Univers de Milne
Symétrique matière-antimatière

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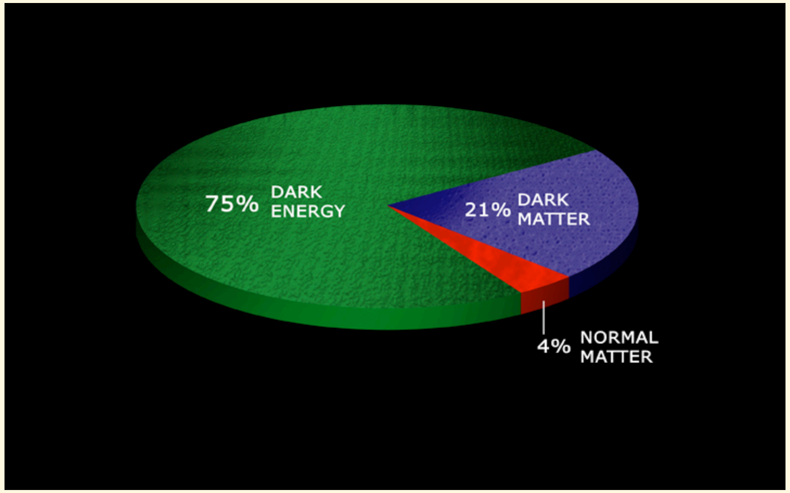
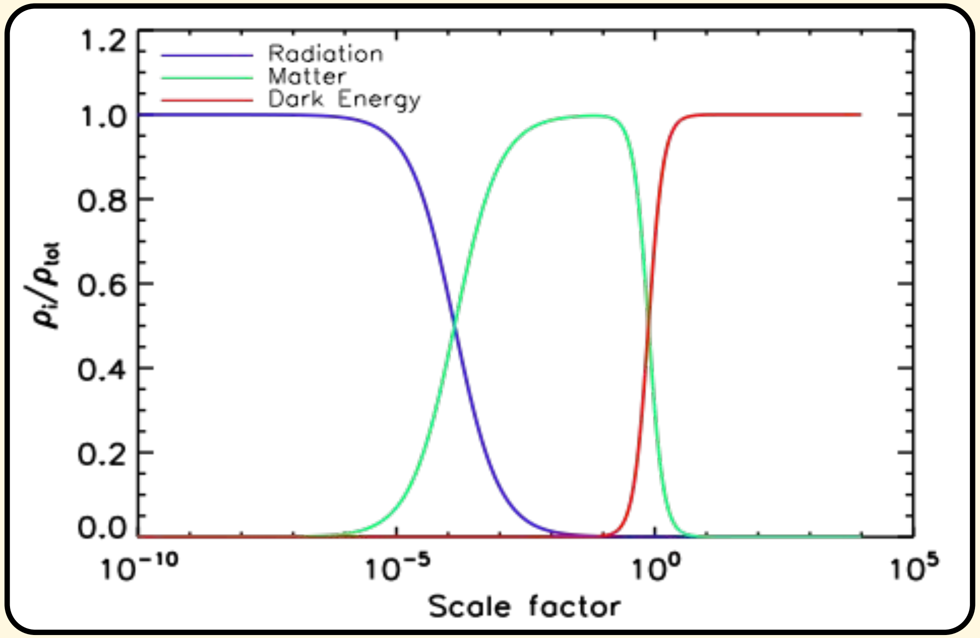
- The composition of the Universe according to concordance model is rather surprising: 95% is unknown!
- Three components successively predominant and then completely negligible.



Before accepting such a strange Universe, necessity to consider the possibility of simpler alternatives



The Symmetric Milne Universe: a flat *spacetime* with no Dark Matter and no Dark Energy

- Presentation and motivations
- Confrontation to Type Ia SN, BBN, and CMB

The Symmetric Milne Universe

- A coasting Universe, with linear scale factor, could be an interesting alternative to a strong deceleration at early times and then a phase of exponential expansion. This Universe has a slower evolution at high temperature. Spends about 10^8 times more time at QGP transition.
- Universe very homogeneous above QGP transition. Separation of matter and antimatter during phase transition that creates domains is possible with such a long time available (cf Omnes 70's)
- Equal quantities of matter and antimatter. Antimatter has negative active gravitational mass
- Without Dark Energy or Dark Matter
- Gravitationally empty Universe at large scales, no acceleration and no deceleration. Scale factor evolves linearly with time: $a(t) \propto t$

$a(t) = t$ an $k = -1$ in FRW metric implies *flat space-time* and *open space*. Compared to usual assumption of *flat space*.

→ Milne Universe is the second "natural" universe

Motivations

- Symmetry in Kerr-Newmann geometry under space, mass and charge reversal.
  Two CP conjugate spaces connected by the ring
  Elementary particles as “black holes”
  B. Carter 66&68, Arcos & Pereira 04

- SNIa observations reveals effective repulsive gravity which is unexplained

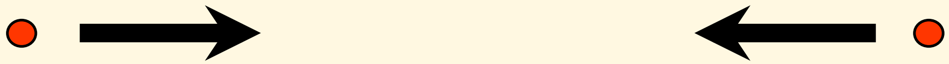
- High level of fine-tuning in standard model

- Removes need for inflation

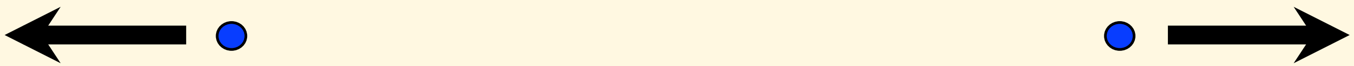
In the following, antimatter gravitational mass is taken negative. Gravitational repulsion between matter and antimatter.

Negative mass in GTR (Bondi) ?

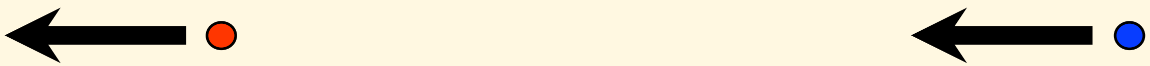
Two positive masses attract each other



Two negative masses repulse each other



One positive mass and one negative mass : runaway



Positive mass particle

Negative mass particle

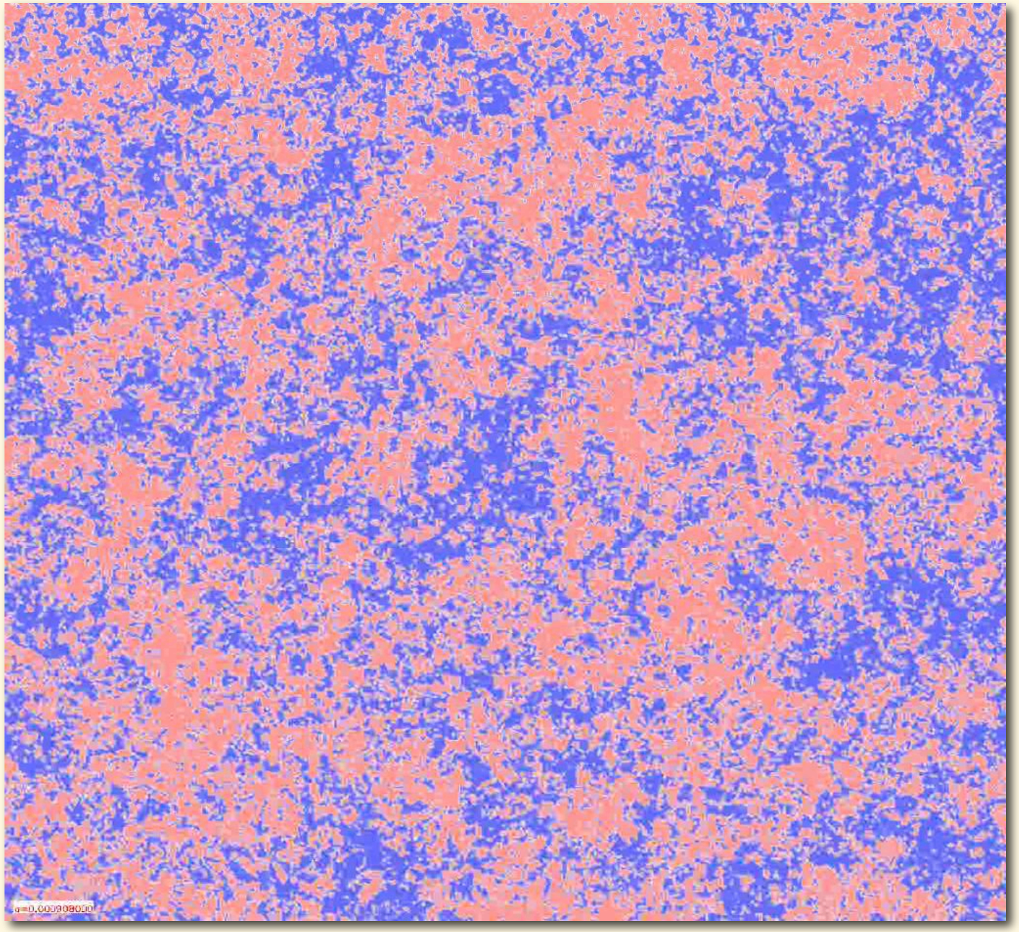
A classical example of "antigravity"

