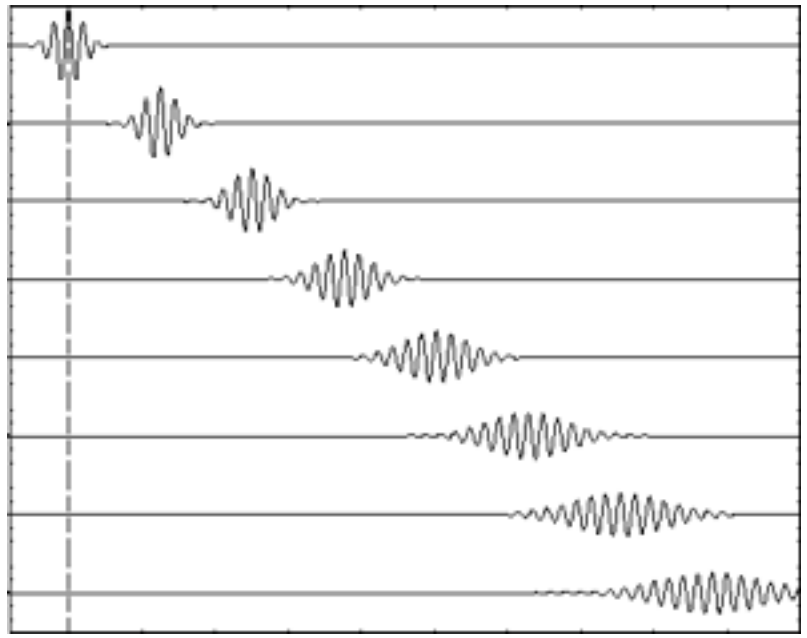
What can we learn about dark matter and dark energy from gravitational waves?

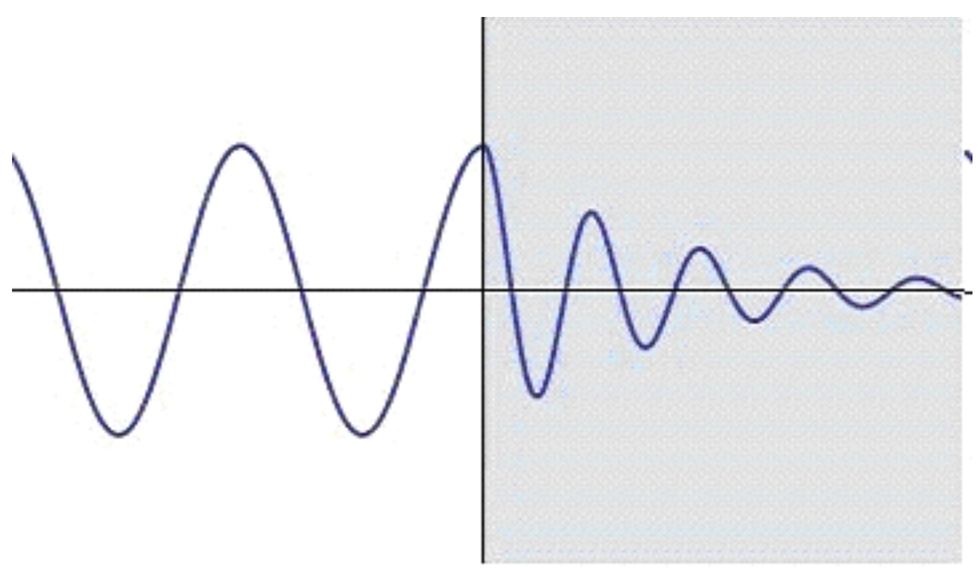
Subhendra Mohanty
Physical Research Laboratory, Ahmedabad

Dark Sector of the Universe , Bergen, 24-29, July, 2016

Dispersion of waves in a medium



Absorption in medium



There is no dispersion or absorption of gravitational waves in an ideal fluid medium.

$$T_{\mu\nu} = (\rho + p)u_\mu u_\nu - p g_{\mu\nu}$$

Ehlers, Prasanna, Breuer, 1987

No absorption or dispersion of gravitational waves by CDM, HDM, Dark energy, Chaplygin gas etc

….however fluids with shear viscosity absorb gravitational waves - Prasanna (general treatment 1999).

$$T_{\mu\nu} = (\rho + p)u_\mu u_\nu - p g_{\mu\nu} - 2\eta\,\sigma_{\mu\nu} - \xi\,\theta(u_\mu u_\nu + g_{\mu\nu})$$

Shear viscosity

Bulk viscosity

G.Goswami, SM, Prasanna hep-ph 1603.02635

FRW metric with tensor perturbations

$$ds^2 = a(\tau)^2[d\tau^2 - (\delta_{ij} + 2\,h_{ij})\,dx^i dx^j]$$

From Einstein's equation we get

$$h_{ij}^{''} - \nabla^2 h_{ij} + 2\mathcal{H}\,h_{ij} = -16\pi a^2\,\eta\,\sigma_{ij}$$

The shear perturbations in velocity are caused by gravitational waves

$$\sigma_{ij} = h_{ij}^{'} + \mathcal{H}\,h_{ij}$$

Predicted gravitational wave amplitude

$$A_0 = 2(4\pi)^{1/3}\ \frac{G^{5/3}}{c^4}\ f^{2/3}\ M_{ch}^{5/3}$$

Chirp mass

$$M_{ch} = \frac{(m_1\, m_2)^{3/5}}{(m_1 + m_2)^{1/5}} = \frac{c^3}{G}\left[\frac{5}{96}\pi^{-8/6} f^{-11/3} \dot{f}\right]^{3/5}$$

Measured GRW strain

$$h(t,r) = \frac{A_0}{r} e^{-16\pi G\, \eta\, r}$$

Need independent determination of source distance to measure shear viscosity of the dark matter

Bound on shear viscosity from GW150914

If the amplitude can be predicted with a 1% accuracy

$$\eta \times 16\pi G \times 410\mathrm{Mpc} < 0.01$$

$$\Rightarrow \eta < 5 \times 10^{-7}\,\mathrm{GeV}^3 = 6 \times 10^6 \;\mathrm{Pa\,sec}$$

G.Goswami, SM, Prasanna hep-ph 1603.02635

Self interaction cross section from Abell 3827 cluster

F. Kahlhoefer, K. Schmidt-Hoberg, J. Kummer and S. Sarkar, Mon. Not. Roy. Astron. Soc. 452, no. 1, L54 (2015) [arXiv:1504.06576 [astro-ph.CO]].

Hubble Image of the Galaxy Cluster Abell 3827. Credit: ESO

$$\frac{\sigma}{m} = (1.5 - 3)\ \frac{\mathrm{cm}^2}{\mathrm{gm}}$$

Shear viscosity of self-interacting dark matter

$$\eta = \frac{1}{3}\ m\ n\ v\ l$$

Mean free path $$l = \frac{1}{n\ \sigma}$$

Typical cross section of SIDM in galaxies and clusters

$$\frac{\sigma}{m}\ \sim\ \frac{\mathrm{cm}^2}{\mathrm{gm}} = 2\ \frac{\mathrm{barn}}{\mathrm{GeV}}$$

$$\Rightarrow \eta\ \sim\ 10^{-7}\mathrm{GeV}^3 = 10^6\ \mathrm{Pa\ sec}$$

Dark matter with self interaction cross section predicted in typical models can be detected with Gravitational waves.

Thank You.