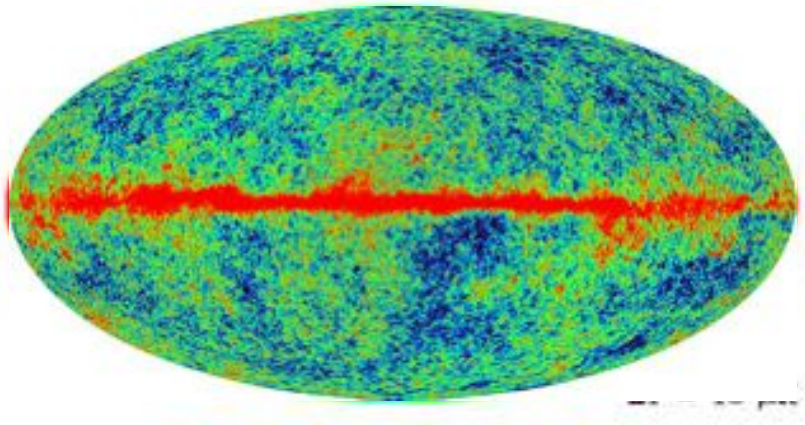
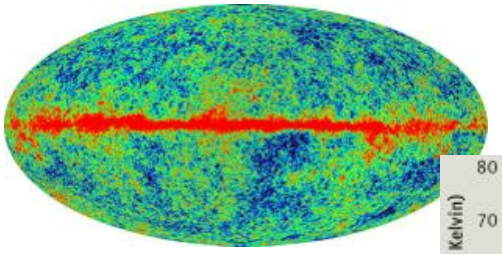
Predictions of Inflation

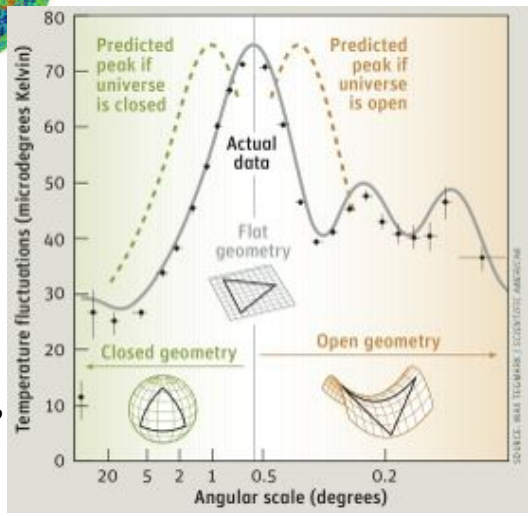
- $\Omega_o = 1$
- washed-out (low amplitude) clumpiness in post-inflationary Universe
- small fluctuations in Cosmic Background Radiation at all spatial scales
- effects first seen in COBE data with Temperature fluctuations of 1 part in 100,000
- these fluctuations form the early seeds for structure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

from COBE to WMAP



CMB Fluctuations in WMAP





"Sizing Up Inflation"
S. Nadis, S&T 2005

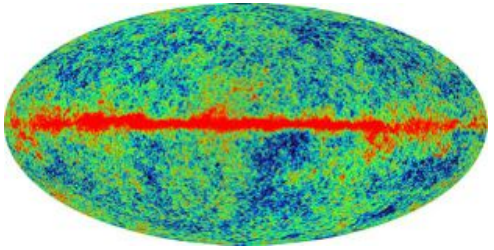
Early seeds of galaxy clusters (pre-recombination)

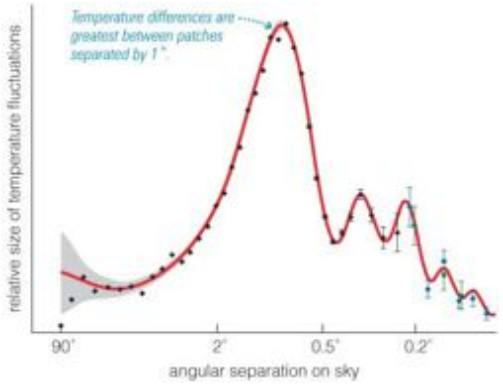
- BARYONIC matter thoroughly stirred by photons
- how did structures seen in CBR form?
- need to clump *something* before Z=1000
- NEED NON-BARYONIC MATTER TO CLUMP AND GROW INTO STRUCTURES SEEN IN CMB
  - **non-baryonic matter dos not interact with photons** and so is not stirred up before Z=1000
- these structures seed the BARYONIC matter growth after Z=1000

