The Dirac-Milne universe
Concordance and challenges

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The Dirac-Milne Universe

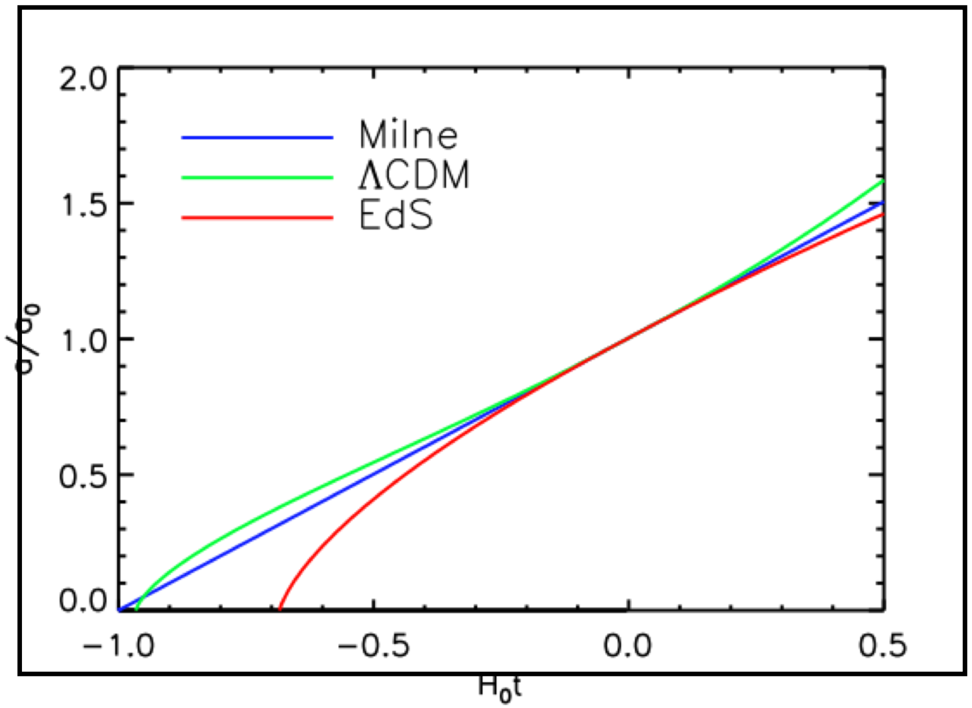
- A symmetric matter-antimatter universe
- With particles $m_g > 0$, and antiparticles « $m_g < 0$ » (see later)
- Analog of the electron-hole system in a semiconductor : the system exists in Nature…
- As seen at large distance (> few 100 Mpc), universe appears empty gravitationally
- Neither Dark Matter, nor Dark Energy components
- The Dirac-Milne universe presents impressive elements of concordance with our Universe

Age of the Universe

- Age of Einstein-de Sitter universe = 2/3 age of Lambda-CDM
- Age of Dirac-Milne is $1/H_0$
- Also, H(z) follows a simple expression : $H(z) = H_0 (1 + z)$
- No other parameter
- Fit to this expression provides low value for $H_0 \approx 63$ km/s/Mpc
- Note : although excluded for other reasons, the so-called $R_H = ct$ universe has same z dependence of H(z)

