RESEARCH ARTICLE

NEAR-FIELD COSMOLOGY

A whirling plane of satellite galaxies around Centaurus A challenges cold dark matter cosmology

Oliver Müller,[1]* Marcel S. Pawlowski,[2] Helmut Jerjen,[3] Federico Lelli[4]

The Milky Way and Andromeda galaxies are each surrounded by a thin plane of satellite dwarf galaxies that may be corotating. Cosmological simulations predict that most satellite galaxy systems are close to isotropic with random motions, so those two well-studied systems are often interpreted as rare statistical outliers. We test this assumption using the kinematics of satellite galaxies around the Centaurus A galaxy. Our statistical analysis reveals evidence for corotation in a narrow plane: Of the 16 Centaurus A satellites with kinematic data, 14 follow a coherent velocity pattern aligned with the long axis of their spatial distribution. In standard cosmological simulations, <0.5% of Centaurus A–like systems show such behavior. Corotating satellite systems may be common in the universe, challenging small-scale structure formation in the prevailing cosmological paradigm.

The presence of planes of satellite dwarf galaxies around the Milky Way (*1*–*4*) and Andromeda (*5*–*7*) galaxies has challenged our understanding of structure formation on galactic and subgalactic scales. Similar structures are rare in galaxy formation simulations based on the standard Lambda cold dark matter (ΛCDM) cosmological model, which predicts close to isotropic distributions and random kinematics for satellite systems (*8*). The existence of planes of satellite galaxies around these two largest galaxies in the Local Group is difficult to explain within the ΛCDM framework. Some authors have argued that preferential accretion of satellites along filaments may explain such flattened structures (*9*). Others suggest that the Local Group should be considered a rare exception in an otherwise successful cosmological model (*10*–*12*). This interpretation, however, has been challenged by emerging evidence for anisotropic satellite distributions around massive galaxies beyond the Local Group (*13*, *14*).

The cosmic expansion of the Local Void (a vast, empty region of space adjacent to the Local Group) has been suggested as a possible origin for the formation of these planar structures (*15*). An issue that is mostly ignored in this context is the coherent kinematics of the satellite galaxies, which are likely corotating around their host. This is clear for the Milky Way (*16*, *17*), where accurate proper motions are available for several satellites, but it remains more uncertain for Andromeda (*7*) because only velocities projected along the line of sight (LoS) are measurable. Such orderly kinematic motions are extremely rare in high-resolution cosmological *N*-body simulations (*18*) and statistically should not be observed in typical galaxy groups. It remains unclear whether such planes of satellites are unique to the Local Group or ubiquitous in the nearby universe.

In this Research Article, we study the galaxy group in the constellation Centaurus. The Centaurus Group is the richest assembly of galaxies within a distance of 10 megaparsecs (Mpc) from the Milky Way, the so-called Local Volume (*19*, *20*). It comprises two concentrations: the Cen A subgroup dominated by a radio-active elliptical galaxy Centaurus A (Cen A, NGC 5128) at a distance of 3.8 Mpc, and the M 83 subgroup dominated by a late-type spiral galaxy M 83 (NGC 5236) at a distance of 4.9 Mpc (*19*, *20*). The galaxies, which are gravitationally bound to Cen A, were claimed to be distributed in two parallel planes (*21*). The discovery of additional satellite galaxies in the group weakened the case for a double-planar structure, and a single-plane interpretation has become more statistically significant (*22*–*24*). This plane has a small-scale height with a root-mean-square (RMS) thickness of 69 kiloparsecs (kpc) and a major-axis RMS length of 309 kpc (*25*). We investigate the kinematics of this planar structure and compare it with galaxy formation simulations in ΛCDM cosmology.