- Analogy with solid state physics : electron-hole pairs, reminiscent of Dirac sea…
- Superfluid helium as a medium (static/Earth)
- Place an electron in this medium : vacuum bubble ➔ negative mass relative to He backgrd
- Motion of this pseudoparticle : accelerates *upwards* with (nearly) perfect acceleration +*g*
- Of course, helium fluid propagates downwards

http://www.physics.brown.edu/physics/researchpages/cme/bubble/index.html

Simulation structures

- Simulation cosmologique 2D 2048 x 2048 (masses + et –)



The Symmetric Milne Universe

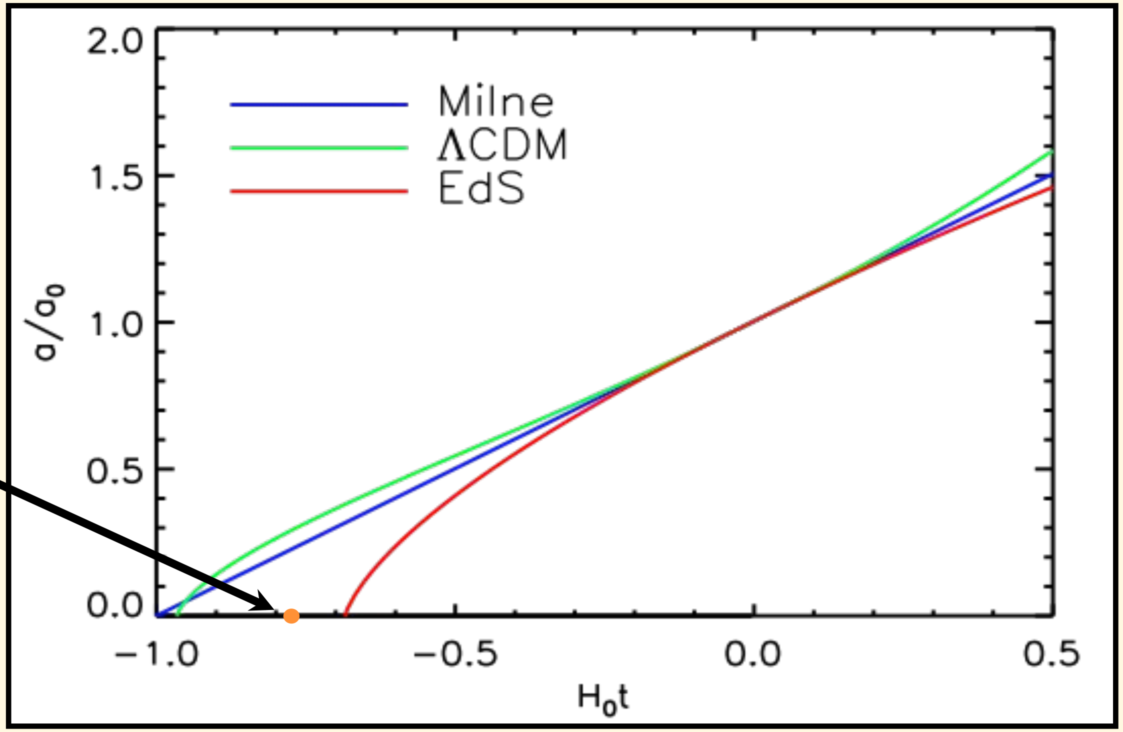
- As radial coordinate of a z redshift object: $\chi(z) \overset{z\to+\infty}{\longrightarrow} +\infty$, a Universe with linear scale factor has no horizon. There is no need for an inflation scenario.

- Age of the Milne Universe is almost exactly the same as the age of ΛCDM Universe

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

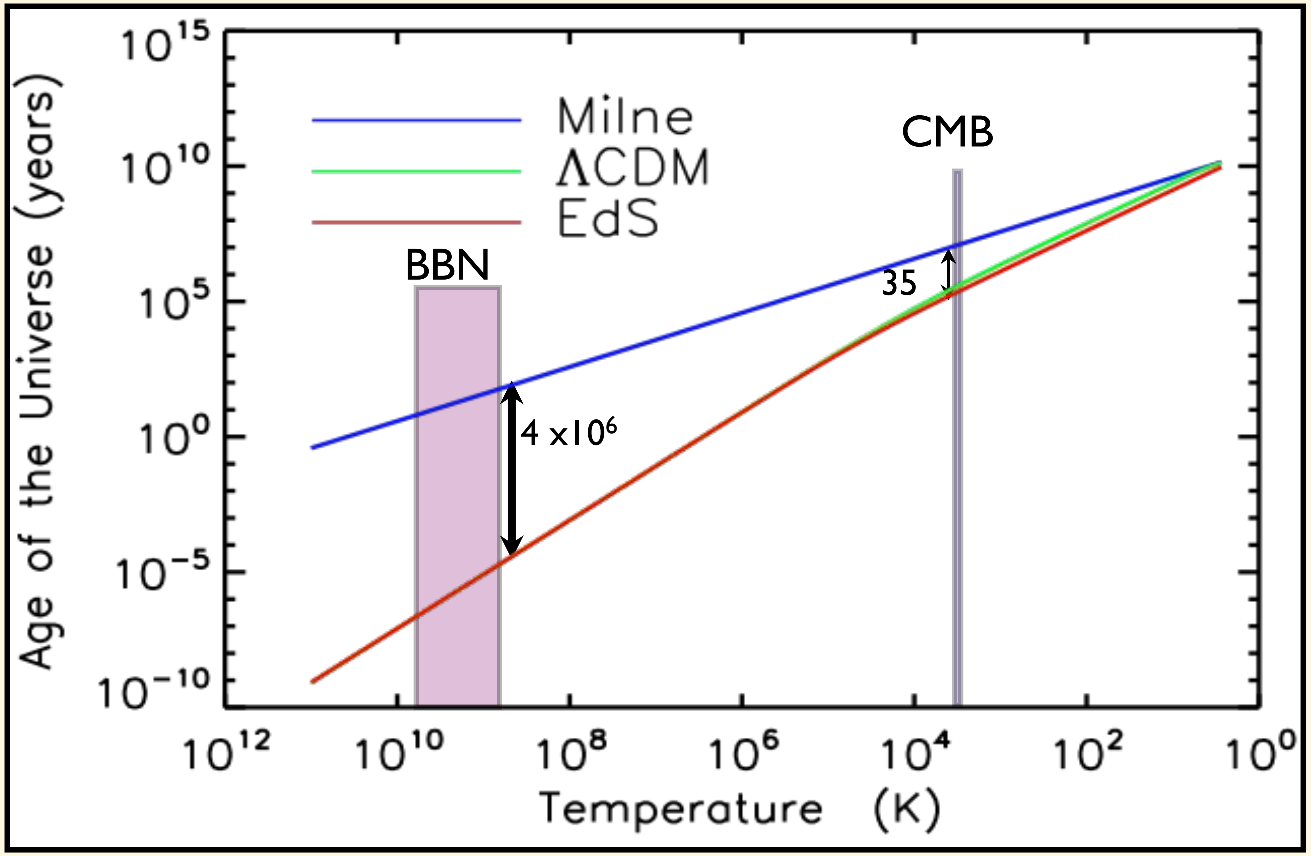
Age of the Universe was a problem for a Einstein-de Sitter model, which was solved by ΛCDM, but is also solved by Milne Universe

oldest globular clusters (Chaboyer et al.,98)



Time scale of primordial Universe is extremely different !

