Surface photometry and mass distributions in the spiral galaxies NGC 1087 and NGC 1090

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Summary. Photographic surface photometry and rotation curves based on long-slit spectra have been obtained for NGC 1087 and NGC 1090. Both galaxies were originally considered to be members of the Cetus I group, but NGC 1090 has a velocity 5σ higher than that of the group so is probably a background object. Total masses and luminosities for the galaxies are $2.7 \pm 0.2 \times 10^{10} M_\odot$, $1.4 \times 10^{10} L_\odot$ for NGC 1087 and $1.1 \pm 0.2 \times 10^{11} h^{-1} M_\odot$, $2.7 \times 10^{10} h^{-2} L_\odot$ for NGC 1090, where $H_0 = 100$ km s$^{-1}$ Mpc$^{-1}$. NGC 1094/ANON, apparently in the same group, are a background binary pair with combined masses $> 9.4 \times 10^9 h^{-1} M_\odot$ and luminosities of $5.4 \times 10^{10} h^{-2} L_\odot$.

1 Introduction

NGC 1087 and NGC 1090 are both members of de Vaucouleurs’ NGC 1068 group (de Vaucouleurs et al. 1976 — hereinafter RC2), itself a subset of the Cetus I cloud or G15 group (de Vaucouleurs 1975), for which de Vaucouleurs (1979) gives a corrected distance modulus $\mu_0^M = 30.83$. This value is based on only three members, presumably including NGC 1087 ($\mu_0^M = 30.45$) and NGC 1090 ($\mu_0 = 30.68$). As Plate 1 illustrates, the galaxies are separated by only ~3 mean diameters so are likely candidates to form a binary system. They were studied for this reason in an attempt to redress the bias towards very small separations in previous work e.g. NGC 935/IC 1801 (Blackman 1977) and NGC 5426/7 (Blackman 1979, in preparation). On the basis of its apparent diameter and separation, NGC 1094 is also a candidate for the putative system and accordingly its velocity was also measured. All the galaxies lie near the centre of Zwicky et al.’s (1965) ‘near’ open cluster 0246.1—0045, but apart from the anonymous companion to NGC 1094 appear to be certain foreground objects. RC2 morphological types and luminosity classes for NGC 1087 and NGC 1090 are SAB(rs)c, III? and SB(rs)bc, IV? respectively. Nilson (1973) classifies NGC 1094 as Sa/Sb, $L_c < IV$. No classification is available for the anonymous galaxy.

2 Surface photometry

Two plates of the galaxies were obtained in the B system (IlAO emulsion, GG13 filter) with the 1-m telescope at the University Observatory, St Andrews on 1975 November 1.

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after each exposure the plates were calibrated by means of a 15 step density wedge. Full details are given elsewhere (Blackman 1979a — hereinafter BI). The plates were scanned using the computer controlled Joyce Loebl microdensitometer at St Andrews and the data reduced with the University’s IBM 360/44 computer and the programmes described in BI.

Absolute calibration was provided by photoelectric observations of NGC 1087 through four different apertures and of NGC 1090 through one aperture (de Vaucouleurs & de Vaucouleurs 1964). The mean sky brightness, in $B$ mag arcsec$^{-2}$ ($B\mu$), was $20.5 \pm 0.2$ (NGC 1087) and $20.6$ (NGC 1090).

Isophote maps of both galaxies are shown in Fig. 1. Because of the faintness of NGC 1090, it was not possible to draw reliable isophotes to the same level, $26 B\mu$, as in NGC 1087, but even so the faintest isophote shown is ~1.5 per cent of the sky brightness. Fig. 1 also shows the adopted major axes of both galaxies, as determined from the outermost isophotes. ($B \gtrsim 23.5 B\mu$). These lie in position angles $0 \pm 5^\circ$ (NGC 1087) and $111 \pm 5^\circ$ (NGC 1090), in fair agreement with Nilson’s (1973) values, $0^\circ$ and $102^\circ$. The major axis of the inner isophotes in NGC 1090, discussed below, is also indicated. It lies in position angle $124^\circ$. The mean axial ratio of the outer isophotes, used below to estimate inclinations, is given in Table 1.

