The Vela Supercluster - does it provide the missing link to explain the local flow fields?

A Elagali, R C Kraan-Korteweg and M E Cluver

Astrophysics, Cosmology and Gravity Centre (ACGC), Department of Astronomy, University of Cape Town, Private Bag X3, Rondebosch 7701, SA

E-mail: ahmedagali70@gmail.com

Abstract. As part of a larger effort to uncover the structures hidden behind the Milky Way, we analyse $4,756$ optical redshifts of galaxies in the Hydra/Antlia and Vela region ($245^\circ \leq l \leq 295^\circ, |b| \leq 10^\circ$). These redshifts were mainly obtained with the 2dF+AAOmega spectrograph at the Anglo-Australian Telescope (88% of the redshifts), the remaining data are obtained with other telescopes as well as taken from literature. This analysis is suggestive of the existence of a supercluster in this region, hereafter called the Vela Supercluster (Vela SCL). The Vela SCL is at a mean redshift of $cz \sim 18,000\,\mathrm{km\ s^{-1}}$, and extends about $70 \times 70\,\mathrm{Mpc}$ ($20^\circ \times 20^\circ$) on the sky. We use a nearest neighbour algorithm to identify the galaxy clusters and groups members, to determine their velocity dispersions and the corresponding virial masses. Although the Vela SCL is sparsely sampled, we find 13 galaxy clusters and 19 galaxy groups contained within it. The masses of these galaxy clusters/groups range from a few times $10^{14} - 10^{15}\,\mathrm{M_\odot}$. Taking account of the sparse sampling, the Vela SCL seems comparable to the Shapley Supercluster (Shapley SCL). This may have considerable implications on the bulk flow and peculiar velocity of the Local Group (LG), since the Shapley SCL contribution to the LG motion is $\sim 9\%$ (Muñoz & Loeb 2008).

1. Introduction

In this paper, we investigate an excess of galaxies discovered in the Zone of Avoidance (ZoA) in the Hydra/Antlia and Vela regions ($245^\circ \leq l \leq 295^\circ, |b| \leq 10^\circ$) at approximately $cz \sim 18,000\,\mathrm{km\ s^{-1}}$. This overdensity seems to extend over a large area of the sky, straddling the Galactic Plane. Based upon the velocity distribution of the galaxies and the number of galaxy clusters and groups found, we argue that this overdensity has the signature of a massive supercluster, hidden by the dust of the Milky Way. To put our results in context to known superclusters, we first give a short overview on the typical properties of superclusters at similar distances.

Superclusters are the largest, most massive and extended extragalactic systems in the Universe. These structures can extend over $\sim 30 - 100\,\mathrm{Mpc}$, and have masses of a few $10^{16}\,\mathrm{M_\odot}$ [1]. In general, superclusters tend to associate with regions of comparable size and very low density called "voids" [1]. In most cases they are connected through filaments and sheets of galaxies [2]. Studying the dynamics of these structures can provide us with an enhanced picture for structure formation theories [3, 4] as well as the distribution of dark matter in the universe [5, 6].

During the past few decades, large-scale surveys have revealed relatively nearby superclusters. One of the best studied superclusters in the local Universe is the Shapley Supercluster (Shapley SCL). It was first noted by Shapley [7], it has been explored spectroscopically [8], later in X-ray

[9], followed by multi-wavelength imaging [10]. This structure is centred at approximately (RA, Dec)=($13^{\rm h}\ 25^{\rm m}$,$-30°$). At redshift of $z \sim 0.05$, it extends over an area of $12° \times 30°$ and contains 33 galaxy clusters. The Shapley SCL occupies a spatial volume of $\sim 10^{15}\,{\rm Mpc}^3$, and has a mass of about $\sim 5 \times 10^{16}\,{\rm M}_\odot$ [10, 11]. In comparison with the Shapley SCL, the Horologium-Reticulum Supercluster (HRSC) is considered as the second most massive supercluster within 300 Mpc [12, 13]. The HRSC is centred at approximately (RA, Dec)= ($3^{\rm h}\ 19^{\rm m}$,$-50°$), extends over an area of $12° \times 12°$ at mean redshift $z \sim 0.066$, and contains 21 galaxy clusters [13]. Another massive supercluster within 300 Mpc is the the Corona Borealis Supercluster (CSC) [1, 14]. The CSC is centred at approximately (RA, Dec)= ($15^{\rm h}23^{\rm m}$, $30°$), extends over an area of $6° \times 6°$ at mean redshift $z \sim 0.07$, contains 12 galaxy clusters, and has a mass of about $\sim 12 \times 10^{16}\,{\rm M}_\odot$ [14]. In summary, the Shapley SCL stands out more prominently compared to the other two massive superclusters in the nearby universe because of its significant extent and unusual massive structures.