Dynamics of the Cen A satellite system

From Earth, the satellite plane around Cen A is seen nearly edge-on at an inclination of 14.6° (*25*). This coincidental geometrical alignment allows us to scrutinize the kinematics of the plane. We use all available heliocentric velocities for the Cen A satellites, taken from the Local Volume catalog (*19*, *20*). The vast majority of satellites have accurate distances derived from the tip magnitude of the red giant branch (TRGB) method with a typical uncertainty of ≈5%. There are 31 confirmed satellites of Cen A with accurate distance measurements. Half of them have measured LoS velocities. One sample galaxy (KKs 59) has a measured velocity but lacks a TRGB distance: We adopt the same distance as for Cen A; excluding this galaxy does not change our results. The adopted data are listed in table S1.

The on-sky distribution of the satellites is plotted in Fig. 1 together with their motions relative to Cen A. Figure 1 also shows the positions and kinematic information for 1239 planetary nebulae (PNe) (*26*) and the three-dimensional (3D) distribution of the satellites with measured velocities. The mean velocity of the Cen A satellite system (555 km s^{-1}) is equal to the recession velocity of Cen A (556 ± 10 km s^{-1}) within the measurement uncertainties. Hereafter, the recession velocity of Cen A is used as a zero-point reference, and the terms "approaching" and "receding" are intended with respect to this velocity. The dust lane of Cen A serves as a natural dividing line: Its position angle (*PA* = 110°) roughly coincides with the geometrical minor axis of the satellite plane (*25*). Clearly, approaching and receding satellites tend to lie to the southwest and northeast of the dividing line, respectively, indicating a kinematically coherent structure.

To determine the statistical significance of the kinematic coherence, we compare the velocities of Cen A satellites to a random phase-space distribution. Every galaxy has a 50% chance of approaching or receding along the LoS. The probability of finding at least 14 out of 16 galaxies with coherent velocity movement is 0.42%. Consequently, the observed velocity pattern of the Cen A satellites is statistically different from a random phase-space distribution at the 2.6σ confidence level.

Figure 2 shows the heliocentric velocities of the satellite galaxies as a function of their distances to Cen A. The geometrical minor axis of the plane (or equivalently the dust lane) is used to assign a positive or negative sign to the distance between satellite galaxies and Cen A. Figure 2 shows a clear trend: Galaxies to the south of Cen A are approaching, whereas galaxies to the north are receding. This is to be expected if the satellites are rotating around Cen A. Only two satellite galaxies (KK 221 and ESO 269-058) deviate from this trend and may potentially be counter-rotating, analogous to the Sculptor dwarf in the Milky Way halo (*27*). An inspection of their properties and alignment inside the plane does not reveal any peculiar characteristics (e.g., they are not more massive or luminous than other satellites). The velocity field of the planetary nebulae within Cen A follows a similar trend: Planetary nebulae in the northern and southern hemisphere are (on average) systematically blue and red shifted, respectively.

To explore the observed velocity pattern for the satellite galaxies, we ran three statistical tests: namely, Pearson's *R*, Spearman's Rho, and Kendall's Tau. These are standard methods to test correlations between independent variables. Whereas

[1]Departement Physik, Universität Basel, Klingelbergstrasse 82, CH-4056 Basel, Switzerland. [2]Department of Physics and Astronomy, University of California, Irvine, CA 92697, USA. [3]Research School of Astronomy and Astrophysics, Australian National University, Canberra, ACT 2611, Australia. [4]European Southern Observatory (ESO), Karl-Schwarzschild-Strasse 1, 85748 Garching bei München, Germany.
*Corresponding author. Email: oliver89.mueller@unibas.ch

