Observational constraints of a Matter-Antimatter Symmetric Milne Universe

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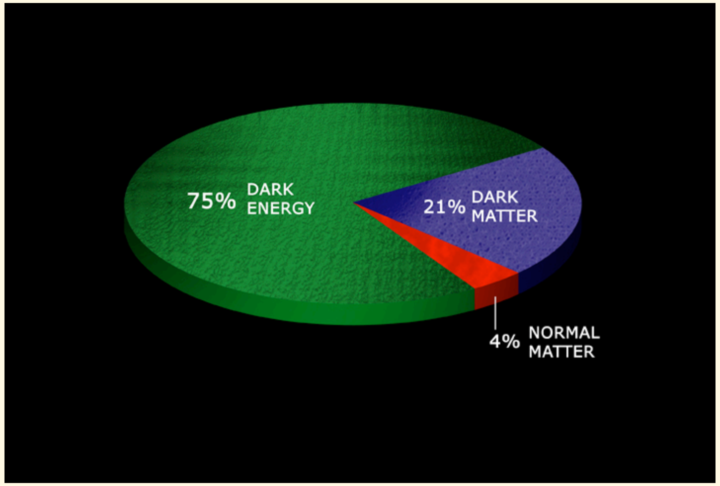
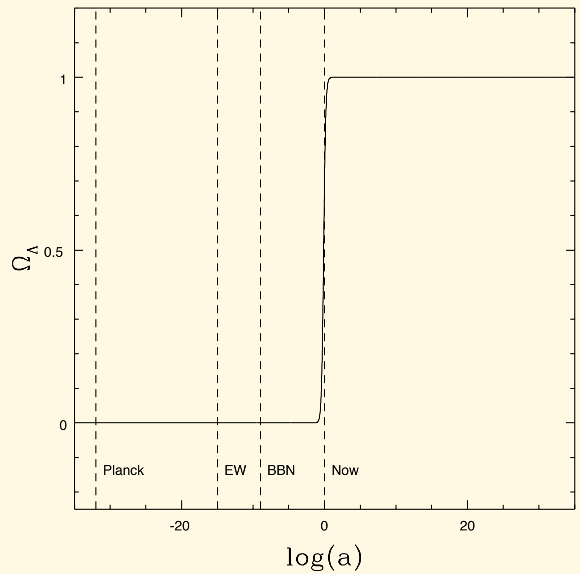
Problems in standard cosmology

- 95 % of the Universe in unknown
- Horizon problem (causality): need for an inflation scenario
- Coincidence problem and cosmological constant





The Symmetric Milne Universe

FRLW metric

$$ds^2 = c^2 dt^2 - a(t)^2 \left[\frac{dr^2}{1 - kr^2} + r^2 \left(d\theta^2 + \sin^2\theta d\phi^2 \right) \right]$$

Friedmann equation

$$\left(\frac{\dot{a}}{a} \right)^2 = H_0^2 \left[\Omega_M \left(\frac{a_0}{a} \right)^3 + \Omega_R \left(\frac{a_0}{a} \right)^4 + \Omega_k \left(\frac{a_0}{a} \right)^2 + \Omega_\Lambda \right]$$

Standard model (LCDM) $\Omega_M \approx 0.3,\ \Omega_\Lambda \approx 0.7,\ \Omega_k = 0$

Einstein-de Sitter model $\Omega_M = 1,\ \Omega_\Lambda = 0,\ \Omega_k = 0$

Milne model $\Omega_M = 0,\ \Omega_\Lambda = 0,\ \Omega_k = 1$

The Symmetric Milne Universe

$$\Omega_M = 0,\ \Omega_\Lambda = 0,\ \Omega_k = 1$$

$$\xrightarrow{\text{Friedmann equation}} \quad \boxed{a(t) \propto t}$$

One first immediate consequence:

Radial coordinate of a z redshift object: $\chi(z) \xrightarrow{z \to +\infty} +\infty$

No horizon problem $\Longrightarrow$ no need of inflation

The Symmetric Milne Universe

Empty Universe: equal quantities of matter (with positive mass) and antimatter (with negative mass).
No Dark Matter and no Dark Energy.

This is considered here as a working hypothesis, and it could have justification from GR

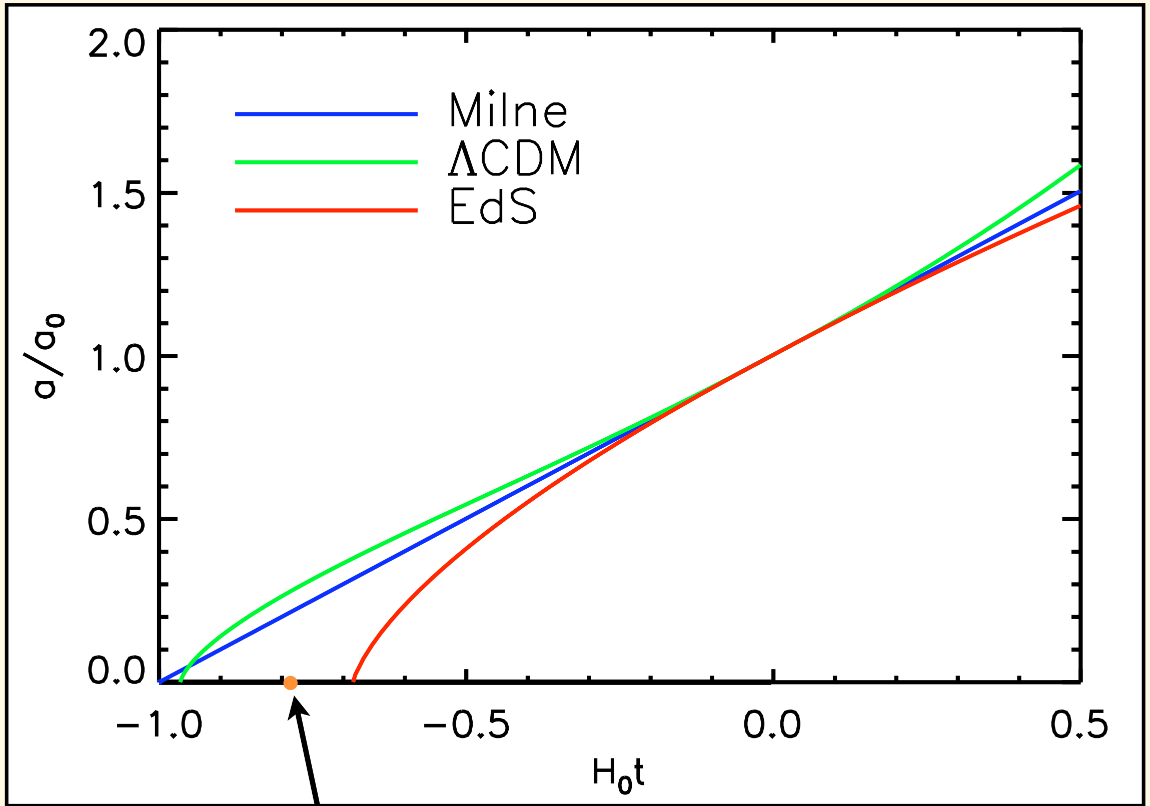
Aim: check consistency with cosmological tests :

