AGN Activity in Giant LSB Galaxies

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ABSTRACT

A search of large, HI-rich disk galaxies finds a significantly higher fraction of low luminosity AGN signatures compared to other late-type galaxies. Approximately half of the galaxies selected in this sample have AGN-like behavior in their cores, the rest have HII nuclei resulting from simple star formation. Since AGN behavior is not evident in all the sample galaxies, which where selected by high gas mass, we speculate that it is the fuel flow rate that is the common feature between late-type LSB disks and other active nuclear galaxies.

Subject headings: galaxies: active — galaxies: nuclear — galaxies: spiral

1. INTRODUCTION

There are several key questions to the evolution of active galactic nuclei (AGN) phenomenon only a few of which have begun to be addressed with current telescope technology. One concerns the amount of activity in the cores of galaxies, in the sense of whether it is common for galaxies to harbor a central engine or whether secondary effects, such as the availability of gas for fuel, determines the existence and nature of an AGN. A second problem as been the evolution of distant QSO’s, in particular, the fact that QSO’s are so dominant in the past and, yet, non-existent at the present epoch. It is assumed that the AGN in QSOs has faded with time as their fuel supply was depleted. But, the low luminosity, present-day counterparts have never successfully been identified (Filippenko 1989).

The amount of energy released by AGN’s occurs in such a small volume of space, based on variability analysis, that the implication is that their ultimate source of energy is gravitational release, most plausibly an accretion disk surrounding a massive black hole. An AGN is rarely directly visible from the radiation emitted through a flat, nonstellar photoionizing continuum; rather it is detected indirectly by reprocessed energy through optical lines. Therefore, although AGN’s are a strong source of $\gamma$-rays, x-rays and radio emission, detection by optical emission lines is the most reliable method for classification at low luminosities.

The occurrence of AGN’s in normal and starburst galaxies has been the subject of several studies (see Heckman 1987). For example, Kennicutt, Keel and Blaha (1989) find that half of galactic nuclei they surveyed showed evidence of a secondary nuclear component with either AGN or LINER characteristics. Ho, Filippenko and Sargent (1997, hereafter HFS) found that over half the galaxies in their magnitude-limited sample had AGN or LINER nuclear spectra, most frequent in early-type spirals. Many authors claim that a majority of spiral nuclei are composite in nature, with a central AGN surrounded by star forming regions (Pogge 1989). This makes a search for quiescent AGNs even more difficult since identification requires the separation of star-forming emission features from true non-thermal activity (i.e. the detection of low ionization lines characteristic to Seyfert and LINER phenomenon).

Previous searches for ‘dead’ AGN’s have centered on deep spectra of the cores of bright galaxies to detect low luminosity effects (Filippenko and Sargent 1985, HFS) or dynamic surveys of nearby galaxies.
to detect the high stellar velocities around massive black holes, assumingly the fuel-starved engines of the past (see Kormendy and Richstone 1995). This study pursues a different sample set by selecting the class of giant, low surface brightness (LSB) galaxies, known as Malin objects (Impey and Bothun 1989). Large LSB galaxies have been shown to have an unusually high occurrence of low level AGN activity, making them possible candidates for the present-day remnants of QSO’s (Sprayberry et al. 1993). Malin 1 and F568-6 (the prototypes to the Malin class) both display Seyfert 2 characteristics, although at very low luminosities (Impey and Bothun 1989, Bothun et al. 1990). Sprayberry et al. (1993) finds two of the eight large LSB galaxies in their survey have broad line, AGN spectra in their cores. This could be an observational selection effect, since it would be easier to detect a low intensity line emission in objects with low surface luminosity densities compared to the bright bulges of normal galaxies. However, it is unlikely that deep spectral surveys to have missed similar activity in higher surface brightness, late-type galaxies (see HFS).

In order to determine if AGN activity is common in giant LSB galaxies, and if such activity is unique to their intrinsic LSB nature, this project’s goal is to complete a spectroscopic survey of the nuclei of 34 giant, low surface brightness and nine giant, high surface brightness (HSB) galaxies selected to be massive in HI gas \((M_{HI} > 5 \times 10^9 \, M_\odot)\) and with diameters greater than 20 kpc. In general, AGN host galaxies are high in surface brightness with strong star formation signatures (Smith et al. 1986, Heckman et al. 1986, HFS). The fact that giant LSB galaxies are suspected to have a high rate of AGN activity, even at a low intensity level, may suggest that AGN’s are more frequent than previously thought and that a connection exists between surface density (either gas or stellar) and AGN intensity.

