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Adiabaticity and gravity theory independent conservation laws for cosmological perturbations

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Summary

We carefully study the implications of adiabaticity for the behavior of cosmological perturbations. There are essentially three similar but different definitions of non-adiabaticity: one is appropriate for a thermodynamic fluid δPnad, another is for a general matter field δPc,nad, and the last one is valid only on superhorizon scales. The first two definitions coincide if c2s=c2w where cs is the propagation speed of the perturbation, while c2w=$\dot{P}/\dot{\rho}$. Assuming the adiabaticity in the general sense, δPc,nad=0, we derive a relation between the lapse function in the comoving sli\-cing Ac and δPnad valid for arbitrary matter field in any theory of gravity, by using only momentum conservation. The relation implies that as long as cs≠cw, the uniform density, comoving and the proper-time slicings coincide approximately for any gravity theory and for any matter field if δPnad=0 approximately. In the case of general relativity this gives the equivalence between the comoving curvature perturbation Rc and the uniform density curvature perturbation ζ on superhorizon scales, and their conservation.

We then consider an example in which cw=cs, where δPnad=δPc,nad=0 exactly, but the equivalence between Rc and ζ no longer holds. Namely we consider the so-called ultra slow-roll inflation. In this case both Rc and ζ are not conserved. In particular, as for ζ, we find that it is crucial to take into account the next-to-leading order term in ζ's spatial gradient expansion to show its non-conservation, even on superhorizon scales. This is an example of the fact that adiabaticity (in the thermodynamic sense) is not always enough to ensure the conservation of Rc or ζ.

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