- Age of the Universe
- Big-Bang Nucleosynthesis
- Type Ia Supernovae
- CMB

First simple test: Age

Age of the Universe in Milne Cosmology

$$t_0 = \frac{1}{H_0} = 13,9 \times 10^9 \text{ years, with } \mathrm{H}_0 = 70 \text{ km/s/Mpc}$$

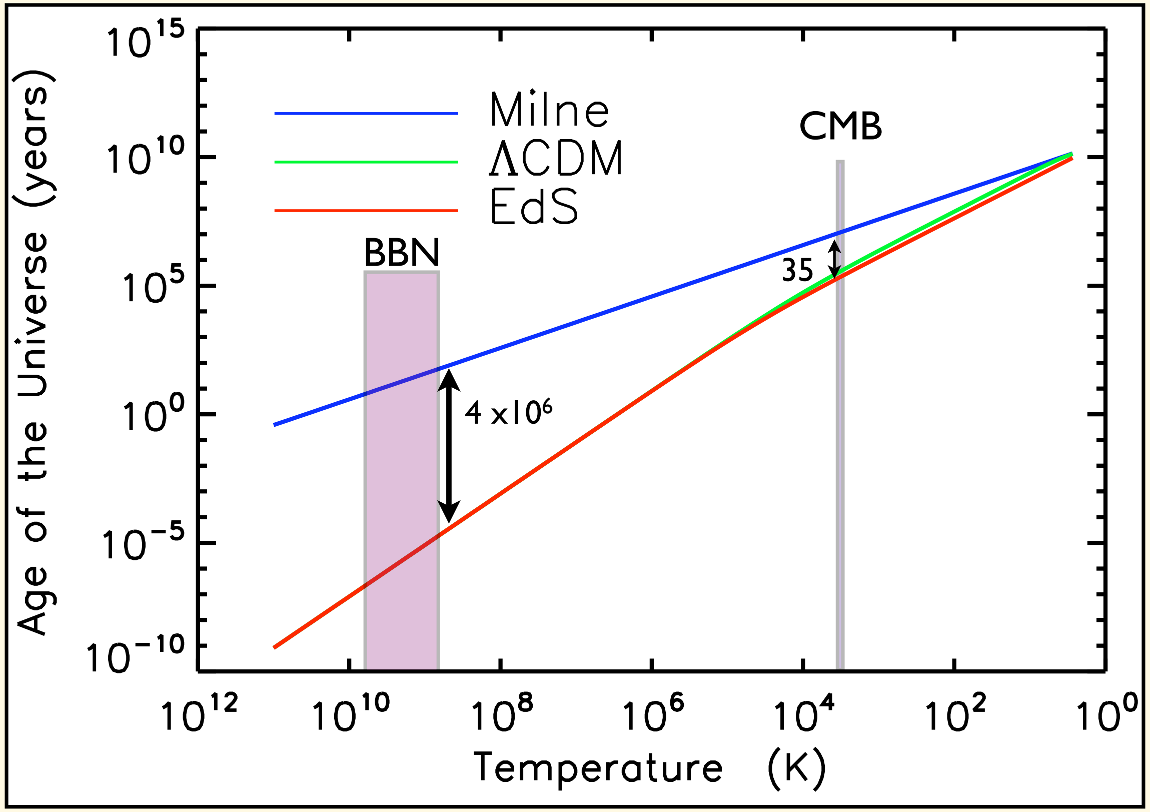


Globular clusters

EdS model seems excluded by oldest globular clusters (Chaboyer et al, 98)

