Probing the Environment with Galaxy Dynamics

Aaron J. Romanowsky

Departamento de Física, Universidad de Concepción, Casilla 160-C, Concepción, Chile romanow@astro-udec.cl

Summary. I present various projects to study the halo dynamics of elliptical galaxies. This allows one to study the outer mass and orbital distributions of ellipticals in different environments, and the inner distributions of groups and clusters themselves.

1 Introduction: Halos and the environment

Elliptical galaxies are intriguingly homogeneous. Besides being more prevalent in high density regions, low-redshift ellipticals have observable central properties (e.g. color, velocity dispersion, metallicity, star formation history) whose environmental dependencies are relatively subtle (e.g. [1, 2]), in contrast to the case of spiral galaxies. Larger differences might be found in the ellipticals’ outer parts, which should be the most strongly affected by environmental influences. For example, the tidal fields in higher-density environments could cause stripping of the galaxies’ stellar and dark matter (DM) halos, and of their globular cluster (GC) systems—also affecting the anisotropy of the remaining halo stars and GCs. Indeed, a deep Virgo Cluster image seems to show stellar halo stripping in progress, a process which may be facilitated by dynamical halo heating in the pre-infall groups [3]. Gravitational lensing studies also indicate some DM halo stripping in high-density environments [4, 5, 6, 7].

The large radial extent of GC systems makes them handy tracers for halo stripping, and in fact it may be possible to use GCs as a proxies for the DM itself [8]. Very extended GC systems are found in cluster-dominant ellipticals (such as M87, M49, and NGC 1399) [9], which is consistent with them being agents rather than victims of stripping. Wide-field studies of more normal ellipticals are now getting underway—and provocatively, the Virgo galaxy NGC 4636 turns out to have a GC system with a sharp edge [10].

Groups should dominate the error budget of the Universe, but their mass distributions are among the most poorly determined. Observations from weak lensing and internal group dynamics don’t agree on their total masses, much
less the detailed distribution with radius (e.g. [11, 12, 13, 14]). Additional constraints, especially nearer the group centers, are essential. Fortunately, studies of elliptical galaxy halos allow one to probe the mass distributions in galaxy groups as well as in individual galaxies. This is because many of the easiest-studied ellipticals are central group or cluster galaxies (e.g. [15, 16, 17])—a frustration for galaxy research but a boon for group studies.

Whether in galaxies or in groups, there are several useful independent dynamical tracers: GCs, X-ray gas, and planetary nebulae (PNe), which are a powerful proxy for faint starlight. In groups with only a handful of galaxy velocities, there may be hundreds or thousands of GC and PN velocities attainable (albeit at relatively small radii). In M49 and M87, massive DM halo cores are found from constant-to-rising profiles of gas temperature, and of velocity dispersion profiles of PNe and GCs [18, 19, 20, 17, 21]. Different orbital properties are implied between the PNe and GCs, which should constrain central galaxy evolution scenarios. NGC 4636 has a constant GC dispersion profile, implying a fairly normal DM halo [22]—unsurprisingly different from X-ray results, given the evident departures from gas equilibrium [23]. NGC 1399 has a rising PN and GC dispersion profile, indicating either the DM core of the Fornax Cluster, or a recent interaction with another galaxy [24, 25]. Note that for halo tracers to be fruitful, it is imperative to combine them with constraints on the central galaxy’s stellar mass, which is otherwise a major source of systematic uncertainty [17].

2 The Eridanusc A Group

Based on its X-ray gas and member galaxy velocities, Eridanus A appears to be a “dark cluster” with a virial mass $\sim 10^{14} M_\odot$ and mass-to-light ratio $\Upsilon_B \sim 1500 \Upsilon_{B,\odot}$ [26, 27, 17, 28]. To probe this possibility further, we have acquired velocities of $\sim 100$ GCs around the central giant elliptical NGC 1407, using LRIS, FLAMES, and LDSS-3. Initial results with 36 GCs, comparing the GC dispersion profile to various models, do indeed support the presence of a super-halo (see Fig. 1). Based on typical empirical and theoretical values for the virial $\Upsilon$ of a group like Eri A [29, 14, 30], the profile should decrease outside 10 kpc—but a flat dispersion is observed. Combining more constraints from stellar, GC, X-ray, and group galaxy dynamics will allow us to trace the mass profile in more detail.

