Mon. Not. R. astr. Soc. (1982) **199**, 905–913

NGC 4388: a Seyfert 2 galaxy in the Virgo cluster

M. M. Phillips★ and D. F. Malin *Anglo-Australian Observatory, PO Box 296, Epping, NSW 2121, Australia*

Received 1981 August 24

Summary. New optical photographic and spectroscopic observations of the edge-on spiral galaxy NGC 4388 are reported. This galaxy, which is almost certainly a member of the Virgo cluster, appears to be a barred spiral of morphological class SB(s)b pec. The nucleus emits a high-excitation, narrow emission-line spectrum of relatively low luminosity, but which is otherwise indistinguishable from that of a classical Seyfert 2 galaxy. We therefore group NGC 4388 with the Seyfert 2 galaxies, since its optical, X-ray and radio nuclear properties are logical extensions of the ranges observed for this class of object. The radial velocity of the peaks of the asymmetric nuclear emission lines is 55 km s^{-1} less than the H I 21 cm systemic velocity. This difference could be due to obscuration by dust, or perhaps is a consequence of the Seyfert activity itself. NGC 4388 is the first Seyfert galaxy to be identified in the Virgo cluster – which, along with the recent discoveries of two Seyfert galaxies in the Fornax cluster, suggests that such objects are considerably more common in clusters than had previously been thought.

1 Introduction

NGC 4388 is a spiral galaxy located in the core of the Virgo cluster. Because of the galaxy's nearly edge-on orientation to the line-of-sight, its exact morphology has proved difficult to establish. In the *Second Reference Catalogue of Bright Galaxies,* de Vaucouleurs, de Vaucouleurs & Corwin (1976) gave an uncertain classification of SA(s)b, although in an early paper, de Vaucouleurs (1963) suggested that the type might be SBc. Sandage (1978) has listed NGC 4388 as Sa/Sb.

The presence of high-excitation emission lines in the nucleus of NGC 4388 was first noted by Ford, Rubin & Roberts (1971) who observed a rich spectrum of Hα, Hβ, He I λ5876, He II λ4686, [O I] λ6300, [O III] λλ4959, 5007, [N II] λλ6548, 6584 and [S II] λλ6716, 6731 emission at a heliocentric velocity of 2604 km s^{-1}. They further reported that the emission lines extended 63 arcsec along the major axis of the galaxy. Confirmation of

★ Guest investigator at Las Campanas Observatory which is run by the Mt Wilson and Las Campanas Observatories. Also at Cerro Tololo Inter-American Observatory during parts of this investigation.

the extended emission was made by Sandage (1978), who also commented on the high-excitation nature of the nuclear spectrum. It should be noted that Sandage's value of 2450 km s^{-1} for the heliocentric radial velocity is lower by 154 km s^{-1} than that of Ford *et al.*, and is 78 km s^{-1} less than an independent measurement made by de Vaucouleurs & de Vaucouleurs (1973). On the other hand, 21 cm spectral profile observations by Helou *et al.* (1981) yield a heliocentric systemic velocity of 2515 ± 7 km s^{-1}.

In the course of a 5.0 GHz survey of bright galaxies, Sramek (1975) made the first radio detection of NGC 4388. In a later survey at 2.38 GHz by Dressel & Condon (1978), NGC 4388 was again detected at a flux density of 129 ± 6 mJy. Combining this measurement with a recent 5.0 GHz observation of 76 ± 5 mJy by Turtle & Phillips (1982) yields a spectral index of $\alpha = -0.71 \pm 0.15$, indicating a non-thermal source for the emission.

The most recent evidence of unusual nuclear activity in NGC 4388 was found by Forman *et al.* (1979) who reported *Einstein* X-ray Observatory observations of the core of the Virgo cluster. Excluding the previously known sources associated with NGC 4486 (M87), a total of nine cluster galaxies were detected in the range 0.5–4.5 keV. Of these, NGC 4388 was the third most luminous, being surpassed only by the two giant elliptical galaxies NGC 4374 (M84) and NGC 4406 (M86).

Thus all the evidence to date points to the presence of an 'active' nucleus in NGC 4388. The proximity of this galaxy makes it a particularly good candidate for detailed study, and we have therefore undertaken new spectroscopic and photographic observations to determine better the nature of the nuclear activity and the morphological properties of the galaxy as a whole. In this paper we present the direct photographic data and preliminary spectroscopy.

2 Direct photography

Three direct plates of NGC 4388 were obtained in 1981 January at the prime focus of the 3.9-m Anglo-Australian telescope. Two of these were made on hypersensitized IIIa-J emulsions (passband 3850–5500 Å) with exposure times of 5.5 and 15 min, while the third was a 60 min exposure on a hypersensitized 098-04 emulsion through a 100 Å (FWHM) Hα interference filter. The three plates are reproduced in Plate 1(a)–(c).

In the 5.5 min IIIa-J and the Hα plates, the bright nucleus is clearly seen, together with two slightly curved arm-like structures running east–west. The most northern of these is marked by a particularly conspicuous chain of H II regions and blue stars. Both arms can readily be construed as originating in a bar seen almost end on and at a position angle of about 30°. This feature is most noticeable in the 15 min IIIa-J plate (Plate 1c) where the two arms and nucleus appear to form a flattened 'S' shape. If this central structure is in fact a bar, then the nucleus is oddly off-centre towards the south. The central regions of the galaxy are rather dusty, with two prominent dark lanes lying slightly to the north and running either east or west from the nucleus.

