

Galaxy Zoo-UKIDSS : near-infrared morphologies[★]

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ABSTRACT

GZ-UKIDSS: the abstract.

Key words:

galaxies: bars — galaxies: evolution — galaxies: general — galaxies: spiral

1 INTRODUCTION

Because galactic stellar bars form only within dynamically cold, rotationally supported disks (Combes 2009; Athanassoula, Machado & Rodionov 2013), the evolution of the fraction of disk galaxies with bar features traces the overall evolution of disk galaxy dynamics. Locally, bars are present in $\sim 25 - 50\%$ of disk galaxies (e.g. Masters et al. 2011; Aguerri, Méndez-Abreu & Corsini 2009), with their abundance steadily decreasing to $\sim 10\%$ of disk galaxies at $z \sim 1$ (Sheth et al. 2008; Elmegreen, Elmegreen & Hirst 2004).

However, these results have shown that the observed bar fraction in large samples of galaxies has a strong dependence on the observing wavelength. Optical studies consistently reveal results toward the lower end of this range (Masters et al. 2011), while infrared results uncover older stellar populations that trace the bar potential in larger numbers of galaxies (Sheth et al. 2008). As a result, it is critical for cosmological studies that the rest frame of the galaxies remain constant as a function of redshift (see Melvin et al. 2014 in press, Simmons et al. 2014 in prep).

In this paper, we use combine previous optical studies of bars in the local Universe collected by the Galaxy Zoo 2 (GZ2) project (Willett et al. 2013) with new classifications in the infrared. The new images were taken with the United Kingdom Infrared Telescope (UKIRT) as part of the UKIRT Infrared Deep Sky Survey (UKIDSS; Lawrence et al. 2007; Warren et al. 2007). The Large Area Survey (LAS) portion of UKIDSS covered the SDSS observations at high Galactic latitudes, allowing for *YZJHK* coverage for 71,052 galaxies that had also been classified in GZ2. This paper compares the optical and infrared morphologies of these galaxies and

study the evolution of their overall bar fraction as a function of wavelength and colour.

In Section 2 we describe the sample selection, including a summary of Galaxy Zoo 2 classifications of UKIDSS galaxies and the identification of bars in non-inclined disks. We also explore any potential biases that may affect our results. We present our results in Section 3, with discussion in Section 4 and a summary in Section 5.

This paper uses a cosmology consistent with Λ CDM, having $H_0 = 70 \text{ km s}^{-1} \text{ Mpc}^{-1}$, $\Omega_m = 0.3$ and $\Omega_\Lambda = 0.7$ (Bennett et al. 2013; Planck Collaboration et al. 2013).

2 DATA

2.1 UKIDSS

Details about UKIDSS area coverages and depth.

Number of objects total above some flux limit, from which we have visual classifications from the Galaxy Zoo project.

2.2 SDSS

2.3 Morphological classifications

The Galaxy Zoo project provides quantified visual classifications of galaxies by obtaining multiple independent classifications for each galaxy. Beginning in 2007, more than 1,000,000 galaxy images total from both the Sloan Digital Sky Survey and the *Hubble Space Telescope* were each classified by ~ 40 independent volunteers via a web interface¹. The initial version of the project (Lintott et al. 2008,

[★] This publication has been made possible by the participation of more than 200,000 volunteers in the Galaxy Zoo project.

¹ www.galaxyzoo.org

2011) asked a single question per galaxy; subsequent versions have collected more detailed morphological information, including finer sub-structures of disk galaxies such as bulge strength and bars, via a tiered classification tree (e.g., Willett et al. 2013).

This work uses classifications collected during the second release of the project: Galaxy Zoo 2.

The classification tree used for GZ-UKIDSS is identical to that in GZ2, precisely so that the two datasets can be compared using the same morphological definitions. The tiered decision tree (Willett et al. 2013) first asks volunteers to choose whether a galaxy is mostly smooth, has features, or is a star/artifact. The bar classification question (“Is there a sign of a bar feature through the centre of the galaxy?”) is reached once a volunteer has chosen “Features or Disk” as an answer to the first question and has subsequently said the galaxy is *not* an edge-on disk. The bar vote is therefore a third-tier question, and the number of volunteers per galaxy who answer the question varies depending on each volunteer’s answers to the earlier questions about the galaxy.

What are average number of answers N for the bar classification question overall? In non-edge-on disks?

