Redshift and velocity dispersion of the cluster of galaxies around NGC 326

P. N. Werner, D. M. Worrall and M. Birkinshaw

Department of Physics, University of Bristol, Tyndall Avenue, Bristol BS8 1TL

Accepted 1999 March 22. Received 1999 February 22

ABSTRACT

Redshifts of several galaxies thought to be associated with NGC 326 are determined. The results confirm the presence of a cluster and find a mean redshift of \( \bar{\zeta} = 0.0477 \pm 0.0007 \) and a line-of-sight velocity dispersion \( \sigma_v = 599(\pm230,-110) \text{ km s}^{-1} \). The velocity dispersion and previously measured X-ray gas temperature of \( kT = 1.9 \text{ keV} \) are consistent with the cluster \( \sigma_v/kT \) relation, and NGC 326 is seen to be a slowly moving member of the cluster.

Key words: galaxies: clusters: general – galaxies: distances and redshifts – galaxies: individual: NGC 326.

1 INTRODUCTION

The radio galaxy NGC 326 (\( \alpha = 0^h58^m22^s6, \delta = 26^\circ51'59'', J2000.0 \)) has been studied in soft X-rays (using the ROSAT PSPC) by Worrall, Birkinshaw & Cameron (1995). A peak in X-ray emission coincides with the core of the radio source. A comparison of the X-ray image with the digitized Palomar Observatory Sky Survey (POSS) revealed diffuse X-ray emission asymmetrically distributed around NGC 326 and roughly coincident with the brightest objects in the north-western quadrant of Zwicky cluster 0056.9+2636 (Zwicky & Kowal 1968). Zw 0056.9+2636 is described as ‘medium compact’ and ‘near’ (i.e. with \( cz < 15,000 \text{ km s}^{-1} \), where the velocity was estimated from the apparent magnitude and diameter of the brightest cluster members), and extends over roughly a square degree with 145 galaxies brighter than 15.7 in photographic magnitude.

Worrall et al. called for optical spectral measurements to determine the redshift of the galaxies thought to be associated with the observed X-ray emitting gas, and test NGC 326’s cluster membership. This paper reports spectra and redshifts for eight galaxies (including NGC 326 itself).

NGC 326 is a dumbbell system, classified by Valentijn & Casertano (1988) as ‘type 1’, which means that it consists of two bound D-type galaxies with photographic brightnesses \(<1\text{ mag}\) apart. Throughout this paper, the two components are referred to as ‘core 1’ and ‘core 2’, with ‘core 1’ being the brighter of the two (by \( \sim 25\% \) per cent). The radio source is associated with core 1 of NGC 326.

2 OBSERVATIONS

Observations of the galaxies listed in Table 1 were carried out on the nights of 1995 February 21 and 24, using the blue channel spectrograph on the Multiple Mirror Telescope (MMT). All images were obtained on a 3072 x 1024 CCD with a 300 line mm\(^{-1}\) grating.

The CCD images were processed using the IRAF software collection (in particular, the CCDPROC task and the APEXTRACT package), then wavelength-calibrated to an accuracy of 0.8 Å in \( \lambda = 4000–9000\text{ Å} \), using HeNeAr lamp images for each object. Those flat-field images (using a quartz lamp) taken on February 21 presented an unusual systematic pattern, which distorted the object spectra at the low- and high-wavelength ends; affected regions were not used in our analysis.

3 REDSHIFTS FROM EMISSION LINES

Three galaxies showed emission lines which could be used to measure their redshift (Table 2 – all redshifts and velocities in this paper are heliocentric). In particular, the spectrum of G2 had eight strong emission lines, whereas four weaker emission features were detected in G5. For G3, one line was found at an observed wavelength of 4575.8 \( \pm \) 3.1 Å, yielding a redshift of 0.0487 \( \pm \) 0.0008 if identified as [O iii] 4363 Å.

Emission lines can be a valuable diagnostic tool for determining the radiation mechanism in galaxies, and hence their nature. Only for G2 are the emission lines sufficiently strong and numerous to provide useful information. The line strengths, ratios, and spatial distribution indicate that the radiation arises from gas which is photoionized by hot stars. Spectra for the galactic nucleus and for the outer edges of the galaxy show that the emission lines are slightly stronger in the off-axis spectra, indicating a likely association of the photoionizing stars with spiral arms.

