OBJECTIVE PRISM SPECTRA IN THE NEAR INFRARED

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ABSTRACT

Infrared objective prism spectra of M, S, C, and WR stars are presented at different exposures in order to assist in the detection and in many cases in the classification of such stars. The dispersion of these spectra at the A-band is 1700 Å/mm and the wavelength range is from λ 6800 to λ 8800.

INTRODUCTION

A number of investigations have been carried out and currently are in progress for the identification and the classification of stars in the near infrared. Many of the techniques have been published in a number of papers covering a period of about 14 years. The present paper summarizes these techniques by describing the principal features of the spectra. To facilitate the detection and classification, typical spectra of different densities are shown. This also minimizes errors in the classification which may arise from overexposed or underexposed spectra. All spectra are shown unwidened as they provide the following advantages: (*a*) It is possible to detect very faint red stars; in the case of M-type stars later than M4, stars of the 13.5 infrared magnitude are observed; (*b*) the appearance of the unwidened spectra actually assists in the detection and classification of M stars and particularly the detection of carbon and S stars.

In the case of the M-type stars, the spectra shown here define the system of classification which is currently used at the Warner and Swasey Observatory and elsewhere.

All spectra were taken with a 4° prism attached to the 24-inch Schmidt-type telescope of the Warner and Swasey Observatory, utilizing 1N emulsion and a Wratten No. 89 filter or its near-equivalent, RG8 Schott filter. This yields a dispersion at the A-band of 1700 Å/mm. The wavelength range is from λ 6800 to λ 8800.

M-TYPE STARS

The classification of the M-type stars presented here is based on the work of Nassau and van Albada (1949) and of Cameron and Nassau (1955). For standards, the Mount Wilson list (Adams, Joy, and Humason 1926) was used principally for the early-type stars (Figs. 1 and 2). For the later types beginning with M6.5 the strengthening of the TiO bands and the presence of the VO bands form the bases of classification (Fig. 3). No particular standards were used for classes M8, M9, and M10. They were made to represent a sequence of advancing subclasses which can be readily distinguishable. Also, we were guided by the spectral changes of variables as they were correlated with the variations in magnitude.

No means for separating giant and dwarf M stars was found possible. From the known early M dwarf stars, it was established that the same criteria are valid for both groups. However, the late dwarfs do not seem to show the VO bands at λ 7900 observed in the giants. The classifications presented here assume that the system deals with giants.

Objective-prism infrared spectra of abnormally reddened M-type stars show a wedge-shaped appearance. Many of these stars, where they appear in regions of relatively light obscuration, turn out to be M supergiants (Nassau, Blanco, and Morgan 1954). This was confirmed by Sharpless (1956) by securing slit spectra of some of the stars in our published lists. In Figure 4, *a* and *b*, we show two supergiants, T Per, M2 Ia-Ib and HV 10644, M4 Ib (Bidelman 1947). However, overexposed spectra of early M supergiants appear similar to the spectra of S-type stars where the latter have weak LaO bands or these bands are absent. The overexposed spectra of T Per (Fig. 4, *a*) and R And (Fig. 4, *c*) present similar appearance.

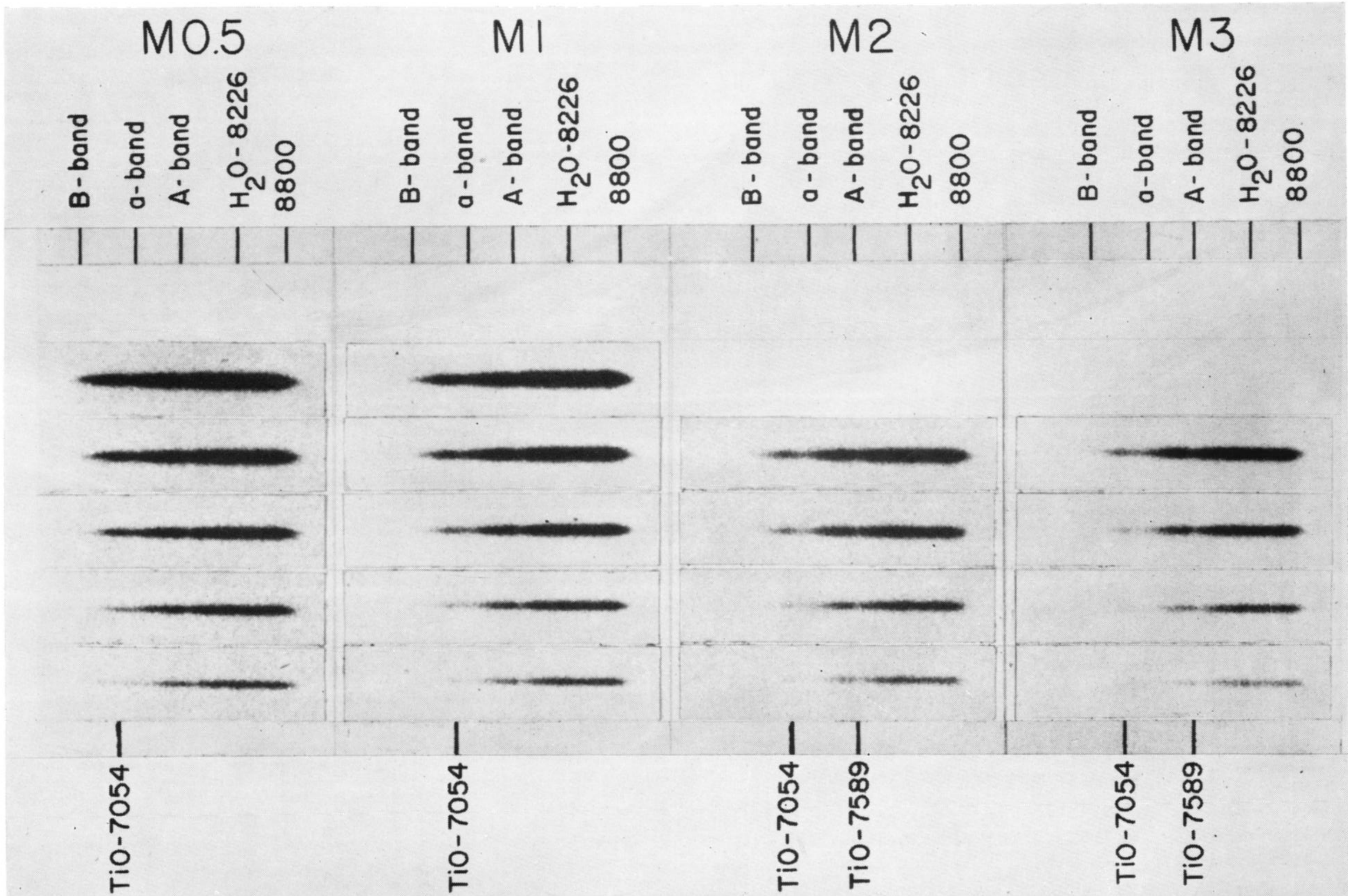

FIG. 1.—For M0.5 and M1 the TiO band near λ 7054 is visible. For M2 and M3 we observe the TiO band at λ 7589 as well as the growth of λ 7054.