2. The Redshift Catalogue

Our redshift catalogue is based on deep optical galaxy catalogues in the Hydra/Antlia and Vela regions ($245° \leq l \leq 295°, |b| \leq 10°$) [15, 16], and the near infrared 2MASS Extended Source Catalogue(XSC) [17]. The major part of the redshift data is based on recent observations by two of us (Kraan-Korteweg and Cluver) using the 2dF+AAOmega spectrograph on the Anglo Australian Telescope in February 2014. A total of 4,344 galaxy spectra were obtained in 25 fields in the Hydra/Antlia and Vela regions. The majority of these redshifts, 95.8% yield reliable galaxy redshifts, while the remaining spectra were dominated by a foreground star for which it was not possible to extract the spectrum of the targeted galaxy. These remaining 4.2% redshifts were not included in our analysis.

Other redshift data are the result of earlier unpublished and complementary work by Kraan-Korteweg and collaborators. These are from the 6dF instrument on the Australian Astronomical Observatory's UK Schmidt Telescope, the Optopus multi-object spectrograph facility on the European Southern Observatory's 3.6 m Cassegrain focus telescope, the Southern African Large Telescope (SALT), and the South African Astronomical Observatory (SAAO) using the 1.9 m telescope. We also searched the extragalactic database HYPERLEDA for redshifts in our ZoA survey region. Where crossmatches existed, we compared the literature values with the AAOmega observations. After we compiled all the above redshifts, we eliminated the doubly observed galaxies. In our subsequent analysis we only used the redshifts with higher reliability. We have a total of 4,756 galaxies redshifts for the galaxies within the Hydra/Antlia and Vela regions ($245° \leq l \leq 295°, |b| \leq 10°$). The majority of these redshifts (88%) result from the AAOmega February Observations.

3. The Velocity Distribution and Structure of the Vela Overdensity

In Fig. 1 we present the on-sky distribution of all the galaxies with redshifts in the direction of the Vela overdensity. These galaxies are colour-coded according to different velocity ranges. Black are galaxies with velocities $v < 15000\,{\rm km\ s}^{-1}$, red are galaxies in the velocities range $15000 < v < 25000\,{\rm km\ s}^{-1}$, and cyan are galaxies with velocities $v > 25000\,{\rm km\ s}^{-1}$. The black circles mark the AAOmega observation fields from which the majority of our data originate. The Vela overdensity (red dots) is conspicuous in 20 of the 25 AAOmega fields and can be traced for $\Delta l \sim 25°$ above the plane in the range($285° > l > 260°$), and for $\Delta l \sim 20°$ below the plane in the range ($280° > l > 260°$). Moreover, the velocity histograms on both side of the plane are remarkably similar, which brings to perspective that the Vela overdensity might be connected across the plane (despite the current lack of redshift data in the mostly obscured ZoA) and consequently having a width of about $\Delta b \sim 20°$.