2.4 Sample selection

A full reduction of the GZ-UKIDSS classifications, resulting in a catalog of morphological vote fractions for each galaxy, is ongoing. Here we use the raw vote fractions, which have been neither weighted nor debiased (by a procedure similar to Willett et al. 2013). We also use the raw GZ2 vote fractions for strict comparison, rather than the “debiased” data products available from Willett et al. (2013). The effects of using raw versus the reduced classifications are twofold. First, the unweighted vote fractions are likely biased in the first question toward an excess of votes for “Star or Artifact”. Second, the effects of surface brightness dimming are not accounted for in the vote fractions, which is a minor effect for galaxies in which disk structure is previously identified and within a relatively small spatial volume ($z < 0.1$).

To minimize the impact of the lack of user weighting, we employed a lower vote fraction threshold when selecting “featured” galaxies compared to thresholds using weighted data. We select as “featured” galaxies those where at least 20% of votes (out of at least 10 volunteers total) were registered for “Features or Disk”. After the first question, the user weighting used by previous Galaxy Zoo data reductions affects vote fractions by typically no more than a few percent; we therefore expect the lack of weighting to have little to no systematic effect on additional vote fractions.

Further, we also require that 50% of volunteers (of at least 10) registered a vote for not-edge-on.

3 RESULTS: BAR FRACTIONS

4 DISCUSSION

5 CONCLUSIONS

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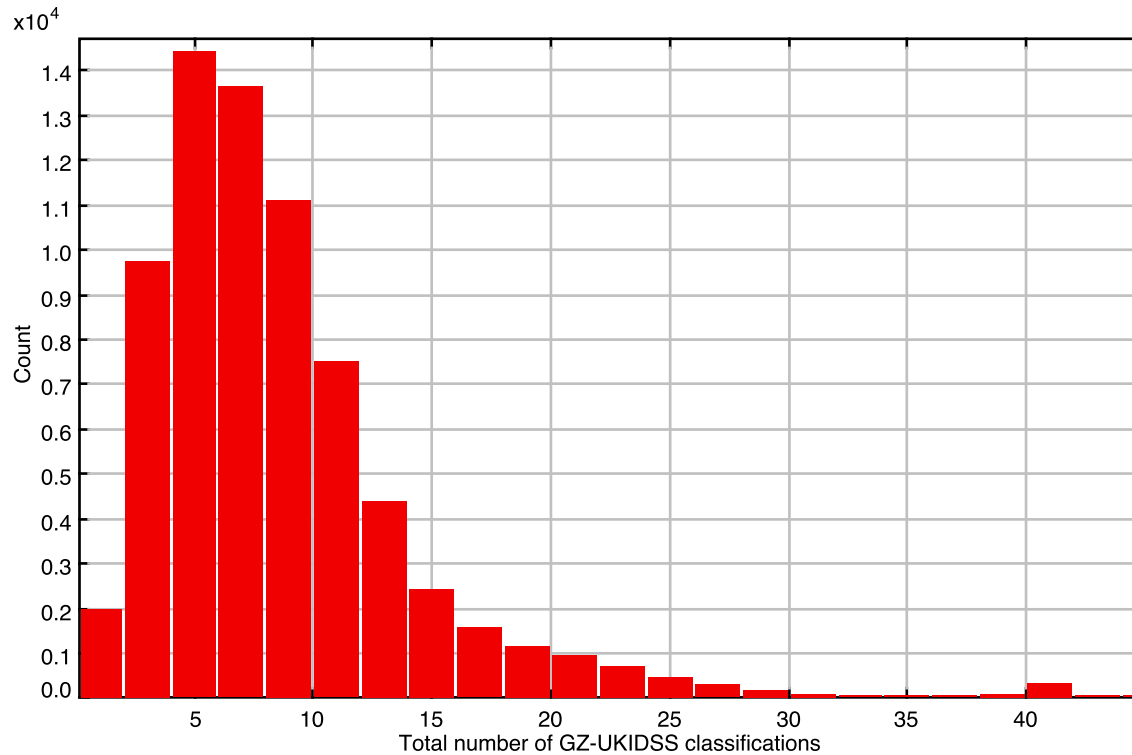


Figure 1. Total number of classifications in GZ-UKIDSS as of 12-Jan-2014. The median is 7 and mean 7.9 classifications per galaxy, with a long tail stretching out (log-normal distribution?) to $N = 44$. I do not know whether there is an active retirement algorithm in place for the UKIDSS images. Preliminary results suggest we will need at least 40 classifications per galaxy, though, since the shot noise for even relatively high-level questions is quite high.

