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# CCD SPECTROSCOPY OF NEW M-TYPE SUPERGIANTS IN THE SOUTHERN MILKY WAY

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RESUMEN. Estamos obteniendo espectros CCD de posibles M supergigantes nuevamente identificadas en placas I-N tomadas cerca del plano galáctico austral con prisma objetivo de baja dispersión. Los espectros cubren el rango 6400-8800 A con una resolución de 8 A. Hemos tomado espectros de 180 estrellas al menos una vez, y obtuvimos los espectros de 40 estándares MK de tipo tardío y luminoso. Se usan las estrellas estándar para calibrar los anchos equivalentes del triplete del Ca II como función de luminosidad y temperatura, y usamos la calibración como criterio principal para la clasificación de los espectros. El análisis de este material indica que encontramos >60 nuevas supergigantes K/M, algunas de alto enrojecimiento, y algunas nuevas estrellas tipo S. Esta búsqueda al menos dobla el número de supergigantes tardías conocidas en las areas buscadas. Creemos que algunas de estas estrellas están a distancias de 5 a 6 kpc y que la búsqueda tendrá un impacto significativo en estudios de estructura galáctica y de la evolución de estrellas masivas.

ABSTRACT. We are obtaining CCD spectra of possible new M supergiants identified on low-dispersion, I-N objective-prism plates taken near the southern galactic plane. The spectra cover the range 6400-8800 A with a resolution of 8 A. The spectra of 180 stars have been observed at least once, and the spectra of about 40 late-type, luminous MK standards have been obtained as well. The standards are used to calibrate equivalent widths of the Ca II triplet as a function of luminosity and temperature, and this is the principal criterion used to classify the CCD spectra. Analysis of this material indicates that there are >60 new K/M supergiants, some very heavily reddened, and a few new S stars in the sample. This at least doubles the number of late supergiants known in the areas searched. We expect that some of these stars lie at distances of 5 to 6 kpc and that the survey will have a significant impact on studies of galactic structure and massive star evolution.

*Key words:* STARS-CLASSIFICATION -- STARS-LATE-TYPE -- STARS-SUPERGIANTS

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## I. INTRODUCTION

In an attempt to improve knowledge of the distribution of cool supergiants along the southern galactic plane, some years ago the first author began a low-dispersion, objective-prism survey on near-infrared plates taken with the Curtis Schmidt camera at CTIO. The dispersion of the plates is 3400 A/mm at the A-band and the deepest reach I~13. Candidate supergiants are selected by their wedge-shaped appearance and weak TiO bands; the method was first used by Nassau, et al. (1954) on shallow, northern plates and by Blanco and Münch (1955) in the south and led to the discovery of several dozen M supergiants. In the present survey, 59 fields have been searched thus far resulting in about 2000 candidates. The outline of the region surveyed to date, two windows about 40 deg in length centered on the galactic plane, is shown in Figures 1a and 1b.