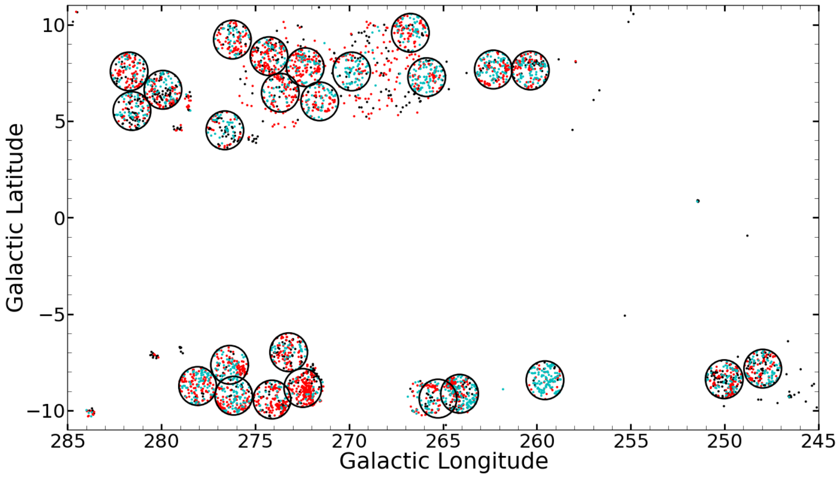

Figure 1. The on-sky distribution of all the galaxies available in the direction of the Vela overdensity, these galaxies are colour-coded according to there different velocities. Black ($v < 15000\,\mathrm{km\ s^{-1}}$), red ($15000 < v < 25000\,\mathrm{km\ s^{-1}}$), and cyan ($v > 25000\,\mathrm{km\ s^{-1}}$). The black circles delimit the AAOmega observation fields.

In Fig. 2, we show the velocity distribution of the galaxies in the direction of the Vela overdensity with velocity range from $0 < v < 50000\,\mathrm{km\ s^{-1}}$. In this histogram one can identify three peaks. The main body of the Vela overdensity is represented by the prominent peak centred at $v \sim 18000 \pm 1000\,\mathrm{km\ s^{-1}}$ and associated extended shoulders that range from $15000 - 22000\,\mathrm{km\ s^{-1}}$. This velocity distribution is very similar to that of Shapley SCL, which extends from $13000 - 18000\,\mathrm{km\ s^{-1}}$, based on a full systematic map of the Shapley SCL (refer to Fig.2 in [8]). Although, Vela is a bit further away on average (by a factor f = 1.3). This is the first indication that the Vela overdensity likely is a massive supercluster. The other two velocity peaks likely belong to further large scale structures hidden within the Zone of Avoidance.

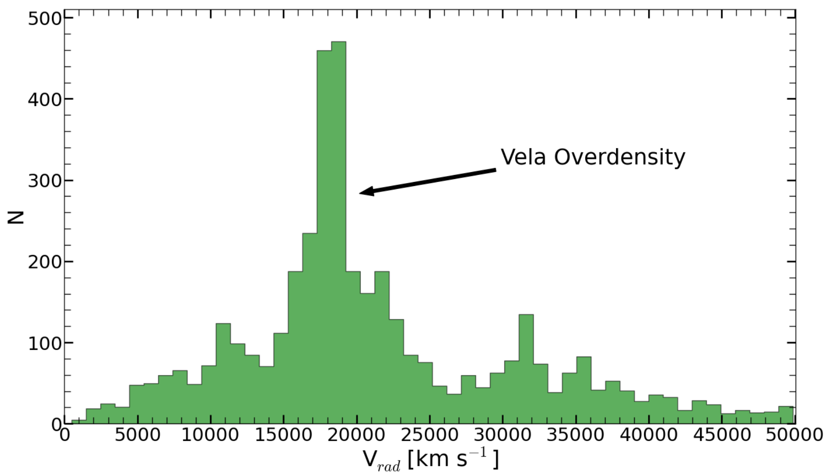

Figure 2. Velocity distribution of the galaxies in the direction of Vela overdensity for the survey area $245° \leq l \leq 295°; |b| \leq 10°$, most of these redshifts are from the AAOmega observations.