4 REDSHIFTS FROM ABSORPTION LINES

We measure the absorption redshifts of the galaxies by the standard method of cross-correlating their stellar spectra with the...
stellar absorption-line spectrum of an object of known redshift (Tonry & Davis 1979). The cross-correlation was carried out using the IRAF task FXCOR in the rv package. Information about the observing conditions from the observing log, and trial-and-error cross-correlations, indicated that the spectrum of G7 was a good template against which the relative velocities of the other cluster members could be measured. To provide absolute velocities, a previously processed, high-quality, normalized, zero-velocity cross-correlations, indicated that the spectrum of G7 was a good template against which the relative velocities of the other cluster members could be measured. To provide absolute velocities, a previously processed, high-quality, normalized, zero-velocity spectrum of NGC 4486B was correlated with the spectrum of G7.

Before carrying out the cross-correlation, emission features, any remaining cosmic ray hits, and the broad telluric absorption feature around 7600 Å resulting from atmospheric oxygen were deleted from the spectra.

The cross-correlation of G7 with NGC 4486B yielded a velocity for G7 of $V = 14,404 \pm 33$ km s$^{-1}$ (corresponding redshift: $z = 0.0480 \pm 0.0001$), with an unambiguous and narrow correlation peak, implying a satisfactory fit.

Having obtained an absolute velocity for G7, all object spectra were smoothed by the boxcar method using a 5-pixel (~8 Å) smoothing window, and cross-correlated with the unsmoothed spectrum of G7. The spectral range 5000–6500 Å (containing the strong Mg feature) was best suited for the cross-correlation. In some cases, a slightly smaller range was used to avoid regions of excessive noise. The results from this procedure are shown in Table 3. The emission and absorption redshifts for G2, G3 and G5 are in good agreement.

### 5 VELOCITY DISPERSION

We used the data in Table 3 to compute the mean redshift and the velocity dispersion of the cluster of galaxies using the method described in Danese, De Zotti & di Tullio (1980). The two cores of NGC 326 were treated independently, bringing the total number of galaxies to nine. As the sample is small, uncertainties are dominated by the sampling ($\chi^2$) term in equation (10) of Danese et al. The measurement errors of the individual redshifts have an almost insignificant effect on the result for the velocity dispersion.

© 1999 RAS, MNRAS 307, 722–724

---

**Table 1.** Observational details; adapted from table 1 in Worrall et al. (1995).

| Object | Name(s) | Coordinates (J2000) | Exp(s) | Date observed |
|--------|---------|---------------------|--------|---------------|
| G1     | NGC 326, Zw 0055.7+2636 | 0^h58^m22^s 26^m51^s 59^s | 300 | 21 Feb 1995 |
| G2     | UGC 613, Zw 0056.7+2647 | 0^h59^m24^s 27^m03^s 33^s | 300 | 21 Feb 1995 |
| G3     | MCG 04-03-030 | 0^h59^m03^s 27^m02^s 33^s | 300 | 21 Feb 1995 |
| G4     | – | 0^h58^m47^s 26^m58^s 40^s | 300 | 21 Feb 1995 |
| G5     | MCG 04-03-024 | 0^h58^m04^s 26^m53^s 47^s | 300 | 21 Feb 1995 |
| G6     | – | 0^h58^m28^s 26^m53^s 43^s | 600 | 21 Feb 1995 |
| G7     | – | 0^h59^m00^s 27^m08^s 47^s | 480 | 21 Feb 1995 |
| G8     | – | 0^h58^m09^s 26^m48^s 00^s | 600 | 21 Feb 1995 |

**Table 2.** Redshifts obtained from emission lines.

| Object | Emission lines used | $z^{(em)}$ |
|--------|---------------------|------------|
| G2     | H$\alpha$, [O iii] 4958, [O iii] 5007, [O i] 6300, [N ii] 6583, H$\alpha$, [S ii] 6716, [S ii] 6731 | 0.0462 ± 0.0001 |
| G3     | [O iii] 4363 | 0.0487 ± 0.0008 |
| G5     | [O iii] 5007, H$\alpha$, [S ii] 6716, [S ii] 6731 | 0.0457 ± 0.0004 |

