Modified GW propagation

Belgacem, Dirian, Foffa, MM
PRD 2018, 1712.08108
and PRD 2018, 1805.08731

in GR : $$\tilde{h}''_A + 2\mathcal{H}\tilde{h}'_A + k^2\tilde{h}_A = 0$$

writing $$\tilde{h}_A(\eta, \mathbf{k}) = \frac{1}{a(\eta)}\tilde{\chi}_A(\eta, \mathbf{k})$$

we get $$\tilde{\chi}''_A + \left(k^2 - a''/a\right)\tilde{\chi}_A = 0$$

inside the horizon $a''/a \ll k^2$, so $\tilde{\chi}''_A + k^2\tilde{\chi}_A = 0$

1. GWs propagate at the speed of light
2. $h_A \propto 1/a$

   For coalescing binaries this gives $h_A \propto 1/d_L(z)$

in several modified gravity models (eg the RR nonlocal model):

$$\tilde{h}''_A + 2\mathcal{H}[1-\delta(\eta)]\tilde{h}'_A + k^2\tilde{h}_A = 0$$

$$\tilde{h}_A(\eta,\mathbf{k}) = \frac{1}{\tilde{a}(\eta)}\tilde{\chi}_A(\eta,\mathbf{k}) \qquad \frac{\tilde{a}'}{\tilde{a}} = \mathcal{H}[1-\delta(\eta)]$$

$$\tilde{\chi}''_A + (k^2 - \tilde{a}''/\tilde{a})\tilde{\chi}_A = 0$$

and again inside the horizon $\tilde{a}''/\tilde{a} \ll k^2$

1. $c_{GW} = c$ ok with GW170817

2. $\tilde{h}_A \propto 1/\tilde{a}$

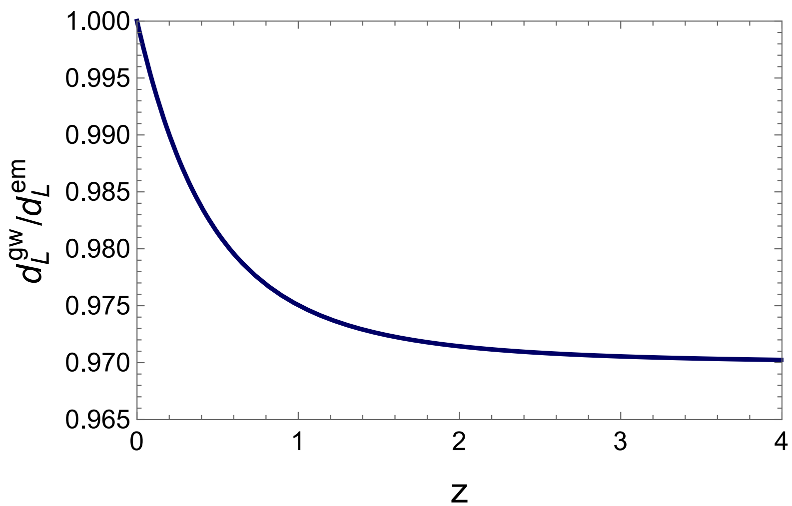
the ``GW luminosity distance" is different from the standard (electromagnetic) luminosity distance !

Deffayet and Menou 2007
Saltas et al 2014,
Lombriser and Taylor 2016,
Nishizawa 2017,
Belgacem et al 2017, 2018

in terms of δ(z) :

$$d_L^{\rm gw}(z) = d_L^{\rm em}(z) \exp\left\{ - \int_0^z \frac{dz'}{1+z'}\, \delta(z') \right\}$$

prediction of the RR model :

