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Photometry of the galaxies in the Bootes Void

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PHOTOMETRY OF THE GALAXIES IN THE BOOTES VOID

by

Shawn T. Cruzen

**Thesis Adviser
Dr. Donna Weistrop**

**A thesis submitted in partial fulfillment
of the requirements for the degree of**

Master of Science

in

Physics

**Department of Physics
University of Nevada, Las Vegas
May 1995**

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ABSTRACT

As part of an investigation into the nature of galaxies in voids, 27 galaxies in the Bootes Void were observed in B, V, R & I filters. Absolute V magnitudes have been calculated for most of the galaxies in the sample to an accuracy of ± 0.15 mag or better using apertures that correspond to the 24.0 mag/arcsec² isophote in V. The color indices, B-V, V-R and R-I, have been determined. The results of BVRI photometry on the Bootes Void galaxies indicate that these galaxies appear comparable in magnitude and color to a sample of field emission line galaxies.

Analysis of the morphology of these galaxies as determined from their appearance on the CCD images shows that approximately 40% of the galaxies are asymmetric or disturbed. Color changes across several galaxies might indicate recent periods of star formation. Also, the properties of these galaxies are inconsistent with the properties of galaxies predicted to be found in voids.

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CHAPTER 1

INTRODUCTION

An investigation of the properties of galaxies in voids or, more accurately, regions of low density in the galaxy distribution will provide information on the role of environment in galaxy formation and evolution, as well as on the internal structure of voids. Because these are key parameters in current cosmological models, a thorough study of a sample of void galaxies will provide information that will advance certain models and discount others. To assist in this effort, my collaborators and I have conducted a photometric survey of the 27 galaxies in the large void which lies in the direction of the constellation Bootes.

The existence of the Bootes Void was first proposed by Kirshner et al. (1981). Based on data from a redshift survey in the direction of the north galactic cap, they suggested the possibility of a $3.1 \times 10^5 \text{ Mpc}^3$ void ($H_0 = 75 \text{ km s}^{-1} \text{ Mpc}^{-1}$) in the galaxy distribution centered at $RA = 14^h 50^m$, $Dec = +46^\circ$, $v = 15,500 \text{ km/sec}$, corresponding to a redshift range of $z = 0.041$ to $z = 0.062$. The same group later confirmed the existence of the Bootes Void by using a pencil-beam survey to sample the galaxy distribution within the region (Kirshner et al. 1987).

Galaxies were chosen by Kirshner et al. (1987) from 283 small fields arranged to form a grid covering the region.

These fields were 15' on a side and covered ~ 2% of the area of the grid. Spectra were obtained and redshifts were measured for 239 galaxies lying in the direction of the void. They found no normal galaxies (galaxies without strong emission lines) from this sample within a spherical region of radius 42 Mpc ($H_0=75 \text{ km s}^{-1} \text{ Mpc}^{-1}$) centered on the above coordinates. They expected to find 31 normal galaxies if the sample distribution had been similar to the normal field distribution. This result helped to confirm the existence of the large region of low density to a high statistical significance.

CHAPTER 2

THE GALAXY SAMPLE

Since the discovery of the Bootes Void, 27 galaxies have been found to lie within its boundaries (see Figures 1-48). Note that since the time when these observations were made, other void galaxies have been reported in addition to these 27 by Szomoru (1994, hereafter known as S94) and Aldering et al. (1995). At least 26 of the 27 galaxies are emission line galaxies. The number density of bright emission line galaxies in the void is estimated to be only about one third that of a normal field distribution of bright emission line galaxies (Weistrop 1989). The number of galaxies in the void detected by the Infrared Astronomical Satellite (IRAS) is between 1/3 and 1/6 that of the normal density of IRAS galaxies having the highest flux quality at 60 μm (Dey et al. 1990).

Several objective prism surveys in the direction of the Bootes Void have been undertaken (Sanduleak & Pesch 1987, 1989, Moody et al. 1987, Pesch & Sanduleak 1989). Eleven of the 27 galaxies in the void were identified by measuring the redshifts of galaxy candidates from these surveys. Because redshifts have not been measured for all the galaxy candidates from these surveys, the subsample of galaxies identified in

this manner is not complete, meaning that the sample of 27 galaxies is not complete.

The sample of galaxies identified in objective prism surveys is also subject to an important selection effect. Because candidate objects are chosen on the basis of unusual spectral features, galaxies identified in this manner are commonly emission line or unusually blue galaxies.

Several groups have made spectroscopic observations to determine the redshifts of galaxy candidates in the direction of the Bootes Void from the objective prism surveys. Galaxies 1457+4228 and 1517+3956 were found to be in the void by Tifft et al. (1986). Galaxies 1446+4457, 1506+5138, 1507+5445 and 1510+4727 were identified as void members by Moody et al. (1987). The galaxy 1432+5302 was found to be in the void by Weistrop & Downes (1988). Two other void galaxies, 1408+4852 and 1505+3958, were identified by Weistrop (1989), while galaxies 1458+4944 and 1503+5428 were identified by Lipovetsky and reported to Weistrop in a private communication (see Weistrop et al. 1995, hereafter referred to as W95).

The second type of survey from which galaxies in the Bootes Void were identified is that of infrared sources carried out with the IRAS satellite. Because an IRAS sample is flux-limited, the only galaxies at higher redshifts that were

detected are those having strong infrared flux densities. Xu & Sulentic (1991) suggested that, at redshifts similar to that of the Bootes Void ($z \approx 0.05$), the IRAS catalog might be dominated by interacting pairs. The data of Rush et al. (1993) suggest that at this redshift the $12\ \mu\text{m}$ galaxy sample is dominated by active galaxies. Therefore, galaxies detected by IRAS with redshifts comparable to those of the Bootes Void galaxies tend to be unusual or emission line galaxies.

Dey et al. (1990) carried out a redshift survey of all objects listed in the IRAS Point Source Catalogue having the highest flux quality at $60\ \mu\text{m}$ and lying in the direction of the Bootes Void. The faintest flux density in their sample was 25 mJy. Twelve of these IRAS sources were found to be galaxies or galaxy pairs within the void, with seven systems being identified as void members for the first time.

The IRAS source 1406+4905 was previously identified as I Zwicky 81 (Sargent 1970). The redshift for this galaxy has been known since before the discovery of the Bootes Void. The IRAS source 1517+3956 is one of the two galaxies previously identified by Tifft et al. (1986). Three other IRAS galaxies, 1407+4840, 1428+5255 and 1547+5121, were identified in a redshift survey of $60\ \mu\text{m}$ sources by Strauss & Huchra (1988). The seven IRAS galaxy systems discovered in the Dey et al. (1990) survey are 1413+5056, 1444+4402, 1519+5050 (pair), 1530+4332 (pair), 1535+3831, 1537+5315 and 1540+5013.

This sample of IRAS galaxies is not complete at the limiting flux density of 25 mJy at 60 μ m. It is only complete above a 60 μ m flux density of 60 mJy, the completeness limit of the IRAS Point Source Catalog. Five of the twelve IRAS galaxies in the void have 60 μ m fluxes greater than 60 mJy. The remaining seven systems, including the two known galaxy pairs, have 60 μ m fluxes between 25 mJy and 60 mJy. Dey et al. (1990) discuss the completeness fraction of their sample at flux densities between 25 mJy and 60 mJy. Because this sample of IRAS galaxies in the Bootes Void is not itself complete, a complete subsample of galaxies within the void has yet to be defined.

The remaining three Bootes Void galaxies were identified in various ways. Two galaxies, 1345+4641 and 1357+4641, were identified in a search for high redshift quasars (Schneider et al. 1994). The galaxy 1517+3949 was reportedly discovered in an HI survey by Szomoru et al. (1993), but may be the same object reported earlier in a survey at 408 MHz (Ficarra et al. 1985). It is possible that this galaxy is the only normal galaxy known in the Bootes Void, although it is reported to be associated with the emission line object 1517+3956. Spectra of 1517+3949 are needed before this determination can be made.

CHAPTER 3

OBSERVATIONS

All of the observations for this project were made at the National Undergraduate Research Observatory. The telescope used was the Lowell 31-inch telescope located on Anderson Mesa near Flagstaff, Arizona. Images were obtained on nights during three separate observing runs: U.T. 1993 April 26, U.T. 1994 April 16, and U.T. 1994 June 10-13.

The images were recorded on the NURO CCD. This CCD is a TEK 512x512 back-illuminated, metachrome coated chip. When used with the Lowell 31-inch telescope, the image scale is 0.49 arcsec/pixel. The filters used were the NURO BVRI broadband filter set based on the Bessell (1990) system. The NURO filter set is made up of the following Schott glass components:

B 1mm GG385 + 2mm BG12 + 3mm BG39

V 2mm GG495 + 2mm BG39

R 2mm OG570 + 3mm KG3

I 3mm RG9 + 2mm WG305

The ranges, widths and response peaks for the standard passbands as defined by Bessell (1990) are listed in Table 1.

Table 1 The range, full width at half-maximum and peak for each of the standard passbands defined by Bessell (1990).

