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On the Propagation of Gravitational Waves in an Expanding Universe

Abstract
In [1,2], the influence of the cosmological constant in the propagation and measurement of Gravitational Waves (GW) was analyzed. In [3], a similar influence produced by non-relativistic matter was obtained. Thus, in this work we have generalized the effect for the case of an arbitrary perfect fluid, with equation of state $p = \omega_i \rho$, as the Universe background and used this for ΛCDM model, developing a numerical analysis that shows a potential usefulness of the results through Pulsar Timing Array future observations.

Results
From the linearization of the transformation between comoving coordinates of a cosmological observer and the coordinates that emerge from the GW source, the perturbation of the spacetime metric for ΛCDM model becomes

$$\mathrm{h}_{\mu\nu}^{GW} = \frac{1}{R}\left(1 - R\sqrt{\frac{\Lambda+\kappa\rho_{d0}+\kappa\rho_{r0}}{3}}\right)(E_{\mu\nu}\cos[w_{eff}T - k_{eff}R] + D_{\mu\nu}\sin[w_{eff}T - k_{eff}R])$$

where ρ_{r0} is the energy density of radiation, ρ_{d0} is the density of non–relativistic matter and

$$\mathrm{w}_{eff} = \Omega\left(1 - R\sqrt{\frac{\Lambda+\kappa\rho_{d0}+\kappa\rho_{r0}}{3}}\right) \quad k_{eff} = \left(1 - \frac{R}{2}\sqrt{\frac{\Lambda+\kappa\rho_{d0}+\kappa\rho_{r0}}{3}}\right)$$

In [2] it is explained how the perturbation in space-time due to a pass of Gravitational Waves affect the arrival time of a light beam coming from a nearby pulsar. In this research, we considered two models: A very simplified one-pulsar configuration and a realistic model with a set of pulsar randomly distributed. The following figure shows the first simplified model,

![][4]

The figure shows that cosmological components can be perceived by a timing residual of a nearby pulsar emission due to a pass of Gravitational Waves.

In the realistic model, we simulated the statistical significance of the measurement of the peak observed in the simplified model. We used the data from ATNF pulsar catalogue, obtaining the following figure

![][5]

These results show that it is potentially possible to differentiate the Minkowski spacetime and the ΛCDM spacetime (and its cosmological components) through observations of timing residuals in PTA projects.

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References
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