TWO PLANES OF SATELLITES IN THE CENTAURUS A GROUP

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ABSTRACT

Tip of the red giant branch measurements based on Hubble Space Telescope and ground-based imaging have resulted in accurate distances to 29 galaxies in the nearby Centaurus A Group. All but 2 of the 29 galaxies lie in either of two thin planes roughly parallel with the supergalactic equator. The planes are only slightly tilted from the line of sight, leaving little ambiguity regarding the morphology of the structure. The planes have characteristic rms long axis dimensions of \(~300\) kpc and short axis dimensions of \(~60\) kpc, hence axial ratios \(~0.2\), and are separated in the short axis direction by \(303\) kpc.

\textit{Key words:} galaxies: distances and redshifts – galaxies: groups: individual (Cen A) – large-scale structure of universe

1. INTRODUCTION

There is convincing evidence that half of the Messier 31 satellites lie in a thin plane (Conn et al. 2013; Ibata et al. 2013). Shaya & Tully (2013) argued that a majority of the other M31 satellites lie in a second, almost parallel plane. The latter authors derived plausible orbits for the galaxies in the two planes. It was suggested that the satellites were born in a strata above M31 within the emerging Local Void and collectively chased M31 into the Local Sheet with the expansion of the void. The Milky Way has played a shepherding role.

Preliminary evidence has been presented (Tully 2015) that something similar may be happening in the nearby Centaurus A (Cen A) Group. The group is rich in satellites and almost all of them appear to lie within one of two thin planes. This Letter presents more detailed observational evidence for this claim.

The Cen A Group is very nearby, with the peculiar elliptical Cen A itself at \(3.66\) Mpc. Karachentseva & Karachentsev (1998, 2000) have carried out intense surveys for possible group members and follow-up observations with Hubble Space Telescope (HST) have resulted in accurate distance measurements for many targets from the luminosities of resolved stars at the tip of the red giant branch (TRGB). The properties of the group have been discussed by Karachentsev et al. (2002) and Karachentsev (2005).

The accurate distances obtained with HST using the TRGB method have clarified a problem created by a projection effect. A group around Messier 83 partially overlaps on the sky with the Cen A Group and it completely overlaps in velocities, but distance measurements reveal that the M83 Group lies to the background with a clearly resolved 1 Mpc gap. Maps of the projected and three-dimensional distributions of galaxies in the adjacent groups are to be found in Tully (2015).

The effort to obtain accurate distances and velocities of galaxies in the Cen A region is ongoing. A small number of known galaxies still exist that may potentially be group members. Observations in HST cycle 21 program 13442 have lead to four new distances. Two galaxies are confirmed as members of the Cen A Group: KKs 53 and KK 203 at \(2.93\) and \(3.78\) Mpc, respectively. One galaxy, NGC 5264, is a member of the M83 Group at \(4.78\) Mpc. The fourth galaxy, ESO 270-17, is also known as Fourcade-Figueroa (Fourcade 1971) and is found only \(3^\circ\) from Cen A. This large and low surface brightness galaxy is of interest, but it lies in the background with no known neighbors at 6.94 Mpc. The reduction procedures that lead to these distance measurements are most recently described by Karachentsev et al. (2015). Color–magnitude diagrams (CMDs) and TRGB fits for the newly observed targets and for all the previous cases are made available in the CMDs/TRGB catalog at the Extragalactic Distance Database.\textsuperscript{7}

Recently, distances for two dwarfs in close proximity to Cen A from an ongoing survey with the Magellan Clay 6.5 m telescope have been reported by Crnojević et al. (2014). Table 1 identifies all of the galaxies confirmed with distance measurements to lie in the Cen A group and those known possible members which lack distance confirmations.

2. TWO PLANES

The distribution of galaxies in the Cen A Group are shown in two supergalactic projections in Figure 1. Remember that the equator of the supergalactic system was defined (de Vaucouleurs et al. 1964) by the concentration of galaxies to a band on a scale of \(3,000\) km s\(^{-1}\). Galaxies within 7 Mpc are strongly confined to the Local Sheet (Tully et al. 2008) which is coincident with the supergalactic equator. Returning to Figure 1, galaxies with known distances are represented by filled symbols: 14 circles, 11 squares, 2 overlapping crosses, and 2 triangles. Typical 5\% TRGB distance errors of 175 kpc at the Cen A Group project largely in the SGX direction and almost not at all in the SGZ direction. It can be seen in the top panel that the circles and squares appear to lie in two separate, roughly parallel bands that are slightly slanted from horizontal.

