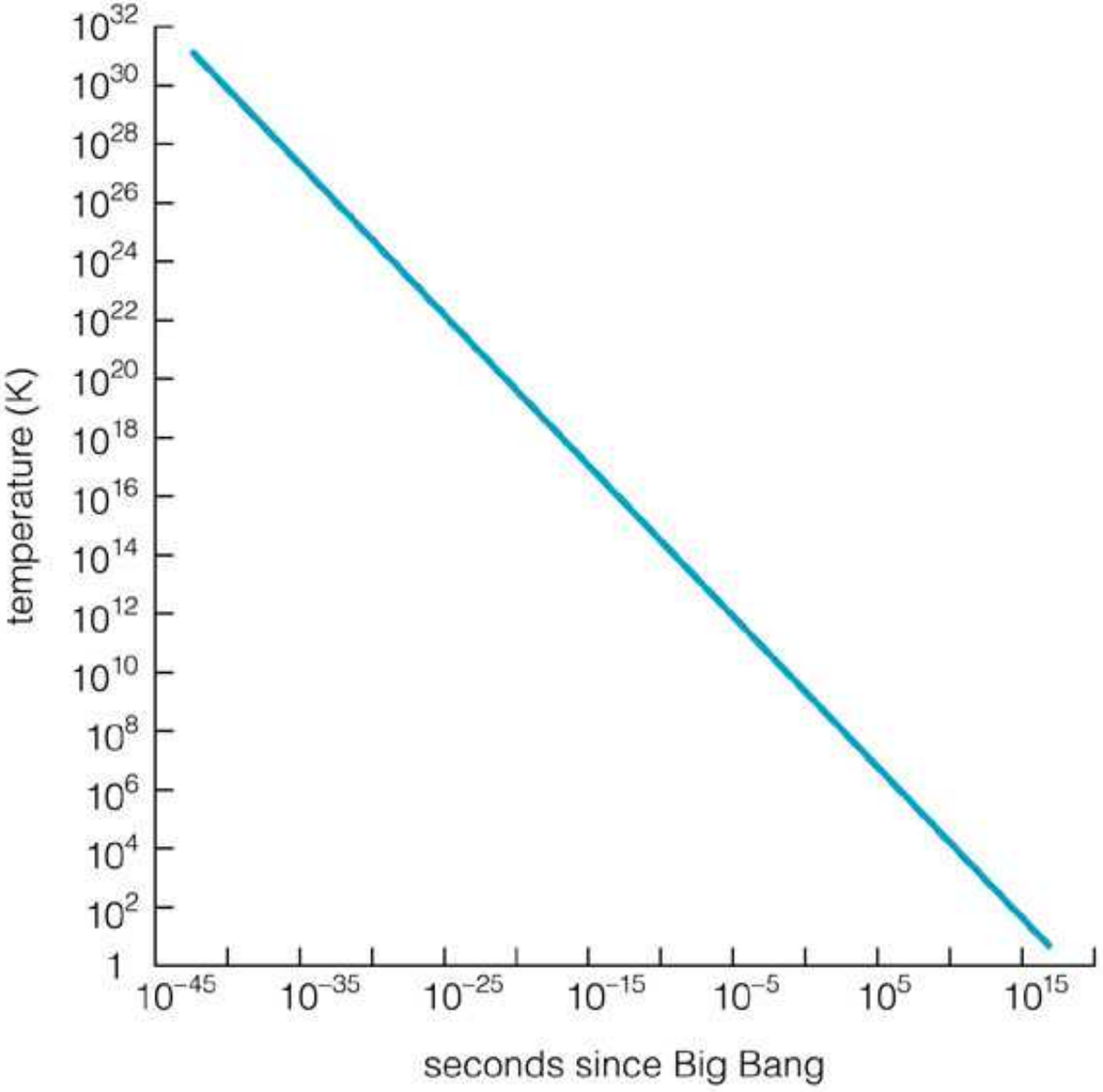
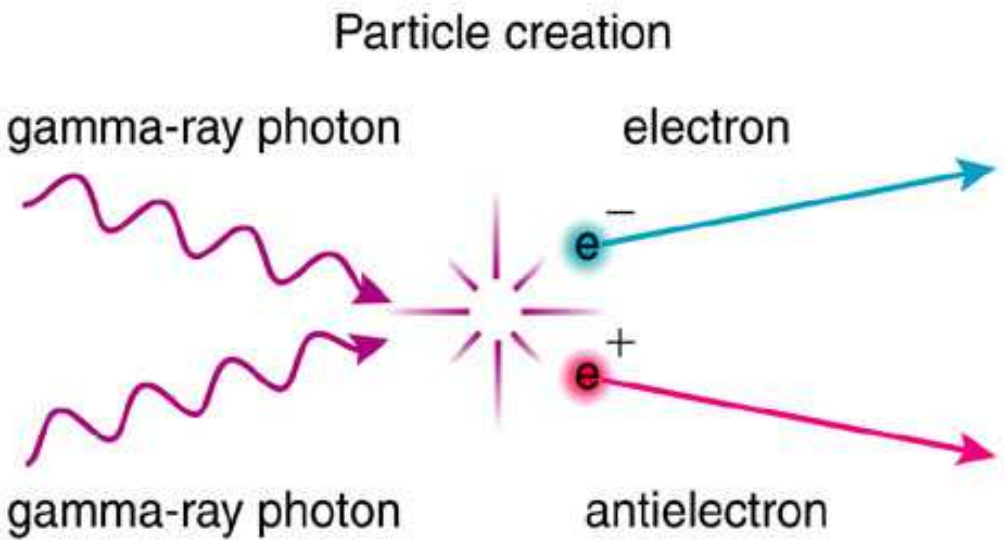

the BIG BANG THEORY

Most people are familiar with the term 'Big Bang' theory. However when astronomer Sir Fred Hoyle first coined the phrase 'Big Bang' he did so in order to mock the theory. Hoyle was a firm believer in the alternative steady state theory which gives the universe no start or end. However the name stuck and the term Big Bang is now widely used although the irony has been lost.

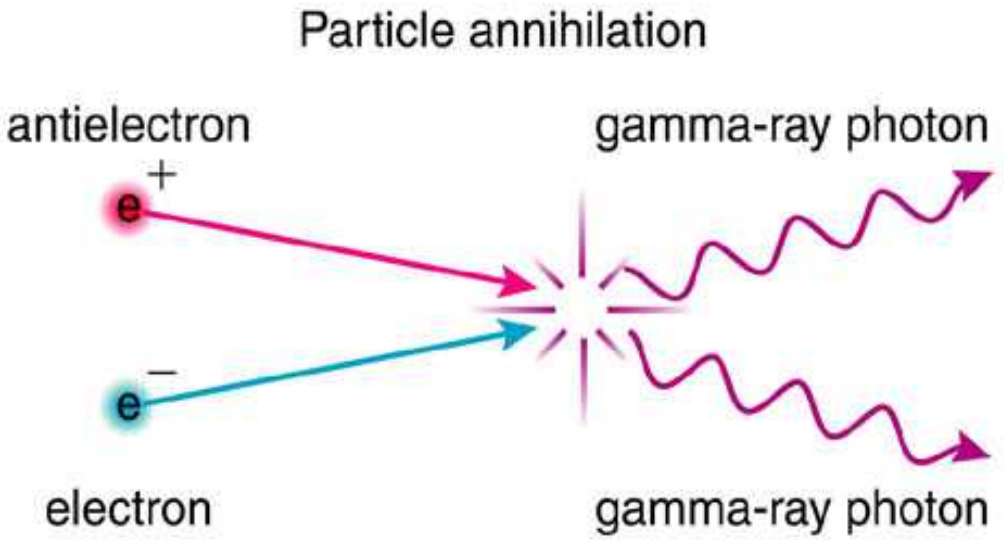


The early universe must have been extremely hot and dense

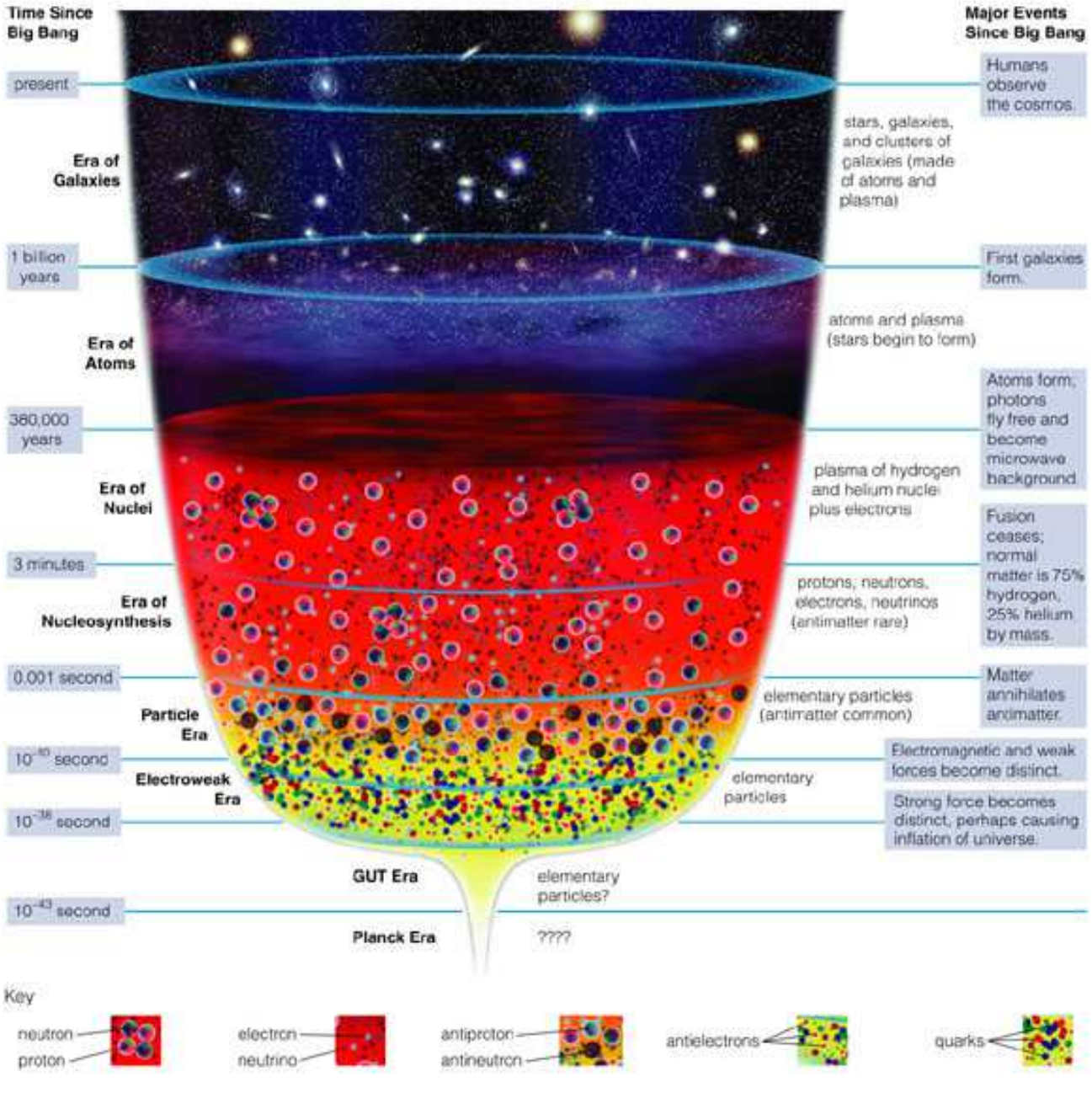


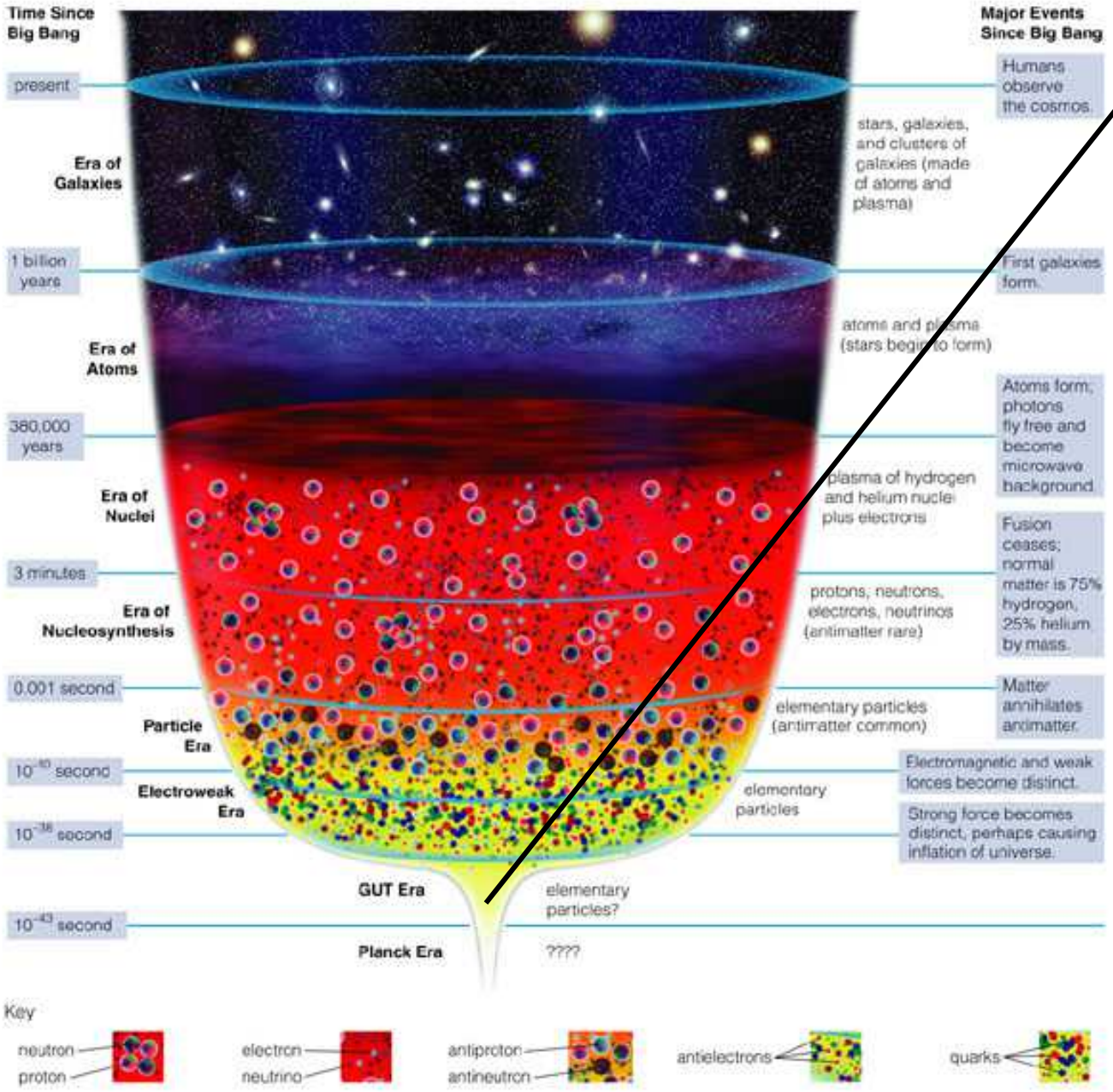
Photons converted into particle-antiparticle pairs and vice-versa

$$E = mc2$$



Early universe was full of particles and radiation because of its high temperature