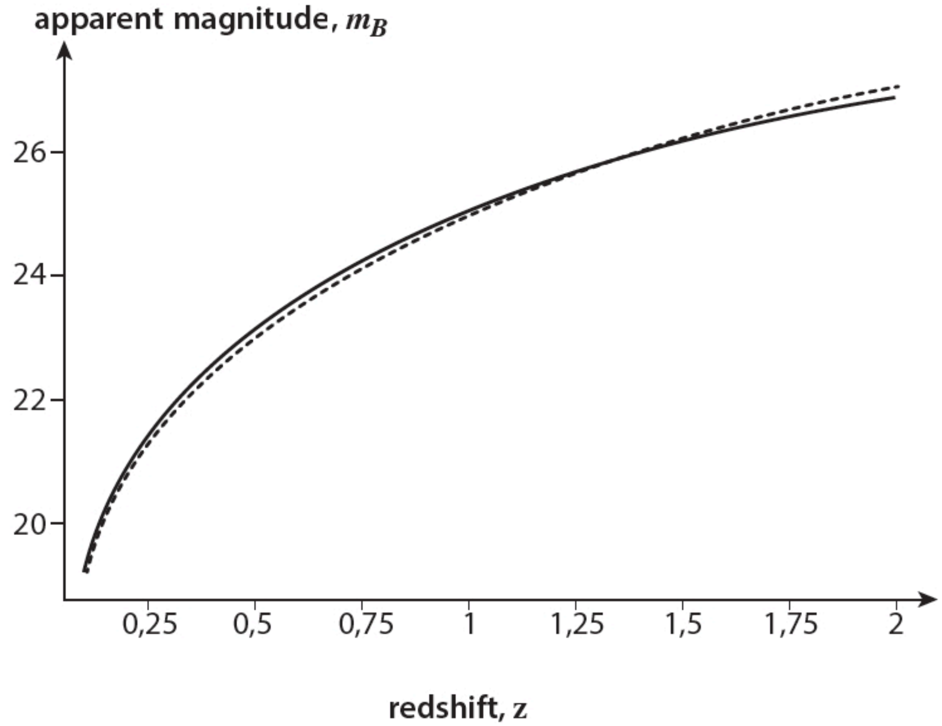
Age of the Universe

- Compared scale evolution for Lambda-CDM, Dirac-Milne and Einstein-de Sitter
- Linear evolution of the scale factor solves the initial age problem that led to the introduction of a fine-tuned cosmological constant



SN1a luminosity distance

- Lambda-CDM luminosity distance is remarkably similar to Milne's, while Milne universe has no parameter (apart from its age)
- Chodorowski (2005) « Cosmology under Milne's shadow »



Nucleosynthesis

- As early as 1998, Lohiya et al. showed that in parallel to the standard nucleosynthesis scenario (the « first three minutes »), there is a second branch, lasting 10^5 longer, ≈40 years, that produces adequate amounts of H, He-4 and Li-7
- This is the coasting universe a(t) = t, i.e. the same a(t) history as the Dirac-Milne universe (or the R_H = ct universe)
- But Kaplinghat and Steigman showed deuterium and helium-3 are almost completely destroyed in this « simmering » universe
- Not so in the Dirac-Milne universe, where deuterium is adequately produced by helium-4 nucleodisruption and photodisintegration
- At the time of nucleosynthesis, $\eta = n_B/n_\gamma$, the baryonic content, must be $\approx 10^{-8}$, about 15 times higher than the standard value
- Remarkably, excess baryons will be destroyed in the period between ≈ 80 keV and ≈ 30 eV, temperature where matter-antimatter annihilation stops, recovering $\eta \approx 10^{-9}$

CMB angular scale

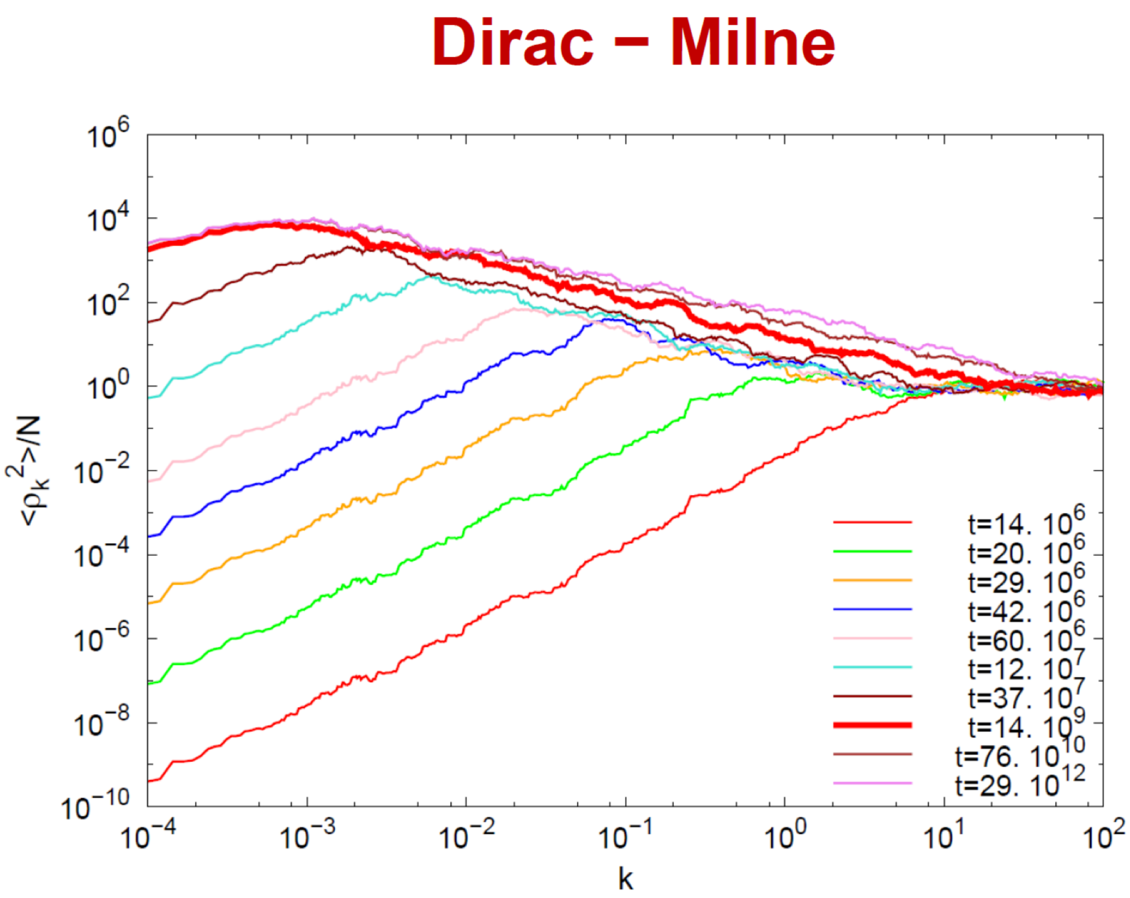
- First note that CMB sound spectrum has a completely different origin in Dirac-Milne compared to Lambda-CDM
- The Dirac-Milne universe is extremely homogeneous for all temperature above ≈ 170 MeV (temperature of QGP transition)
- In Dirac-Milne, the CMB spectrum is the coherent sound produced by the matter-antimatter annihilation, between T ≈ 170 MeV and T ≈ 30 eV, at the time when matter and antimatter « domains » decouple, ending the annihilation
- Remarkably, this angular scale is ≈ 1° (see Benoit-Lévy and Chardin (2012))

