

The big bang – is it true?

Theory, models and evidence in 20th century physics



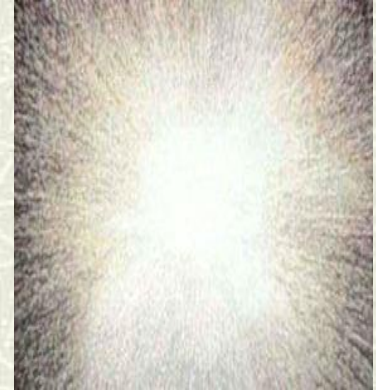
Cormac O'Raifeartaigh FRAS (WIT)

Overview

The big bang model

U was once superdense and superhot

Expanding and cooling over time



The evidence

The runaway galaxies; the abundance of the elements

The distribution of the galaxies; the background radiation



The theory

Cosmology and the general theory of relativity

What does a historian do?

Review how models develop

Consider roads not taken



1st evidence: Hubble's law

- The recession of the galaxies
- Linear relation between redshift (velocity) and distance
- Hubble's Law (1929)

*Far-away galaxies rushing away
at a speed proportional to distance*

Velocity-Distance Relation among Extra-Galactic Nebulae.

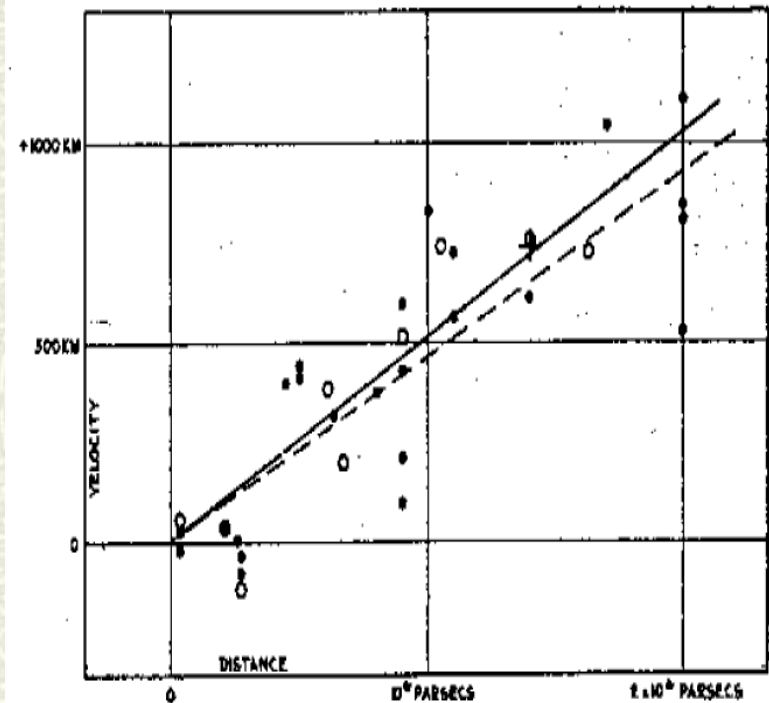


FIGURE 1

$$v = H_0 d$$

Motion of galaxies: redshift

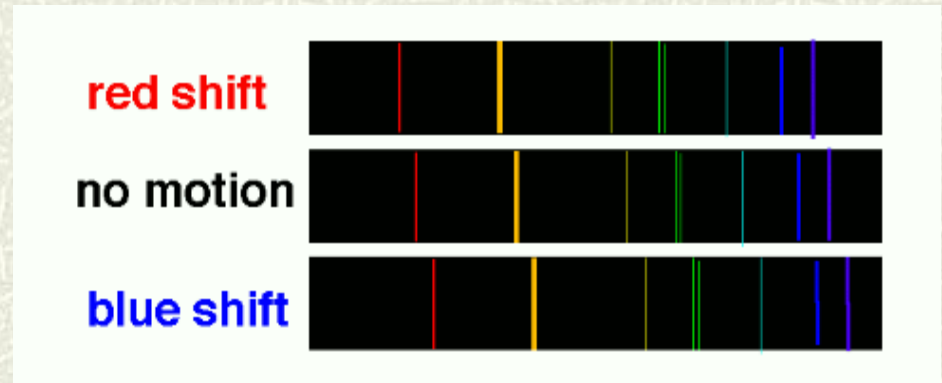
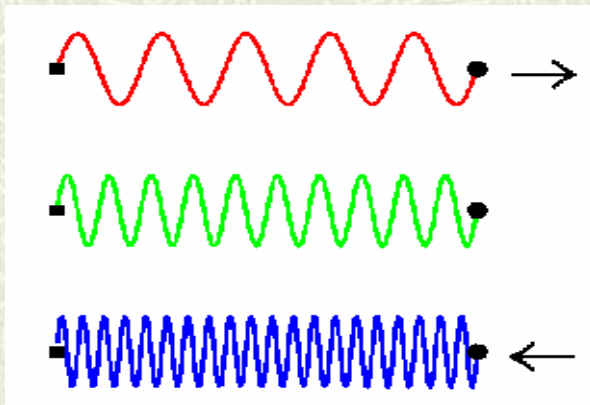


Vesto Slipher (1915)

frequency of light depends on
motion of source relative to observer

Doppler Effect

measure motion of stars and galaxies
from light emitted

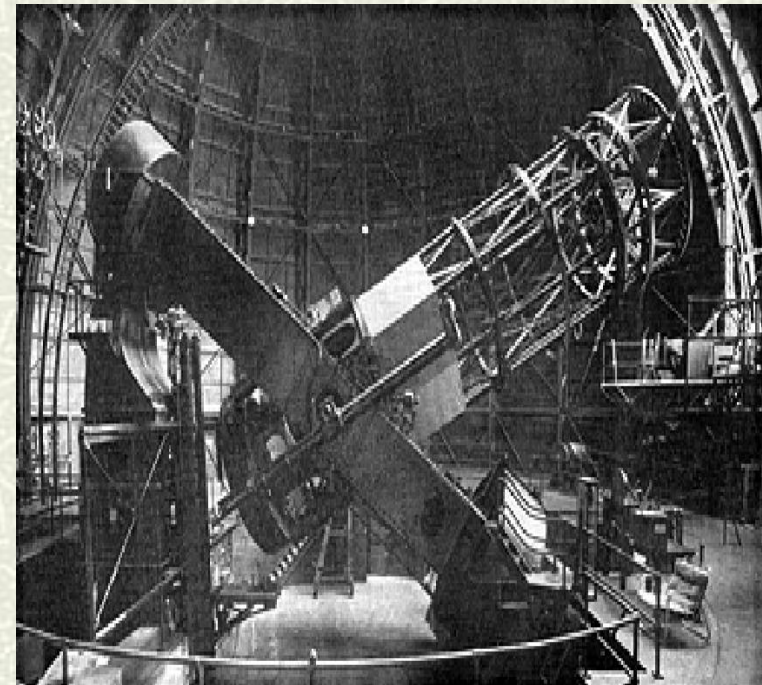


The distance of the galaxies



Edwin Hubble

- Identification of Cepheid variables stars in spiral nebulae (1925)
- Use of Leavitt period-luminosity method
- Nebulae far beyond Milky Way
- Distinct galaxies



Explanation for runaway galaxies?

Newton

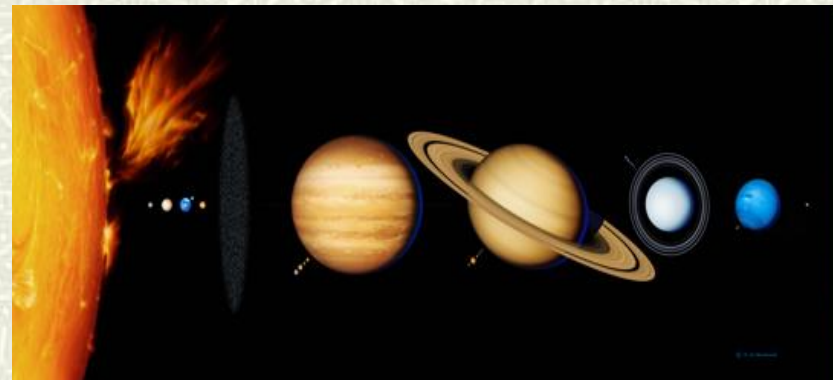
- Gravity pulls in not out
- Space is fixed



Isaac Newton

How can galaxies be receding?

