# Astronomy 100
# Exploring the Universe
# Tuesday, Wednesday, Thursday


Tom Burbine

tomburbine@astro.umass.edu

# Mass-to-Light Ratio

- You can compare the measured mass to the luminosity of a galaxy

# Milky Way

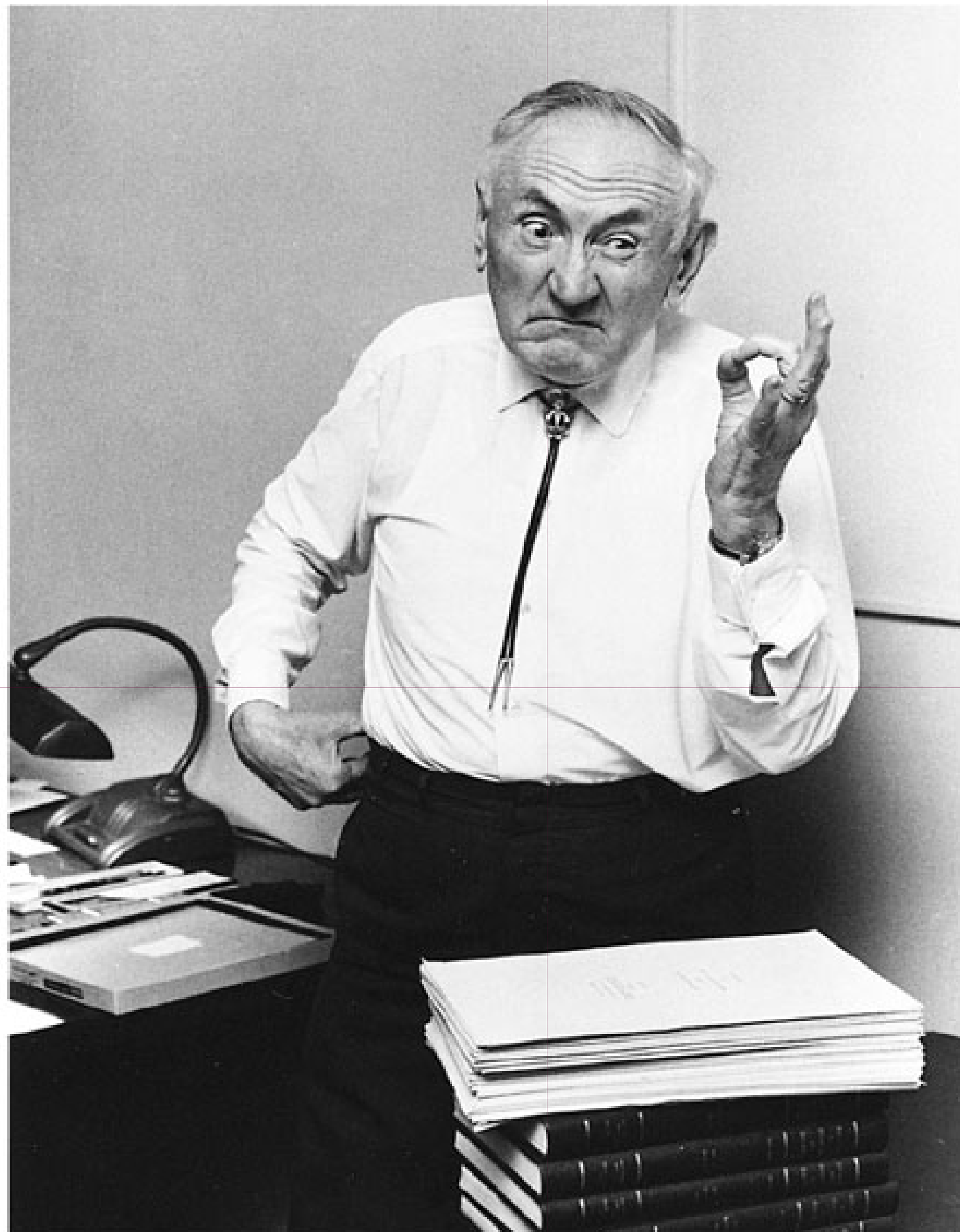
- Milky Way contains 90 billion solar masses of material within the Sun's orbit
- Luminosity of Milky Way at this orbit is 15 billion solar luminosities
- Mass-to-Light ratio of our Galaxy at this orbit is 6 solar masses per solar luminosities

# This tells us that …

- The value of 6 solar masses per solar luminosity tells us that most of the matter is dimmer than the Sun out to the Sun's orbit
- Mass-to-Light ratio of our Sun is 1 solar mass per solar luminosity
- So most matter is dimmer than the Sun

# For some ..

- For some galaxies, they have mass-to-light ratios of 50 solar masses to solar luminosity
- This is too high to be accounted for by stars alone



# Fritz Zwicky (1898-1974)

- Was among the first to suggest that there is a relationship between supernovae and neutron stars
- Suggested in the 1930s that dark matter was found in Galactic Clusters

# Cluster

- Cluster is a collection of galaxies (that can number dozens to thousands) that are gravitationally bound

# Zwicky

- By calculating the speed of galaxies as the rotate around in a cluster
- He found that galaxies in the clusters had huge mass-to-light ratios

# Types of Dark Matter

- MACHOs
- WIMPS

# MACHOs

- Massive Compact Halo Objects
- Includes
  - Brown Dwarfs – failed stars
  - Faint red stars
  - Jupiter-sized objects

# WIMPs

- Weakly interacting massive particles
  - No electrical charge
  - Do not emit electromagnetic radiation
  - Have mass so do interact some with matter

# Neutrinos

- Dark matter in galaxies can’t be neutrinos because neutrinos escape from galaxies with enormous speeds

# WIMPS

- Have to have masses larger than neutrinos
- Have not been discovered yet

# Dark Energy

- Gravity should be slowing the expansion of the universe down
- However the universe appears to be accelerating
- Dark Energy is the name for what is causing the expansion to accelerate

- http://www.nasa.gov/centers/marshall/mov/100452main_accel_expanding_univ_sm.mov

- Two teams of astronomers were looking for distant type Ia supernovae in order to measure the expansion rate of the universe with time.
- They expected that the expansion would be slowing (due to gravity) which would be indicated by the supernovae being brighter than their redshifts would indicate.
- Instead, they found the supernovae to be fainter than expected.
- The universe appears to be expanding

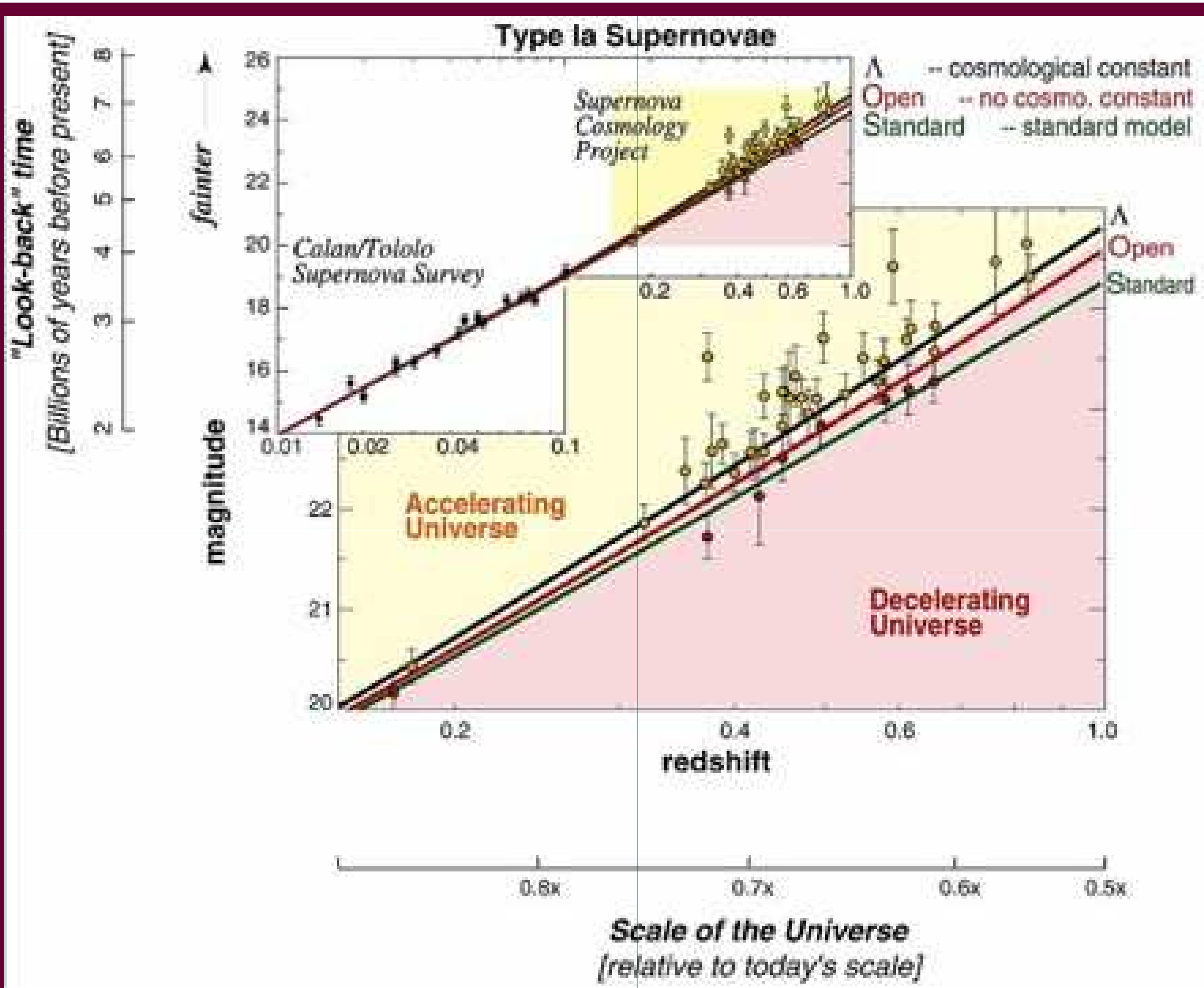
# Supernova Ia

- Are exploding white dwarfs
- Have the same masses when they explode
- Have the same peak luminosities
- These supernovas are bright enough to be seen in far-away galaxies

