How barred is our nearby universe?

A detailed NIR study of the local bar population - Setting the stage for studies of galaxy evolution

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Bars are ubiquitous in the nearby universe and play a critical role in evolving a galaxy: the gas inflow induced by the non-axisymmetry of the bar changes a galaxy's chemical abundance gradient [1], induces nuclear star formation [2-5], and may form bulges [6] and fuel active galactic nuclei [7]. These dramatic changes evolve a galaxy in a relatively short time (only a few hundred million years). Models have shown [8] that a disk is naturally unstable towards bar formation, unless the disk is dynamically hot and/or there exists a large enough central mass concentration. For this reason, at higher redshifts the presence of bars may signal the presence of massive, dynamically cold, rotationally-supported disks. Therefore, understanding their formation and evolution, both locally and cosmologically, is key to our understanding of galaxy dynamics and evolution. But we must first set the groundwork by performing a detailed study of the bar population and bar properties in the local universe.

We selected the Two Micron All Sky Survey [9] (2MASS) to undertake such a study because the bar potential, which is mainly composed of the old stellar population, is best traced in the K-band [10]. The effects of dust extinction and star formation are also minimized in the near infrared compared to optical bands. My research focused on characterizing the bar fraction, bar sizes, strengths and the correlations between these properties and the host galaxy properties. From a sample of approximately 500 large galaxies in 2MASS, we selected all spirals S0/a - Sd, as classified in the RC3 catalog [11], with inclinations i < 65° (as provided by LEDA [12]), which resulted in a final sample of 134 spirals. Figure 1 shows the Hubble Type distribution of our final sample. [1]

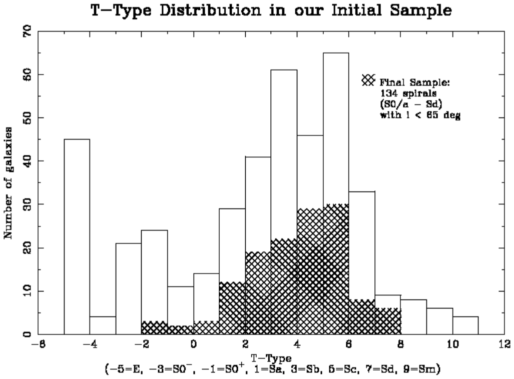

Figure 1: Histogram of T-types in initial 2MASS sample. The shaded region represents our final sample.

A bar is characterized by (1) a monotonic increase in ellipticity (ϵ = 1 - b/a) accompanied by a constant position angle (PA) followed by (2) a sharp drop in ϵ together with a change in PA. For each spiral, we fit elliptical isophotes to the J+H+K_s 2MASS image, examine the ϵ and PA profiles, and identify bars by requiring that $\Delta\epsilon > 0.1$ and $\Delta\mathrm{PA} > 10°$. An example of a nearly ideal bar with the ϵ and PA signatures is shown in Figure 2. The presence of spiral arms, signal-to-noise variations, etc., make the profiles deviate from the ideal signature. For instance, open spiral arms can mimic the ϵ signature but have a continuously varying PA (Figure 3). In galaxies where the bar and disk PAs are aligned, the ϵ signature is often present but there is no sharp change in the PA. Galaxies like these ones, with only one of the two signatures (typically ϵ), are identified as candidate bars.

Demanding that both signatures for a bar be

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[1] The galaxies incorporated into our sample were chosen to be S0/a - Sd spirals using their RC3 classification. Figure 1 shows the distribution as a function of T-types, which were provided by LEDA. Inconsistencies between RC3's Hubble and LEDA's T-type spiral class just reflect a slight difference between their classification schemes.

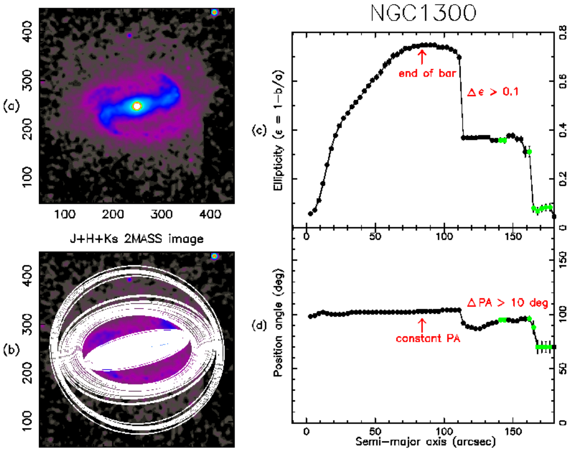

Figure 2: NGC 1300, an ideal bar signature: (a) J+H+K_s 2MASS image; (b) ellipse fit with IRAF; (c) ellipticity and (d) position angle profiles.

