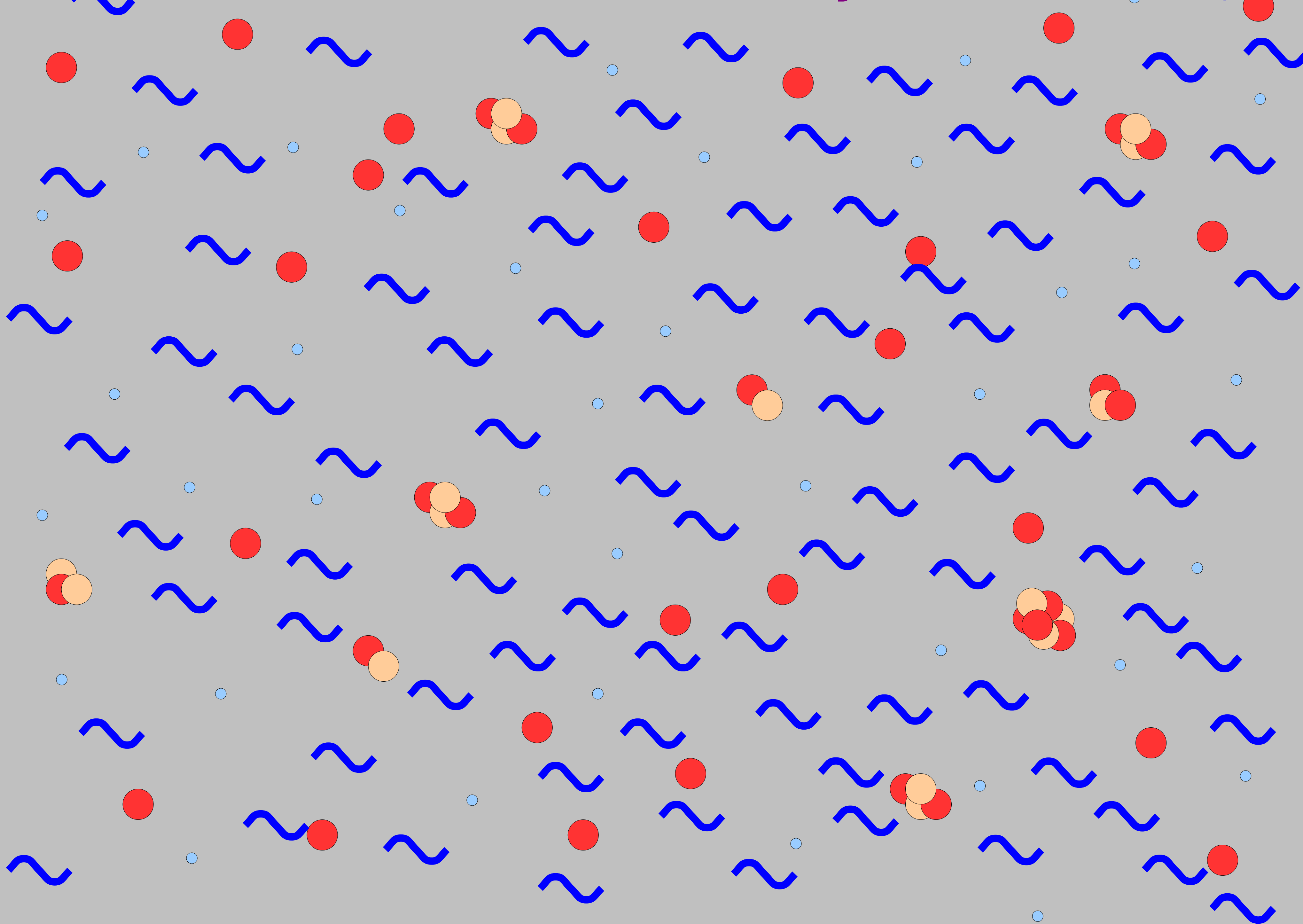
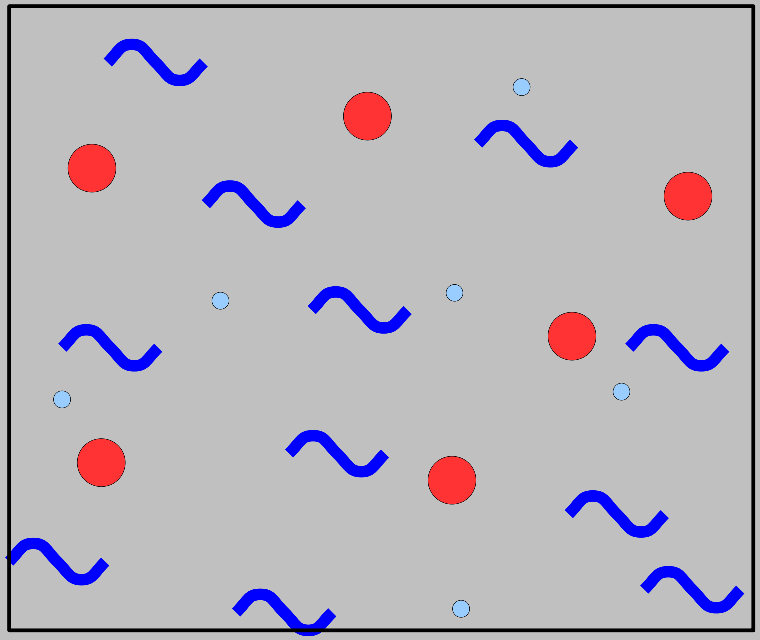


Image: Ned Wright http://www.astro.ucla.edu/~wright/BBNS.html

For the next ~400,000 years...