Time Since Big Bang
Major Events Since Big Bang
present
Humans observe the cosmos.
Era of Galaxies
stars, galaxies, and clusters of galaxies (made of atoms and plasma)
1 billion years
First galaxies form.
Era of Atoms
atoms and plasma (stars begin to form)
380,000 years
Atoms form; photons fly free and become microwave background.
Era of Nuclei
plasma of hydrogen and helium nuclei plus electrons
3 minutes
Fusion ceases; normal matter is 75% hydrogen, 25% helium by mass.
Era of Nucleosynthesis
protons, neutrons, electrons, neutrinos (antimatter rare)
0.001 second
Matter annihilates antimatter.
Particle Era
elementary particles (antimatter common)
10^{-10} second
Electromagnetic and weak forces become distinct.
Electroweak Era
elementary particles
10^{-36} second
Strong force becomes distinct, perhaps causing inflation of universe.
GUT Era
elementary particles?
10^{-43} second
Planck Era
????
Key
neutron
proton
electron
neutrino
antiproton
antineutron
antielectrons
quarks



Planck Era

Before Planck time (~10-43 sec)

No theory of quantum gravity

The Planck Regime:

2 important length scales:

$$r_{sch} = \frac{2Gm}{c^2}$$

$$\lambda_{compton} = \frac{h}{mc}$$

$$\frac{2Gm}{c^2} = \frac{h}{mc}$$

$$Gm^2 = \hbar c$$

$$m^2 = \frac{\hbar c}{G}$$

$$m_{pl} = \sqrt{\frac{\hbar c}{G}}$$

2 Theories:

Gravitation

Quantum Mechanics

factor of π!

$$\hbar = \frac{h}{2\pi}$$

The Planck mass

$$m_{pl} = \sqrt{\frac{\hbar c}{G}}$$

Planck mass = 5.46 x 10-5 gm

$$\lambda_{pl} = \left(\frac{G\hbar}{c^3}\right)^{1/2}$$

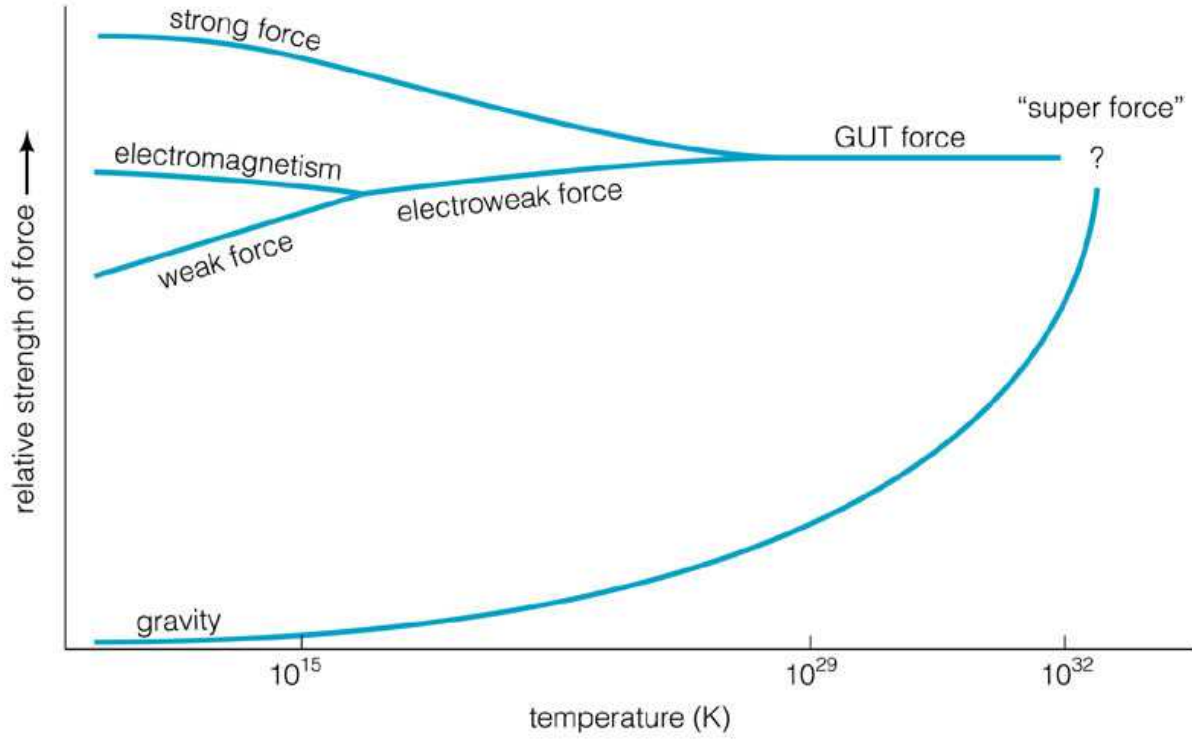
Planck length ~ 10-33 cm

$$t_{pl} = \left(\frac{G\hbar}{c^5}\right)^{1/2}$$

Planck time ~ 10-43 sec

$$E_{pl} = \sqrt{\frac{\hbar c^5}{G}}$$

Planck energy ~ 1019 GeV



Four known forces in universe:

Strong Force

Electromagnetism

Weak Force

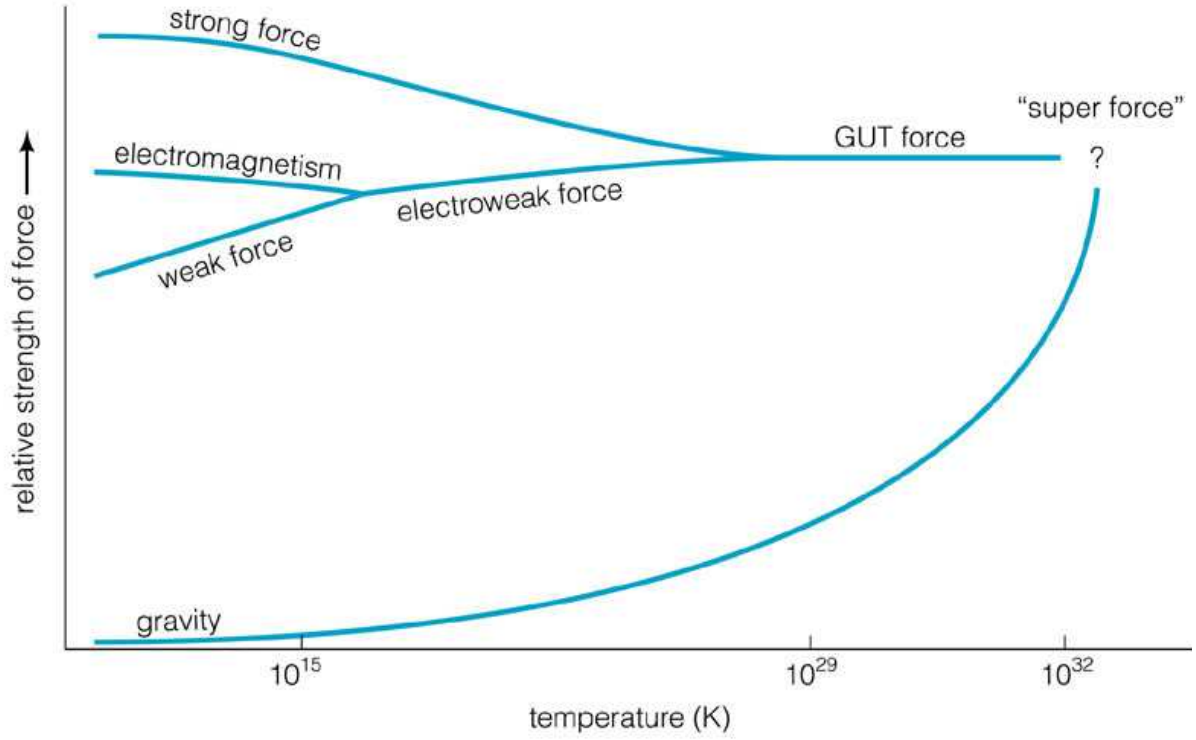
Gravity

Thought Question

Which of the four forces keeps you from sinking to the center of the Earth?

A. Gravity
B. Electromagnetism
C. Strong Force
D. Weak Force

Do forces unify at high temperatures?



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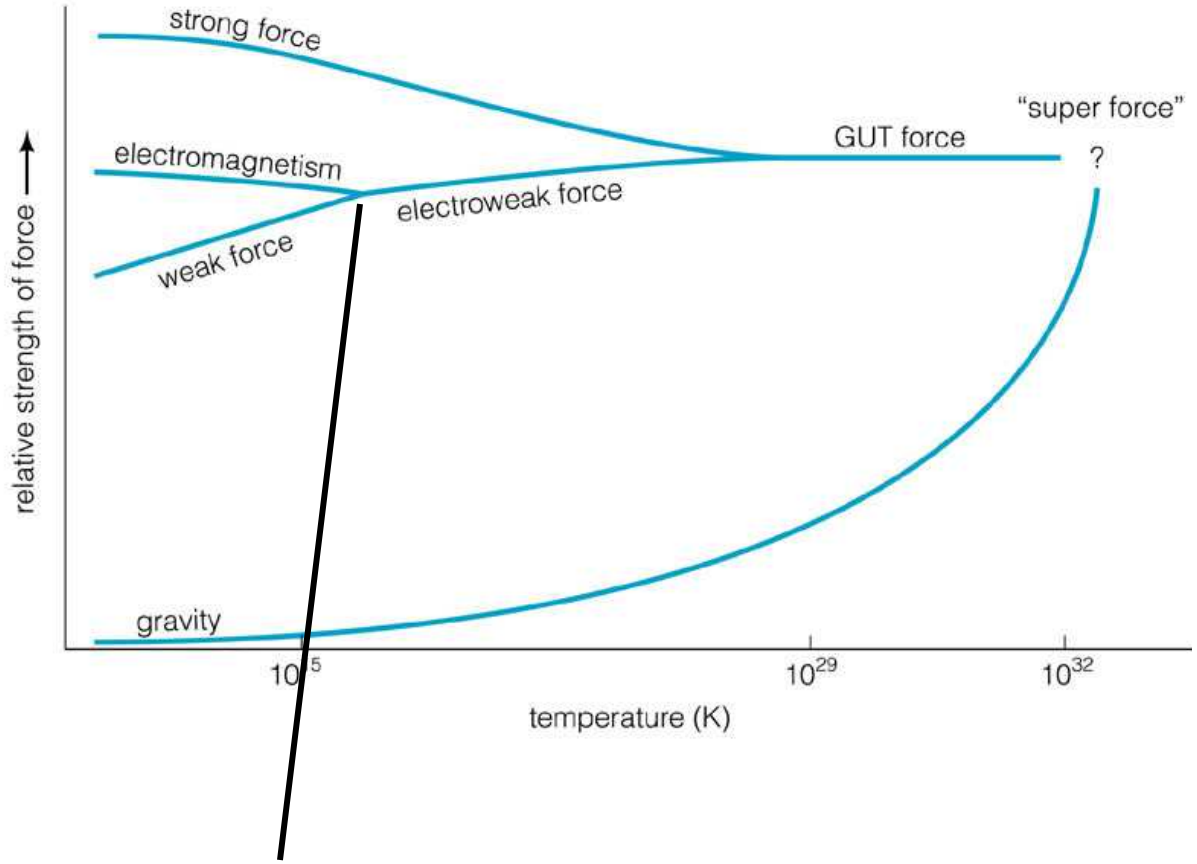

Yes!
(Electroweak)

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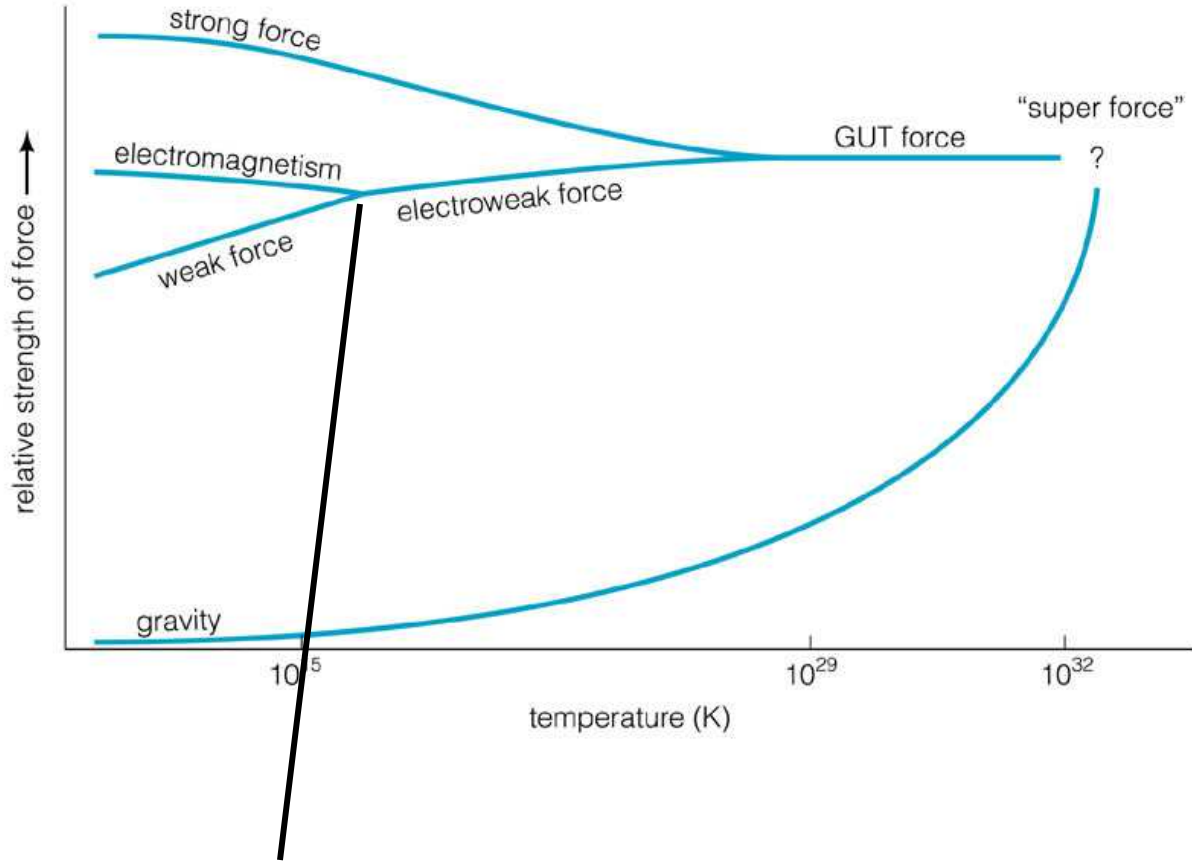