<u>Filter</u>	<u>Range (Å)</u>	<u>FWHM (Å)</u>	<u>Peak (Å)</u>
B	3600 - 5600	940	4200
V	4700 - 7000	850	5300
R	5500 - 9000	1540	6000
I	7000 - 9200	1500	8050

Although the B and V filters in the NURO filter set differed from the Bessell filter set by 1mm in the thickness of the BG39 glass component, the difference in the passband shape was estimated to be less than 10% at the peak transmission wavelength. Any difference that did occur was compensated for in the calibration of the transformation equations using the standard stars (see discussion under Reductions).

With CCD photometry, it is necessary to acquire various calibration images which are later used to remove the effects of the pixel-to-pixel sensitivity variations and any other types of spatially systematic effects across the chip. The two types of calibration images applied to these data were bias frames and flat field images. Images were also taken to measure the dark current, but the effects were found to be negligible so no dark corrections were made.

A bias frame is a zero-second exposure which acts as a map of the additive stationary pattern introduced into each image

by the CCD electronics. A flat field image is used to correct for quantum efficiency and optical transmission variations across the CCD. In essence, the flat field image is a measure of the sensitivity with which each pixel responds to light. Therefore, the corresponding flat field correction involves dividing the measured signal in each pixel by some fraction which represents the sensitivity of that pixel.

Ten zero-second exposures were taken at the beginning and end of each night to ensure that changes in the bias level of the CCD over the course of the night would be recorded. It was found that these changes were negligible. These frames were later combined using a median filter into a median bias frame for each night.

Data are retrieved from CCD's by transferring the charge in each pixel across the chip to the readout amplifier located at one corner. A fixed amount of charge is lost in this process. The ratio of the charge received by the amplifier to the charge originally placed on the chip is defined as a charge transfer efficiency (CTE).

Because the CTE increases with the amount of charge on the CCD, a pedestal of charge is added to the chip before each exposure. All images, including the bias frames and flat field images, contain this base level of counts. It is subtracted from the data during data reduction.

To determine the magnitude of this pedestal, a region of the CCD is not exposed to light; therefore, this region

contains only the number of counts corresponding to the base level. On the NURO CCD, this region, defined as the overscan region, is 20 columns of pixels at one end of the chip. The number of counts per pixel in each row of the overscan region was averaged. A polynomial function of second order, running parallel to the columns, was fitted to these averaged values. This function defined the pedestal of counts which was subtracted from each image.

Flat field frames were obtained for each night by observing the sky during astronomical twilight either after sunset or before sunrise. Because the flat field response is wavelength dependent, three sky flats were taken in each filter. These images were taken with the telescope tracking turned off so that faint stars in the field of view would not appear as point sources and would not be in the same position on subsequent frames. Combining these images with a median filter removed any faint stars from the median flat field image.

The exposure times for the sky flats were adjusted so that the number of counts per pixel above the bias level was between 3000 and 7000 counts. This range of counts was chosen to yield good statistics but still be below the point at which the CCD no longer responds linearly.

Standard stars from the list of UBVRI photometric standards compiled by Landolt (1992) were observed on all nights through the same filter set used to observe the galaxies. The standard observations were made at the beginning, middle and end of

each night. Three to four fields of standard stars were observed each night. Since a field usually contained three or four standards, nine to eleven different standard stars were observed per night. Integrations were typically 180 seconds in the R and I filters, and 240 seconds in B and V.

When observing the galaxies, integration times of 240 seconds were used. The typical number of exposures per filter was two. Occasionally, when time permitted, three exposures per filter were taken. The airmass range over which the galaxy images were taken was approximately 1.00 to 1.30.

CHAPTER 4

REDUCTIONS

The data were reduced using IRAF, the Interactive Reduction and Analysis Facility. The processing steps included subtraction of the average counts in the overscan region, subtraction of the median filtered bias frame and division by a median filtered flat field image in each filter. The images of the standard stars were processed in the same manner as those of the galaxies.

If cosmic rays struck the CCD close enough to the object of interest to fall within the aperture selected for aperture photometry, they were removed by one of two methods. Cosmic rays were removed from objects with three images per filter by combining them with a median filter.

When only two images per filter had been taken, cosmic rays were removed using the COSMIC RAY task in the CCDRED package in IRAF. This task replaces the value of a pixel where a cosmic ray has struck with the average value of the surrounding pixels. Because a cosmic ray can strike more than one pixel, this process is iterated several times until the values of the pixels in question fall below a given multiple of the average value of the surrounding pixels. Values used to

define cosmic rays were between 10 and 20 times the average counts in the surrounding pixels.

Great care was taken to ensure that the process to remove cosmic rays did not affect the data. A 10x10 array of pixels surrounding the pixel with the maximum number of counts for each object of interest was inspected to insure that the COSMIC RAY task had not clipped the peak counts in the object. If the peak counts were clipped, the parameter defining the ratio of the cosmic rays to the average of surrounding pixels was increased and the task was run again. This process was repeated until the peak counts were found to be unchanged.

Once the image frames were processed, all images of a particular object in the same filter were registered and combined. The relative shifts required to register frames to be combined were determined by examining 3 to 5 stars common to each frame. The center of each star was determined using the IRAF task IMAGE EXAMINE. The relative shift for each frame was calculated as the average of the shifts needed to align each common star. Image registration accuracy was estimated to be approximately 0.25 arcsec. This resolution is within that allowed by the seeing on each night of observing.

When three images per filter had been taken, the images were combined using a median filter. If only two images per filter were taken, the images were averaged.

Aperture photometry was performed on the combined images using the APPHOT package in IRAF. Elliptical apertures were used to measure the light from the galaxies, while circular apertures were used for the standard stars. The galaxy apertures were chosen corresponding to isophotes of 24.0 magnitude/arcsec² on the V images. At this level, the number of counts per pixel was approximately 1 σ above the sky background. Ellipses were fitted to these isophotes using the task ELLIPSE in STSDAS (Space Telescope Science Data Analysis System).

The elliptical isophotes were converted to apertures for use with the IRAF task POLYPHOT. This task measures the total number of counts within an aperture, subtracts the sky contribution and converts the counts in the object to an instrumental magnitude. The expression for this conversion is

$$(1) \quad m_i = -2.5 \log F + 26 .$$

where m_i is the instrumental magnitude, F is the flux through the aperture in counts per second and 26 is the zero-point of the magnitude scale. The same elliptical apertures used to measure the instrumental magnitudes on the V images were then applied to the B, R and I images.

The instrumental magnitudes were converted to apparent magnitudes and colors. This conversion was accomplished using the following transformation equations (Cousins 1976):

$$(2) \quad V = v + \alpha_1 + \beta_1(b-v) - \kappa_1 X$$

$$(3) \quad B-V = \alpha_2 + \beta_2(b-v) - \kappa_2 X$$

$$(4) \quad V-R = \alpha_3 + \beta_3(v-r) - \kappa_3 X$$

$$(5) \quad R-I = \alpha_4 + \beta_4(r-i) - \kappa_4 X$$

where the upper-case letters represent standard apparent magnitudes and colors, the lower-case letters represent instrumental magnitudes and colors and X is the airmass at which the measurements were made. The Greek characters are coefficients to be determined using the instrumental and published apparent magnitudes and colors of the standard stars.

The coefficients in the transformation equation were found using the method of least squares. A program was written which employs subroutines from the text Numerical Recipes (Press et al. 1992). These subroutines perform a singular value decomposition from which the coefficients can be determined. The coefficients were calculated for each night using the standard stars observed on that night. Nine to eleven standard stars were observed per night. The transformation coefficients were reasonably consistent from night to night (Table 2).

Table 2 Coefficients of the transformation equations calculated for each night of observing.

	<u>4/26/93</u>	<u>4/16/94</u>	<u>6/10/94</u>	<u>6/11/94</u>	<u>6/12/94</u>	<u>6/13/94</u>
α_1	-5.99	-6.09	-5.88	-5.95	-5.97	-6.13
β_1	0.01	-0.06	< 0.01	< 0.01	< 0.01	0.01
κ_1	0.10	0.18	0.27	0.22	0.21	0.08
α_2	-1.13	-1.36	-1.06	-0.91	-0.97	-0.66
β_2	0.97	1.02	0.95	0.97	0.98	0.97
κ_2	-0.03	-0.03	-0.02	0.15	0.11	0.32
α_3	-0.01	0.07	0.10	0.02	0.00	-0.23
β_3	1.07	1.02	1.09	1.08	1.08	1.10
κ_3	-0.02	-0.01	-0.08	0.01	-0.01	-0.17
α_4	0.70	0.32	0.19	0.15	0.13	0.35
β_4	0.78	0.74	0.81	0.81	0.79	0.77
κ_4	0.42	0.10	0.05	0.02	0.01	0.17

Once the coefficients in the transformation equations were found, the apparent magnitudes and colors for the galaxies were calculated (Table 3, columns 3-6). Contributions to the uncertainties in the apparent magnitudes and colors due to this transformation were determined by treating the standard stars as unknowns, converting their instrumental magnitudes to apparent magnitudes and colors, then calculating the standard deviation between the measured and published values.