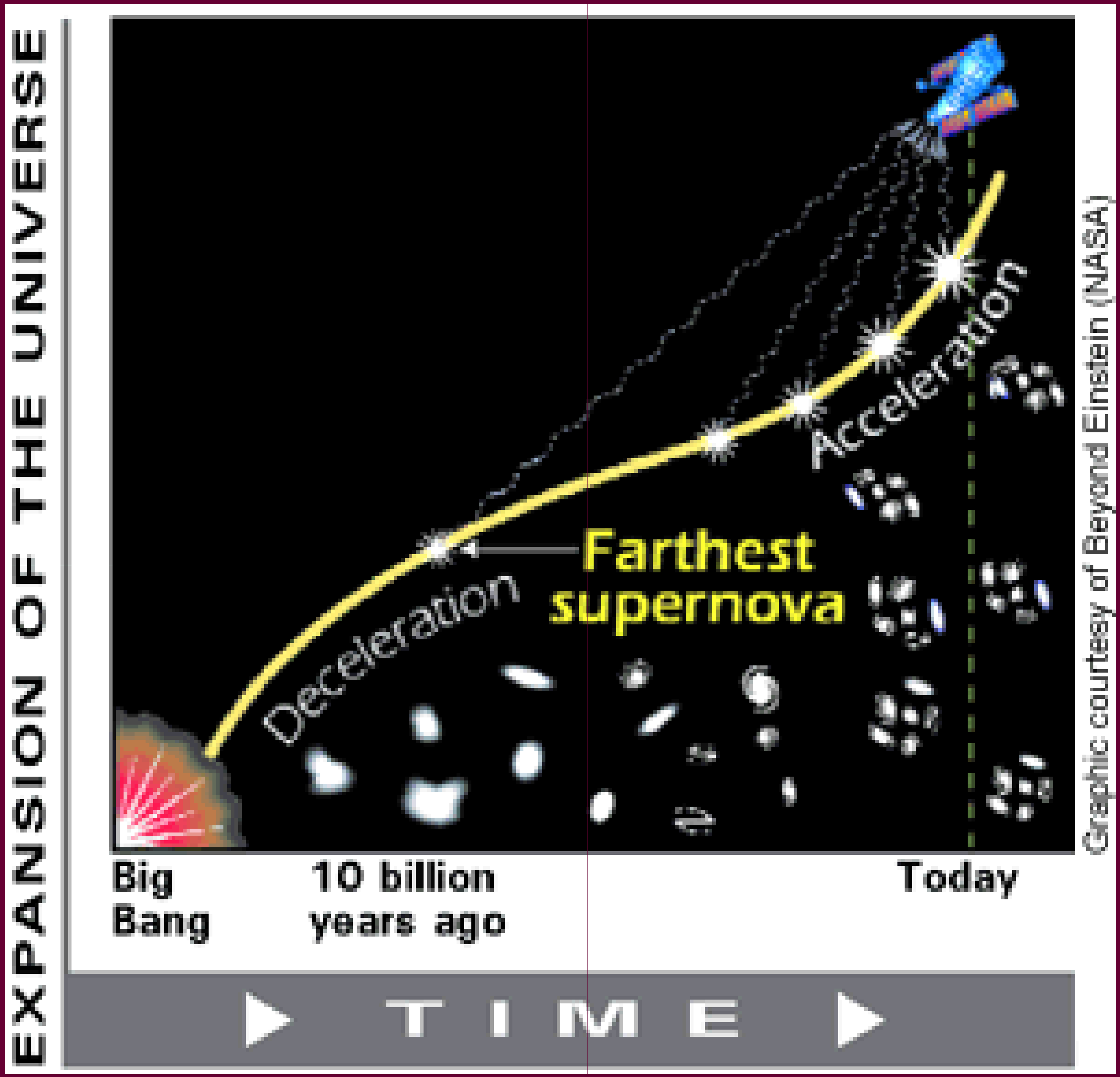
- Measuring the brightness of Supernova Ia's allows you to calculate the distance to the Supernova
- Measuring the Doppler Shift of the spectral lines of the Supernova allows you to calculate the speed the object is moving away

# Supernova Ia

- The ones with the highest redshifts were dimmer than expected
- That means they were farther away than expected
- Something had caused the universe to expand faster than expected




*http://www.jyi.org/articleimages/1182/originals/img0.jpg*




*http://www.fnal.gov/pub/ferminews/ferminews04-01-01/expansionOfUniverse.gif*

- You would expect gravity to cause the universe to stop expanding and start decelerating
- It appears the universe is accelerating

# Olber's paradox

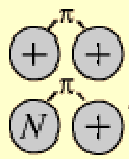
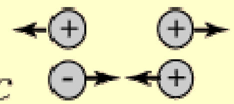
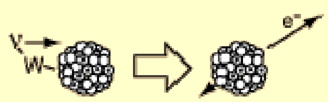
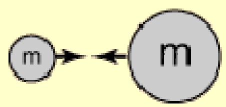
- How can the night sky be dark if the universe is infinite and full of stars?

# Answer?

- We can only see a finite number of stars
- Looks like the Big Bang theory works:
- The universe began at a particular time

# 4 Forces that operate in the universe

- Gravity
- Electromagnetism
- Strong Force
- Weak Force

| Force | Diagram | Strength | Range (m) | Particle |
|---|---|---|---|---|
| *Strong* |   Force which holds nucleus togeher | 1 | $10^{-15}$ (diameter of a medium sized nucleus) | gluons, π(nucleons) |
| *Electro-magnetic* |  | $\frac{1}{137}$ | Infinite | photon<br>mass = 0<br>spin = 1 |
| *Weak* |   neutrino interaction induces beta decay | $10^{-6}$ | $10^{-18}$ (0.1% of the diameter of a proton) | Intermediate vector bosons<br>$W^+$, $W^-$, $Z_0$,<br>mass > 80 GeV<br>spin =1 |
| *Gravity* |   | $6 \times 10^{-39}$ | Infinite | graviton ?<br>mass = 0<br>spin = 2 |

# Gravity

- Massive particles interact with other massive particles
- Acts on big distances

# Electromagnetism

- Charged particles act with other charged particles
- Act on small distances

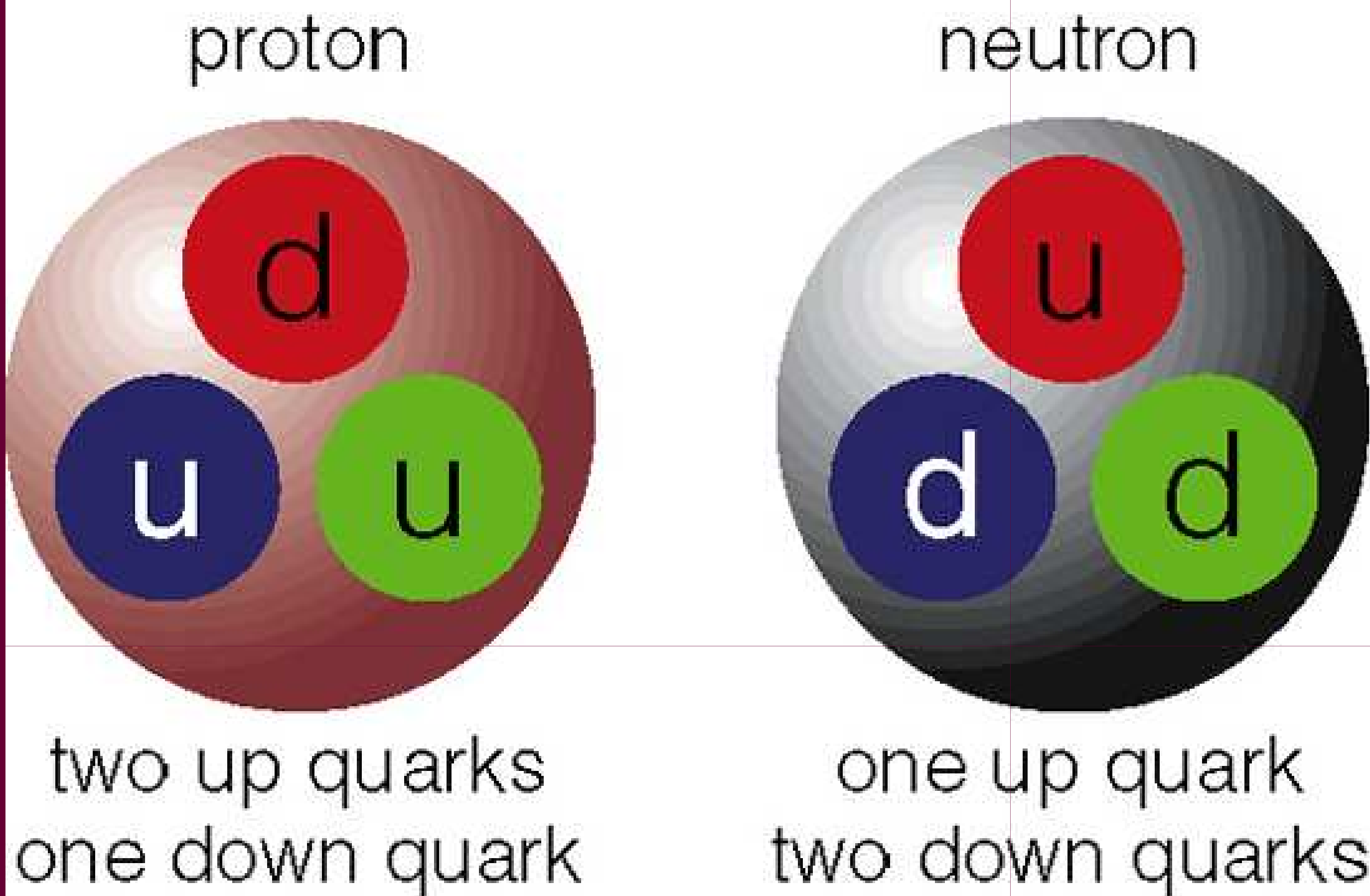
# Strong Force

- Force that holds atomic nuclei together
- Keeps protons together in a nucleus
- Protons would fly apart
- Occurs over very small distances like diameters of nuclei

*These two types of particles are the two basic constituents of matter.*

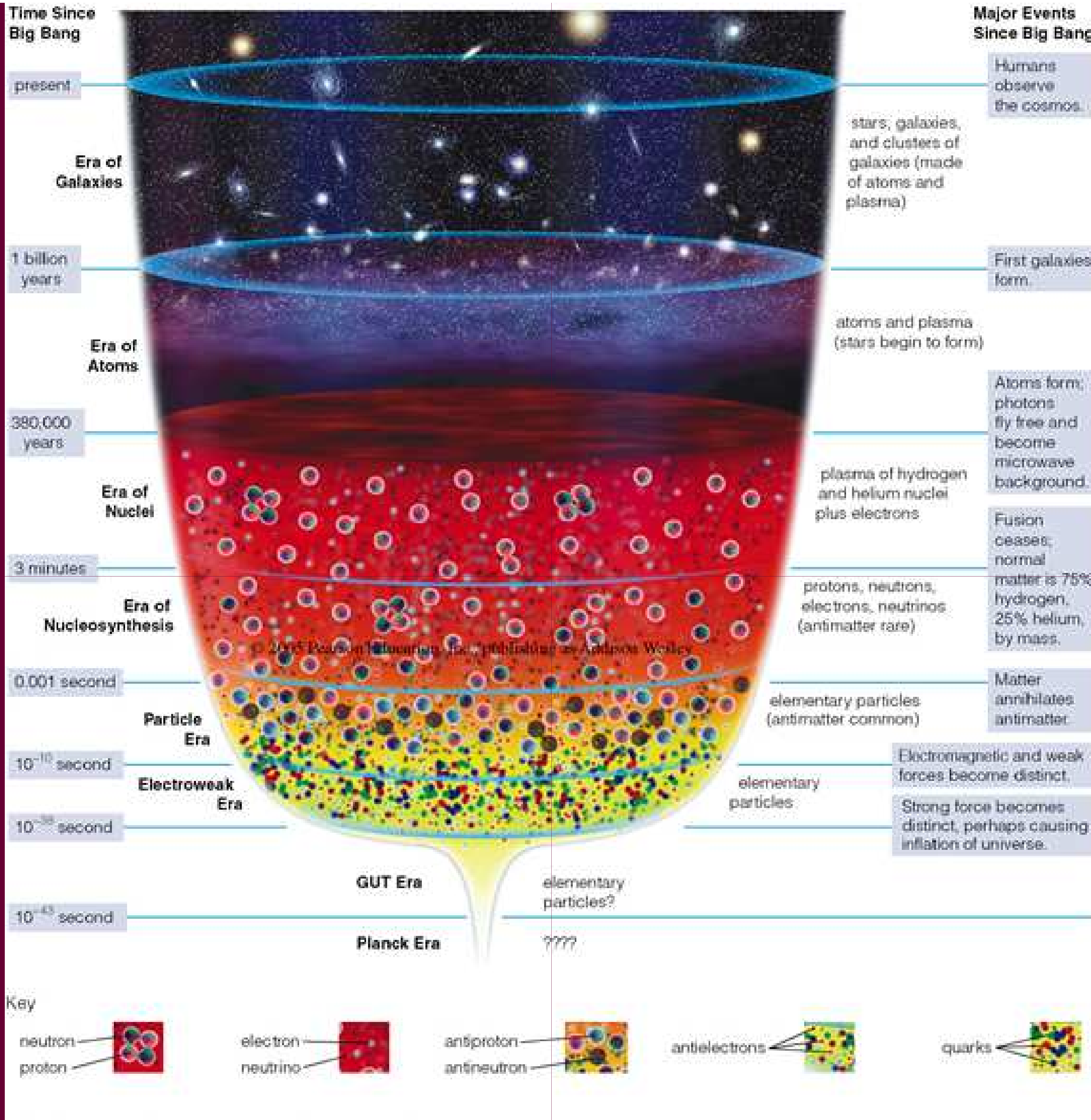
**Table S4.1 Fundamental Fermions**

| *The Quarks* | *The Leptons* |
|---|---|
| Up | Electron |
| Down | Electron neutrino |
| Strange | Muon |
| Charmed | Mu neutrino |
| Top | Tauon |
| Bottom | Tau neutrino |

