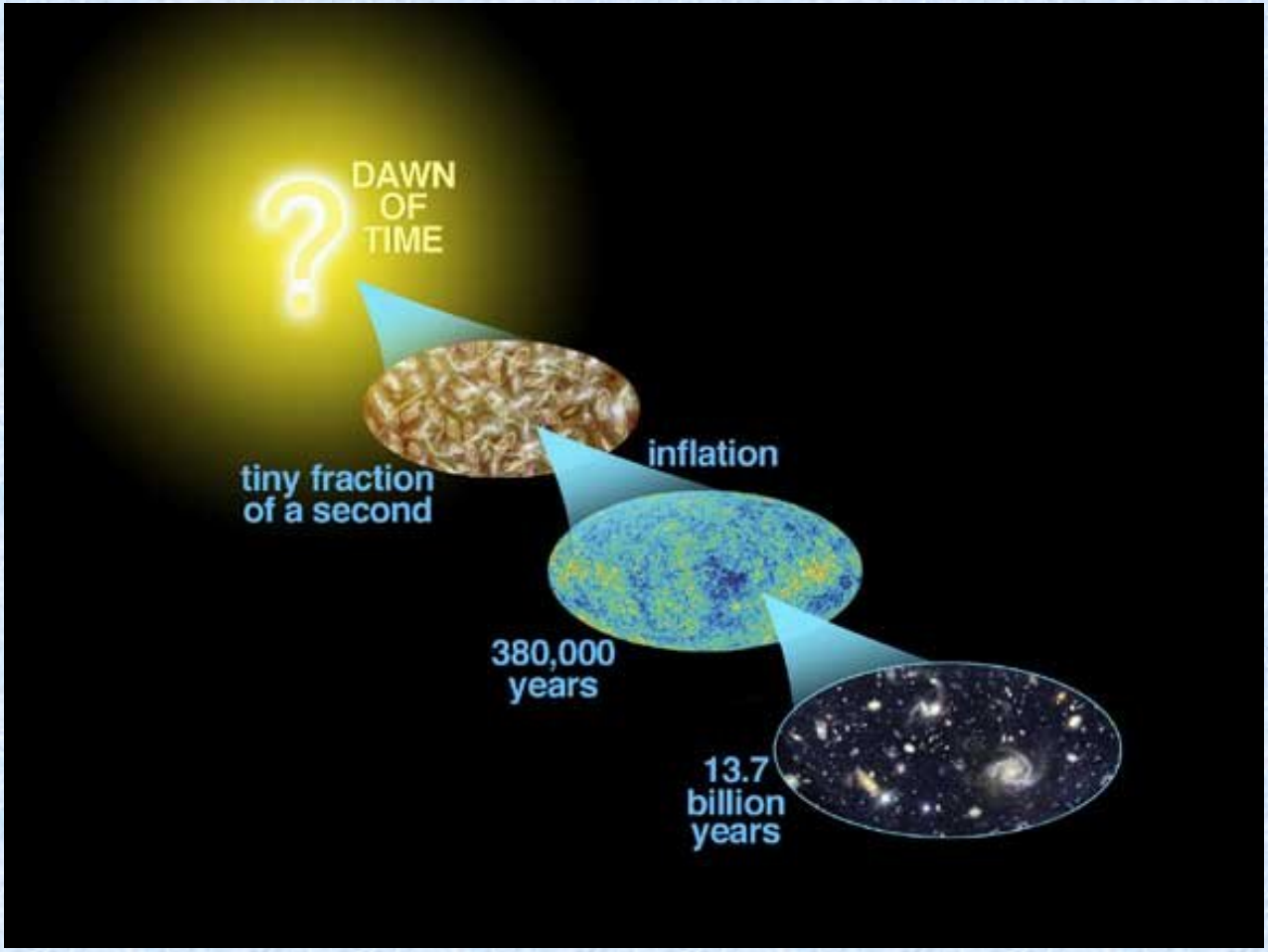
Physics 133: Extragalactic Astronomy ad Cosmology



Lecture 7; January 29 2014

Previously. I:

- Curvature only:
  - a(t) linear in time
  - t0H0=1
  - Horizon infinite
- Flat with w:
  - a(t) scales as t to the power of 2/(3+3w)
  - t0H0=2/3(1+w)
  - Horizon can be finite

Previously. II:

- Matter only:
  - a(t) scales as t to the power of 2/3
  - t0H0=2/3
  - Horizon finite
- Radiation only:
  - a(t) scales as t to the power of 1/2
  - t0H0=1/2
  - Horizon finite

Previously. III:

- Λ only:
  - a(t) exponential in t
  - Infinite Age
  - Infinite horizon

Multiple component Universes. Introduction

- The universe is more complicated than this. We know for sure that there are at least two components
- They are?
- What happens when we have multiple components?

