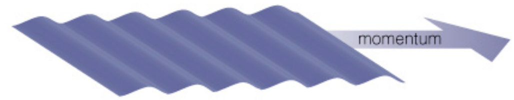
Lecture 22: The Big Bang (Continued)
& The Fate of the Earth and Universe
A2020 Prof. Tom Megeath

Review: The Wave Nature of Matter



Louis de Brogilie in 1928 proposed (in his PhD thesis) that matter had a wave-like nature

Wavelength given by $\lambda = h/p = h/mv$ where
h = Planck's constant (remember $E = h\nu$ for photons)

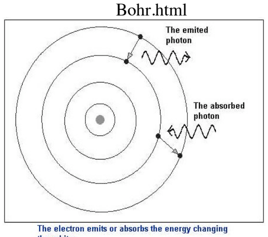
Objects are moving fasting have smaller wavelenghts

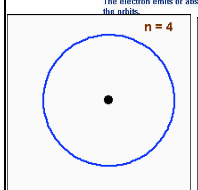
Less massive objects have a larger wavelength

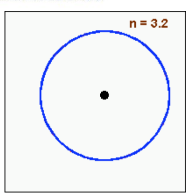
De Brogilie won the Nobel Prize for this work in 1929

The Bohr Hydrogen Atom

see: http://www.7stones.com/Homepage/Publisher/Bohr.html







Introduced by Niels Bohr in 1913

$n \lambda = 2 \pi r$
n = integer (1, 2, 3, ..)
r = radius of orbit
$2\pi r$ = circumference of orbit
$\lambda = h/mv$ (de Broglie)
$n\, h/mv = 2\pi r$

$r = n\, h/(2\pi mv)$

$E = k\, e2/r$ (e charge of electron or proton, k = Coulomb constant)

Balance centrifugal and coulomb force between electron and proton

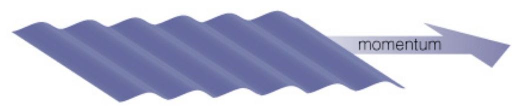
$mv^2/r = ke^2/r^2$

$1/2\ m\, (nh/2\pi m)^2\, r)^3 = ke^2/r^2$

$2\, (nh/2\pi m)^2/ke^2 = r$

$E = 2\pi^2 k^2 e^4 m^2/n^2 h^2$

The Wave Nature of Matter



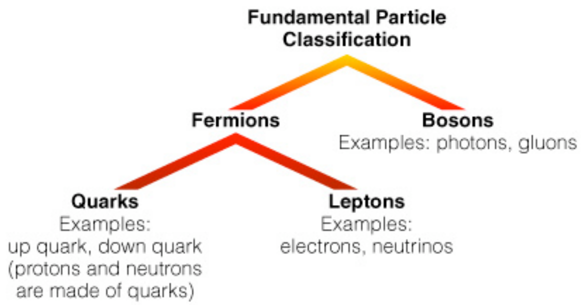
What does the amplitude of an electron wave mean?

Sound wave: amplitude is loudness

Light wave: amplitude is strength of electric field/intensity

Electron wave: amplitude is probability that electron will be found there.

Fundamental Particles



(Baryons are particles made of 3 quarks)

Uncertainty Principle

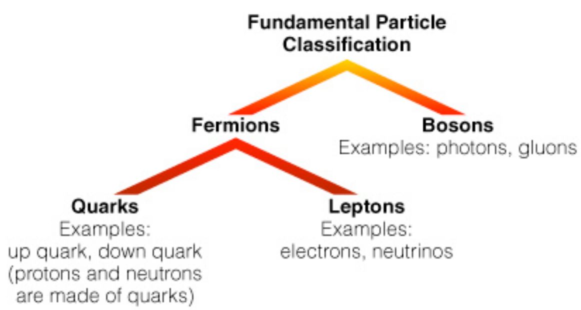
Location and Momentum

Uncertainty in position X Uncertainty in momentum > Planck's Constant (*h*)

Energy and Time

Uncertainty in energy X Uncertainty in time > Planck's Constant (*h*)

Fundamental Particles



(Baryons are particles made of 3 quarks)

Quarks

- Protons and neutrons are made of quarks
- *Up quark* (u) has charge +2/3
- *Down quark* (d) has charge -1/3

Four Forces

- Strong Force (holds nuclei together)
  - Exchange particle: gluons
- Electromagnetic Force (holds electrons in atoms)
  - Exchange particle: photons
- Weak force (mediates nuclear reactions)
  - Exchange particle: weak bosons
- Gravity (holds large-scale structures together)
  - Exchange particle: gravitons

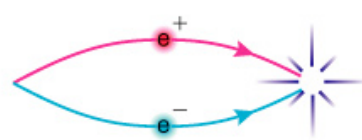
Matter and Antimatter

- Each particle has an antimatter counterpart
- When a particle collides with its antimatter counterpart, they annihilate and become pure energy in accord with $E = mc^2$

Matter and Antimatter

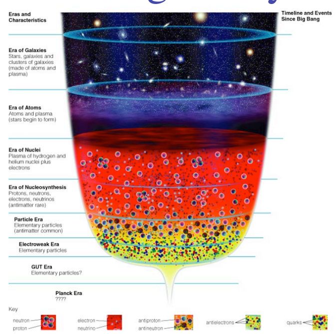
- Energy of two photons can combine to create a particle and its antimatter counterpart (pair production)

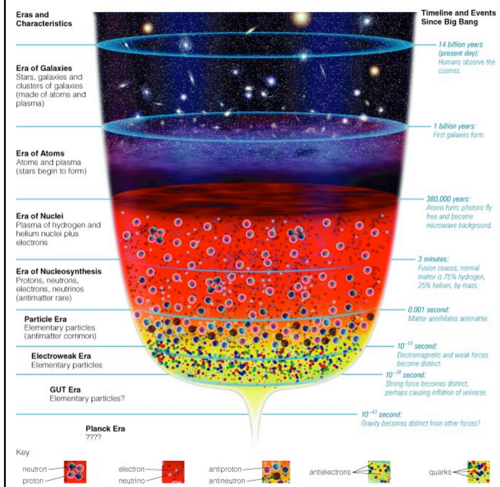
Virtual Particles



- Uncertainty principle (in energy & time) allows production of matter-antimatter particle pairs
- But particles must annihilate in an undetectably short period of time

What is the history of the universe according to the Big Bang theory?

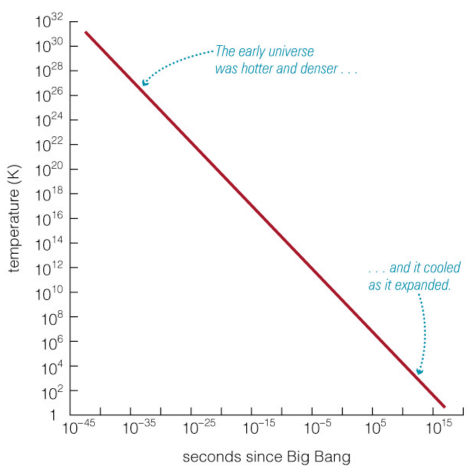




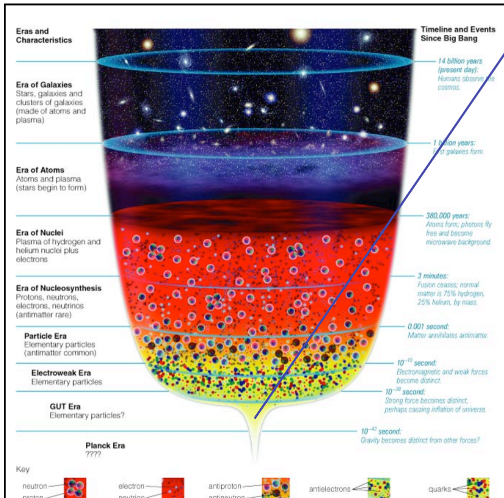
The different Eras of the Universe

Around 300,000 after the big band, the universe cooled to the points that atoms formed from a hot gas of electrons and protons

(we'll look at this in more detail in the next lecture)



The early universe must have been extremely hot and dense

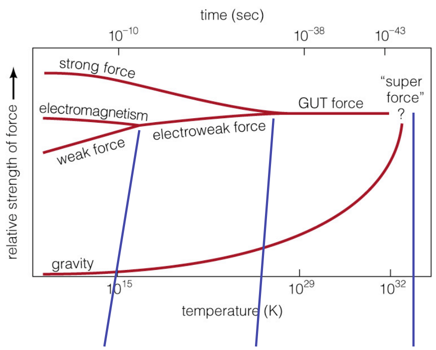


Planck Era

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

No theory of quantum gravity

Do forces unify at high temperatures?