Milne and LCDM almost similar

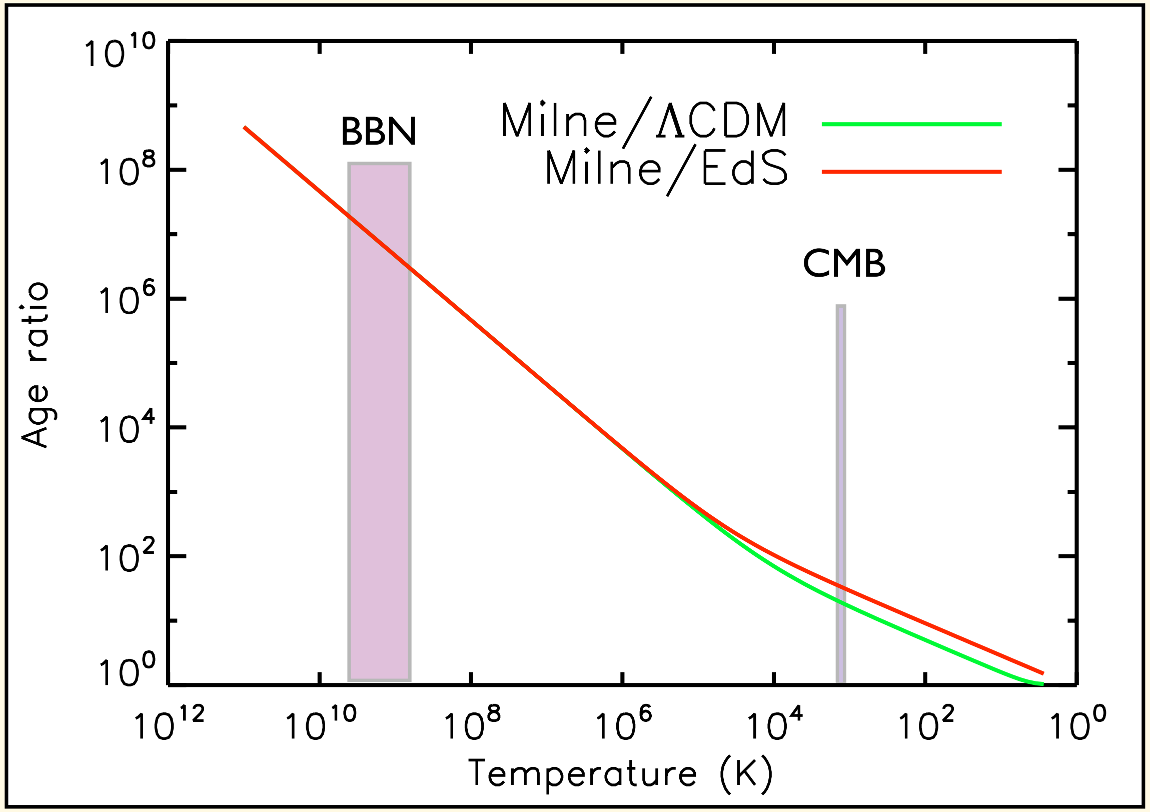
Age of the Universe in Milne Cosmology



At high temperature, the Milne Universe is much older !

BBN duration.
Standard ≈ 200 sec
Milne ≈ 30 years

Age of the Universe in Milne Cosmology



Age of the Universe at recombinaison:
14 Gy/1000 ≈ 14 My

Big-Bang Nucleosynthesis

Brief summary of Standard BBN

- T ≥ 800 Kev, neutrons and protons are in thermal equilibrium by weak interaction

$$\frac{n}{p} = e^{-Q/T}$$

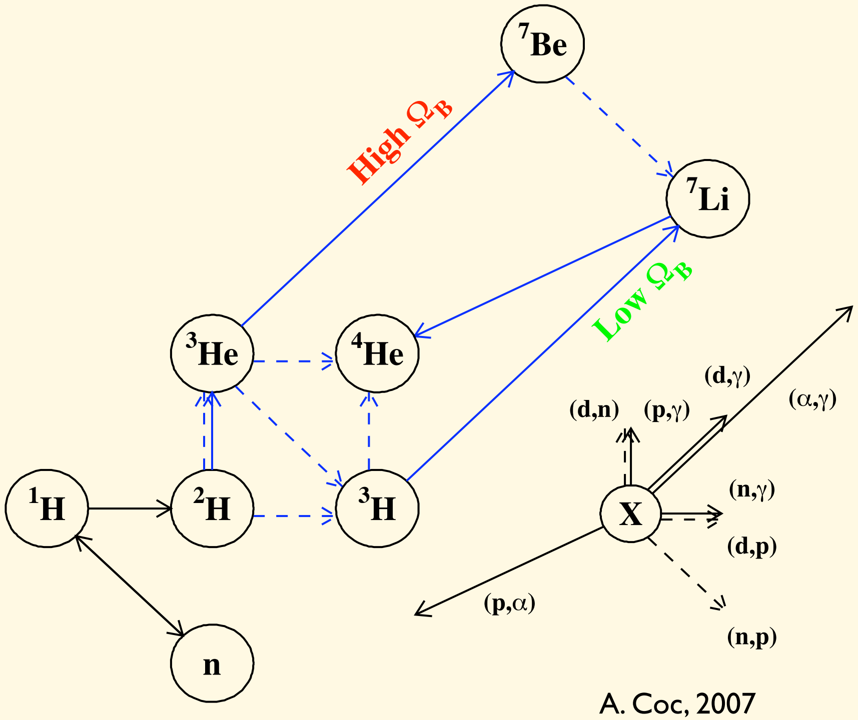
- T ≈ 800 KeV, t=1s : freeze-out of weak interactions. Free decay of neutrons.

$$\frac{n}{p} \approx \frac{1}{6}$$

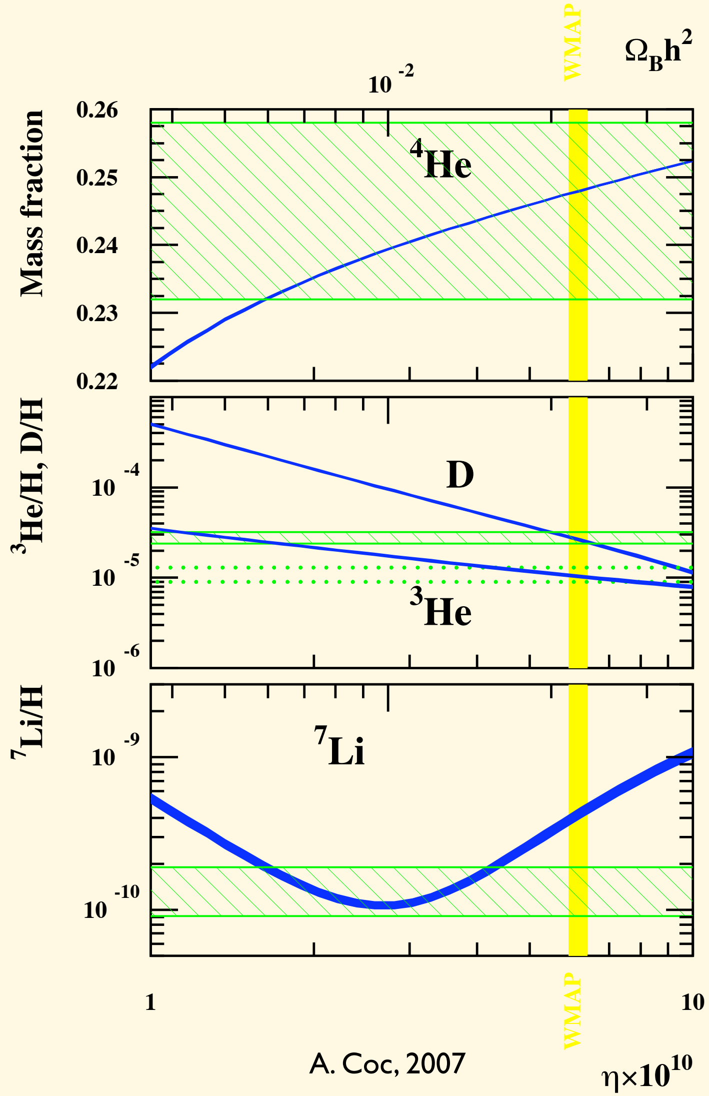
- T ≈ 80 KeV, t=200 s : Deuterium begins to survive its photodisintegration. Begin of BBN

$$\frac{n}{p} \approx \frac{1}{7} \qquad Y_p = \frac{2(n/p)}{1+(n/p)} \approx 0.25$$