Several deeper plates of the Virgo cluster were kindly made available to us by Drs Bernard and Janet Jones. These were 70 min IIIa-J exposures covering a slightly narrower bandpass (3950–5500 Å) made on the 1.2-m UK Schmidt telescope. The best of these is reproduced in Plate 2(a), and shows a faint outer region which can be traced more than 6 arcmin along the major axis and which is distinctly asymmetric towards the west when compared with the bright inner parts. This structure was previously noted and described by Markaryan, Oganesyan & Arakelyan (1966). An extension to the east is vaguely suggestive of spiral structure, although its sense is opposite to that observed in the bright inner region.

An even deeper image of NGC 4388 has been made by superimposing photographically

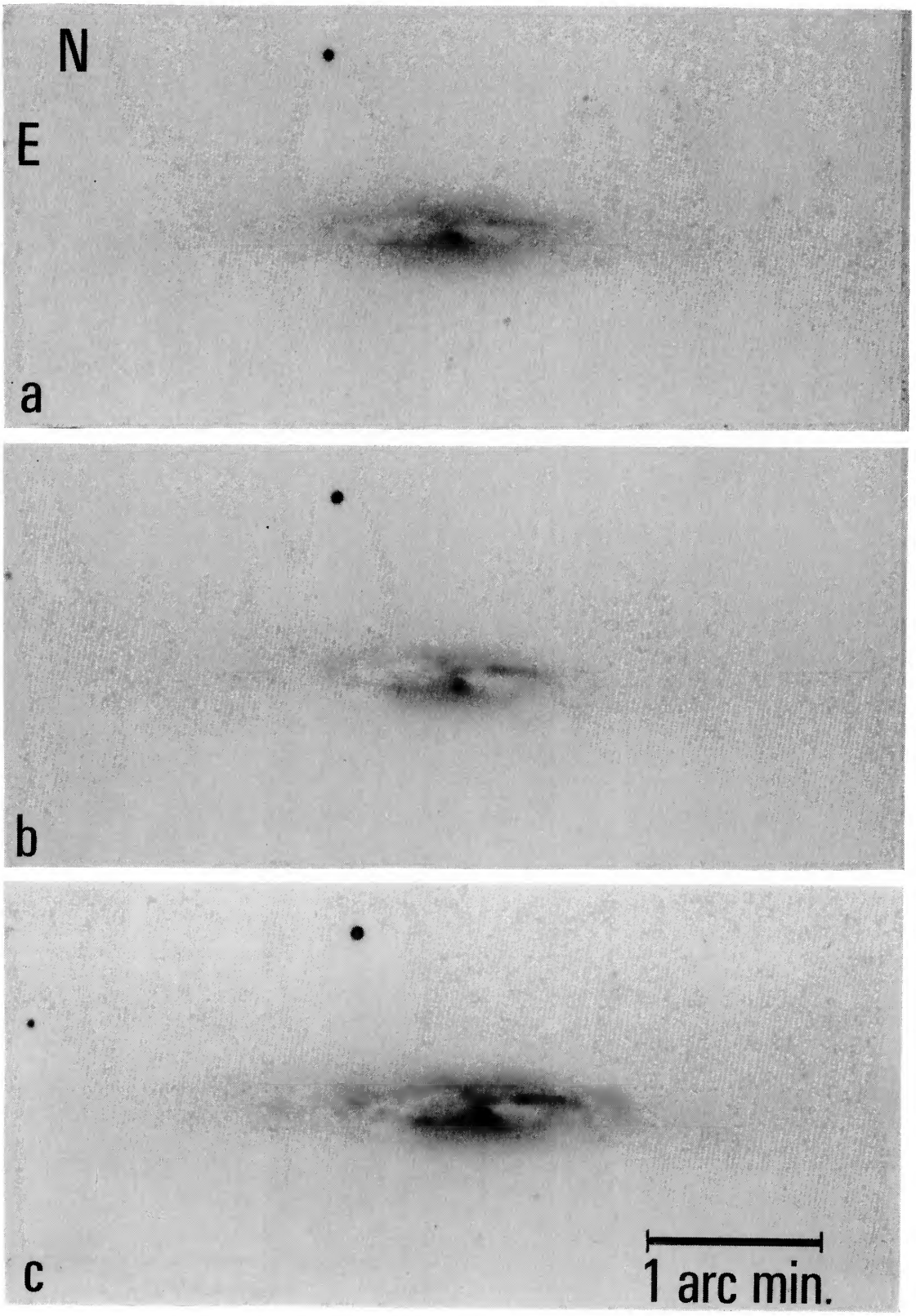

Plate 1. AAT prime focus plates of NGC 4388: (a) 60 min 098–04+Hα interference filter, (b) 5.5 min IIIa–J+GG385 filter, and (c) 15 min IIIa–J+GG385 filter.