**Table 3.** Results of the cross-correlations.

| Object | $v^{(abs)} = v^{(abs)}$ | $v^{(abs)}$ | $v_{rel}$ | $v_{rel}/\sigma_c$ |
|--------|-------------------------|-------------|-----------|-----------------|
| G1     | 14 206 ± 37             | 0.0474 ± 0.0001 | −96       | −0.16          |
| G1-2   | 14 832 ± 48             | 0.0495 ± 0.0002 | 500       | 0.83           |
| G2     | 13 840 ± 41             | 0.0462 ± 0.0001 | −447      | −0.75          |
| G3     | 14 582 ± 29             | 0.0486 ± 0.0001 | 262       | 0.44           |
| G4     | 13 504 ± 33             | 0.0450 ± 0.0001 | −768      | −1.28          |
| G5     | 13 842 ± 62             | 0.0462 ± 0.0002 | −445      | −0.74          |
| G6     | 15 575 ± 30             | 0.0520 ± 0.0001 | 1209      | 2.02           |
| G7     | 14 404 ± 33             | 0.0480 ± 0.0001 | 93        | 0.15           |
| G8     | 13 986 ± 28             | 0.0467 ± 0.0001 | −307      | −0.51          |

The average velocity of the cluster was found to be $c\bar{v} = 14,307 ± 224$ km s$^{-1}$, equivalent to an average redshift of $\bar{z} = 0.0477 ± 0.0007$. The one-dimensional line-of-sight velocity dispersion was computed to be $\sigma_c = 599(+230, −107)$ km s$^{-1}$, yielding a three-dimensional physical velocity dispersion of $\sigma = 1037(+427, −241)$ km s$^{-1}$.

The last two columns of Table 3 list the velocities of the galaxies relative to the cluster velocity, $V_{rel}$, in units of km s$^{-1}$ and in units of line-of-sight velocity dispersion $\sigma_c$. They show that the velocity of core 1 of NGC 326 (the radio core) is near to the cluster velocity, indicating that the radio source is not moving quickly in the gas. The velocity of G6 is found to differ from the cluster velocity by slightly more than $2\sigma_c$. Leaving it out of the calculations leads to significantly reduced one- and three-dimensional velocity dispersions of 419(+178, −79) and 725(+329, −178) km s$^{-1}$, respectively. However the justification for dropping it from the cluster membership is weak because there is a 39 per cent probability that one out of nine galaxies would lie more than 2.02$\sigma_c$ from the mean.

### 6 DISCUSSION

#### 6.1 Earlier measurements of the velocity of NGC 326

Three previous redshift measurements for NGC 326 are compared with our results in Table 4.

The earliest measurement, from H and K absorption features in the two components of NGC 326, appears in a list of 51 galaxies identified with radio sources in the 4C catalogue where NGC 326 is 4C26.03 (Sargent 1973). The absence of quoted errors on these velocities makes it difficult to compare them with our results.

De Vaucouleurs et al. (1991) gives a velocity of $14,138 ± 59$ km s$^{-1}$, equivalent to a redshift of $z = 0.0472 ± 0.0002$, without reference to the dumbbell nature of NGC 326. This agrees with our result for core 1, the brighter of the two components.
mean three-dimensional velocity dispersions were found to be a measure of total mass. For richness classes \( R \), velocity dispersion might be expected if the galaxy population contains much of the galaxy count, but little hot gas. The physical relationship of this galaxy concentration with the cluster around NGC 326 remains unclear.