Brief summary of Standard BBN



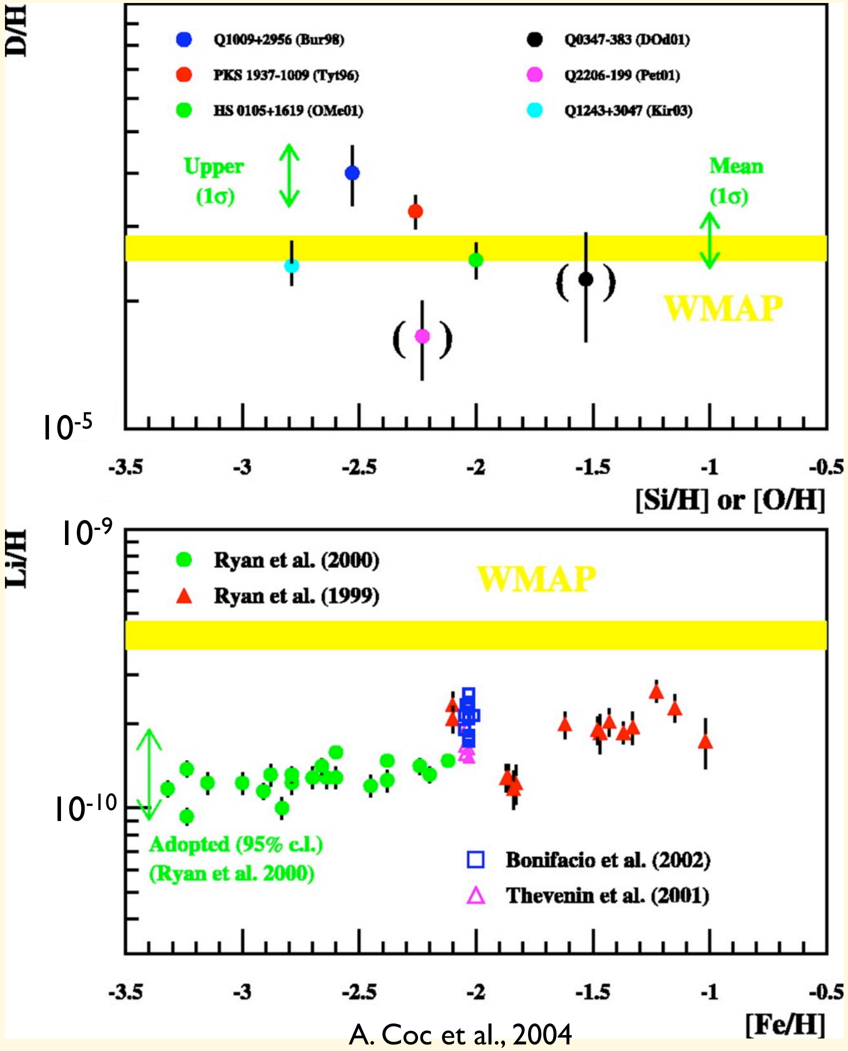
A. Coc, 2007



A. Coc, 2007

Observational status

Large dispersion of deuterium observations but deuterium is believed to be a good probe as it cannot be produced after BBN



A. Coc et al., 2004

Tension on Li-7: WMAP gives 3 times more Li-7 than observed.

Tension on Li-6: 1000 times more observed than predicted.

Coasting nucleosynthesis

Work and discussion between Lohiya et al. and Steigman et al.

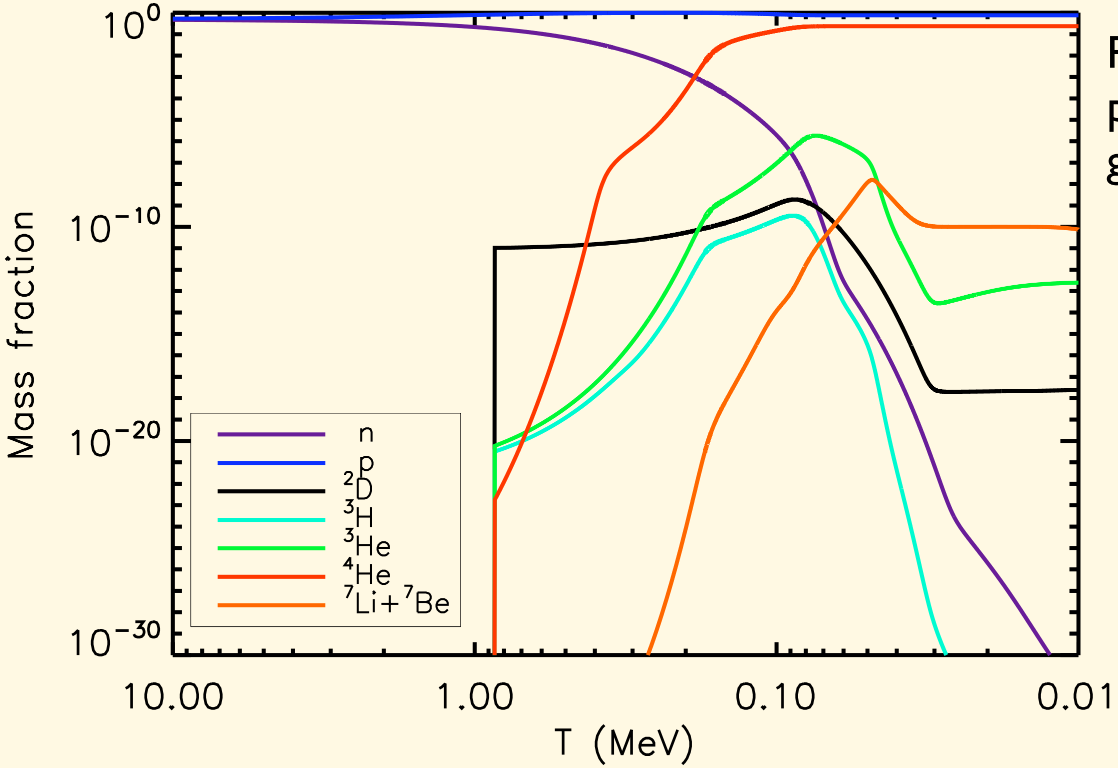
Timescale is radically different: 4×10^6 more time !

