Dark Galaxies and Lost Baryons
Proceedings IAU Symposium No. 244, 2007
J. I. Davies & M. J. Disney, eds.

doi:10.1017/S1743921307013932

The Local Void is Really Empty

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Abstract. Are voids in the distribution of galaxies only places with reduced matter density and low star formation efficiency or are they empty of matter? There is now compelling evidence of expansion away from the Local Void at very high velocities. The motion is most reasonably interpreted as an evacuation of the void, which requires that the void be very large and very empty.

Keywords. Galaxies: distances and redshifts, intergalactic medium, large-scale structure of universe

1. Introduction

The dipole pattern in the Cosmic Microwave Background (CMB) gives precise information about our motion with respect to the mean expansion of the universe. What is the cause of this motion?

Several component influences are well known. The Sun orbits in our Milky Way Galaxy at 220 km/s. The Milky Way is falling toward Andromeda Galaxy at 135 km/s. The neighborhood of our Galaxy is retarded from the cosmic expansion by the Virgo Cluster by 185 km/s, and by large-scale structure in the direction of the Centaurus constellation by 455 km/s. But there must be something else.

The pattern of motions of nearby galaxies reveals the extra component. We are moving together with all our neighbors within 7 Mpc, the *Local Sheet*, but there is a discontinuity in the pattern of velocities as one passes beyond 7 Mpc. It will be argued that our Local Sheet is repelling from the Local Void at 260 km/s! In a ΛCDM universe with the energy density parameter $\Omega_\Lambda = 0.7$, a spherical void in an otherwise homogeneous universe evacuates with expansion velocities of 16 km/s/Mpc. The Local Void is inferred to be at least 45 Mpc across and really empty.

The following pages will contain a brief outline of the evidence for these claims. A more complete discussion has been submitted to the Astrophysical Journal by Tully, Shaya, Karachentsev, Courtois, Kocevski, Rizzi, and Peel (Tully *et al.* 2007).

2. Observations

An accurate distance, d, for a galaxy allows us to separate the radial component of deviant motions, V_{pec}, from the cosmic expansion: $V_{pec} = V_{obs} - \mathrm{H}_0 d$, where a galaxy has an observed motion V_{obs} and H_0 is the Hubble Constant (taken to be 74 km/s/Mpc). The present analysis is based on 1797 measured distances for galaxies in 743 groups within 3000 km/s. In 601 cases, the distance estimates are based on Cepheid Period-Luminosity (CPL: Freedman *et al.* 2001), Tip of the Red Giant Branch (TRGB: Sakai *et al.* 1996), or Surface Brightness Fluctuation (SBF: Tonry *et al.* 2001) methods. The rest are provided by the correlation between the luminosity of a galaxy and its line width (Tully & Fisher 1977; Tully & Pierce 2000; Karachentsev *et al.* 2002).