[*facing page* 906

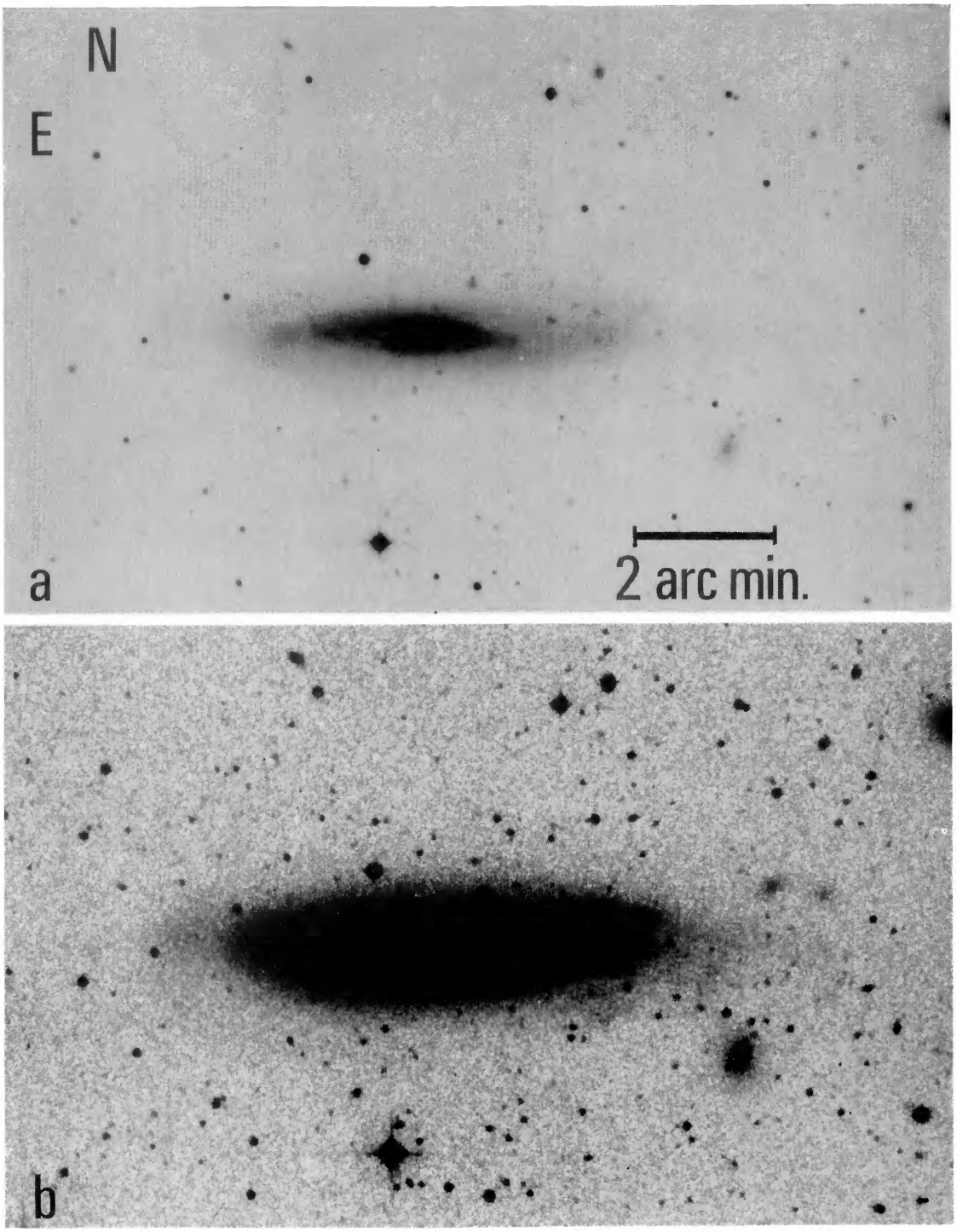

Plate 2. (a) 70 min UK Schmidt IIIa–J plate of NGC 4388; (b) superposition of photographically amplified derivatives of three UK Schmidt IIIa–J plates of the same field as in (a).

