Bars in Starbursts and AGNs – A Quantitative Reexamination

Lei Hao, Shardha Jogee, Fabio D. Barazza, Irina Marinova, and Juntai Shen
1. Department of Astronomy, University of Texas, Austin, Texas 78712, USA.
2. Laboratoire d’Astrophysique, École Polytechnique Fédérale de Lausanne (EPFL), Observatoire de Sauverny CH-1290 Versoix, Switzerland

Abstract. Galactic bars are the most important driver of secular evolution in galaxies. They can efficiently drive gas into the central kiloparsec of galaxies, thus feed circumnuclear starbursts, and possibly help to fuel AGN. The connection between bars and AGN activities has been actively debated in the past two decades. Previous work used fairly small samples and often lacked a proper control sample. They reported conflicting results on the correlation between bars and AGN activity. Here we revisit the bar-AGN and bar-starburst connections using the analysis of bars in a large sample of about 2000 SDSS disk galaxies (Barazza, Jogee, & Marinova 2008). We find that AGN and star-forming galaxies have similar optical bar fractions, 47% and 50%, respectively. Both bar fractions are higher than that in inactive galaxies (29%). We discuss the implications of the study on the relationship between host galaxies and their central activities.

1. Introduction

Large-scale bars are very common in disk galaxies. At near infrared (NIR) wavelengths, the optical bar fraction averaged across different Hubble types is \( \sim 60\% \) from quantitative bar identification methods, such as the ellipse fitting and structural decomposition (e.g. Laurikainen et al. 2004; Marinova & Jogee 2007; Menéndez-Delmestre et al. 2007; Weinzierl et al. 2009), and is \( \sim 72\% \) from visual classification (Eskridge et al. 2000). At optical wavelengths, quantitative methods yield an average optical bar fraction of 45% to 52% (Marinova & Jogee 2007; Barazza, Jogee, & Marinova 2008; Aguerri, Méndez-Abreu, & Corsini 2009), while visual classification yields \( \sim 60\% \) (de Vaucouleurs 1963). The optical bar fraction is somewhat lower than the NIR fraction due to the obscuration of bars by dust lanes and star formation along the bar.

Several studies have now moved beyond considering only the bar fraction averaged over many Hubble types. They investigated how the optical bar fraction varies with the Hubble types or host properties. The optical bar fraction rises in galaxies with low Bulge-to-Disk ratio or/and high luminosity (Odvhalnin 1996; Barazza et al. 2008, 2009; Aguerri et al. 2009; Marinova et al. 2009).

The non-axisymmetric stellar bar can drive gas from the outer disk to the central kiloparsec, where they trigger star formation. This is supported by
several observations, which show that barred galaxies host high gas densities and circumnuclear starbursts (e.g. Jogee, Scoville, & Kenney 2005) and that the central gas concentration is larger in barred than unbarred galaxies (e.g. Sakamoto et al. 1999; Sheth et al. 2004). Due to their efficiency in driving gas inflows in the disks, bars are strong candidates for the triggering of nuclear activities.

There is strong evidence for a connection between large-scale bars and circumnuclear starbursts. Barred galaxies show enhanced radio continuum and infrared emissions compared with unbarred ones (e.g. Hummel 1981; Hawarden et al. 1986), and starburst galaxies tend to be more barred compared with the non-starburst galaxies (e.g. Arsenault 1989; Huang et al. 1996; Ho, Filippenko, & Sargent 1997; Hunt & Malkan 1999). Bars can also set up resonances, such as the inner Lindblad resonances (ILRs), which can prevent the gas from going further in. Therefore, gas often builds up on a ring (a few hundred parsecs in radius) and the circumnuclear starbursts can occur there (e.g. Jogee et al. 2005).