## 6.2 Velocity dispersion and X-ray temperature

Previous authors have found a relation between the velocity dispersion of a cluster of galaxies and the X-ray temperature of the gas within the cluster. Slightly different but consistent expressions for this relation have been derived by Lubin & Bahcall (1993), Bird, Mushotzky & Metzler (1995) and Girardi et al. (1996). Girardi et al.’s expression, \( \sigma_T (\text{km s}^{-1}) = 10^{2.53(\pm 0.04)} \times (T/\text{keV})^{0.61(\pm 0.05)} \), leads to a predicted velocity dispersion \( \sigma_T = 501(+232,-113)\text{km s}^{-1} \) based on the temperature of \( kT = 1.9(+0.9,-0.4)\text{keV} \) (1\( \sigma \) error) found by Worrall et al. (1995). The result is in good agreement with our measured one-dimensional velocity dispersion, supporting the argument that the X-ray gas detected by Worrall et al. (1995) is associated with the cluster containing NGC 326.

## 6.3 Velocity dispersion and cluster richness

In their study of 43 clusters, Danese et al. (1980) found a correlation between Abell’s (1958) richness class and the physical velocity dispersion, as might be expected if the galaxy population is a measure of total mass. For richness classes \( R = 0, 1 \) and 2, the mean three-dimensional velocity dispersions were found to be \( 820 \pm 64\text{km s}^{-1} \), \( 1400 \pm 210\text{km s}^{-1} \) and \( 1760 \pm 120\text{km s}^{-1} \), respectively. From our (three-dimensional) velocity dispersion of \( \sigma = 1037(+427,-241)\text{km s}^{-1} \), it can be deduced that the cluster studied in this paper falls between the richness classes 0 and 1. A visual inspection of the optical sky survey image suggests that this appears to be a reasonable richness estimate for the western side of the cluster Zw 0056.9+2636.

## 7 CONCLUSIONS

In his 1968 catalogue, Zwicky indicated a population of 145 for the cluster Zw 0056.9+2636. Our velocity dispersion (an indication of Abell richness class) suggests that the galaxies detected by Zwicky are not all physically associated, because our measured velocity dispersion is too low. This conclusion is consolidated by the findings of Worrall et al. (1995), who detected X-ray gas only in the western part of the cluster. Subdividing the cluster into two halves, the following can be concluded.

(i) In the north-western part of Zwicky cluster Zw 0056.9+2636, dominated by the dumbbell radio galaxy NGC 326, the physical and line-of-sight velocity dispersions are consistent with the cluster richness and the X-ray gas temperature. The gas morphology, which is asymmetric but peaked at NGC 326, and the modest temperature suggest that this cluster segment is rather young. The radio core of NGC 326 is slowly moving relative to the mean velocity of the galaxies in the cluster.

(ii) No redshift or velocity dispersion information is available for the south-eastern end of Zw 0056.9+2636, which appears to contain much of the galaxy count, but little hot gas. The physical relationship of this galaxy concentration with the cluster around NGC 326 remains unclear.

## ACKNOWLEDGMENTS

We thank Glenn Baggeley, Claire Halliday and Brian McNamara for assistance with the optical observing. Observations reported in this paper were obtained at the Multiple Mirror Telescope Observatory, a facility operated jointly by the University of Arizona and the Smithsonian Institution.

## REFERENCES

Abell G. O., 1958, ApJS, 3, 211
Bird C. M., Mushotzky R. F., Metzler C. A., 1995, ApJ, 453, 40
Danese L., De Zotti G., di Tullio G., 1980, A&A, 82, 322
Davoust E., Considère S., 1995, A&AS, 110, 19
de Vaucouleurs G., de Vaucouleurs A., Corwin H. G., Jr, Buta R. J., Paturel G., Fouque P., 1991, Third Reference Catalogue of Bright Galaxies, Springer Verlag, New York
Girardi M., Fadda D., Giuricin G., Mardirossian F., Mezzetti M., Biviano A., 1996, ApJ, 457, 61
Lubin L. M., Bahcall N. A., 1993, ApJ, 415, L17
Sargent W. L. W., 1973, ApJ, 182, L13
Tonry J., Davis M., 1979, AJ, 84, 1511
Valentijn E. A., Casertano S., 1988, A&A, 206, 27
Worrall D. M., Birkinshaw M., Cameron R. A., 1995, ApJ, 449, 93
Zwicky F., Kowal C. T., 1968, Catalogue of Galaxies and of Clusters of Galaxies, Vol. VI. California Institute of Technology

This paper has been typeset from a \LaTeX\ file prepared by the author.