Beta, local SNIa data and the Great Attractor

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Abstract. We compare the measured peculiar velocities of 98 local (< 150h^{-1} Mpc) type Ia supernovae (SNIa) with predictions derived from the PSCz. There is excellent agreement between the two datasets with a best fit $\beta_{I} (= \Omega_{m}^{0.6}/b_{I})$ of 0.55±0.06. Subsets of the SNIa dataset are further analysed and the above result is found to be robust with respect to culls by distance, host-galaxy extinction and to the reference frame in which the analysis is carried out.

We briefly review the peculiar motions in the direction of the Great Attractor. Most clusters in this part of the sky out to a distance of 14,000 km s^{-1}, i.e. those closer than the Shapley Concentration, have sizable positive peculiar velocities, i.e. ($\sim +400$ km s^{-1}). There are nine local SNIa in the GA direction that are in the foreground of Shapley. All these SNIa have positive peculiar velocities. Hence both the cluster and local SNIa data strongly support the idea of a sizable flow into Shapley.

1. Introduction

Peculiar motion studies are a powerful tool for examining the underlying mass distribution of the local universe. In the linear regime, where density fluctuations are small, the mass over-density $\delta_{m}$ can be related to the fluctuation in galaxy number-density $\delta_{g}$ via $\delta_{g}(r) = b\delta_{m}(r)$, where $b$ is the linear bias parameter. This bias parameter together with the cosmological mass density parameter $\Omega_{m}$ can be used to predict peculiar velocity fields from all-sky redshift surveys. The predicted velocities scale linearly with the dimensionless quantity $\beta (= \Omega_{m}^{0.6}/b)$. By comparing the peculiar velocities predicted by a galaxy density field with direct measurements, $\beta$ can be determined.

All-sky galaxy samples derived from IRAS satellite data have been used extensively to map the local density field. Currently the most complete redshift survey of IRAS sources is provided by the PSCz (Saunders et al. 2000). This survey consists of redshifts for 15,411 galaxies uniformly distributed over 84.1% of the sky with a median redshift of 8,500 km s^{-1}. The PSCz survey’s depth, excellent sky coverage and density allow for the reliable mapping of the distribution of
galaxies in the local universe \cite{Branchini:1999}. Typically velocity-velocity comparisons give values for $\beta_I$ in the range 0.4 - 0.6 (see Zaroubi \cite{Zaroubi:2002}).

With distance errors less than 10\%, Type Ia supernovae (SNIa) are an important probe of the local velocity field. An early attempt to use SNIa was carried out by Riess et al. \cite{Riess:1997} who compared the measured peculiar velocities of 24 SNIa to the velocities predicted from the 1.2 Jy IRAS \textit{redshift survey} \cite{Fisher:1995} and the Optical Redshift Survey \cite{Santiago:1995, Baker:1998}. They derived $\beta_I = 0.4 \pm 0.15$ and $\beta_O = 0.3 \pm 0.1$ respectively, with the relatively large error resulting from the small sample size.

Recently Tonry et al. \cite{Tonry:2003} have produced a homogenized compendium of 230 SNIa for constraining cosmological quantities. The local ($< 150 \, h^{-1} \, \text{Mpc}$) SNIa in this compendium are a new valuable resource to investigate the local peculiar velocity field. Here we discuss two applications: the new measurement of $\beta_I$ and the flow in the direction of the Great Attractor.

2. $\beta_I$ determination

We have compared the peculiar velocities measured from this local SNIa sample to the peculiar velocity field derived from the smoothed PSCz density field determined by Branchini et al. \cite{Branchini:1999}. In our analysis we only consider the 107 SNIa that are closer than $150 \, h^{-1} \, \text{Mpc}$ as the PSCz density field suffers from sizable shot noise at greater distances. The median distance error of this sample is $\sim 8\%$.