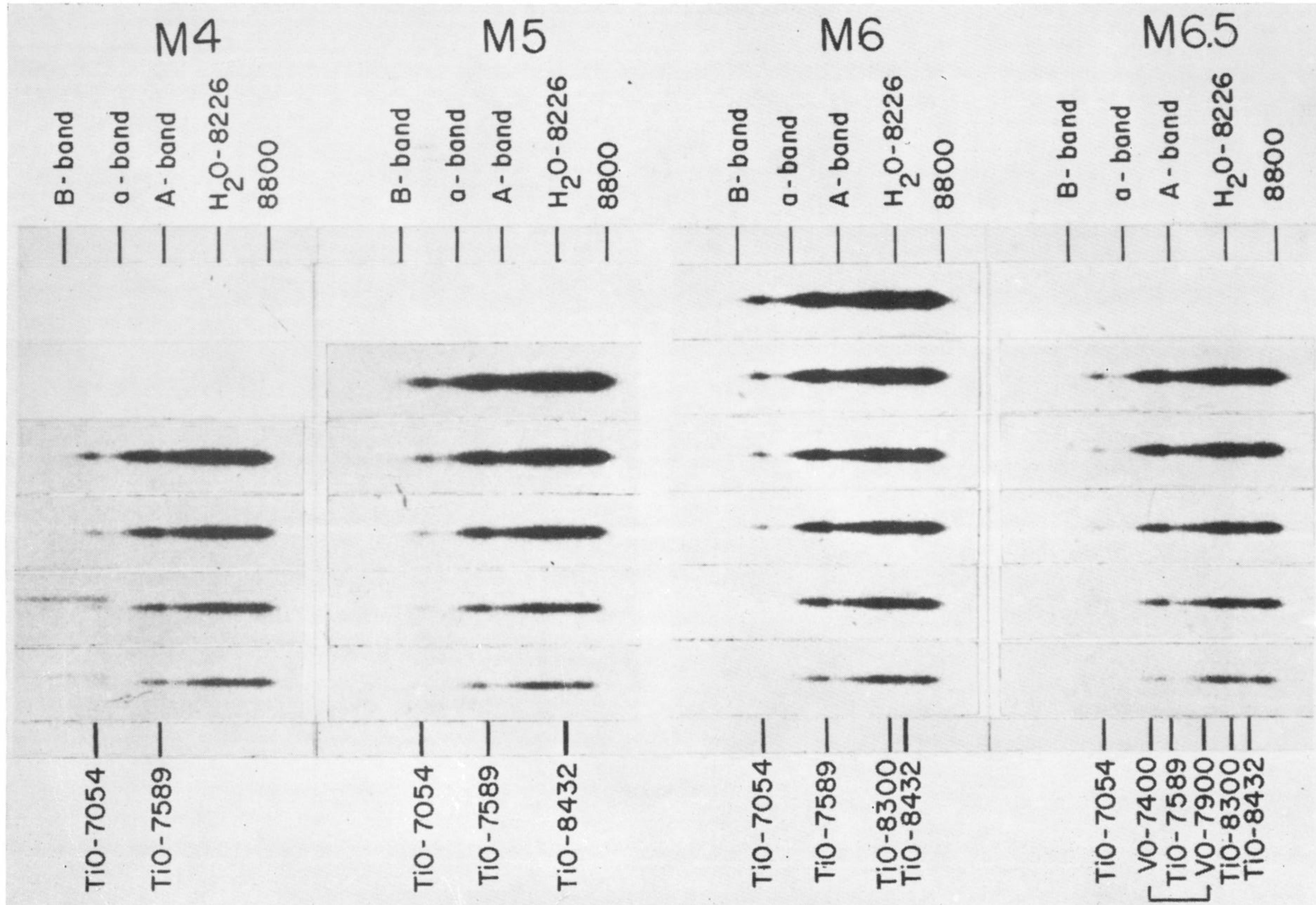

FIG. 2.—The TiO band at λ 8432 first appears with M5 and the TiO band at λ 8300 with M6.5

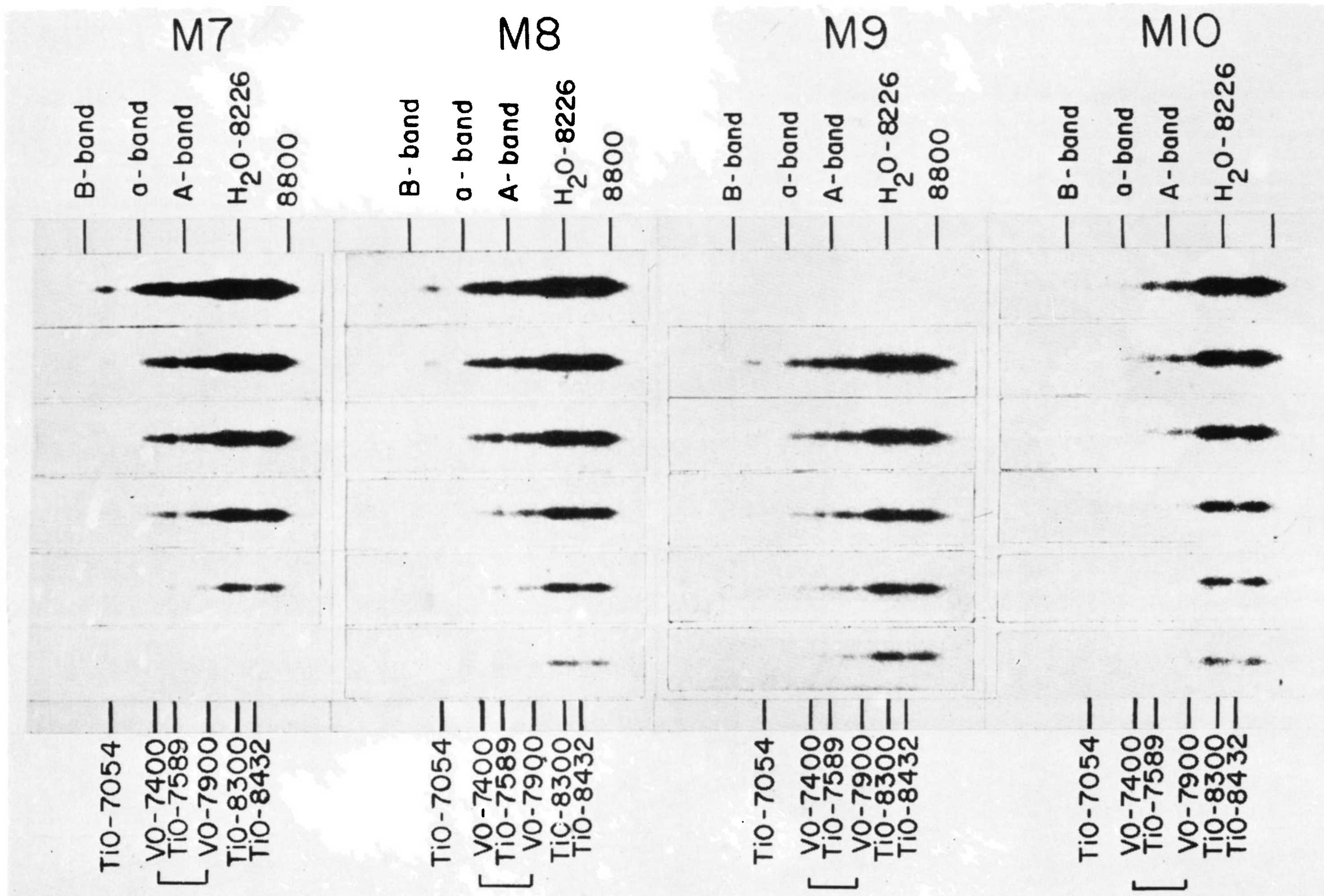

FIG. 3.—With M7 and later classes, the VO bands at λ 7400 and λ 7900 appear and the TiO bands continue to increase in strength

