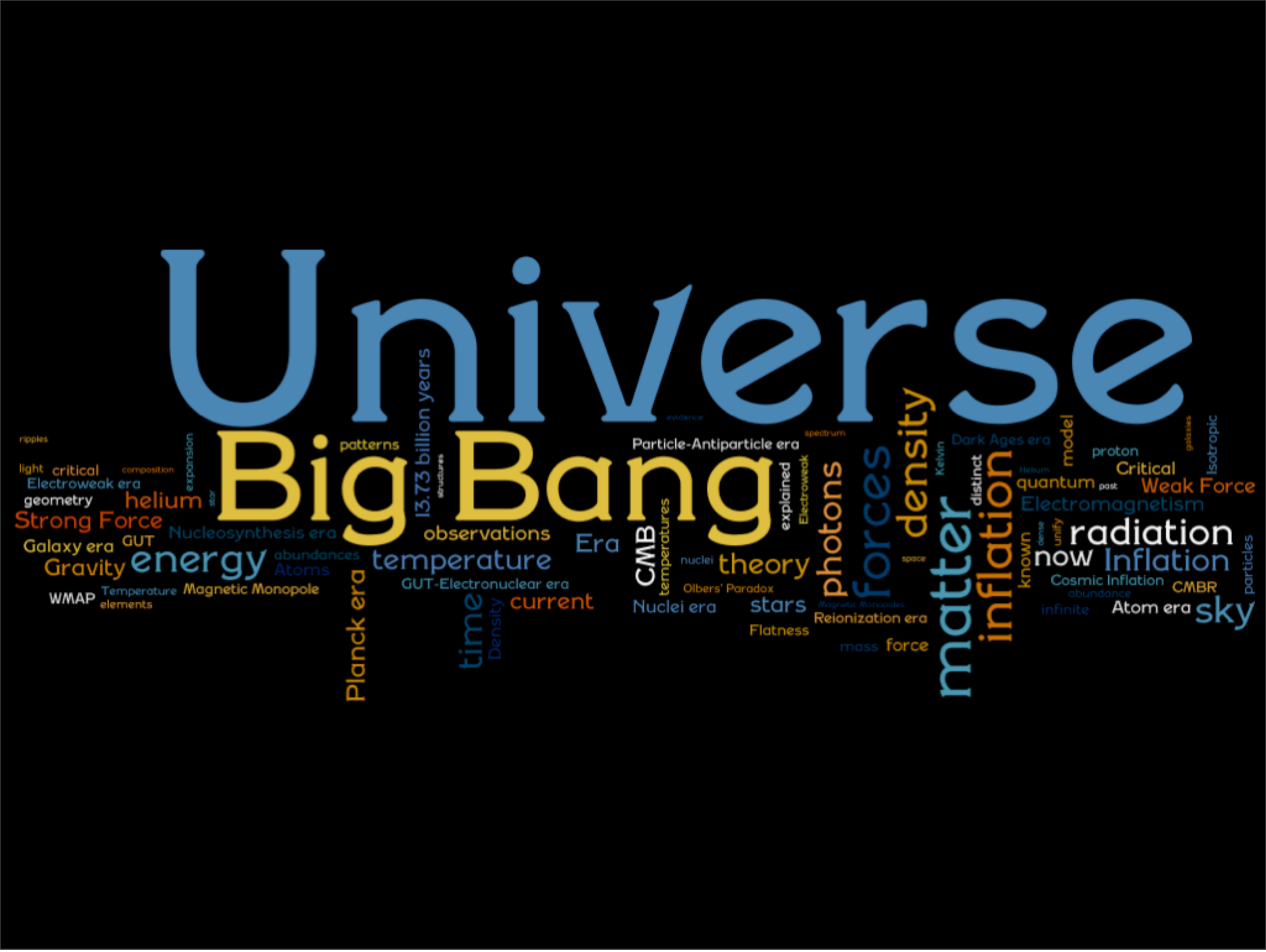
# From the Beginning to the End of our Universe

## Chapter 17


Universe
Big Bang
billion years
patterns
ripples
expansion
13.73 billion years
structures
star
evidence
spectrum
Particle-Antiparticle era
density
Dark Ages era
model
proton
galaxies
isotropic
light
critical
composition
Electroweak era
geometry
helium
Strong Force
Nucleosynthesis era
observations
Era
CMB
temperatures
explained
Electroweak
photons
forces
Kelvin
distinct
matter
inflation
Helium
quantum
past
Critical
Weak Force
Electromagnetism
Galaxy era
GUT
energy
abundances
Atoms
temperature
nuclei
theory
space
known
dense
unify
radiation
Gravity
Planck era
GUT-Electronuclear era
Olbers' Paradox
now
Inflation
Cosmic Inflation
CMBR
abundance
particles
WMAP
Temperature
elements
Magnetic Monopole
time
Density
current
Nuclei era
stars
Magnetic Monopoles
Reionization era
Flatness
infinite
Atom era
sky
mass
force

# The Big Bang

* The **Big Bang** is the event which **led to the formation of our Universe**

* The theory of its evolution is the most comprehensive and accurate explanation supported by numerous scientific evidence and observations

* It started about 13.81 billions years ago

# Conditions in the Early Universe

* As it expands, the Universe is cooling
* This implies it must have been hotter and denser in the past
* We can exactly work out the conditions of the early Universe from the first $10^{-32}$ second! (Right after the Inflationary Epoch)

$10^{-32}$ second = 0.00000000000000000000000000001 second

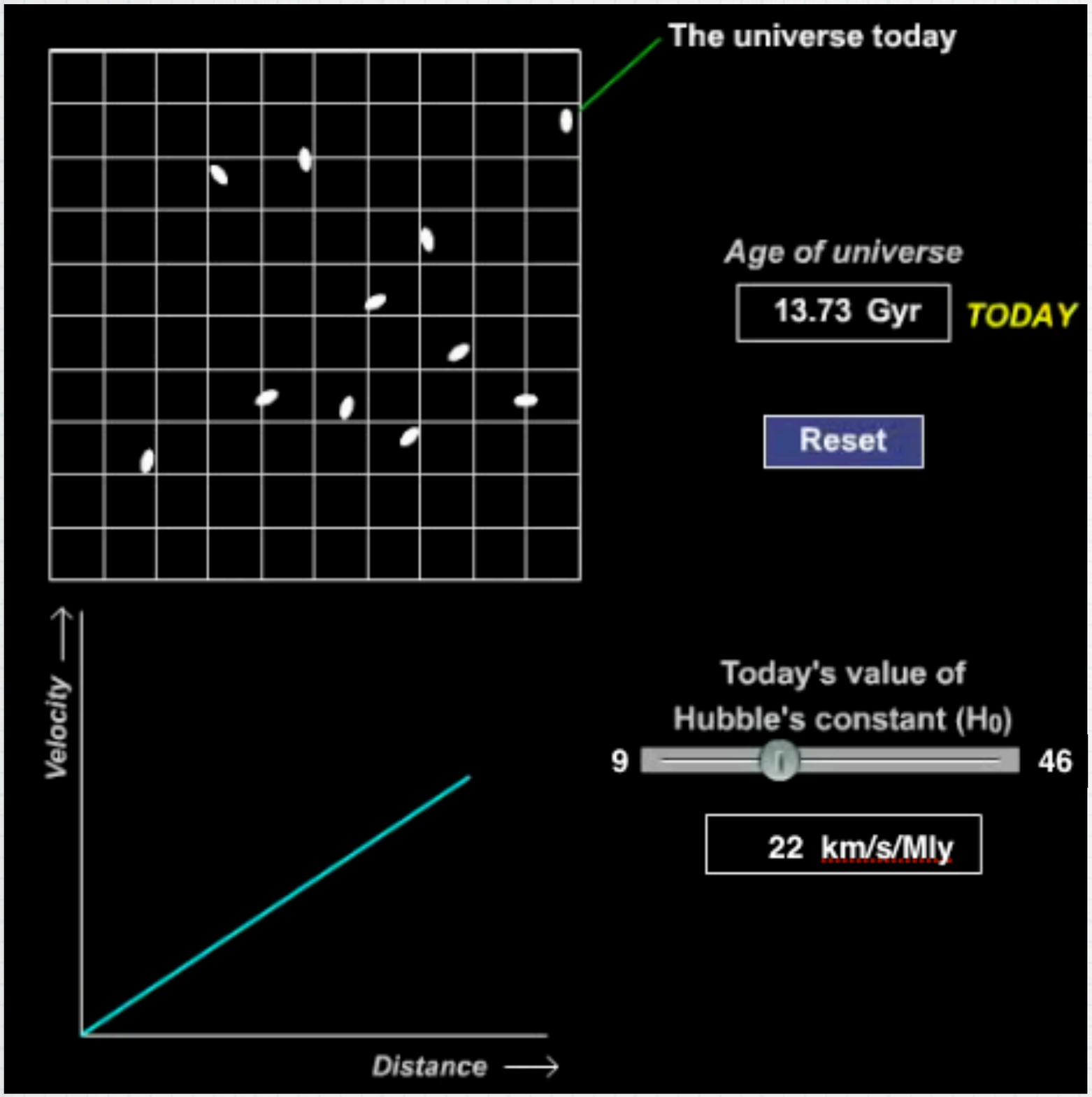
# Conditions in the Early Universe

* Between $10^{-32}$ and $10^{-43}$ second, we have some good ideas but no observations yet (need more powerful particle accelerators)

* Before $10^{-43}$ second (the Planck epoch), space and time do not yet exist (quantum foam)

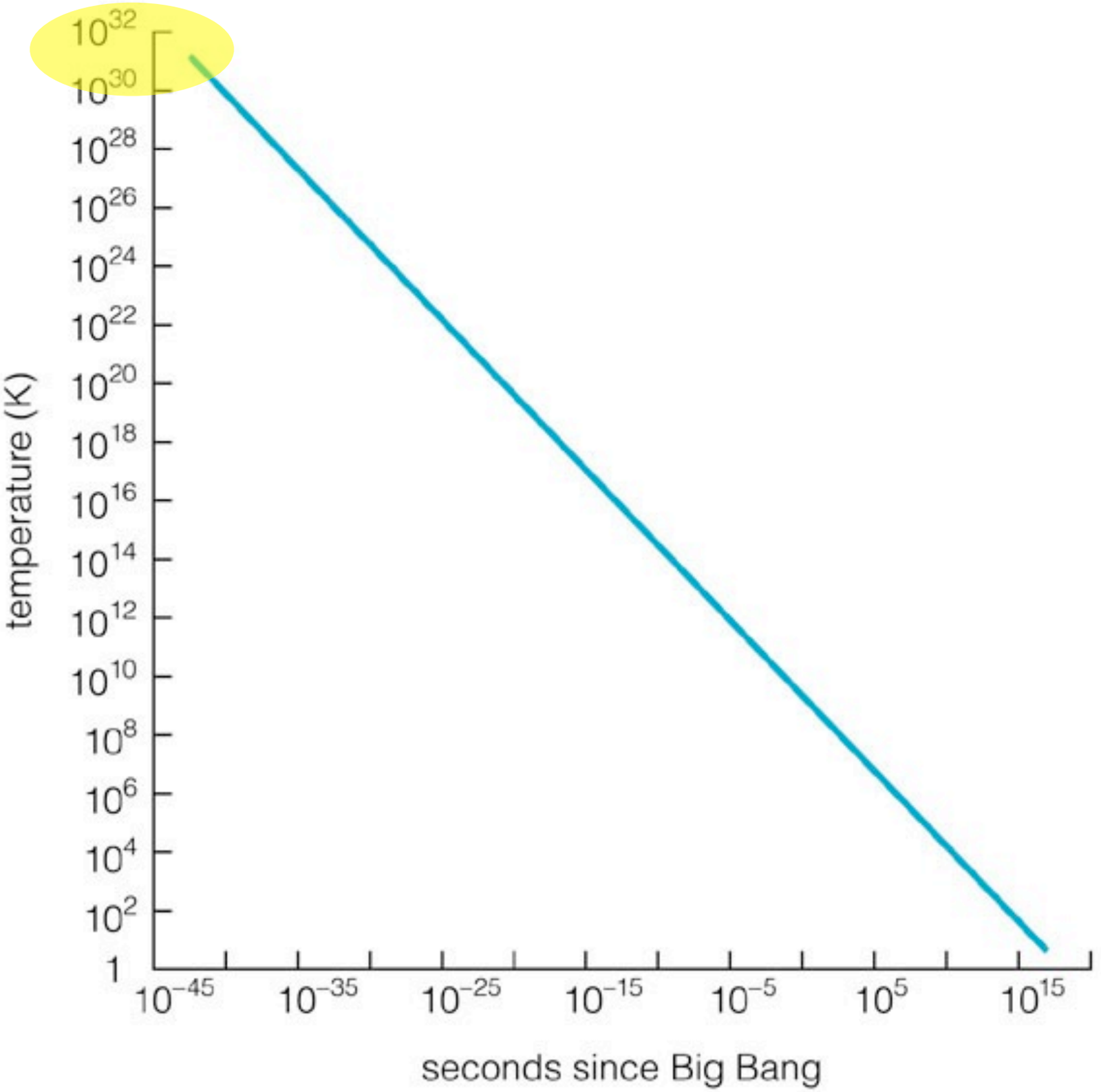
* The smallest theoretical time step is $10^{-43}$ second!

$10^{-43}$ = 0.00000000000000000000000000000000000001




Universe must have been much hotter and denser early in time

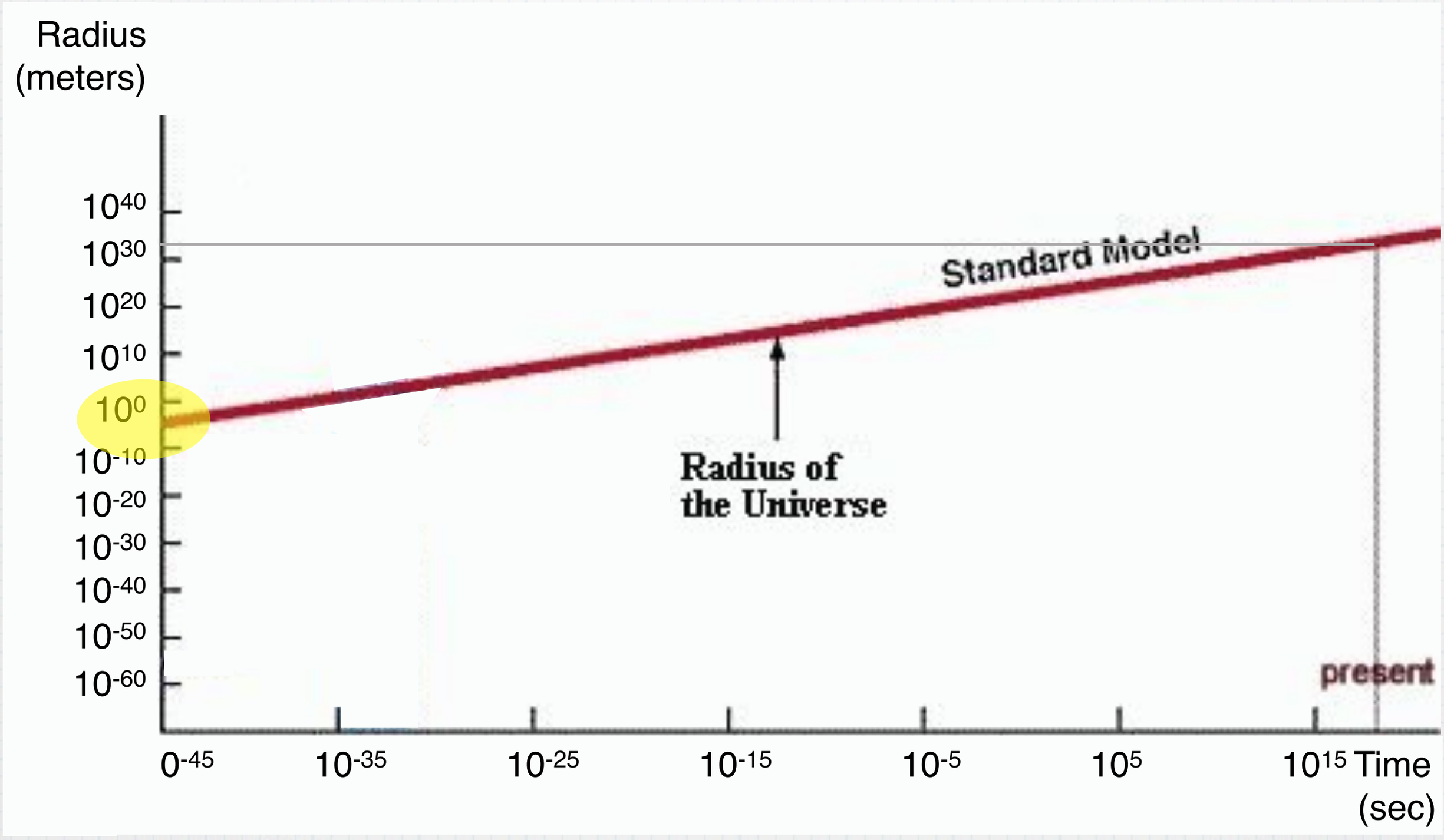
All the matter and energy contained in the Universe condensed to a size smaller than the nucleus of an atom (possibly as small as a proton...)

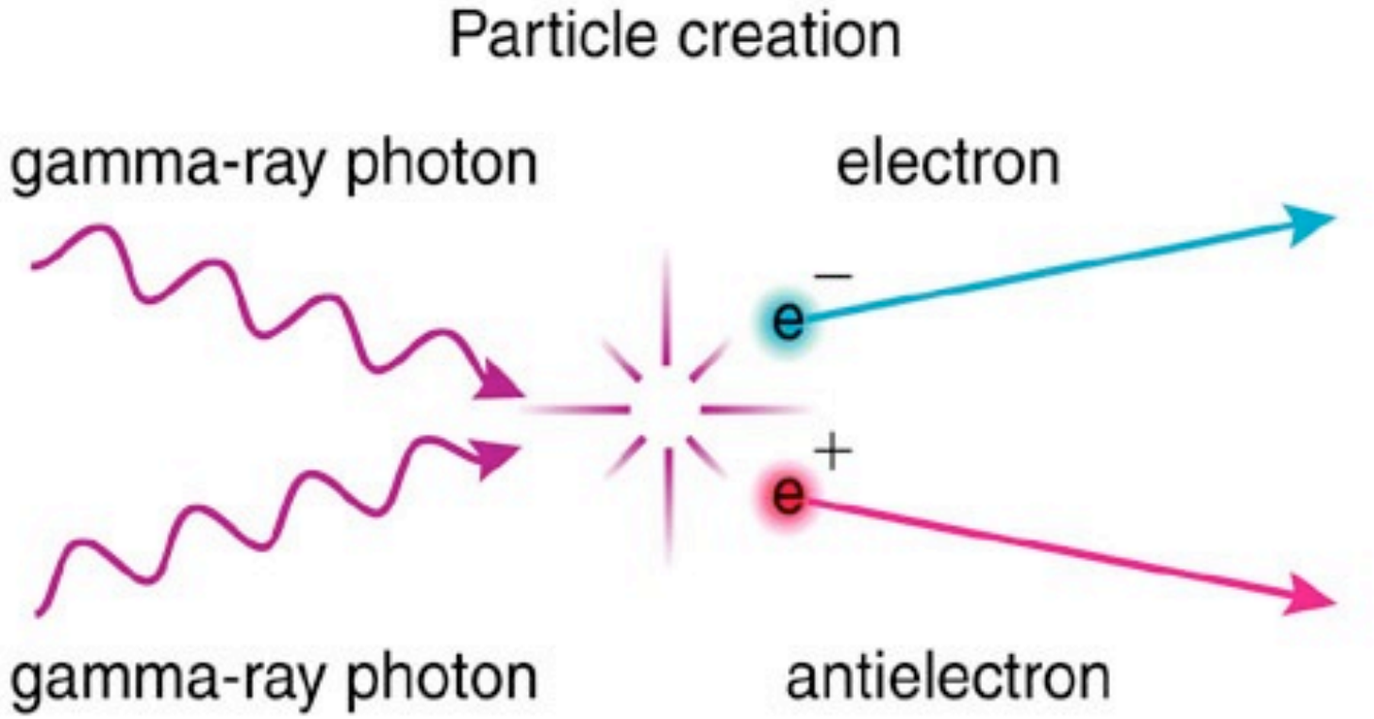



How much hotter and denser?

The early Universe must have been extremely hot and dense

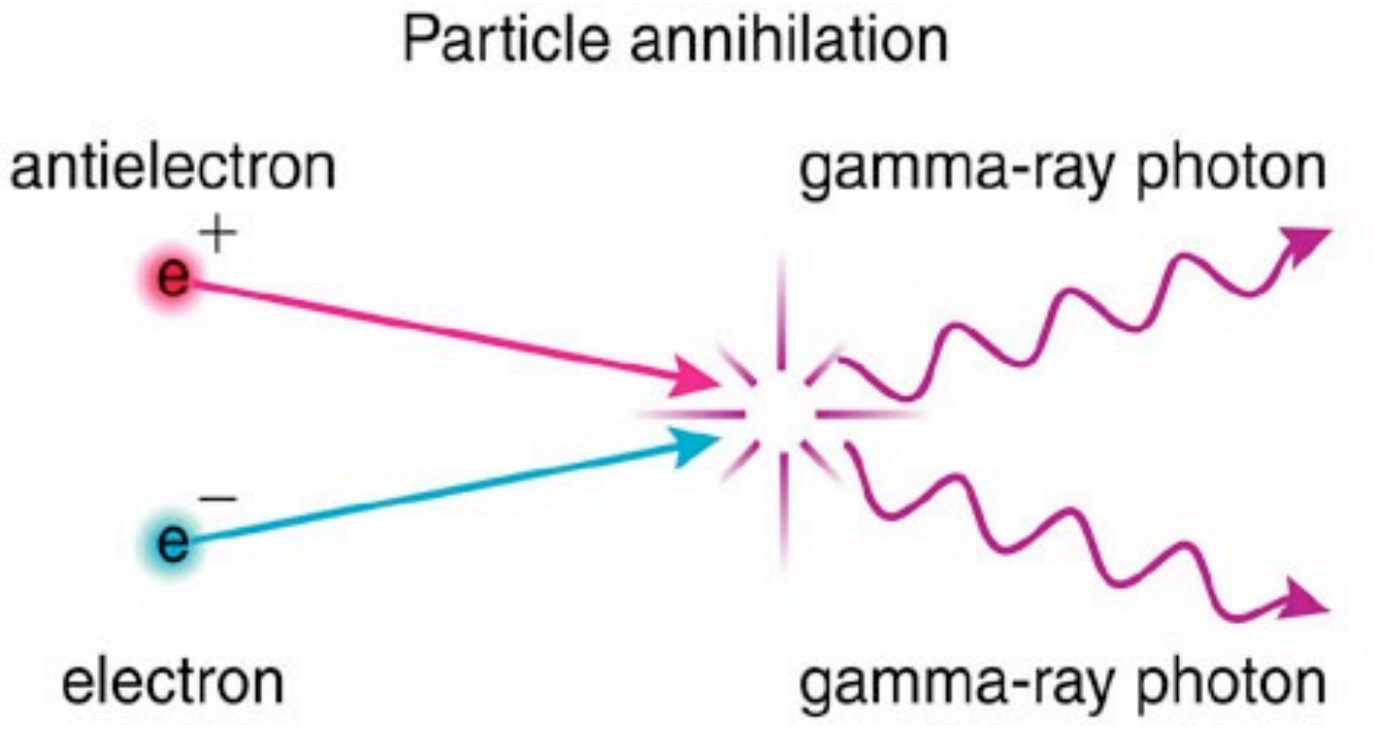
# The Universe has been growing





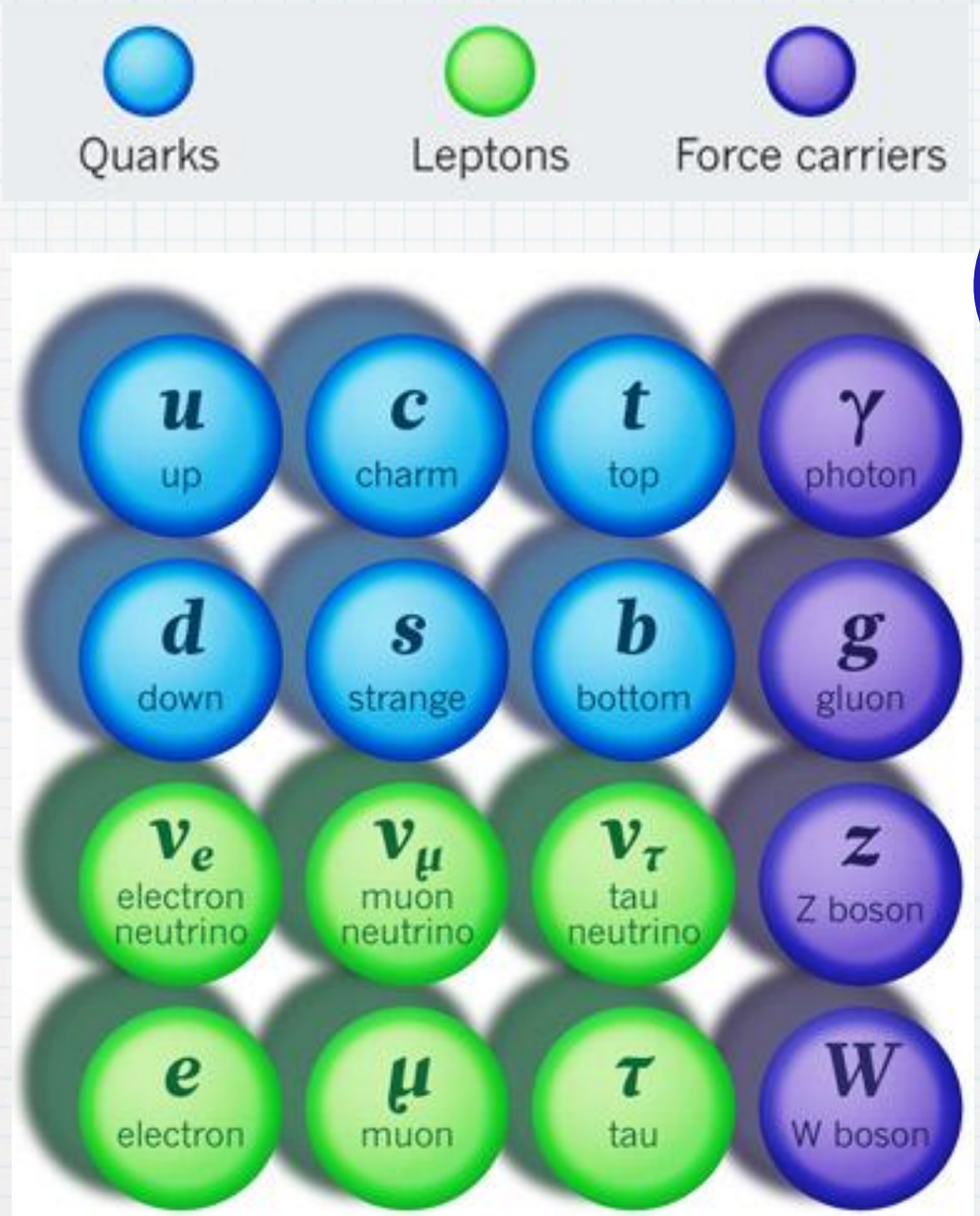

Photons converted into elemental particle-antiparticle pairs and vice-versa

$E = mc^2$




Early Universe was full of basic particles and radiation because of its high temperature

# Fundamental Particle Soup




G graviton **Not yet found**

**Quarks** & **Leptons** are called **Fermions**

**Force carriers are called Bosons**

**Fermions are related with matter**

**Bosons are related with radiation**

**I II III**

**Three Generations of Matter**

$H^0$ Higgs **New**

Found!

