Detecting a cosmic bulk flow with Type Ia supernovae

Benjamin Rose, Peter Garnavich, Grant Mathews

Department of Physics, University of Notre Dame, Notre Dame, IN 46556

Motivating a bulk flow search

ΛCDM assumes that the universe is isotropic. In 2008, Kashlinsky et al. found an anisotropic expansion using the kinetic Sunayev-Zeldovich effect. Type Ia supernovae (SN) have been effective distance indicators and should also show a bulk flow signature. Dai et al., and many others, have not found the same result as Kashlinsky, but rather a much smaller bulk flow that is consistent with ΛCDM.

Method for finding a bulk flow

If there is a cosmic scale bulk flow, then all of the residuals of the Hubble diagram (distance versus velocity) will have a directionally dependent component. The residuals will scatter around a cosine distribution of the angular distance on the sky between the direction of the bulk flow and the SN. We performed a five parameter fit, minimizing the bulk flow redshift, the bulk flow direction, and two cosmological parameters. We assumed a flat cosmology: $\Omega_m + \Omega_\Lambda = 1$.

The data set

The analysis was done on the Union2.1 SN data set. We performed the analysis in two separate redshift bins ($z < 0.05$ & $z > 0.05$) with 191 and 387 SN in each bin respectively.

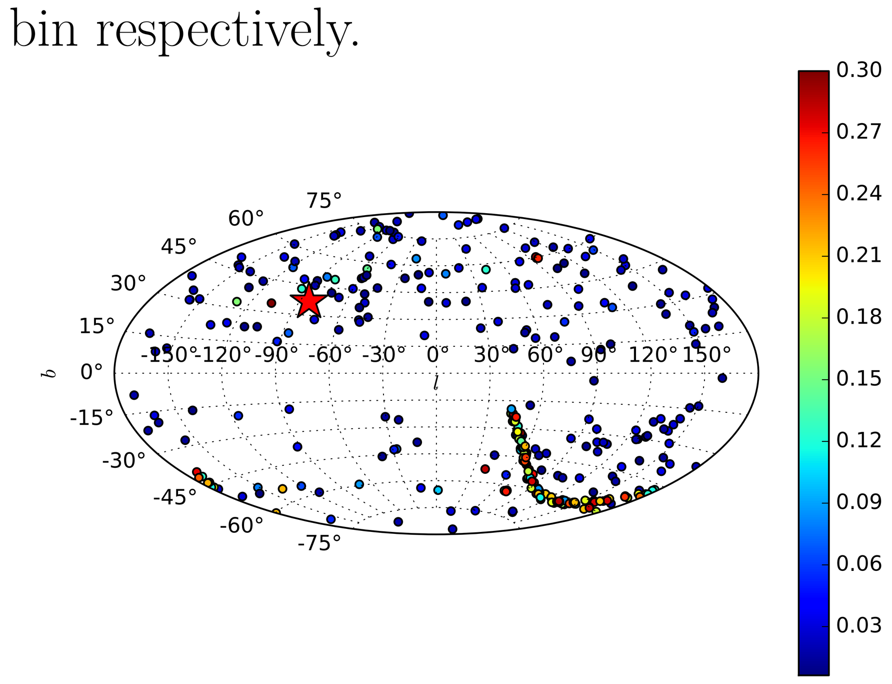

Figure 1: Positions of a subset of the Union2.1 data set, with $z < 0.3$. The color represents the redshift of each SN and the bulk flow direction, $(l, b) = (276°, 37°)$, is shown as a star.