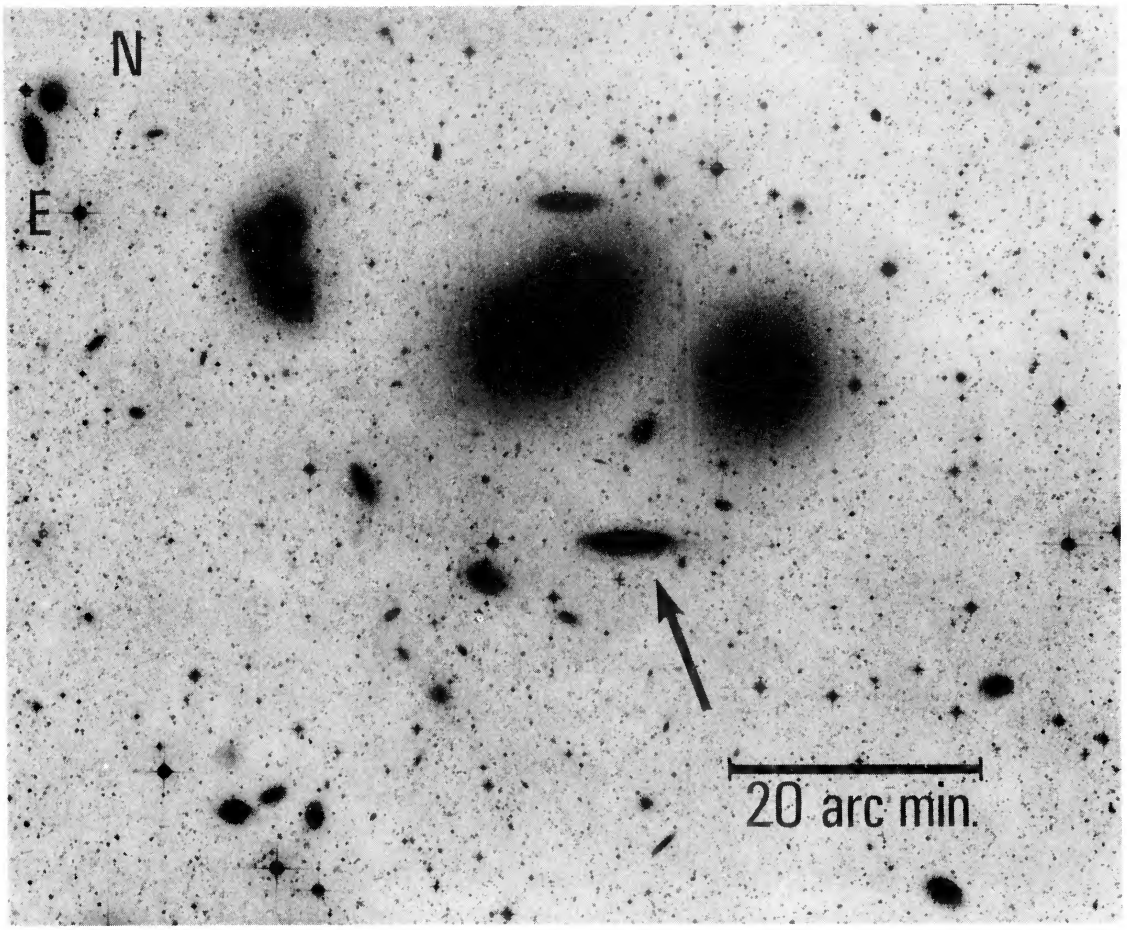

Plate 3. Larger area of the superposition of UK Schmidt plates described in Plate 2(b), showing the core of the Virgo cluster. The arrow identifies NGC 4388.

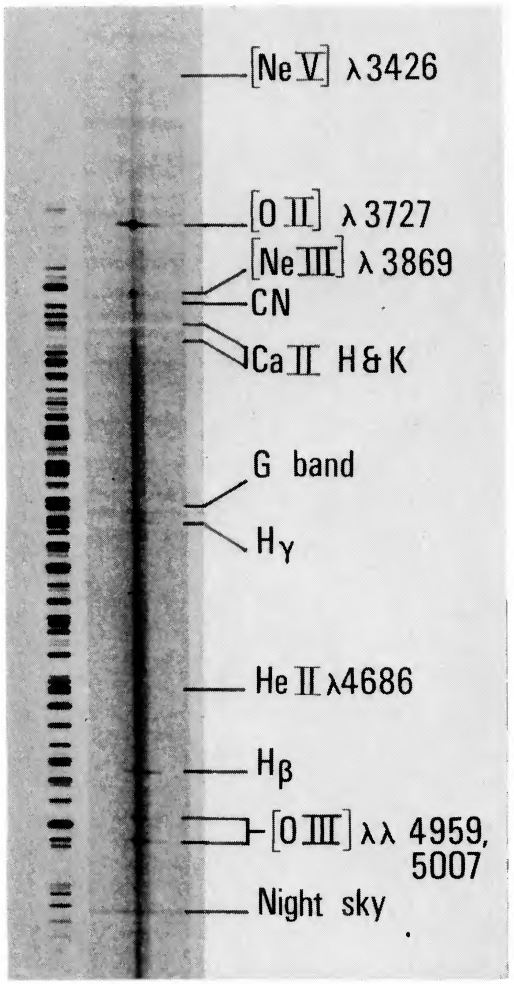

Plate 4. Thirty minute image-tube spectrum of NGC 4388 taken at a position angle of 90° with the CTIO 1-m Yale telescope. East is at the top.

amplified (Malin 1978) derivatives of three UK Schmidt IIIa-J plates. The result appears as Plate 2(b), where the asymmetrical distribution of light with respect to the nucleus is again seen along the major axis. In addition, there are very faint extensions visible at both the eastern and western edges, suggestive of tidal interactions. This would seem particularly likely for NGC 4388 considering its apparent proximity to the giant elliptical galaxies NGC 4374, 4406. However, we cannot rule out the possibility that NGC 4388 has interacted with one of the less massive galaxies shown in Plate 3, which illustrates the high population density of galaxies in the region. Plate 3 was prepared from the same three derivatives used to make Plate 2(b). Including the faint wisps, the total extent of the major axis as measured from these photographs is approximately 10 arcmin. Assuming a distance of 13.8 Mpc, equal to that of the cluster (Hanes 1979), this corresponds to a diameter of 40 kpc.

3 Spectroscopy

3.1 IMAGE-TUBE SPECTROGRAMS

Three spectrograms of NGC 4388 were obtained in 1979 May using the Carnegie image-tube spectrograph at the Cassegrain focus of the 1-m Yale telescope located on Cerro Tololo. The spectra were recorded at a dispersion of 121 Å mm^{-1} on N_2-baked IIIa-J plates. Exposure times were 7, 15 and 30 min. A 2.8 arcsec slit was employed at a position angle of 90°, corresponding to the major axis of NGC 4388. The plate scale perpendicular to the dispersion was 137 arcsec mm^{-1}. The 30 min spectrum is reproduced in Plate 4.

In the shortest-exposure spectrum, the bright concentrated nuclear emission is predominant, while in the longer exposures the tilted extended component of the emission noticed by Ford *et al.* (1971) and Sandage (1978) becomes more and more visible. The nuclear emission is clearly of considerably higher excitation than the extended component, as witnessed by the large [O III] λ5007/Hβ ratio and the presence of the He II λ4686 and [Ne V] λ3426 lines in the former. In the extended emission, the excitation rapidly drops and [O II] λ3727 and Hβ become the most prominent lines. Also note that the widths of the lines change with radius, being relatively broad in the nuclear core and narrow in the outer low-excitation gas.