# The Higgs Boson
## or why matter has mass

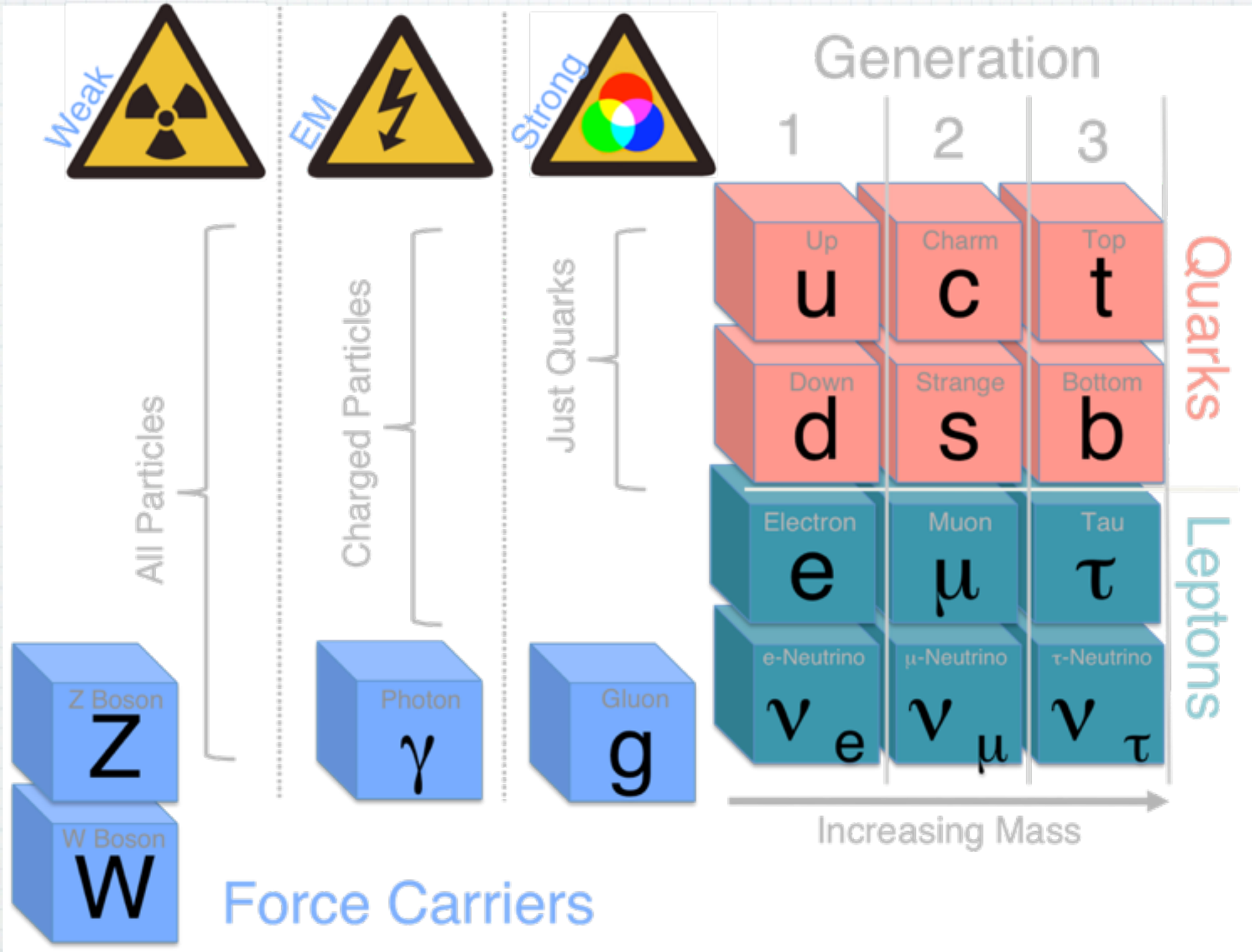
* Mass is due to some particles interacting with a uniform field permeating space

* This field is now called the Higgs field

* Theoretically calculated, this field appears when the Electroweak force split into the E&M and Weak forces

* The Higgs boson was recently observed (we think)

# Trying to understand why/how forces merge



# The Universe's History According to the Big Bang Theory

* **The Big Bang theory** describes how the expansion and cooling of an incredibly hot and dense collection of matter and radiation **leads to our current Universe - using nothing but tested laws of physics**

# The Four Forces

1. **Gravity**: spacetime curves but is caused by the presence of mass and energy: gravitons not observed yet
2. **Electromagnetism**: light, magnets, ionization; caused by charge; transmitted by photons
3. **Strong Force**: keeps nuclei bunched together; transmitted by gluons
4. **Weak Force**: keeps particles stable; transmitted by the Z and W bosons

# The Four Forces become three

* Theoretical studies and observations have demonstrated that the electromagnetic force and the weak nuclear force are the same thing at high temperature (energies)

* demonstrated: The electroweak force is valid when temperatures are above $10^{15}$ K

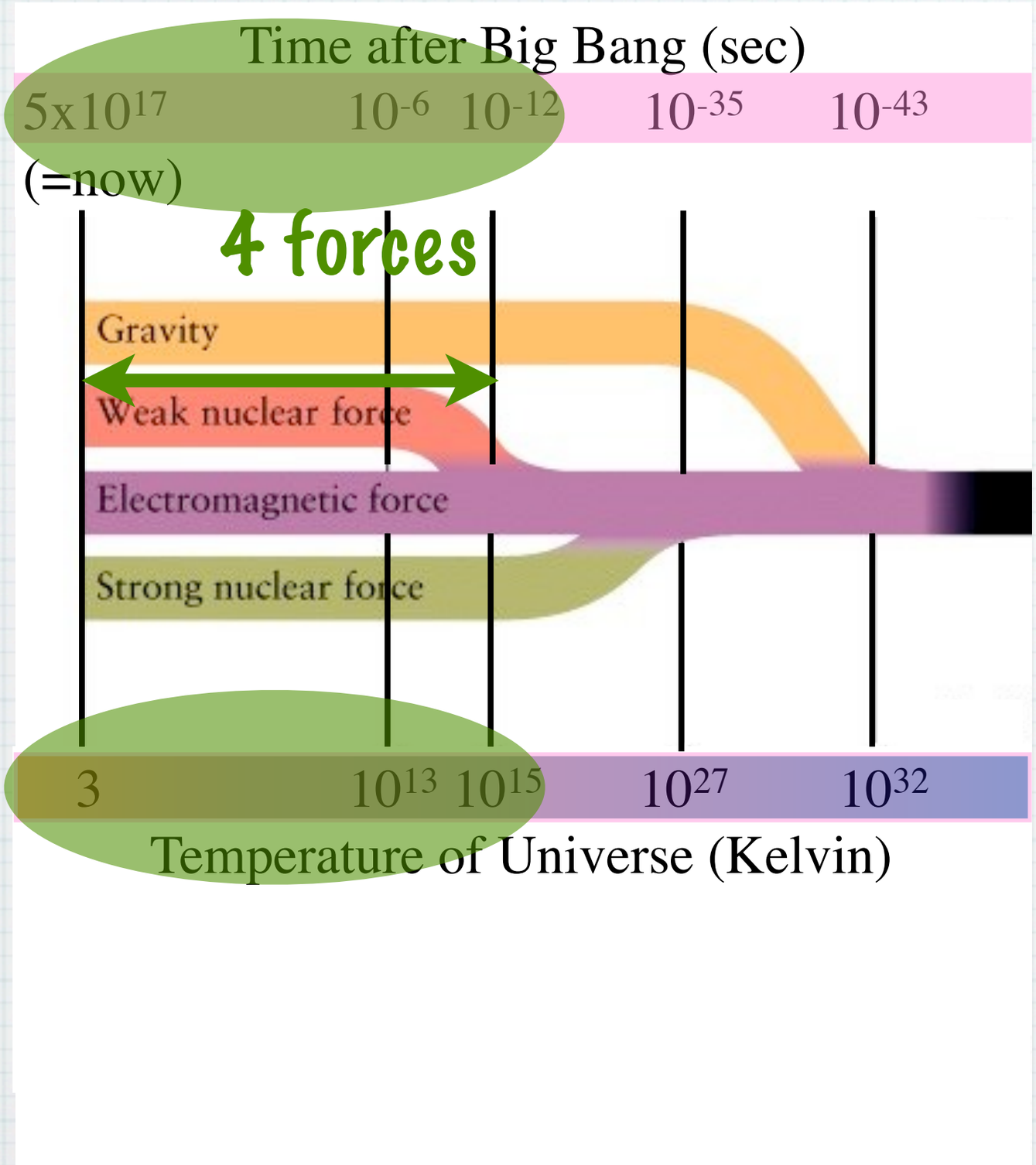
$10^{15}$ K = 1,000,000,000,000,000 K

# The Four Forces may become two

* Theoretical studies have shown that the electroweak force and the strong nuclear force are the same thing at high temperature
* theoretical: The electronuclear force is valid when temperatures are above $10^{27}$ K

$10^{27}$ K = 1,000,000,000,000,000,000,000,000,000 K

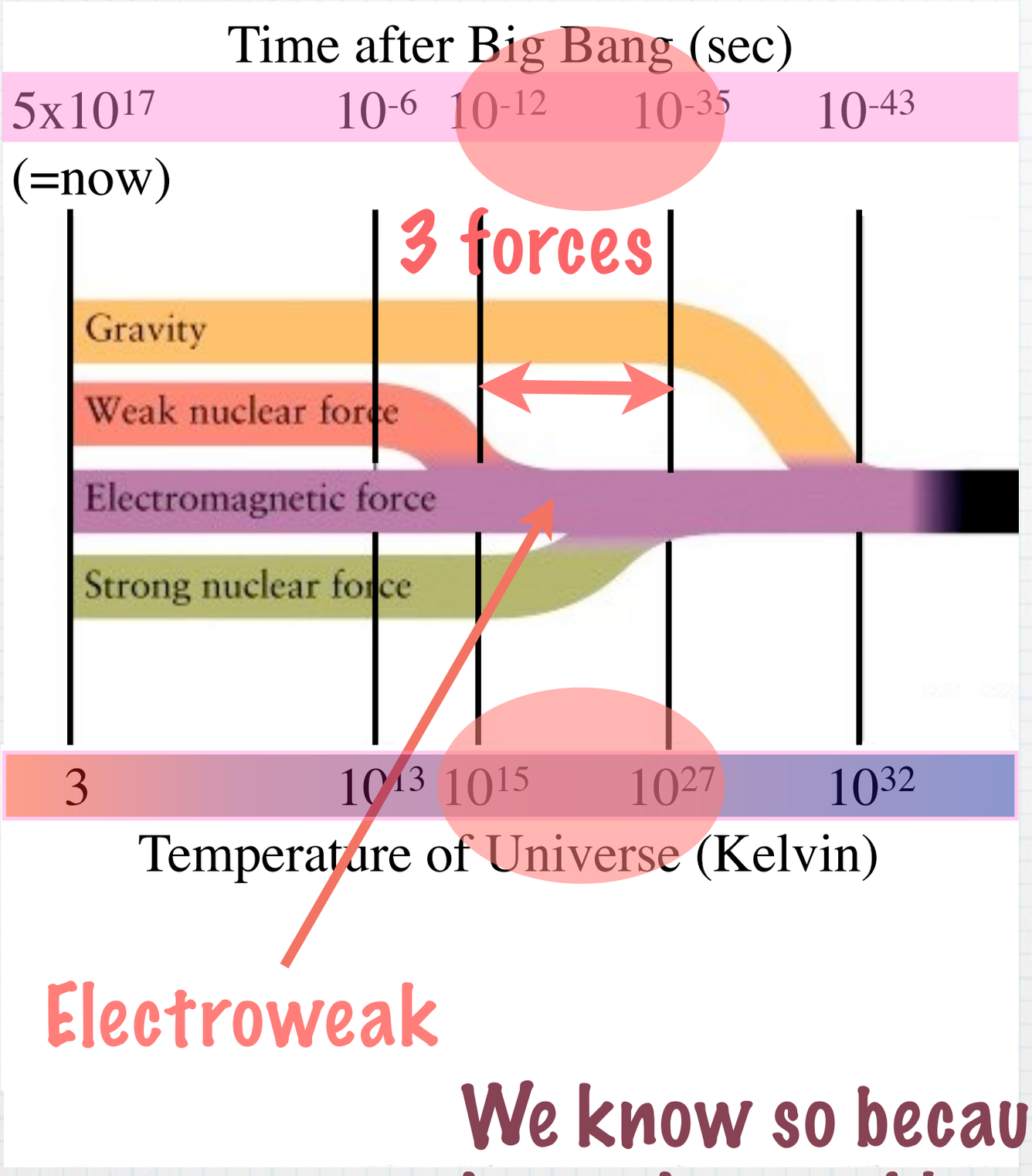
# Do forces unify at high temperatures? We think so...




## 4 known forces in current Universe:

1. Strong Force
2. Electromagnetism
3. Weak Force
4. Gravity

# Do forces unify at high temperatures?



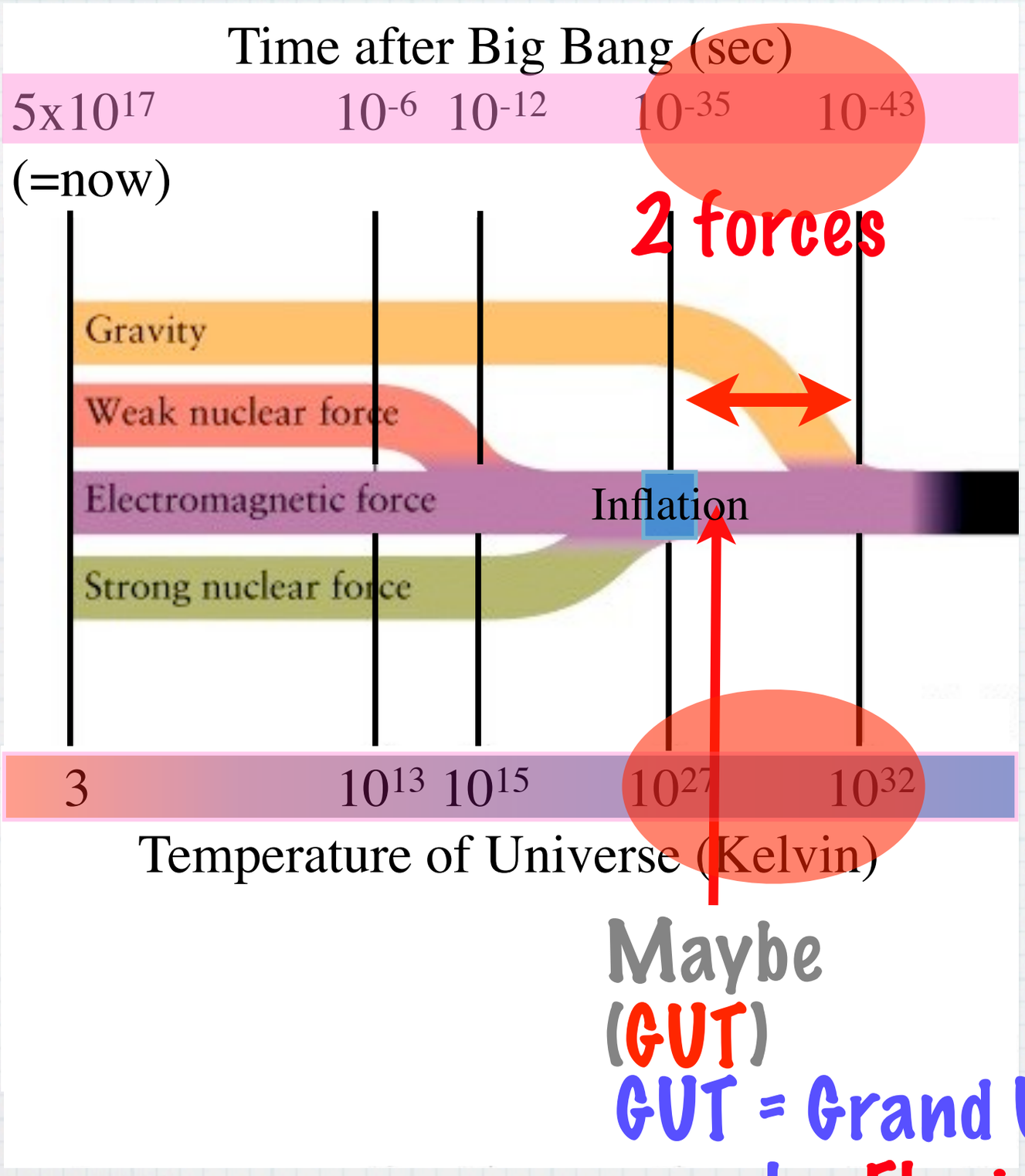

## 4 known forces in current Universe:

1. Strong Force
2. Electromagnetism
3. Weak Force
4. Gravity

Now 3

We know so because Electroweak has been observed in particle accelerators!

# Do forces unify at high temperatures?




## 4 known forces in current Universe:

1. Strong Force
2. Electromagnetism
3. Weak Force
4. Gravity

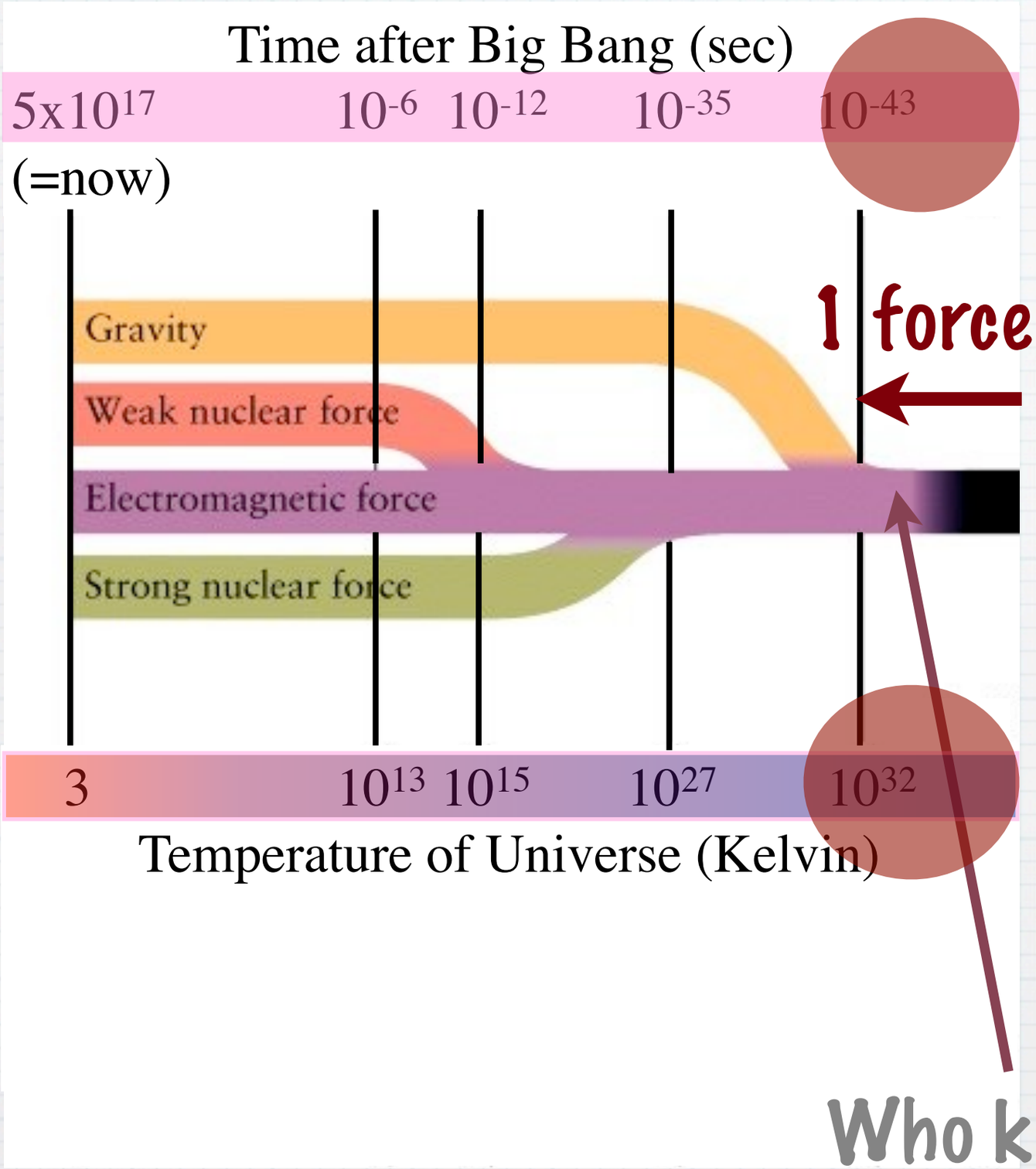
Only 2 there

GUT = Grand Unification Theory

aka Electronuclear Force

# Do forces unify at high temperatures?

## The Holy Grail of Physics




1 force

4 known forces
in current Universe:

1. Strong Force
2. Electromagnetism
3. Weak Force
4. Gravity

Only 1 originally

Who knows?
(String Theory)

# Unfreezing the Forces

* The Physics of the Forces tells us that they became distinct one by one as the Universe cooled
* They "froze out"
* Which is analogous to water freezing out at 0° Celsius from a liquid state
* This is known as a "phase state" change

# Unfreezing the Forces

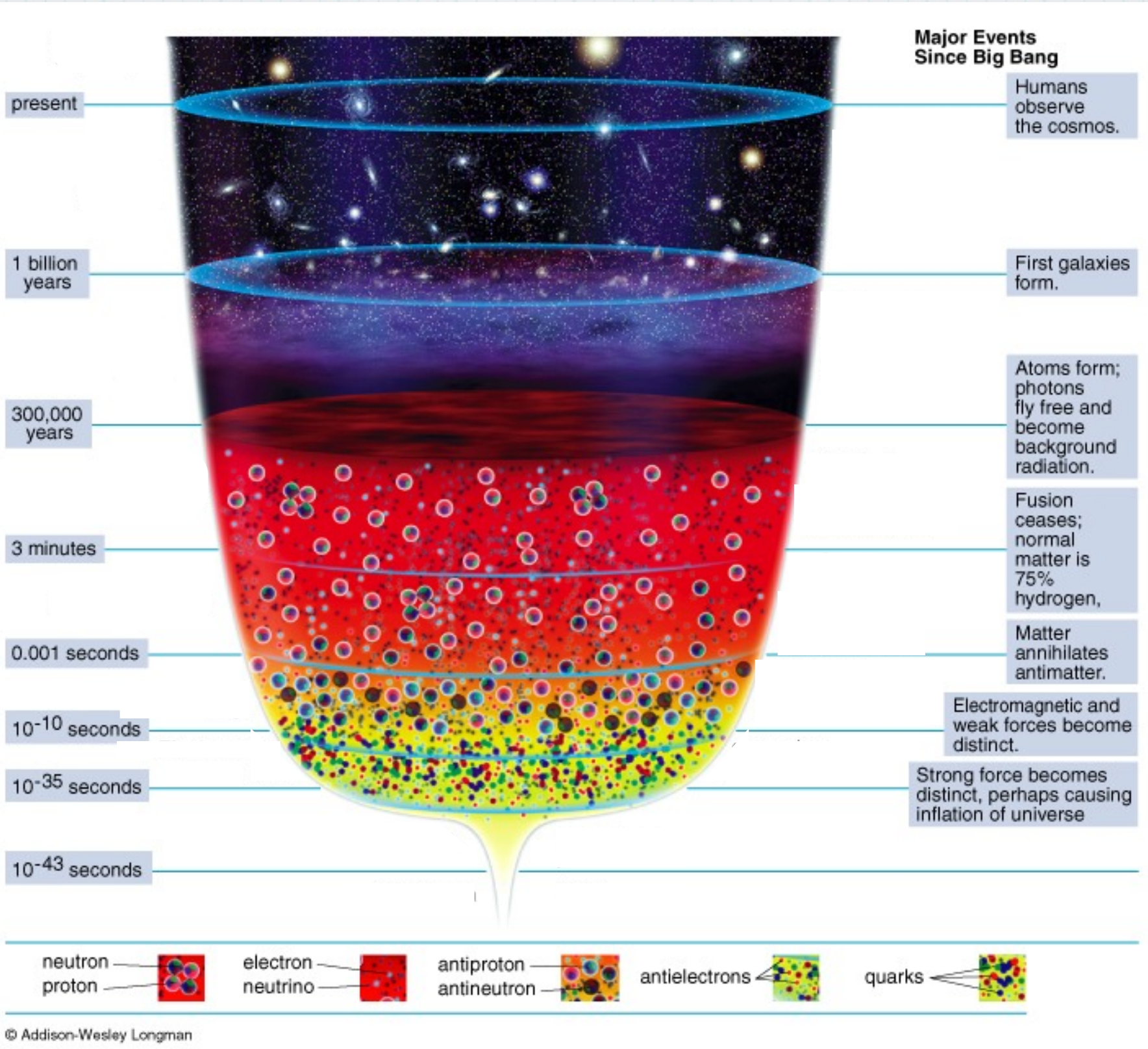
* So, at the birth of the Universe, imagine all 4 forces as liquids of different potential "colors" but equivalent then

* As the temperature drops, each "liquid" becomes distinct, in turn, because each "freezes" at a different temperature than the others and takes then a unique "color" or characteristic

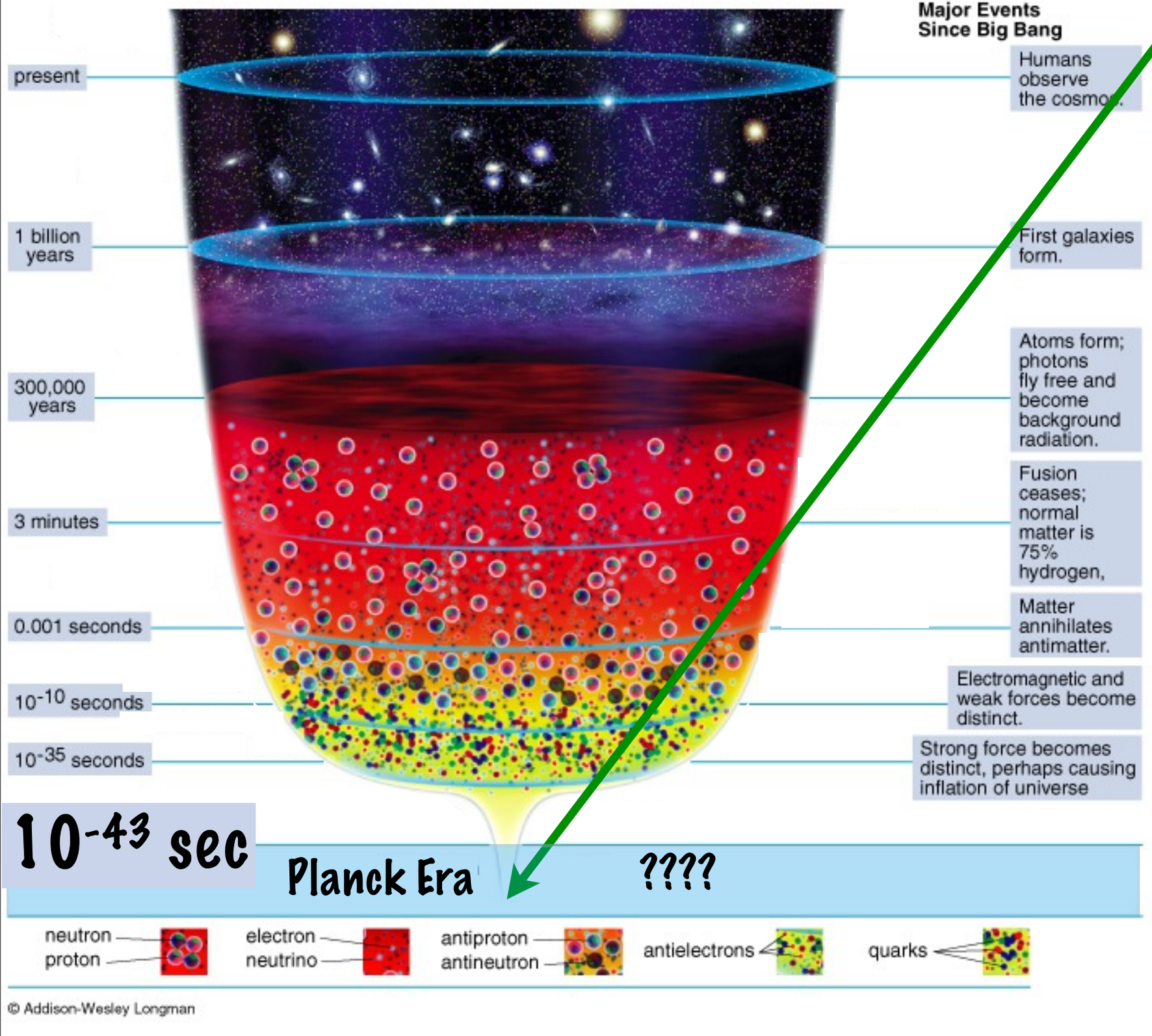
# The Big Bang, a computed history

* The Big Bang Model is a broadly accepted theory for the origin and evolution of our Universe
* Starting with a size much smaller than an atom it has since expanded from this hot dense state into the vast and much cooler cosmos we currently inhabit

time




events




# Planck Era

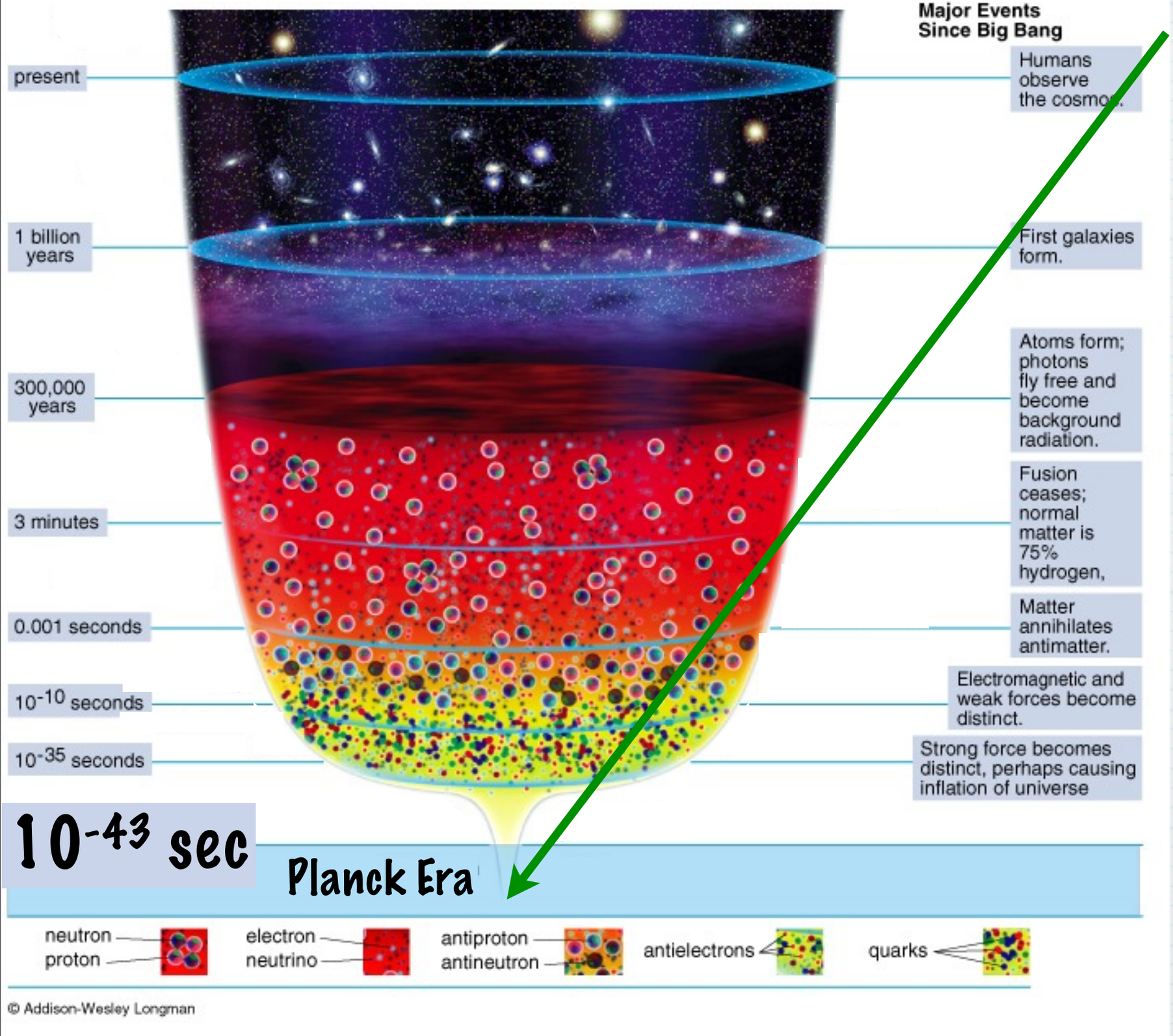
Before Planck time (~$10^{-43}$ sec)

No theory of quantum gravity yet exist

Size of Universe is smaller than the nucleus of an atom!