Whyte L. F., Abraham R. G., Merrifield M. R., Eskridge
P. B., Frogel J. A., Pogge R. W., 2002, MNRAS, 336, 1281
Willett K. W. et al., 2013, MNRAS, 435, 2835
Wright E. L., 2006, PASP, 118, 1711

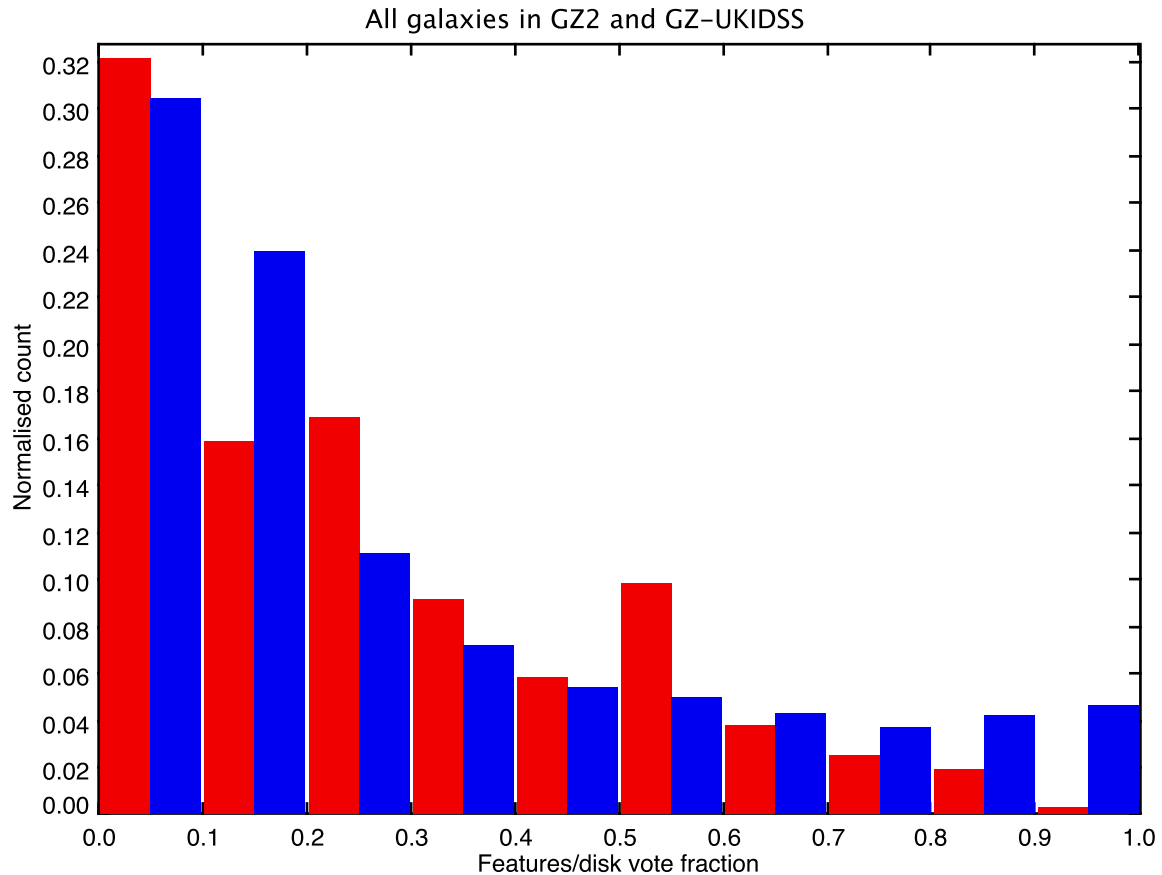


Figure 2. Distribution of the fraction of galaxies with features or disks ($f = N_{features/disk}/N_{classifications}$) in both **UKIDSS** and **GZ2**. UKIDSS galaxies have significantly fewer examples of feature/disk-dominated morphology than their GZ2 counterpart classifications, especially at $f > 0.9$. This sample contains 53,868 galaxies (note: this should match the entire GZ-UKIDSS sample of 71,052 galaxies; not yet sure why some aren't showing up in both).

