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General Relativistic Evolution Equations for Density Perturbations in FLRW universes and the Problem of Structure Formation

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Due to the general covariance of the Einstein equations and conservation laws, the linearized equations have solutions which are gauge-dependent and have, therefore, no physical significance.

In this talk I will show that the decomposition theorems for symmetric second-rank tensors of the maximally symmetric subspaces of constant time imply that there are exactly two, unique, gauge-invariant quantities which describe the true, physical perturbations to the energy density and particle number density. In the limit of zero spatial fluid velocity, and hence zero pressure, the set of linearized Einstein equations and conservation laws, combined with the new gauge-invariant quantities reduce to the Poisson equation of the Newtonian Theory of Gravity and the energy-mass relation of the Special Theory of Relativity. The relativistic gauge transformation reduces to the Newtonian gauge transformation in which time and space are decoupled.

The cosmological perturbation theory consists of a second-order ordinary differential equation (with source term entropy perturbations) which describes the evolution of perturbations in the total energy density, and a first-order ordinary differential equation which describes the evolution of entropy perturbations.

The cosmological perturbation theory is applied to a flat FLRW universe. For large-scale perturbations the entropy perturbations do not play a role, so that the outcome is in accordance with treatments in the literature. In the radiation-dominated era small-scale perturbations grew proportional to the square root of time and perturbations in the CDM particle number density were, due to gravitation, coupled to perturbations in the total energy density. Therefore, structure formation could have begun successfully only after decoupling of matter and radiation. After decoupling density perturbations exchanged heat with their environment. This heat exchange may have enhanced the growth rate of their mass sufficiently to explain structure formation in the early universe, a phenomenon which cannot be understood from adiabatic density perturbations.

https://arxiv.org/abs/1410.0211

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