1 force ?

Cannot yet be explained

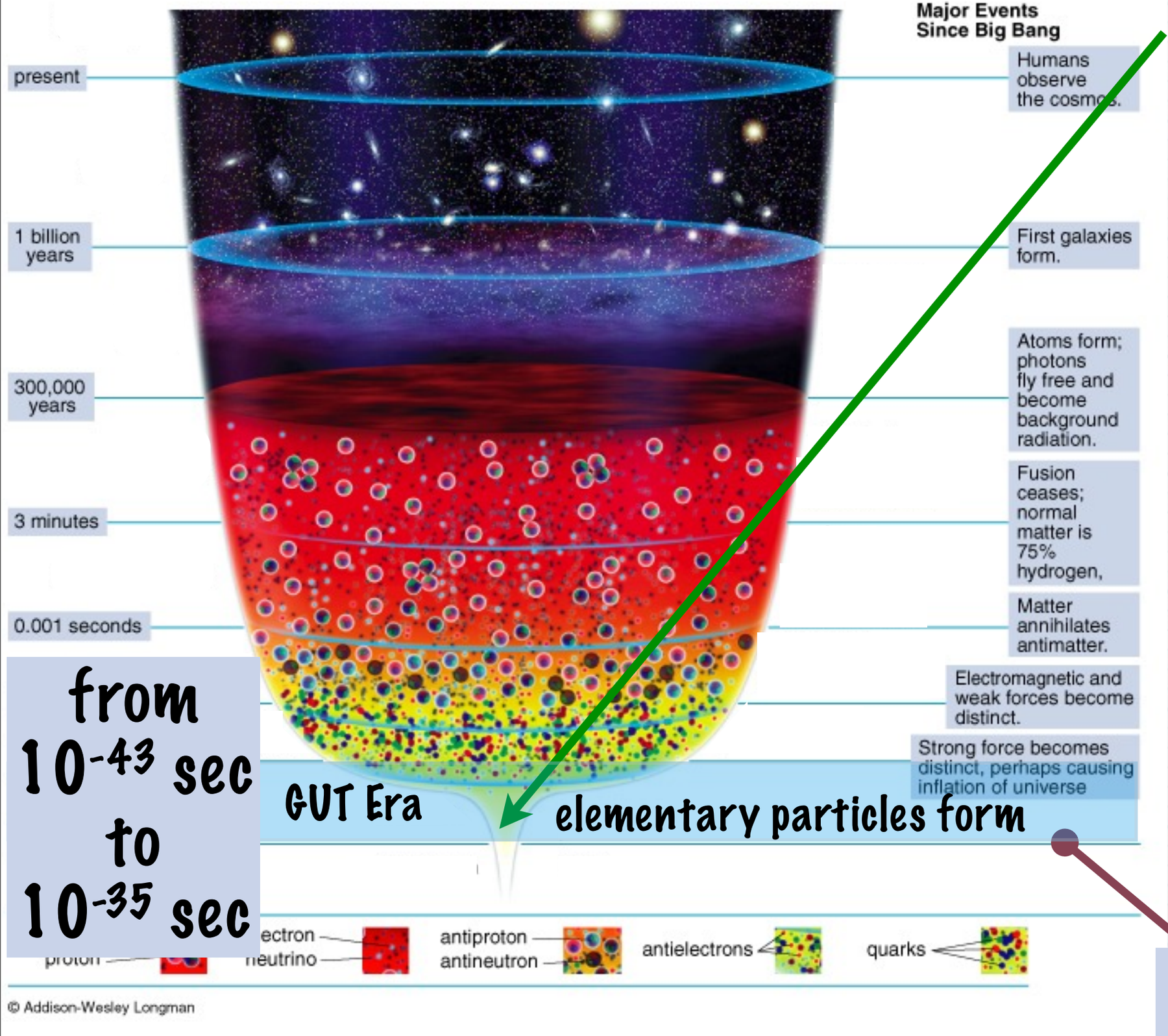



# Planck Era

Might be understood with Super String theory

Space & time are not yet shaped

Cannot yet be explained




GUT or Electronuclear Era

photons, elementary particles and anti-particles form

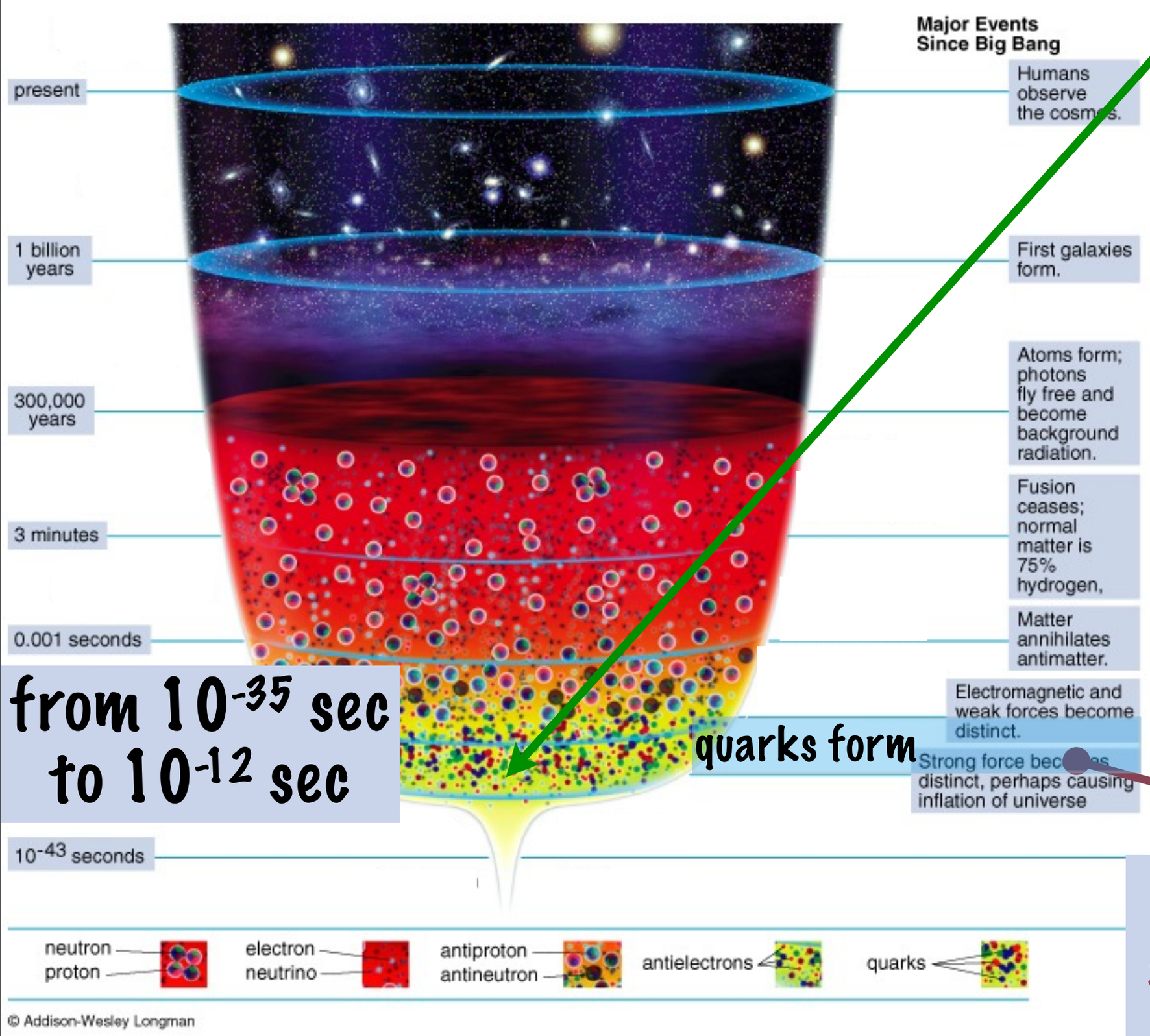
2 forces

Gravity and Electronuclear forces separate

from $10^{-43}$ sec to $10^{-35}$ sec

Partially explained - no observation

# Electroweak Era




from $10^{-35}$ sec to $10^{-12}$ sec

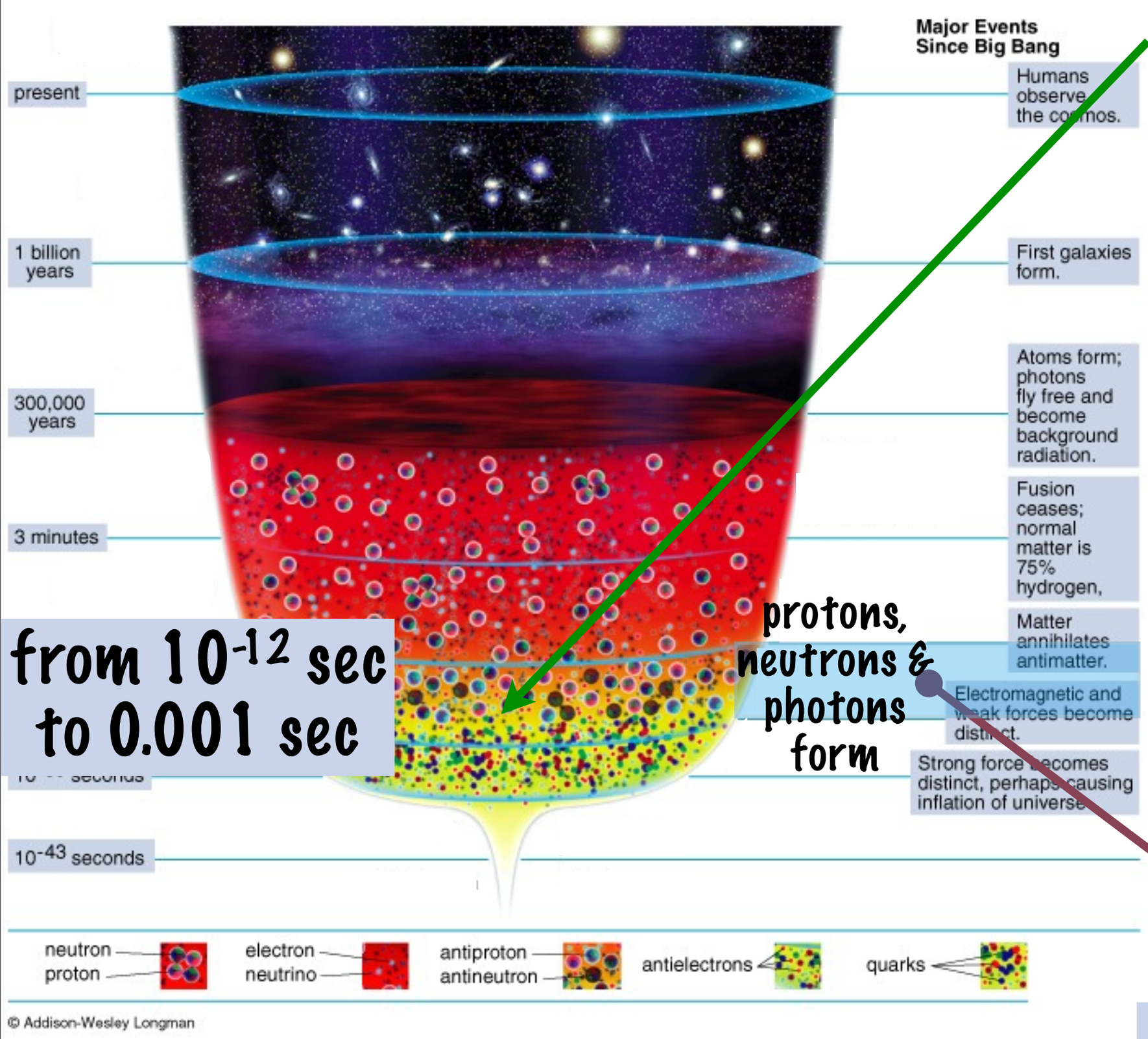
quarks form

quarks, anti-quarks, gluons, electrons and anti-electrons form

3 forces

Strong Force separates, (maybe) causing the sudden inflation of the Universe

Pretty much explained




from $10^{-12}$ sec to 0.001 sec

## Particle - Anti-particle Era

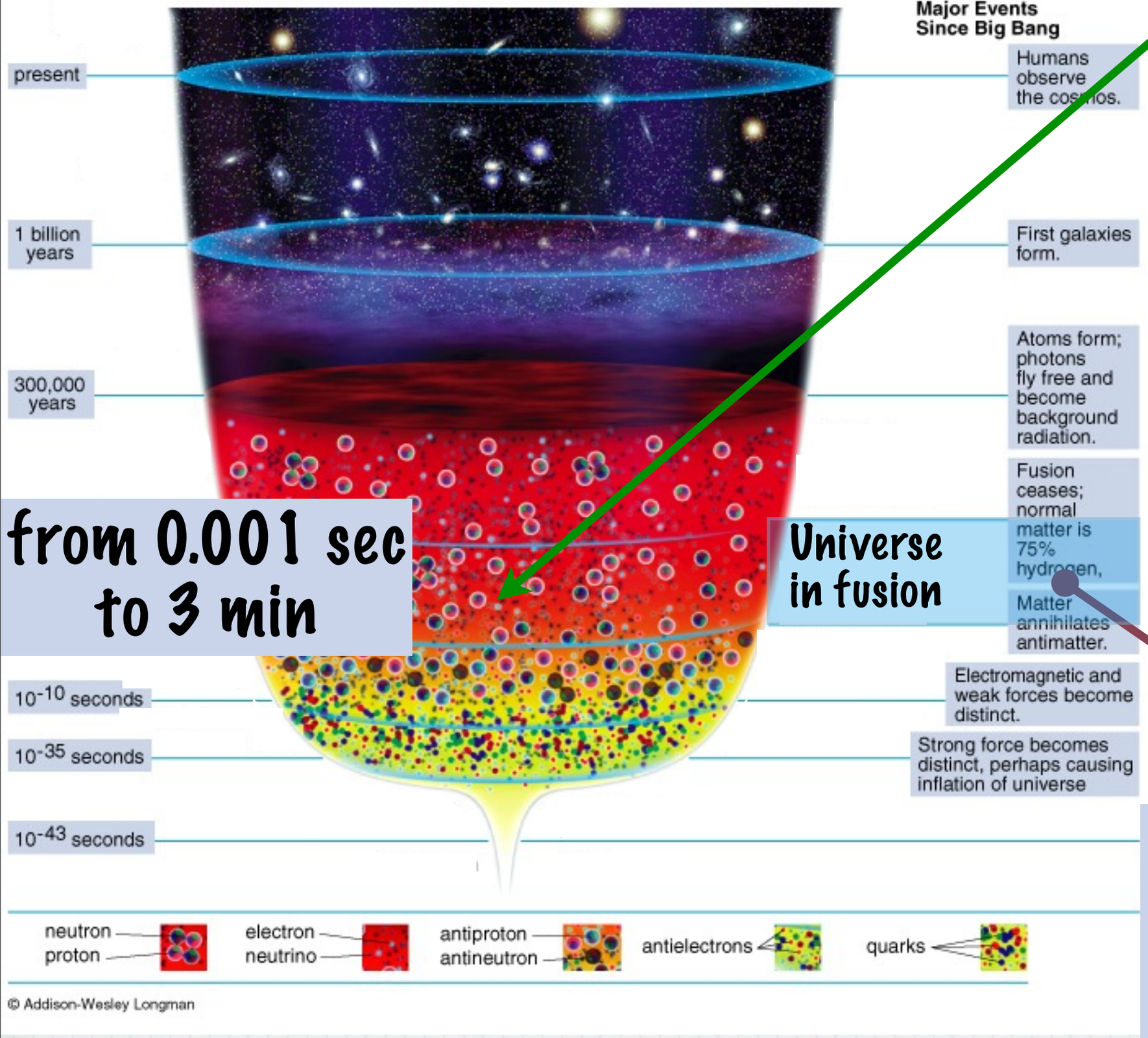
Starts with nearly equal amounts of matter-antimatter, ends with only matter and radiation

(About 1 extra proton for every $10^{10}$ proton-antiproton pairs!)

Then on perfectly explained

4 forces

Electromagnetic & Weak Forces become distinct



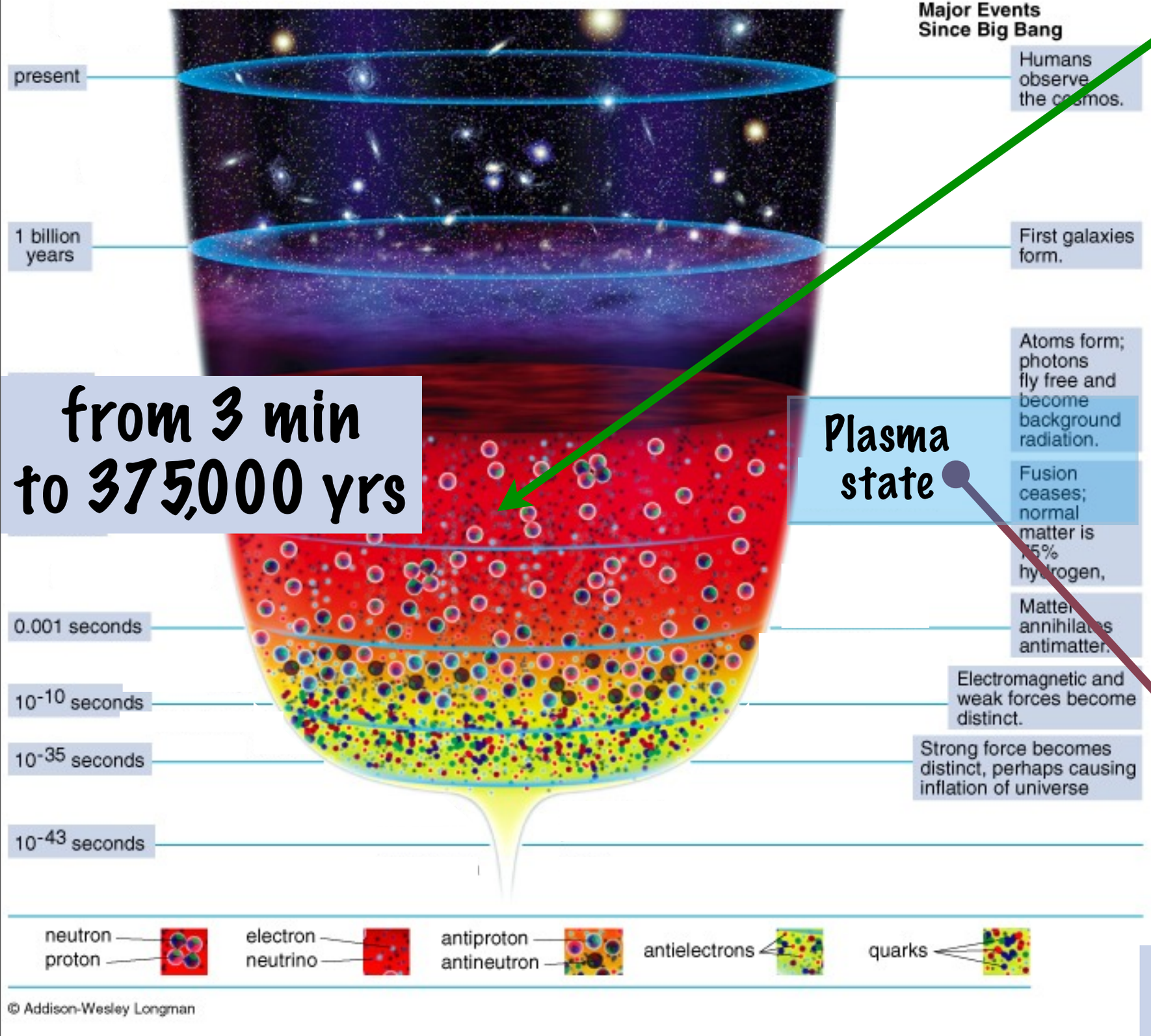

from 0.001 sec to 3 min

Universe in fusion

# Era of Nucleo-synthesis

Nuclei begin to fuse and produce Deuterium, Helium, Lithium and neutrinos

Fusion in the entire Universe resulting in forming ionized matter (75% H & 25% He by mass)




# Era of Nuclei

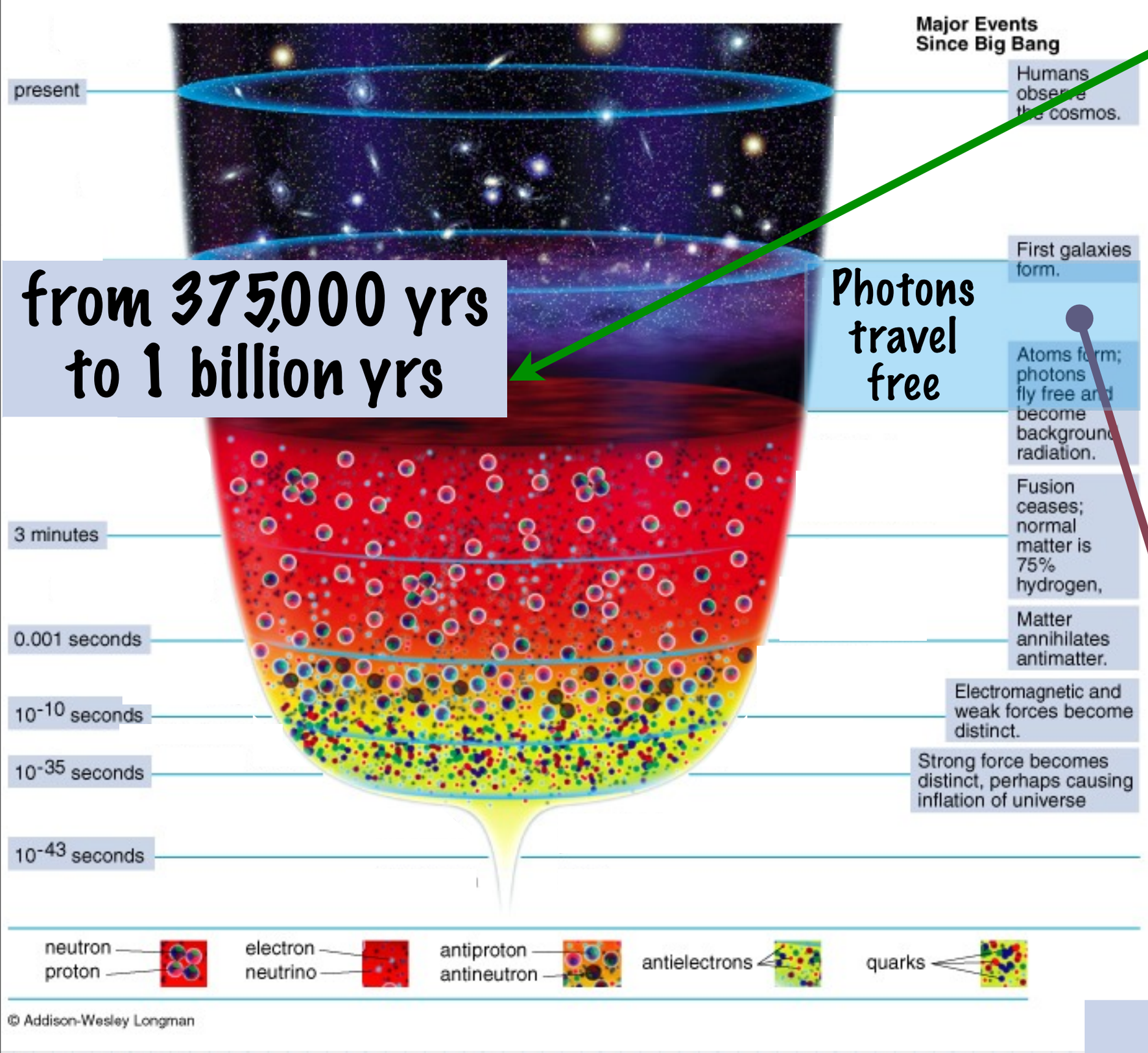
## Fusion stops

## Universe is entirely ionized and non-transparent to photons

## Hydrogen, Helium, electron, neutrino in plasma state

# Era of Atoms

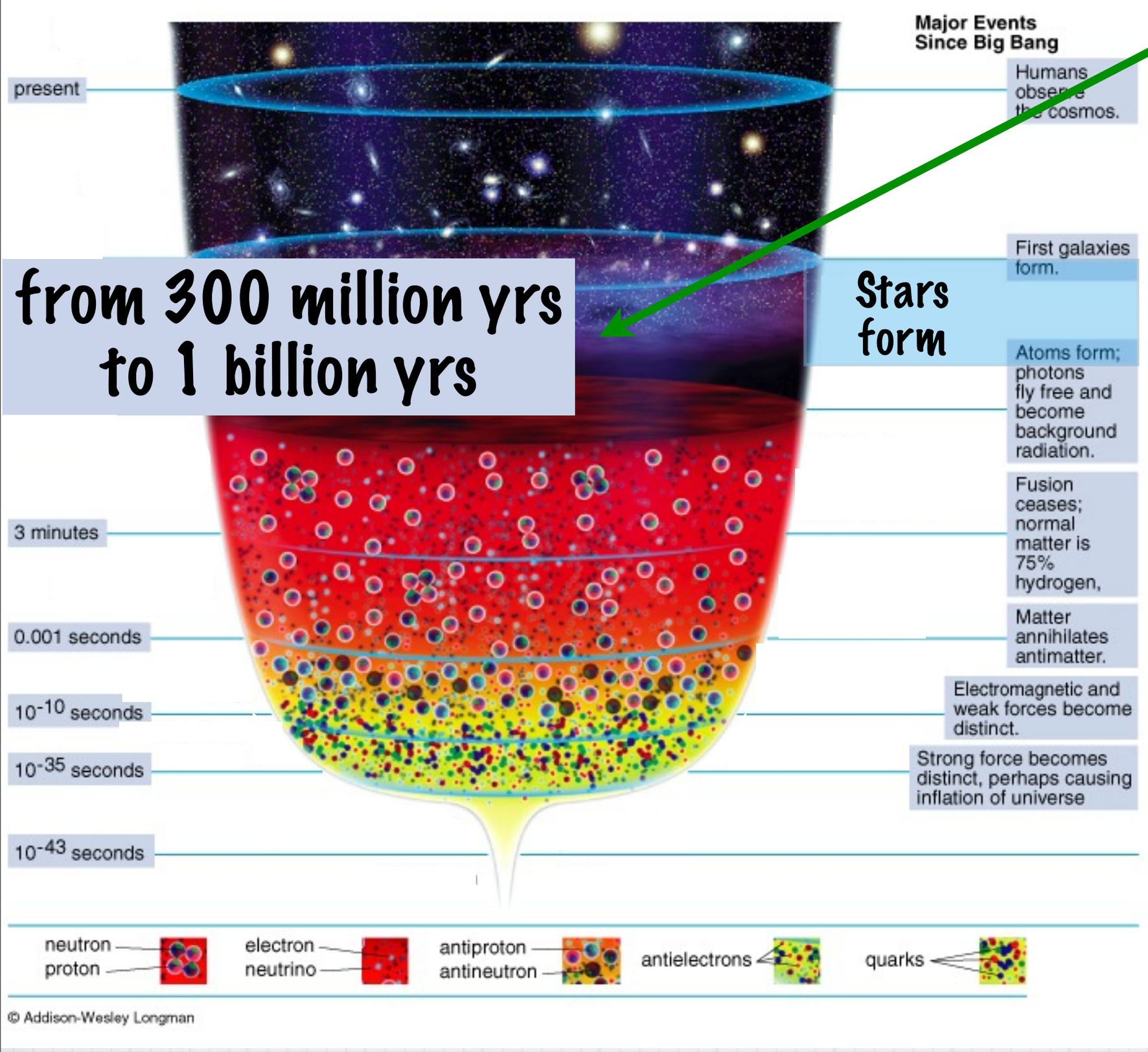
Neutral atoms form when electrons bind to the nucleii




The Dark Ages start: there are no stars!

