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I4329A: AN EXTREME SEYFERT GALAXY

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ABSTRACT

The southern spiral I4329A is found to be the most extreme Seyfert yet discovered. Hα is 13,000 km s^{-1} wide, and f(Hβ) is 7×10^{42} ergs s^{-1}, which approaches that from the QSOs even if they are at cosmological distances. The hydrogen line profiles rule out electron scattering as the broadening mechanism, but there are differences of profile from line to line which are not understood.
Subject headings: line profiles — Seyfert galaxies

I. INTRODUCTION

In a redshift survey of southern galaxies with the Mount Stromlo 74-inch (188-cm) telescope, Sandage (private communication) noted that the spiral companion to I4329 had very broad emission lines. The object was therefore included in a wider survey of southern emission galaxies which we are carrying out at this observatory (to be published).

The galaxy, which we refer to as I4329A, is a 13th magnitude, edge-on SA spiral (see fig. 1[pl. L2]) close to the giant elliptical I4329 which is the brightest in a rich cluster of ellipticals and spirals in the Centaurus region. The position of I4329A is $\alpha(1950) = 13^{\mathrm{h}}46.4^{\mathrm{m}}$, $\delta(1950) = -30°04'$.

Despite the intervening dust lane, a prominent stellar nucleus is seen, although the galaxy appears to be otherwise undisturbed. Spectroscopy reveals that the object is the most extreme Seyfert galaxy yet found. For instance, Hα has a full width at zero intensity (FW0I) of 13,000 km s^{-1} and an intensity equivalent width of 400 Å, while f(Hβ) $\sim 7 \times 10^{42}$ ergs s^{-1}. In addition to its classical Seyfert properties (somewhat modified by foreground dust and stars) it exhibits unique characteristics. For these reasons, and because of the short time scales sometimes associated with Seyferts, we thought it worthwhile to write a short note on this object, though a more detailed investigation will be published elsewhere.

II. OPTICAL OBSERVATIONS

Seven trailed and untrailed spectra were taken with the Carnegie image-tube spectrograph on the 74-inch between April and August 1972. They cover the range from 3600 to 7000 Å, at dispersions between 46 and 200 Å mm^{-1}. The width of the slit subtends 2″ on the sky and 30 μ on the plate, and exposures varied between 20 and 130 minutes. Absorption lines of Ca II K, Na D, and Mg (5178) yield a mean radial velocity (corrected) of 4137 km s^{-1}.

Table 1 lists prominent emission features with their relative intensities (Hβ = 100) crudely corrected for the instrumental response. Besides those listed, there appear to be other features above the noise level. However, the extremely broad profiles make it difficult to draw the continuum, and identification is uncertain. There is evidence that the coronal line [Fe XIV] 5303 is present with a *broad* profile.

The direct plates (see fig. 2) were taken (plate scale = 25″ mm^{-1}) with the 40-inch at Siding Spring in good seeing using 103 aD emulsions through a GG-13 filter. The photometry was taken with the 24-inch at the same site on the nights of 1972 June a.

b.

