nature portfolio

Peer Review File

Laser-Driven Annular Shock Waves as Laboratory Analogues of wCDM Cosmologies and Cosmological Gravitational Waves

Corresponding Author: Dr Felipe Asenjo

This file contains all reviewer reports in order by version, followed by all author rebuttals in order by version.

Version 0:

Reviewer comments:

Reviewer #1

(Remarks to the Author)
I have read this manuscript with attention, but despite several interesting connections between laboratory and cosmological systems, I think this work requires some major revisions before it can be published.

First of all, I recommend that the authors should look carefully at the paper of Crowther et al. (https://link.springer.com/article/10.1007/s11229-019-02190-0). It clearly discusses the meaning of analogue experiments and how they can be used in scientific discovery. However, in just a few words, the point that is applicable to the manuscript here is that the physical laws that describe the shock wave propagation are clearly very different from the physical laws governing the expanding Universe. This cannot be understated - meaning that whatever new behaviour is found in the laboratory experiment cannot be associated with new physics in the Universe. So what is the role of a laboratory experiment of this type? The answer, in my opinion, is that the use of these laboratory experiments must only be related to the advantage given by a laboratory setting to solve a given problem in a way that is more accurate than, for example, running numerical simulations. This is essentially what laboratory astrophysics has been doing in the context given by Drake et al. (the reference cited in the manuscript).

So, in order to convince me that this work is worth publishing in this journal, the authors need to explain in much better detail what is the use of the analogue construction they have developed. Do they intend to solve for some particular dynamical model of an expanding Universe? Why would this be better than just solving the FLWR equations directly? Or is there some particular advantage in doing these types of analogue experiments?

I suggest the authors revise the manuscript with the above questions in mind.

Reviewer #2

(Remarks to the Author)
The manuscript by Asenjo, et al. describes a series of experiments with laser-driven shocks, in which the dynamics of the shocks can be described with equations analogous to several used to model cosmological processes. The authors derive equations of motion from Sedov-Taylor theory for different geometries of shocks (planar, cylindrical, etc.), and show that those equations are analogous to the equations that describe different types of cosmological models, such as models dominated by matter, radiation, etc. The equations of motion for the shocks modeling different cosmologies are validated with experimental measurements based on refractive imaging of the evolving (and merging) shock fronts.

Overall, the authors claim that there is a one-to-one correspondence between Sedov-Taylor theory and the isotropic FLRW cosmological models. Indeed, the measurements of shock dynamics are well described by the experimental models derived. It is an interesting idea to suggest that these classical models can serve as an analog for cosmological models, and fits well within the long physics tradition of looking for insight in one system from another seemingly very different one.

My main comment is that, while the authors present a compelling case that their experiments are well-modeled by equations analogous to those in cosmological models, there is very little discussion of what utility this comparison would have. Essentially, the question is what, even in principle, would cosmologists learn from these types of experiments? The authors only briefly highlight one example, where the physics underlying the changing dimensionality of colliding cylindrical shock waves could “have some usefulness” to understanding the emergence of the dark energy contribution in cosmological models. But there’s no further discussion elaborating on this idea.

Given the central importance to the paper of the one-to-one correspondence between the experiments and cosmological models, I would like to see the authors include more discussion about how this correspondence would be useful to understanding cosmological models before recommending publication.

Other comments:
• The experimental setup suggests that one schlieren image (and so one measurement time) is taken per laser shot. If that’s correct, can the authors comment on the reproducibility of their experiments, as presumably many shots would need to be assembled to get a full time series? While the experiment is described elsewhere [9], since the data is presented here, it would be good to comment on this in the manuscript.
• There are a large number of minor grammatical mistakes throughout the manuscript.

Version 1:

Reviewer comments:

Reviewer #1

(Remarks to the Author)
The authors have replied to my comments satisfactorily. I have no further queries.

Reviewer #2

(Remarks to the Author)
The authors have added additional discussion and context to the manuscript on the analogy between their experiments and cosmological models, including additional examples of how results from the experiments could influence thinking about cosmological models. The authors have also made it clear that these experiments are not able to directly model observational cosmology, i.e. directly replicate the physics at play, in contrast to other areas of laboratory astrophysics.

I appreciate the added context and believe the authors have satisfactorily addressed the main question raised by both reviewers, namely what exactly is the connection between the experiments and cosmological models. They have also addressed my other concerns. While the ultimate impact of these kinds of experiments on our understanding of cosmological models is unclear, I believe this is an interesting analogy and worthy of publishing in Commutations Physics.

Responses to Reviewer 1:

Reviewer # 1 (Remarks to the Author):

I have read this manuscript with attention, but despite several interesting connections between laboratory and cosmological systems, I think this work requires some major revisions before it can be published.
First of all, I recommend that the authors should look carefully at the paper of Crowther et al. (https://link.springer.com/article/10.1007/s11229-019-02190-0). It clearly discusses the meaning of analogue experiments and how they can be used in scientific discovery. However, in just a few words, the point that is applicable to the manuscript here is that the physical laws that describe the shock wave propagation are clearly very different from the physical laws governing the expanding Universe. This cannot be understated - meaning that whatever new behaviour is found in the laboratory experiment cannot be associated with new physics in the Universe. So what is the role of a laboratory experiment of this type? The answer, in my opinion, is that the use of these laboratory experiments must only be related to the advantage given by a laboratory setting to solve a given problem in a way that is more accurate than, for example, running numerical simulations. This is essentially what laboratory astrophysics has been doing in the context given by Drake et al. (the reference cited in the manuscript).
So, in order to convince me that this work is worth publishing in this journal, the authors need to explain in much better detail what is the use of the analogue construction they have developed. Do they intend to solve for some particular dynamical model of an expanding Universe? Why would this be better than just solving the FLWR equations directly? Or is there some particular advantage in doing these types of analogue experiments?
I suggest the authors revise the manuscript with the above questions in mind.