Atoms form; photons fly free and will become CMB

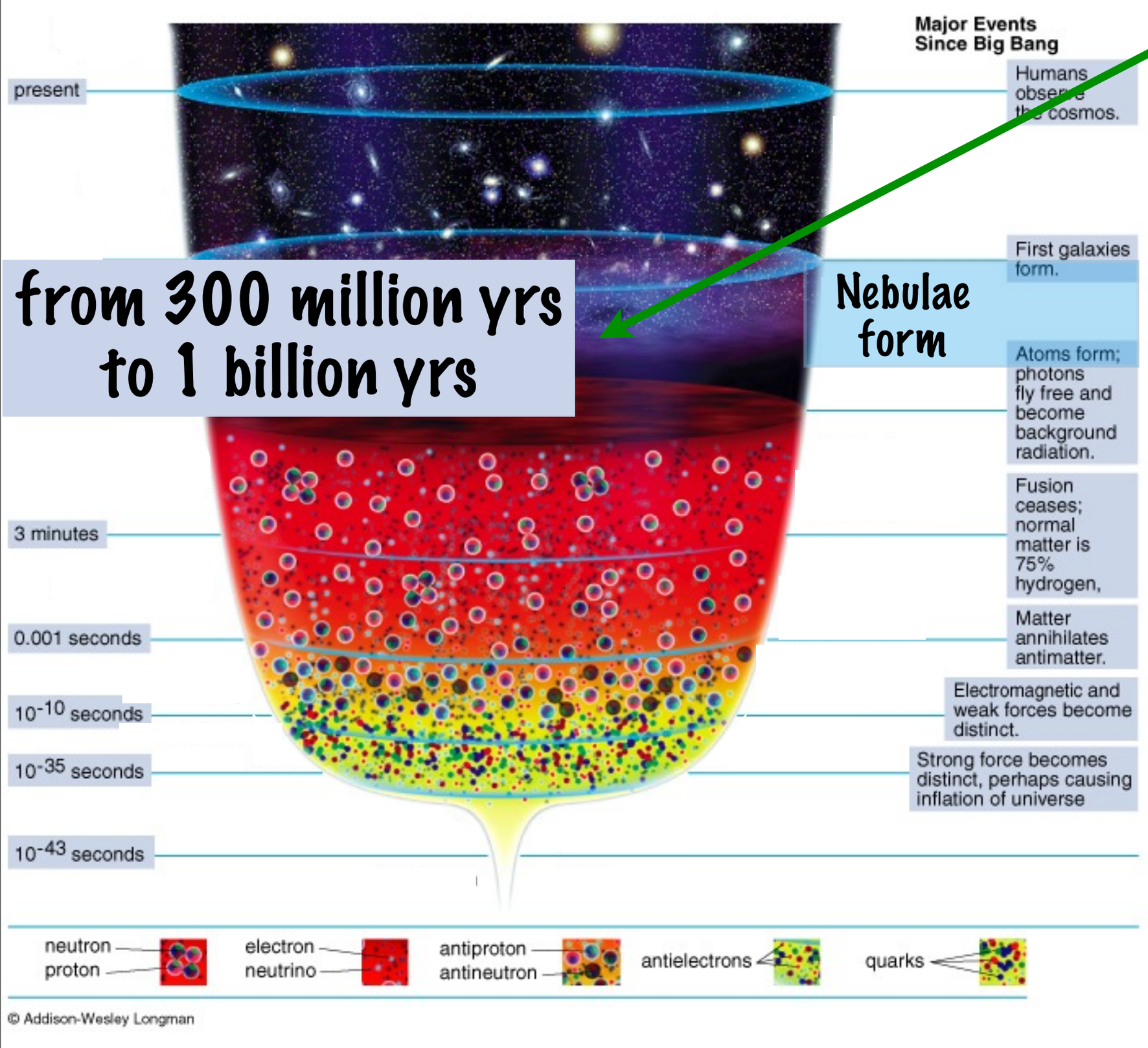
# Era of Stars




from 300 million yrs to 1 billion yrs

The first stars start forming about 300 million years later

# Re-ionization Era

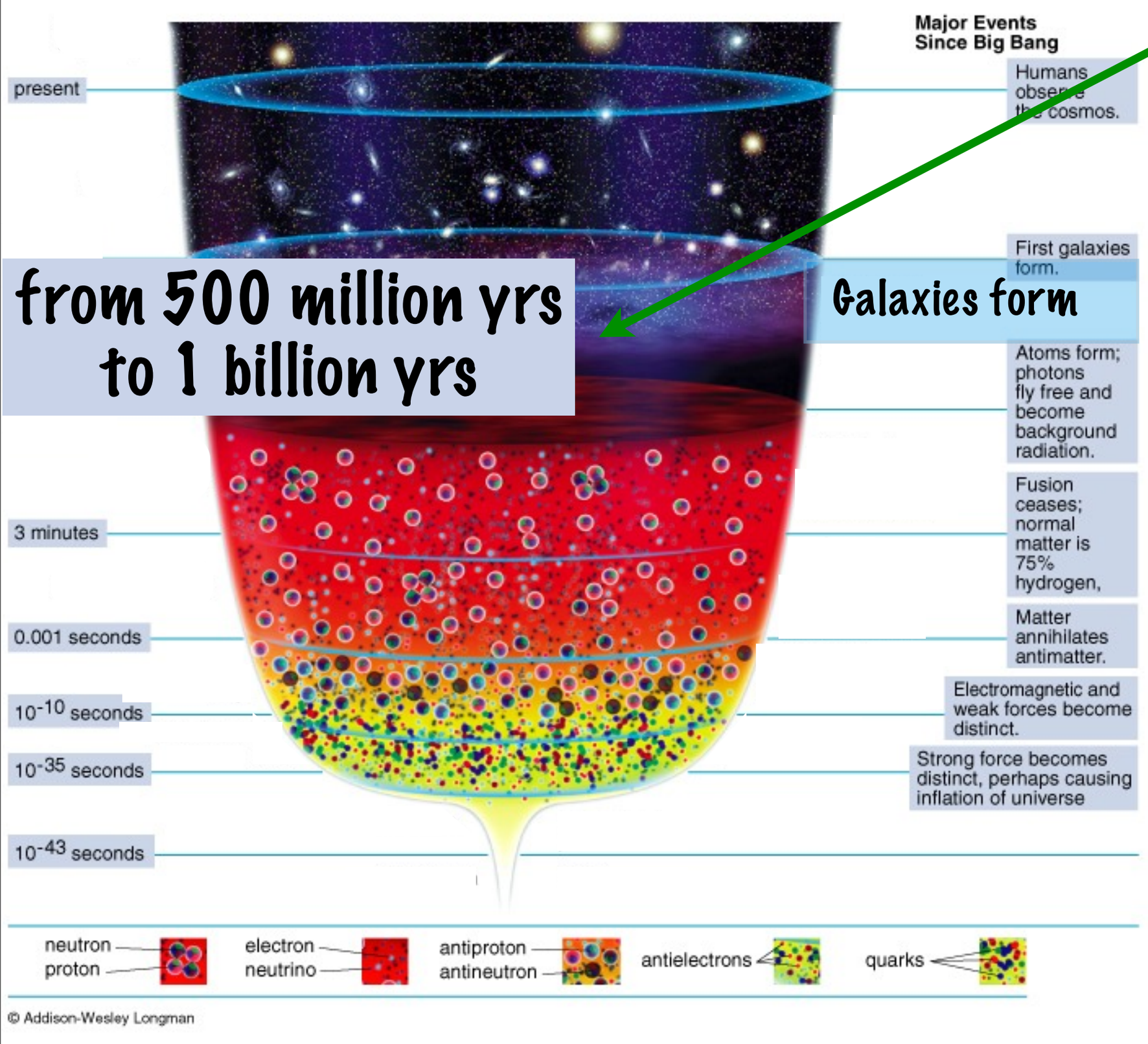



from 300 million yrs to 1 billion yrs

Stars start to seed Universe with heavier elements

Ionized atoms are ejected from stars from stellar winds

# Re-ionization Era



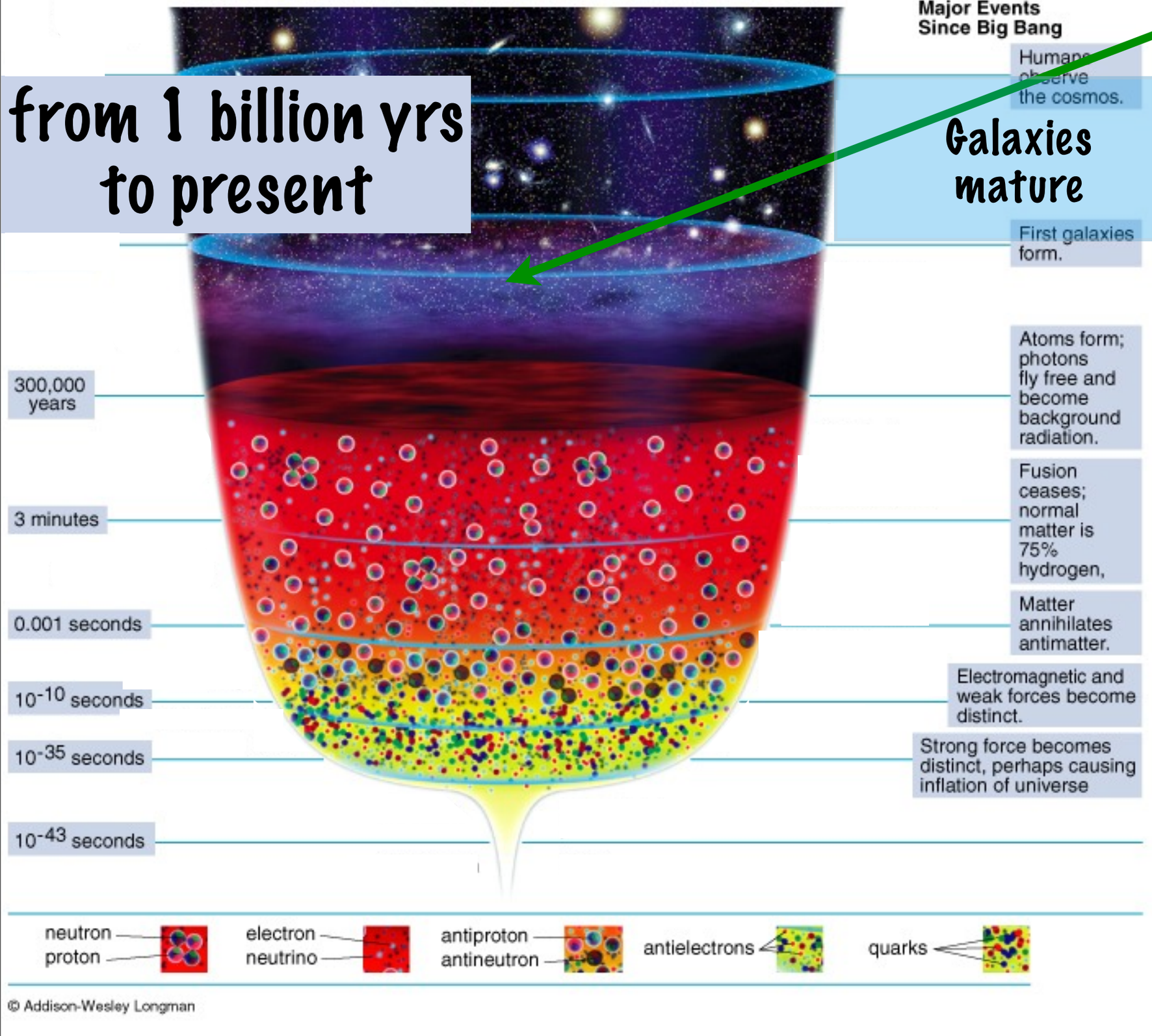

from 500 million yrs to 1 billion yrs

Galaxies form

Galaxies start forming at about 500 million years by pulling hydrogen and helium gas together

# Era of Galaxies

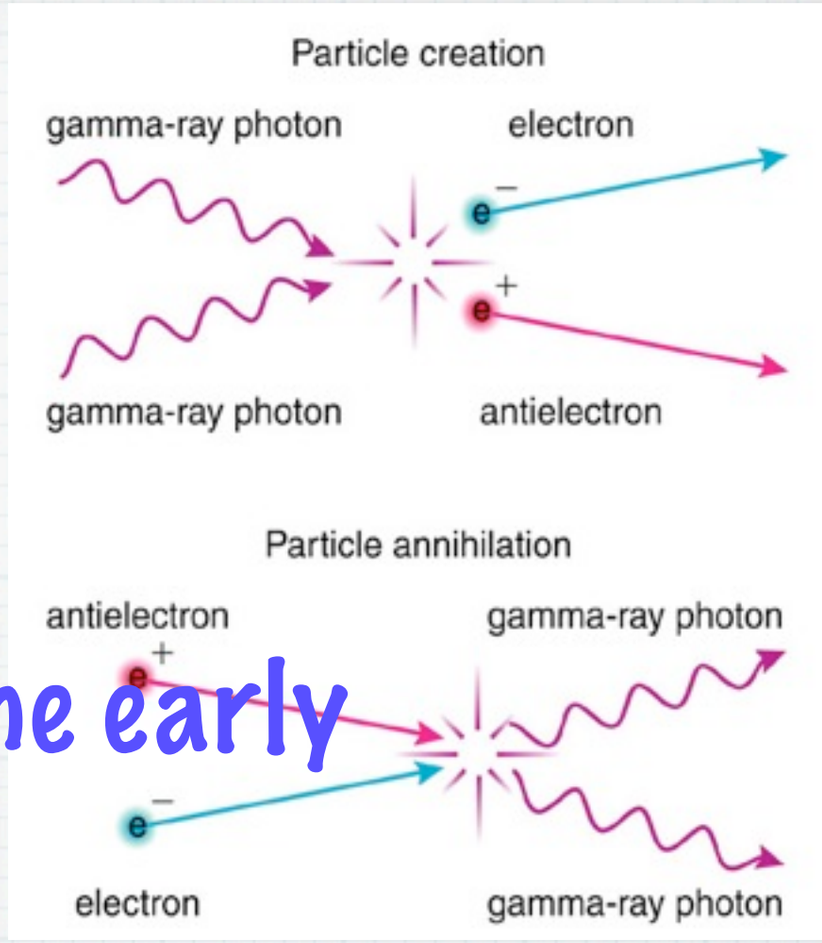
from 1 billion yrs to present






The Dark Ages end when the entire Universe is reached by starry light at about 1 billion years after the Big Bang

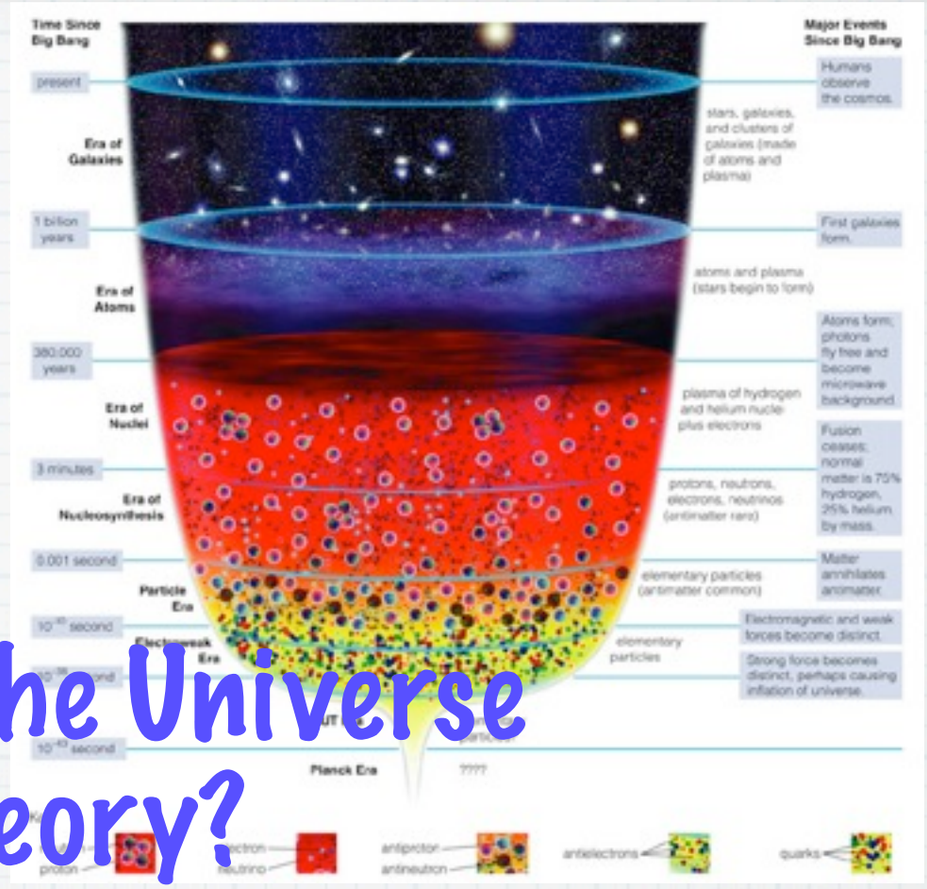
# Snapshot




* What were conditions like in the early Universe?

* **The early Universe was filled with high-energy photons and elementary particles.**
  It was so hot and dense that the energy of photons could turn into particles of matter and antimatter, which then collided and turned back into photons

# Snapshot




* Do we know the history of the Universe according to the Big Bang theory?

* Physicists are able to account for most of the history of the Big Bang but for the first $10^{-43}$ second, an era called the Planck Era which needs the reconciliation of QM and GR. Maybe the Superstring theory will solve this

# Primary Evidence

This is a nice theory

What are the facts?

1. We have detected the radiation created when atoms became neutral and photons could travel freely
2. The Big Bang theory correctly predicts the abundance of helium and other light elements (helium, deuterium and lithium)

# 1) Observing the radiation left over from the Big Bang

* Once the Universe became transparent for them, photons have been traveling in an expanding and cooling place
* These original photons are easily detectable (once you know what to look for!)

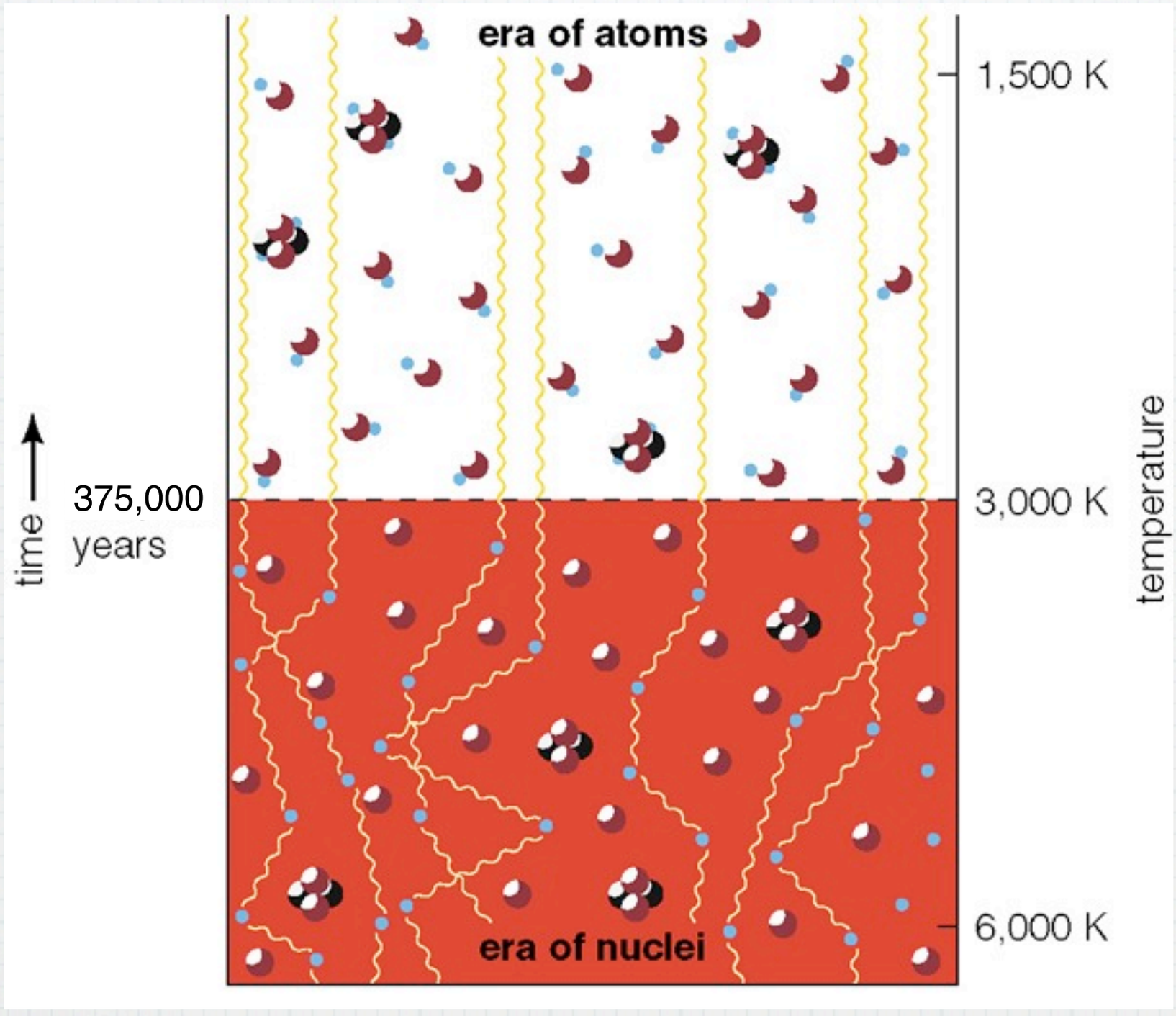
# CMBR

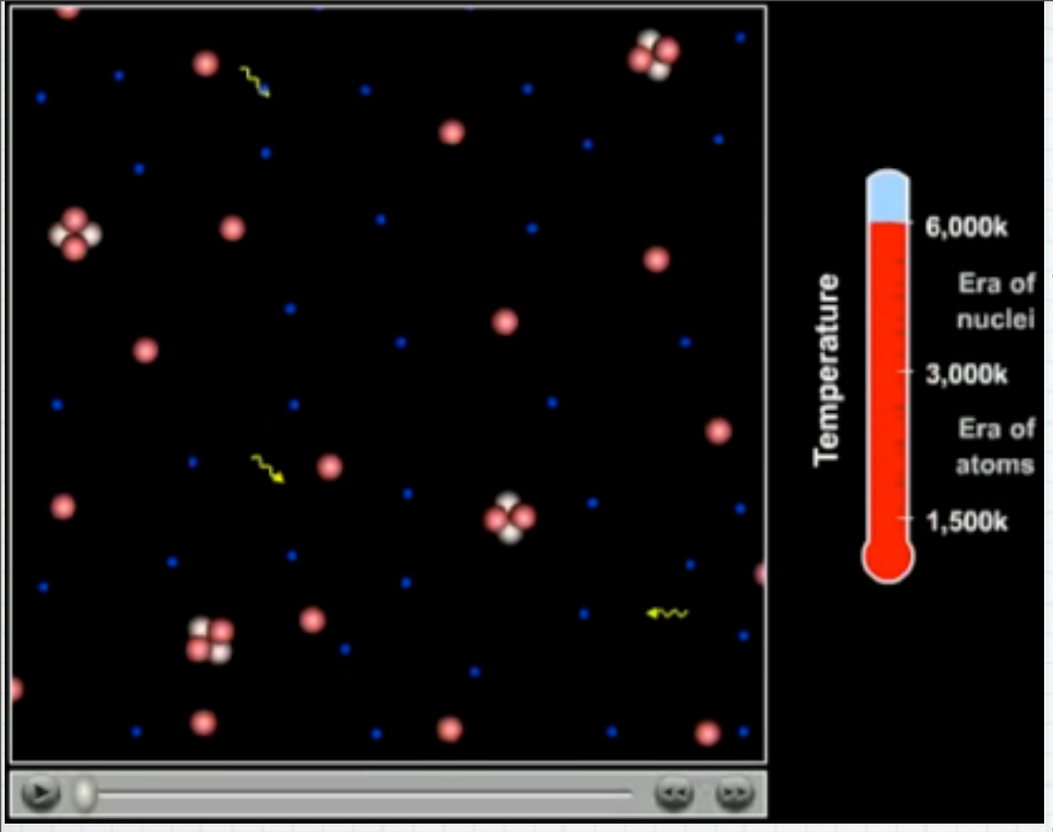
The
Cosmic
Microwave
Background
Radiation

The radiation left over from the Big Bang

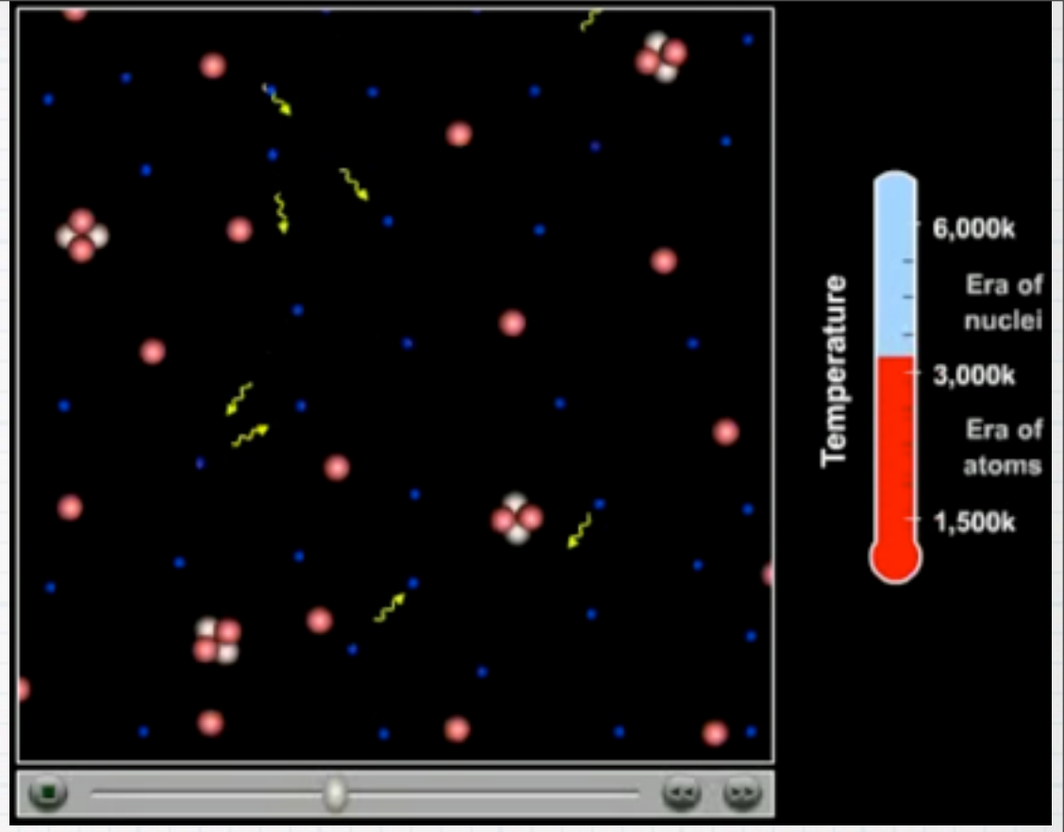
It was detected by Penzias & Wilson in 1965

# Background radiation from Big Bang has been freely streaming across Universe since atoms formed at temperature ~3,000 K (visible/IR)