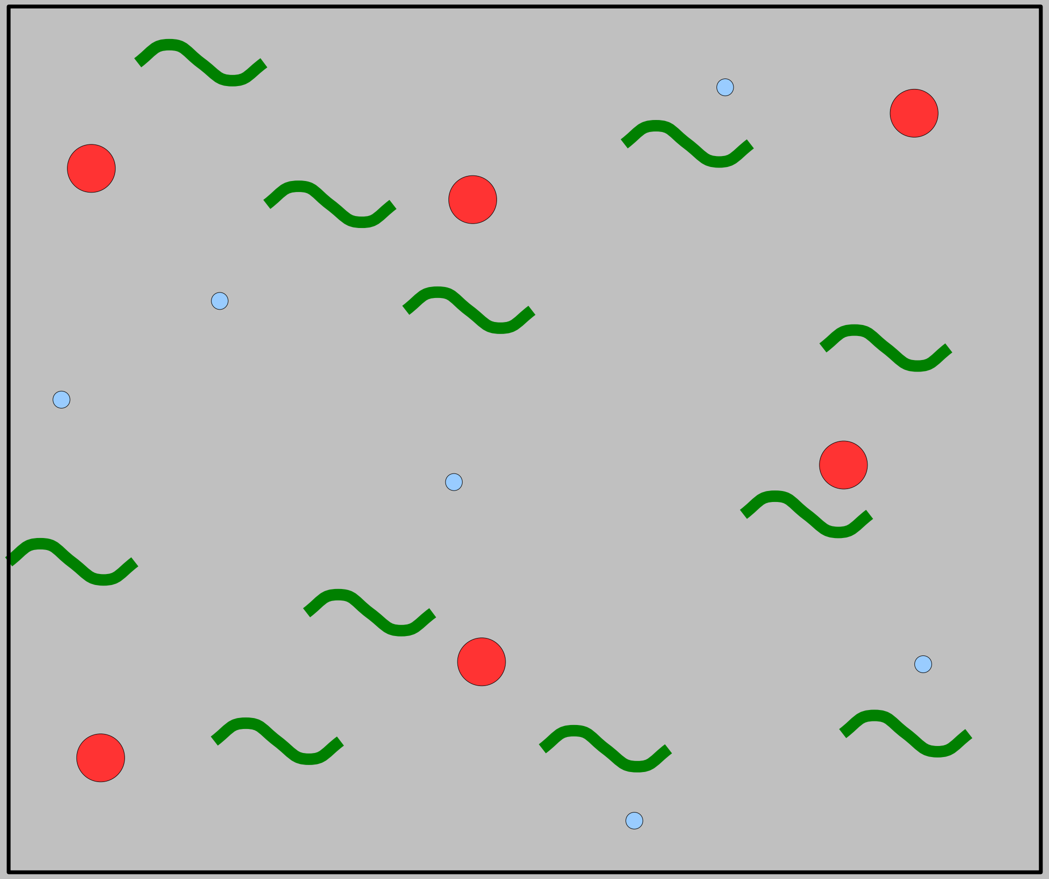


As the Universe Expands...



Everything spreads out, so the density of matter goes as:

$$\text{density} \propto \frac{1}{\text{size}^3}$$



But, photons also redshift, so the energy density in radiation goes as:

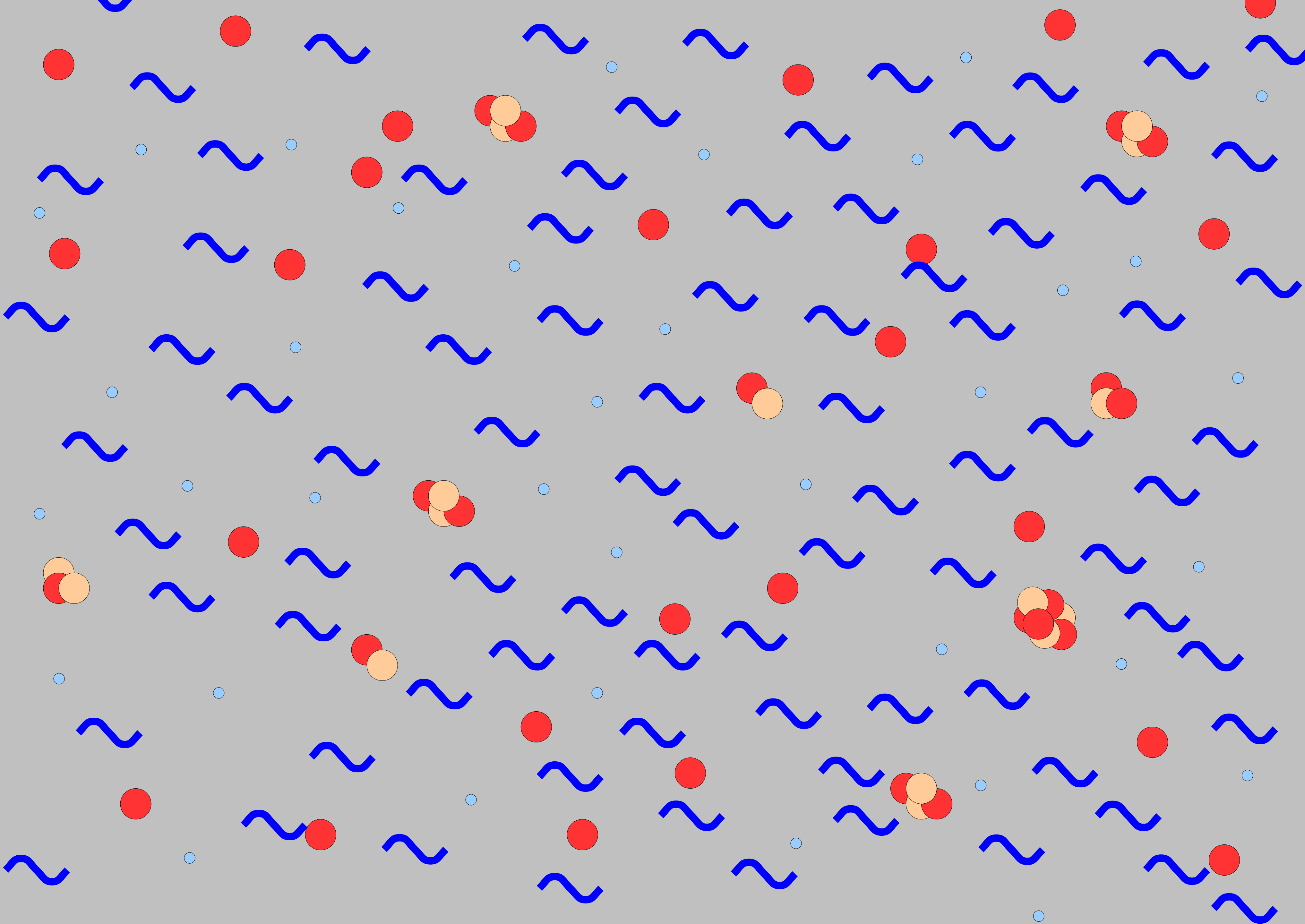
$$\text{density} \propto \frac{1}{\text{size}^4}$$

Matter Domination

