QUANTIFYING BAR STRENGTH: MORPHOLOGY MEETS METHODOLOGY

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Abstract
A set of objective bar-classification methods have been applied to the Ohio State Bright Spiral Galaxy Survey (Eskridge et al. 2002). Bivariate comparisons between methods show that all methods agree in a statistical sense. Thus the distribution of bar strengths in a sample of galaxies can be robustly determined. There are very substantial outliers in all bivariate comparisons. Examination of the outliers reveals that the scatter in the bivariate comparisons correlates with galaxy morphology. Thus multiple measures of bar strength provide a means of studying the range of physical properties of galaxy bars in an objective statistical sense.

Keywords: galaxies: fundamental parameters — galaxies: spiral — galaxies: statistics — galaxies: structure — infrared: galaxies

1. Introduction

The existence and importance of bars in spiral galaxies has been recognized for the entire history of extragalactic astronomy (Curtis 1912). Hubble (1936) included the barred (SB) and unbarred (S) classes as the tines of the tuning fork. de Vaucouleurs (1959) first noted that “barredness” is not a binary state, and invented the class SAB for galaxies that are detectably, but not strongly barred. The relevance of observed wavelength to the detection of bars was first pointed out by Hackwell & Schweizer (1983) who discovered a strong bar in their H-band image of the optical SAB NGC 1566. The most extensive demonstration of this issue to date is that of Eskridge et al. (2000). One of the shortcomings of the above-cited work is that it uses subjective bar classification. Subjective classification is a useful starting point, but to move toward a physical understanding of morphology requires the general adoption of an appropriate, quantifiable and objective metric. The problem is that bars do not lend themselves naturally to scalar quantification. There have been a large number of “bar-strength quantifiers” proposed and implemented by different groups, and all of them measure somewhat different things (e.g., Elmegreen &
Elmegreen 1985; Ohta et al. 1990; Martin 1995; Wozniak et al. 1995; Abraham & Merrifield 2000; Buta & Block 2001).

This presentation reports on the progress of a study to intercompare a set of different bar-strength quantifiers using a single large, and statistically complete sample of nearby spiral galaxies (the OSU sample – see Eskridge et al. 2002). The main purposes of the study are two-fold:

1) To determine how well different bar-strength classifiers compare to one another and study the sorts of situations in which they fail to agree.
2) To address how reliably we can study the bar fraction of high-$z$ galaxies. This follows from a comparison of the results from techniques that are most demanding of the observational data with those that are the least demanding.

Section 2 presents the methods included in this study. Section 3 presents some of the bivariate relations found. Section 4 includes a discussion of the findings to date and a summary of issues yet to be fully investigated.

2. Summary of Methods

The most data intensive method included in this study is the $Q_g$ “disk-torque” measure of Buta et al. (2004). It is a refinement of the $Q_b$ “bar-torque” measure of by Buta & Block (2001). Both of these methods are pure NIR methods by definition. The goal of these methods is to express the strength of the bar in terms of its gravitational effect on the surrounding disk. In principle, this is an excellent physical means of measuring bar strength. In practice, the methods requires assumptions about disk structure that are difficult to verify. They also require high spatial resolution, high S/N images, and are very laborious to implement.

Both of these methods are based on Fourier-mode decomposition. In its simplest guise, the Fourier-mode method amounts to measuring the strength of the constant-phase $m = 2$ mode in an image. This study uses analysis by D. Elmegreen and her students, following Elmegreen & Elmegreen (1985).

A method proposed by Abraham & Merrifield (2000) measures bar strength by the maximum ellipticity of the inclination-corrected disk. It is thus most sensitive to long, thin bars. The method was refined by Whyte et al. (2002), who also applied it to the OSU survey sample. This study uses the results of Whyte et al. (2002).

The complete study will consider the neural-net method of Odewahn et al. (2002), developed for automated classification of high-redshift galaxies. It is the most forgiving of data quality. These results are not yet available.

3. A Selection of Bivariate Results

Figures 1–3 show a selection of bivariate comparisons amongst $Q_g$ (Buta et al. 2004), the $H$-band $m=2$ Fourier mode amplitudes (from D. Elmegreen),
and the $B$- and $H$-band Abraham bar parameter $F_{\text{bar}}$ (Whyte et al. 2002). In all cases, statistically significant correlations exists (at better than the $10^{-4}$ level from a variety of tests), but with substantial scatter and large outliers. The dashed lines are the ordinary least-squares bisectors.

![Figure 1. H-band $m=2$ Fourier mode against $Q_g$.](image)

4. Summary and Future Work

It is a great reassurance that all the methods examined here provide statistically self-consistent results, even when comparing different methods in different wave-bands (NIR torque methods compared with $B$-band bar ellipticity, as an example). Thus any of the methods discussed here can provide a good statistical means of measuring bar strength. This argues that bar-strength analysis of high-redshift galaxy samples can, at least in principle, be compared with analysis of nearby systems even when the observations are different rest-frame wavelengths, and at very different spatial sampling. The inclusion of neural-net techniques to the current study promises to be a very interesting advance.

A more careful examination of the bivariate results reveals that even very similar methods tend to have significant scatter between them, and the occasional very substantial outlier. The existence of these outliers actually gives us the opportunity to study the failure modes of the various techniques under consideration. As an example, the two systems with the largest $H$-band $F_{\text{bar}}$ for their $Q_g$ values (the points on the bottom right of Fig. 2b) are NGC 3166 and NGC 4772. Both these galaxies have $H$-band morphologies of SB0 (Eskridge
et al. 2002), with relatively large bulges and weak disks. The $F_{\text{bar}}$ statistic is very good at describing such bars, but $Q_g$ is not. This is due to the relatively strong bulges causing the effective torque from the bars to be small. In the same plot, the two galaxies with the largest $Q_g$ for their $H$-band $F_{\text{bar}}$ values are NGC 1042 and NGC 3319. Both these systems have grand design spiral patterns and short bars. The shortness of the bars appears to drive the low $F_{\text{bar}}$ values. But the combination of the bars and the strong spiral patterns results in
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a large disk torque. A true $Q_b$ analysis, as discussed in Buta et al. (2003), will improve the sensitivity of torque-based analysis to pure bar components. The scatter in the bivariate plots is generally correlated with morphological patterns in the sample. The use of multiple measures of bar strength thus offers us the opportunity to study full range of the physical properties of bars in an objective, statistical sense.

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