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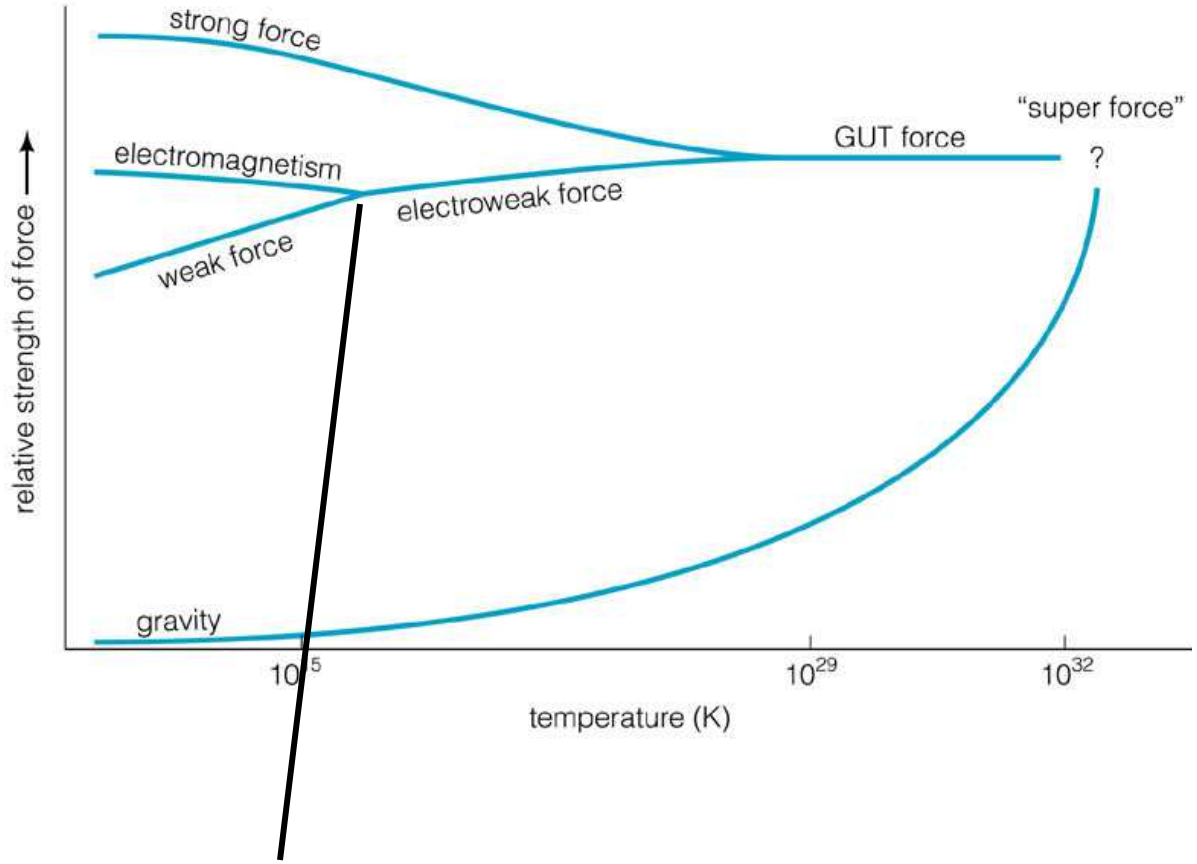

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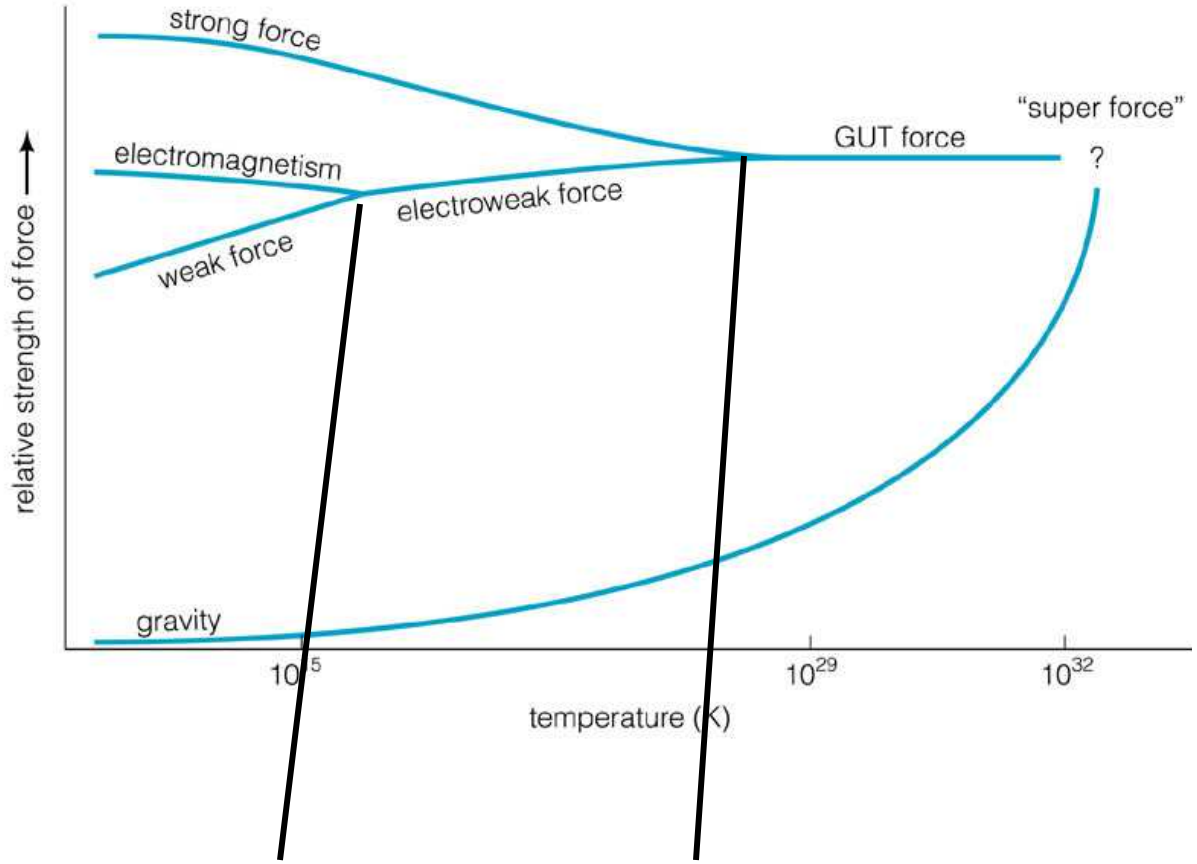

Yes!
(Electroweak)

Maybe
(GUT)

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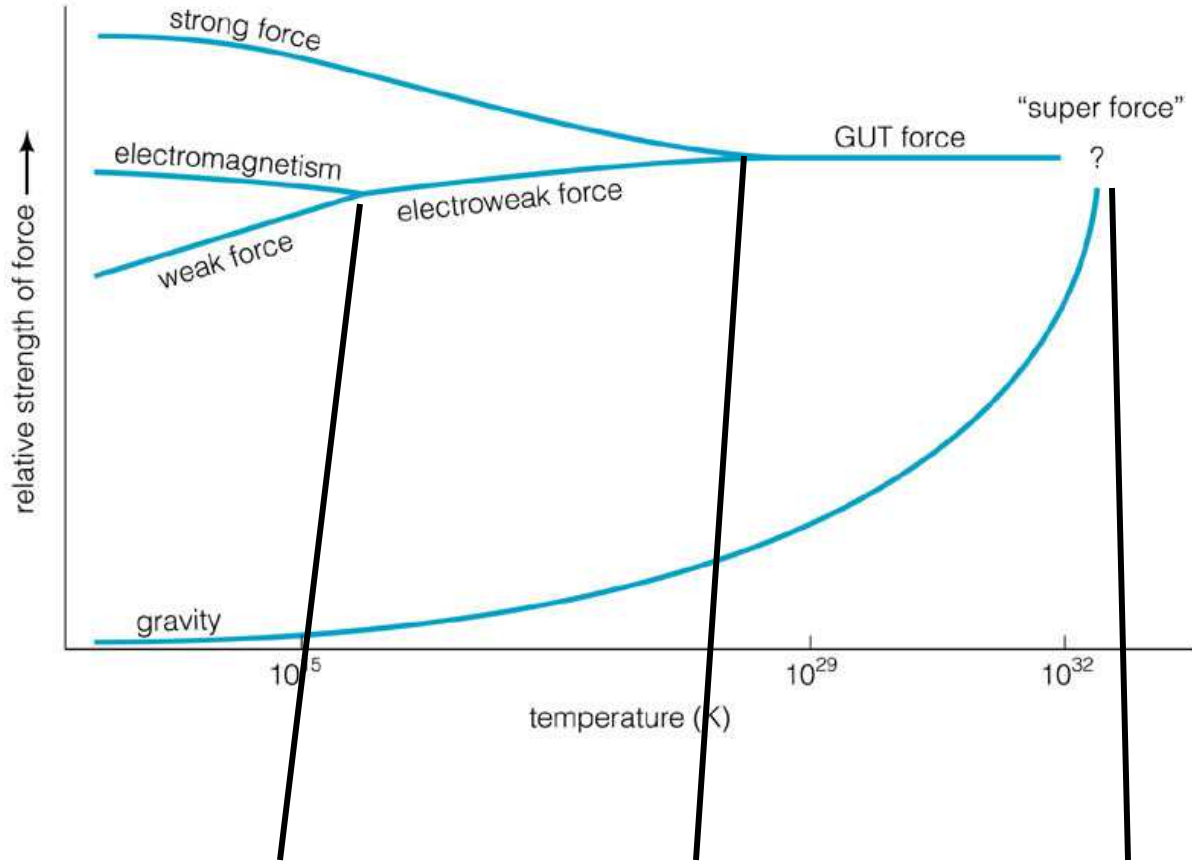

Yes!
(Electroweak)

Maybe
(GUT)

Who knows?
(String Theory)

Four known forces in universe:

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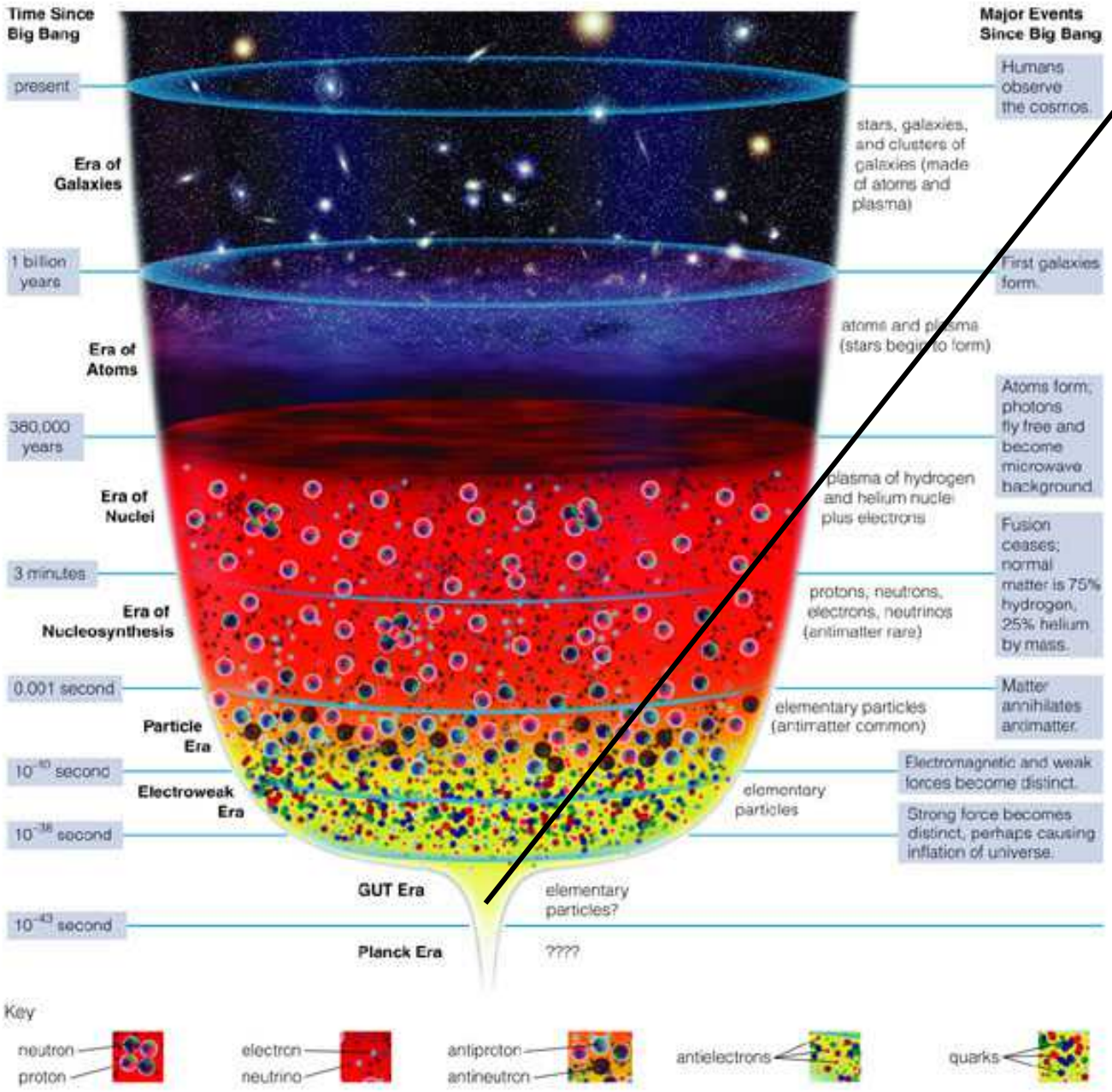
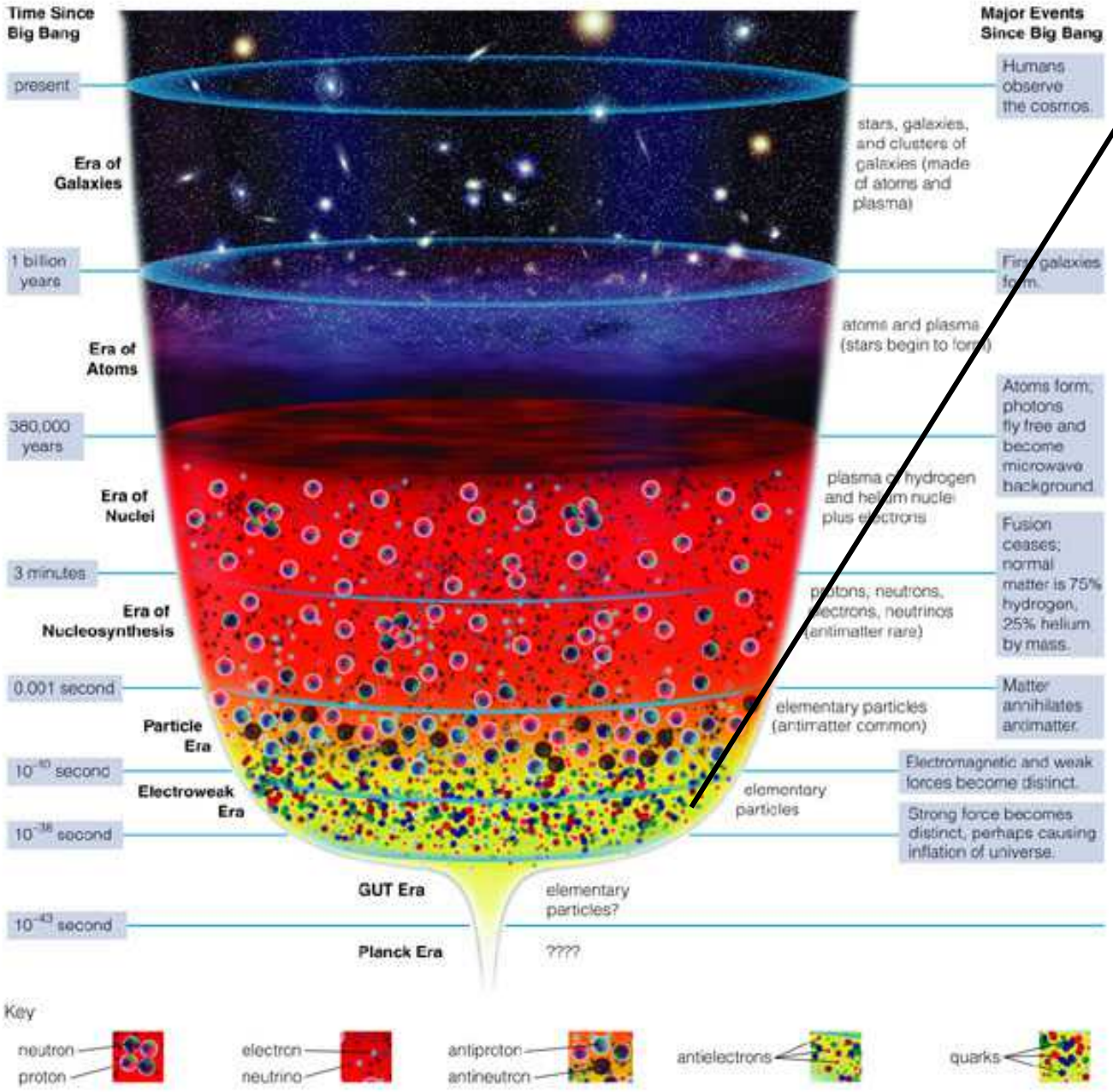


