Cosmology

- The contents of the Universe
- Einstein's greatest blunder
- Accelerating Universe
- Dark energy

How was the review?

A) Great!

B) Useful

C) OK

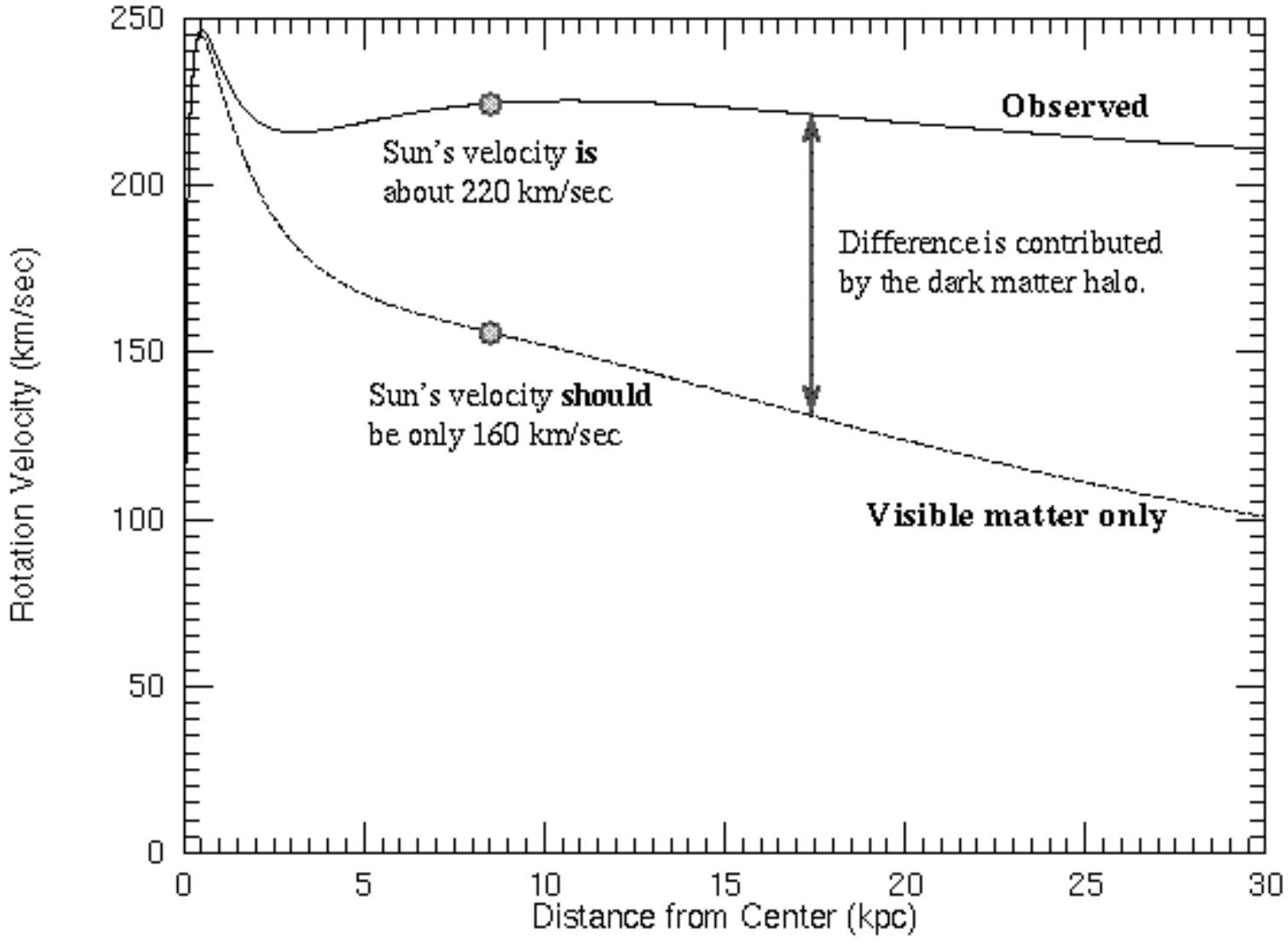
D) Could have been better

E) Useless

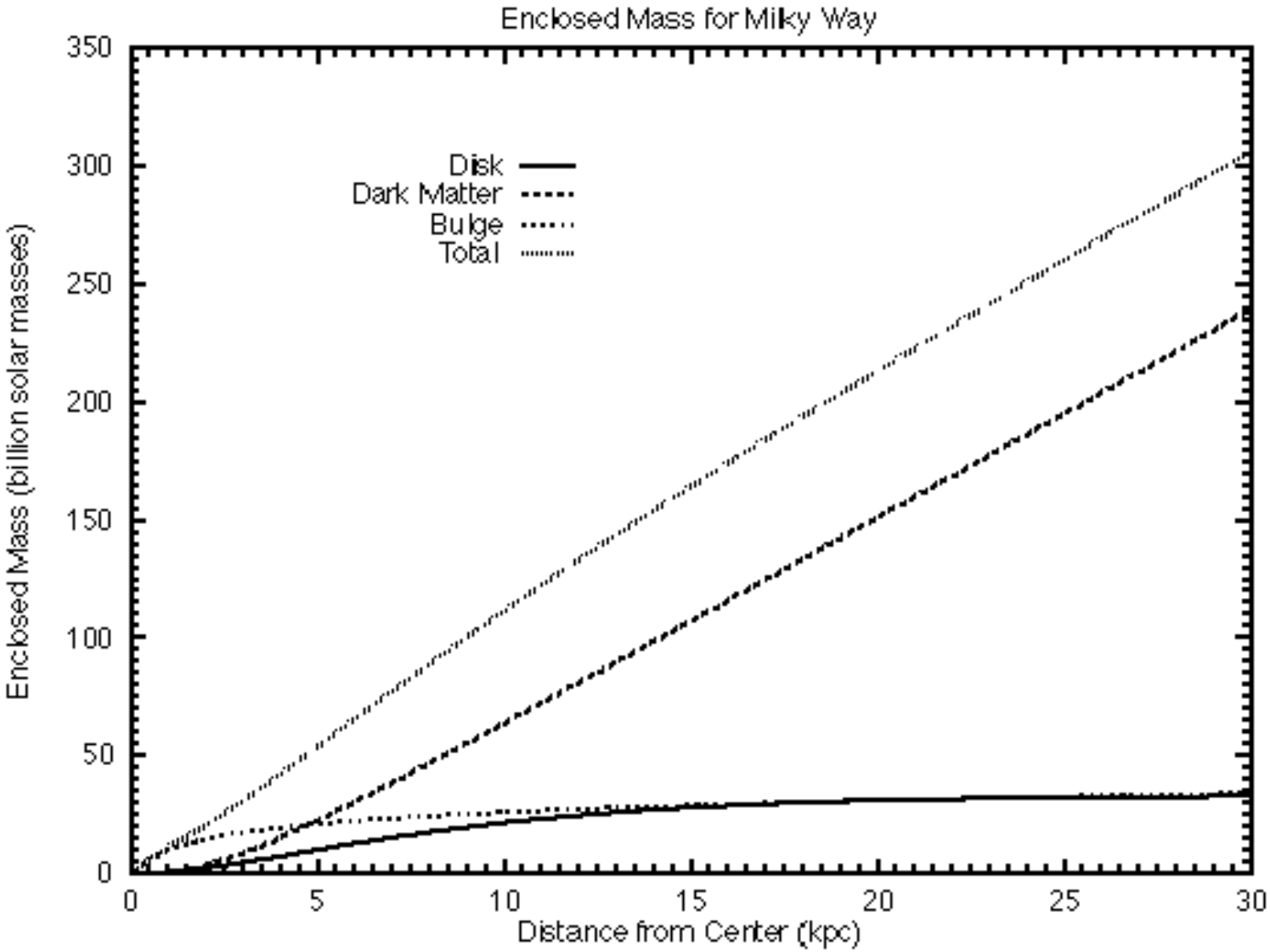
Contents of the Universe

- Normal matter
  - Stars
  - hot gas
  - anything made of atoms
- Total is 4% of ρ_C

Rotation curve of Milky Way



Mass of the Milky Way



Dark Matter

- Dark – it doesn't produce light (any kind)
- Does have mass, produces gravity
- Nature is unknown

- Most likely it is elementary particles

Contents of the Universe

- Normal matter is 4% of ρ_C
- Dark matter is 23% of ρ_C
- Total of normal and dark matter is $\Omega_M = 0.3$

- But, we need 100% of ρ_C
- Remainder, 73%, is dark energy $\Omega_\Lambda = 0.7$

Contents of the Universe

What produced the photons that we see as the 3 degree cosmic background radation?