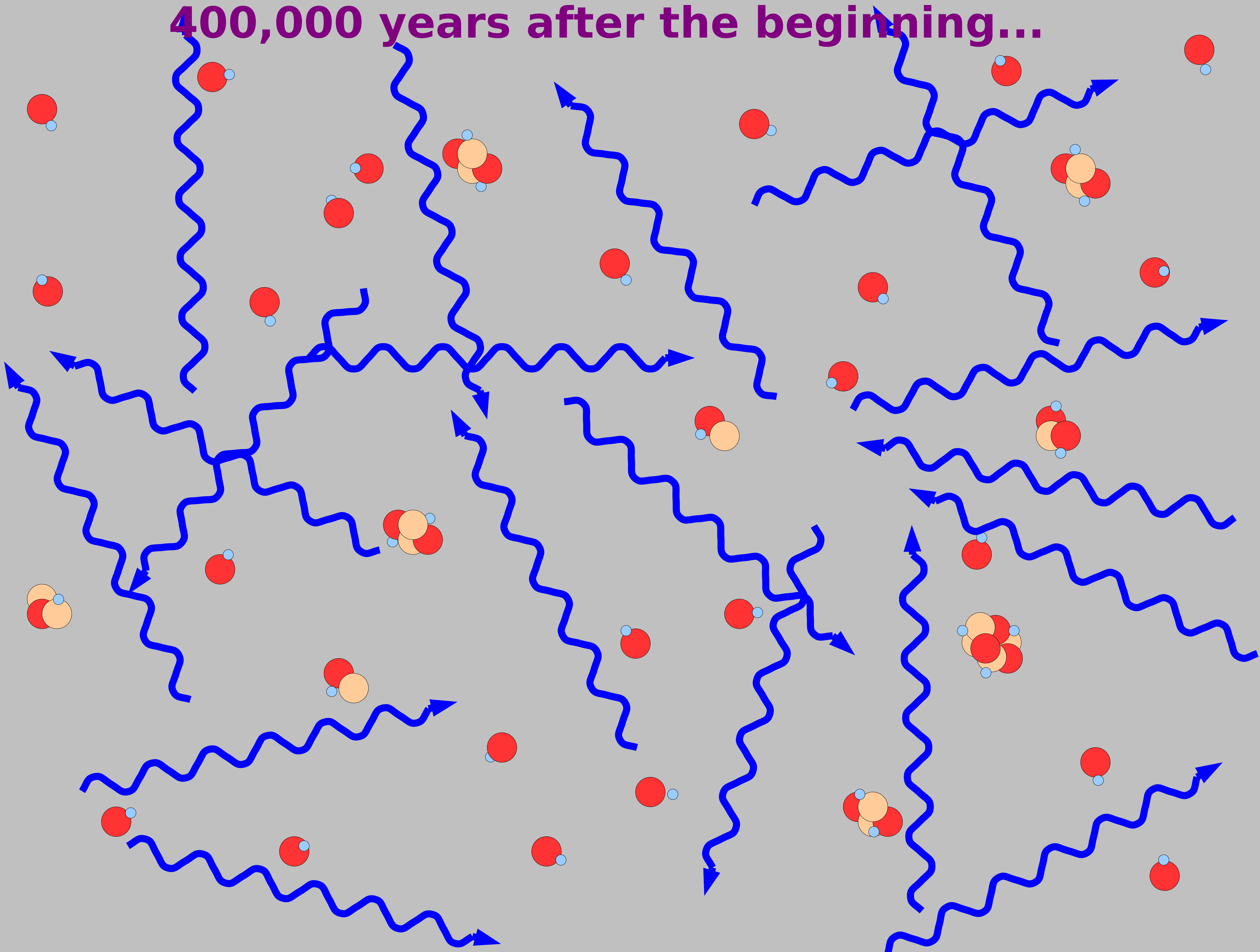
The density of matter passes the density of radiation at z=3200, about 100,000 years after the beginning.