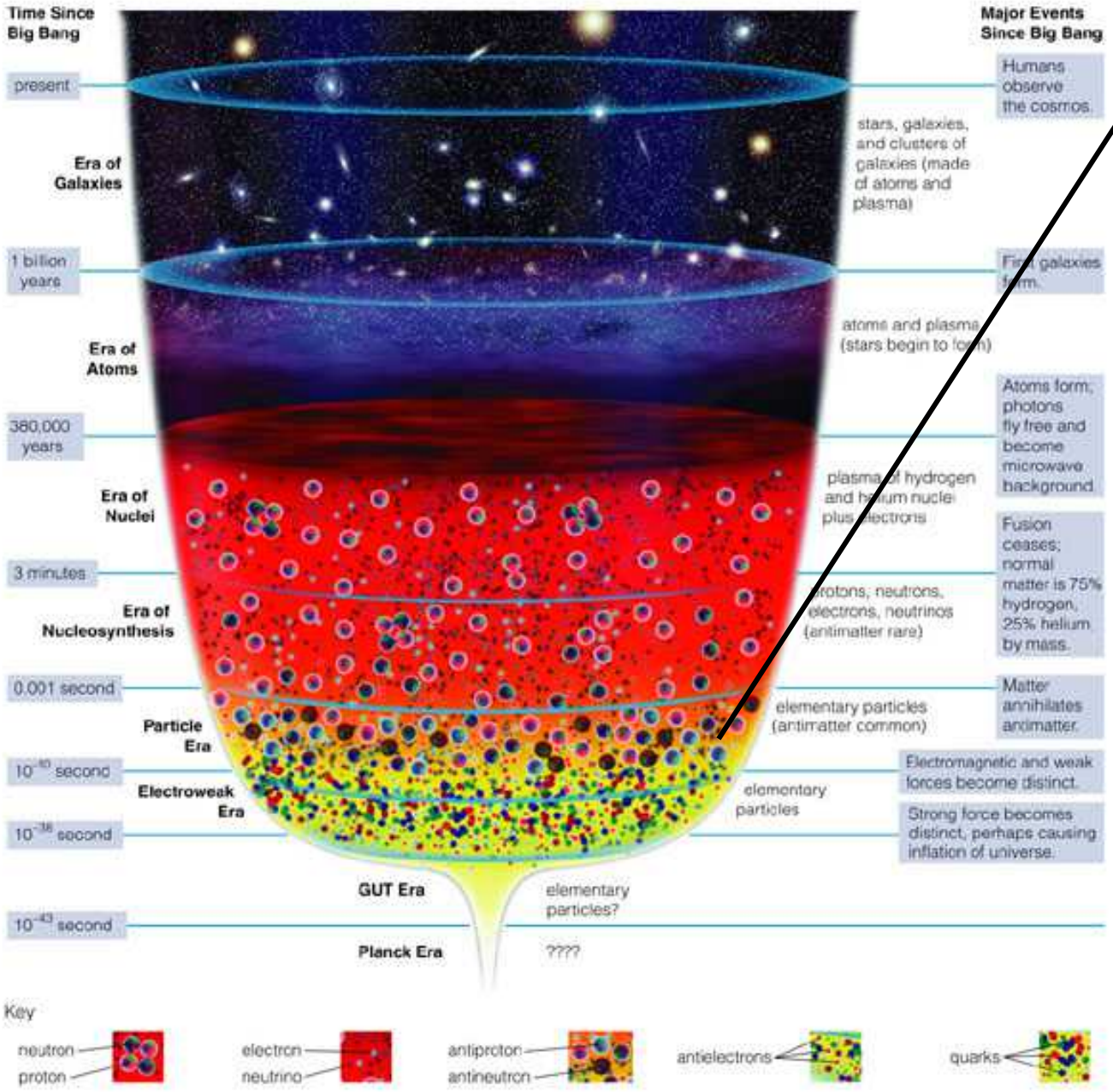
GUT Era

Lasts from Planck time (~10-43 sec) to end of GUT force (~10-38 sec)



Electroweak Era

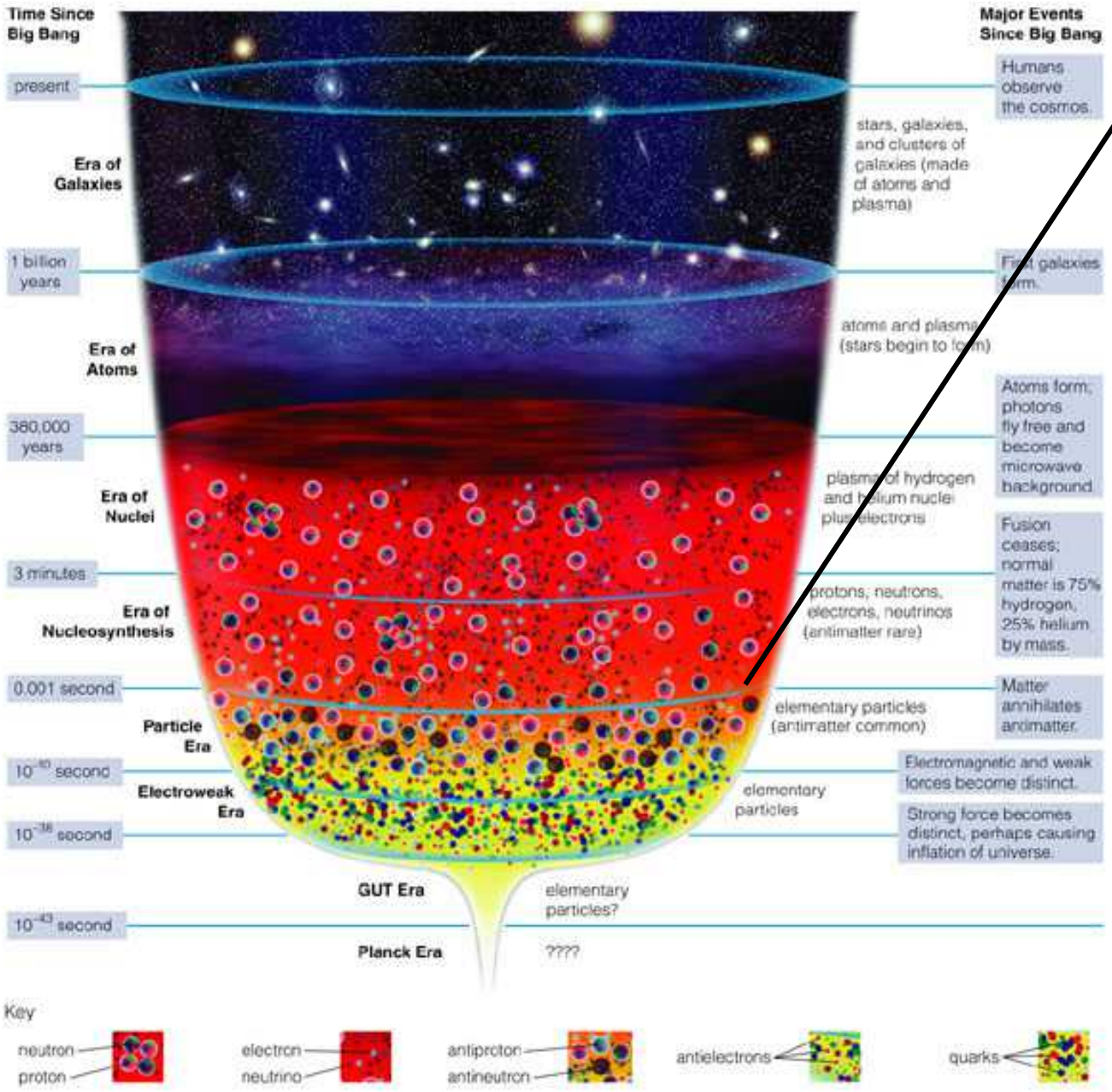
Lasts from end of GUT force (~10-38 sec) to end of electroweak force (~10-10 sec)



Particle Era

Amounts of matter and antimatter nearly equal

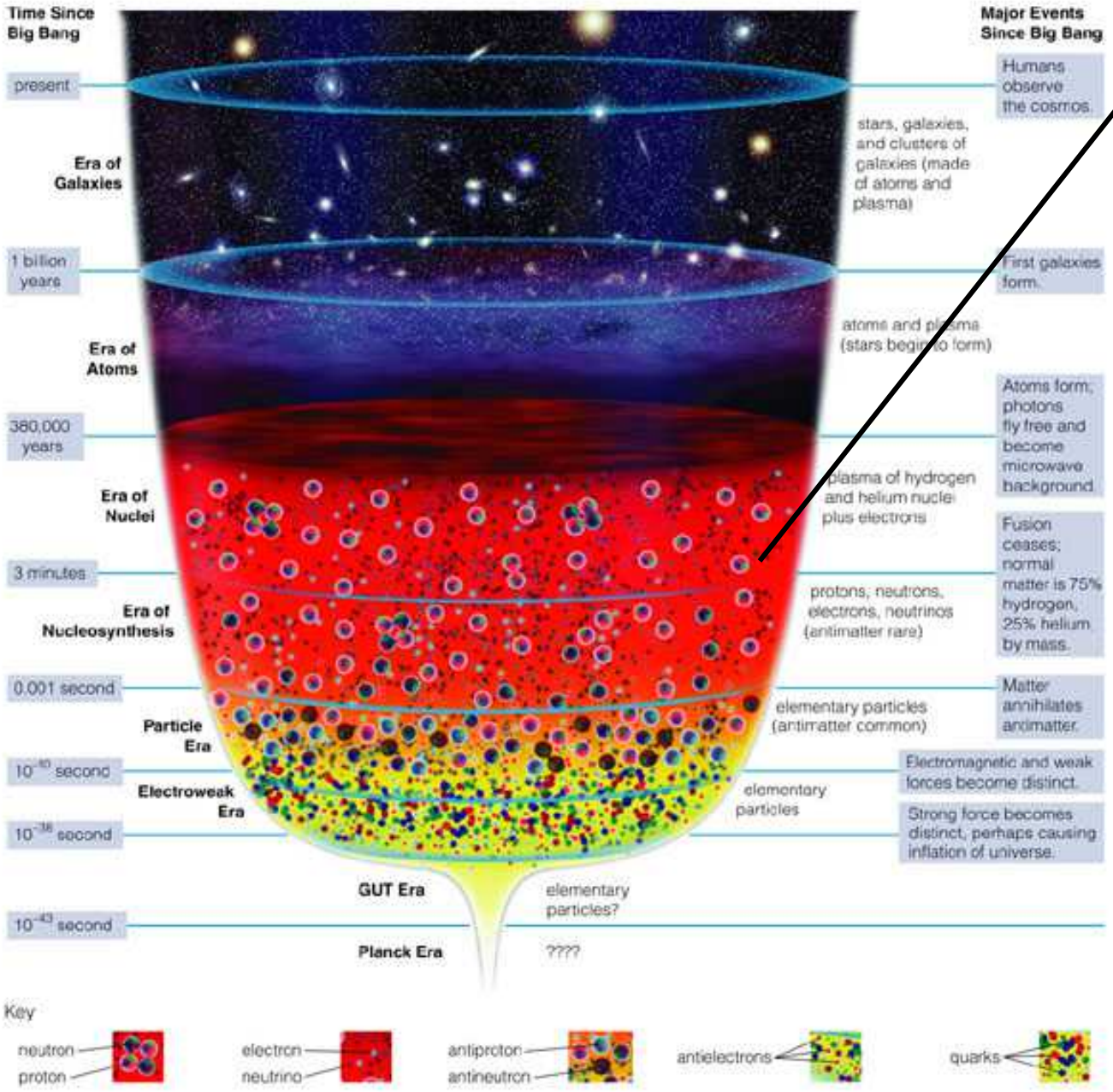
(Roughly 1 extra proton for every 109 proton-antiproton pairs!)