Weak n<>p reactions decouple at lower temperature: ≈80 keV instead of ≈800 keV

→ $e^- e^+$ annihilation occurs before weak decoupling:
photon and neutrinos background should have the same temperature.

Some neutrons are slowly regenerated to maintain equilibrium value, enabling nucleosynthesis to occur.

Coasting nucleosynthesis



Production of adequate He-4 is possible in coasting BBN. It needs a greater baryon to photon ratio

$$\eta \approx 7 \times 10^{-9}$$

Complete disparition of deuterium

Diffusion, spallation, nucleodisruption and photodisintegration

Matter and antimatter are separated in domains: diffusion of (anti-)nucleons lead to production of D, T, He-3

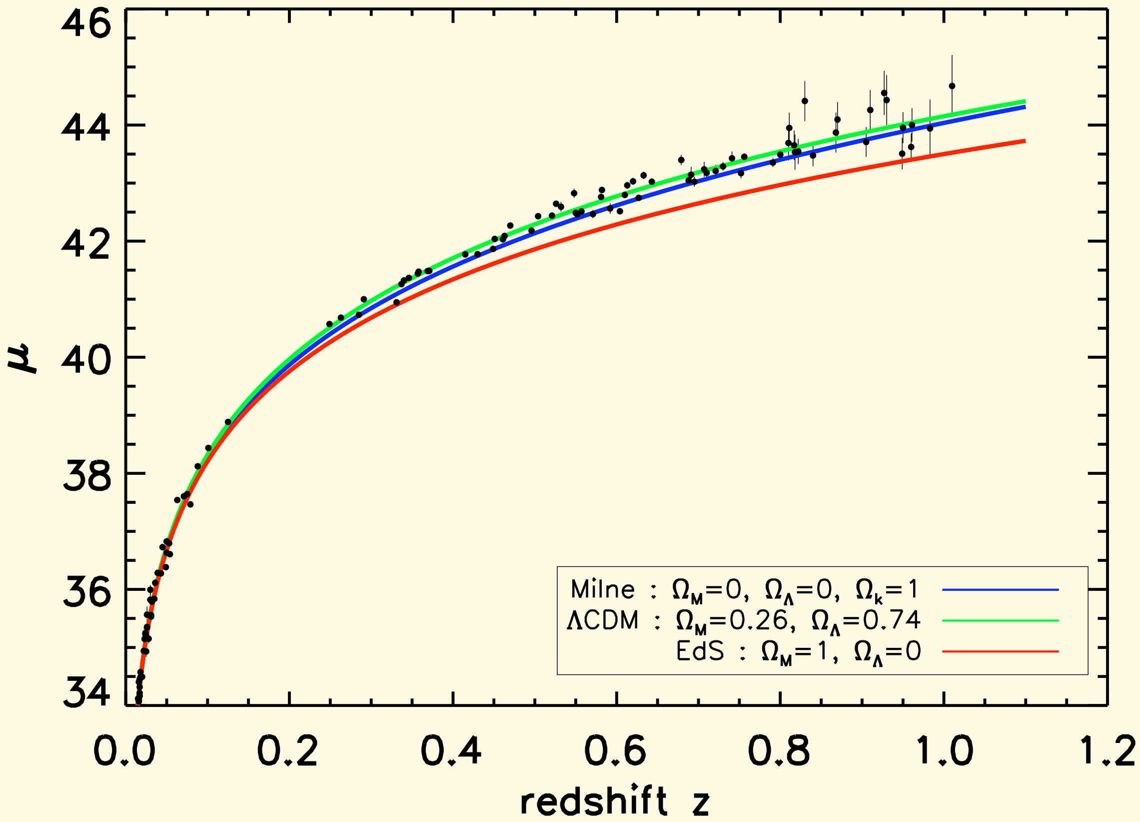
- T ≥ 80 keV, only neutrons diffuse (neutral)
- 80 keV ≥ T ≥ 5 keV, annihilation stalled. No neutron available.
- 5 keV ≥ T ≥ 1 keV: Proton diffusion becomes efficient. Convection toward annihilation zone. Nucleodisruption products deuterium (and others ...)