2. OBSERVATIONS

The data for this project was acquired on the Michigan-Dartmouth-M.I.T. (MDM) 2.4m telescope located on the southwest ridge of Kitt Peak National Observatory. There were two runs in September 1992 and January 1993 using the MkIIIb spectrograph at Cassegrain focus. The spectrograph detector was a TI CCD with 32 micron sized pixels. The September run used a 300 lines mm\(^{-1}\) grism blazed at 6000 Å with a resolution of 4.9 Å, the January run used 300 lines mm\(^{-1}\) grism blazed at 6400 Å with a resolution of 6.6 Å. A 2.8 arcsec slit was used to examined the 4800 to 8000 Å region of the spectrum, although there was no useful data below 5600 Å due to the poor blue response of the CCD. The data was flattened using turret flats. Both runs suffered from light cirrus, thus spectrophotometry calibration was not attempted. All the sample galaxies were exposed for 3600 secs between 1.0 and 1.2 of airmass.

Data reduction was performed using the IRAF spectra package. Debiasing was completed using overscan lines and dark frames. Wavelength calibration used Ne-Ar lamps taken before and after each object. The grism was centered on the rest frame velocity of H\(\alpha\) emission. Over 90% of the sample displayed detectable optical emission. Figure 1 displays several examples of emission near the H\(\alpha\) line, rest frame (marked by the arrow). Also visible in each frame are the \([\text{N II}]\) feature at 6583 Å and the \([\text{S II}]\) doublet at 6716 and 6731 Å. Although the wavelength range covers \(H\beta\) and \([\text{O III}]\), these features are rarely seen in the data due to poor blue sensitivity of the CCD and low S/N in the emission lines themselves. Of the final sample containing 45 galaxies, two were eliminated during reduction since the H\(\alpha\) line was buried in OH emission.

3. DISCUSSION
3.1. Optical Emission

The sample for in this project was drawn from the UGC (Nilson 1973) with the intent of adopting a set of large, HI-rich disk galaxies over a range of central surface brightnesses and between 5,000 and 15,000 km sec$^{-1}$. To this end, 34 LSB and nine high surface brightness (HSB) galaxies were selected as listed in Table 1 along with their morphological class, redshift, surface brightness category, HI mass, diameter and presence of a sizable bulge (outside of morphological class). The division between HSB and LSB is roughly at central surface brightness of 22 $B$ mag arcsec$^{-2}$ or a mean surface brightness of 24 $B$ mag arcsec$^{-2}$. All the galaxies have diameters greater than 20 kpc and $M_{HI} > 3.1 \times 10^9 M_\odot$ (the typical spiral is 15 kpc in diameter and $1.5 \times 10^9 M_\odot$ in HI mass). Figure 2 displays the range of HI masses for the sample compared to the Huchtmeier and Richter (1989) HI catalog of all galaxies types. From this figure it can be seen that the sample defines the extreme end of the HI mass function, but this list is by no means complete, rather chosen to satisfy the observing window.

The line emission detections and type of nuclear emission are also summarized in Table 1. Optical emission is, of course, common in disk galaxies, usually associated with HII regions powered by the UV radiation from young, massive stars. Table 1 lists the characteristics of the optical emission, whether the lines were detected in the nucleus as well as disk, whether strong [N II] or [S II] was found and whether [O I] was detected. The low-ionizations transitions, such as [N II] at 6548, 6583Å and [S II] at 6716, 6731Å are normally weak compared to H$\alpha$ in objects whose spectra are dominated by HII regions. Strong [N II] and [S II] lines and the presence of [O I] are taken to be an indicator of an AGN behavior (see below).