What is pushing out?



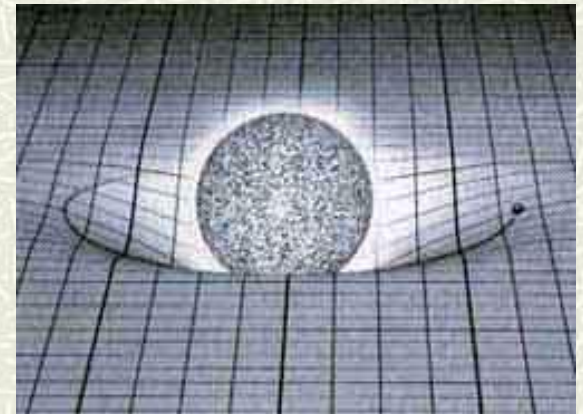
Modern theory of gravity

General theory of relativity (Einstein, 1915)

- space + time not fixed
- spacetime
- affected by motion
- affected by mass

$$G_{\mu\nu} = -kT_{\mu\nu}$$

gravity = curvature of space-time



Relativistic cosmology



Alexander Friedman
(1888 -1925)

Alexander Friedman (1922)

Time-varying solutions for the cosmos
Expanding or contracting universe

Evolving universe

Time-varying radius and density of matter
Rejected by Einstein

Georges Lemaître (1927)

Relativistic universe of expanding radius
Agreement with emerging astronomical data
Also rejected by Einstein



Georges Lemaître
(1894-1966)



Why?

The paradigm shift (1930)

- **RAS meeting (1930)**

Eddington, de Sitter

If redshifts are velocities and effect is non-local

- **Hubble's law = expansion of space?**

Static models don't fit data

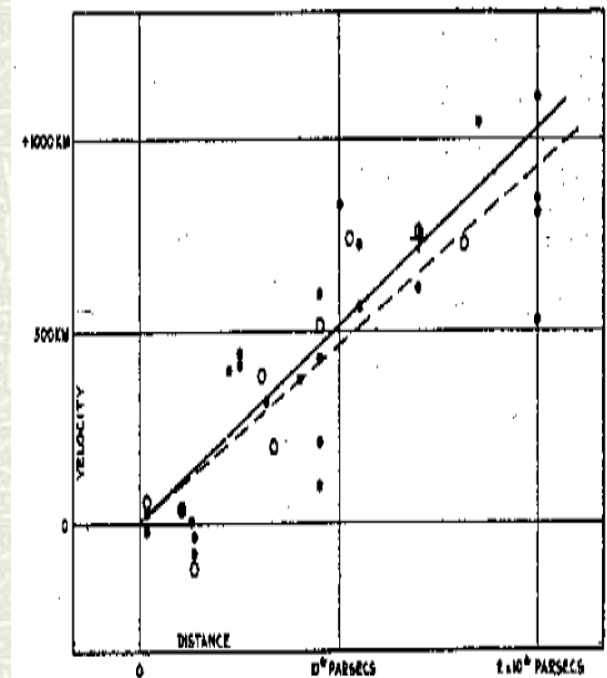
Dynamic relativistic models required

- **Friedman-Lemaître models accepted**

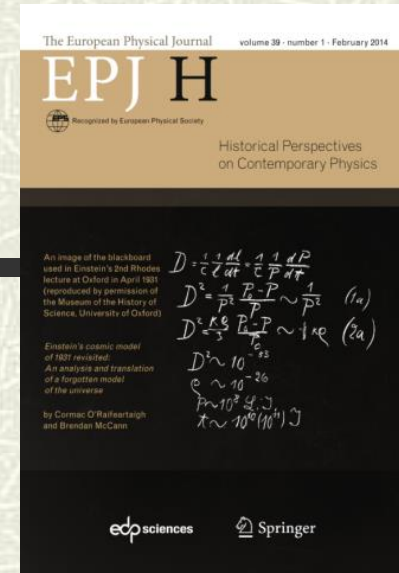
Time-varying radius

Density of matter decreases

Velocity-Distance Relation among Extra-Galactic Nebulae.



