

## Cosmology: Part II

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- A. Distant Supernovas & Dark Energy
- B. Cosmic Background Radiation
- C. Cosmogony

Updated June 6, 2007

## Accelerating Universe

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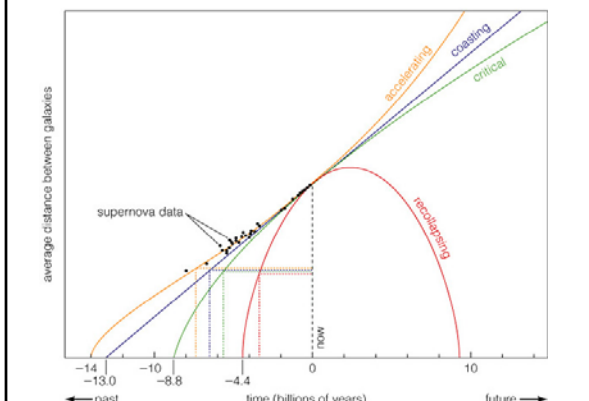
Recent Evidence suggest universe is accelerating (i.e. expanded slower in past)

If the universe is "coasting" then gravitational attraction should be slowing it down.

What is adding energy to make it expand faster? (what is the "repulsive" force?)

## C2. Distant Supernova Data

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## C3. Dark Energy

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How do we explain this?

- Propose Universe is
  - 4% normal stuff
  - 23% weird dark matter
  - 73% "DARK ENERGY"



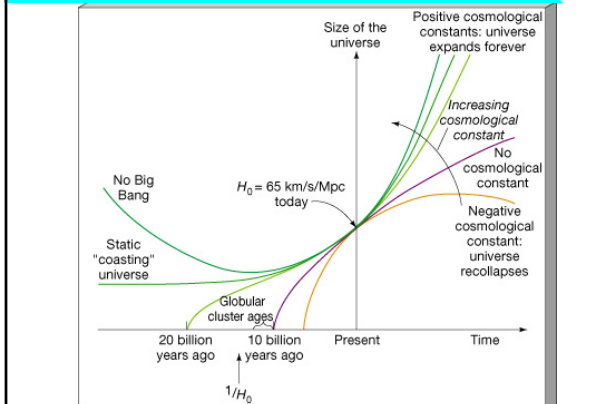
The Dark Energy provides the negative pressure.

**But is the universe really 96% weird stuff?**

• Alternative: Revive Einstein's Cosmological Constant?

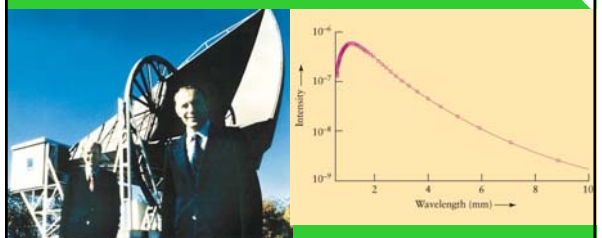
## C4. Possible Models

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## D1. Cosmic Background Radiation

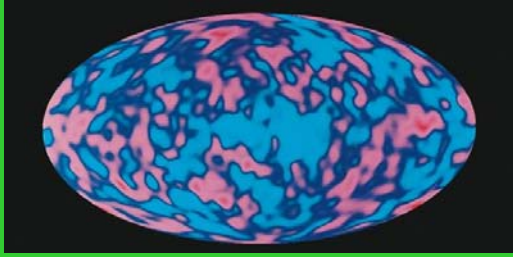
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1960 Penzias & Wilson measure it, get Nobel Prize in 1978. It was predicted in 1948 by Alpher, Bethe and Gamow in a famous paper, that there would be leftover radiation after the big bang explosion, corresponding to a black body curve at 3000 degrees. Today its at 3 degrees, telling us the universe has expanded 1000x since that time.

