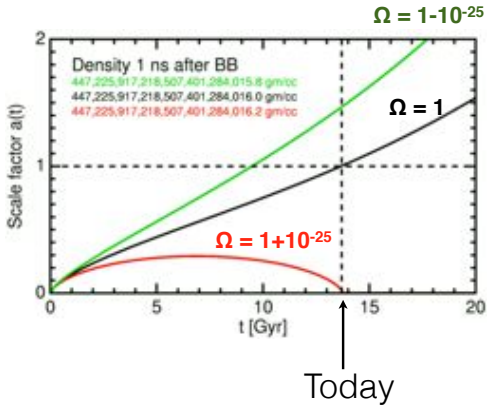
so what if $\Omega_o < 1$?

- if $\Omega_o > 0.1$, then the dark matter in galaxies must be **non-baryonic (?!)**
- the "flatness problem" looms:
  - if $\Omega_o = 1.0$ now, then Ω has *always* been 1.0
  - if $\Omega_o < 1.0$ now, it was much closer to 1.0 in the distant past, but still less than 1.0
  - if $\Omega_o > 1.0$ now, it was much closer to 1.0 in the distant past, but still greater than 1.0

the flatness problem

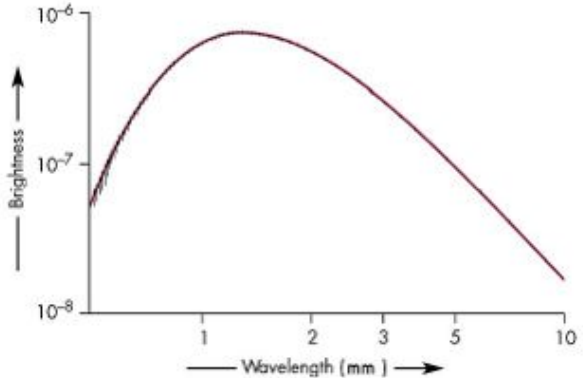
- if not *exactly* 1.000... at the Big Bang, then Ω diverges very rapidly away from it as the universe expands.
- If Ω was only slightly *smaller* than 1.000... at the Big Bang, then Ω_o should be *nearly zero* today.
- If Ω was only slightly *bigger* than 1.000... at the Big Bang, the Universe should have collapsed long ago.



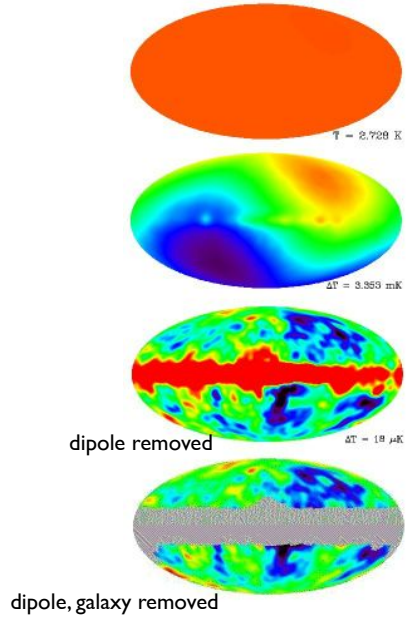
(From Ned Wright's cosmology tutorial)

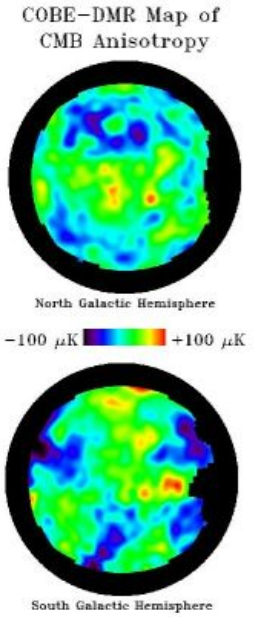
The 3 degree background radiation

- **1965:** 3 K Background radiation discovered by Penzias and Wilson (Nobel Prize, 1978)
- **1990: Cosmic Background Explorer: "COBE"**
  - precisely a black body (to 1 part in 100,000)
  - very uniform distribution in space



COBE maps of the Microwave background





CMB anisotropies

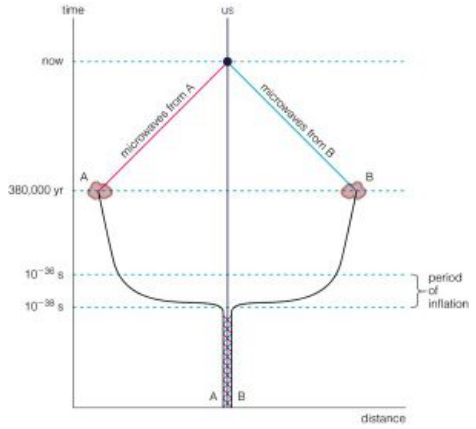
- non-uniformity in matter distribution
- CMB photons are gravitationally redshifted as the leave areas of higher gravity
- **dense** areas of matter distribution show up as cooler spots on the CMB map

