Pressuron's phenomenology

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Where leaders learn

The Pressuron :

- scalar particle

- couples **non-minimally** to both **curvature** and **matter**

But

- **is not sourced** by **pressure-less** fields !!!

(weird isn't it ?!)

Basics of the pressuron

$$S = \int d^4x \sqrt{-g} \left(\Phi R - \frac{\omega(\Phi)}{\Phi} (\partial_\sigma \Phi)^2 - 2\sqrt{\Phi}\epsilon \right)$$

[Minazzoli, Hees, Phys. Rev. D, 88, issue 4 (2013)**]**

Effective Lagrangian for perfect fluid :

$$L_m = -\epsilon = -c^2 \rho - \int \frac{P(\rho)}{\rho} d\rho$$ with $$\nabla_\sigma (\rho U^\sigma) = 0$$

[Minazzoli, Harko, Phys. Rev. D, 86, issue 8 (2012)**]**
[Minazzoli, Phys. Rev. D, 88, issue 2 (2013)**]**

$$T_{\alpha\beta} = \frac{-2}{\sqrt{-g}} \frac{\delta(\sqrt{-g}\,\epsilon)}{\delta g^{\alpha\beta}} = [\epsilon + P] U_\alpha U_\beta + P g_{\alpha\beta}$$

Basics of the pressuron

$$S=\int d^4x\sqrt{-g}\left(\Phi R-\frac{\omega(\Phi)}{\Phi}(\partial_\sigma\Phi)^2+2\sqrt{\Phi}\epsilon\right)$$

[Minazzoli, Hees, Phys. Rev. D, 88, issue 4 (2013)]

$$\frac{2\omega+3}{\Phi}\nabla^2\Phi+\frac{\omega_{,\Phi}}{\Phi}(\nabla\Phi)^2=\frac{1}{\sqrt{\Phi}}(T+\epsilon)$$

$$T=-\epsilon+3P$$

$$\boxed{\frac{2\omega+3}{\Phi}\nabla^2\Phi+\frac{\omega_{,\Phi}}{\Phi}(\nabla\Phi)^2=\frac{3P}{\sqrt{\Phi}}}$$

A simple way to understand the mechanism :

<u>the dust case</u>

the dust case

$$S=\int d^4x\sqrt{-g}\left(\Phi R-Z(\Phi)(\partial\Phi)^2\right)+\sum_A\int\sqrt{\Phi}\,m_A\,d\tau_A$$

↓ Conformal transformation $\tilde{g}_{\alpha\beta}=\Omega^2 g_{\alpha\beta}$

$$S=\int d^4x\sqrt{-\tilde{g}}\left(\frac{\Phi}{\Omega^2}\tilde{R}-F\left(\Omega,\Phi,(\tilde{\partial}\Phi)^{2,}(\tilde{\partial}\Omega)^2\right)\right)+\sum_A\int\frac{\sqrt{\Phi}}{\Omega}m_A\,d\tilde{\tau}_A$$

the dust case

$$S=\int d^4x\sqrt{-g}\left(\Phi R-Z(\Phi)(\partial\Phi)^2\right)+\sum_A\int\sqrt{\Phi}\,m_A\,d\tau_A$$

$\downarrow$ Going to the Einstein frame $\tilde{g}_{\alpha\beta}=\Phi g_{\alpha\beta}$

$$\boxed{S=\int d^4x\sqrt{-\tilde{g}}\left(\tilde{R}-\tilde{Z}(\Phi)(\tilde{\partial}\Phi)^2\right)+\sum_A\int m_A\,d\tilde{\tau}_A}$$

Dust field in Einstein frame

In other words :

In the dust case, the pressuron reduces to

« veiled » general relativity

cf. Deruelle & Sasaki

$$S=\int d^4x\sqrt{-g}\left(\Phi R - Z(\Phi)(\partial\Phi)^2\right)+\sum_A \int \sqrt{\Phi}\, m_A\, d\tau_A$$

$$S=\int d^4x\sqrt{-\tilde{g}}\left(\tilde{R} - \tilde{Z}(\Phi)(\tilde{\partial}\Phi)^2\right)+\sum_A \int m_A\, d\tilde{\tau}_A$$

Dust field in Einstein frame

Or equivalently :

$$S=\int d^4x\sqrt{-g}\left(h^2R-Z(h)(\partial h)^2+V(h)\right)+\sum_A\int h\,m_A\,d\tau_A$$

$$S=\int d^4x\sqrt{-\tilde{g}}\left(\tilde{R}-\tilde{Z}(h)(\tilde{\partial}h)^2+\tilde{V}(h)\right)+\sum_A\int m_A\,d\tilde{\tau}_A$$

Dust field in Einstein frame

Brans-Dicke :

$$S=\int d^4x\sqrt{-g}\left(\Phi R-Z(\Phi)(\partial\Phi)^2\right)+\sum_A\int m_A d\tau_A$$

$$S=\int d^4x\sqrt{-\tilde{g}}\left(\tilde{R}-F(\Phi)(\tilde{\partial}\Phi)^2\right)+\sum_A\int \frac{m_A}{\sqrt{\Phi}}d\tilde{\tau}_A$$

Pressuron :

$$S=\int d^4x\sqrt{-g}\left(\Phi R-Z(\Phi)(\partial\Phi)^2\right)+\sum_A\int \sqrt{\Phi}\, m_A d\tau_A$$

$$S=\int d^4x\sqrt{-\tilde{g}}\left(\tilde{R}-F(\Phi)(\tilde{\partial}\Phi)^2\right)+\sum_A\int m_A d\tilde{\tau}_A$$