The continuum visible in the image-tube spectra shows strong Ca II H and K absorption lines across the entire 3.9 arcmin length of the slit (see Plate 4), and rough measurements yield a velocity gradient which is consistent with that of the extended emission. The CN band at 3883 Å and, more weakly, the CH G-band at 4300 Å are present in absorption as well, implying that the Ca II absorption is largely stellar in origin and that the stellar population throughout much of the galaxy is of late type. This is consistent with the photographic photometry of Markaryan *et al.* (1966), who deduced an average $B-V$ colour in the outer regions (except in the vicinity of the blue stars and H II regions in the northern spiral arm) of 0.9, which is roughly equivalent to K2 in spectral type.

3.2 IMAGE INTENSIFIER/RETICON SCANNER

A 16-min spectrum of the nucleus of NGC 4388 was obtained in 1980 January with the photon-counting image intensifier/reticon scanner (Shectman & Hiltner 1976) on the Las Campanas 2.5-m DuPont telescope. This instrument is a two-channel detector, mounted on a Boller and Chivens spectrograph at the Cassegrain focus. The twin apertures of the spectrograph were set at 2 × 4 arcsec for the observations of NGC 4388, but were opened to 8 × 8 arcsec for standard stars. The grating gave coverage over the wavelength range λλ 3500–6900 at a resolution of approximately 5 Å. The data were reduced and calibrated in the usual

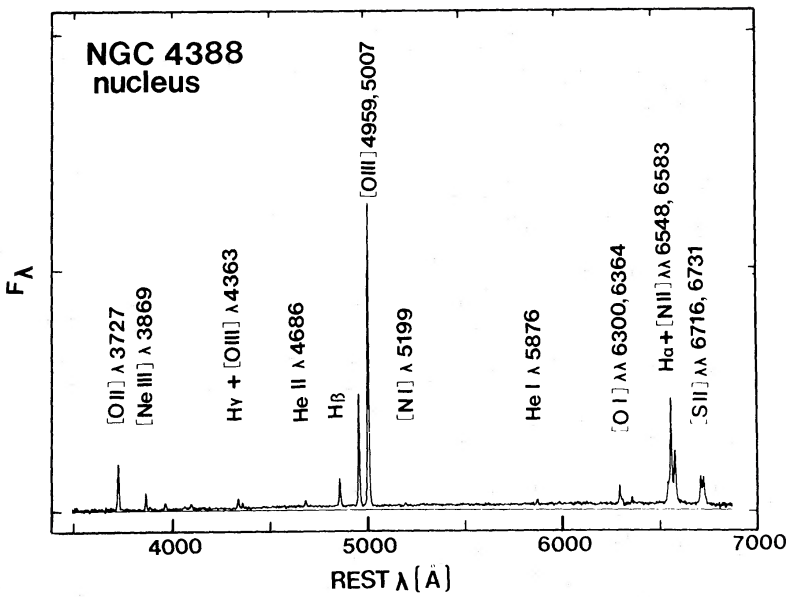

Figure 1. Image intensifier/reticon scanner spectrum of the nucleus of NGC 4388 taken with the Las Campanas Observatory 2.5-m DuPont telescope.

manner. The flux calibration, which was derived from observations of three Oke (1974) and Stone (1974, 1977) standard stars, should be accurate in a relative sense to approximately 10 per cent over the wavelength region 4000–6500 Å, and to better than 20 per cent outside this range. The absolute scale of the flux calibration is somewhat less reliable still, owing to the smaller apertures used for the galaxy observations.

Table 1. Observed and reddening-corrected relative emission-line intensities in the nucleus of NGC 4388. Also listed are the average reddening-corrected relative intensities for classical Seyfert 2 galaxies as given by Koski (1978).

ID	Wavelength (Å)	NGC 4388 $F(\lambda)/F(H\beta)$	$I(\lambda)/I(H\beta)$	Average Seyfert 2 $I(\lambda)/I(H\beta)$
[Ne V]	3426	Present	Present	1.00
[O II]	3727	1.72	2.74	3.00
[Ne III]	3869	0.48	0.72	1.50
He I + H8	3889	0.095:	0.14:	0.20
[Ne III] + Hε	3967	0.22	0.32	0.61
[S II]	4071	0.096:	0.13:	0.20
Hδ	4102	0.22	0.30	0.26
Hγ	4340	0.36	0.46	0.47
[O III]	4363	0.13	0.16	0.20
He II	4686	0.20	0.22	0.30
Hβ	4861	1.00	1.00	1.00
[O III]	4959	3.83	3.68	3.70
[O III]	5007	11.20	10.50	11.00
[N I]	5199	0.094:	0.082:	0.10
He I	5876	0.16	0.11	0.10
[O I]	6300	0.78	0.49	0.50
[O I]	6364	0.20	0.12	0.17
[N II]	6548	0.86	0.50	0.77
Hα	6563	4.86	2.84	2.85
[N II]	6584	2.59	1.50	2.30
[S II]	6716	1.27	0.72	1.50
[S II]	6731	1.12	0.63	

The spectrum of NGC 4388 derived from these data is displayed in Fig. 1. Our measurements of the relative fluxes for all of the emission lines are listed in the third column of Table 1. In general, the accuracy is 10–20 per cent, but errors as large as a factor of 2 are possible for those entries followed by a colon.

