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Mergers to Bars to Boxy Bulges: A Galaxy Evolution Story

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1. Introduction

Deviations from ellipticity in the bulges of edge-on disk galaxies, seen as "boxy", "peanut-shaped", or "X-shaped" isophotes, have been known for some time (Jarvis 1986, Whitmore & Bell 1988). Contrary to earlier proposals that these features represent accreted material, recent numerical work (Combes et al. 1990; Raha et al. 1991) suggests that they form when the bars in barred galaxies experience a vertical bending instability and deform out of the disk plane. We have found this latter mechanism at work in simulations in which a bar is induced when a large disk galaxy accretes a small companion galaxy, thus incorporating the mechanism into the evolutionary framework of galaxy interactions. In support of this picture we present observations of Hickson 87a, an edge-on S0 galaxy whose morphological peculiarities exactly match those seen in the simulation.

2. Simulation

The simulation shown here employed an exponential disk, truncated isothermal halo, and Hernquist model satellite in the mass ratio 10:58:1. See Walker, Mihos, & Hernquist (1995) for a full analysis. The satellite started at a radius of 6 disk scalelengths on an initially circular, prograde orbit inclined 30° to the disk plane and quickly spiraled to the center by dynamical friction. Because of the prograde orbit, the satellite interacted resonantly with the disk particles. It pulled leading particles back so that they lost energy and dropped into lower orbits, clearing a gap in the disk ahead of the satellite (Quinn & Goodman 1986; Walker et al. 1995). Although the gap closed up when the satellite reached the center, the disk did not return to complete axisymmetry but retained a bar. The bar subsequently buckled into a saddle shape (Raha et al. 1991; Mihos et al. 1995) and eventually thickened (Figure 1) to form a peculiar bulge which, viewed along the bar minor axis (Figure 2), appears boxy or X-shaped.

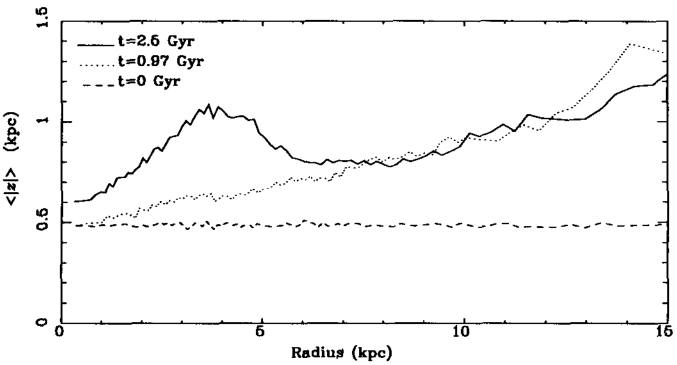

Figure 1. Disk thickness, measured by $\langle |z| \rangle$ for disk particles (only) in cylindrical shells, comparing the thickening during the merger ($t < 1$) with that occurring after. Note that nearly all the post-merger change occurs in the bar region where the buckling produces a significant bump. The flaring at large radii is due to the inclined satellite orbit.

3. Observation

Figure 2 shows this end state in greyscale plots of the disk and satellite combined and projected along the minor axis of the bar. For comparison, Figure 3 shows an R-band image of Hickson 87a. Ignoring the dust lane, it is remarkably similar to the model in both its peculiar isophotal shapes (left panel) and its bright, central knot (middle panel), which, in Figure 2, is the satellite core. The right hand panels show the result of subtracting median-smoothed images from the raw images and reveal the underlying X-shape of the morphological peculiarity (compare IC 4767 in Whitmore & Bell 1988). A quantitative comparison based on the $\cos(4\theta)$ term in a Fourier expansion of the deviations of the isophotes from their best-fitting ellipses is given in Mihos et al. (1995).

4. Discussion

We have found that minor mergers can lead to the formation of X-structures, not by depositing satellite material, but by driving a bar whose buckling molds the morphological peculiarities out of disk material. Such minor mergers are thought to be fairly common. Should we expect these peculiar bulges to be equally common? No. Only those mergers which are prograde and not too highly inclined will tend to drive bars. Also, if the primary is gas-rich, its gas may be driven to the center which steepens the rotation curve and can disrupt the bar. Mergers not dominated by this competing effect will cause the primary to evolve to a Hubble type with larger bulge-to-disk ratio and with the morphological peculiarities discussed here present at some level.

We have demonstrated that the boxy-bulge-from-bar-instability process studied by Raha et al. (1991) and Combes et al. (1990) can be a facet of merger-driven galaxy evolution. Together with the settling of the satellite core into

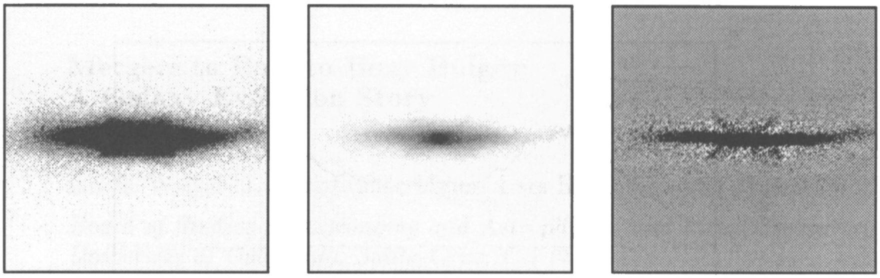

Figure 2. Surface density greyscales of disk and satellite material in the simulation, showing faint features (left), bright features (middle), and an "unsharp masked" image (right) to highlight sharp features.

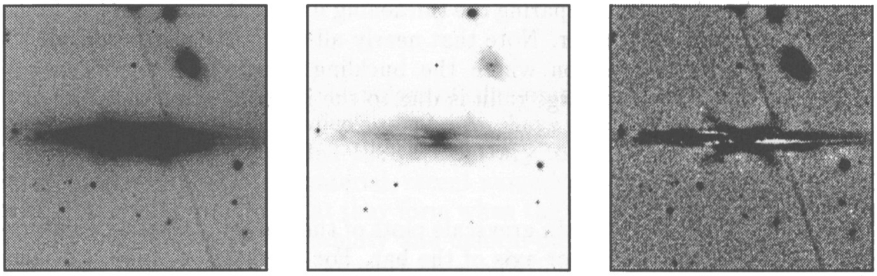

Figure 3. Intensity greyscales for Hickson 87a, as in Figure 2. Similar morphologies are seen in NGC 128, NGC 7332 and IC 4767.

the galactic center, it contributes to bulge-building which, along with heating of the disk in the merger, helps to turn spirals into S0 galaxies. Hickson 87a may be an excellent example. Our model galaxy started with no bulge, only a dark matter halo. The disk survived the encounter *and* developed a small bulge. Because of its origin in the disk, this bulge has significant rotation. A thorough observational study of the kinematics of these systems would now be helpful.

References

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