Wide-Field Near-Infrared Images with the 2MASS Camera:

Unveiling the Boxy Bulge and Bar in M31

Rachael L. Beaton[1], E. Athanassoula[2], Steven R. Majewski[1], Puragra Guhathakurta[3], Michael F. Skrutskie[1], Richard J. Patterson[1], Martin Bureau[4]

(1) University of Virginia, (2) Observatoire de Marseille, (3) University of California Santa Cruz, (4) Columbia University

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 mapping 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.

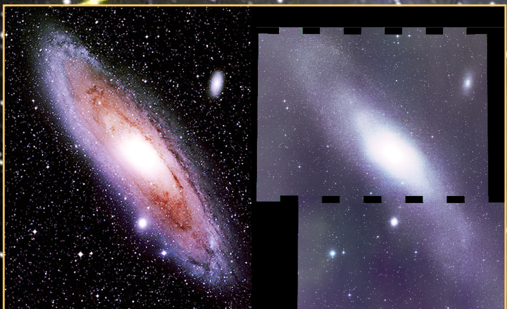


Figure 1: Comparison of an optical *BVRZ* image (left) with our deep near infrared *JHK* image (right) obtained with the 2MASS telescope*. Each image covers about 1.5° × 2°. There are small gaps in the coverage of *JHK* image mosaic. The effects of dust are greatly reduced in the near infrared and this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

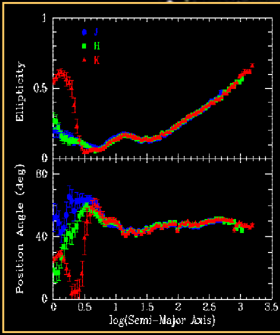


Figure 2: Ellipticity, $1 - b/a$, (top) and position angle (PA) measured from N to E (bottom) of the isophotes as a function of semi-major axis length a (in arcsec). These quantities were derived by fitting ellipses to the isophotes; the profiles in the *J*, *H*, and *K* bands are in excellent agreement outside the nucleus ($a > 3''$). The bulge has a higher surface brightness than the disk out to $\log(a) \approx 3$. The inner bulge region ($a = 3''$–$50''$) exhibits isophotal twisting from PA = 60° to 40°. The outer bulge region ($a = 50''$–$1000''$) maintains a near constant PA of 50°, which is misaligned by about +10° with respect to the major axis of M31's disk (PA = 40°). The outer bulge becomes increasingly elongated with increasing radius.

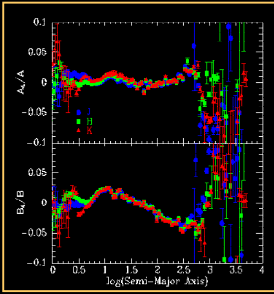


Figure 3: Same as Figure 2 for A_4/A and B_4/B, two parameters that quantify the degree of departure of the isophotal shape from a perfect ellipse. Negative values of B_4/B indicate 'boxy' features while positive values indicate 'pointed' or disk-like features. Most of the outer bulge region ($a = 50''$–$1000''$) is boxy but the inner bulge region ($a = 3''$–$50''$) is not. As for the ellipticity and PA, the *JHK* A_4/A and B_4/B profiles agree everywhere, except within the nucleus ($a < 3''$). Overall, the M31 B_4/B profile strong resembles those of the boxy galaxies NGC 660 and NGC 5859 (Shaw 1993). Like M31, both of these galaxies exhibit strong isophotal twists.

***ACKNOWLEDGEMENTS** This project is based on data products from the Two Micron All Sky Survey (2MASS), a joint project of the University of Massachusetts and the Infrared Processing and Analysis Center/California Institute of Technology, funded by the National Aeronautics and Space Administration and the National Science Foundation. The M31 data are part of a 6× deeper targeted extension of the main survey. For details see— http://www.ipac.caltech.edu/2mass/releases/allsky/doc/seca3_1.html. This work was supported by NSF grants AST-0307842 and AST-0307966, as well as a SIM Key Project grant, NASA/JPL contract 1228235. M.F.S. acknowledges support from NASA/JPL contract 1234021. This work was also partially supported by the Celerity Foundation. E.A. thanks the INSU/CNRS, the Region PACA and the University of Aix-Marseille.