## D2. COBE Data

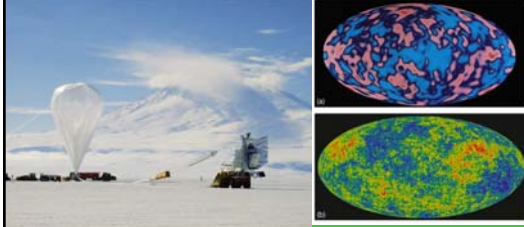
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1989 COBE data shows afterimage of the expanding fireball (i.e. "photosphere") of the Big Bang explosion. The size of the irregularities (in temperature) is consistent with later formation of galaxies.

## D3. Boomerang Data

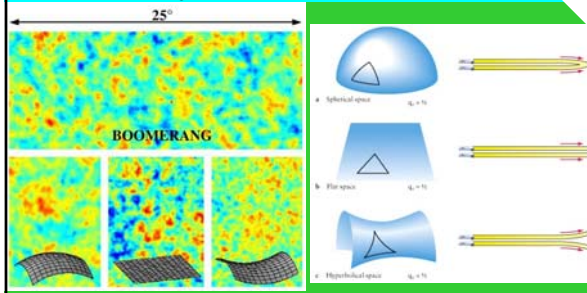
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2003 Boomerang experiment improved resolution by factor of 35x. Shows the irregularities are about 1 degree in size. This is exactly the size predicted for a flat universe.

## D4. CBR says Flat Universe

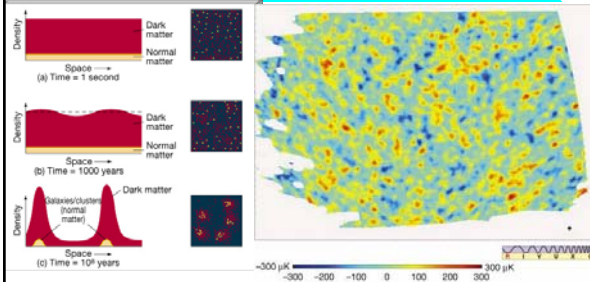
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Theory predicts irregularities should be 1 degree in size (why?). If the universe was positive curved, the irregularities would appear bigger than 1 degree. Since they appear exactly as 1 degree, the universe is flat.

## D4. Galaxy Formation

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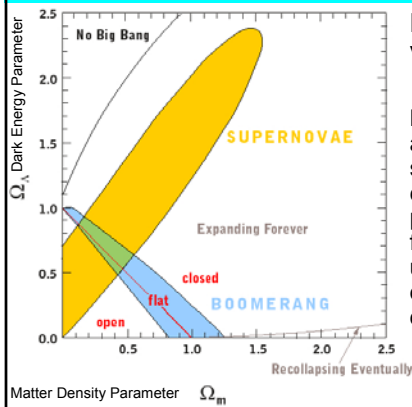


Irregularities led to the formation of galaxies.

- Size of irregularities tell us the universe is "flat"
- In order for galaxies to form, there must be dark matter to aid in the contraction, else the gravity isn't strong enough!

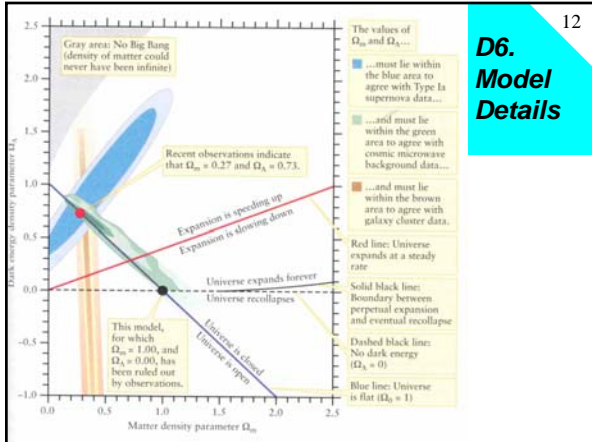
## D5. Possible Models

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Dark Energy vs Matter.

Boomerang and distant supernova data constrain the possibilities to a flat open universe, dominated by dark energy



## D6. Model Details

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## Cosmogony

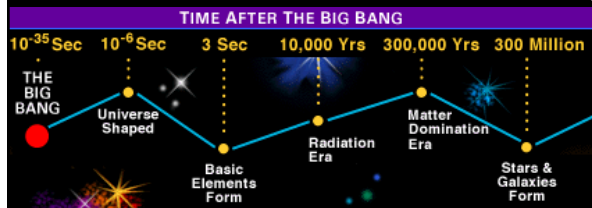
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Cosmogony is any theory concerning the coming into existence or origin of the universe, or an origin belief about how reality came to be.