The dimensionless $\log J$, $\rho^*$ reduced luminosity profiles (as defined in BI) and the corresponding cumulative luminosity distributions of NGC 1087 and NGC 1090 are presented in Figs 2 and 3. Both galaxies are characterized by having two near-exponential sections in their reduced profiles similar to those in NGC 157 (BI) and NGC 1084 (Blackman 1979b). This is not unexpected as all four galaxies have morphological stages $bc$ or $c$.

Table 1 lists the standard integrated parameters of the galaxies according to the scheme in BI. These galaxies are ~1 mag fainter than those studied previously, so have relatively large total luminosity corrections, ~20 per cent or 0.2 mag. Because of this the integrated parameters are subject to greater uncertainty. For example if it is assumed that the entire total luminosity correction is spurious then the half-light effective radius, $r_e^*$, will be reduced.
Table 1. Photometric parameters of NGC 1087 and NGC 1090.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>NGC 1087</th>
<th>NGC 1090</th>
</tr>
</thead>
<tbody>
<tr>
<td>$r_0$ (arcsec)</td>
<td>27.0</td>
<td>29.3</td>
</tr>
<tr>
<td>$r_e$ (arcsec)</td>
<td>50.9</td>
<td>52.4</td>
</tr>
<tr>
<td>$r_s$ (arcsec)</td>
<td>117.9</td>
<td>104.7</td>
</tr>
<tr>
<td>$C_{21}$</td>
<td>1.89</td>
<td>1.79</td>
</tr>
<tr>
<td>$C_{32}$</td>
<td>2.32</td>
<td>2.00</td>
</tr>
<tr>
<td>Axial ratio</td>
<td>0.57 ± 0.06</td>
<td>0.47 ± 0.04</td>
</tr>
<tr>
<td>log $J/</td>
<td></td>
<td></td>
</tr><tr>
<td>ho^*$ gradient</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Inner exponential</td>
<td>-1.06</td>
<td>-0.83</td>
</tr>
<tr>
<td>Outer exponential</td>
<td>-0.33</td>
<td>-0.47</td>
</tr>
<tr>
<td>log $J$ intercept</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Inner exponential</td>
<td>1.02</td>
<td>0.78</td>
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<tr>
<td>Outer exponential</td>
<td>0.00</td>
<td>0.26</td>
</tr>
<tr>
<td>$B(O)_c$</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Inner exponential</td>
<td>20.88</td>
<td>22.23</td>
</tr>
<tr>
<td>Outer exponential</td>
<td>23.43</td>
<td>23.53</td>
</tr>
<tr>
<td>Proportion of total luminosity</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Inner exponential</td>
<td>0.61</td>
<td>0.57</td>
</tr>
<tr>
<td>Outer exponential</td>
<td>0.39</td>
<td>0.43</td>
</tr>
</tbody>
</table>

by ~ 10 arcsec, compared to ~ 2 arcsec in NGC 157 (BI). Despite this the parameters lie within the ranges found for normal, isolated spirals (Blackman 1979c).

Total apparent magnitudes for NGC 1087 and NGC 1090 are 11.47 and 12.10 respectively, in fair agreement with the RC2 values 11.55 and 12.60, allowing for the uncertainties in the extrapolation correction and in the sky brightness.

Figure 2. Reduced luminosity profiles for NGC 1087 (b) and NGC 1090 (a). $J = I/I_e$ and $\rho^* = r^*/r_e^*$ where $I_e$ is the intensity corresponding to $r_e^*$, the isophotal area – equivalent effective radius enclosing half the total luminosity. For convenience profile b has been shifted by one unit. log $J = 0.0$ corresponds to $B = 23.11$ $B_\mu$ in NGC 1087 and $B = 23.55$ $B_\mu$ in NGC 1090. Both profiles extend to 1 per cent of the sky brightness.