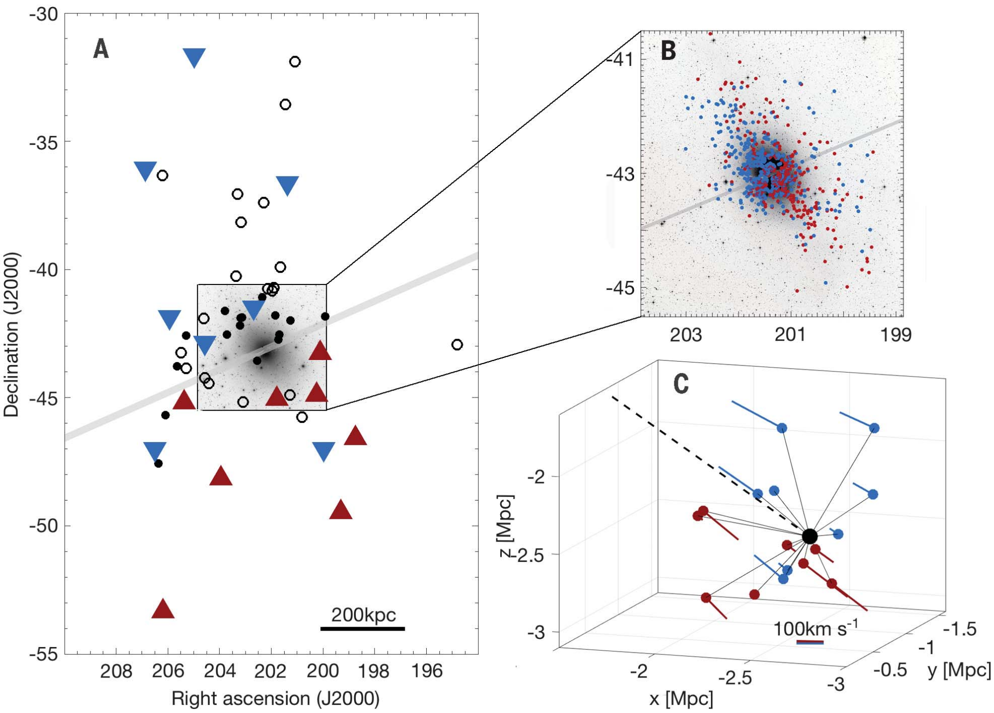

Fig. 1. On-sky and 3D distribution of the satellite system. (**A**) The on-sky distribution of the Cen A subgroup. The central image of Cen A has been scaled up by a factor of 5 to illustrate the features of the host galaxy. Blue downwards- and red upwards-pointing triangles show approaching and receding satellite galaxies with respect to Cen A velocity, respectively. Open circles are group member candidates; filled circles are confirmed satellites without velocity measurements. The line that optimally separates the approaching and receding satellites is indicated with the wide gray band; it coincides with the dust lane of Cen A. (**B**) The kinematic distribution of 1239 planetary nebulae (*26*). Blue PNe are approaching, and red PNe are receding relative to Cen A. (**C**) A 3D representation of the spatial distribution of the Cen A satellite galaxies in equatorial Cartesian coordinates (with the origin at Earth). The length of the colored lines is proportional to the observed velocity; the dashed line is our line of sight toward Cen A.

the Pearsons's method tests for a strictly linear correlation, the Spearman's Rho and Kendall's Tau methods test for a general correlation between the variables. The null hypothesis is that velocities and separations are uncorrelated. The velocity pattern is significant within a confidence interval of 2σ (P value < 0.03) for the projected separation and 3σ (P value < 0.01) for the 3D separation (*28*). These low P values lead us to reject the null hypothesis, implying a small chance of finding such a correlation in random, normal distributed data. We further consider how much more likely the hypothesis of correlated data is with respect to the hypothesis of uncorrelated data. We applied a Bayesian correlation test (*29*) and found that the scenario of coherently moving satellites is 4.5 times more likely using the projected separation and 16.5 times more likely using the full 3D information than uncorrelated satellite movements (*28*). Projected separations consistently give lower statistical significance than 3D distances because they contain less physical information: This highlights the importance of having TRGB distance measurements for dwarf galaxies in Centaurus.

Implications for galaxy formation

The satellite galaxies in the Cen A subgroup collectively form a coherent kinematical structure. Comparable structures have been discovered in the Milky Way halo, where the majority of the 11 classical satellites share a coherent orbital motion (established with proper motion measurements of individual stars from the satellites) (*16*), and for the Andromeda galaxy, for which 13 out of 15 satellites follow a coherent LoS velocity trend (*7*).

