Dynamic Simulations Analysis of Merging Galaxy Cluster

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Abstract

Cluster collisions are extreme events in the Universe, the study of which allows for the understanding of the nature of dark matter based on its behavior during the collision, among other factors. Given the impossibility of direct observation of parameters such as the relative velocity of the components and their evolution over time, one of the strategies used to study this type of phenomenon is the analysis of dynamic simulations. This project aims to evaluate the accuracy of one of these simulations in differentiating between the various temporal passages of the interacting objects through the center of the collision. To do so, public data and programming knowledge were used. The results indicated good efficiency of the dynamic analysis, but with a tendency to return systematically lower values than the correct ones, which needs to be analyzed more deeply. The methodology used proved to be viable for this type of analysis and should be expanded to simulations of different collision scenarios.

1 Introduction

Galaxy clusters are giant structures in the Universe composed of galaxies, gas, and a type of matter that cannot be seen, called dark matter.

Figure 1: The Bullet Cluster, an example of a merging galaxy cluster with a mass ratio of 1:10. The photograph shows the field galaxies, overlaid with representations of where the gas (in red) and dark matter (in blue) would be. Illustrative colors. Source: National Geographic Bullet Cluster.

- As Dark Matter doesn't emit, reflect or absorb light, it can only be studied through its gravitational interactions.
- Galaxy cluster collisions are very energetic events and serve as laboratories for the study of dark matter, as during the collision, each component exhibits a unique behavior.
- These events last billions of years, so to fully understand them, there are two strategies:

Type	Analysis of Dynamic Equations	Computer Simulations
Reference	Dawson (2013)	ZuHone (2017)
Strong points	Computationally easy	More precisely
Weak points	Complex Equations	Computationally Expensive

Table 1. Comparison between the positive and negative aspects of using simulations and dynamic analyses for studying merging galaxy clusters.

2 Objective

Contributing to the field of dark matter study that uses cluster collisions as a laboratory.
To analyze the effectiveness of the parameter provided by a widely used analytical code (Dawson 2013), using high-precision simulations by (ZuHone 2017) as reference.

Given the stability of the bias it is conceivable that it could be corrected in the model results. However, to have any confidence in this bias correction the model results should be compared with a range of merger scenarios, which is beyond the scope of this current work.

Figure 2. Excerpt from Dawson's article (2013) illustrating the need for further investigation of the effectiveness of their model, suggesting the use of different merger scenarios.

3 Methodology

- Familiarization with the problem and Astronomy concepts;
- Compilation and understanding of Dawson's method and code;
- Obtaining and understanding of ZuHone's data;
- Application of Dawson's method to each available simulation and analysis of the results.

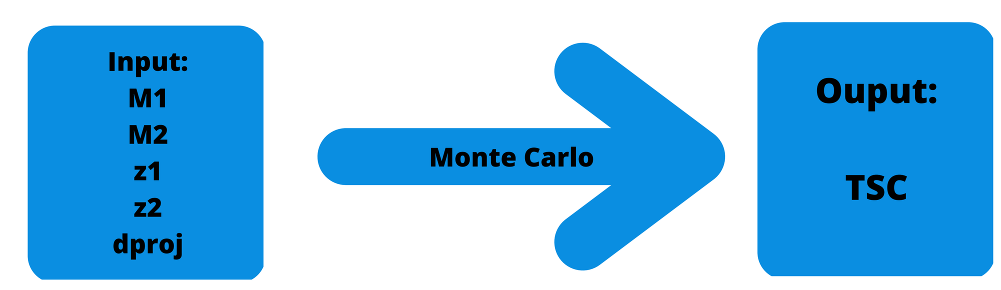


Figure 3. Computational analysis scheme. On the left, the input data that are obtained from the simulation by ZuHone (2017): the masses of the two clusters, their redshifts and the projected distance. After applying Dawson's code (2013), which uses the Monte Carlo method, the output is the time since collision (TSC) parameter.

5 Conclusion and Perspective

The code proposed by Dawson (2013) has good reliability within the error intervals for situations of interval between the first collision and the separation for different mass ratios. There is a tendency to always present data lower than reality, which needs to be further investigated by later works.

Apply the methodology again for the other datasets from ZuHone's simulation (2017), in this case, with impact parameters inclined with respect to the plane of the sky.

4 Results

Figure 4. Comparison between simulation data (ZuHone, in red) and analytical code (Dawson, in blue) for each mass ratio scenario. Each red point on the graph represents a simulated scenario, with the relative separation between the clusters and their corresponding time considered as the initial instant (zero) of the simulation being the first collision. The simulations continue until the point of maximum separation after the first collision, and subsequently new approximations and separations occur, with the decrease in maximum separation associated with energy loss in the system. Dawson's points are presented with their upper and lower uncertainties, statistically calculated from a thousand interactions of the code at each point. It should be noted that Dawson's code calculates the time after the first collision, with its validity guaranteed between this and the first separation.