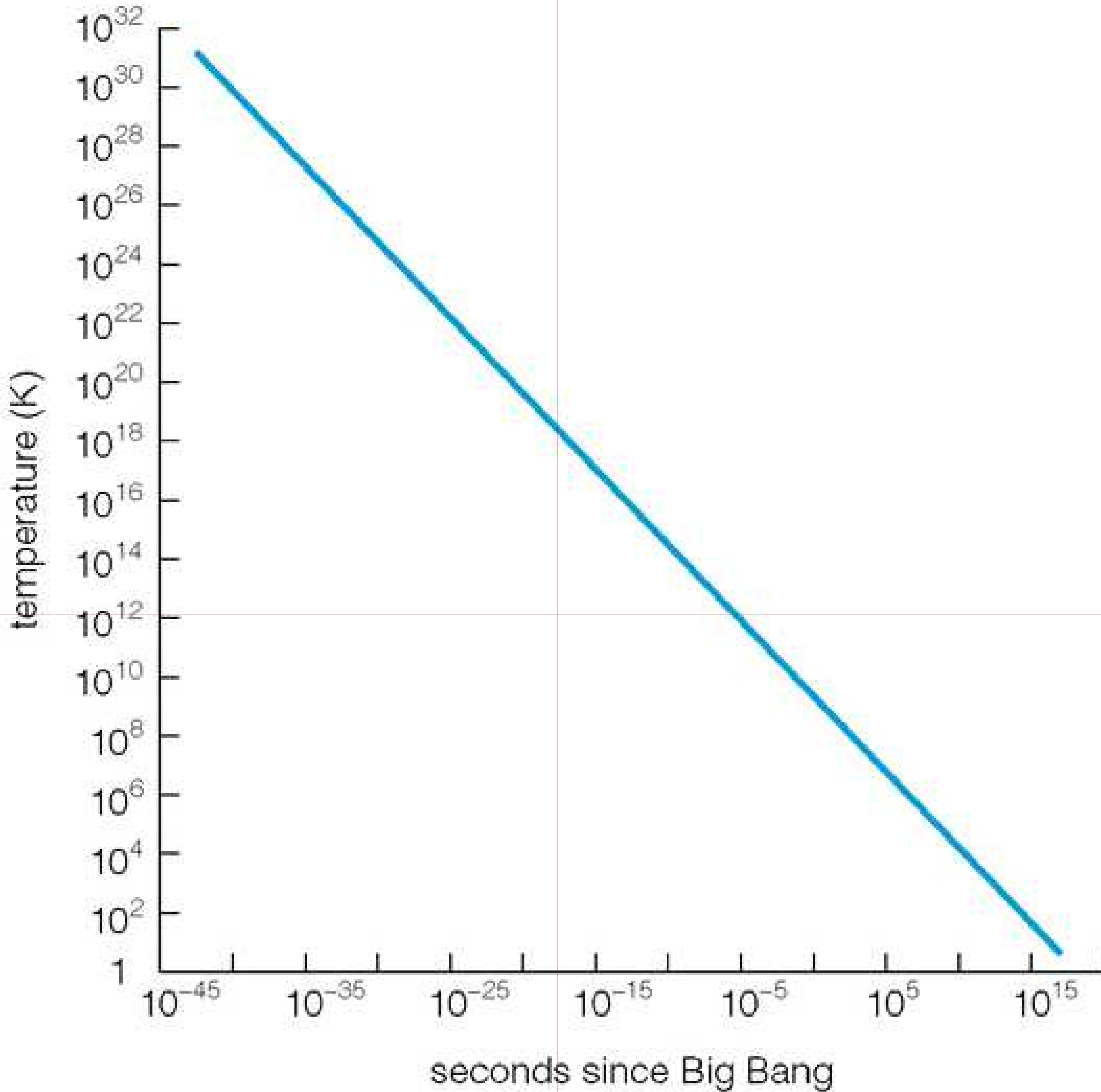

proton
d
u
u
two up quarks
one down quark
neutron
u
d
d
one up quark
two down quarks

# Weak Force

- Weak forces govern nuclear reactions
- Occurs over distances 0.1% the diameter of a proton
- The weak interaction changes one flavor of quark into another.

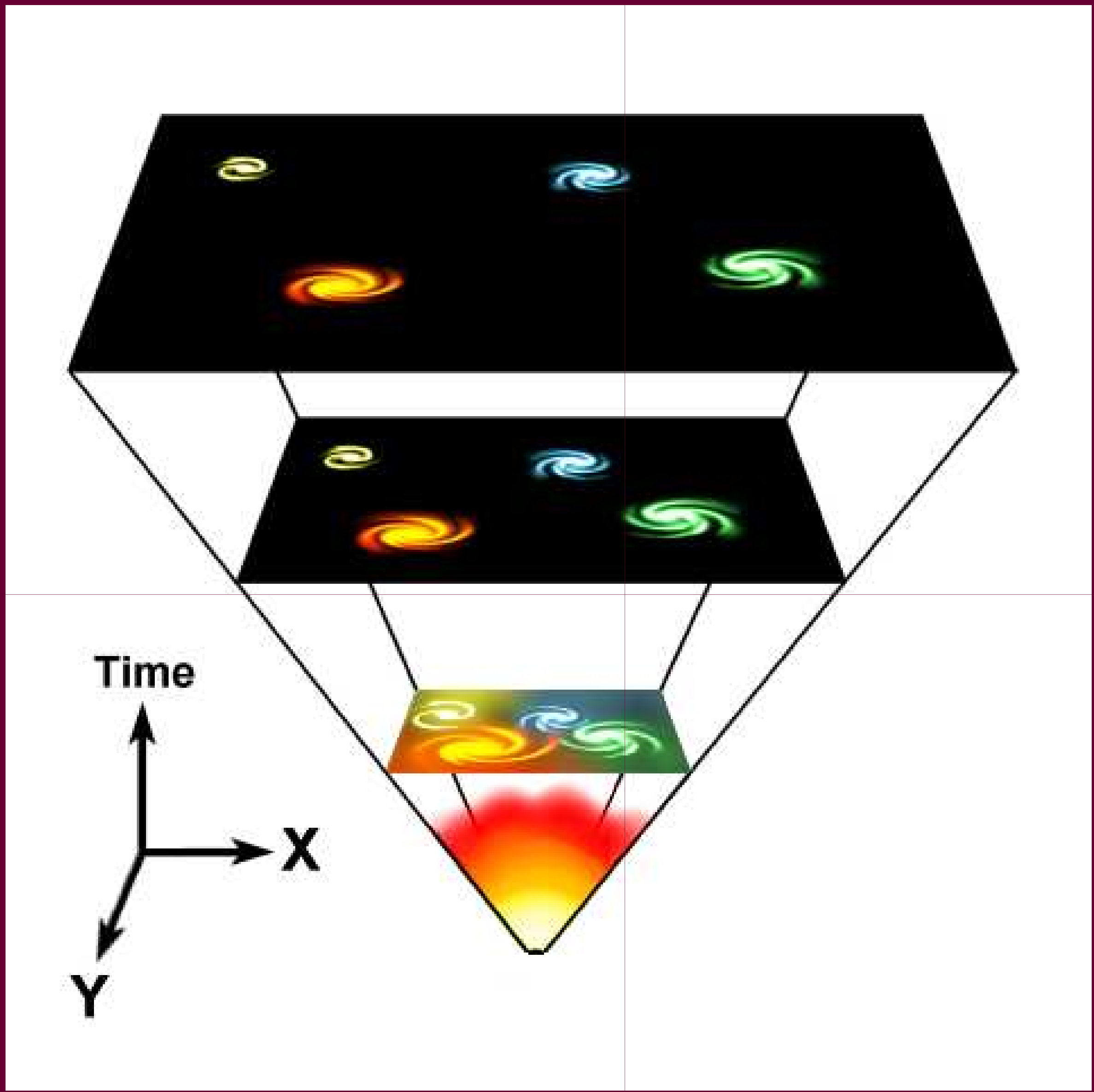


Time Since Big Bang
Major Events Since Big Bang
present
Humans observe the cosmos.
Era of Galaxies
stars, galaxies, and clusters of galaxies (made of atoms and plasma)
1 billion years
First galaxies form.
Era of Atoms
atoms and plasma (stars begin to form)
380,000 years
Atoms form; photons fly free and 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^-35 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


temperature (K)
$10^{32}$
$10^{30}$
$10^{28}$
$10^{26}$
$10^{24}$
$10^{22}$
$10^{20}$
$10^{18}$
$10^{16}$
$10^{14}$
$10^{12}$
$10^{10}$
$10^{8}$
$10^{6}$
$10^{4}$
$10^{2}$
1
$10^{-45}$
$10^{-35}$
$10^{-25}$
$10^{-15}$
$10^{-5}$
$10^{5}$
$10^{15}$
seconds since Big Bang

# Big Bang

- The event that gave birth to the universe
- One consequence of the Big Bang is that the conditions of today's universe are different from the conditions in the past or in the future.




*http://upload.wikimedia.org/wikipedia/en/3/37/Universe_expansion2.png*

# The Name

- Fred Hoyle proposed an alternative Steady State model in which the universe was both expanding and eternal
- Hoyle christened the theory, referring to it disdainfully in a radio broadcast as "*this 'Big Bang' idea*".

# Planck Time

- $10^{-43}$ seconds after Big Bang
- Before Planck Time, the universe was concentrated in a single point
- At Planck Time, the universe was $10^{32}$ Kelvin and it had the size of $10^{-33}$ cm.

# Before Planck Time

- Before a time classified as a Planck time, all of the four fundamental forces are presumed to have been unified into one force.
- All matter, energy, space and time are presumed to have exploded outward from the original singularity.
- Nothing is known of this period.