\textsuperscript{7} http://edd_ifa.hawaii.edu
The table shows members and possible members of the Cen A Group. The band of circles will be called plane 1 and the band of squares will be called plane 2. Of the 29 Cen A group members with good distances, only the 2 galaxies represented by triangles are clearly not associated with one of these two bands. There are six candidates for Cen A membership that lack distance measurements. The galaxy ESO 219-010 has a surface brightness fluctuation distance of 4.78 Mpc (Jerjen et al. 2000) that places it in the background but the distance is uncertain and this galaxy is also retained as a candidate. These seven potential members are plotted as open triangles in Figure 1 assuming the distance of Cen A. Four of these are plausible members of plane 1, two could be in plane 2, and only one cannot be assigned tentatively to either of the two planes. We conclude that the argument of this paper will not be fundamentally changed with new distance measurements. The two dwarfs from the Crnojević et al. (2014) survey represented by the almost merged crosses adjacent to Cen A qualify as members of plane 1 but will not be considered further.

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Table 1

Members and Possible Members of the Cen A Group

| PGC No. | Name      | D (Mpc) | Vhel (km s⁻¹) | Ty  | MB (mag) | SGL (deg) | SGB (deg) |
|---------|-----------|---------|----------------|-----|----------|-----------|-----------|
| Plane 1 |           |         |                |     |          |           |           |
| 46957   | NGC 5128  | 3.66    | 547            | −2  | −20.54   | 159.7529  | −5.2494   |
| 45279   | NGC 4945  | 3.72    | 560            | 6   | −19.33   | 165.1793  | −10.2161  |
| 46674   | NGC 5102  | 3.74    | 467            | −1  | −17.84   | 153.4179  | −4.0673   |
| 47171   | ESO 324-024 | 3.78   | 525            | 10  | −15.47   | 158.3895  | −4.4130   |
| 45717   | ESO 269-058 | 3.75   | 400            | 10  | −15.14   | 162.9226  | −8.8312   |
| 45917   | NGC 5011C | 3.73    | 647            | −2  | −14.01   | 159.3867  | −7.4704   |
| 45916   | ESO 269-066 | 3.75   | 784            | −1  | −13.86   | 160.9727  | −7.8860   |
| 46680   | KK 197    | 3.84    | ...            | −3  | −12.29   | 159.1091  | −5.7166   |
| 46663   | KK 196    | 3.96    | 741            | 10  | −12.04   | 161.5396  | −6.4539   |
| 45104   | ESO 269-037 | 3.15   | 744            | −3  | −11.62   | 162.2485  | −9.9058   |
| 2815820 | Ksks 53   | 2.93    | ...            | −3  | −10.42   | 155.0355  | −6.7223   |
| 166158  | KK 189    | 4.23    | ...            | −3  | −10.86   | 157.9678  | −7.1880   |
| 166167  | KK 203    | 3.78    | ...            | −3  | −10.33   | 162.1021  | −5.5762   |
| 2815822 | Kks 55    | 3.85    | ...            | −3  | −10.05   | 159.3040  | −5.7388   |
| Plane 1? |          |         |                |     |          |           |           |
| 45628   | PGC 45628 | ...     | 681            | 10  | −13.06   | 143.5511  | −3.9565   |
| 44110   | ESO 219-010 | 4.8:   | ...            | −4  | −12.62   | 165.5514  | −11.8156  |
| 166164  | KK 198    | ...     | ...            | −3  | −10.47   | 150.5421  | −2.9955   |
| 2815821 | Kks 54    | ...     | ...            | −3  | −10.24   | 148.8408  | −2.7877   |
| Plane 2 |           |         |                |     |          |           |           |
| 48334   | NGC 5253  | 3.55    | 403            | 8   | −17.19   | 149.8146  | 1.0062    |
| 49050   | ESO 383-087 | 3.19   | 326            | 8   | −16.55   | 154.6356  | 1.3283    |
| 47762   | NGC 5206  | 3.21    | 577            | −3  | −16.12   | 165.1068  | −5.3769   |
| 48139   | NGC 5237  | 3.33    | 361            | −3  | −14.82   | 160.2663  | −3.0706   |
| 48738   | ESO 325-011 | 3.40   | 543            | 10  | −14.02   | 159.7855  | −1.4605   |
| 48515   | KK 211    | 3.68    | 600            | −5  | −11.99   | 162.7605  | −3.0833   |
| 4689187 | Cen N     | 3.66    | ...            | −3  | −10.93   | 165.3378  | −2.8987   |
| 166175  | KK 217    | 3.50    | ...            | −3  | −10.67   | 163.4596  | −2.5533   |
| 166179  | KK 221    | 3.82    | 507            | −3  | −10.52   | 164.8401  | −2.6023   |
| 2815823 | Kks 057   | 3.83    | ...            | −3  | −10.21   | 160.2545  | −2.933   |
| 166172  | KK 213    | 3.77    | ...            | −3  | −9.80    | 161.4948  | −2.3517   |
| Plane 2? |          |         |                |     |          |           |           |
| 48937   | Kks 59    | ...     | 688            | 10  | −15.77   | 170.7716  | −4.9166   |
| 2815824 | Kks 58    | ...     | ...            | −4  | −10.76   | 154.6544  | 0.6160    |
| Other   |           |         |                |     |          |           |           |
| 39032   | ESO 321-014 | 3.28   | 611            | 10  | −12.63   | 152.2641  | −17.6207  |
| 51659   | PGC 51659 | 3.62    | 390            | 10  | −11.85   | 166.9467  | 3.8360    |
| Other?  |           |         |                |     |          |           |           |
| 2815819 | Kks 51    | ...     | ...            | 0   | −11.50   | 157.9323  | −12.5448  |
Cromie et al. survey is restricted to an area around Cen A that only reaches the edge of plane 2 and so does not contribute to a fair sample of the full group.