What about BAO ?

- The flat space-time of Dirac-Milne has a remarkably different angular scale distance as a function of z compared to Dirac-Milne
- An object with comoving size 100 x h^{-1} Mpc (today) is seen at z = 1080 as 1 degree on the sky in the Lambda-CDM universe
- An object with *the same comoving size* 100 x h^{-1} Mpc (today) is seen at z = 1080 as **1/165 degree** on the sky in the Dirac-Milne universe
- How can there be any observable BAO signal in the Dirac-Milne cosmology ?

What about BAO ?

- Manfredi et al. (2018) : bottom-up formation of structure from 300 pc at z ≈ 1080 (comoving at z = 0) to ≈O(100 Mpc) now



Helium-3

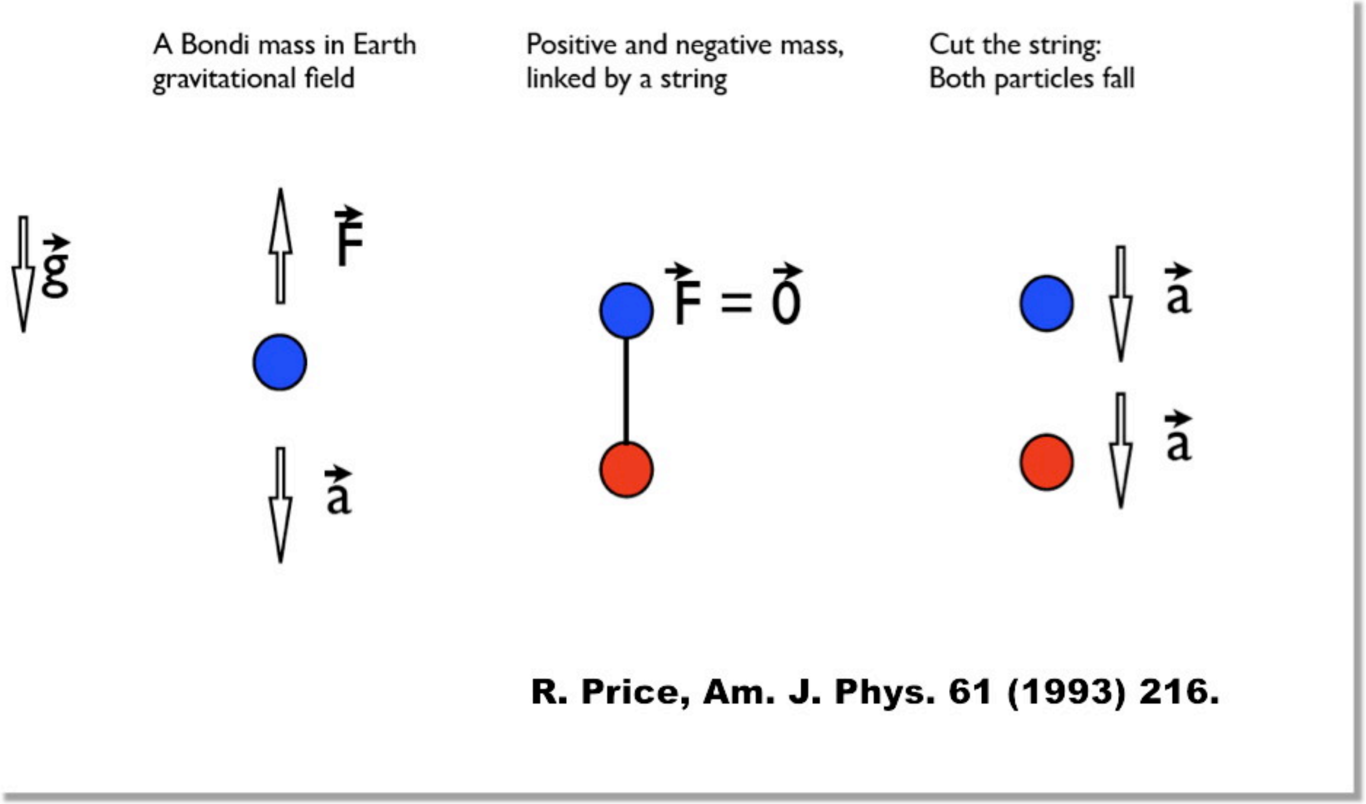
- Helium-3 is overproduced by a factor 5 to 10 compared to its value predicted by the Lambda-CDM cosmological model
- Is that a problem ?
- Helium-3 can be destroyed and produced after primordial nucleosynthesis
- Mostly one group has measured helium-3 in our galaxy (see below)
- Robert T. Rood, T. M. Bania, Dana S. Balser, Ap. J., 280 (1984) 629 : « If this difference is due to the general chemical evolution of the galaxy, our result for He-3 is *exactly the opposite* of what one would expect (…) The utility of He-3/H as a probe of the cosmological baryon-to-photon ratio rests on the resolution of this puzzle. »
- « He-3 (…) was most abundant where it was least expected… », Science 295 (2002) 804