To ensure that no systematic errors had been introduced in this transformation process, the residuals between the measured and published apparent magnitudes and colors for the standard stars were plotted against the published apparent magnitudes and colors and against the airmass at which the stars were observed. No systematic errors were apparent. Some

examples of these plots from the night of 12 June 1994 are shown in Figures 49-57.

The largest contribution to the uncertainties in the apparent magnitudes and colors of the galaxies was due to the uncertainty in the number of background counts in the sky. The mean value of and standard deviation in the number of counts in the sky was determined by sampling pixel arrays surrounding the galaxies. The mean value of the sky counts for each combined image was subtracted from the total number of counts in the aperture in order to calculate instrumental magnitudes.

The uncertainty in the sky counts had a greater influence on images with fewer counts from the galaxy, such as the B images. Images taken through the B filter typically had fewer galaxy counts than images in V, R and I because, at shorter wavelengths, CCDs are less sensitive and the optical transmission through the telescope is less efficient. Thus, the uncertainties in the magnitudes and colors derived from the B images are large compared to the other uncertainties (Table 3). This effect was more pronounced for faint galaxies or galaxies with large apertures.

CHAPTER 5

ANALYSIS

The apparent magnitudes were corrected for galactic reddening according to the method described by Burstein and Heiles (1978). The column density of neutral hydrogen along the line-of-sight to each galaxy, N_H , was determined from the maps of Heiles (1975), where N_H is shown as a function of the galactic latitude and longitude, l and b . An expression for the color excess, $E(B-V)$, as a function of N_H is derived from a least-squares fit by Burstein and Heiles (1978):

$$(6) \quad E(B-V) = -0.0372 + 0.357 \times 10^{-3} N_H - 0.346 \times 10^{-4} R N_H$$

where R is a residual representing the departures from the average gas-to-dust ratio in the galaxy. R is determined from maps published by Heiles (1976). The absorption in units of magnitude, A , can be determined from the relationship

$$(7) \quad A = 3[E(B-V)] .$$

Values for A ranged from 0.00 mag to 0.07 mag, with a median value of 0.04 mag.

The reddening corrected apparent V magnitudes were converted to absolute V magnitudes according to the equation (Peebles 1971)

$$(8) \quad m_{\lambda} - M_{\lambda} = 5 \log z + K_{\lambda}(2) + K(3)$$

where

$$K_{\lambda}(2) = 2.5 \log \left[\frac{f(\lambda)}{f(\lambda/(1+z))} \right]$$

$$K(3) = 42.38 - 5 \log(h) + 5 \log \left[\left(\frac{\sqrt{1+z}}{q^2 z} \right) (qz + (q-1)(\sqrt{1+2qz}-1)) \right]$$

and

where z is the corrected redshift, q is the cosmological deceleration parameter, and h is a scaling factor for the Hubble constant defined by the relationship $H_0 = 100h \text{ km sec}^{-1} \text{ Mpc}^{-1}$. The value of the deceleration parameter used was $q = 0.5$, and the value of the Hubble constant was taken to be $H_0 = 75 \text{ km sec}^{-1} \text{ Mpc}^{-1}$, corresponding to $h = 0.75$. This value of H_0 was chosen because it is consistent with several of the latest published measurements. The value of q was chosen to maintain consistency between this sample and comparison samples discussed later.

The $K(2)$ term takes into account that the measured $f(\lambda)$ (the flux per unit wavelength) is not the same as the $f(\lambda)$ emitted by the galaxy because of the cosmological redshift. This term was neglected because $f(\lambda)$ is unknown for the Bootes Void galaxies. Standard forms of $f(\lambda)$ derived from normal

galaxies cannot be adopted because the majority of the Bootes Void galaxies are peculiar galaxies, and spectra needed to determine $f(\lambda)$ uniquely for each void galaxy are not available. Using a standard form of $f(\lambda)$ for spiral galaxies, the possible error in the absolute V magnitude, M_V , due to the omission of this term is estimated to be no more than 0.10 mag.

The expansion of the universe contributes to the difference between the energy per unit time emitted by the galaxy and the energy per unit time measured by the observer in two additional ways. Because of the cosmological redshift, the wavelengths of the photons observed are longer than the wavelengths of the photons emitted by the galaxy. This increase in wavelength corresponds to an observed decrease in the energy per photon. Also, an observer measures fewer photons per unit time than were emitted by the galaxy due to relativistic time dilation. The $K(3)$ term is the relativistic correction factor needed to compensate for the decreased energy per unit time measured by the observer.

The published observed redshifts of the galaxies (z_0) were corrected for the Sun's motion according to

$$(9) \quad z = z_0 + [300 \sin l \cos b]/300,000$$

where l and b are the galactic longitude and latitude, respectively (de Vaucouleurs, de Vaucouleurs and Corwin 1976).

The absolute V magnitudes for the Bootes Void galaxies are listed in Table 3 (column 7). The uncertainties in the

calculated values of M_v include contributions from the uncertainties in the apparent magnitudes and the published redshifts, z . Because the uncertainties in z for some galaxies in the sample are unknown, the maximum published uncertainty in z for a void galaxy was used as an upper limit for the contribution to the uncertainty in M_v for all the galaxies. This approximation appears to be reasonable because the contribution to the uncertainty in M_v was only ~ 0.03 mag.

In order to verify the accuracy of the measurements reported in this study, the results were compared with other data on the same galaxies, where available, and to data on samples of similar galaxies. S94 report values of the apparent magnitude, m_b , including uncertainties, for eleven of the 27 galaxies in this sample. The magnitudes for four of these galaxies were estimated by eye from the Palomar Observatory Sky Survey (POSS) plates. Because it is difficult to estimate the uncertainty in these magnitudes, they have not been considered. For the remaining seven galaxies, the values of m_b were systematically brighter in S94 than the values of m_b in this study. The average difference was 0.24 mag, with an average uncertainty in their measurements of ± 0.13 mag.

The greater magnitudes measured by S94 can be explained by the selection of apertures in their study. They applied fixed circular apertures of either 30" or 60" in radius to galaxies in their sample. These apertures were larger than the elliptical apertures used in this study. Consequently, more of

the faint outer edges of the galaxies were included. Considering this factor, agreement in the values of m_b between the two studies is good.

Nearly all of the known galaxies in the Bootes Void are emission line galaxies, so a comparison to a complete sample of emission line galaxies is included here. Salzer et al. (1989) conducted a survey of a complete sample of 155 field emission line galaxies selected from the University of Michigan objective-prism survey (hereafter referred to as the UM sample). A comparison between the sample of Bootes Void galaxies and a subsample of the UM galaxies was conducted.

The UM sample was limited by a combination of emission line flux and equivalent width, with an implicit redshift limit due to the long-wavelength cutoff in sensitivity of the photographic emulsion used. Because of the latter limit, the properties of this sample are similar, although not equivalent, to a volume-limited sample. Fainter dwarf galaxies, which are more numerous than normal galaxies, tend to dominate the UM sample. Because the magnitude limits of the IRAS and objective-prism surveys exclude dwarf galaxies at the redshift of the Bootes Void, they must not be included in any comparison made between the void galaxies and the UM sample. Two methods for choosing a proper comparison sample involve imposing either redshift or magnitude limits.

A subsample of galaxies was selected from the UM sample by considering only those galaxies having redshifts within the

redshift boundaries of the Bootes Void ($z \approx 0.041$ to 0.062). The number of UM galaxies meeting this redshift criterion is 23. The apertures used for photometry in the UM sample were chosen to correspond to isophotes of ~ 25 mag arcsec $^{-2}$ in V. The range of absolute B magnitudes, M_b , for this subsample is -17.29 to -21.43 with a mean value of $M_b = -19.29$ and a standard deviation of 1.12 . The range for M_b in the sample of Bootes Void galaxies is -17.08 to -21.14 with a mean $M_b = -19.40$ and a standard deviation of 0.98 .

The range in (B-V) colors for this same subsample of UM galaxies is 0.04 to 1.08 with a mean of 0.52 and a standard deviation of 0.28 . The range of (B-V) colors for the Bootes Void galaxies is 0.29 to 1.19 with a mean of 0.71 and a standard deviation of 0.24 .

The agreement between the magnitudes and colors of the UM redshift-limited subsample and the Bootes Void sample indicates that these properties in the void galaxies are very similar to those of field emission line galaxies. However, the subsample selected in this way is subject to the uncertainty of small number statistics. It would be useful to compare the void galaxies with a larger subsample selected in an alternative way.

A second subsample was selected from the UM survey by considering only those galaxies with M_b brighter than -18.0 . Because this value of M_b is brighter than the faintest M_b observed for the void galaxies, this criterion should assure

that the galaxies selected would be visible at redshifts large enough to place them within the Bootes Void. This magnitude-restricted subsample of UM galaxies is larger than the redshift-restricted sample. However, because the lower magnitude limit of the UM subsample is brighter than the faintest void galaxy, only the 23 void galaxies with M_B brighter than -18.0 were considered. The range of M_B for this subsample of Bootes Void galaxies was -18.36 to -21.14 with a mean value of -19.72 and a standard deviation of 0.65 . The range in M_B for the UM subsample chosen in the same manner was -18.05 to -23.33 with a mean value of -19.58 and a standard deviation of 1.13 .