First noticed by Dev et al. 02



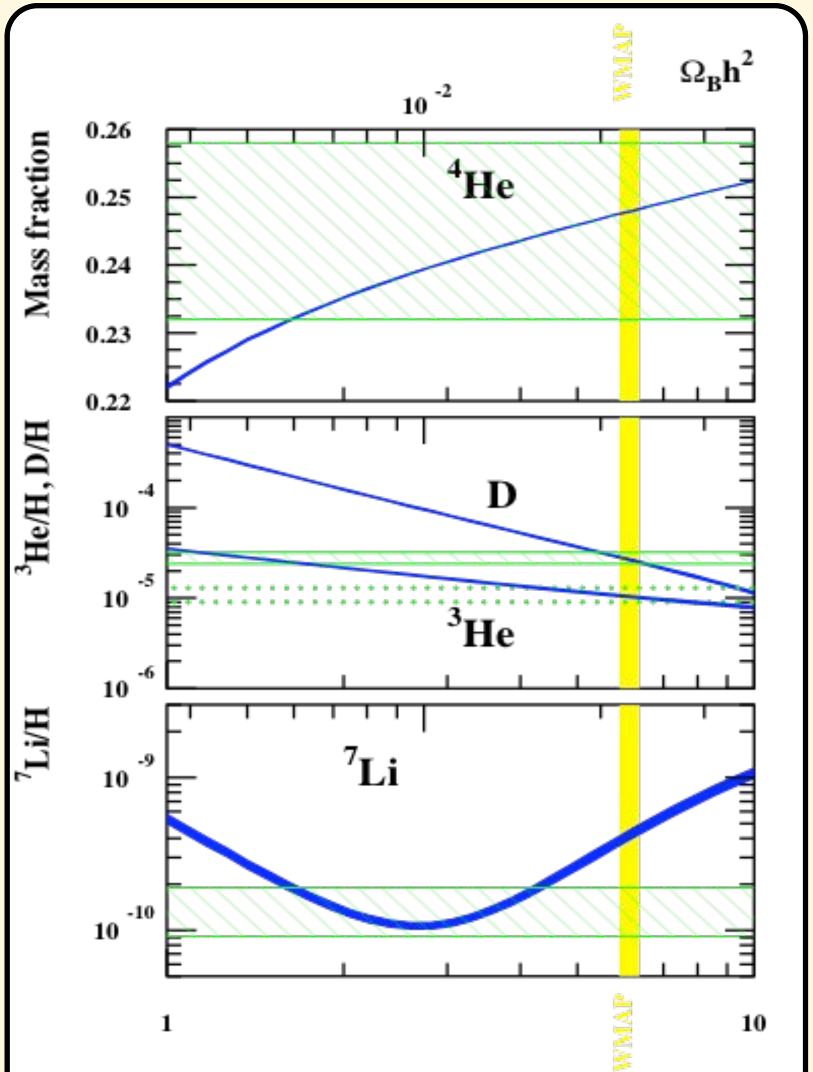
Milne Universe spends much more time at high temperature than conventional Universe.

BBN duration:
Standard BBN ≈ 200 sec
Milne BBN ≈ 30 years

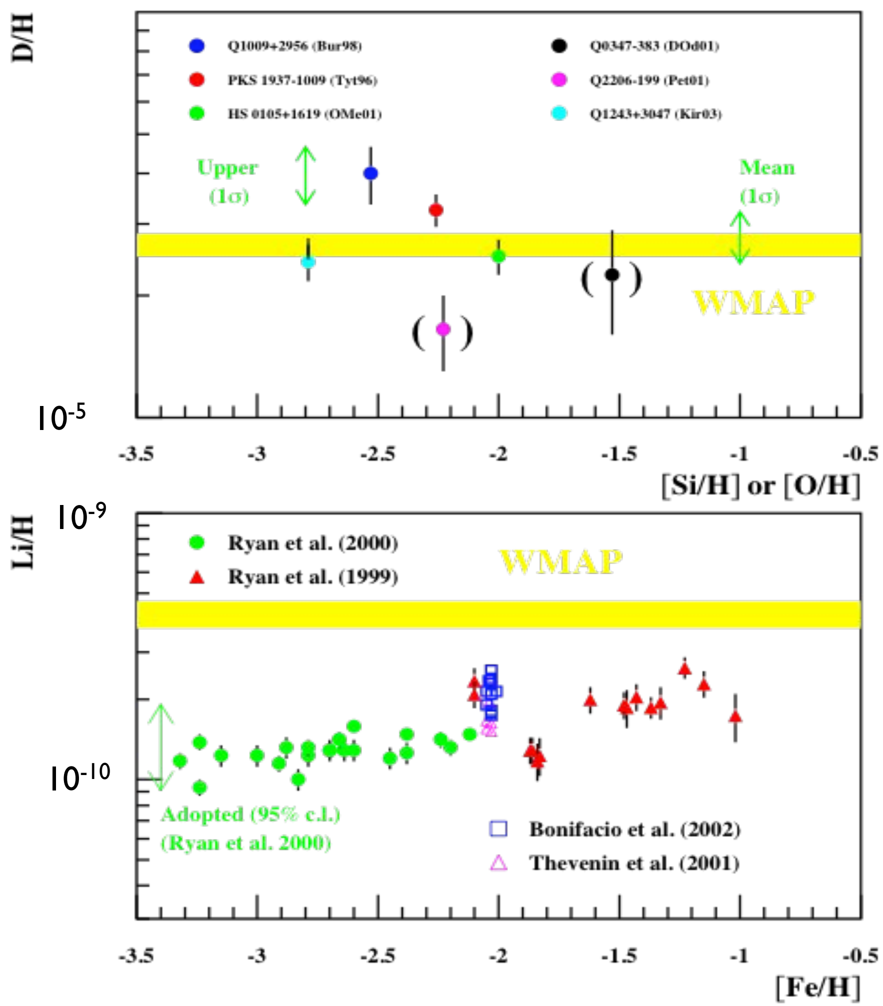
Age of the Universe at recombinaison:
14 Gy/1000 ≈ 14 My
(compared to 0.38 My in ΛCDM)

Big-Bang Nucleosynthesis

Predictions and observational status



A. Coc, 2007



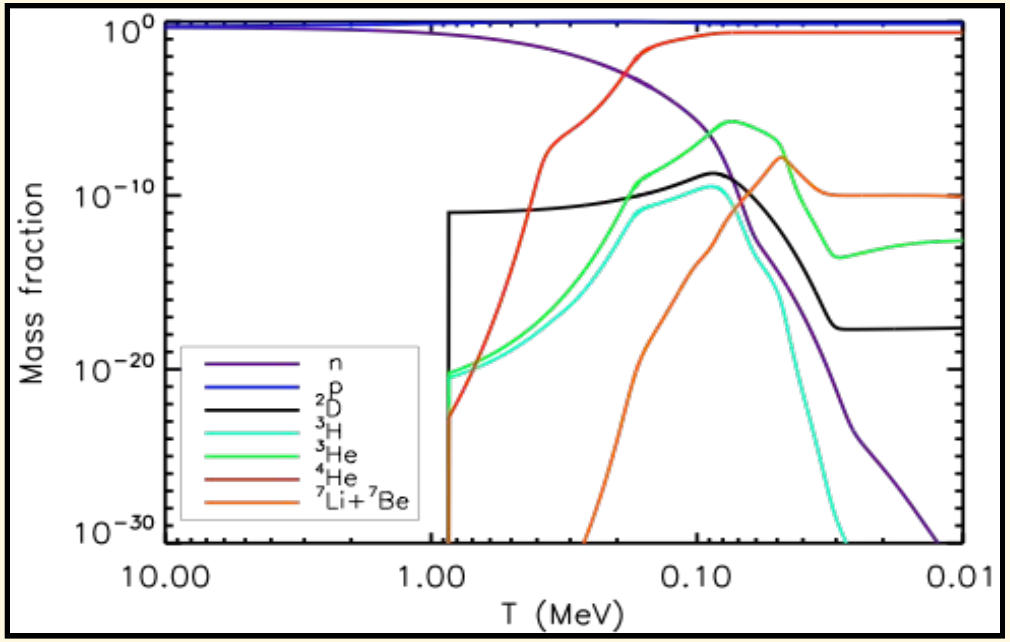
A. Coc et al., 2004

Big-Bang Nucleosynthesis in Milne Universe

Studied in Lohiya et al. (astro-ph/9902022) and Kaplinghat et al. (astro-ph/9805114)