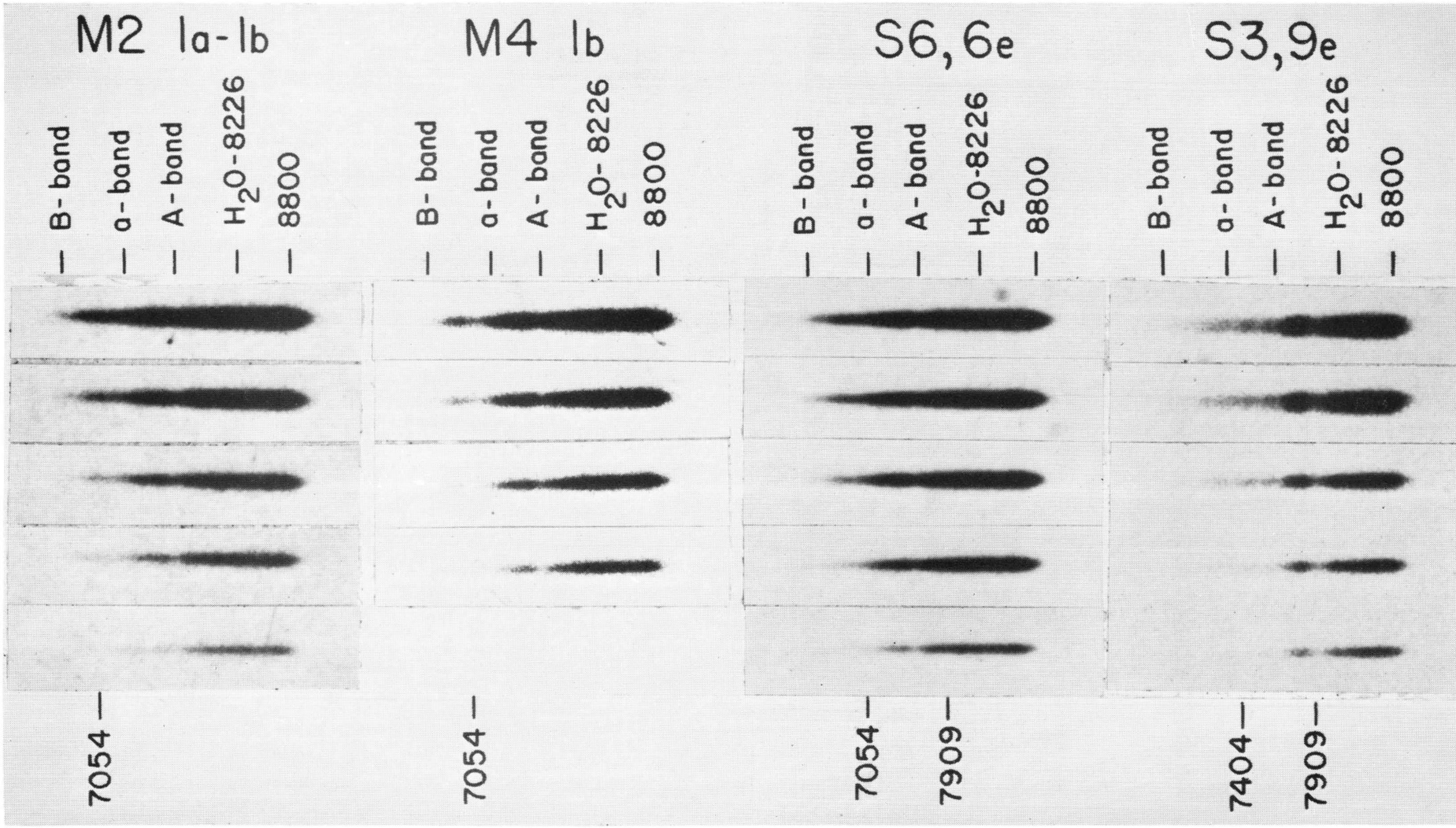

FIG. 4.—The spectra of the supergiants show a taper appearance as compared to the giants. The spectra of the S-type stars show the LaO bands

