Linearized Gravity and its Effects on Oscillon Formation and Properties

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Abstract

One of the greatest issues in particle physics is understanding the period of reheating after cosmic inflation. After inflation, the universe is left in an extremely cold state with the majority of its energy trapped in the homogeneous condensate of the inflaton field. We need a mechanism through which energy can be transferred out of the inflaton field and into matter fields in order to thermalize the universe and create standard model particles. One way to accomplish this is through a process known as preheating. I specifically investigated the mechanism of parametric resonance found in an Axion Monodromy inflationary model.

One byproduct of many models of preheating is the production of massive, non-topological, long-lived regions of localized oscillation in the inflaton field known as oscillons. These oscillons contain a huge amount of energy, and if they do not decay quickly enough create inconsistencies with our observations of the thermal history of the universe.

I used computational techniques, specifically a GPU based implementation of our GABE software using CUDA, to evolve the universe according to a model of preheating that creates oscillons. I observed the effects that the introduction of local linearized gravity had on the dynamics and decay of oscillons. I found that local gravity, especially in the presence of a coupled field, had a dramatic effect on the formation, decay, and interaction of these oscillons.

Preheating and Reheating

After the period of cosmic inflation, the universe is left in an extremely cold state with the majority of the universe's energy trapped in inflaton field potential. We need a model to describe the mechanism by which energy is transferred out of this field and into other matter fields to thermalize the universe sufficiently for standard model particle production.

The Old Model of Reheating accomplishes this task through perturbative quantum decays of the inflaton field. However, there are some questions about the speed of this mechanism. In some models it is difficult for Old Reheating to thermalize the universe quickly enough to be consistent with the thermal history we observe.

A model that includes a period of what is known as preheating can accomplish the goal of thermalizing the universe much faster. Preheating involves a non-perturbative mechanism such as the parametric resonance that occurs in non-linear potentials. Specifically, I worked with the following Axion Monodromy Potential for the inflaton with initial conditions based on the work of Mustafa Amin.

$$V = m^2 M^2 \left(\sqrt{1 + \frac{\phi^2}{M^2}} - 1\right)$$

Oscillons and Linearized Gravity

A unique feature of non-linear potentials is the production of massive, localized, long lived oscillations in the inflaton field. We are interested to see how these structures are affected by the inclusion of local linearized gravity in our model. We accomplish this by perturbing the metric as follows

$$ds^2 = -(1 + 2\Phi)dt^2 + a^2(1 - 2\Phi)d\mathbf{x}^2$$

And calculating the gravitational potential using linearized GR.

CUDA Implementation

This investigation was aided by the use of CUDA enabled GABE, which is able to utilize the parallel processing of GPUs to make computation more efficient. This was important in making the calculation of the Newtonian potential computationally feasible.