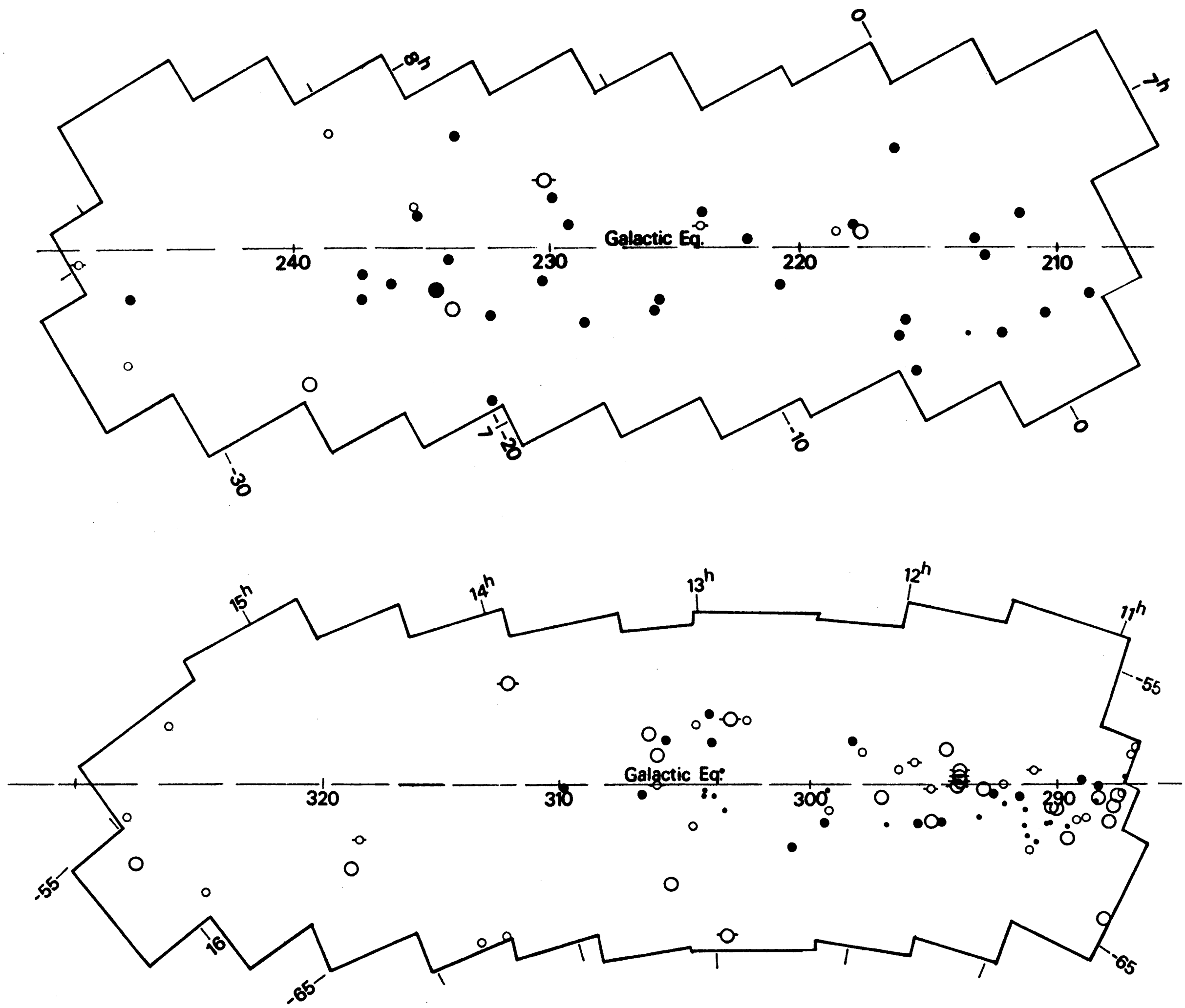



Fig. 1a. Surface distribution of K and M supergiants in the northern sector of the survey. Filled circles are probable new supergiants according to the CCD spectra, and open circles denote ones in the literature (slit-confirmed). The largest circles indicate stars of V < 8, intermediate circles are for stars of 8 < V < 12, and the smallest ones are for stars of V > 12. Lines extending from open circles denote known supergiants refound in the present survey.

Fig. 1b. Same as Figure 1a for the southern sector of the survey.

The cool supergiants are important by reason of their youth and relatively large mass. They populate the spiral arms and can be seen over large distances particularly in the near-infrared where the interstellar extinction is half that at visual wavelengths. The distribution of red supergiants fainter than V=10 is poorly known due to the lack of previous deep surveys as Humphreys and co-workers (see e. g. Humphreys and McElroy 1984) have made clear. This is especially the case interior to the solar circle where the lack of red supergiants (and the decrease in the ratios OB/red and WR/red with galactocentric distance) has been interpreted as a metallicity gradient. The ratios are also important constraints on evolutionary models of massive stars as Meylan and Maeder (1983) and Brunish, et al. (1986) have emphasized.

## II. THE CCD SPECTROSCOPY

The candidate stars found in the survey can, in fact, come from several natural groups. Aside from true K/M supergiants, some S stars and giants of types K and M and even earlier stars of all luminosities if sufficiently reddened may appear in the sample. In order to classify the program stars, we have been obtaining follow-up observations in the Wing eight-color system since early 1984 and near-infrared CCD spectra since early 1985. We have used the 1.0- and 1.5-m telescopes at CTIO for these observations. Wing, et al. (1986) have discussed the photometry, and here we consider the spectra.