The range of colors for the 76 UM galaxies in the magnitude-restricted subsample is 0.04 to 1.08 with a mean of 0.56 and a standard deviation of 0.23 . The range of colors for the Bootes Void subsample chosen in the same manner is 0.29 to 1.19 with a mean value of 0.67 and a standard deviation of 0.24 .

The agreement in the magnitudes and colors between the magnitude-restricted subsamples of Bootes Void galaxies and UM galaxies is similar to the agreement for the redshift-restricted subsamples, so the above conclusions still apply.

Because several of the galaxies in the Bootes Void were detected by IRAS, a comparison to a sample of IRAS galaxies might be informative. Roth (1994, hereafter referred to as R94) obtained V-I colors for 159 spiral galaxies selected from

an IRAS survey of objects with $60\ \mu\text{m}$ flux densities greater than $1.9\ \text{Jy}$. These 159 galaxies were also selected to have recessional velocities less than $4000\ \text{km s}^{-1}$ and with inclinations suitable for the application of the Tully-Fisher relation (Tully & Fisher 1977). This sample is described as quasi-volume limited.

Because neither absolute magnitudes nor redshifts were reported, the sample of Bootes Void galaxies is compared to the entire sample of R94. For the R94 galaxies, V-I colors were measured with isophotal apertures corresponding to $\sim 22.0\ \text{mag arcsec}^{-2}$ on the I frames. The range in V-I colors for the R94 sample is 0.82 to 2.43 with a mean value of 1.26 and a standard deviation of 0.22. The V-I colors for the Bootes Void galaxies range from -0.01 to 1.33 with a mean of 0.91 and a standard deviation of 0.30.

The sample of Bootes Void galaxies appears to be slightly bluer on average than the sample of R94. This difference might be due to the inclusion of many low-redshift galaxies in the sample of R94. In order to be detected by IRAS, these low-redshift galaxies would not need to be as luminous in the infrared as the higher-redshift void galaxies. Therefore, they might not be undergoing star formation to the same extent as the galaxies in the void. Thus, their stellar populations may be older and their colors redder than those of the void galaxies.

Another possible explanation for this difference in color involves a selection effect due to the choice of galaxies to be used to determine the Tully-Fisher relation. Determination of the Tully-Fisher relation requires measurement of the rotational velocity of spiral galaxies. This rotational velocity is most easily measured when a galaxy is seen edge-on. However, in this orientation, the light from the galaxy can be reddened significantly by dust in the plane of that galaxy. This selection effect might be responsible for the redder colors of the R94 galaxy sample.

CHAPTER 6

GALAXY MORPHOLOGY AND COLOR

Twenty galaxies of the 27 are clearly disk systems (Table 3, column 8). Nine galaxies have some spiral structure. Two of the seven galaxies not classified as disk systems could be described as irregular galaxies. The remaining five galaxies appear as point sources. These objects are probably the bright cores of galaxies with the faint surrounding disks undetected.

At least ten galaxies show some type of disturbed morphology. Of these, five possess asymmetries that may indicate they are one-armed spirals. The galaxies 1519+5050 (northwest galaxy) and 1537+5315 are clearly one-armed spirals (See Figures 37 & 43). Three galaxies in the sample are good candidates for having double nuclei. Also, at least two galaxy pairs are included in the sample.

To investigate the physical processes within a galaxy, it would be useful to know the V-I colors of given features in that galaxy. A feature with a V-I color that was blue compared to the integrated color of the galaxy is possibly a region with a young stellar population. This color difference might suggest that the galaxy had experienced a recent period of star formation. Conversely, a feature with a red V-I color

compared to that of the galaxy might indicate either the presence of H α emission or an older stellar population.

The average redshifted wavelength of H α for the Bootes Void is approximately 6900 Å. At this wavelength the H α emission would be primarily visible in the R images, but strong emission could also cause intensity enhancements in I. Because nearly all the galaxies in this sample are known to be emission line galaxies, there is a strong possibility of the R and I passbands including H α emission features.

Unfortunately, performing aperture photometry on individual features within a galaxy is complicated because it is difficult to determine the amount of signal contamination due to the rest of the galaxy. However, to obtain the desired information, it is sufficient to determine the color difference between the feature and the surrounding galaxy. The following is a description of the procedure used to determine the color differences between various features within a galaxy.

The IRAF task PVEC allows the intensity per pixel to be plotted as a function of position between any two given endpoints on an image. This task allows the user to examine an intensity profile across an object in any chosen orientation. One or more of these intensity profiles were plotted on both

the V and I images to look for color gradients across the surface or relative color differences between features within the galaxy. To ensure that the profiles were sampling the same location on both the V and I frames, the I images were registered to the V frames. The orientations of the profiles were chosen to sample the most interesting features within a particular galaxy. The intensity along the chosen vector was averaged across a perpendicular width of 3 pixels, which corresponded to approximately 1.5 arcsec.

It was assumed in this procedure that, in most cases, the galaxy's integrated colors (Table 3, columns 4-6) were dominated by the colors of the nucleus. Therefore, if the integrated colors were relatively blue compared to the average color of the sample of Bootes Void galaxies and a given feature had a color profile which appeared blue with respect to the nucleus, then it was concluded that the feature possessed a blue enhancement. The same argument applied to features which appeared red compared to the nuclei of galaxies with relatively red colors. In cases where it was not clear whether the feature or the nucleus was responsible for the contrast in a color profile, the difference is simply reported.

The intensity profiles were always plotted in the direction from the most northerly endpoint to the most southerly endpoint. Thus, on the figures comparing intensity profiles, the zero-point of the pixel position axis

corresponds to the most northerly endpoint of the profile. In the case of Figure 8b where the profile runs directly east-to-west, the zero-point of the pixel position is the eastern end of the profile.

For galaxies with no visible extended structure, color profiles were not created. Instead, the point spread function (PSF) for each of these galaxies was compared to stars of similar intensity on the same image to determine whether or not any extended structure was detected. The results of this analysis are included in the discussion of individual galaxies where appropriate.

The following are individual descriptions of the morphology and color features of the known Bootes Void galaxies:

1345+4641: Examination of the PSF for this galaxy shows it is less than 0.5 arcsec (FWHM) more extended in I than the average of three stars on the I frame. It is essentially unresolved (Figure 1).

1357+4641: Examination of the PSF for this galaxy shows it to be less than 0.5 arcsec (FWHM) more extended in I than the average of four stars on the I frame. It is essentially unresolved (Figure 2).

1406+4905 (CG 359): This galaxy is I Zwicky 81. It appears featureless in all four filters, which is consistent with the continuum images described in W95. Because Veilleux & Osterbrock (1987) classify this galaxy as a Seyfert 1, it is

probably a disk galaxy seen nearly face-on (Figure 3). Intensity profiles of this galaxy were not included because no difference in color was evident across the disk. S94 has shown that this galaxy shares an HI envelope with the nearby edge-on spiral galaxy BHI 1406+4907 located approximately 2 arcmin to the north. This companion, which is visible at the northern edge of Figure 4, was unknown at the time of the observations for this project. Interactions between these galaxies might be responsible for the reported nuclear activity in I Zwicky 81. The nearby uncatalogued void galaxy 1406+4901 was also identified by S94.

1407+4840 (CG 910): This galaxy is seen as an elongated disk with no apparent spiral arms (Figure 5). The galaxy nucleus appears to be bright compared to the disk in the I image. An intensity profile plotted along the extended axis from east to west shows that the nucleus is redder than the outer structure (Figures 6a,b). The B-V color of the galaxy is 0.37 ± 0.41 (see Table 3), suggesting that the integrated light from the galaxy is relatively blue. This color might suggest a young stellar population in the disk of the galaxy.

1408+4852 (CG 370): This galaxy has a bright nucleus surrounded by a faint asymmetric disk. Directly west of the nucleus is a faint bulge that might be part of a spiral arm (Figure 7). An intensity profile plotted through the nucleus and the bulge shows little or no color difference between them (Figure 8a,b). The surrounding structure to the east extends

nearly twice as far from the nucleus as the structure to the west. The structure to the east and west is connected continuously north of the nucleus. South of the nucleus almost no structure is visible. This galaxy appears to be a disturbed spiral galaxy, although no companion galaxy is visible.

1413+5056: This galaxy has a bright nucleus with a compact circular bulge to the southwest. These two sources are embedded in a faint asymmetric disk (Figure 9). An intensity profile plotted through the nucleus and the bulge shows the bulge to be enhanced in the I filter, suggesting that it might have H α emission (Figure 10a,b). The nucleus is situated to the northeast of the geometric center of the faint disk. This configuration suggests the possibility of a system with a double nucleus.

1428+5255: This galaxy appears as a large, elongated disk with a very bright nucleus. Surrounding the nucleus is a bright elliptical region slightly larger than the nucleus but much smaller than the faint disk. On the south end of the ellipse is a small, bright protrusion making the region appear asymmetric. The orientation of this feature is nearly north to south, while the major axis of the disk is oriented from northwest to southeast (Figure 11). A contour plot of this galaxy clearly shows a rotation of the isophotes following this trend (Figure 12). Intensity profiles of this galaxy were not included because no difference in color was evident across the galaxy surface.