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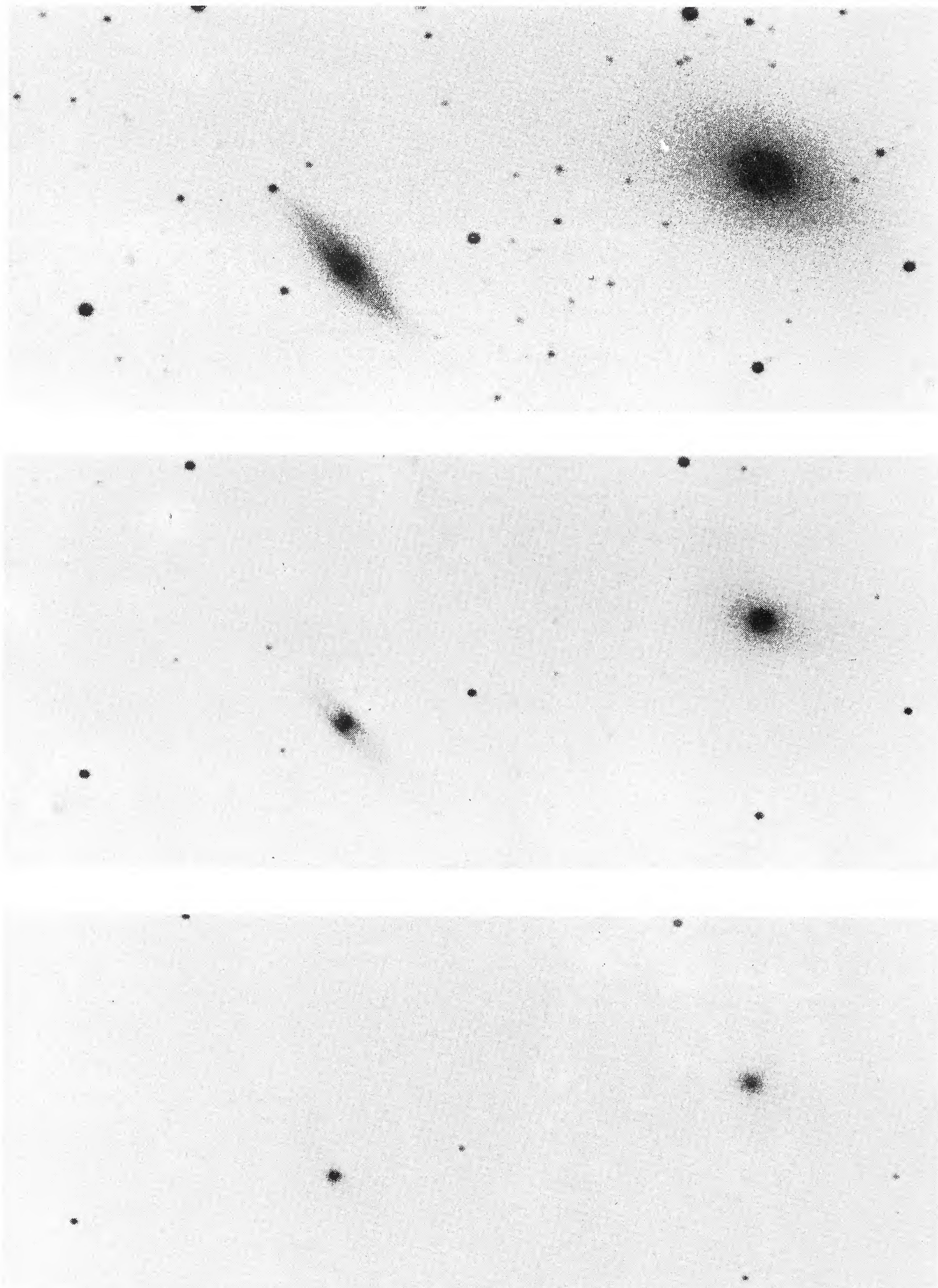

FIG. 2.—I4329 and its Seyfert companion. Exposures 75 min, 15 min, and 5 min. North is up; east, to the left. The galaxies are 3′ apart.

