Is the 'Fingers of God' effect evidence for a galactocentric universe?

John Hartnett

The Fingers of God effect can be simply explained by reasonable assumptions on the dynamics of galaxies within their clusters. It would be very naïve to use it as evidence in support of a galactocentric universe.

On occasion I have heard discussed among creationists and even once received a paper for review that considered the Fingers of God effect as evidence for a galactocentric[1] even a geocentric[2] universe. The phenomenon is well known and you can find references to it on the web.[3] It apparently results from Doppler motion of galaxies within their clusters causing a line of sight effect in redshift space[4] (explained below) which produces the effect of fingers of galaxies all pointing towards the observer if plotted on a map. But if one realizes that we cannot definitively know how galaxies in the universe are distributed without making certain assumptions, could it be that this effect is evidence for a galactocentric universe?

Galaxies cluster. We see them in clusters of thousands. Within those clusters the galaxies have random orbit trajectories. Generally clusters appear to be approximately spheroidal or elliptical in shape. And they are believed to be virialised.[5] If the mass of the cluster, which includes large quantities of hot intercluster gas comprising about 3 to 4 times the mass of the constituent galaxies, is in hydrodynamic equilibrium then the galaxies are mutually bound to each other. This means on the Hubble timescale or the usually stated age of the universe,[6] more than ten billion of years, the cluster will not break up. Using this fact, astrophysicists estimate the dynamical mass of the cluster by either measuring the temperature of the x-ray emitting gas or calculating the dispersion[7] of a number of constituent galaxies, which act as tracers.

From the virial theorem, Fritz Zwicky,[8] in 1933, first deduced the existence of unseen dark matter. The total mass deduced from the dynamics is much greater than the luminous matter and hence it is said there is a lot of unseen, therefore dark, matter present. However if one introduces new physics, hence a new degree of freedom into the calculations, which is the velocity of the expansion of the fabric of space in which all the galaxies sit, then one gets almost exactly the measured temperature for massive elliptical and dwarf spheroidal galaxy clusters.[9] No dark matter need be assumed.

In astronomy, the real space positions of galaxies are determined by measuring their redshifts, z, and then applying in the Hubble law,

$$r = (cH_0^{-1})z, \tag{1}$$

where r is the radial distance to the galaxy, H_0 is the Hubble constant and c the vacuum speed of light.

For redshifts $z < 0.2$ it is generally assumed that the Hubble Law is essentially independent of the details of any particular cosmological model. So for a redshift-distance relation only the Hubble Law (1) need be assumed. No cosmology is necessary. Thus galaxy redshifts, z, may be converted into real space Hubble distances, r, using the natural scale length $cH_0^{-1} = 4154$ Mpc,[10] assuming $H_0 = 72$ km s^{-1} Mpc^{-1}.

Fingers of God

An effect that has been seen in galaxy clusters for quite some time is the so-called Fingers of God (FOG) effect. In redshift space, galaxy clusters tend to be elongated towards the observer at Earth. But in every direction in the sky you look you see galaxy clusters pointing towards Earth. So does that mean we are at the centre of the Universe? No! Though it cannot be definitively proven, the evidence supports the idea that what we see in redshift is not the same as in real space. And in real space, once we understand what the sources of galaxy redshift are, we don't see this effect at all. However, it must be added that there is no independent way to verify this if redshifts are the only method to determine the distance to the cluster members.

There are a number of possible contributions to the observed redshift of a galaxy and the two to consider here

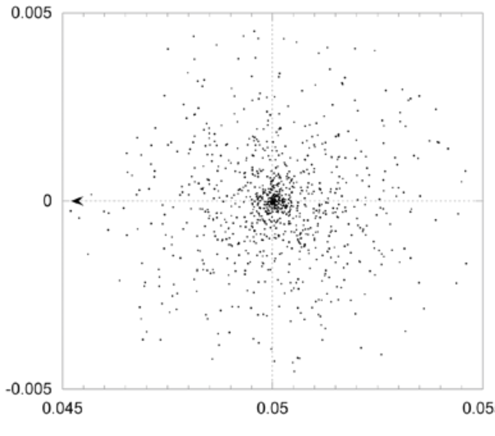

Figure 1. Simulated spherical galaxy cluster containing 1,000 galaxies at a redshift of $z = 0.05$, mapped in rectangular coordinates (x, y). This is a real space map with units of cH_0^{-1}. With unity aspect ratio the cluster is seen as a sphere, as in real space. From the origin, each galaxies redshift is $z = \sqrt{x^2 + y^2}$.