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3 Spectroscopic observations

Long-slit spectra were obtained of all four galaxies using the 2.5-m Isaac Newton telescope with image tube spectrograph at a dispersion of \( \sim 210 \, \text{Å mm}^{-1} \). Details of the observations are given in Table 2. The spectrometers were measured and the data reduced using standard techniques described elsewhere (Blackman 1977).

3.1 NGC 1087

Spectrogram 1183, along the minor axis of NGC 1087, shows H\(\alpha\) and [N II] 6584 Å emission lines from 9 arcsec east of the nucleus to 12 arcsec west, with an isolated H II region 26 arcsec west. The velocity measurements show no significant trend with radius, so the mean (heliocentric) velocity of \( 1449 \pm 55 \) (m.e.) km s\(^{-1}\) may be taken as the systemic velocity of the galaxy.

The short exposure major axis spectrograms, 1218 (1) and 1218 (2) show inclined H\(\alpha\) and [N II] 6548 Å emission lines covering the region from 35 arcsec north of the nucleus.

Table 2. INT spectroscopic observations.

<table>
<thead>
<tr>
<th>Spectrogram number</th>
<th>Object</th>
<th>Date</th>
<th>Exposure (min)</th>
<th>PA (°)</th>
<th>Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td>1183</td>
<td>NGC 1087</td>
<td>1975 Oct. 13</td>
<td>84</td>
<td>90</td>
<td>Minor axis</td>
</tr>
<tr>
<td>1204 (2)</td>
<td>NGC 1090</td>
<td>1975 Dec. 6</td>
<td>90</td>
<td>201</td>
<td>Minor axis</td>
</tr>
<tr>
<td>1206</td>
<td>NGC 1094</td>
<td>1975 Dec. 7</td>
<td>90</td>
<td>0</td>
<td>Both galaxies</td>
</tr>
<tr>
<td>1218 (1)</td>
<td>NGC 1087</td>
<td>1976 Jan. 25</td>
<td>29</td>
<td>0</td>
<td>Major axis</td>
</tr>
<tr>
<td>(2)</td>
<td>NGC 1087</td>
<td>1976 Jan. 25</td>
<td>24</td>
<td>0</td>
<td>Major axis</td>
</tr>
<tr>
<td>1219 (1)</td>
<td>NGC 1087</td>
<td>1976 Jan. 27</td>
<td>60</td>
<td>0</td>
<td>Major axis</td>
</tr>
<tr>
<td>(2)</td>
<td>NGC 1090</td>
<td>1976 Jan. 27</td>
<td>75</td>
<td>111</td>
<td>Major axis</td>
</tr>
</tbody>
</table>
to 15 arcsec south. The mean central velocity was $1440 \pm 51$ km s$^{-1}$. On the long exposure spectrogram, 1219 (1), these lines extend over 60 arcsec from the nucleus, about 65 per cent of the diameter is shown in Plate 1, and in addition [S II] 6717 Å, 6731 Å, H$\beta$ and [O III] 3727 Å are also seen, extending to ~ 35 arcsec radius. Unfortunately the [O III] line could not be measured as the spectrogram was not sharply focussed in the blue. In the central ($r \leq 15$ arcsec) region all the lines show a linear increase of velocity with distance, similar to that in the short exposure data, but at larger radii a definite turn off occurs. The mean central velocity was $1428 \pm 10$ km s$^{-1}$ in H$\beta$ and $1508 \pm 26$ km s$^{-1}$ in the H$\alpha$, [N II] and [S II] lines.

The adopted mean heliocentric velocity of the galaxy, $1453 \pm 32$ km s$^{-1}$, does not agree well with Humason, Mayall & Sandage's (1956) estimate of $1824 \pm 183$ km s$^{-1}$. It is difficult to see how such an error could be present in the current observations, however, as the mean 6300, 6364 and 6862 Å night-sky line velocity, subtracted from the data, was $13 \pm 59$ km s$^{-1}$.

