Mon. Not. R. astr. Soc. (1976) **177**, 91–97.

THE DWARF EMISSION GALAXY He2–10

David A. Allen

Anglo-Australian Observatory, PO Box 296, Epping, New South Wales 2121, Australia

Alan E. Wright and W. Miller Goss

CSIRO Division of Radiophysics, PO Box 76, Epping, New South Wales 2121, Australia

(Received 1976 April 21)

SUMMARY

Optical, infrared and radio observations of He2–10 are presented. Originally classified as a planetary nebula, He2–10 is shown to be a dwarf emission galaxy with a non-thermal radio continuum. Features resembling Wolf–Rayet bands are present in the spectrum. The galaxy is particularly rich in neutral hydrogen and radiates most of its energy in the infrared.

1. INTRODUCTION

He2–10 was discovered by Henize (1967) during his Hα survey of the southern galactic plane. Finding strong Hα and no continuum, Henize classified it as a planetary nebula, and its non-stellar appearance was demonstrated by Westerlund & Henize (1967) from direct plates taken with the Mount Stromlo 74-in. telescope. More recently Sanduleak & Stephenson (1972), also from objective prism plates, drew attention to the strong [O II] line in its spectrum and described it as a very low-excitation nebula. The galactic coordinates are $l^{II} = 248°{\cdot}6$, $b^{II} = 8°{\cdot}6$. He2–10 was included in the infrared survey of planetary nebulae by Cohen & Barlow (1974) and was detected by them at wavelengths of 10 and 18 μm. V is about 13 mag. Our attention was drawn to this object for the following reasons: (i) in our possession is a third-hand reprint of Henize (1967) containing, alongside entry no. 10, the anonymous marginalia '$v = 920$ km s^{-1} Galaxy'. (ii) He2–10 is included in the *Morphological catalogue of galaxies IV* (Vorontsov-Velyaminov & Arkhipova 1968) where it is described as an elliptical galaxy and given the designation −4/21/5. The 1950 coordinates are RA $08^{h}\,34^{m}\,07^{s}{\cdot}1$, Dec. $-26°\,14'\,04''$ (Sanduleak & Stephenson 1972).

2. THE NEW DATA

(i) *Optical*

Spectra of the central region taken with an image-dissector scanner on the Anglo–Australian telescope show a strong continuum and confirm the high radial velocity: we find $v \simeq 870$ km s^{-1} for the emission lines. Correction for galactic rotation and our motion in the Local Group (following Gouguenheim 1969) reduces this to 750 km s^{-1}, rather small for a reliable application of Hubble's law, but suggestive of a distance of about 14 Mpc and thus of an absolute magnitude, $M_V \simeq -18$. This is near the lower end of the luminosity function for galaxies and indicates that He2–10 is a dwarf system.

The emission-line spectrum is of moderate excitation, [O II] being strong and [Ar III] and [O III] fairly weak. The ratio Hα:Hβ is high: if a normal radiative Balmer decrement were assumed, this would correspond to reddening of $A_V \simeq$ 2·3 mag. Hβ:Hγ is, however, more nearly normal and indicates no significant reddening. The standard galactic reddening law would imply $A_V \simeq$ 1 mag at the latitude of He2–10. The continuum has $B-V$ = 0·4 and $V-R$ = 0·7. Since the Mg I *b*-band and Na I *D*-lines appear in absorption, each with equivalent widths of about 1 Å, there must be a significant contribution to the observed continuum from late-type stars. It is therefore unlikely that A_V exceeds 1 mag. Instead, the Balmer decrement probably does not conform to case B.

TABLE I

Relative intensities of the emission lines in He2–10

Wavelength (Å)	Ion	Intensity (Hβ = 100)	
3727	[O II]	150	
3869	[Ne III]	Weak	Confused by structure in continuum
3970	Hϵ (+[Ne III])	1 :	
4102	Hδ	10	
4340	Hγ	35	
4363	[O III]	3	
4471	He I	4	Wolf–Rayet bands
4511–35	N III	3	Wolf–Rayet bands
4634–41	N III	6	Wolf–Rayet bands
4686	He II	4	Wolf–Rayet bands
4861	Hβ	100	
4959	[O III]	50	
5007	[O III]	150	
5199	[N I]	3	
5411	He II	3 :	Wolf–Rayet band
5876	He I	12	
6300	[O I]	6	
6548	[N II]	(60)	Blended with Hα
6563	Hα	620	
6584	[N II]	180	
6717	[S II]	32	
6731	[S II]	30	
7065	He I	8	
7135	[Ar III]	12	
7319–31	[O II]	18	

Table I lists the line intensities. These may be manipulated to deduce the physical conditions. The [S II] doublet ratio and the [O III] (5007+4959):4363 ratio imply N_e = 2000 ± 500 cm^{-3} and T_e = 14 000 ± 2000 K respectively. Confirmation of these values is provided by the [O II] 3727:7325 ratio if A_V is in the range 0–0·5 mag. The data are marginally adequate for deriving abundances, and suggest that He is underabundant by a small amount and N and O by factors approaching 10.

Fig. 1 reproduces our spectrum in the blue; two unusual features are present. First the higher Balmer lines appear in absorption, second there are broad bands corresponding to N III, N IV and He II emission. The latter are strongly suggestive

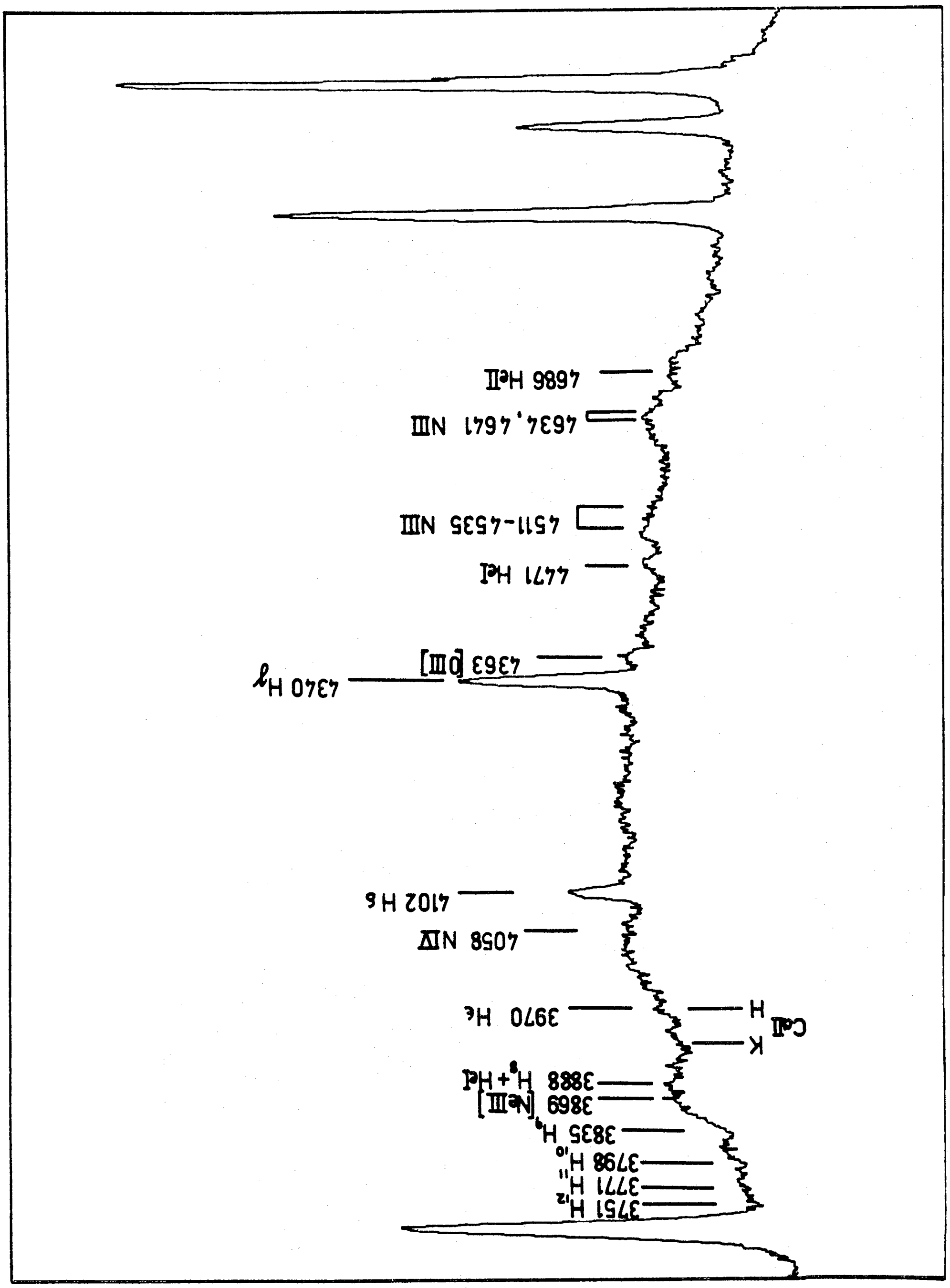

FIG. 1. *The spectrum of He2–10 between* [O II] λ 3727 *and* [O III] λ 5007. *The wavelengths of the important lines are marked.*

of the bands seen in WN spectra. If these were produced in the ionized interstellar gas of He2–10, we should expect a much higher excitation forbidden-line spectrum than is observed. The H and K lines of Ca II and the *G* band are not present in the velocity frame of the galaxy (interstellar absorption may be present), so the natural conclusion is that the stellar population of He2–10 includes a large proportion of O, B, A and Wolf–Rayet stars. 10^{3-4} WN stars would be needed to produce the observed bands. He2–10 appears to be the first example of an extragalactic object in which there is evidence for a large population of Wolf–Rayet stars.

A direct photograph of He2–10, taken in the blue by K. P. Tritton with the AAT, is reproduced in Plate I. The object is irregular in outline, and is double or possibly crossed by a dust lane. The angular dimensions on the plate are $30'' \times 20''$, giving linear dimensions of $2{\cdot}0 \times 1{\cdot}4$ kpc.

(ii) *Radio and infrared*

Using the observed equivalent width of Hβ of 30 Å, $m_V \simeq 13$ and assuming $A_V \ngtr 1$ we predict the thermal radio flux density to be < 5 mJy at all radio frequencies in the absence of internal reddening.

A radio detection of He2–10 was first obtained by Purton (private communication) using the Algonquin Park 46-m radio telescope. The object was later observed in five sessions between 1974 November and 1975 August using the Parkes 64-m radio telescope at frequencies of 2·7, 5·0, 6·2 and 8·9 GHz. An unresolved point source ($\lesssim 2'$ diameter) was found coincident with the optical position of the object and with flux densities greater than those predicted for a thermal source. Table II lists all available radio continuum data: these indicate a non-thermal radio spectrum of the form $S_\nu \propto \nu^{-0{\cdot}6 \pm 0{\cdot}15}$.

Non-thermal radio continua are not known in other dwarf emission galaxies, although in many cases this might be because sufficiently sensitive searches have not been made. A galaxy very similar to He2–10 is II Zw 40 (Searle & Sargent 1972, and references therein); Jaffe (1972) was able to demonstrate a continuum at 1415 MHz in II Zw 40, but could readily explain this by the expected free–free emission alone.

Table III lists the infrared data measured in a 22-arcsec aperture with the 60-in. flux collector on Tenerife. Although a faint source and therefore measured with a rather low accuracy, it is apparent that He2–10 has normal colours for a galaxy

TABLE II

Radio continuum fluxes of He2–10

Date observed	Frequency (GHz)	Flux (mJy[1])
1975[2]	0·408	240 ± 80
1975 January 8	2·7	75 ± 35
1974 November 15	5·0	55 ± 10
1975 February 23	6·2	45 ± 10
1975 January 28, August 16	8·9	35 ± 8
1974[3]	10·6	40 ± 15

Notes

1. 1 mJy = 10^{-29} W m^{-2} Hz^{-1}.
2. Provided by A. G. Little with the Molonglo radio telescope.
3. C. R. Purton (private communication).

TABLE III

Magnitudes of He2–10

Waveband	Mag	Flux (mJy)	
V	13:	25:	
J	10.47 ± 0.12	100 ± 12	
H	9.80 ± 0.10	123 ± 11	
K	9.53 ± 0.09	100 ± 9	
10 μm	3.5 ± 0.2	1600 ± 300	Cohen & Barlow
18 μm	0.85 ± 0.3	4600 ± 1300	Cohen & Barlow

in the 1·2–2·2 μm region (*cf.* Glass 1973). The detection at 10 and 18 μm by Cohen & Barlow, also listed in Table III, therefore represents a dramatic rise in the energy distribution, corresponding to a colour temperature below 600 K. Infrared data on other dwarf emission galaxies are not available for comparison, but Neugebauer *et al.* (1976) found similar behaviour in the much more massive non-Seyfert Markarian galaxies.

H I observations of He2–10 were made with the Parkes 64-m telescope in 1975 September. The half-power beamwidth was 15 arcmin and the velocity resolution 16 km s^{-1}. We found a peak flux in the line of 110 mJy with a full width at half maximum of 160 ± 20 km s^{-1}. The heliocentric velocity of the line, 880 ± 20 km s^{-1}, leaves no doubt of its identification with the galaxy. For a distance of 14 Mpc, the mass of neutral hydrogen implied is $8 \times 10^8 M_\odot$. The distance-independent parameter mass of neutral hydrogen/visible luminosity (M_H/L) is 1·0 in solar units if we ignore the poorly-determined infrared luminosity; as noted above, the infrared luminosity is far from insignificant. For comparison, in II Zw 40 Chamaraux, Heidmann & Lauqué (1970) found $M_H = 2.3 \times 10^9 M_\odot$ and $M_H/L = 0.33$.

The velocity dispersion can be used to derive the indicative mass (M_I) for comparison with other objects, but a knowledge of the Holmberg diameter of He2–10 is needed. Bottinelli, Gouguenheim & Heidmann (1973) give a logarithmic relation between the Holmberg and Vorontsov-Velyaminov diameter. This is of doubtful validity for a compact object such as He2–10, but we will adopt the derived Holmberg diameter of 5 kpc in what follows. Because we cannot estimate the inclination we use $\sin i = 1$ as an upper limit.

Table IV compares the H I parameters of He2–10 with the mean values for dwarf galaxies (Balkowski *et al.* 1974), Zwicky compact galaxies (Lauqué 1973), Haro galaxies (Bottinelli *et al.* 1973) and Markarian galaxies (Bottinelli *et al.* 1973). The most outstanding feature of Table IV is the high projected surface

TABLE IV

HI properties of He 2–10 compared to average values for other compact galaxies

Type	Holmberg diameter (kpc)	Luminosity L ($10^9 L_\odot$)	Mass of H I M_H ($10^9 M_\odot$)	M_H/L	Indicative mass M_I ($10^9 M_\odot$)	M_H/M_I (%)	Surface density of H I (10^{-3} g cm^{-2})
He2–10	5	0·8:	0·82	1·0:	>4	<20	8·3
Dwarf	9·0	0·3	0·3	1·2	3·0	11	1·1
Zwicky	21	2·4	1·6	0·7	36	4	1·3
Haro	13	4·3	1·3	0·3	19	7	1·8
Markarian	15	3·0	1·1	0·4	28	4	1·3

density of H I, which is a distance-independent parameter and which will be underestimated if, as seems likely, the derived Holmberg diameter is too large. This surface density exceeds the highest previously known (Markarian 5).

3. DISCUSSION

About 5000 supernova remnants of the luminosity of those in the Large Magellanic Cloud (Westerlund & Mathewson 1966) would be required to account for the non-thermal continuum. So large a number is extremely unlikely to be present, and a high rate of formation of supernova remnants would be inconsistent with the low metal abundance of He2–10. The origin of the non-thermal continuum therefore remains a mystery. But its presence offers one source of ionization of the gas and, perhaps, of heating of the dust which produces the infrared excess. Since other dwarf emission galaxies do not have non-thermal continua, and since the visible continuum appears to be of stellar origin, we first seek, and find, an explanation of the ionization based on early-type stars.

Constraints are imposed by the luminosity, colour and spectral features of the stellar continuum of He2–10. The masses of neutral and ionized hydrogen are comparable, and ignoring internal reddening the required amount of hydrogen could be ionized by a population ranging from early O to cool stars. The WN stars would represent about 10 per cent of those capable of ionizing the gas. The mean density of neutral gas is $\sim 2\ \mathrm{cm}^{-3}$, whereas the ionized material has a mean density 1000 times higher. Thus we expect the galaxy to contain many isolated Strömgren spheres around the WN and O stars. Some of these might be resolved on an Hα plate taken in good seeing. The large surface area of these Strömgren spheres would normally lead to strong [O I] and [N I] emission, but because of the low densities probably prevailing where the ionized gas abuts against the neutral hydrogen, these lines need be no stronger than we observe.

The heating of the dust might be by the stars directly or by Lyman α trapped within the H II regions. If the dust in He2–10 is similar to that in galactic planetary nebulae, and Lyman α heating is important, we may adopt the discussion of Cohen & Barlow (1974) to relate dust temperature and electron density. We then deduce $N_e \sim 10^{3-4}$, in agreement with the value derived from the [S II] lines. Thus Lyman α heating is probably important.

In our Galaxy, WC stars have circumstellar dust but not WN stars (Allen, Harvey & Swings 1972; Cohen, Barlow & Kuhi 1975). We cannot estimate the carbon abundance because of the absence of suitable emission lines in the nebular gas; infrared spectrophotometry of the dust would indicate whether it is blackbody in nature, as found around WC stars, or has the silicate features found in the Orion Nebula (Stein & Gillett 1969) and other H II regions. One outstanding question is why is there no evidence of WC stars? Does their absence indicate different requirements for the formation of WN and WC stars?

We conclude by summarizing the unusual features of the dwarf galaxy He2–10:

(i) Non-thermal radio continuum.
(ii) Prominent infrared excess.
(iii) Wolf–Rayet bands in the visible spectrum.
(iv) High surface density of neutral hydrogen.

1976MNRAS.177...91A

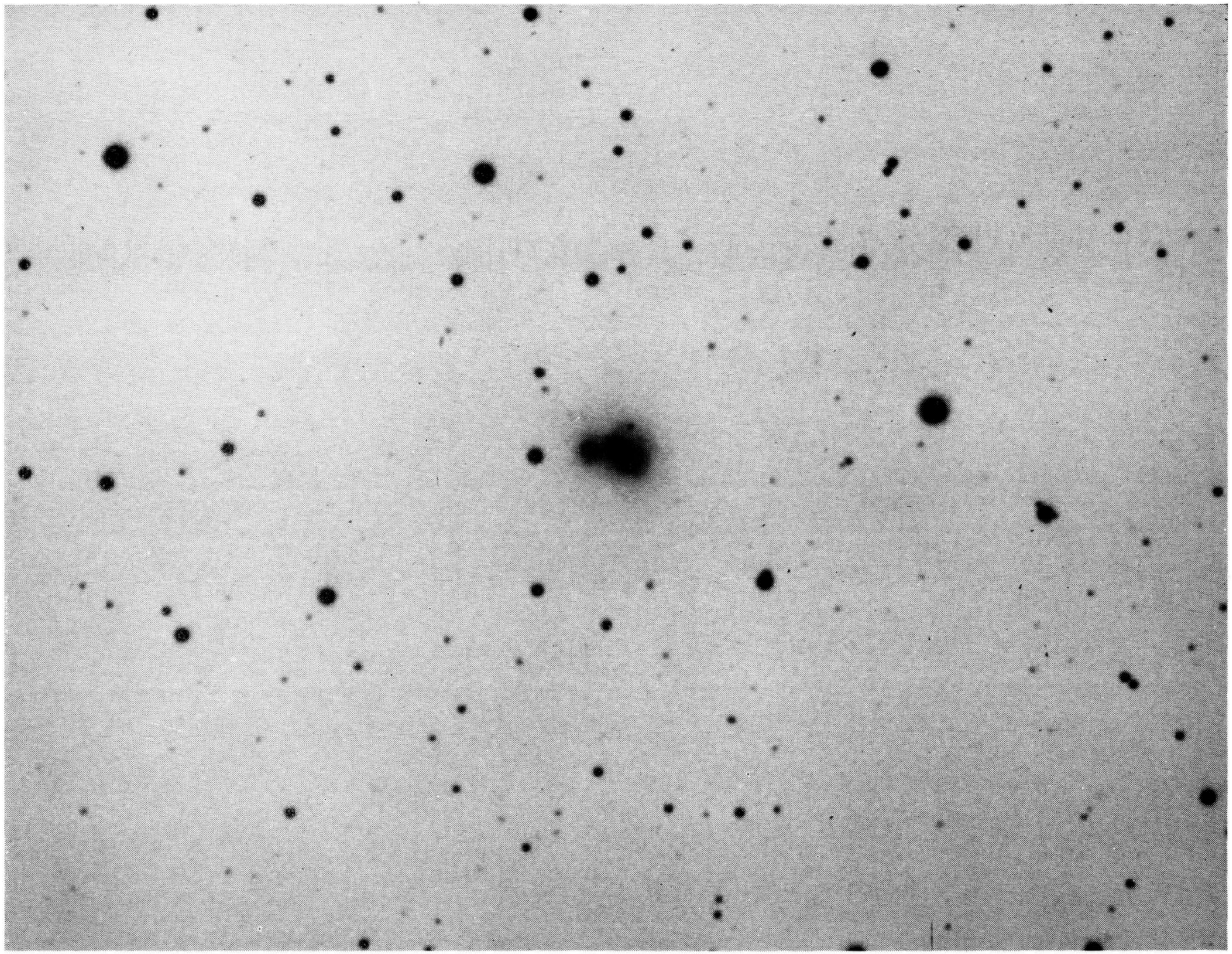

PLATE I. *A 5-min plate of He2–10 taken at the prime focus of the AAT with IIaD emulsion and GG 385 filter. North is at the top and east to the right, and the scale is 2·5 arcsec mm*$^{-1}$.

[*facing page* 96]

ACKNOWLEDGMENTS

We thank K. P. Tritton for taking the plate reproduced here, C. R. Purton for providing the 10·6-GHz data, A. G. Little for the 408-MHz data from the Molonglo survey, and H. van Woerden and U. Mebold for assistance with the H I observations. Time on the AAT was allocated by the LTUP and the PATT. DAA thanks the Science Research Council for an AAT Fellowship.

REFERENCES

Allen, D. A., Harvey, P. M. & Swings, J. P., 1972. *Astr. Astrophys.*, **20,** 333.
Balkowski, C., Bottinelli, L., Charmaraux, P., Gouguenheim, L. & Heidmann, J., 1974. *Astr. Astrophys.*, **34,** 43.
Bottinelli, L., Chamaraux, P., Gouguenheim, L. & Heidmann, J., 1973. *Astr. Astrophys.*, **29,** 217.
Bottinelli, L., Gouguenheim, L. & Heidmann, J., 1973. *Astr. Astrophys.*, **22,** 281.
Chamaraux, P., Heidmann, J. & Lauqué, R., 1970. *Astr. Astrophys.*, **8,** 424.
Cohen, M. & Barlow, M. J., 1974. *Astrophys. J.*, **193,** 401.
Cohen, M., Barlow, M. J. & Kuhi, L. V., 1975. *Astr. Astrophys.*, **40,** 291.
Glass, I. S., 1973. *Mon. Not. R. astr. Soc.*, **164,** 155.
Gouguenheim, L., 1969. *Astr. Astrophys.*, **3,** 281.
Henize, K. G., 1967. *Astrophys. J. Suppl.*, **14,** 125.
Jaffe, W. J., 1972. *Astr. Astrophys.*, **20,** 461.
Lauqué, R., 1973. *Astr. Astrophys.*, **23,** 253.
Neugebauer, G., Becklin, E. E., Oke, J. B. & Searle, L., 1976. *Astrophys. J.*, **205,** 29.
Sanduleak, N. & Stephenson, C. B., 1972. *Astrophys. J.*, **178,** 183.
Searle, L. & Sargent, W. L. W., 1972. *Astrophys. J.*, **173,** 25.
Stein, W. A. & Gillett, F. C., 1969. *Astrophys. J.*, **155,** L157.
Vorontsov-Velyaminov, B. A. & Arkhipova, V. P., 1968. *Morphological catalogue of galaxies*, Vol. IV, Moscow University.
Westerlund, B. E. & Henize, K. G., 1967. *Astrophys. J. Suppl.*, **14,** 154.
Westerlund, B. E. & Mathewson, D. S., 1966. *Mon. Not. R. astr. Soc.*, **131,** 371.