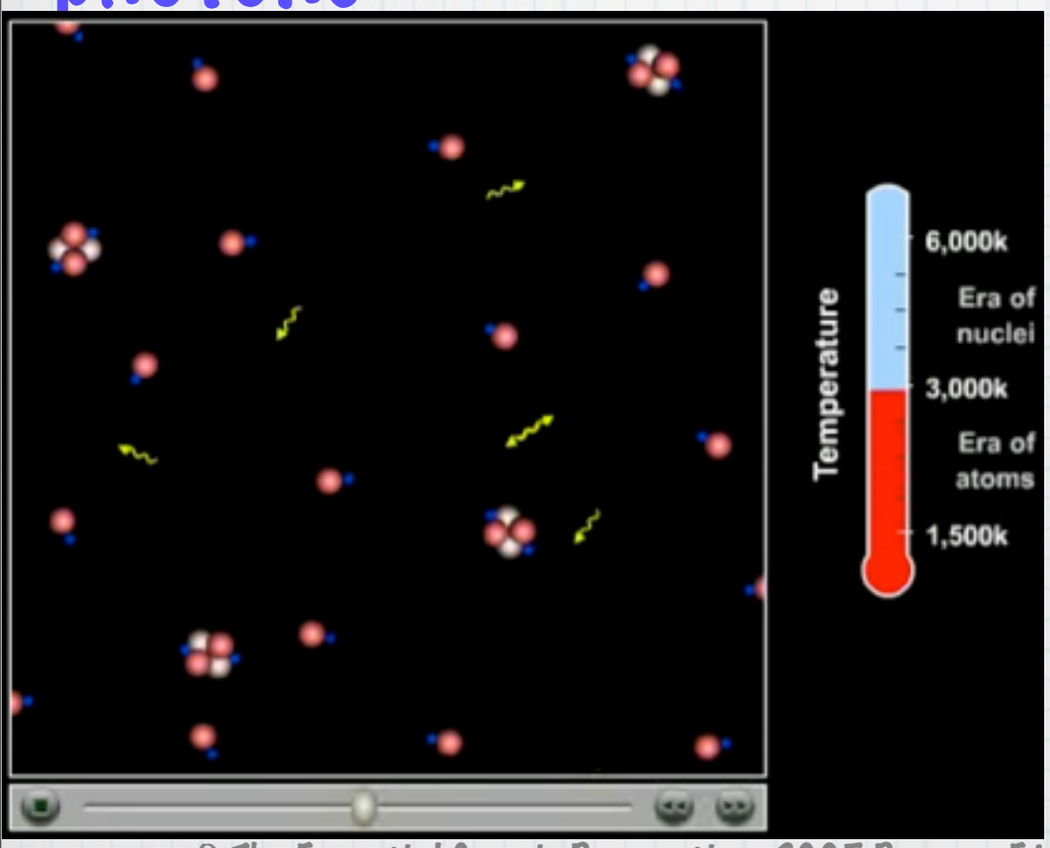




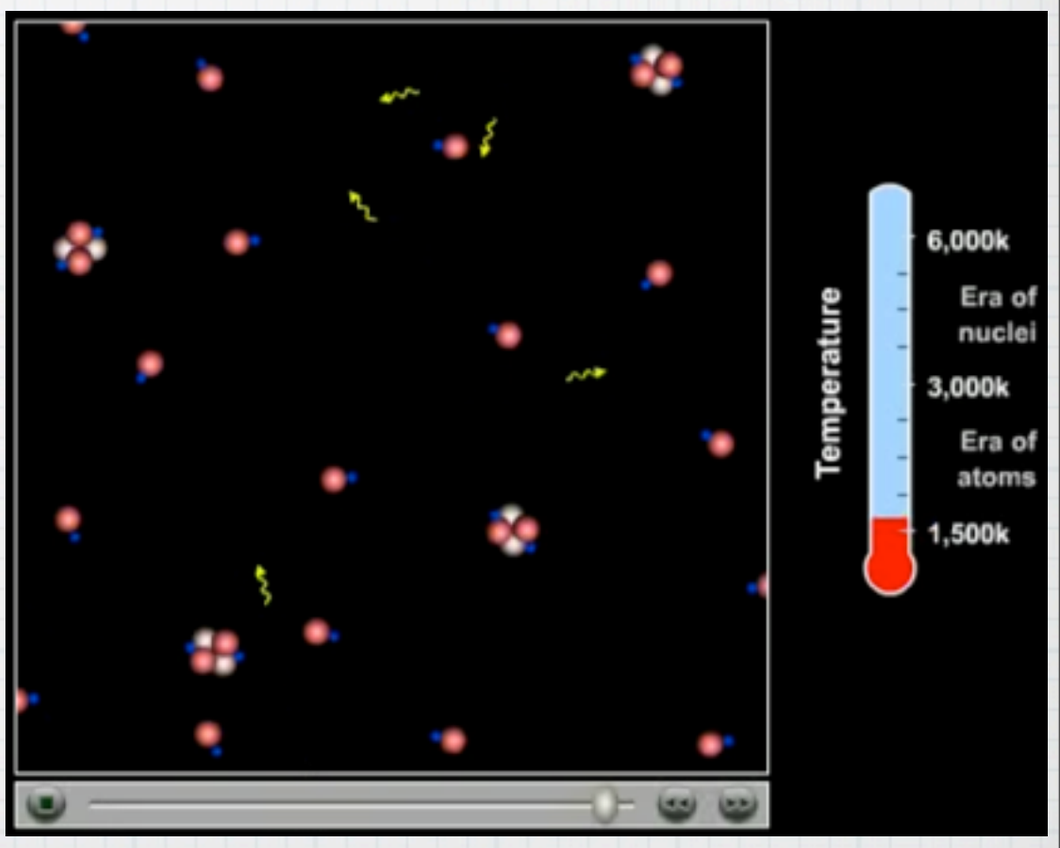

Too hot for electrons to be captured by nuclei, photons cannot travel far




## The moment when the Universe became transparent for photons

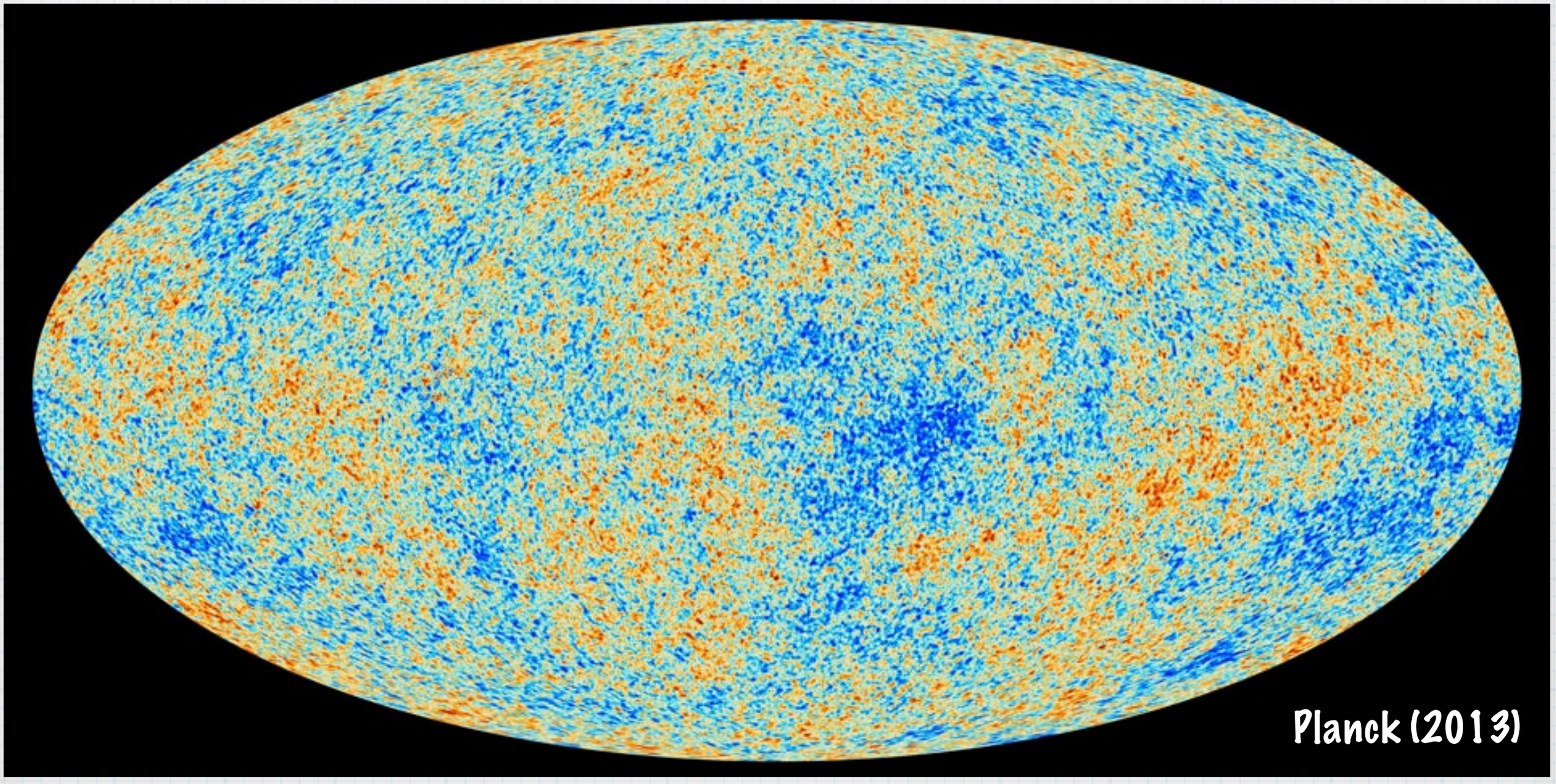



Photons can now travel un-impeded

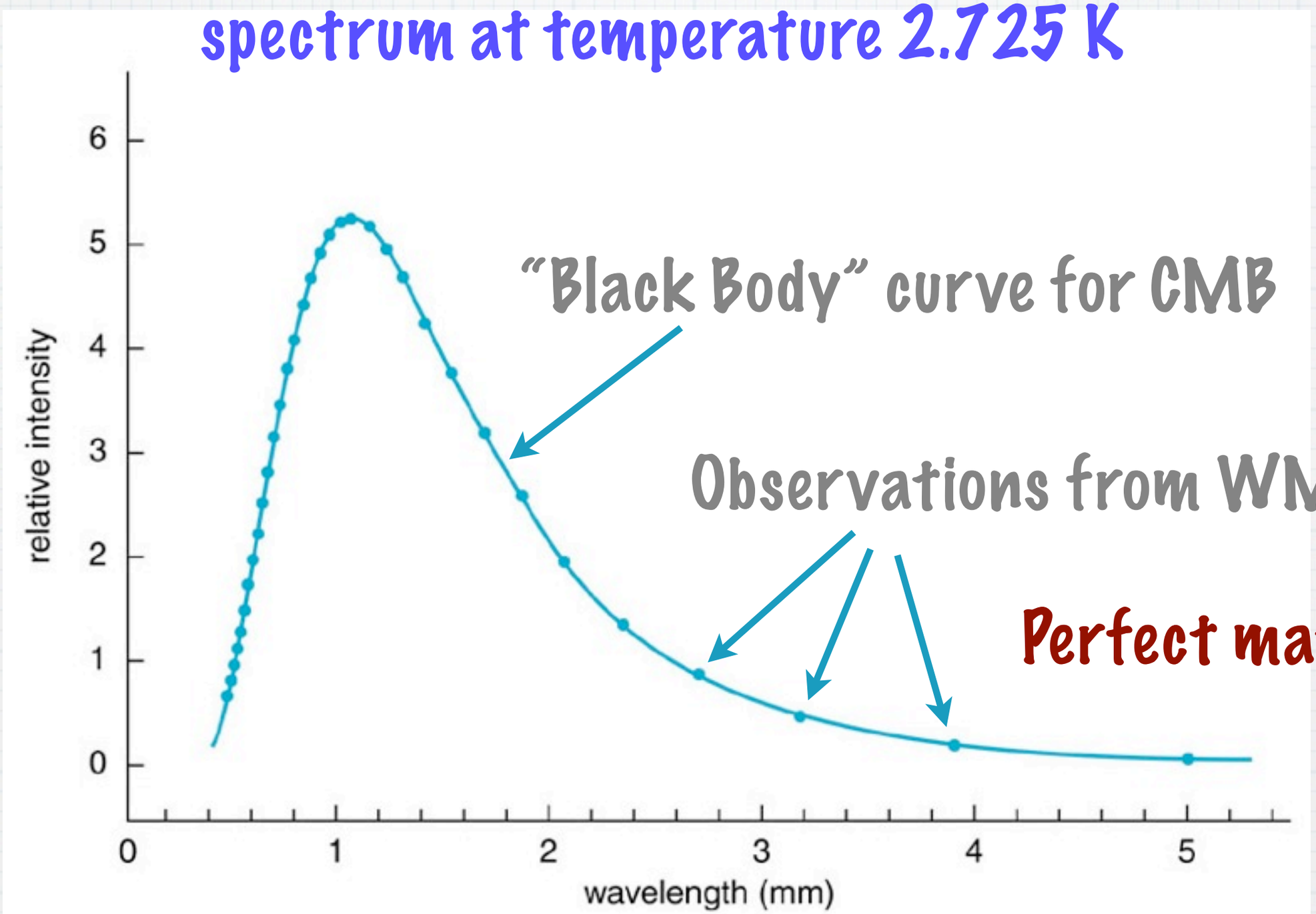


# Cosmic Microwave Background Radiation map

## It is a detailed baby picture of structures in the Universe

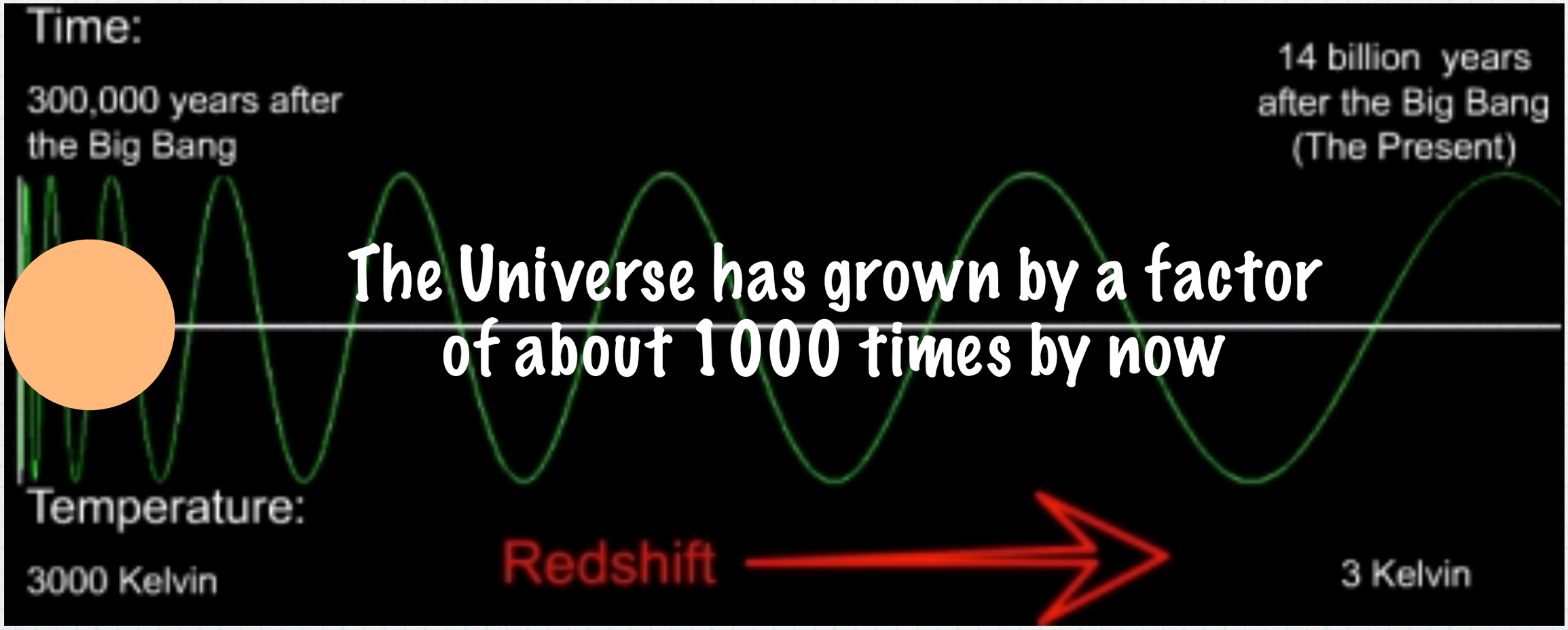


# CMB has perfect thermal radiation spectrum at temperature 2.725 K




# Expansion of Universe has redshifted thermal radiation from that time to ~1000 times longer wavelength: microwaves

# When photons were able to travel freely, the Universe was at 3000K



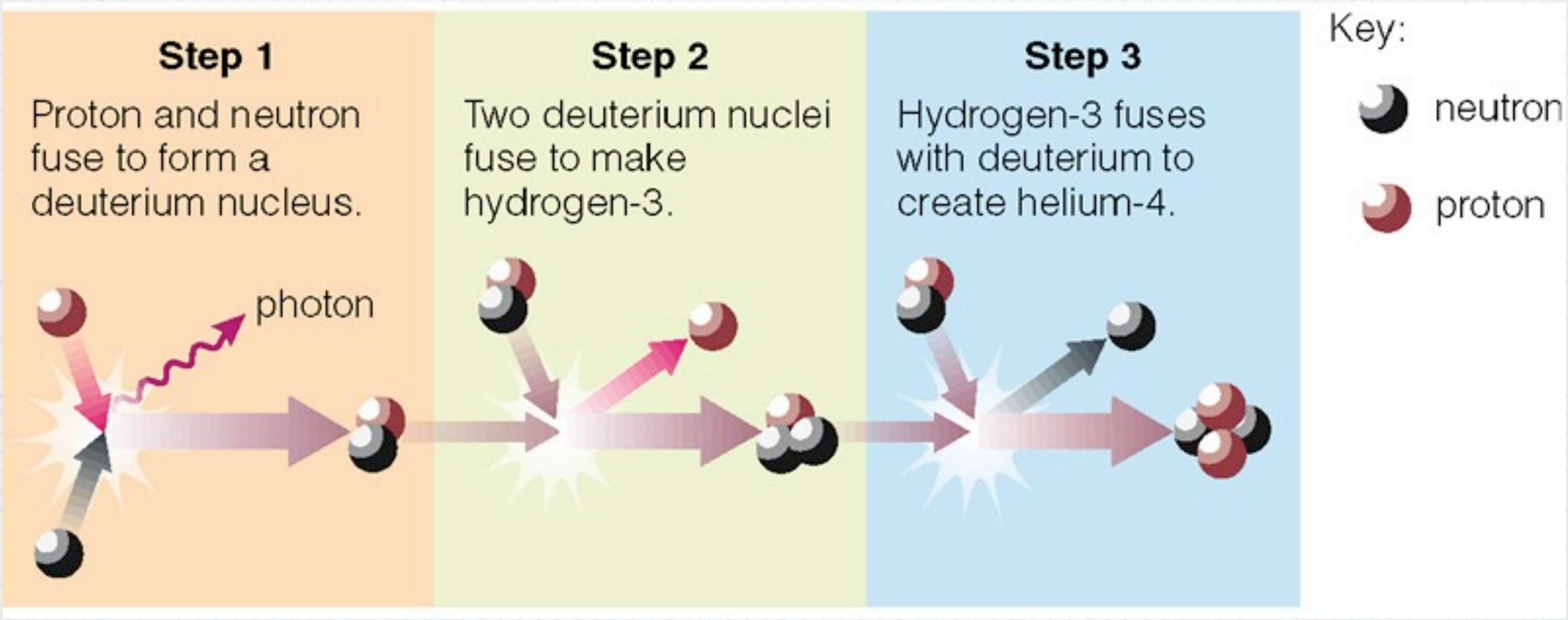

The Universe is now around 2.725K

The expansion of Universe has redshifted the (orange reddish) photons to the longer wavelength of microwaves

# 2) The abundances of elements support the Big Bang

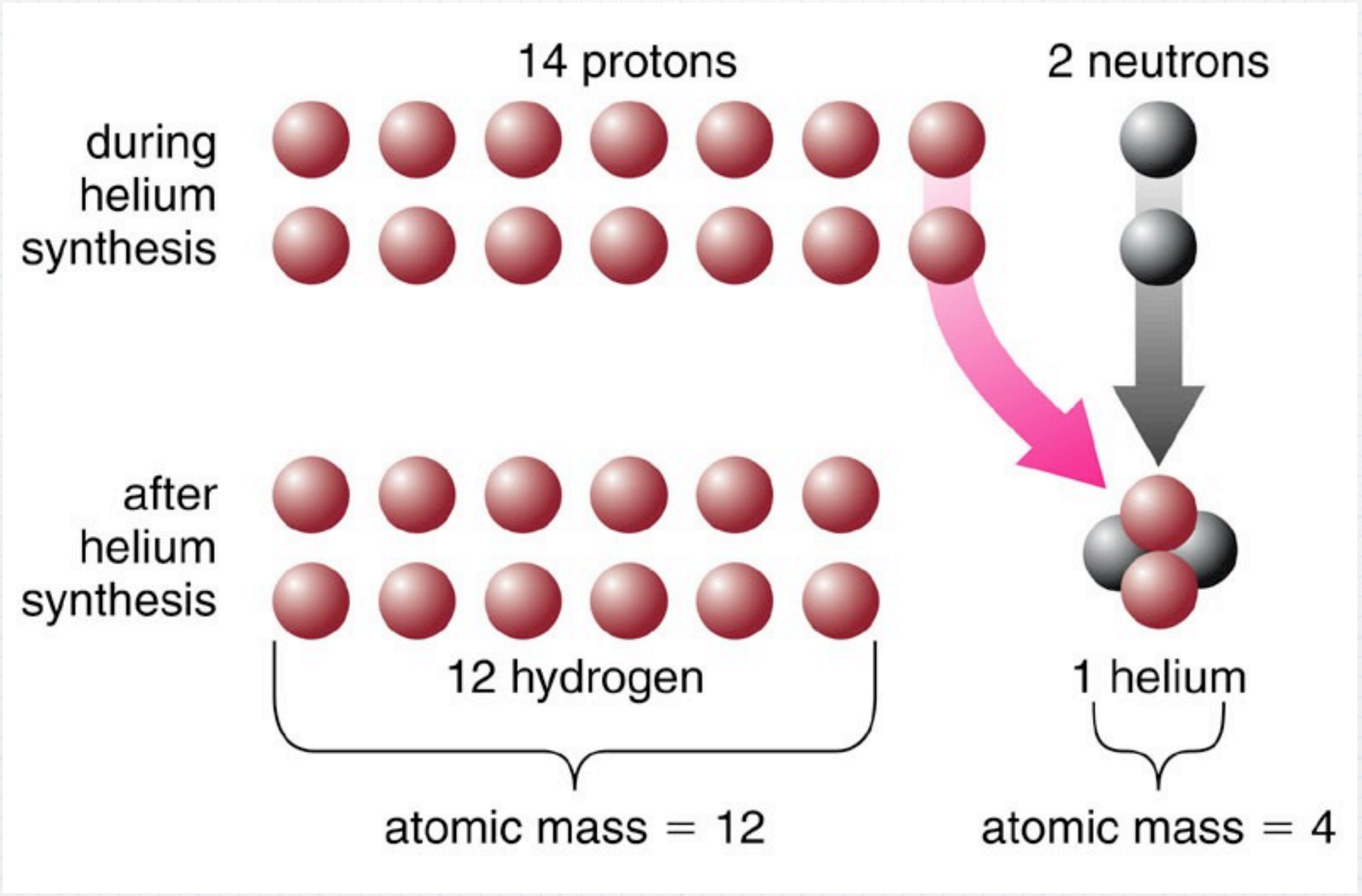
* Cosmic helium had been detected in the past but its origin were unknown
* CMBR's current temperature tells us how hot the Universe had been in the past, stating how much helium was created along with the cosmic hydrogen (25% He, 75% H)

# Protons and neutrons combined to make long-lasting helium nuclei when Universe was ~3 minutes old (or about 180 seconds)




# The entire Universe was undergoing fusion

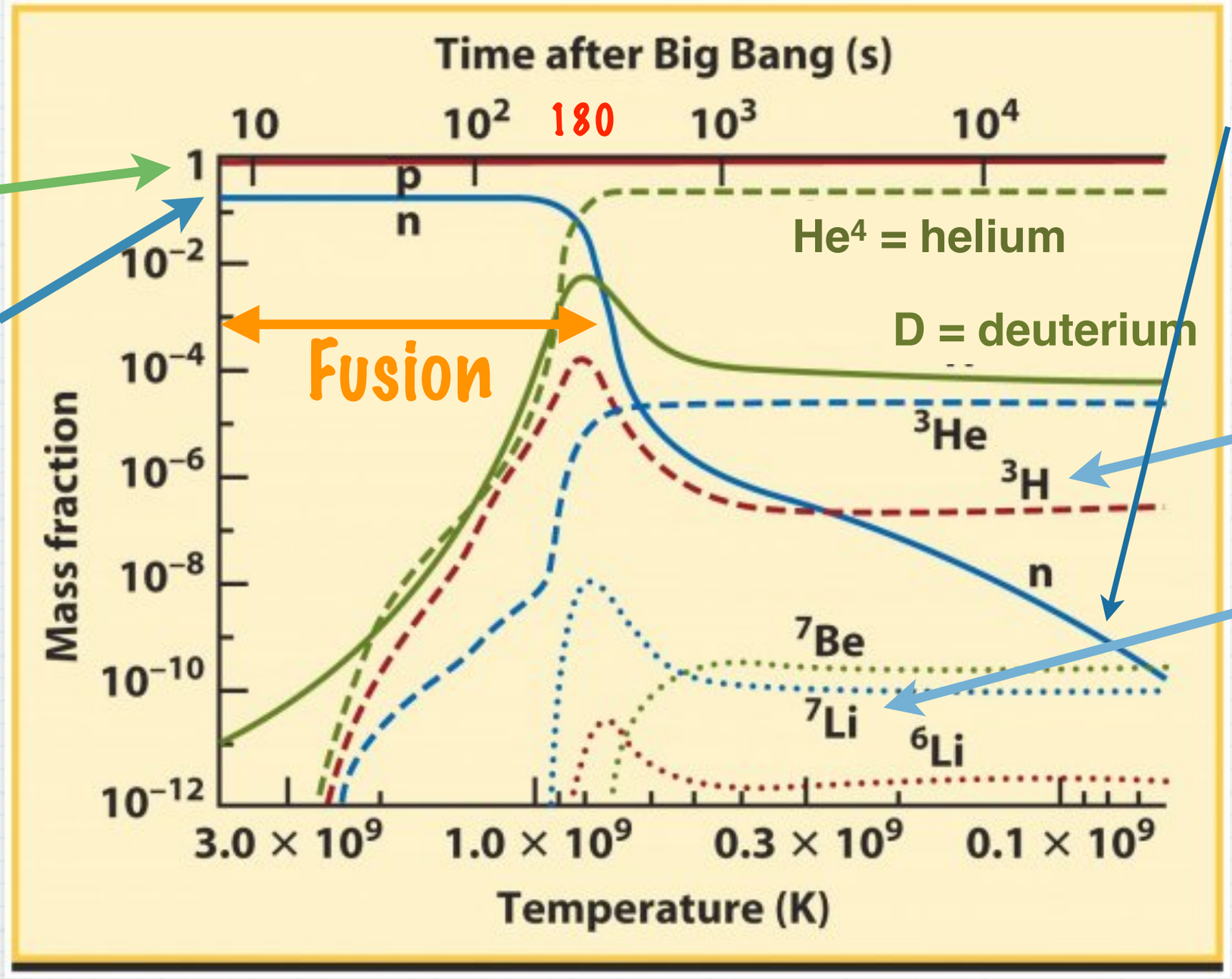
# Calculations: proton to neutron ratio was 7 to 1