Although we find that the kinematics of the Cen A satellites are unlikely to occur by chance, this does not immediately allow us to draw conclusions about its agreement with predictions from ΛCDM cosmology. Satellite galaxy systems in cosmological simulations generally exhibit some degree of phase-space coherence, owing to the accretion of subhalos from preferred directions, along filaments and in groups (*9*). To judge whether this effect is sufficient to explain the observed coherence in the Cen A satellites, we determined the occurrence of such extreme structures in two cosmological simulations: Millennium II (*30*) and Illustris (*31*). Millennium II is a dark-matter-only N-body simulation that includes gravitational effects such as subhalo accretion from filaments, but neglects baryonic effects such as stellar and black-hole feedback and possible destruction of satellite galaxies due to the enhanced tidal effects from the baryonic disk (*32*). The relative importance of these effects is highly debated (*33*–*36*). Hence, we also analyze the hydrodynamical Illustris simulation (*31*), which additionally includes gas physics, star formation, and feedback processes.

Our approach is analogous to recent studies of the frequency of the satellite planes around the Milky Way and the Andromeda galaxy (*18*, *37*). We identify Cen A analogs within the simulations by selecting dark matter halos with masses between 4×10^{12} and 12×10^{12} solar masses ($M_\odot$) and by rejecting any candidate hosts that have a

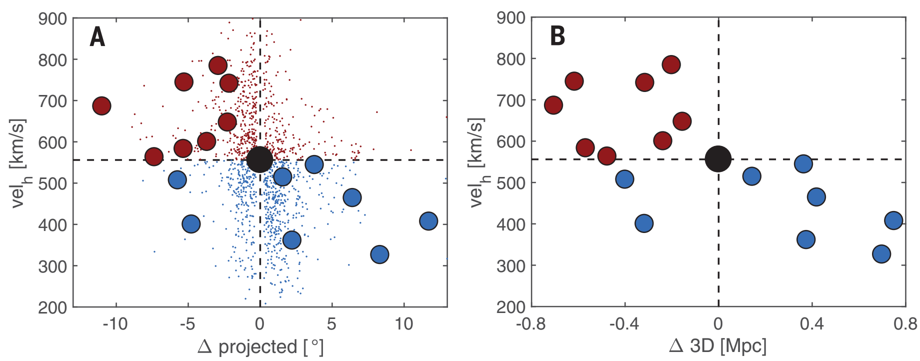

Fig. 2. Velocities and separations to Cen A. Heliocentric velocities versus angular (**A**) and 3D (**B**) distances Δ from Cen A (black sphere), in the north (positive Δ) or south (negative Δ) of the dust lane. Large and small spheres show, respectively, satellite galaxies and planetary nebulae. Blue and red colors indicate, respectively, approaching and receding objects with respect to the Cen A velocity. The angular distances of the PNe are scaled up by a factor of 10.

