Observing the Movement of Galaxies Can Unlock Secrets About the Early Universe

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Bulk flow is a very useful tool in understanding the movement of galaxies through the universe and, from that, underlying properties that govern the formation of the structure of the universe we can see today. It can even help us challenge theories about the origins of the universe that have been widely accepted for decades! But first, let's define it. Bulk flow is a measurement of the average velocity of galaxies within a certain, specified distance of earth. Usually, it is calculated from a data set which describes many qualities of different galaxies, which, in turn, are used to calculate the velocity of each galaxy. These velocities are averaged in some way to produce a bulk flow describing the movement of galaxies within a given region.

So how exactly is bulk flow calculated? Typically, these individual galaxy velocities are weighted in an average based on the uncertainty of their measurements. However, this method presents potential problems in that this results in more distant galaxies being underrepresented in bulk flow due to them both having more uncertainty and due to them being less prevalent in typical data sets. In addition, these sorts of uncertainty-centered methods to calculating bulk flow make it difficult to compare bulk flow results on different data sets of galaxies, which would have different distributions and uncertainties of galaxies. To try to avoid these issues, the authors of this paper implement a method they introduced in a previous article called the minimum variance (MV) method [1]. Essentially, the MV method, while still utilizing uncertainty data for each galaxy, provides a standardized model for calculating bulk flow that is reliable when there is a representative distribution of galaxies within the data set.

This method turns out to be very suitable for the data set used in this article, Cosmic Flows 2 (CF2). What makes this data so suitable for this form of analysis? There are a few reasons why. This data set is actually, in large part, a collection of other data sets from many different regions of space. Overall, it contains distance and velocity data (which is what is needed to compute bulk flow) for over 8000 galaxies, including good coverage of distant galaxies. All of these qualities make this data suitable for the MV method of analysis. In fact, ever since the publication of this paper, more recent versions of the cosmic flows data set, including Cosmic Flows 3 and Cosmic Flows 4, have been the subject of similar analysis by these authors [2, 3]. Nevertheless, the combination of the MV method for bulk flow calculation and the use of the CF2 data set in this article will produce reliable results.

Now we can dive into how bulk flow analysis can challenge our understanding of the universe. To be specific, the results of this paper challenged what is called the standard cosmological model, which is a well-established theory that describes the theoretical progression of the universe and formation of galaxies after the Big Bang. This model generally supports small Bulk Flow values, which should decrease as we look at bulk flow of larger regions, as larger regions should be less influenced by noise and average out to having zero bulk flow. While the analysis of this paper did find bulk flow values consistent with the standard cosmological model at small scales, at larger scales, the measured bulk flow increased substantially. To be more specific, since bulk flow is a vector describing average velocity, it is generally described in the galactic "x, y, and z" directions. The "x direction" is the direction pointing from earth to the center of the galaxy, the "z direction" is defined as the direction perpendicular to the plane of the galaxy, and the "y direction" is just perpendicular to those two directions. In this analysis, bulk flow in the x and z galactic directions remained small at large scales, but bulk flow in the negative-y direction increased substantially in magnitude at larger scales, and thus overall bulk flow increased. The authors measured the probability of the large measured bulk flow values occurring concurrently within the small values supported by the standard cosmological model, and they consistently measured probabilities less than 5 percent. These results thus suggest that the standard cosmological model may not be entirely accurate, and present a strong challenge to it.

The previously mentioned subsequent studies further supported these conclusions, and thus prompts the academic cosmological community to re-evaluate the standard cosmological model through bulk flow analysis.

[1] H. A. Feldman, R. Watkins, and M. J. Hudson, Cosmic flows on 100 hâ1 mpc scales: standardized minimum variance bulk flow, shear and octupole moments, Monthly Notices of the Royal Astronomical Society (2010).
[2] R. Watkins, S. Peery, and H. A. Feldman, Easily interpretable bulk flows: Continuing tension with the standard cosmological model, Monthly Notices of the Royal Astronomical Society (2018).
[3] R. Watkins, T. Allen, C. J. Bradford, A. R. Jr., A. Walker, H. A. Feldman, R. Cionitti, Y. Al-Shorman, E. Kourkchi, and B. Tully, Analyzing the large-scale bulk flow using cosmicflows4: Increasing tension with the standard cosmological model, Monthly Notices of the Royal Astronomical Society (2023).