The connection between bars and AGNs is less clear (see Jogee 2006 for a review). Over the last two decades a large number of studies were carried out to identify if such a correlation exists. Most of them compared the bar fraction of the AGN sample with that of a control sample of inactive galaxies. The results are controversial. For example, studies like Ho et al. (1997), Hunt & Malkan (1999), Mulchaey & Regan (1997), and Martini et al. (2003) found no excess of bars in Seyfert galaxies, while Knapen, Shlosman, & Peletier (2000), Laine et al. (2002), and Laurikainen, Salo, & Buta (2004b) reported a higher fraction of bars in Seyferts.

Previous studies are limited in several aspects. Firstly, the sizes of the samples are often small, including only a few tens of AGNs and control galaxies. In some cases, the control sample was not well matched to the active sample. Secondly, identifications method for bars are not always consistent across samples. Thirdly, the spectral classifications of galaxies as AGNs or inactive galaxies are significantly inconsistent. Most studies adopted the galaxy classifications in NASA/IPAC NED, which could be done by different people using different criteria. Our study tries to overcome some of these limitations by systematically investigating the optical bar fraction of AGNs and non-AGNs in a large number of galaxies from the Sloan Digital Sky Survey (SDSS), using matched active and control samples, and the same consistent quantitative method for identifying bars across samples.

2. The Sample and Their Spectral Classifications

Our sample is based on the one in Barazza et al. (2008). From the 3692 galaxies in the Sloan Digital Sky Survey (SDSS) with $18.5 < M_g < -22.0$ mag and redshift $0.01 < z < 0.03$, Barazza et al. (2008) selected 1961 disk galaxies via their blue colors. They applied ellipse fitting to find and characterize bars in these disk galaxies. They exclude 169 disk galaxies with failed or messy ellipse fittings, or ambiguous classifications from the final analysis. 648 galaxies were classified as highly-inclined galaxies ($i > 60^\circ$) and disregarded as morphological analysis is unreliable for such systems. In the final sample of 1144 moderately inclined galaxies, 553 were barred galaxies, and 591 were unbarred galaxies.
All the 1792 disk galaxies have corresponding SDSS spectra, which are taken with a 3" aperture, with a spectral resolution of 2200 covering a wavelength range from 3700 Å to 9000 Å. The 3" aperture size corresponds to 606 pc to 1.78 kpc over 0.01 < z < 0.03, therefore, our spectra and the corresponding spectral classifications are done to the circumnuclear region of a typical disk galaxy. The spectral classification of these galaxies are done with various emission lines in the SDSS spectra. We process the spectra, measure the emission lines, and classify the galaxies following Hao et al. (2005). In particular, we measure the emission lines after removing the stellar absorption using a set of well-developed absorption-line templates. Galaxies with weak or no emission lines, defined specifically by having EW(Hα) < 3Å, are selected first. Such galaxies have little gas and are considered “inactive” in our study. The rest have strong enough emission lines indicating some activities in their nuclei. Galaxies with broad Hα emission lines (FWHM(Hα) > 1200 km/s) are automatically classified as AGNs, as broad emission lines are distinctive features of Seyfert 1 like AGNs. In our sample, there are 6 broad-line AGNs. For the remaining emission line galaxies, we classify them using the BPT diagram (Baldwin, Phillips, & Terlevich 1981).

In Figure 1, we plot on the BPT diagram our sample of barred and unbarred galaxies in the upper and lower panel respectively. In the diagram, galaxies naturally distribute in two branches, indicating different excitation mechanisms. AGNs locate in the right branch, with stronger AGNs typically having higher [NII]/Hα and [OIII]/Hβ ratios. Galaxies with pure stellar excitation are located in the left branch, and those with lower metallicities have higher [OIII]/Hβ but lower [NII]/Hα ratios. The solid line, empirically defined by Kauffmann et al. (2003), separates the two branches. These authors classify galaxies below the line as star forming galaxies, and those above it as AGNs. The dot-dashed line is taken from Kewley et al. (2001), and demarcates the maximum position that can be obtained by pure photo-ionization models. Galaxies located above the line require an additional excitation mechanism, such as an AGN, or strong shocks. The general classification scheme using the two separation lines considers objects above Kewley’s line as AGN dominated sources, between Kewley’s and Kauffmann’s line as composite AGN and starburst sources, and below the Kauffmann’s line as star forming galaxies.

