Neil F. Comins

Discovering the Essential Universe

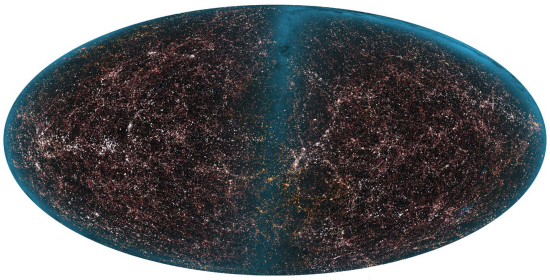
Fifth Edition

CHAPTER 14

Cosmology

1

Einstein's theory of general relativity predicts a contracting or expanding universe
- but not a static universe



Einstein did not believe the prediction and "fudged" his theory. Later he said that that was his biggest blunder!

2

Discovery of the 3 K cosmic microwave background radiation (CMB)

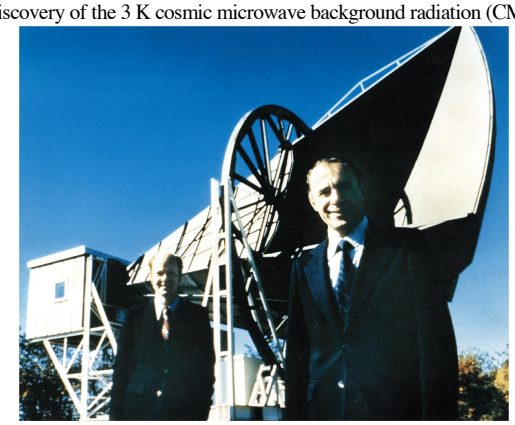
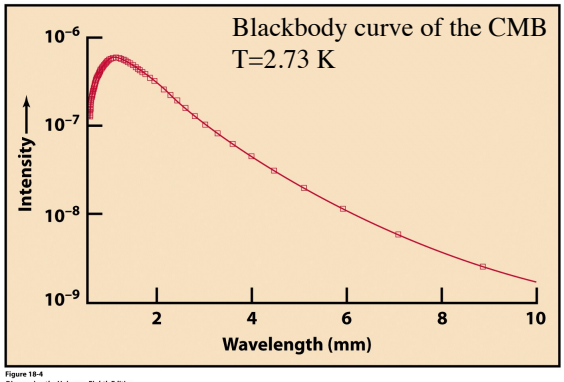


Figure 18-2

3



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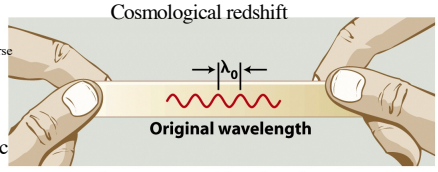
Cosmological redshift

Hubble discovered the expansion of the universe

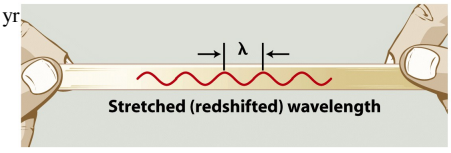
H_0=v/d
= 71 km/s/Mpc

1/H_0=d/v
=13.7 10^9 yr

==> Big Bang



a A wave drawn on a rubber band …



b … increases in wavelength as the rubber band is stretched.

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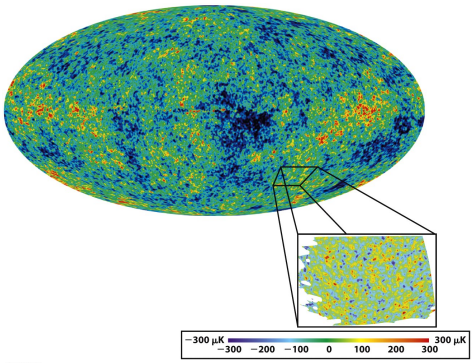
Cosmic microwave background - CMB



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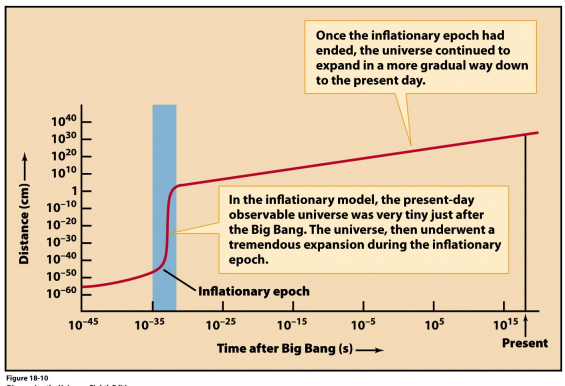