BBN lasts in Milne Universe lasts 30 years instead of 3 minutes

Due to slower evolution, weak reactions decouple around 80 keV, maintaining equilibrium between protons and neutrons. Slowly, deuterium is formed and burnt into helium.
Neutrons are regenerated to restore equilibrium value



In collaboration with A. Coc (CSNSM/Orsay)

Production of adequate He-4 is possible in coasting BBN. It needs a greater baryon to photon ratio $\eta \approx 7 \times 10^{-9}$

No deuterium left

Production of Deuterium and Lithium-6

BBN in presence of small-scale domains of antimatter studied in Jedamzik et al. 2001& Kurki Suonio et al. 2000

- Annihilation zone between domains of matter and antimatter is regulated by nucleon diffusion:
  - $T \geq 80$ keV, massive annihilation by neutron diffusion
  - 80 keV $\geq T \geq$ 5 keV, no more neutrons, annihilation drops by a factor $\approx 10^4$.
  - 5 keV $\geq T \geq$ 1 keV: Proton diffusion becomes efficient. Convection toward annihilation zone. Nucleodisruption and photodisintegration produce deuterium and lithium-6 by non-thermal reactions
  - 1 keV > T: annihilation stops due to gravitational repulsion

- Domain size: around 10^{15} m @ 1 keV (Mpc scale comoving)
  Deuterium production at the level of $\approx 3 10^{-5}$
  ^{6}Li production : using $\left\langle P_{T\,^4He \rightarrow n\,^6Li} \right\rangle \approx 2 \times 10^{-6}$ and $\left\langle P_{^3He\,^4He \rightarrow p\,^6Li} \right\rangle \approx 5 \times 10^{-7}$

  (Jedamzik and Rehm 2000)

Production of Lithium-6

- Normalize ^6Li production to deuterium production (≈ 3 × 10^{-5})

- ^6Li production : using $\left\langle P_{T\,^4He \to n\,^6Li} \right\rangle \approx 2 \times 10^{-6}$ and $\left\langle P_{^3He\,^4He \to p\,^6Li} \right\rangle \approx 5 \times 10^{-7}$

  we find :
$$\left\langle ^6Li \right\rangle \approx \frac{\langle D \rangle}{\left\langle P_{\bar{p}\,^4He \to D} \right\rangle} \left(\left\langle P_{\bar{p}\,^4He \to T} \right\rangle \left\langle P_{T\,^4He \to n\,^6Li} \right\rangle + \left\langle P_{\bar{p}\,^4He \to ^3He} \right\rangle \left\langle P_{^3He\,^4He \to p\,^6Li} \right\rangle \right)$$

$$\left\langle ^6Li \right\rangle \approx \frac{3 \times 10^{-5}}{0.13} \left(0.43 \times 2 \times 10^{-6} + 0.21 \times 5 \times 10^{-7} \right) \approx 2.2 \times 10^{-10}$$

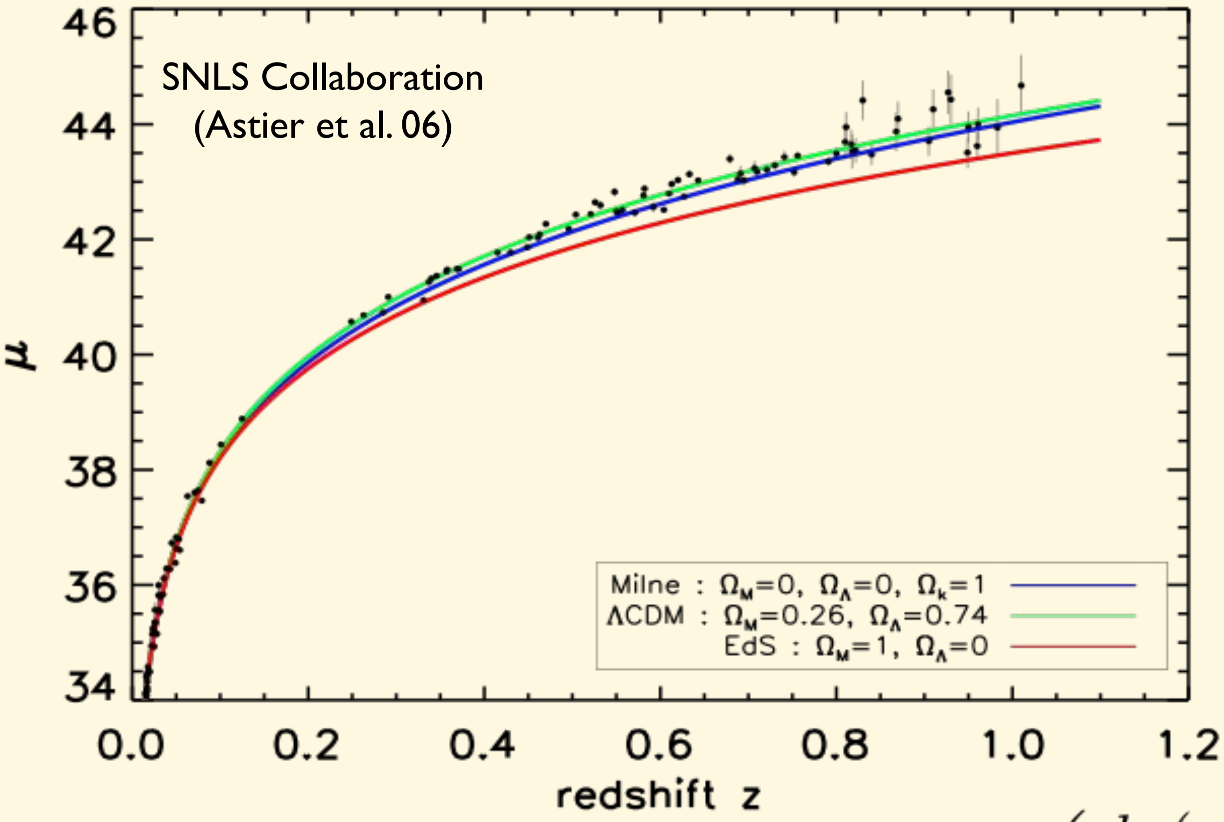
O. Richard, et al., Astrophys.J. 580 (2002) 1100, astro-ph/0112113

- O. Richard, G. Michaud, J. Richer, Astrophys.J. 619 (2005) 538 ; astro-ph/0409672

  A. J. Korn, et al., Nature 442 (2006) 657 ; astro-ph/0608201v1

Type Ia Supernovae

Hubble diagram of Type Ia Supernovae



Milne Universe (blue) is very close to ΛCDM (green) as noted in Perlmutter et al. 99

Einstein-de Sitter model seems totally ruled out

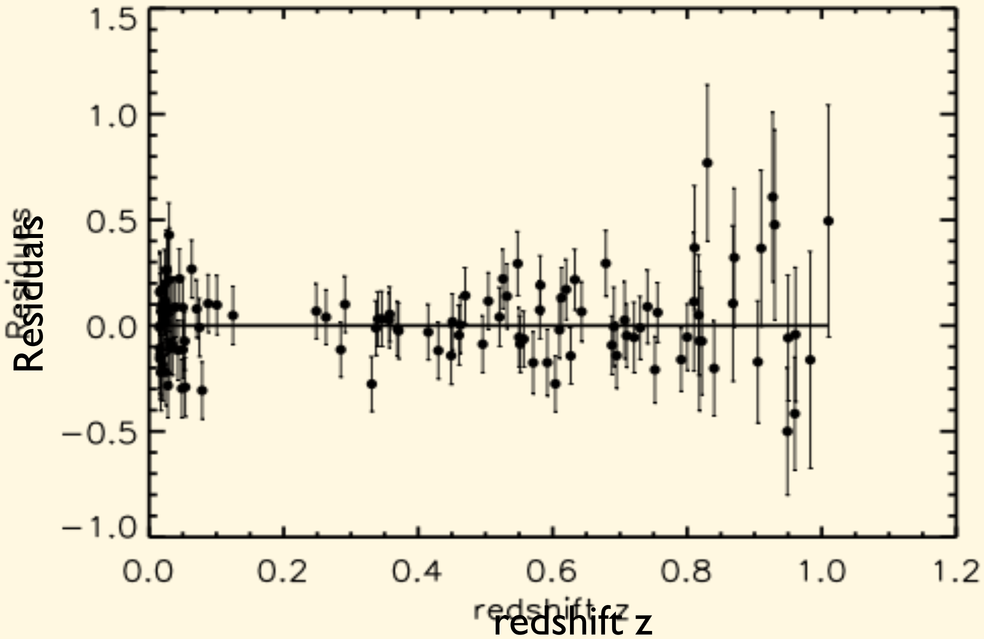
$$\mu = m - M = -5 + 5\log\left(\frac{d_L(z)}{1\mathrm{pc}}\right)$$