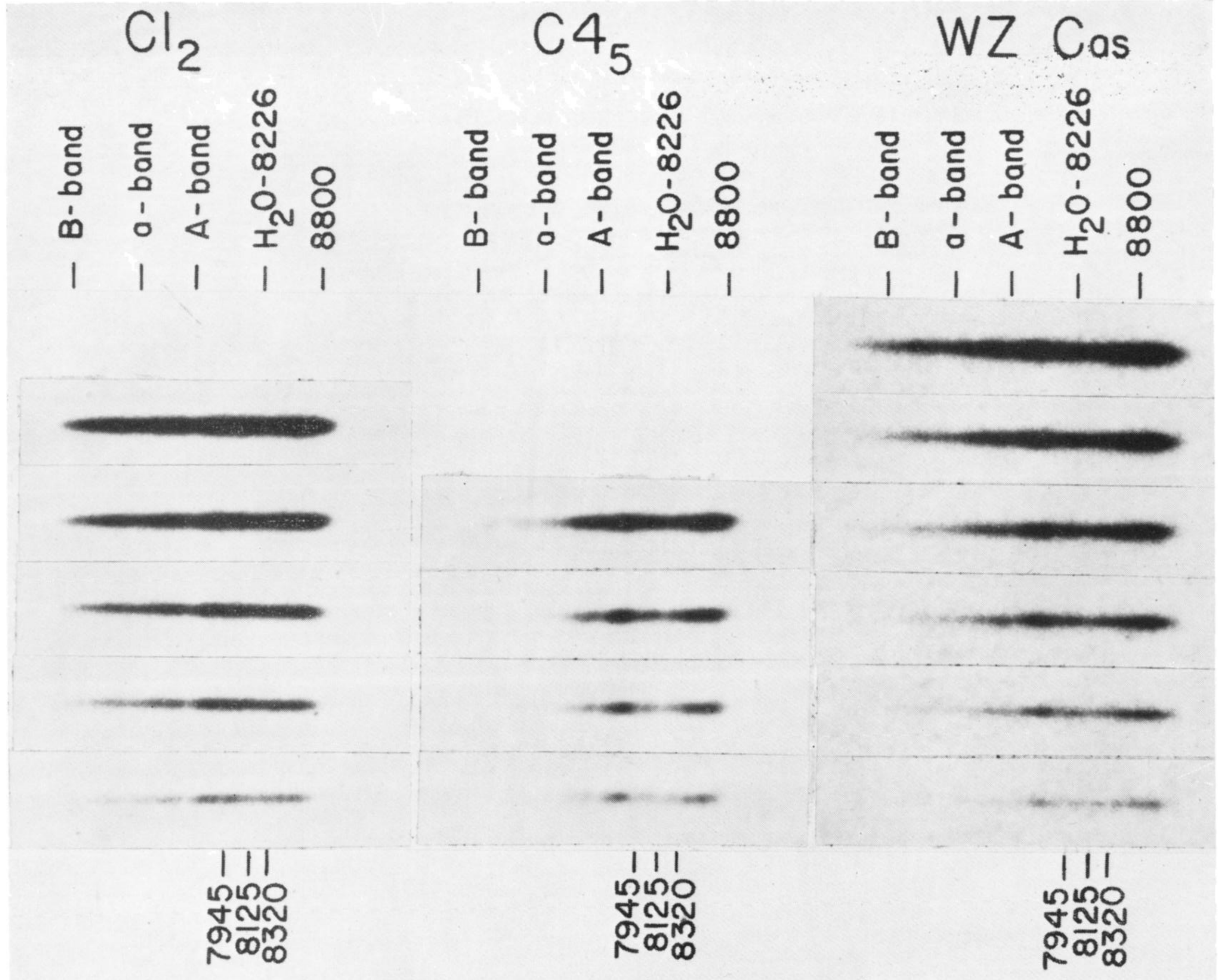

FIG. 5.—The three CN bands characterize the spectra of the Carbon Stars. The spectrum of WZ Cas ($C9_1$) was taken on September 5, 1961.

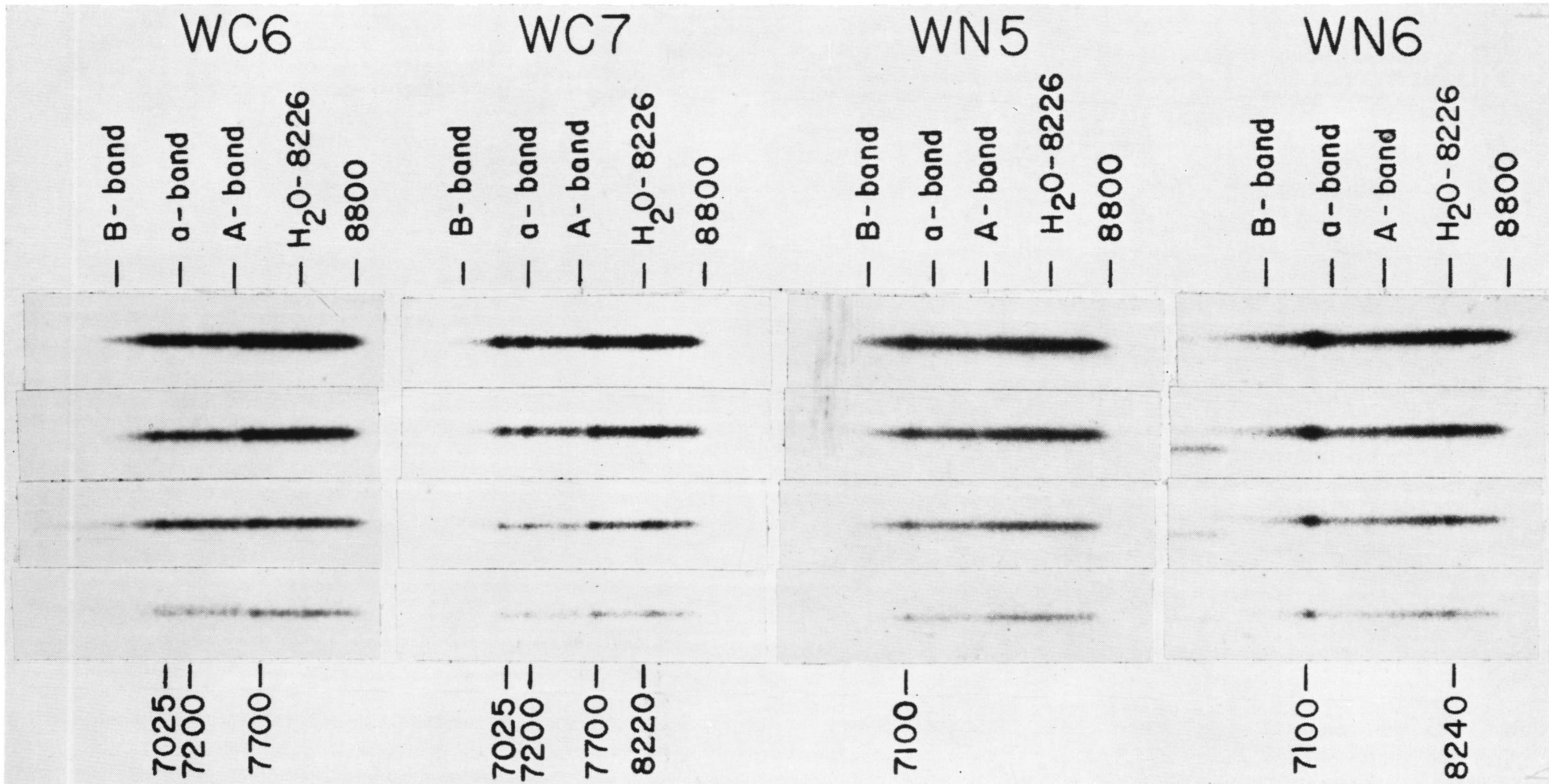

FIG. 6.—WC6 (HD 192641) shows three principal features: λ 7700 (N IV) strong and λ 7025 (C III) and λ 7200 (C II) weak. WC7 (HD 192103) shows the following four features: λ 7025 (C III), λ 7200 (C II), λ 7700 (C IV) and λ 8220 (C II + C III). WN5 (HD 193077) shows the principal emission at λ 7100 (N IV), while WN6 (HD 191765) shows this emission more pronounced and shows λ 8240 (N III:) as well.

S-TYPE STARS

The detection of S-type stars in the infrared region is made possible by the presence of the LaO bands. The two principal bands of LaO present are λ 7404 and λ 7909 (Nassau and van Albada 1948; Keenan 1948). As it has been pointed out by Keenan (1954), many of the S stars do not show these bands. Here we present two S-type stars (Fig. 4), one with LaO weak or nearly absent and the second with LaO strong: R And (S6, 6e; S7, 5e) spectrum taken September 4, 1954, and X And (S3, 9e) spectrum taken September 18, 1957. The classifications are from Keenan's paper.

CARBON STARS

The detection of the carbon stars in the infrared region is made possible by the presence of the infrared bands of CN. These stars are easily detectable nearly to the limit of the plates. In well-exposed spectra it is possible to classify approximately (Nassau and Colacevich 1950) carbon stars on the Keenan-Morgan (1941) system. The three CN bands observed in this spectral region are of λ 7945, λ 8125, and λ 8320. Figure 5 shows three carbon stars: HD 182040 (Cl_2), HD 1994 ($C4_5$) and WZ Cas ($C9_1$). The spectrum of the variable WZ Cas was taken September 5, 1961.