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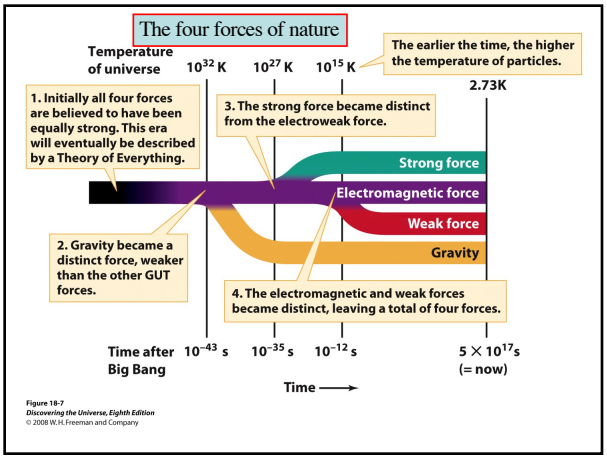


8

Mysteries Needing Explanation

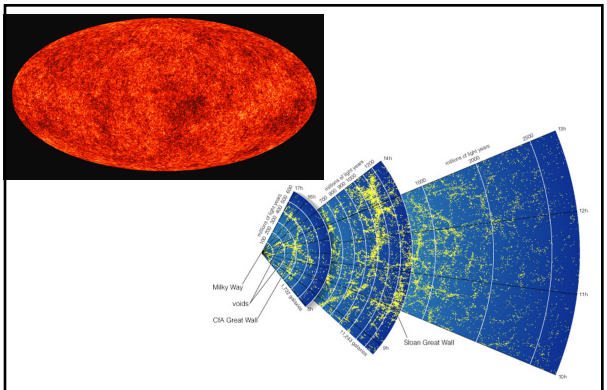
1. Where does structure come from?
2. Why is the overall distribution of matter so uniform?
3. Why is the density of the universe so close to the critical density?

9

Inflation explains these features of the universe

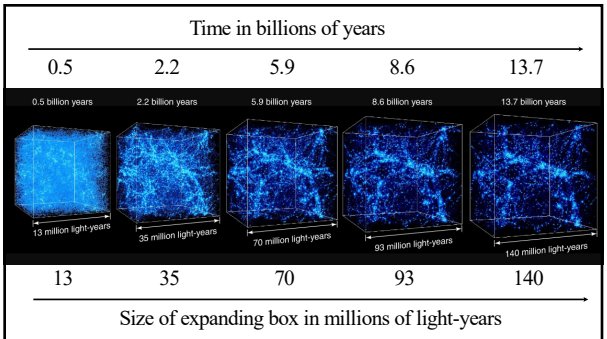
- Structure: Giant quantum fluctuations
- Uniformity: equal temperatures and densities before inflation
- Density: with matter and dark energy
  => density = critical density

10



Maps of galaxy positions reveal extremely large structures: ***superclusters*** and ***voids.***

11



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

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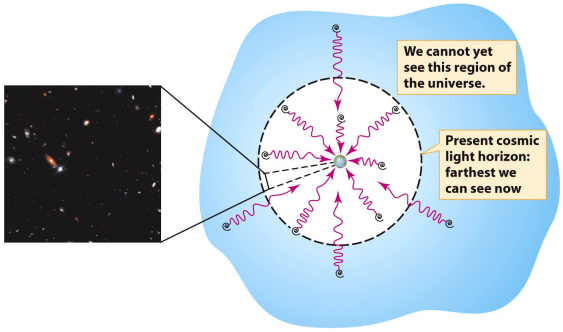
The observable universe –
out to 13.8 billion lightyears



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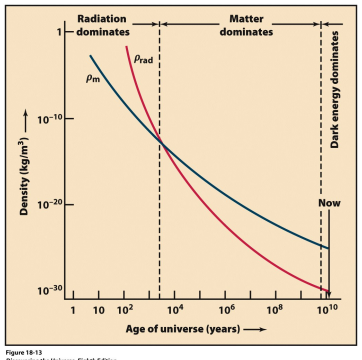
Evolution of radiation and matter density



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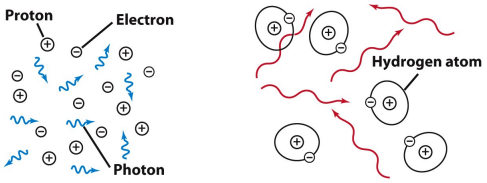
The universe was opaque during the first 380,000 years
Dark Ages



a Before recombination:
- Temperatures were so high that electrons and protons could not combine to form hydrogen atoms.
- The universe was opaque: Photons underwent frequent collisions with electrons.
- Matter and radiation were at the same temperature.

b After recombination:
- Temperatures became low enough for hydrogen atoms to form.
- The universe became transparent: Collisions between photons and atoms became infrequent.
- Matter and radiation were no longer at the same temperature.