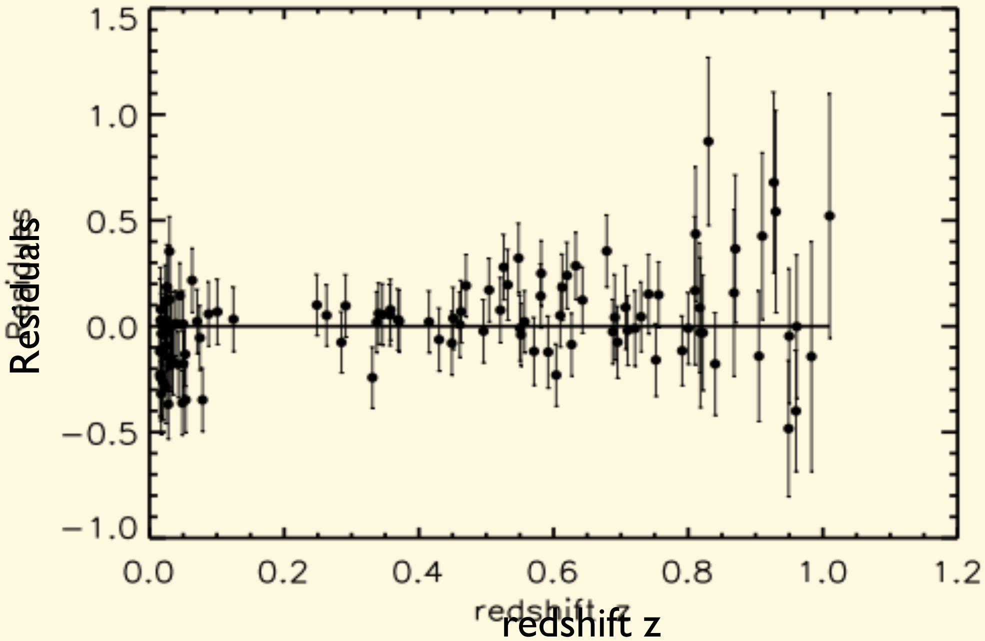
Unknown parameter

Residuals of Hubble diagram for the two models

Absolute magnitude parameter M unconstrained for Milne

Which one is Milne ? Which one is ΛCDM ?

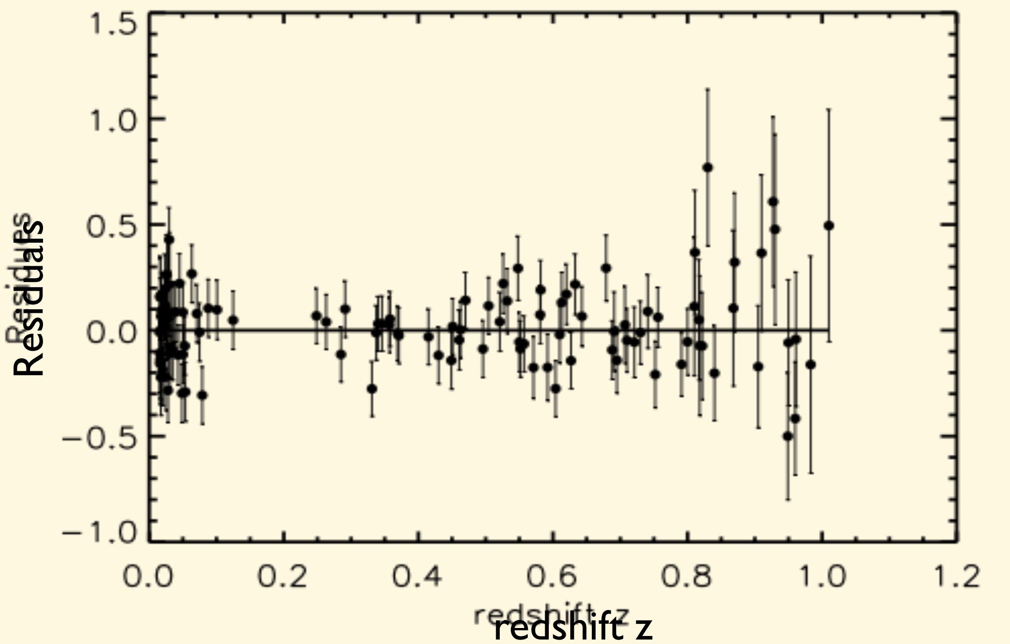




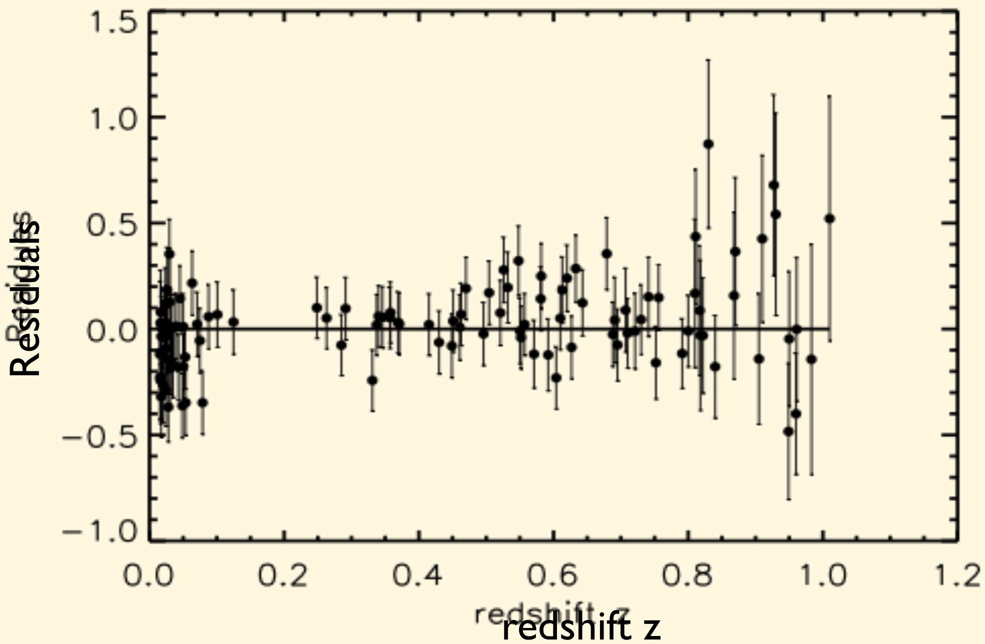
Residues of Hubble diagram for the two models

Absolute magnitude parameter M unconstrained for Milne

LCDM Best fit



Milne - our analysis



Type Ia SN test most probably does not allow to exclude the Milne model !