Outline:

- Modeling the Universe. Let's get real!
- Generalized Friedmann Equation.
- Multiple components:
  - Matter + Curvature
  - Matter + Λ
  - Matter+curvature+Λ
  - Radiation + Matter
- The current best guess. Concordance cosmology or "benchmark model"

Generalized Friedmann Equation

$$H^2(t) = H_0^2 \left[\Omega_{\gamma,0} a^{-4} + \Omega_{m,0} a^{-3} + \Omega_\kappa a^{-2} + \Omega_\Lambda\right]$$

$$H^2(t) = H_0^2 \left[\Omega_{\gamma,0}(1+z)^4 + \Omega_{m,0}(1+z)^3 + \Omega_\kappa(1+z)^2 + \Omega_\Lambda\right]$$

$$\Omega_{\gamma,0} + \Omega_{m,0} + \Omega_\kappa + \Omega_\Lambda = 1$$

[Blackboard]

Matter + curvature

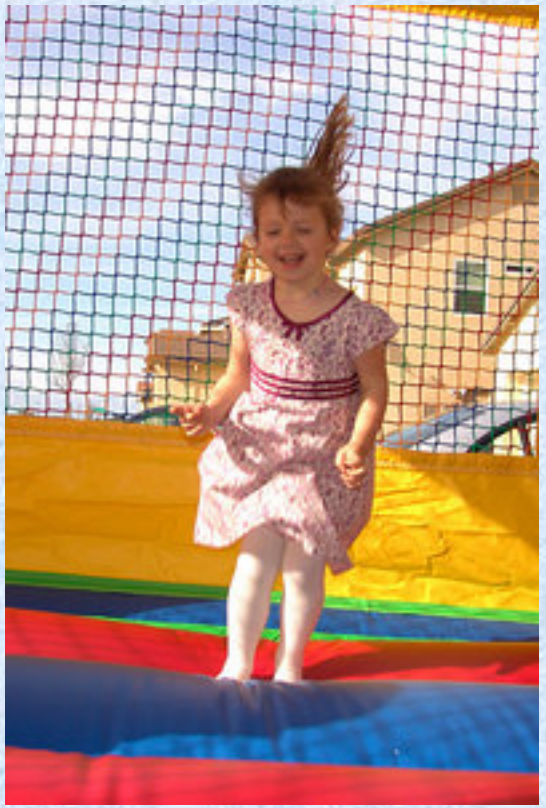
- New phenomena appear…
- For example, the big crunch!
- [Black board]

Matter + Λ

- The cosmological constant can induce acceleration
- The big chill
- Close to our model of the universe
- [Black board]

Matter + Curvature + Λ

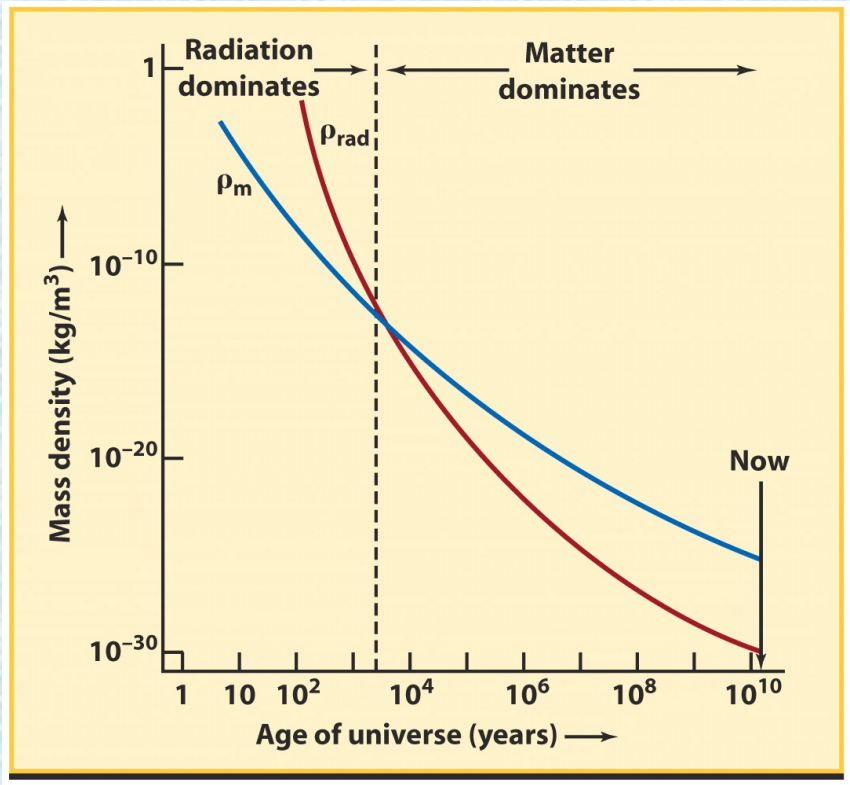
- **New phenomena..**
- **For example the "Big Bounce"**
- **[Black board]**



"Big bounce"

Matter + Radiation

- Good description of the Universe at early times.
- Is what we need to find epoch of radiation dominance
- [Black board]



“Concordance cosmology” or “Benckmark model”

