Astron. Astrophys. 143, 393–398 (1985)

ASTRONOMY AND ASTROPHYSICS

The NGC 4593 group of active galaxies

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Received March 20, accepted September 17, 1984

Summary. The optical properties of the Seyfert 1 galaxy NGC 4593 are described in detail on the basis of spectra from different epochs. NGC 4593 is found to be a member of a group of galaxies. Almost all of the members of this group detected show strong emission line activity. The implications of this finding for the origin and evolution of galactic nuclear activity are briefly discussed.

Key words: Seyfert galaxies – variability – groups and clusters of galaxies

1. Introduction

NGC 4593 is one of the brigthest Seyfert 1 galaxies. The Seyfert character of this barred spiral galaxy has been recognized only recently (MacAlpine et al., 1979). Subsequently it has been detected in X-rays (Dower et al., 1980) and in the UV (Clavel et al., 1983) and shown to be variable in these spectral ranges which led to an ongoing monitoring program particularly in the UV. Short and long term variability has been found in the UV. Indications for optical variability have first been noted from FES estimates using IUE (Clavel, 1983) and from spectrophotometry of Hβ (Peterson et al., 1982).

In this paper we present optical spectroscopic data from 2 epochs, $4^1/_2$ months apart, showing variability of the continuum and of the permitted line intensities and profiles (Sect. 3).

We find NGC 4593 to be a member of a small group of galaxies. Contrary to an original conjecture by van den Bergh (1975), during the last decade several Seyfert galaxies have been found to occur in groups or clusters (e.g. Huchra et al., 1982). A first assessment of the statistical situation is given by Dahari (1984) who reports a definite excess of companions in his sample as compared to a control sample of field galaxies. A fundamental aspect of the association of Seyfert galaxies with companions concerns the origin of their activity by mass accretion from the surroundings and/or by tidal interaction. In turn it is interesting to investigate to which extent activity might be triggered inside the companion galaxies by the presence of the dominating Seyfert galaxy and the other group members. Hutchings and Campbell (1983) provide evidence for the association of QSO's with close companions. The NGC 4593 system appears to be very interesting in this respect as all of its members but one show emission lines in their spectra (Sect. 4). The relevance of these observations will be discussed briefly in Sect. 5.

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2. Observations

We have obtained IDS spectra of NGC 4593 and of 11 further galaxies within 20′ from NGC 4593 at two epochs on March 1, 1982 and July 18, 1982. We have used the Boller & Chivens spectrograph attached to the ESO 3.6 m telescope with an aperture of 4″ × 4″. The spectra have a dispersion of 172 Å/mm and wavelength ranges 3700–7150 Å and 3920–7120 Å, in epoch 1 and 2, respectively. Seeing was approx. 2″. During epoch 2 clouds were affecting absolute photometry. In epoch 1 we obtained the spectra of the following objects: NGC 4593, with 20 min exposure time and SVEN 314, MCG-01-32-33, MCG-01-32-37, NGC 4602 with 6 min exposure time each. From epoch 2 are the spectra of NGC 4593, SVEN 320, and SVEN 321 with 12 min exposure time each and of SVEN 328, 319, 327, 308, NGC 4597 with 3 min exposure time each.

A first spectrum of NGC 4593 was taken on Feb. 23, 1982 at the ESO 1.5 m telescope with the IDS and Boller&Chivens spectrograph through an aperture 8″ × 8″ with 114 Å/mm dispersion and a wavelength range 4850–7000 Å. Exposure time was 20 min in this case.

The spectra were calibrated using Oke standards (Oke, 1974). Flat field corrections and wavelength calibrations were done at the image processing systems in Garching and Göttingen.

3. The optical spectrum of NGC 4593

3.1. Characteristics of the line spectrum

From the three spectra of this galaxy we determined a redshift $z = 0.0082 \pm 0.0002$. The internal accuracy of z for the individual spectra is even better. MacAlpine (1979) gives $z = 0.0087$. The spectrum of NGC 4593 must be classified as of type Sy 1.2 or Sy 1.3 since a narrow component is clearly present in the Hα-line (cf. Fig. 1).

NGC 4593 is known to be one of the Seyfert galaxies having strong Fe II emission in the optical and in the UV. The lines from higher ionization states of iron, [Fe VII] and [Fe X], are blueshifted relative to the other forbidden lines by $\Delta z = -0.0004 \pm 0.0002$. This phenomenon has been previously observed in other Seyfert galaxies and has been attributed to relative motions between the regions of different degrees of ionization (Grandi, 1978; Osterbrock, 1981; Kollatschny et al., 1983).

