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ON THE OPTICAL IDENTIFICATION OF THE X-RAY SOURCE CEN XR-2 AS WX CEN

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ABSTRACT

The variable star WX Cen (α[1950] = $13^h09^m38^s$, δ[1950] = $-$ 63°08′) is within the error radius of the best-determined X-ray position of Cen XR-2. Optical observations show that the star has the peculiar colors $\langle B - V\rangle \simeq + 0.45$, $\langle U - B\rangle \simeq - 0.72$, similar to those of Sco X-1; it varies from night to night with an observed range $\Delta V \simeq 0.4$ mag; and has a rare optical emission-line spectrum which resembles Sco X-1.

Feast (1967) and Blanco (1967) have suggested the planetary nebula NGC 5189, or its associated star, to be the optical counterpart of the variable X-ray source Cen XR-2, first discovered by Harries *et al.* (1967) and subsequently studied by many other workers (cf. Cooke *et al.* 1967; Chodil *et al.* 1967; Lewin, Clark, and Smith 1968). Identification with NGC 5189 was considered doubtful by Lewin *et al.* (1968) on the basis of positional disagreement with the best X-ray data. Nor was a convincing candidate found by Eggen and Lyngå (1968) in their search for blue objects near the early X-ray positions.

The more accurate position of Lewin *et al.* (1968), at $\alpha(1950) = 13^h09^m$ and $\delta(1950) = -62°$ with an error radius of 1°5, suggested that a new search be made farther west. The variable star WX Cen (α[1950] = $13^h09^m38^s$, δ[1950] = $-63°08'$), whose short-term optical fluctuations were unphaseable and whose nature was unknown, was observed photoelectrically with the 40-inch Siding Spring reflector on eight nights in July, with the results shown in Table 1. The star has a pronounced ultraviolet excess and exhibits night-to-night variations with a total observed range of 0.4 mag.

Three spectrograms were obtained of WX Cen at a dispersion of 180 Å mm^{-1} with the Carnegie Institution's image-tube spectrograph attached to the Mount Stromlo 74-inch reflector. The spectra cover a wavelength range from about 4300 to 7000 Å, with the region of good focus confined to $\lambda > 4600$ Å. The reproduction in Figure 1 (Plate L5) shows strong emission lines of Hα, Hβ, Hγ, He II λ4686, He II λ5412, C IV λ5802, together with many fainter lines. A direct-intensity tracing of the spectrum is shown in Figure 2.

This unusual spectrum closely resembles that of Sco X-1 in the overlap region $4300 < \lambda < 5000$ Å, with the exception that all lines between Hγ and He II λ4686 in WX Cen, which are only marginally visible in Sco X-1 (Sandage *et al.* 1966, Fig. 4), are clearly seen on our present spectrograms. In particular, the broad, diffuse, high-excitation band near 4640 Å, attributed to N III, C III, and possibly O II, together with the band at 4533–4544 Å (N III?) and an unmarked feature in the Sco X-1 spectrum near 4600 Å, are all well above the continuum in WX Cen.

A comparison with Sco X-1 in the near-red is made possible by a spectrogram taken by L. Searle with the same equipment. The only prominent feature on Searle's plate of Sco X-1 is Hα, considerably narrower than in WX Cen. The Hβ and He II λ4686 lines are just visible but are very faint. No positive trace of He II λ5412 or C IV λ5802 is present either by direct inspection or by microphotometry.