The Hα/Hβ ratio observed in NGC 4388 is significantly greater than the normal case *B* value of 2.85. The extinction due to our own Galaxy should be quite small in view of the high galactic latitude of NGC 4388 ($E_{B-V} \simeq 0.03$). Thus if dust is the cause of the steep decrement, such dust must lie within NGC 4388 itself – which is not surprising in view of the obvious signs of obscuration seen in the direct photographs. Assuming case *B* values for the intrinsic ratios for the Hα, Hβ and Hγ emission lines, an average extinction of A_V = 1.5 mag is derived. The relative intensities of the emission lines corrected for this amount of reddening are listed in the fourth column of Table 1.

The continuous spectrum in the nucleus of NGC 4388 shows weak absorption lines at the wavelengths of Ca II K, Mg Ib and the G-band, and is most similar to the continua found in elliptical galaxies or in the nuclei of spirals such as M31. However, the Ca II 'break' at λ3970 Å is quite weak which may imply the presence of hot stars or a weak non-thermal UV component. Over the wavelength range λλ4100–6400, where the flux calibration is most reliable and the match to a late-type continuum is best, we have compared the average spectral energy distribution of the integrated light of the elliptical galaxies NGC 4472 and 4486 as measured by Schild & Oke (1971). We find good agreement if the nuclear continuum of NGC 4388 is reddened by an amount corresponding to $A_V = 1.0 \pm 0.2$ mag.

3.3 IMAGE PHOTON-COUNTING SYSTEM

Spectroscopy of NGC 4388 was obtained on two nights in 1980 June with the University College London image photon-counting system (IPCS) (Boksenberg & Burgess 1973) on the AAT. The 25 cm camera of the RGO spectrograph was employed with a slit width of 2 arcsec at a dispersion of 33 Å mm^{-1} (= 1.3 Å resolution), and with a spatial resolution of 2.5 arcsec along the slit. As in the case of the previously discussed image-tube spectra, the slit was oriented at a position angle of 90°. Data were taken at two different grating tilts, centred at Hβ and Hα, respectively, with the total wavelength coverage at each tilt amounting to approximately 990 Å. Exposure times were 2000 s at both settings. The slit length for the Hβ observations was 146 arcsec, while that for Hα was 65 arcsec.

In the IPCS spectra, the emission can be followed for a distance of more than 90 arcsec along the major axis of NGC 4388. In the nuclear region, the profiles are skewed towards the red and there is some evidence of multiple components. We measure a full width at half intensity for the lines in the nucleus of 210 km s^{-1}. The heliocentric radial velocity of the nucleus as calculated from the peaks of the Hβ, Hα, [O III] λ5007, and [N II] λ6584 lines is 2460 ± 5 km s^{-1}, in excellent agreement with the value given by Sandage (1978), but in disagreement by 55 ± 9 km s^{-1} with the previously mentioned H I 21 cm systemic velocity (Helou, Salpeter & Krumm 1981).

4 Discussion and conclusions

From the preceding data, it is clear that NGC 4388 possesses several unusual properties. To organize the discussion in this section, we shall consider three major topics: (1) morphology, (2) the nature of the nuclear activity and (3) Virgo cluster membership.

4.1 MORPHOLOGY

The observations presented in Section 2 suggest that NGC 4388 is quite probably a barred spiral galaxy, albeit with some peculiar properties. On the basis of the vigorous H II region

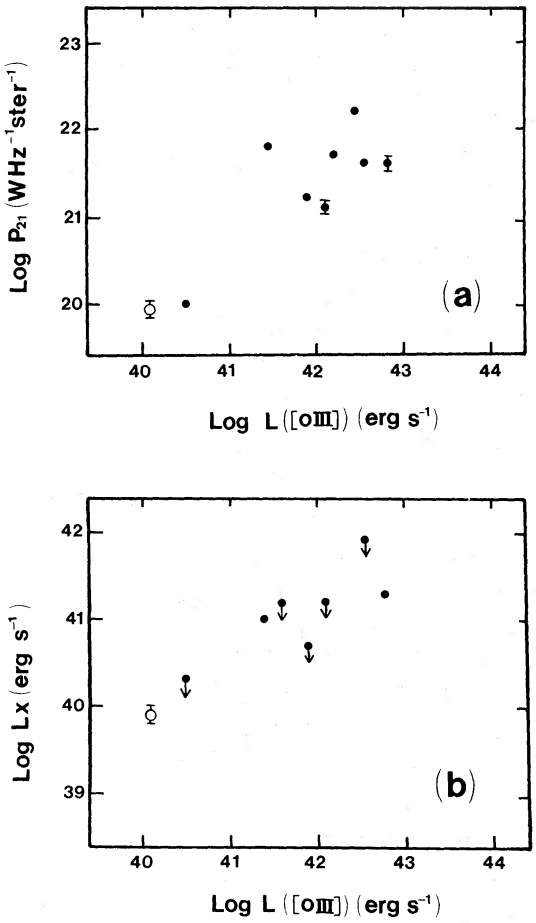

Figure 2. Plots of reddening-corrected nuclear [O III] λ5007 luminosity versus (a) continuum power at 21 cm, and (b) X-ray luminosity (0.5–4.5 keV) for 'classical' Seyfert 2 galaxies (filled circles) and NGC 4388 (open circle). The [O III] λ5007 luminosities of the classical type 2 Seyferts are taken from Koski (1978) and Adams & Weedman (1975), the 21 cm powers from de Bruyn & Wilson (1976) and the X-ray luminosities from Kriss, Canizares & Ricker (1980). The 21 cm power for NGC 4388 is an extrapolation of the 2.38 and 5.0 GHz measurements of Dressel & Condon (1978) and Turtle *et al.* (1981). H_0 = 100 km s^{-1}/Mpc^{-1} was assumed in calculating the distances of the classical Seyferts, while a distance of 13.8 Mpc, equal to that of the Virgo cluster (Hanes 1979), was taken for NGC 4388.

activity in the S-shaped spiral arms, the likely presence of dust in the bar, and the relatively small nuclear bulge, a type of SB(s)b pec in the de Vaucouleurs (1964) system would seem most appropriate. However, the uncertainty of this classification is considerable owing to the edge-on orientation and the possibility that dust is significantly obscuring our view (see Section 4.2).