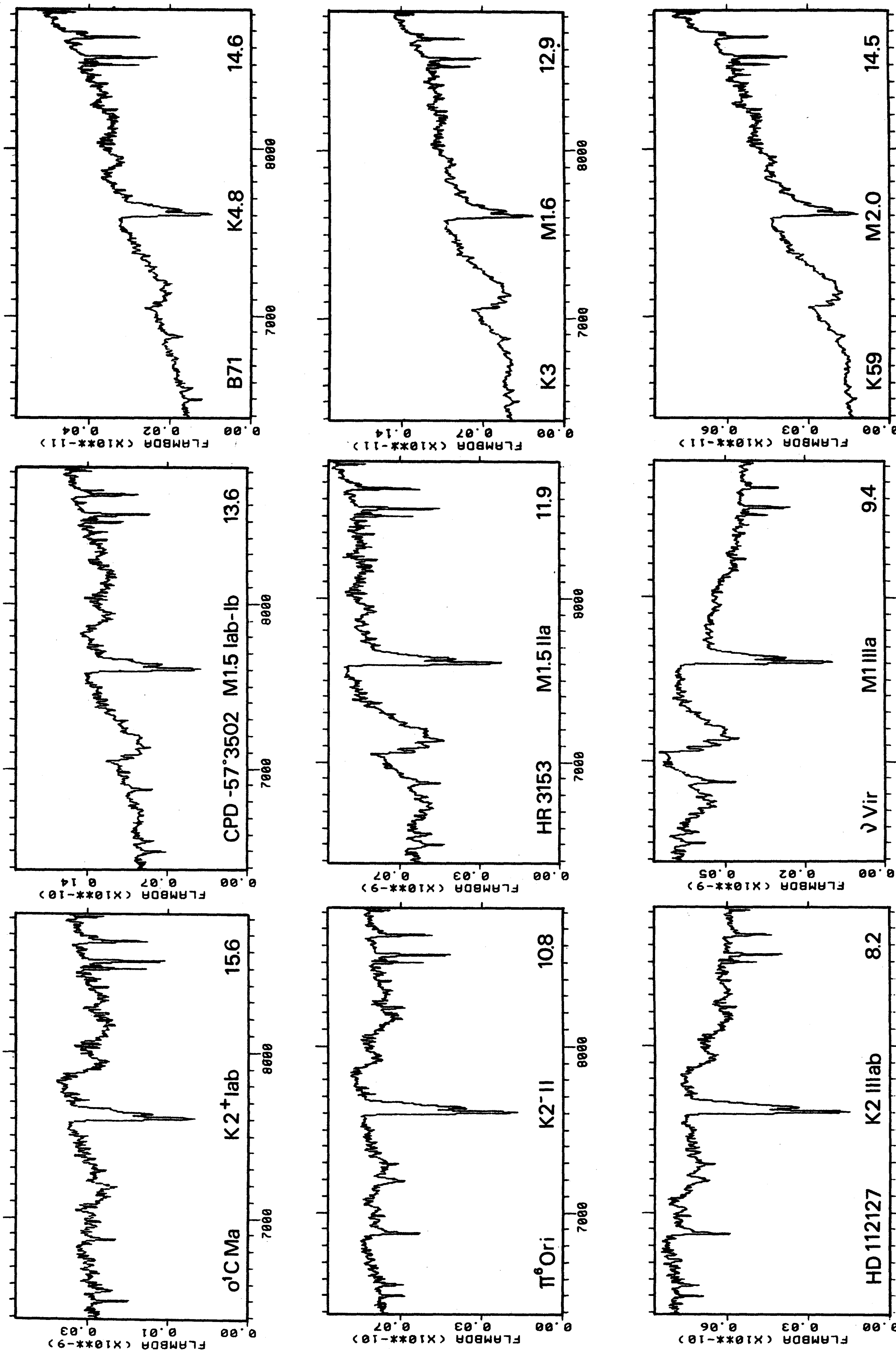
We have spectra available for 180 candidate stars taken at 4 A/pixel over the range 6400-8800 A and for a subset of 35 stars taken at 1.6 A/pixel over the range 7975-8900 A. The stars observed were selected with some bias toward the brightest and those with the most prominent wedged shape. We also have spectra of about 40 Keenan standards of type K0 and later and of giant luminosity and brighter at both dispersions. Figures 2a,b and 3a,b show the spectra of the same sample of early K and M standards at the low and high dispersions, respectively. The positive correlation between CN-band strength (either side of 8000 A), Ca II line depth, and luminosity is evident. The CN strength at 8120 A (and at 1.1μ) determines the luminosity in the Wing system, and here we have used the sum of the equivalent widths of the Ca triplet, given in the lower right of each tracing, as the luminosity discriminant. The usefulness of the triplet as a luminosity indicator was first discussed by Merrill (1934) and most recently by Jones, et al. (1984) and by Schulte-Ladbeck (1986). To obtain the equivalent widths, we have used the ALINES program, written by Dr. J. Baldwin at CTIO, and the ROO package at Michigan State Univ. as implemented by Dr. S. Simkin; the results are nearly independent of the software used.

