The Extragalactic Distance Database: Hawaii Photometry Catalog

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ABSTRACT

B, R, I photometry of relatively nearby galaxies has been carried out over the course of several years with the University of Hawaii 2.2m telescope and a camera with a 7.5 arcmin field of view. The primary scientific purpose was to provide global magnitudes and inclinations for galaxies for the purpose of measuring distances through the correlation between galaxy luminosities and rotation rates. The observations typically extend to 7–8 exponential disk scalelengths so the data are useful for studies of the structural properties of galaxies. **This paper is still under construction.**

Subject headings: astronomical data base; catalogs; galaxies: photometry; galaxies: distances

1. Introduction

The motivation for this program is the measurement of distances based on the correlation between the rotation rates of galaxies and their luminosities (Tully & Fisher 1977). Other papers in this series discuss the compilation of rotation rate information (Courtois et al. 2009) and the synthesis of data into the final product of distances. The global program involves many components which are being assembled for dissemination in EDD, the Extragalactic Distance Database, on the web at http://edd.ifa.hawaii.edu (Tully et al. 2009).

The determination of a distance with the correlation between luminosities and linewidths requires knowledge of three observational parameters: measures of the rotation rate of a galaxy, the total luminosity of the system, and its inclination. The latter two parameters are determined through area photometry. It must be asked if there are preferred passbands that optimize the correlation for the purpose of distance measurements. The best correlation is expected to arise in a wavelength interval that samples the peak of the black body emission from old stars since this population should be the best thermal representative and contributor to the potential well. This consideration favors wavelengths in the $1 - 2$ μm range, where there is the added advantage of minimal obscuration. Aaronson et al. (1979) were early advocates of the virtues of observing in the near infrared.

Unfortunately, ground-based observations at wavelengths longer than 0.8 microns are hampered by severe and variable sky emission from OH auroral lines. As a consequence, imaging at these longer wavelengths is much more difficult, requiring constant monitoring of the sky and stacking of short exposures, and with a given integration one typically reaches one exponential scalelength less deep compared with what can be achieved at shorter wavelengths (Tully et al. 1996). From experience, it is found that the tightest correlations between luminosity and linewidth are found at R and I bands, at wavelengths between 6000 Å and 8000 Å (Tully et al. 2008). Scatter is slightly higher at the redward bands H and K' because of sky noise and higher at the shorter wavelength of B band because of active star formation and obscuration. The focus of the present discussion is on data collected in the sweet spot at Cousins I band. We retain an ongoing interest in photometry at longer wavelengths (McDonald et al. 2009) and will discuss observations at K' band relevant to our program in another paper.

2. Observations

Our galaxy photometry program is a continuation of work discussed by Pierce & Tully (1988, 1992), Tully et al. (1996), and Tully & Pierce (2000). The material discussed here has been obtained since 2000, mostly since 2006, at the University of Hawaii 2.24m telescope using a Tek 2048 CCD. The instrument is mounted at the f/10 Cassegrain focus and provides a 7.5 diameter field with a pixel scale of 0.22 arcsec. Monitoring of the sky to assure photometric conditions has mostly relied on SkyProbe at the Canada-France-Hawaii

Table 1
Summary Observing Log

Date	Phot./Nights	Gal.	Observers
2000/02/01	5.0 of 5	134	BT
2003/01/31	3.0 of 3	17	BT (optic)
2006/12/19	5.5 of 6	162	KC, HC, LR, BT
2007/03/12	2.5 of 8	?	KC, HC, LR, BT, MZ
2007/09/14	1.8 of 3	84	BT, MZ
2007/10/06	1.0 of 3	55	BT, MZ
2008/02/28	3.0 of 5	137	HC, BT
2008/07/23	0.7 of 2	24	HC, BT

Telescope[1]. Only data acquired in photometric conditions are accepted. Table 1 provides a brief summary of the observing runs. Roughly 600 galaxies were observed in I band and 40 of these in B and R bands during 19.5 photometric of 32 scheduled nights. The observers were among the authors plus Kristin Chiboucas (KC).