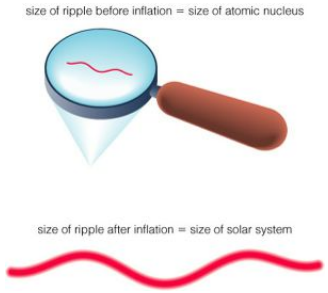
The Uniformity Problem

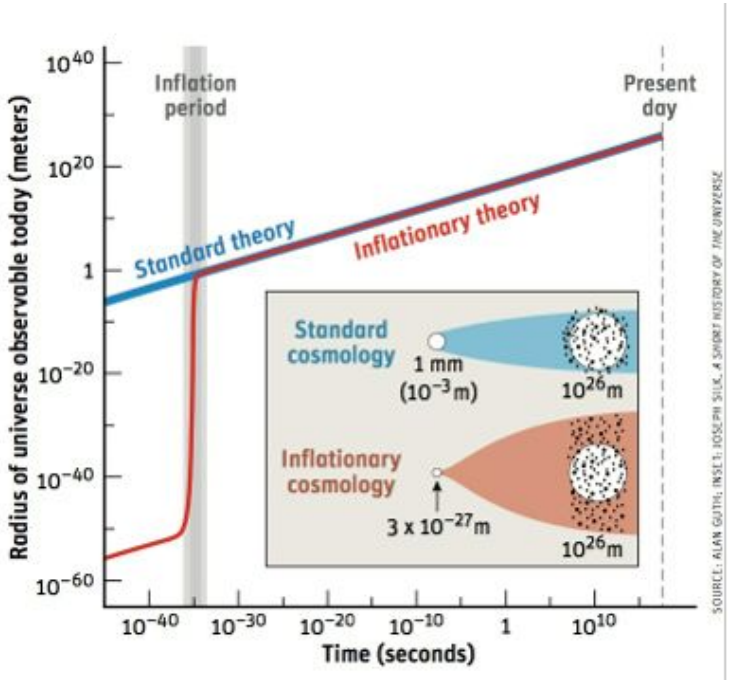
- 2.7 Kelvin in all directions
  - smoothed by rapid expansion
  - smooth Universe today
- **but** opposite points in sky can't communicate (d > c t)
- **Superclusters**: organized and old
  - how did they form from a smooth medium
  - how did they form in such large sizes
- **for Big Bang to "work":**
  - at early times, all must have been in causal contact
  - followed by later rapid expansion
  - need some early structure to seed galaxies
- **Dramatically confirmed by COBE in 1992** (2006 Nobel Prize)

Inflation - a solution to the uniformity problem

- t ~ 10^{-37}sec
  - gravity repulsive
  - brief accelerated expansion
- before inflation: all points in space could communciate
- after inflation: too distant for further contact







Inflation - a solution to the uniformity problem

- $t \sim 10^{-37}$ sec
  - gravity repulsive
  - brief accelerated expansion
- before inflation: all points in space could communciate
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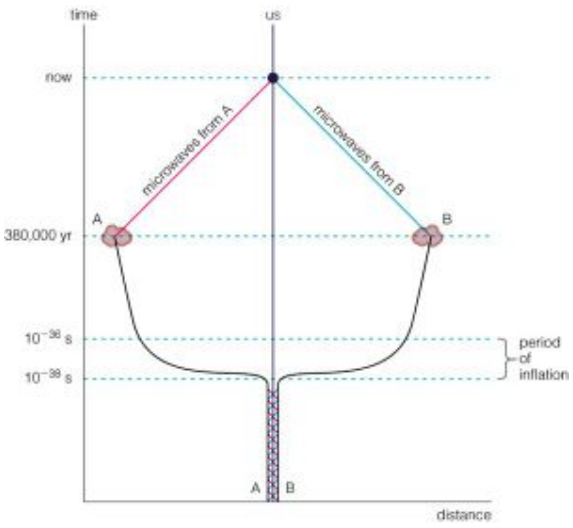
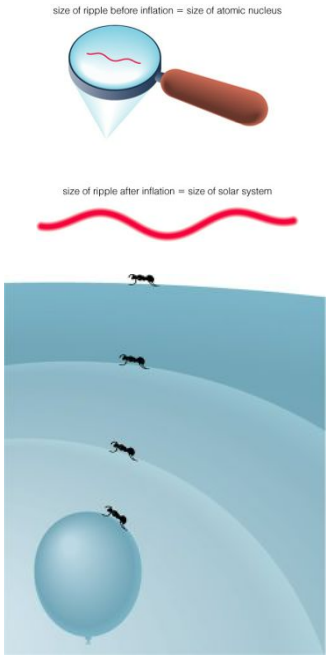
inflation *requires* $\Omega_o = 1$

- **if true:**
  - we live in 1 part of an inflated Universe
  - our Universe **is FLAT** ($\Omega_o = 1.000000000...$)
- **note**: from B.B. nucleosynthesis:
  - $\Omega_o < 0.1$ for "normal" matter
  - **so any $\Omega > 0.1$ is in a new, unknown form**

Inflation and large-scale structure





and flatness

Predictions of Inflation

- $\Omega_o = 1$
- washed-out (low amplitude) clumpiness in post-inflationary Universe
- small fluctuations in Cosmic Background Radiation at all spatial scales
- effects first seen in COBE data with Temperature fluctuations of 1 part in 100,000
- these fluctuations form the early seeds for structure formation

from COBE to WMAP