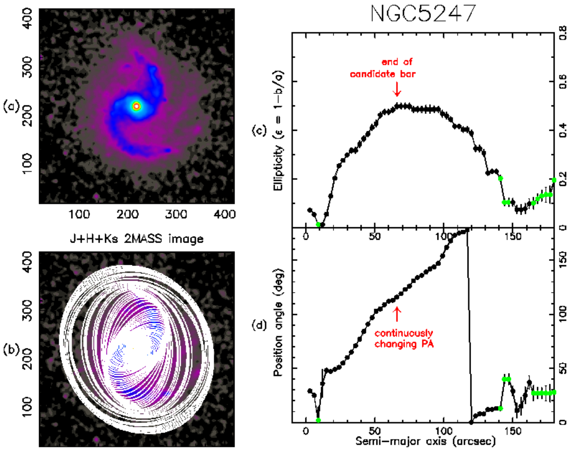

Figure 3: Same as Figure 2 for NGC 5247. Profiles show only an ϵ signature, mimicked by spiral arms, with no supporting PA signature.

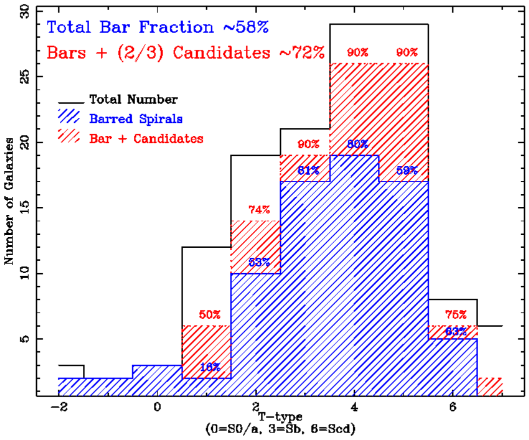

Figure 4: Bar fraction as a function of T-type. Histogram of spirals (top solid line), bars (blue) and candidate bars (red) as a function of T-type, including the bar fraction (blue) and the bar+candidate fraction (red).

present leads us to measure a bar fraction of 0.58. This is a lower limit given our conservative approach. Next, we visually inspected each candidate bar and found that approximately 2/3 are "real" bars. Including these raises the total bar fraction to 0.72 (see Figure 4). Neither of these fractions is substantially different from the 0.63 found by de Vaucouleurs [11]. Thus, although bars are easiest to identify in the infrared (and best characterized at these wavelengths), the bar fraction is not dramatically different from the B-band to the K-band. This is in contrast to previous studies that have suggested that many more bars may be unveiled in the infrared [13-17]; however, one caveat is that the 2MASS resolution is inadequate for detecting small (nuclear) bars.

To better understand the cosmological evolution of bars, it is necessary to understand their properties locally, such as the bar length and strength (characterized by the maximum ellipticity, [18, 19]). For the 2MASS sample, we measure a deprojected bar length median of approximately 10 kpc and an ellipticity of 0.51 (see Figures 5 and 6). Figure 5 shows

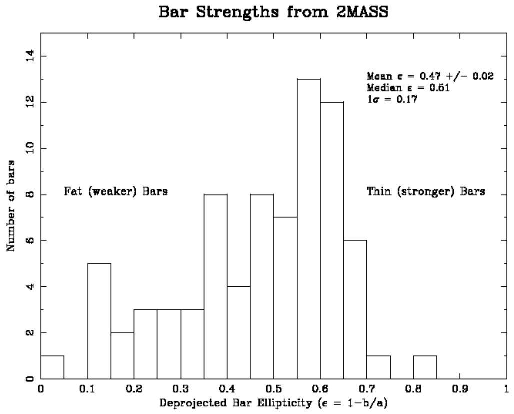

Figure 5: Distribution of ellipticities in the 2MASS bar sample. There is a marked decrease of very strong bars.

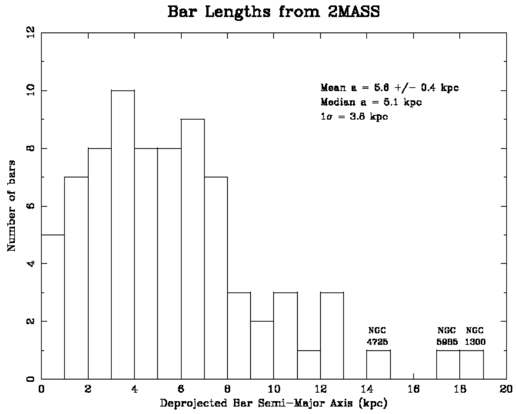

Figure 6: Distribution of bar semi-major axis sizes. The typical bar in 2MASS is approximately 10 kpc in length.

a marked dearth of strong bars; this result may be interpreted as evidence for bar destruction and reformation. The basic idea is that if bars are long-lived then one expects them to grow stronger; since we do not see many strong bars today, the current population may be a 2nd or a later generation of bars [20, 21]. However, there is an important caveat: in addition to the x1-family of periodic stellar orbits, which support the bar, there is the x2-family, whose orbits run perpendicular to the bar major axis. The finite extent of the x2 orbits thus sets a limit to how thin a bar may get. It is therefore possible that the dearth of strong bars is reflective of a lower limit on the extent of x2 orbits and not of bar destruction and reformation.