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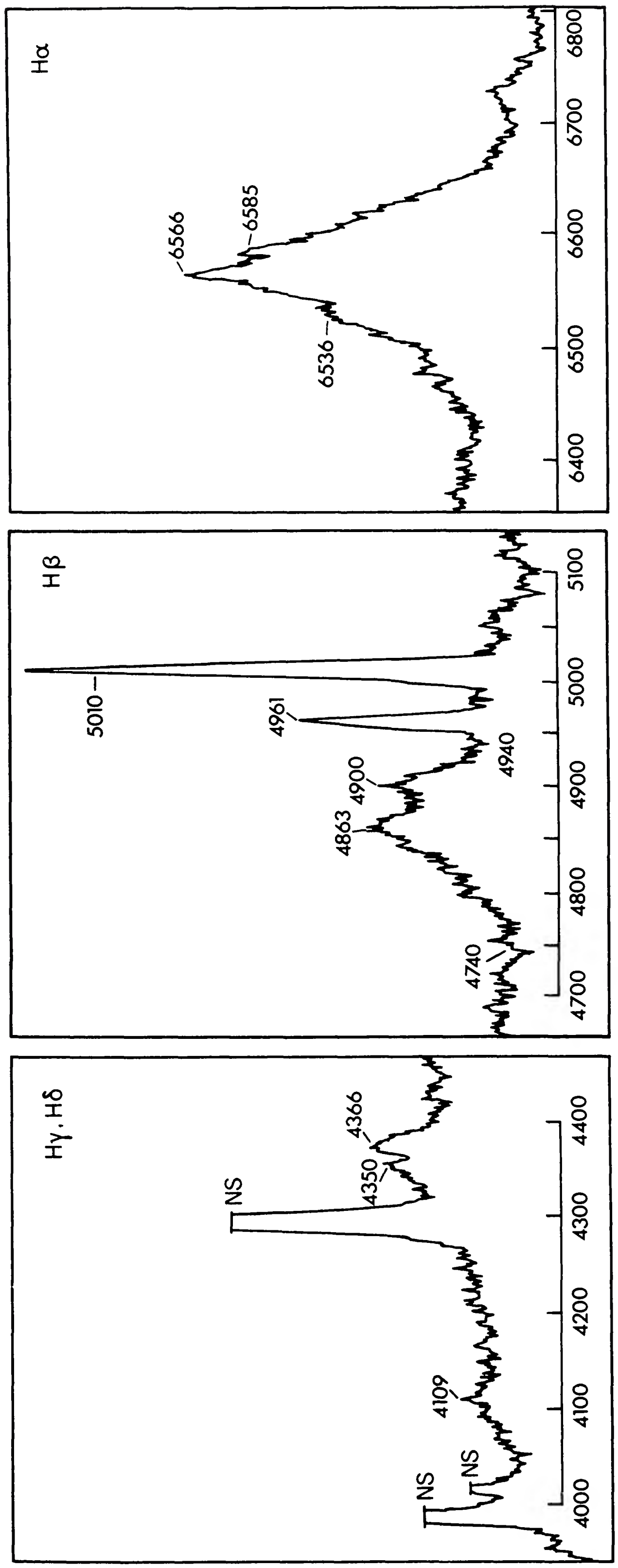

FIG. 1.—Line profiles of hydrogen lines. Intensity tracing of a 100 Å mm−1 plate, projected slit width 3Å. Two-hour exposure trailed E/W.

TABLE 1

EMISSION LINES, WIDTHS, AND RELATIVE INTENSITIES

λ(Å)	Identification	FW0I (km s^{-1})	Intensity Relative to Hβ = 100	Unreddened Intensity ($A_v = 4.2$)
3728	[O II] 3727		2	10
4109	Hδ 4101	6,500	9	25
4350	Hγ 4340	8,000	26	50
4366	[O III] 4363		4.5–1.5	9–3
4863	Hβ 4861	10,500	100	100
4961	[O III] 4959	1,500	20	18
5010	[O III] 5007	1,500	66	56
5873	He I 5876	9,000	46	18
6304	[O I] 6300	2,000	16	5
6566	Hα 6563	13,000	817	201
6585	[N II] 6584		8	2
6728	[S II] (blend)		25	6

18 and 19. In a 10″ aperture $V = 14.44$, $B - V = 0.96$, $U - B = 0.51$; in a 37″ aperture $V = 13.33$, $B - V = 0.97$, and $U - B = 0.25$. Even in the 10″ diaphragm there is heavy contamination by foreground stars and dust, which rules out discussion of the nuclear continuum.

III. RADIO AND INFRARED OBSERVATIONS

A. E. Wright of CSIRO Radiophysics kindly examined the position with the Parkes 210-foot (64-m) dish at 11 cm. Using an 8′ beam, he reports the presence of a weak source (~ 0.15 f.u.) with probable E/W extension. Assuming a spectral index of 0.7 yields a total radio output of 1.5×10^{39} ergs s^{-1}, which is no more than is expected from a normal spiral. A search for an unresolved source would be worthwhile.