are cosmological, resulting from the expansion of the fabric of space, and Doppler, resulting from the motion of the source galaxy through space. Doppler motion is expected for all members of a galaxy cluster. Besides this, it is expected, if the cluster is a single gravitationally bound virialised group,[11] that there will be centre of mass motion of the cluster and this is due to cosmological expansion of the universe.

In figure 1 I have drawn a hypothetical galaxy cluster in real space, but have used units of redshift. In other words, to convert to real space distance multiply each axis by cH_0^{-1}. The arrow indicates the observer at the origin of coordinates. I have simulated a very large spherical cluster of 1,000 galaxies, represented by black dots, about 42 Mpc in diameter assuming our scale length above. The central galaxy in the cluster is located at z = 0.05 or about 207 Mpc. This means the centre of mass motion has the cluster moving away from us at 5% the speed of light. This is reproduced in figure 2a.

Figures 2b and 2c then illustrate what happens if we give each galaxy in the cluster a Doppler redshift due to its orbital speed but with random trajectories around their mutual centre of mass. The best way to model the effect is by adding a random redshift component to the individual redshifts of these galaxies, which has the effect of introducing a random radial velocity component. Since we can only see the radial component of any Doppler velocity arising from real motion within the galaxy cluster, this additional component will be either positive—a redshift (motion away from the observer) or negative—a blueshift (motion toward the observer). If the motion is transverse to the observer's line of sight then the additional component is zero.

Figures 2b and 2c are effectively redshift space maps with but plotted in rectangular coordinates with redshift $z = \sqrt{x^2 + y^2}$. Because the Doppler velocities add to the total redshift of the source galaxy but not to its cosmological distance it helpful to view these figures as redshift space. We would incorrectly conclude this is real space if the additional component was not corrected for.

In the case of figure 2b, I have added an orbital velocity of 1,500 km s^{-1}, which is very large for a cluster. They typically have x-ray temperatures of 4 to 7 keV or dispersion[12] velocities of around 700 km s^{-1}. In redshift space you can see that this addition of a Doppler component distorts the map—elongates the cluster like a finger pointing towards the observer at the origin. In real space the cluster would still look like it does in figure 1. Only the galaxies have motion around their mutual centre of mass.

To really exaggerate this in figure 2c, I have added an orbital velocity of 15,000 km s^{-1}, which is more typical of cosmological expansion than peculiar Doppler motion. In this case the FOG points back and meets the origin. Of course this is deliberately exaggerated for effect. This is what is seen in redshift space, but if the interpretation is correct all that would be seen in real space is in figure 1 and 2a.

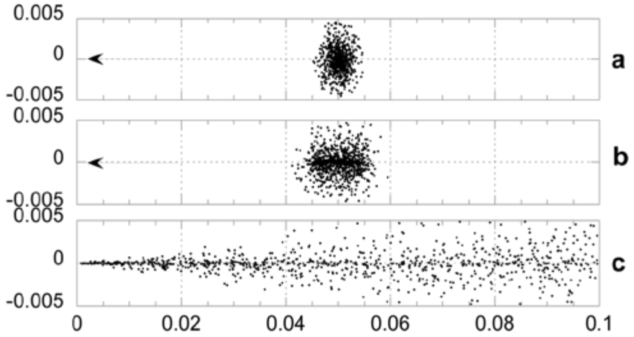

Figure 2. (a) Figure 1 reproduced but including the origin. (b) Map of the same galaxy as figure 1 but with addition of an orbital velocity of 1,500 km s^{-1} to constituent galaxies. (c) Map of the same galaxy as figure 1 but with addition of an orbital velocity of 15,000 km s^{-1} to constituent galaxies. From the origin each galaxies redshift is $z=\sqrt{x^2+y^2}$.