The absolute intensities for the emission lines of NGC 4593 in epoch 1 are listed in Table 1.

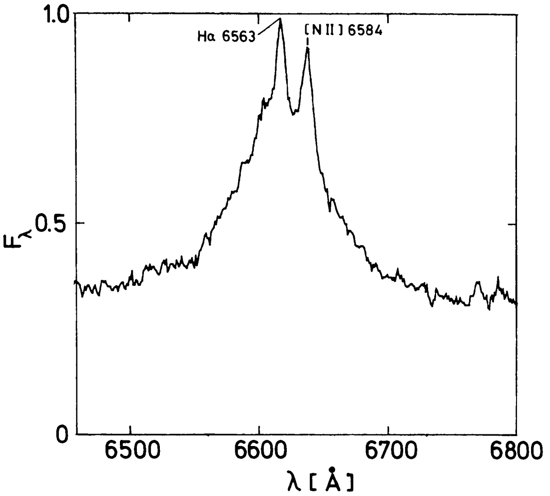


Fig. 1. The Hα+[N II] complex in the spectrum of NGC 4593 obtained on Feb. 23, 1982 showing a substantial narrow line contribution

Table 1. Line intensities of NGC 4593 in March 1982

Line	$I_\lambda[10^{-14}\,\mathrm{erg\,cm^{-2}\,s^{-1}\,Å^{-1}}]$
Fe II 4500	52.80
He II 4686	4.41
Hβ	105.3
[O III] 4959	8.26
[O III] 5007	24.76
Fe II 5400	63.33
[Fe VII] 5721	1.14
He I 5876	17.93
[Fe VII] 6086	4.41
[O I] 6300	2.42
[Fe X] 6374	2.14
Hα+[N II]	315.1
[S II] 6717	2.99
[S II] 6736	2.85

Estimated relative errors for the strong lines are ~20% and ~50% for the weak lines

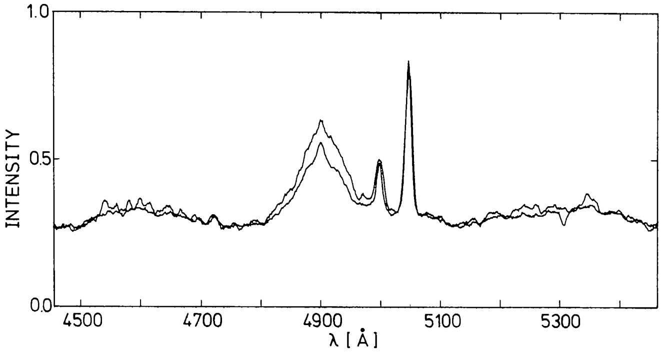


Fig. 2a. The Hβ+Fe II 4500, 5400 spectral region of NGC 4593 from epochs 1 and 2 assuming the flux of the line [O III] 5007 to be constant with time. In epoch 2 Hβ is enhanced

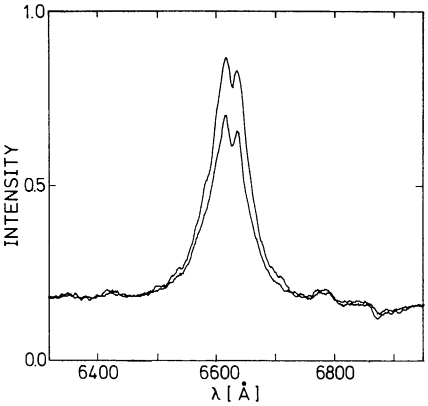


Fig. 2b. Same as in Fig. 2a for the Hα-region

Table 2. HWHM of Hα and Hβ (narrow and broad components) of NGC 4593 for three epochs

Epoch	Hβ	Hα	Hβ/Hα
	$[\mathrm{km\,s^{-1}}]$		
29. 4. 79	2100	1300	1.62
1. 3. 82	2443	1616	1.51
18. 7. 82	2881	1786	1.61

Estimated errors for the line widths are 10–20%

3.2. Variability of NGC 4593

In order to allow variability studies we applied much care to center NGC 4593 accurately in the 4″×4″ aperture to avoid different degrees of contamination by the background galaxy in the two epochs and in comparison to MacAlpine et al. (1979).