The Friedman-Einstein model



$$D = \frac{1}{c} \frac{1}{\ell} \frac{d\ell}{dt} = \frac{1}{c} \frac{1}{P} \frac{dP}{dt}$$

$$D^2 = \frac{1}{P^2} \frac{P_0 - P}{P} \sim \frac{1}{P^2} \quad (1a)$$

$$D^2 = \frac{K_0}{3} \frac{P_0 - P}{P} \sim \frac{1}{P^2} \quad (2a)$$

$$D^2 \sim 10^{-53}$$

$$\rho \sim 10^{-26}$$

$$P \sim 10^8 \text{ G.y}$$

$$t \sim 10^{10} (10^{11}) \text{ y}$$

■ Einstein's first expanding model (1931)

Friedman model with cosmological constant set to zero

First English translation

■ Use Hubble to extract parameters

Cosmic radius $R \sim 10^8 \text{ LY}$

Density of matter $\rho \sim 10^{-26} \text{ g/cm}^3$

Timespan of expansion: 10^{10} yr

■ Numerical error in calculations

Source of error not clear

■ Made clear on Oxford Blackboard

Nature of error clear on blackboard

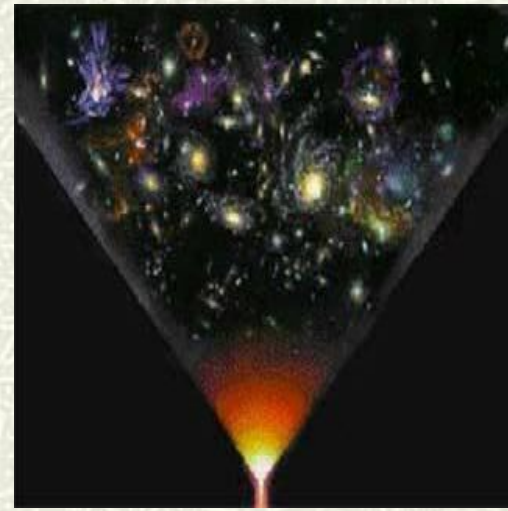
The first 'big bang' model (1931)

- ✦ Expanding U smaller in the past
- ✦ Rewind Hubble graph to 'origin'
- ✦ Extremely dense, extremely hot
- ✦ Explosive beginning at $t = 0$?

Expanding and cooling ever since



Fr Georges Lemaître



Not accepted

A second piece of evidence

- # How did the chemical elements form?
- # Nuclear physics (1940s)
- # Not in the stars
- # In Lemaître's infant universe ?
- # ***H, He*** nuclei (*1 s*)
- # $U = 75\% \text{ *H*, } 25\% \text{ *He*}$
- # Agrees with observation



Georges Gamow



Big bang nucleosynthesis

A third piece of evidence?

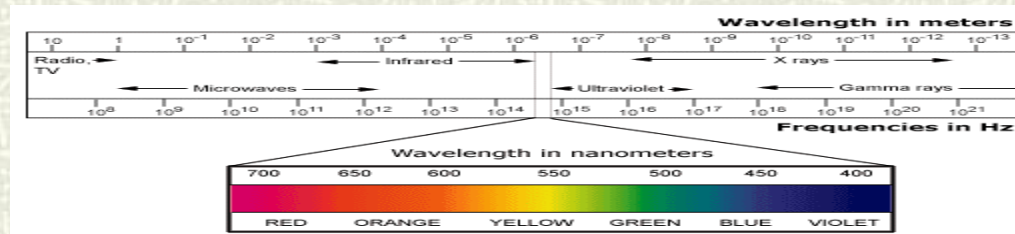
- # Radiation from infant universe
- # Released when atoms formed
(300,000 yr)
- # Still observable today?