Since the locations of galaxies on the BPT diagram broadly reflect the properties of their nuclear activities, such as the dominance of the AGN component or the metallicity of the pure stellar-excited galaxies, we further divide galaxies into spectral classes of 0 to 6 based on their locations on the diagram (as shown in Figure 1). We would like to investigate whether the optical bar fraction changes with these nuclear properties. Galaxies with spectral classes of 0 to 3 are broadly considered as star-forming galaxies, and 4 to 6 as AGNs. We assign inactive galaxies, which have little emission lines as spectral class of −1.

We check the distributions of various host galaxy properties of galaxies with different spectra classifications, such as the redshift range, the r-band absolute magnitude, the stellar mass, and the sersic index. We found no significant differences of the host galaxy properties between inactive galaxies and star-forming galaxies or active galaxies.
Figure 1. The BPT diagram for optically barred (upper) and optically unbarred (lower) galaxies in our sample. The solid line is taken from Kauffmann et al. (2003), and the dot-dashed line is taken from Kewley et al. (2001). We divide galaxies into seven spectral classes (indicated by dashed, solid, and dot-dashed lines) by their locations on the diagram, marked with the numbers.

3. Results

In Figure 1 we find no clear differences between the distributions of barred and unbarred galaxies on the BPT diagram. Another way to look at it is shown in the upper panel of Figure 2 where we plot the optical bar fraction of galaxies with different spectral classifications (−1 to 6) defined by their locations on the BPT diagram (see Section 3). We find that inactive galaxies have the lowest optical bar fraction with only 29%. Galaxies with other spectral classes have similar bar fraction within the error bars. This is more obvious when we combine the spectral class of 0 to 3 as starbursts and 4 to 6 as AGNs. The optical bar fraction of inactive galaxies, starburst galaxies, and AGNs are shown in the lower panel of Figure 2. We find that the optical bar fractions of AGNs and starburst galaxies are similar, at 50% and 47% respectively, both are about \( \sim 1.6 \) times higher than the optical bar fraction of the inactive galaxies.
Figure 2. The optical bar fractions as a function of spectral classes defined in Figure 1 are shown in the upper panel. Galaxies with spectral class of $-1$ are inactive galaxies, 0 to 3 can be considered as star-forming galaxies, and 4 to 6 as AGNs. In the lower panel, we show the optical bar fraction for galaxies of the three broad classifications. The numbers at the top of each figure are the total number of moderately inclined disk galaxies in each spectral class.

Our result suggests that AGNs have an excess optical bar fraction compared with the inactive galaxies, but show no excess compared with the starburst galaxies. Therefore accurate and consistent spectroscopic classification of both the AGN sample and the control sample is important in evaluating the excess of bars in AGNs. Many previous studies have overlooked this issue. Among three studies (Ho et al. 1997; Hunt & Malkan 1999; Laurikainen et al. 2004b) where we can clearly decide the dominant spectral classes of the comparing sample, our result agrees with two of them. The comparing sample in Ho et al. (1997) is mainly composed of star-forming galaxies and they found no excess optical bar fraction in AGNs, which agrees with our result. Based on the classification in NED, Laurikainen et al. (2004b) divide galaxies into Seyferts, LINERs, starbursts, and inactive galaxies. They found a similar NIR bar fraction for Seyfert galaxies, LINERS, and HII/starburst galaxies at 72%, compared to 55% in non-active galaxies. The pattern also agrees with our result. The absolute values of
the NIR bar fraction in [Laurikainen et al. (2004b)] are higher than our optical bar fraction. This could be due to two factors. Firstly, the NIR bar fraction is known to be higher than the optical one by a factor of $\sim 1.3$ (see § 1), due to the obscuration of bars by dust and star formation. Secondly, the number of barred galaxies could be underestimated by a factor of 1.14 in [Barazza et al. (2008)], as they regard galaxies with twisted position angles, but otherwise bar-like features to be unbarred galaxies. These galaxies could be weakly barred galaxies.