Figure 3 shows a wedge diagram out to velocities of $v = 30000\,\mathrm{km\ s^{-1}}$ in the general Vela SCL region, covering longitude range $255° \leq l \leq 285°$ and $\Delta b = 20°$, hence covering the ZoA within $|b| \leq 10°$. Based on this figure, the Vela SCL shows up as a prominent wall-like structure. It actually consists of two walls, the main wall (Wall One) at $v \sim 18000\,\mathrm{km\ s^{-1}}$ and a smaller one (Wall Two) at slightly higher velocity. Tracers of Wall One appear both above and below the Galactic plane. The second wall is present only above the plane. This is a second indicator that the Vela overdensity may form a massive supercluster. Based on Fig. 3, the Vela overdensity occupies the region from $l = 262°$ to $l = 282°$ and in velocity space from approximately $v \sim 16000\,\mathrm{km\ s^{-1}}$ extending to $v \sim 25000\ \mathrm{km\ s^{-1}}$. This indicates a very broad and extremely massive extended object of size of at least 20 degrees both in Galactic longitude and Galactic latitude, which corresponds to $70 \times 70\,\mathrm{Mpc}$ on the sky (assuming a value of $\mathrm{H_0} = 75\,\mathrm{km\ s^{-1}Mpc^{-1}}$).

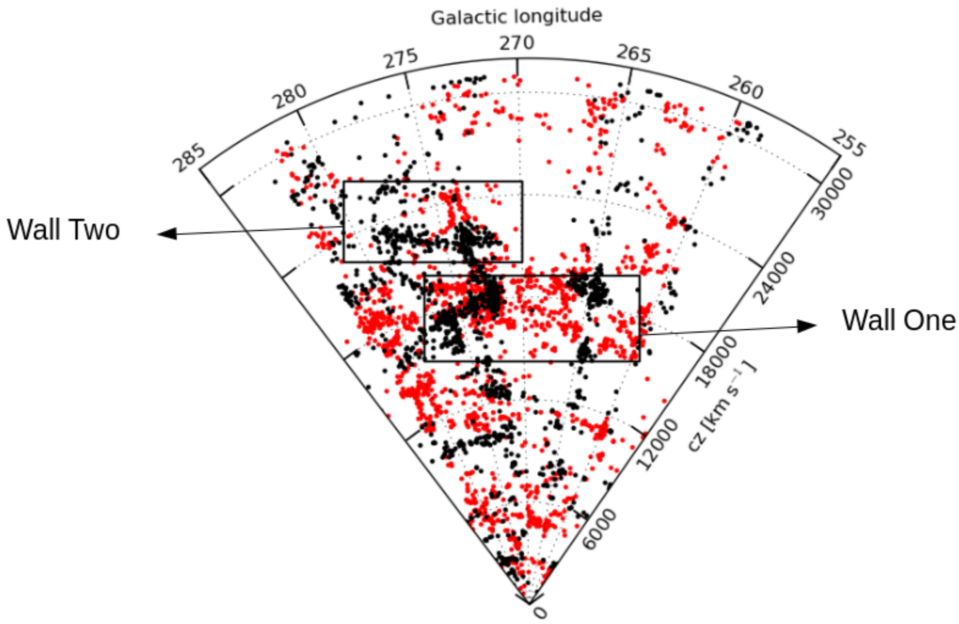

Figure 3. Velocity wedge diagram out to velocities of $v = 30000\,\mathrm{km\ s^{-1}}$ in the general Vela SCL longitude range $255° \leq l \leq 285°$ with a width of $\Delta b = 20°$, centred around the ZoA $|b| \leq 10°$. Black and red dots denote galaxies above and below the Galactic plane, respectively.