Low temp, microwave frequency

No-one looked (1948); why not?



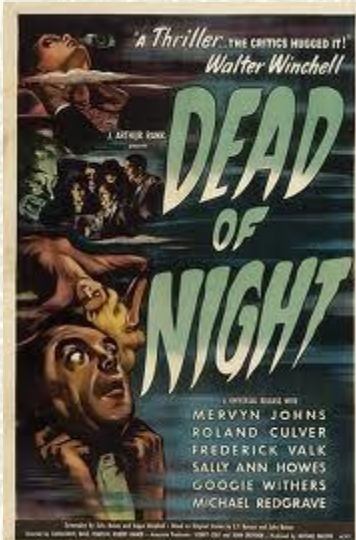
Alpher, Gamow and Herman



Steady-state model (1950s)



Fred Hoyle



≠ Rival model

≠ Expanding universe

BUT

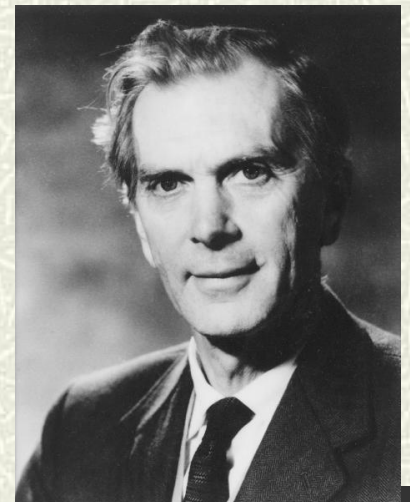
≠ Matter continuously created

≠ No beginning

A famous debate (1950-1965)

- # Bitter debate between BB and SS
- # Radio-astronomy: study most distant galaxies
- # Compare with local galaxies
- # Distribution the same at all times? (SS)
- # Or different? (BB)

Answer: different

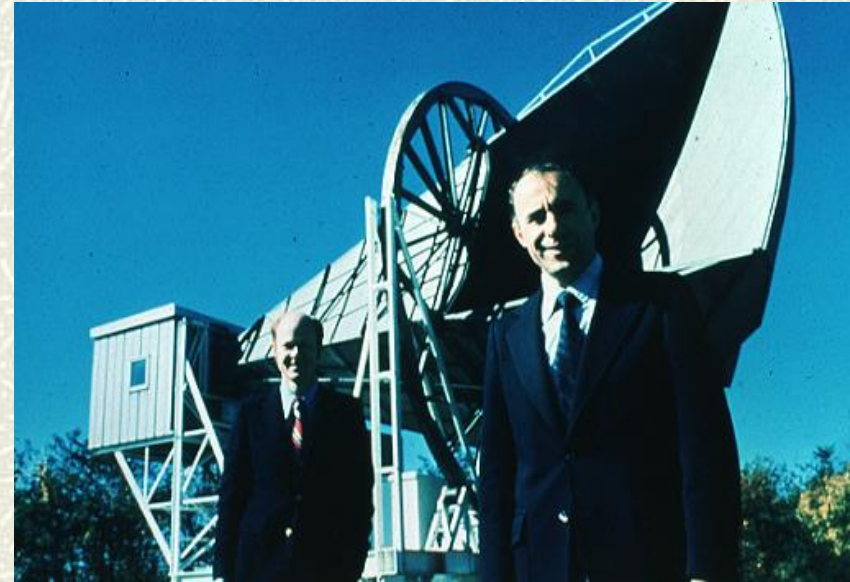


End of steady-state model

Bonus: cosmic background radiation

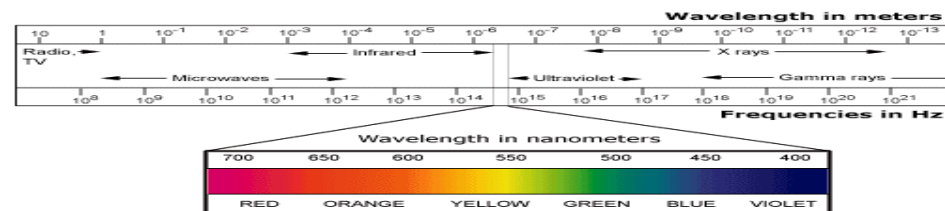
CMB discovered accidentally

- # Universal signal (1965)
- # Low frequency (microwave)
- # Low temperature (3K)