Figures 4a,b give the sum of the Ca EWs using ALINES for the standard stars as a function of spectral type and luminosity for the 4 A/pixel and 1.6 A/pixel spectra, respectively. It is clear from the diagrams that the most consistent results are obtained for the K stars and that the results degrade as one approaches the mid-M stars. The increasing strength of the TiO band at 8432 A after M4 makes it difficult to assign the continuum level for stars this late. The lines in each diagram divide the stars into supergiants and non-supergiants with a few notable exceptions.

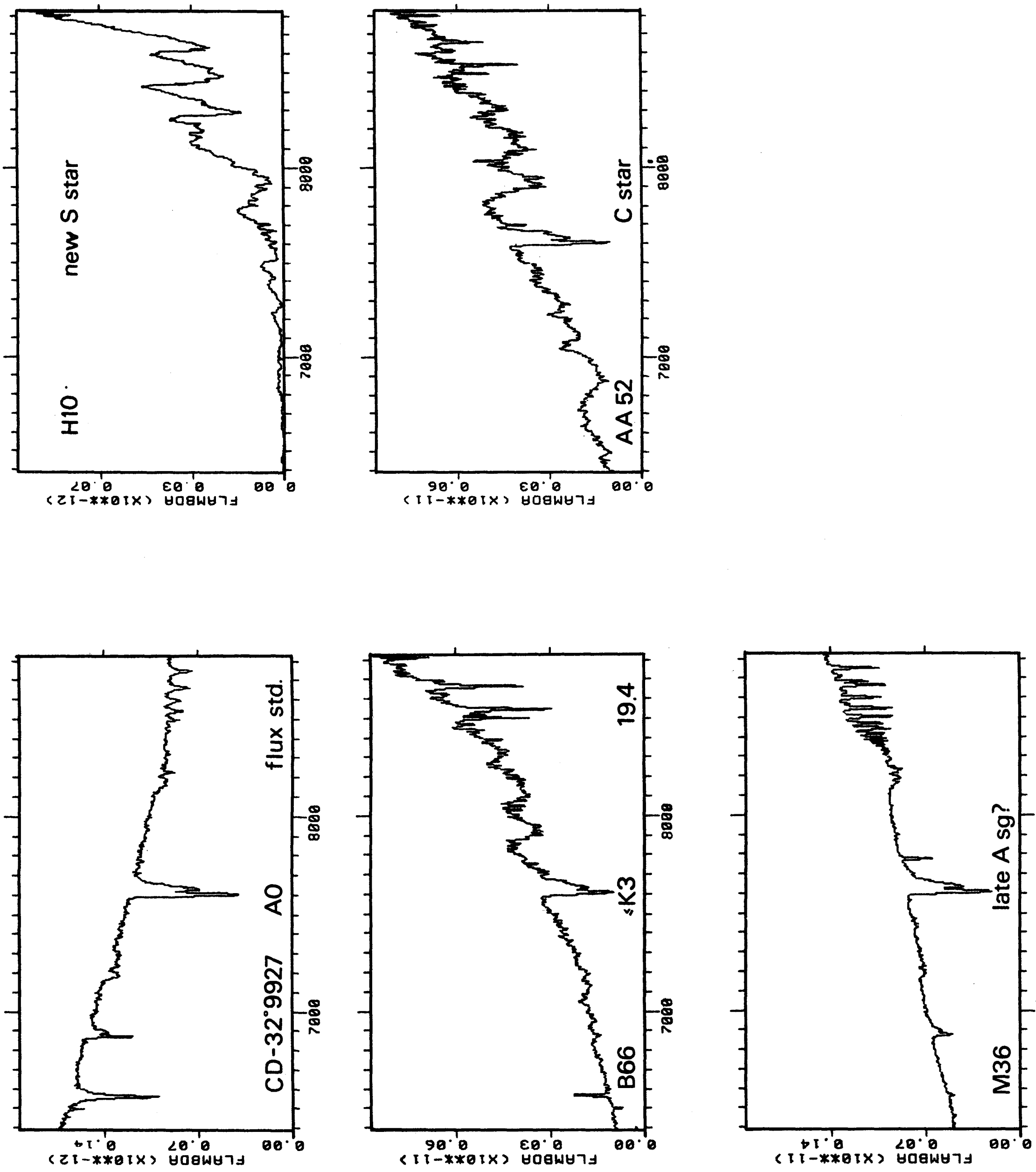
Figures 2c and 3c give the spectra at the two dispersions of three program stars found to be supergiants on the basis of their positions in Figs. 4a,b; their temperature types are known from the 8-color photometry. The effect of interstellar reddening is especially evident in Fig. 2c. These spectra are typical of the program stars we expect are new supergiants. In Figs. 2d,e we give a montage of spectra of non-M-type stars. The star CoD-32 9927 is a flux calibration standard and was included to show the positions of the telluric absorption bands, H-alpha, and the higher members of the Paschen series. The other four stars were found in the survey: B66 is earlier than K3, has very strong CN and Ca II, H-alpha in emission, and very large reddening; M36 is a new (probable) late A supergiant which shows the luminosity-sensitive O I line at 7774 A and a large Paschen jump. Again, its reddening is evident. Figure 2e shows two intrinsically red stars. The top spectrum is of a new, pure S star with three prominent Keenan bands, and the bottom spectrum shows the very strong CN bands (although they are not seen on the survey plates) of a rediscovered carbon or C-S star of Stephenson (1985, 1986).