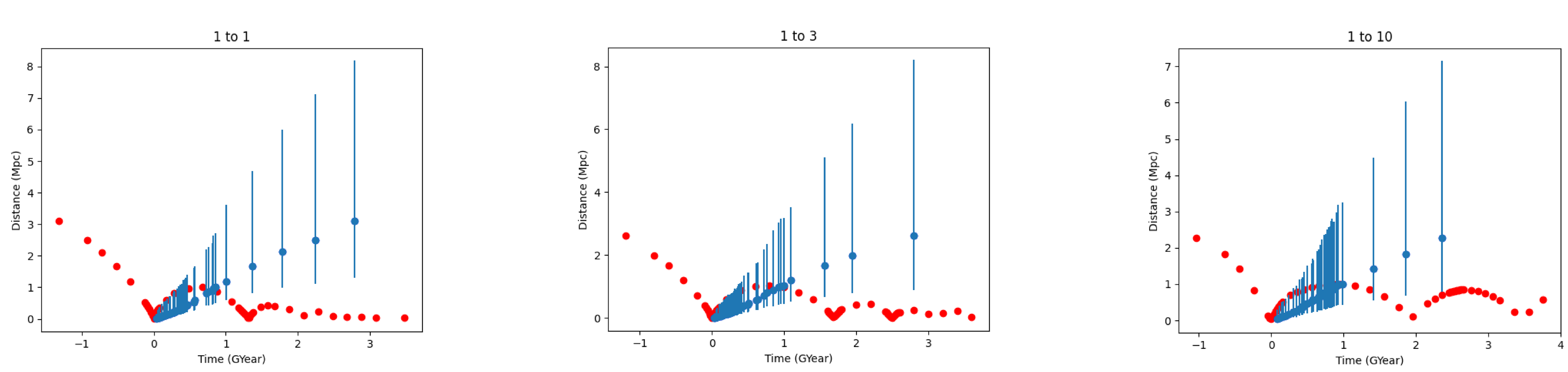
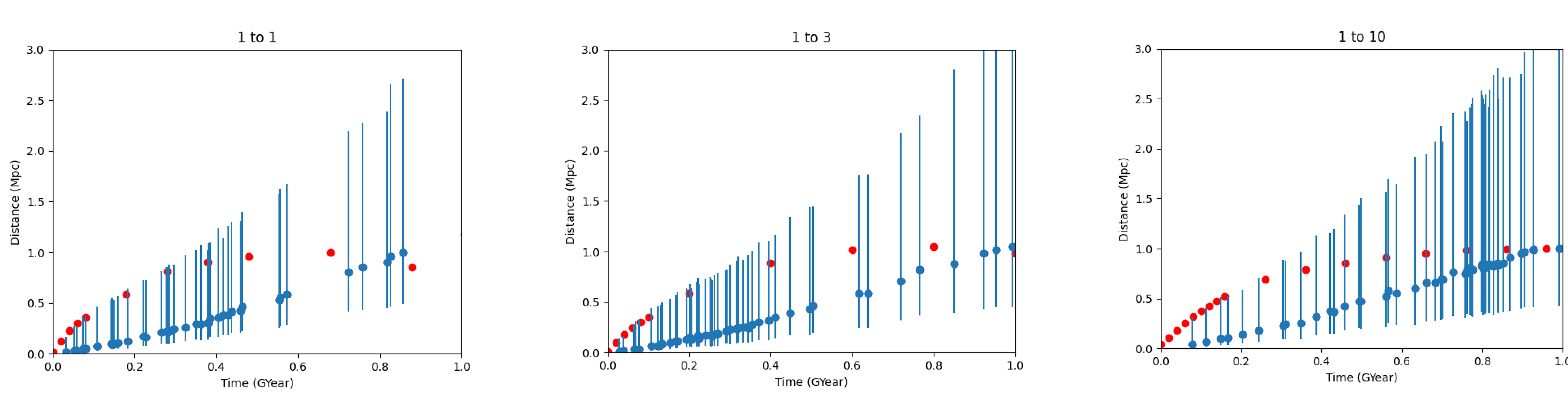


Figure 5. Highlight of the validity region of Dawson's simulations, between the first collision and the post-first collision separation, for the comparison of each mass ratio scenario. It can be observed that for all cases, there are coincidences between the estimated times by the analytical code and the actual data at the upper limits of uncertainties. However, it is noted that the reference results are systematically below the actual for all scenarios, indicating a tendency of the code that should be explored more deeply.



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