Penzias and Wilson

*Echo of **Big Bang!***



Einstein's lost theory uncovered

Physicist explored the idea of a steady-state Universe in 1931.

Davide Castelvecchi

24 February 2014



New Discovery Reveals Einstein Tried To Devise A Steady State Model Of The Universe

2 comments, 2 called-out + Comment Now + Follow Comments

Almost 20 years before the late Fred Hoyle and his colleagues devised the [Steady State Theory](#), Albert Einstein toyed with a similar idea: that the universe was eternal, expanding outward with a consistent input of spontaneously generating matter.

An Irish physicist came across the paper last year and could hardly believe. According to this week's article in [Nature](#),

model of the universe very different to today's [Big Bang](#) Theory.

The manuscript, which hadn't been referred to by scientists for decades,



Adobak The straight talking savings bank

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Einstein's Lost Theory Uncovered

The famous physicist explored the idea of a steady-state universe in 1931

nature

Feb 25, 2014 | By Davide Castelvecchi and Nature magazine

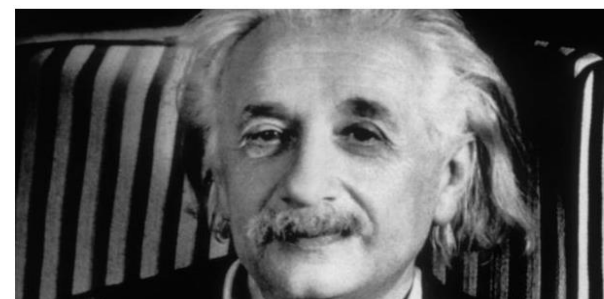
A manuscript that lay unnoticed by scientists for decades has revealed that Albert Einstein once dabbled with an



www.irishtimes.com/news/science/wit-researchers-discover-lost-einstein-model-of-universe-1.1713487

WIT researchers discover 'lost' Einstein model of universe

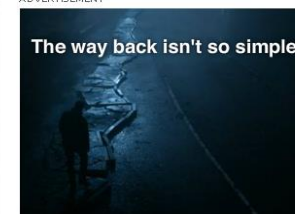
Scientists uncovered misfiled papers while searching Jerusalem university's online archive



Latest Ireland »

- 12:26 Quinn confirms Flannery approached him with Rehab concerns
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- 08:42 Gardaí investigate death of woman in Dublin
- 08:25 Flannery faces call from all parties to attend PAC

ADVERTISEMENT



The big bang – is it true?



- ✓ 1. The expansion of the U
- ✓ 2. The abundance of H and He
- ✓ 3. The distribution of galaxies
- ✓ 4. The cosmic background radiation