Most of the observations were made through a Cousins I filter with a standard integration of 300 sec. Instances of nuclear saturation (conservatively, counts in excess of 30,000) prompted the acquisition of complementary short exposures. For a small fraction of the galaxies, images were also obtained in Cousins R (300 sec integrations) and Johnson B (600 sec integrations). The observations were usually but not always guided. Image quality is erratic, ranging from FWHM 0.7" to 1.5", but this was not a great concern since our interest is in global photometry and the target galaxies have typical dimensions of 1–5 arcmin. Photometric calibrations in the Vega system were made with observations of Landolt (1992) standard fields on several occasions each night and over air masses ranging up to 2 and beyond. Flat fields were built from multiple twilight exposures of blank sky supplemented by dome flats. The properties of the mechanical shutter were studied in order to compensate for variations across the field caused by the finite time required to open and close. The telescope is at a latitude of $+20°$. Targets were observed as far north as $+85°$ and as far south as $-40°$. We report on observations of 600??? galaxies.

3. Photometric Reductions

Initial reduction steps involved the construction of flat fields from summations of typically 5 twilight exposures. Aperture photometry of Landolt standards gave the conversion from counts to flux in magnitudes. Flux corrections were applied to account for shutter effects.

The flattened and flux calibrated images were then analyzed with the Archangel

[1] http://www.cfht.hawaii.edu/Instruments/Elixir/skyprobe

software package developed by Schombert (2007)[2]. The suite of programs performs such basic procedures as masking of stars and flaws, ellipse fitting at expanding radii from the galaxy center, and compression of two-dimensional information into one-dimensional growth curves of surface brightness as a function of radius and total luminosity as a function of radius. An example of output from the Archangel analysis are shown in Figure 1.

Summary data and graphic displays for all the galaxies that have been observed are found in EDD in the catalog *Hawaii Photometry*. The graphic material is accessed by selecting on the common name of a candidate and includes displays of star masks and ellipse fits, major axis position angle and ellipticity as functions of radius, surface brightness profiles, and magnitude–radius growth curves. The radial information used for the construction of the plots is provided in ascii tables that can be downloaded. The tabulated data includes information about the observations (detector, date, filter, etc.) and the measured parameters. The parameters include isophotal and total magnitudes, mean axial ratios and position angles, exponential disk central surface brightnesses and scalelengths, radii and surface brightnesses enclosing 80%, 50%, and 20% of the total light, and a concentration index, the ratio of the radii enclosing 80% and 20% of the light.