But Pressuron
no longer « veiled » general relativity

when there is Pressure !

$$\frac{2\omega+3}{\Phi}\nabla^2\Phi+\frac{\omega_{,\Phi}}{\Phi}(\nabla\Phi)^2=\frac{3P}{\sqrt{\Phi}}$$

Scalar field couples to matter via pressure

Phenomenology : basics

Weak field :

- PN parameters = 1
- Same trajectories as GR at 1.5PN level
- No Nordtvedt effect at 1.5PN
- Light wave trajectory different from GR at 2PN
- Gravitational redshift different from GR at 10^{-6} relative level

Cosmology :

- Cosmologically quickly converges toward GR in matter era (no coupling)
- Decouples dynamically in radiation era (Damour & Nordtvedt like) (ie. $\omega(\Phi) \rightarrow$ Big)
- Cannot explain DE without potential or Λ

Why is it interresting ?

1/ Unusual phenomenology

2/ One of the possible solutions to the presence of very light coupled scalar fields (while we live in a GR-like wolrd).

What remains to do

- Strong field : Pressuron should appear in regimes with high-pressure, how about black holes ?

  To be done (several difficulties)

What remains to do

- Strong field : Pressuron should appear in regimes with high-pressure, how about black holes ?

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- Link to microphysics : what coupling effectively leads to $S_m \propto \int d^4x \sqrt{-g} \sqrt{\Phi} \rho$?

  in progress

  - **Dilaton (multiplicative)** → **partial** decoupling in general (still UFF violation but weaker)
  - **Higgs-like** coupling

Thank you for your attention

References :

- Minazzoli & Hees, Physical Review D, vol. 88, Issue 4 (2013)
- Minazzoli, Physics Letters B, Volume 735 (2014)
- Minazzoli & Hees, Physical Review D, Volume 90, Issue 2 (2014)

About microphysics :

- Minazzoli & Hees (or switched around), to be submited soon

Anatidaephobia : The fear that one is being constantly watched by a duck.

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Perfect fluid Lagrangian

$$L_m = \frac{-\alpha\epsilon + \beta P}{\gamma}$$
$$\gamma \equiv \alpha + \beta$$

⇒ $T^{\mu\nu} = (\epsilon + P) U^\mu U^\nu + P g^{\mu\nu}$

$S_m \propto \int d^4 x \sqrt{-g}\, L_m$ ⇒ Degenerate : one can take any value of $\{\alpha, \beta\}$

$S_m \propto \int d^4 x\, f(\Phi) \sqrt{-g}\, L_m$ ⇒ No longer degenerate : only one value of $\{\alpha, \beta\}$

Which one ? Dust case : $L_m = -c^2 \rho$ ⇒ $\alpha = 1, \gamma = 1 \Rightarrow \beta = 0$

⇒ $\boxed{L_m = -\epsilon}$ Only possible choice of effective Lagrangian

Basics of the pressuron

$$S=\int d^4x\sqrt{-g}\left(\Phi R-\frac{\omega(\Phi)}{\Phi}(\partial_\sigma\Phi)^2+2\sqrt{\Phi}L_m\right)$$

[Minazzoli, Hees, Phys. Rev. D, 88, issue 4 (2013)**]**

Lets consider a dust (pressure-less) field :

$$T^{\mu\nu}=\sum_i \mu_i\delta(\vec{x}_i)u_i^\mu u_i^\nu \qquad L_m=-\sum_i \mu_i\delta(\vec{x}_i) \qquad \mu_i=m_i/(u^0\sqrt{-g})$$

m_i Conserved mass

$$R^{\mu\nu}=\frac{1}{\sqrt{\Phi}}\left(T^{\mu\nu}-\frac{1}{2}g^{\mu\nu}T\right)+\frac{1}{\Phi}\left(\nabla^\mu\partial^\nu\Phi-g^{\mu\nu}\nabla^\sigma\partial_\sigma\Phi\right)$$
$$+\frac{\omega}{\Phi}\left(\partial^\mu\Phi\,\partial^\nu\Phi-\frac{1}{2}g^{\mu\nu}(\partial_\alpha\Phi)^2\right)$$

$$\boxed{\frac{2\omega+3}{\Phi}\nabla^\sigma\partial_\sigma\Phi+\frac{\omega_{,\Phi}}{\Phi}(\partial_\sigma\Phi)^2=\frac{1}{\sqrt{\Phi}}(T-L_m)}$$

Damour & Polyakov dilaton

$$S=\int d^4x\sqrt{-g}\,B(\phi)\left[\frac{1}{\alpha'}\left(R+4\nabla^2\phi-4(\nabla\phi)^2\right)-\frac{k}{4}F^2-\bar{\Psi}D\Psi\ldots\right]$$

[Damour and Polyakov, Nucl. Phys. B, 423 (1994)**]**

$$\Downarrow$$

$$S=\int d^4x\sqrt{-g}\left(\Phi R-\frac{\omega(\Phi)}{\Phi}(\partial_\sigma\Phi)^2+2\Phi^n L_m\right)$$

With n=1

Electromagnetism does not take the form of a perfect fluid

$$L_{EM} = F^2$$

↓

[Peter and Uzan,
Primordial cosmology (2009)
Oxford U. Press**]**

$$T^{\alpha\beta} = (\rho + P) u^\alpha u^\beta + P g^{\alpha\beta} + (u^\alpha q^\beta + q^\alpha u^\beta) + \pi^{\alpha\beta}$$

Heat vector flux

Viscous shear tensor

Photons : not perfect fluid