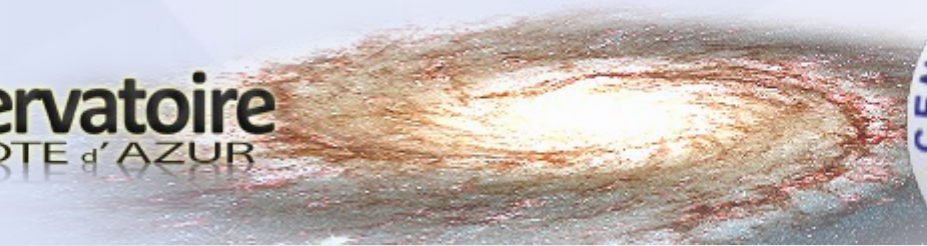


# Pressuron's phenomenology

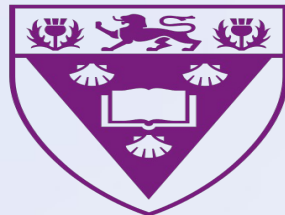
Olivier Minazzoli



Observatoire  
de la CÔTE d'AZUR



Aurélien Hees



**RHODES UNIVERSITY**

*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

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

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

Effective Lagrangian for perfect fluid :

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

[Minazzoli, Harko, Phys. Rev. D, 86, issue 8 (2012)]

[Minazzoli, Phys. Rev. D, 88, issue 2 (2013)]

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

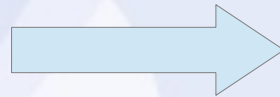
# Basics of the pressuron

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

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

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

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



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

A simple way to understand the  
mechanism :

the dust case

# the dust case

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



Conformal transformation

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

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

# 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

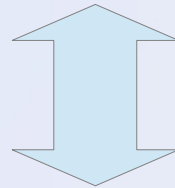
In other words :

In the dust case, the pressuron reduces to

**« veiled » general relativity**

cf. Deruelle & Sasaki

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



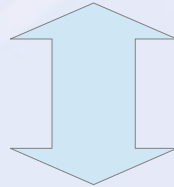
$$S = \int d^4 x \sqrt{-\tilde{g}} \left( \tilde{R} - \tilde{Z}(\Phi) (\tilde{\partial} \Phi)^2 \right) + \sum_A \int m_A d\tilde{\tau}_A$$



# Dust field in Einstein frame

Or equivalently :

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



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

# Dust field in Einstein frame

Brans-Dicke :

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

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

Pressuron :

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

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

But Pressuron  
no longer « veiled » general relativity  
when there is Pressure !

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

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.  $\omega(\Phi) \rightarrow \text{Big}$ )
- 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 ?

To be done (several difficulties)

- 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 :

- 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 submitted soon



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



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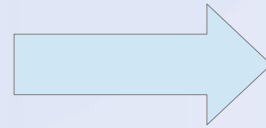
Peer-reviewed totally free encyclopedia

(already contributed : 12 Nobel laureates, 4  
Fields medalists, 8 Dirac medalists, Etc.)

# Perfect fluid Lagrangian

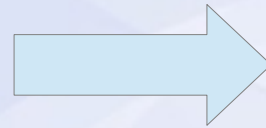
$$L_m = \frac{-\alpha \epsilon + \beta P}{\gamma}$$

$$\gamma \equiv \alpha + \beta$$



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

$$S_m \propto \int d^4 x \sqrt{-g} L_m$$




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

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

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

Lets consider a dust (pressure-less) field

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

$m_i$  Conserved mass

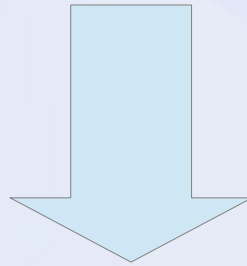
$$R^{\mu\nu} = \frac{1}{\sqrt{\Phi}} \left( T^{\mu\nu} - \frac{1}{2} g^{\mu\nu} T \right) + \frac{1}{\Phi} \left( \nabla^\mu \partial^\nu \Phi - g^{\mu\nu} \nabla^\sigma \partial_\sigma \Phi \right) \\ + \frac{\omega}{\Phi} \left( \partial^\mu \Phi \partial^\nu \Phi - \frac{1}{2} g^{\mu\nu} (\partial_\alpha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

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

# Damour & Polyakov dilaton

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

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

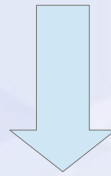


$$S = \int d^4 x \sqrt{-g} \left( \Phi R - \frac{\omega(\Phi)}{\Phi} (\partial_\sigma \Phi)^2 + 2 \Phi^n L_m \right)$$

With  $n=1$

# Electromagnetism does not take the form of a perfect fluid

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



[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