- http://en.wikipedia.org/wiki/Graphical_timeline_of_the_Big_Bang

# Video

- http://hubblesite.org/newscenter/newsdesk/archive/releases/2003/27/video/b

# Sounds

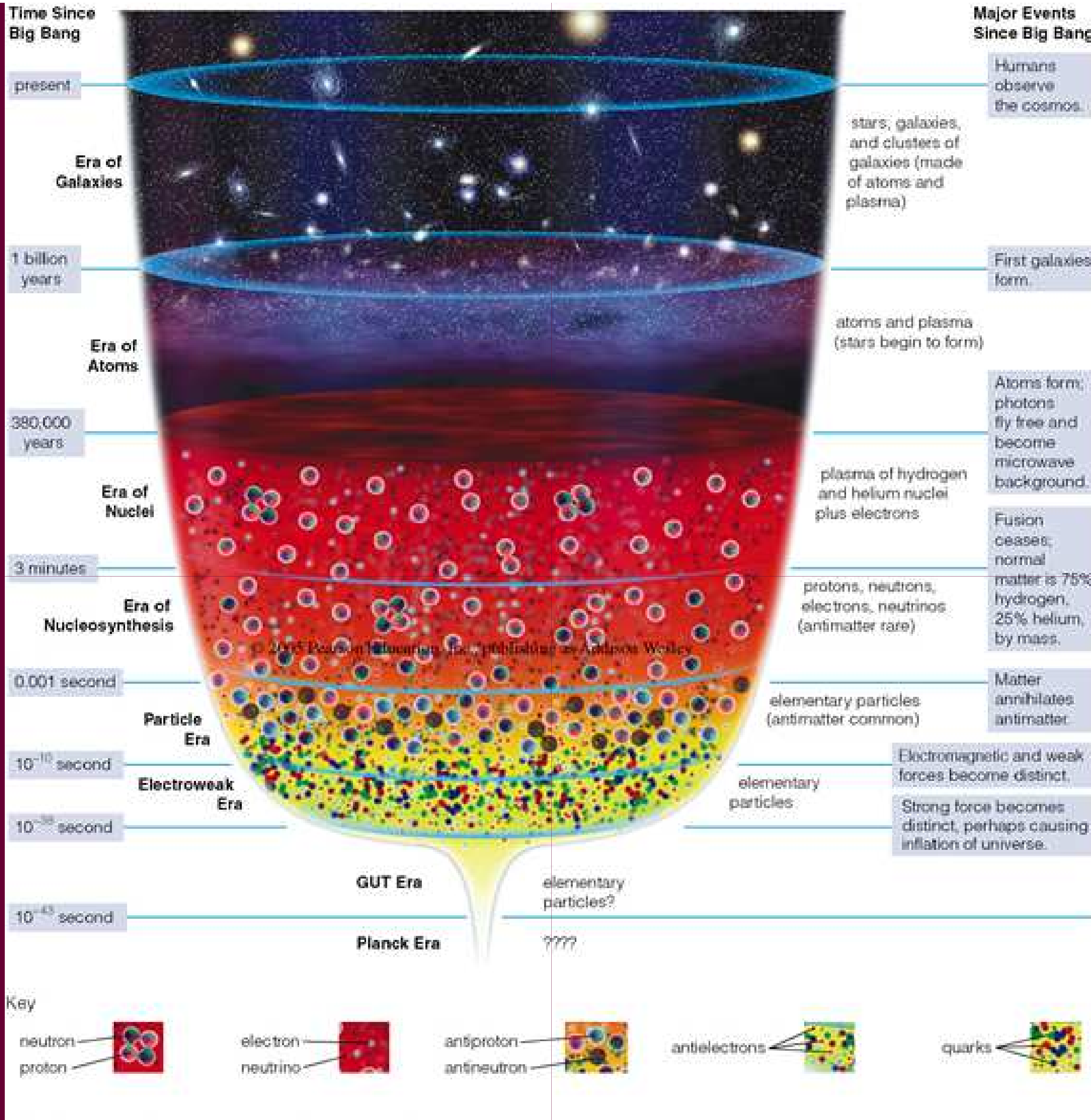
- http://staff.washington.edu/seymour/altvw104.html

# GUT Era

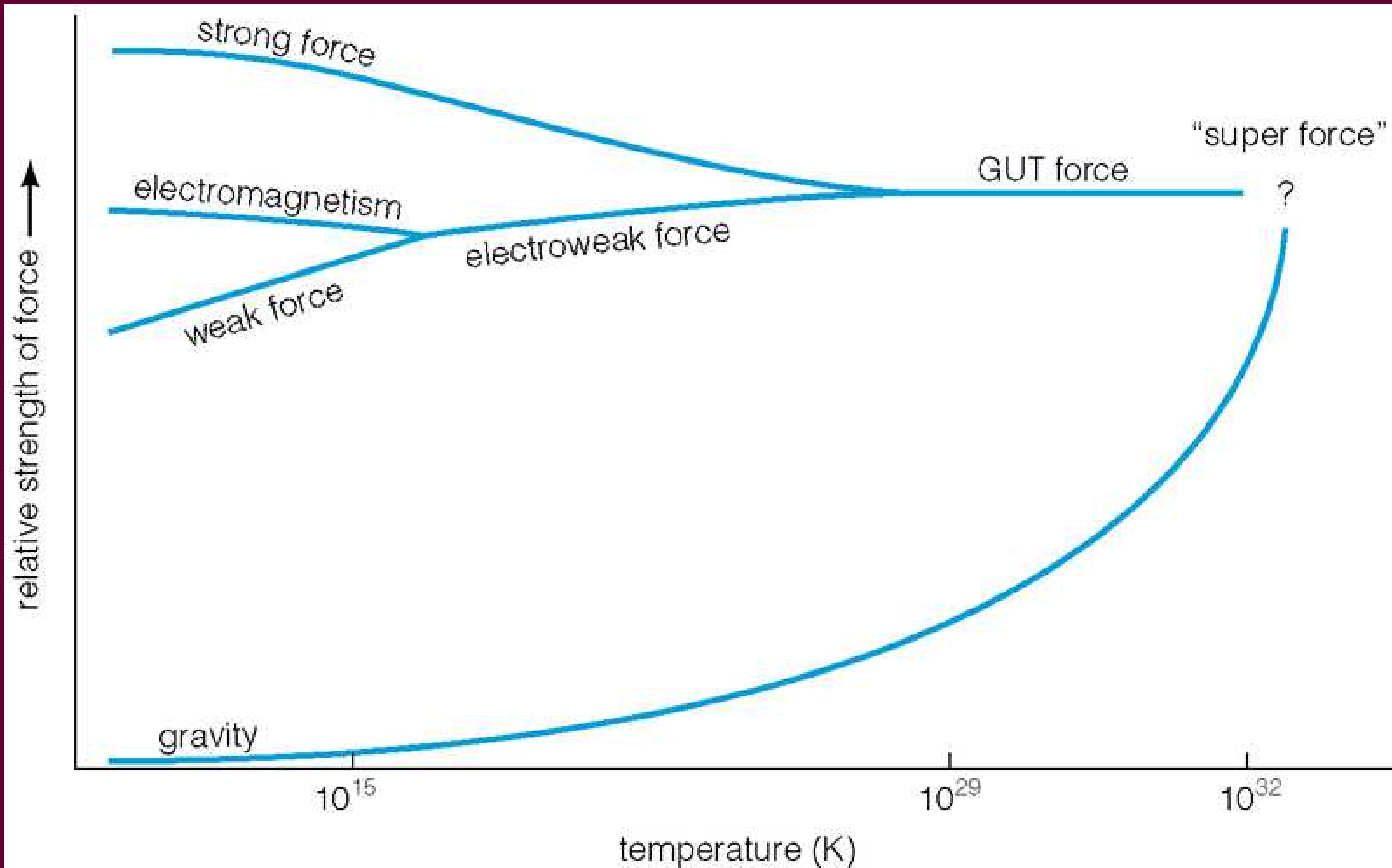
- Lasts from $10^{-43}$ until $10^{-38}$ seconds after Big Bang
- GUT – Grand Unified Theory
- At high enough temperatures, electromagnetism, strong force, and weak force all act as one force
- Gravity still acts separately

# Inflation

- During GUT era, there was inflation
- Rapid expansion of universe



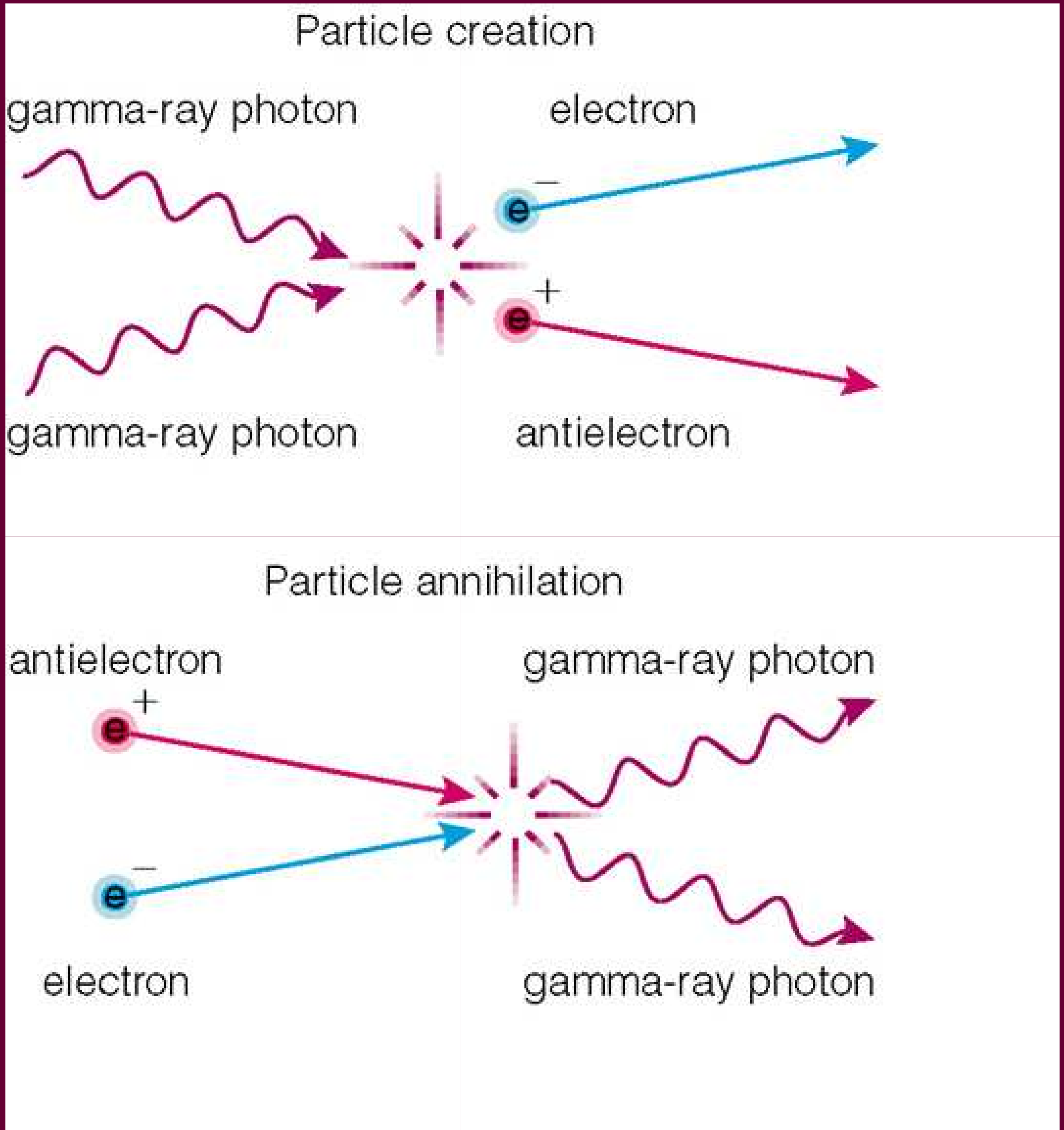
Time Since Big Bang
Major Events Since Big Bang
present
Humans observe the cosmos.
Era of Galaxies
stars, galaxies, and clusters of galaxies (made of atoms and plasma)
1 billion years
First galaxies form.
Era of Atoms
atoms and plasma (stars begin to form)
380,000 years
Atoms form; photons fly free and 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
$10^{-38}$ 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


strong force
"super force"
GUT force
?
electromagnetism
electroweak force
weak force
relative strength of force
gravity
$10^{15}$
$10^{29}$
$10^{32}$
temperature (K)

