Bhishan's note on compilation:
Using Texmaker
==============
1. Latex F5 (my shortcut) creates dvi,log,aux files
Pdflatex F6 (my shortcut) creates pdf without fig.
viewpdf F8 (my shortcut) opens pdf without fig.

2. Latex F5 (my shortcut) creates dvi,log,aux files
dvi-pdf F7 (my shortcut) creates pdf with overlapped fig.
viewpdf F8 (my shortcut) opens pdf with overlapped fig.

Using Terminal
==============
Open in terminal ctrl shf T opens the terminal
latex ousample.tex creates dvi,log,aux files
dvipdf ousample.dvi creates pdf with no overlapped fig.
xdg-open ousample.pdf opens pdf with no overlapped fig.
note: my alias for xdg-open is get

Ohio University Observing Proposal **Category:** Galaxies
Date: September 15, 2015

The Surface Brightness Profile of the Elliptical Galaxy NGC 3379

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Abstract of Scientific Justification:
NGC 3379 is regarded in the astronomical literature as a near-perfect illustration of the famous $r^{1/4}$ law, introduced by G. de Vaucouleurs to describe the radial dependence of the surface brightness in elliptical galaxies. The goal of this project is to independently reproduce this result and confirm that the de Vaucouleurs law accurately describes this galaxy, through deep imaging in the R band. In addition this project will test the ability of the current hardware to perform accurately at low surface brightness levels.

Summary of Observing Run

Telescope	Instrument	No. Nights	Moon age	Optimal months	Accept. months
GOT	Direct CCD	1	14	any	Apr - May

Scheduling constraints and non-usable dates *(up to four lines).*

Scientific Justification *Be sure to include the significance of the project in the context of previous work. Limit text to one page, with figures, captions and references on no more than one additional page.*

The giant elliptical galaxy NGC 3379 (M105) is one of the best-studied galaxies in the sky. Determinations of its surface brightness profile date back all the way to the work of Hubble (1930), who was able to measure the azimuthally averaged radial profile extending over $\sim$ 1.5 orders of magnitude in radius, corresponding to $\sim$ 2 orders of magnitude in surface brightness. Much later, in what is generally recognized as a *tour de force* of photographic and photoelectric photometry, de Vaucouleurs & Capaccioli (1979) extended the measured profile to nearly 4 orders of magnitude in surface brightness. They showed convincingly that the observed profile was remarkably well fit by the formula suggested by de Vaucouleurs (1948),

$$\Sigma(r) = \Sigma_e \exp\left\{-7.67\left[(r/r_e)^{1/4} - 1\right]\right\}. \tag{1}$$

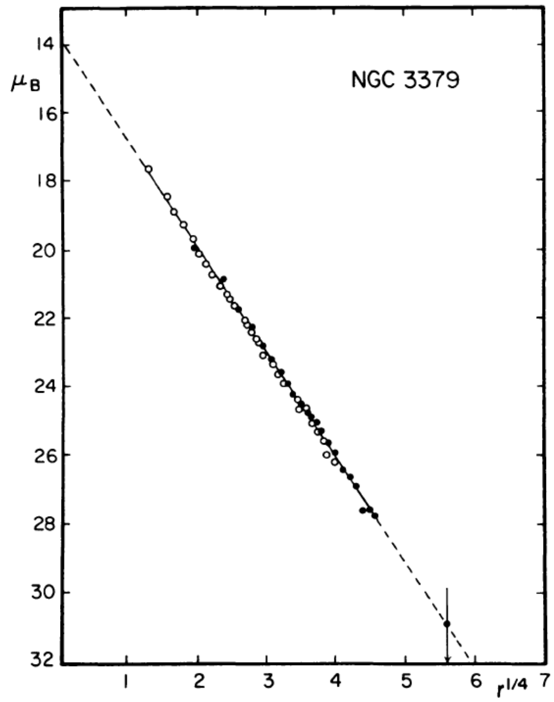
In equation (1), $\Sigma(r)$ is the surface brightness at radius r on the sky, expressed in linear (physical) units, r_e is the "effective radius" of the galaxy, and Σ_e is the surface brightness at $r = r_e$. For a galaxy that precisely obeys equation (1), half its total light comes from $r < r_e$. The functional form is such that if one plots Σ on a logarithmic scale, e.g., as $\mathrm{mag\,arcsec^{-2}}$, against $r^{1/4}$, one obtains a straight line. The data for NGC 3379, plotted in this way, are shown in Figure 1 (Fig. 2 of de Vaucouleurs & Capaccioli 1979).