## Big Bang theory prediction: 75% H, 25% He (by mass)
## Matches observations of primordial gasses

# Computed mass fraction of various isotopes versus time and temperature

7-to-1 proton to neutron ratio




$He^4$ becomes permanent 180 seconds after the BB

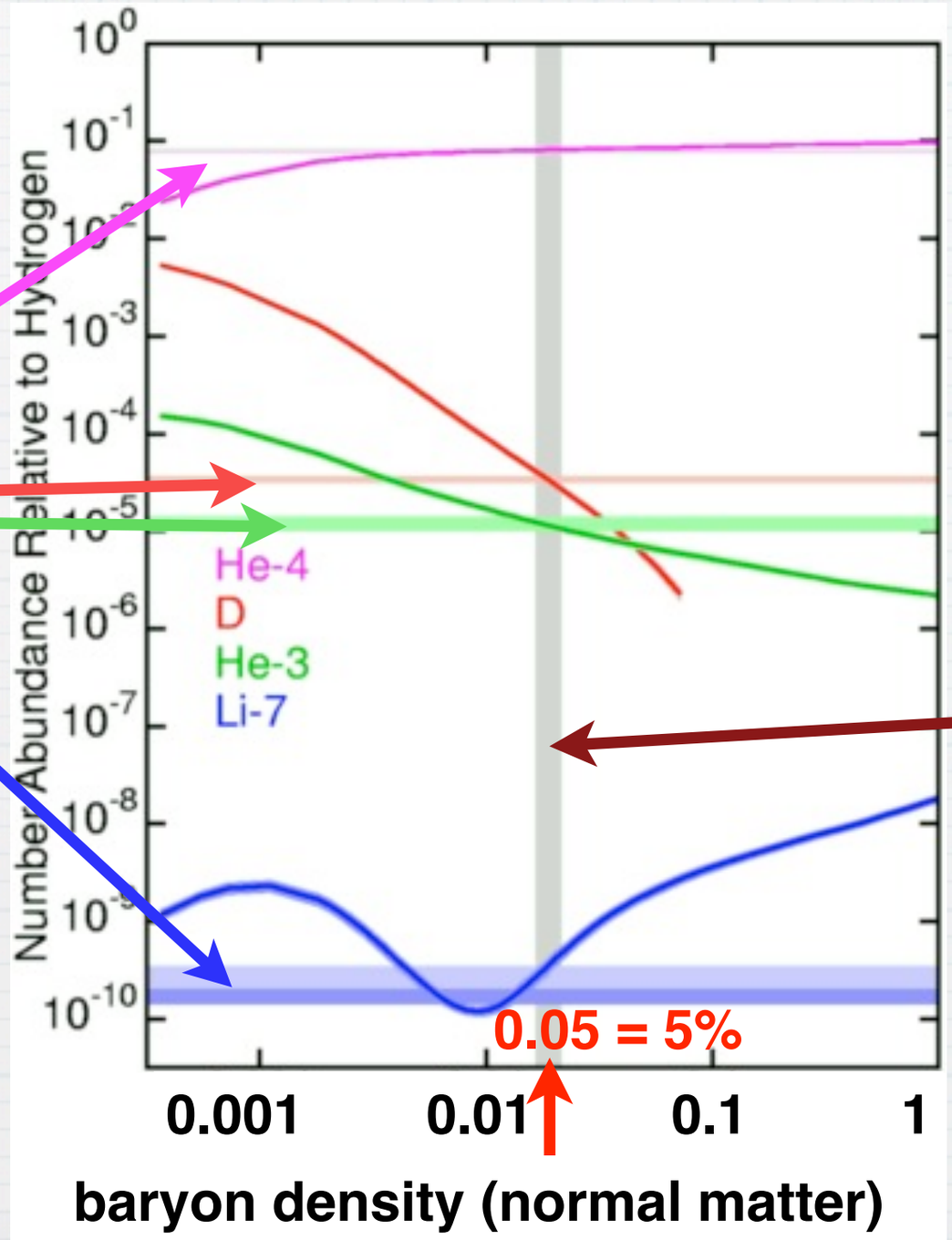
Neutrons not in helium decay (15 mn half-life)

short radioactive decay: none survive for us to view them

# Abundances of other light isotopes agree with Big Bang model having 5% normal matter – more evidence for WIMPS!

predicted ratio of elements vs. baryon density

observed ratios




Helium-4

Deuterium

Helium-3

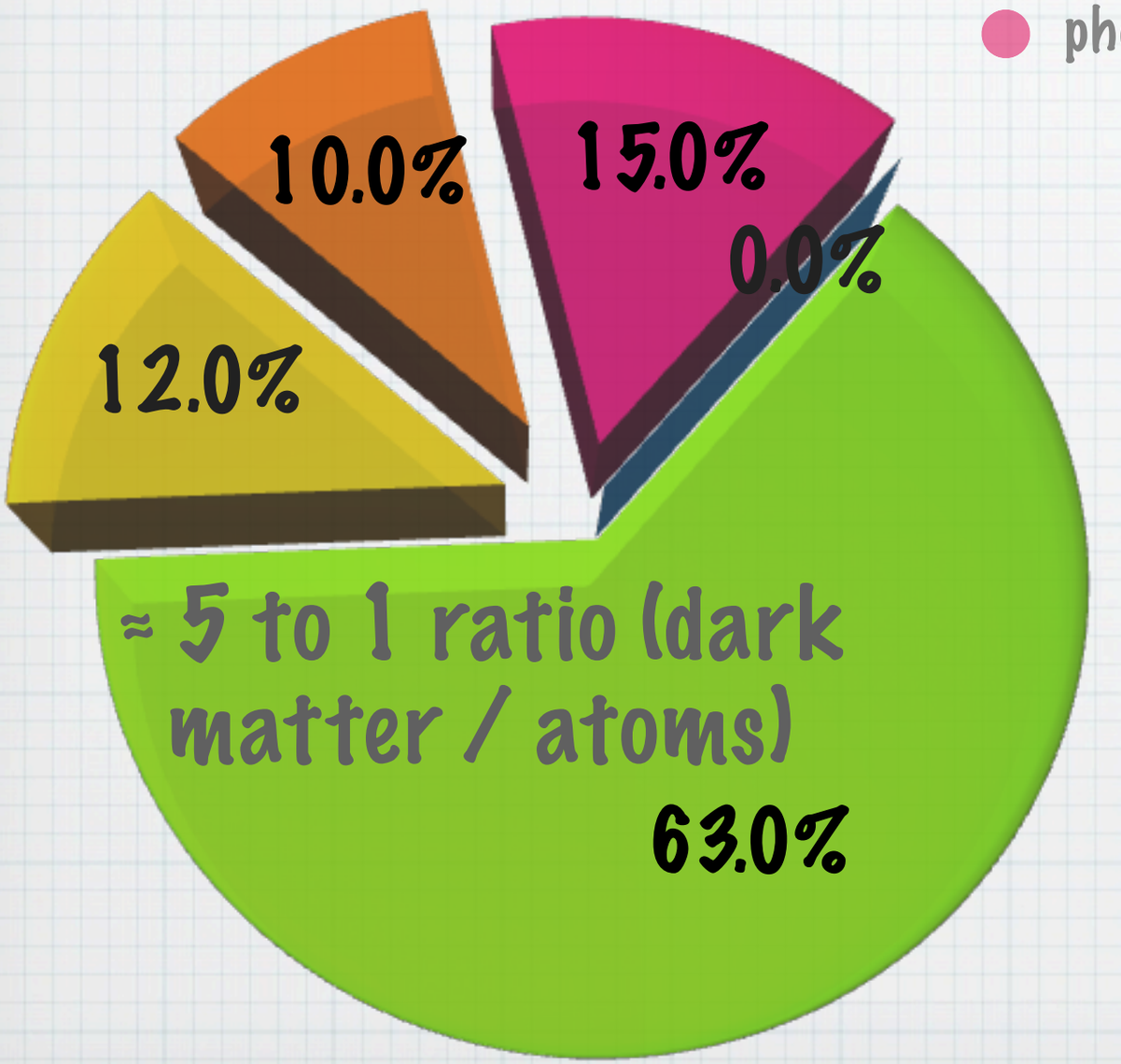
Lithium-7

computed baryon density

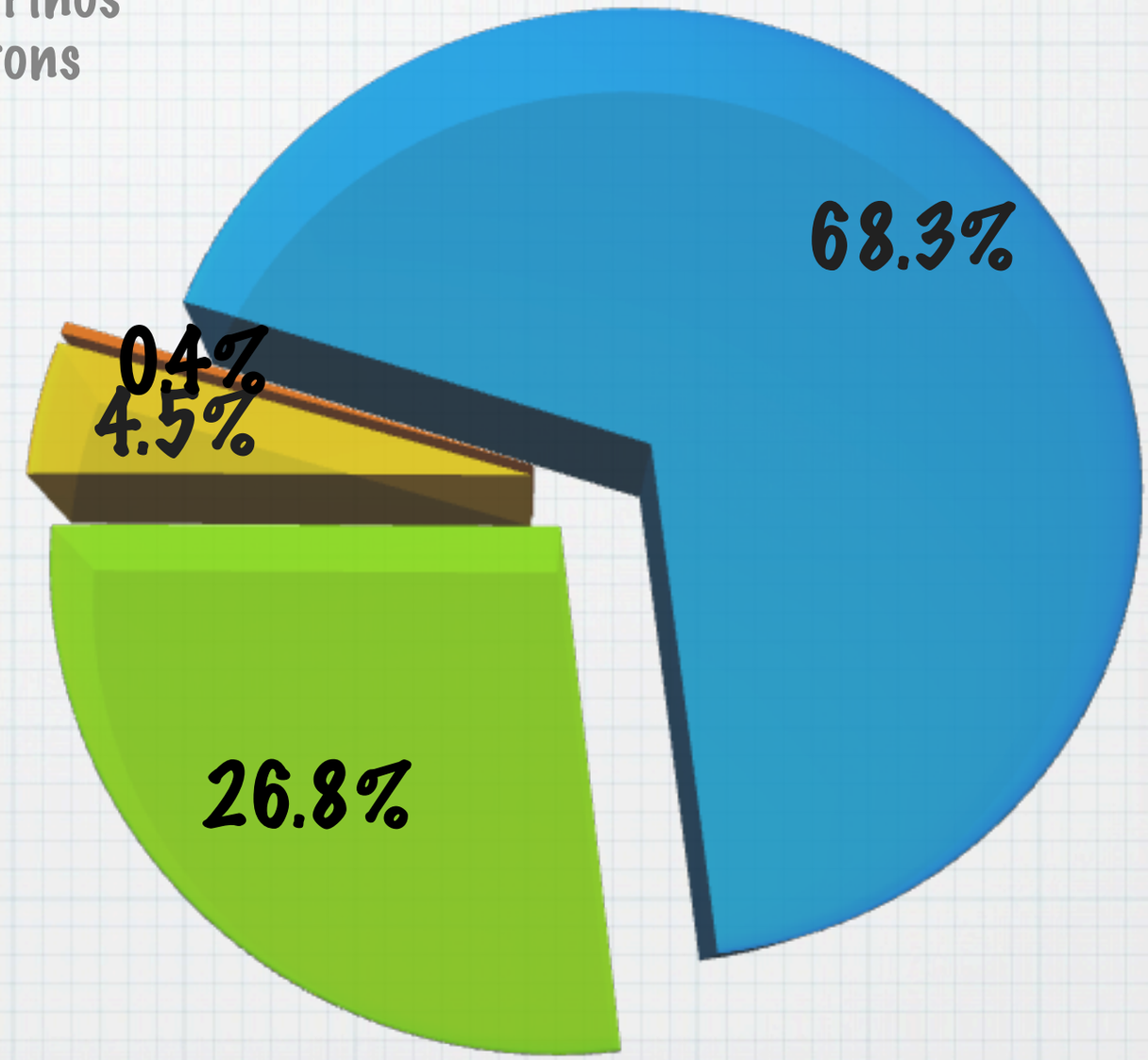
# WMAP and the Composition of the Universe

dark energy
dark matter
atoms
neutrinos
photons

## 375,000-year old: CMB released




## 13.77 billion-year old: Now



# Question

Which of these abundance patterns is an unrealistic chemical composition for a star?

A. 70% H, 28% He, 2% other

B. 95% H, 5% He, less than 0.02% other

C. 75% H, 25% He, less than 0.02% other

D. 72% H, 27% He, 1% other

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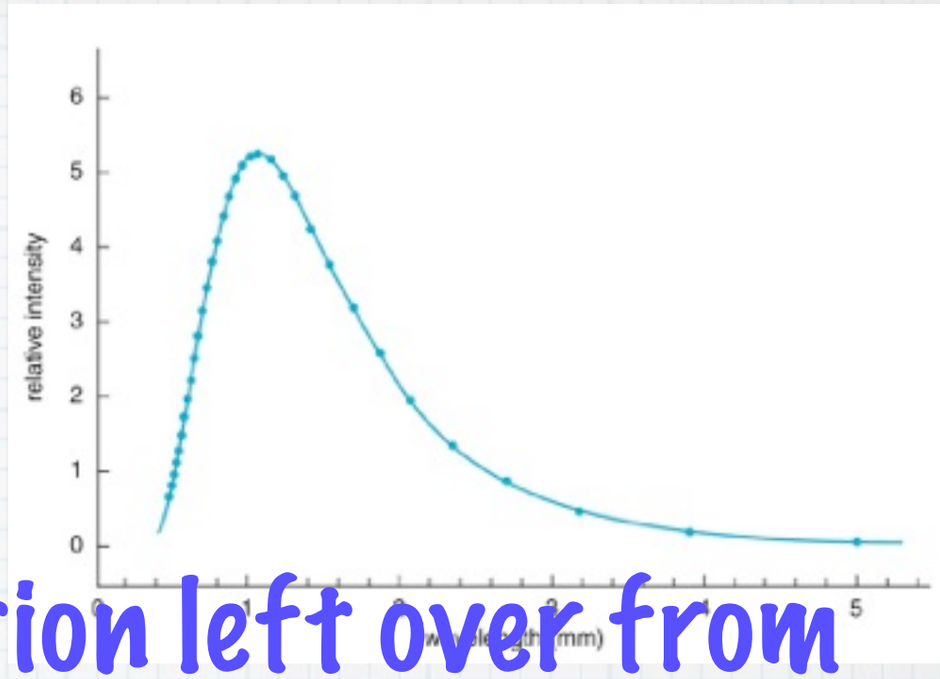
# Snapshot




* How do we observe the radiation left over from the Big Bang?

* Telescopes that can detect microwaves allow us to observe the cosmic microwave background—radiation left over from the Big Bang. Its spectrum matches the characteristics expected of the radiation released at the end of the era of nuclei, spectacularly confirming a key prediction of the Big Bang theory

# Snapshot

* How do the abundances of elements support the Big Bang?

* The Big Bang theory predicts the ratio of protons to neutrons during the era of nucleosynthesis, and from this predicts that the chemical composition of the Universe should be about 75% hydrogen and 25% helium (by mass). This matches observations of the cosmic abundances, another spectacular confirmation of the Big Bang theory

# Unexplained Aspects by the Big Bang Model by Itself

* The Big Bang model, as it is, has 3 flaws that need to be solved:

i. The Isotropic Problem

ii. The Flatness Problem

iii. The Magnetic Monopole Problem

# i. The Isotropic Problem

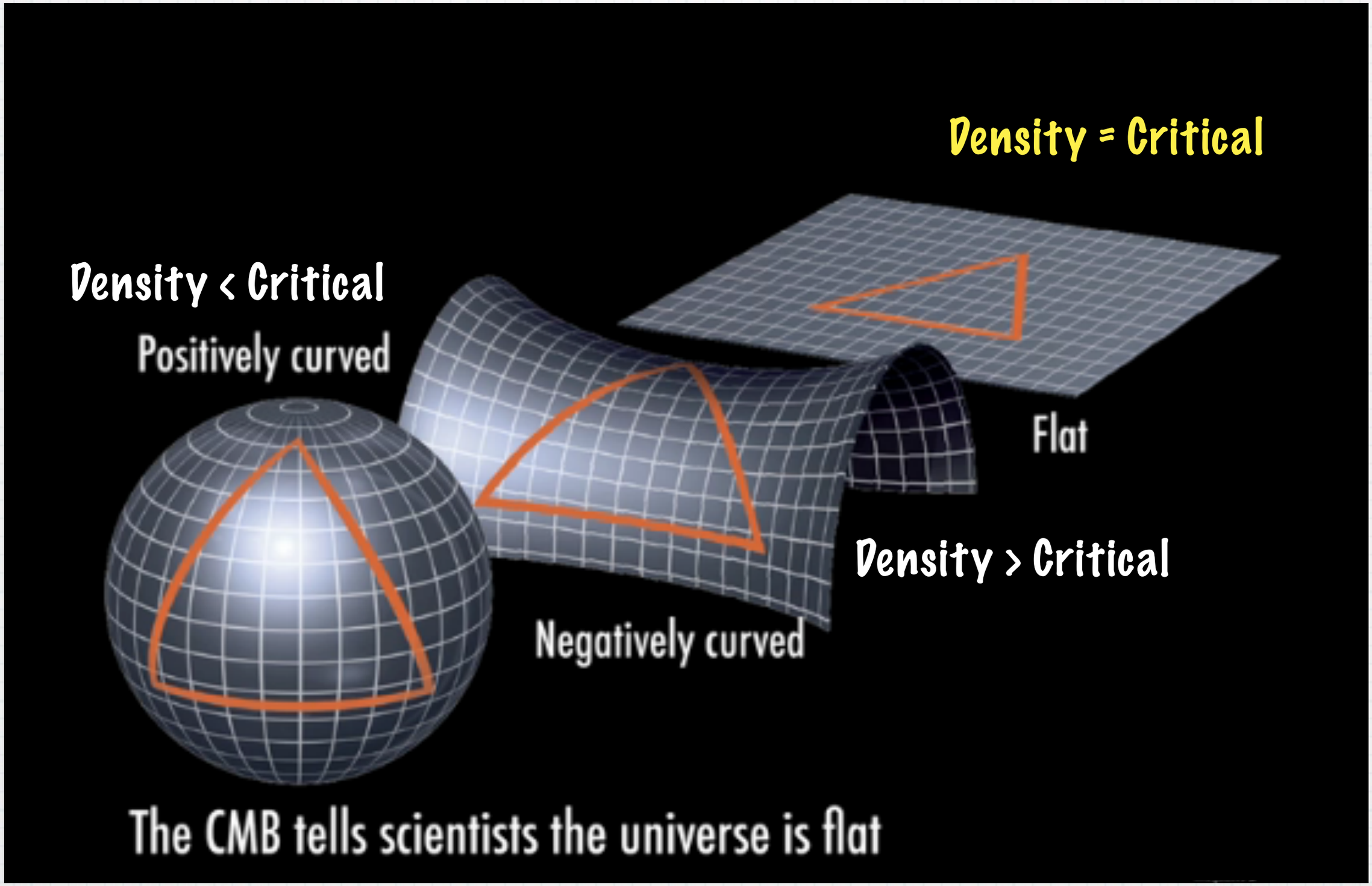
* CMBR is amazingly smooth in all directions

* In our Universe, photons cannot get from one side to the other (Universe is too large) to explain this observed isotropy

# ii. The Flatness Problem

* The Universe seems to contain enough energy density to provide zero spatial curvature
* The Big Bang must have started with immeasurably small deviations from the critical point

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



# iii. The Magnetic Monopole Problem

* GUT and superstring theory predicts magnetic monopoles should exist in innumerable quantities
* None have ever been observed

# Unexplained Aspects by the Big Bang Model by Itself

i. The Isotropic Problem

ii. The Flatness Problem

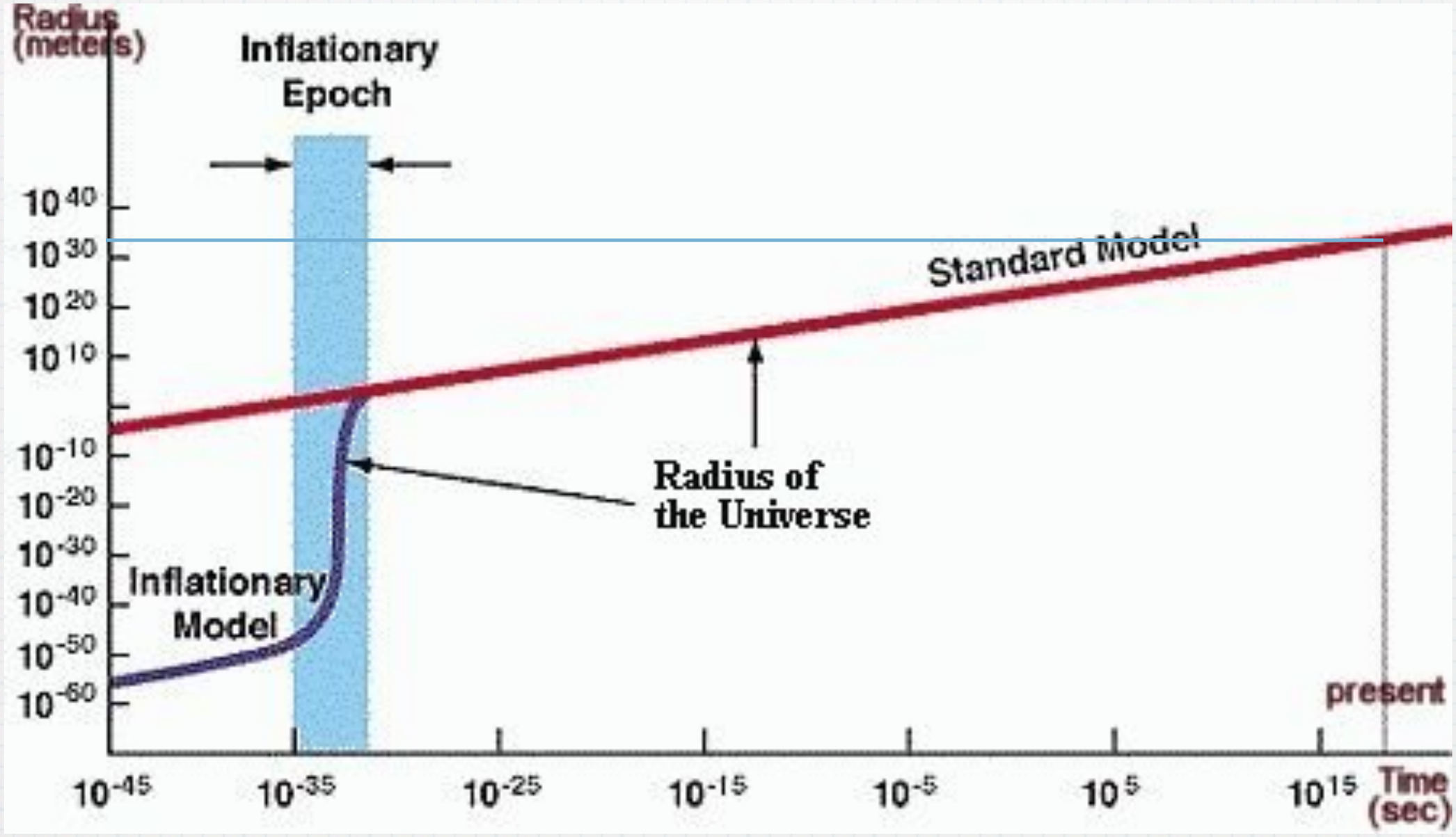
iii. The Magnetic Monopole Problem

An early episode of rapid Inflation can solve all three mysteries!

# The Solution: Inflation

* **Inflation** is an extraordinarily brief event where the Universe suddenly became much bigger as it was expanding
* It grew by a volume factor of $10^{78}$ from $10^{-36}$ to about $10^{-32}$ second after the Big Bang
* After that event, expansion resumes at a constant speed
* This event was proposed by Alan Guth in 1980

# Inflation Growth Curve



# What Powers Inflation?

* Inflation may be the result of the Strong Nuclear force separating from the Electronuclear force or ...
* Whatever mechanism behind the splitting of the Electronuclear force into the Strong Nuclear force and the Electroweak force caused Inflation or ...
* something else entirely...

# Inflation

* While the detailed mechanism responsible for Inflation is not known, the basic picture makes a number of predictions that have been confirmed by observation

# Inflation

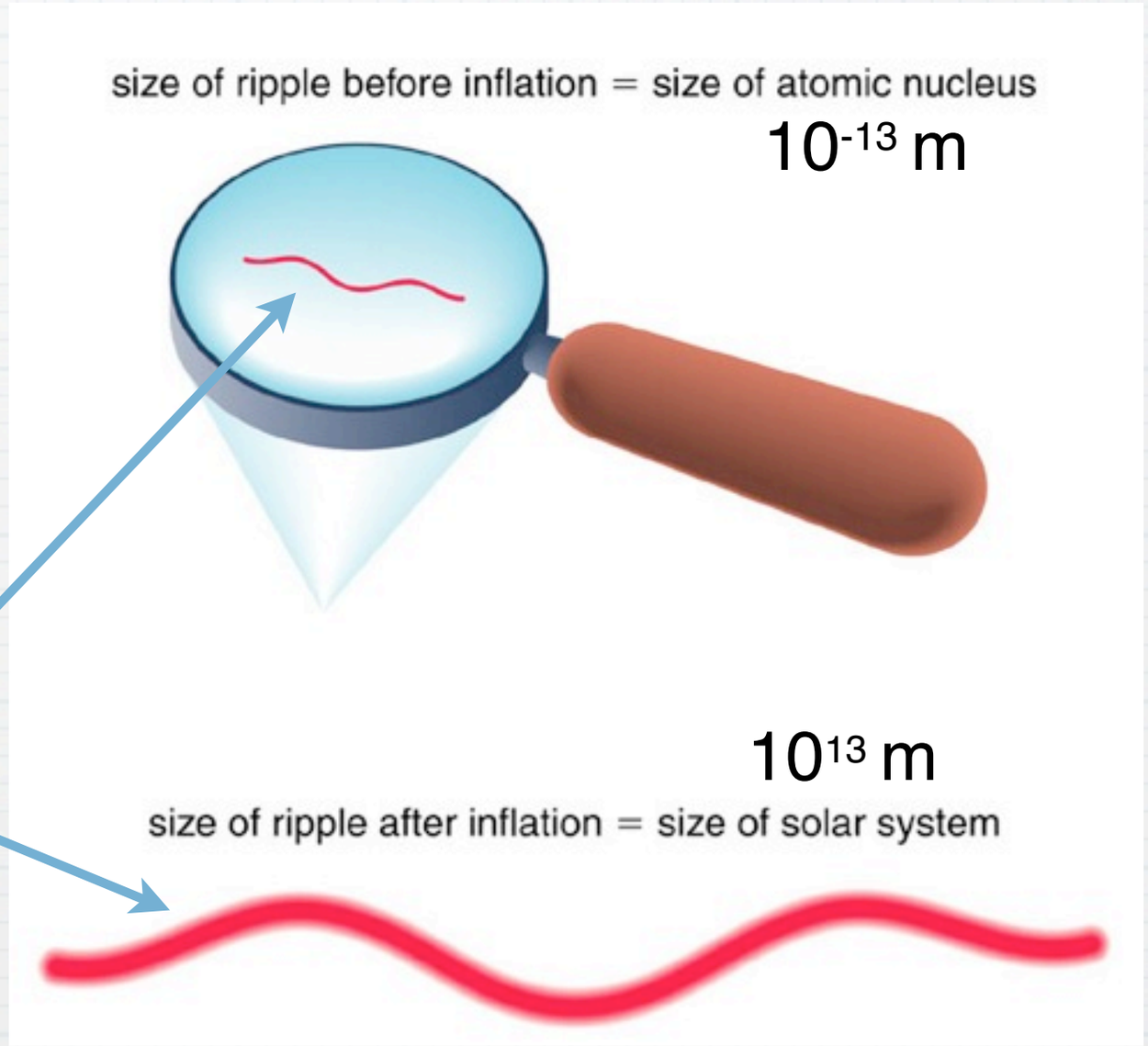
* As a direct consequence of this event,
* quantum fluctuations grow in the microscopic inflationary region magnified to cosmic size
* and become the seeds for the growth of structure (super-clusters and super-voids) in the Universe

# Inflation to the Rescue

## i. The Isotropic Problem

Inflation can make all the structure by stretching tiny quantum ripples to enormous size

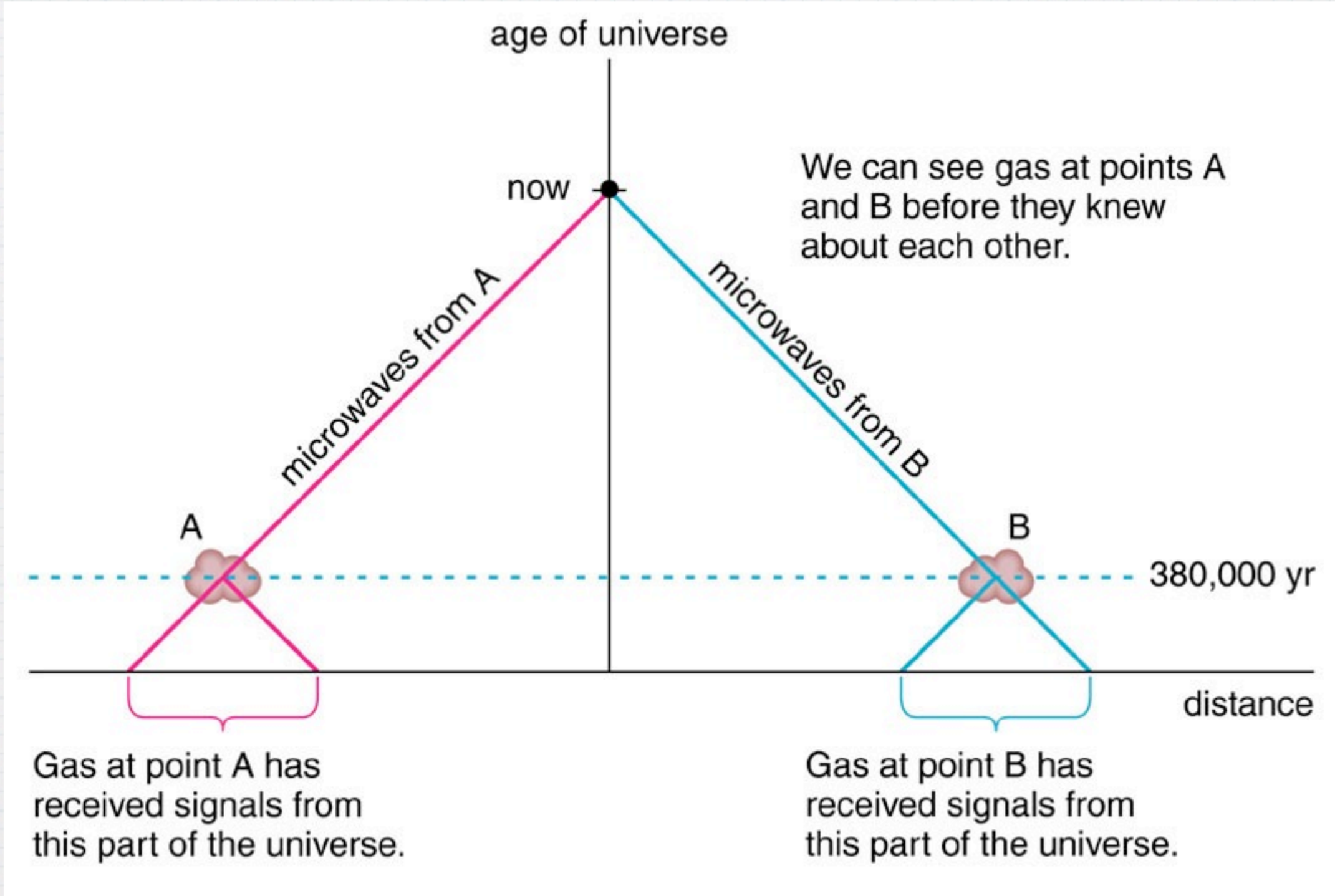
Inflation: instant $10^{26}$ linear growth