# Electroweak era

- Lasts from $10^{-38}$ until $10^{-10}$ seconds after Big Bang
- Strong Force becomes separated
- Left with Electroweak force

*Particles being created and destroyed*



# Particle Era

- Lasts from $10^{-10}$ until 0.001  seconds after Big Bang
- Quarks, electrons, neutrinos formed
- Quarks started to make protons and neutrons and antiprotons and antineutrons

# Antimatter

- Particle with same mass as ordinary particle but other basic properties are precisely opposite

# Big Question

- If there were equal numbers of protons and antiprotons
- And neutrons and antineutrons
- All the particles would have annihilated each other
- Creates photons

# Must have

- There must have been a very slight excess of matter over antimatter
- Like for every one billion antiprotons
- There were one billion and one protons
- So the billion antiprotons annihilated the billion protons
- Left one proton

# Era of Nucleosynthesis

- Lasts from 0.001 seconds to 3 minutes after Big Bang
- Fusion started to occur
- 75% of the universe was hydrogen
- 25% of the universe was helium

# Era of Nuclei

- Lasts from 3 minutes to 380,000 years after Big Bang
- Cool enough so hydrogen and helium could capture electrons
- Photons stopped hitting electrons and instead were able to stream through the universe

# Era of Atoms

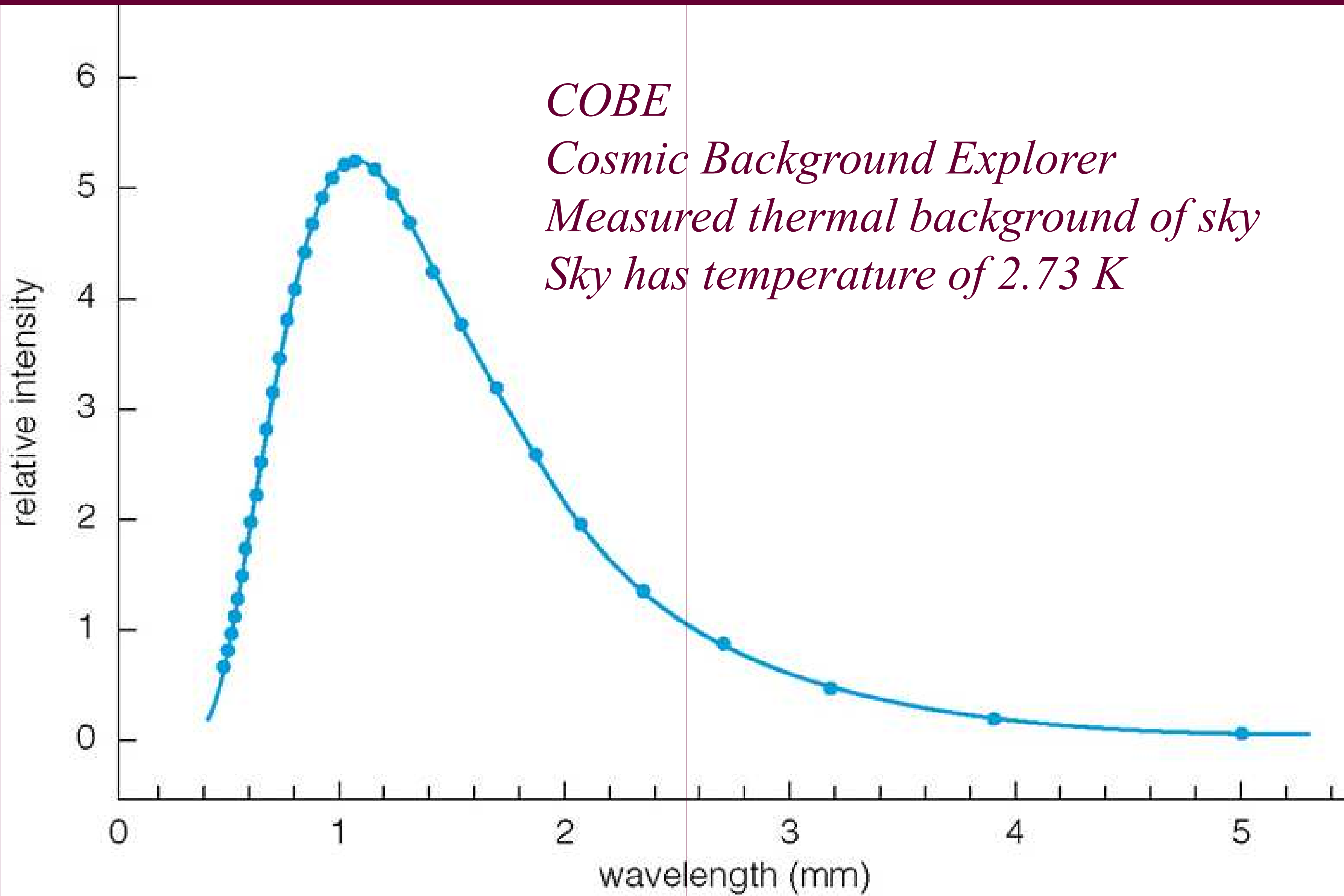
- Lasts from 380,000 to one billion years after Big Bang
- Protogalactic clouds start to form

# Era of galaxies

- Lasts from one billion years after Big Bang to present
- Galaxies form

# Evidence for Big Bang

- Cosmic Microwave Background is the form of electromagnetic radiation that fills the whole of the universe.

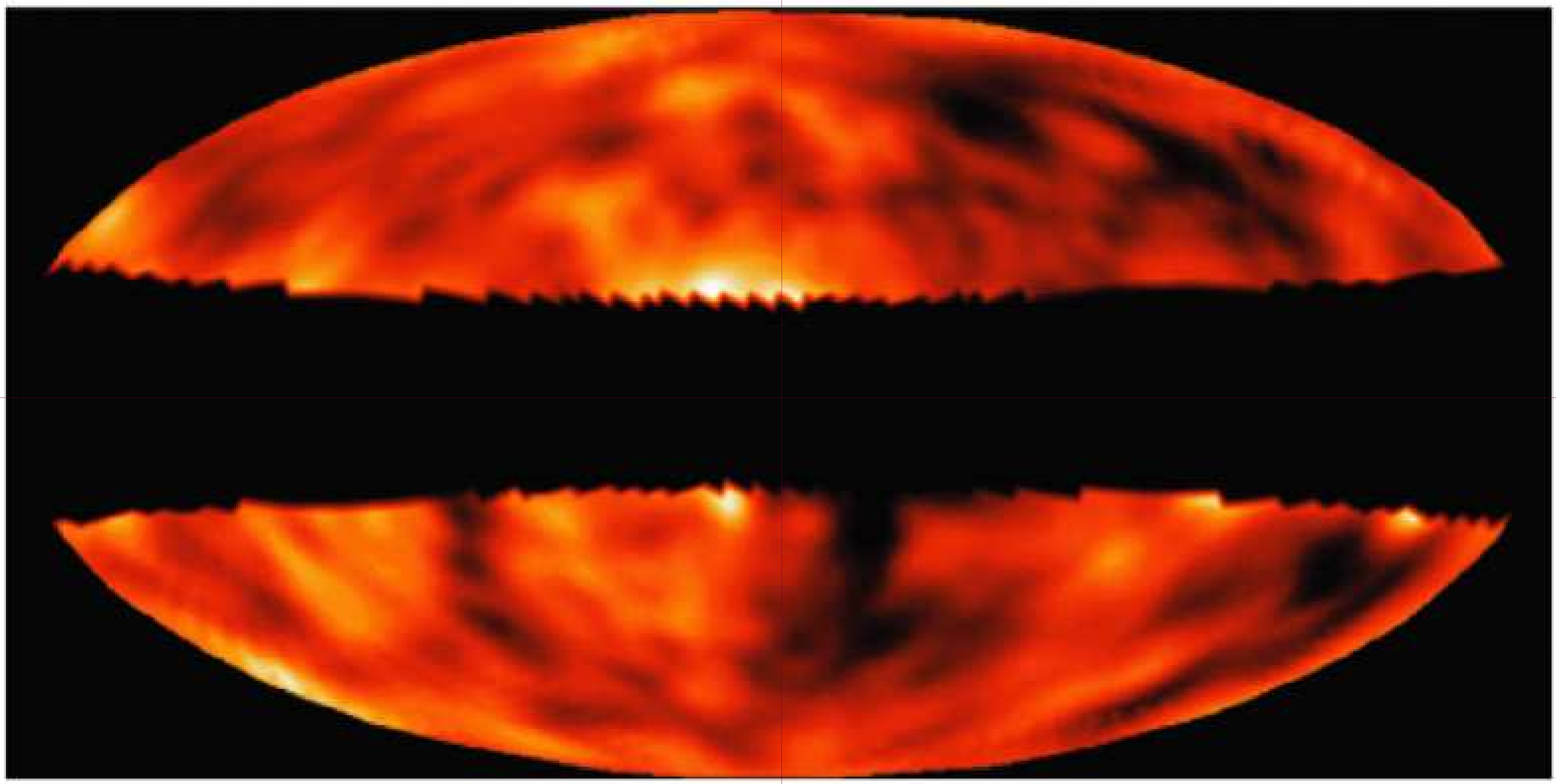



*COBE*
*Cosmic Background Explorer*
*Measured thermal background of sky*
*Sky has temperature of 2.73 K*

# Due to

- Photons that streamed out during the era of nuclei had temperature of 3,000 K
- Had blackbody spectrum
- Has temperature now of 2.73 K since universe has expanded and stretched the wavelength of the photons