WOLF-RAYET STARS

The detection of the Wolf-Rayet stars in the infrared spectral region is made possible by the presence of rather strong emission features. Also it is possible, in a number of cases, to segregate these stars into the WC and WN classes. Here we present (Fig. 6) four examples:

a) HD 192641; WC6. The principal emission is at about λ 7700 (C IV) and two somewhat fainter emissions at λ 7025 (C III) and λ 7200 (C II).
b) HD 192103; WC7. Four emission features are clearly shown as follows: λ 7025 (C III), λ 7200 (C II), λ 7700 (C IV), and λ 8220 (C II + C III).
c) HD 193077; WN5. The principal emission shown is at about λ 7100 (N IV).
d) HD 191765; WN6. The stronger of the two emissions shown is at about λ 7100 (N IV) and the weaker at about λ 8240 (N III:)

The above classifications were secured from Roberts' (1962) list. The probable identifications of the emissions are from Swings and Jose's (1950) work. The given wavelengths were secured by a rough measurement of the infrared objective-prism spectra and, hence, are approximate.

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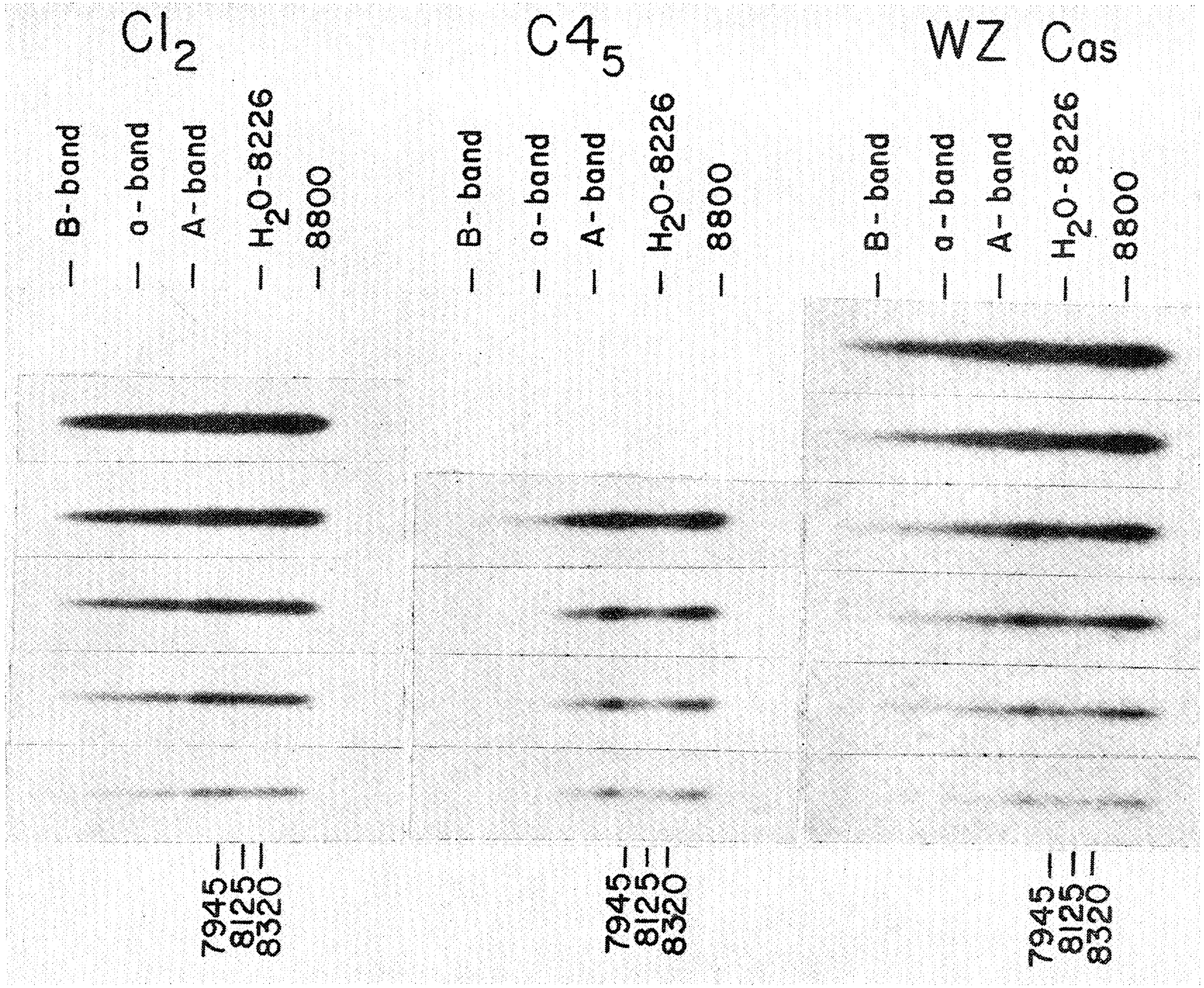

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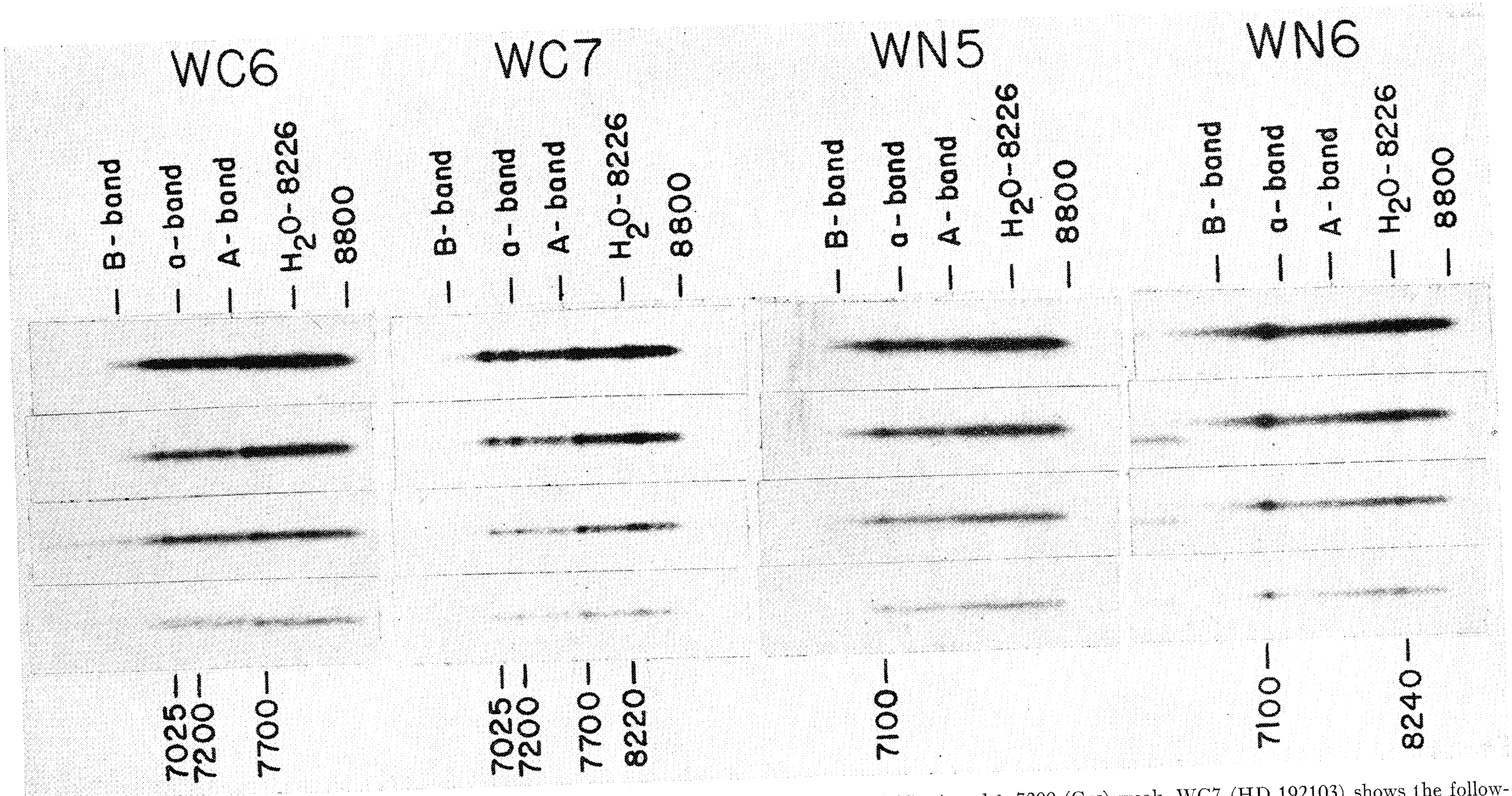