Line emission is not always the best choice for AGN searches since optical lines may be obscured by dust. One advantage to searching a sample of LSB galaxies is there has been no evidence for heavy dust obscuration based in IRAS far-IR emission or deep imaging to detect absorbing lanes (Schombert et al. 1990). There is also very little current star formation in LSB galaxies (McGaugh, Schombert and Bothun 1995) and what little does exist is usually found in small, isolated HII regions in their outer disks (McGaugh 1992). Thus, there is the expectation that there will be little contamination to nuclear emission lines due nearby star formation or absorption from intervening dust clouds. The nine HSB galaxies in this study displayed evidence of dust in their disks, but their bulges appear smooth and symmetric on blue Sky Survey prints.

The goal of this study is the separation of objects whose cores display emission line radiation due to an exotic, non-stellar source (AGN) from standard emission line radiation due to photoionization from star formation (HII nuclei). These non-stellar sources would include both Seyfert and LINER (low ionization nuclear emission-line region) behavior, although the nature of LINER activity is unclear (Filippenko 1996). For this study, we will define a core to be ‘active’ if it has low ionization features (strong [N II] and [S II]) combined with [O I]. Thus, LINERS would be included as active. While it would be clearly preferable to have several lines (such as [O III]) for classification, the low S/N nature of the blue region makes that impossible. Ho and Filippenko (1997) also found that the ratios of H$\alpha$ to [N II] and [S II] were the primary characteristic to distinguish HII nuclei from active ones. Thus, we will adopt their definition of active versus HII nuclei and limit our conclusions within this context of AGN-like behavior without determination of the nature of this behavior to be Seyfert or LINER.

One clear example of the difference between HII regions and non-stellar nuclear activity is the spectrum from the LSB galaxy UGC 4422. A section of the spectrum from the core and disk regions are shown in Figure 3. The core spectrum displays two of the most common features of active classification in this study; strong [N II] and [S II] compared to H$\alpha$ and [O I] emission. Opposite characteristics are seen in the disk
spectrum, dominant and narrow H$\alpha$, no evidence of [O I], indicative of ionized gas from star formation. While there is some weak possibility that these features could be shock induced emission lines, supernova remnants are unlikely to be undergoing shocks since cores of LSB galaxies are low in gas surface density (McGaugh 1992).

### 3.2. Nuclear Activity

Of the 43 galaxies in this study, 41 (95%) have detectable amounts of H$\alpha$ emission in their core regions, coincident with the optical center (see Table 1). The spatial extend varies, although typically the intensity of the emission was correlated to the underlying stellar luminosity. Of these 41 galaxies with nuclear emission, 21 (51%) have signatures of HII nuclei and 20 (49%) have active signatures. Galaxies with active signatures (strong [N II] and [S II] plus [O I] emission) all displayed unresolved spatial extent as is expected for their nuclear origin. Although the data presented here was not calibrated, the exposures were similar in depth with respect to distance. A majority of the 20 galaxies with an active classification have very weak emission lines (based on comparison to continuum levels), such that the AGN would be characterized as low luminosity ($L(\text{H}\alpha) < 10^{40}$ ergs s$^{-1}$). For comparison, HFS found from a magnitude-limited survey of 341 disk galaxies that 97% of their sample had detectable amounts of ionized gas in their cores and approximately 40% of the nuclear emission line galaxies could be regarded as active. This is effectively identical to the numbers found herein, despite radically different selection criteria, i.e. selecting for HI mass and large metric diameter.

The two galaxies without any sign of nuclear or disk emission (UGC 11977 and 12740) are both LSB in nature. Since the optical emission in LSB galaxies is typically restricted to small isolated HII regions in the outer disk, the lack of detection probably indicates a positioning of the slit that fortuitously missed any HII regions, even in the core. All the HSB galaxies were detected in emission, usually with characteristic rotation curves expected for bright, disk galaxies of various inclinations. We interpret the difference in detection rates as merely reflecting the higher current star formation rates in HSB as compared to LSB galaxies and the resulting enhanced frequency of bright HII regions.