J. A. Thomas and A. R. Hyland included the object in their program of infrared observations with a germanium bolometer on the Mount Stromlo 50-inch. At 2.2 μ no source was found above the 1 f.u. level. However, this is hardly significant, for it implies (assuming a normal Seyfert infrared spectrum) only that the total infrared output is less than $3 \times 10^{13} L_{\odot}$. This should be compared with the most powerful Seyfert infrared emitter 3C 120 which has an output (Kleinemann and Low 1970) of $1 \times 10^{13} L_{\odot}$. In view of the large flux in emission lines, more sensitive observations would be interesting.

IV. LINE PROFILES

Figure 1 reveals several interesting features: (*a*) The forbidden lines are much narrower (1500 km s^{-1} FW0I) than the permitted lines, a common feature of Seyfert spectra. (*b*) The profiles of the hydrogen lines are not at all smooth (see in particular Hβ). The reality of the double peak is not in doubt as it appears on all spectra, nor is it akin to the core/wing profile of NGC 4151. This, together with other evidence summarized by Shields *et al.* (1972), must be considered conclusive evidence against electron scattering as the line broadening mechanism. Hereafter we assume the broadening to be a pure Doppler effect. (*c*) The profiles of the different hydrogen lines are quite unlike one another. Note particularly Hβ (Hγ is probably blended with [O III] 4363). This unique feature we find particularly puzzling. The Balmer decrement suggests that the hydrogen lines are formed by recombination. Since the Balmer decrement for recombination in only weakly temperature dependent, it is not easily possible to argue that a small number of filaments with widely different excitation conditions are responsible for the complex profiles. Moreover, the absence of He II 4686 as against strong He I 5876 *suggests* uniformly low ionization in the permitted line region. (*d*) In contrast to He I 5876, the hydrogen lines have fairly sharp peaks close to zero velocity in the galaxy system. This suggests that a portion of the hydrogen emission is formed in an outer low-velocity region. (*e*) Beside their detailed structure, the H lines appear to be asymmetrical, being generally more extended to the blue than the red. This could be due to absorption within the explosive material which preferentially dims the filaments receding on the far side of the explosion.

V. THE BALMER DECREMENT AND THE REDDENING

Osterbrock (1971) has recently reviewed methods for the analysis of Seyfert spectra, and the procedures in this section and the next are based on his summary.

In common with other Seyferts the Balmer decrement is very steep. However, if it is compared with the calculations of Osterbrock, Capriotti and Bautz (1963), it lies not too far from the line for recombination radiation provided a reddening of $A_v = 4.2$ (mean) is assumed. That this is rather more than for other Seyferts (Osterbrock 1971) is not surprising considering the galaxy's inclination. We shall henceforth assume that the emission is by recombination and that the Balmer lines are optically thin (Capriotti 1964). However, the fit is crude at best, and we cannot rule out some excitation by collisions or other mechanisms.

VI. PHYSICAL CONDITIONS

There are fewer forbidden lines than in some other Seyferts, and those that are present are sometimes entangled with the broad permitted lines. With the provisos that the data are necessarily crude and the conclusions are tentative, we proceed in the normal manner.

a) Forbidden-Line Region (FLR)

Only the [S II] lines at 6717 and 6731 (Saraph and Seaton 1970), which are sensitive in the range $10^3 < N_e < 10^5$, can be used to estimate the electron density. The flux $f(6731)$ is probably more than twice $f(6717)$, which implies $N_e > 5 \times 10^4$. T_e can be found from the [O III] lines using (Aller and Liller 1968)

$$\frac{f(5007) + f(4959)}{f(4363)} = \frac{7.1 \text{ dex } (14{,}300/T_e)}{1 + 0.00028 N_e/T_e^{1/2}} \tag{1}$$

There is a strong line (fig. 1) at 4366 on top of the Hγ profile. Unfortunately it cannot be wholly due to [O III] 4363 for it is wider than the other forbidden lines. The maximum intensity for 4363 in table 1 is arrived at by assuming that the height of the line above a smoothed Hγ profile is entirely due to 4363, but the width is commensurate with other forbidden lines. Using this maximum value and ignoring the term in N_e in equation (1) yields $T_e > 10^5$ ° K, which is certainly too high (Souffrin 1968). We must assume that either 4366 is mostly Hγ and the wavelength agreement is purely coincidental or, as seems more likely, 4363 is strong but $N_e > 10^6$.