Yes! (Electroweak)

Maybe (GUT)

Who knows? (String Theory)

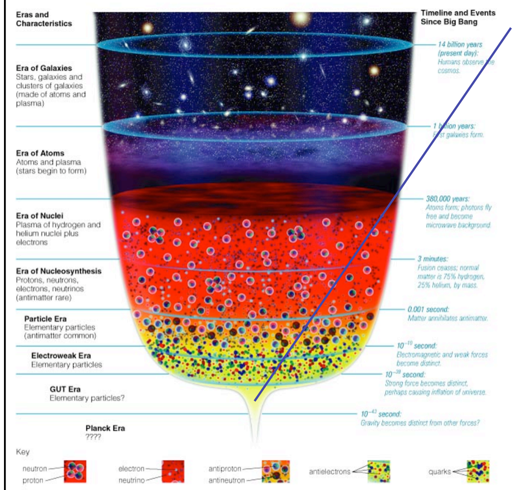
Four known forces in universe:

Strong Force

Electromagnetism

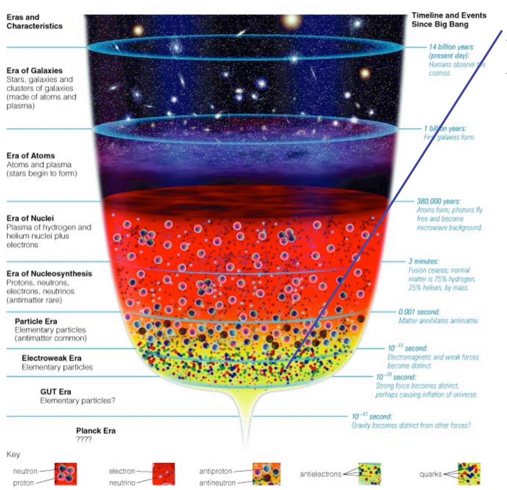
Weak Force

Gravity



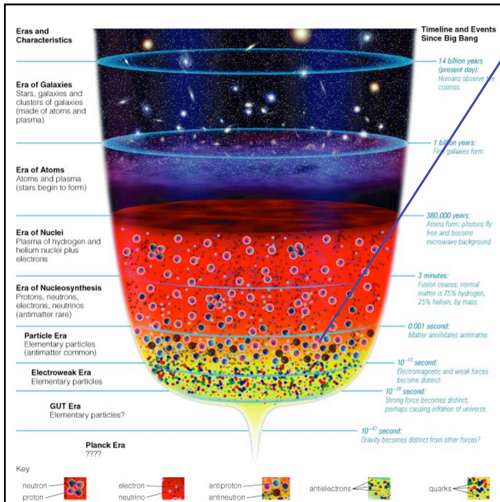
GUT Era

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



Electroweak Era

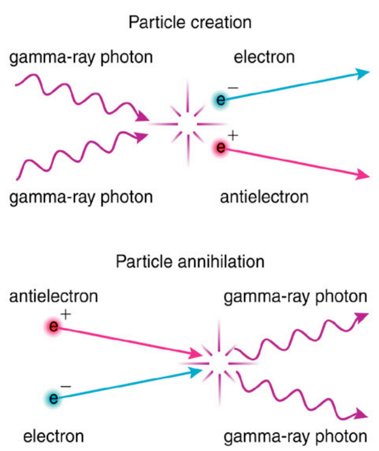
Lasts from end of GUT force (~10^{-38} sec) to end of electroweak force (~10^{-10} sec)



Particle Era

Amounts of matter and antimatter nearly equal

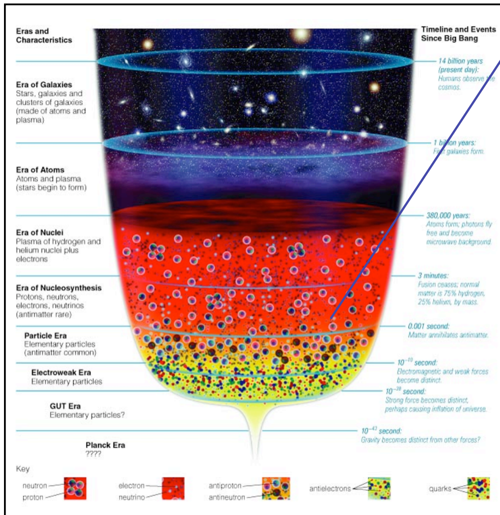
(Roughly 1 extra proton for every 10^9 proton-antiproton pairs!)



Photons converted into particle-antiparticle pairs and vice-versa

$$E = mc^2$$

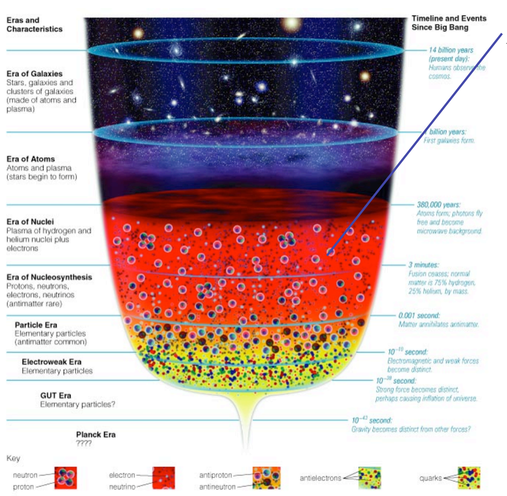
Early universe was full of particles and radiation because of its high temperature



Era of Nucleo-synthesis

Begins when matter annihilates remaining antimatter at ~ 0.001 sec

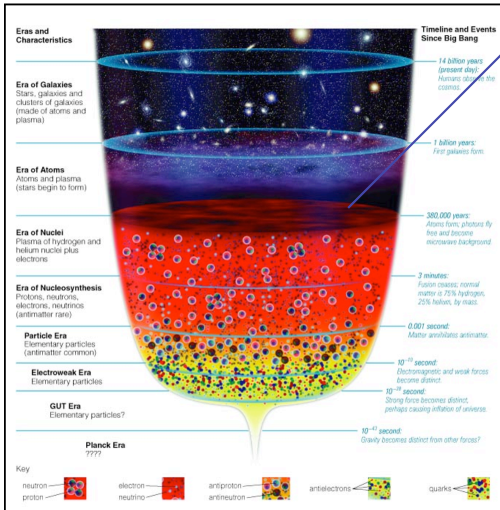
Nuclei begin to fuse



Era of Nuclei

Helium nuclei form at age ~ 3 minutes

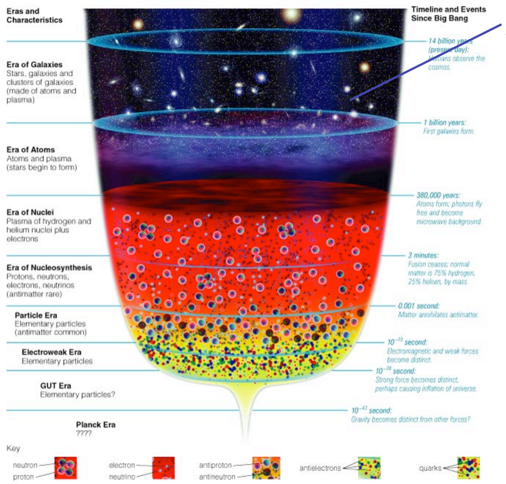
Universe has become too cool to blast helium apart



Era of Atoms

Atoms form at age ~ 380,000 years

Background radiation released



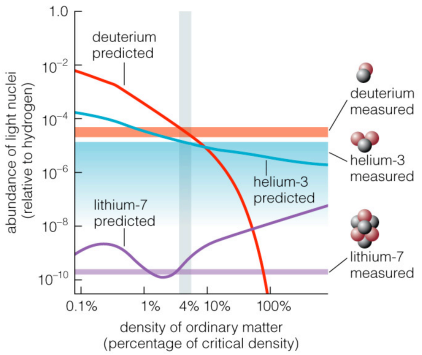
Era of Galaxies

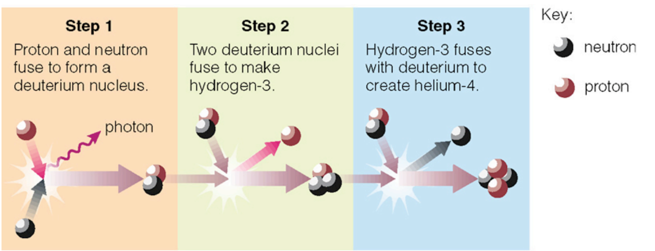
Galaxies form at age ~ 1 billion years

What have we learned?