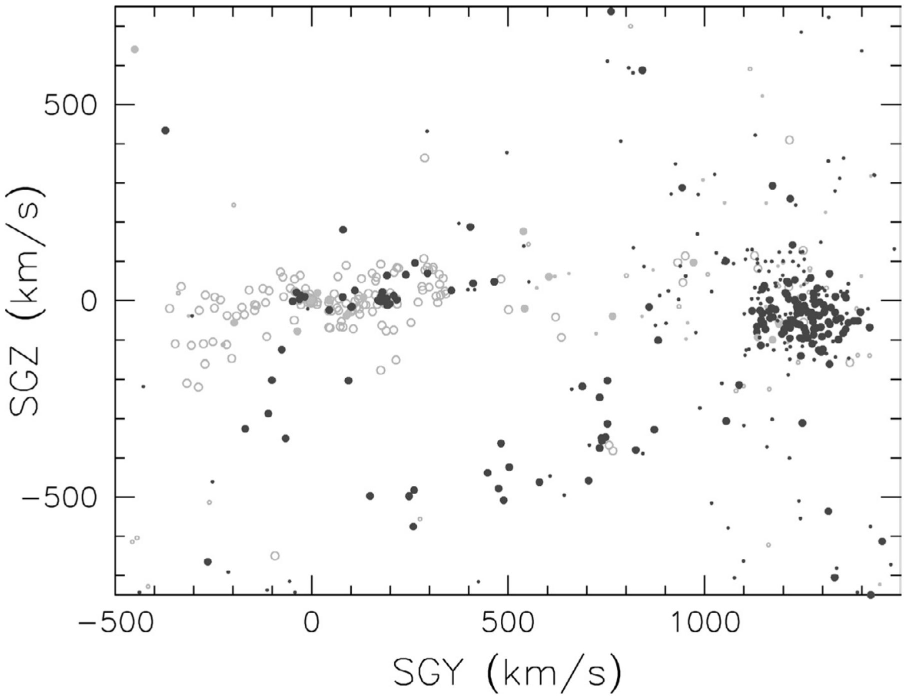

Figure 1. Peculiar velocities in the vicinity of the Local Sheet. Peculiar velocities < -100 km/s are coded solid purple (black), peculiar velocities $> +100$ km/s are coded solid orange (grey), and peculiar velocities within 100 km/s of zero are coded green (grey) with open symbols. Our Galaxy lies at SGY = SGZ = 0 and the dense clump of galaxies at the right is the Virgo Cluster.

The large number of accurate TRGB distances to nearby galaxies demonstrates clearly that the 'Local Sheet' of galaxies within 7 Mpc has very low internal motions in co-moving coordinates (Karachentsev *et al.* 2003). It is shown in Figure 1 that our Milky Way Galaxy has an insignificant random motion with respect to 159 galaxies outside the Local Group but within 7 Mpc. We are travelling with the Local Sheet as a unit.

However it is seen in Figure 1 and the pan to Figure 2 that there is a *discontinuity* in velocities between the Local Sheet and the next nearest structures. The nature of this discontinuity provides a clue to the origin of our relative motion.

The vector of the motion of the Local Sheet with respect to the other galaxies with distance measures within 3000 km/s but beyond 7 Mpc has an amplitude of 323 km/s, toward SGL = 80, SGB = −52. Part of this motion is suspected to be due to the influence of the Virgo Cluster, 17 Mpc away (Mohayaee & Tully 2005). The component of the Local Sheet vector toward the Virgo Cluster in the direction SGL = 102.7, SGB = −2.3 is 185 km/s, consistent with expectations. The residual is a vector of 259 km/s toward SGL = 11. SGB = −72. This vector is not directed toward anything of interest, but it is directed *away* from the Local Void.

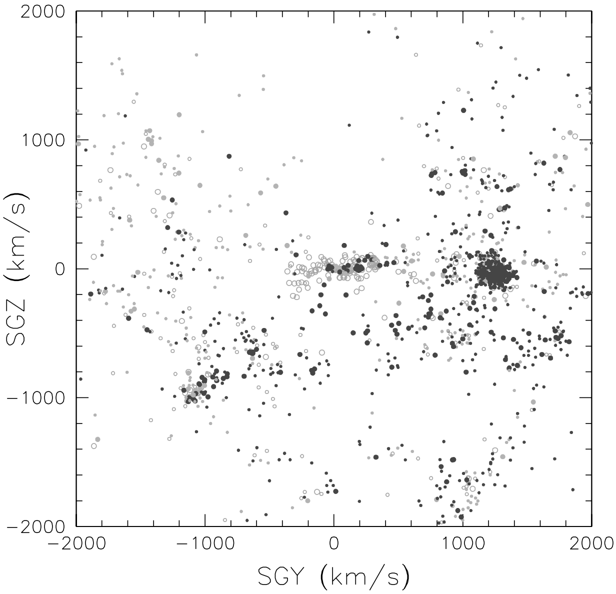

Figure 2. Pan to view peculiar velocities within the Local Supercluster. Symbol code is the same as in previous figure.

Following on with this decomposition of the vectors of our motion, we take note that in the Local Sheet rest frame the CMB dipole vector is 631 km/s toward SGL = 139, SGB = –37. If the motion of the Local Sheet with respect to galaxies within 3000 km/s is subtracted from the CMB vector, the residual is 455 km/s toward SGL = 162, SGB = –16. This motion must be attributed to influences on scales larger than 3000 km/s. The vectors described above are graphically illustrated in Figures 3 and 4.

3. The Local Void

The Local Void was first identified in the Nearby Galaxies Atlas (Tully & Fisher 1987). It is poorly defined because so much of it lies behind the plane of the Milky Way, but recent surveys such as the HI Parkes All Sky Survey (HIPASS: Meyer *et al.* 2004) confirm its general properties. There is an underabundance, though not a total lack, of galaxies in a very large part of the sky at low redshifts. The empty region begins at the edge of the Local Group, with the Local Sheet a bounding surface. Figure 5 represents an attempt to illustrate the Local Void. In detail, there are wispy filaments of galaxies that lace through the underdense region, causing us to disect it into a nearby part and more distant 'north' and 'south' parts.