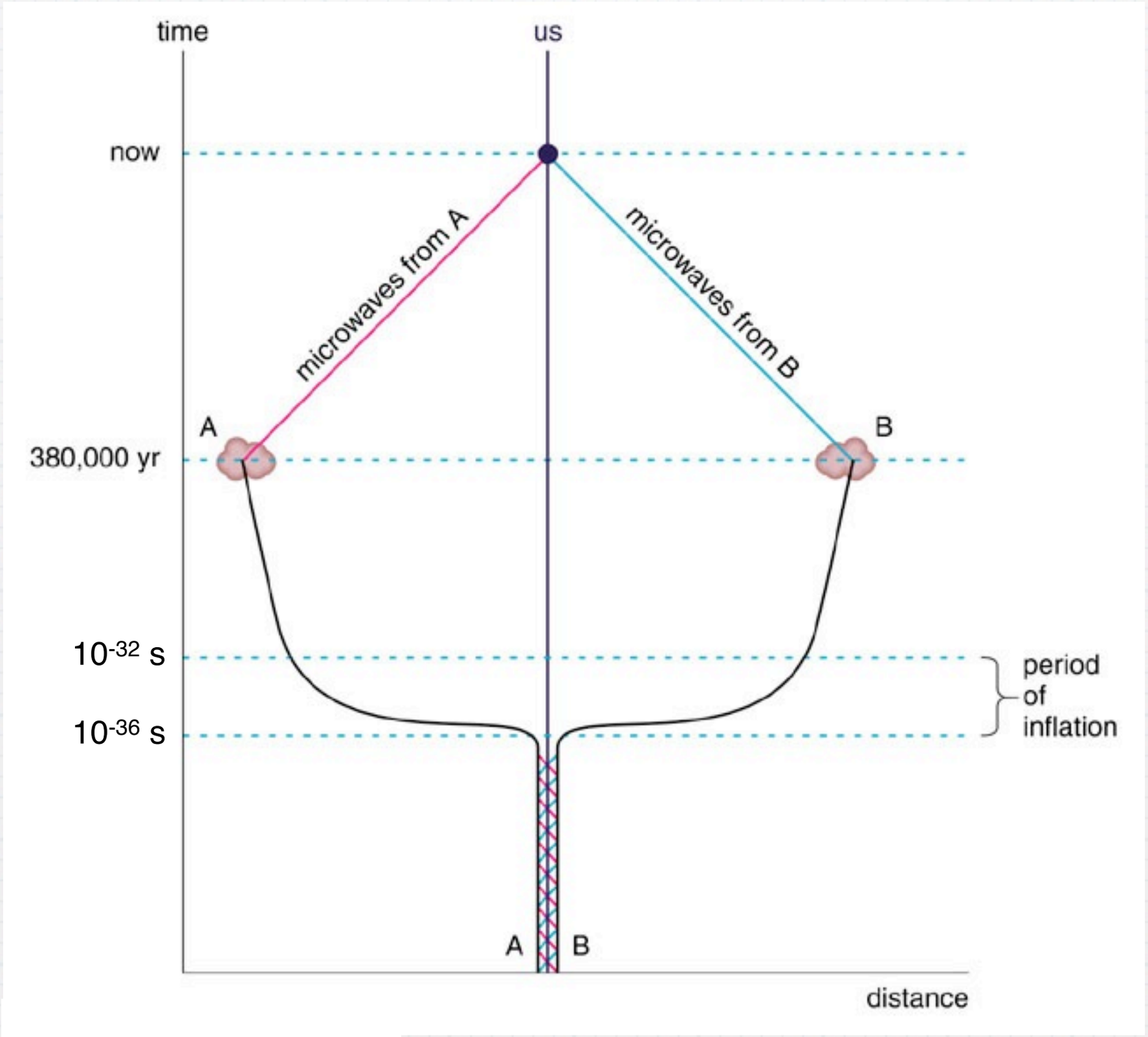

These ripples in density then become the seeds for all structures

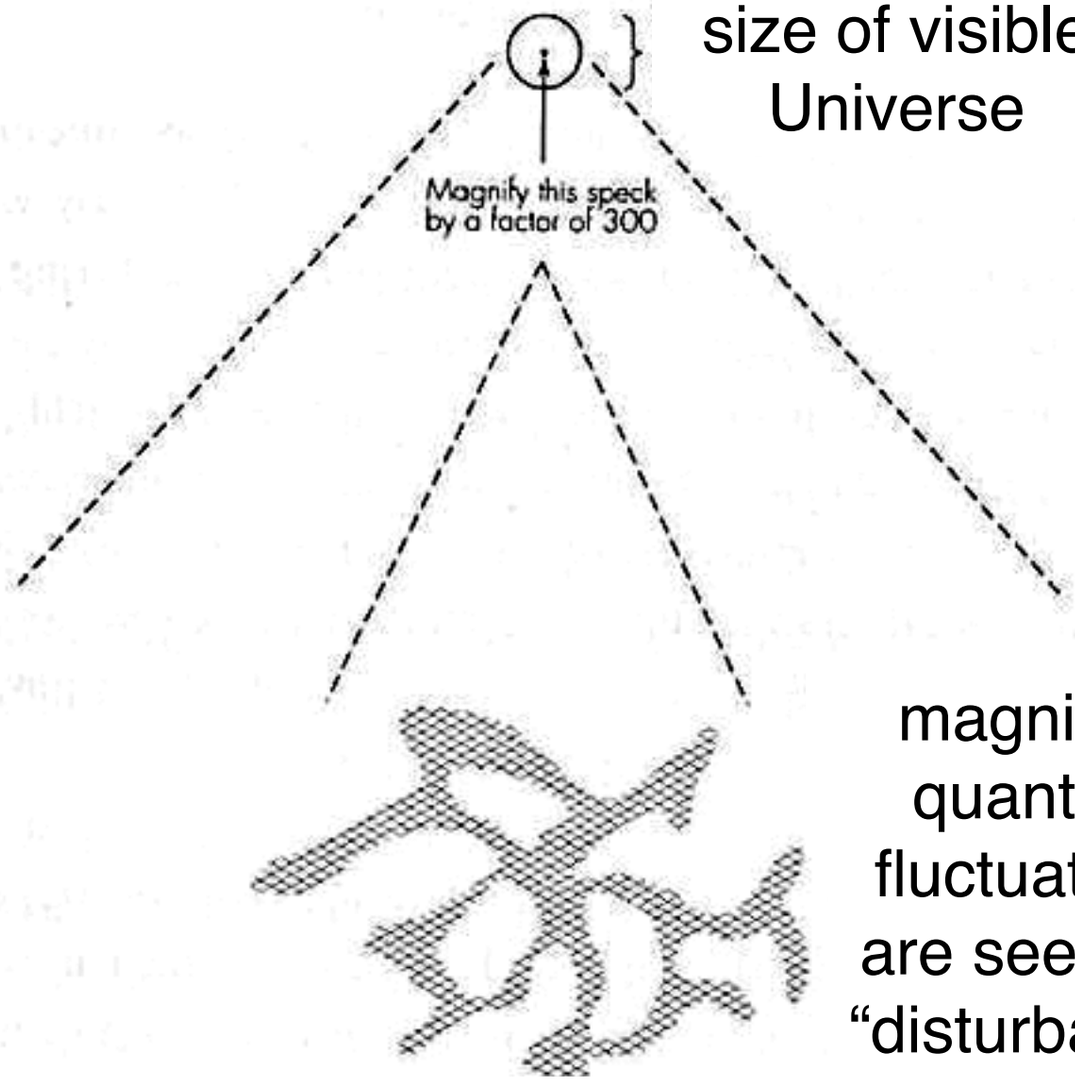
# i. The Isotropic Problem

## How can microwave temperature be nearly identical on opposite sides of the sky?



# Regions now on opposite side of the sky were close together before Inflation pushed them far apart

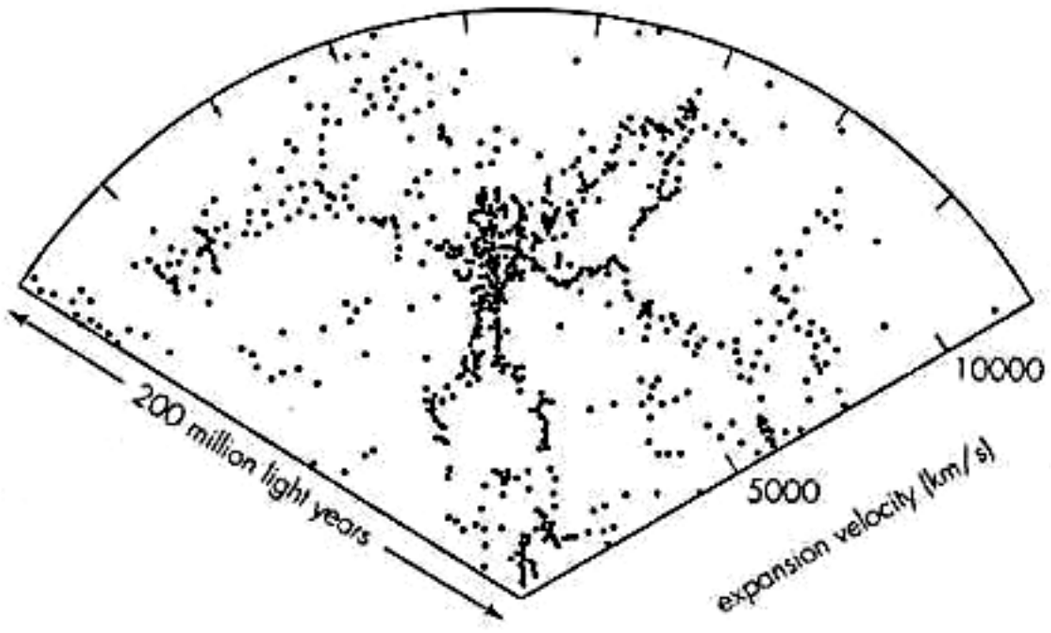





size of visible Universe

magnified quantum fluctuations are seeds of "disturbance"

After Inflation and billions of years of expansion

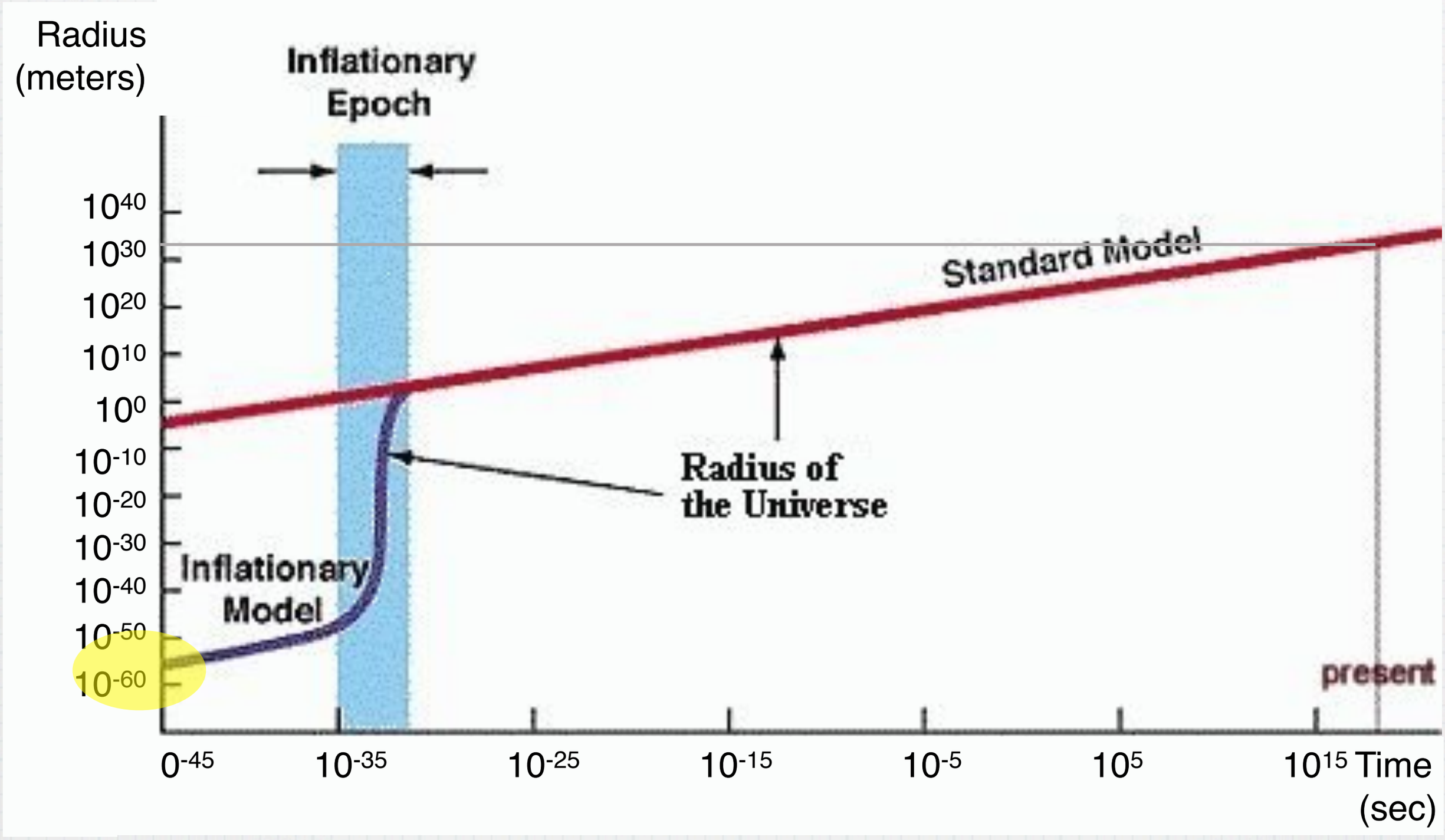



# Source for the Universe largest Structures

Inflation of quantum fluctuations provide the background disturbances needed for establishing the skeletons of the largest structures of the Universe: supervoids and superclusters and the dark matter tendrils

Tiny quantum fluctuations have become the homes for the superclusters of galaxies

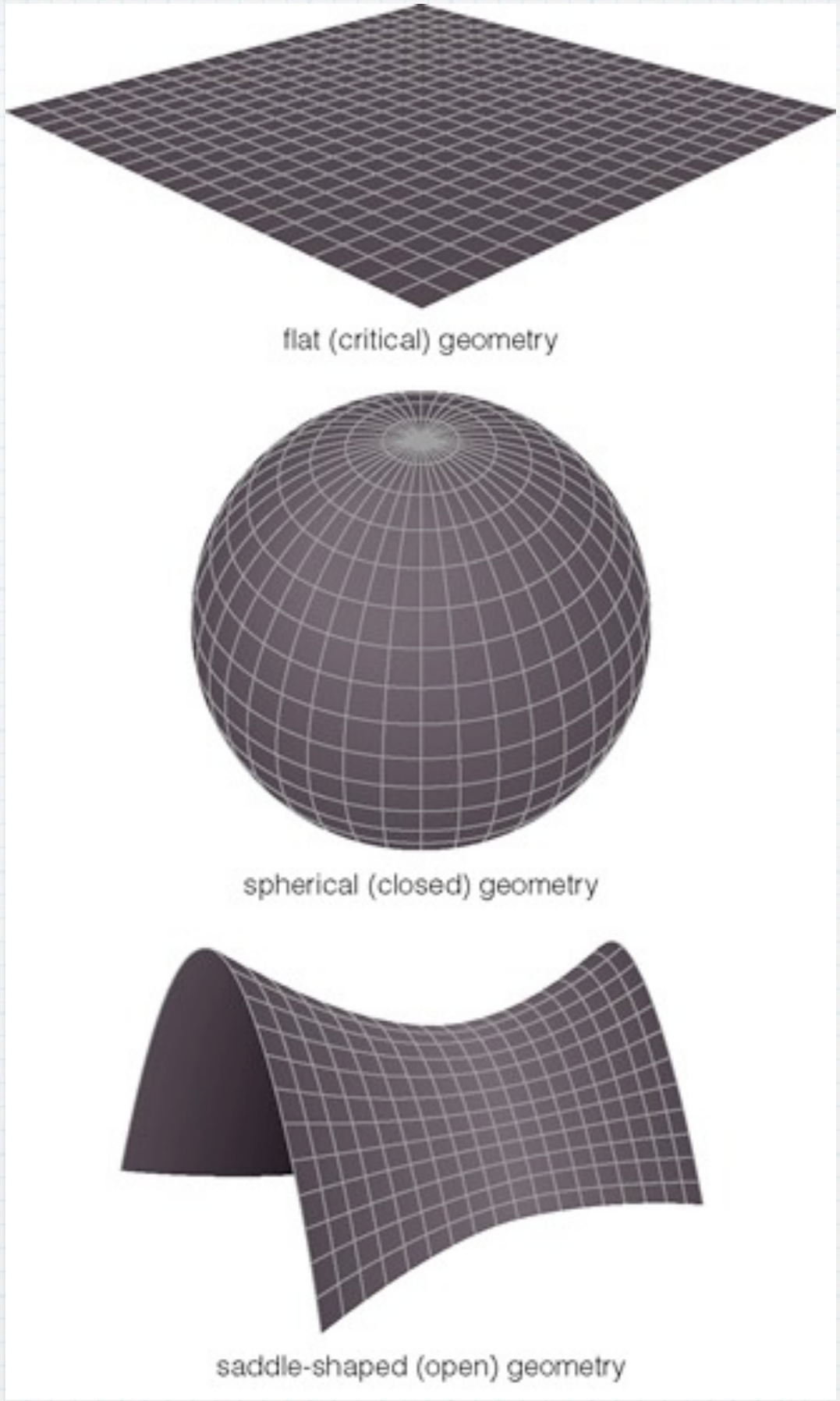
# The Universe has been growing and very small at start time



# ii. The Flatness Problem:

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

Einstein's equations tell us that if the Universe looks flat now, it had to start very flat




Density = Critical

Density > Critical

Density < Critical

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=
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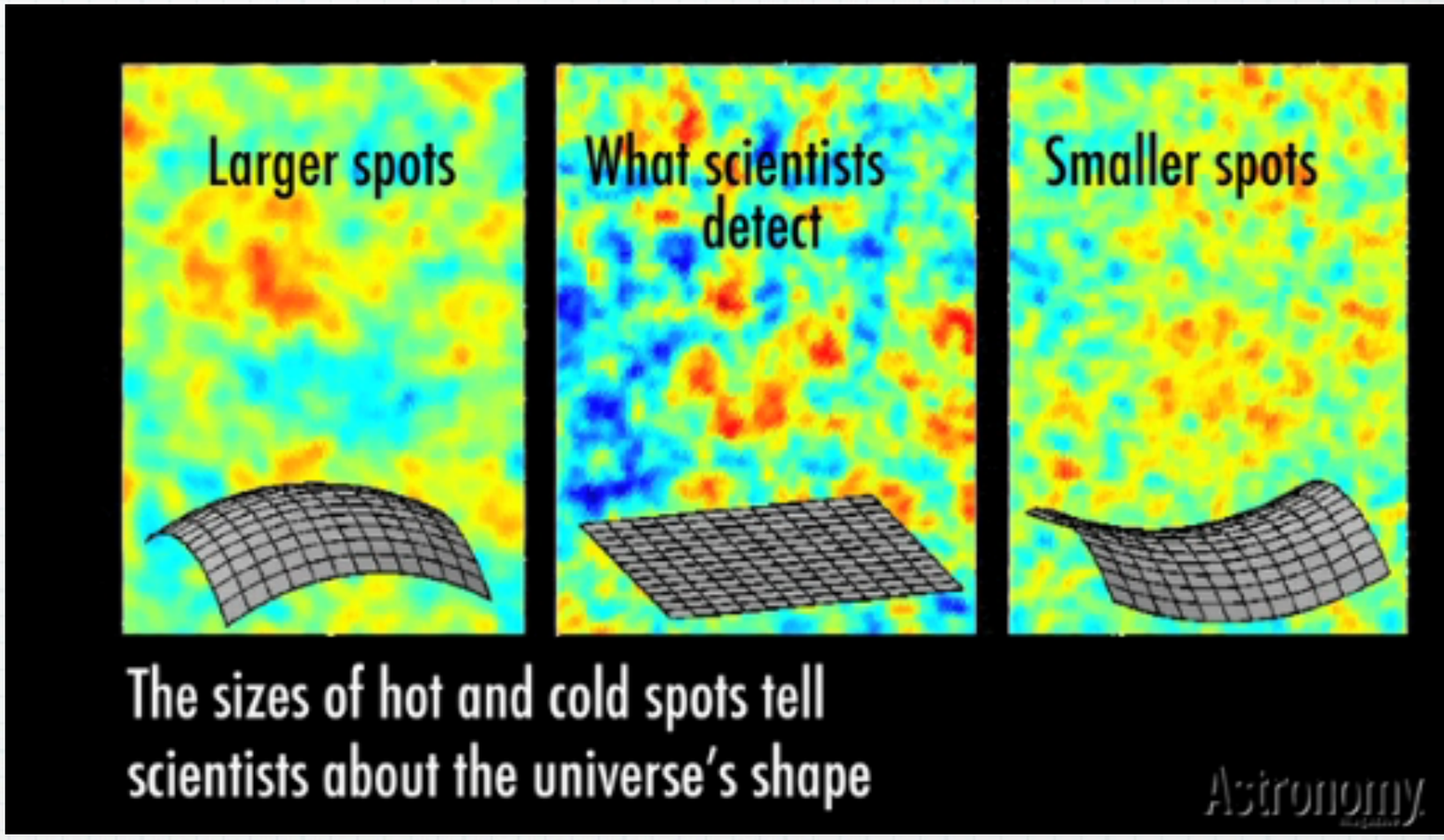


Density
>
Critical

Density
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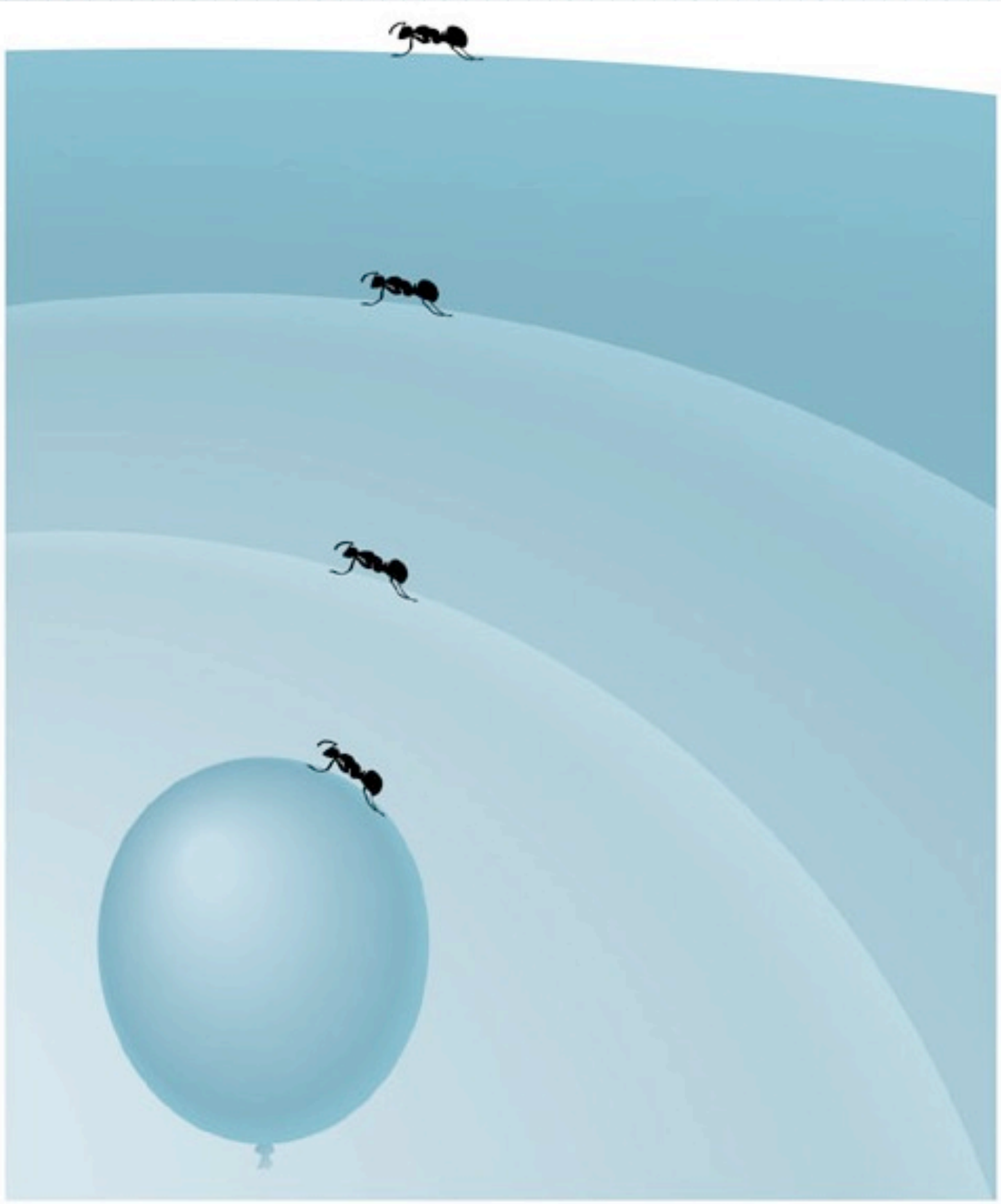
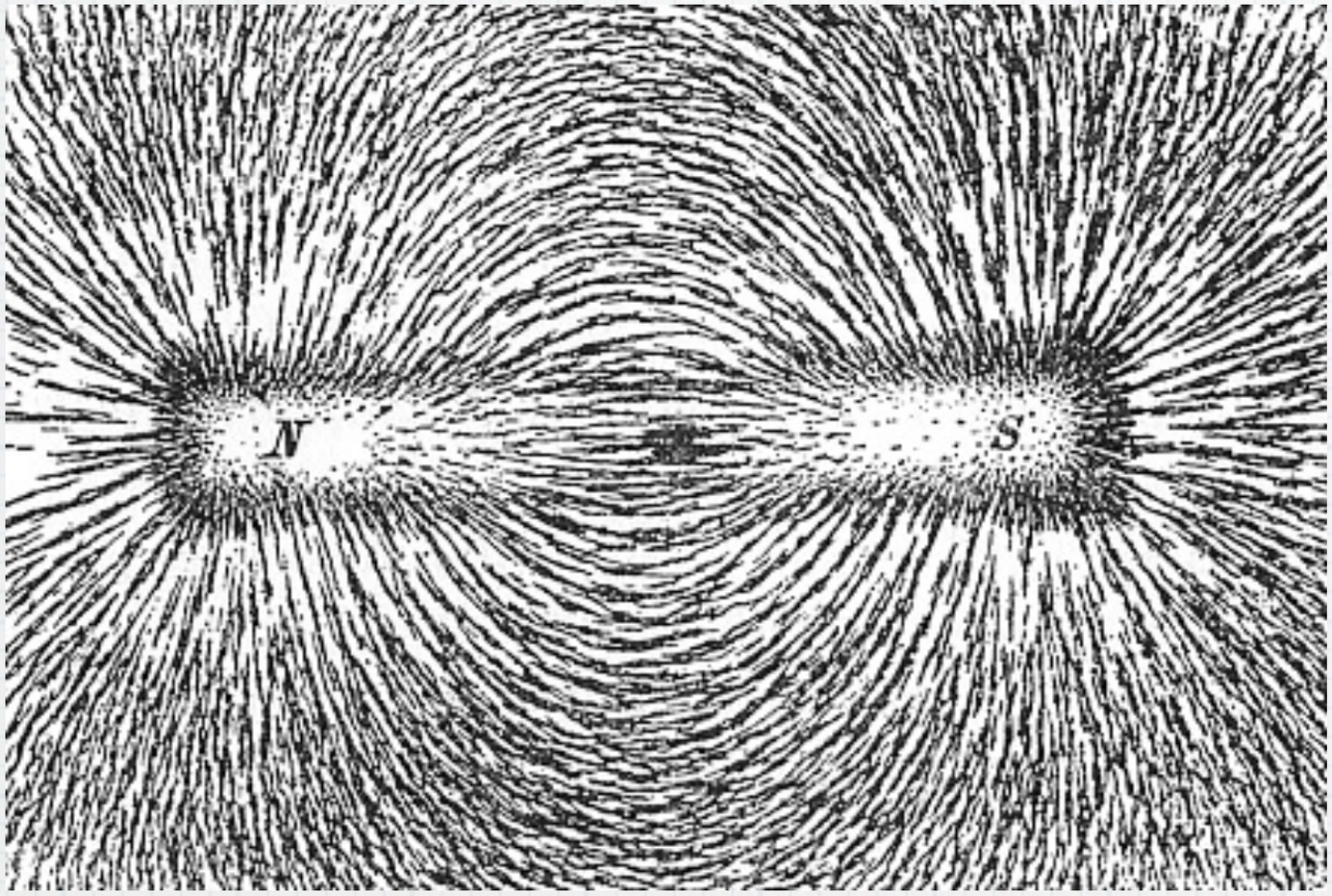
Critical



## ii. The Flatness Problem:

**Inflation** of **Universe** **flattens overall geometry** like the inflation of a balloon, causing overall density of matter plus energy to be very close to critical density




## iii. The Magnetic Monopole Problem:

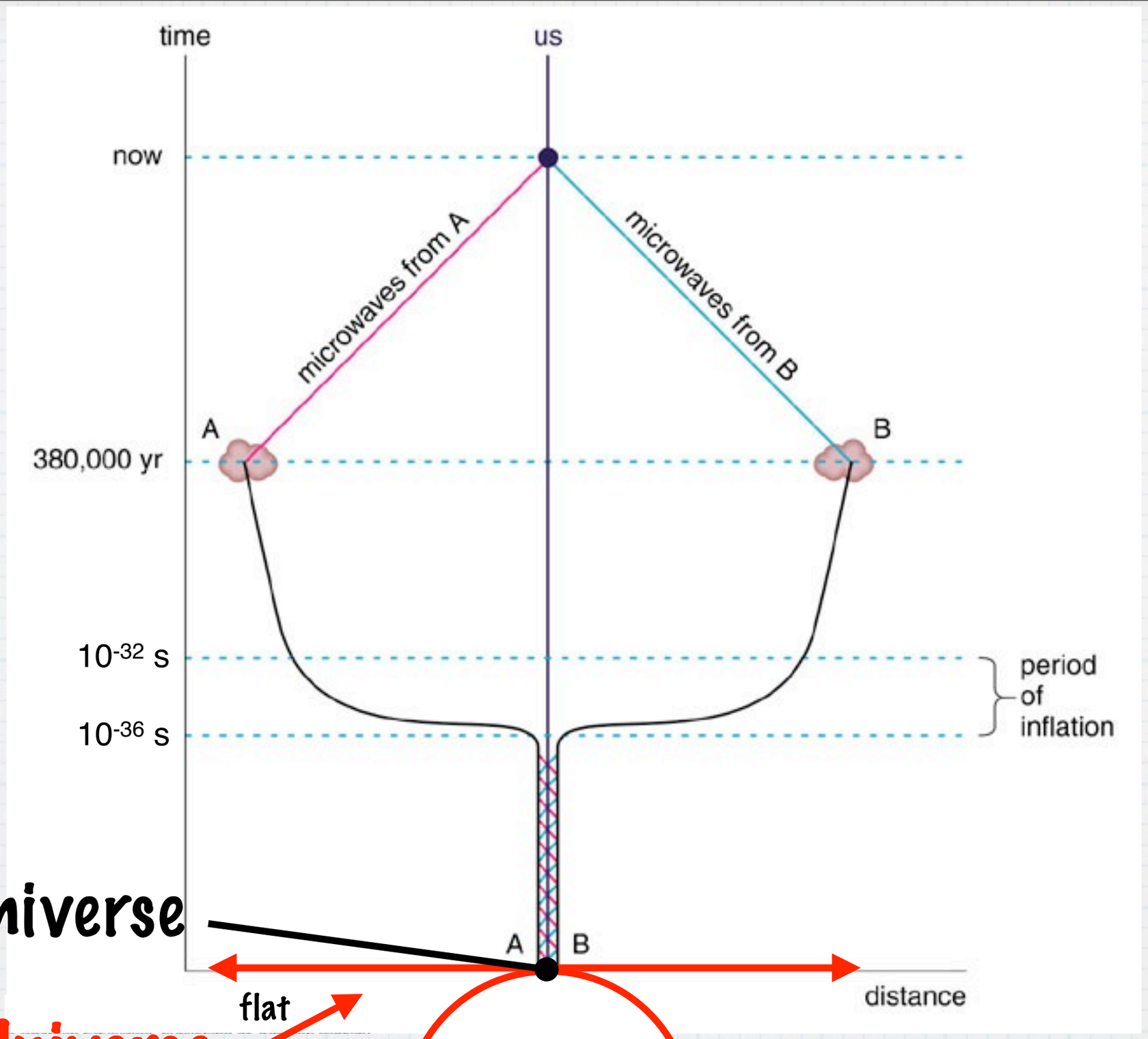
It disappears with Inflation as the magnetic monopoles "evaporate"