In our observations the mean continuum gradient between 4000 and 6800 Å stayed constant at a value of $\alpha=2.67\pm0.09$ ($F_\nu \propto \nu^{-\alpha}$) but differs strongly from the value $\alpha=1.79$ as derived from MacAlpine et al.'s (1979) spectra for the same wavelength range. Lacking an absolute calibration for epoch 2 we made the assumption that the intensity of the forbidden line [O III] 5007 remained constant. Then, notwithstanding the stationary continuum gradient the absolute intensity must have increased by a factor of 1.5 between epochs 1 and 2 (i.e. within $4^1/_2$ months). Under the assumption of the constancy of the [O III] 5007 line we can quantitatively compare the permitted line spectra in the two epochs. This is done in Fig. 2a for the spectral region around Hβ containing also the strong Fe II multiplets around 4500 and 5400 Å. In Fig. 2b we show the variation of Hα under the same assumption. The hydrogen lines have evidently increased in intensity by factors 1.3–1.4 from epoch 1 to 2. In the (permitted) Fe II-line spectral regions several distinct components are strongly enhanced in the second epoch. The hydrogen line profiles have evidently varied in shape and width.

In the Balmer lines stratification effects with regard to the velocity dispersion are seen. The ratio of the HWHM of Hβ/Hα ~ 1.56 ± 0.05. This ratio remains apparently unchanged with time, i.e. it seems not to be influenced by any outburst of the continuum source although the line widths themselves are changing strongly with time. The latter are listed for three epochs in Table 2.