The occurrence of core emission in the sample divides evenly by surface brightness. Of the HSB sample, nine of nine (100%) have H$\alpha$ emission in their core regions, three (33%) of which are classified as active. From the LSB sample, 32 of 34 galaxies (94%) have H$\alpha$ emission in their core regions, 17 (53%) of these are active. The fraction of emission nuclei is nearly identical between LSB and HSB galaxies. Of that fraction, slightly more LSB galaxies are active, but not significantly so. We note that LSB and HSB galaxies have neither their past star formation rates, their current star formation rates, their morphological appearances, the disk kinematics, mass to light ratios, gas ratios nor their molecular gas content in common. Although the evolutionary histories of LSB galaxies is unclear, it is obvious that their development differs sharply from HSB galaxies. Therefore, the similar occurrence of AGN behavior between HSB and LSB galaxies is perhaps the only characteristic that the two classes have in common and may signify that the AGN mechanism is decoupled from the global disk properties of a galaxy (see below).

In order to consider the effects of the central stellar population, the sample was divided into those galaxies with morphologically distinct bulges, based on visible inspection of POSS prints, and those without a symmetric, central concentration of light. Of the 43 sample galaxies, 32 were classified with bulges, 11 with none. Of the 32 bulge galaxies, 31 (97%) displayed nuclear H$\alpha$ emission, of which 17 (55%) of these had active signatures. Of the 11 galaxies without bulges, 10 of the 11 (91%) have H$\alpha$ emission in their core regions, but only three (27%) had active signatures. This is also in agreement with HFS who found that
very few spiral types without bulges have AGN signatures, even though the number of HII nuclei was high among all spiral types. Normally one would expect a lower detection rate of emission lines against the bright bulges of early-type spirals. Thus, there is the expectation of a higher detection rate in LSB galaxies is due to contrast enhancement. However, the statistics herein suggest the opposite, reinforcing the conclusion that AGN nuclei are more common in systems with bulges and that the existence of a stellar population (and the associated gravitational gradient) appears to be a prerequisite for an active nuclear region.

Although the initial comparison between this HI massive, large metric size sample, and HFS’s magnitude-limited sample indicates an identical frequency of galaxies with active signatures (49% for this sample versus 43% for the entire HFS sample), this ignores the inherent basis in this study to select late-type galaxies. Of the original HFS sample, 341 of the 486 galaxies are disk systems (morphological class Sa or later). Of the disk galaxies, 331 displayed nuclear emission (97%) of which 132 (40%) of these also displayed evidence of an active core. Again, this is similar to the numbers found for this studies sample. However, if the HFS sample is divided into early and late-type disk galaxies (where early is defined from Sa to Sbc, late-type as Sc and beyond) then there is a sharp difference in the frequency of active nuclear signatures. The early-type galaxies have 60% of their nuclear emission to be of the active variety, whereas the late-type subset has only 17% with active nuclear cores. Dividing this study’s sample into early and late-types (see Table 1) does not produce the same separation with respect to active signatures. Of early-type galaxies in this sample (13 of the 43 galaxies), six have active signatures (46%). Among the late-type galaxies (30 of the 43 galaxies), 14 active signatures (50%), identical within the counting statistics to the early-type galaxies. The most immediate conclusion to be drawn from this comparison of early and late-type galaxies is that the sample selected for this study (HI massive, large metric size) has a much higher occurrence of AGN signatures in the late-type galaxies relative to the magnitude-limited sample of HFS, i.e. gas supply has an impact on the detection of an AGN by optical emission.

### 3.3. Broad Line AGN’s in LSB Galaxies

The widths of the active galaxies in this sample are typically quite narrow, less than 2,000 km sec$^{-2}$. Only five of the 20 galaxies with active signatures have widths approaching 5,000 km/sec, which is consistent with the estimate from HFS that their sample contained only 20% of active systems with broad H$\alpha$ emission.

An interesting example a broad line LSB galaxy is UGC 6614, shown in Figure 1. UGC 6614 has similar characteristics to Malin 1 and F586-6 (Bothun et al. 1990, a large, HI-rich galaxies with large, low surface brightness disk. The appearance of the disk of UGC 6614 is also typical of the Malin class of galaxies, weak, faint spiral arms with a distinct, but small, bulge. The H$\alpha$ line is broad, about 4,500 km sec$^{-1}$ FWHM with a lower peak intensity than the nearby [N II] feature. This would lead to a Seyfert 2 classification, although on the low end of the width distribution of AGN’s, as is the case for Malin 1 and F568-6.