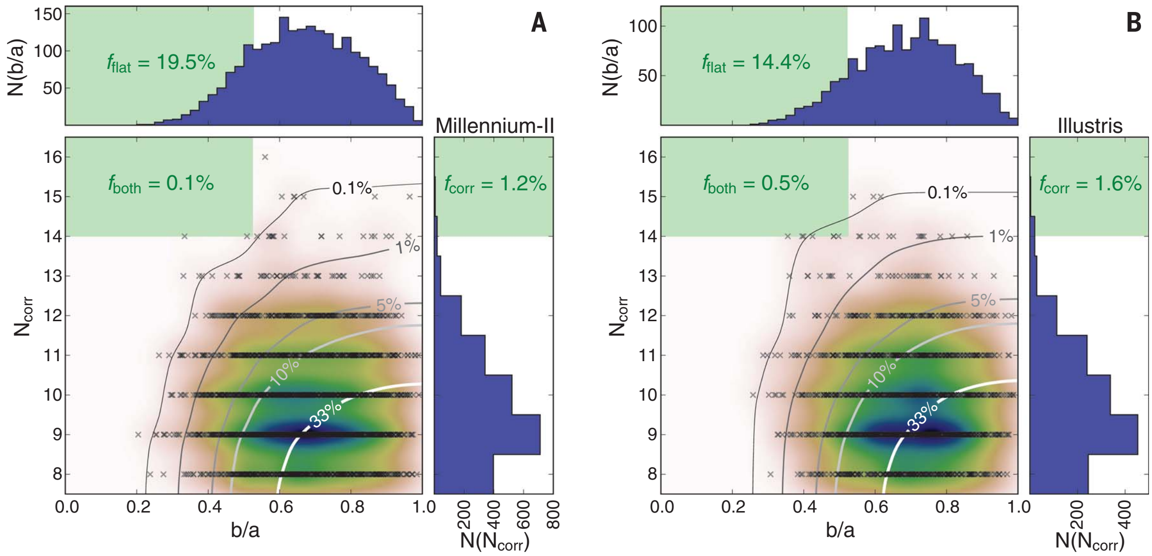

Fig. 3. Comparison to ΛCDM cosmological simulations. The number of kinematically correlated satellites N_{corr} and the on-sky axis-ratio flattening *a* are plotted for Cen A analogs from the Millennium II (**A**) and Illustris (**B**) simulations. The density of simulated systems is indicated by the color map. The contours show the frequency of more extreme realizations, i.e., the number of points to the upper left of each position divided by the total number of realizations. The top and right histograms show the number of realizations with a given axis ratio $N(b/a)$ and a given number of correlated velocities $N(N_{corr})$, respectively. The green areas delineate the regions in which systems are as extreme as or more extreme than the observed one: f_{flat}, f_{corr}, and f_{both} give the frequency of realizations that are, respectively, at least as flattened as the observed system, at least as kinematically correlated, or both. A system must fulfill both conditions simultaneously to reproduce the observed properties of the Cen A satellite system.

companion galaxy with dark matter halo mass $\geq 1 \times 10^{12} M_\odot$ within 1.4-Mpc distance. We require a simulated galaxy-satellite system to fulfill two simplified criteria to be considered similar to the observed system: (i) The projected on-sky axis ratio of the system must be $b/a \leq 0.52$, where a and b are the semimajor and semiminor axes, respectively; and (ii) the kinematic coherence along the long axis is at least 14 out of 16 satellites. We find that the occurrence of arrangements similar to those of Cen A in the cosmological simulations is 0.1% for Millennium II and 0.5% for Illustris (Fig. 3). These estimates must be considered upper limits, because we do not take into account the full 3D distribution of satellite galaxies. Even though the hydrodynamical Illustris simulation does contain a higher frequency of systems analogous to Cen A than the dark-matter-only Millennium II simulation, they are rare cases in both. The observed Cen A satellite system is thus in serious tension with the expectations from these ΛCDM simulations, to a similar degree as the satellite planes in the Local Group.

Could the coherent motion be the result of cosmic expansion? If that were the case, a correlation between the velocities of the satellites and their distances to the Milky Way would be expected. This is not found for the sample of Cen A satellite galaxies (Fig. 1C). We thus can rule out that the cosmic expansion is responsible for the observed velocity field. Another possible origin of a velocity gradient is a perspective effect. For angular offsets δ along the direction of motion, a fraction sin(δ) of a system's bulk tangential velocity is projected along the LoS (*38*, *39*). The velocity gradient found for the Cen A system in Fig. 2 implies a tangential velocity on the order of 1000 km s^{-1}, comparable to what would be required for the Andromeda satellite plane (*7*). This is unphysically high given that it exceeds the cosmic expansion at the distance of Cen A by a factor of 3.7. Such an interpretation of the velocity gradient would imply that the Cen A group moves in the direction defined by the satellite plane, which is unlikely. Another potential systematic issue is the contribution to the LoS velocity by the motion of the Sun around the Galactic center. However, we found that this contribution is negligible: −2 to −4 km s^{-1}, depending on the sky position, well within the uncertainties of the heliocentric velocity measurements (table S1).