Analytic calculations of the expansion of an underdense spherical region in an otherwise uniform distribution of matter are discussed in the refereed article. It is found that an entirely empty region is evacuated at 16 km/s/Mpc. N-body models provide confirmation (Schaap 2007). To generate the observed motion of 260 km/s away from the Local Void, we infer that the void at our doorstep must have a diameter of at least 45 Mpc and be very empty.

It may seem incredible that the CMB dipole motion of the Local Group can be decomposed into just three primary contributions: one away from the Local Void, a second toward the Virgo Cluster, and a third toward large-scale structure in the direction of

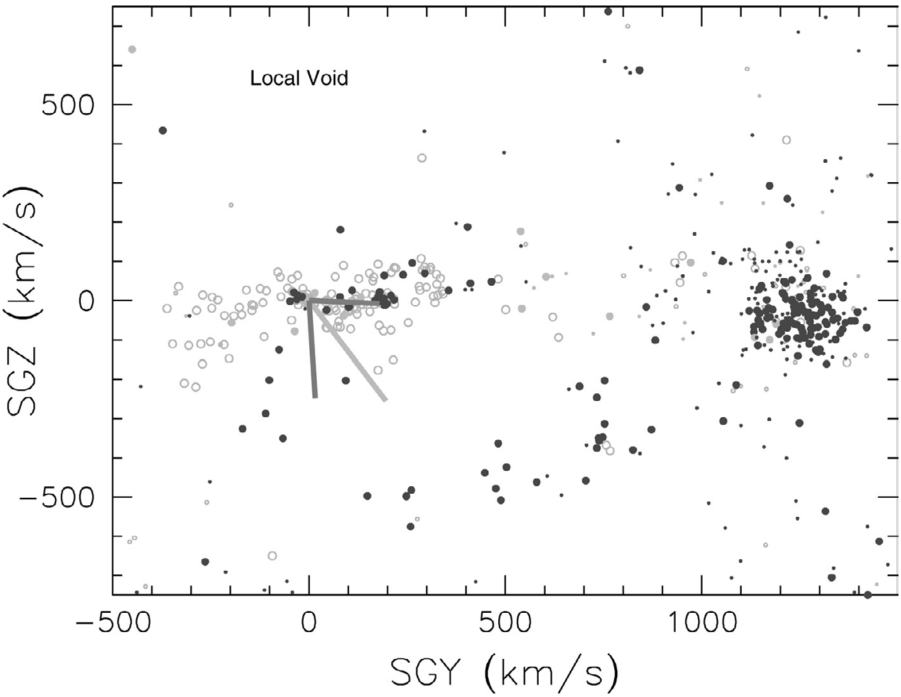

Figure 3. Vectors of the motion of the Local Sheet superposed on the data of Figure 1. The motion of the Local Sheet with respect to galaxies with measured distances within 3000 km/s is indicated by the orange (grey) bar pointing toward the lower right. A component of this motion is directed toward the Virgo Cluster, indicated by the blue (black) horizontal bar. The residual if the component toward Virgo is subtracted from the observed motion is the red (black) bar directed downward.

Centaurus. Of course, this is a simplification. The reason the three contributions are distinct is because they arise on distinct scales and are almost orthogonal in direction.

Our attention here is on the nearest component, the motion away from the Local Void. There is ongoing discussion about whether places where nothing is seen are truly empty. The Local Void generates a 'push' of 260 km/s. Perhaps we are seeing here the best evidence available that voids in the distribution of galaxies are really empty.

Acknowledgements

My collaborators in this research are Ed Shaya, Igor Karachentsev, Hélène Courtois, Dale Kocevski, Luca Rizzi, and Alan Peel. Support has been provided by grants from Space Telescope Science Institute and the US National Science Foundation. The motion of our Galaxy with respect to the structure in the distribution of galaxies is illustrated in videos at http://www.ifa.hawaii.edu/ tully/