- **Our current best guess**
- **[Black board]**

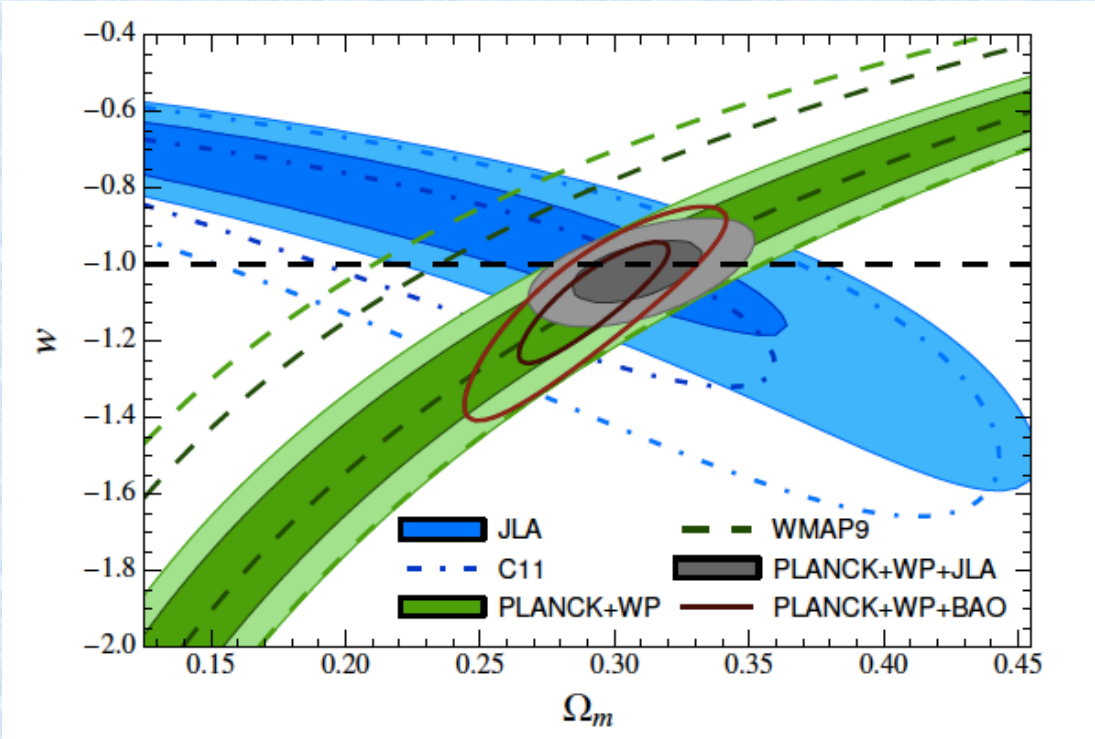
Concordance cosmology or Benchmark model

	Planck		*Planck*+lensing		*Planck*+WP	
Parameter	Best fit	68% limits	Best fit	68% limits	Best fit	68% limits
$\Omega_b h^2$	0.022068	0.02207 ± 0.00033	0.022242	0.02217 ± 0.00033	0.022032	0.02205 ± 0.00028
$\Omega_c h^2$	0.12029	0.1196 ± 0.0031	0.11805	0.1186 ± 0.0031	0.12038	0.1199 ± 0.0027
$100\theta_{MC}$	1.04122	1.04132 ± 0.00068	1.04150	1.04141 ± 0.00067	1.04119	1.04131 ± 0.00063
τ	0.0925	0.097 ± 0.038	0.0949	0.089 ± 0.032	0.0925	$0.089^{+0.012}_{-0.014}$
n_s	0.9624	0.9616 ± 0.0094	0.9675	0.9635 ± 0.0094	0.9619	0.9603 ± 0.0073
$\ln(10^{10} A_s)$	3.098	3.103 ± 0.072	3.098	3.085 ± 0.057	3.0980	$3.089^{+0.024}_{-0.027}$
Ω_Λ	0.6825	0.686 ± 0.020	0.6964	0.693 ± 0.019	0.6817	$0.685^{+0.018}_{-0.016}$
Ω_m	0.3175	0.314 ± 0.020	0.3036	0.307 ± 0.019	0.3183	$0.315^{+0.016}_{-0.018}$
σ_8	0.8344	0.834 ± 0.027	0.8285	0.823 ± 0.018	0.8347	0.829 ± 0.012
z_{re}	11.35	$11.4^{+4.0}_{-2.8}$	11.45	$10.8^{+3.1}_{-2.5}$	11.37	11.1 ± 1.1
H_0	67.11	67.4 ± 1.4	68.14	67.9 ± 1.5	67.04	67.3 ± 1.2

Plank paper XVI

Concordance cosmology.

- Do the various methods agree?
- They do!
- This is called "concordance cosmology"



Betoule et al. 2014

We will come back to all these measurements…

Concordance cosmology.
Happy campers?

Multiple component Universes. Summary

- Generalized Friedmann Equation. Four free parameters
- They are?
- Matter + Curvature (Big Crunch)
- Matter + Λ (Big Chill), simplest model close to concordance cosmology.

Summary:

- Matter + Curvature + Λ
  - Big Bounce or various scenarios
- Radiation + Matter
  - Good for the early universe
- The current best guess. Concordance cosmology or "benchmark model"
  - Next time we will see how people get to this answer!

The End

See you on monday!