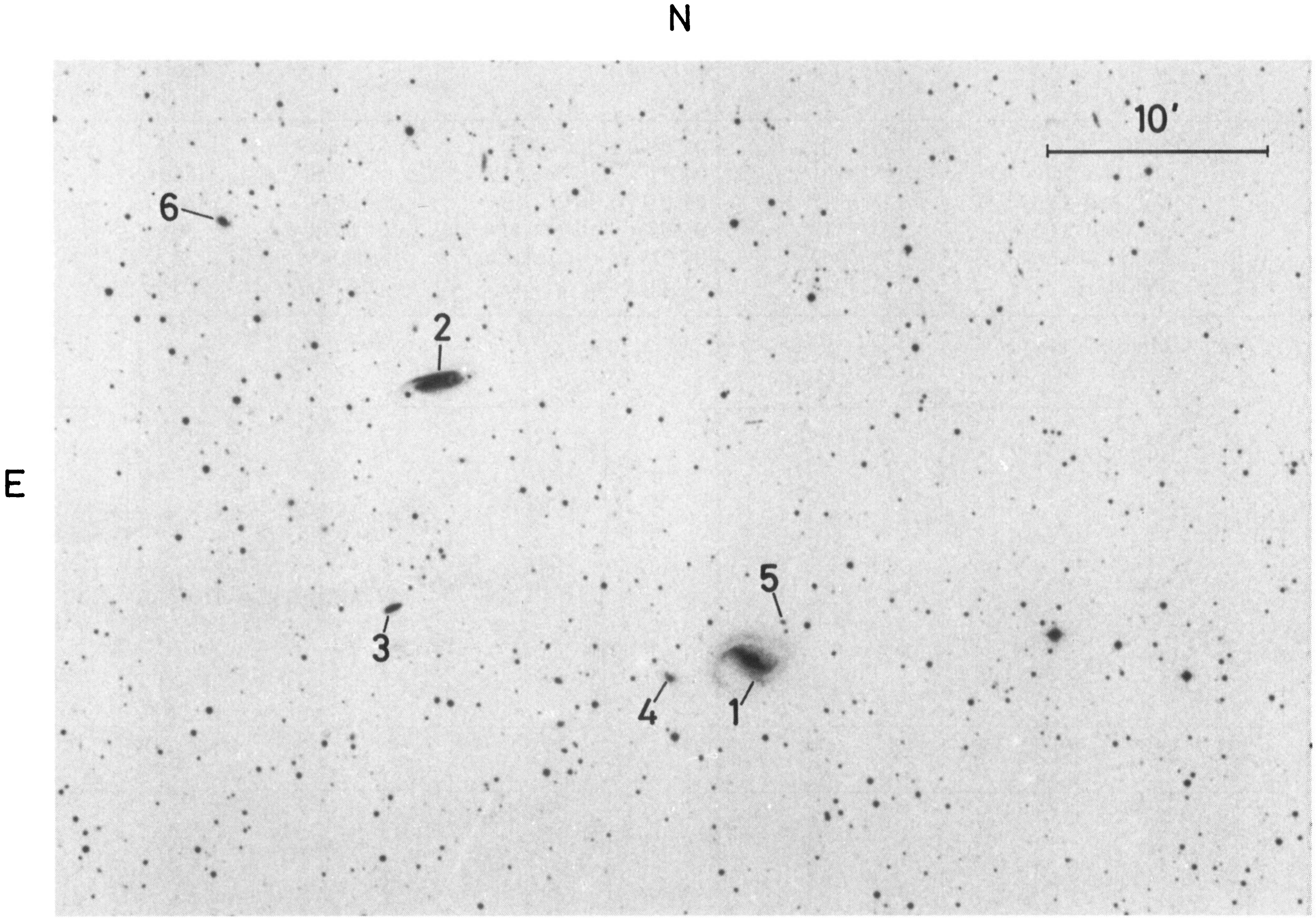


Fig. 3. The NGC 4593 group on the POSS print. The detected members as listed in Table 3 are identified by their numbers

This observation reflects a decrease of the velocity dispersion outwards as is expected if the line widths are caused, e.g. by rotation of the emitting gas around the center or by wind-driven mass loss from the central condensation.

The observed ratio of the $H\beta/H\alpha$ line widths strongly support the model for the BLR by Collin-Souffrin et al. (1979, 1981) and Clavel et al. (1983). From this model this ratio is predicted to be $\sim 2/3$ which is in perfect agreement with our observations. The apparent discrepancy between theory and observation which has been strongly stressed in the paper by Clavel et al. (1983) is obviously based on the erroneous assumption that the widths of $H\alpha$ and $H\beta$ are equal in the spectrum of NGC 4593 (Bergeron et al., 1982). This contradiction is resolved by our present and MacAlpine's (1979) measurements of the width ratio for $H\alpha/H\beta \sim 0.64$.

It is worth mentioning that occasionally drastic changes in the profile of the permitted lines may occur in NGC 4593. In epoch 1 and 2 of our observation we see roughly the same profile of $H\beta$ as MacAlpine did in 1979. This almost symmetrical profile presumably represents the normal state of $H\beta$ emission. An $H\beta$ profile with a strongly enhanced blue shoulder has been reported by Peterson et al. (1982) for Jan. 10, 1981. It might be conjectured that a similar feature noticed in the C IV 1550 line on May 7, 1981 by Clavel (1983) may be of the same origin, possibly due to an outburst of the continuum source.

4. The NGC 4593 group of galaxies

NGC 4593 is located in the direction of the Virgo II (V) cloud ($v \sim 1000$ km s^{-1}) and has originally been considered to be a possible member of that group (de Vaucouleurs, 1975). This presumption has been abandoned later-on. NGC 4593 does not occur, e.g., in the listings of nearby groups of galaxies by Huchra and Geller (1982). Some of the galaxies in the field of NGC 4593 belong to the Coma supercluster which is much farther away ($v \sim 7000$ km s^{-1}). A few of these objects are listed in Corwin and Emerson (1982). An objective prism investigation of the region has been attempted by Cooke et al. (1977) which is, however, not suitable to establish the group membership of NGC 4593.

