On the pressure-less fluid approximation for large scale structure

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In perturbative studies of large scale structure, it has been customary to employ the pressure-less fluid approximation – not that the fluid is strictly pressure-free, but that pressure can be neglected on the scales of interest. This was called into question recently. It was argued that the discrepancy between standard perturbation theory (SPT) and N-body simulations (at the level of tens of percent or more beyond the nonlinear scale) should be interpreted as a failure of the pressure-less approximation. In this paper, we present a series of hydrodynamic simulations (of dark matter as a fluid) with progressively lower pressure or sound speed, and compare them against N-body simulations from the same initial condiitons. We find that the power spectra from hydrodynamic and N-body simulations agree well (at the percent level around $k \sim 0.2$ h/Mpc), as long as the sound speed is below 100 km/s. There is no sign that introducing sound speed improves the agreement. On the contrary, if the sound speed is above 100 km/s, results from hydrodynamic simulations start to deviate significantly from that of the N-body simulations. This suggests the failure of SPT to match N-body simulations at and beyond the nonlinear scale is primarily a failure of perturbation theory itself, and *not* the failure of the pressure-less approximation. Effective field theory arguments no doubt correctly identify pressure as a physical effect that should be present at some level, but care should be taken in assessing its importance. At $k \gtrsim 0.2$ h/Mpc, non-perturbative methods such as hydrodynamic simulations should be used for this purpose.

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I. INTRODUCTION

Lam. Motivation for carrying out this exercise. Discussion of effective field theory. Also discussion of the fact that fluid can never be strictly pressure-free; it's a degenerate limit.

II. HYDRODYNAMIC SIMULATIONS

Greg. Discussion of the hydrodynamic code, and the simulations we have run. Discussion of the distinction between adiabatic and isothermal. Discussion of what happens at shocks

III. DISCUSSION

Lam. Conclusion and ideas for future investigation.

Acknowledgements

We thank Roman Scoccimarro for useful discussions, and for kindly providing the one-loop power spectrum. This work was supported by the DOE and NASA under cooperative agreements DE-SC0011941 and NNX16AB27G.

Appendix A: Tests

Rasmi. Tests should include: match with linear theory prediction at $z = 10$; box size tests; resolution tests.

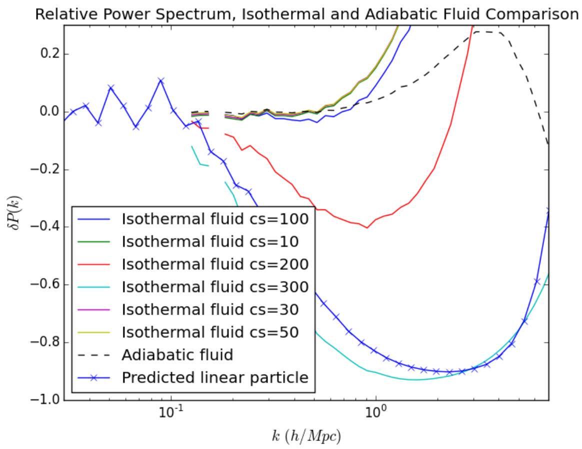
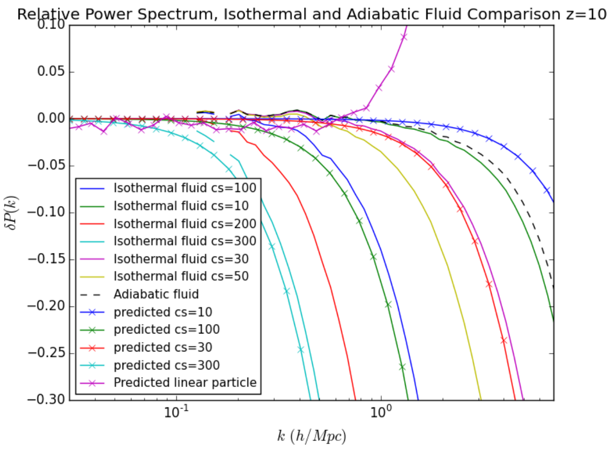

Relative Power Spectrum, Isothermal and Adiabatic Fluid Comparison
Isothermal fluid cs=100
Isothermal fluid cs=10
Isothermal fluid cs=200
Isothermal fluid cs=300
Isothermal fluid cs=30
Isothermal fluid cs=50
Adiabatic fluid
Predicted linear particle
$\delta P(k)$
$k\ (h/Mpc)$
0.2
0.0
−0.2
−0.4
−0.6
−0.8
−1.0
10^{-1}
10^{0}

FIG. 1:



Relative Power Spectrum, Isothermal and Adiabatic Fluid Comparison z=10
0.10
0.05
0.00
−0.05
−0.10
−0.15
−0.20
−0.25
−0.30
$\delta P(k)$
10^{-1}
10^{0}
$k\ (h/Mpc)$
Isothermal fluid cs=100
Isothermal fluid cs=10
Isothermal fluid cs=200
Isothermal fluid cs=300
Isothermal fluid cs=30
Isothermal fluid cs=50
Adiabatic fluid
predicted cs=10
predicted cs=100
predicted cs=30
predicted cs=300
Predicted linear particle

FIG. 2: