Mon. Not. R. astr. Soc. (1976) **176**, *Short Communication*, 61P–66P.

NGC 4151 AND MARKARIAN 6—TWO INTERMEDIATE-TYPE SEYFERT GALAXIES

D. E. Osterbrock and A. T. Koski

Lick Observatory, Board of Studies in Astronomy and Astrophysics, University of California, Santa Cruz, California 95064, USA

(Received 1976 April 26)

SUMMARY

Scans are presented showing there is a continuous transition between Seyfert 1 and Seyfert 2 galaxies, and that NGC 4151 and Markarian 6, with Balmer-line profiles consisting of sharp components superimposed on broad weak components, are intermediate objects in this classification scheme. Relative emission-line intensity measurements of NGC 4151 from these scans are presented and compared with other recent published results. In confirmation of the conclusion of Boksenberg *et al.*, the broad line profiles of H and He do not agree with those predicted from the model of Ptak & Stoner based on charge exchange with suprathermal ions in a gas at rest.

A fruitful idea in the observational study of Seyfert galaxies is their classification into two types on the basis of their optical spectra. This classification scheme was set up and described in detail by Khachikian & Weedman (1971a), and is summarized by Weedman (1973) and Khachikian & Weedman (1974). The primary division between the two types is on the basis of the widths of the emission lines; the Seyfert 1 galaxies have broad Balmer lines and narrow forbidden lines, while the Seyfert 2 galaxies have relatively narrow Balmer lines and forbidden lines of the same width. (In both types of galaxies the emission lines are considerably wider than in other, non-Seyfert galaxies with emission lines; among the Seyfert galaxies a 'narrow' line has a width typically in the range 400–1000 km s^{-1}, while a 'broad' line has a width of several thousand km s^{-1}.) A secondary classification criterion is that the forbidden lines tend to be relatively stronger in Seyfert 2 galaxies, and that in particular the intensity ratios [O III]/Hβ and [N II]/Hα are larger in Seyfert 2 galaxies than in Seyfert 1 galaxies (Khachikian & Weedman 1974; Adams & Weedman 1975).

In our spectrophotometric survey of Seyfert galaxies at Lick Observatory, carried out with the image-tube image-dissector system (Robinson & Wampler 1972) in the Cassegrain spectrograph (Miller, Robinson & Wampler 1976) on the 120-in (3-m) telescope, most of the objects observed clearly fit into one or other of these two types. Two typical examples are shown in Fig. 1, Markarian 509, a Seyfert 1 galaxy, and Markarian 176, a Seyfert 2. However a certain number of galaxies have spectra intermediate between the Seyfert 1 and Seyfert 2 groups. Two good examples, NGC 4151 and Markarian 6 = IC 450, are shown in Fig. 1. Though their spectra appear quite similar, NGC 4151 is classified as Seyfert 1 by Khachikian & Weedman (1974), while Mk 6 is classified as Seyfert 2, with

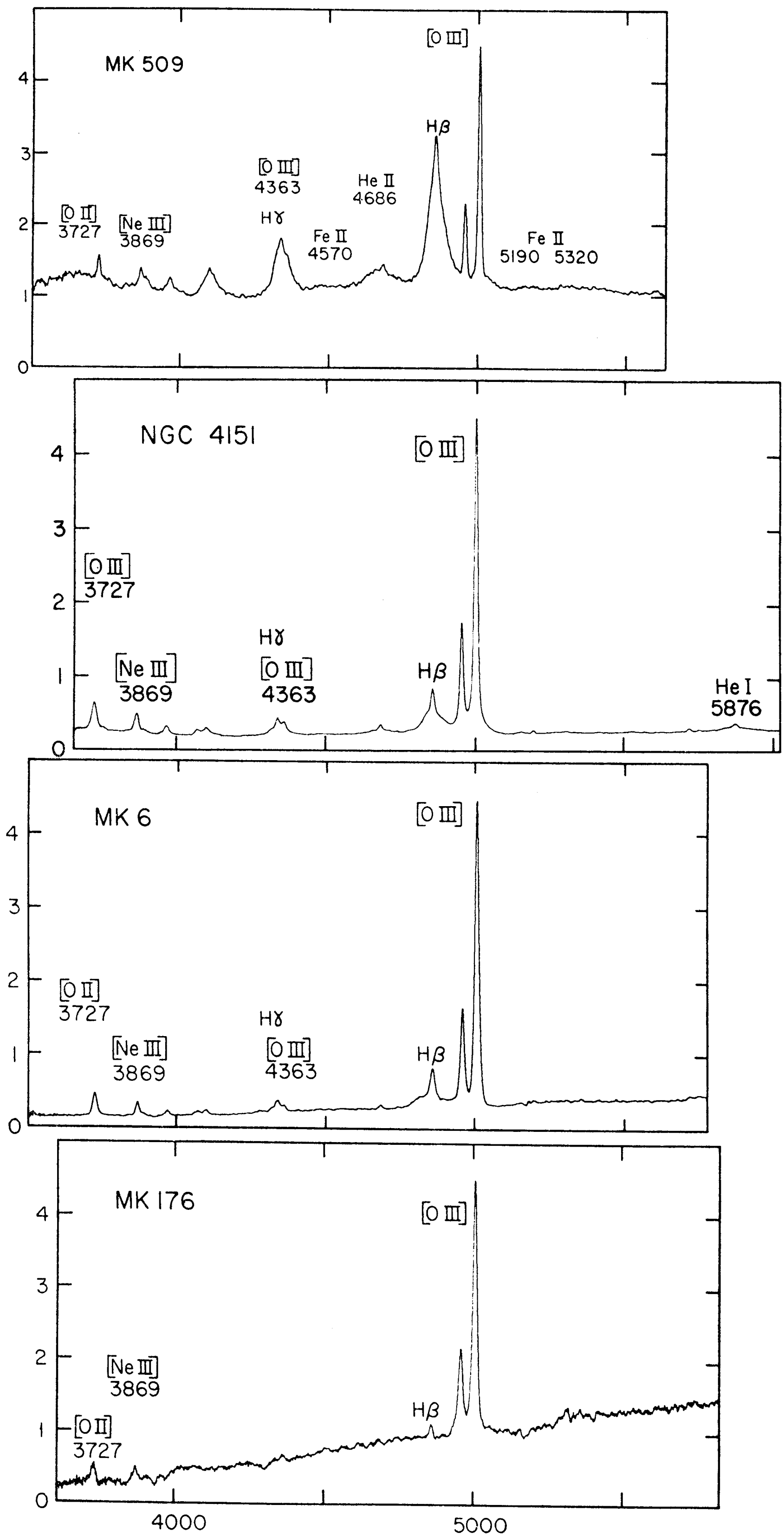

FIG. 1. *Spectra of four Seyfert galaxies, from Mk 509, typical Seyfert 1, with broad Balmer emission lines, to Mk 176, typical Seyfert 2, with narrow Balmer lines. NGC 4151 and Mk 6 have Balmer-line profiles with both narrow and broad components and are intermediate between these two classes.*

the remark that the Balmer emission lines contain an unusual blueshifted component, but the primary component has the same width as the forbidden lines. In both these Seyfert galaxies the best description of the Balmer-line profile as seen on our scans is that it has a sharp component with the same redshift and width as the forbidden lines, superimposed on a much broader component. The profiles of these galaxies have been described previously, for instance for NGC 4151 by Seyfert (1943) and Oke & Sargent (1968), and for Mk 6 by Khachikian & Weedman (1971b) and Adams (1972), but they are most clearly seen on spectrophotometric scans such as those of Fig. 1. In fact the broad component of the H I profiles in Mk 6 was very recently noticed on lower-resolution scans by Neugebauer *et al.* (1976), who therefore reclassified this galaxy as Seyfert 1.

It seems to us that the best way to describe the emission-line spectra of Fig. 1 is as various linear combinations of two basic components, one consisting of the broad Balmer (and weaker He I and He II) emission lines, the other of the sharp Balmer and forbidden lines with Hβ/[O III] λ4959 $\approx$ 0·1–0·2. Galaxies in which the broad Balmer-line component is relatively strong are classified as Seyfert 1, while galaxies in which it is invisible are classified as Seyfert 2. NGC 4151 and Mk 6, with relatively weak but still visible Balmer-line components, are near the middle of the continuum of objects between these two extremes. Other Seyfert galaxies with more or less similar, intermediate-type spectra, are NGC 5548 and Markarian 372.

Physically, different Seyfert galaxies must have different relative amounts of the material and physical conditions which emit these two components. The idea, now generally accepted, that the broad Balmer lines are emitted in regions of relatively high density ($N_e \gtrsim 10^8$ cm^{-3}) was first proposed by Souffrin (1969) in the context of NGC 4151. The extreme Seyfert 1 galaxies must contain a relatively high proportion of excited gas under these dense conditions, while the extreme Seyfert 2 galaxies apparently contain little if any. The narrow lines arise in a lower density region, most likely excited by photoionization, and evidently a wide variety of combinations of these two types of regions can occur in nature.

