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SN1987A constraints to BSM models with extra neutral bosons near the trapping regime

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New physics beyond the Standard Model (BSM) with an extra neutral boson can be constrained from the observation of SN1987A, since the production of this neutral boson in a supernova (SN) could accelerate the SN cooling and potentially lead to a period of the neutrino burst incompatible with the observation.% for certain ranges of model parameters. The constraint to the model is formulated by the condition $L_{\rm NB} \leq 3 \times 10^{52}$ erg/s according to G. Raffelt with $L_{\rm NB}$ the luminosity of BSM neutral boson. Computing the above luminosity in the large coupling case, the so-called trapping regime, is non-trivial since the luminosity is a competition between the large production rate and the efficient absorption or decay rate of the neutral boson. We illustrate such a subtlety using $U(1)_{L_\mu - L_\tau}$ model as an example where the Z' luminosity, $L_{Z'}$, from the neutrinosphere is calculated.

We calculate Z' production, absorption, and decay rates through pair-coalescence, semi-Compton, loop-bremsstrahlung from proton-neutron scattering, and their inverse processes in a benchmark SN simulation with muons. We point out that, as the coupling constant $g_{Z'}$ increases, $L_{Z'}$ shall be approaching to a constant plateau value for a given $m_{Z'}$ instead of monotonically decreasing down to zero as obtained in the previous literature. We demonstrate that this plateau phenomenon can be understood by physical arguments and justified by numerical calculations. With a different result on $L_{Z'}$ from the previous one, we discuss impacts on the constraints to $U(1)_{L_\mu - L_\tau}$ parameter space by SN1987A. The implication of our result to the similar constraint on a generic BSM model with an extra neutral boson is also discussed.

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