Surface Photometry of Dwarf Galaxies in the Virgo Cluster

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We present ongoing research on the evolutionary connections between dwarf elliptical, dwarf irregular, and blue compact dwarf galaxies, utilizing galactic surface photometry on 24 galaxies in the Virgo cluster.

Introduction

Dwarf galaxies comprise the majority of the known galactic population. They are currently believed to serve as the "building blocks" for giant galaxies, which form from the accretion of these smaller galactic types (Patterson & Thuan 1996). Thus, the study of dwarf galaxies offers us a kind of primordial understanding of galactic evolution as a whole.

Dwarf galaxies can be classified into three major types based on their morphologies and other properties. Dwarf irregular galaxies, or dIs are characterized by asymmetrical morphologies, high gas contents, low surface brightnesses, and somewhat bluer colors than the other two types indicating the presence of young stellar populations. In contrast to dIs, dwarf elliptical galaxies (hereafter dEs), have generally ellipsoidal shapes, redder spectral colors than dIs, little or no gas content, and appear to contain mostly old stars. Finally, BCDs have a morphology that tends to fall between that of dIs and dEs. Their distinguishing characteristics include a blue appearance at visible wavelengths and high surface brightnesses which are probably attributable to heavy star formation (Vaduvescu et al. 2006).

One popular hypothesis suggested that dEs were former dIs that had been stripped of their gas (James 1994). Processes proposed for this stripping include ram pressure with the interstellar medium, tidal interactions with neighboring galaxies, and ejection via supernova explosions (Davies & Phillips 1989). Evidence supporting this hypothesis includes a higher dE/dI ratio inside galactic clusters than outside of them (James 1994). However, much evidence against this type of evolution is also present, including a study that suggests dIs may have too much mass to shed their gassy components through the stripping processes described above (Davies & Phillips 1989).

Other studies, including those conducted by James, have led to the conclusion that dEs and dIs have no evolutionary connection. In support of this, James finds over-all morphological differences between the two galactic types, which assert themselves even at near-IR wavelengths. In his paper James also cites Tammann et al. (1985) who mention that the Virgo cluster contains several times more dEs than dIs, implying a shortage of precursors for the former. Bothun et al. argue that for dEs to become dIs through gas stripping, dIs would have to "fade by 1.5 magnitudes in the blue." Since this would leave them far dimmer than currently known dEs, the former could not be the latter's precursor (James 1994).

An alternative hypothesis is that dIs evolve into dEs by going through a "BCD phase," where by most of their gas is converted into stars or ejected during a succession of star bursting phases (Davies & Phillips 1989). During these phases the dwarf galaxies would take on the features of BCDs. Supporting this notion Davies and Phillips cite a certain amount of overlap in the morphologies of dEs, dIs, and BCDs and suggesting that the star bursting phases would eventually lead to the formation of the "young stellar population" they claim have been observed in the nuclei of some dEs.

Observations and Reduction

Overview

The ultimate operational goal of the present study involves attempting to fit mathematical functions to galactic brightness profiles. The brightness profile of a galaxy is determined by the distribution of its constituent stars, which likewise tends to describe the galaxy's morphology. While BCDs, dIs, and dEs share roughly exponential profiles (Davies & Phillips 1989), dEs not uncommonly have profiles which fall off as $\exp(-r^{1/4})$, where r is the radial distance to the galactic center. This is in contrast to dIs, which always have exponential profiles. Furthermore, the profiles of dEs generally have shorter scale-lengths than those of dIs, reflecting a more centrally-concentrated brightness distribution.

If dEs are in fact the evolutionary descendants of dIs, then one should expect to find intermediate links between the two types of dwarfs. Presumably, the brightness profiles would reflect this intermediacy by exhibiting a set of characteristics which would be a superposition of those exhibited by the profiles of dEs and dIs. Finding such profiles is the essential intention of our research, which still remains to be completed.

Observations

Observations were made at the Kitt Peak Observatory in Arizona between the nights of 27 Feb. and 3 March, 1997. 24 dwarf galaxies in the Virgo cluster were surveyed through standard B and R filters. Seeing varied up to 2 arcseconds for all three nights. Non-photometric conditions rendered measurement of the objects' true brightnesses impossible; however, brightness gradients can still be measured. For most of the galaxies, multiple images (2-5) through the same filter were taken with slight angular offsets from one another. Combining of such images has the effect of reducing errors caused by bad pixel lines and cosmic ray events by averaging them out a bit.

Image Calibration & Data Reduction

Image calibration was performed using IRAF. After biasing and flat-fielding, images of the same object taken through the same filter were aligned using the IRAF task imalign and then combined using imcombine. The combined images were then examined for flaws. A prominent line of bad pixels ran vertically through all of the frames, both flat fields and galaxies. Combining dampened the effect of the line somewhat, but also multiplied its presence, so that rather than appearing in one location along a given image's horizontal axis, it appeared in several. In many cases the line crossed through the actual galaxy being imaged. In order to gauge its effect on our ability to gather accurate data, many plots of the pixel counts verses horizontal location were made using implot. The resulting curves exhibit abrupt spikes and/or dips at the locations of bad pixel lines. By measuring the vertical extent of these anomalies one can deduce how significant of a problem they pose. A safe range is less than about 2 times the rms value for the background noise. However, in many cases the error was significantly larger than this value. Re-running imcombine with the "combine" setting changed to "median" and the "reject" setting changed to "avsigclip" improved the results some, but the anomalies remained. However, many of them occurred beyond the extent of the actual galaxy and their potential effect on the ability to perform scientific analysis was deemed minimal.