A listing of the definite emission lines in WX Cen, together with measured wave-

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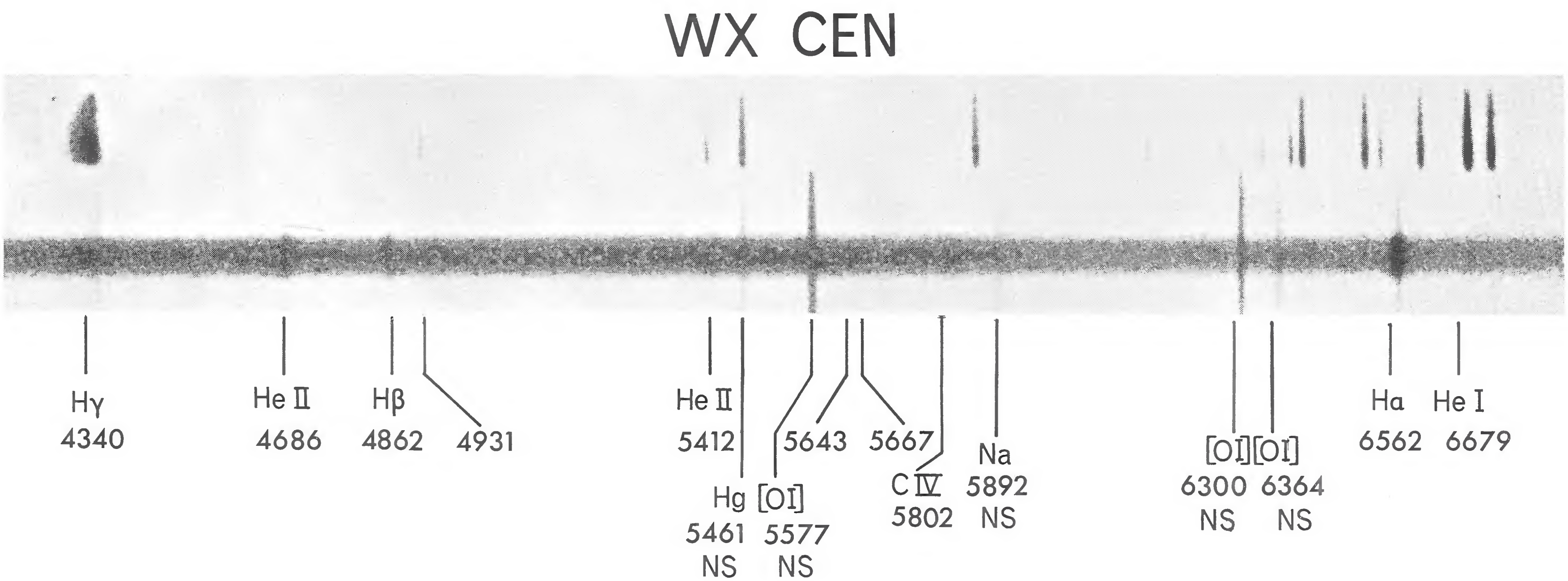

FIG. 1.—Spectrum of WX Cen obtained with the Carnegie Institution's image-tube spectrograph attached to the Mount Stromlo 74-inch reflector. Original dispersion 180 Å mm⁻¹. The comparison spectrum is neon plus mercury.

EGGEN *et al.* (*see* page L27)