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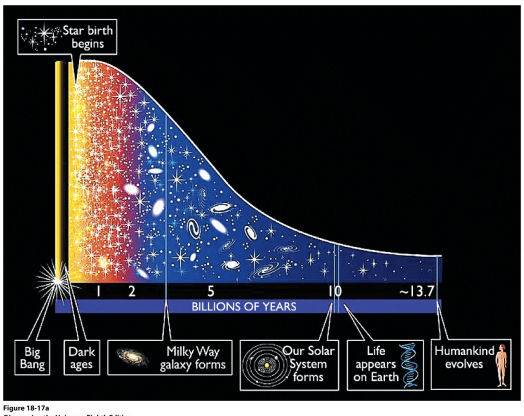

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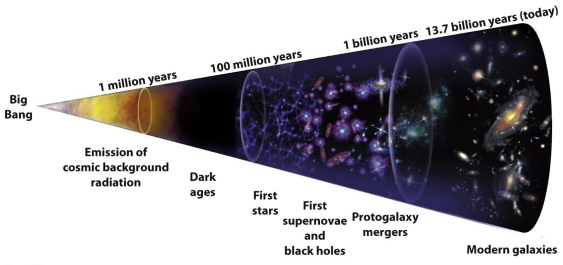
The cosmic timeline



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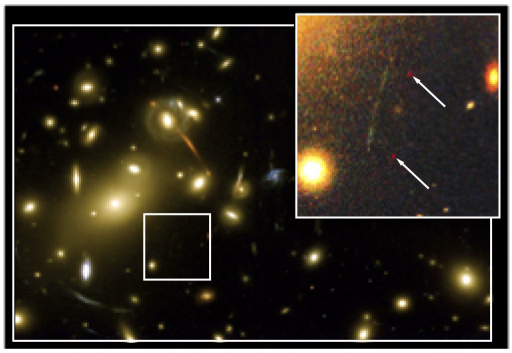

Arrows indicate galaxies beginning to form 13.4 billion years ago

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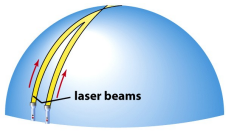
Possible shapes of space

ρ_0 :density, ρ_c: critical density, $\Omega_0 = \rho_0/\rho_c$

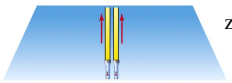
$\rho_0 > \rho_c$: $\Omega_0 > 1$



a Parallel light beams converge

positive curvature of space
closed universe
⇨ **Big Crunch**

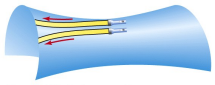
$\rho_0 = \rho_c$: $\Omega_0 = 1$



b Parallel light beams remain parallel

zero curvature of space
flat universe
⇨ expansion for ever (just barely)

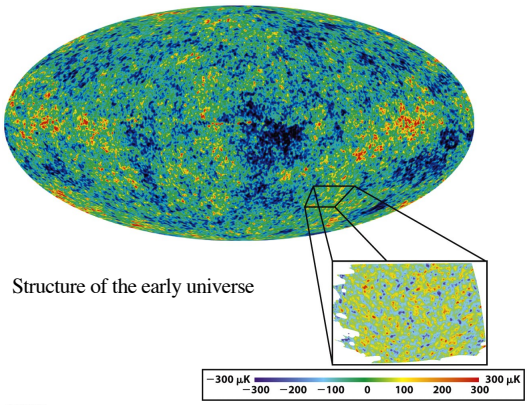
$\rho_0 < \rho_c$: $\Omega_0 < 1$



c Parallel light beams diverge

negative curvature of space
open universe
⇨ expansion for ever

19



Structure of the early universe

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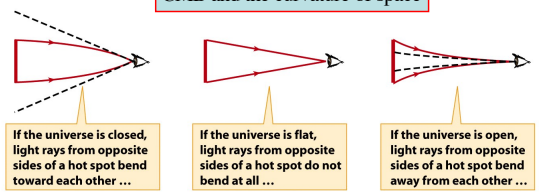
CMB and the curvature of space



If the universe is closed, light rays from opposite sides of a hot spot bend toward each other …

If the universe is flat, light rays from opposite sides of a hot spot do not bend at all …

If the universe is open, light rays from opposite sides of a hot spot bend away from each other …

a

… and as a result, the hot spot appears to us to be larger than it actually is.

b

… and so the hot spot appears to us with its true size.

c

… and as a result, the hot spot appears to us to be smaller than it actually is.