A) Neutrinos

B) Hot gas

C) Stars

D) Formation of helium nuclei

When did the universe first become transparent?

A) 1 year after the big bang

B) 10^3 years after the big bang

C) 10^6 years after the big bang

D) 10^9 years after the big bang

E) 10^{12} years after the big bang

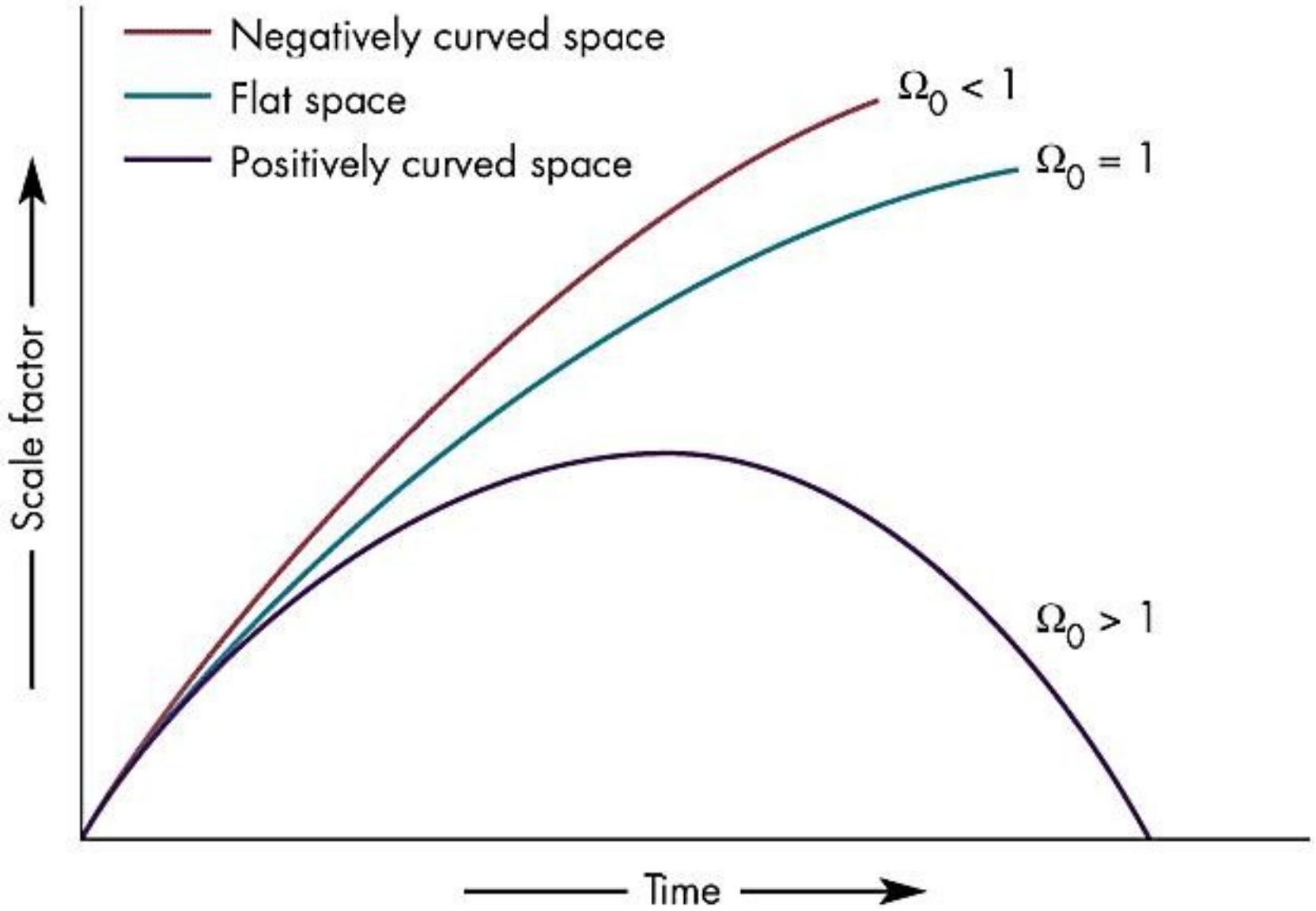
Einstein and Cosmology

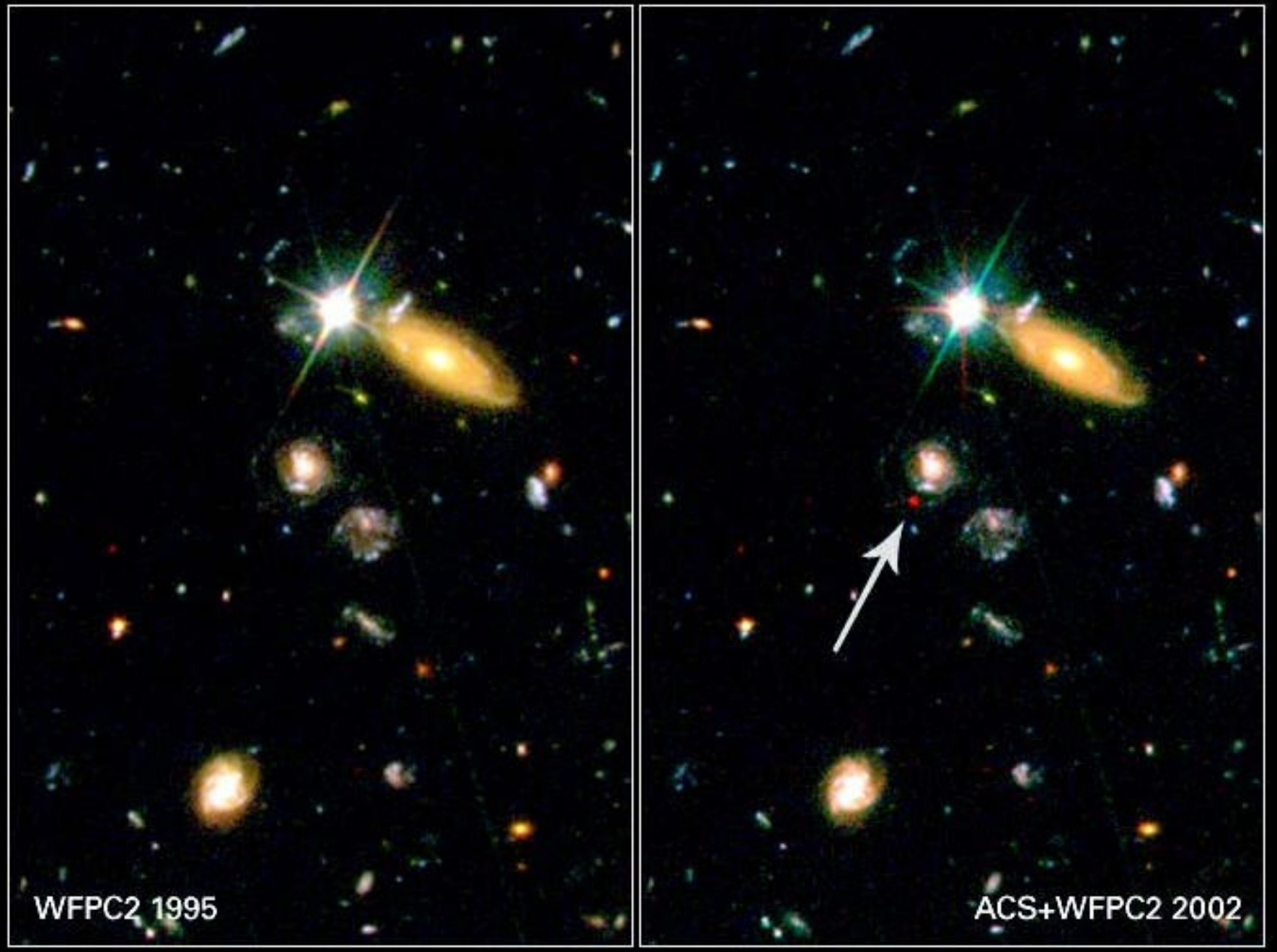
- After Einstein wrote down the equations for General Relativity, he made a model of the Universe and found that the Universe had to be either expanding or contracting.
- He introduced a new term, the cosmological constant or Λ, in his equations representing a energy field which could create antigravity to allow a static model.
- After Hubble found the expansion of the Universe, Einstein called Λ his greatest blunder.

