Overlap scenarios and theory-specific constraints

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Einstein-aether theory

The action of the theory is

$$S_{æ} = \frac{1}{16\pi G_{æ}} \int d^4x \sqrt{-g}(-R - M^{\alpha\beta\mu\nu}\nabla_\alpha u_\mu \nabla_\beta u_\nu)$$

where

$$M^{\alpha\beta\mu\nu} = c_1 g^{\alpha\beta} g^{\mu\nu} + c_2 g^{\alpha\mu} g^{\beta\nu} + c_3 g^{\alpha\nu} g^{\beta\mu} + c_4 u^\alpha u^\beta g_{\mu\nu}$$

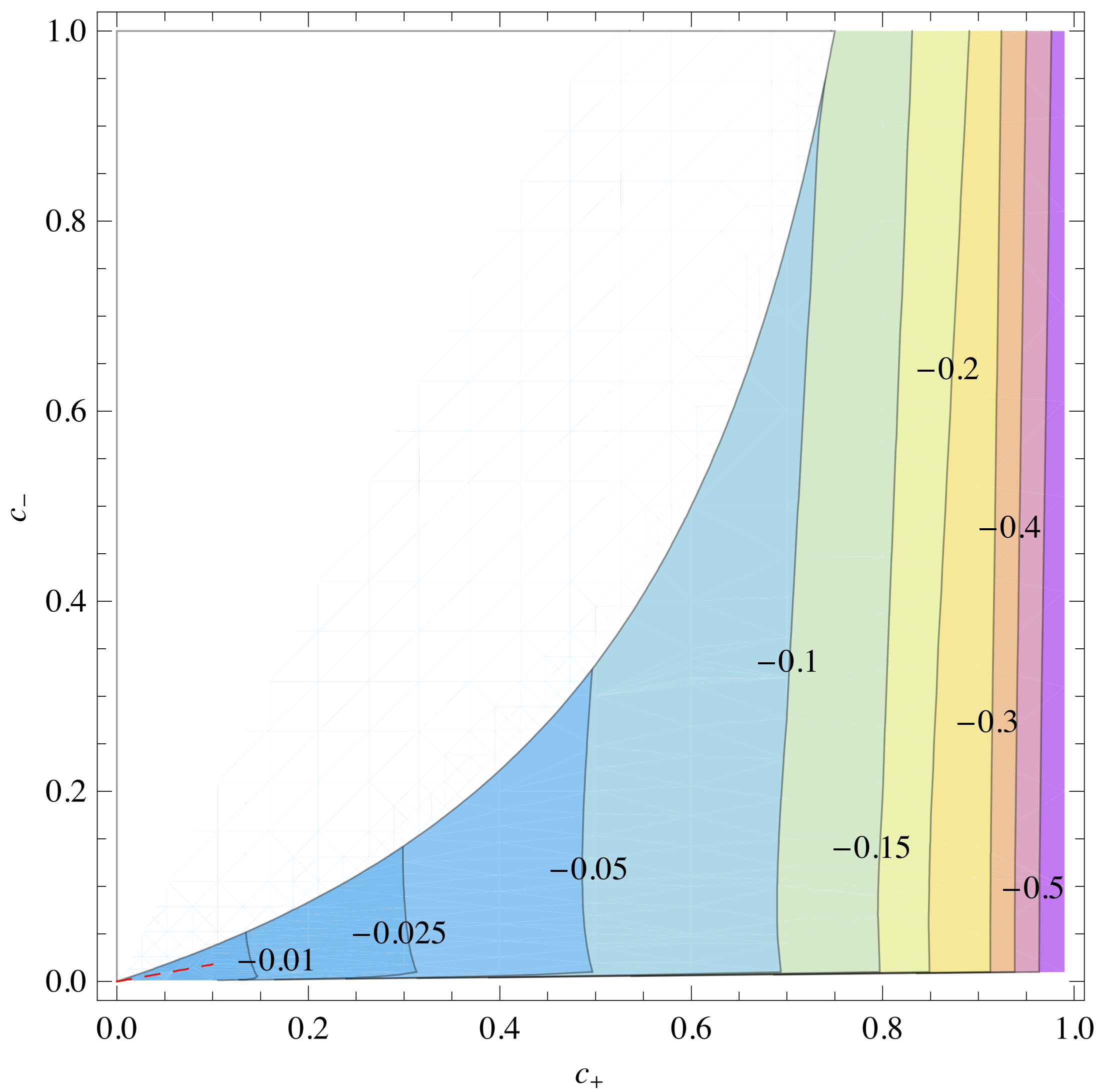
and the aether is implicitly assumed to satisfy the constraint