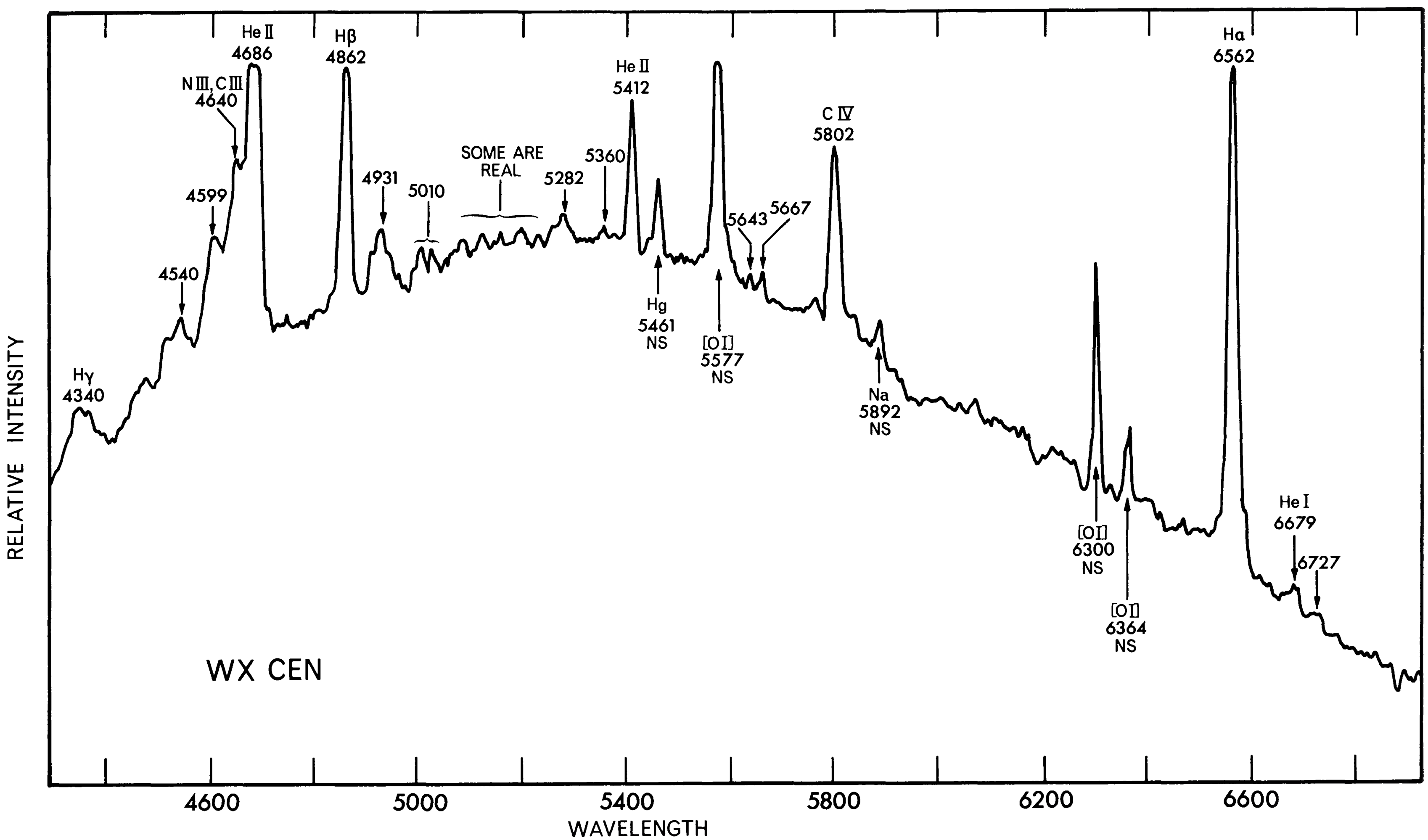

FIG. 2.—Relative-intensity microphotometer trace of the WX Cen spectrum. Lines attributed to the star are marked above the continuum level. Contamination lines from the night sky are marked below. The region of good focus extends from λ = 4600 Å.

lengths, strengths on an arbitrary scale as estimated from our most dense spectrogram (strongest is Hα at 20; just-detected lines are assigned strength 1; lines with strength 2 or greater are easily visible), suggested identifications, equivalent widths, and total widths (W) at half-intensity corrected for instrumental broadening, are given in Table 2. We estimate the error in the measured wavelength for the strongest lines to be at least ± 1 Å, corresponding to $\pm 5\ \mu$ on the plate. The errors are considerably larger for the weaker features.

All lines except He II λ5412 show appreciable line broadening, averaging about 20 Å in total width at half-intensity. He II λ5412 is as sharp as the instrumental profile, determined from the nightsky line of [O I] 6300 Å. The lines are appreciably wider than the Balmer lines and He II λ4686 in Sco X-1. If the line broadening is caused by electron scattering, an electron temperature of the order of 5×10^4 ° K is indicated. However, the fact that He II λ5412 is so narrow, as well as the simultaneous presence of the low-

TABLE 1

PHOTOELECTRIC OBSERVATIONS OF WX CEN

Date July 1968	WX Cen			Comp. Star		
	V	$B-V$	$U-B$	V	$B-V$	$U-B$
15	13.93	+0.40	−0.70	...	...	...
16	13.60	.51	.72	...	...	...
20	13.84	.34	.60	...	...	...
23	13.66	.59	.88	13.68	+0.63	...
24	13.52	.42	.69	13.65	.61	...
25	13.70	.47	.72	13.67	.61	...
26	13.69	.49	.72	13.66	.60	+0.18
27	13.59	+0.50	−0.73	13.66	+0.60	+0.20

TABLE 2

DEFINITE EMISSION LINES IN WX CEN

λ (Å)	Int.	Identification	Equivalent Width (Å)	W (Å)	Remarks
4340.4	4	Hγ	...	...	
4400	1	...	...	...	
4448	2	...	...	...	
4539.2	3	He II, N III?	...	...	
4599.6	3	...	...	...	
4642.4	4	N III, C III	16	27:	Diffuse
4683.4	15	He II	29.8	28	
4862.3	10	Hβ, He II	18.5	15	
4931	2	...	5.5	36	Diffuse
5010	2	...	...	...	Diffuse
5282	1	...	...	...	
5412.5	6	He II	4.3	0	Sharp
5643	1	...	...	...	
5667	1	...	...	...	
5803.0	10	C IV	10.1	23	
6561.9	20	Hα, He II	60.9	21	
6679	3	He I?	...	...	
6727	2	[S II]?	...	...	

excitation lines of the Balmer series and of He I λ6678 together with the high-excitation lines of He II, C IV, and N III, suggests that the physical conditions in which line formation occurs must have appreciable gradients, as in Sco X-1.