Three additional large LSB galaxies with AGN signatures were found by Sprayberry et al. (1995), two with Seyfert 1 type lines of greater than 10,000 km sec$^{-1}$ and one with a Seyfert 2 width of 3,800 km sec$^{-1}$. From the small sample of this study and Sprayberry et al., it is difficult to draw any general conclusions other than to note that AGN behavior in large LSB galaxies is not restricted to narrow line emission, but most of the nuclei found in this study would be not be classed as Type 1.
3.4. Fuel Deficiency Hypothesis

There is no correlation between the classification of nuclear emission as active and the gas mass of the underlying galaxy, although this is not surprising since the entire sample herein represents the most extreme HI mass objects in current galaxy catalogs, i.e. there is little range to investigate the dependence on gas mass. However, one trend is clear from the data, in an HI-rich sample the frequency of AGN’s for late-type LSB galaxies is much higher than found in a magnitude-limited sample.

This correlation with LSB galaxies is contrary to studies that have shown that most AGN host galaxies are high in luminosity and surface brightness (Smith et al. 1986). The only common trait among these bright, HSB host galaxies, and the LSB Malin objects, is the gas fraction. This leads one to the speculation that it is not the stellar mass or the total mass of a galaxy that is correlated with the AGN behavior, but rather the gas mass or the surface density. And that the underlying physics is the amount of gas available as fuel to the central engine.

Correlating the existence of AGN emission with gas properties has been attempted by many studies. In this instance, the occurrence and strength of the optical emission is based on the availability and flow of the fuel supply. Enhanced AGN emission within a particular class of galaxies can be due to any number of processes that increases the flow of gas (for example, the gravitational gradient associated with a bulge or a high surface gas density in the inner disk) or simply a quiescent, static situation where the gas supply is uninterrupted (for example, a lack of star formation in the core regions of LSB galaxies). The reverse can also be true where the fuel supply is cut off due to ionization from the accretion disk in the low density gas. The fuel deficiency may explain why almost all disk galaxies either have an HII nuclei or an AGN.

The higher frequency of AGN’s in large LSB galaxies, those with an ample fuel supply, would suggest that the fueling hypothesis has merit. In addition, this hypothesis implies that there might be an AGN’s present in the core of all galaxies yet may remain quiescent because the fueling rate is low (van der Marel 1997). Since the intensity of the optical line emission is also quite faint in LSB galaxies, this suggests that the fueling rate is influenced by the local surface density of gas, not the total gas mass.

4. CONCLUSIONS

This project has been a spectroscopic survey for low luminosity optical nuclear emission in disk galaxies. The sample used was selected to cover a range of central surface brightness for the largest, and most HI-rich, galaxies in the UGC catalog. The suspicion is that large LSB galaxies have a higher frequency of AGN behavior compared to HSB disk systems (Sprayberry et al. 1995). The results are summarized as the following:

- Of galaxies selected by large absolute size and high HI mass, 95% have nuclear emission. Approximately 1/2 of those objects display emission line characteristics indicative of non-thermal excitation in the sense of having high ratios of [N II]/Hα and [S II]/Hα and [O I] emission, which is interpreted AGN-like behavior.

- The occurrence of AGN behavior was similar for the high and low surface brightness members of the sample. This is surprising since the two families of galaxy types have little else in common, neither their past star formation rates, current star formation rates, morphological appearances, disk kinematics, mass to light ratios, gas ratios nor molecular gas content. This indicates that the AGN mechanism is decoupled from the global disk properties of a galaxy.
The occurrence of AGN nuclei was highest in systems with bulges, regardless of morphological type or mean surface brightness. The existence of a stellar population (and the associated gravitational gradient) appears to be a prerequisite for an active nuclear region.

The sharpest difference between this HI selected sample and a magnitude selected sample was the frequency of AGN behavior in late-type systems. In a magnitude-limited sample (HFS), 60% early-type galaxies are found to have their nuclear emission of the active variety, whereas the late-type subset had only 17% with active nuclear cores. However, in this study, 46% early-type galaxies have active signatures whereas 50% of the late-type galaxies are active, identical within the counting statistics to the HI massive, early-type galaxies. That there is no difference between the frequency of AGN’s in the LSB versus HSB subsets reinforces the fact that not all LSB galaxies are late-type. The LSB Malin objects have significant bulges and, therefore, are mid to early-type in morphological appearance.