Fig. 4 shows the combined major axis velocities from three spectrograms after reflection in the nucleus, subtraction of systematic velocities and constructing of mean points. Every four adjacent points were averaged in H$\alpha$ and every six in H$\beta$ and the other lines. A total of 240 measurements are therefore included. Fig. 4 also shows the adopted rotation curve used in the subsequent analysis.

The observed velocities were deprojected into the plane of the galaxy assuming an inclination of $56 \pm 4^\circ$, corresponding to the mean isophotal axial ratio, $0.57 \pm 0.06$, and an assumed intrinsic axial ratio of 0.15. Radial distances and mass models were derived using de Vaucouleurs (1979) distance modulus, $\mu_0^{\phi} = 30.83$, which corresponds to $V_0/\Delta = 99$ km s$^{-1}$ Mpc$^{-1}$.

The total mass of NGC 1087 was estimated by fitting Brandt (1960) formulae to the adopted rotation curve. Six best-fitting solutions yielded a mass of $2.7 \pm 0.2 \times 10^{10} M_\\odot$ and all are characterized by $n = 1$, the flattest form considered. The mean residual with respect to the adopted rotation curve was $\sim 5$ km s$^{-1}$. The data within 35 arcsec (2.5 kpc) were also

![Figure 4](https://example.com/figure4.png)

Figure 4. Observed velocities along the major axis of NGC 1087. Filled circles, crosses and open circles represent mean points in H$\alpha$, H$\beta$ and [N II], [S II] lines as described in the text. The full line is the adopted rotation curve.
analysed using the polynomial model of Burbidge, Burbidge & Prendergast (1959). A mass of $0.61 \pm 0.04 \times 10^{10} M_\odot$ was derived, with a mean rotation curve residual of $\sim 3.5$ km s$^{-1}$. Rotation curves from the individual models are not shown in Fig. 4 to avoid confusion because of the small residuals.

From Figs 1 and 3 the limiting radius of 35 arcsec corresponds to $B = 22.1 \mu$ and encloses $34 \pm 4$ per cent of the total luminosity. Using the total magnitude (11.47) and absorption corrections (0.46 mag) given above the total luminosity of NGC 1087 is $1.14 \times 10^{10} L_\odot$. Thus $M/L (r < 35$ arcsec) = 1.37 $\pm$ 0.11, $M/L (r < \infty)$ = 2.04 $\pm$ 0.18 and $M/L (35$ arcsec < $r < \infty)$ = 2.36 $\pm$ 0.55.

3.2 NGC 1090

The emission in NGC 1090 is noticeably weaker than in NGC 1087, H$\alpha$ being the only line distinctly visible. Along the minor axis this emission is confined to the nucleus ($r \leq 3$ arcsec), whose velocity is $2645 \pm 25$ km s$^{-1}$. The major axis spectrogram shows inclined H$\alpha$ from 30 arcsec east of the nucleus to 25 arcsec west, with an isolated HII region 60 arcsec west. Fig. 5 shows the trend of velocity with distance after reflecting measurements in the nucleus (mean velocity $2753 \pm 25$ km s$^{-1}$) and obtaining means of four adjacent points.

In the absence of extended emission along the minor axis it is not certain whether large scale expansion or other non-circular motions are present or not. These are rarely observed, however, so it will be assumed that Fig. 5 represents a true rotation curve. There may be some signs of a turn-off interior to the last measured point but in view of the large scatter, and the lack of data in the region $30 < r < 50$ arcsec, the subsequent analysis will assume a rotation curve passing through $V = 185$ km s$^{-1}$ at $r = 57$ arcsec radius, the mean of the outer two points.