The next step after calibration was to fit elliptical contours to the galactic images using the IRAF package isophote under stsdas.analysis. The primary task for doing this is ellipse. This task utilizes an iterative method to fit a series of elliptical contours of constant magnitude to a galactic image. Parameters for ellipse are specified in the geompar and controlpar tasks. These include initial estimates for the location of the galactic center, the position angle of the galactic semi-major axis (sma), and the ellipticity of the isophotes. The output is a multi-column table saved as a .tab file containing an array of information on the image including the sma-dependant surface brightness. The user specifies initial estimates for the location of the galactic center and the position angle of the sma. These values can be allowed to vary within user-specified boundaries during subsequent iterations of the task or can be held fixed throughout the

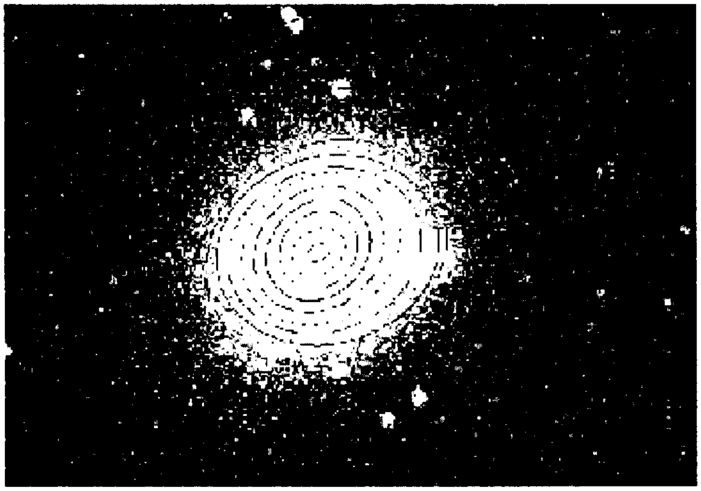

Fig. 1: isophotal fitting to vcc1825.

fitting process. After the table has been produced, the task isoimap can be used to visually graph the isophotes onto the galactic image in question (Fig. 1).

For ellipse, no generic set of parameters was found to be applicable to all of the images at once. Instead, parameters had to be "tweaked" on an image-by-image basis, and determining whether the isophotes actually fitted the galactic shape required considerable "eyeballing" of the images produced by isoimap. Generally, it was preferable to leave as much up to the computer as possible in terms of figuring out the position angle, centers, and ellipticities, though initial values for these had to be entered. However, especially in dimmer galaxies the ellipse task often had trouble "finding" the center specified by the user, and would not uncommonly fit isophotes around a point completely outside the galaxy if the "wander" parameter was set too high.

Thus, the "wander" value was generally set to roughly twice the seeing width of the image in question, and occasionally it was necessary to hold the center completely fixed. The ellipticities and position angles were generally allowed to vary out to roughly the visual radius of the galaxy (i.e. the radius deduced just from looking at the galactic image), after which point the ellipticities, position angles, and centers were held fixed. This safeguarded against the isophotes being fitted too wildly out beyond the visual edges of the galaxies, where the signal-to-noise ratio is high, while at the same time giving the task enough freedom to produce an accurate fit within the main body of the galaxy.

At other times, especially in the cases of dimmer galaxies, it was necessary to fix the centers and position angles throughout the iteration process. Since the initial values for these parameters are entered manually by the user based on a certain amount of guess work, this increased the likelihood of errors.

Initial estimates for the galactic centers were generally determined by making magnitude plots along the horizontal and vertical axes of the images using implot, and visually deducing x and y locations of the "hump" produced by the galaxy. For brighter galaxies, the centers could sometimes be located more quickly by producing contour plots in imexam.

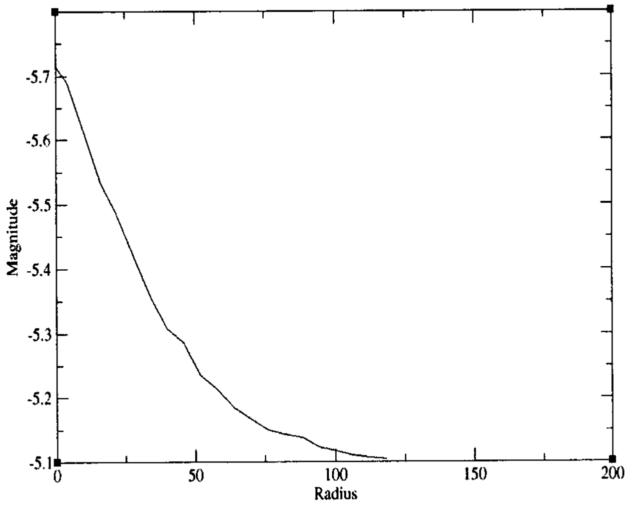

Fig. 2: brightness profile for vcc1825 in B.

Conclusions

Time constraints stopped the data analysis process at the point of beginning to produce brightness profiles. At the moment, the only such profile produced was done using a Unix program in Redhat called xmgrace. It shows the light profile for vcc1825, taken through a B filter (Fig. 2).

Once the light profiles are produced directly from the ellipse .tab files, the task nfit1d under stsdas.analysis.fittings will be implemented to begin fitting mathematical functions to the light profiles. The inputs for this task are the .tab files produced by ellipse. The user can select between several pre-defined functions in the epar menu, including one specifically for galactic profiles. An option for entering a user-defined function is also available.

Once fittings have been created for all of the galactic brightness profiles, we can compare to published data on similar galaxies. If our galaxies are truly are intermediate between dIs, and dEs, then we expect to find that our fitted functions behave accordingly.

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