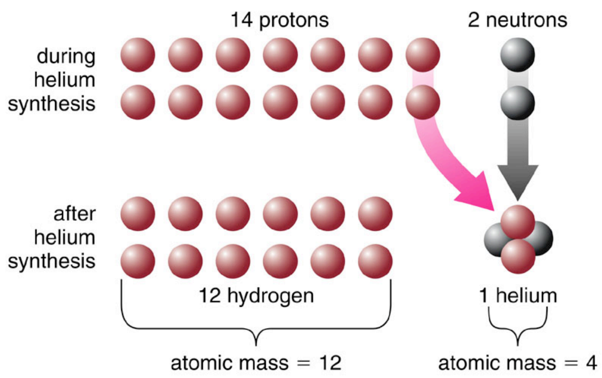
- What were conditions like in the early universe?
  - The early universe was so hot and so dense that radiation was constantly producing particle-antiparticle pairs and vice versa
- What is the history of the universe according to the Big Bang theory?
  - As the universe cooled, particle production stopped, leaving matter instead of antimatter
  - Fusion turned remaining neutrons into helium
  - Radiation traveled freely after formation of atoms

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



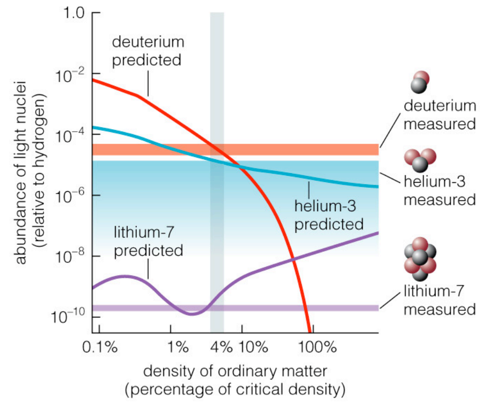


Protons and neutrons combined to make long-lasting helium nuclei when universe was ~ 3 minutes old



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!*

Thought 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

Thought Question

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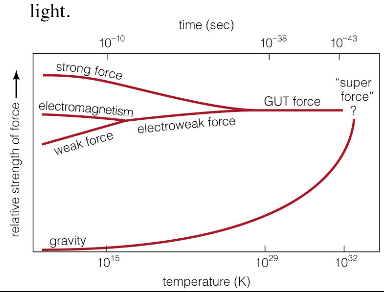
How do we probe the physics of the big bang?

To probe the physics of the Particle, Electroweak and GUT era, we need to simulate the incredible temperatures of that era.

We cannot heat a gas to this temperature, but we can collide individual particles like protons or electrons accelerated to speeds near the speed of light.



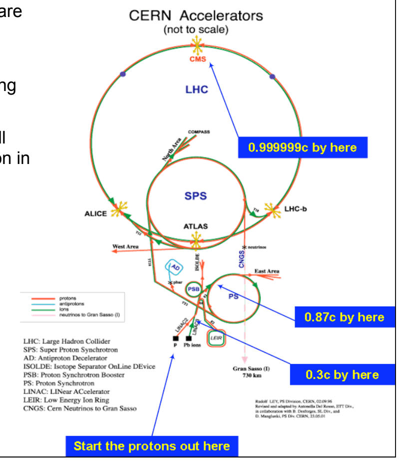
The Large Hadron Collider

When protons arrive in the LHC they are travelling at 0.999997828 times the speed of light.

Each proton goes around the 27km ring over 11,000 times a second.

A nominal proton beam in the LHC will have an energy equivalent to a person in a Subaru driving at 1700 kph.

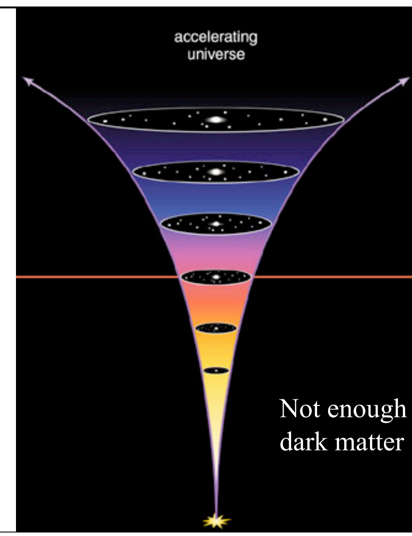
Equivalent to temperatures of 10^{17} K



Evidence for the Big Bang

- Why are the Galaxies expanding away from us and follow Hubble's law?
  - The observed expansion can be simply explained by the expansion of space. If we follow back that expansion, the density of matter increases dramatically.
- Why is the darkness of the night sky evidence for the Big Bang?
  - If the universe were eternal, unchanging, and everywhere the same, the entire night sky would be covered with stars
  - The night sky is dark because:
    - we can see back to a time when there were no stars
    - Cosmic expansion
- How do we observe the radiation left over from the Big Bang?
  - Radiation left over from the Big Bang is now in the form of microwaves—the cosmic microwave background—which we can observe with a radio telescope on the ground or from satellite.
  - Radiation gives us information on the curvature of the universe and the origin of structure (i.e. of clusters of galaxies and galaxies)
- How do the abundances of elements support the Big Bang theory?
  - Observations of helium and other light elements agree with the predictions for fusion in the Big Bang theory

Now the future of the Universe



The Arrow of Time

If I showed you a movie, you could tell me if I was playing that movie forward or in reverse. Time has a distinct direction.

Newton's laws, Relativity and Quantum Mechanics don't have an intrinsic arrow of time. If I showed you a movie of the planets going around the solar system, you would have a hard time deciding if I was showing forward or in reverse.

Consider two situations:

A ball falls to the ground. It bounces, but on each bounce, some of its kinetic energy is converted into heat energy, until it sits on the ground (conservation of energy).

Can the heat energy get absorbed by the ball and the ball fly into the air?

You put an ice cube in your water. The heat from the water is absorbed by the ice cube, and it melts the ice cube until you have a glass of water at one temperature.

Can an ice cube reform spontaneously by the heat energy leaving from a "cube" of water?

Entropy

Entropy is a measure of disorder in a system.

2nd law of Thermodynamics: Entropy always increases.

Processes in which entropy increases are called irreversible.

Examples:

As the ice cube melts, the entropy increases.

When ball hits ground and heats up and entropy increases.

Question: how does life form?

Answer: we can lower the entropy in one particular place by dumping entropy somewhere else. Entropy decreases locally, but total entropy increases in the universe.

Example: your refrigerator can reduce entropy locally and produce ice cubes, but it increases entropy in the universe (by heating up your house).

Entropy

If we think of that quantity which with reference to a single body I have called entropy, as formed in a consistent way, with consideration of all the circumstances, for the whole universe, and if we use in connection with it the other simpler concept of energy, we can express the fundamental laws of the mechanical theory of heat in the following simple form:

1. The Energy of the Universe is Constant
2. The Entropy of the Universe Tends towards a Maximum

Claussius 1865

What is the Future of the Universe?

Can we predict this using the laws of physics and our understanding of cosmic evolution?

