Observational constraints of a Dirac-Milne universe

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Marcel Grossman 12 Meeting
Paris July 09
Concordance Model of Cosmology

Works well with lots of cosmological tests

BUT

No one really knows what are Dark Energy and Dark Matter.
And what about Inflation?
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And what about Inflation?

Expansion goes through different stages:

- deceleration (radiation),
- acceleration (inflation),
- deceleration (radiation),
- deceleration (matter),
- acceleration (dark energy)

Is this really natural?
Concordance Model of Cosmology

- Works well with lots of cosmological tests

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No one really knows what are Dark Energy and Dark Matter.
And what about Inflation?

75% Dark Energy,
21% Dark Matter,
4% Baryons,
Inflation

Expansion goes through different stages:

- deceleration (radiation),
- acceleration (inflation),
- deceleration (radiation),
- deceleration (matter),
- acceleration (dark energy)

Is this really natural?

Necessity to study alternatives

Could it be that our Universe is just coasting?
The Dirac-Milne Universe: a linear cosmology

- No Dark Energy, no Dark Matter, no inflation
- Assumed equal quantities of matter and antimatter. Matter and antimatter are separated in domains.
- Antimatter has negative active gravitational mass.

Given these hypothesis, Dirac-Milne universe is gravitationally empty at large scales. No acceleration and no deceleration. Scale factor evolves linearly with time:

\[ a(t) \propto t \]
Motivations

95% of our Universe is unknown!

Usuals problems with DE
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SNe Ia observations revealed that our Universe is not decelerating at present epoch. Usually interpreted as DE:

\[ \rho + 3p < 0 \]

ie cosmological antigravity
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Kerr-Newmann geometry: describe charged, rotationg black hole.

Elementary particles as “black holes”: singularity connects two \( \mathbb{R}^4 \) spaces

B. Carter 66&68, Arcos & Pereira 04

Solution symmetric under \((r, e, m) \leftrightarrow (-r, -e, -m)\)

Evoke CP symmetry. Makes the link between antimatter and negative mass

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Evoke CP symmetry. Makes the link between antimatter and negative mass

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

Admittedly, these are just motivations and no justifications.

But what kind of cosmology do these hypothesis lead to?
The Dirac-Milne universe: no Dark Energy and no inflation

Horizon problem?

Integral defining horizon diverges
Dirac-Milne universe has no horizon
There is no need for an inflation scenario

\[
\int_0^{t_0} \frac{dt}{a(t)} = +\infty
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Age problem?

Age of the Dirac-Milne universe is exactly $H_0^{-1}$

$$t_0 = \frac{1}{H_0} = 13.9 \times 10^9 \text{ years, with } H_0 = 70 \text{ km/s/Mpc}$$

Solves the age problem in a natural way without invoking extra component
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\( a(t) = t \) an \( k = -1 \) in FRW metric implies flat space-time and open space. Compared to usual assumption of flat space.

Dirac-Milne Universe is the second “natural” universe
Time scale of primordial Universe is extremely different!

First noticed by Dev et al. 02

Time-temperature relation

\[ t = \frac{1}{H_0} \frac{T_0}{T} \]

Dirac-Milne Universe much older at given (high)temperature than conventional universe.

BBN duration:
Standard BBN ~ 200 sec
Dirac-Milne BBN ~ 40 years

Age of the Universe at recombination:
14 Gy/1000 ~ 14 My
(compared to 0.38 My in \( \Lambda \)CDM)

Different thermal history
Big-Bang Nucleosynthesis
Big-Bang Nucleosynthesis in Dirac-Milne Universe

Lasts 40 years instead of 3 minutes

Weak interactions decouple at $T \sim 90$ keV (1 MeV in SBBN)

Neutrons and protons in the equilibrium ratio

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

Few neutrons, but some of them go into D and $^4$He. Inverse beta decay regenerates neutrons from protons to restore equilibrium value

Enables slow production of $^4$He and $^7$Li

But D and $^3$He are not produced!

$$8.8 \times 10^{-9} < \eta < 9.6 \times 10^{-9}$$

15 times higher than standard baryonic density: removes needs for non-baryonic Dark Matter
Big-Bang Nucleosynthesis in Dirac-Milne Universe

- Deuterium & helium-3 production by photodisintegration of $^4$He nuclei induced by annihilation photons

- Emulsion size is constrained to get D/H $\sim 3 \times 10^5$

- Typical size of the matter-antimatter emulsion:

  $z_{\text{end}} \sim 3 \times 10^4$

  $\sim 5 \times 10^{15}$ cm comoving at 1 keV ($\sim 7$ kpc today)

- Rather small size but structure formation should be really different with negative and positive masses!
Some differences between Dirac-Milne and Standard Model:

- Not the same initial conditions (no inflation)
- No Dark Matter
- Linear scale factor

Is it possible to explain CMB anisotropies in Dirac-Milne universe?
CMB

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Is it possible to explain CMB anisotropies in Dirac-Milne universe?

We do not have yet the answer but

- Recombination process almost unchanged ($z_{\text{rec}} \sim 1020$)

  \[ \text{Age} = 14 \times 10^6 \text{ years} \quad \text{instead of} \quad 380 \, 000 \, \text{y} \]

- First acoustic peak (should there be peaks) at degree scale, despite open geometry
Position of the first acoustic peak in Dirac-Milne universe

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

In Dirac-Milne universe, spacetime is flat and 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_{\text{Milne}}} = \frac{d^A_{\text{Milne}}(z)}{d^A_{\Lambda CDM}(z)} \quad z=1100 \quad \# \quad 173
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**Sound horizon**

Wave propagation between formation of emulsion (~40 MeV ?) and stop of annihilations

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Finally : first acoustic peak at the degree scale !
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\rho = \int c_s \frac{dt}{a(t)}
\]

Finally: first acoustic peak at the degree scale!

Surely not enough, but encouraging to continue
Type Ia Supernovae
Hubble diagram with SNLS 1st year (Astier et al 06)

No doubt that EdS is excluded

Dirac Milne and $\Lambda$CDM quite close!
Hubble diagram residues Dirac-Milne vs $\Lambda$CDM
Hubble diagram residues Dirac-Milne vs $\Lambda$CDM
If we offset low-z sample by $\Delta m \sim 0.06\text{mag}$ (corresponds to 1.5 estimated systematics)

Then Dirac-Milne become as good as $\Lambda\text{CDM}$

*Can we conclude that our Universe is not coasting?*
Conclusion

Dirac-Milne universe is a linear cosmology without Dark Energy, Dark Matter, nor inflation.

Symmetric matter/antimatter universe. Antimatter has negative active gravitational mass.
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Nucleosynthesis

\[ ^4\text{He} & ^7\text{Li} : \text{OK, gives} \quad \eta \sim 9 \times 10^{-9} \]

\[ \text{D & } ^3\text{He} : \text{produced in a second stage by photodisintegration} \]
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Degree scale for first acoustic peak, despite open geometry

A lot more to do ...
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Thank you!