Cosmology with Mimetic Matter

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26.11.14

Plan

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- What is mimetic matter?

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- Cosmology of "dust" with arbitrary equation of state

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This talk is mostly based on

e-Print: arXiv: **1403.3961,**

JCAP 1406 (2014) 017

with *A. H. Chamseddine and V. Mukhanov*

and

1412.XXXX with L. Mirzagholi

Mimetic Matter

Chamseddine, Mukhanov (2013)

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- One can encode the conformal / scalar part of the physical metric $g_{\mu\nu}$ in a scalar field ϕ :

$$g_{\mu\nu}\left(\tilde{g},\phi\right) = \tilde{g}_{\mu\nu}\,\tilde{g}^{\alpha\beta}\,\partial_\alpha\phi\,\partial_\beta\phi$$

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But it is still a system with one degree of freedom + standard two polarizations for the graviton!

Hamilton-Jacobi equation

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Indeed,

$$u^\lambda \nabla_\lambda u_\alpha = \nabla^\lambda\phi\nabla_\lambda\nabla_\alpha\phi = \frac{1}{2}\nabla_\alpha\left(\nabla^\lambda\phi\nabla_\lambda\phi\right) = 0$$

Dissformal Transformation

Nathalie Deruelle and Josephine Rua (2014)

One obtains the same dynamics
(***the same Einstein equations***),
if instead of varying the Einstein-Hilbert action
with respect to the metric $g_{\mu\nu}$

one plugs in a *dissformal transformation*

$$g_{\mu\nu} = F\left(\Psi, w\right)\ell_{\mu\nu} + H\left(\Psi, w\right)\partial_\mu\Psi\partial_\nu\Psi$$

with $w = \ell^{\mu\nu}\partial_\mu\Psi\partial_\nu\Psi$ and $w^2 F\dfrac{\partial}{\partial w}\left(H + \dfrac{F}{w}\right) \neq 0$

and varies with respect to $\ell_{\mu\nu},\ \Psi$

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Mimetic gravity is an exception! And it does provide new dynamics!

Mimetic Dark Matter

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- one implements constraint through $\lambda\left(g^{\mu\nu}\partial_\mu\phi\partial_\nu\phi - 1\right)$

$$S\left[g_{\mu\nu}, \phi, \lambda, \Phi_m\right] = \int \mathrm{d}^4x\sqrt{-g}\left(-\frac{1}{2}R\left(g\right) + \mathscr{L}\left(g, \Phi_m\right) + \lambda\left(g^{\mu\nu}\partial_\mu\phi\partial_\nu\phi - 1\right)\right)$$

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- The system is equivalent to standard GR + irrotational dust, moving along timelike geodesics with the velocity $u_\mu = \partial_\mu\phi$ and energy density $\rho = 2\lambda$

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"Cold Dark Matter"?

Mimicking **any** cosmological evolution,
But always with **zero sound speed**

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$$2\dot{H} + 3H^2 = V(t)$$

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- In particular $V(\phi) = \frac{1}{3}\frac{m^4\phi^2}{e^{\phi}+1}$ gives the same cosmological inflation as $\frac{1}{2}m^2\phi^2$ potential in the standard case

The simplest way to generate needed cosmological evolution

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e.g. for $V(\phi) = \frac{4}{3} \frac{\alpha}{\left(\phi^2 + \phi_0^2\right)^2}$

Perturbations I

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Even with potential, the energy
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$$c_{\mathrm{S}} = 0$$

Newtonian potential:

$$\Phi = C_1(\mathbf{x})\left(1 - \frac{H}{a}\int a dt\right) + \frac{H}{a}C_2(\mathbf{x})$$

*Here on **all scales** but in the usual cosmology it is an approximation for **superhorizon** scales*

How to give a sound speed to Mimetic Matter?

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Back to waves, oscillators and normal quantum fluctuations!

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- There are only minor changes (rescaling) in the background evolution equations e.g.

$$2\dot{H} + 3H^2 = \frac{2}{2-3\gamma}V(t)$$

Imperfect Dark Matter?

Mirzagholi, Vikman (to appear 2014)

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option for DE

$$p \simeq -\varepsilon$$

Violation of the Einstein's equivalence principle?

Raychaudhuri at work!

$$\dot{\theta} = -\frac{1}{3}\theta^2 - \sigma^2 - R_{\mu\nu}u^\mu u^\nu$$

$$R_{\mu\nu} = T_{\mu\nu} - \frac{1}{2}T g_{\mu\nu}$$

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charge density $n = 2\lambda - \gamma\dot{\theta}$

Perfect Tracker in Cosmology?

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$$\varepsilon_{\star} = \frac{12\pi\gamma}{1 - 12\pi\gamma}\rho_{\text{ext}}$$

Perturbations HD

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Newtonian potential: $\quad \Phi = \delta\dot{\phi}$

Quantization

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short wavelength quantum fluctuations

$$\delta\phi_k \sim \sqrt{\frac{c_s}{\gamma}}\; k^{-3/2}$$

match with the
long-wave-length limit

Perturbations in Mimetic Inflation

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on scale $\lambda \simeq k^{-1}$

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- **spectral indices** $n_\mathrm{S} - 1 = n_\mathrm{T}$

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- Newtonian potential $\Phi_\lambda \simeq \sqrt{c_\mathrm{s}/\gamma} \cdot H_{c_\mathrm{s} k \simeq H}$

for $c_\mathrm{S} \ll 1$ $\quad \Phi_\ell \sim c_s^{-1/2}\, H_{c_s k \sim Ha}$

for $c_\mathrm{S} \gg 1$ $\quad \Phi_\ell \sim c_s^{1/2}\, H_{c_s k \sim Ha}$

- Gravitational Waves *are unchanged* $h_\lambda \simeq H_{k \simeq H}$

- spectral indices $n_\mathrm{S} - 1 = n_\mathrm{T}$
- small sound speed $\Rightarrow$ $\Phi_\lambda \gg h_\lambda$

But it seems that there is no usual Non-Gaussianity!

Conclusions

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Thanks a lot for attention!