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Bell violation in the Sky [talk via Skype]

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In the present article, we have addressed the following points:

Firstly we have briefly reviewed Bell's inequality in quantum mechanics and its implications. For this we reviewed the proof of Bell's inequality.
Further we have discussed the violation of Bell's inequality in the context of quantum mechanics. Also we have given the explanation for such violation, which finally give rise to new physical concepts and phenomena.

Next we have briefly discussed about the setup for Bell's inequality violating test experiment in the context of primordial cosmology. Further we have studied creation of new massive particles as introduced in the context of inflationary paradigm for various choice of time dependent mass profile. To describe a very small fraction of particle creation after inflation we have computed the expression for Bogoliubov coefficient β in FLRW space-time, which characterizes the amount of mixing between the two types of WKB solutions. Next using the results for Bogoliubov co-efficients we have further calculated reflection and transmission co-efficients, number density and energy density of the created particles for various mass profiles. Here we have provided the results for three specific cases:-super horizon, horizon crossing, sub horizon.Further we have studied cosmological scalar curvature fluctuations in presence of new massive particles for arbitrary choice of initial condition and also for any arbitrary mass profile. Here we have explicitly derived the expression for one point and two point correlation function using in-in formalism. Here in our computation we have introduced a new cosmological observable which captures the effect of Bell's inequality violation in cosmology. Further we have expressed the scale of inflation in terms of the amount of Bell's inequality violation in cosmology experimental setup using model independent prescription like EFT. Additionally we have derived a model independent expression for first Hubble slow roll parameter $\epsilon = -\dot{H}/H^2$ and tensor-to-scalar ratio in terms of the Bell's inequality violating observable within the framework of EFT. Additionally, we have given an estimate of heavy field mass parameter m/H
to violate Bell's inequality within cosmological setup.

It is important to note that when all the EFT interactions are absent in that case effective sound speed $c_S \sim 1$ and one can get back the results for canonical slow-roll models.
On the other hand when the EFT interactions are switched on within the present description, one can able to accommodate the non-canonical as well
as non-minimal interactions within this framework. In that case both c_S and $\tilde{c}_S$ are less than
unity and in such a situation one can always constraint the sound speed parameter as well the strength
of the EFT interactions using observational probes (Planck 2015 data).
One can easily compare the present setup with effective time varying mass
parameter with the axions with time varying decay constant.
For $m << h$ case the last term in the effective action is absent and in that case the reduced form of the action will able to explain
the EFT of inflation in presence of previously mentioned non-trivial effective interactions. Once we switch off all such interactions the above action mimics the case for single field slow-roll inflation.

Further we have given an example of axion model with time dependent decay constant as appearing in the context of string theory. Hence we have mentioned the effective axion interaction of axion fields.
Now to give a analogy between the newly introduced massive particle and the axion we have further discussed the creation of axion in early universe.
Next we have established the one to one correspondence between heavy field and axion by comparing the particle creation mechanism, one and two point correlation functions.

Additionally, we have given an estimate of axion mass parameter $m_{axion}/f_a h$
to violate Bell's inequality within cosmological setup. Finally, we have discussed the specific role of isospin breaking interaction for axion type of heavy fields to measure the effect of Bell's inequality violation in primordial cosmology.

Next we have explicitly shown the role of quantum decoherence in cosmological setup to violate Bell's inequality. Additionally here we have also
mentioned a possibility to enhance the value of primordial non-Gaussianity from Bell's inequality violating setup in presence of massive time dependent field profile. Further we have discussed the role of
three specific time dependent mass profile for producing massive particles and to generate quantum fluctuations. Finally, we have discussed the role of arbitrary spin heavy field to violate Bell's inequality.
Here we have provided a bound on the mass parameter for massive scalar with spin S=0, axion with spin S=0, graviton with spin S=2 and for particles with high spin S>2 in horizon crossing, super horizon
and sub horizon regime.

Summary

In this work, we have studied the possibility of setting up Bell's inequality violating experiment in the context of cosmology, based on the basic principles of quantum mechanics. First we start with the physical motivation of implementing the Bell's inequality violation in the context of cosmology. Then to set up the cosmological Bell violating test experiment we introduce a model independent theoretical framework using which we have studied the creation of new massive particles by implementing the WKB approximation method for the scalar fluctuations in presence of additional time dependent mass contribution in the cosmological perturbation theory. Here for completeness we compute total number density and energy density of the newly created particles in terms of Bogoliubov coefficients using WKB approximation method. Next using the background scalar fluctuation in presence of new time dependent mass contribution, we explicitly compute the expression for the one point and two point correlation functions.Furthermore, using the results for one point function we introduce a new theoretical cosmological parameter which can be expressed in terms of the other known inflationary observables and can also be treated as a future theoretical probe to break the degeneracy amongst various models of inflation. Additionally, we also fix the scale of inflation in a model independent way without any prior knowledge of primordial gravitational waves. Also using the input from newly introduced cosmological parameter, we finally give a theoretical estimate for the tensor-to-scalar ratio in a model independent way. Next, we also comment on the technicalities of measurements from isospin breaking interactions and the future prospects of newly introduced massive particles in cosmological Bell violating test experiment. Further, we cite a precise example of this set up applicable in the context of string theory motivated axion monodromy model. Then we comment on the explicit role of decoherence effect and high spin on cosmological Bell violating test experiment. In fine, we provide a theoretical bound on the heavy particle mass parameter for scalar fields, graviton and other high spin fields from our proposed setup.

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