*Brighter regions are 0.0001 K hotter*



# Importance

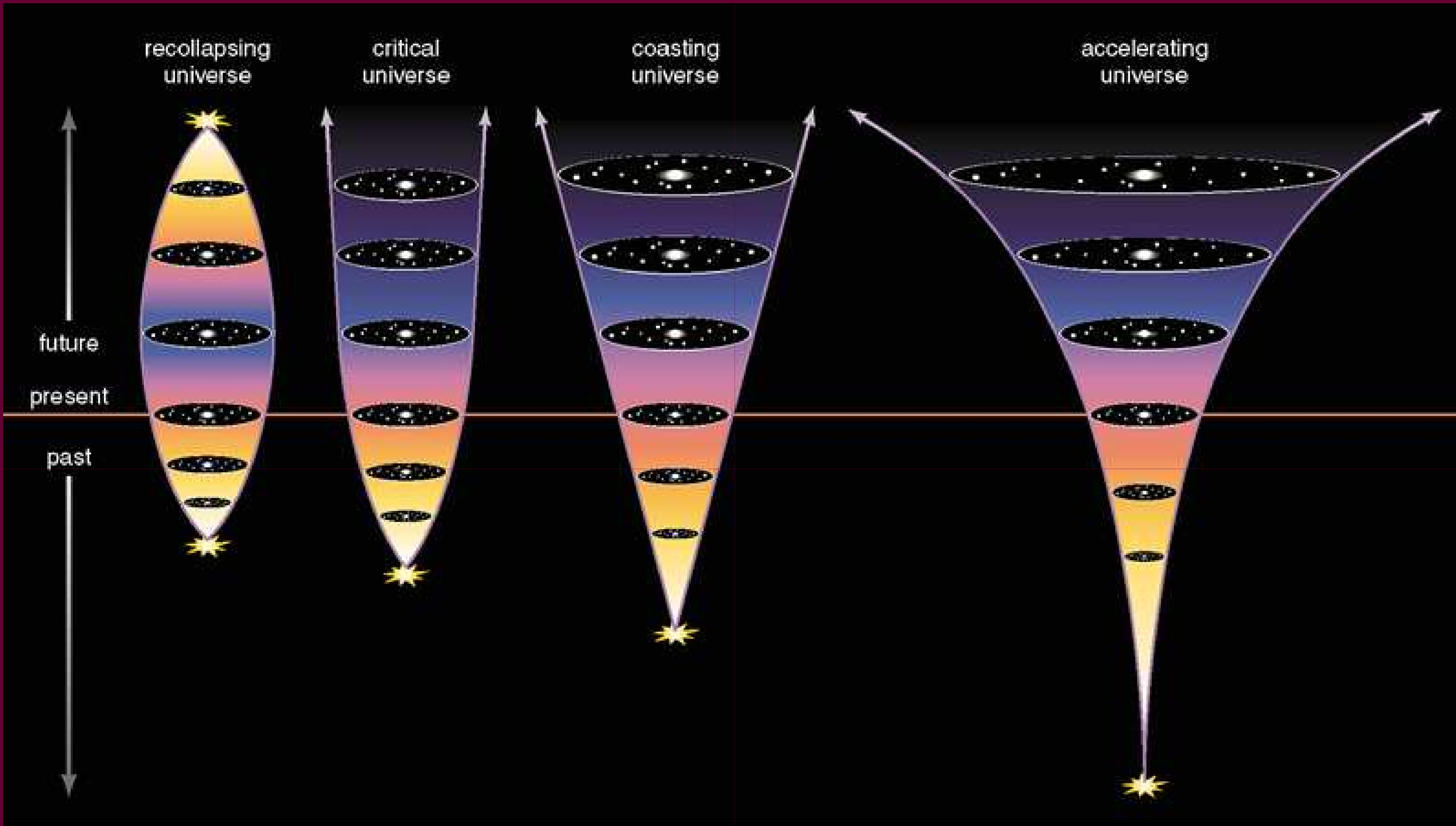
- This 2.73 K is very uniform across the sky
- Permeates the whole sky
- Evidence for Big Bang

# Other evidence

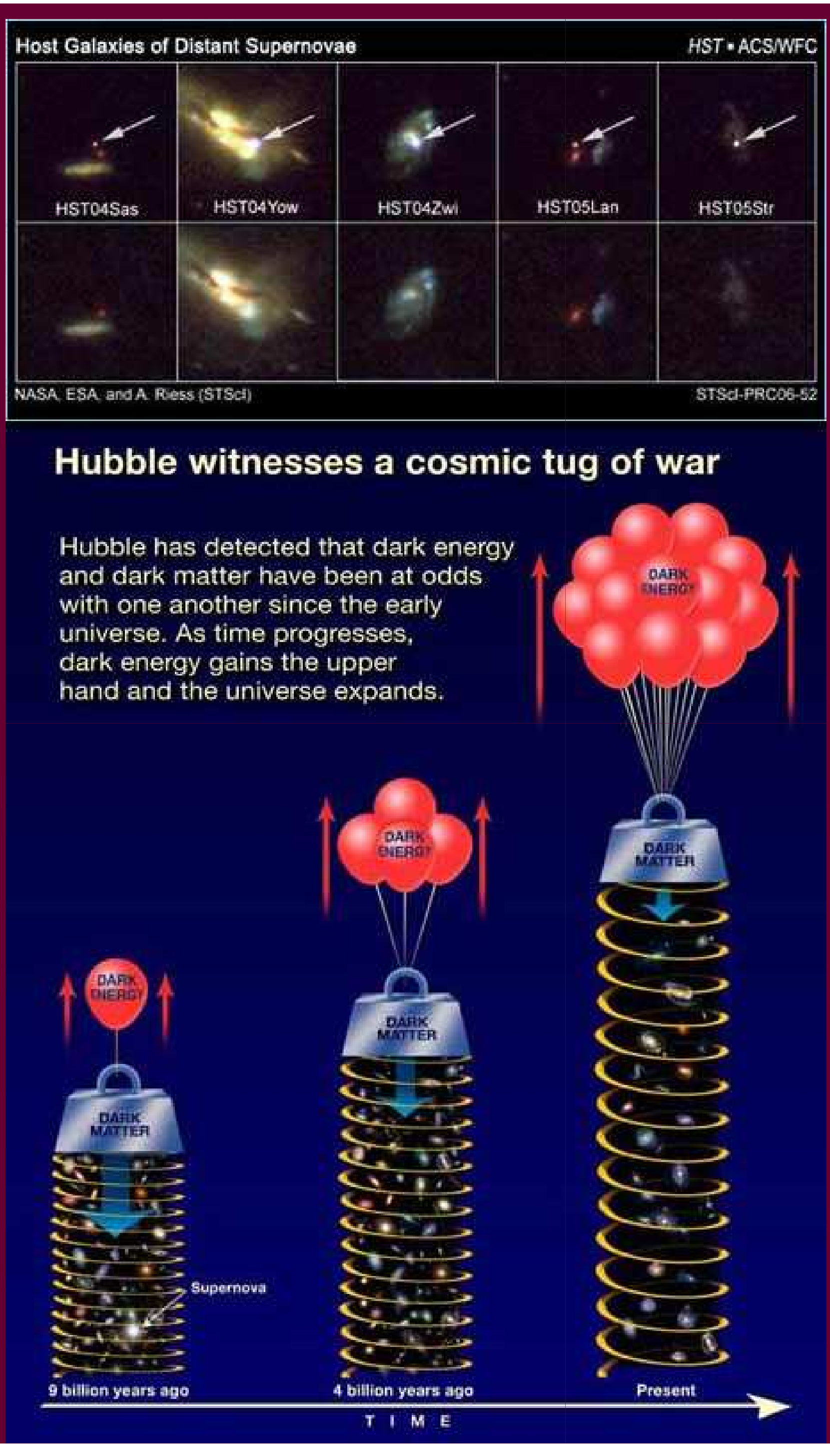
- Predicted to have produced 75% hydrogen and 25% helium during the era of nucleosynthesis
- That is approximately what we see today

# End of Universe

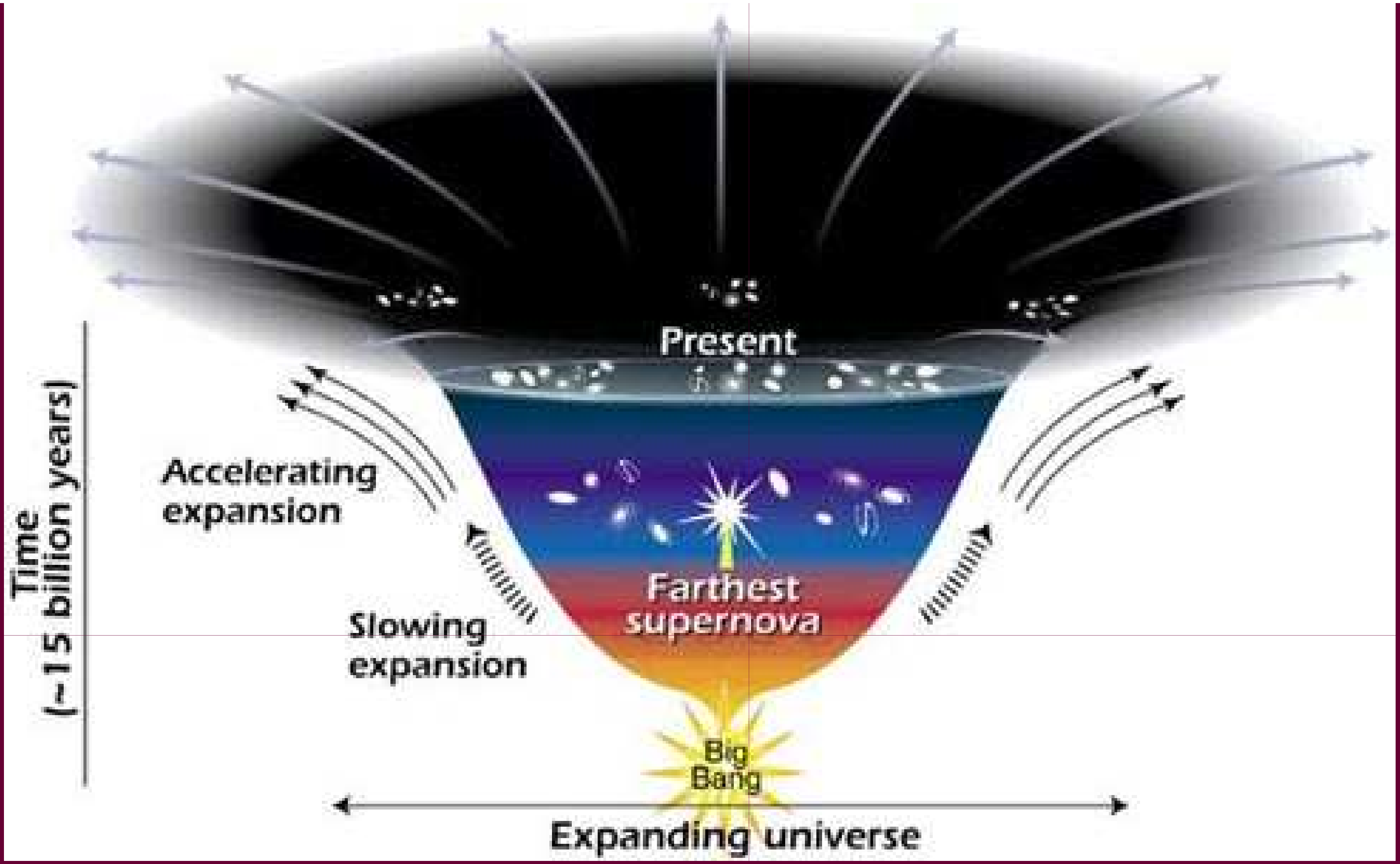
- Critical Density – Density marking the dividing line between eternal expansion and eventual collapse


recollapsing universe
critical universe
coasting universe
accelerating universe
future
present
past

- Dark energy started its long history in 1917 and was introduced by Albert Einstein. A constant (which he called $\Omega$) was needed in his equations of General Relativity in order to allow for a static Universe, where space is not expanding