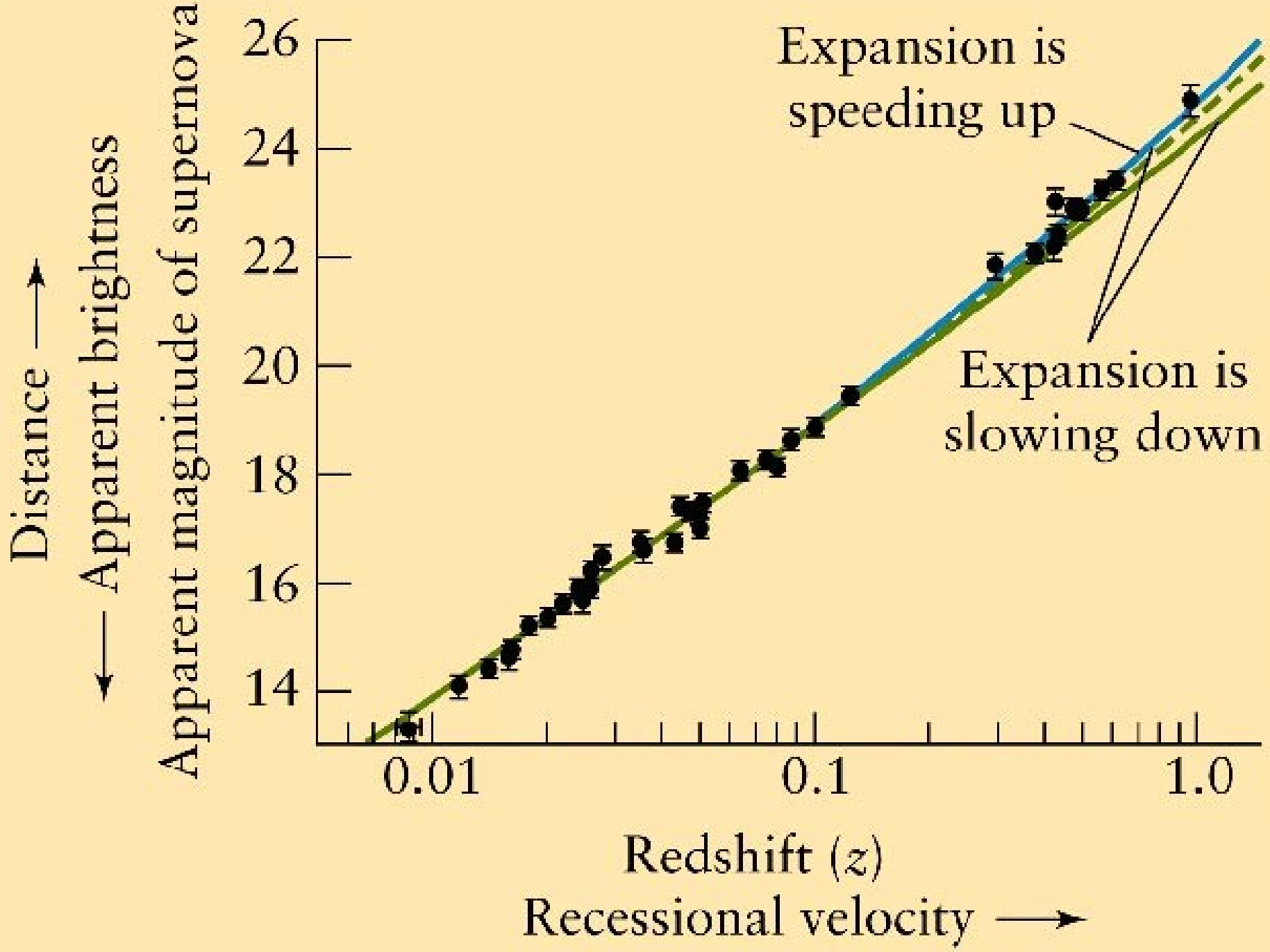
Cosmological Constant

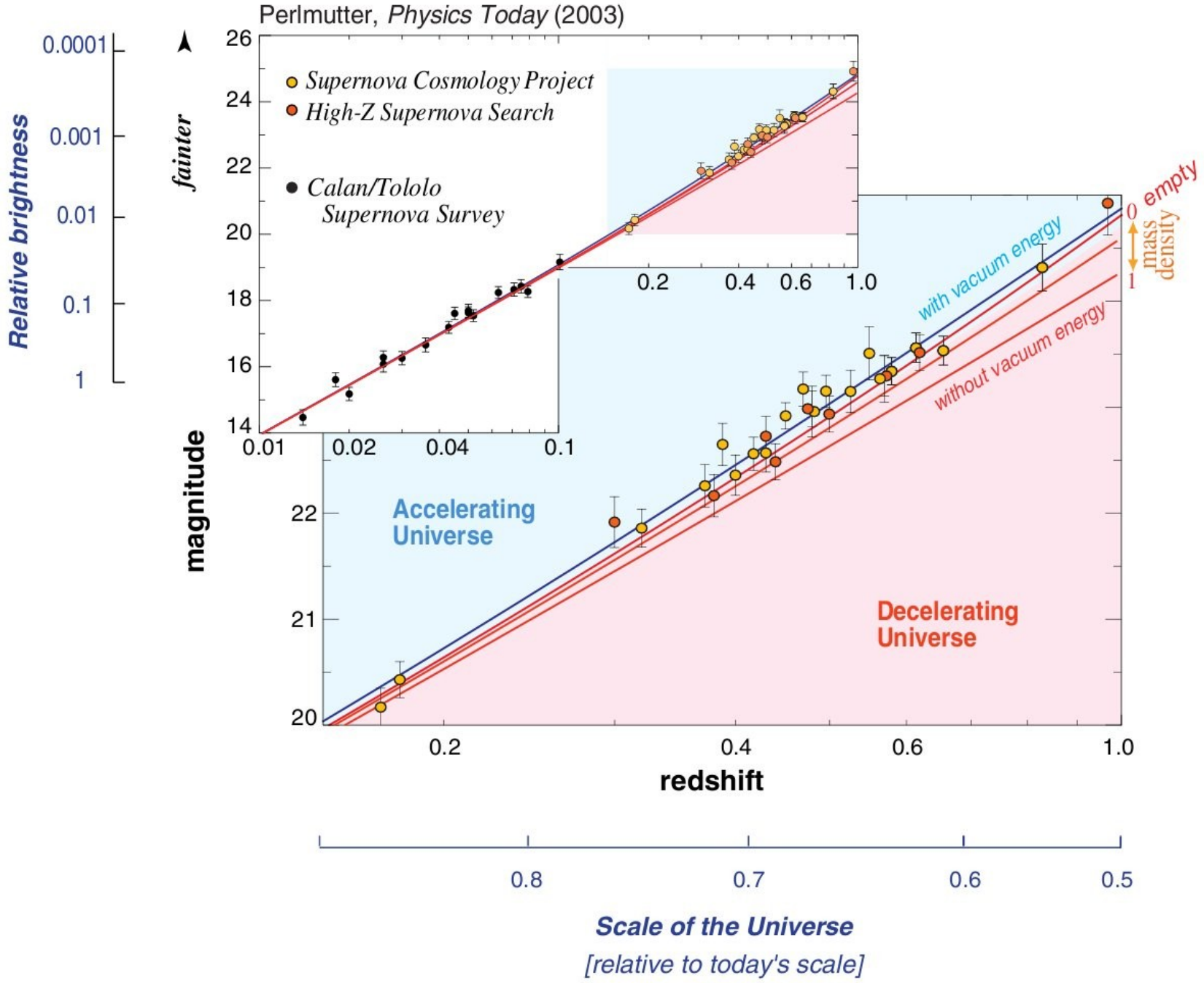
- Quantum physics predicts that some energy fields that act like Λ.
- One such field is the one thought to cause the rapid expansion of the Universe during inflation.
- Another such field appears to be operating today.