We thank the referee for pointing this issue out. The referee is right. We apologize for creating a confusion on the main aim of our work.
The whole purpose of this paper is show the correctness of the analogy between the dimension-dependent evolution of the shock wave, and the nowadays used cosmological models (derived from the isotropic FRW equations). We do not intend to claim that we can measure physical phenomena in laboratory that cannot be measured in observational cosmological settings. In this sense, our work is aligned with the reasoning presented in the Crowther, Linnemann and Wüthrich's work.
We have re-written several parts of our work in order to explicitly clarify this point (and to avoid any confusion we could have created in the old version of our paper).

In general, in the new version, we have stated that the analogy is mathematical formal, not physical, as we are not replicating the spacetime metric expansion. A striking example of this is the negative value of the shock wave dimension, used as the analogue of dark energy contribution, which is a phenomenological parameter, not being physically rigorous within shock theory. Thus, our experiment and analysis have heuristic value but no cosmological confirmatory power. Despite of that, the value of our work is that creates an experimental bridge between plasma dynamics with cosmological concepts at a macroscopic, classical level. This is the advantage of the presented results, as any other current cosmological laboratory setting are in the quantum mechanical context. This is the first classical experimental analogue to cosmology. Therefore, it enriches our methodological toolkit, promotes interdisciplinary dialogue, and offers an elegant example of physics-inspired modeling beyond its empirical limits.
The only digression that we allow ourselves to give to the Crowther, Linnemann and Wüthrich's ideas is in the Discussion section, where we adventure to propose the idea that dark energy could be studied in a nonlinear context within cosmology (as it is not done today). This is based in the mimic results of our experiments, that are based on nonlinear plasma dynamics. However, we do not claim that that is the real physical cosmological nature of dark energy.

We hope that our answers will be satisfactory, and our work can be published in Communication Physics.

Responses to Reviewer 2:

Reviewer #2 (Remarks to the Author):

The manuscript by Asenjo, et al. describes a series of experiments with laser-driven shocks, in which the dynamics of the shocks can be described with equations analogous to several used to model cosmological processes. The authors derive equations of motion from Sedov-Taylor theory for different geometries of shocks (planar, cylindrical, etc.), and show that those equations are analogous to the equations that describe different types of cosmological models, such as models dominated by matter, radiation, etc. The equations of motion for the shocks modeling different cosmologies are validated with experimental measurements based on refractive imaging of the evolving (and merging) shock fronts.
Overall, the authors claim that there is a one-to-one correspondence between Sedov-Taylor theory and the isotropic FLRW cosmological models. Indeed, the measurements of shock dynamics are well described by the experimental models derived. It is an interesting idea to suggest that these classical models can serve as an analog for cosmological models, and fits well within the long physics tradition of looking for insight in one system from another seemingly very different one.
My main comment is that, while the authors present a compelling case that their experiments are well-modeled by equations analogous to those in cosmological models, there is very little discussion of what utility this comparison would have. Essentially, the question is what, even in principle, would cosmologists learn from these types of experiments? The authors only briefly highlight one example, where the physics underlying the changing dimensionality of colliding cylindrical shock waves could "have some usefulness" to understanding the emergence of the dark energy contribution in cosmological models. But there's no further discussion elaborating on this idea.
Given the central importance to the paper of the one-to-one correspondence between the experiments and cosmological models, I would like to see the authors include more discussion about how this correspondence would be useful to understanding cosmological models before recommending publication.

We thank the referee for her/his comments to our work. In the new version of our work, we have extended this issue in the Discussion section. We have given more other research directions that can be followed by doing more analysis of the experiment, or changing some of its initial conditions. In all of these, we have explained the cosmological analogues we can simulate and study, and why cosmologists can be interested on them.

Other comments:

• The experimental setup suggests that one schlieren image (and so one measurement time) is taken per laser shot. If that's correct, can the authors comment on the reproducibility of their experiments, as presumably many shots would need to be assembled to get a full time series? While the experiment is described elsewhere [9], since the data is presented here, it would be good to comment on this in the manuscript.

We thank the reviewer for raising this important point regarding reproducibility. Indeed, each schlieren image corresponds to a single laser shot at a fixed delay time, and the full temporal evolution shown in the manuscript is reconstructed by combining images from different shots taken at different delays. The experiment is highly reproducible shot-to-shot. This reproducibility is ensured by excellent laser energy stability, with shot-to-shot fluctuations below 1%; and very low timing jitter in the optical diagnostics, below 1 ns, which is negligible compared with the hydrodynamic timescales of the shock evolution. As a result, the plasma dynamics are reproducible to a degree that allows reliable reconstruction of the shock evolution by assembling single-shot images taken at different delays. We have now clarified this explicitly in the version of the manuscript.

• There are a large number of minor grammatical mistakes throughout the manuscript.

In the new version, we have revised and corrected the found grammatical mistakes.

We think our work have been improved by the referee's comments. We hope that it can fulfill the publication standard of Communication Physics.