The excess number of galaxies with AGN signatures are primarily LSB galaxies with bulges, the Malin objects. The discovery of a high fraction of AGN’s in large LSB galaxies has an impact on AGN density models since low-level AGN’s could hide in a LSB galaxies population, whose numbers are currently not known. The unknown number of giant LSB galaxies, like Malin 1, opens the possibility that these objects are the missing remnants of distant QSO’s, although it is unclear how such a thin disk could have survive an early QSO epoch.

Previous work (Smith et al. 1986) related AGN behavior with star formation and high surface brightness. The enhanced number of AGN’s in LSB galaxies indicates that another parameter other than star formation is correlated with nuclear emission. One candidate is, of course, the fuel supply which is a source for both star formation and optical AGN emission. Not all of the HI massive galaxies studied here have AGN signatures, so gas mass is clearly not primary. Whereas the total fuel supply is necessary, it is the amount of fuel available to the central engine that is more relevant. Thus, it seems plausible that these galaxies share some common property related to the fuel flow in the central regions. This would also explain the correlation between active nuclear emission and the presence of a bulge, the bulge being a secondary consequence of a sharp gravitational gradient that influences the inward fuel flow. In any case, the future study of large, LSB galaxies will find spectroscopic examination of the central regions to be instructive.

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**Fig. 1.**— The above spectra display the H\(\alpha\)/[N II]/[S II] and [O I] features for six galaxies from the sample, all are classed as giant LSB systems except for UGC 12511. The arrow signifies H\(\alpha\) rest frame. Note the strong [N II] and [S II] relative to H\(\alpha\), the signature of an active core.

**Fig. 2.**— A comparison histogram of the HI mass for the objects in this study and the distribution from galaxies from the UGC catalog. The typical spiral is \(1.5 \times 10^9\) M\(\odot\) in HI mass, all the objects for this sample were selected to be greater than \(5 \times 10^9\) M\(\odot\) in HI mass.