Read the full paper at arXiv:1412.1529

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Finding a bulk flow when z < 0.05

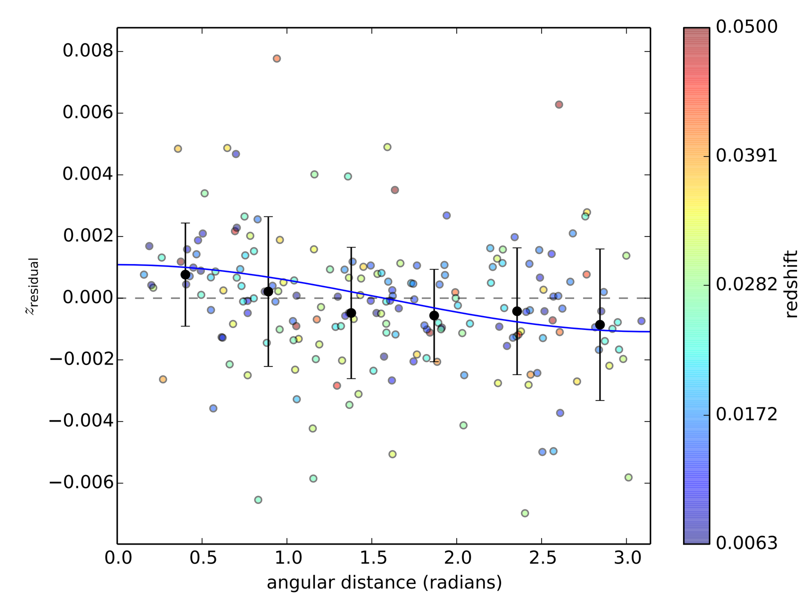

Figure 2: The minimization of the Union2.1 data set with $z < 0.05$, resulting in a $v_{\rm bf} = 325$ km s^{-1} in the direction of $(l, b) = (276°, 37°)$. The black points are bins of the data showing that there is a slight cosine distribution.

Analyzing the first bin we measured a best fit of $v_{\rm bf} = 325$ km s^{-1} in the direction of $(l, b) = (276°, 37°)$. The result of the minimization is seen in fig. 2.

To analyze the robustness and uncertainties of this method we created simulated data sets. These have the same number, sky position, and redshift distribution as the Union2.1 data set. A known bulk flow could be added to these sets making us able to statically analyze unique sets with known properties to test the quality of our analysis method. These resulted in uncertainties in velocity of ± 100 km s^{-1} and in directional uncertainty of over 100 square degrees.