The two spiral arms visible in H α (W95) are not seen on these images. From the dimensions of the arms measured in W95, they lie within the area of the large, outer disk. The bulge south of the nucleus might be where the fainter of these spiral arms is joined to the nucleus. This feature might also be part of a nuclear bar. It should be noted that W95 also suggest the possibility of a foreground star located at this position.

S94 observed the HI distribution around this galaxy to be offset with respect to the optical center and irregular in appearance which might suggest some type of interaction with an unseen companion. They also identified four previously uncatalogued galaxies in the region surrounding 1428+5255. This galaxy is also reported to be an X-ray source by Boller et al. (1992).

1432+5302 (CG 474): This galaxy appears as a small, smooth object elongated in the northwest to southeast direction and having a compact nucleus (Figure 13). H α images of this object reveal strong emission from the nucleus. An intensity profile plotted along the galaxy's major axis shows no changes in color (Figure 14a,b). The integrated colors for this object are very blue compared to the mean values of the sample. It is likely that only the nuclear region of this galaxy is resolved.

1444+4402 (CG 538): An elongated disk system, this galaxy has a bright elliptical nucleus and a large faint surrounding

disk. Also, a faint knot is shown to the northeast of the nucleus which does not appear to be a foreground star (Figure 15). An intensity profile plotted through the galaxy along the line between the knot and nucleus shows the knot to be slightly extended. The galaxy disk also appears to be slightly bluer than the nucleus (Figure 16a,b). Because the galaxy's integrated colors are relatively red, it is not known if the color difference is an indication of young stars in the disk, H α emission in the nucleus or some combination of factors. S94 report an asymmetric surrounding distribution of HI extending east of the galaxy.

1446+4457 (CG 547): Images of this galaxy show it to be a flattened disk system. It has a small, bright, elliptical nucleus located off-center in an elongated disk. Some substructure in the disk is visible in the I filter east of the nucleus (Figure 17). An intensity profile plotted along the major axis of the galaxy shows that the region in the disk directly east-southeast of the nucleus is clearly enhanced on the V image (Figure 18a,b). This color difference might indicate a younger stellar population in this region. The object north of the nucleus which was seen in H α (W95) is not visible on these images.

1457+4228 (CG 598): This galaxy is a flattened disk system with a bright, round nucleus. It has a smooth, elongated surrounding disk which is asymmetric with respect to the nucleus (Figure 19). S94 report a previously uncatalogued

companion galaxy, BHI 1457+4228, located approximately 1 arcmin west of 1457+4228. This galaxy is visible in Figure 20, the I image of this field. S94 observe the peak in the HI distribution to be centered between these two galaxies, forming a common envelope around both. It is likely that a tidal interaction with BHI 1457+4228 is responsible for the asymmetric appearance of 1457+4228.

Although similar in appearance to 1446+4457, no color differences are visible in an intensity profile plotted along the major axis of 1457+4228 (Figure 21a,b).

1458+4944 (CG 922): It is difficult to determine whether this galaxy is resolved (Figure 22). Comparison of the PSF of the galaxy with stars of similar brightness on the I frame shows that the galaxy is approximately 0.9 arcsec (FWHM) more extended than the stars. The image probably shows a galaxy with a bright nucleus and a hint of an underlying disk. The point source galaxies are generally the fainter galaxies in the sample, but this galaxy is fairly bright, with $M_V = -19.84 \pm 0.09$. It is possible that this galaxy is a Seyfert galaxy.

1503+5428 (CG 620): Examination of the PSF for this galaxy shows it to be only 0.63 arcsec (FWHM) more extended in I than the average of four stars on the I frame. It is essentially unresolved (Figure 23).

1505+3958 (CG 629): This galaxy appears to be a disk system observed nearly face-on. It has a small elliptical nucleus within a large, smooth and faint elliptical disk (Figure 24).

The intensity profile shows that the galaxy might have a slight blue enhancement in a region extending from 3 to 8 arcsec southeast of the nucleus (Figure 25a,b). This enhancement might indicate a period of recent star formation within the galaxy.

1506+5138 (CG 636): This galaxy has been previously identified as Markarian 845. The galaxy is apparently a disk system viewed-edge-on. It has a very bright circular nucleus with an elongated disk extending from northwest to southeast. A knot is visible south of the nucleus and approximately halfway along the plane of the galaxy. It is not known whether this feature is associated with the galaxy (Figure 26). An intensity profile plotted along the major axis of the galaxy (NW to SE) shows little or no color change (Figure 27a,b). The I profile falls off a little more slowly than the V profile in a plot running approximately north to south intersecting both the nucleus and the knot (Figure 28a,b). No color difference is noticeable between the knot and the nucleus. S94 observe the HI distribution to be only slightly asymmetric about this galaxy.

1507+4554 (CG 642): Comparison of the PSF of this galaxy with stars of similar brightness on the I frame shows that the galaxy is approximately 1.15 arcsec (FWHM) more extended than the average of the stars. This difference in width suggests that some faint structure surrounding the nucleus has been resolved (Figure 29).

1510+4727 (CG 657): A galaxy with a disturbed morphology, it has an irregularly shaped core consisting of a nucleus with either an elongation or a knot of emission to the northwest. Surrounding this region is faint extended structure (Figure 30).

An intensity profile was plotted to pass through both the nucleus and the northwest feature. The V and I profiles across the nucleus are nearly identical, but the I profile shows an enhancement through the northwest elongation (Figure 31a,b). The enhancement could mean that this feature is an area of increased H α emission. This interpretation is consistent with W95 having found this object to be a very strong source of H α emission. However, it must be noted that the integrated color of this galaxy is very blue. Therefore, the difference in profiles might be due to a blue nuclear color. This galaxy may have a double nucleus, or it could be a galaxy merger.

1517+3949: This galaxy is an extended circular object with a small, faint nucleus. Two knots are visible to the southwest of the galaxy (Figure 32). It is not known whether these objects are associated with the galaxy or not. They are clearly visible on the R and I frames, but they are very faint in V and disappear completely on the B image. Intensity profiles through the nucleus and each knot respectively show that both knots are very red compared to the nucleus (Figure 33a,b & Figure 34a,b). Considering the color and position of the knots, they could be interpreted as two large HII regions

along an extended spiral arm. Spectra of these features are needed to make this determination.

S94 observed this galaxy to be rich in HI. The greatly extended HI envelope would easily encompass the two knots if they are at the same redshift. S94 report this galaxy to be associated with the galaxy 1517+3956.

1517+3956 (CG 684): This galaxy appears to have a disturbed morphology. Two distinct bright regions are visible in the center. The brighter of the two is north and slightly east of the fainter. These sources are surrounded by faint outer structure extending from north to south (Figure 35). The appearance of this object is consistent with the presence of a double nucleus or a merging galaxy pair.

Preliminary analysis of spectra taken across each of the two bright regions shows an apparent shift in the spectral features of these objects, supporting the idea that this may be a pair of merging galaxies (Weistrop 1994). An intensity profile plotted through both brightness centers shows no appreciable difference in color between the two (Figure 36a,b). S94 observed a large HI envelope surrounding this system.

1519+5050 (CG 692/CG 693): This system is a pair of interacting spiral galaxies. The larger (northwest) of the pair is clearly a one-armed spiral. Spiral structure is also visible in the smaller (southeast) galaxy (Figure 37). S94 observed that the galaxies are within a common HI envelope. A

thorough description of these galaxies is given by Weistrop et al. (1992).

1530+4332: This galaxy pair was identified by Dey et al. (1990). The larger of the two galaxies is located to the west of the smaller. The larger galaxy appears as a disk system seen almost face-on. It has an elliptical nuclear region surrounded by a large, faint disk (Figure 38).

An intensity profile plotted along the major axis of this galaxy from north to south shows the outer disk to be blue compared to the nucleus, especially on the north side (Figure 39a,b). This area of enhancement on the V frame is just east of a large source of H α emission observed northwest of the nucleus by W95. Both of these features would be consistent with a recent period of star formation within the disk of this galaxy. Such an episode of star formation could have been triggered by gravitational interactions with the companion galaxy.

The smaller (companion) galaxy has a bright nucleus with no visible surrounding structure. A knot is visible directly north of this nucleus (Figure 38). It is not known if this feature is associated with the companion galaxy. An intensity profile plotted through both the nucleus of the companion and the knot to the north indicates that the knot is much redder than the nucleus (Figure 40a,b). However, this feature was not significantly brighter in H α than in the nearby continuum on images taken by W95.

S94 observe an HI envelope centered on the larger (west) galaxy and extending far beyond both galaxies. They also observe the uncatalogued galaxy BHI 1530+4331 in a nearby field.

1535+3831: This galaxy is a disk system seen edge-on. It has a large, bright elliptical nucleus. The nucleus is surrounded by an elliptical outer disk with a tail-like protrusion extending to the west (Figure 41). This extended feature could be a single spiral arm. An intensity profile plotted along the major axis (and through the tail) of this galaxy shows that the V profile is much broader than the I profile in the disk (Figure 42a,b). Thus, regions in the disk of this galaxy appear to be blue compared to the nucleus.