The strongest statement we can make about the FLR is that N_e is certainly more than 5×10^4, probably more than 10^6, and certainly less than 10^8 (when forbidden lines are suppressed).

b) Permitted-Line Region (PLR)

Shields, Oke, and Sargent (1972) find for 3C 120 that He II 4686 is strong compared with He I 5876 and that T_e(PLR) $= 6000°$ K. This suggests $T_e < 6000°$ K here, for

4686 is absent. The forbidden lines have no broad components; thus $N_e(\mathrm{PLR}) \geqslant 10^8$.

We have not yet measured $f(\mathrm{H}\beta)$ with a scanner, but a preliminary estimate can be made from the spectroscopy and photometry. Assuming $B(\mathrm{nucl}) = 15.4$, $A_v = 4.2$, $H_0 = 100$ km s^{-1} Mpc^{-1}, and $f(\mathrm{H}\beta) = 0.05\, f_{\mathrm{nucl}}(B)$, we obtain $f(\mathrm{H}\beta) \sim 7 \times 10^{42}$ ergs s^{-1}. This flux is larger than from any other Seyfert, and is only 3 times less than the flux from the QSO 3C 48. This suggests (in the lines at least) that outbursts in nearby galaxies can produce optical fluxes which are *quantitatively* as well as qualitatively similar to the fluxes from QSOs, even assuming that QSO distances are cosmological.

From $f(\mathrm{H}\beta)$ we estimate the volume $R_{\mathrm{PLR}}{}^3$ of the emitting region using

$$f(\mathrm{H}\beta) \sim \epsilon N_e{}^2 R_{\mathrm{PLR}}{}^3 .$$

Assuming $T_e(\mathrm{PLR}) = 5000°$ K, and radiative case B, the emissivity $\epsilon = 2.2 \times 10^{-25}$ ergs cm^{-3} s^{-1} (Aller and Liller 1968). If then $N_e = N_i \geqslant 10^8$, we have

$$R_{\mathrm{PLR}} \leqslant 1.5 \times 10^{17} \text{ cm.}$$

A number of time scales can be defined for nuclear outbursts. The simplest is

$$T_1 \sim \frac{R_{\mathrm{PLR}}}{\text{Vel. expansion}} \leqslant 3 \times 10^8 \text{ seconds here.}$$

In time T_1 we might expect significant diminution in the broad lines. Andrillat and Souffrin (1968) have observed just such effects in NGC 3516 ($T_1 \sim 24$ years), and Pastoriza (1972) and Freeman (1972) have observed them in NGC 1566. Osterbrock (1971) has suggested that the total hydrogen-line flux in Seyferts $\sim 40\, f(\mathrm{H}\beta)$, in which case the total *line* energy in the outburst is

$$E \sim 40\, f(\mathrm{H}\beta)\, T_1 \leqslant 8 \times 10^{52} \text{ ergs.}$$

VII. SUMMARY

I4329A is an edge-on spiral with the most extreme Seyfert characteristics yet found. The inclination of the galaxy means that the continuum of the nucleus is heavily contaminated by foreground dust and stars, making analysis difficult. On plausible arguments the line flux approaches that from QSOs even if their distances are cosmological. The hydrogen line profiles rule out electron scattering as the broadening mechanism. The broad lines are probably formed by recombination following a powerful explosion into a dense ($N_e > 10^6$) medium, but there are differences in the profiles from line to line which are difficult to understand. The time scale for the eruption could be very short ($\sim$ 10 years). Further observations are required at all wavelengths. In particular, the definite identification of broad coronal lines at 5303, 6374, 10747, and 10798 would imply the presence of a hot ($\sim 10^6$ ° K) high-velocity region.

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