4.2 THE NATURE OF THE NUCLEAR ACTIVITY

The optical emission-line spectrum of the nucleus of NGC 4388 is most like that of a Seyfert 2 galaxy. To illustrate this, the reddening-corrected intensities published by Koski (1978) for the 'average' Seyfert 2/narrow-line radio galaxy are reproduced in the final column of Table 1. (We have averaged the intensities of the weaker lines ourselves, since Koski did not include these in his Table 9.) The close similarity of the spectra points to the same basic energy input mechanism, which Koski argued was photo-ionization by a central non-thermal source of radiation.

As discussed in the introduction, the nucleus of NGC 4388 is unusually active at radio and X-ray wavelengths. To test whether these properties are also similar to those of classical Seyfert 2 galaxies, we have plotted in Figs 2(a) and (b) the reddening-corrected [O III] λ5007 luminosity against (a) the continuum power at 21 cm and (b) the X-ray luminosity (0.5–4.5 keV) for NGC 4388 and for those classical Seyfert 2 galaxies found by Koski to be of similar high ionization. These figures show that NGC 4388 is consistently at the low end of the luminosity distribution for Seyfert 2 galaxies in all three wavelength regions. The width of 210 km s^{-1} for the nuclear emission lines is also roughly 100 km s^{-1} less than the narrowest widths measured by Koski for the classical type 2 Seyferts plotted in the figures. However, in each case, these properties of NGC 4388 appear to be smooth extensions of the ranges observed in the type 2 Seyferts, and thus we feel little hesitation in concluding that the same basic nuclear activity is occurring in all. The historical criteria in classifying a Seyfert galaxy are (a) a bright nucleus, and (b) 'broad' emission lines (Khachikian & Weedman 1974), and this naturally has resulted in the selection of a group of objects with high intrinsic luminosity and broad lines. But in our opinion, the most fundamental consideration should be given to the basic physics of the processes which are creating the unusual radio, X-ray, and optical emission, and in this respect NGC 4388 clearly deserves to be classed with the type 2 Seyferts.

We are currently engaged in an investigation of the dynamical properties of NGC 4388 and several other nearby Seyfert galaxies, and so we defer a detailed discussion of this topic to a future paper. However, the discrepancy between the observed radial velocity of the Seyfert nucleus and the 21 cm systemic velocity deserves further brief consideration. Rubin, Ford & Thonnard (1978) compared uniform optical and 21 cm radial velocities for a sample of eight spiral galaxies and found an average difference of only $\langle | V_{21} - V_{\rm opt} | \rangle = 7 \pm 5$ km s^{-1}. The measurements for NGC 4388 are equal in quality to the data of Rubin *et al.*, and thus the difference of 55 km s^{-1} we find is almost certainly significant. This effect may possibly be due to dust obscuration along the line of sight to the nucleus. Some support for this hypothesis is afforded by the Balmer emission-line intensities and the stellar continuum in the Seyfert nucleus, which, as we have shown, are both significantly reddened. Alternatively, the problem could lie in an unusual distribution of the H I gas (recalling the evidence for tidal distortion in the optical photographs). Yet a third possibility is that the discrepancy arises from some unknown processes in the Seyfert nucleus which are related to the activity there. For example, the broad [O III] λλ4959, 5007 emission lines observed in the nucleus of the Seyfert 1 galaxy NGC 7469 show a peculiar trend in radial velocity quite different from the general rotation motion of that galaxy (Briggs 1981). Presumably this is somehow connected with the flow pattern and geometry of the high ionization gas. Further spatially resolved spectroscopy of NGC 4388 at a variety of position angles would be of considerable aid in evaluating the likelihood of such an explanation.

4.3 VIRGO CLUSTER MEMBERSHIP

The question of the Virgo cluster membership of NGC 4388 is intimately connected with the controversy over a possible difference in mean radial velocity of the spiral and elliptical/SO populations in the cluster (see de Vaucouleurs & de Vaucouleurs 1973; Sandage & Tammann 1976; Sulentic 1977; Helou *et al.* 1979). Although NGC 4388 appears to be located in the midst of the cluster core, its radial velocity is larger than those of all 86 other Shapley-Ames Catalogue galaxies which lie within the canonical 6° radius limit of the cluster. On the basis of the large radial velocity alone, de Vaucouleurs & de Vaucouleurs (1973) considered NGC 4388's membership in the Virgo cluster to be questionable. On the other hand, Sandage

& Tammann (1976) placed more weight on the central position of NGC 4388 in the cluster and concluded that its high velocity could be reconciled with the overall distribution of radial velocities of the entire sample of galaxies in the region.