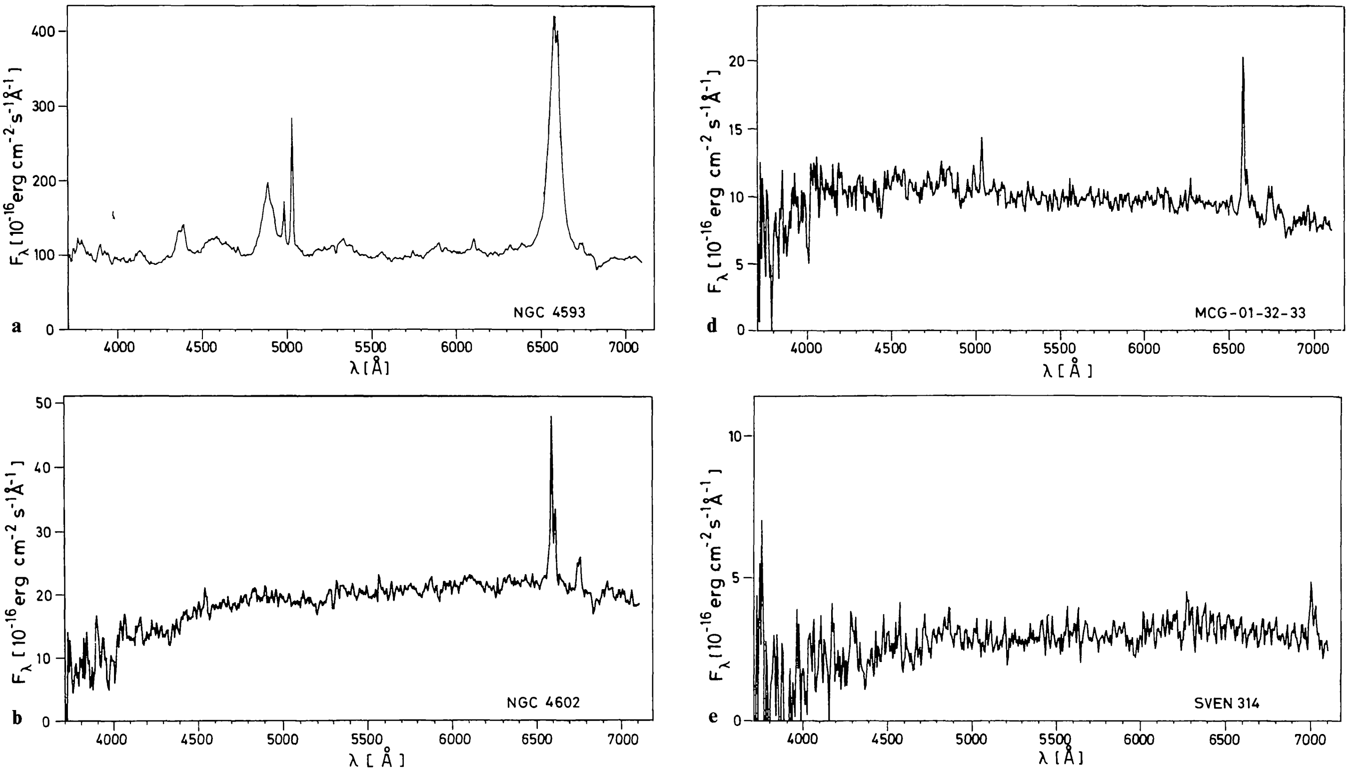
In Fig. 3 we show a section of the POSS print containing NGC 4593. We have taken IDS spectra of 9 other galaxies in this area. Of these, 5 galaxies are found to have redshifts very close to NGC 4593. These galaxies are listed together with their names and coordinates in Table 3. The spectra of the active members are shown in Fig. 4.

The remaining galaxies have redshifts consistent with those found in the Coma supercluster. With the exception of SVEN 328 all galaxies of the group show emission lines in their spectra. SVEN 328 is lying at the outskirts of the group judging from its relatively large angular distance and its redshift deviation from the mean redshift of the group. In the following a brief description is given of the individual members:

Table 3. The NGC 4593 galaxy group

No.	Name	α (1950)	δ (1950)	m_v	z	Projected distance[a] to NGC 4593 [kpc]
1	NGC 4593	$12^h37^m01^s$	$-05°04'$	12	0.0082	–
2	NGC 4602	$12^h38^m01^s$	$-04°52'$	12.5	0.0088	185
3	MCG-01-32-37	$12^h38^m11^s$	$-05°01'$	13.7	0.0079	160
4	MCG-01-32-33	$12^h37^m17^s$	$-05°05'$	14.6	0.0078	36
5	SVEN 314	$12^h36^m59^s$	$-05°02'$	15.4	0.0082	22
6	SVEN 328	$12^h38^m41^s$	$-04°44'$	13.8	0.0100	303

[a] $H_0 = 75$ km/s/Mpc



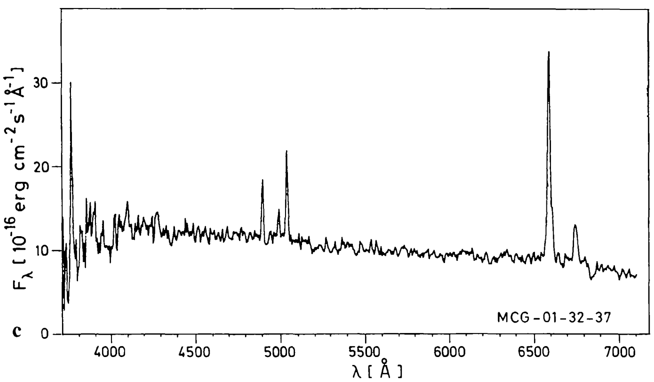


Fig. 4a–e. The spectra between 3700 and 7100 Å of the active group members **a** NGC 4593 (No. 1), **b** NGC 4602 (No. 2), **c** MCG-01-32-37 (No. 3), **d** MCG-01-32-33 (No. 4), **e** SVEN 314 (No. 5)