Amsler et al., (PDG), 2008, PhL B667, 1 – 2009 PDG Review;
using WMAP 7-year cosmology from Komatsu *et al.*, arXiV:1001.4538v2

For the first ~400,000 years...



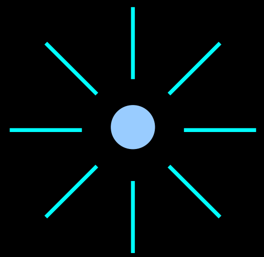
400,000 years after the beginning...



...and then...

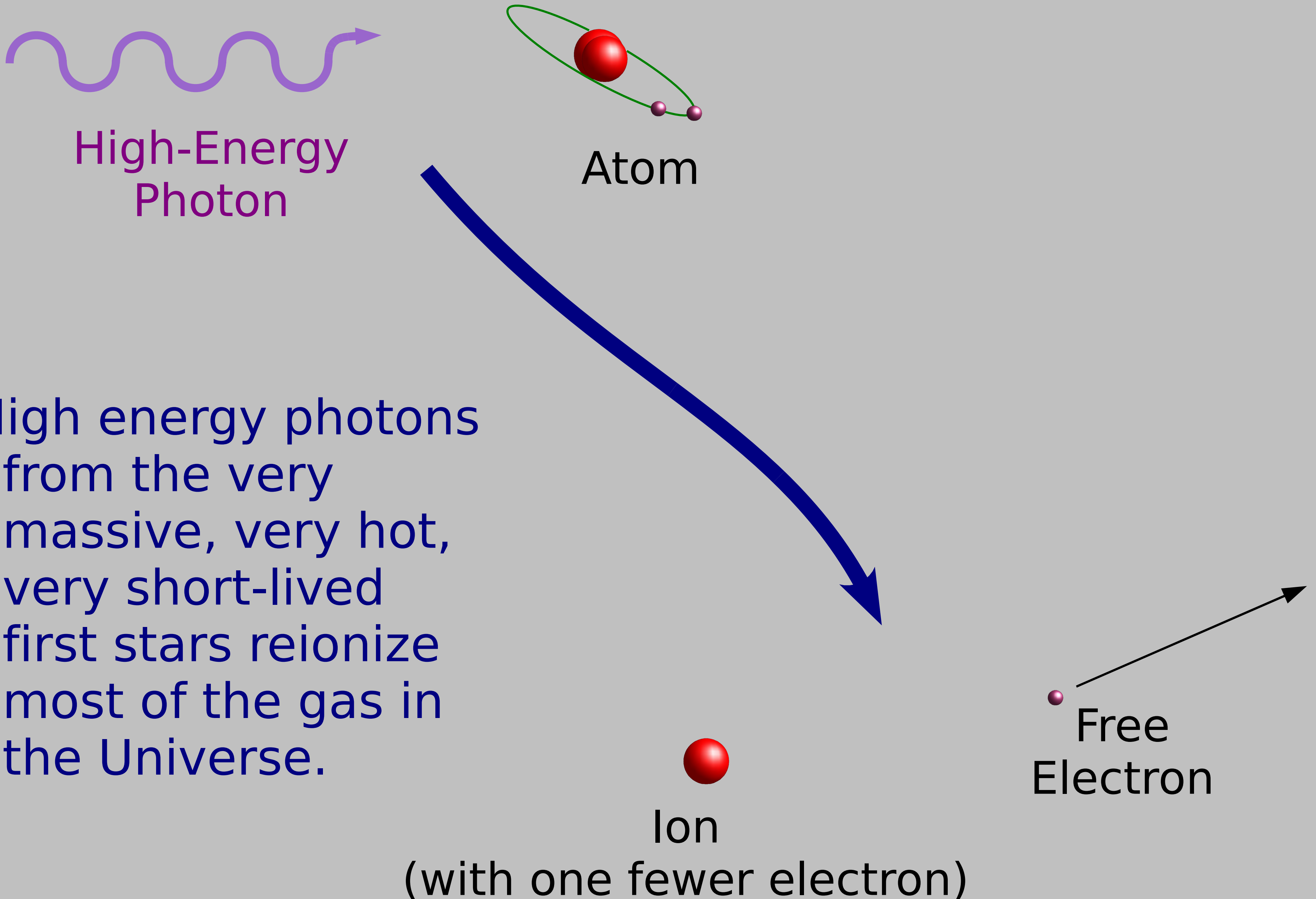
THE DARK AGES

At z=10, 500 million years after the beginning...



...cue "Thus Spake Zarathrustra"

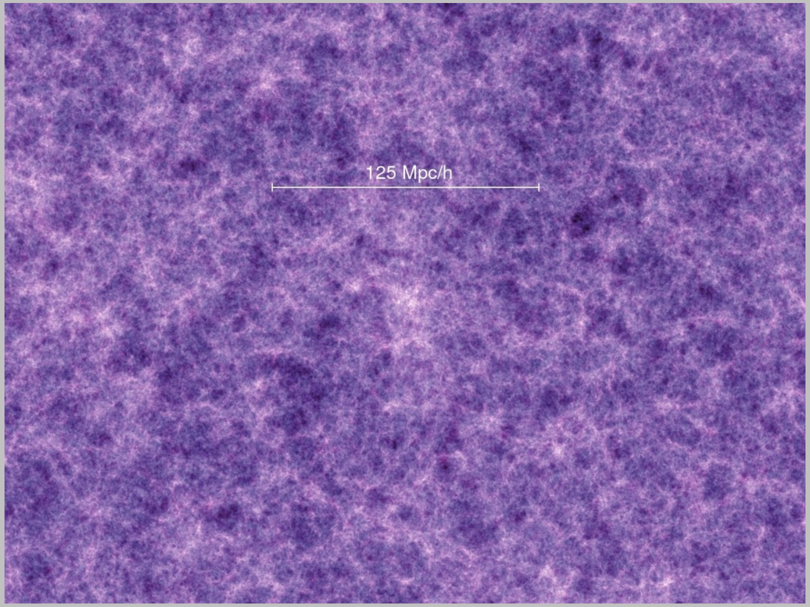
Reionization – the first stars



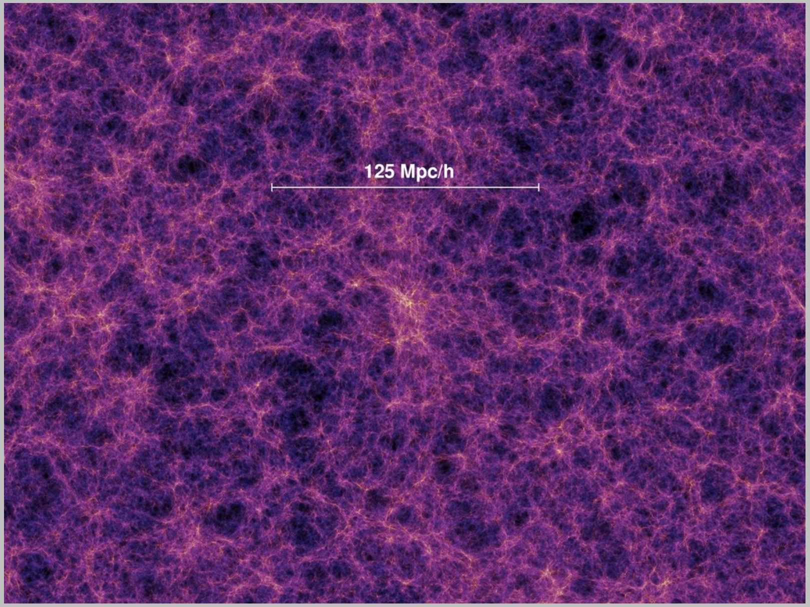
High energy photons from the very massive, very hot, very short-lived first stars reionize most of the gas in the Universe.