4. Clusters/Groups Results

To locate potential galaxy clusters and groups within the Vela overdensity, we used a nearest neighbour algorithm that searches for galaxies with the highest number of neighbours in velocity space. These neighbours must lie within one Abell radius at that specific redshift from the respective centre [19]. We then examined each galaxy cluster/group candidate by producing a velocity histogram to study the velocity dispersion, a velocity distribution as a function of cluster-centric distance from the optimized centre of the candidate, a K_s-band luminosity function, and a B-band luminosity function for the candidate members. From these figures, the dispersion velocities, and the masses of each candidate, we were able to approximately classify these structures. A total of 13 galaxy clusters with masses in the range $3 - 36 \times 10^{14}\,\mathrm{M_\odot}$, and 19 galaxy groups with masses in the range $0.2 - 20 \times 10^{14}\,\mathrm{M_\odot}$ were identified. This is a typical profile of a supercluster, for instance, the Shapley SCL contains 33 clusters and galaxy groups, with masses in the range of $8.3 \times 10^{14} - 3.3 \times 10^{15}\,\mathrm{M_\odot}$ [8]. Figure 4 shows the velocity distribution as a function of the distance from the centre for one of the prominent cluster candidates. It lies at $(l, b) \sim (272.2°, -8.9°)$ and has an average extinction of $E(B-V) \sim 0.2$ [15]. The red dots are the galaxies that belong to the cluster and lie within one Abell radius from the optimized centre, and the blue dots are the galaxies in the background and foreground of the cluster. There are 108 galaxies that belong to this cluster candidate and have a velocity dispersion of $\sigma \sim 500$ km s^{-1}. Figure 5 displays the on-sky distribution of the galaxies in this cluster candidate. The black dot represents the optimized central galaxy, the red points shows the galaxies that belong to the cluster and lie within one Abell radius, and the blue represents the foreground and background surrounding galaxies. The many number of clusters/groups found in the sparsely sampled Vela overdensity (see Fig. 1) is a further strong indicators that this overdensity is a supercluster.

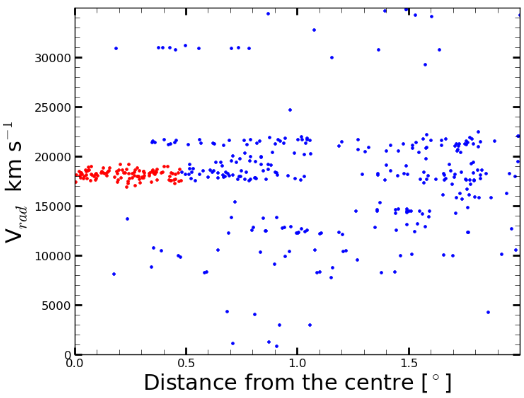

Figure 4. Velocity distribution as a function of distance from the optimized centre of one of the cluster candidates. The red dots are the galaxies that lie within one Abell radius from the optimized centre around the mean velocity of the cluster, while the blue are the galaxies in the central area of this cluster.

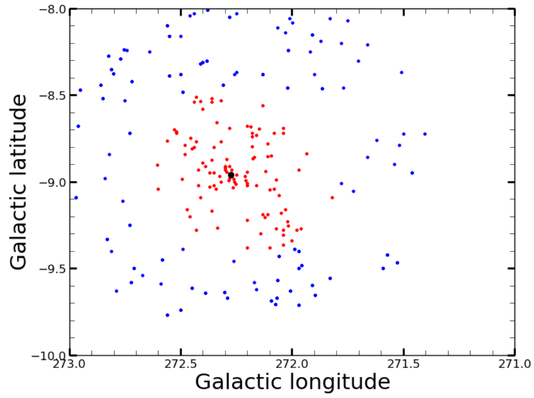

Figure 5. On-sky distribution of the galaxies in the same cluster candidate. The red dots again mark the galaxies that lie within one Abell radius from the optimized centre (the black dot).

5. Conclusions

Based on the prominent peak in the velocity distribution of the galaxies in the Vela overdensity above/below the Galactic plane at $v \sim 18,000$ km s^{-1}, the main broad wall that can be traced on either side of the plane (Fig.3), and the many massive galaxy clusters/groups found in the Vela overdensity, the evidence for the existence of a massive supercluster in the Hydra/Antlia and Vela region is strong. We call it Vela SCL. The extent of Vela SCL, as derived from the distribution of these galaxies, is 70×70 Mpc, which is comparable at $v \sim 18,000$ km s^{-1} to the extent of the Shapley SCL 30×75 Mpc [8]. It is 1.3 times further away than Shapley SCL. Given the fact that the Shapley SCL contributes about 9% of the Local Group motion [11] (if not more; see [18]), the proximity of a further supercluster (Vela) in its vicinity, might have implications on bulk flows studies. Consequently, the discovery of this supercluster might play a role in resolving the long-enduring bulk flow controversies and the misalignment of flows with the Cosmic Microwave Background (CMB) measurement.

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