NGC 4151 is a relatively bright object in which many faint emission lines can be detected and measured, and it has been observed by many authors, most recently by Boksenberg *et al.* (1975). To give an idea of the accuracy of relative line-intensity measurements that can be attained in practice, we list in Table I our own measurements and the results of these authors, made completely independently, both expressed as ratios to the sharp component of Hβ. Our observational data consist of two 16-min scans of NGC 4151, one in the blue region, shown in Fig. 1, the other in the red. The methods of reduction and calibration procedures we used are described by Osterbrock, Koski & Phillips (1975). Errors in line-intensity measurements are due partly to errors in the calibration into energy units, partly to poor contrast with the continuum for weak lines, and partly due to the uncertainties in dividing up the observed spectrum, composed of many blends, into individual emission lines. This can be particularly seen in the table in the differences between the ratios of the strong [O III] $\lambda\lambda$4959, 5007 lines to Hβ. The observed narrow-line spectrum can be matched approximately by a photoionization model with an input power-law spectrum (MacAlpine 1971); more models of this type covering a wide range of possible input spectra and geometries would undoubtedly be helpful in understanding the narrow-line region.

TABLE I
Emission-line intensities in NGC 4151
(Hβ narrow = 1·00)

Wavelength	Ion	Intensity: This Paper	Intensity: Boksenberg *et al.*
3727	[O II]	2.41	1.47
3760	[Fe VII]	0.23	0.14
3869	[Ne III]	1.38	1.35
3889	H 8	0.15	0.21
3889	He I		
3967	[Ne III]	0.52	0.69
3970 n	H ε		
3970 b	H ε	0.57	
4071	[S II]	0.38	0.28
4102 n	H δ	0.23	0.14
4102 b	H δ	0.92	0.60
4102 Σ	H δ	1.15	0.74
4340 n	H γ	0.42	0.38
4340 b	H γ	1.85	2.00
4340 Σ	H γ	2.27	2.38
4363	[O III]	0.38	0.34
4471 n	He I	0.05:	0.07
4658	[Fe III]	0.02	0.07
4686 n	He II	0.22	0.15
4686 b	He II	1.03	0.50
4686 Σ	He II	1.25	0.65
4711	[Ar IV]	0.02	0.04
4740	[Ar IV]	0.03	0.06
4861 n	H β	1.00	1.00
4861 b	H β	6.34	4.88
4861 Σ	H β	7.34	5.88
4922 b	He I	0.06	
4959	[O III]	4.57	6.47
5007	[O III]	13.63	15.29
5016 b	He I	0.15	
5159	[Fe VII]	0.09	0.05:
5199	[N I]	0.10	0.09
5278	[Fe VII]	0.04	0.05:
5309	[Ca V]	0.06	0.08:
5412 n	He II	0.02:	0.05:
5577	[O I]	0.01	
5721	[Fe VII]	0.13	0.11
5755	[N II]	0.04	0.07
5876 n	He I	0.22	0.15
5876 b	He I	0.93	1.65
5876 Σ	He I	1.15	1.80
6087	[Fe VII]	0.15	0.22
6300	[O I]	0.75	1.06
6312	[S III]	0.12	
6364	[O I]	0.24	0.38
6374	[Fe X]	0.08	
6548	[N II]	0.73	0.76
6563 n	H α	3.64	5.29
6563 b	H α	23.10	15.88
6563 Σ	H α	26.74	21.17
6583	[N II]	2.19	2.23
6601	[Fe VII]	0.31:	
6678 n	He I	0.07	
6678 b	He I	0.47	
6678 Σ	He I	0.54	
6716	[S II]	0.95	0.82
6731	[S II]	1.11	1.00
7006	[Ar V]	0.02	0.07
7065 n	He I	0.04	0.04
7065 b	He I	0.52	>0.71
7065 Σ	He I	0.56	>0.75
7136	[Ar III]	0.26	0.25
7320	[O II]	0.21	0.24
7330	[O II]	0.14	
7751	[Ar III]	0.05	0.05:

Notes:
n = narrow component. b = broad component. Σ = total broad + narrow components.