The growth of structure

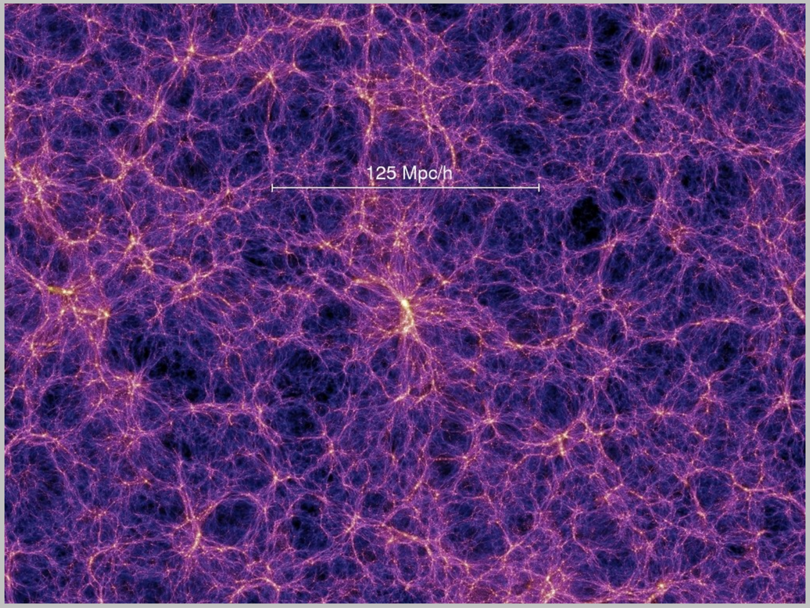
z=18.3 (0.2 Gyr)



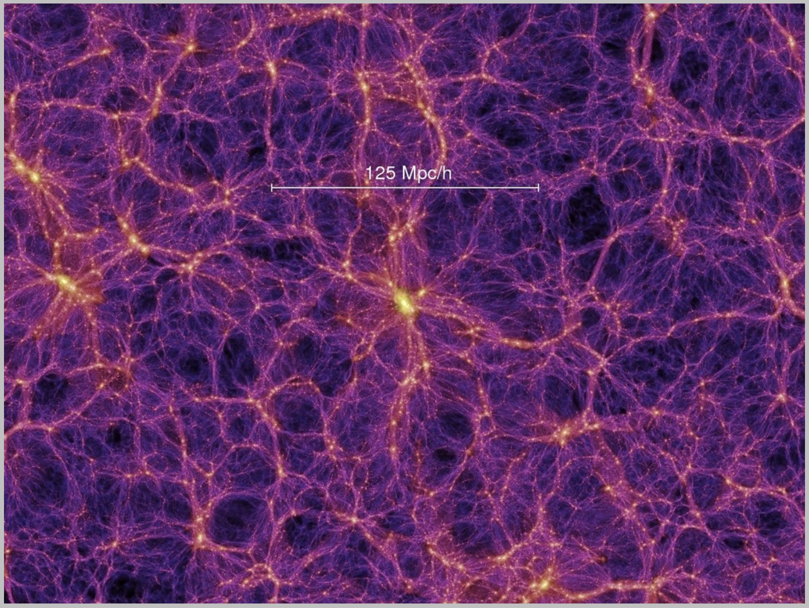
z=5.7 (1.0 Gyr)



z=1.4 (4.7 Gyr)