Our result however, disagrees with [Hunt & Malkan (1999)], who found that the Seyfert and LINERs in the Extended 12 $\mu$m Galaxy Sample (E12GS) have an optical bar fraction of 68% and 61%, similar to the inactive galaxies in the E12GS at 69%. Star-forming galaxies in their sample have a higher optical bar fraction (85%) than both inactive galaxies and Seyferts. Our disagreement could be due to two factors. Firstly, [Hunt & Malkan (1999)] used RC3, which is the visual classification to identify bars. Therefore, their optical bar fractions are higher than ours where bars are identified by ellipse fitting (see § 1). Secondly, the spectral classifications of galaxies in [Hunt & Malkan (1999)] are adopted from NED. Galaxies with composite AGN and star-forming contributions can easily be mis-identified.

![Figure 3](image-url)

**Figure 3.** The bar ellipticity of optically-visible bars as a function of the spectral classes defined in Figure 1. The big asterisks are the mean ellipticity of galaxies in each spectral class.

From the ellipse fitting, [Barazza et al. (2008)] also obtained the ellipticity of optically visible bars. In Figure 3, we show the bar ellipticity of barred galaxies in different spectral classes. The value of the bar ellipticity varies widely for
every spectral class. We plot the mean of the bar ellipticity of each spectral class with big asterisk and find it does not change with spectral classes. In particular, galaxies with stronger AGN component (from spectral class 4 to 6) do not show weaker bar strengths. Therefore, we find no indication of bar weakening by AGNs. This is consistent with the theoretically robustness of bars (e.g. Shen & Sellwood 2004; Athanassoula, Lambert, & Dehnen 2005). They estimate that central mass concentrations in the form of super-massive black holes in present-day galaxies fall well below the limit to significantly weaken bars.

4. Conclusions

With the classification and structural information of \(\sim\) 2000 disk galaxies from the SDSS (Barazza et al. 2008), we study the optical bar fraction of AGNs, star-forming, and inactive galaxies from the sample. We find that the optical bar fraction of the AGNs is 47%, similar to the optical bar fraction of the star-forming galaxies (50%). Both are higher than the optical bar fraction of the inactive galaxies (29%). This suggests that accurate and consistent spectral classification is important in evaluating whether there is an excess of bars in AGNs, and could be the reason for controversial results reported in previous studies on the issue. Our study has several improvements compared to previous ones. The size of our sample is large. We have consistent SDSS spectra for all our galaxies, therefore, we can obtain accurate and consistent spectral classifications for the sample. In addition, the SDSS spectra are taken with the 3'' aperture, which corresponds to 606 pc to 1.78 kpc in the redshift range of 0.01 < \(z\) < 0.03. This scale matches well with the typical circumnuclear region of a galaxy, therefore, the spectra are perfect at probing the circumnuclear stuburs.

We find an excess of the optical bar fraction of star-forming galaxies and AGNs compared to the inactive galaxies. This suggests that large-scale primary bars drive gas to inner kpc where they pile up near the ILRs, fueling circumnuclear starbursts. The gas pile up is in someway also related with the increase of the AGN activity. But to feed the AGN directly, the gas in the inner kpc still has to reduce its angular momentum by several orders of magnitude (see Figure 3 in Jogee 2006) and a secondary mechanism is then needed to drive the gas further in (e.g., nuclear bars, dynamical friction). The latter may not be necessarily coupled to the primary bar. This agrees with our result that we do not observe an excess of bar fraction of AGNs compared to the star-forming galaxies. Furthermore, we find no evidence of bar weakening by AGNs. This agrees with previous theoretical expectations (Shen & Sellwood 2004; Athanassoula et al. 2005).