CMB

Position of the first acoustic peak in Milne Universe

Angular scale of first peak corresponds to the angle under which is seen sound horizon at decoupling

Angular distance

In Milne Universe, spacetime is flat. Therefore space is hyperbolic, angular distance is drastically changed. An object in the sky will be seen with a much smaller angle than in standard cosmology

$$\frac{\theta_{\Lambda CDM}}{\theta_{\rm Milne}} = \frac{d_A^{\rm Milne}(z)}{d_A^{\Lambda CDM}(z)} \overset{z=1100}{=} \sharp \quad 173$$

Sound horizon

Sound generation during QGP transition, caused by matter-antimatter annihilation

$$r_s = \int_{t_{\rm 170MeV}}^{t_{\rm rec}} c_s \frac{dt}{a(t)}$$

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

A symmetric matter-antimatter Milne universe requires neither inflation, nor Dark Energy, nor Dark Matter and is in surprisingly good agreement with main cosmological tests

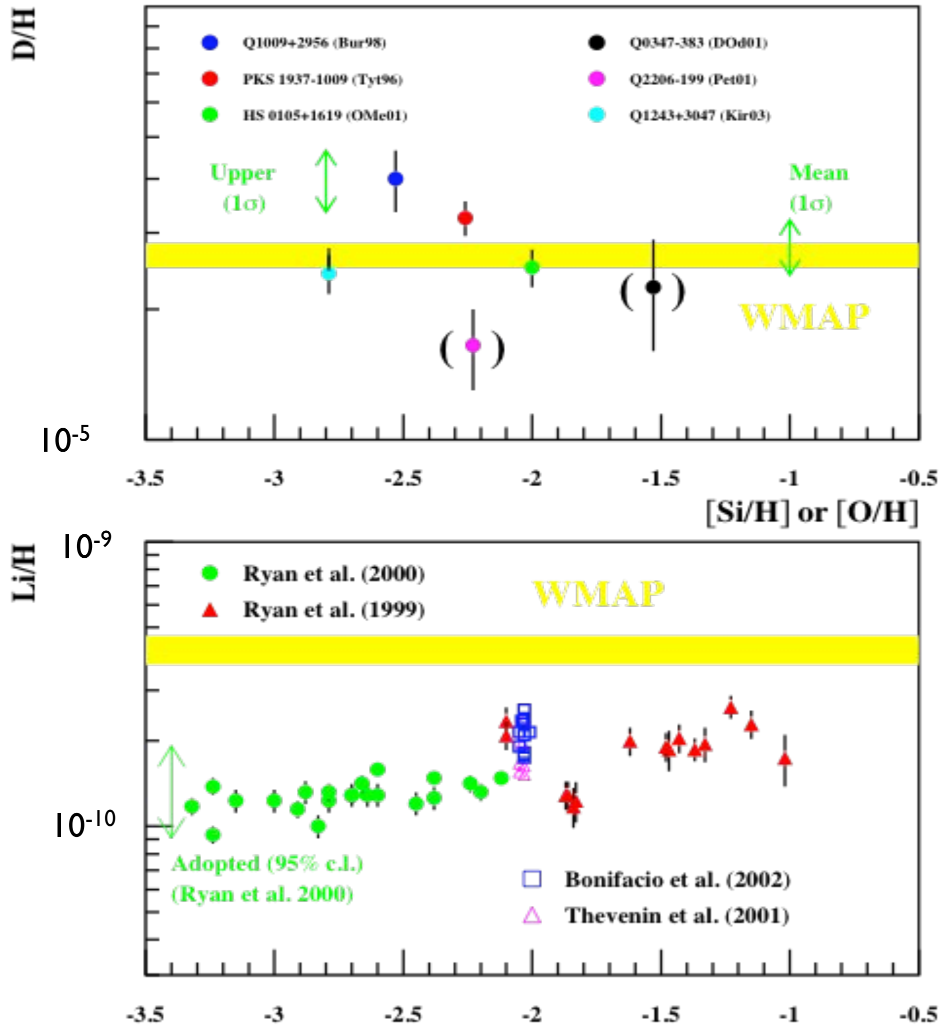
- BBN: good agreement for helium-4, realistic mechanism for deuterium and lithium-6 production at the observed levels
- Type Ia SN: Milne Universe very hard to distinguish from ΛCDM with current data
- CMB: degree scale for first peak for Milne Universe !

Still, a number of questions remain:
- angular spectrum of temperature fluctuations (CMB),
- is it possible to hide so many baryons ? (molecular gas ?)
- consistency with other cosmological probes

BACKUP SLIDES

Observational status

- Large dispersion of deuterium observations but deuterium is believed to be a good probe as it cannot be produced after BBN
- Tension on Li-7: WMAP gives 3 times more Li-7 than observed
- Tension on Li-6: 1000 times more observed than predicted by standard BBN



A. Coc et al., 2004

Age of the Universe in Milne Cosmology

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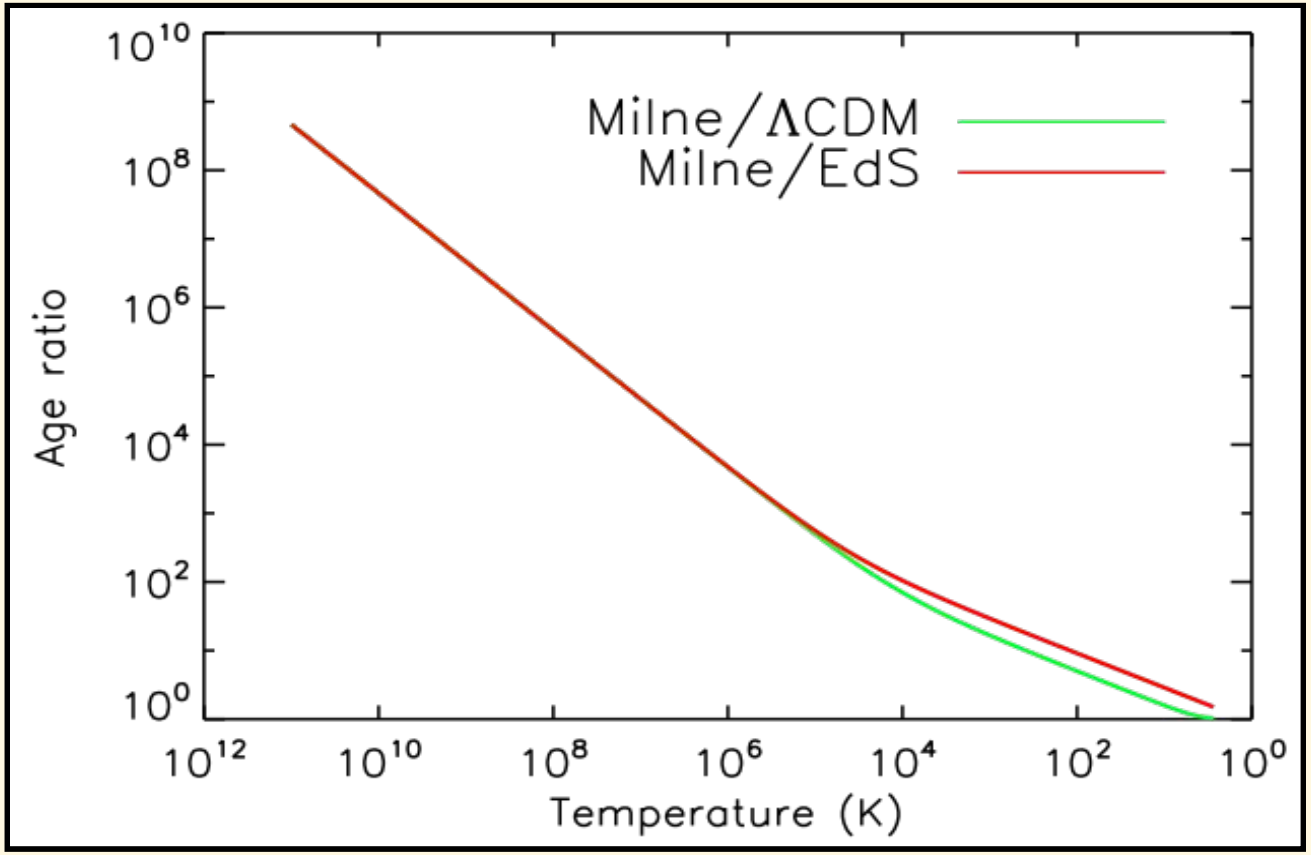
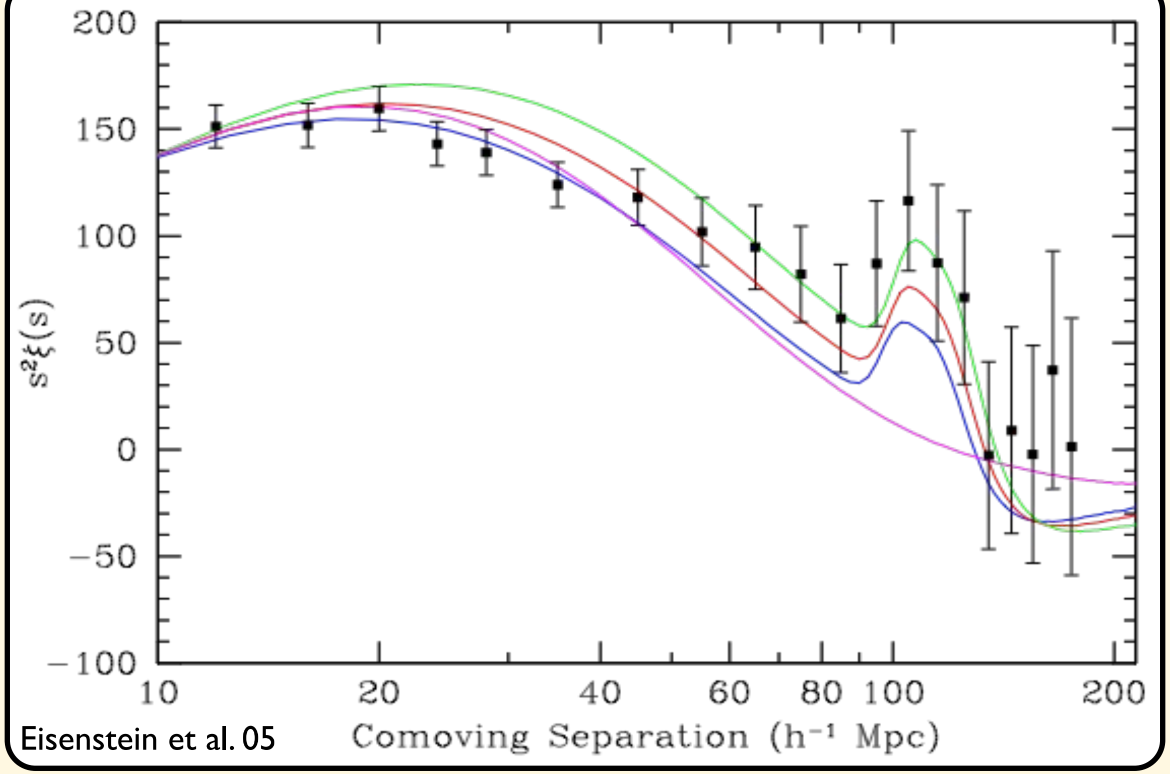