Excess redshift

Halton Arp has contended that there is evidence for an excess of redshift within cluster members when compared to the redshift of the massive central (usually elliptical) galaxy.[13] He is suggesting an additional redshift component not due to Doppler motion but due to some intrinsic as-yet-unknown effect. He shows a FOG effect that would result in his figure 3-11, when a spherical galaxy cluster is assumed. Based on this assumption, the fingers that stretch out, in redshift space, both blueward and redward of the centre of the cluster in figures 2b and 2c, would instead only stretch out redward or out away from the observer. If the central galaxy is correctly identified, with the least redshift of all those in the cluster, then, in redshift space, a FOG would also point to towards the observer with the massive central galaxy at the tip of the finger. Nevertheless with this interpretation there is no suggestion that the FOG would be seen in real space.

SDSS Data

From the Fifth Data Release (DR5) of the Sloan Digital Sky Survey[14] I sampled the data within ±2° declination of the celestial equator, and plotted each galaxy in redshift space. This resulted in about 49 thousand galaxies as shown in figure 3 as a function of Right Ascension (RA) in degrees around the circle. In this map one can see large continuous clusters arcing around the centre, particularly on the left hand side. In the middle there is clearly visible the 'Great Wall'—a filament of thousands of galaxies. This map suggests concentric structure with us the observer at the centre. This appears as a 'Bull's eye' if viewed from a distance. Because it is shown as a polar plot, spherical clusters would be stretched out along great circles. These maps need to viewed in real space with rectangular coordinates to see the shape of the clusters.

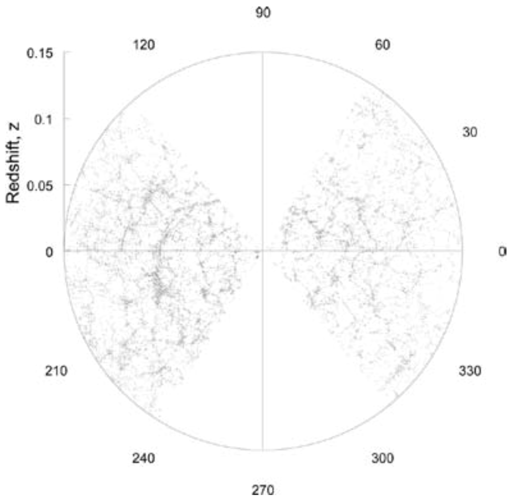

Figure 3. Polar plot, redshift space of SDSS galaxies sampled from within ±2 degrees of the celestial equator and plotted as a function of RA. About half of the sample is shown out to z = 0.15.

This so-called ‘Bull’s-eye’ effect[15] has been analysed[16] using *N*-body simulations, and suggested that it results from large-scale infall plus small-scale virial motion of galaxies. It is believed that these two effects can bias such determinations. It is a combination of the FOG effect which acts on small scales in addition to a much larger effect. The latter acts on much larger scales and where overdensities of galaxies occur, like at the ‘Great Wall’ for instance. Galaxies tend to have local motions toward the centre of such structures. These motions are not random but coherent and add or subtract to the observer’s line-of-sight redshift determination. These effects preferentially distort the map in redshift space toward the observer due to the velocities of galaxies within clusters, i.e. non-cosmological redshift contributions. However the latter can only enhance, in redshift space, existing weak real space structures, *it cannot create concentric structures* centred on the Galaxy. And the FOG effect tends to smooth out the finer detailed stuctures in redshift space.

In order to model this on different scales, to the observed redshift data, additional orbital velocities for the galaxies in figure 3 are added as random redshift components $\leq 1 \times 10^{-3}$. (figure 4) and $\leq 5 \times 10^{-3}$ (figure 5). These additional components represent maximum local orbital velocities of 300 km s^{-1} and 1,200 km s^{-1}, with respect to the centres of mass of their particular cluster. By comparing figure 4 with figure 3, one can see a slight FOG effect—the additional random redshift causes clusters to be elongated toward the origin of the map. And in figure 5 the effect is very strongly seen. However the very large scale *bull’s-eye* pattern still appears to be present. To the eye, the FOG effect smooths out the concentric arcs of the original—reducing the fine detail.