NGC 4602

This is the second brightest galaxy of the group after NGC 4593. The morphological type is SXbc. It has a total mass of 7 10^{11} $M_\odot$ and an H I-mass of 1.7 10^9 $M_\odot$ (Fisher and Tully, 1981). The continuum is dominated by the stellar component of the galaxy and shows many prominent absorption lines. The ratio of Hα to Hβ emission is ~19. This steep Balmer decrement as compared to the predicted value of ~3.5 of case *B* recombination theory suggests the presence of much dust. The Hα complex shows marginal evidence for a broad component with FWZI ~10,000 km s^{-1} (Fig. 5a). From a line synthetic analysis the

Table 4. Spectral properties of three active group members

Line	NGC 4602		MCG-01-32-37		MCG-01-32-33	
	I_λ [10^{-15} erg cm^{-2}s^{-1}Å^{-1}]	$I/I_{H\beta}$	I_λ [10^{-15} erg cm^{-2}s^{-1}Å^{-1}]	$I/I_{H\beta}$	I_λ [10^{-15} erg cm^{-2}s^{-1}Å^{-1}]	$I/I_{H\beta}$
[O II] 3727			29.81	2.44		
Hγ 4340			2.30	0.19		
[O III] 4363					1.70:	0.44:
Hβ 4861	3.83	1.0	12.19	1.0	3.85	1.0
[O III] 4959			5.42	0.44	3.09	0.80
[O III] 5007			15.85	1.30	6.63	1.72
[N II] 6548	1.74	0.46	0.95	0.08	1.08	0.28
Hα 6563	73.86	19.27	53.52	3.24	17.43	4.52
[N II] 6584	12.54	3.27	4.74	2.87	4.17	1.08
[S II] 6717	7.14	1.86	5.42	3.28	2.70	0.70
[S II] 6736	13.07	3.41	6.23	3.77	2.85	0.74
Cont. spectral index (4000–6800 Å)	$\alpha=2.82$		$\alpha=1.16$		$\alpha=1.86$	

Estimated relative errors are ~20% for the strong lines and up to ~50% for the weak lines

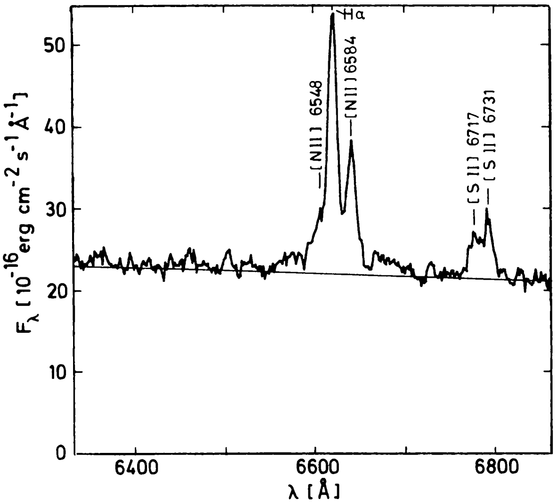


Fig. 5a. The spectral region around Hα for NGC 4602 (No. 2)

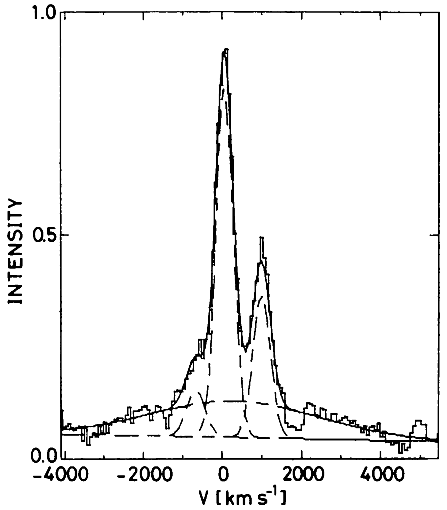


Fig. 5b. The decomposition of the measured Hα+[N II] line complex (binned representation) into a narrow and broad Hα component and the [N II] lines using a line synthetic analysis. The fitted composite curve (smooth solid line) is the sum of the four individual Gauss profiles (dashed curves)