Superhot, superdense

Expanding and cooling over time



Cosmology today

- **Satellite measurements of CMB**

No interference from atmosphere

- **Expected temperature**

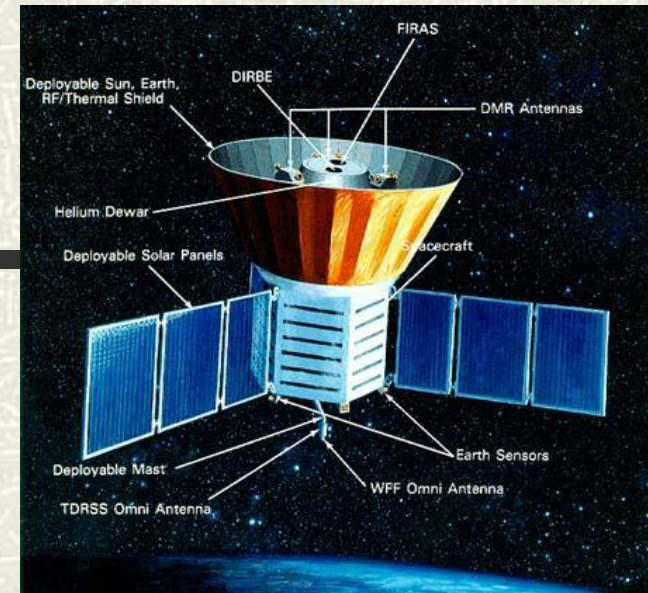
Expected frequency

- **Full spectrum**

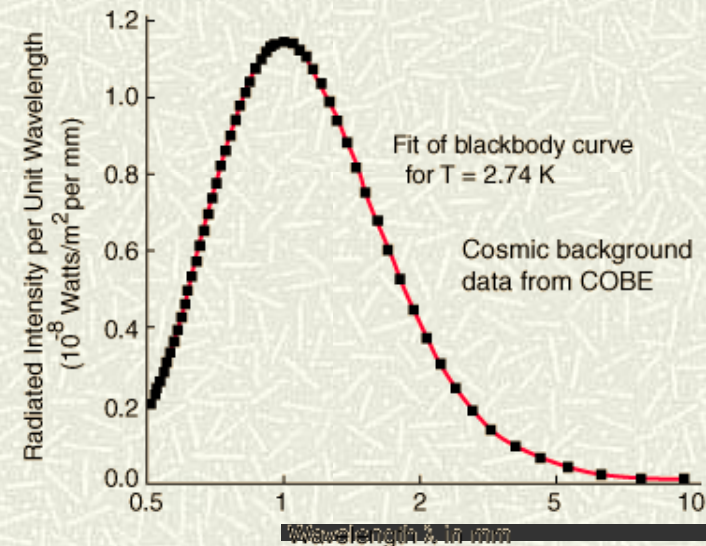
Perfect blackbody spectrum

- **Perturbations**

Variation of 1 in 10^5



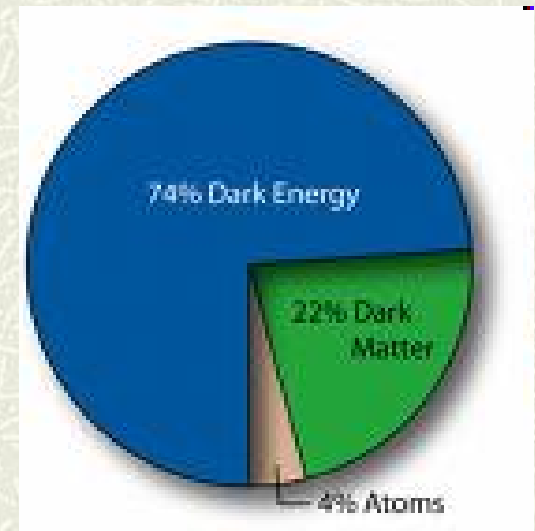
COBE satellite (1992)