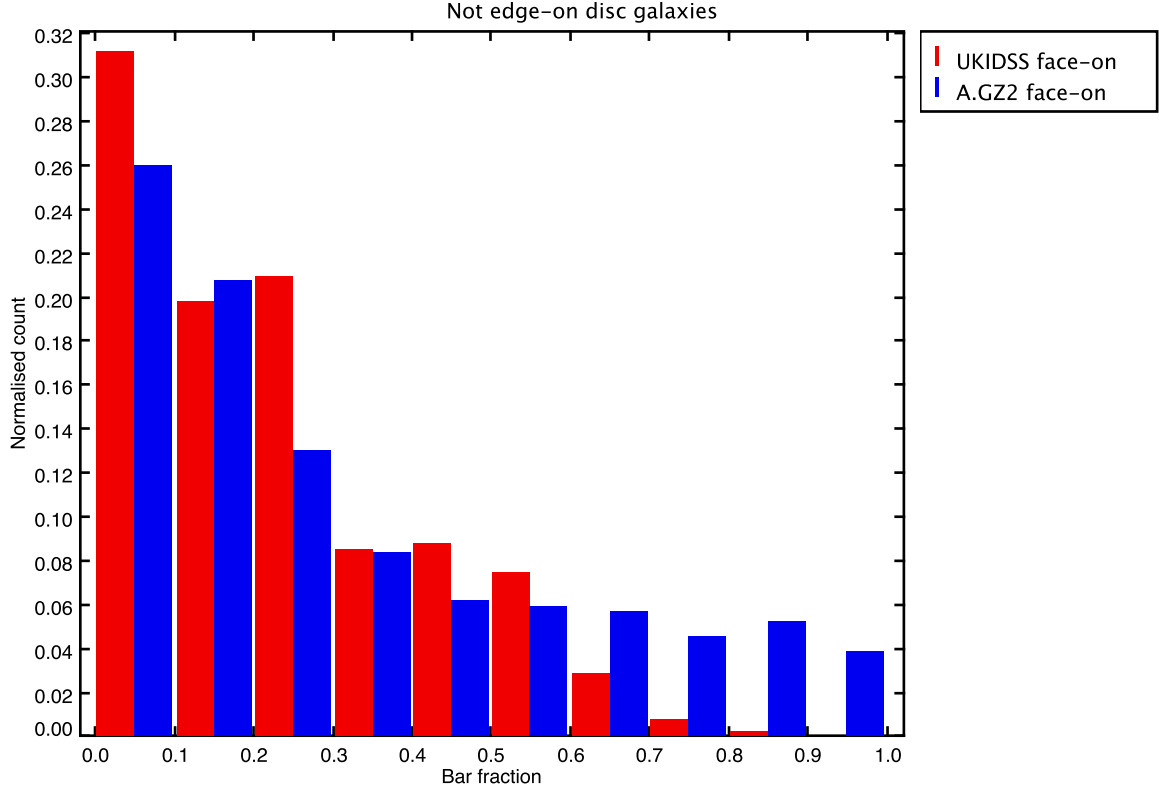


Figure 3. Distribution of the bar fraction ($N_{\text{bar}}/N_{\text{notedgeondisks}}$) in both **UKIDSS** and **GZ2**. The distributions are similar for low and intermediate bar fractions; however, UKIDSS has virtually no galaxies above a bar fraction of 0.7 (a common “clean” threshold in GZ1 and GZ2). The bar fraction is only measured for disk galaxies with $N_{\text{classifications}} \geq 10$, $f_{\text{features/disk}} \geq 0.2$, and $f_{\text{notedgeon}} \geq 0.5$; this is 1,178 galaxies, or 2% of the total sample. These disk galaxy criteria are significantly lower than those in GZ2 ($N_{\text{classifications}} \geq 20$, $f_{\text{features/disk}} \geq 0.430$, and $f_{\text{notedgeon}} \geq 0.715$).