Because very few counts were measured in the B filter for this galaxy, the uncertainty in the B-V color is very large due to the uncertainty in the sky counts. Thus, B-V for this galaxy is essentially unknown and is included only for the sake of completeness (see Table 3). The other integrated colors of this galaxy are fairly red, so it is not known whether the color difference in the intensity profile is due to blue stars in the disk or, possibly, H α emission in the nucleus.

1537+5315: This galaxy is a one-armed spiral seen face-on. The galaxy has a bright, circular nucleus. Beginning at the northern edge of this nucleus and wrapping around to the southwest is a single spiral arm. This spiral arm contains a

knot of emission located directly to the west of the nucleus (Figure 43). No evidence for a second spiral arm can be seen on the southeast side. The intensity profile plotted through both the nucleus and the knot in the spiral arm shows the knot to be blue compared to the nucleus (Figure 44a,b). The integrated colors of this galaxy are fairly red, so the color difference could be caused by either blue stars in the arm, or by redder stars or H α emission in the nucleus.

1540+5013: This galaxy has an elliptical nucleus with a bright compact core. The nucleus is contained within a faint, elongated disk (Figure 45). An intensity profile plotted along the major axis of the galaxy indicates a V profile that is slightly wider than the I profile (Figure 46a,b). This difference might indicate a younger disk population.

1547+5121: This object is a disk galaxy seen edge-on. It has a bright elliptical nucleus surrounded by faint extended structure. The outer structure is greatly elongated to the northwest of the nucleus (Figure 47). With such an asymmetry, this galaxy may be a one-armed spiral. A small faint knot is visible on the southeast tip of the nucleus. It is not known if this feature is associated with the galaxy. An intensity profile plotted along the major axis of this galaxy shows no changes in color across the galaxy surface (Figure 48a,b).

CHAPTER 7

CONCLUSIONS

Broadband photometry was performed on the 27 known Bootes Void galaxies. The significance of the results of this photometry is best illustrated by comparing the properties of these galaxies with the properties of galaxies in the field and galaxies predicted by theoretical models to inhabit low-density regions. The models of Hoffman et al. (1992) suggest that voids should be inhabited by giant low surface brightness galaxies similar to the object Malin I. In addition, Lacey et al. (1993) state that their models imply no luminous galaxies forming in voids due to a lack of tidal interactions needed to trigger star formation.

The range of M_B for this sample of Bootes Void galaxies is between -17.1 and -21.1 and the mean value for $M_B \sim -19.4$. This mean value for M_B is slightly higher than the mean M_B for the galaxies in the UM sample having redshifts that would place them at the distance of the Bootes Void. Thus, the void galaxies appear to have a magnitude distribution similar to that of field emission line galaxies. Consequently, the void galaxies have high optical luminosities compared to predictions for galaxies in low-density environments.

One possible interpretation of this inconsistency is that localized regions of normal density in the distribution of matter exist within voids, and that void galaxies having properties similar to field galaxies form within these regions. It is possible that these localized regions have an even higher density of matter than normal space, accounting for an increase in the number of active galaxies and galaxy pairs. This interpretation would be consistent with models predicting non-uniform filamentary distributions of matter within voids as suggested by van de Weygaert & van Kampen (1993) and Dubinski et al. (1993).

Nearly all of the galaxies known to be in the void are disk systems. This result is not surprising because the galaxies were identified from either objective prism surveys or IRAS detections. Both types of observations tend to identify disk systems.

Approximately 40% of the galaxies exhibit unusual, asymmetric or disturbed morphologies. At least two galaxy pairs are included in the sample. It is likely that a third object (1517+3956) is also a galaxy pair. This number might suggest a greater occurrence of galaxy pairs in the void than the 8% reported in the UM sample, although this estimate is uncertain due to the small numbers involved. S94 observed

close companions to the galaxies 1406+4905 and 1457+4228 in HI.

Intensity profiles indicate that several galaxies show enhanced blue color in their disks which suggests the possibility of young stellar populations. Other profiles indicate color differences between features within certain galaxies indicating possible H α emission or differences in stellar population. Each of these properties might indicate recent star formation activity.

It has not been determined whether the unusual nature of the galaxies in the Bootes Void is indicative of galaxies in voids or is entirely a product of selection effects. However, because Kirshner et al. (1987) found no normal galaxies in their survey of this region, it is more likely that this sample is a suitable representation of the galaxy population in the Bootes Void. More extensive surveys in regions of low density are needed in order to determine the nature of galaxies in voids.

Further investigations into the properties of void galaxies are in progress. Observations of the Bootes Void sample have been made with a long-slit spectrograph to study the galaxies in more detail. Galaxies in other large voids are also being observed in order to reach more general conclusions about the characteristics of void galaxies.

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Table 3 Summary of photometric data and morphological characteristics for Bootes Void galaxies.

Galaxy	Alternate Identification	V (red. corr.)	B-V	V-R	R-I	M _V	Morphology
1345+4641		18.21±0.22	0.79±0.68	0.29±0.25	0.53±0.21	-18.48±0.22	point source
1357+4641		18.22±0.15	0.98±0.70	0.52±0.19	0.46±0.19	-18.55±0.15	point source
1406+4905	I Zwicky 81	15.29±0.07	0.73±0.36	0.57±0.10	0.59±0.09	-21.40±0.08	disk, face-on
1407+4840	CG 910	16.75±0.09	0.37±0.41	0.68±0.11	0.65±0.08	-19.55±0.09	disk, edge-on
1408+4852	CG 370	16.65±0.19	0.29±0.55	0.25±0.26	0.58±0.30	-19.69±0.19	asymmetric disk
1413+5056		16.42±0.10	0.93±0.50	0.50±0.12	0.72±0.10	-20.16±0.11	disk with knot
1428+5255		14.88±0.10	0.87±0.50	0.63±0.12	0.62±0.09	-21.49±0.10	spiral, face-on
1432+5302	CG 474	16.90±0.08	0.32±0.20	0.06±0.10	0.40±0.14	-19.45±0.09	elongated disk
1444+4402	CG 538	15.29±0.12	0.76±0.63	0.54±0.15	0.49±0.14	-21.02±0.13	disk, face-on
1446+4457	CG 547	16.18±0.10	0.44±0.38	0.42±0.13	0.43±0.13	-20.10±0.11	edge-on, asym. disk
1457+4228	CG 598	15.98±0.12	0.55±0.33	0.32±0.16	0.44±0.16	-20.95±0.12	edge-on, asym. disk
1458+4944	CG 922	16.65±0.09	0.42±0.35	0.28±0.14	0.44±0.14	-19.84±0.09	point source
1503+5428	CG 620	18.39±0.12	1.03±0.60	0.47±0.16	0.56±0.19	-18.11±0.12	point source
1505+3958	CG 629	16.00±0.13	0.81±0.42	0.29±0.17	0.43±0.17	-20.67±0.13	disk, face-on

Galaxy	Alternate Identification	V (red. corr.)	B-V	V-R	R-I	M_V	Morphology
1506+5138	MRK 845	14.77±0.09	0.95±0.45	0.52±0.11	0.65±0.09	-21.65±0.09	disk with knots
1507+4554	CG 642	17.76±0.11	0.92±0.51	-0.21±0.18	0.20±0.30	-18.80±0.11	point source
1510+4727	CG 657	16.51±0.08	0.45±0.30	0.06±0.12	0.28±0.15	-20.21±0.09	irregular
1517+3949		16.98±0.20	0.63±0.75	0.35±0.26	0.41±0.25	-19.50±0.20	disk, face-on
1517+3956	CG 684	16.16±0.13	0.57±0.59	0.29±0.16	0.48±0.16	-20.33±0.14	irregular
1519+5050	CG 692	15.27±0.11	0.47±0.37	0.38±0.14	0.43±0.14	-21.61±0.11	1-armed spiral
1519+5050	CG 693	16.35±0.13	0.90±0.63	0.52±0.16	0.54±0.14	-20.54±0.13	companion (SE), spiral
1530+4332		16.44±0.14	0.74±0.60	0.59±0.17	0.49±0.16	-20.26±0.14	disk, face-on
1530+4332		17.83±0.10	0.51±0.32	0.41±0.13	0.41±0.15	-18.87±0.10	companion (E), disk
1535+3831		16.06±0.17	1.19±1.40	0.52±0.21	0.69±0.17	-20.60±0.17	edge-on, asym. disk
1537+5315		16.54±0.14	1.00±0.73	0.58±0.17	0.61±0.15	-20.18±0.14	1-armed spiral
1540+5013		15.99±0.09	0.84±0.45	0.67±0.11	0.56±0.10	-20.83±0.09	disk, edge-on
1547+5121		16.50±0.11	0.62±0.42	0.50±0.14	0.49±0.13	-20.13±0.11	edge-on, asym. disk

Figure 1 Image of the galaxy 1345+4641 taken in the I filter and displayed with north at the top and east at the left. The size of the field is $1.32' \times 1.32'$. This galaxy is unresolved in the image and is listed as one of the point source galaxies in Table 3.