Antigravity and gravitational polarization in General Relativity

- Price (1993) : very counter-intuitive behavior of a system comprising both positive and « negative mass » particles
- Although +m and –m masses individually fall at the same rate, the bound system *levitates* and is *polarized*, with the –m mass lying above the +m mass
- This will induce significant modifications both in the weak field limit (MOND), and in the strong field limit (the vacuum will break down and pair produce near the horizon of a black hole,)
- Analog to Maxwell's equations in the vacuum versus in matter
- Note important difference : gravitational « antiscreening » instead of electromagnetic charge screening

Antigravity and gravitational polarization in General Relativity

- Although +m and –m masses individually fall at the same rate, the bound system *levitates* and is *polarized*, with the –m mass lying above the +m mass, see Price (1993)



Additional benefits

- No need for inflation : Milne itself is a permanent inflationary universe (just at the limit of inflation, horizon at infinity, no causality problem)
- Dirac-Milne matter-antimatter universe may provide justification of MOND through gravitational polarization (of the vacuum)
- Blanchet (2008), Blanchet and Le Tiec (2008, 2009), Famaey and McGaugh (2012), etc.
- This gravitational polarization is *a prediction of General Relativity* as soon as (virtual) negative mass components exist in the vacuum
- Universe with equal amounts of particles m>0 and « m<0 » allows Machian expression of General Relativity (Einstein's dream coming true, see S.W. Hawking Proc. Royal Soc. London A286, 313 (1965))
- Structure formation probably much more compatible with data in Dirac-Milne than in Lambda-CDM universe (to be checked)

Future studies

- 3D simulation of structure formation
- Calculation of $\eta = n_B/n_\gamma$ parameter
- Compute CMB spectrum from sound generated in matter-antimatter emulsion
- Realize global fit of cosmological parameters and compare to likelihood of Lambda-CDM

Summary

- The Dirac-Milne cosmology presents impressive elements of concordance with our universe (age, SN1, nucleosynthesis, etc.)
- Structure formation in Dirac-Milne universe is very different from that in Lambda-CDM : structures are formed very early, and without the need for Dark Matter since contrast is O(1) as soon as universe becomes transparent
- Polarization and « antigravity » is a feature of general relativity as soon as negative mass components exist in the vacuum (Price, 1993)
- Three experiments at CERN are aiming at measuring the gravitational acceleration of antihydrogen, testing the hypothesis of Dirac-Milne

For more information, please read :

- A. Benoit-Lévy and G. Chardin, , “ Introducing the Dirac-Milne-Universe ”, A&A 537 A78 (2012).
- G. Manfredi, J-L. Rouet, B. Miller, and G. Chardin, “ Cosmological structure formation with negative mass ”, Phys. Rev. D 98, 023514 (2018) ; https://arxiv.org/abs/1804.03067
- G. Chardin and G. Manfredi, “ Gravity, antimatter and the Dirac-Milne universe ”, Hyperfine Interact (2018) 239: 45 ; arXiv:1807.11198 (Proceedings LEAP 2018)
- G. Chardin, « L'insoutenable gravité de l'univers », Editions Le Pommier, Collection Idées, Mars 2018
- G. Chardin, « L’antimatière tombe-t-elle vers le haut ? » Pour la Science, Avril 2019