A noteworthy feature of Figure 1 (Plate L0) is the faint, narrow extension of the Hα line over the entire Decker window above and below the spectrum of the star. Either WX Cen could be located within an associated nebulosity, or the line could be part of the general diffuse galactic Hα emission which is prominent throughout the region (Rodgers, Campbell, and Whiteoak 1960). For a decision, we took a spectrogram of 30-minute exposure of a blank area 5′ from WX Cen. The narrow Hα emission line appears on this plate, showing that we have no evidence for nebulosity associated directly with the star.

The optical history of WX Cen extends over the past sixty years. The star was discovered to be a rapid fluctuator (time scale of the order of a day) by Miss Leavitt (Pickering 1906). Using a magnitude scale and zero point which must be considered uncertain, Pickering quotes $12.5 \geq m_{pg} \geq 11.5$. Shapley and Swope (1934) observed the star on a number of plates taken before 1934 and give a range $14.3 \geq m_{pg} \geq 13.5$. These early data, combined with the data of Lyngå in the following Letter and with those in Table 1, show that the star has not undergone violent outbursts during any of the intervals of optical observation.

These considerations, especially Lyngå's recent data, bear on the speculations of Chodil *et al.* (1968) and of Edwards and Harries (1968) on a nova-like optical outburst of Cen XR-2. These authors argue that if the X-ray and optical flux are coupled through the spectral extrapolation of a thin free-free thermally radiating gas, the optical object must be highly variable. Edwards and Harries (1968) predict that optical Cen XR-2 should have been as bright as $V \simeq 4$ mag in March 1967. The fact that WX Cen did not have such an outburst does not argue against the present suggested identification, for two reasons.

a) It has recently become clear that the optical and X-ray flux from Sco X-1 and Cyg X-2 are probably not coupled by the thermal bremsstrahlung extrapolation (Kristian, Sandage, and Westphal 1967 for Cyg X-2; Westphal, Sandage, and Kristian 1968 for Sco X-1). The most telling argument is the presence of absorption lines of appreciable depth in Cyg X-2 (Lynds 1967; Kristian *et al.* 1967); its presence shows that much less contamination of the optical continuum can be tolerated than that given by a hot plasma fitted to the X-ray and optical data.

b) A recent measurement of the X-ray spectrum (Lewin *et al.* 1968) of Cen XR-2 to 100 keV shows that the radiation is harder than that consistent with a single exponential spectrum. The same is true for Sco X-1 (Lewin, Clark, and Smith 1967; Buselli *et al.* 1968). Apparently, therefore, there are no good reasons to couple the variation of X-radiation with optical fluctuations on the basis of an isothermal spectrum of a hot plasma.

An estimate of the distance of WX Cen can be made if we adopt $M_v \simeq +4$ as for Sco X-1 (Westphal *et al.* 1968). Although the Coalsack is quite near, WX Cen lies at the edge of a region of high transparency. To distances of 500 pc, the photoelectric data of Eggen and Lyngå (1968, Table 1) suggest that $E(B - V) \simeq 0.3$ would not overestimate the reddening. With $\langle V_0 \rangle = 12.6$ from Table 1 and $A_v \simeq 1.0$, then $(m - M)_0 \simeq 8.6$, or $D = 500$ pc, which is similar to Sco X-1 (Westphal *et al.* 1968), implying similar absolute X-ray fluxes in the 2–8 keV range during the maximum phase of Cen XR-2, when it was as bright as Sco X-1.

To add weight to the suggested identification, it will be important not only to improve the X-ray position but also to establish the time scale of the optical fluctuations of WX Cen to compare with Sco X-1 and Cyg X-2. Optical observations with a high time resolution are planned for next season.

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