BAO



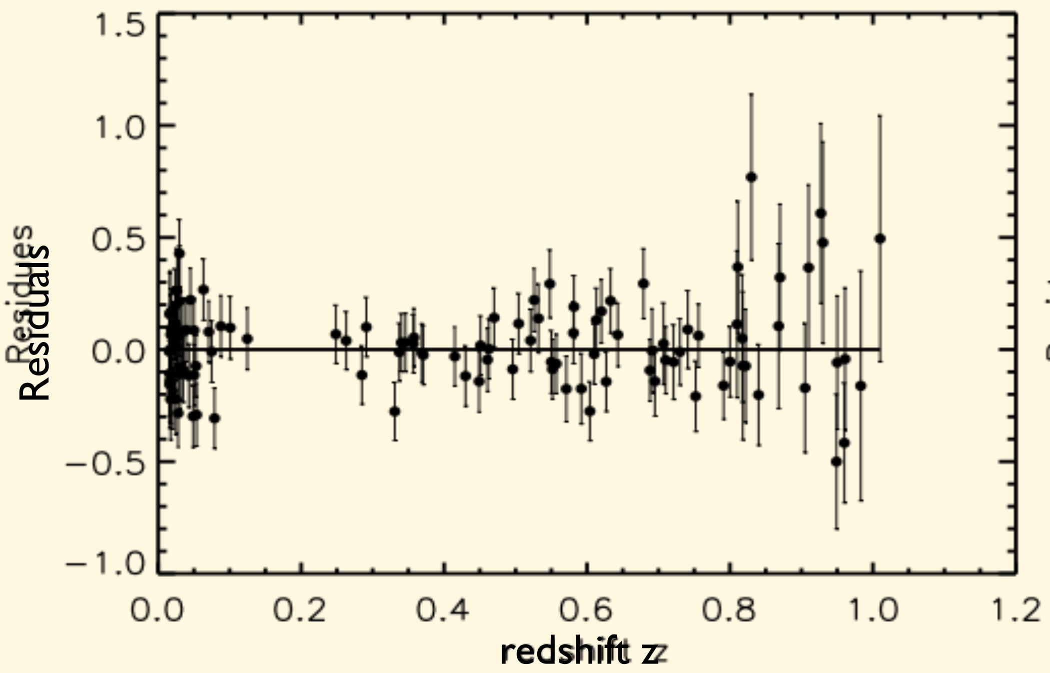
Eisenstein et al. 05

Future experiments will be decisive to conclude on BAO.

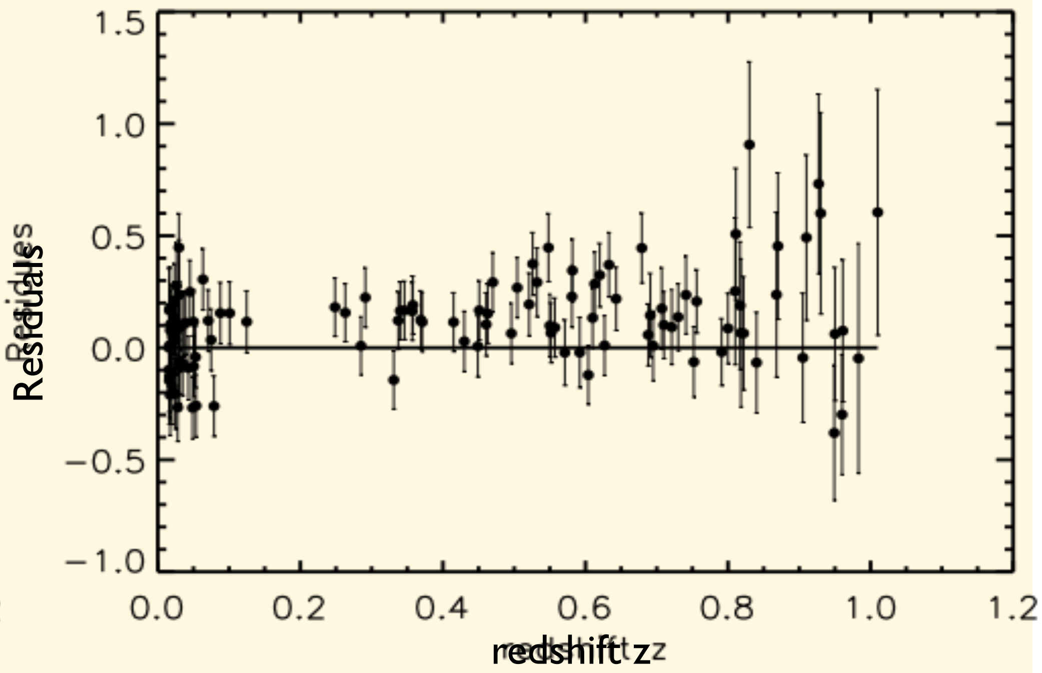
Two characteristic scales in Milne Universe
- Sound horizon
- Size of domains

