On a possibility of the gravitational wave detection at the high energy colliders

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Main Points

Abstract

A strong follow up of a previous proposal (ICHEP, Valencia 2014) is made leading to the first experiment to observe the gravitational waves at the collision sites at the colliders such as the Large Hadron Collider at CERN. The amplitudes have been calculated with regard to the sensitivity of the detector. Compared with the standard model physics, it is shown to have a measurable impact on the particle motions and corresponds to ‘missing’ energy in form of the gravitational wave loss. This is unlike the cosmological detectors like BICEP2 etc. where the indirect B mode polarization on CMBR were masked by dust. In contrast, this experiment would be the first experiment where the energy-momentum tensor of the source can be controlled.

Cosmic connections

- Dark energy has emerged as a major component of the universe following the observations of type Ia supernovae (SNe Ia).
- The acoustic peak at the multipole ($l \sim 197$) in the Cosmic Microwave Background Radiation (CMBR) power spectrum.
- The SNe Ia luminosity-redshift data called for a component with negative pressure that could generate required acceleration not explained by the conventional model.
- CMBR data required just to plug in the gap with positive energy density, provided it indicates the flat space-like hypersurfaces at constant cosmic time.
- We have shown previously that a three-phase universe works well with the first and the third (current) phases without interaction.
- However, in the (second) intermediate Q-phase, λ must vary due to interaction (then we call it a parameter).

Cosmological constant

- Reincarnation of the early Einsteinian blunder(?)
- Eddington-Lemaitre loitering models for $k = 1$
- Low distance, large Hubble constant, low age(?)
- High QSO concentration around $z = 5$ (?)

It has the negative pressure but constant positive energy(?) Constant equation of state ($w = -1$) More compelling reasons –inflation, dark energy

With whom does λ sit ?

$$A = \frac{c^3}{16\pi G}\int (R+2\lambda)\sqrt{-g}d^4x + \int L_{phys}\sqrt{-g}d^4x \quad (1)$$

$$R_{ik} - \frac{1}{2}g_{ik}R + \lambda g_{ik} = \frac{8\pi G}{c^4}T_{ik} \quad (2)$$

Q-phase analysis : A decaying Λ and the GW generation in Colliders

- The Q-phase scalar field follows

$$\ddot{\phi} + 3H\dot{\phi} + V'(\phi) = -\frac{Q}{\dot{\phi}} \quad (3)$$

- The solutions provide $\rho_n \propto f a^{-3(1+w_n)}$ with $f(\lambda/M_P) = a^{Q/H\rho_n}$ as the coupling function and keeping $Q/H\rho_n$ constant, while $\rho_\lambda \propto a^{-Q/H\rho_\lambda}$.
- The interaction parameter clearly depends on the variation of the coupling function as

$$Q \propto \dot{f}/a^{3(1+w_n)} \quad (4)$$

- In the absence of interaction $f = 1$ and ρ_n declines as $a^{-3(1+w_n)}$ as expected. Regardless of the background being matter or radiation, $f \propto Qt^3$ for constant Q.
- The rapid increase of coupling function with time during Q phase is mainly responsible for conversion of energy of cosmological constant into dark matter particles as also for slowing down the rate of fall of ρ_n in the concave-like manner.
- Thus with a non-zero Q we have higher matter density at the end of Q phase than without interaction.

dynamics continued...

- For a spatially flat region around the collision site with $\Omega_n^0 + \Omega_\lambda^0 = 1$ we have

$$\frac{Q}{\dot{\phi}} \sim H_0^2 M_P^2 (1+z)^{3(1+w_n)} f'(\phi) \tag{5}$$

$$V'(\phi) = -\frac{Q}{\dot{\phi}} \tag{6}$$

- It is found that for the observed range of $w_\phi \simeq -1$, ($w = -0.969 \pm 0.061$ (stat)$\pm$0.065 (sys)) (Kowalski, M. et al, 2008) $\dot{\phi} \approx 0$ and thus the right hand side of the (3) and (6) will be too high even for small value of Q.
- This shows the important role played by the interaction even if there is no cosmological constant proper with $w_\lambda = -1$, but instead, a set of quintessence fields having $w_\phi \approx -1$.
- Thus the range of present observational uncertainties in determining EOS of dark energy is consistent with the concept of interaction and generation of GW's.

Coupling Function for the GW signatures in colliders

- The coupling function shows the time dependence of the ratio of energy densities $r = \rho_\lambda / \rho_n$ as

$$rf^{1+1/r} \propto a^4 \tag{7}$$

in radiation and $\propto a^3$ in matter at the colliding sites. This gives

$$\rho_\lambda \propto f^{-1/r}. \tag{8}$$

- It is seen that the effects of interaction for fixed w_λ are masked by those of varying $w_{\lambda eff}$ with no interaction.
- Thus

$$w_{\lambda eff} = -1 + \frac{1}{3r}\left(\frac{\ln f}{\ln a}\right). \tag{9}$$

State-finders for cosmic GW signatures

- State-finders for pinning down the interaction among the components

$$u = \frac{\ddot{\alpha}}{aH^3} \tag{10}$$

$$s = \frac{u-1}{3(q-1/2)} \tag{11}$$

where $\alpha = \dot{a} = aH$.