A familiar pattern is seen in the distribution of galaxies around Cen A. E/S0/dSph are more centrally concentrated than spirals and irregulars. Every E/S0/dSph is within or at the boundary of the estimated second turnaround circle, an approximation of the virial radius (Tully 2015). Spirals and irregulars are more dispersed, yet they can be assigned to one of the planes. The second major galaxy in the group, the spiral NGC 4945, is located at the edge of the virial domain. It appears to belong to plane 1.

If the planes have physical significance, it would be fortuitous if they are viewed exactly edge-on from our vantage point. A search for an optimal viewing orientation will be carried out next. However, we are evidently near an optimal viewing direction. As a consequence, an evaluation of the reality of the planes is hardly affected by distance uncertainties because uncertainties project essentially within the planes. Galaxies lacking distance measures are retained in order to evaluate if the analysis might fundamentally change with their addition.

3. A CEN A REFERENCE FRAME

It is evident from inspection that the normals to the two posited planes are similar. A quantitative evaluation leads to the conclusion that the best-fit normal directions differ by only 7° and that this difference is not statistically significant. We accept an average of the two normal directions, weighted by the numbers of plane members, and find that it differs from the SGZ axis by 17°. The direction along the derived normal to the two planes will be called CaZ. The origin of the Cen A reference frame is taken to coincide with Cen A. By construction, the CaX and CaY axes are parallel to the planes. There are no meaningful extensions within the planes, so these two axes are taken in directions that approximate supergalactic coordinates. CaX is ~4° from SGX with positive values toward our location, and CaY is ~16° from SGY with positive values toward the Virgo Cluster.

The coordinate transformation is achieved with

\[ CaX = R_{cx} SGX + R_{cy} SGY + R_{cz} SGZ \]  
\[ CaY = R_{yx} SGX + R_{yy} SGY + R_{yz} SGZ \]  
\[ CaZ = R_{zx} SGX + R_{zy} SGY + R_{zz} SGZ . \]

The coordinate transformation is centered on Cen A:

\[ SGX_c = SGX + 3.41 \]  
\[ SGY_c = SGY - 1.26 \]  
\[ SGZ_c = SGZ + 0.33. \]

The rotation matrix is

\[ R = \begin{bmatrix} +0.994 & -0.043 & +0.102 \\ -0.001 & +0.919 & +0.393 \\ -0.111 & -0.391 & +0.914 \end{bmatrix} \]

An edge-on view after the transformation is shown in Figure 2. Considering only those galaxies with distance measures and the best-fit normals for the two planes considered separately, the rms dimensions on the longest and shortest axes are 346 and 73 kpc for plane 1 and 250 and 46 kpc for plane 2: minor to major axial ratios of 0.21 and 0.19, respectively. With the averaged common normal, the rms plane thicknesses are 77 kpc for plane 1 and 55 kpc for plane 2. These thicknesses may be inflated by distance errors. A 5% error at the Cen A distance is 175 kpc and the CaZ projection of such an error is ~50 kpc.