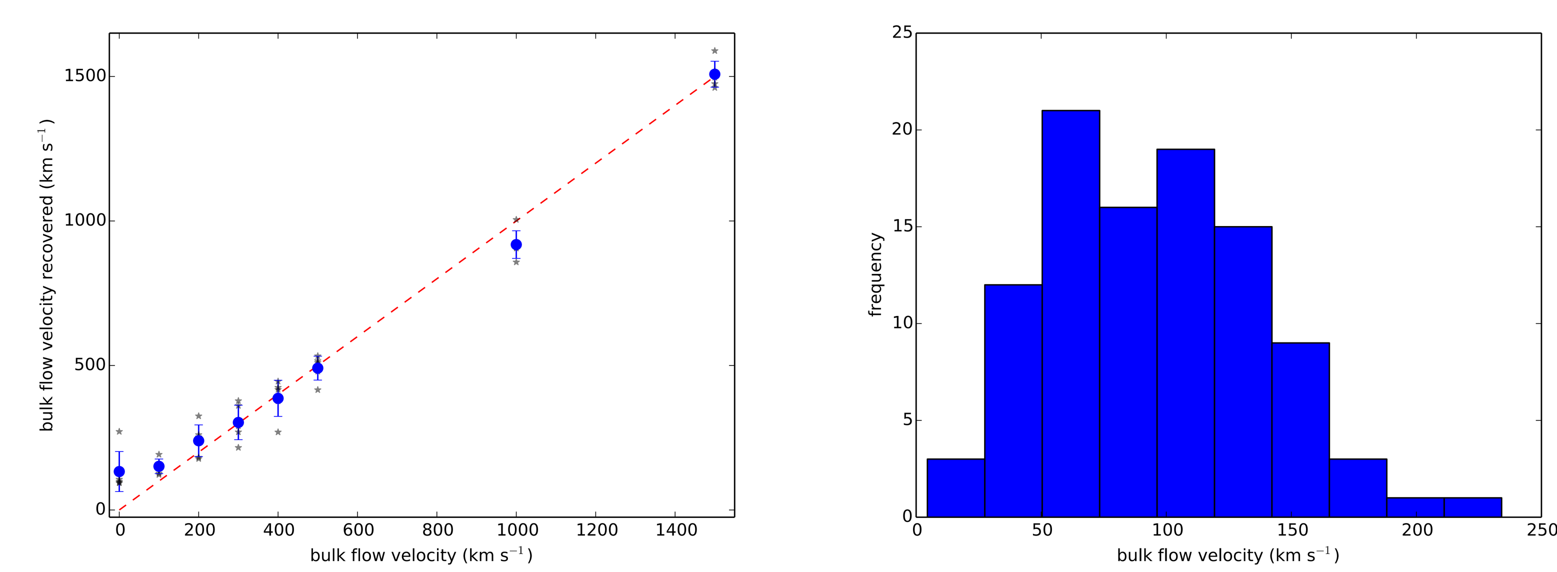

Figure 3: Robustness and error testing for the lower redshift bin of the Union2.1 data set. left: Five different data sets were created with varying bulk flow velocities. As seen, even small bulk flows can be detected. right: One hundred data sets without a bulk flow were analyzed showing that a bulk flow of > 300 km s^{-1} is different from null to 99% confidence.

Not finding a bulk flow when z > 0.05

For the higher redshift bin, $z > 0.05$, we were unable to detect anything meaningful. As seen below, we need a very large bulk flow both to distinguish it from the null hypothesis and to get a consistent measurement. From the low redshift bin and other works, we do not expect a bulk flow ~ 5000 km s^{-1}.