[2]http://abyss.uoregon.edu/∼js/archangel

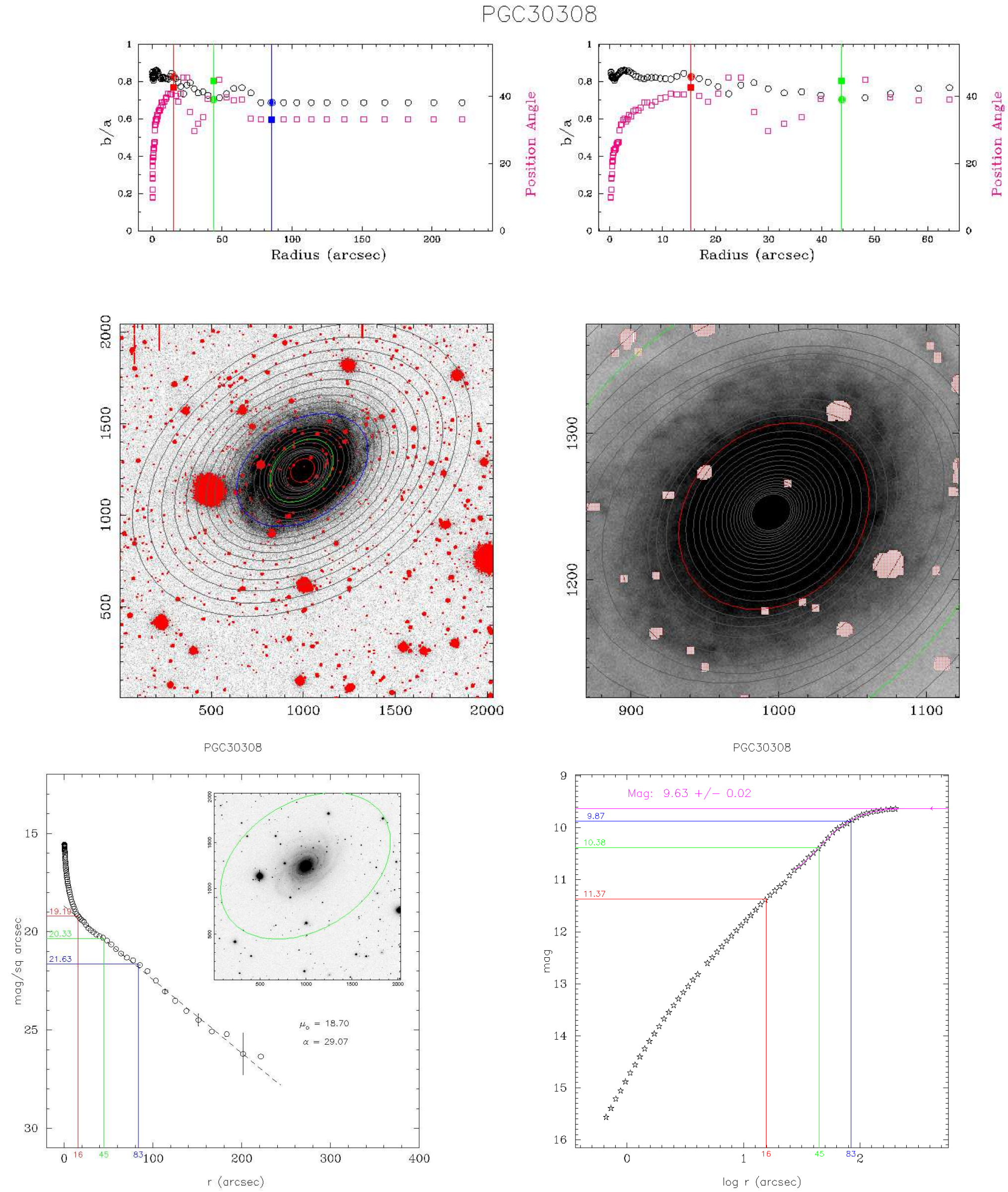

Fig. 1.— Photometry of NGC 3223. Graphic output from the Archangel photometry program. *Top:* in black the run with radius of ellipticity measures, b/a = ratio of minor to major diameter, and in red the run with radius of the position angle of the major axis. The radii enclosing 20, 50, and 80 percent of the total light of the galaxy are indicated by the red, green, and blue vertical strips respectively. The portion of the left panel at small radii is seen more easily with the expanded scale of the right panel. *Middle:* I band CCD image of the target with stars and bad pixels masked and ellipse fits shown at radial increments. The red, green, and blue ellipses enclose 20, 50, and 80 percent of the total light. *Bottom:* the run of surface brightness with radius is shown on the left and the growth of enclosed magnitude with radius is shown on the right. Radii enclosing 20, 50, and 80 percent of the light are indicated in red, green, and blue respectively. The surface brightness and enclosed magnitude at each of these radii are identified. An I band image of the galaxy is shown in the inset. The green ellipse is drawn at the surface brightness level 27.0 mag./sq. arcsec.

4. Magnitudes and Inclinations

The two parameters we care about most for the determination of distances through the correlation between luminosities and rotation rates are total magnitudes and inclinations. Consider, first, issues that affect the measurement of luminosities. A significant source of uncertainty arises from the setting of the sky level, where a change of 1 count per pixel typically affects total fluxes by 2% (0.02 mag). Almost all our targets are modest in size compared with the CCD field so there is reasonable control of the sky level. If sky is set properly then the magnitude growth curve should go asymptotically flat at large radii. One is suspicious of a poor sky setting if surface brightness as a function of radius either flares or drops precipitously at the sky level, although the latter occurrence is not physically excluded (MacArthur et al. 2003).

It is never possible to directly detect 100% of the light of a galaxy. Measurement is made to an isophotal level dictated by the telescope, exposure time, and the brightness of the sky. The interest of this program is with spiral galaxies which characteristically decay exponentially in luminosity with radius. The luminosity, L, of a galaxy grow as

$$L_x \propto \int_0^x x e^{-x/\alpha} \mathrm{d}x. \tag{1}$$

The radial dependence is described by the scalelength, α. Assuming the exponential decay in light can be extrapolated, the contribution lost below the sky level can be estimated and added to what is observed to give a 'total magnitude' (Tully et al. 1996). Fortunately the extrapolation from an isophotal to a total magnitude is almost always small in our cases because our exposures typically capture 7–8 exponential scalelengths. Extrapolations are usually below 0.02 mag and uncertainties are less than half the extrapolation. For the small extrapolations that are required we use the procedure involving rational function fits to the magnitude growth curve at large radii provided within Archangel. The only situations where the extrapolations are significant are either with galaxies that extend beyond the CCD field or with extremely low surface brightness galaxies.