- In our case of cosmological constant this set becomes

$$u = 1 - \frac{9}{2}\left(\frac{Q}{3H(\rho_n + \rho_\lambda)}\right) \tag{12}$$

$$s = \frac{Q}{3H\rho_\lambda} \tag{13}$$

- In terms of (13) we have the coupling function as

$$f = a^{3rs} \tag{14}$$

Dark matter generation in Q-phase at the colliders

- In non-interacting phases (initial phase I and the presently ongoing phase III) no mechanism to generate dark matter can operate and so $s = 0$. However, such mechanism can clearly work in Q phase with $s \neq 0$ (though not constant).
- In cosmological case, the universe has greater matter density ρ_n at the end of Q phase, thus alleviating the problem of producing light nuclei like deuterium-2 and lithium-7 in the standard Friedmann-Robertson-Walker (FRW) model.
- In addition to it, the part of the decaying λ energy is used up in generation of dark matter and GW's.
- These processes must have a deep influence on the missing energy among decaying byproducs.

Pattern of GW due to dark matter

- We envisage a scenario to generate particles of dark matter (with Lorentz factor γ) each with energy

$$\xi = \int \Theta^{00} d\tau = \gamma m c^2 \tag{15}$$

where Θ^{00} is contributed by the T^{00} of λ field.
- For the same given ξ the more massive particles would travel more slowly than the lighter particles. Thus, the more massive particles would settle further away from the light cone envelopes, while the lighter particles traveling with relativistic speeds remain closer to the particle horizon.
- This particle mass distribution would in effect generate a multiple arc-like pattern on the GW background , each arc identifiable with a characteristic mass of definite dark matter particle (or its decay product releasing nett energy $\tilde{\xi}$).
- Equation (4) shows the decay rate depends on the strength of interaction, and as coupling grows with time as $\propto t^3$ during Q phase greater is the amount of λ field energy used up to create the dark matter particles of broad mass spectrum.

Estimation of the missing energy density

- It is expected to have an isotropic streaming of particles, produced simultaneously but leaving their signatures in form of multiple arcs at the GW background.
- The arcs of smaller radii correspond to more massive particles and those of large radius towards the horizon R_H (e.g., in the Universe, cosmic horizon size $\approx$ 0.18 Mpc at $t_{recombination}$ now blown to $\approx$ 200 Mpc) correspond to the lighter particles. The size of an arc $L \sim R_H v/c$ for a typical particle having streaming velocity v can be related to its mass as

$$m = \xi(1 - L^2/R_H^2)^{1/2}. \tag{16}$$

- Thus, the mass density may be estimated from the vacuum considerations with a suitable cut-off as

$$\Pi = \frac{\hbar}{4\pi^2} \int_0^{k_m} \omega_k k^2 dk (1 - L^2/R_H^2)^{1/2} \tag{17}$$

Uncertainty in dark matter mass

- Putting present energy scales $\sim 10^{-52} GeV^4$, $\rho_\lambda^0 \simeq 4$ GeV.
- This must include the uncertainty in mass given as

$$\triangle m \geq \hbar / \triangle L \tag{18}$$

where putting the maximum value of the horizon R_H^0, we get $\triangle m \sim 10^{-32}$ eV.

Conclusion

- We propose that the GW can be observed in colliders with measurable amplitudes.
- This is the same effect as in Q-phase of the (three-phased) universe when Λ interacts with the background (radiation/ baryonic matter).
- The interaction makes Λ to decay sharply, while the fall of the background density gets slower.
- This interaction further generates particles of dark matter from (at least a part of) the decaying Λ.
- The arc-like pattern on GW is expected due to dark matter particles.
- This must include the uncertainty in missing mass of the decay products at the collision.
- The future experiments may detect this uncertainty and associated signatures.

- Thus a new concept of single Higgs-like scalar field in tachyonic form with several components.
- It is proposed that the tensor fluctuations of the gravitational waves must be unleashed from the LHC conditions of high energy densities similar to those resulting from the early inflation or the present acceleration of the universe and could well be observed at LHC with some additional new GW detector, in contrast with the cosmological detectors like BICEP 2, LIGO etc that must wait for the fluctuations of the cosmic origin.

References

- Perlmutter, S. et al, Ap. J., **517**, 565 (1999).
- Reiss, A. G. et al, Ap. J., **607**, 665 (2004).
- Kowalski, M. et al., Ap. J., **686**, 749 (2008).
- Verma, M. M., *TEXAS Symposium on Relativistic Astrophysics, 06-10 December 2010, Heidelberg, Germany*, Proceedings of Science, 218 (2010).
- Verma, M. M., Astrophys Space Sci, **330**, 101 (2010).
- Sahni, V. et al, JETP Lett., **77**, 201 (2003).

And finally...

THANK YOU