so what if $\Omega_0 < 1$?

- if $\Omega_0 > 0.1$, then the dark matter in galaxies must be non-baryonic (?!)
- the “flatness problem” looms:
  - if $\Omega_0 = 1.0$ now, then $\Omega$ has always been 1.0
  - if $\Omega_0 < 1.0$ now, it was much closer to 1.0 in the distant past, but still less than 1.0
  - if $\Omega_0 > 1.0$ 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 $\Omega$ diverges very rapidly away from it as the universe expands.
- If $\Omega$ was only slightly smaller than 1.000... at the Big Bang, then $\Omega_0$ should be nearly zero today.
- If $\Omega$ was only slightly bigger than 1.000... at the Big Bang, the Universe should have collapsed long ago.

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

(COBRE DMR Map of CMB Anisotropy)
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

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

![Graph showing the expansion of the universe during inflation](source: [Alan Guth](https://www.youtube.com/watch?v=HqjC1200c70))
**Inflation - a solution to the uniformity problem**

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**inflation requires $\Omega_0 = 1$**

**if true:**
- we live in 1 part of an inflated Universe
- our Universe is FLAT ($\Omega_0 = 1.000000000...$)

**note: from B.B. nucleosynthesis:**
- $\Omega_\omega < 0.1$ for “normal” matter
- so any $\Omega > 0.1$ is in a new, unknown form

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**Predictions of Inflation**

- $\Omega_0 = 1$
- 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

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**Inflation and large-scale structure**

- from COBE to WMAP