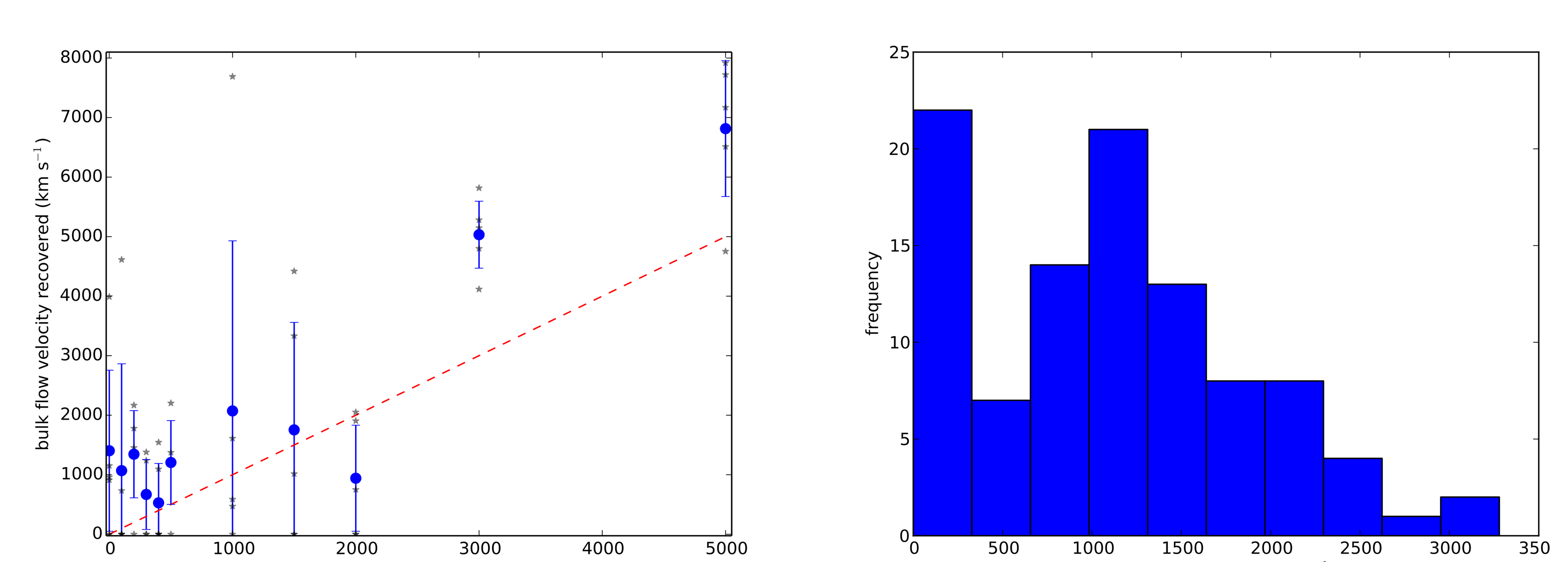

Figure 4: Robustness and error testing for the upper redshift bin of the Union2.1 data set. left: Five different data sets were created with varying bulk flow velocities. As seen, a bulk flow needs to be very large to be consistently detected. right: One hundred data sets without a bulk flow were analyzed showing that a bulk flow of < 3000 km s^{-1} cannot be distinguished from no bulk flow.

How to improve the search

After some trial and error, it was discovered that if δv, the change in velocity from the observational error, is of the same order or less then $v_{\rm bf}$ then this method works. At high redshift nothing is detected because, with constant observational errors, the change in velocity increases with redshift. Using the definition of errors presented in Davis et al., we calculated the needed distance modulus error for a given redshift.

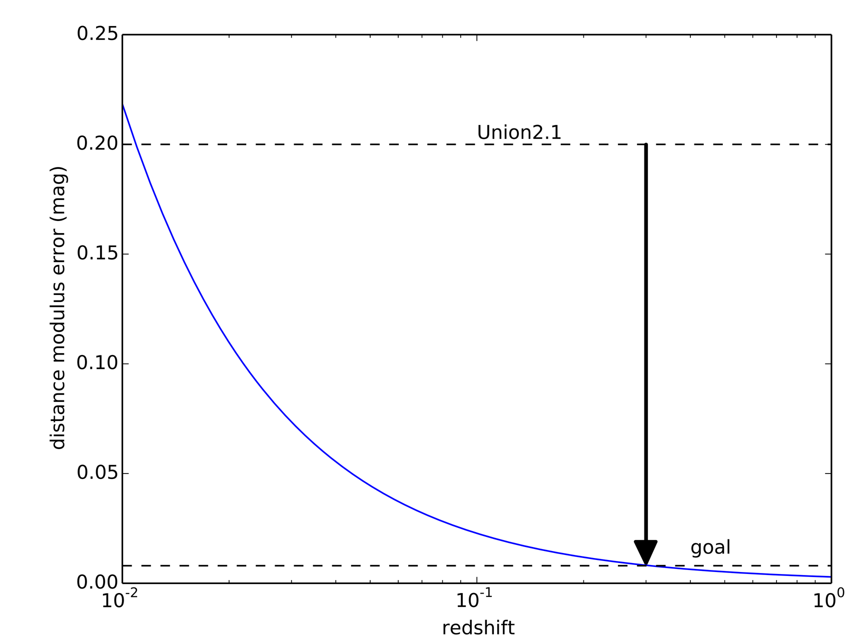

Figure 5: Assuming $v_{\rm bf} \sim 500$ km s^{-1}, then the needed effective distance modulus error for a given redshift is presented above. To see out to $z = 0.3$, $\mu_{\rm error}$ needs to be ~ 0.02 mag.

What is still needed?

To decrease the error by a factor of 10 we can increase the size of the data set by 100 times, easily achievable by LSST.

Conclusion

We have detected a bulk flow in the local neighborhood but were unable to detect it on a cosmic scale. With a much smaller distance error it is possible to see out to the desired redshift. This distance error can be obtained by decreasing the statical errors with a data set 100 times larger, $\sim 35,000$. This will make a bulk flow of < 500 km s^{-1} be visible out to a redshift of $z \sim 0.3$.

References

[1] Dai, D., et al. 2011, J. Cosmol. Astropart. Phys, 2011, 015

[2] Davis, T. M., et al. 2011, ApJ, 741, 67

[3] Kashlinsky, A., et al. 2008, ApJL, 686, L49