The coherent kinematics of the Cen A satellites is, instead, best explained by corotation within the plane. We explored a toy model with purely circular orbits and tried to deproject the LoS velocities into circular velocities (*28*). The results were unsatisfactory as many satellites would have unrealistic circular velocities, which randomly vary with the distance from Cen A. This suggests that the satellites must be on elliptical orbits, as expected for collisionless objects. Two galaxies do not follow the general trend: They may be counterrotating, or on highly elliptical orbits, or simply unrelated to the planar structure. Planetary nebulae provide additional evidence (*40*): They also show coherent motion, although this is less pronounced than for the dwarf satellites: Only 65% of PNe partake in the common motion (Fig. 1). Because the same trend is present in two independent populations of objects with different orbital times, we can expect this correlation to be long-lived and thus indicative of corotation within the planes.

Corotation outside the Local Group has been investigated with satellite galaxy pairs on opposite sides of their hosts (*41*). The LoS velocities of satellite pairs are preferentially anticorrelated, suggesting a high incidence (>50%) of corotating satellite pairs in the universe (*41*), although that result remains controversial (*42*–*44*). For the Cen A subgroup, the presence of a plane of satellite galaxies is known independently of velocity information and is established by using multiple group members. This is unlike previous studies, which could not determine whether specific pairs of satellites actually lie in a plane (*41*).

In alternative frameworks for the formation of dwarf galaxies, corotating planes of satellites could be a consequence of past interactions and mergers between disk galaxies (*16*). During galaxy mergers, tidal tails form from disk material as a result of angular momentum conservation and can collapse into tidal dwarf galaxies (*45*–*47*). Hydrodynamical simulations show that these may survive the interaction and begin orbiting around the central merger remnant as dwarf satellites (*48*, *49*). In the Local Group, a major merger forming the Andromeda galaxy has been proposed as a possible origin of the observed satellite galaxy planes around both the Milky Way (*50*) and the Andromeda galaxy (*51*). The recent finding of a correlation between the size of spiral galaxy bulges (thought to form via major mergers) and the number of satellites is in agreement with this picture (*52*). Even the existence of some counterrotating satellites can be understood in this framework (*27*).

Here, we have provided evidence for a kinematically coherent plane of satellite galaxies around Cen A, demonstrating that the phenomenon is not restricted to the Milky Way and Andromeda galaxies. The kinematic coherence can be understood if the satellites are corotating within the plane, as seen around the Milky Way. Considering that the likelihood of finding a single kinematically coherent plane is ≲0.5% in cosmological ΛCDM simulations, finding three such systems in the nearby universe seems extremely unlikely.