## III. DISCUSSION AND CONCLUSIONS

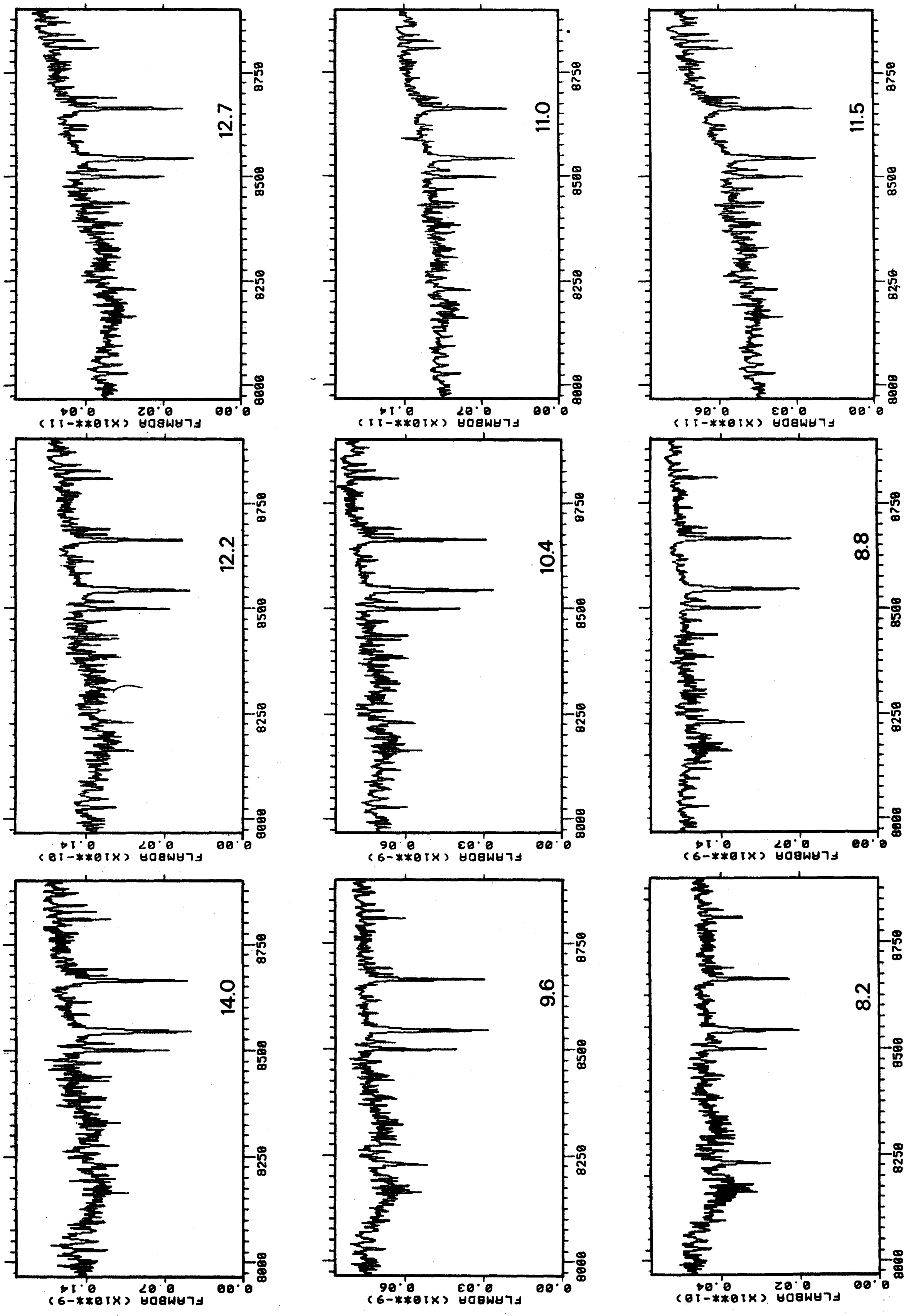
The data on hand are still undergoing analysis, and we have many further candidate stars to observe and more plates to survey, so we will not attempt to draw any far-reaching conclusions. Figures 1a,b give the distribution of the cool supergiants with symbols dis-




Figs. 2a-c. CCD spectra at 4 A/pixel of a sample of cool MK standards and program stars. The sum of the CA II equivalent widths