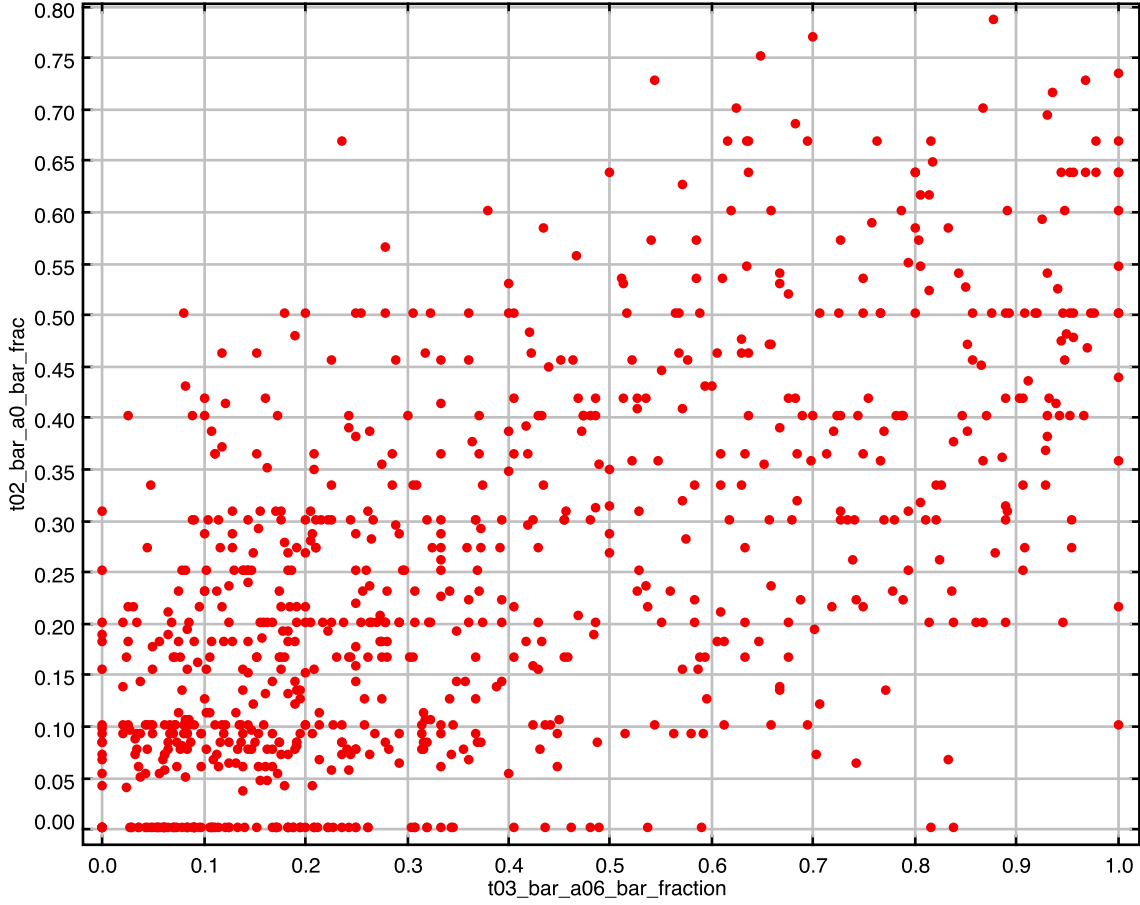


Figure 4. Bar fractions for matched disk galaxies classified in both GZ2 and GZ-UKIDSS (same as Figure 3). The data have a Spearman’s correlation coefficient of $\rho = 0.612$; this is statistically significant ($p < 10^{-85}$), but clearly the scatter is enormous. The best-fit line has a slope less than 1, consistent with the lack of strongly-identified bars in GZ-UKIDSS. Interestingly, there are very few galaxies in the upper left, which would be undetected in the optical and appearing in the infrared. This contradicts some of the initial expectations of the GZ-UKIDSS project and the higher bar fractions ($\sim 65\%$) measured in infrared studies Whyte et al. (2002); Marinova & Jogee (2007); Menéndez-Delmestre et al. (2007); Sheth et al. (2008) compared to optical (Barazza, Jogee & Marinova 2008; Masters et al. 2011; Lee et al. 2012).