P_n	P_p	P_{D}	P_{T}	$P_{^3\mathrm{He}}$
0.51	0.28	0.13	0.43	0.21

Creation probability by $\bar{p}^4He$ reaction

Jedamzik et al. PRD(64)2, Kurki Suonio et al. PRD(62)10

Type Ia Supernovae



Hubble Diagram
SNLS first-year data

relative magnitude

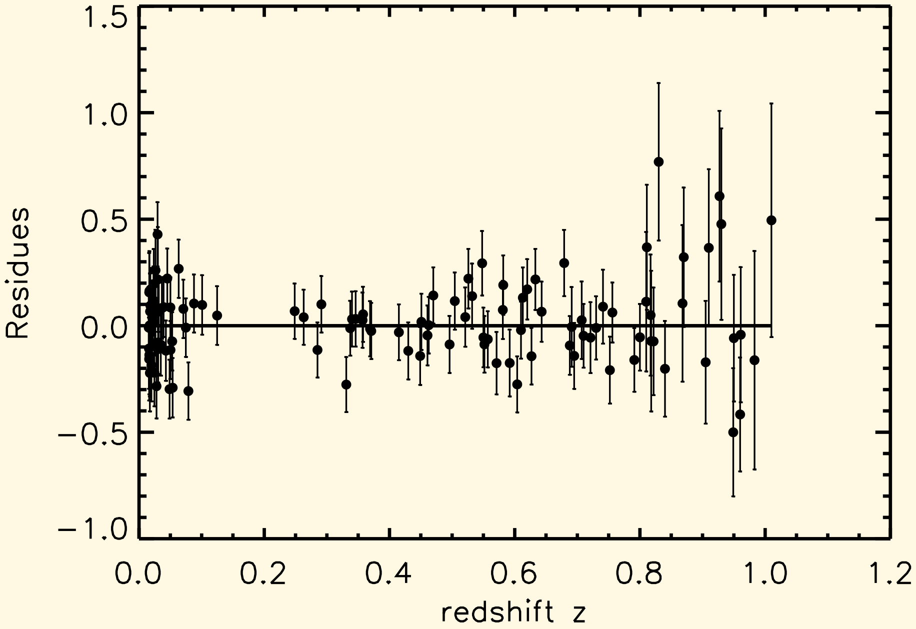
luminosity distance

$$\mu = m - M = -5 + 5\log\left(\frac{d_L(z)}{1\mathrm{pc}}\right)$$

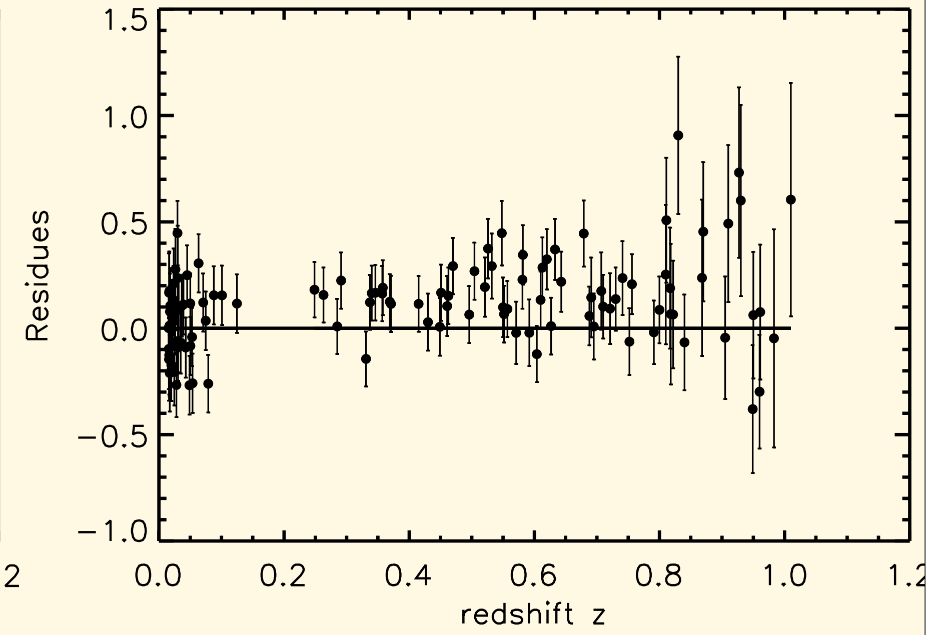
absolute magnitude

Residues Diagram for Milne, LCDM

LCDM Best fit



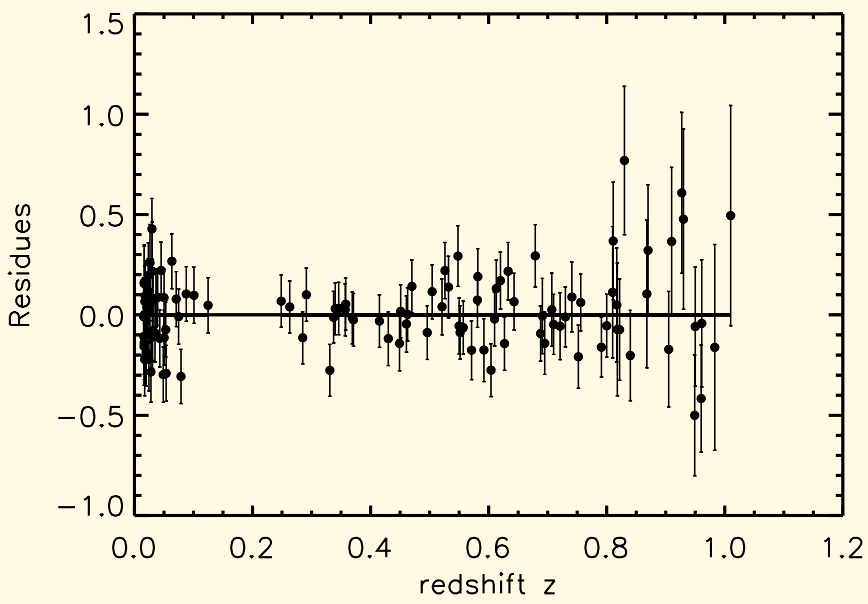
Milne - SNLS analysis

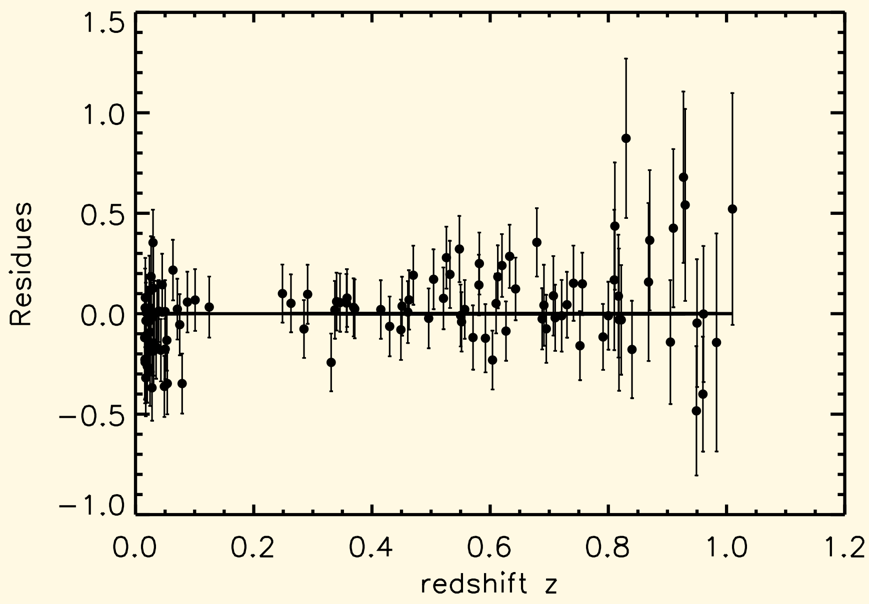


Residues Diagram for Milne, LCDM

Absolute magnitude parameter M unconstrained for Milne

Which one is the best ?