Era of Nucleo-synthesis

Begins when matter annihilates remaining antimatter at ~ 0.001 sec

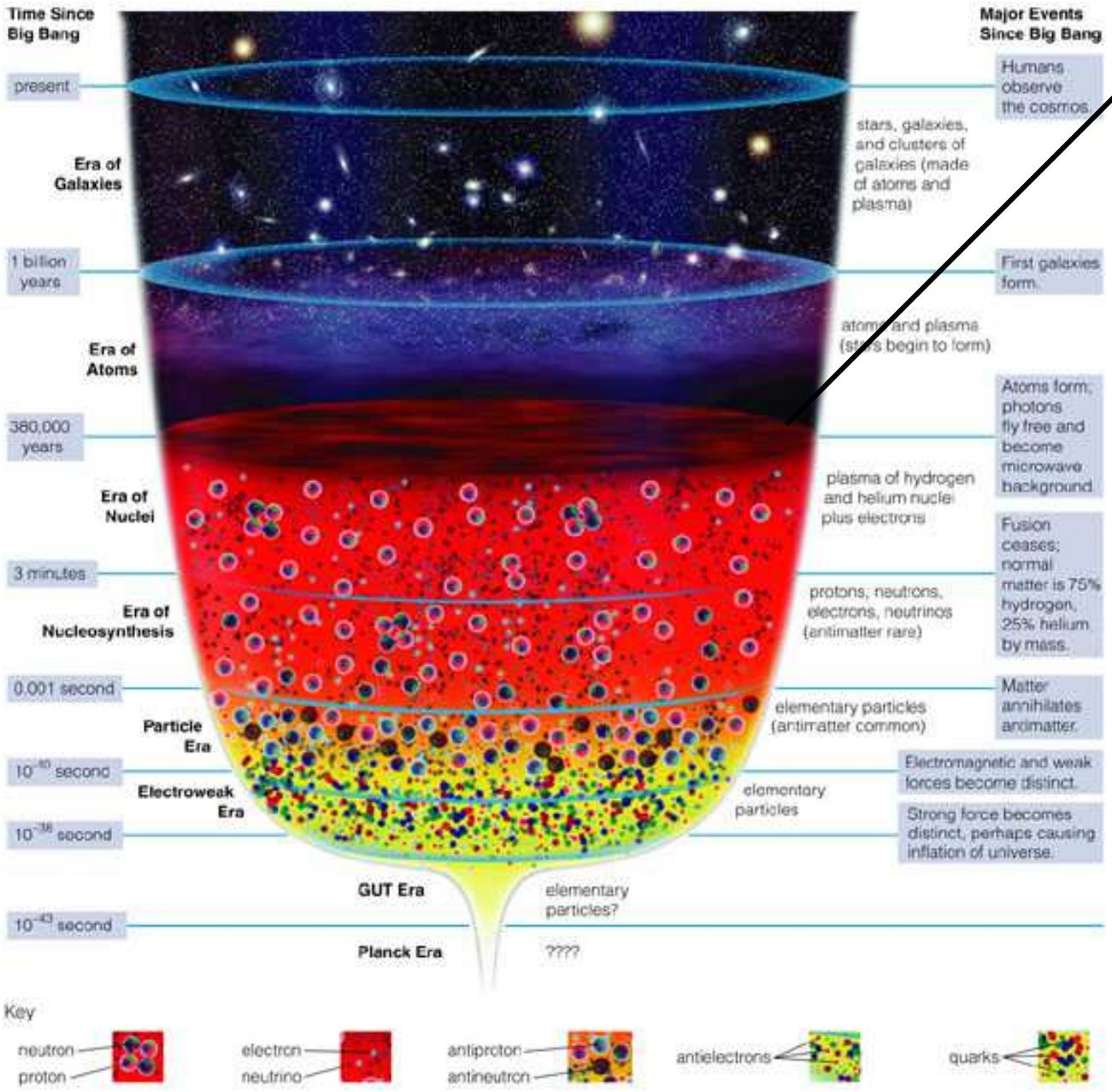
Nuclei begin to fuse



Era of Nuclei

Helium nuclei form at age ~ 3 minutes

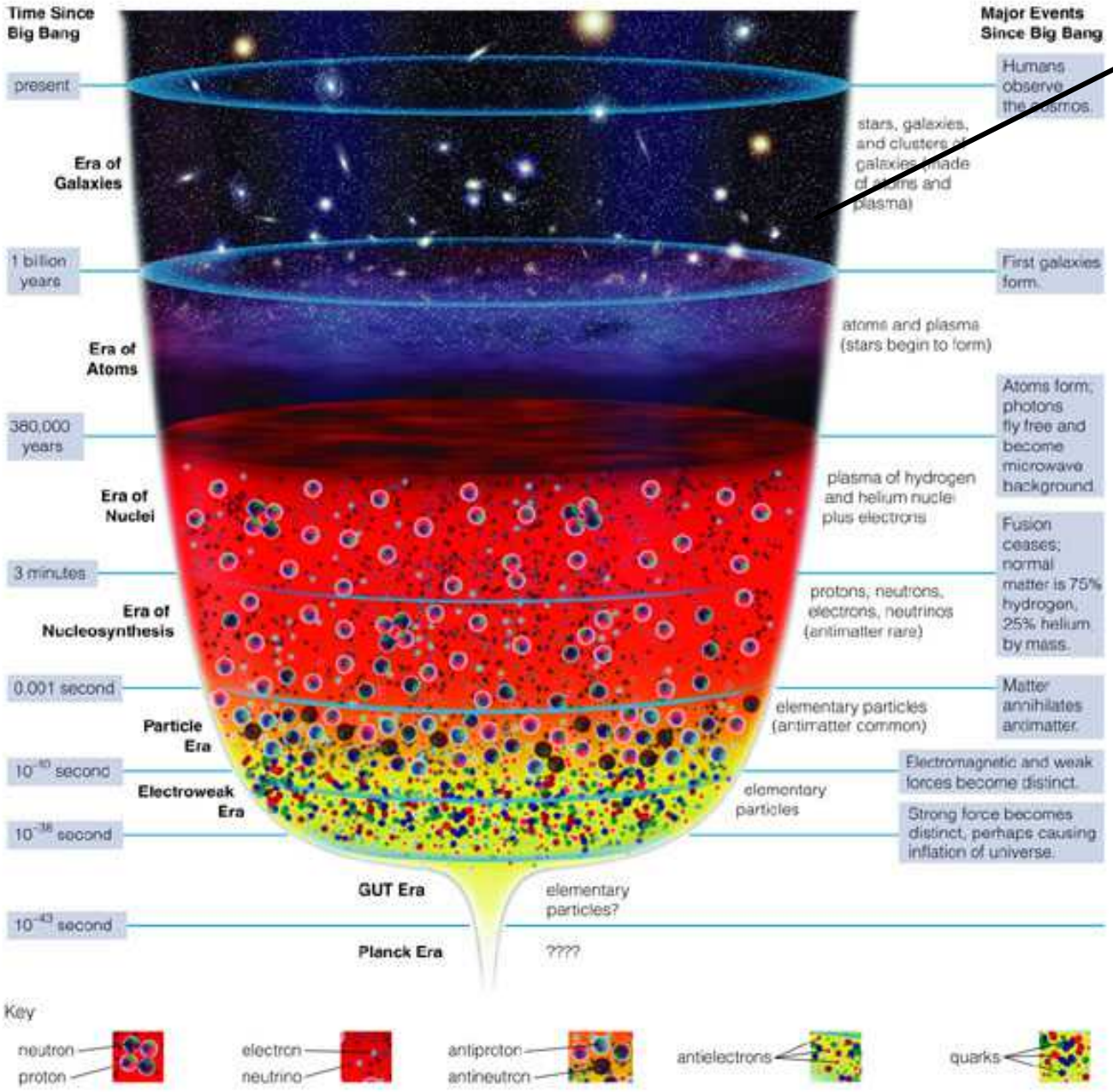
Universe has become too cool to blast helium apart



Era of Atoms

Atoms form at age of ~ 380,000 years

Background radiation released



Era of Galaxies

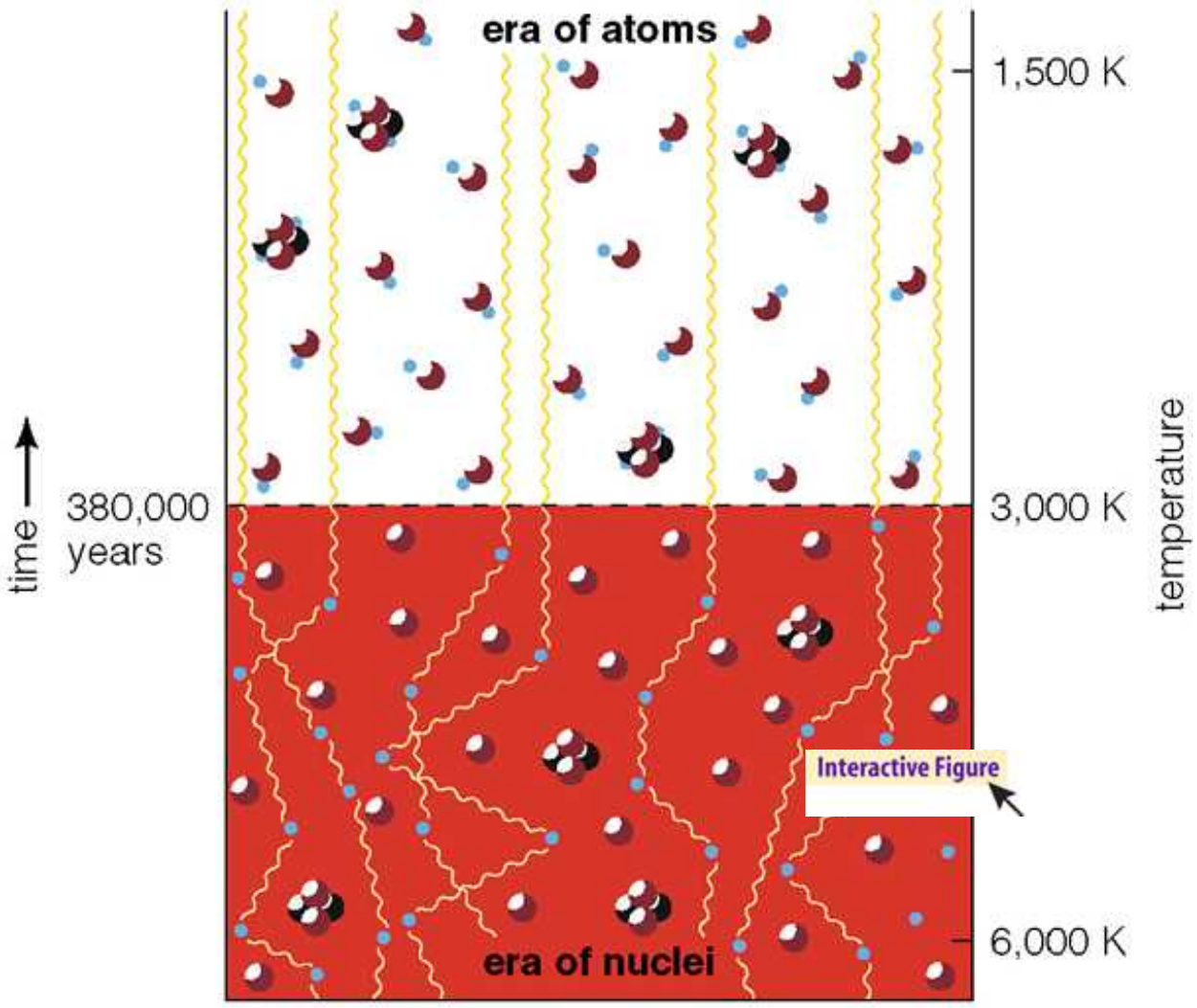
Galaxies form at age ~ 1 billion years

Primary Evidence

1) We have detected the leftover radiation from the Big Bang.

2) The Big Bang theory correctly predicts the abundance of helium and other light elements.

Evidence #1



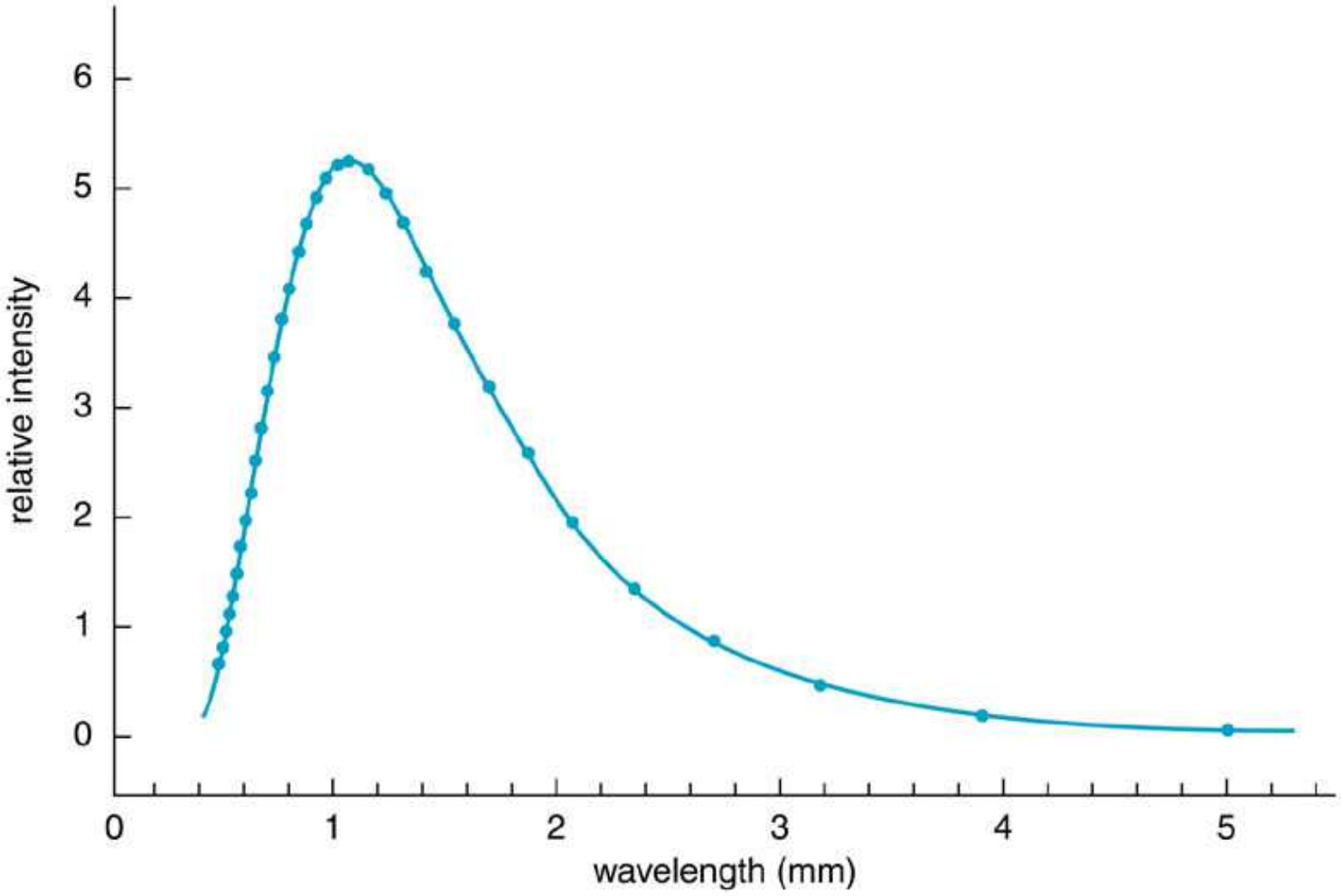
Background radiation from Big Bang has been freely streaming across universe since atoms formed at temperature ~ 3,000 K: *visible/IR*

The radiation left over from the Big Bang – how do we observe it?

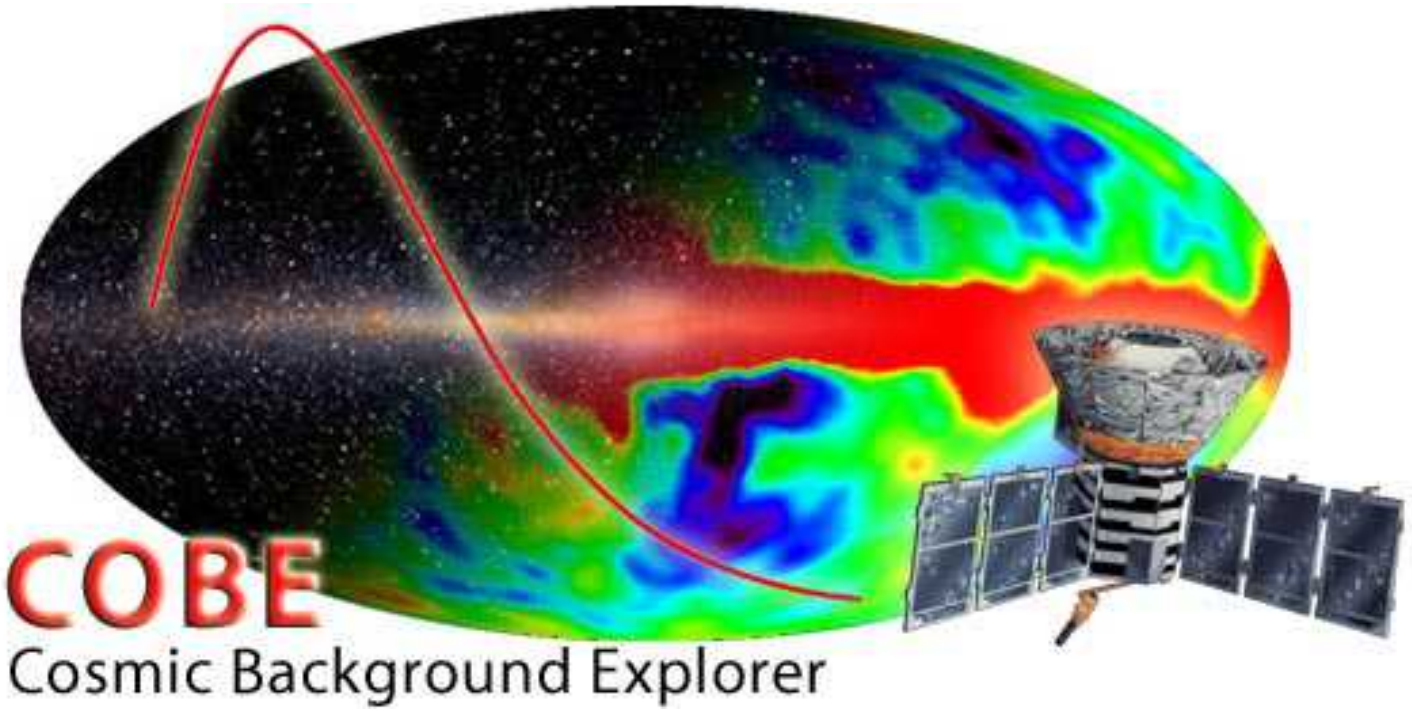
The ***cosmic microwave background*** – the radiation left over from the Big Bang – was detected by Penzias & Wilson in 1965 (they won the Nobel prize in 1978 for this discovery)

Bob Dicke and his Princeton group – which included Dave Wilkinson and Jim Peebles – were building a radiometer to look for the relic radiation from the early universe. Pensias and Wilson had already discovered it – but they didn't know what it was!!!

