Constraints on Einstein-aether theory after GW170817

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Implication of GW170817 on gravity theories @ late time

- $|c_{gw}^2 - c_\gamma^2| < 10^{-15}$
- Horndeski theoy (scalar-tensor theory with 2nd-order eom):
  Among 4 free functions, $G_4(\phi,X)$ & $G_5(\phi,X)$ are strongly constrained. Still $G_2(\phi,X)$ & $G_3(\phi,X)$ are free.
- Generalized Proca theory (vector-tensor theory):
  Among 6 (or more) free functions, $G_4(X)$ & $G_5(X)$ are strongly constrained.
  Still $G_2(X,F,Y,U)$, $G_3(X)$, $G_6(X)$, $g_5(X)$ are free.
- Horava-Lifshitz theory (renormalizable quantum gravity):
  The coefficient of $R^{(3)}$ is strongly constrained
  → IR fixed point with $c_{gw}^2 = c_\gamma^2$? How to speed up the RG flow?
- Ghost condensation (simplest Higgs phase of gravity):
  No additional constraint
- Massive gravity (simplest modification of GR):
  Upper bound on graviton mass ≈ 10^{-22}eV
  Much weaker than the requirement from acceleration

c.f. "All" gravity theories (including general relativity):
The cosmological constant is strongly constrained ≈ 10^{-120}.

Einstein-aether theory

- LV gravity: GR + timelike unit vector u^μ
  → Useful for test of GR
- Low-E limit of non-projectable HL gravity
  → predictions of a quantum gravity theory
- 4 parameters (c_1, c_2, c_3, c_4)

$$M^{\alpha\beta}{}_{\mu\nu} = c_1 g^{\alpha\beta} g_{\mu\nu} + c_2 \delta^\alpha_\mu \delta^\beta_\nu + c_3 \delta^\alpha_\nu \delta^\beta_\mu - c_4 u^\alpha u^\beta g_{\mu\nu}$$

$$\mathcal{L}_{æ} \equiv -M^{\alpha\beta}{}_{\mu\nu} \left(D_\alpha u^\mu\right)\left(D_\beta u^\nu\right) + \lambda\left(g_{\alpha\beta} u^\alpha u^\beta + 1\right)$$

$$S_{æ} = \frac{1}{16\pi G_{æ}} \int \sqrt{-g}\, d^4x \left[R(g_{\mu\nu}) + \mathcal{L}_{æ}\left(g_{\mu\nu}, u^\lambda\right)\right]$$

$$S = S_{æ} + \int \sqrt{-g}\, d^4x \left[\mathcal{L}_m\left(g_{\mu\nu}, \psi\right)\right]$$

Constraints

- Stability $q_{S,V,T} > 0 \qquad c^2_{S,V,T} \geq 0$
- Gravi-Cerenkov $c^2_{S,V,T} \gtrsim 1$
- GW170817 $-3 \times 10^{-15} < c_T - 1 < 7 \times 10^{-16}$
- BBN $\left| \frac{G_{\rm cos}}{G_N} - 1 \right| \lesssim \frac{1}{8}$
- PPN $|\alpha_1| \leq 10^{-4} \qquad |\alpha_2| \leq 10^{-7}$
- Pulsars $|\hat{\alpha}_1| \leq 10^{-5} \qquad |\hat{\alpha}_2| \leq 10^{-9}$

Some formulae

$$c_{ij} \equiv c_i + c_j \qquad c_{ijk} = c_i + c_j + c_k$$

- Stability & Gravi-Cerenkov & GW170817

$$q_S = \frac{(1-c_{13})\,(2+c_{13}+3c_2)}{c_{123}} \qquad q_V = c_{14} \qquad q_T = 1-c_{13}$$

$$c_S^2 = \frac{c_{123}(2-c_{14})}{c_{14}(1-c_{13})(2+c_{13}+3c_2)} \qquad c_V^2 = \frac{2c_1 - c_{13}(2c_1-c_{13})}{2c_{14}(1-c_{13})} \qquad c_T^2 = \frac{1}{1-c_{13}}$$

- BBN

$$G_N = \frac{G_{æ}}{1-\frac{1}{2}c_{14}} \qquad G_{\rm cos} = \frac{G_{æ}}{1+\frac{1}{2}(c_{13}+3c_2)}$$

- PPN

$$\alpha_1 = -\frac{8(c_3^2+c_1c_4)}{2c_1-c_1^2+c_3^2}$$

$$\alpha_2 = \frac{1}{2}\alpha_1 - \frac{(c_1+2c_3-c_4)(2c_1+3c_2+c_3+c_4)}{c_{123}(2-c_{14})}$$

- Pulsars

$$\hat{\alpha}_1 = \alpha_1 + \frac{c_-(8+\alpha_1)\sigma_{æ}}{2c_1}$$

$$\hat{\alpha}_2 = \alpha_2 + \frac{\hat{\alpha}_1-\alpha_1}{2} - \frac{(c_{14}-2)(\alpha_1-2\alpha_2)\sigma_{æ}}{2(c_{14}-2c_{13})}$$

Constraints on (c_1, c_2, c_3, c_4)

$$c_{ij} \equiv c_i + c_j \qquad c_{ijk} = c_i + c_j + c_k$$

- Strongest constraint ← GW170817

  $$|c_{13}| < 10^{-15}$$

- (c_1, c_{14})-plane

  $$0 < c_{14} \leq 2.5 \times 10^{-5}$$

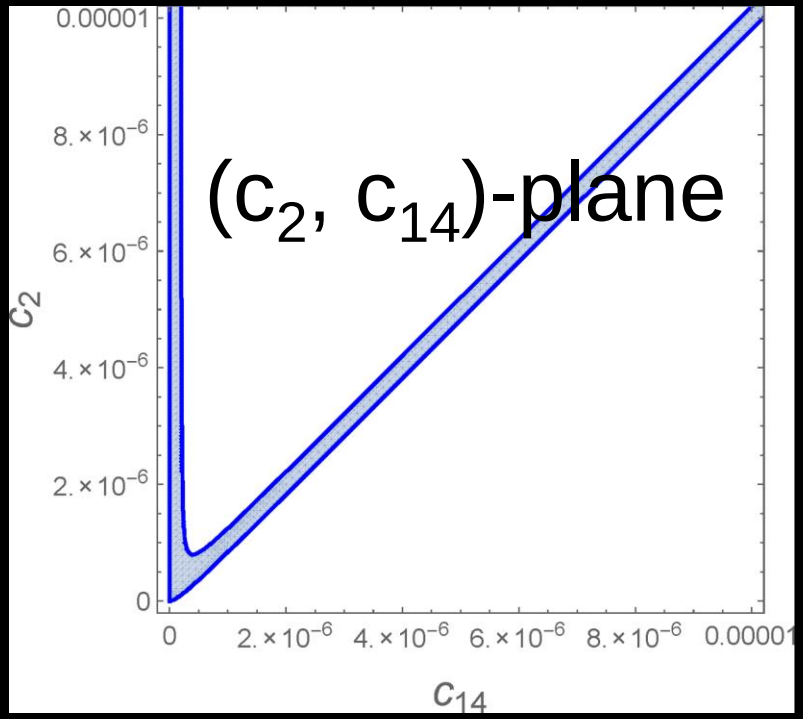
  $$c_{14} \lesssim c_1$$

- (c_2, c_{14})-plane

  $$c_{14} \leq 2.5 \times 10^{-5}$$

  $$c_2 \lesssim 0.095$$

- Sensitivity $\sigma_{æ}$
  not known in those range



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