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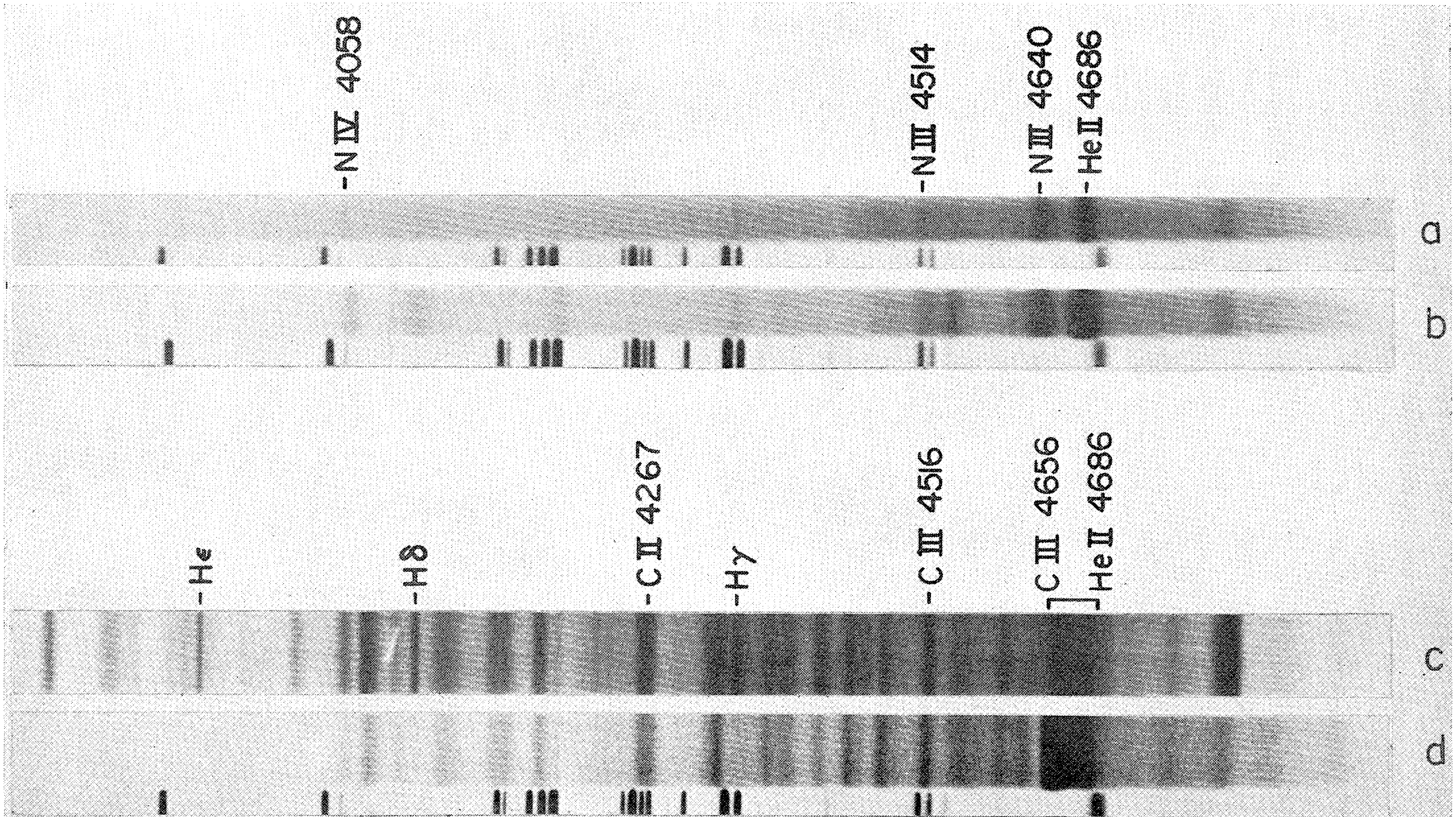
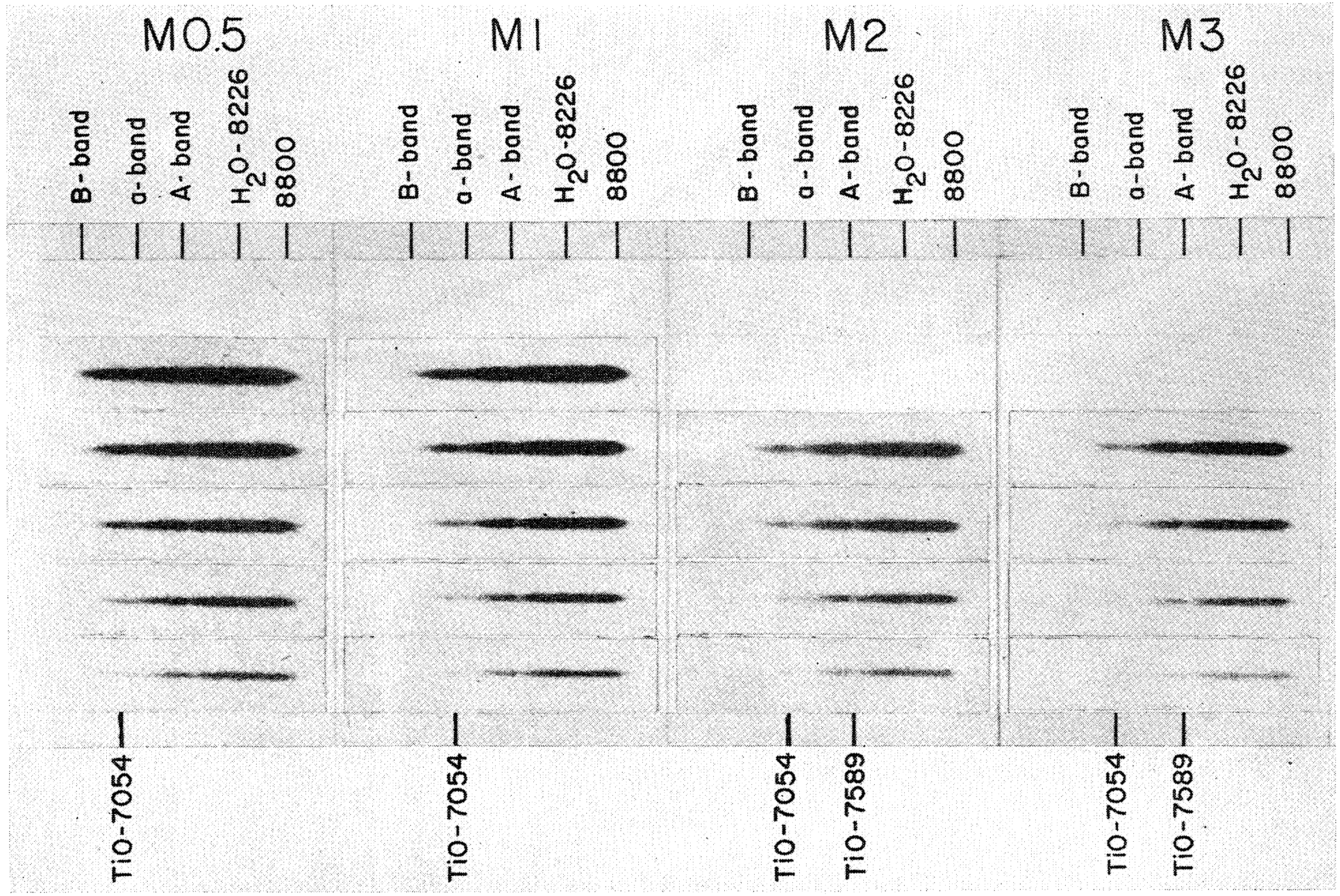