There is one caveat of our study. Our bar identification is based on the optical data instead of NIR, therefor our bar fraction is in general lower than the typical NIR bar fraction. However, we do not expect our comparative results to change, unless the obscuration of bars by dust and star formation have preferential effects.

References

Aguerri, J. A. L., Méndez-Abreu, J., & Corsini, E. M. 2009, A&A, 495, 491
Arsenault, R. 1989, A&A, 217, 66
Athanassoula, E., Lambert, J. C., & Dehnen, W. 2005, MNRAS, 363, 496
Baldwin, J. A., Phillips, M. M., & Terlevich, R. 1981, PASP, 93, 5
Barazza, F. D., et al. 2009, A&A, 497, 713
Barazza, F. D., Jogee, S., & Marinova, I. 2008, ApJ, 675, 1194
de Vaucouleurs, G. 1963, ApJS, 8, 31
Eskridge, P. B., et al. 2000, AJ, 119, 536
Hao, L., et al. 2005, AJ, 129, 1783
Hawarden, T. G., Mountain, C. M., Leggett, S. K., & Puxley, P. J. 1986, MNRAS, 221, 41P
Ho, L. C., Filippenko, A. V., & Sargent, W. L. W. 1997, ApJ, 487, 591
Huang, J. H., Gu, Q. S., Su, H. J., Hawarden, T. G., Liao, X. H., & Wu, G. X. 1996, A&A, 313, 13
Hummel, E. 1981, A&A, 93, 93
Hunt, L. K., & Malkan, M. A. 1999, ApJ, 516, 660
Jogee, S. 2006, in Lecture Notes in Physics, Berlin Springer Verlag, Vol. 693, Physics of Active Galactic Nuclei at all Scales, ed. D. Alloin, 143
Jogee, S., Scoville, N., & Kenney, J. D. P. 2005, ApJ, 630, 837
Kauffmann, G., et al. 2003, MNRAS, 346, 1055
Kewley, L. J., Dopita, M. A., Sutherland, R. S., Heisler, C. A., & Trevena, J. 2001, ApJ, 556, 121
Knapen, J. H., Shlosman, I., & Peletier, R. F. 2000, ApJ, 529, 93
Laine, S., Shlosman, I., Knapen, J. H., & Peletier, R. F. 2002, ApJ, 567, 97
Laurikainen, E., Salo, H., Buta, R., & Vasilyev, S. 2004a, MNRAS, 355, 1251
Laurikainen, E., Salo, H., & Buta, R. 2004b, ApJ, 607, 103
Marinova, I., & Jogee, S. 2007, ApJ, 659, 1176
Marinova, I., et al. 2009, ApJ, 698, 1639
Martini, P., Regan, M. W., Mulchaey, J. S., & Pogge, R. W. 2003, ApJ, 589, 774
Menéndez-Delmestre, K., Sheth, K., Schinnerer, E., Jarrett, T. H., & Scoville, N. Z. 2007, ApJ, 657, 790
Mulchaey, J. S., & Regan, M. W. 1997, ApJ, 482, L135
Odewahn, S. C. 1996, in Astronomical Society of the Pacific Conference Series, Vol. 91, IAU Colloq. 157: Barred Galaxies, ed. R. Buta, D. A. Crocker, & B. G. Elmegreen, 30
Sakamoto, K., Okumura, S. K., Ishizuki, S., & Scoville, N. Z. 1999, ApJ, 525, 691
Shen, J., & Sellwood, J. A. 2004, ApJ, 604, 614
Sheth, K., Blain, A. W., Kneib, J.-P., Frayer, D. T., van der Werf, P. P., & Knudsen, K. K. 2004, ApJ, 614, L5
Weinzirl, T., Jogee, S., Khochfar, S., Burkert, A., & Kormendy, J. 2009, ApJ, 696, 411