Structure seeding

- two important issues:
  - average density variation: $\delta\rho/\rho$ ($\approx 10^{-5}$ in CMB)
  - mass dependence of density variations:
    stronger variations for smaller sized masses:
    * Most clumps are small but with high contrast
    * few large clumps with low contrast
- Effect of *Inflation*
  - flattens out background (reduces $\delta\rho/\rho$)
  - preserves mass dependence of $\delta\rho/\rho$
  - emphasizes structures that are large (supercluster size)
  - EARLY STRUCTURE FORMATION depends entirely on non-baryonic Dark Matter

CMB Fluctuations in WMAP





Dark Matter "flavors"

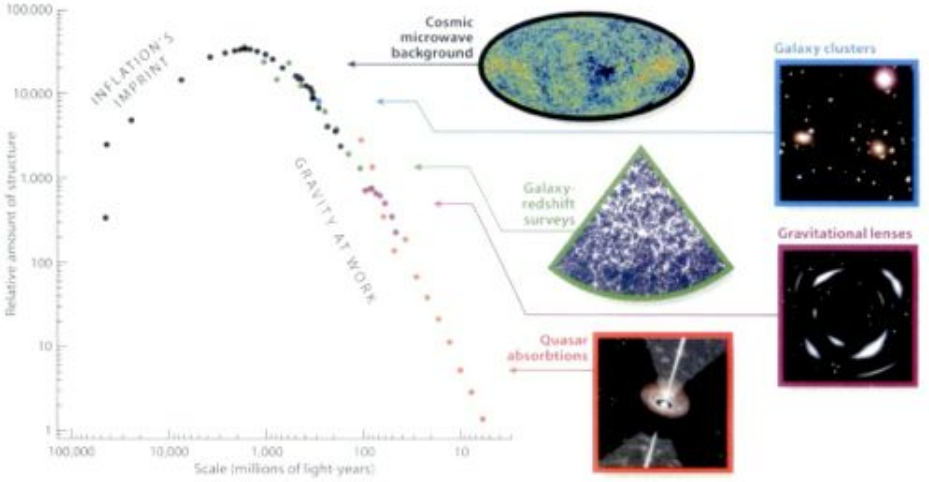
"warm" DM

- weak intereaction, long range
- high velocity at freeze-out
- makes huge structures first
- slow, "top-down"

"cold" DM

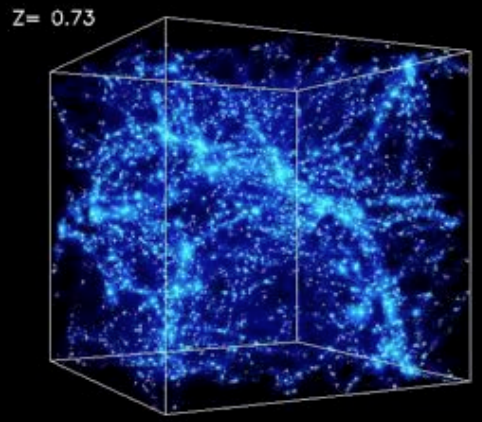
- small-scale, close range
- slowly moving (hence cold)
- makes small structures first
- small structures grow into larger ones
- fast, "bottom-up"

Structure today



from *Cosmology in the New Millenium*

The Cosmic Web



http://cosmicweb.uchicago.edu/sims.html

... a lingering issue

- Theory: $\Omega = 1$
  - via fine-tuning, inflation, structure seeds & formation
- Observations:
  - $\Omega_o \sim 0.3$ (< 0.1 baryonic, 0.2 non-baryonic CDM)
  - $H_o = 72 \pm 7$
- $H_o = 72$, $\Omega_o \sim 0.3$ → $t_{univ} = 11.8 \times 10^9$ yr
  - **but oldest stars > 12.0×10^9 yr!!**
  - if $\Omega_{matter} = 1$ then $H_o = 72$ implies $t_{univ} = 9 \times 10^9$ yr !
- **we're still missing something...**