3 The Leo I Group

Leo I is the nearest (10 Mpc) example of a group containing multiple giant early-type galaxies, including the “archetypal” $L^*$ elliptical at its center, NGC 3379. It is unclear if the group is reasonably relaxed, with a group halo centered on NGC 3379. This galaxy has been the focus of numerous dynamical
Fig. 1. Projected velocity dispersion radial profiles in the Eridanus A group. Points with error bars show data for stars and GCs in NGC 1407 [31], and for group galaxies. Curves show model predictions for the GCs, for a spherical isotropic assumption, and either no dark matter, a “normal” halo, or a “super” halo.

studies, most recently employing PNe [32, 33] and GCs [34, 35, 36]. The PNe imply surprisingly little DM inside 15 kpc, but leave the possibility that there are large amounts of DM spread further out in a massive, diffuse halo. The GC kinematics reach to 40 kpc, and do suggest a massive, even group-sized, halo (see Fig. 2). Another remarkable constraint comes from the HI gas ring which appears to orbit the core of the group, and implies $\Upsilon_\nu \sim 30$ inside 100 kpc [37]. This suggests a lot of DM, but much less than one would expect for a $\Lambda$CDM halo (whether galaxy- or group-sized), and appears to be at odds with the GC results (the PNe are technically compatible with either the GCs or the HI). However, the GC constraints are hampered by small-number statistics (49 velocities), and newly-acquired FLAMES data should clarify the situation with a doubled or tripled data set. As an interesting note of comparison, Leo I and Eri A are groups with nearly the same optical luminosity, but apparently differ in mass by at least a factor of 10.

4 Mass profiles of ordinary ellipticals

The halo mass profiles of “ordinary” ($\sim L^*$) ellipticals have long been elusive. The first inroads have come from new data on halo PN kinematics [35, 36].
The first 5 ellipticals studied all have a projected velocity dispersion profile which declines markedly with radius. The obvious implication is that the measurable DM content of these galaxies is remarkably low, as discussed above for NGC 3379. One might expect this effect to be strongest for the highest-density environments, where DM stripping could have occurred, but this does not appear to be the case. An alternative possibility is that the galaxy halo concentrations are lower than expected with $\Lambda$CDM, a possibility strengthened by analysis of literature data on early-type galaxies \[40\]. This is supported by some independent studies of ellipticals \[41, 42, 15\], and is paralleled by many studies of late-type galaxies.

Theoretical studies \[43, 44\] have pointed out various effects which could contribute to the declining dispersions, including oversimplified DM profiles, radial anisotropy variations, galaxy flattening, and biased PN-stellar correspondence. There are reasons to doubt that these effects could entirely explain the observations—for example, the modeling of NGC 3379 already incorporated a direct derivation of the (radial) anisotropy profile from the data. But certainly much more clarification is needed. Current work focuses on obtaining a large, systematic sample of independent mass tracers around ordinary ellipticals in different environments, and on refining the modeling—including direct calibratory comparisons with simulations.
References