If we bin the redshifts between $z–\delta z/2$ and $z+\delta z/2$ and calculate the resulting number density as a function of redshift, we get $N(z)$, known as the *N-z* relation. This was done with a bin size $\delta z = 10^{-3}$ and the result in shown in figure 6 as the black curve. The peaks show periodic structure above or below the expected initial increase due to increasing surface area sampled, then later a fall off as the galaxies become too dim to see. Again, after a random redshift component $\leq 5 \times 10^{-3}$ was added $N(z)$ was calculated again and is shown in figure 6 as the dotted (grey) curve overlaid on the original. It is evident from this that the addition of random velocities has the effect of eliminating or smoothing out the finer detail in the number density. But in figure 5 it gives a striking impression when all the fingers point back to the origin.

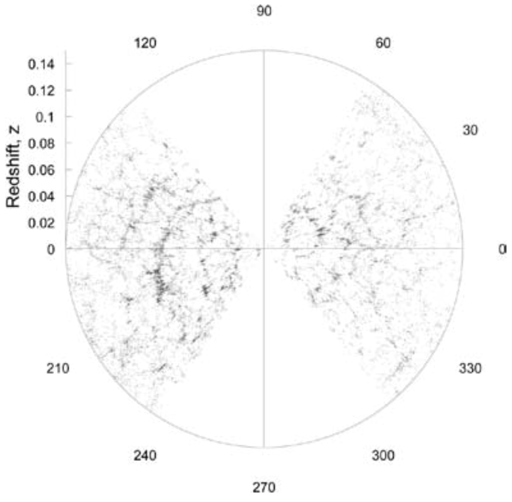

Figure 4. Polar plot, redshift, as a function of RA, of the data from figure 3 with random additional redshift components $\leq 1 \times 10^{-3}$.

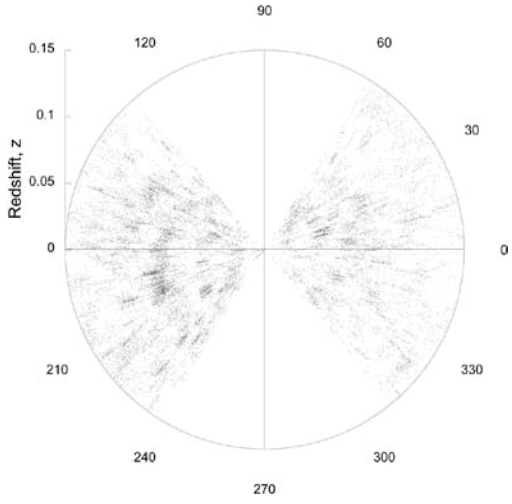

Figure 5. Pole plot, redshift, as a function of RA, of the data from figure 3 with random additional redshift components $\leq 5 \times 10^{-3}$.

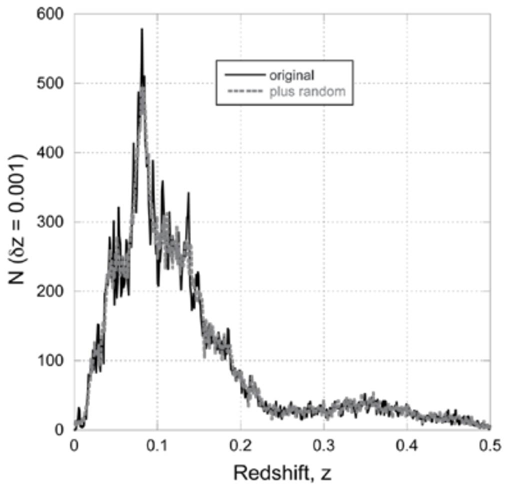

Figure 6. The SDSS *N*-*z* relation (with bins $\delta z = 10^{-3}$) from the 49,045 galaxies sampled from within ±2 degrees of the celestial equator (from figure 3) (black curve) and *N*-*z* for the same data but with random additional redshift components (dotted (grey) curve). The massive peak at $z = 0.08$ is due to the 'Great Wall'.

Conclusion

From what we have seen in the above, the FOG effect cannot be used to justify a unique position for our galaxy in the Universe if either the Doppler or excess redshift interpretations are valid. There is good evidence for both. The heating of hydrogen gas within clusters is good evidence for virialised motion and that gives us reasonable Doppler motions of many hundreds km s^{-1} within clusters. Arp has explored a number of lines of evidence for excess redshifts—including shifting of abundance histograms—indicating there are more redshifts than blueshifts in a cluster. If the difference were totally from Doppler motion we should see equal red and blueshifts. I conclude that it is most probable that Doppler effects are the dominant cause, besides there possibly being an additional intrinsic component as suggested by Arp. But the FOG effect cannot be used to support a galactocentric universe.