FIG. 2.—Spectra of faint Wolf-Rayet stars. *a* and *b* are Robert's Nos. 97 and 87, respectively. *c*, "Campbell's hydrogen envelope star" *d*, "New Wolf-Rayet star" (see Pik-Sin The 1963)



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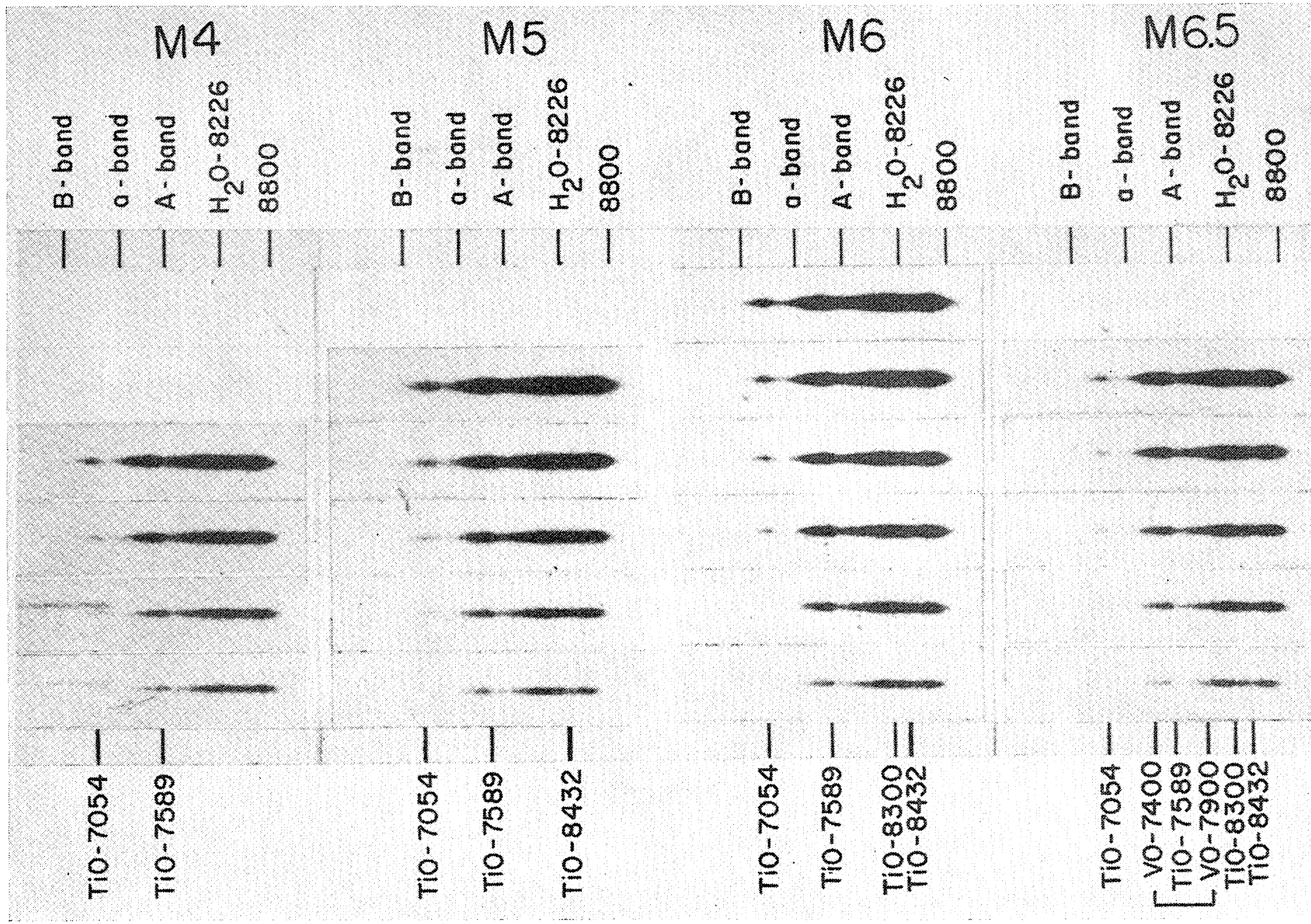