Following lecture based on the paper: *A Dying Universe: The Long Term Fate and Evolution of Astrophysical Objects* by Fred Adams & Gregory Laughlin

Cosmological Decade

$$t = 10^{n}\ years$$

Courtesy F. C. Adams

Example: Decades on Seconds

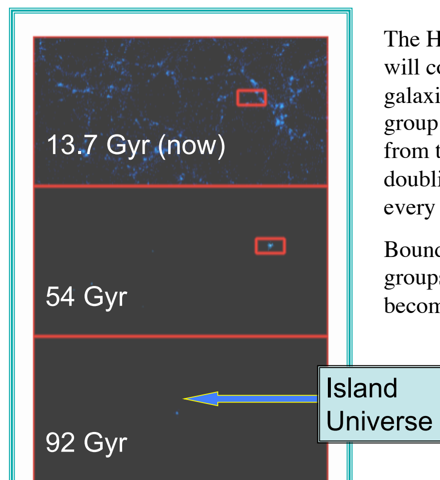
$t = 10^{n}$ seconds

Minute: n = 1.8
Hour: n = 3.6
Day: n = 4.3
Year: n = 6.88
Decade: n = 7.88
Century: n = 8.88
Millenium: n = 9.88

Five Ages of the Universe (from Adams and Laughlin 1996)

- Primordial Era n < 6
- Stelliferous Era n = 6 - 14
- Degenerate Era n = 14 - 40
- Black Hole Era n = 40 - 100
- Dark Era n > 100

Courtesy F. C. Adams



Courtesy F. C. Adams

The Hubble Expansion will continue and galaxies outside the local group will move away from the Earth, roughly doubling their distance every 13.7 Gyr

Bound clusters and groups of galaxies will become island universes.

Primordial Era

- The Big Bang
- Inflation
- Matter > Antimatter
- Quarks -> protons, neutrons
- Nuclear synthesis of the light elements
- Cosmic Microwave Background
- Universe continues to expand

The Stelliferous Era (n = 6 to 14)

- Stars dominate energy production
- Lowest mass stars of increasing importance
- Star formation and stellar evolution end near cosmological decade n = 14 when galaxies run out of gas to make new stars.

The Lifetime of Stars

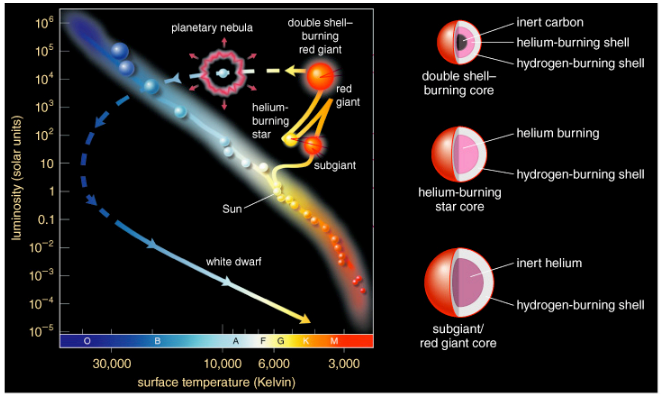
The lifetime of a star depends on its mass:

- An O star (40 solar masses) last a few million years
- The Sun (G star: 1 solar mass) will last 10 billion years.

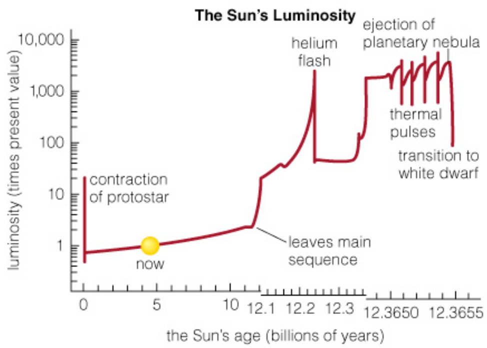
Most stars are low mass M stars (red dwarfs)

- Stars with masses with slightly less than the Sun (0.8 solar masses) have lifetimes equal to the age of the universe.
- A star with a mass 0.1 solar masses would have a lifetime of 10^{13} years (the universe is only 1.37 x 10^{10} years old)

The fate of the Earth: Life Track of a Sun-Like Star

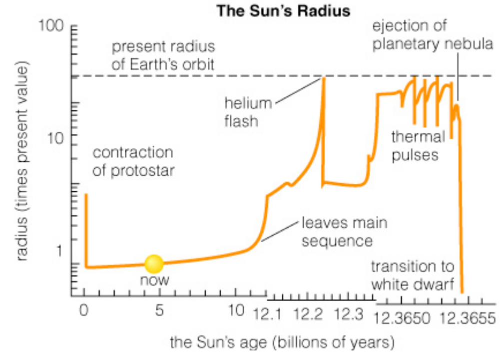


Earth’s Fate



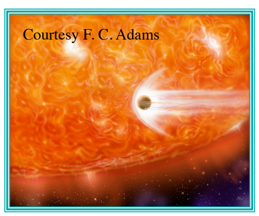
- While on the main sequence, the Sun’s luminosity will double. By this time, the Ocean’s will have evaporated.
- When Sun leaves the main sequence, its luminosity will rise to 1,000 times its current level—too hot for life on Earth

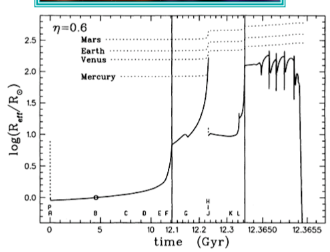
Earth’s Fate



- Sun’s radius will grow to near current radius of Earth’s orbit

Earth’s Fate



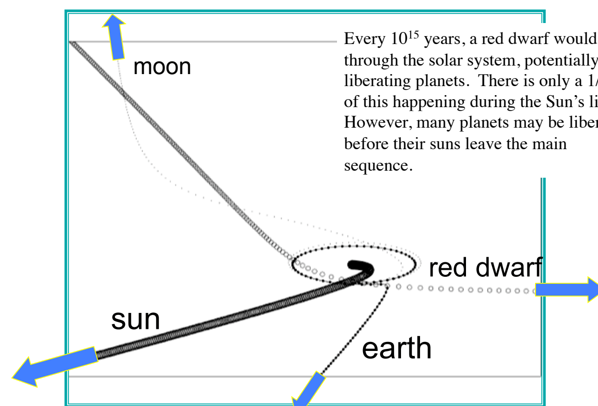


The hot death: earth is swallowed up by Sun. The drag will cause the orbit to decay, and the Earth will end up deep in side the Sun in 50 years.

The eventual cold death: during the red giant phase, the sun loses mass by strong stellar winds. As a result of the mass loss, the planets move outward. Although the planets are initially fried, they survive and orbit the white dwarf. The white dwarfs cool, and the planets freeze.

(Sackmann et al. 1993)

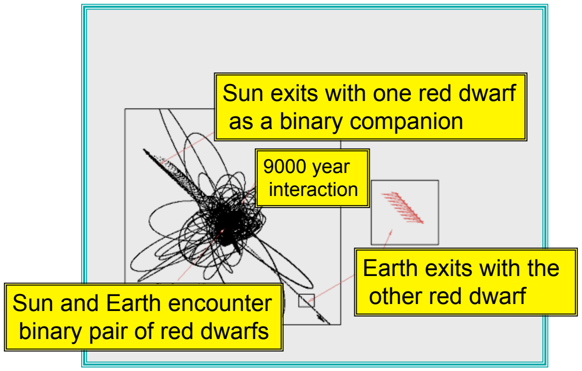
Red Dwarf saves the Earth



Every 10^{15} years, a red dwarf would pass through the solar system, potentially liberating planets. There is only a $1/10^5$ of this happening during the Sun’s life. However, many planets may be liberated before their suns leave the main sequence.

Courtesy F. C. Adams

Red dwarf captures the Earth



Courtesy F. C. Adams

Running out of Gas

Mass of gas in typical spiral is 10^{10} solar masses

Assume a few solar masses are converted into a star very year.

Approximately half of the mass ends up in a white dwarf or neutron star.

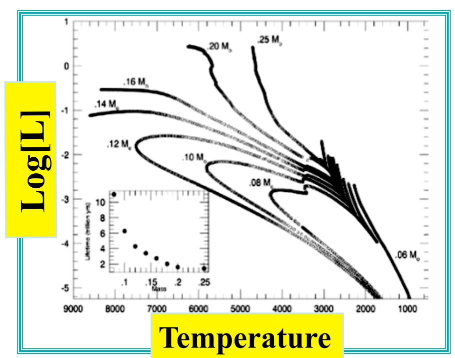
Star formation can continue for 10^{10} years

Star formation may continue for 10^{11} years if rate of star formation decreases with time.

At this point, there won't be enough gas for star formation, all matter locked up into degenerate matter.

Finally, the lowest mass stars will run out of hydrogen by n=14, thus ending the stelliferous era.