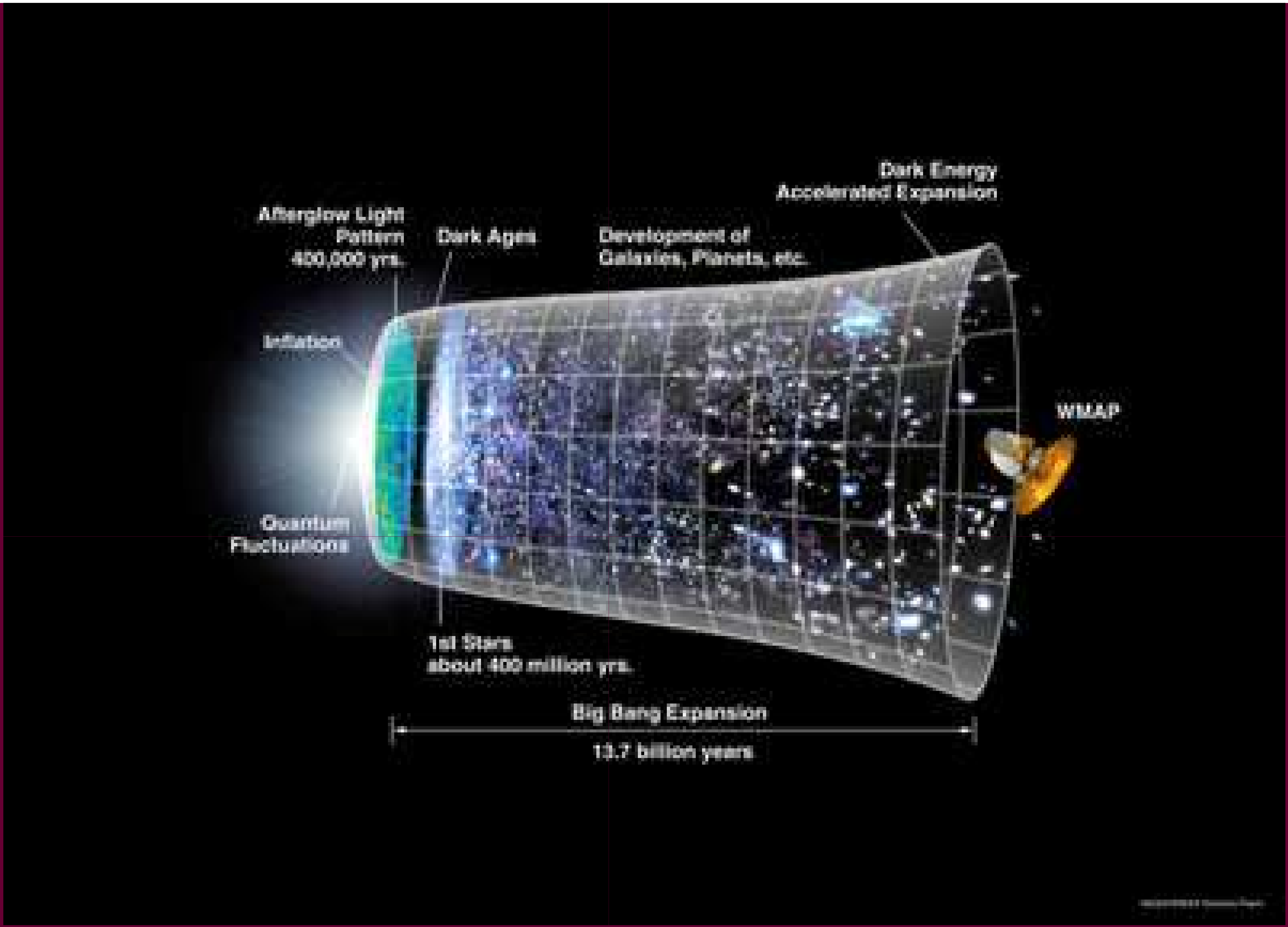



*http://news.nationalgeographic.com/news/bigphotos/75852487.htm*




*The more shallow the curve, the faster the rate of expansion.
The curve changes noticeably about 7.5 billion years ago, when objects
in the universe began flying apart as a faster rate. Astronomers theorize that
the faster expansion rate is due to a mysterious, dark force that is pulling galaxies apart.*

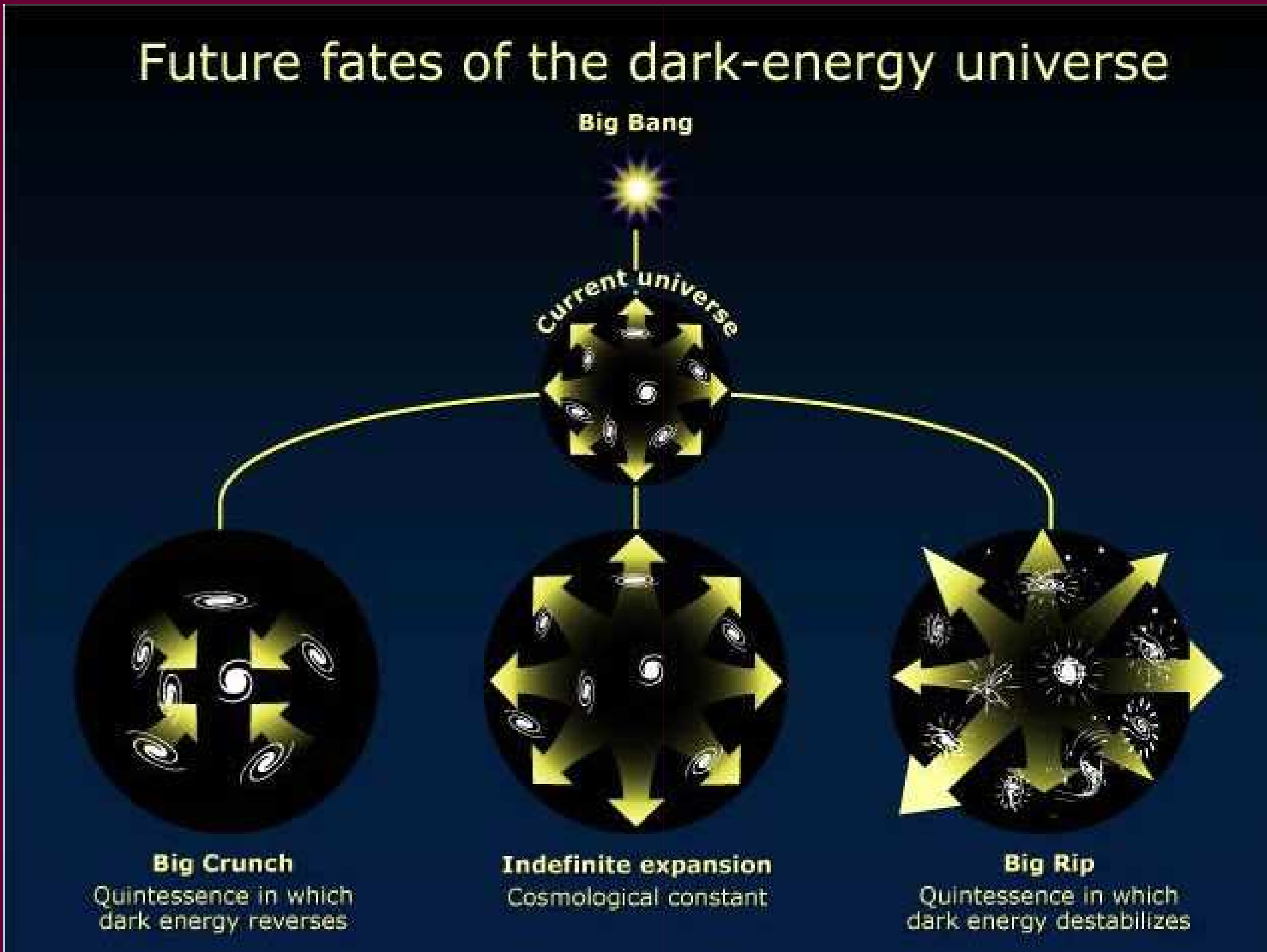
*http://science.hq.nasa.gov/universe/science/images/dark_expansion.jpg*