# How can we test the idea of Inflation?

* If Inflation happened, then it should predict some effects that we can observe

* Indeed, observations are consistent with the predictions but more observations are needed

* As a consequence of Inflation, our observable Universe is just a tiny portion of the entire Universe born in the Big Bang

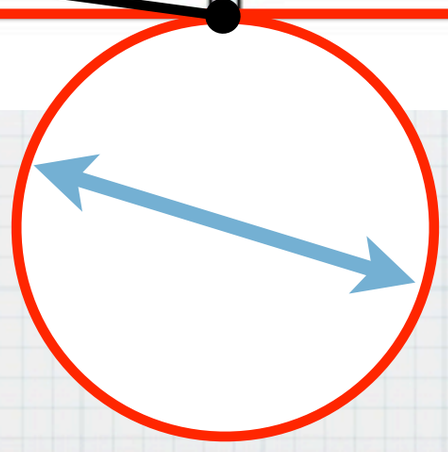



visible Universe

invisible Universe

flat

closed



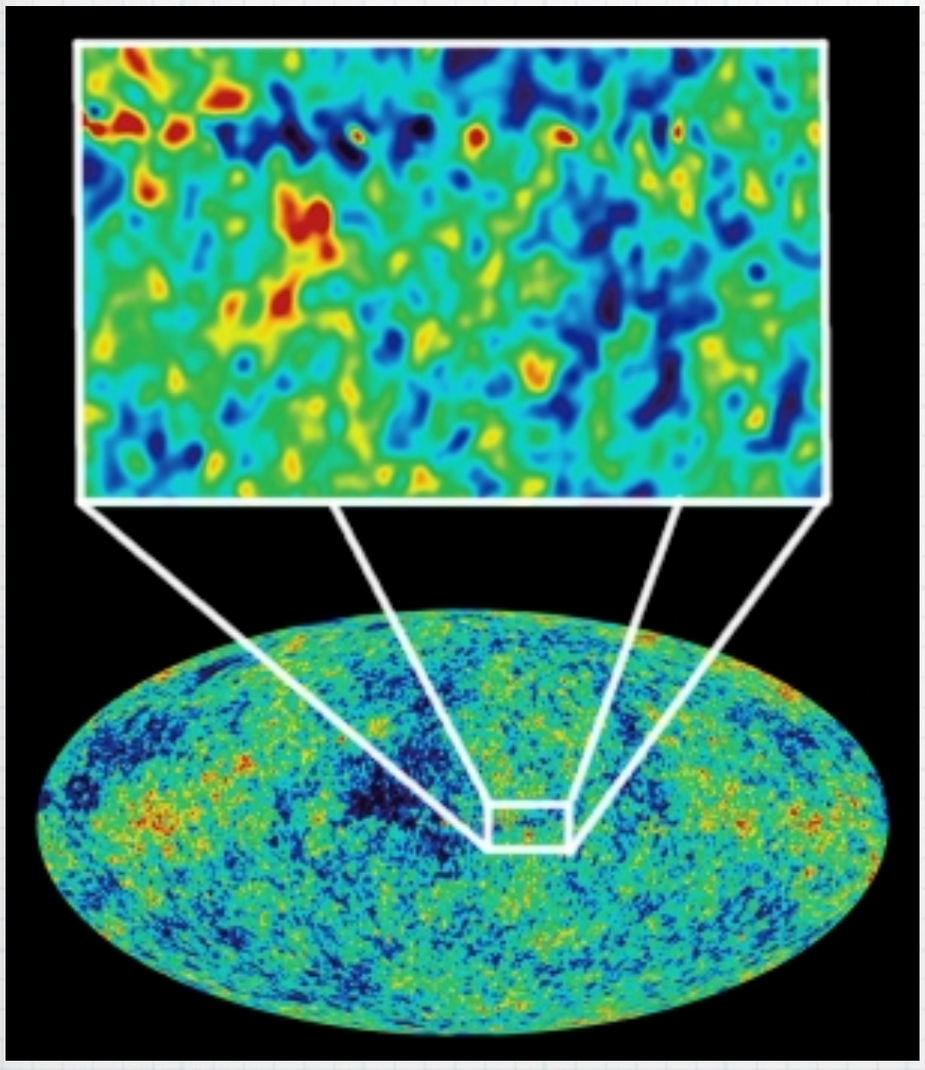
what is the true size of the Universe??

# Inflation and General Relativity

* The Inflation event created an expansion that goes much faster than the speed of light
* Is Einstein's General Relativity Theory violated?
* No
* What is expanding is the fabric of space

# Patterns of structure observed by WMAP tell us the "genetic code" of Universe

tiny variations of density



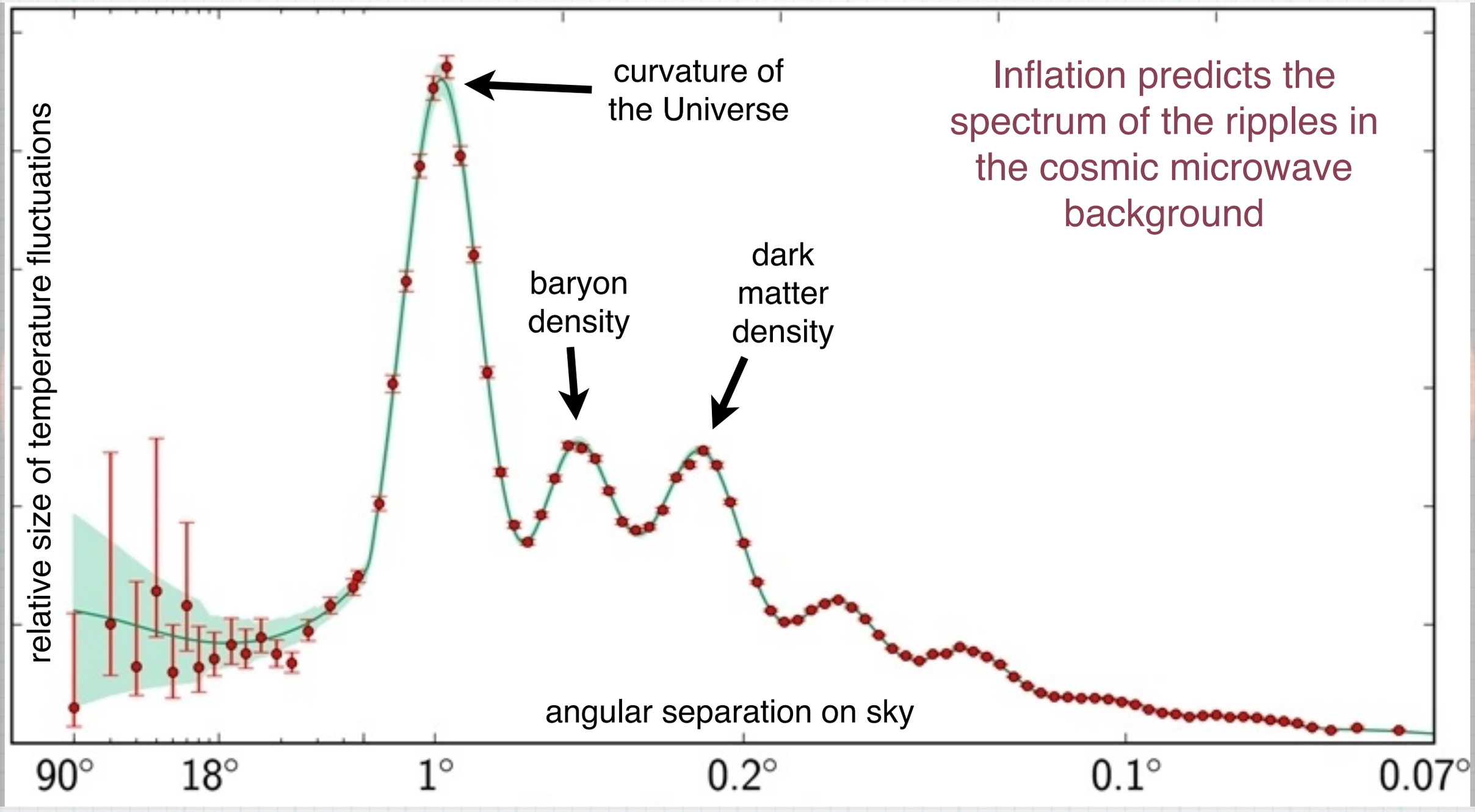
What can it tell about Inflation?

1 - Gravity, after billions of years, turned the denser ones into stars, galaxies & clusters

2 - Analyzing how the typical temperature differences between patches of sky depends on their angular size predicts the proportions of energy and matter

3 - Analyzing the shape of these variations throughout the map tells us the geometry of the Universe

# Observed patterns of structure in Universe agree (so far) with what Inflation should produce




Inflation predicts the spectrum of the ripples in the cosmic microwave background

# "Genetic Code" Inferred from CMBR

1. Overall geometry is flat and implies the Universe is infinite in size
2. Total mass+energy has critical density
3. Ordinary matter ~5% of total
4. Dark matter is ~27% of total
5. Total matter is ~32% of total
6. Dark energy is ~68% of total

➡ Age of 13.81 (± 0.03) billion years

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➡ Age of 13.81 (± 0.03) billion years

**In excellent agreement with observations of present-day Universe and models involving inflation and WIMPs!**

# Observing before CMB?

* CMB (cosmic microwave background) is the radiation of earliest photons (375,000 years after Big Bang)

* CvB (cosmic neutrino background) decoupled from matter when the Universe was 2 seconds old

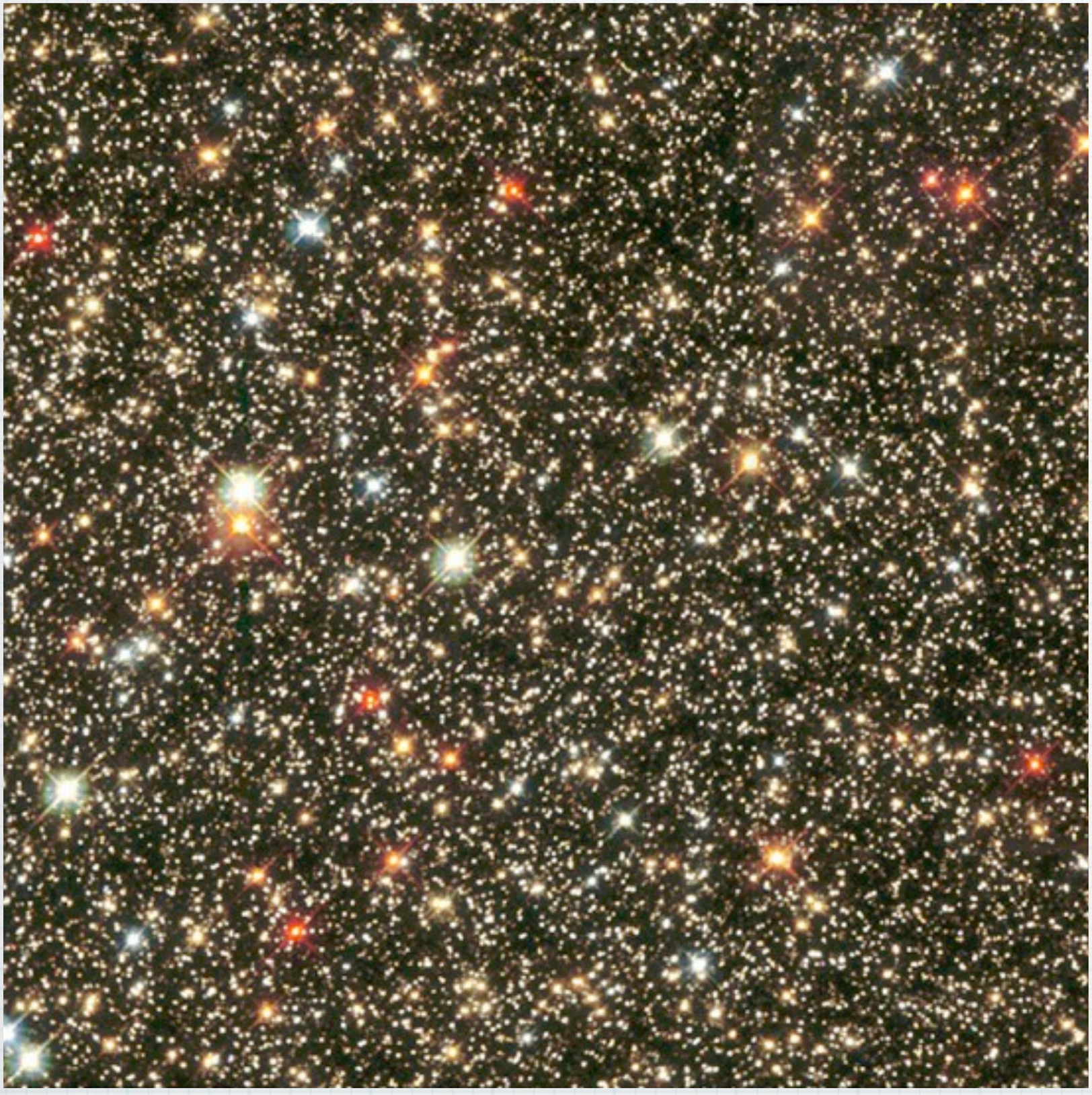
* Its temperature is estimated at 1.95 K

# CvB

* Since low-energy neutrinos interact only very weakly with matter, they are notoriously difficult to detect and the CvB might never be observed directly
* There is, however, compelling indirect evidence for its existence

# Darkness of the Night Sky is Evidence for the Big Bang

* Why is the darkness of the night sky evidence for the Big Bang, or ... why is the sky dark at night?
* An infinite Universe should have star lights coming from all directions, making it bright



# Olbers' Paradox

If Universe were

1) infinite

2) unchanging

3) everywhere the same

Then, stars would cover the night sky

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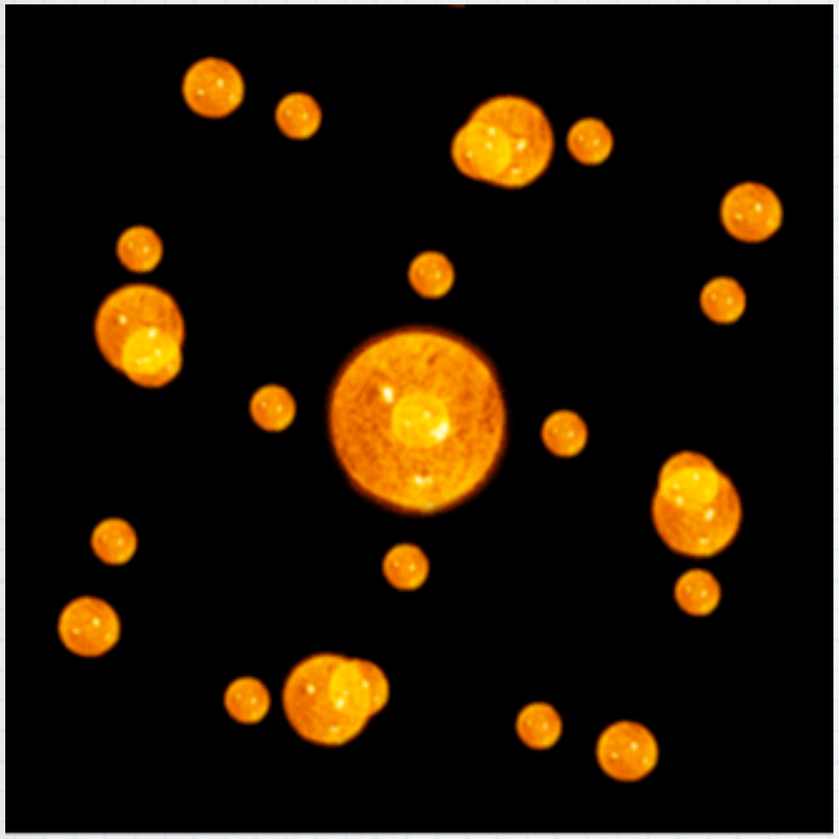

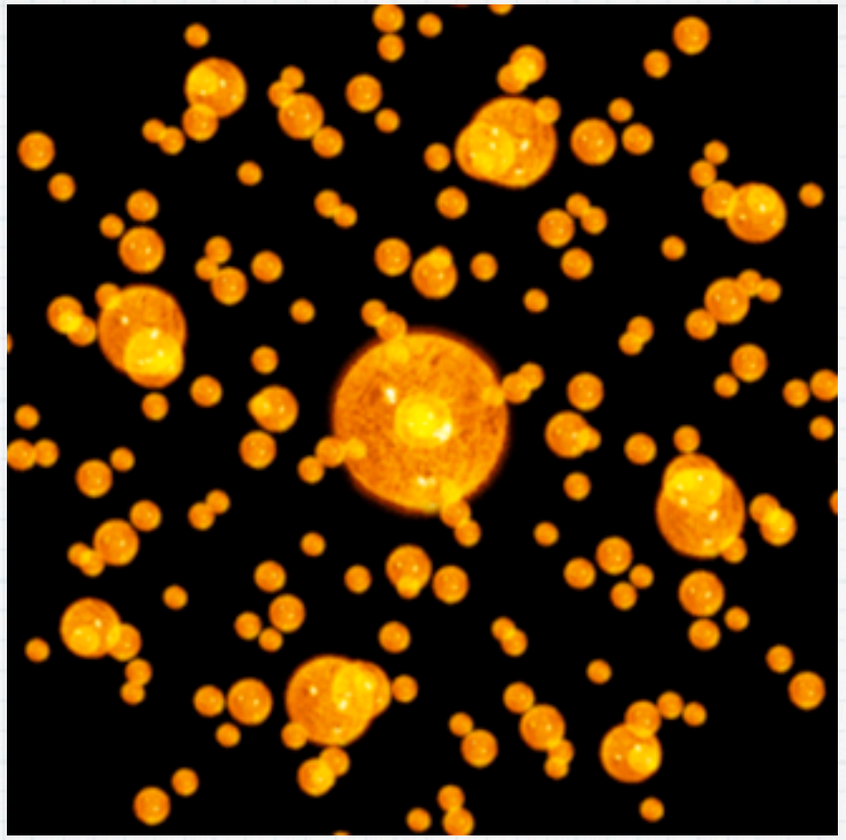

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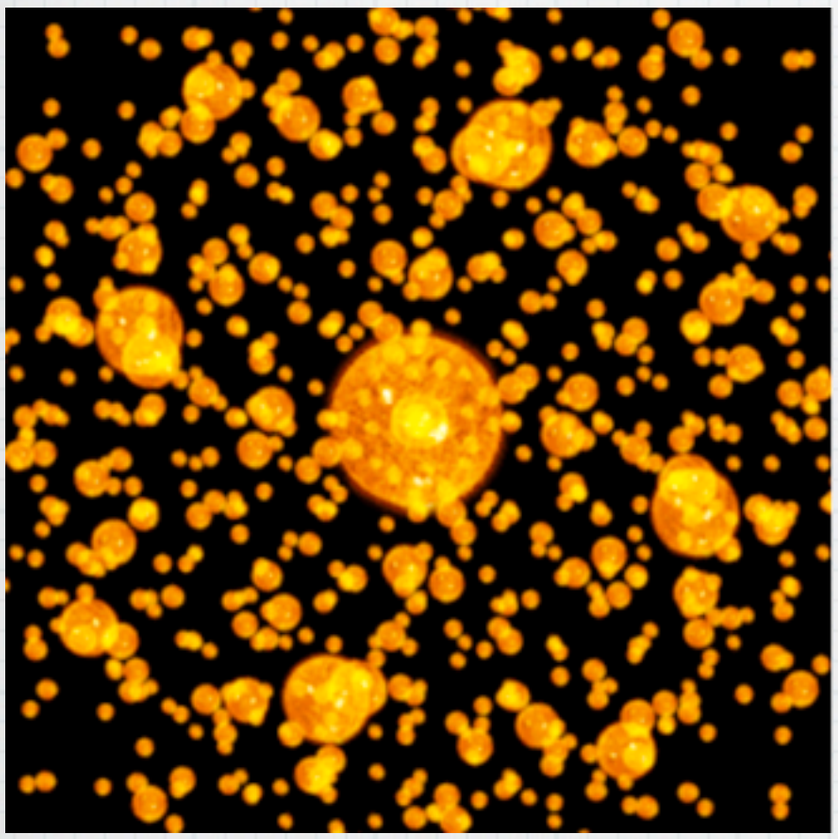
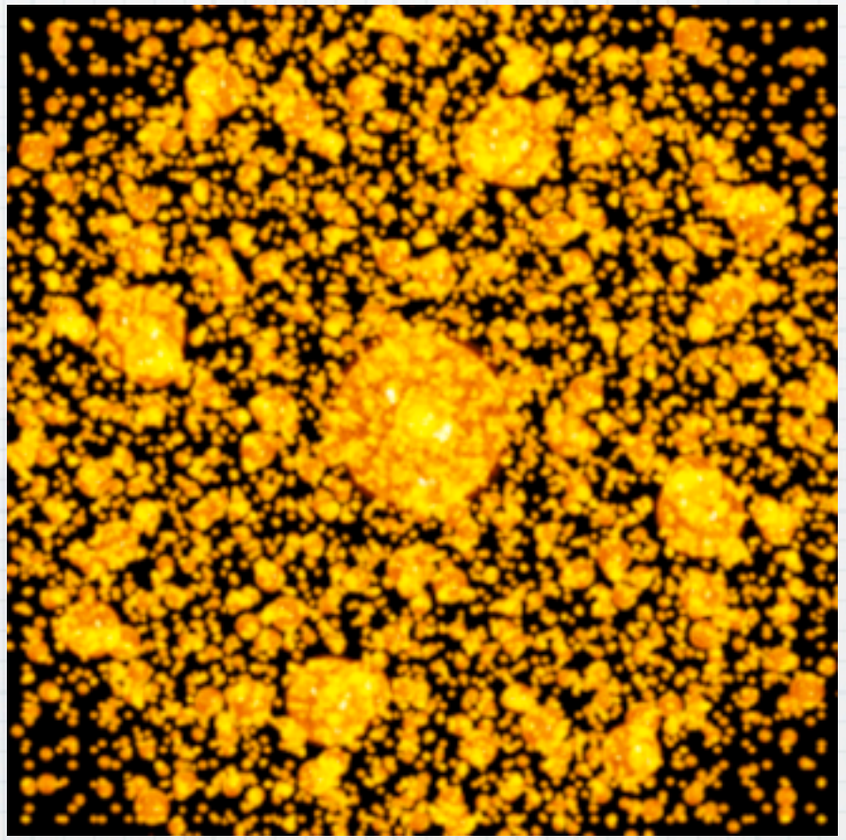
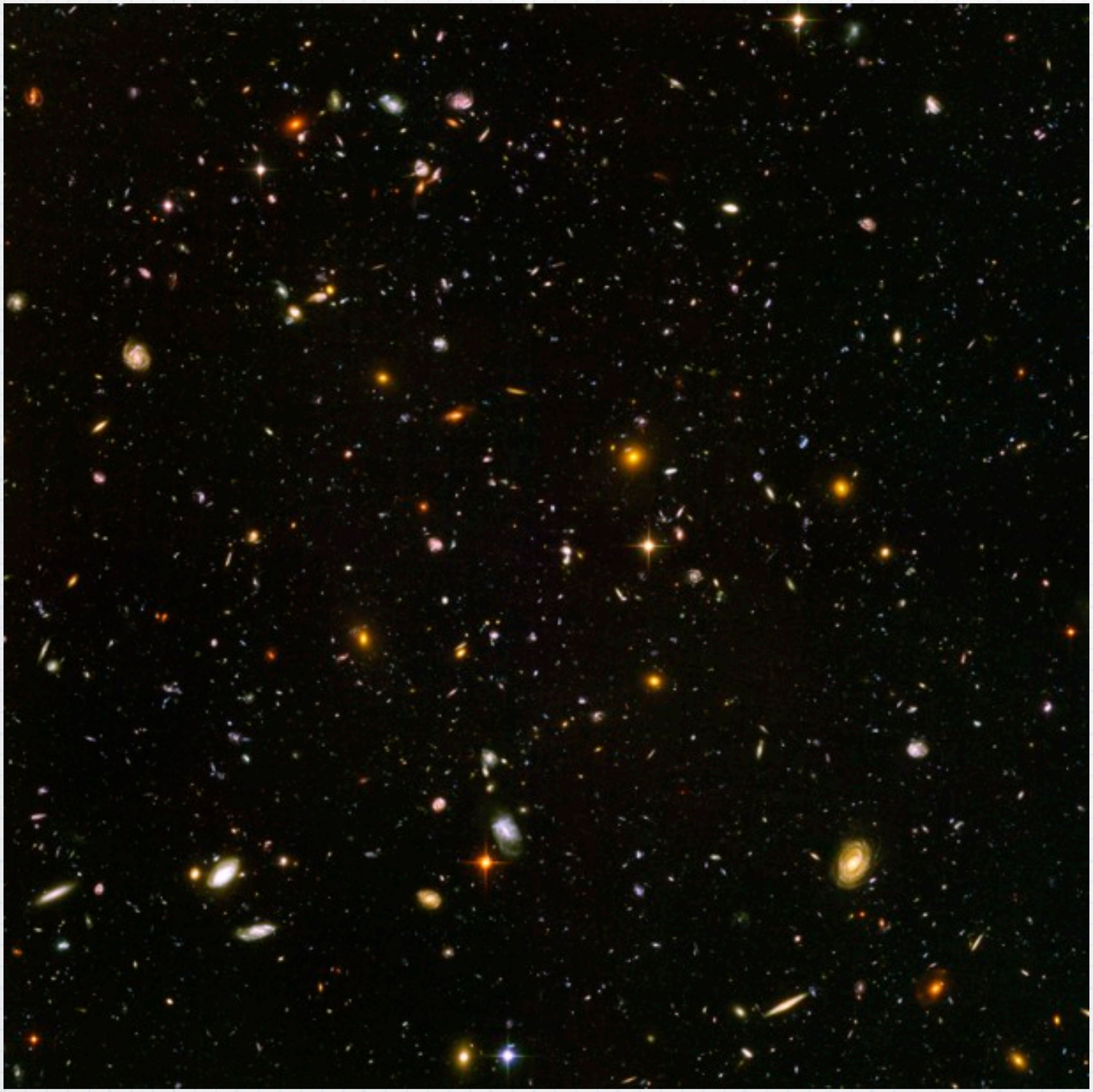




3) everywhere the same

**Then, stars would cover the night sky**

Night sky is dark because the Universe changes with time



# Night sky is dark because the Universe changes with time

# Snapshot

* Why is the darkness of the night sky evidence for the Big Bang?

* Olbers' paradox tells us that if the Universe were infinite, unchanging, and filled with stars, the sky would be everywhere as bright as the surface of the Sun, and it would not be dark at night. The Big Bang theory solves this paradox by telling us that the night sky is dark because the Universe has a finite age, which means we can see only a finite number of stars in the sky

# Now

* Where are we at? A short summary
  * Space-time is flat
  * Space and time are expanding forever
  * The expansion rate is accelerating
  * Dark energy is now 68% of the energy of the Universe

# The Distant Future: A Cold & Black Universe

- Tens of billions of years from now, no other galaxy will be seen (all located beyond observable cosmic horizon)
- All that will be left in the cosmos will be
  - black holes
  - burnt-out cinders of stars
  - dead husks of planets

# Finally

* That is not the end!
* 1 trillion trillion trillion trillion trillion trillion years from now, all matter **may** decay back to radiation due to their respective half-lives
* What is left is a featureless, infinitely large void where time is inconsequential

# Unless...

* All this rests upon our understanding of dark matter & energy and the flatness of space-time
* If future observations change our current understanding, this "written" end will have to be re-written
* Stay tuned

# References

* The Standard Model Of Particle Physics
  * http://www.youtube.com/watch?v=V0KjXsGRvoA
* Mass & The Higgs
  * http://www.youtube.com/watch?v=RIg1Vh7uPyw
  * http://www.youtube.com/watch?v=1_HrQVhgbeo
* When Will Time End?
  * http://www.youtube.com/watch?v=5OFTh0RmR-s