The offset between the means of the two planes is 303 kpc. The gap in CaZ between the top of plane 1 and the bottom of plane 2 is 94 kpc.

If it is accepted that the distribution of almost all group members is separable into two components, then Figure 3 evaluates the likelihood that the observed distributions are compatible with random yet flattened sets of points that

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8 Varying distances randomly within 5% of measured values, the mean normal values differ from the SGZ axis in the range 15.6–20.6 for 99.7% of 10,000 trials.
maintain the same radial distribution as the satellites of Cen A. The test involves the construction of 100,000 Cen A analogs, where the azimuthal and longitudinal positions of Cen A satellites are randomized, but their original radial distances and the intrinsic flattening of the system as a whole are kept fixed. For each of these 100,000 Cen A analogs, we separate the satellites into two groups with the same number of members as plane 1 and plane 2, but which also minimizes the rms about two best-fit parallel planes. The rms values about these two planes are plotted against each other as blue contours in Figure 3. The labels indicate the percentage of random draws that are within each white contour. The probability of randomly finding two planes with rms values less than or equal to the observed values is 0.03%. The probability is even less if the assumption of global intrinsic flattening is dropped.

4. SUMMARY

While modest coordinate transforms peak up the contrast of major to minor axes for the posited planes in the Cen A Group, the splitting into two thin strata is already evident in projection, with distance information serving simply to exclude the confusion caused by non-members. The two planes lie almost parallel with the supergalactic equator. If it might seem unlikely that we would be in such a favorable viewing position edge-on to the planes, it is to be recalled that we, too, are in the flattened distribution of galaxies on the supergalactic equator. Indeed, on scales from the historic Local Supercluster at 40 Mpc to the Local Sheet at 7 Mpc, down now to a scale of 300 kpc, structures are nested with similarly oriented aspects. The two planes of satellites around M31 (Ibata et al. 2013; Shaya & Tully 2013) are also nearly parallel to the supergalactic equator.

While the issue of two planes remains to be explained, there is a probable cause for the organization in the flattened orientations. The suspected agent lurks in the upper left corner of the top panel of Figure 1. All of the galaxies around us within 7 Mpc are part of a wall of the Local Void. The void is expanding, causing the wall, our Local Sheet, to descend toward negative SGZ at 260 km s\(^{-1}\) (Tully et al. 2008; Karachentsev et al. 2015). One possible scenario is that initially there were two proto-groups at significantly different distances from the center of the Local Void that headed outward in roughly the same direction. Both entities would have been stretched out parallel to the SGZ plane by radial repulsion from the void, and they could either be just now coming together or have had a crossing, in which case Cen A would have strongly influenced the distributions of both planes. A high fraction of the satellites in plane 2 are dSph, suggesting that there has indeed been a crossing. It is worth noting that NGC 4945 is not a negligible player. This galaxy, in plane 1 at 480 kpc from Cen A, has a luminosity that is 1/3 that of Cen A. Otherwise, there is no other immediate influence until M83 and its companions 1 Mpc away (which, by the way, aligns in projection with plane 1: a shepherd?). The brightest galaxy in plane 2, NGC 5253, is fully 20 times fainter than Cen A. If plane 2 were viewed as a separate group, then it would have the properties of one of the associations of dwarfs discussed by Tully et al. (2006).

In the case of the planes around M31, Shaya & Tully (2013) reconstructed orbits suggesting that the satellites were formed in strata early in the development of the void and that a memory of the initial conditions has been preserved. To have a chance at a similar reconstruction with the Cen A Group, a reasonably complete set of velocities is required. Currently, as seen in Table 1, many velocities are unknown. The present discussion is limited to providing evidence that almost all the galaxies in the Cen A Group lie in two almost parallel thin planes embedded and close to coincident in orientation with planes on larger scales. The two-tiered alignment is unlikely to have arisen by chance.
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