There is excellent agreement between the predicted PSCz peculiar velocities and those measured from the SNIa sample. This is illustrated in Figure 1 where the Hubble flow for the local SNIa sample is shown. The lower panel of this figure has the predicted PSCz velocities for the $\beta_I = 0.5$ case removed. In the range 20-80 $h^{-1} \, \text{Mpc}$, where the majority of SNIa lie, the rms scatter around the Hubble flow is reduced from 490 to 390 km s$^{-1}$. In Figure 1 nine SNIa with $A_V > 1.0$ are plotted as open circles. Three of these nine SNIa are distinct outliers. Hence in our analysis we have chosen to exclude the SNIa with $A_V > 1.0$.

To determine $\beta_I$ we minimise the $\chi^2$ relation:

\[
\chi^2 = \sum_i \left( \frac{(v_i, \text{PSCz} - v_i, \text{SN})^2}{\sigma_{i,d}^2 + \sigma_{i,cz}^2} \right)
\]

where $v_i$ is the peculiar velocity of the $i^{th}$ supernova, $\sigma_d$ is the distance error and $\sigma_{cz}$ incorporates both an estimate of the error in redshift determination as well as an additional dispersion factor. Our preferred value of $\sigma_{cz}^2$ is $\sigma_{cl}^2 + 150^2$ km s$^{-1}$, where $\sigma_{cl}$ is an extra factor included for SNIa that lie near known rich clusters. Undertaking the analysis in the Local Group (LG) frame with this choice of weighting, we derive a $\beta_I$ of $0.55 \pm 0.06$ with a reduced $\chi^2$ of about 1 (see Figure 2 top panel).

For other reasonable choices of $\sigma_{cz}$ we find values for $\beta_I$ in the range 0.54 to 0.57. We have explored the robustness of these results by considering various subsamples of the local SNIa dataset. We find that the derived $\beta_I$ is insensitive to the distance range of the local SNIa considered, the $A_V$ cut adopted and the reference frame used for the analysis, i.e. LG or CMB (Figure 2 lower panel). Hence
the measured peculiar velocities from the local SNIa sample are in very good agreement with the peculiar velocities predicted from the PSCz density field. A full account of this comparison is given in Radburn-Smith, Lucey & Hudson (2004).

3. Great Attractor Flow

The unexpected discovery by Lynden-Bell et al. (1988) of a large (~600 km s$^{-1}$) outflow (positive peculiar velocities) in the Centaurus region led to the concept of a large extended mass distribution, nicknamed the Great Attractor (GA), dominating the dynamics of the local universe. Lynden-Bell et al. estimated that this structure was located at $(l, b, cz) \sim (307^\circ, 7^\circ, 4,350 \pm 350$ km s$^{-1}$) and had a mass of $\sim 5 \times 10^{16} M_\odot$. Despite over 15 years of study our understanding of the GA is very limited. In particular the GA’s extent and precise location is still poorly known. For example, Tonry et al. (2004), using SBF distances to 300 early-type galaxies, derived a much closer distance for the GA, i.e. $(289^\circ, 19^\circ, 3200 \pm 260$ km s$^{-1}$) and a mass of $\sim 8 \times 10^{15} M_\odot$, i.e. a factor of $\sim 6$ less than the original GA value. Alternatively Woudt, Kraan-Korteweg & Fairall.
Figure 2. Comparison of SNIa peculiar velocities to PSCz predicted peculiar velocities in the range $0h^{-1}\text{Mpc}$ to $150h^{-1}\text{Mpc}$ with $A_V < 1.0$ and $\beta_I = 0.55$. The size of the data point is inversely proportional to the total error ($\sigma = \sqrt{\sigma_d^2 + \sigma_{cz}^2}$) on each SNIa. The smallest and largest circles correspond to values of $\sigma = 1290\text{ km s}^{-1}$ and $170\text{ km s}^{-1}$ respectively. The 1-to-1 line is shown in each panel.

(1999) have argued that the very rich Norma cluster (Abell 3627) at $(325^\circ, -7^\circ, 4,800\text{ km s}^{-1})$ may mark the “core” of the GA.