Residues of Hubble diagram for the two models in SNLS analysis

LCDM Best fit



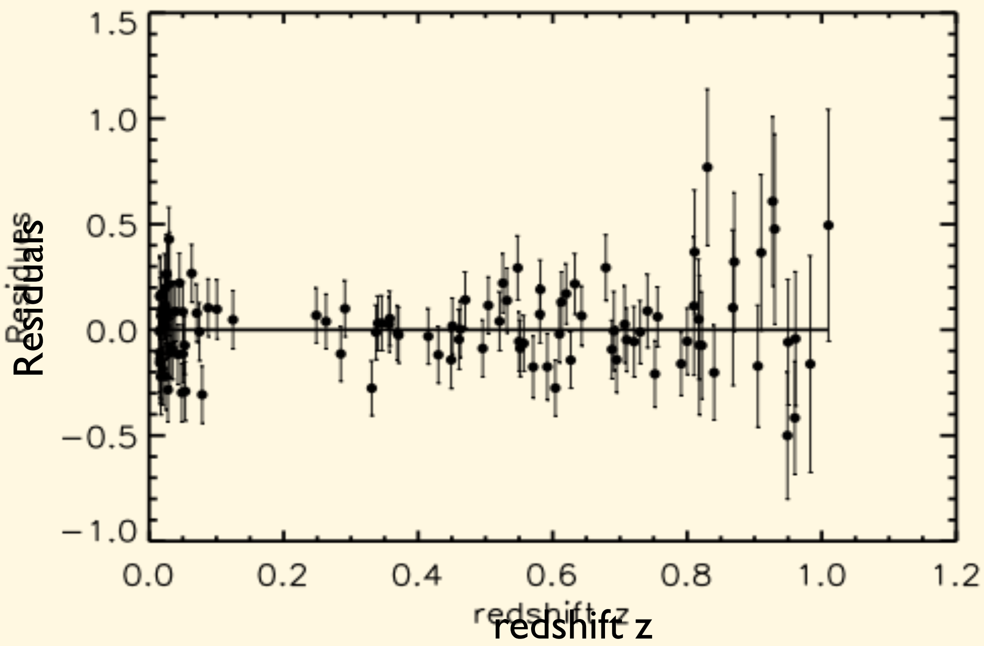
Milne - SNLS analysis



Residues of Hubble diagram for the two models

Absolute magnitude parameter M unconstrained for Milne

LCDM Best fit



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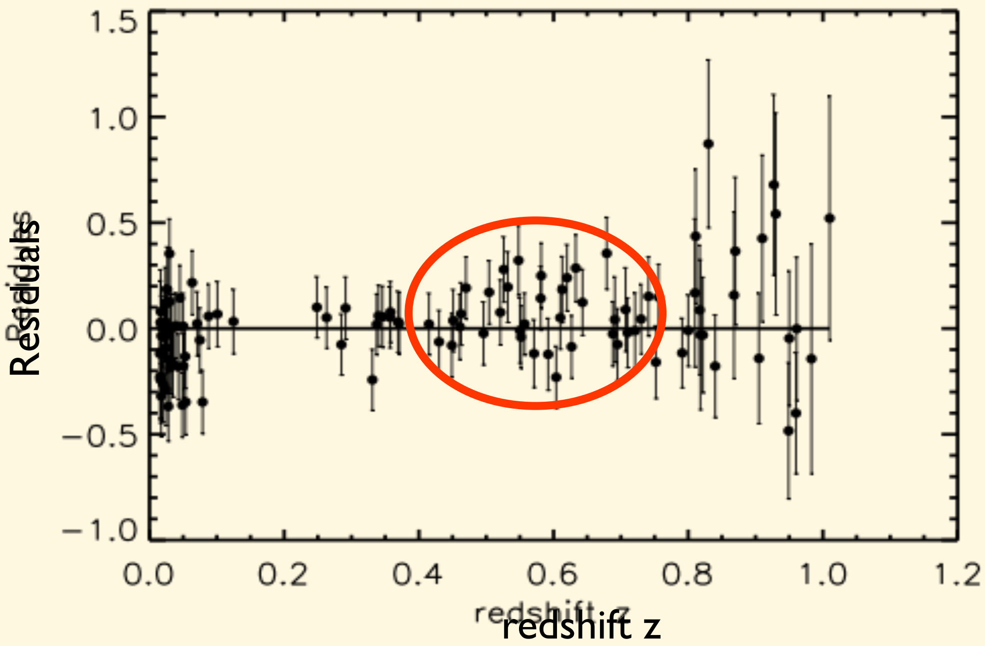
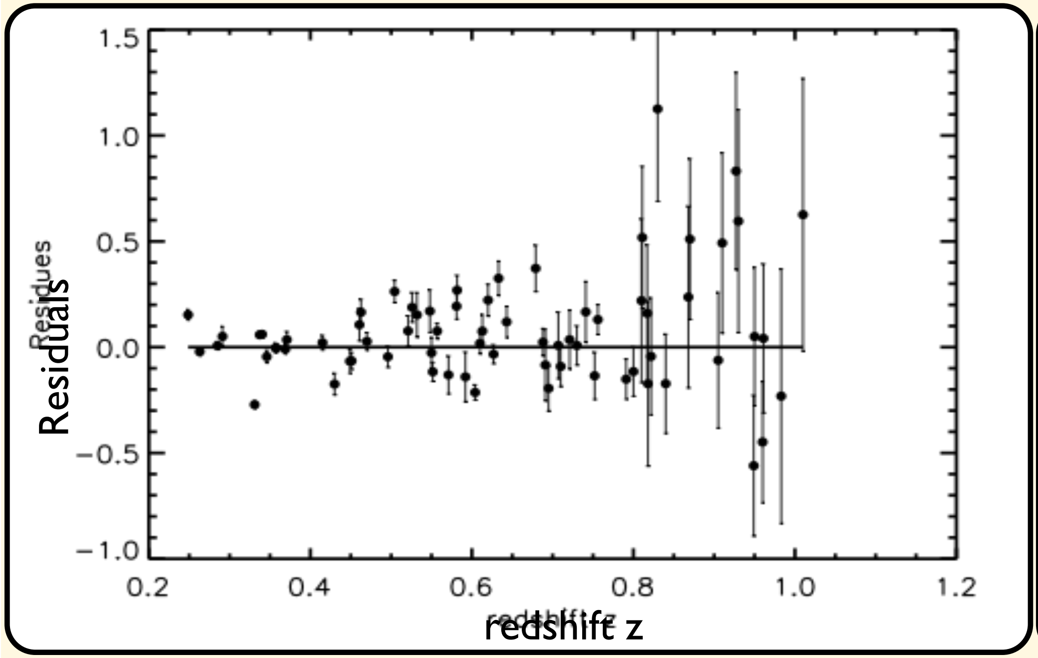


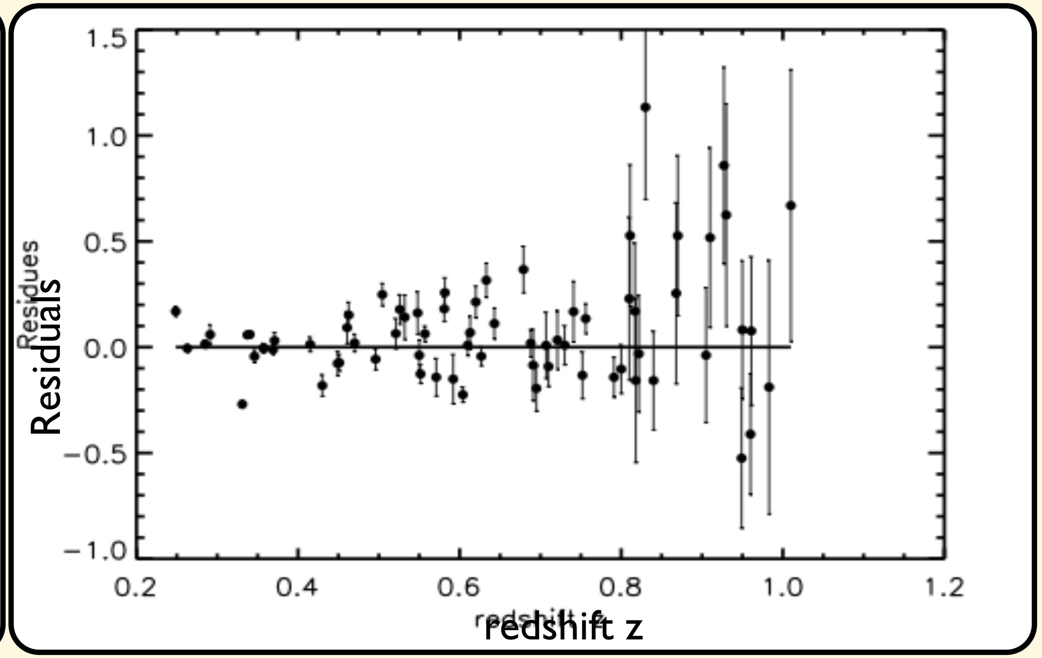
Type Ia SN test most probably does not allow to exclude the Milne model !

Type Ia SN

Milne



ΛCDM



Without low redshift SN, Milne fit is slightly better !