REFERENCES AND NOTES

1. W. E. Kunkel, S. Demers, *Royal Greenwich Observatory Bull.* **182**, 241 (1976).
2. D. Lynden-Bell, *Mon. Not. R. Astron. Soc.* **174**, 695–710 (1976).
3. M. S. Pawlowski, J. Pflamm-Altenburg, P. Kroupa, *Mon. Not. R. Astron. Soc.* **423**, 1109–1126 (2012).
4. M. S. Pawlowski, P. Kroupa, H. Jerjen, *Mon. Not. R. Astron. Soc.* **435**, 1928–1957 (2013).
5. A. W. McConnachie, M. J. Irwin, *Mon. Not. R. Astron. Soc.* **365**, 902–914 (2006).
6. A. Koch, E. K. Grebel, *Astron. J.* **131**, 1405–1415 (2006).
7. R. A. Ibata *et al.*, *Nature* **493**, 62–65 (2013).
8. P. Kroupa, C. Theis, C. M. Boily, *Astron. Astrophys.* **431**, 517–521 (2005).
9. A. R. Zentner, A. V. Kravtsov, O. Y. Gnedin, A. A. Klypin, *Astrophys. J.* **629**, 219–232 (2005).
10. J. P. Ostriker, P. J. Steinhardt, *Nature* **377**, 600–602 (1995).
11. S. D. M. White, J. F. Navarro, A. E. Evrard, C. S. Frenk, *Nature* **366**, 429–433 (1993).
12. D. J. Eisenstein *et al.*, *Astrophys. J.* **633**, 560–574 (2005).
13. O. Müller, R. Scalera, B. Binggeli, H. Jerjen, *Astron. Astrophys.* **602**, A119 (2017).
14. K. Chiboucas, B. A. Jacobs, R. B. Tully, I. D. Karachentsev, *Astron. J.* **146**, 126 (2013).
15. N. I. Libeskind *et al.*, *Mon. Not. R. Astron. Soc.* **452**, 1052–1059 (2015).
16. M. S. Pawlowski, P. Kroupa, *Mon. Not. R. Astron. Soc.* **435**, 2116–2131 (2013).
17. M. S. Pawlowski, S. S. McGaugh, H. Jerjen, *Mon. Not. R. Astron. Soc.* **453**, 1047–1061 (2015).
18. M. S. Pawlowski *et al.*, *Mon. Not. R. Astron. Soc.* **442**, 2362–2380 (2014).
19. I. D. Karachentsev, V. E. Karachentseva, W. K. Huchtmeier, D. I. Makarov, *Astron. J.* **127**, 2031–2068 (2004).
20. I. D. Karachentsev, D. I. Makarov, E. I. Kaisina, *Astron. J.* **145**, 101 (2013).
21. R. B. Tully *et al.*, *Astrophys. J.* **802**, L25 (2015).
22. O. Müller, H. Jerjen, B. Binggeli, *Astron. Astrophys.* **583**, A79 (2015).
23. O. Müller, H. Jerjen, B. Binggeli, *Astron. Astrophys.* **597**, A7 (2017).
24. D. Crnojević *et al.*, *Astrophys. J.* **823**, 19 (2016).
25. O. Müller, H. Jerjen, M. S. Pawlowski, B. Binggeli, *Astron. Astrophys.* **595**, A119 (2016).
26. J. R. Walsh, M. Rejkuba, N. A. Walton, *Astron. Astrophys.* **574**, A109 (2015).
27. M. S. Pawlowski, P. Kroupa, K. S. de Boer, *Astron. Astrophys.* **532**, A118 (2011).
28. Materials and methods are available as supplementary materials.
29. R. Wetzels, E.-J. Wagenmakers, *Psychon. Bull. Rev.* **19**, 1057–1064 (2012).
30. M. Boylan-Kolchin, V. Springel, S. D. M. White, A. Jenkins, G. Lemson, *Mon. Not. R. Astron. Soc.* **398**, 1150–1164 (2009).
31. M. Vogelsberger *et al.*, *Nature* **509**, 177–182 (2014).
32. S. Garrison-Kimmel *et al.*, *Mon. Not. R. Astron. Soc.* **471**, 1709–1727 (2017).
33. J. S. Bullock, M. Boylan-Kolchin, *Annu. Rev. Astron. Astrophys.* **55**, 343–387 (2017).
34. T. Buck, A. A. Dutton, A. V. Macciò, *Mon. Not. R. Astron. Soc.* **460**, 4348–4365 (2016).
35. N. Gillet *et al.*, *Astrophys. J.* **800**, 34 (2015).
36. H. Bahl, H. Baumgardt, *Mon. Not. R. Astron. Soc.* **438**, 2916–2923 (2014).
37. M. Cautun *et al.*, *Mon. Not. R. Astron. Soc.* **452**, 3838–3852 (2015).
38. R. P. van der Marel, P. Guhathakurta, *Astrophys. J.* **678**, 187–199 (2008).
39. J.-B. Salomon, R. A. Ibata, B. Famaey, N. F. Martin, G. F. Lewis, *Mon. Not. R. Astron. Soc.* **456**, 4432–4440 (2016).
40. E. W. Peng, H. C. Ford, K. C. Freeman, *Astrophys. J.* **602**, 685–704 (2004).
41. N. G. Ibata, R. A. Ibata, B. Famaey, G. F. Lewis, *Nature* **511**, 563–566 (2014).
42. J. I. Phillips, M. C. Cooper, J. S. Bullock, M. Boylan-Kolchin, *Mon. Not. R. Astron. Soc.* **453**, 3839 (2015).
43. M. Cautun, W. Wang, C. S. Frenk, T. Sawala, *Mon. Not. R. Astron. Soc.* **449**, 2576–2587 (2015).
44. R. A. Ibata, B. Famaey, G. F. Lewis, N. G. Ibata, N. Martin, *Astrophys. J.* **805**, 67 (2015).
45. J. E. Hibbard, J. M. van der Hulst, J. E. Barnes, R. M. Rich, *Astron. J.* **122**, 2969–2992 (2001).
46. F. Bournaud *et al.*, *Science* **316**, 1166–1169 (2007).
47. F. Lelli *et al.*, *Astron. Astrophys.* **584**, A113 (2015).
48. F. Bournaud, P.-A. Duc, *Astron. Astrophys.* **456**, 481–492 (2006).
49. S. Ploeckinger, S. Recchi, G. Hensler, P. Kroupa, *Mon. Not. R. Astron. Soc.* **447**, 2512–2525 (2015).
50. S. Fouquet, F. Hammer, Y. Yang, M. Puech, H. Flores, *Mon. Not. R. Astron. Soc.* **427**, 1769–1783 (2012).
51. F. Hammer *et al.*, *Mon. Not. R. Astron. Soc.* **431**, 3543–3549 (2013).
52. M. López-Corredoira, P. Kroupa, *Astrophys. J.* **817**, 75 (2016).