Bernie Burke at MIT (a radio astronomer) had heard the complaints of Pensias and Wilson and knew of Dicke's program. He suggested that Penzias contact Dicke… and the rest is history.



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



COBE detected the seeds of future structure formation

FIRAS Spectrum of CMB

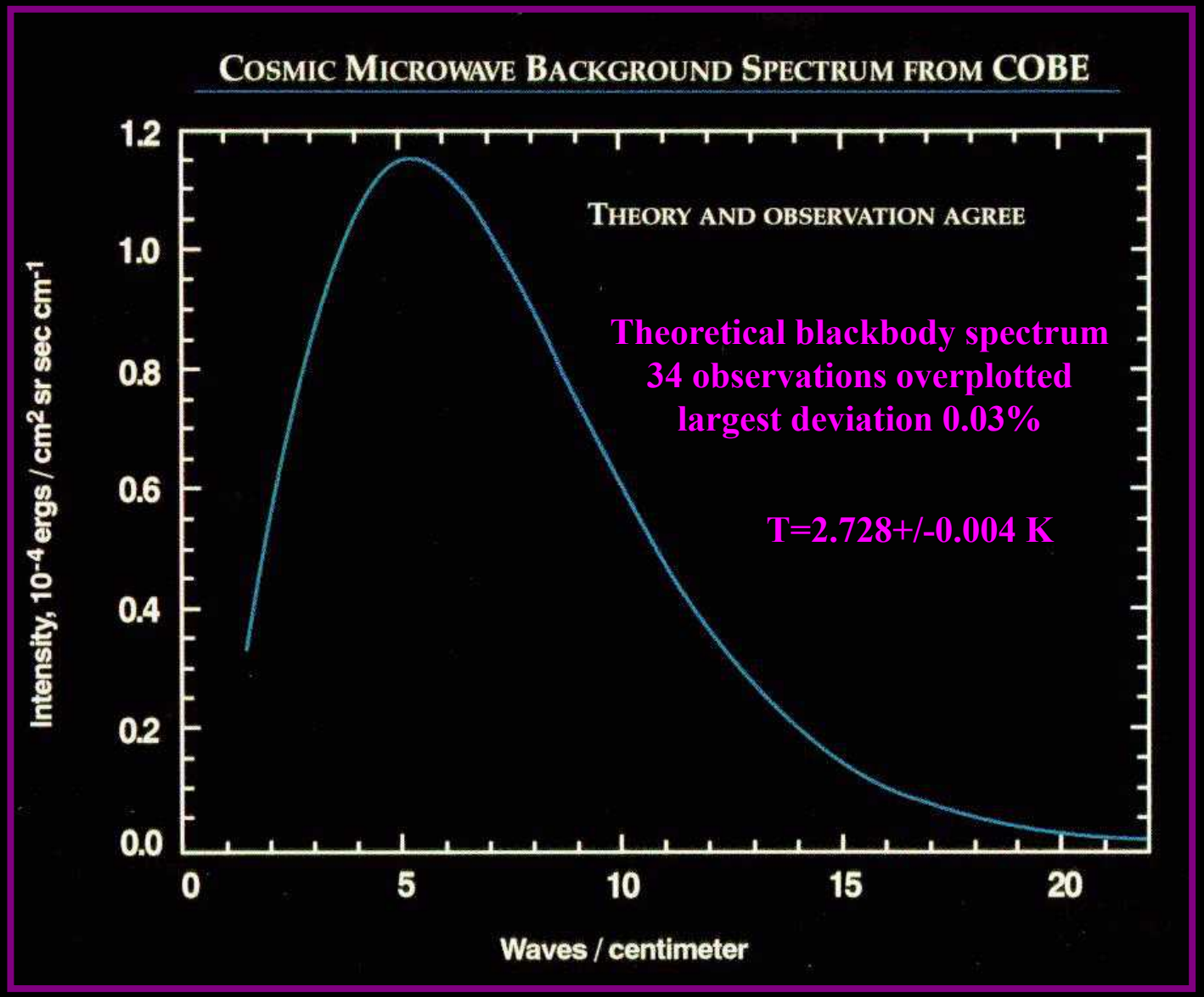
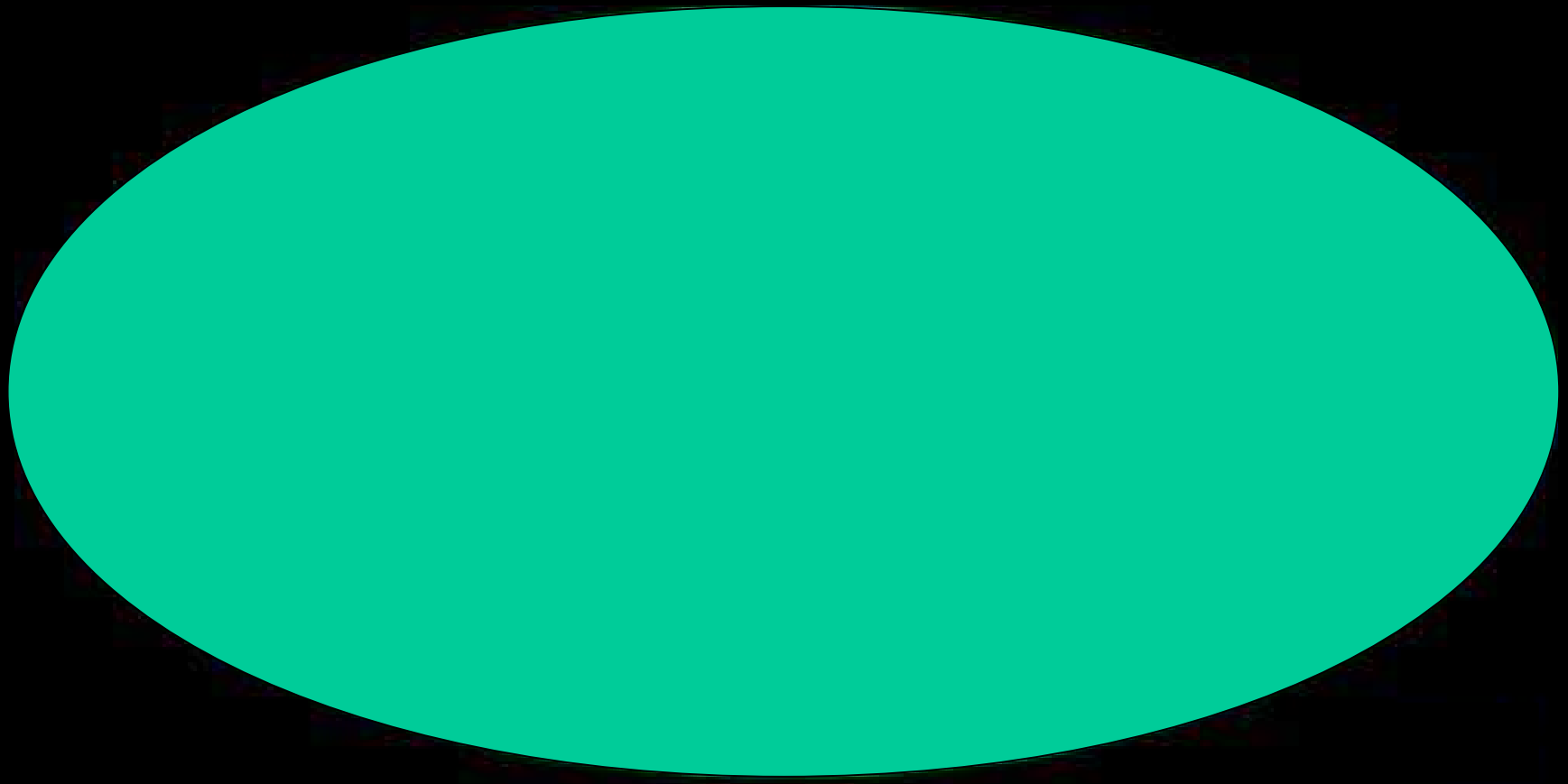
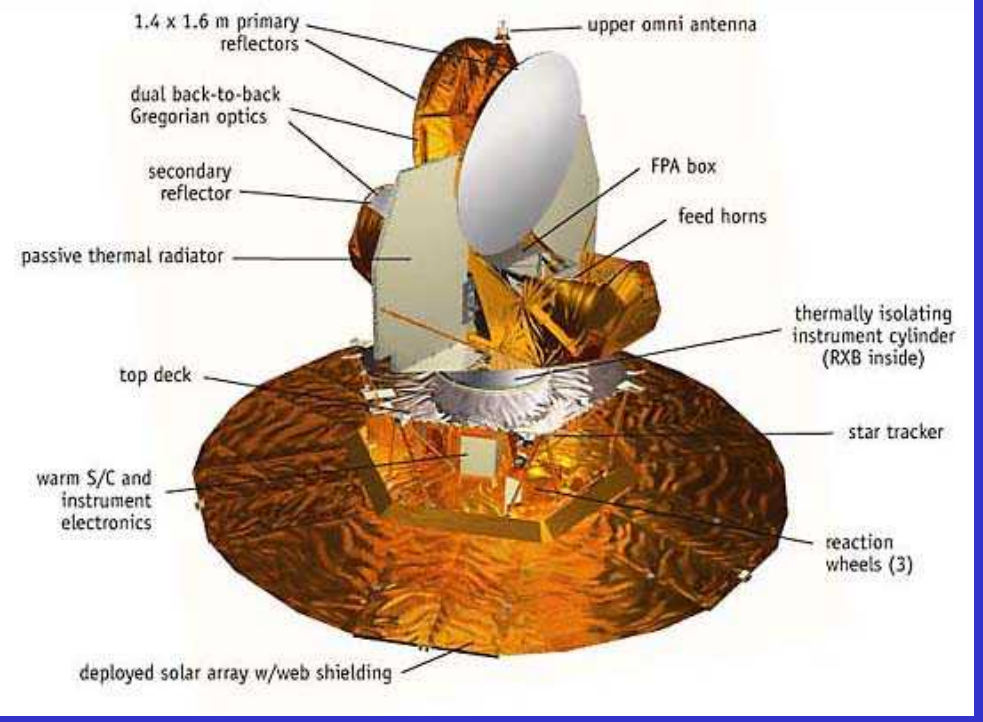


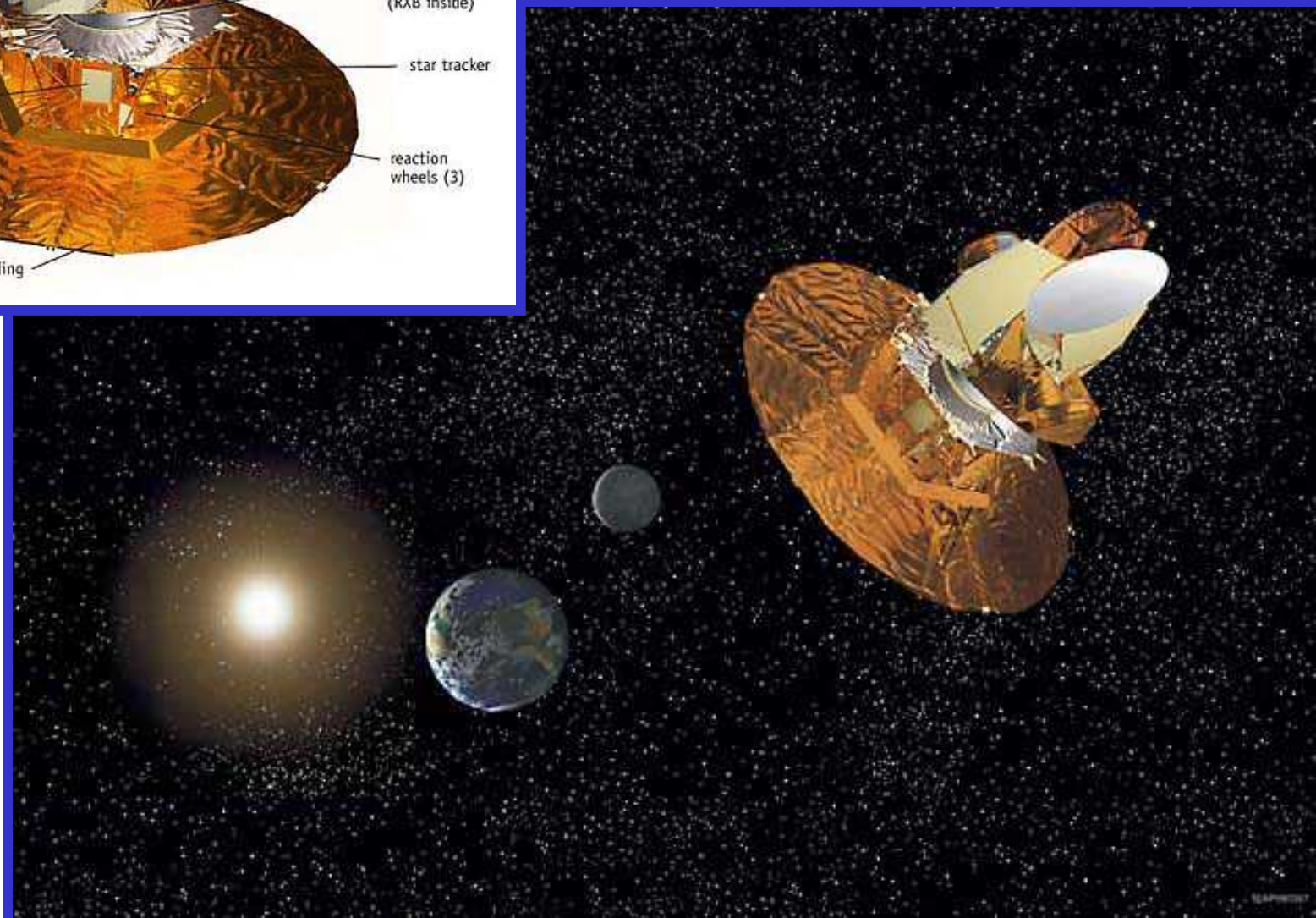
Image courtesy COBE homepage.