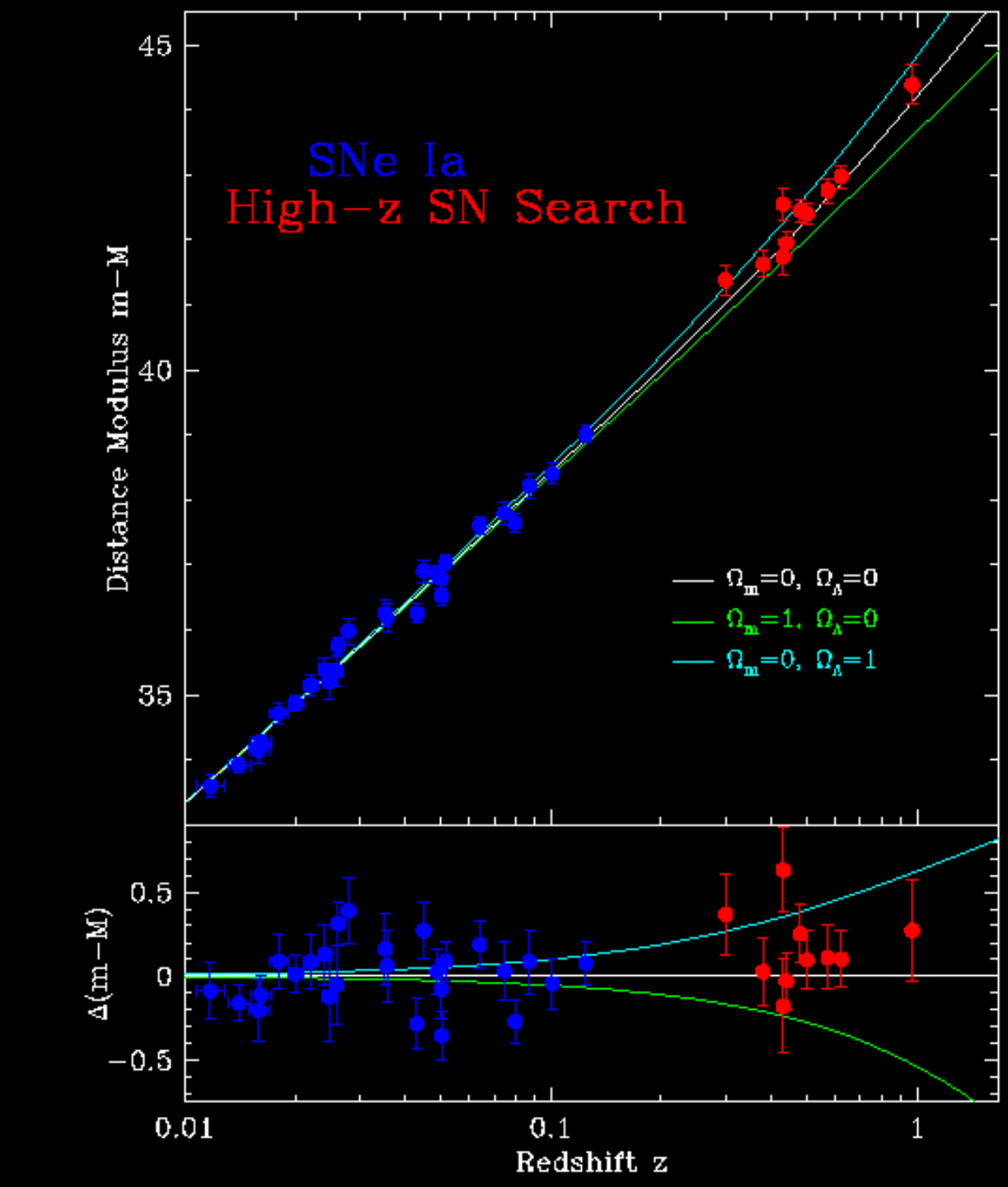
Matter slows down expansion




SN2002dd in the Hubble Deep Field North
HST ▪ WFPC2 ▪ ACS
WFPC2 1995
ACS+WFPC2 2002


Distance ⟶
⟵ Apparent brightness
Apparent magnitude of supernova
26
24
22
20
18
16
14
0.01
0.1
1.0
Redshift (z)
Recessional velocity ⟶
Expansion is speeding up
Expansion is slowing down


Perlmutter, Physics Today (2003)
Relative brightness
0.0001
0.001
0.01
0.1
1
fainter
magnitude
26
24
22
20
18
16
14
Supernova Cosmology Project
High-Z Supernova Search
Calan/Tololo
Supernova Survey
0.01
0.02
0.04
0.1
0.2
0.4
0.6
1.0
with vacuum energy
without vacuum energy
0 empty
mass density
1
Accelerating
Universe
Decelerating
Universe
22
21
20
0.2
0.4
0.6
1.0
redshift
0.8
0.7
0.6
0.5
Scale of the Universe
[relative to today's scale]


SNe Ia
High−z SN Search
Distance Modulus m−M
45
40
35
Ω_m=0, Ω_Λ=0
Ω_m=1, Ω_Λ=0
Ω_m=0, Ω_Λ=1
Δ(m−M)
0.5
0
−0.5
0.01
0.1
1
Redshift z

Accelerating Universe

- Hubble expansion appears to be accelerating

- Normal matter cannot cause acceleration, only deceleration of expansion
- Dark energy is required
  - may be cosmological constant
  - may be something else
  - major current problem in astronomy