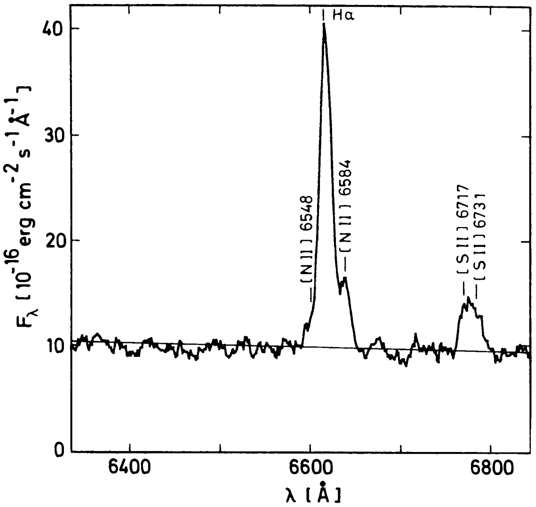


Fig. 5c. The spectral region around Hα for MCG-01-32-37 (No. 3)

different components of the measured Hα+[N II] complex (binned representation) and their superposition are presented in Fig. 5b. The reality of such a component in NGC 4602 is supported by the comparison with the spectrum of MCG-01-32-37 which was obtained under exactly the same conditions during the same night and does not show this feature (cf. Fig. 5c). Therefore, tentatively, NGC 4602 might be classified as a Sy 1.9 galaxy. Regarding its strong Balmer decrement and its strong stellar component NGC 4602 is similar to the Seyfert galaxies NGC 7213 (Phillips, 1979) and NGC 4235 (Abell et al., 1978).

MCG-01-32-37 (No. 3) and MCG-01-32-33 (No. 4)

These are relatively compact members of the group and show very blue (starburst) continua. The first (No. 3) has an Hα/Hβ decrement 3.2 which corresponds to case *B* recombination and implies the absence of internal dust. Considering the continuum energy distribution, the weakness of the absorption lines and the greater widths of the Balmer lines, object No. 3 appears more active than No. 4. In the latter galaxy the measured Balmer decrement is 4.5, probably due to the presence of some dust.

SVEN 314 (No. 5)

This dwarf galaxy is only 22 kpc away from NGC 4593 and thereby that member of the group which is closest to it. The continuum spectrum as seen in Fig. 4 is fairly noisy; its mean spectral index in the range 4000–6800 Å is 2.7. Only a narrow [O II] λ 3727 emission line is visible.

SVEN 328 (No. 6)

This late type galaxy is with a distance of 303 kpc the member farthest away from NGC 4593. It shows a pure absorption line spectrum.

5. Discussion

5.1. The NGC 4593 group represents a striking counter example to the hypothesis that Seyfert galaxies are isolated (van den Bergh, 1975). Our preliminary search in the NGC 4593 field already revealed six group members. There may be many more of them. If this result could be generalized it would imply that many Seyfert galaxies do occur in similar groups. Huchra et al. (1982) already suggested "that the mythology that Seyfert galaxies occur only rarely in clusters or groups must definitely be treated with a grain of salt". Support for this also comes from Dahari (1984) wo recently collected evidence that Seyfert galaxies are more often to be found in groups than normal galaxies. Group membership might therefore be one of the factors which favor nuclear activity in galaxies but can alone neither be necessary nor sufficient in this respect. Triggering of nonthermal and/or starburst activity in groups might be effected by tidally released gas or in encounters with companion galaxies and by the resulting cooling flows (Fabian et al., 1980; Sarazin and O'Connell, 1983) or – if there is no external gas around – by tidal perturbations of the gas in the galaxy itself which then is funnelled into the nucleus. The latter process is most effective if a central bar is present (Simkin et al., 1980; Norman and Silk, 1983) as is the case in many Seyfert galaxies (Fricke et al., 1984), including NGC 4593.

The association of QSO's with nearby galaxies or compact objects has been demonstrated, in particular for low redshift systems, by Stockton (1980) and Hutchings and Campbell (1983). Consequently, the latter authors interpret the QSO phenomenon as resulting from interactions between galaxies in clusters or smaller groups. If similarly the association of Seyfert galaxies with groups could be substantiated, this would strengthen the idea that QSO's and Seyfert galaxies are physically related phenomena.

5.2. A very intriguing property of the NGC 4593 group is that 80% of the detected group members show moderately to highly excited spectra. This evidence seems to weaken the conjecture by Dressler and Gunn (1983) that high redshift groups or clusters show a systematically higher fraction of excited galaxies than present-epoch groups or clusters. The Dressler-Gunn argument is based on a survey of the 3C295 cluster of galaxies. However, in this cluster, the relative content of blue (star burst and Seyfert) galaxies is much less (20% only) than in the NGC 4593 group.