The word comes from the Greek κοσμογονία (or κοσμογενία), from κόσμος "cosmos, the world", and the root of γί(γ)νομαι / γέγονα "to be born, come about".

## Cosmogony Overview

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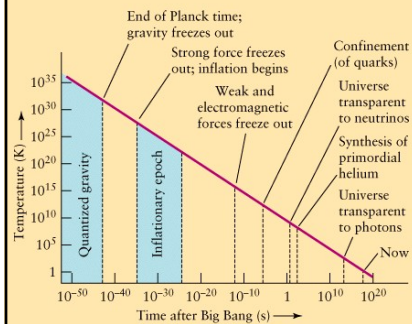


We divide it into 4 eras

1. Planck Era
2. Radiation Era
3. Matter Era
4. Dark Energy Era

## Eras of the Universe

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As universe expands, it cools. At certain critical temperatures things happen.

## 0. Cosmogenesis

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First Cause: what caused the big bang?

If space and **time** was created at the big bang, then can we talk about before the big bang?

Violation of Conservation laws: how can something come from nothing?

## 1. Planck Era

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Due to Quantum Mechanics, in the first instance after the big bang, the universe is so small that space is not "smooth", but granular

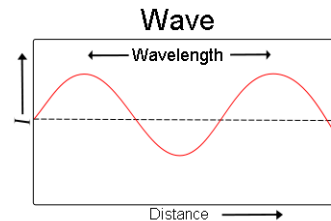
Time is not continuous, but broken into small chunks. Time "ticks" between these chunks rather than "flows".

Because of this, the universe might be stuck in a "quantum quagmire" in the first tick for an indeterminate time.

## 1b. Quantum Size

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Quantum mechanics says particles are really waves, with wavelength size  $\lambda = h/mc$



The electron for example is  $2.4 \times 10^{-12}$  meters  
A particle 2x more massive would be 2x smaller

**1c. Quantum Size** 19

For example, assuming the universe was expanding at the speed of light, then the entire universe was smaller than a single electron in the first  $10^{-20}$  seconds (0.000,000,000,000,000,01 seconds)

If we used a more massive fundamental particle, then the size and time would be smaller

**1d. Planck Size** 20

If we assume a big enough particle, then its small size would make it a black hole.

Set wavelength= Schwarzschild Radius

Results in:

- No particle bigger than Planck mass  $5.5 \times 10^{-8}$  kg
- Smallest Size: Planck Length  $10^{-35}$  meters
- Smallest Time: Planck Time  $10^{-43}$  seconds
- Temperatures above  $10^{32}$  degrees make no sense

**2. Gravitational Era** 21

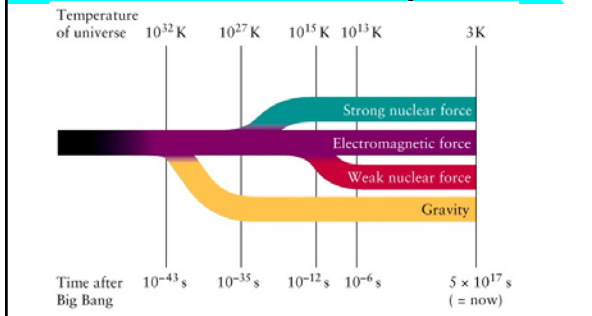
From  $10^{-43}$  to  $10^{-35}$  seconds the universe expands.

Gravity is opposing the expansion, so the universe loses energy. This causes it to cool from  $10^{32}$  to  $10^{27}$  K.