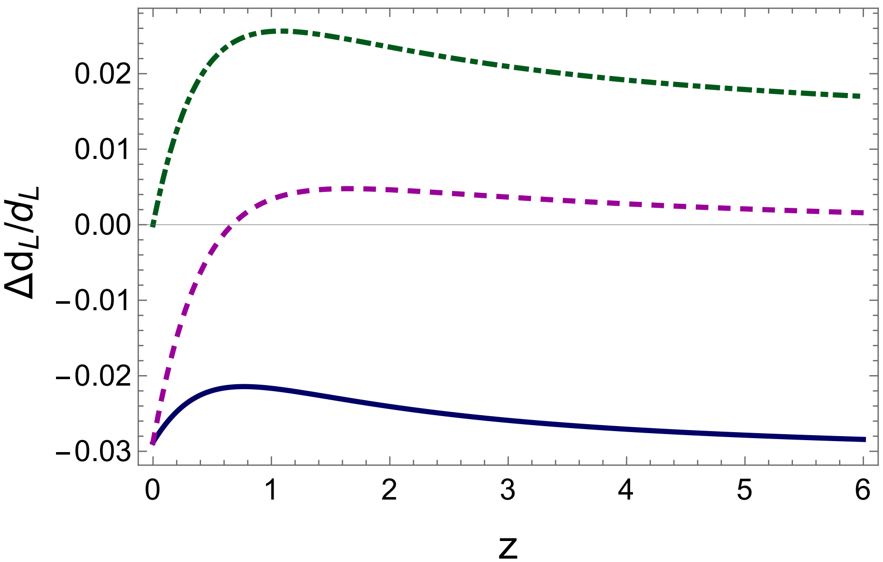


at ET and LISA this propagation effect dominates over that from the dark energy EoS !

recall that

$$d_L(z) = \frac{1+z}{H_0} \int_0^z \frac{d\tilde{z}}{\sqrt{\Omega_M (1+\tilde{z})^3 + \rho_{\rm DE}(\tilde{z})/\rho_0}}$$

(neglect radiation for standard sirens)



relative difference of e.m. luminosity distance RR-LCDM for the same values of Ω_M and H_0

relative difference with the respective best-fit parameters

relative difference of gw luminosity distance

a general parametrization of modified GW propagation

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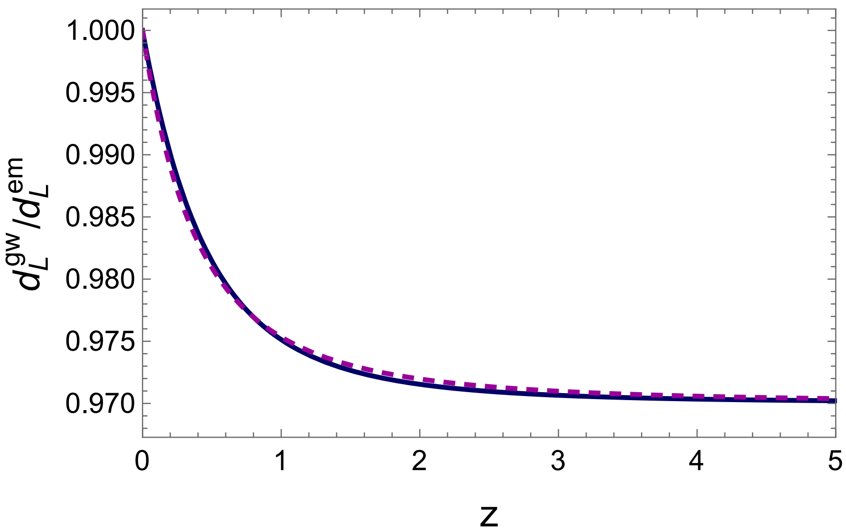

$$\frac{d_L^{\rm gw}(z)}{d_L^{\rm em}(z)} = \Xi_0 + \frac{1-\Xi_0}{(1+z)^n}$$

for the minimal RR model:

$$\Xi_0 = 0.970, \quad n = 5/2$$

However, the parametrization looks very natural and convenient in general !

parametrizing the DE sector:

- background: (w_0, w_a)
- scalar sector: (Σ, μ) tensor sector: (Ξ_0, n)

for standard sirens, the most important parameters are w_0, Ξ_0

The observation of GW170817 already gives a limit modified GW propagation

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at low z:

$$\frac{d_L^{\rm gw}(z)}{d_L^{\rm em}(z)} = e^{-\int_0^z \frac{dz'}{1+z'}\delta(z')} \simeq 1 - z\delta(0)$$

- comparing directly d^{em} for the host galaxy (obtained from surface brightness fluctuations):

$$\delta(0) = -7.8^{+9.7}_{-18.4}$$

- comparing the values of H_0 inferred from GW170817 with the Riess et al. value from standard candles:

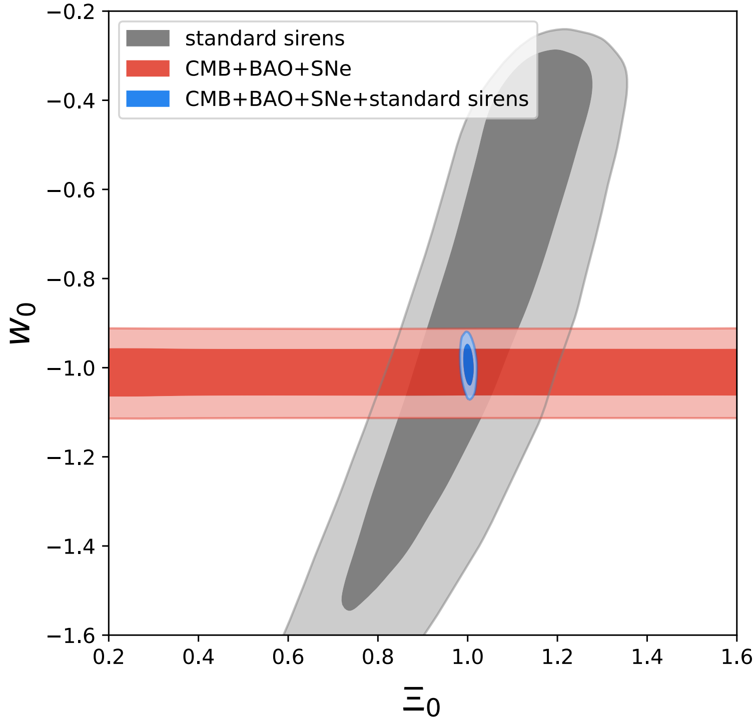
$$\delta(0) = -5.1^{+20}_{-11}$$

Forecasts for the Einsten Telescope

ET could detect ~10^5 - 10^6 BNS/yr up to large z

assume ~10^3 em counterparts

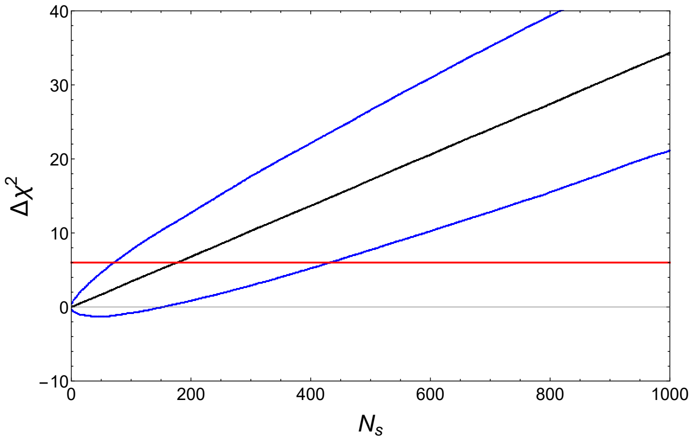
(more detailed modelization of the GRB detection and of a ET+CE+CE network in progress, with T.Regimbau and E. Howell)



$\Delta w_0=3.2\%$, $\Delta\Xi_0=0.8\%$

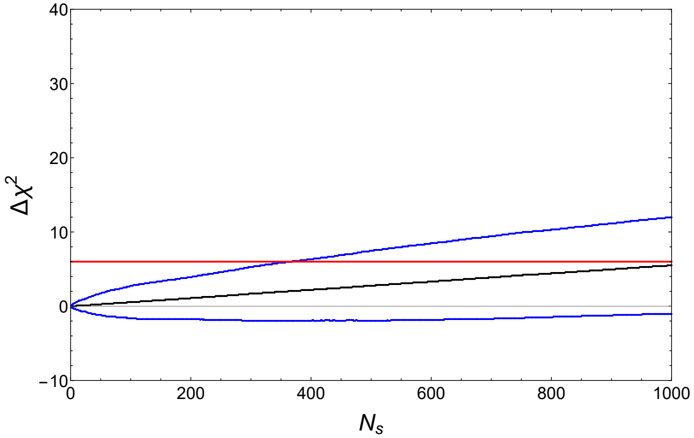
forecasts for LISA under completion
(within the LISA cosmology WG)

- Example: RR model testable at ET with O(100) standard sirens!



standard sirens at 0.07<z<2

The contribution basically comes from O(40) sources at 0.07 <z< 0.7



without modified GW propagation we would need O(1000) sources!

Take-away message:

modified GW propagation can become a major science driver for 3G detectors

- it is specific to GW observations

(while the accuracy of GW observations on w_{DE} will not be terribly competitive even with present Planck/DES observations)

- Ξ_0 can be measured with better accuracy than w_0

significant test of dark energy and modified gravity