1. F.M. Reda, D.A. Forbes, G.K.T. Hau: MNRAS 360, 693 (2005)
2. M.S. Clemens, A. Bressan et al: MNRAS, submitted (astro-ph/0603714)
3. J.C. Mihos, P. Harding et al: ApJ 631, L41 (2005); C.S. Rudick et al., this vol.
4. P. Natarajan, J.-P. Kneib, I. Smail: ApJ 580, L11 (2002)
5. R. Gavazzi, Y. Mellier, B. Fort et al.: A&A 422, 407 (2004)
6. P. Natarajan, J.-P. Kneib, I. Smail, R. Ellis: ApJ, submitted (astro-ph/0411426)
7. R. Mandelbaum, U. Seljak, G. Kauffmann et al: MNRAS 368, 715 (2006)
8. K. Bekki, M.A. Beasley, J.P. Brodie, D.A. Forbes: MNRAS 363, 1211 (2005)
9. D.E. McLaughlin: AJ 117, 2398 (1999)
10. B. Dirsch, Y. Schuberth, T. Richtler: A&A 433, 43 (2005)
11. R.G. Carlberg, H.K.C. Yee, S.L. Morris, H. Lin et al: ApJ 552, 427 (2001)
12. R.B. Tully: ApJ 618, 214 (2005)
13. I.D. Karachentsev: AJ 129, 178 (2005)
14. L.C. Parker, M.J. Hudson, R.G. Carlberg, H. Hoekstra: ApJ 634, 806 (2005)
15. Y. Fukazawa, J.G. Botoya-Nonesa, J. Pu et al.: ApJ 636, 698 (2006)
16. C.S. Kochanek, N.D. Morgan, E.E. Falco et al: ApJ 640, 47 (2006)
17. P.J. Humphrey, D.A. Buote et al: ApJ, in press (astro-ph/0601301)
18. A.J. Romanowsky, C.S. Kochanek: ApJ 553, 722 (2001)
19. K. Matsushita, E. Belsole, A. Finoguenov, H. Böhringer: A&A 386, 77 (2002)
20. P. Côté, D.E. McLaughlin, J.G. Cohen, J.P. Blakeslee: ApJ 591, 850 (2003)
21. G. Bergond et al: in prep; N.G. Douglas, A.J. Romanowsky, K. Kuijken: in prep
22. Y. Schuberth, T. Richtler, B. Dirsch et al: A&A, in press (astro-ph/0604309)
23. E. O’Sullivan, this vol.
24. N.R. Napolitano, M. Arnaboldi, M. Cappaccioli: A&A 383, 791 (2002)
25. T. Richtler, B. Dirsch et al: AJ 127, 2094 (2004); Y. Schuberth et al., in prep
26. A. Gould: ApJ 403, 37 (1993)
27. H. Quintana, P. Fouqué, M.J. Way: A&A 283, 722 (1994)
28. S. Brough, D.A. Forbes et al: MNRAS, in press (astro-ph/0603778)
29. F.C. van den Bosch, H.J. Mo, X. Yang: MNRAS 345, 923 (2003)
30. V.R. Eke, C.M. Baugh, S. Cole et al.: MNRAS, submitted (astro-ph/0510643)
31. G.K.T. Hau: in prep; P. Sánchez-Blázquez et al: in prep
32. A.J. Romanowsky, N.G. Douglas, M. Arnaboldi et al: Science 301, 1696 (2003)
33. A.P.N. Sluis, T.B. Williams: AJ 131, 2089 (2006)
34. T.H. Puzia, M. Kissler-Patig, D. Thomas et al.: A&A 415, 123 (2004)
35. M. Pierce, M.A. Beasley, D.A. Forbes et al: MNRAS 366, 1253 (2006)
36. G. Bergond, S.E. Zepf, A.J. Romanowsky et al: A&A 448, 155 (2006)
37. S.E. Schneider: ApJ 288, L33 (1985)
38. R.H. Méndez, A. Riffeser, R.-P. Kudritzki et al: ApJ 563, 135 (2001)
39. A.M. Teodorescu, R.H. Méndez, R.P. Saglia et al: ApJ 633, 290 (2005)
40. N.R. Napolitano, M. Capaccioli et al: MNRAS 357, 691 (2005)
41. A. Borriello, P. Salucci, L. Danese: MNRAS 341, 1109 (2003)
42. D. Rusin, C.S. Kochanek, C.R. Keeton: ApJ 595, 29
43. G.A. Mamon, E.L. Lokas: MNRAS 363, 705 (2005)
44. A. Dekel, F. Stoehr, G.A. Mamon, T.J. Cox et al: Nature 437, 707 (2005)