Figure 2 Image of the galaxy 1357+4641 taken in the I filter and displayed with north at the top and east at the left. The size of the field is 1.32' X 1.32'. This galaxy is unresolved in the image and is listed as one of the point source galaxies in Table 3.

Figure 3 Image of the galaxy 1406+4905 (I Zw 81) taken in the I filter and displayed with north at the top and east at the left. The size of the field is 1.15' X 1.15'. Although the galaxy appears featureless in this image, it has been described as a Seyfert I, and so it is probably a spiral galaxy.

Figure 4 Image of the field surrounding 1406+4905 taken in the I filter and displayed with north at the top and east at the left. The size of the field is 4.10' X 4.10'. The associated spiral BHI 1406+4907 is shown by the arrow at the extreme northern edge of the image.

Figure 5 Image of the galaxy 1407+4840 (CG 910) taken in the I filter and displayed with north at the top and east at the left. The size of the field is 1.41' X 1.41'. The galaxy appears as an elongated disk with a bright nucleus.

Figure 6a Image of the galaxy 1407+4840 (CG 910) taken in the I filter and displayed with north at the top and east at the left. The size of the field is $0.67' \times 0.67'$. The orientation of the intensity profile is shown. The zero of the intensity profile is at the most northern endpoint.

Figure 6b Normalized intensity (i) profiles from V and I images of 1407+4840, plotted as a function of position. The dashed line is the V profile and the solid line is the I. The zero of the intensity profile is at the most northern endpoint. The V profile appears to be enhanced in the outer region of the galaxy.

Figure 7 Image of the galaxy 1408+4852 (CG 370) taken in the I filter and displayed with north at the top and east at the left. The size of the field is 1.58' X 1.58'. This asymmetric galaxy appears to be disturbed. Part of a spiral arm might be visible west of the nucleus.

Figure 8a Image of the galaxy 1408+4852 (CG 370) taken in the I filter and displayed with north at the top and east at the left. The size of the field is 1.44' X 1.44'. The orientation of the intensity profile is shown. The zero of the intensity profile is at the most northern endpoint.

Figure 8b Normalized intensity (i) profiles from V and I images of 1408+4852, plotted as a function of position. The dashed line is the V profile and the solid line is the I. The zero of this intensity profile is at the most eastern endpoint. The two peaks in the profile are the nucleus and the feature to the west.

Figure 9 Image of the galaxy 1413+5056 taken in the I filter and displayed with north at the top and east at the left. The size of the field is 0.93' X 0.93'. This asymmetric galaxy has a knot of emission southwest of the core which might be part of a double nucleus.

Figure 10a Image of the galaxy 1413+5056 taken in the I filter and displayed with north at the top and east at the left. The size of the field is $0.93' \times 0.93'$. The orientation of the intensity profile is shown. The zero of the intensity profile is at the most northern endpoint.

Figure 10b Normalized intensity (i) profiles from V and I images of 1413+5056, plotted as a function of position. The dashed line is the V profile and the solid line is the I. The zero of the intensity profile is at the most northern endpoint. The two peaks in the profile are the nucleus and the knot to the southwest.

Figure 11 Image of the galaxy 1428+5255 taken in the I filter and displayed with north at the top and east at the left. The size of the field is 1.44' X 1.44'. The protrusion from the elliptical region surrounding the nucleus is visible to the south.

Figure 12 Contour plot of the galaxy 1428+5255 showing the rotation of isophotes from the center to edge. The scale of this plot is approximately $1.0' \times 0.7'$. It is displayed north at the top and east at the left.

Figure 13 Image of the galaxy 1432+5302 (CG 474) taken in the I filter and displayed with north at the top and east at the left. The size of the field is 0.9' X 0.9'. It is possible that only the bright nucleus of this galaxy is resolved.

Figure 14a Image of the galaxy 1432+5302 (CG 474) taken in the I filter and displayed with north at the top and east at the left. The size of the field is $0.9' \times 0.9'$. The orientation of the intensity profile is shown. The zero of the intensity profile is at the most northern endpoint.

Figure 14b Normalized intensity (i) profiles from V and I images of 1432+5302 (CG 474), plotted as a function of position. The dashed line is the V profile and the solid line is the I. The zero of the intensity profile is at the most northern endpoint.

Figure 15 Image of the galaxy 1444+4402 (CG 538) taken in the I filter and displayed with north at the top and east at the left. The size of the field is 1.15' X 1.15'. A very faint knot is visible northeast of the nucleus.

Figure 16a Image of the galaxy 1444+4402 (CG 538) taken in the I filter and displayed with north at the top and east at the left. The size of the field is 1.15' X 1.15'. The orientation of the intensity profile is shown. The zero of the intensity profile is at the most northern endpoint.

Figure 16b Normalized intensity (i) profiles from V and I images of 1444+4402 (CG 538), plotted as a function of position. The dashed line is the V profile and the solid line is the I. The zero of the intensity profile is at the most northern endpoint. The faint knot is visible on the profile to the left of the nucleus.

Figure 17 Image of the galaxy 1446+4457 (CG 547) taken in the I filter and displayed with north at the top and east at the left. The size of the field is 0.72' X 0.72'. The galaxy has an elliptical shape and an asymmetric morphology.

Figure 18a Image of the galaxy 1446+4457 (CG 547) taken in the I filter and displayed with north at the top and east at the left. The size of the field is 0.70' X 0.70'. The orientation of the intensity profile is shown. The zero of the intensity profile is at the most northern endpoint.

Figure 18b Normalized intensity (i) profiles from V and I images of 1446+4457 (CG 547), plotted as a function of position. The dashed line is the V profile and the solid line is the I. The zero of the intensity profile is at the most northern endpoint. The V profile is enhanced to the east-southeast of the nucleus.

Figure 19 Image of the galaxy 1457+4228 (CG 598) taken in the I filter and displayed with north at the top and east at the left. The size of the field is 1.76' X 1.76'. The galaxy has an elliptical shape and an asymmetric morphology.

Figure 20 Image of the field surrounding 1457+4228 (CG 598) taken in the I filter and displayed with north at the top and east at the left. The size of the field is 3.52' X 3.52'. The companion, BHI 1457+4228, is indicated by the arrow.

Figure 21a Image of the galaxy 1457+4228 (CG 598) taken in the I filter and displayed with north at the top and east at the left. The size of the field is 1.76' X 1.76'. The orientation of the intensity profile is shown. The zero of the intensity profile is at the most northern endpoint.

Figure 21b Normalized intensity (i) profiles from V and I images of 1457+4228 (CG 598), plotted as a function of position. The dashed line is the V profile and the solid line is the I. The zero of the intensity profile is at the most northern endpoint.

Figure 22 Image of the galaxy 1458+4944 (CG 922) taken in the I filter and displayed with north at the top and east at the left. The size of the field is 2.44' X 2.44'. The PSF for this galaxy is slightly wider than the PSF's of stars on the frame. It is listed as a point source galaxy in Table 3.

Figure 23 Image of the galaxy 1503+5428 (CG 620) taken in the I filter and displayed with north at the top and east at the left. The size of the field is 2.26' X 2.26'. The PSF for this galaxy is slightly wider than the PSF's of stars on the frame. It is listed as a point source galaxy in Table 3.

Figure 24 Image of the galaxy 1505+3958 (CG 629) taken in the I filter and displayed with north at the top and east at the left. The size of the field is 1.44' X 1.44'. This galaxy is a disk system observed nearly face-on.

Figure 25a Image of the galaxy 1505+3958 (CG 629) taken in the I filter and displayed with north at the top and east at the left. The size of the field is $1.44' \times 1.44'$. The orientation of the intensity profile is shown. The zero of the intensity profile is at the most northern endpoint.

Figure 25b Normalized intensity (i) profiles from V and I images of 1505+3958 (CG 629), plotted as a function of position. The dashed line is the V profile and the solid line is the I. The zero of the intensity profile is at the most northern endpoint. The V profile appears to be enhanced in the outer regions of the disk.

Figure 26 Image of the galaxy 1506+5138 (MRK 845) taken in the I filter and displayed with north at the top and east at the left. The size of the field is 1.44' X 1.44'. This galaxy is an edge-on disk system. A knot is visible south of the nucleus.

Figure 27a Image of the galaxy 1506+5138 (MRK 845) taken in the I filter and displayed with north at the top and east at the left. The size of the field is 1.58' X 1.58'. The orientation of the intensity profile is shown. The zero of the intensity profile is at the most northern endpoint.

Figure 27b Normalized intensity (i) profiles from V and I images of 1506+5138 (MRK 845), plotted as a function of position. The dashed line is the V profile and the solid line is the I. The zero of the intensity profile is at the most northern endpoint.

Figure 28a Image of the galaxy 1506+5138 (MRK 845) taken in the I filter and displayed with north at the top and east at the left. The size of the field is 1.44' X 1.44'. The orientation of the intensity profile is shown. The zero of the intensity profile is at the most northern endpoint.