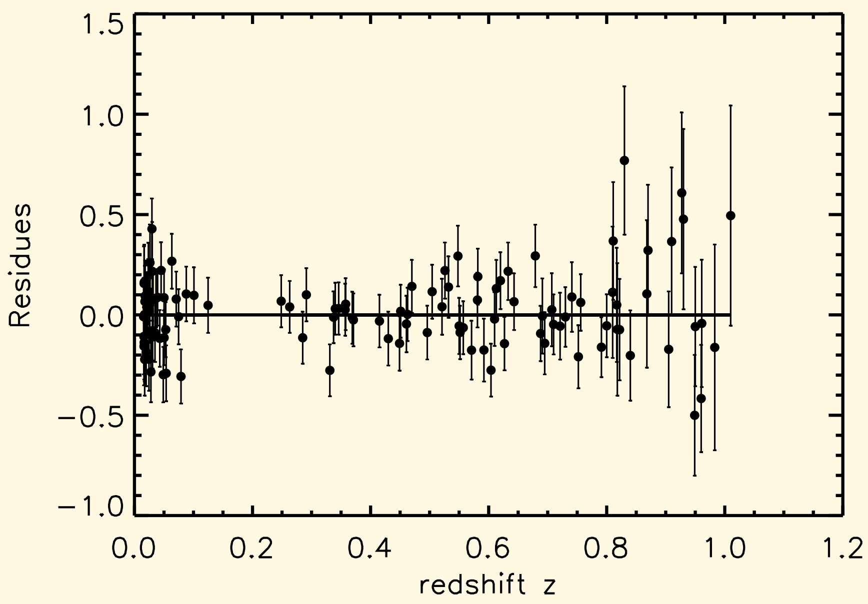




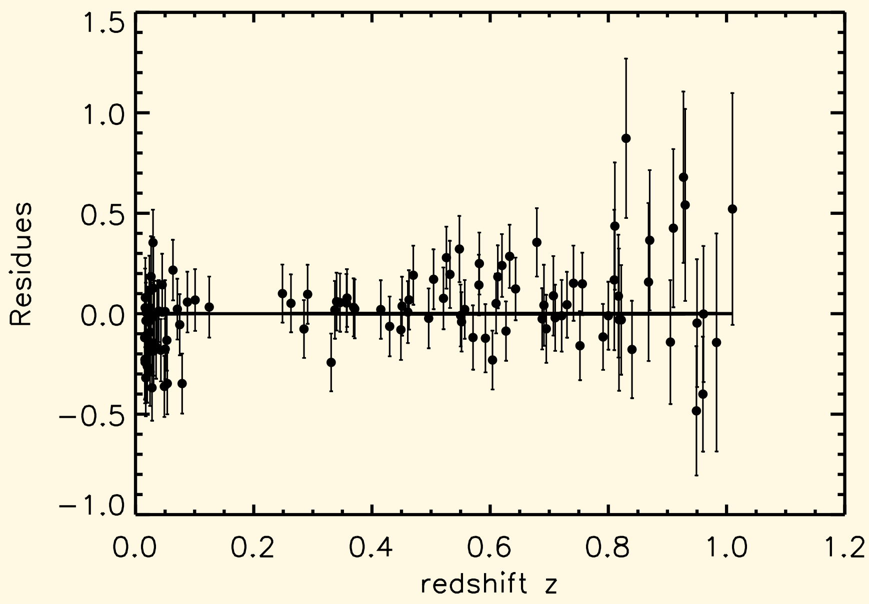
Residues Diagram for Milne, LCDM

Absolute magnitude parameter M unconstrained for Milne

LCDM Best fit

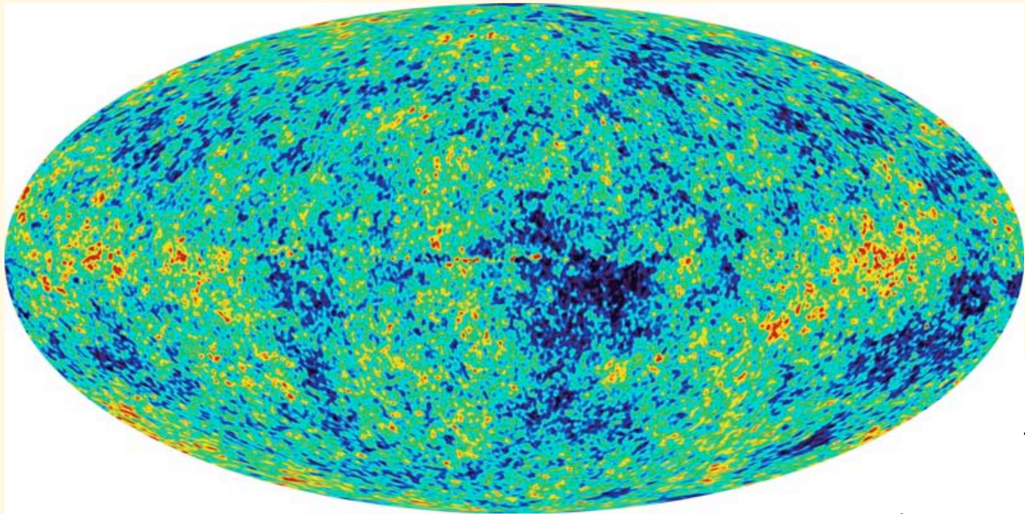


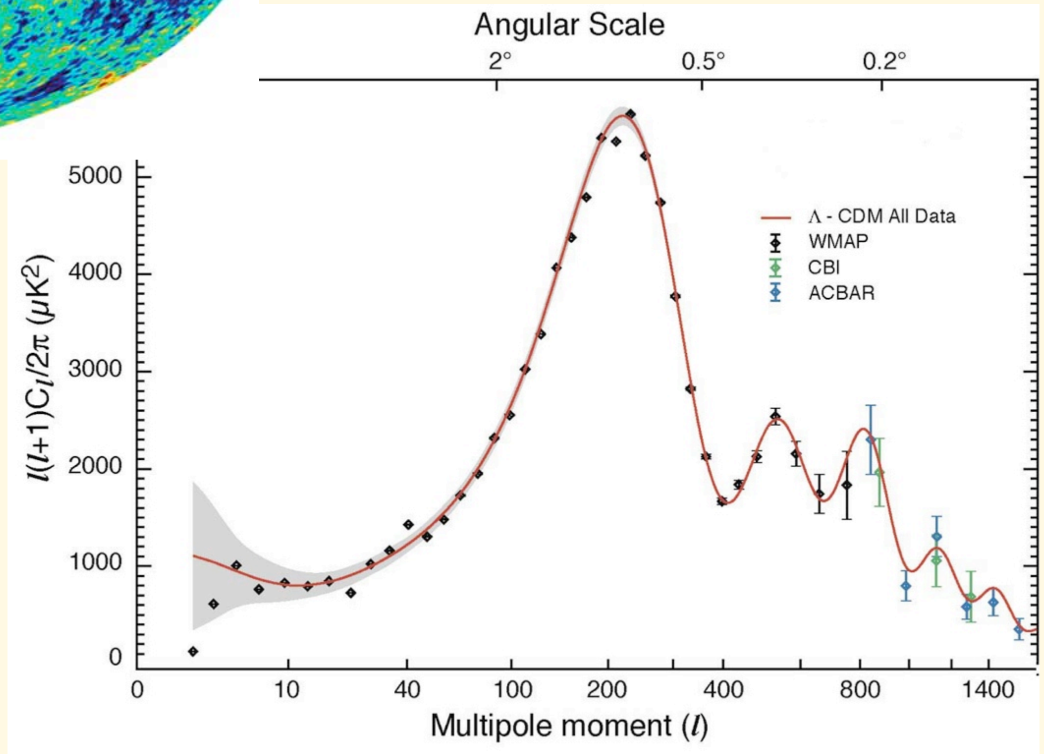
Milne - our analysis

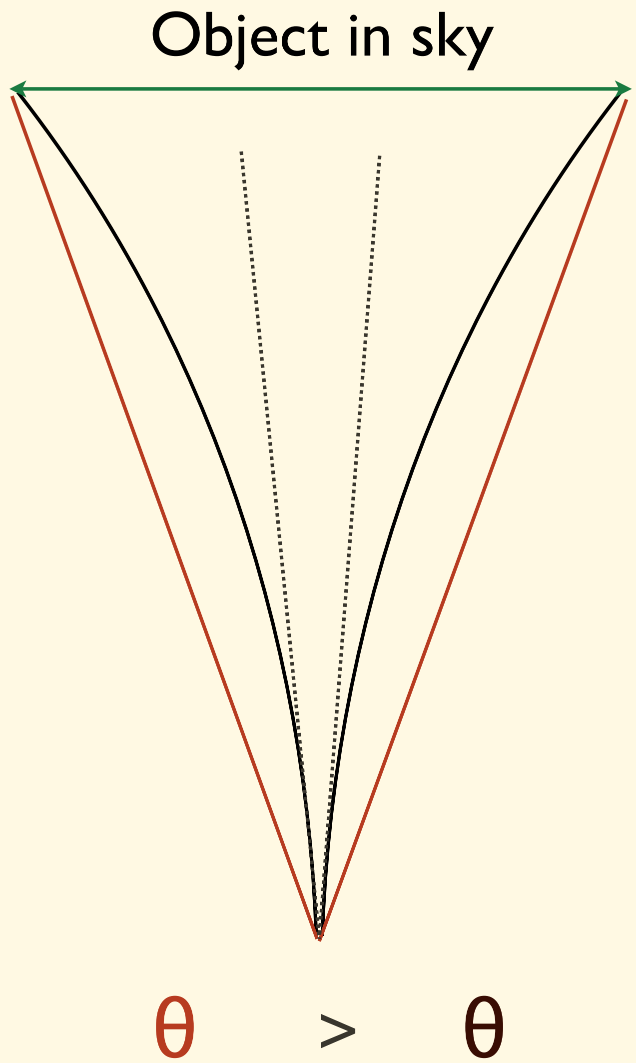


Type Ia test does not permit to exclude the Milne model !

CMB




Angular Scale
2°
0.5°
0.2°
5000
4000
3000
2000
1000
0
$l(l+1)C_l/2\pi$ (μK^2)
Λ - CDM All Data
WMAP
CBI
ACBAR
0
10
40
100
200
400
800
1400
Multipole moment (l)



Standard Model: Space-time is curved and space is flat

Milne Model: Space-time is flat (empty) and space is curved

This changes drastically the angular distance

$$\frac{\Delta\theta_{\mathrm{EdS}}}{\Delta\theta_{\mathrm{Milne}}} = \frac{\sinh(\ln(1+z))}{2\left(1-\frac{1}{\sqrt{1+z}}\right)} \overset{z=1100}{\sharp} 284$$

The same object is seen under a much smaller angle in Milne Universe

$$\theta = \frac{\text{Sound horizon at recombinaison}}{\text{Angular distance to the last scattering surface}}$$

Sound horizon
$$r_s = \int_0^{\eta_{\rm rec}} c_s d\eta = \int_0^{t_{\rm rec}} c_s \frac{dt}{a(t)}$$

sound speed

conformal time

Sound speed
$$c_s = \frac{c}{\sqrt{3(1+R)}}\ , R = \frac{3\rho_b}{4\rho_\gamma}$$

Initial condition: sound wave generation at QGP transition around 150 MeV

Under these simple hypothesis

$\theta_{\rm Milne} \approx 1.2^\circ$ One degree scale, just like the observed scale !

Conclusion

Standard model is a good fit but is not natural (two unobserved components)

Surprisingly, the symmetric Milne Universe seems to satisfy cosmological tests:
Age, Big-Bang Nucleosynthesis, Type Ia Supernovae and CMB.

Still, number of questions unsolved:
- angular spectrum of temperature fluctuations (CMB),
- How to hide so much baryons ?
- Check consistency with other cosmological tests

Questions ?