$$u^\mu u_\mu = 1$$

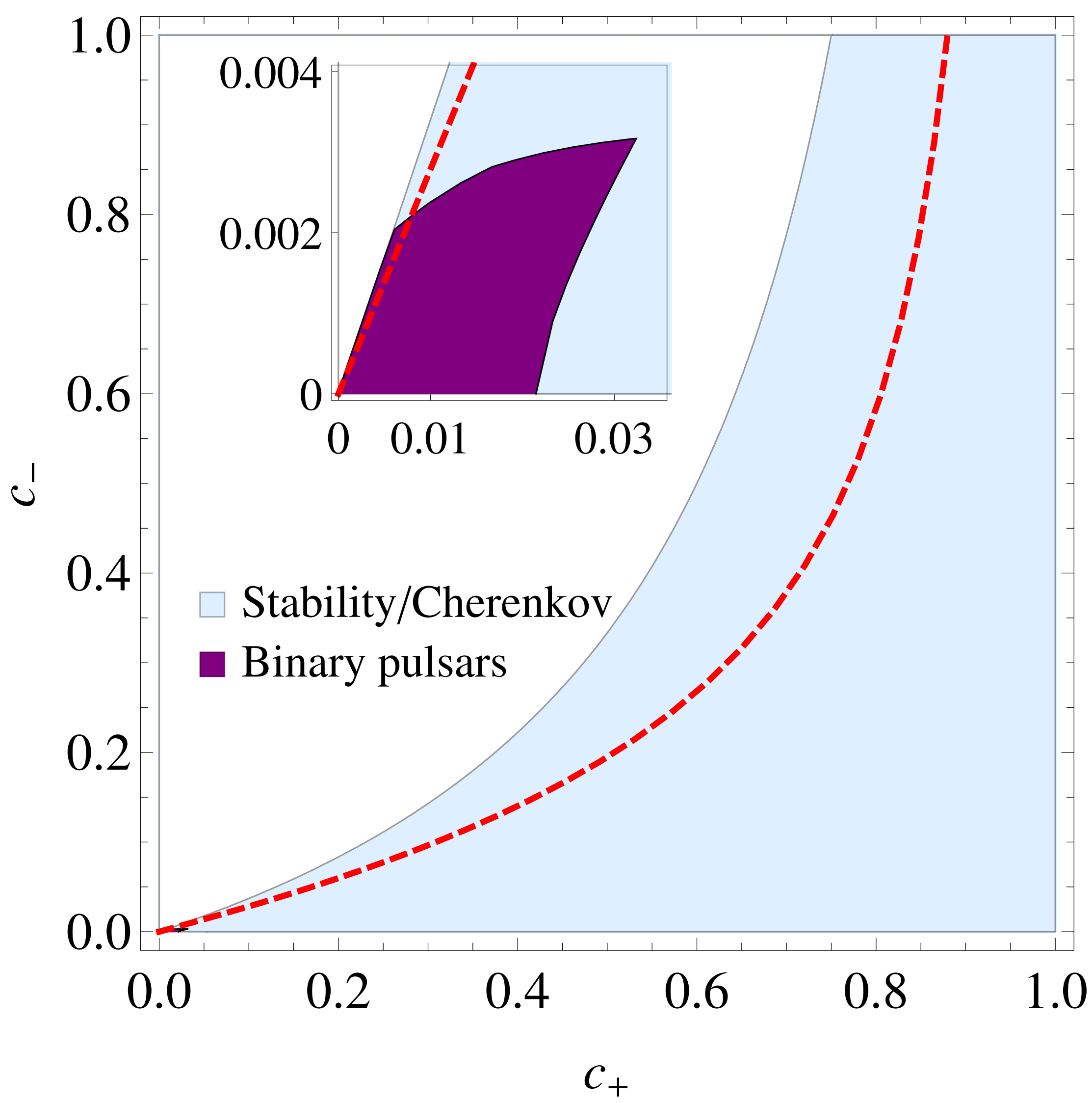
- Most general theory with a unit timelike vector field which is second order in derivatives

