

Simulating the Formation and Evolution of Oscillons after Inflation

Henry Daniels-Koch, 2017

After the Big Bang, there was a period of rapid expansion in our universe known as inflation. During and after inflation, the energy in the universe can be modeled spatially and temporally as a scalar field of matter. As the universe evolved after inflation, it has been shown that initially small and random perturbations in the scalar field grew into larger “blobs” of matter known as oscillons. Oscillons are an important phenomenon in the field of cosmology because while little is known about them, oscillons are hypothesized to have driven the first formation of large scale structure in the universe through accretion of matter and mergers. Additionally, oscillons may have led to the formation of primordial black holes—black holes formed in the early universe that are too small to be detected currently and strong candidates for dark matter.

While oscillons have been shown to arise as natural artifacts of the immense potential energy of inflation, little research has been conducted on the effects of oscillons on the gravitational field that permeates the universe. Ultimately our goal is to determine if oscillons produce substantial gravitational waves and characterize other gravitational effects on long, post-inflationary timescales. However, we first emulate M. A. Amin’s simulation of a scalar field in 1+1-dimensions (one spatial dimension over time) to confirm the emergence of oscillons (2010). Following M. A. Amin’s numerical set-up and initial conditions, we use a modified wave equation with a non-linear inflation potential, dependent on the oscillonic solution. We add a first time derivative into the wave equation to accommodate the expanding homogeneous background. We initialize our model with random fluctuations of the scalar field and evolve the fluctuations over time. Once the inflation potential is sufficiently small, we observe and confirm the formation of oscillons in our model.

Our computational model (in C++) uses a finite difference grid in which grid points at equally spaced positions have an associated energy value which changes over time. To obtain an accurate model, we strive to use as many grid points as possible at very small time increments. With the high resolution required of a large and accurate model, we are forced to use a model with a long runtime. To speed up the runtime of our code, we employ parallel processing and use OpenMP software on Bowdoin’s High Performance Grid, which splits up the processing job to many processors. In addition to parallelizing our code, we test other various runtime optimization methods such as compilation flags that force functions to execute inline. Achieving a faster code allows the user to quickly test a host of parameters as well as modify the code throughout the research process.

Future work will first involve designing the same simulation in 3+1 dimensions, but with only one fully formed oscillon in spherical polar coordinates. We will utilize this method as a steppingstone before our final model of the gravitational effects of oscillons in which we must accommodate gravitational waves propagating from an oscillon point source. To observe gravitational waves emitted from a point source, one can gain a more accurate model near the point source with spherical polar coordinates. Our gravitational model of oscillons has the potential to shed light on fundamental questions in cosmology such as the early evolution of our universe as well as the dark matter mystery.

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References: M. A. Amin, (2010) arXiv:1006.3075 [astro-ph.CO].

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