The expansion obeys:

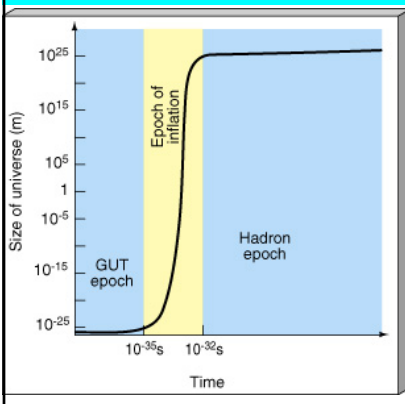
- Temperature  $\propto 1/\text{size}$
- Size  $\propto \text{Time}^{1/2}$

**3a Radiation Era: GUT Epoch** 22



In the Planck Era ( $< 10^{-43}$  sec) all the forces are in equilibrium. Afterwards, Gravity separates out from the other forces and dominates. [GUT=Grand Unified Theory]

**3b Radiation Era: Inflation Epoch** 23



Why is the Universe so perfectly flat?

Blamed on "Inflation" of Universe

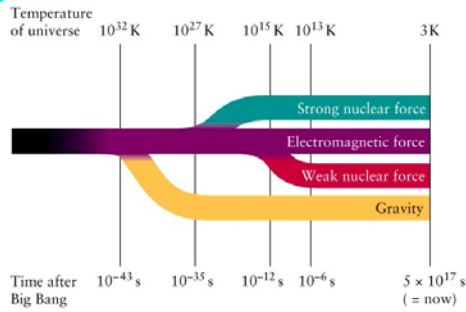
**3c Inflation associated with quarks** 24

At  $10^{-35}$  seconds the universe cooled to  $10^{27}$  K.

This is the critical temperature at which quarks can form.

Quarks are the fundamental particles from which protons and neutrons are made.

### 3d Radiation Era: Electroweak Epoch 25



At  $10^{-35}$  seconds strong force separates out (inflation), at  $10^{-12}$  seconds electric splits from weak force.

### 3e Electrons and Neutrinos 26

At  $10^{-12}$  seconds the universe cooled to  $10^{15}$  K.

This is the critical temperature at which electrons and neutrinos are formed

Below this temperature, electromagnetic force separates from the “weak” force.

Above this temperature, they act together as the “electroweak force”

### 3f Protons and Neutrons 27

At  $10^{-6}$  seconds the universe cooled to  $10^{12}$  K.

This is the critical temperature at which quarks can stick together and make protons & neutrons

Proton: up+up+down quarks

Neutron: up+down+down quarks

### 4a Where is all the antimatter? 28

The universe should be completely symmetric with just as much matter as antimatter.

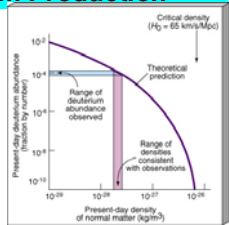
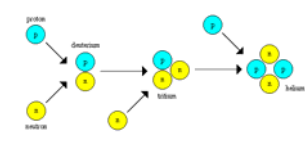
1 sec: neutrinos are set free at  $10^{10}$  K

15 sec: ( $3 \times 10^9$  K) electrons and positrons (antielectrons) would annihilate each other. It’s a mystery why there are electrons left over.

And why is the number of electrons just about equal to the number of protons so that the universe is neutral?

### E5 Hadron Epoch: Helium Production 29

**Nucleosynthesis**  
as the Universe cools, protons and neutrons can fuse to form heavier atomic nuclei



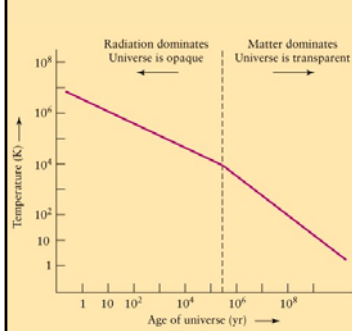
At about 1 minute after the big bang, it was cool enough for neutrons to stick to protons. Deuterium and helium is made, but only a few minutes later the universe cooled so that it stopped with about 25% of hydrogen converted to helium. Today the ratio of Deuterium to hydrogen (e.g. on the moon) tells us about this phase of the universe.

### E6 Summary of Radiation Era 30

TABLE 27.1 Major Epochs in the History of the Universe

Era	Epoch	Time (after Big Bang)	Density (kg/m <sup>3</sup> )	Temperature (K)	Main Events	
Radiation Era	Planck	0 s	$\infty$	$\infty$	Unknown physics; quantum gravity	
	GLUT	$10^{-43}$ s	$10^{95}$	$10^{32}$	Strong, weak, and electromagnetic forces unified	
	Hadron	$10^{-35}$ s	$10^{75}$	$10^{27}$	Heavy and light particles all in thermal equilibrium	
	Lepton	$10^{-4}$ s	$10^{16}$	$10^{12}$	Only light particles still in thermal equilibrium; neutrinos decouple	
	Nuclear		$10^2$ s	$10^4$	$10^9$	Deuterium and helium formed by fusion of protons and neutrons during first 1000s
			$10^3$ yr ( $\approx 3 \times 10^{10}$ s)	$10^{-13}$	$6 \times 10^4$	

## E7 CBR: where did it come from 31



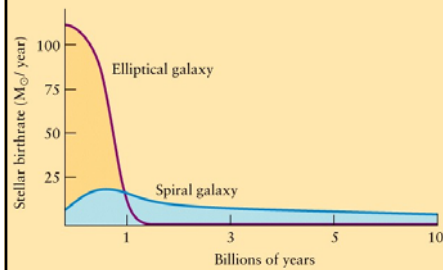
About 300,000 years after the universe formed, it expanded to the point where the temperature dropped below 3000 degrees. Electrons combined with protons to make neutral atoms. The universe became transparent.

## E8 Matter Era Summary 32

TABLE 27.1 Major Epochs in the History of the Universe

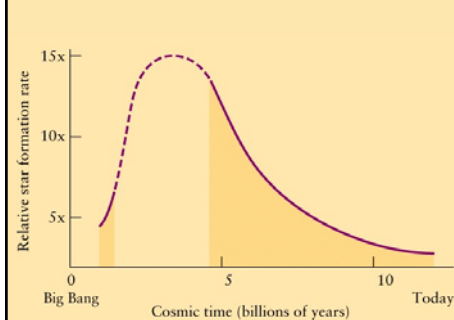
Era	Epoch	Time (after Big Bang)	Density (kg/m <sup>3</sup> )	Temperature (K)	Main Events
Matter Era	Atomic	$10^3$ yr ( $\approx 3 \times 10^{10}$ s)	$10^{-13}$	$6 \times 10^4$	Matter begins to dominate; atoms form; electromagnetic radiation decouples
	Galactic	$10^8$ yr ( $\approx 3 \times 10^{13}$ s)	$10^{-19}$	$10^3$	
	Stellar	$10^9$ yr ( $\approx 3 \times 10^{16}$ s)	$3 \times 10^{-25}$	10	Galaxies and larger-scale structure form
		$> 10^{10}$ yr ( $3 \times 10^{17}$ s)	$10^{-26}$	3	All galaxies have formed; stars continue to form

## E9 Matter Era: Galaxy Formation 33



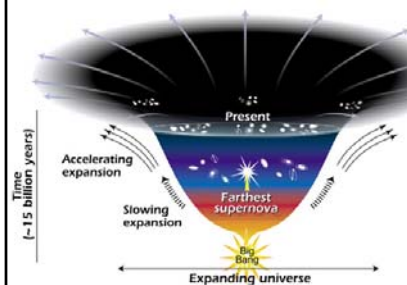
Million to Billion years after big bang, large scale structure forms, and matter condenses into blobs that will eventually evolve into galaxies.

## E10 Matter Era: Star Formation 34



Star formation continues in galaxies to the present.

## E11 Dark Energy Era 35



Universe has just become dominated by the Dark Energy, causing acceleration of expansion.

This diagram reveals changes in the rate of expansion since the universe's birth 15 billion years ago. 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 at a faster rate. Astronomers theorize that the faster expansion rate is due to a mysterious, dark force that is pushing galaxies apart.

## Things to do

- Things to do
- Spectra observation
- Lookback time animations
- More movies on galaxy formation?
- Fix outline structure of part II
- How about solving for when universe was size of an electron? Quark? Is this related to the times that phase transitions took place, or is it more of a mass issue?