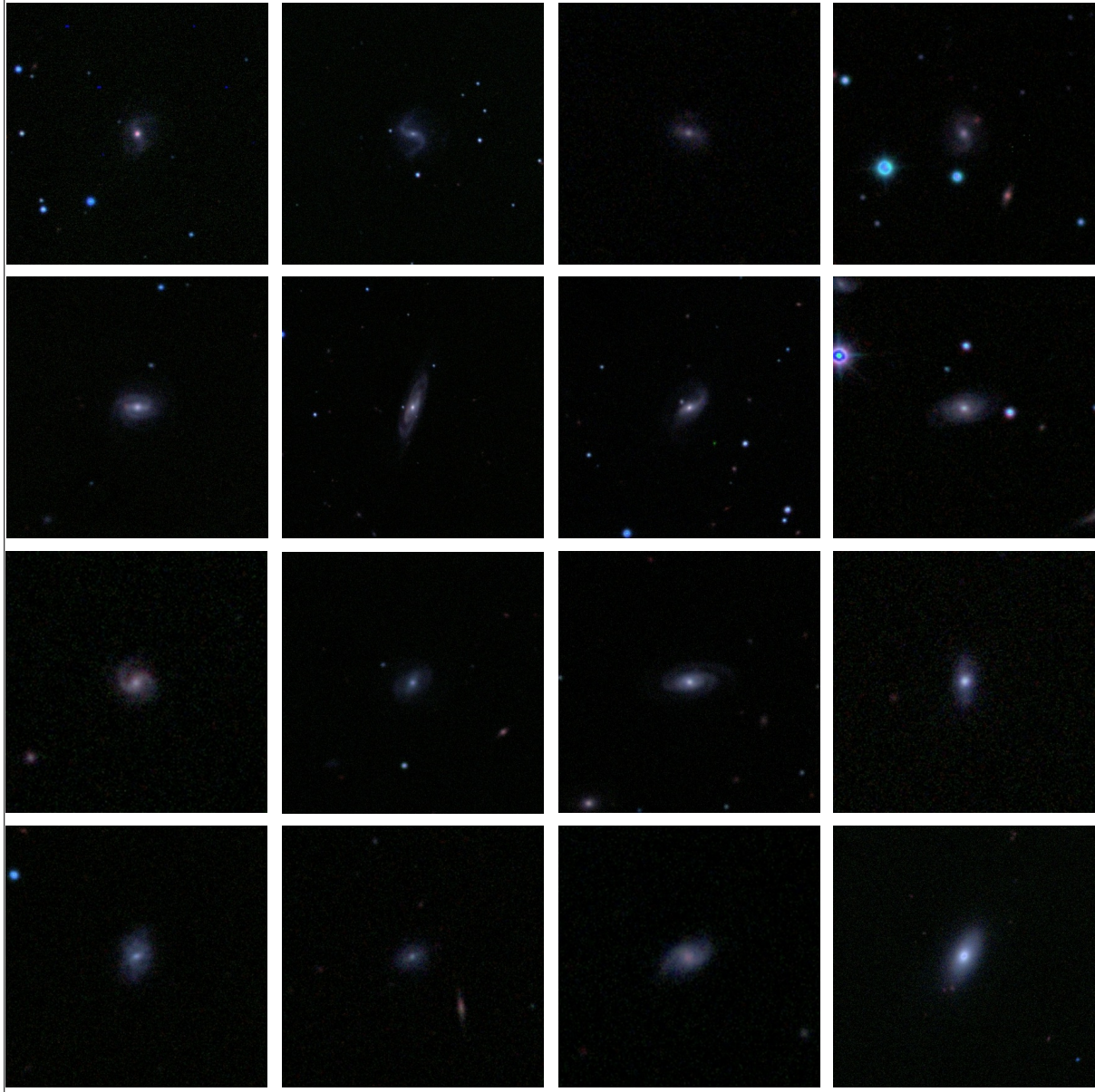


Figure 5. Example *YHK* images for various values of f_{bar} of GZ-UKIDSS disk galaxies (not edge-on). Starting in the top left and moving down, then rightward to the bottom right, the vote fraction for bars goes from $f_{bar} = 0.785$ (the highest in the matched category) to $f_{bar} = 0$. Interestingly, there are visible bars (according to experts KS and KWW) in almost all these randomly-selected images, and down to vote fractions as low as $f_{bar} = 0.1$. This suggests that GZ-UKIDSS classifiers have a much lower threshold for possible bar identification than GZ2, and *must* be evaluated with different criteria.



Figure 6. Example *YHK* images for two galaxies with very different bar classifications in GZ2 and GZ-UKIDSS. The top galaxy is a strong bar in the optical and a very weak bar in the infrared ($f_{bar,GZ2} = 1.0$, $f_{bar,UKIDSS} = 0.1$). The bottom galaxy is a strong bar in the infrared and weak bar in the optical ($f_{bar,GZ2} = 0.235$, $f_{bar,UKIDSS} = 0.667$). These represent the extreme examples of galaxies in the lower right and upper left corners, respectively, of Figure 4.