ACKNOWLEDGMENTS

We thank B. Binggeli and M. Rejkuba for interesting discussions and helpful inputs. O.M. thanks E. Schnider for inputs concerning the figures. O.M. is grateful to the Swiss National Science Foundation for financial support. M.S.P. acknowledges support for this work provided by NASA through Hubble Fellowship grant HST-HF2-51379.001-A awarded by the Space Telescope Science Institute, which is operated by the Association of Universities for Research in Astronomy, Inc., for NASA, under contract NAS5-26555. H.J. acknowledges the support of the Australian Research Council through Discovery Project DP150100862. The work of F.L. is supported by an ESO postdoctoral fellowship. The Millennium-II Simulation databases used in this paper and the web application providing online access to them were constructed as part of the activities of the German Astrophysical Virtual Observatory. The Illustris Simulation databases are provided by the Illustris Collaboration. The observational data we used are given in table S1. The software for our Monte Carlo analysis is provided in data file S1, and the catalogs of Cen A analogs in the simulations are in data files S2 and S3. We thank the anonymous referees for helpful comments that improved the paper.

SUPPLEMENTARY MATERIALS

www.sciencemag.org/content/359/6375/534/suppl/DC1
Materials and Methods
Supplementary Text
Figs. S1 and S2
Tables S1 and S2
References (*53*–*70*)
Movie S1
Data Files S1 to S3

24 June 2017; accepted 20 December 2017
10.1126/science.aao1858

Science

A whirling plane of satellite galaxies around Centaurus A challenges cold dark matter cosmology

Oliver Müller, Marcel S. Pawlowski, Helmut Jerjen and Federico Lelli

Science **359** (6375), 534-537.
DOI: 10.1126/science.aao1858

Dwarf galaxies move in unexpected ways

Massive galaxies like our Milky Way are orbited by satellite dwarf galaxies. Standard cosmological simulations of galaxy formation predict that these satellites should move randomly around their host. Müller *et al.* examined the satellites of the nearby elliptical galaxy Centaurus A (see the Perspective by Boylan-Kolchin). They found that the satellites are distributed in a planar arrangement, and the members of the plane are orbiting in a coherent direction. This is inconsistent with more than 99% of comparable galaxies in simulations. Centaurus A, the Milky Way, and Andromeda all have highly statistically unlikely satellite systems. This observational evidence suggests that something is wrong with standard cosmological simulations.

Science, this issue p. 534; see also p. 520