Long term Evolution of M (Red) Dwarfs



Courtesy F. C. Adams

The Degenerate Era (n=14-40)

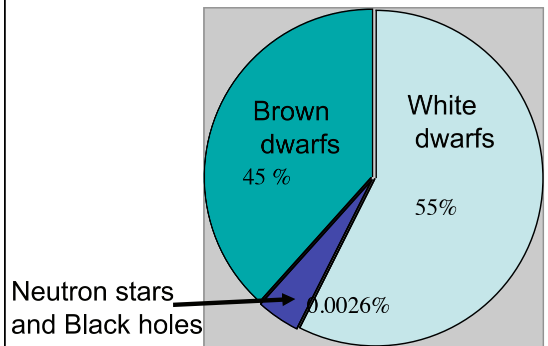
- Inventory includes Brown Dwarfs, White Dwarfs, Neutron Stars, and Black Holes
- Star formation through brown dwarf collisions
- White dwarfs capture dark matter particles
- Galaxy relaxes dynamically
- Black holes accrete stars, gas, and grow
- ***Era ends when Protons decay at cosmological decade n = 40***

Inventory of Degenerate Era

- Brown dwarfs (from brown dwarfs)
- White dwarfs (from most stars, M=0.08-8)
- Neutron stars (from massive stars M > 8)
- Stellar Black Holes (from the largest stars)

Courtesy F. C. Adams

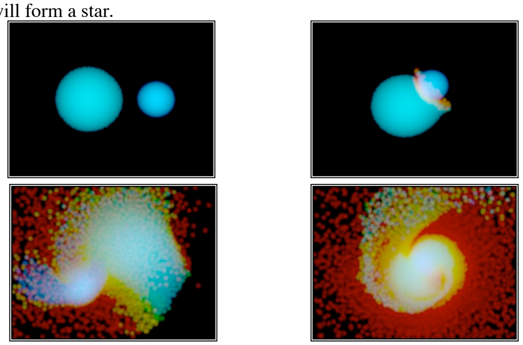
Inventory of the Degenerate Era



Courtesy F. C. Adams

Star Formation Through Brown Dwarf Collisions

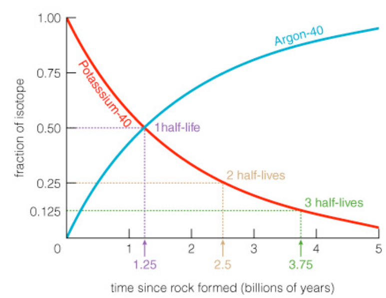
In our galaxy, a brown dwarf will collide with another brown dwarf every 10^{11} years. If the combined object will have more than 0.08 solar masses, it will form a star.



Courtesy F. C. Adams

J. Barnes

Brief Digression: Half Life of Radioactive Decay



A radioactive isotope of Potassium (40P) undergoes beta decay and changes into Argon

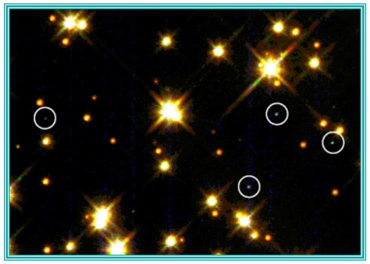
$^{40}P \dashrightarrow {}^{40}Ar + \beta$

Half life = 1.25 billion years ago

P is parent species
Ar is daughter species

Why is this important? WIMPS and Baryons Probably Decay

White Dwarfs of Degenerate Era Accrete WIMPS



White dwarfs capture WIMPS from our galaxies dark halo.
WIMPS decay and keep white dwarfs at 63 K.
Entire galaxy has only the luminonsity of our Sun.
However, WIMPS eventually annihilate each other, depriving white dwarfs of this energy.

The Death of Galaxies

Disk galaxies will “relax” into a new configuration:

1. some mass concentrated into center
2. most objects ejected outward

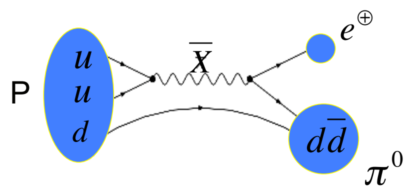
Objects in the center will accreted into large black holes.

The Milky Way and Andromeda

Proton Decay

- Many possible channels
- Half life is recklessly uncertain
- Experiments show that $n > 33$
- Theory implies that $n < 45$
- Dramatically changes the universe

Proton decay channel



Courtesy F. C. Adams

Proton Decay

Proton half life 10^{32} to 10^{41} years

Decay initially can power a white dwarf or neutron star.

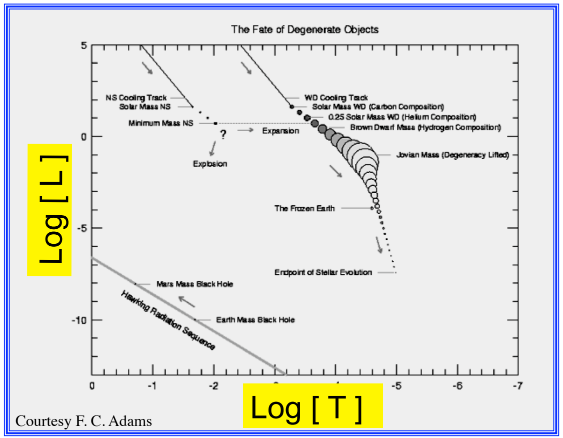
A White Dwarf would have luminosity of 400 W light bulb

What about the neutrons?

They would decay into protons (beta decay), the the protons would decay.

Over time, white dwarfs and neutrons stars would loose mass until they vanished………..

Fate of Degenerate Objects



Courtesy F. C. Adams

The Black Hole Era (n = 40-100)

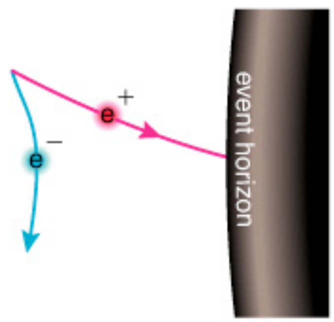
- Black holes are the brightest objects
- Generation of energy via Hawking radiation
- Every galaxy contributes one supermassive and about one million stellar black holes
- Black hole lifetime is mass dependent:

One solar mass:	n=65
Million solar mass:	n=83
Galactic mass:	n=98
Horizon mass:	n=131

$$\tau \propto M^3$$

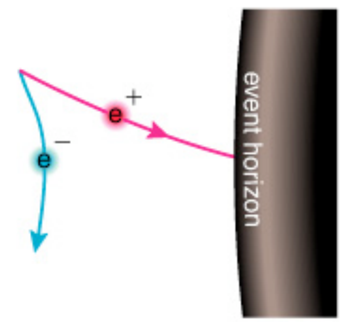
Courtesy F. C. Adams

Virtual Particles near Black Holes



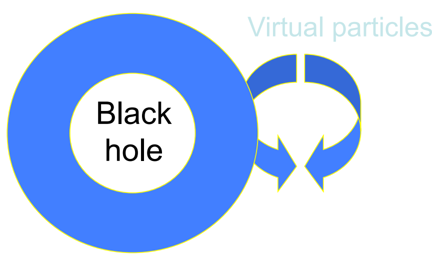
- Particles can be produced near black holes if one member of a virtual pair falls into the black hole
- Energy to permanently create other particle comes out of black hole's mass

Hawking Radiation



- Stephen Hawking predicted that this form of particle production would cause black holes to "evaporate" over extremely long time periods
- Only photons and subatomic particles would be left

Hawking Radiation



$$\lambda \approx GM \approx R_s$$

$$T_H = 1/(8\pi GM)$$

$$\tau = 10^{65}\,yr\,\left[M/M_o\right]^3$$

Courtesy F. C. Adams

The Dark Era

- No stellar objects of any kind
- Inventory of elementary particles: electrons, positrons, neutrinos, & photons
- Positronium formation and decay
- Low level annihilation

It may be even worse: The Big Rip

Dark energy accelerates the universe more and more.

10^{22} years, the big rip occurs - dark energy rips apart all matter

As time progresses, dark energy pulls apart the galaxy (60 Myr before rip), solar system (3 months), Earth explodes (30 minutes).

Unlikely given our understanding of dark energy.