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

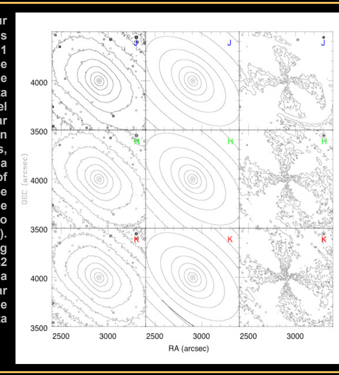
★ Deep wide-field near-infrared images of the Andromeda spiral galaxy (obtained as part of the targeted extension of the 2MASS survey) provide a remarkably clear view of the stellar distribution of the bulge, one largely unaffected by dust obscuration in the disk of the galaxy.

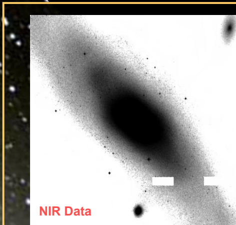
★ These data reveal a clear signature of a boxy bulge due to a central bar in M31. We confirm previous suggestions of twisting of the bulge isophotes and misalignment between the major axes of the bulge and disk.

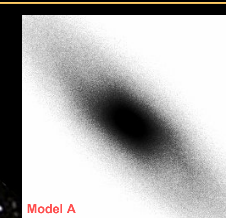
★ There is beautiful agreement between these M31 data and dynamical models of disk galaxies in which a boxy bulge has been stirred up by a central bar. These models further suggest the existence of an additional classical bulge component at the center of M31, and imply that the bar itself extends beyond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

Figure 4: Contour plots of *JHK* images (top to bottom) of M31 (left), the best-fit ellipse model (center), and the residual image: data minus ellipse model (right). These is a clear "X" shaped feature in each of the right panels, indicative of a substantial degree of boxiness in the shape of M31's bulge isophotes (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).







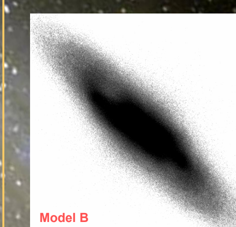
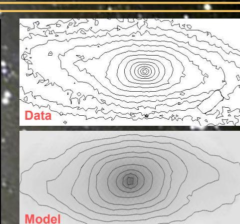


Figure 5: Comparison of images of M31's bulge and bar in *K* (upper left), to models (above & left) from Athanassoula & Beaton (2006, in preparation). The models features a boxy/peanut-shaped bulge, a central classical bulge and a moderately strong central bar. The bar in Model B is stronger and extends 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, measured relative to the line of nodes in the disk plane, is 30°. Though many factors, such as inclination, affect the apparent bulge shape, M31 is by, the angle φ and by observation, classified as a boxy bulge.

Figure 6: Comparison of contour plots of M31 in *K* (top) to a model with i = 78° and φ = 30°. The oblong and asymmetrical nature of the isophotes beyond the bulge is due to the outermost parts of the bar, which extend beyond the end of the boxy bulge. It is thus clear that the extent of the boxy bulge is shorter than that of the bar, as theoretically predicted (see Athanassoula 2005 for a discussion). Furthermore, the strong central concentration suggests an additional classical bulge component.



REFERENCES

- Athanassoula, E. 2005, MNRAS, 138, 1477
- Athanassoula & Beaton 2006, in preparation
- Beaton et al. 2006, in preparation
- Bettoni, D. & Galletta, G. 1994, *A&A*, 281, 1
- Lindblad, B. 1956, *Stockholms Observatoriums Annaler*, 2
- Shaw, M. 1993, *MNRAS*, 261, 718
- Stark, A. & Binney J. 1994, ApJL, 426, 31