**Fig. 3.**— A comparison plot of emission from the disk and core of UGC 4422. The core spectrum displays two of the most common features of active classification in this study; strong [N II] and [S II] compared to H\(\alpha\), a broad H\(\alpha\) width and [O I] emission. The disk spectrum displays dominant and narrow H\(\alpha\) plus no indication of [O I], indicative of ionized gas from star formation.
| Object | class         | sfb | V   | $M_{HI}/M_\odot$ | D (kpc) | disk em | nuc em | Of? | active | bulge |
|--------|---------------|-----|-----|-------------------|---------|---------|--------|-----|--------|-------|
| U369   | SA(rs)c       | H   | 4366| 10.18             | 48.0    | Y       | Y      | N   | N      | N     |
| U416   | SABdm         | L   | 5346| 9.93              | 20.2    | Y       | Y      | :   | N      | Y     |
| U905   | S?            | L   | 11465| 9.79            | 47.3    | N       | Y      | :   | N      | Y     |
| U1230  | Sm:           | L   | 3836| 9.70              | 27.7    | Y       | Y      | N   | N      | N     |
| U1378  | (R)SB(rs)a:   | L   | 2940| 10.12             | 34.4    | N       | Y      | Y   | Y      | Y     |
| U1455  | SAB(rs)bc     | L   | 5123| 9.97              | 49.3    | Y       | Y      | Y   | Y      | Y     |
| U1491  | Sm:           | L   | 12187| 9.95            | 37.7    | Y       | Y      | Y   | Y      | N     |
| U1752  | SA(s)cd       | L   | 17836| 10.64           | 92.0    | N       | Y      | Y   | N      | Y     |
| U1920  | (R)SB(s)a     | L   | 6196| 9.98              | 32.0    | Y       | Y      | Y   | Y      | Y     |
| U1922  | S?            | L   | 10894| 10.26           | 78.7    | :       | Y      | Y   | Y      | Y     |
| U2360  | SAd:          | L   | 10562| 10.15            | 43.6    | Y       | :      | :   | :      | N     |
| U2399  | SAB(s)cd      | L   | 8006| 9.79              | 35.8    | Y       | Y      | N   | N      | N     |
| U2965  | Sm            | L   | 7319| 9.98              | 22.7    | Y       | Y      | :   | N      | N     |
| U2975  | Im?           | L   | 19937| 10.53            | 89.1    | Y       | Y      | N   | N      | N     |
| U3059  | SAdm          | L   | 4811| 10.00             | 43.0    | Y       | Y      | :   | Y      | Y     |
| U3968  | SB(r)c        | L   | 6780| 9.98              | 32.6    | Y       | Y      | :   | :      | Y     |
| U4219  | SA(rs)b       | L   | 12433| 10.47            | 89.8    | Y       | Y      | Y   | Y      | Y     |
| U4422  | SAB(rs)c      | L   | 4300| 9.91              | 47.3    | Y       | Y      | Y   | Y      | Y     |
| U4658  | SAB(rs)c      | H   | 4382| 9.92              | 33.2    | Y       | Y      | Y   | Y      | Y     |
| U4985  | SAB(s)b       | L   | 10180| 10.26            | 56.0    | Y       | Y      | :   | N      | N     |
| U5366  | SAB(rs)c      | H   | 5141| 10.02             | 40.7    | Y       | Y      | :   | N      | Y     |
| U6614  | (R)SA(r)a     | L   | 6358| 10.16             | 37.2    | N       | Y      | Y   | Y      | Y     |
| U6754  | SA(rs)b       | L   | 7023| 10.13             | 72.5    | :       | Y      | N   | N      | N     |
| U6968  | Sc            | L   | 8232| 10.25             | 79.3    | N       | Y      | Y   | Y      | Y     |
| U7357  | SAB(s)c       | L   | 6683| 10.20             | 36.8    | Y       | Y      | Y   | N      | Y     |
| U9061  | SB(r)bc       | H   | 5442| 10.61             | 101.1   | Y       | Y      | N   | N      | Y     |
| U9322  | SAB(s)bc      | H   | 5098| 9.22              | 15.8    | Y       | Y      | :   | Y      | Y     |
| U1961  | SABs(b)       | H   | 1924| 10.18             | 45.7    | Y       | Y      | N   | N      | Y     |
| U2563  | SAB(rs)bc     | H   | 6697| 10.01             | 23.0    | N       | Y      | N   | N      | N     |
| U1265  | Dwarf         | L   | 3114| 10.29             | 43.2    | Y       | Y      | N   | N      | N     |
| U10104 | SA(rs)bc      | L   | 9841| 10.37             | 91.4    | Y       | Y      | N   | N      | Y     |
| U10891 | SAB(r)bc      | H   | 1665| 10.04             | 35.5    | Y       | Y      | :   | N      | Y     |
| U10908 | S?            | L   | 5818| 10.08             | 20.0    | Y       | Y      | N   | N      | N     |
| U11578 | Sdm           | L   | 4602| 9.98              | 23.7    | Y       | Y      | N   | N      | Y     |
| U11754 | SABcd         | L   | 4825| 9.90              | 29.9    | Y       | Y      | :   | Y      | Y     |
| U11977 | SABdm         | L   | 11284| 10.05            | 42.7    | Y       | N      | N   | N      | N     |
| U12128 | S?            | L   | 19507| 10.41           | 67.1    | N       | Y      | Y   | Y      | Y     |
| U12289 | Sd            | L   | 10160| 10.05            | 45.4    | Y       | Y      | Y   | Y      | Y     |
| U12511 | Sdc:          | H   | 3556| 10.05             | 30.6    | Y       | Y      | Y   | Y      | Y     |
| U12740 | Sdc?          | L   | 10522| 9.83            | 36.2    | Y       | N      | N   | N      | N     |
| U12742 | SB(s)cd:      | L   | 5554| 10.08             | 38.2    | Y       | Y      | N   | N      | N     |
| U12845 | Sd            | L   | 4880| 9.90              | 35.2    | Y       | Y      | :   | Y      | Y     |
| U12895 | Sd            | L   | 6752| 9.64              | 18.6    | Y       | Y      | N   | N      | Y     |
Figure 1
Figure 2