Five Ages of the Universe (from Adams and Laughlin 1996)

- Primordial Era n < 6

(the formation of galaxies)

- Stelliferous Era n = 6 - 14

(the current epoch of star formation and recycling - ends when star formation uses up gas & lowest mass stars finally run out hydrogen)

- Degenerate Era n = 14 - 40

(brown dwarf collisions and decaying WIMPS may produce energy - ended by proton decay)

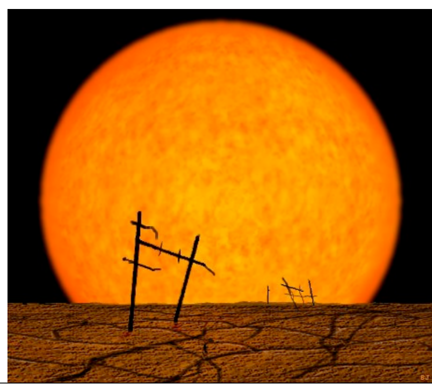
- Black Hole Era n = 40 - 100

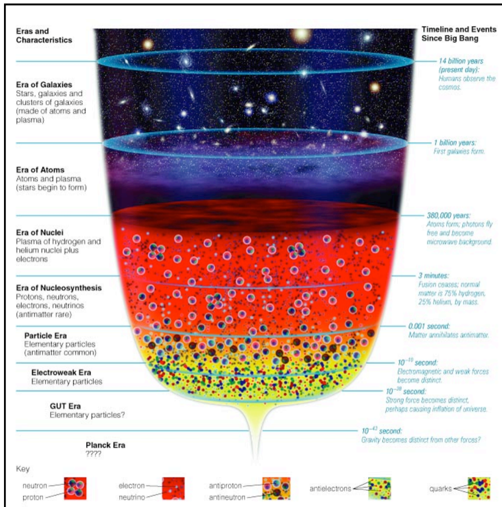
(black holes evaporate due to Hawking radiation)

- Dark Era n > 100

(it's as bleak as it sounds!)

Lecture 22: Death and Taxes:
Science Funding & The Fate of the Earth and Universe
A2020 Prof. Tom Megeath





Review:

The different Eras of the Universe

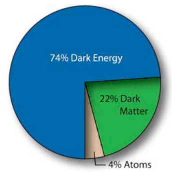
Around 300,000 after the big band, the universe cooled to the points that atoms formed from a hot gas of electrons and protons

(we'll look at this in more detail in the next lecture)

Contents of Universe

Current data indicate the following breakdown:

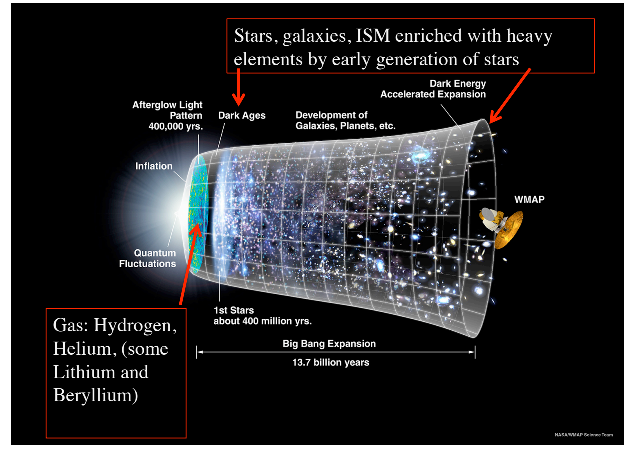
- "Normal" Matter: ~ 4.4%
  - Normal Matter inside stars: ~ 0.6%
  - Normal Matter outside stars: ~ 3.8%
- Dark Matter: ~ 22%
- Dark Energy ~ 75%

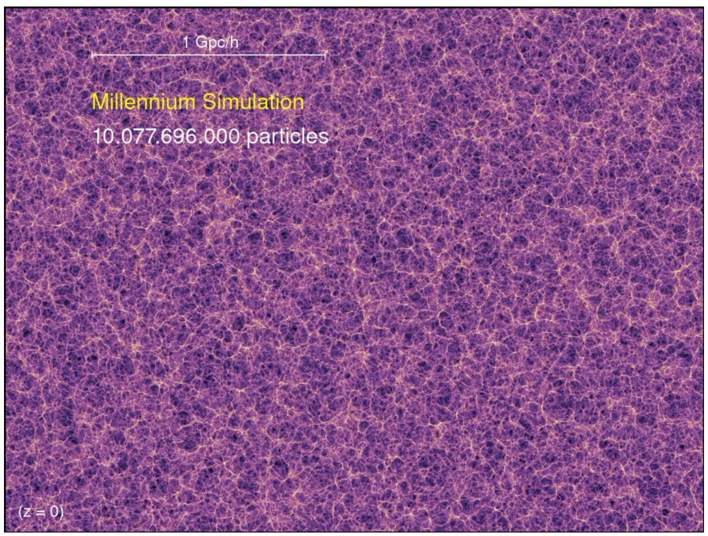


Density of Baryonic Matter + Dark Matter + Dark Energy = Critical Density

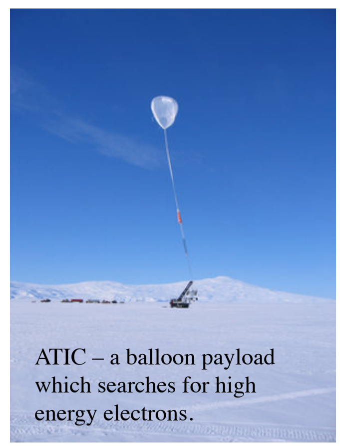
The Universe appears to be Flat (or very close to Flat) !!!

An Overview of the History of the Universe





New Evidence for WIMPS



Weakly Interacting Massive Particles

Thought to be Dominant form of matter in galaxy (by mass)

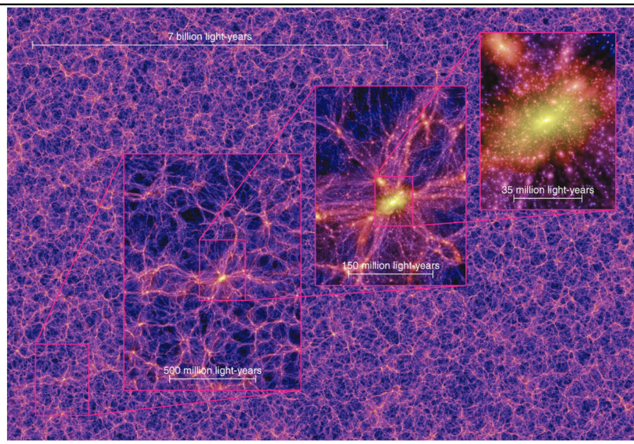
Does not interact (much) with light or "normal" baryonic matter

Can only interact through the weak force

They may decay

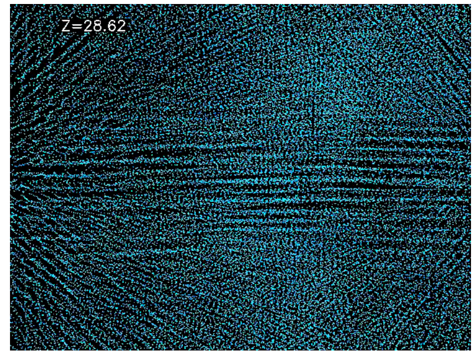
WIMPs have never been detected, yet….

An unusual number of higher energy electrons detected by ATIC can be explained by the decay of WIMPS into positron and electron pairs.