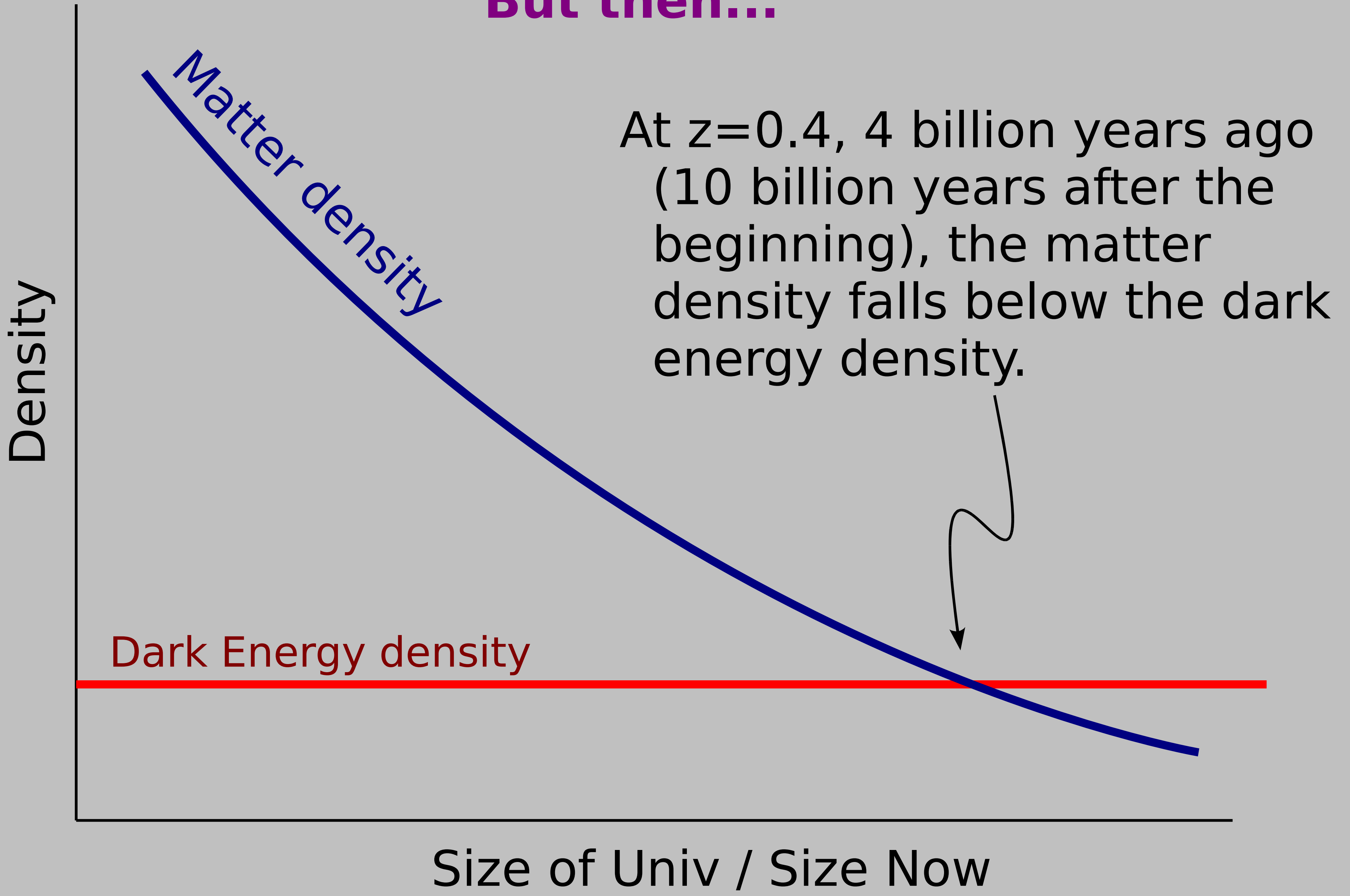


z=0 (13.7 Gyr)



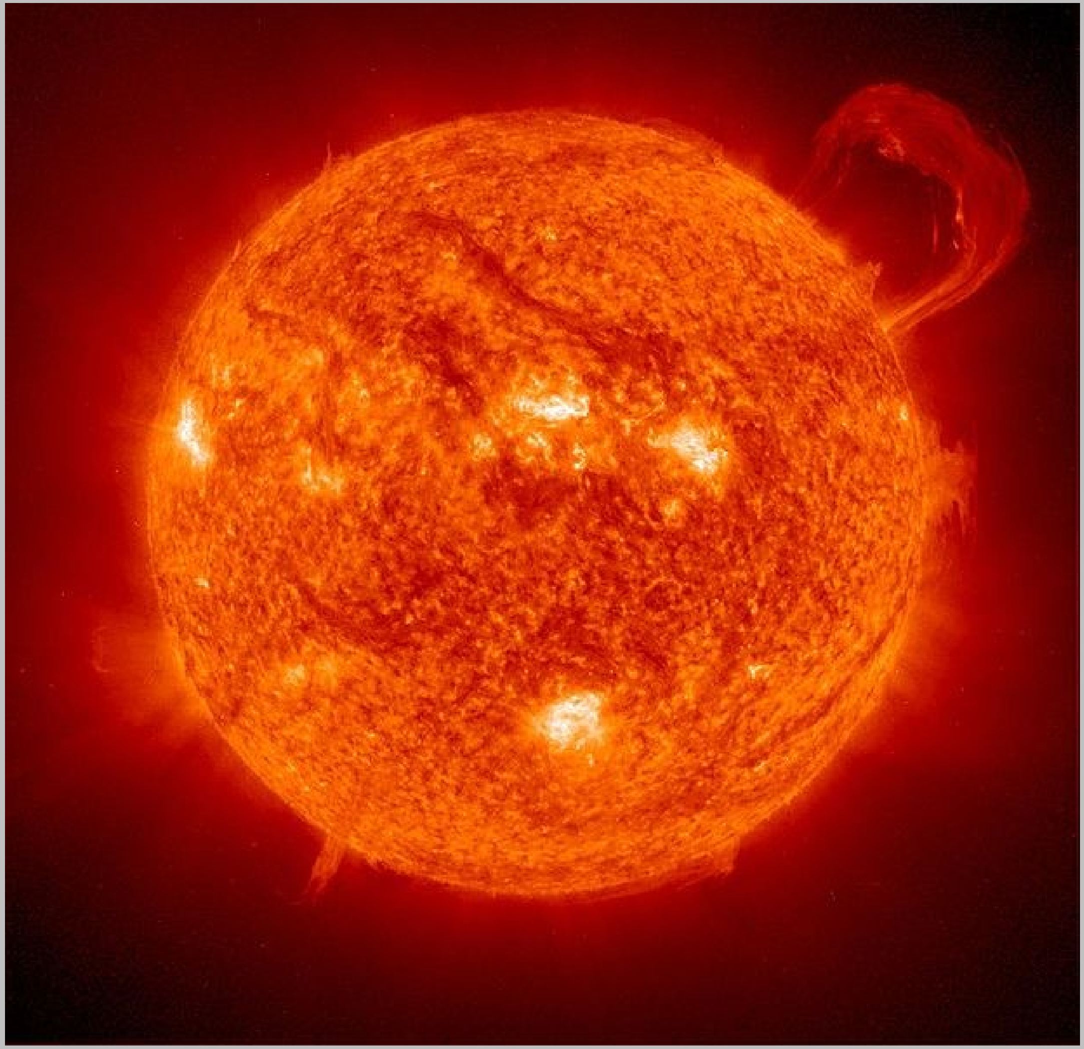
For a long time, Dark Energy isn't important.