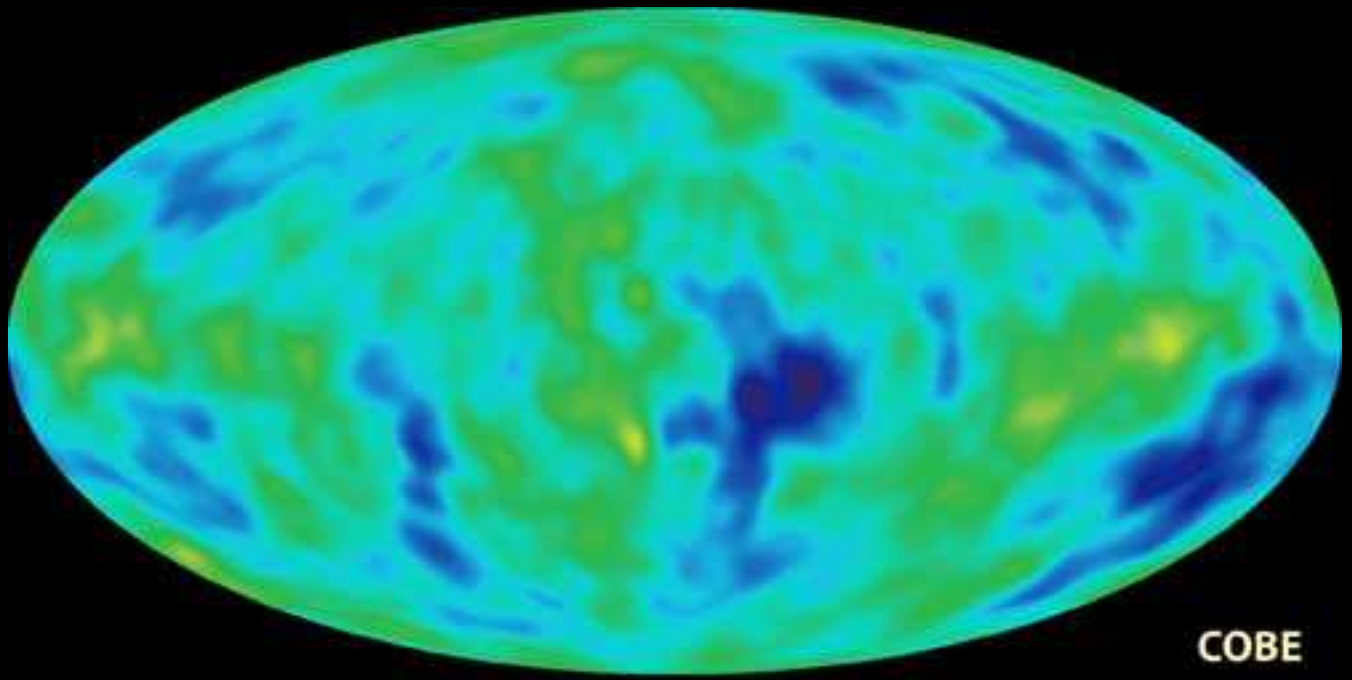


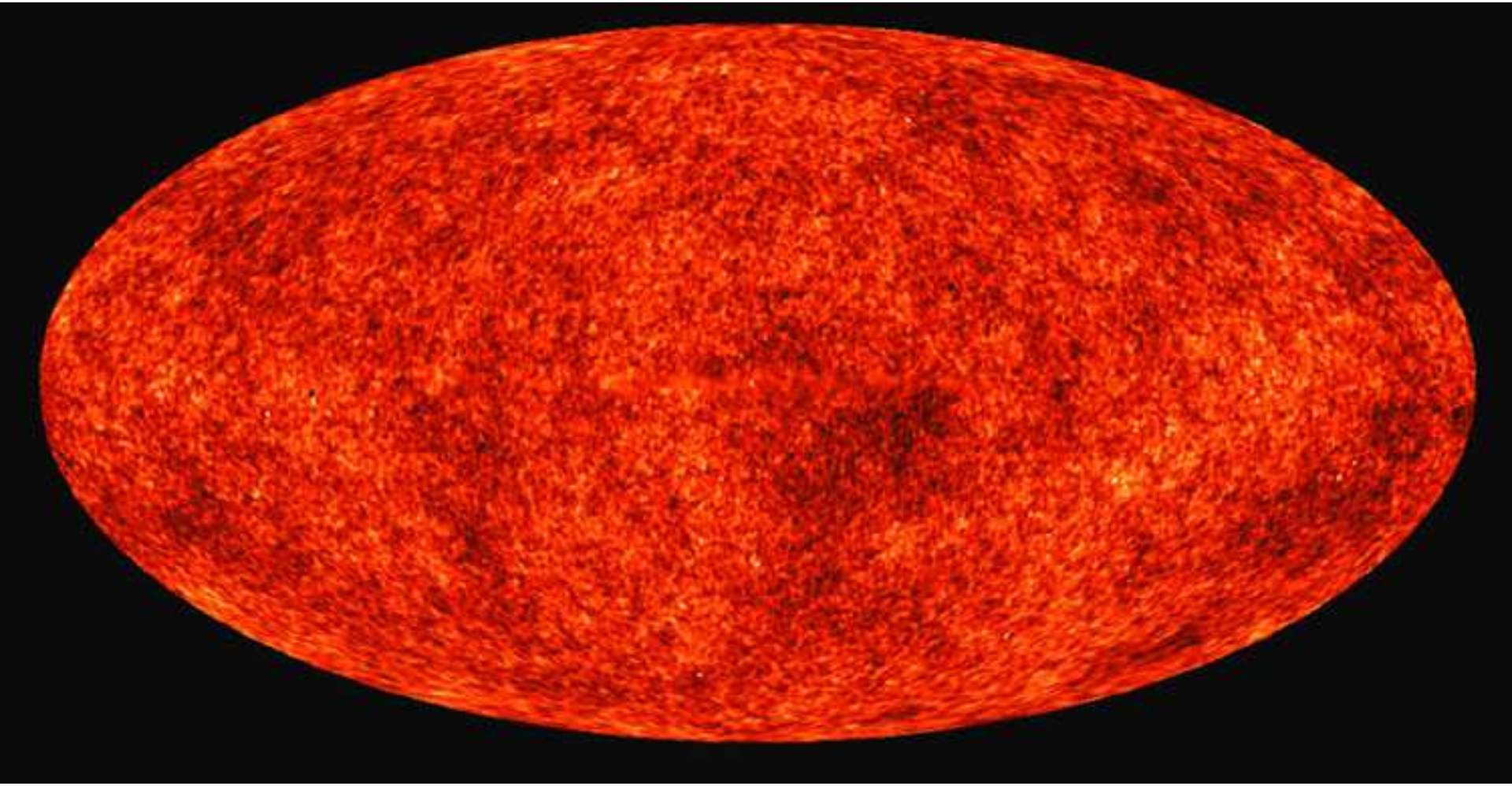
$\Delta T/T \sim 10^{-5}$

WMAP

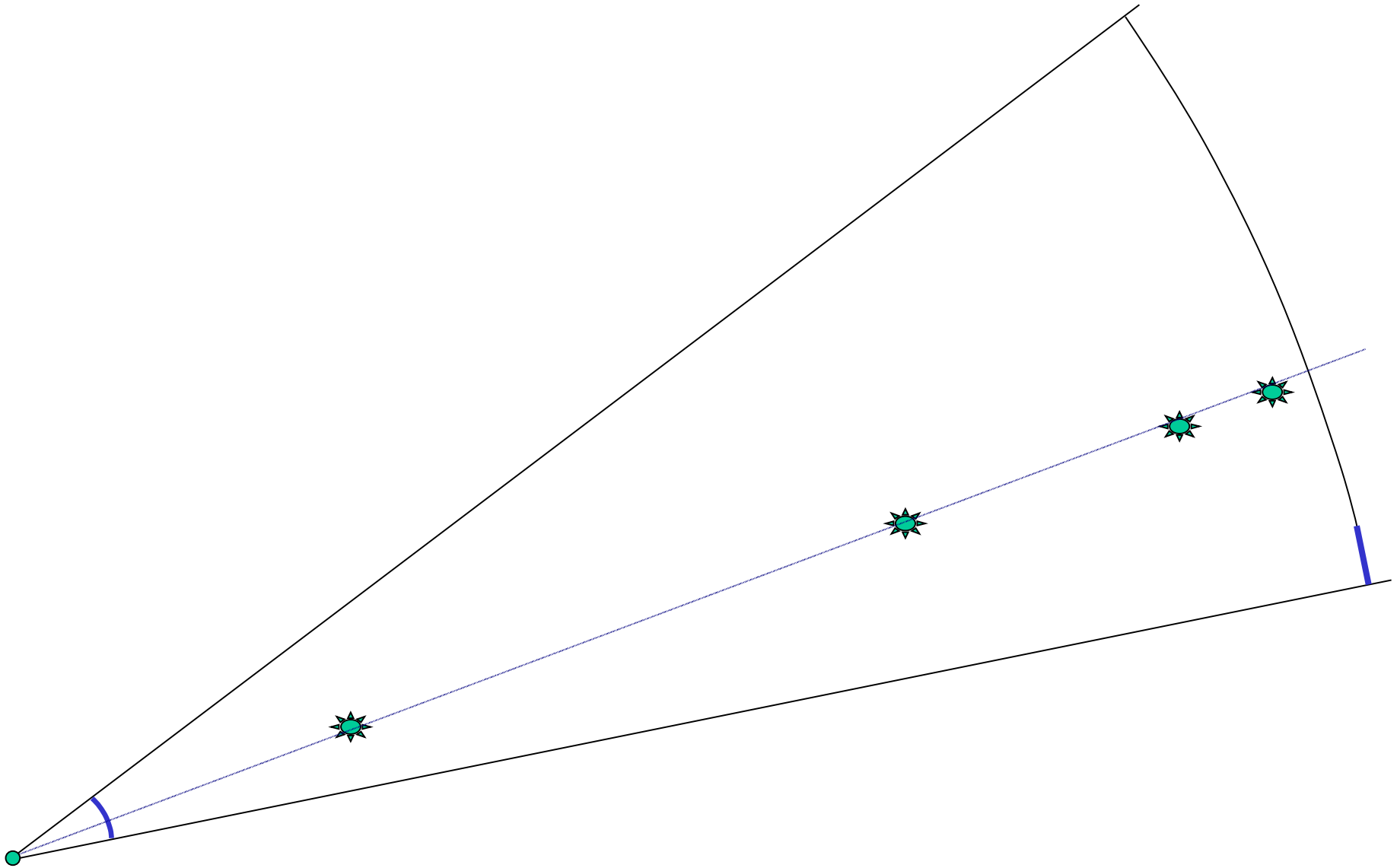

1.4 x 1.6 m primary reflectors
upper omni antenna
dual back-to-back Gregorian optics
secondary reflector
FPA box
feed horns
passive thermal radiator
thermally isolating instrument cylinder (RXB inside)
top deck
star tracker
warm S/C and instrument electronics
reaction wheels (3)
deployed solar array w/web shielding



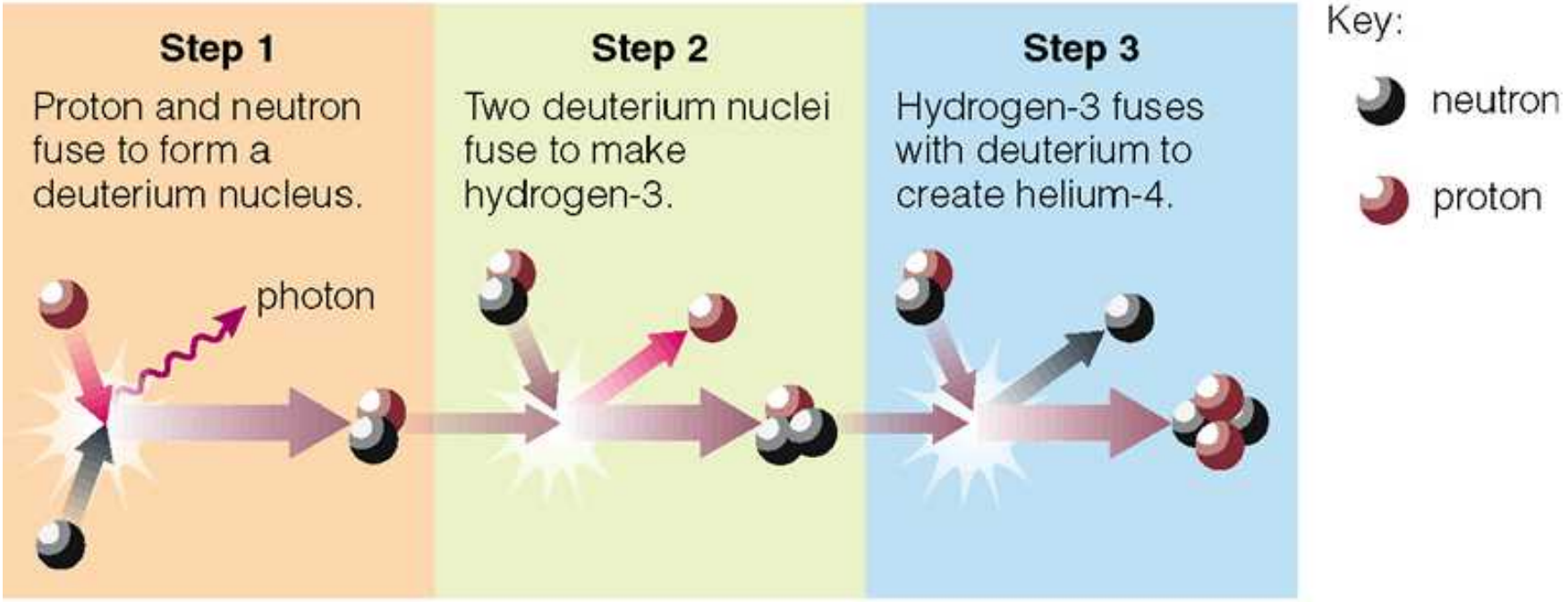

COBE



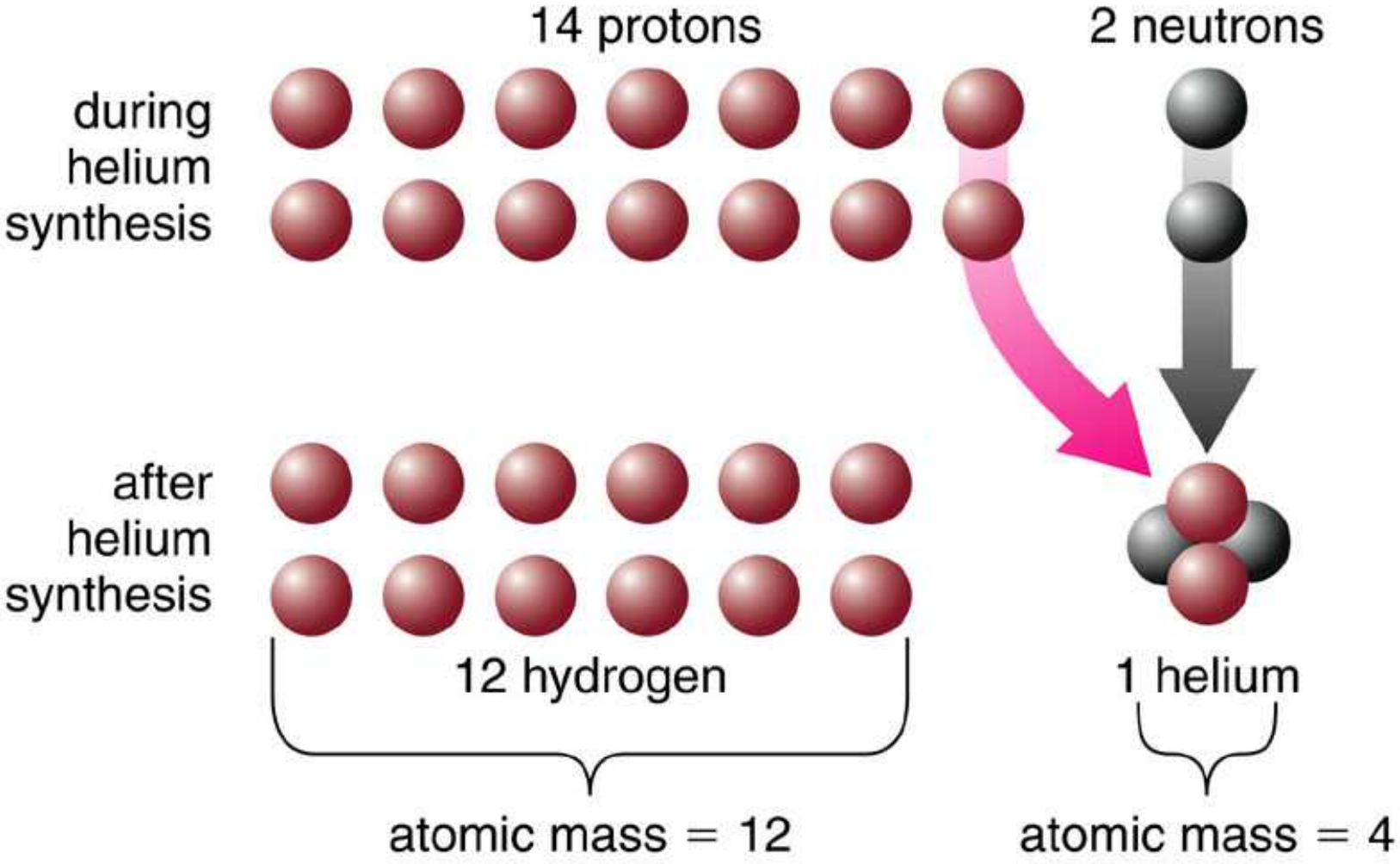
WMAP gives us detailed baby pictures of structure in the universe



EVIDENCE #2: How do the abundances of elements support the Big Bang?