Detailed big bang model: Λ -CDM

A universe containing ordinary matter, dark matter and dark energy

1. Ordinary matter: 4% (astrophysics)
2. Dark matter: 22% (astrophysics)
3. Dark energy : 74% (supernova, CMB)



Λ -CDM

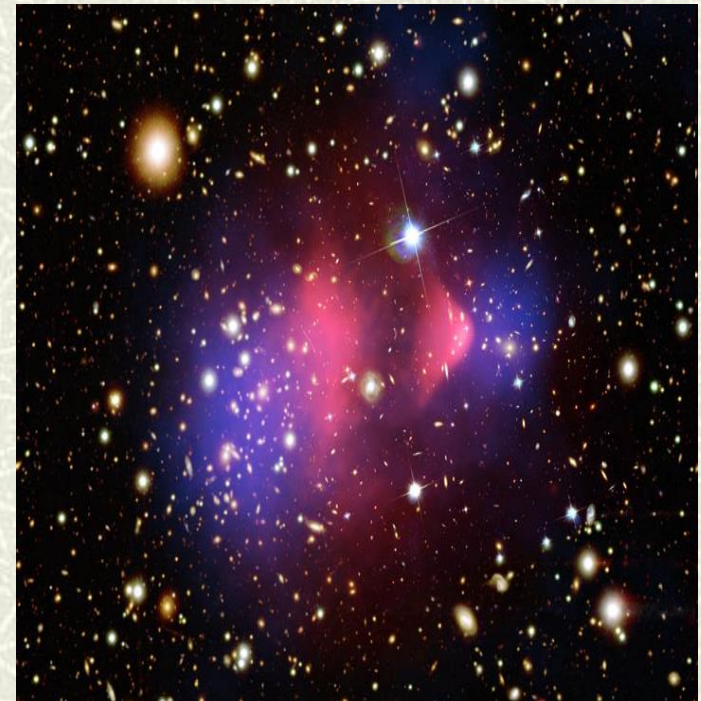
Dark Matter



- ✦ First suggested in 1930s
- ✦ Stellar motion

*normal gravitational effect but
cannot be seen directly*

- ✦ Explains motion of stars
- ✦ Explains motion of galaxies
- ✦ Explains gravitational lensing



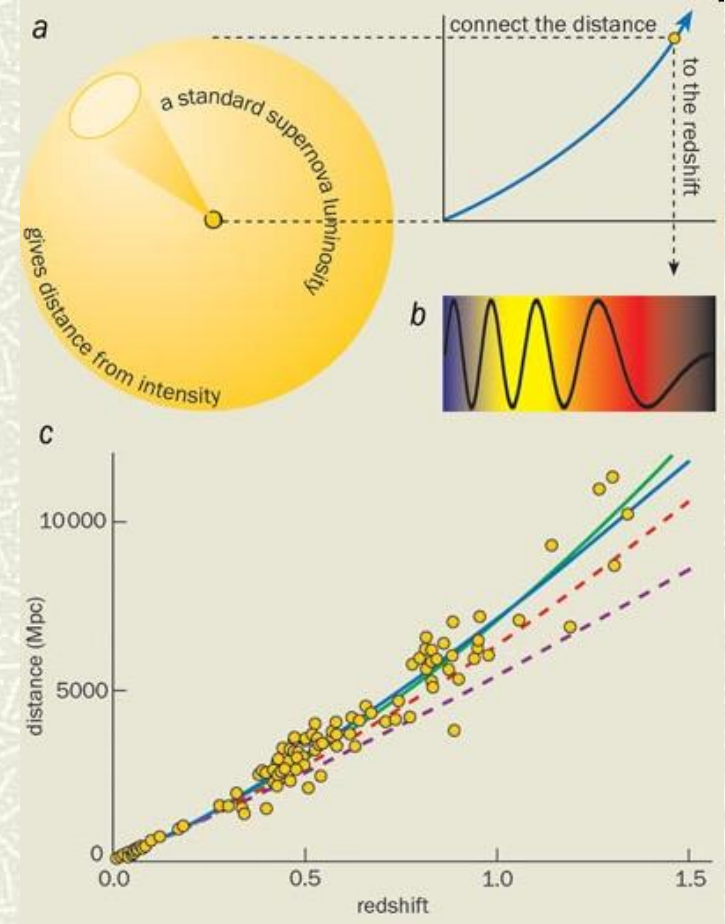
Matter = OM (30%) + DM (70%)

Compatible with nucleosynthesis

$$\Omega = 0.3$$

Dark energy

- # Measurements of supernovae (1998)
- # Furthest galaxies too far away
- # Cosmic expansion accelerating
- # Energy of vacuum?
- # Not well understood



The big bang model - problems

⌘ Nature of dark energy?

Role in BB?



⌘ Nature of dark matter?

Particle experiments?

⌘ The singularity problem

What banged?

What does time zero mean?

Intersection of history with today's science



No-boundary universe