Structures in galaxy maps look very similar to the ones found in models in which dark matter is WIMPs

February -December: Formation and Evolution of Local Group

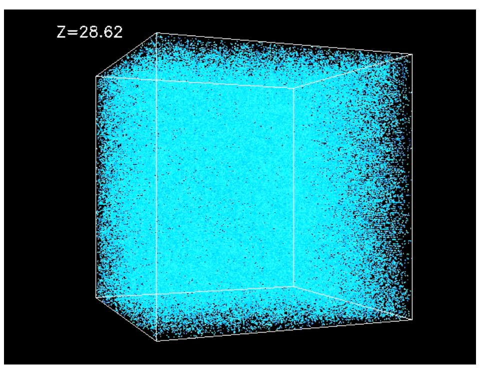


Formation of a group of galaxies like the local group:

Galaxy formation is a dynamic process in which big galaxies cannibalize smaller galaxies.

http://cosmicweb.uchicago.edu/filaments.html

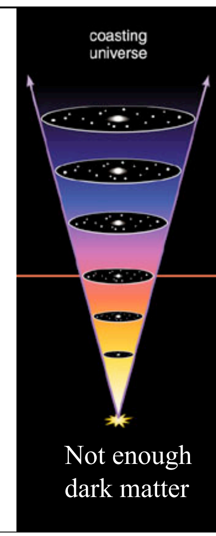
Formation of Galaxies



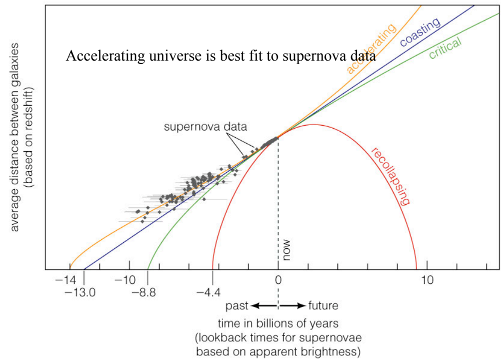
http://cosmicweb.uchicago.edu/filaments.html

The Universe will Expand Forever:

Amount of dark matter is ~25% of the critical density suggesting fate is eternal expansion



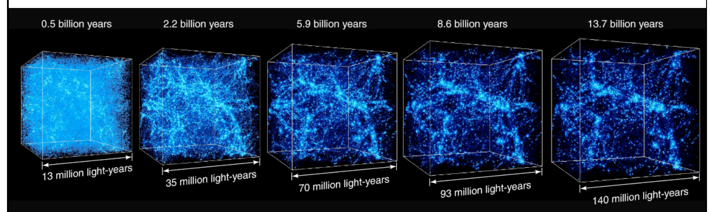
The Expansion Appears to be Accelerating



Dark Energy: An unknown form of energy that seems to be the source of a repulsive force causing the expansion of the universe to accelerate

Time in billions of years

0.5 2.2 5.9 8.6 13.7

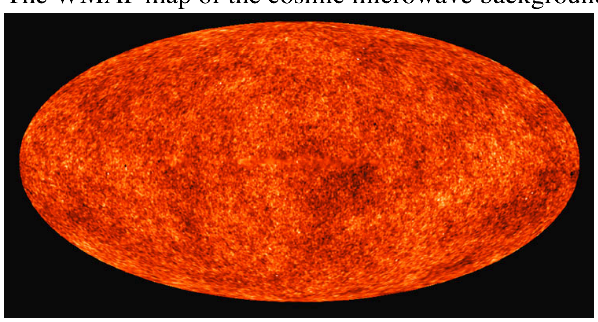


13 35 70 93 140

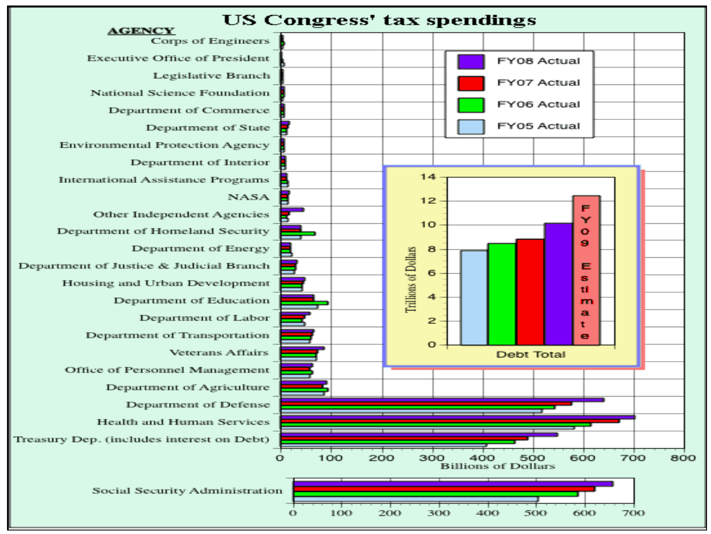
Size of expanding box in millions of lt-yrs

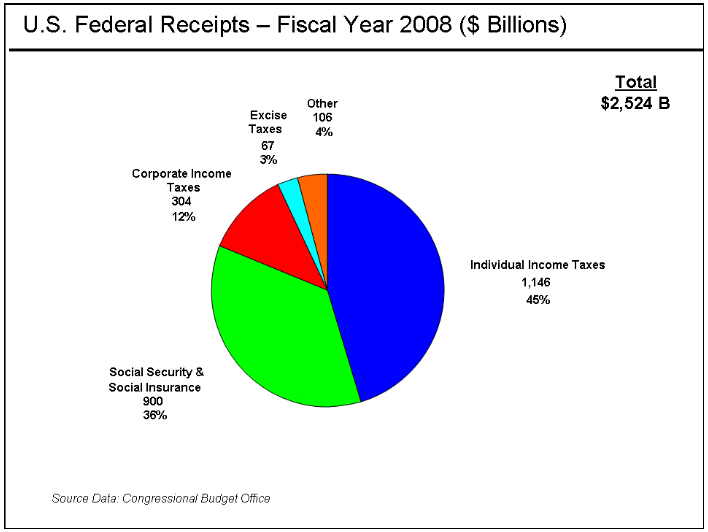
Models show that gravity of dark matter pulls mass into denser regions – universe grows lumpier with time

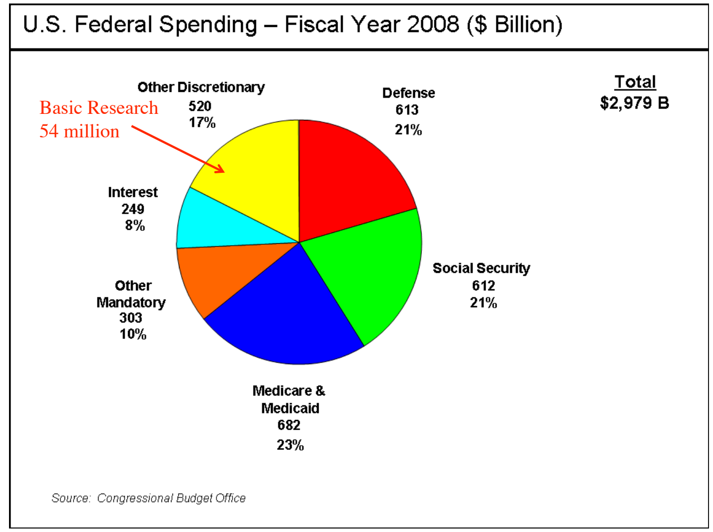
The WMAP map of the cosmic microwave background

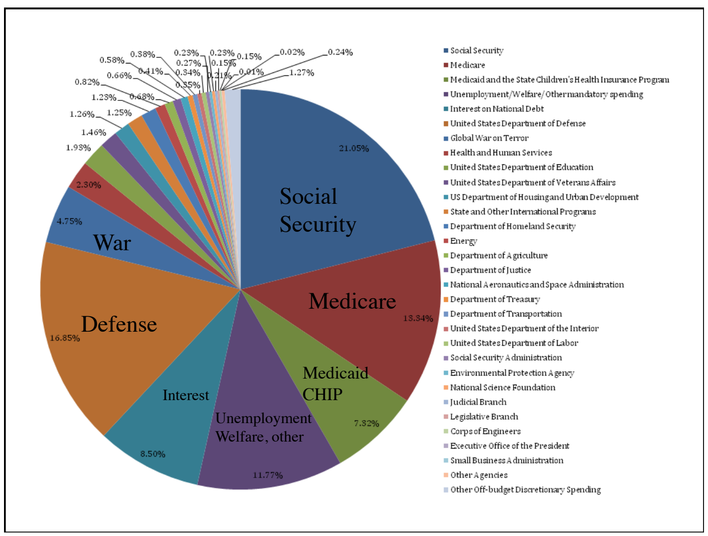


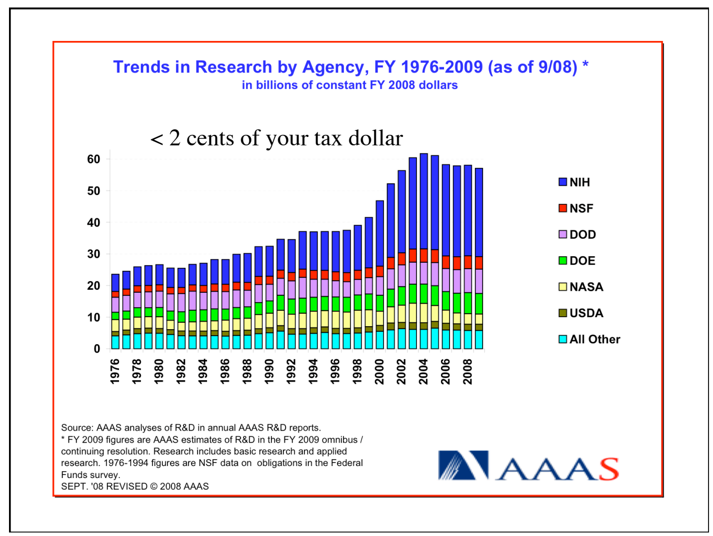
1. The cosmic microwave background is not perfectly smooth
2. The tiny ripples are due to tiny variations in the *temperature* of the cosmic microwave background..
3. These variations are due to slight variations in the density of matter.
4. Areas with higher density can collapse through gravity and form galaxies.
5. The ripples in this maps are the seeds that formed galaxies.