Attempts to measure the expected GA backside infall have proved controversial (see Mathewson, Ford & Buchhorn 1992). Some studies have argued for a continuing high amplitude flow beyond the GA distance resulting from the gravitational pull of the Shapley Concentration (Scaramella et al. 1989; Allen et al. 1990; Hudson et al. 1999; Branchini et al. 1999). The Shapley Concentration is a remarkably rich concentration of galaxies in northern Centaurus (see Reisenegger et al. 2002). This structure contains more than 20 Abell/ACO clusters within $25h^{-1}\text{Mpc}$ of the very rich A3558 cluster at $(312^\circ, 31^\circ, 14,500\text{ km s}^{-1})$. The GA, in contrast, only contains at most five rich clusters.

Shapley’s contribution to the Local Group’s motion is unclear as it is difficult to decouple this from the flow towards the GA. Bardelli et al. (2000) estimated that Shapley was responsible for only $26\text{ km s}^{-1}$ of the Local Group’s motion with respect to the CMB. For the HST key project, Mould et al. (2000) adopted a value for this component of $85\text{ km s}^{-1}$. From peculiar velocities of 10 clusters in this region, Smith et al. (1999) found that both the GA and Shapley
generate $50 \pm 10\%$ of the Local Group motion. Analysis of the local tidal field implied a value in the range $100$ to $200\ km\ s^{-1}$ (Hoffman et al. 2001). Recent observations of the X-ray dipole (Kocevski, Mullis & Ebeling 2004) have implied an even larger contribution from Shapley.

Figure 3. The cluster peculiar velocity data in the GA region from SMAC, ENEARc, SCI, SCI and SBF surveys. The central bold curve shows the PSCz predictions in this direction. Most data points lie above this curve suggesting that the resolution of the sparse PSCz sampling has been unable to reliably measure the high amplitude of the flow in this direction. The other two curves are from Faber-Burstein models which are normalised to produce the Local Group’s CMB motion; the one attractor model is centred on the GA at $\sim 4350\ km\ s^{-1}$ (dashed curve); the two attractor model has the GA and Shapley Concentration equally contributing to the Local Group’s CMB motion (thin line curve). In each case the maximum amplitude of the model is shown.

There are now several peculiar velocity surveys that include measurements in the GA region, i.e. the Tully-Fisher work of SCI/SCII (Giovanelli et al. 1999), the Fundamental Plane work of SMAC (Hudson et al. 2004), the $D_n - \sigma$ work of ENEARc (Bernardi et al. 2002) and the SBF survey (Tonry et al. 2000). Following Smith et al. (1999), in Figure 3 (lower panel) we show the cluster peculiar velocities for the GA/Shapley direction from the above sources together with model predictions. While the large random errors limit our resolution of the
flow pattern, there are a number of features that are apparent: (a) most GA clusters ($cz < 5,000 \, \text{km} \, \text{s}^{-1}$), i.e. those traditionally associated with the GA, have positive peculiar velocities of $\sim 400 \, \text{km} \, \text{s}^{-1}$; (b) clusters that lie immediately beyond the GA have small peculiar velocities and do not display any evidence of backside infall towards the GA; (c) clusters in the range 80 to 120 $h^{-1} \, \text{Mpc}$ have positive peculiar velocities but the significance of this result is low. The original GA model is clearly a very poor fit to the cluster data. A two attractor model (GA and Shapley Concentration) successfully accounts for the lack of observed GA backside infall.

In the GA region there are 10 SNIa and these are plotted in Figure 3 (upper panel). The nine SNIa closer than Shapley all have positive peculiar velocities. Hence both the cluster and SNIa observations provide strong support for the presence of a sizable flow towards Shapley. Unfortunately the random errors on the peculiar velocities for objects in the crucial zone between the GA and Shapley are large and this severely limits how well the GA/Shapley mass ratio can be determined. New surveys, i.e. NOAO Fundamental Plane Survey (Smith et al. 2004), and future observing programmes have the potential to resolve this important issue.

Acknowledgments. The authors would like to thank Enzo Branchini for providing the PSCz velocity field. DJR-S thanks PPARC for a research studentship. MJH acknowledges support from NSERC and the ORDCF.

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