References

1. The universe with our Milky Way galaxy near the physical centre.
2. The universe with the Earth at the physical centre.
3. Fingers of God, <en.wikipedia.org/wiki/Fingers_of_God>, accessed 4 April 2008.
4. Redshift space is the space where redshift is the unit of 'distance'. The real space distances are determined from the Hubble law. If the redshift measured is not all due to the expansion of space then the redshift space picture would not simply be a scaling of the real space picture.
5. Given sufficient time a group of objects under mutual gravitation interchange kinetic and potential energy such that twice the total averaged kinetic energy equals the total averaged potential energy of the system. If true it is a test that the system is gravitationally bound. For more details see Virial theorem, <en.wikipedia.org/wiki/Virial_theorem>, accessed 4 April 2008.
6. Currently about 13.7 Gyr.
7. If the galaxies have peculiar or Doppler motions, the observer can only measure the radial or line of sight component. By sampling many galaxies in a cluster the variance in these line of sight velocities can be calculated. This is used in the Virial theorem to get a figure on the cluster mass.
8. Fritz Zwicky, <en.wikipedia.org/wiki/Fritz_Zwicky>, accessed 4 April 2008.
9. A full explanation can be found in Hartnett, J.G., Spheroidal and elliptical galaxy radial velocity dispersion determined from Cosmological General Relativity, *Int. J. Theor. Phys.* DOI 10.1007/s10773-007-9558-0, 2007; available as a pdf at <arxiv.org/PS_cache/arxiv/pdf/0707/0707.2858v1.pdf>
10. Mpc = megaparsec = 3.26 million light-years.
11. Of course the argument could be made that clusters are not virialised because there has been insufficient time in the universe, when considered against the biblical time line. Still in time dilation creationist cosmologies hundreds of millions if not billions of astronomical years are needed just to grow the spiral galaxies that we see, so I would not assume that astronomical time scales are so very short.
12. This is a thermodynamic concept. The line of sight radial velocities are measured and there is a variance among them. If galaxies are treated as particles this can be viewed as measure of the random component of their velocities.
13. See chapter 3 of Arp, H., *Seeing Red: Redshifts, Cosmology and Academic Science*, Apeiron, Montreal, 1998.
14. Astrophysical Research Consortium (ARC) and the Sloan Digital Sky Survey (SDSS) Collaboration. Funding for the Sloan Digital Sky Survey (SDSS) has been provided by the Alfred P. Sloan Foundation, the Participating Institutions, the National Aeronautics and Space Administration, the National Science Foundation, the U.S. Department of Energy, the Japanese Monbukagakusho, and the Max Planck Society. The SDSS Web site is www.sdss.org.
15. Also known as the Kaiser effect.
16. Praton, E.A., Melott, A.L. and McKee, M.Q., The bull's-eye effect: Are galaxy walls observationally enhance? *Ap. J.* **479**:L15–L18, 1997; Melott, A.L., Coles, P., Feldman, H.A. and Wilhite, B., The bull's-eye effect as a probe of Ω, *Ap. J.* **496**:L85–L88, 1998; Thomas, B.C., Melott, A.L., Feldman, H.A. and Shandarin, S.F., Quantifying the bull's-eye effect, *Ap. J.* **601**:28–36, 2004.

John G. Hartnett received his B.Sc. (hons) and his Ph.D. with distinction from the Department of Physics at the University of Western Australia (UWA). He currently works as an ARC QEII Fellow with the Frequency Standards and Metrology research group there. His research interests include ultra-low-noise radar, ultra-high-stability microwave clocks based on pure sapphire resonators, tests of fundamental theories of physics such as Special and General Relativity and measurement of drift in fundamental constants and their cosmological implications. He is developing new cosmological models and has an interest in explaining a universe without dark matter. He has published more than 100 papers in scientific journals and conference proceedings, *holds two patents* and co-authored *Dismantling the Big Bang*. This work or the ideas expressed are those of the author and do not represent those of UWA or any UWA research.