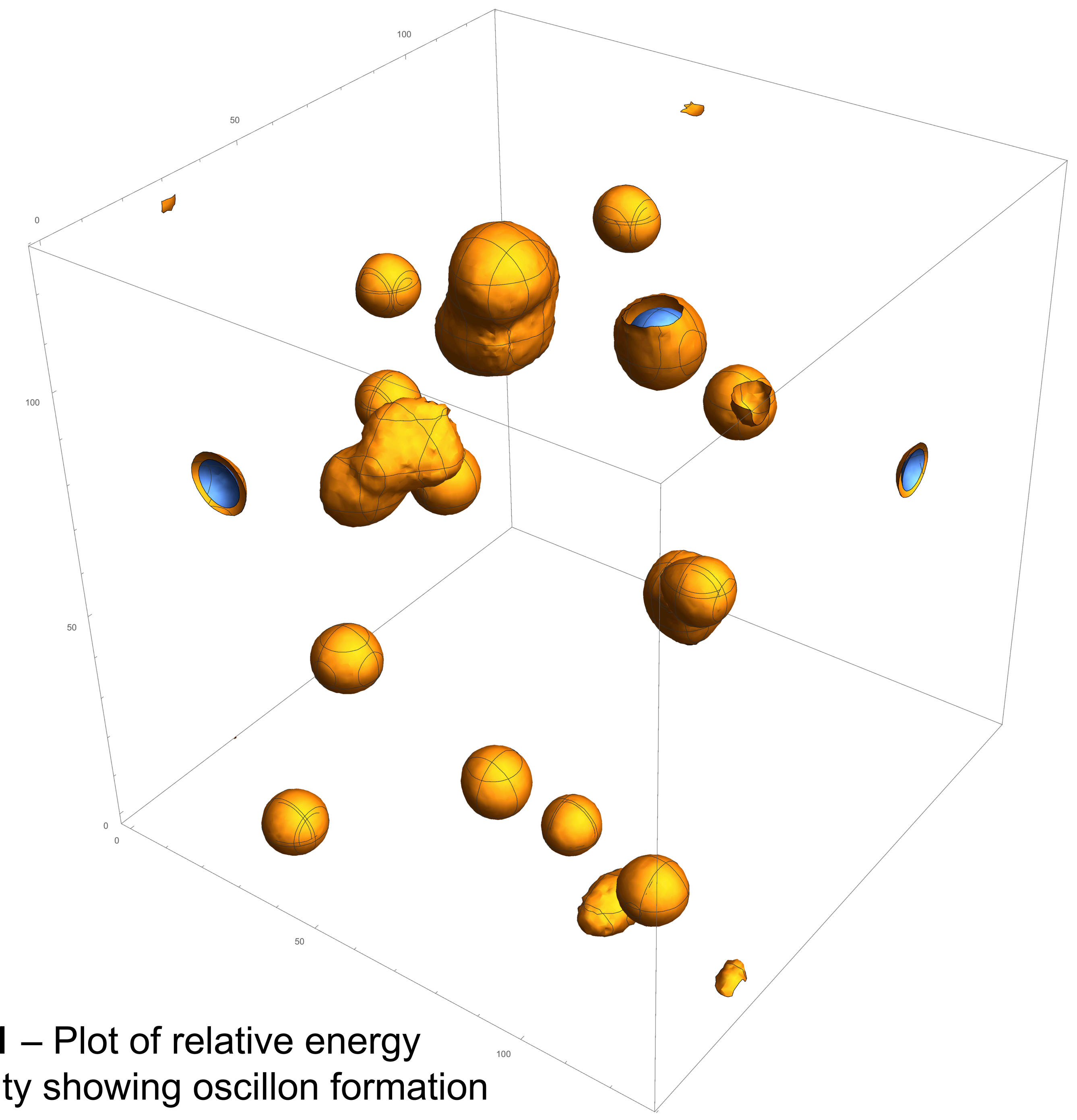

Fig. 1 – Plot of relative energy density showing oscillon formation

Single Field Results

Evolution of the Klein-Gordon equation of motion yielded the following results for a single field with an Axion Monodromy potential:

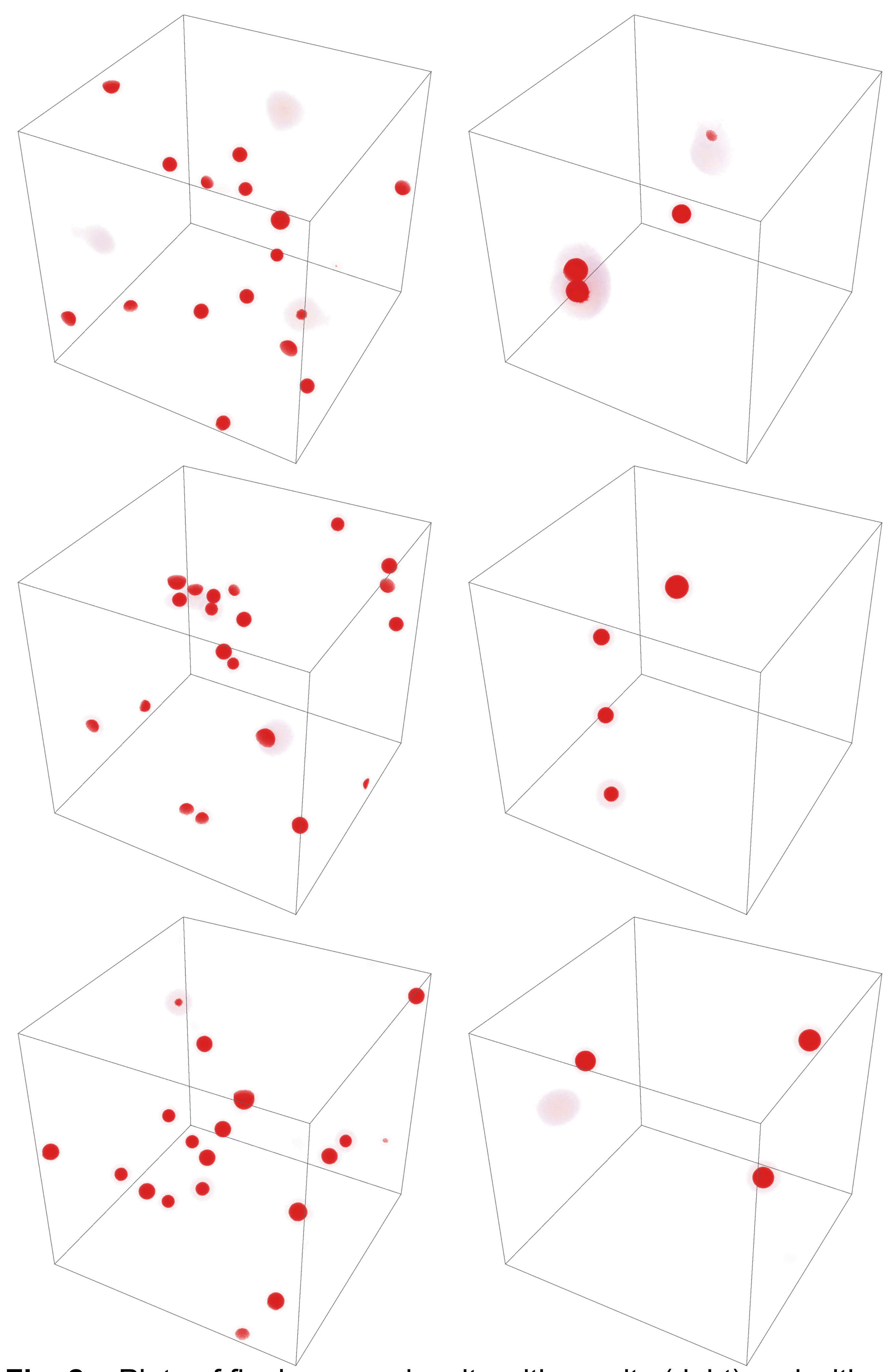

Fig. 2 – Plots of final energy density with gravity (right) and without gravity (left) for three realizations of a single field

Coupled Field Results

Next we analyzed the affects of gravity on a model with a second coupled matter field and analyzed oscillon decay:

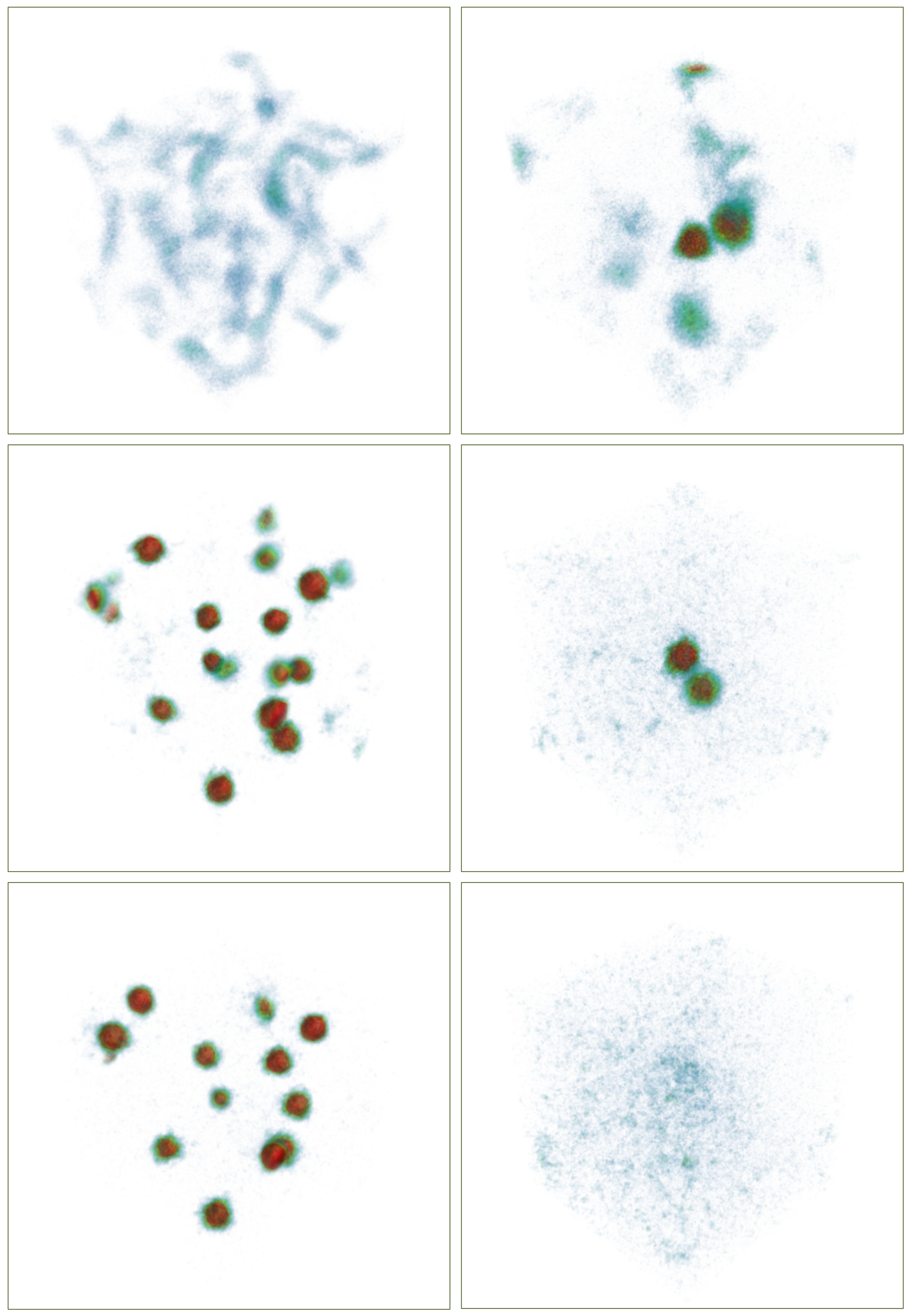

Fig. 3 – Frames from coupled field evolutions through time with gravity (right) and without (left). We see gravity leads to faster decay,

Conclusion

We see from these results that n the case of a single non-linear field the inclusion of localized gravity has a marked effect on oscillon properties. Localized gravity causes oscillons to clump leading to fewer, more massive oscillons.

The coupled field runs show that the inclusion of local gravity can have a dramatic affect on the rate at which oscillons decay. This is an exciting result because oscillons are problematic for many models of preheating because they decay too slowly trapping energy in in the inflaton which is inconsistent with our observations of the thermal history of the universe.

References and Acknowledgements

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[2] Mustafa Amin, Richard Easther, et. al. "Oscillons After Inflation" arXiv: 1106.3335v2
[3] Mustafa Amin. "Inflaton Fragmentation: Emergence of Pseudo-Stable Inflaton Lumps (Oscillons) After Inflation" arXiv: 1006.3075v2

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