Figure 18-22
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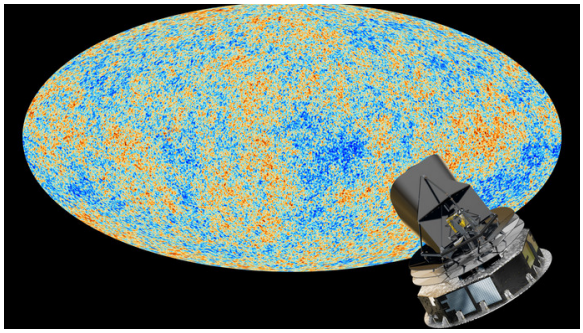
CMB with Planck satellite - 2013



Esa.int

22

Type Ia supernova

The supernova is dimmer than expected, indicating that the distance to it is greater than it would be if the expansion of the universe were slowing down.

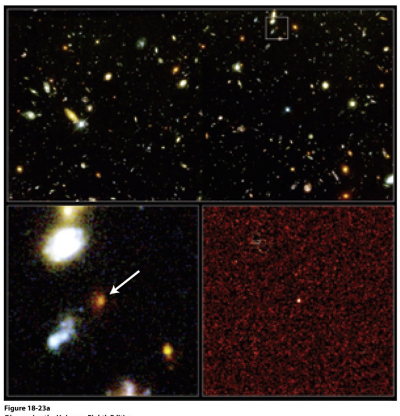


Figure 18-23a
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There must be an outward cosmological force! ⟹Dark Energy

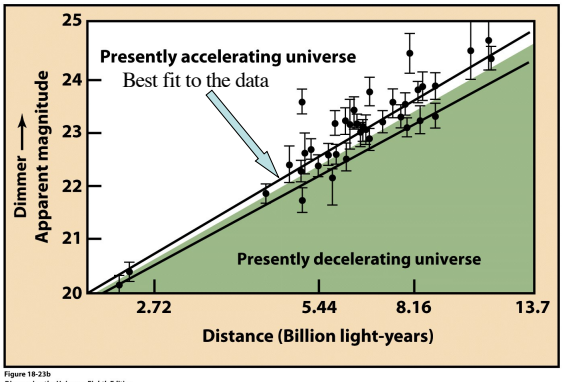

Figure 18-23b
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The major components of the Universe

5% normal matter
27% dark matter
68% dark energy

$$\Omega_{0,\,M} + \Omega_{0,\,\Lambda} = \Omega_0 = 1$$

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Why is it so dark in the night?

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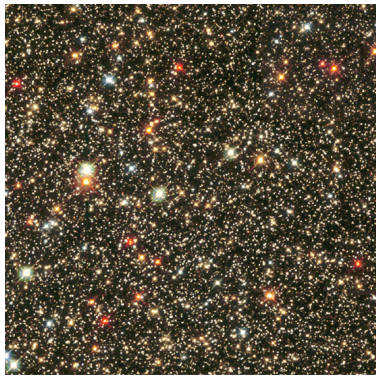

Olbers' Paradox

If the universe were

1. infinite
2. unchanging
3. everywhere the same

then stars would cover the night sky.

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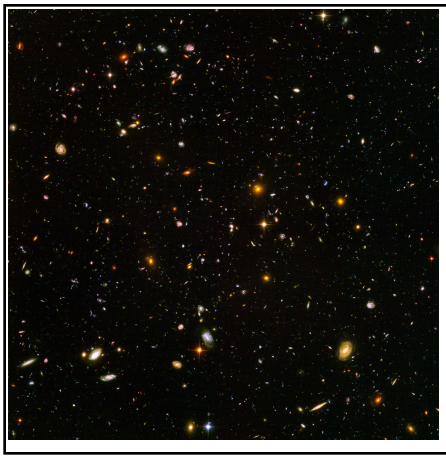
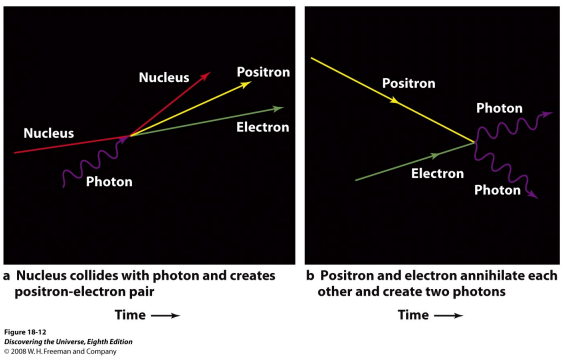


The night sky is dark because we see only the observable universe up to 13.8 billion light years distance.

28



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