Even though subsequent work has shown that equation (1) does not fit all elliptical galaxies at all radii, it has proved sufficiently useful that it is now commonly referred to as the $r^{1/4}$ *law* or the *de Vaucouleurs law.* The primary goal of this project is, in effect, to rediscover the $r^{1/4}$ law using CCD imaging of NGC 3379 with the GOT.

A number of more recent CCD studies of NGC 3379 have been published, (e.g., Peletier et al. 1990), extending to radii $> 100''$, showing small deviations from the $r^{1/4}$ law. Though the interpretation of these deviations has been a matter of some debate (Capaccioli et al. 1991, Hjorth & Madsen 1991, Statler 1994), the availability of high-quality data in the literature provides a means of checking our results. In particular, we have an opportunity to test the performance of the GOT at low surface brightness levels; this is the secondary goal of the project. The Peletier et al. data indicate that $\mu_R(200'') \approx 23.5\,\mathrm{mag\,arcsec^2}$, or about 6% of the R band sky brightness at new moon.

Potentially lying within the same CCD field as NGC 3379 are the SB0 galaxy NGC 3384 and the Sc galaxy NGC 3389. Their presence is both a hindrance and a benefit. Because these galaxies will collectively fill the frame, it will be necessary to observe a separate blank-sky field to determine the sky surface brightness. On the other hand, we will also be able to measure their surface brightness profiles and demonstrate the difference between the profiles of E, S0, and S galaxies.

Finally, the entire NGC 3379 group is known to reside within a ring of neutral hydrogen (Figure 2; Schneider 1985). While there are no known optical signs of interaction between NGC 3379, NGC 3389, and NGC 3384, our long exposures will, as a byproduct, produce a deep—and presumably highly photogenic—image of this attractive three galaxy set.



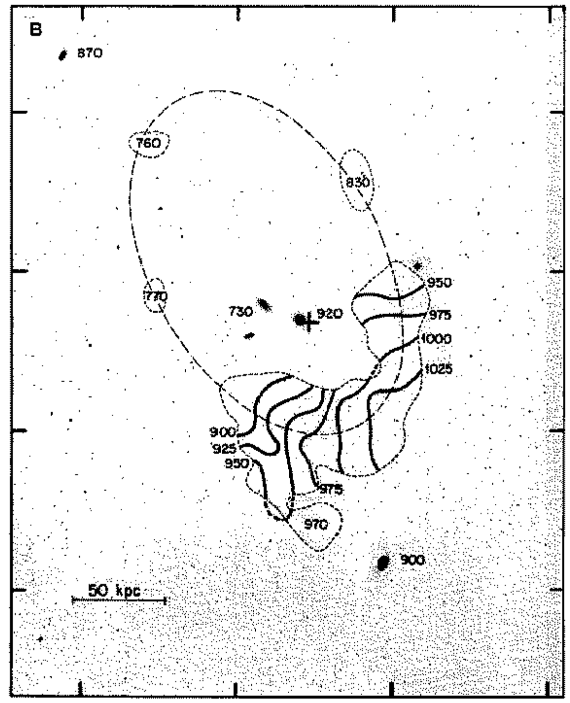


Figure 1: (Left) Radial surface brightness profile of NGC 3379, reproduced from de Vaucouleurs & Capaccioli (1979). The V-band surface brightness μ_V (in mag arcsec^{-2}) is plotted against the radius in arcsec to the 1/4 power. Points show the data (error bars omitted by the authors); the line is the best fit $r^{1/4}$ law.

Figure 2: (Right) Map of the intergalactic HI ring surrounding NGC 3379 (near the field center), NGC 3389, and NGC 3384 (reproduced from Schneider 1985). Dotted outline shows a characteristic 21 cm isophote; solid contours indicate radial velocity. Field is approximately 1.5×2 degrees.

References

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Experimental Design & Technical Description *Describe the observations to be made during this observing run. Include exposure time calculations to demonstrate that these observations will accomplish the science goals outlined in the previous section. Include estimates for calibration exposures. Justify the number of nights and the lunar phase requested. List objects, coordinates, and magnitudes (or surface brightness, if appropriate) in the Target Table below.*

We choose R band as the best compromise between the general red color of elliptical galaxies, the very red night sky, and the maximum sensitivity of the detector. (In addition, more published R-band than I-band photometry is available for NGC 3379.)