More recent observations by Helou *et al.* (1979) solidly favour the conclusion that NGC 4388 is indeed a member of the Virgo cluster. Using the Fisher–Tully relationship between luminosity and H I 21 cm velocity width, Helou *et al.* showed that NGC 4388 and several other questionable cluster members are all best understood if they lie at the same distance as the non-controversial cluster galaxies. We believe that the distortions observed in the outermost optical isophotes of NGC 4388 are also naturally explained as a consequence of interactions with the nearby galaxies in the cluster core. Hence we conclude that it is highly probable that NGC 4388 is a genuine member of the Virgo cluster.

It is important to note that NGC 4388 is the first Seyfert galaxy to be identified in the Virgo cluster. Van den Bergh (1975) has previously commented on the apparent lack of Seyfert galaxies in clusters. However, with the discovery of NGC 4388, the two Seyfert galaxies NGC 1365 (Véron *et al.* 1980) and NGC 1386 (Phillips & Frogel 1980) in the Fornax cluster, and the Seyfert 1 galaxy IC 4329A (Disney 1973) in the nearby cluster Klemola 27, it is not at all evident that such a deficiency actually exists. In our opinion, the fact that the Seyfert nature of NGC 4388 was overlooked for so long casts suspicion on all previous attempts to determine the frequency of such objects in clusters or in the field. Clearly a much more effective method of locating Seyfert galaxies will have to be found before this question can be properly addressed.

Acknowledgments

We are grateful to Bernard and Janet Jones for allowing us to use their UK Schmidt plates of the Virgo cluster. We would also like to thank Dave Allen and Dave Hanes of the AAO for critical readings of early versions of this paper. This work would not have been possible but for the generous allocations of telescope time granted to one of us (M.M.P.) by the respective time assignment committees of the Mt Wilson and Las Campanas Observatories, Cerro Tololo Inter-American Observatory and the Anglo-Australian Observatory.

References

Adams, T. F. & Weedman, D. W., 1975. *Astrophys. J.*, **199**, 19.

Boksenberg, A. & Burgess, D. E., 1973. *Proceedings of Symposium on Astronomical Observations with Television Type Sensors,* University of British Columbia, Vancouver, ed. Glaspey, J. W. & Walker, G. A. H.

Briggs, S., 1981. Herstmonceux Conference on the Nuclei of Galaxies.

de Bruyn, A. G. & Wilson, A. S., 1976. *Astr. Astrophys.*, **53**, 93.

de Vaucouleurs, G., 1963. *Astrophys. J. Suppl.*, **8**, 31.

de Vaucouleurs, G., 1964. *Astrophys. J.*, **139**, 899.

de Vaucouleurs, G. & de Vaucouleurs, A., 1973. *Astr. Astrophys.*, **28**, 109.

de Vaucouleurs, G., de Vaucouleurs, A. & Corwin, H. G., 1976. *Second Reference Catalogue of Bright Galaxies,* University of Texas Press, Austin.

Disney, M. J., 1973. *Astrophys. J.*, **181**, L55.

Dressel, L. L. & Condon, J. J., 1978. *Astrophys. J. Suppl.*, **36**, 53.

Ford, W. K., Rubin, V. C. & Roberts, M. S., 1971. *Astr. J.*, **76**, 22.

Forman, W., Schwarz, J., Jones, C., Liller, W. & Fabian, A. C., 1979. *Astrophys. J.*, **234**, L27.

Hanes, D. A., 1979. *Mon. Not. R. astr. Soc.*, **188**, 901.

Helou, G., Giovanardi, G., Salpeter, E. E. & Krumm, N., 1981. *Astrophys. J. Suppl.*, **46**, in press.

Helou, G., Salpeter, E. E. & Krumm, N., 1979. *Astrophys. J.*, **228**, L1.

Khachikian, E. Ye. & Weedman, D. W., 1974. *Astrophys. J.*, **192**, 581.

Koski, A. T., 1978. *Astrophys. J.,* **223,** 56.
Kriss, G. A., Canizares, C. R. & Ricker, G. R., 1980. *Astrophys. J.,* **242,** 492.
Malin, D. F., 1978. *Nature,* **276,** 591.
Markaryan, B. E., Oganesyan, E. Ya. & Arakelyan, S. N., 1966. *Astrofizika,* **2,** 53.
Oke, J. B., 1974. *Astrophys. J. Suppl.,* **27,** 21.
Phillips, M. M. & Frogel, J. A., 1980. *Astrophys. J.,* **235,** 761.
Rubin, V. C., Ford, W. K. & Thonnard, N., 1978. *Astrophys. J.,* **225,** L107.
Sandage, A., 1978. *Astr. J.,* **83,** 904.
Sandage, A. & Tammann, G. A., 1976. *Astrophys. J.,* **207,** L1.
Schild, R. & Oke, J. B., 1971. *Astrophys. J.,* **169,** 209.
Shectman, S. A. & Hiltner, W. A., 1976. *Publs astr. Soc. Pacif.,* **88,** 960.
Sramek, R., 1975. *Astr. J.,* **80,** 771.
Stone, R. P. S., 1974. *Astrophys. J.,* **193,** 135.
Stone, R. P. S., 1977. *Astrophys. J.,* **218,** 767.
Sulentic, J., 1977. *Astrophys. J.,* **211,** L59.
Turtle, A. J. & Phillips, M. M., 1982. In preparation.
van den Bergh, S., 1975. *Astrophys. J.,* **198,** L1.
Véron, P., Lindblad, P. O., Zuiderwijk, E. J., Véron, M. P. & Adam, G., 1980. *Astr. Astrophys.,* **87,** 245.