The Impact of Tidal Interactions on Satellite Galaxies: A Study of the M31 Satellites, M32 & NGC 205

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Surface photometry of the M31 satellites M32 and NGC 205 is compared to numerical simulations of satellite destruction to constrain orbital parameters and the interaction history of the M31 subgroup. Our analysis reveals the following preliminary results: (1) Generic features of tidal disruption in the simulations include an extended “extra-tidal” excess region and an inner depletion zone, both of which are observed in M32 and NGC 205; (2) M32 is likely to be on a highly eccentric orbit well away from pericenter; (3) Surface brightness and luminosity evolution estimates for M32, the prototypical compact elliptical galaxy, imply that it is not simply the residual core of a tidally-stripped normal elliptical galaxy, but was instead formed in a truncated state.

1 Introduction

Recent evidence for tidal streams in the halos of the Milky Way and M31, along with studies investigating extra-tidal material around Local Group globular clusters and dwarf spheroidals, indicate that the tidal disruption and accretion of satellites are ongoing processes in the present epoch. In this paper, preliminary results are presented from a study comparing integrated surface photometry of M32 and NGC 205 to satellite simulations. Spectroscopic observations to determine the internal kinematics in the tidal region of M32 and more finely tuned numerical models will be incorporated in later studies.

2 Observations / Simulations

The observational component of this study is based on 1.7° × 5° B- and I-band CCD mosaic images centered on M31 and covering both satellites. Standard ellipse fitting techniques are used to model and remove M31 disk light and to perform surface photometry on the satellites to limiting isophotes of \[ \mu_B, \mu_I = [27, 25] \text{ mag arcsec}^{-2} \], corresponding to semi-major axis lengths \( r_{\text{lim}}^{\text{M32}} = 420'' \) (1.6 kpc) and \( r_{\text{lim}}^{\text{NGC 205}} = 720'' \) (2.7 kpc). In Figure 1, B-band images of M32, before and after M31 subtraction, illustrate the importance of careful background subtraction. For the numerical simulations, single-
component, spherical satellites are followed through a fixed three-component potential representative of the disk, bulge and halo of a parent galaxy. The models explore a range of orbital eccentricities and initial mass profiles for the satellite. To facilitate comparison, the ellipse fitting technique used for the observations is also adopted for the simulated satellites.

3 Interpretation of Observations in Light of Numerical Simulations

Generic Features of Tidal Interaction: Breaks in the surface brightness, ellipticity and position angle profiles are common features of the numerical simulations (Fig. 2: right). The presence of an extended region of excess material and an inner depletion zone are other generic features. The excess region corresponds loosely to what is conventionally described as an “extra-tidal” region; however, we find that in many cases they are associated with tidally heated, yet bound material. Similar features are observed in M32 (Fig. 2: left) and NGC 205 suggestive of tidal interaction with and stripping by M31.

Discriminating Orbital Parameters for M32: In the case of M32, three of its profile features are suggestive of a highly eccentric orbit:

- There is a triple break in the position angle $\phi$ profile, with two of the breaks coincident with breaks in the surface brightness and ellipticity profiles. This is an atypical feature of the simulations, seen only in satellites approaching apocenter on highly eccentric orbits. In Figure 2, the profiles of one such simulated satellite show striking similarities to those of M32.

Figure 1: Grayscale representations of $B$-band images ($17' \times 17'$) centered on M32 with (left) and without (middle) M31's disk light contribution. Note the steep gradient in the background across M32 caused by the inclined disk of M31 (left) and M31's residual fine-scale structure (dust lanes, spiral arms, etc. (middle)) even after subtraction. Best-fit elliptical isophotes of M32 (right) in the semi-major axis range of $100'' < r < 300''$ highlight the low surface brightness region in which signatures of tidal interactions are observed.
Figure 2: Surface brightness $\mu$, de Vaucouleurs residual $\Delta \mu$, ellipticity $\epsilon$ and position angle $\phi$ profiles plotted in de Vaucouleurs coordinates for a simulation snapshot (right) and M32 (left) in $B$ (triangles) and $I$ (crosses) bands. The surface brightness profile of M32 is well fit by a de Vaucouleurs profile (top left) over the radius range $10'' < r < 65''$ with $r_\text{eff}^B \sim 30''$ and $[\mu_\text{eff}^B, \mu_\text{eff}^I] = [18.0, 19.9]$ mag arcsec$^{-2}$. The residual profile shows a deficiency below the extrapolated de Vaucouleurs fit from $50'' - 150''$ and an excess beyond $150''$. These features, coincident with breaks in the ellipticity and position angle profiles, are comparable to those found in Model 4 (right) in which a satellite with orbital eccentricity $e = 0.88$ is approaching apocenter. The bold line covering the range $100'' < r < 300''$ in the M32 $\mu$ plot (top left) shows the region marked by contours in Figure 1 (right).

- The second piece of evidence is the relationship between the classically defined, theoretical King tidal radius $r_{\text{tidal}}$ and the observed break in the surface brightness profile $r_{\text{break}}$. The ratio $r_{\text{break}}/r_{\text{tidal}}$ typically has values of unity or greater for near-circular orbits and only drops below unity for certain phases of highly eccentric orbits (Fig. 3: top). For M32, the measured upper limit of $r_{\text{break}}/r_{\text{tidal}} \sim 0.5$ suggests that it is on a highly eccentric orbit away from pericenter.

- Finally, $r_{\text{break}}^{M32}$, the radius of the onset of isophotal elongation is coincident with $r_{\text{break}}^{M32} \sim 150''$. This ratio, $r_{\text{break}}/r_{\text{distort}}$ is typically $\geq 2.0$ for near-circular orbits and approaches unity only for the most eccentric orbits (Fig. 3: bottom), suggesting that M32 is in this latter category. Since both radii are directly observable, unlike $r_{\text{break}}/r_{\text{tidal}}$, this deduction is less model dependent and more robust than the previous one.

Implications on Compact Elliptical Galaxy Formation: M32 stands apart from normal ellipticals—its combination of high central surface brightness and low
Figure 3: Ratio of $r_{\text{break}}/r_{\text{tidal}}$ (top) and $r_{\text{break}}/r_{\text{distort}}$ (bottom) as a function of orbital phase. In Models 1–4, satellite orbits range in eccentricity from nearly circular (Model 1) to highly elongated (Model 4) with eccentricities of $e = 0.10/0.29/0.67/0.88$, respectively. Model 5 follows the same orbit as Model 4, but adopts a shallower initial density profile than Models 1–4. The dashed line in each panel represents the measured ratio for M32 and indicates that it is likely to be on an eccentric orbit ($e_{M32} \geq 0.5$).

luminosity make it the prototype of a rare class of galaxies known as compact ellipticals (cEs). cEs tend to reside in close proximity to massive companion galaxies, and it is commonly believed that cEs are the tidally truncated remnant cores of normal ellipticals. Guided by numerical simulations, we estimate the luminosity $L_{\text{orig}}$ and central surface brightness $\mu_{\text{orig}}$ M32 might have had prior to tidal stripping by M31. These estimates are compared to the observed (i.e., present-day) values of $L$ and $\mu_0$ for M32 in order to infer the changes $\Delta L$ and $\Delta \mu_0$. While the changes are in the right direction they are far too small to explain M32’s position in the $L$-$\mu_0$ plane. This suggests that the true impact of environment may be in the formation, rather than in the subsequent evolution, of cEs.

References

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