With NGC 3379 centered in the field we can hope to work to a maximum radius of $360''$; extrapolating the photometry of Peletier et al. indicates $\mu_R \approx 25$ (about 1.5% of sky) at this distance. We set an accuracy goal of ± 0.1 mag ($S/N = 10$) at this radius. We will be fitting isophotes using the IRAF/STSDAS "ellipse" task, which, for each isophote, takes data from a ring effectively 1 pixel wide. This implies, with the $0.7''$/pixel plate scale (and assuming circular isophotes), approximately 3200 pixels will be averaged. However, we expect to be able to use only the western half of the galaxy at this radius because of contamination from NGC 3384 and NGC 3389 to the east. We determine the expected S/N for an average over 1600 pixels using the "ccdtime" calculator, assuming a mean airmass of 1.4 and a CCD temperature of $-15°$C. We obtain $S/N = 3.8$ for a 300 s exposure and $S/N = 6.4$ for a 600 s exposure. Thus we can reach $S/N = 10$ in 7×300 s or 3×600 s. The detector is the primary source of noise, so, since we are working in R band, this project (surprisingly) can be done at any lunar phase.

However, the photometric accuracy will ultimately be limited not by photon counting statistics but by systematic variation of the sky. Since the sky is 70 times brighter than the galaxy at these radii, the sky level must be determined to better than 0.5%. Even in photometric conditions we can expect the sky to vary by more than this as the target moves toward the horizon. Since the galaxies will fill the field we must "beam switch" to a nearby blank field to get sky; and because the sky is varying in time, more rapid switching is advantageous. Therefore we opt for 300 s exposures on the galaxies alternating with blank sky exposures. The mean sky level will be determined by masking out stars and averaging over the entire source-free part of the image, which we can expect to comprise $N \approx 10^6$ pixels. The "ccdtime" task reports that we should expect $\sim 0.43\,\mathrm{e^-\,s^{-1}\,pix^{-1}}$ from the sky at new moon. At an operating temperature of $-15°$C, we should have $0.08\,\mathrm{e^-\,s^{-1}\,pix^{-1}}$ dark current, and the CCD read noise is $11.8\,\mathrm{e^-}$ RMS. Thus

$$\left(\frac{S}{N}\right)_{\mathrm{sky}} = \frac{0.43tN^{1/2}}{[0.43t + 0.08t + (11.8)^2]^{1/2}}, \tag{2}$$

where t is the exposure time in seconds. For a 30 s exposure we should achieve $(S/N)_{\mathrm{sky}} = 1000$, or 0.1% accuracy. These exposures are short enough that they can be unguided, which will reduce overhead substantially.

In early May NGC 3379 will be at airmasses < 2 for at least 3 hours after the end of evening twilight. The total exposure time required is $7 \times 300\,\mathrm{s} + 8 \times 30\,\mathrm{s} = 39$ min. If we allot 10 minutes of overhead for each exposure (CCD readout, moving the telescope, reacquiring the guide star) the total time required sums to 189 minutes. We will therefore be able to acquire the needed data in half a night, neglecting photometric calibration. We emphasize that the primary science of this project will still be doable in non-photometric conditions, but comparison with published data will be possible only to within an undetermined photometric zero point. If we have photometric conditions, then calibrating the photometry will require a minimum of 2 standard star observations. We will choose one or more standards with colors similar to that of NGC 3379 and observe them at airmasses between 1.1 and 2.0. If possible we will scatter the standards among the galaxy exposures. However, if we are running behind schedule we will put off the standards to the second half of the night in order not to sacrifice on-source time, which is essential to the primary science. We estimate standards to require $\sim$ 1 hour total, which may be interspersed between other observations. Beginning observations on NGC 3379 at the end of twilight will require extremely efficient use of the 90 minutes after sunset for flat fields, zeros, darks, polar alignment, focusing, and autoguider calibration. This will be possible only if the observers are very experienced with the equipment.

Target Table for GOT/Direct

Obj ID	Object	α	δ	Epoch	Mag.	Filter	Exp. time	# of exp.	Lunar days	Sky	Seeing	Comment
1	NGC 3379	10 47 49.6	+12 34 55	2000.0	10.3		300	7	0-14			mag is B^T
2	Sky	10 46 30.0	+12 17 00	2000.0	N/A		30	8	0-14			Blank field 25′ SW

NOAO observing proposal LaTeX macros v2.1.