The mean nuclear velocity of $2699 \pm 54$ km s$^{-1}$ agrees with Sandage’s (1978) recent estimate of $2730 \pm 35$ km s$^{-1}$ and is $\sim 5\sigma$ higher than de Vaucouleurs (1975) mean velocity of the G15 group, $1513 \pm 200$ km s$^{-1}$, based on 27 per cent to the assumed members. It

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Figure 5. Observed velocities along the major axis of NGC 1090. Filled circles represent H$\alpha$ mean points.
Plate 1. NGC 1087 (lower right), NGC 1090 (upper right) and NGC 1094 (upper left) from the National Geographic–Palomar Sky Survey prints. North is up, east to the left and the scale is 11 arcsec mm⁻¹. (Photograph from the Hale Observatories.)
does not seem likely that NGC 1090 is a member of this group. In the absence of a reliable distance modulus, de Vaucouleurs' (1979) value being of low weight, a Hubble constant of 100 h km s\(^{-1}\) Mpc\(^{-1}\) was adopted, yielding a distance of 26.8 h\(^{-1}\) Mpc after applying the 21 km s\(^{-1}\) velocity correction in RC2.

The prolate spheroid model of Burbidge, Burbidge & Prendergast (1960) was applied to NGC 1090 because of its barred morphology. Examination of Fig. 1 shows that the inner isophotes \((r \leq 57\) arcsec, \(B \geq 23.8\) \(B\mu\)) are inclined by \(\sim 13^\circ\) to the line of nodes defined by the outer ones. In the plane of the galaxy, \(i = 63^\circ\) for \(b/a = 0.47\) and intrinsic axial ratio 0.15, this amounts to \(27^\circ\) so the deprojected coordinates of the outer mean point are \(V = 230\) km s\(^{-1}\), \(R = 8.3\) h\(^{-1}\) kpc. The mass of the bar within 8.3 h\(^{-1}\) kpc is \(5.3 \pm 0.8 \times 10^{10}\) h\(^{-1}\) M\(_\odot\) and the corresponding luminosity is \(1.3 \times 10^{10}L_\odot\), giving \(M/L = 4.1 \pm 0.6\). If this value applies to the galaxy as a whole, its total mass will be \(1.1 \pm 0.2 \times 10^{11}\) h\(^{-1}\) M\(_\odot\).

3.3 NGC 1094/ANON

Both NGC 1094 and its anonymous companion were observed on a single spectrogram obtained with the slit oriented north–south and centred midway between the two. Emission lines of H\(_\alpha\) and [N \(_\text{II}\)] 6548 \(\AA\) and 6584 \(\AA\) were seen in both galaxies extending to 5 arcsec radius in each. In both galaxies the H\(_\alpha\) was stronger than in NGC 1090, but weaker than in NGC 1087. Mean heliocentric velocities were \(6560 \pm 53\) km s\(^{-1}\) (NGC 1094) and \(6418 \pm 111\) km s\(^{-1}\) (ANON), the former agreeing reasonably well with Sandage's (1978) recent determination of \(6314 \pm 31\) km s\(^{-1}\). If these galaxies form a genuine binary system at 65.1 h\(^{-1}\) Mpc (\(\bar{V} = 6489\) km s\(^{-1}\), \(\bar{V}_0 = 6509\) km s\(^{-1}\)) then the observed velocity difference (142 km s\(^{-1}\)) and separation (64 arcsec = 20.2 h\(^{-1}\) kpc) imply that the combined mass of both must exceed \(9.5 \times 10^{10}\) h\(^{-1}\) M\(_\odot\). From Section 1 the combined luminosity is \(5.5 \times 10^{10}\) h\(^{-2}\) L\(_\odot\), without allowing for inclination corrections, giving an overall \(M/L\) of 1.7 h.

4 Conclusions

The photometry and mass estimates of NGC 1087 and NGC 1090 show that these galaxies are normal spirals. The velocity difference of over 1200 km s\(^{-1}\) is too large for them to be bound despite their small separation of \(\sim 3\) galaxy diameters. NGC 1090 does not appear to be a member of the Cetus I cloud. NGC 1094/ANON are clearly background galaxies. It is plausible that they are gravitationally bound which might account for their enhanced emission line strength.

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References

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