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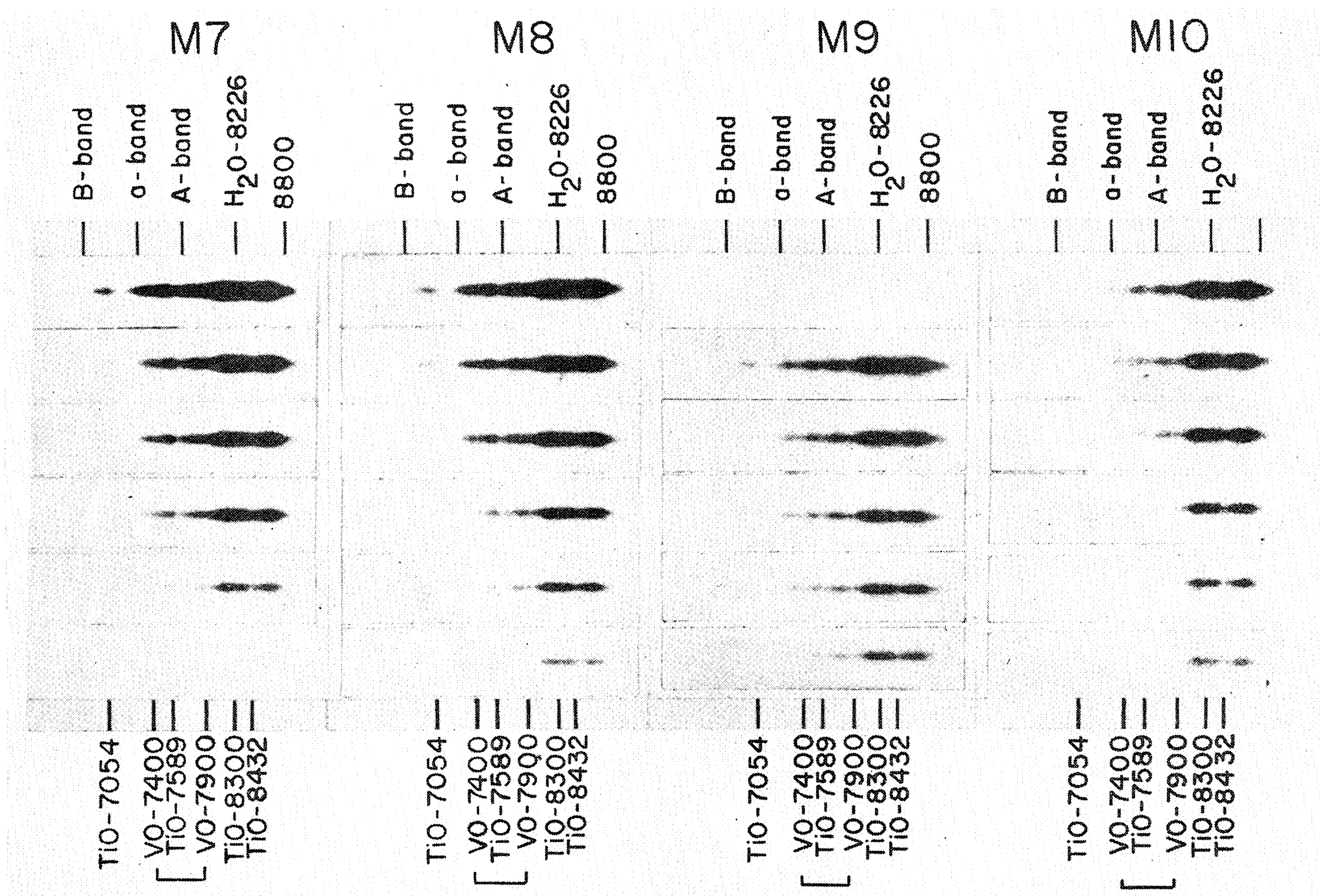

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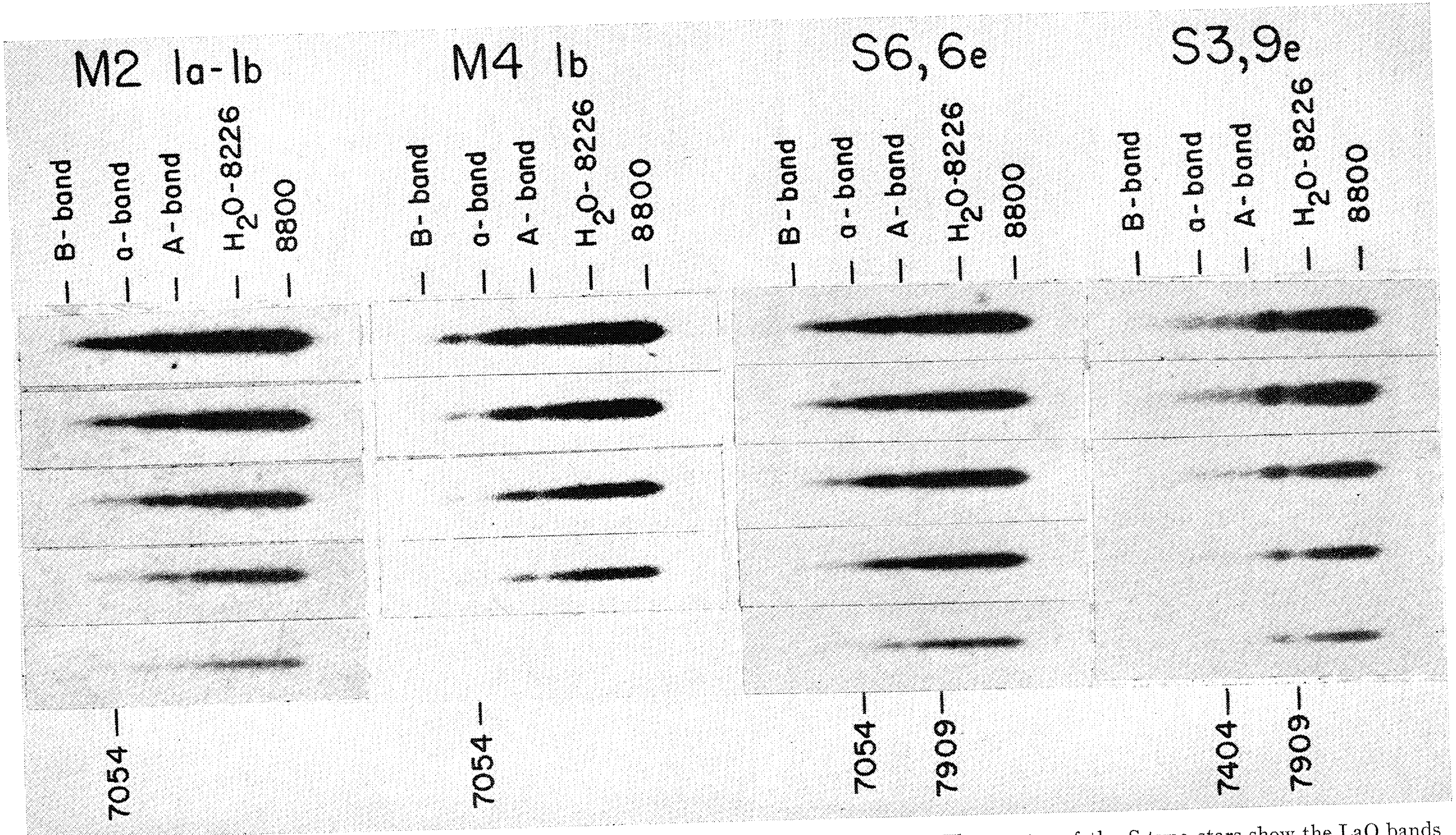

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