But then...



A few billion years before that, the expansion started accelerating.

4.5 billion years ago...



...the Solar System forms

One hour ago...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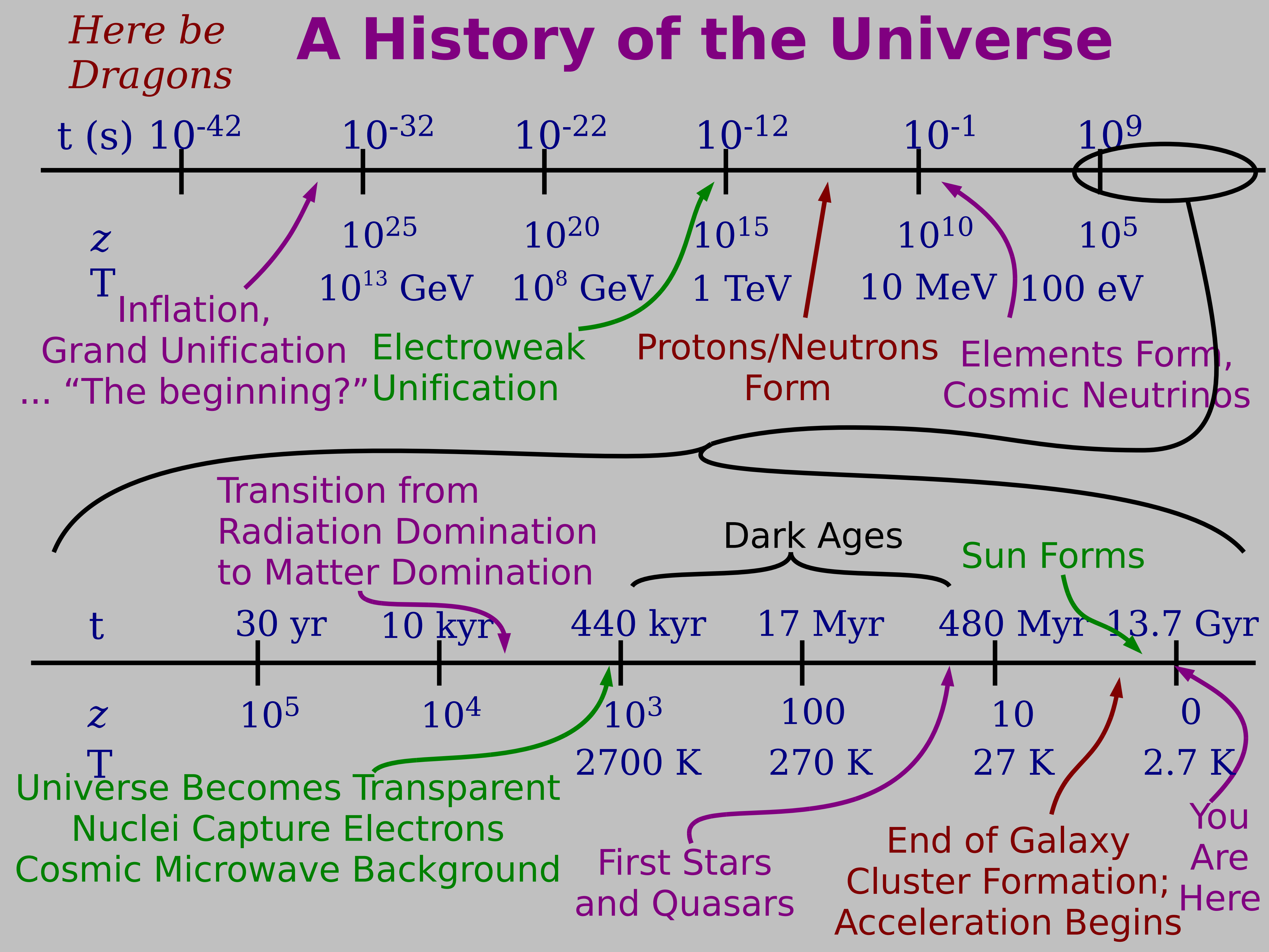
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