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INITIAL CONDITION PROBLEM FOR COSMOLOGICAL N-BODY SIMULATIONS

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Abstract. For a long time, the Lagrangian linear perturbation (Zel'dovich approximation, ZA) is used for initial conditions for cosmological N-body simulations. Recently, Crocce, Pueblas, and Scoccimarro (2006) proposed the improvement of the initial conditions. They applied Lagrangian second-order perturbation (2LPT) for the initial condition. Then they calculated the Lagrangian linear perturbation and showed that 2LPT initial conditions improve the evolution of non-Gaussianity for the density fluctuation in the Universe. Here we have one question. Although 2LPT initial conditions improve the cosmological N-body simulation, is 2LPT initial conditions sufficient? To answer this question, in addition to the ZA and 2LPT, we also calculate the non-Gaussianity with the initial conditions based on third-order Lagrangian perturbation theory (3LPT). Then we show reasonable order of perturbation and redshift for the initial conditions.

1 Summary

The evolution of the large-scale structure in the Universe is one of the most important topic in astrophysics. The standard scenario for the structure formation is that the primordial density fluctuation grows through its gravitational instability. In order to follow the distribution far into the nonlinear region, we must, inevitably, rely on the numerical calculations, named, cosmological N-body simulations.

For accuracy of cosmological N-body simulations, there is a problem about the initial condition. Because of several reasons for numerical computation, we do not start the simulation at recombination era. We analyze the evolution of the density fluctuation with perturbation theory from the recombination era for the time being. Then we treat the result of the evolution for the initial condition.

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for $N$-body simulation. In the standard scheme, we must use the perturbative approach. Until the fluctuations come into the quasi-nonlinear regime and stable numerical calculation become possible.

The method to set up the initial conditions into cosmological $N$-body codes has been almost the same from the first works of this field. In many cases, the Zel’dovich approximation (ZA) (Zel’dovich 1970), i.e., the first-order approximation of Lagrangian perturbation theory (LPT) have been applied for the initial conditions of $N$-body simulations for a long time.

Recently, Crocce, Pueblas, and Scoccimarro (2006) proposed the improvement by adopting different initial conditions. Basically, their initial conditions are based on the approximations valid up to second-order Lagrangian perturbation theory (2LPT) which reproduce exact value of the skewness in the weakly nonlinear region. With these initial conditions, they calculate the statistical quantities and show the effects of transients related with 2LPT initial conditions decrease much faster than the ones related with ZA initial conditions, that is, the transients with 2LPT initial conditions are less harmful than ones with ZA initial conditions.

However, there still exist transients related with 2LPT initial conditions which prevent to reproduce the exact value of higher order statistical quantities like the kurtosis, and there is no guarantee that 2LPT initial conditions are accurate enough for these quantities.

Therefore, as a natural extension of Croce, Pueblas, and Scoccimarro (2006), we examine the impact of transients from initial conditions based on 2LPT in $N$-body simulation. In addition to the ZA and 2LPT, we also calculate the non-Gaussianity and the power spectrum with the initial conditions based on third-order Lagrangian perturbation theory (3LPT) (Tatekawa and Mizuno 2007, 2008).

From our analyses, we conclude that one considers typical $N$-body simulations, which start at $z \sim 50$, the predicted statistics are accurate enough up to the forth-order (kurtosis) and the power spectrum using 2LPT initial conditions.

References

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