Figure 28b Normalized intensity (i) profiles from V and I images of 1506+5138 (MRK 845), plotted as a function of position. The dashed line is the V profile and the solid line is the I. The zero of the intensity profile is at the most northern endpoint. The I profile appears enhanced in the outer disk.

Figure 29 Image of the galaxy 1507+4554 (CG 642) taken in the I filter and displayed with north at the top and east at the left. The size of the field is 1.27' X 1.27'. The PSF for this galaxy is slightly wider than the PSF's of stars on the frame. It is listed as a point source galaxy in Table 3.

Figure 30 Image of the galaxy 1510+4727 (CG 657) taken in the I filter and displayed with north at the top and east at the left. The size of the field is $0.67' \times 0.67'$. The galaxy has a disturbed morphology. It might be a pair of merging galaxies.

Figure 31a Image of the galaxy 1510+4727 (CG 657) taken in the I filter and displayed with north at the top and east at the left. The size of the field is $0.67' \times 0.67'$. The orientation of the intensity profile is shown. The zero of the intensity profile is at the most northern endpoint.

Figure 31b Normalized intensity (i) profiles from V and I images of 1510+4727 (CG 657), plotted as a function of position. The dashed line is the V profile and the solid line is the I. The zero of the intensity profile is at the most northern endpoint. A feature is visible in the I profile northwest of the nucleus.

Figure 32 Image of the galaxy 1517+3949 taken in the I filter and displayed with north at the top and east at the left. The size of the field is 1.44' X 1.44'. Two features visible to the southwest might be associated with the galaxy.

Figure 33a Image of the galaxy 1517+3949 taken in the I filter and displayed with north at the top and east at the left. The size of the field is 1.44' X 1.44'. The orientation of the intensity profile is shown. The zero of the intensity profile is at the most northern endpoint.

Figure 33b Normalized intensity (i) profiles from V and I images of 1517+3949, plotted as a function of position. The dashed line is the V profile and the solid line is the I. The zero of the intensity profile is at the most northern endpoint. The profile shows that the galaxy is much redder than the feature.

Figure 34a Image of the galaxy 1517+3949 taken in the I filter and displayed with north at the top and east at the left. The size of the field is 1.44' X 1.44'. The orientation of the intensity profile is shown. The zero of the intensity profile is at the most northern endpoint.

Figure 34b Normalized intensity (i) profiles from V and I images of 1517+3949, plotted as a function of position. The dashed line is the V profile and the solid line is the I. The zero of the intensity profile is at the most northern endpoint. The profile shows that the galaxy is much redder than the feature.

Figure 35 Image of the galaxy 1517+3956 (CG 684) taken in the I filter and displayed with north at the top and east at the left. The size of the field is $0.97' \times 0.97'$. This unusual system is probably a galaxy merger.

Figure 36a Image of the galaxy 1517+3956 (CG 684) taken in the I filter and displayed with north at the top and east at the left. The size of the field is 0.90' X 0.90'. The orientation of the intensity profile is shown. The zero of the intensity profile is at the most northern endpoint.

Figure 36b Normalized intensity (i) profiles from V and I images of 1517+3956 (CG 684), plotted as a function of position. The dashed line is the V profile and the solid line is the I. The zero of the intensity profile is at the most northern endpoint. Both bright regions are visible in the profile.

Figure 37 Image of the galaxy pair 1519+5050 (CG 692/CG 693) taken in the I filter and displayed with north at the top and east at the left. The size of the field is 1.13' X 1.13'. The disturbed morphology apparent in this system is the result of the tidal interaction between the pair.

Figure 38 Image of the galaxy pair 1530+4332 taken in the I filter and displayed with north at the top and east at the left. The size of the field is 1.13' X 1.13'. Some structure might be visible in the disk of the larger (west) galaxy. A knot is visible north of the smaller (east) galaxy.

Figure 39a Image of the galaxy pair 1530+4332 taken in the I filter and displayed with north at the top and east at the left. The size of the field is $1.22' \times 1.22'$. The orientation of the intensity profile through the larger (west) galaxy is shown. The zero of the intensity profile is at the most northern endpoint.

Figure 39b Normalized intensity (i) profiles from V and I images of 1530+4332 (W), plotted as a function of position. The dashed line is the V profile and the solid line is the I. The zero of the intensity profile is at the most northern endpoint. A pronounced feature is visible in the V profile north of the nucleus.

Figure 40a Image of the galaxy pair 1530+4332 taken in the I filter and displayed with north at the top and east at the left. The size of the field is 1.13' X 1.13'. The orientation of the intensity profile through the smaller (east) galaxy is shown. The zero of the intensity profile is at the most northern endpoint.

Figure 40b Normalized intensity (i) profiles from V and I images of 1530+4332 (E), plotted as a function of position. The dashed line is the V profile and the solid line is the I. The zero of the intensity profile is at the most northern endpoint. The profile shows the feature to the north to be much redder than the galaxy.

Figure 41 Image of the galaxy 1535+3831 taken in the I filter and displayed with north at the top and east at the left. The size of the field is 1.13' X 1.13'. The galaxy has a tail-like extended feature to the west.

Figure 42a Image of the galaxy 1535+3831 taken in the I filter and displayed with north at the top and east at the left. The size of the field is 1.13' X 1.13'. The orientation of the intensity profile is shown. The zero of the intensity profile is at the most northern endpoint.

Figure 42b Normalized intensity (i) profiles from V and I images of 1535+3831, plotted as a function of position. The dashed line is the V profile and the solid line is the I. The zero of the intensity profile is at the most northern endpoint. The V profile is clearly broader in the disk region of the galaxy.

Figure 43 Image of the galaxy 1537+5315 taken in the I filter and displayed with north at the top and east at the left. The size of the field is 1.22' X 1.22'. This galaxy has a single spiral arm visible north and west of the nucleus.

Figure 44a Image of the galaxy 1537+5315 taken in the I filter and displayed with north at the top and east at the left. The size of the field is $0.93' \times 0.93'$. The orientation of the intensity profile is shown. The zero of the intensity profile is at the most northern endpoint.

Figure 44b Normalized intensity (i) profiles from V and I images of 1537+5315, plotted as a function of position. The dashed line is the V profile and the solid line is the I. The zero of the intensity profile is at the most northern endpoint. The V profile is enhanced in the spiral arm of the galaxy.

Figure 45 Image of the galaxy 1540+5013 taken in the I filter and displayed with north at the top and east at the left. The size of the field is 1.13' X 1.13'. This galaxy has a very compact nuclear region within a fainter surrounding disk.

Figure 46a Image of the galaxy 1540+5013 taken in the I filter and displayed with north at the top and east at the left. The size of the field is $1.22' \times 1.22'$. The orientation of the intensity profile is shown. The zero of the intensity profile is at the most northern endpoint.

Figure 46b Normalized intensity (i) profiles from V and I images of 1540+5013, plotted as a function of position. The dashed line is the V profile and the solid line is the I. The zero of the intensity profile is at the most northern endpoint. The V profile appears slightly enhanced in the disk of the galaxy.

Figure 47 Image of the galaxy 1547+5121 taken in the I filter and displayed with north at the top and east at the left. The size of the field is $0.88' \times 0.88'$. The disk of this galaxy is elongated to the northwest.

Figure 48a Image of the galaxy 1547+5121 taken in the I filter and displayed with north at the top and east at the left. The size of the field is 1.13' X 1.13'. The orientation of the intensity profile is shown. The zero of the intensity profile is at the most northern endpoint.

Figure 48b Normalized intensity (i) profiles from V and I images of 1547+5121, plotted as a function of position. The dashed line is the V profile and the solid line is the I. The zero of the intensity profile is at the most northern endpoint.

Figure 49 Plot of the residuals between the measured and published values of V vs. the published values of V for the standard stars. This plot was used to verify that no systematic effects were introduced in the magnitude transformation process.

Figure 50 Plot of the residuals between the measured and published values of $(B-V)$ vs. the published values of $(B-V)$. This plot was used to verify that no systematic effects were introduced in the magnitude transformation process.

Figure 51 Plot of the residuals between the measured and published values of V vs. the published values of $(B-V)$. This plot was used to verify that no systematic effects were introduced in the magnitude transformation process.

Figure 52 Plot of the residuals between the measured and published values of $(V-R)$ vs. the published values of $(V-R)$. This plot was used to verify that no systematic effects were introduced in the magnitude transformation process.

Figure 53 Plot of the residuals between the measured and published values of $(R-I)$ vs. the published values of $(R-I)$. This plot was used to verify that no systematic effects were introduced in the magnitude transformation process.

Figure 54 Plot of the residuals between the measured and published values of V vs. the airmass. This plot was used to verify that no systematic effects were introduced in the magnitude transformation process.

Figure 55 Plot of the residuals between the measured and published values of $(B-V)$ vs. the airmass. This plot was used to verify that no systematic effects were introduced in the magnitude transformation process.

Figure 56 Plot of the residuals between the measured and published values of $(V-R)$ vs. the airmass. This plot was used to verify that no systematic effects were introduced in the magnitude transformation process.

Figure 57 Plot of the residuals between the measured and published values of $(R-I)$ vs. the airmass. This plot was used to verify that no systematic effects were introduced in the magnitude transformation process.