5.3. The origin of the activity in the nuclei of the group members is certainly one of the most important questions in connection with the NGC 4593 group. As possibilities onemight envisage mutual tidal interaction between the group members or the excitation of the neighbours by the dominating Seyfert galaxy. Such an excitation could perhaps be achieved after an outburst of NGC 4593 which generated a shock wave triggering strong star formation bursts and/or nuclear activity in the companion galaxies. The present material does not warrant the construction of detailed physical models for these processes.

For both possibilities mentioned above it is plausible that SVEN 328 which is farthest away from NGC 4593 shows the least signs of activity.

Acknowledgements. We are grateful to the Deutsche Forschungsgemeinschaft (DFG) for partial support of this work under grants Fr 325/15–2 and Fr 325/21–1.

References

Abell, G.O., Eastmond, T.S., Jenner, D.C.: 1978, *Astrophys. J.* **221**, L1
Bergeron, J., Pelat, D., Boksenberg, A.: 1982 (in preparation)
Clavel, J.: 1983, *Monthly Notices Roy. Astron. Soc.* **204**, 189
Clavel, J., Joly, M., Collin-Souffrin, S., Bergeron, J., Penston, M.V.: 1983, *Monthly Notices Roy. Astron. Soc.* **202**, 85
Collin-Souffrin, S., Joly, M., Heidmann, N., Dumont, S.: 1979, *Astron. Astrophys.* **72**, 293
Collin-Souffrin, S., Delache, P., Dumont, S., Frisch, H.: 1981, *Astron. Astrophys.* **104**, 264
Cooke, J.A., Emerson, D., Nandy, K., Reddish, V.C., Smith, M.G.: 1977, *Monthly Notices Roy. Astron. Soc.* **178**, 687
Corwin, H.G., Emerson, J.D.: 1982, *Monthly Notices Roy. Astron. Soc.* **200**, 621
Dahari, O.: 1984, *Astron. J.* **89**, 966
de Vaucouleurs, G.: 1975, in *Galaxies and the Universe*, eds. A. Sandage, M. Sandage, J. Kristian, Chicago, University of Chicago Press, p. 557
Dower, R.G., Griffiths, R.E., Bradt, H.V., Doxsey, R.E., Johnston, M.D.: 1980, *Astrophys. J.* **235**, 355
Dressler, A., Gunn, J.E.: 1983, *Astrophys. J.* **270**, 7
Fabian, A.C., Nulsen, P.E.J., Canizares, C.R.: 1982, *Monthly Notices Roy. Astron. Soc.* **201**, 933
Fisher, J.R., Tully, R.B.: 1981, *Astron. Astrophys. Suppl. Ser.* **47**, 139
Fricke, K.J., Kollatschny, W., Colina, L.: 1984 (in preparation)
Grandi, S.A.: 1978, *Astrophys. J.* **221**, 501
Huchra, J.P., Geller, M.J.: 1982, *Astrophys. J.* **257**, 423
Huchra, J.P., Wyatt, W.F., Davis, M.: 1982, *Astron. J.* **87**, 1628
Hutchings, J.B., Campbell, B.: 1983, *Nature* **303**, 584
Kollatschny, W., Biermann, P., Fricke, K.J., Huchtmeier, W., Witzel, A.: 1983, *Astron. Astrophys.* **119**, 80
MacAlpine, G.M., Williams, G.A., Lewis, D.W.: 1979, *Publ. Astron. Soc. Pacific* **91**, 746
Norman, C., Silk, J.: 1983, *Astrophys. J.* **266**, 502
Oke, J.B.: 1974, *Astrophys. J. Suppl.* **27**, 21
Osterbrock, D.E.: 1981, *Astrophys. J.* **246**, 696
Peterson, B.M., Foltz, C.B., Byard, P.L., Wagner, R.M.: 1982, *Astrophys. J. Suppl.* **49**, 469
Phillips, M.M.: 1979, *Astrophys. J.* **227**, L121
Sarazin, C.L., O'Connell, R.W.: 1983, *Astrophys. J.* **268**, 552
Simkin, S.M., Su, H.J., Schwarz, M.P.: 1980, *Astrophys. J.* **237**, 404
Stockton, A.: 1980, in *Objects of High Redshift*, IAU *Symp* **92**, eds. G.O. Abell, P.J.E. Peebles, p. 89
van den Bergh, S.: 1975, *Astrophys. J.* **198**, L1