U.S. Federal Receipts – Fiscal Year 2008 ($ Billions)
Total
$2,524 B
Other
106
4%
Excise
Taxes
67
3%
Corporate Income
Taxes
304
12%
Individual Income Taxes
1,146
45%
Social Security &
Social Insurance
900
36%
Source Data: Congressional Budget Office


U.S. Federal Spending – Fiscal Year 2008 ($ Billion)
Total
$2,979 B
Basic Research
54 million
Other Discretionary
520
17%
Defense
613
21%
Interest
249
8%
Social Security
612
21%
Other
Mandatory
303
10%
Medicare &
Medicaid
682
23%
Source: Congressional Budget Office


Social
Security
21.05%
Medicare
13.34%
Medicaid
CHIP
7.32%
Unemployment
Welfare, other
11.77%
Interest
8.50%
Defense
16.85%
War
4.75%
Social Security
Medicare
Medicaid and the State Children's Health Insurance Program
Unemployment/Welfare/Othermandatory spending
Interest on National Debt
United States Department of Defense
Global War on Terror
Health and Human Services
United States Department of Education
United States Department of Veterans Affairs
US Department of Housingand Urban Development
State and Other International Programs
Department of Homeland Security
Energy
Department of Agriculture
Department of Justice
National Aeronautics and Space Administration
Department of Treasury
Department of Transportation
United States Department of the Interior
United States Department of Labor
Social Security Administration
Environmental Protection Agency
National Science Foundation
Judicial Branch
Legislative Branch
Corps of Engineers
Executive Office of the President
Small Business Administration
Other Agencies
Other Off-budget Discretionary Spending


Trends in Research by Agency, FY 1976-2009 (as of 9/08) *
in billions of constant FY 2008 dollars
< 2 cents of your tax dollar
NIH
NSF
DOD
DOE
NASA
USDA
All Other
Source: AAAS analyses of R&D in annual AAAS R&D reports.
* FY 2009 figures are AAAS estimates of R&D in the FY 2009 omnibus / continuing resolution. Research includes basic research and applied research. 1976-1994 figures are NSF data on obligations in the Federal Funds survey.
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FY 2009 Budget Request

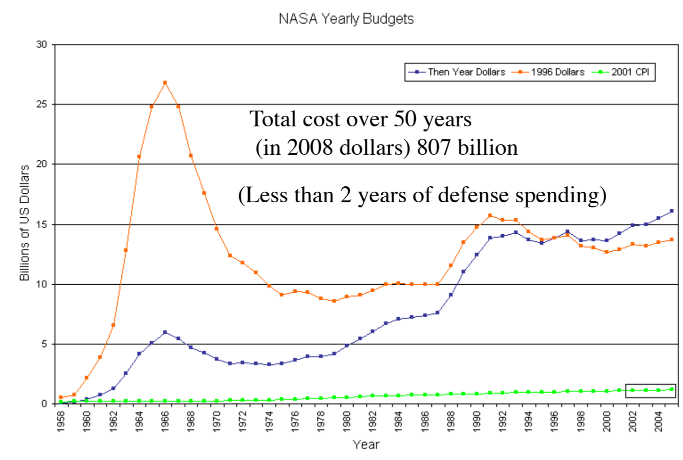
Budget Authority, $ in millions By appropriation account By Theme	FY 2007	FY 2008	FY 2009	FY 2010	FY 2011	FY 2012	FY 2013
Science	**$4,609.9**	**$4,706.2**	**$4,441.5**	**$4,482.0**	**$4,534.9**	**$4,643.4**	**$4,761.6**
Earth Science	$1,198.5	$1,280.3	$1,367.5	$1,350.7	$1,250.9	$1,264.4	$1,290.3
Planetary Science	$1,215.6	$1,247.5	$1,334.2	$1,410.1	$1,537.5	$1,570.0	$1,608.7
Astrophysics	$1,365.0	$1,337.5	$1,162.5	$1,122.4	$1,057.1	$1,067.7	$1,116.0
Heliophysics	$830.8	$840.9	$577.3 *	$598.9	$689.4	$741.2	$746.6
Aeronautics	**$593.8**	**$511.7**	**$446.5**	**$447.5**	**$452.4**	**$456.7**	**$467.7**
Exploration	**$2,869.8**	**$3,143.1**	**$3,500.5**	**$3,737.7**	**$7,048.2**	**$7,116.8**	**$7,666.8**
Constellation Systems	$2,114.7	$2,471.9	$3,048.2	$3,252.8	$6,479.5	$6,521.4	$7,080.5
Advanced Capabilities	$755.1	$671.1	$452.3	$484.9	$568.7	$595.5	$586.3
Space Operations	**$5,113.5**	**$5,526.2**	**$5,774.7**	**$5,872.8**	**$2,900.1**	**$3,089.9**	**$2,788.5**
Space Shuttle	$3,315.3	$3,266.7	$2,981.7	$2,983.7	$95.7	$0.0	$0.0
International Space Station	$1,469.0	$1,813.2	$2,060.2	$2,277.0	$2,176.4	$2,448.2	$2,143.1
Space and Flight Support (SFS)	$329.2	$446.3	$732.8 *	$612.1	$628.0	$641.7	$645.4
Education	**$115.9**	**$146.8**	**$115.6**	**$126.1**	**$123.8**	**$123.8**	**$123.8**
Cross-Agency Support	**$2,949.9**	**$3,242.9**	**$3,299.9**	**$3,323.9**	**$3,363.7**	**$3,436.1**	**$3,511.3**
Center Management and Operations	$1,754.9	$2,013.0	$2,045.6	$2,046.7	$2,088.0	$2,155.3	$2,211.6
Agency Management and Operations	$971.2	$830.2	$945.6	$945.5	$939.8	$950.5	$961.3
Institutional Investments	$223.8	$319.7	$308.7	$331.7	$335.9	$330.4	$338.3
Congressionally Directed Items	$0.0	$80.0	$0.0	$0.0	$0.0	$0.0	$0.0
Inspector General	**$32.2**	**$32.6**	**$35.5**	**$36.4**	**$37.3**	**$38.3**	**$39.2**
*FY08 Rescission***		*($192.5)*					
NASA FY 2009	**$16,285.0**	**$17,116.9**	**$17,614.2**	**$18,026.3**	**$18,460.4**	**$18,905.0**	**$19,358.8**
Year to Year Change		5.1%	2.9%	2.3%	2.4%	2.4%	2.4%

Budgets include all direct costs required to execute the programs. Indirect costs are now budgeted within Cross-Agency Support.

* Deep Space and Near Earth Networks Transfer ($256M) to SFS in FY 2009
** FY08 Appropriation rescinded $192.475M in prior-year unobligated balances, effectively reducing FY 2008 authority.

FY08 budgets are the enacted levels per the Agency's FY 2009 Budget Estimates. Totals may not add due to rounding

5



This is a lot of money, but the achievements were considerable over the last 50 years.

•Putting first satellites in space (leading to weather satellites, communication satellites, GPS, etc)

•Manned exploration of space, landing people on the Moon

•Exploration of Solar System

•Earth sensing and discovery of the Ozone hole

•Space astronomy

•Space shuttle and space station – understanding effects of space environments on humans

•Development of numerous technologies (from solar cells to ear thermometers)