Pressuron's phenomenology

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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

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

Effective Lagrangian for perfect fluid:

\[ L_m = -\epsilon = -c^2 \rho - \int \frac{P(\rho)}{\rho} d\rho \]

with \( \nabla_\sigma (\rho U^\sigma) = 0 \)

\[ T_{\alpha\beta} = \frac{\delta (\sqrt{-g} \epsilon)}{\sqrt{-g} \delta g^\alpha_\beta} = [\epsilon + P] U_\alpha U_\beta + P g_{\alpha\beta} \]
Basics of the pressuron

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


\[ \frac{2 \omega + 3}{\Phi} \nabla^2 \Phi + \frac{\omega \cdot \Phi}{\Phi} (\nabla \Phi)^2 = \frac{1}{\sqrt{\Phi}} (T + \epsilon) \]

\[ T = -\epsilon + 3P \]

\[ \frac{2 \omega + 3}{\Phi} \nabla^2 \Phi + \frac{\omega \cdot \Phi}{\Phi} (\nabla \Phi)^2 = \frac{3P}{\sqrt{\Phi}} \]
A simple way to understand the mechanism:

the dust case
the dust case

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

\[ \downarrow \quad \text{Conformal transformation} \quad \tilde{g}_{\alpha \beta} = \Omega^2 g_{\alpha \beta} \]

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

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

Going to the Einstein frame

\[ \tilde{g}_{\alpha \beta} = \Phi g_{\alpha \beta} \]

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

\[
S = \int d^4 x \sqrt{-g} (h^2 R - Z(h)(\partial h)^2 + V(h)) + \sum_A \int h m_A d \tau_A
\]
Dust field in Einstein frame

Brans-Dicke:

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

Pressuron:

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

\[ S = \int d^4 x \sqrt{-\tilde{g}} \left( \tilde{R} - F(\Phi)(\tilde{\partial} \Phi)^2 \right) + \sum_A \int m_A d \tilde{\tau}_A \]
But Pressuron
no longer « veiled » general relativity
when there is Pressure !

\[
\frac{2 \omega + 3}{\Phi} \nabla^2 \Phi + \frac{\omega}{\Phi} (\nabla \Phi)^2 = \frac{3P}{\sqrt{\Phi}}
\]

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 $\Lambda$
Why is it interesting?

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 world).
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
  \[ S_m \propto \int d^4 x \sqrt{-g} \sqrt{\Phi} \rho \] in progress

- **Dilaton (multiplicative)** → **partial** decoupling in general
  (still UFF violation but weaker)
  - **Higgs-like** coupling
Thank you for your attention

References:

About microphysics:
- Minazzoli & Hees (or switched around), to be submitted soon

Anatidaephobia: The fear that one is being constantly watched by a duck.
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(already contributed: 12 Nobel laureates, 4 Fields medalists, 8 Dirac medalists, Etc.)
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: \[
L_m = -c^2 \rho
\]
\[
\alpha = 1, \gamma = 1 \Rightarrow \beta = 0
\]

\[
L_m = -\epsilon
\]

Only possible choice of effective Lagrangian
Basics of the pressuron

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


Let's consider a dust (pressure-less) field:

\[ T^{\mu\nu} = \sum_i \mu_i \delta(\vec{x}_i) u_i^\mu u_i^\nu \quad L_m = -\sum_i \mu_i \delta(\vec{x}_i) \quad \mu_i = m_i/u_0 \sqrt{-g} \]

\[ \frac{m_i}{L_m} \quad \text{Conserved mass} \]

\[ R^{\mu\nu} = \frac{1}{\sqrt{\Phi}} \left( T^{\mu\nu} - \frac{1}{2} g^{\mu\nu} T \right) + \frac{1}{\sqrt{\Phi}} \left( \nabla^\mu \partial^\nu \Phi - g^{\mu\nu} \nabla^\sigma \partial_\sigma \Phi \right) + \frac{\omega}{\Phi} \left( \partial^\mu \Phi \partial^\nu \Phi - \frac{1}{2} g^{\mu\nu} (\partial_\alpha \Phi)^2 \right) + \frac{2\omega + 3}{\Phi} \nabla^\sigma \partial_\sigma \Phi + \frac{\omega}{\Phi} (\partial_\sigma \Phi)^2 = \frac{1}{\sqrt{\Phi}} (T - L_m) \]
Damour & Polyakov dilaton

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


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

With n=1
Electromagnetism does not take the form of a perfect fluid

\[ L_{EM} = F^2 \]

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


Photons: not perfect fluid