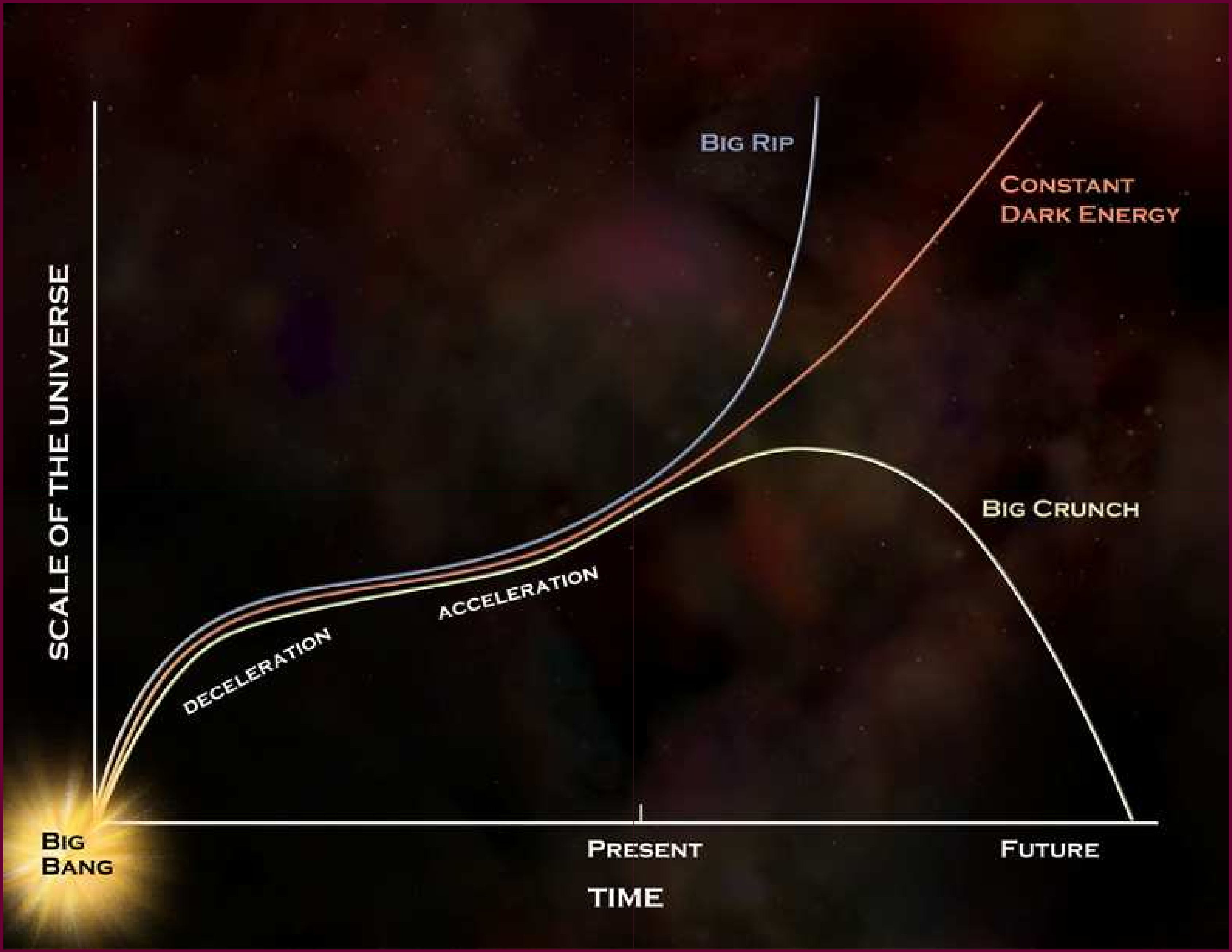

*http://www.science.how**stuffworks**.com/hole-in-universe1.htm*

# Robert Frost Poem

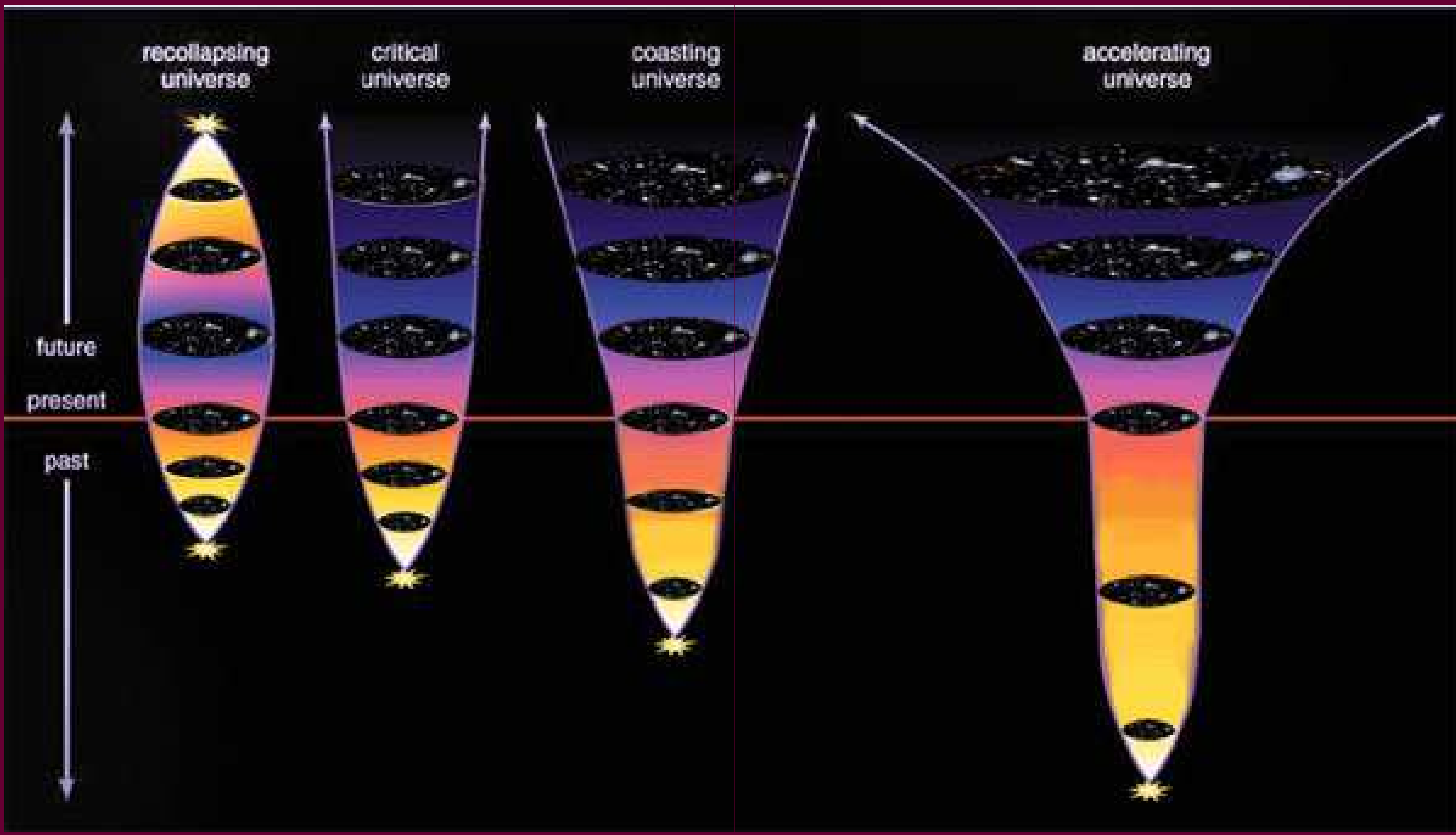
- Some say the world will end in fire,
  Some say in ice.
  From what I've tasted of desire
  I hold with those who favor fire.
  But if it had to perish twice,
  I think I know enough of hate
  To say that for destruction ice
  Is also great
  And would suffice.



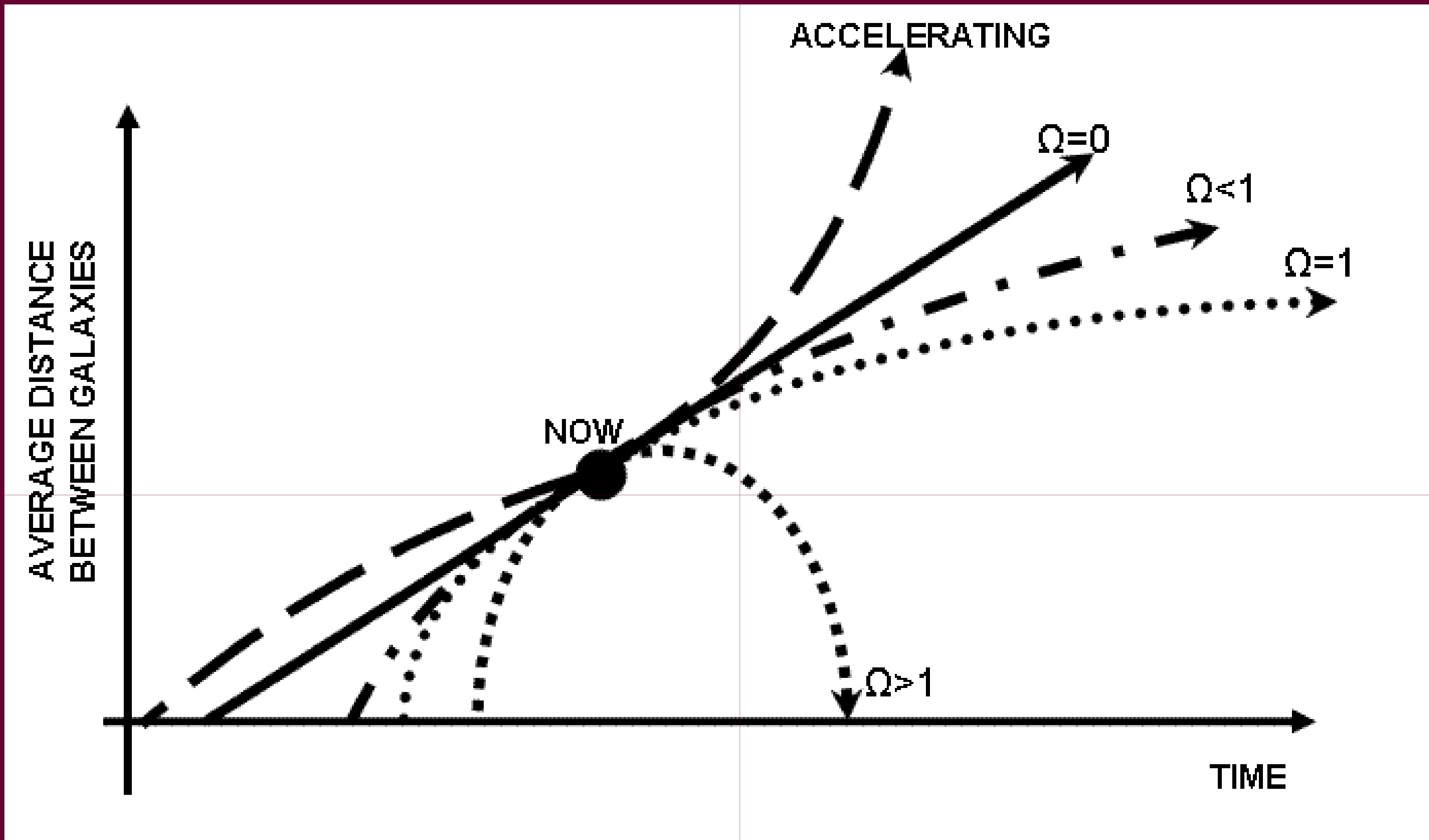

*http://www.nasa.gov/images/content/56197main_dark_schematic-lg.jpg*



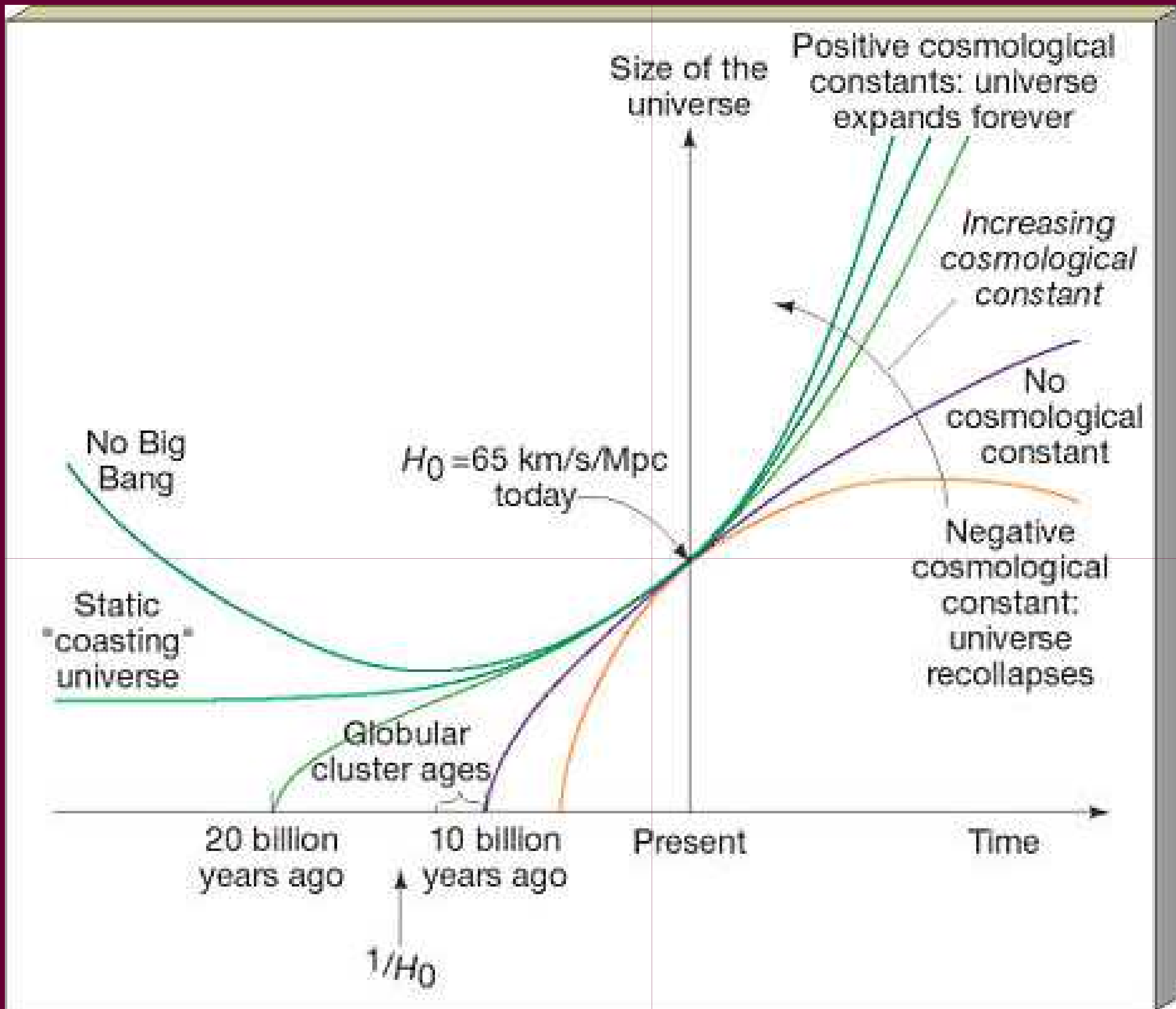

*http://chandra.harvard.edu/photo/2004/darkenergy/future_universe.jpg*




*http://www.lsst.org/Science/images/Universe_fate.jpg*




*http://en.wikipedia.org/wiki/Image:Universes.GIF*




*http://physics.uoregon.edu/~courses/BrauImages/Chap27/IN27_101.jpg*

# Recollapsing or Closed Universe

- Lacking the repulsive effect of dark energy
- Gravity eventually stops the expansion of the universe
- The Universe starts to contract until all matter in the universe collapses to a point
- Called the Big Crunch

# Critical or Flat Universe

- No dark energy
- Expands Forever
- Expands more slowly

# Coasting or Open Universe

- No dark energy
- Keeps on expanding forever
- Little change in the rate of expansion

# Accelerating Universe

- Dark Energy
- Expansion rate increases

- http://www.nasa.gov/centers/marshall/multimedia/video/2004/video04-144.html

- http://www.220.ro/documentare/BBC-The-Planets-Life-Ep-7-8/J433s66jfk/

Any Questions?