T. Jacobson and D. Mattingly, Phys. Rev. D 64, 024028 (2001).

Combined Constraints



$\omega_{\rm ISCO}\, r_g$



E. Barausse, T. Jacobson and T.P.S., Phys. Rev. D 83, 124043 (2011)
K. Yagi, D. Blas, N. Yunes and E. Barausse Phys. Rev. Lett. 112, 161101 (2014)

Hypersurface orthogonality

Now assume $$u_\alpha = \frac{\partial_\alpha T}{\sqrt{g^{\mu\nu}\partial_\mu T \partial_\nu T}}$$

and choose T as the time coordinate

$$u_\alpha = \delta_{\alpha T}(g^{TT})^{-1/2} = N\delta_{\alpha T}$$

Replacing in the action and defining one gets

$$S_{æ}^{ho} = \frac{1}{16\pi G_H}\int dT d^3x N\sqrt{h}\left(K_{ij}K^{ij} - \lambda K^2 + \xi^{(3)}R + \eta a^i a_i\right)$$

with $a_i = \partial_i \ln N$ and the parameter correspondence

$$\frac{G_H}{G_{æ}} = \xi = \frac{1}{1-c_{13}} \qquad \lambda = \frac{1+c_2}{1-c_{13}} \qquad \eta = \frac{c_{14}}{1-c_{13}}$$

T. Jacobson, Phys. Rev. D 81, 101502 (2010).

Horava-Lifshitz gravity

The action of the theory is

$$S_{HL} = \frac{1}{16\pi G_H} \int dT d^3x \, N\sqrt{h}\left(L_2 + \frac{1}{M_\star^2} L_4 + \frac{1}{M_\star^4} L_6\right)$$

where

$$L_2 = K_{ij}K^{ij} - \lambda K^2 + \xi^{(3)}R + \eta a_i a^i$$

L_4 : contains all 4th order terms constructed with the induced metric h_{ij} and a_i

L_6 : contains all 6th order terms constructed in the same way

P. Hořava, Phys. Rev. D 79, 084008 (2009)
D. Blas, O. Pujolas and S. Sibiryakov, Phys. Rev. Let. 104, 181302 (2010)

Percolation of LV

But what about the matter sector and lower order operators?

- Different speeds for different fields in the IR, with logarithmic running!

R. Iengo, J. G. Russo and M. Serone, JHEP 0911, 020 (2009)

Possible ways out:

- Some extra symmetry, e.g. supersymmetry

S. Groot Nibbelink and M. Pospelov, Phys. Rev. Lett. 94, 081601 (2005)

- Assume Lorentz symmetry in matter and let the weak coupling to gravity (the Lorentz-violating sector) do the rest

M. Pospelov and Y. Shang, Phys. Rev. D 85, 105001 (2012)

Hierarchy of scales

Consider the dispersion relation

$$E^2 = m^2 + p^2 + \eta_4 \frac{p^4}{M_{LV}^2} + \mathcal{O}(\frac{p^6}{M_{LV}^4})$$

Assume that there is a universal LV scale, so

$$M_{LV} \sim M_\star$$

Constraint from synchrotron radiation from the Crab Nebula:

$$M_{\rm obs} > 2 \times 10^{16} \mathrm{GeV}$$

S. Liberati, L. Maccione and T. P. S., Phys. Rev. Lett. 109, 151602 (2012)

Strong coupling

The low energy action exhibits strong coupling at energy

$$M_{\rm sc} = f(|\lambda - 1|, \eta) M_{\rm pl}$$

Can be a large energy scale, but problem with renormalizability!

A. Papazoglou and T. P. S., Phys. Lett. B 685, 197 (2010)
I. Kimpton and A. Padilla, JHEP 1007, 014 (2010)

Strong coupling problem can be circumvented if

$$M_{\rm sc} > M_\star$$

D. Blas, O. Pujolas and S. Sibiryakov, Phys.Lett. B 688, 350 (2010)

But then tension with observations!

$$10^{16}{\rm GeV} > M_\star > M_{\rm obs}$$

A. Papazoglou and T. P. Sotiriou, Phys. Lett. B 685, 197 (2010)