Class 27 : Four "initial condition" problems with the hot big bang model

- This class
  - The "vanilla" cosmological model
  - The flatness problem
  - The horizon problem
  - The relic problem
  - The structure problem

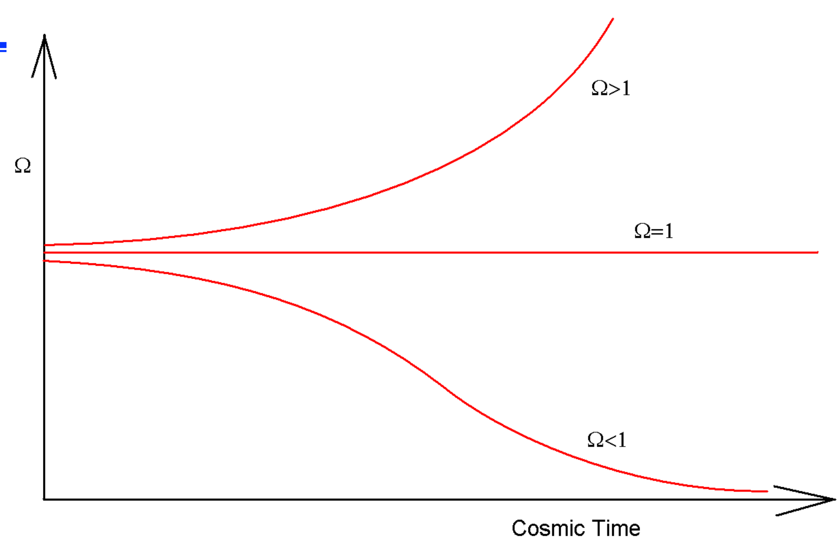
I : Vanilla cosmology

- So, let's recap our "minimal" working cosmological model
  - Universe starts with a hot big bang (a=0)
  - Universe starts almost homogeneous and isotropic
  - Universe is flat
  - Early evolution (z>3000) is radiation-dominated ($a \sim t^{1/2}$)
  - From z~3000 to z~0.5, matter-dominated ($a \sim t^{2/3}$)
  - Late evolution (z<0.5), dark-energy dominated ($d^2a/dt^2>0$)
  - Initially small fluctuations collapse and form structure

- This explains all observations… but it leaves us with some uncomfortable assumptions/issues.

II : The flatness problem

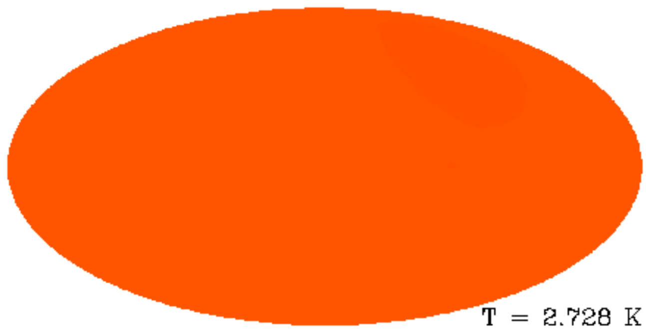
- Universe with a flat geometry is a very special case…
  - $\Omega=1$ (for standard models)
  - $\Omega+\Lambda=1$ (for models with cosmological constant)
- But our universe is very close to flat…
  - CMB results suggest that $\Omega_M+\Omega_\Lambda=1.00\pm0.01$
  - Furthermore, if the Universe deviates from flat, the deviation tends to get amplified as the Universe expands
    - If $\Omega>1$, then it grows larger and larger
    - If $\Omega<1$, then it grows smaller and smaller
- If the universe is approximately flat now, it had to be very very flat at early times…
  - $\Omega\approx1$ now means that at t=1s Ω can only differ from 1 by an amount less than 10^{-16}
  - So, very special conditions were needed in the early universe to give approximate flatness now.
  - This is the flatness problem



III : The horizon problem

- Recall concept : the **particle horizon**
  - There has been a finite amount of time since the big bang… thus, light can only propagate a finite distance
  - Even if the Universe is infinite, our view of the Universe is limited to objects close enough that light can reach us in the time since the big bang
  - This edge of observability is called the particle horizon… it is a limit on how far information can have traveled.
- When we see the CMB, we are looking at a time t_0=380,000 yrs after the big bang… the particle horizon should be $r_0 \approx 3ct_0 \approx 1$Mlyr
  - At the distance of the CMB, the particle horizon spans about 1 degree on the sky… this is supposed to be the limit on how far information can have traveled by this epoch
  - But, the CMB is almost the same temperature across the whole sky… how does it know to do this? This is the **horizon problem**

- How does the CMB “know” that it has to be so uniform across the sky!

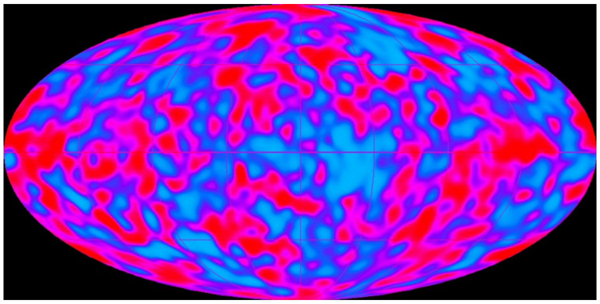


IV : The Relic Problem

- As the Universe cooled, it underwent some dramatic physical changes
- One of the most dramatic was the end of the GUT epoch, when the strong nuclear force and electroweak forces split… this would have has the characteristics of a phase transition (like the freezing of ice)
- The phase transition would not have been perfect… there would be topological defects left behind
  - Magnetic monopoles (0d)
  - Cosmic strings (1d)
  - Domain walls (2d)
  - Textures (3d)
- But our Universe is “very boring”; none of these exotic structures are seen… why not?

V : The Structure Problem

- Structure in the universe (galaxies, clusters of galaxies etc.) came from inhomogeneities in the early universe
- We see those same inhomogeneities in the CMB maps…



- How did those inhomogeneities get there? How come that they are just the right magnitude and size to produce the structures we see today?
- How is it possible to have the same kind of inhomogeneities spread throughout the whole universe, despite the lack of causal contact between different parts of the early universe?
- This is the **structure problem**.

If we close our eyes to physics before the end of the GUT epoch, each of these problems can be phrased as an “initial” condition problem… if the Universe looked “just right” $t \sim 10^{-34}$s, we can explain how it looks today.