The other product of importance to us provided by the photometry program is inclinations, i, derived from a measurement of ellipticities. By convention, a face-on galaxy has $i = 0$. The inclination is derived from the observed ratio of the minor and major axes, b/a, under the assumption that a galaxy is a prolate ellipsoid with a thickness $b/a = q_0$. The inclination is then given by the formula

$$\cos i = \sqrt{\frac{(b/a)^2 - q_0^2}{1 - q_0^2}} \tag{2}$$

The question of the optimal value of q_0 will not be debated here. The *Hawaii Photometry* catalog records only the observable $< b/a >$, determined as described below.

To be candid, the measurement of inclinations is a black art. The orientation of a galaxy must be known to de-project velocities of the rotating disk, with corrections increasing toward face-on, and to account for the effects of obscuration, which increase toward edge-on. Perhaps surprisingly, the latter is not a severe problem. Corrections for obscuration are substantial but predictable (Tully et al. 1998). After applying standard recipes, the scatter in luminosity–linewidth plots is not significantly greater for the most edge-on galaxies ($i \sim 90°$). The greater concern with the measurement of inclinations is with the rectification of velocities. The problem is minor for inclinations $i > 60°$ since the de-projection $W^i = W/\sin i$ is small. However the de-projection adjustment explodes as $i \to 0°$. Inclination uncertainty dominates the scatter in luminosity–linewidth plots for galaxies with $i < 45°$.

If ultimately for the purpose of distance determinations we adopt the policy of excluding galaxies more face-on than 45° then the problematic interval for inclination measurements is $45° - 60°$. From experience, spiral galaxies separate roughly equally into three classes. In about a third of cases, ellipticities and major axis position angles are roughly constant across a wide range of radii and the inclinations of these galaxies can be considered reliable at the level of $2° - 3°$. In another third of cases, uncertainties degrade to $3° - 5°$. Unfortunately, in roughly the last third of cases, ellipticities and position angles vary by large amounts as a function of radius. The reasons for these oscillations might be a large bulge or a bar or prominent spiral structure or a warp. The ellipticity and position angle measurements can depend on the specifics of the ways these features are projected. Anomalies can occur on all scales. In difficult cases, inclinations can be wrong by 5° to 10°, and inclination errors can be the dominant source of luminosity–linewidth scatter.

From experience, it is found that a decent measure of ellipticity can be given by averaging over values obtained for fitted ellipses between the radii enclosing 50% and 80% of the total light of a galaxy. The distortions to ellipticity measurements from bulges and bars are frequently severe inside the radius containing 50% of the light. Beyond the radius enclosing 80% of the light the signal rapidly becomes too weak for a reliable measure of axial ratio and we freeze the ratio at the value of the outermost reliable measurement. Hence, our recorded estimate of the ratio of the minor to the major axis, $< b/a >$, is the average of all measures $(b/a)_i$ between the radius enclosing 50% of the light, a_e, and the radius enclosing 80% of the light, a_{80}. The uncertainty that is tabulated is the r.m.s. dispersion in the measures contributing to the average.

All results obtained through the automated process that has just been described have been scrutinized by eye and, in instances, results have been modified and a large error has been assigned. The estimation of inclinations from the assumption that galaxies are circular disks tilted from the line-of-sight is an uncertain business. In spite of these travails our measured inclinations pass a necessary test: there are no systematic deviations from the mean luminosity–linewidth correlation as a function of inclination.

5. Comparison with Other Photometry

Make comparisons with other photometry recorded in EDD, especially the Cornell photometry.

It was a delight to find that the photometry package Archangel developed by

James Schombert and made available at http://abyss.uoregon.edu/∼js/archangel is quite robust and user friendly. Kristin Chiboucas participated in one of the observing runs and has given help with early steps in the reductions.

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