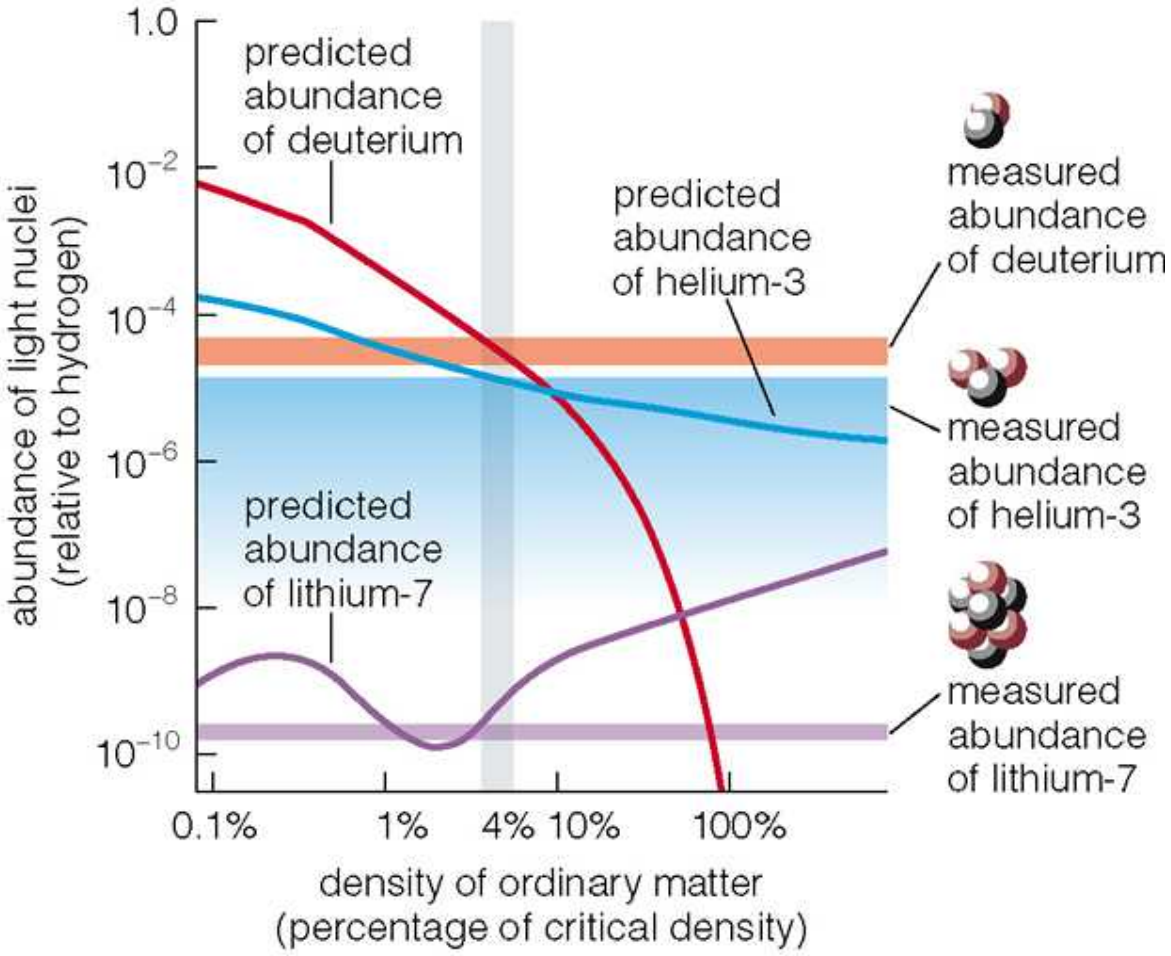


Protons and neutrons combined to make long-lasting helium nuclei when universe was ~ 3 minutes old



Big Bang theory prediction: 75% H, 25% He (by mass)

Matches observations of nearly primordial gases



Abundances of other light elements agree with Big Bang model having 4.4% normal matter – *more evidence for WIMPS!*

Mysteries Needing Explanation

1) Where does structure come from?

2) Why is the overall distribution of matter so uniform?

3) Why is the density of the universe so close to the critical density?

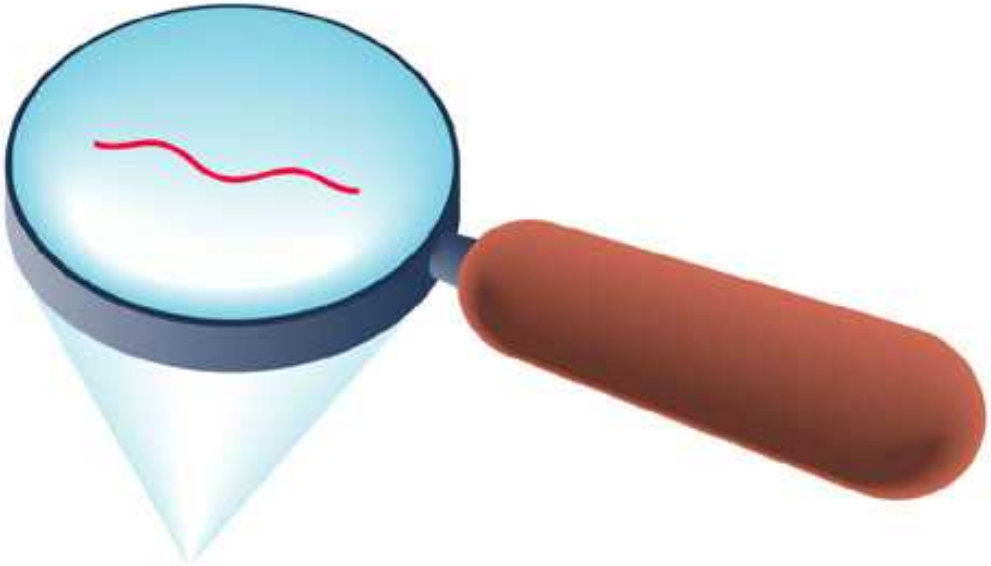
Mysteries Needing Explanation

1) Why is the overall distribution of matter so uniform?

2) Why is the density of the universe so close to the critical density?

An early episode of rapid inflation can solve these problems!

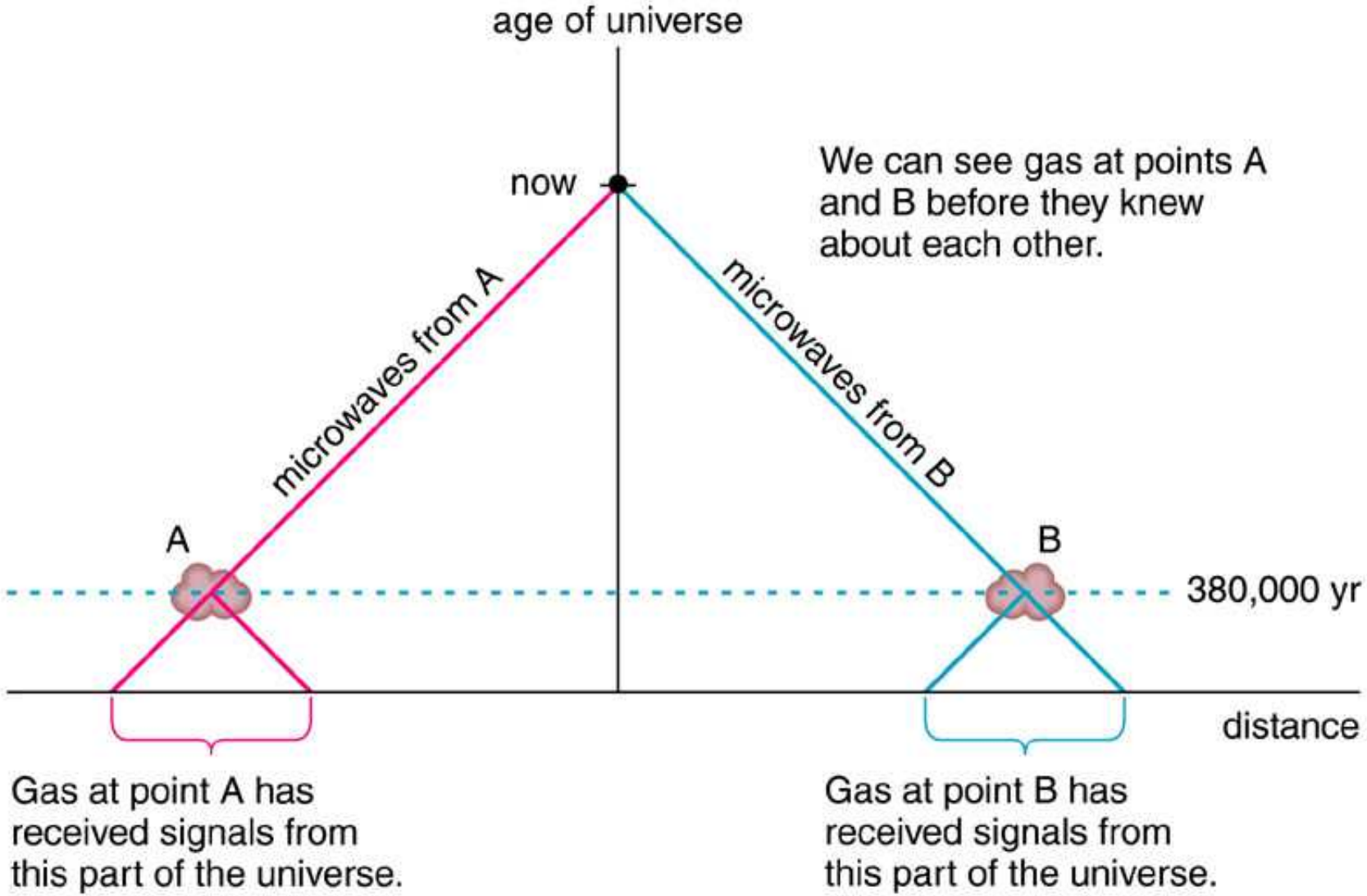
size of ripple before inflation = size of atomic nucleus



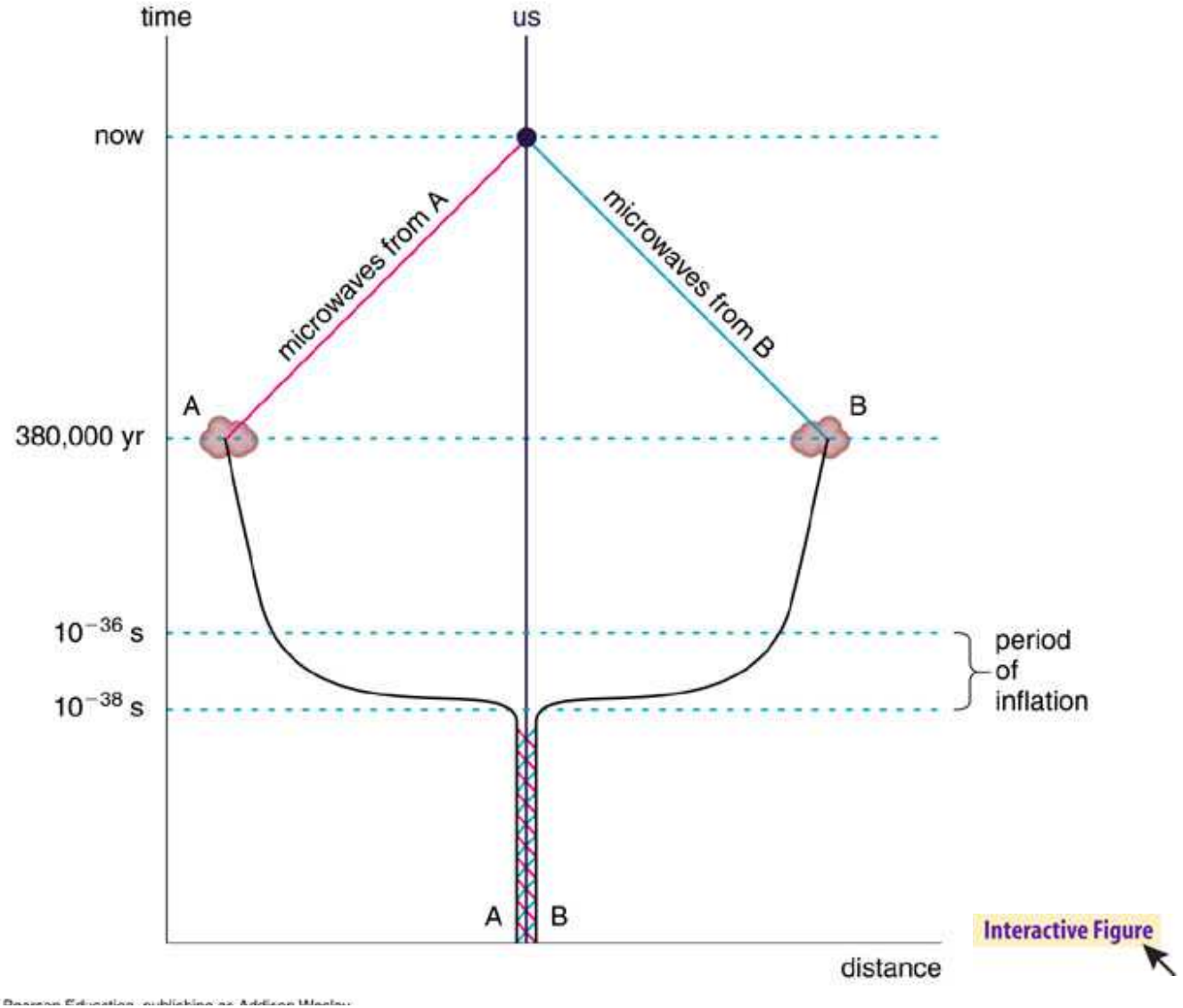
size of ripple after inflation = size of solar system

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

These ripples in density then become the seeds for all structures



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

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

What should you know?

- If there is no dark matter in the Milky Way Galaxy, what is one of the alternative explanation for the observations (mentioned in class) ?
- What might be causing the universe to accelerate?
- How long after the Big Bang was the Planck time, before which our current theories are completely unable to describe conditions in the universe?
- I observe a galaxy that is 100 million light years away and moving toward us: what do I see?
- Where do the photons in the cosmic background radiation originate?
- Approximately how long did the era of nucleosynthesis last?
- Why can't current theories describe what happened during the Planck era?
- What is Hubble's law?
- How many particles are required to explain the hundreds of particles found today?
- Currently, the distribution of galaxies in the universe appears to be?