The local distribution of bar lengths shown in Figure 6 is critical for understanding the evolution of the bar fraction at higher redshifts. The coarse angular resolution and shallow depth of 2MASS is a nice counterpart to high redshift studies, which suffer from surface brightness dimming and coarse linear resolution. In both cases we are sensitive to the largest and brightest galaxies. In 2MASS we find a median bar length of approximately 10 kpc. Comparison of this value with that found at higher redshifts, together with the bar fractions, can provide us with direct information on the change in the properties of the bar and/or galaxy population. Ultimately, we are interested in determining the epoch of bar formation, i.e., when did disks become sufficiently massive and cold to host bars? The relative size of a bar is important for dynamical studies of galaxy evolution. We measure a relative size (a_{25}/R_{25}) of 0.36 for our sample. Has this been the case at all redshifts? We also correlate the bar size to host galaxy parameters such as the galaxy size and brightness. We find that larger bars are typically found in larger and more massive galaxies. The evolution of such relationships with redshift is being tested with data from surveys such as COSMOS, GOODS and GEMS.

Our 2MASS study thus sets the groundwork for understanding the evolution of bars and their properties, along with evolution of the host galaxies. Large amounts of optical data now available can help us understand the bar evolution to z∼0.7 (where I-band observes rest-frame B-band). In the future, longer wavelength data (e.g., JWST, KECK NIR-AO) will allow us to look even further back to $z > 1$ when galaxy disks were forming. The field of bars is a rather young field that has received a great amount of attention in the last decade. However, many questions still remain unanswered. The high fraction of barred galaxies may indicate that (1) bars are very long-lived structures that remain once they are formed, or that (2) bars are being destroyed and reformed in such a way that the population of spirals containing bars remains high. Bar studies at higher redshift have already given rise to intriguing controversies concerning the evolution in the bar fraction [22-26]. Having a complete understanding of the local bar population in the near infrared is thus a prerequisite for understanding galaxy evolution.

References

[1] Martin, P., Roy, J.-R. 1994, ApJ, 424, 599

[2] Sersic, J. L., Pastoriza, M. 1965, PASP, 77, 287

[3] Sheth, K., Vogel, S. N., Regan, M. W., Thornley, M. D., Teuben, P. J., Helfer, T. T. 2004, ApJ, submitted

[4] Hawarden, T. G., Mountain, C. M., Leggett, S. K., & Puxley, P. J. 1986, MNRAS, 221, 41

[5] Ho, L. C., Filippenko, A. V., & Sargent, W. L. W. 1997, ApJ, 487, 591

[6] Norman, C. A., Sellwood, J. A., & Hasan, H. 1996, ApJ, 462, 114

[7] Shlosman, I., Frenk, J., & Begelman, M. C. 1989, Nature, 338, 45

[8] Ostriker, J. P., Peebles, P. J. E. 1973, ApJ, 186, 467

[9] Jarrett, T. H., Chester, T., Cutri, R., Schenider, S. E., Huchra, J. P. 2003, AJ, 125, 525

[10] Rix, H.-W., & Rieke, M. J. 1993, ApJ, 418, 123

[11] de Vaucouleurs, G. 1963, ApJS, 8, 31

[12] http://leda.univ-lyon1.fr

[13] Hackwell, J. A., & Schweizer, F. 1983, ApJ, 265, 643

[14] Scoville, N. Z., Matthews, K., Carico, D. P., Sanders, D. B. 1988, ApJ, 327, 61

[15] Thronson, H. A. Jr., Hereld, M., Majewski, S., Greenhouse, M., Johnson, P., Spillar, E., Woodward, C. E., Harper, D. A, Rauscher, B. J. 1989, ApJ, 343, 158

[16] Mulchaey, J. S., & Regan, M. W. 1997, ApJ, 482, 135

[17] Seigar, M. S., & James, P. A. 1998 MNRAS 299, 672

[18] Athanassoula, E. 1992, MNRAS, 259, 345

[19] Martin, P. 1995, AJ, 109, 2428

[20] Bournaud, F., & Combes, F. 2002, A&A, 392, 83

[21] Block, D. L., Bournaud, F., Combes, F., Puerari, I., Buta, R. 2002, A&A, 394, 35

[22] van den Bergh, S., Abraham, R.G., Ellis, R., Tanvir, N.R., Santiago, B.X., Glazebrook, K.G. 1996 ApJ 112,359

[23] Abraham, R.G., Merrifield, M.R., Ellis, R.S., Tanvir, N.R., Brinchmann, J. 1999 Mon. Not. R. Astron. Soc. 308, 569

[24] van den Bergh, S., Cohen, J.G., Hogg, D.W., Blandford, R. 2000 ApJ 120, 2190

[25] van den Bergh, S., Cohen, J.G., Crabbe, C. 2001 ApJ 122, 611

[26] Sheth, K., Regan, M.W., Scoville, N.Z., Strubbe, L. 2003 ApJ 592 L13