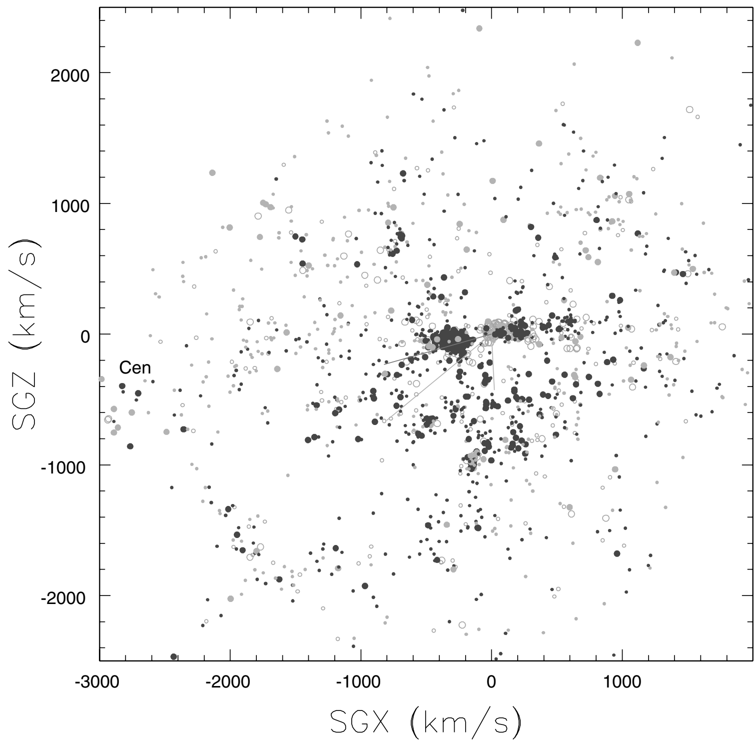

Figure 4. Decomposition of the CMB vector, shown in cyan (grey) and directed from the origin toward the lower left, into the component with respect to galaxies with velocities < 3000 km/s, shown in orange (grey) and directed downward from the origin, and the residual component associated with structure on scales larger than 3000 km/s, shown in brown (black) and directed almost horizontal toward the left from the origin. Symbols for individual galaxies with distance measures follow the scheme used in previous figures. The Centaurus Cluster is at SGX = –2800 km/s, SGZ = –500 km/s.

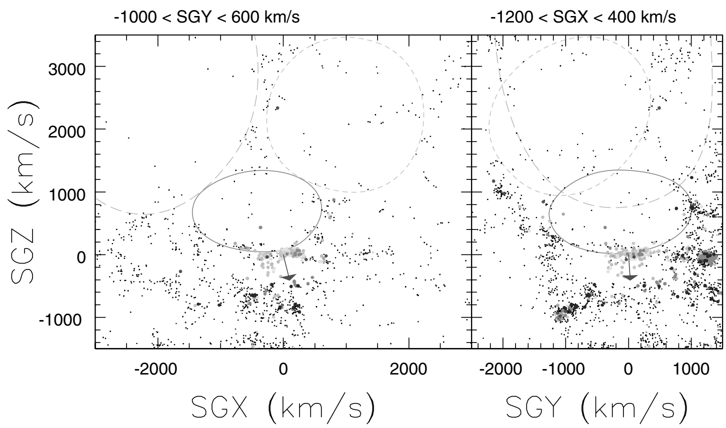

Figure 5. The region of the Local Void. The ellipses outline three apparent sectors of the Local Void. The solid dark blue ellipse shows the projection of the nearest part of the Local Void, bounded at our location by the Local Sheet. North and South extensions of the Local Void are identified by the light blue short–dashed ellipse and the green long–dashed ellipse, respectively. These sectors are separated by bridges of wispy filaments. The red vector indicates the direction and amplitude of our motion away from the void.

References

Freedman, W. L. *et al.* 2001, ApJ, 553, 47
Karachentsev, I. D. *et al.* 2003, A&A, 398, 479
Karachentsev, I. D., Mitronova, S. N., Karachentseva, V. E., Kudrya, Y. N., & Jarrett, T. H. 2002, A&A, 396, 431
Meyer, M. J. *et al.* 2004, MNRAS, 350, 1195
Mohayaee, R. & Tully, R. B. 2005, ApJ, 635, L113
Sakai, S., Madore, B. F, Freedman & W. L. 1996, ApJ, 461, 713
Schaap, W. 2007, PhD Thesis, Groningen U.
Tonry, J. L. *et al.* 2001, ApJ, 546, 681
Tully, R. B., Fisher & J. R. 1977, A&A, 54, 661
Tully, R. B., Fisher & J. R. 1987, *Nearby Galaxies Atlas*, Cambridge University Press, 1987
Tully, R. B., Pierce & M. J. 2000, ApJ, 533, 744
Tully, R. B., Shaya, E. J., Karachentsev, I. D., Courtois, H., Kocevski, D. D., Rizzi, L. & Peel, A. 2007, ApJ, submitted (astro-ph/0705.4139)