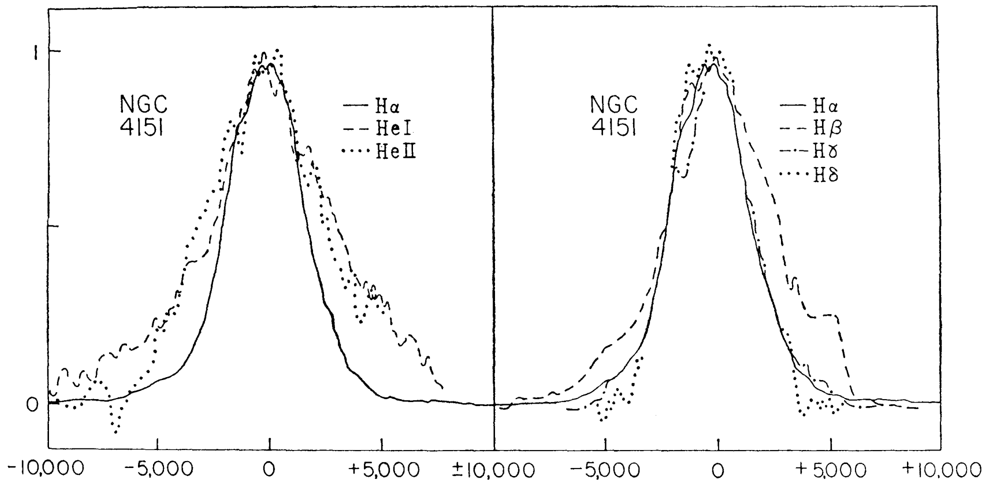

FIG. 2. *Broad components of emission lines in NGC* 4151 *plotted to the same velocity scale and normalized to unit peak intensity. Left, Balmer lines Hα to Hδ; right, Hα, He* I λ5876 *and He* II λ4686.

Line profiles of the broad H I, He I and He II lines in NGC 4151, measured from our scans, are displayed in Fig. 2. Note each of the profiles shown is for the broad component alone, with the narrow component as well as nearby blended lines such as [O III] λλ4959, 5007 and [N I] λλ6548, 6583 removed. This of course introduces a certain amount of arbitrariness into the process. It can be seen in Fig. 2 that Hβ appears to be asymmetric, with an extension to the red, in comparison with the other H I profiles. This is a common phenomenon in Seyfert 1 galaxies, which may possibly be connected with underlying Fe II λ4924 emission. Except for this the H I profiles all appear similar to the accuracy of the data. In contrast He I λ5876 is definitely wider, but more nearly by a factor of 1·5 than 2 as stated by Boksenberg *et al.* (1975). The broad He II λ4686 has nearly the same width as He I λ5876. These observed profiles rule out the model of Ptak & Stoner (1973) involving charge exchange with suprathermal ions for NGC 4151, as Boksenberg *et al.* (1975) have stated, because according to this picture the He I λ5876 should be narrower than Hα, while He II λ4686 should have a slightly larger width, all expressed in velocity units (Mergenthaler 1975). Quantitatively, for instance for a model with zero absorption and a half-ionized ambient medium the full widths at half maximum are Hα, 5900 km s^{-1}; λ5876, 3900 km s^{-1}; and λ4686, 6500 km s^{-1}; while the observed widths are 3900 km s^{-1}, 5500 km s^{-1}, and 5900 km s^{-1} respectively. It seems more likely that the broad profiles are due to mass motions of some sort, that the He I and He II profiles originate at least partly in a region with a larger velocity range than the region in which the H I emission arises.

ACKNOWLEDGMENTS

We are very grateful to R. Costero and M. M. Phillips for their assistance in the observations and reduction of the data, and to the National Science Foundation for partial support of this research under grant MPS 73-08981 A02.

Contribution from the Lick Observatory, No. 408.

REFERENCES

Adams, T., 1972. *Astrophys. J.*, **172**, L101.
Adams, T. F. & Weedman, D. W., 1975. *Astrophys. J.*, **199**, 19.

Boksenberg, A., Shortridge, K., Allen, D. A., Fosbury, R. A. E., Penston, M. V. & Savage, A., 1975. *Mon. Not. R. astr. Soc.*, **173**, 381.
Khachikian, E. Y. & Weedman, D. W., 1971a. *Astrofiz.*, **7**, 389.
Khachikian, E. Y. & Weedman, D. W., 1971b. *Astrophys. J.*, **164**, L109.
Khachikian, E. Y. & Weedman, D. W., 1974. *Astrophys. J.*, **192**, 581.
MacAlpine, G. M., 1971. *PhD. thesis* unpublished, University of Wisconsin.
Mergenthaler, J. L., 1975. *Astrophys. J.*, **199**, 770.
Miller, J. S., Robinson, L. B. & Wampler, E. J., 1976. *Advances in electronics and electron physics*, Academic Press, New York.
Neugebauer, G., Becklin, E. E., Oke, J. B. & Searle, L., 1976. *Astrophys J.*, **205**, 29.
Oke, J. B. & Sargent, W. L. W., 1968. *Astrophys. J.*, **151**, 807.
Osterbrock, D. E., Koski, A. T. & Phillips, M. M., 1975. *Astrophys. J. Lett.*, **197**, L41.
Ptak, R. & Stoner, R., 1973. *Astrophys. J.*, **185**, 121.
Robinson, L. B. & Wampler, E. J., 1972. *Publ. astr. Soc. Pacific*, **84**, 161.
Seyfert, C. K., 1943. *Astrophys. J.*, **97**, 28.
Souffrin, S., 1969. *Astr. Astrophys.*, **1**, 305.
Weedman, D. W., 1973. *Astrophys. J.*, **183**, 29.