Wide-Field Near-Infrared Images with the 2MASS Camera: Unveiling the Boxy Bulge and Bar in M31

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BACKGROUND: A variety of studies over the last five decades have suggested that the Andromeda spiral galaxy (M31) contains a central bar. This includes photometric work by Lindblad (1956) and tri-axial modeling by Stark & Binney (1994). These studies, however, have largely been based on optical data. The highly inclined disk of M31 (i = 77.5°) implies that dust obscuration complicates structural studies of the bulge, especially at blue wavelengths. In addition, the proximity of M31 and the relative large physical size of its bulge combine to subtend a large angle on the sky. The inherent complications of spectroscopic measurements on such wide angular scales has prevented global modeling of its stellar kinematics. While it is relatively easy to identify bars in images of face-on systems, their presence in edge-on systems can only be inferred via a measurement of a boxy or peanut-shaped bulge. The Milky Way bulge suffers from strong dust obscuration but COBE/DIRBE infrared maps revealed a boxy bulge. The Two Micron All Sky Survey (2MASS), providing wide field surveys in the near-infrared J, H, and K bands, is a powerful tool for an in-depth study of the bulge of M31.

CONCLUSIONS: The following is a summary of our main conclusions (see Beaton et al. 2006 for further details)

- Deep wide-field near-infrared images of the Andromeda spiral galaxy (obtained as part of the targeted extension of the 2MASS survey) provide a remarkably clear view of the stellar distribution of the bulge, one largely unaffected by dust obscuration in the disk of the galaxy.

- These data reveal a clear signature of a boxy bulge due to a central bar in M31. We confirm previous suggestions of twisting of the bulge isophotes and misalignment between the major axes of the bulge and disk.

- There is beautiful agreement between these M31 data and dynamical models of disk galaxies in which a boxy bulge has been stirred up by a central bar. These models further support the existence of an additional classical bulge component at the center of M31, and imply that the bar itself extends beyond the observationally established extent of the boxy bulge.

- We are in the process of investigating the structural parameters of the central bar and bulge in M31, such as bar strength and orientation (φ, via a comparison of the data to a grid of dynamical models of disk galaxies with boxy bulges.

REFERENCES

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Figure 1: Comparison of an optical BVR2 image (left) with our deep near infrared JHK mosaic (right) obtained with the 2MASS telescope. Each image covers about 1.5° × 2°. There are small gaps in the coverage of the NIR image mosaic. The effects of dust are greatly reduced in the near infrared and this provides a clear view of the boxy bulge.

Figure 2: Ellipticity, b/a (top) and position angle (PA) measured from N to E (bottom) of the isophotes as a function of semi-major axis length (in arcsec). These quantities were derived by fitting ellipses to the isophotes; the profiles in the J, H, and K bands are in excellent agreement outside the nucleus (a > 3′) but as one moves out to larger radii the ellipticity deviates from the best-fit ellipse model (center), and the ellipticity deviates from a pure boxy model (right), implying that dust obscuration complicates structural studies of the bulge, especially at blue wavelengths. In addition, the proximity of M31 and the relative large physical size of its bulge combine to subtend a large angle on the sky. The inherent complications of spectroscopic measurements on such wide angular scales has prevented global modeling of its stellar kinematics. While it is relatively easy to identify bars in images of face-on systems, their presence in edge-on systems can only be inferred via a measurement of a boxy or peanut-shaped bulge. The Milky Way bulge suffers from strong dust obscuration but COBE/DIRBE infrared maps revealed a boxy bulge. The Two Micron All Sky Survey (2MASS), providing wide field surveys in the near-infrared J, H, and K bands, is a powerful tool for an in-depth study of the bulge of M31.

Figure 3: Same as Figure 2 for A4/B4 and B4/B, two parameters that quantify the degree of departure of the isophote shapes from a perfect ellipse. Negative values of A4/B4 indicate ‘boxy’ features while positive values indicate ‘pointed’ disk-like features. Most of the outer bulge region is B4/B < 0.5, indicating that the outer bulge is boxy. The inner bulge region (∼ 25′–100′) exhibits isophote twisting from PA = 60° to 75°. The outer bulge region (∼ 25′–100′) maintains a near constant PA of 72°, which is misaligned by about 15° with respect to the major axes of M31’s disk (PA = 45°). The outer bulge becomes increasingly boxy with increasing radius.

Figure 4: Comparison of contour plots of M31’s bar and bulge in J (left), the best-fit ellipse model (middle), and the residual image data minus the ellipse model (right). There is a clear boxy shaped feature in each of the right panels, indicative of a substantial degree of boxiness in the shape of M31’s bulge (this is also evident in the raw data). M31 presents strong similarities to NGC 4442 (i = 72°), which has a visually apparent bar and a boxy bulge (Bettoni & Galletta 1994).

Figure 5: Comparison of boxy and sharp models, with models B (top) and A (bottom), to models (above & left) from previous work (Beaton et al. 2006). The models features a strong central bar. The bar in Model B is stronger and extends farther than that of Model A. The models disk inclination is i = 78°, which is close to M31’s disk inclination of 77.7°. The angle φ of the bar in the models, though many factors, such as inclination, affect the apparent bulge shape, M31 is by, the strong central concentration suggests an additional classical bulge component.

Figure 6: Comparison of contour plots and boxy and sharp profiles (left) to a model (right). The models features a boxy/peanut-shaped bulge, a central classical bulge, and a reasonably strong central bar. The bar in Model B is stronger and extends farther than in Model A. The angle φ of the bar in the models, though many factors, such as inclination, affect the apparent bulge shape, M31 is by, the strong central concentration suggests an additional classical bulge component.

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