using the ALINES program is given in the lower right of each panel for the relevant stars. See text for discussion.




Figs. 2d-e. Same as Figures 2a-c.




Figs. 3a–c. Spectra at 1.4 A/pixel of the stars in Figures 2a–c, respectively.

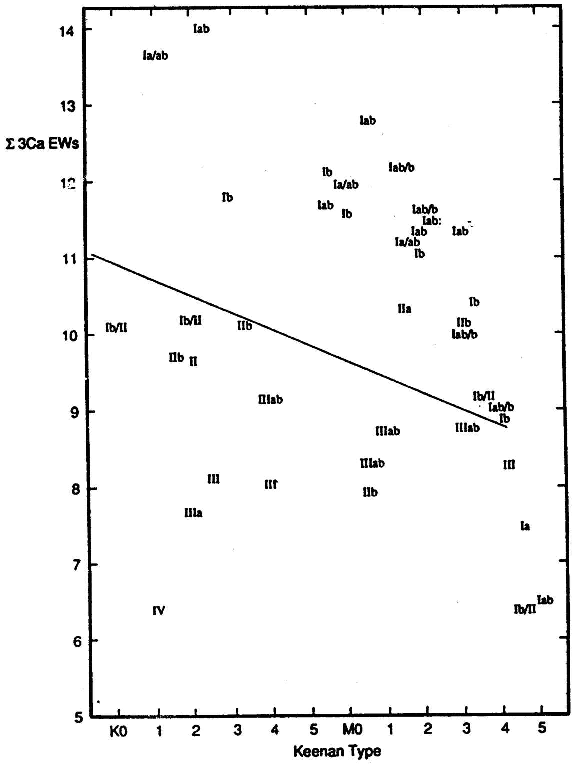



Fig. 4a. Sum of the Ca II equivalent widths as a function of spectral type and luminosity for the MK 4 A/pixel. The line approximately divides the stars into supergiants and non-supergiants.

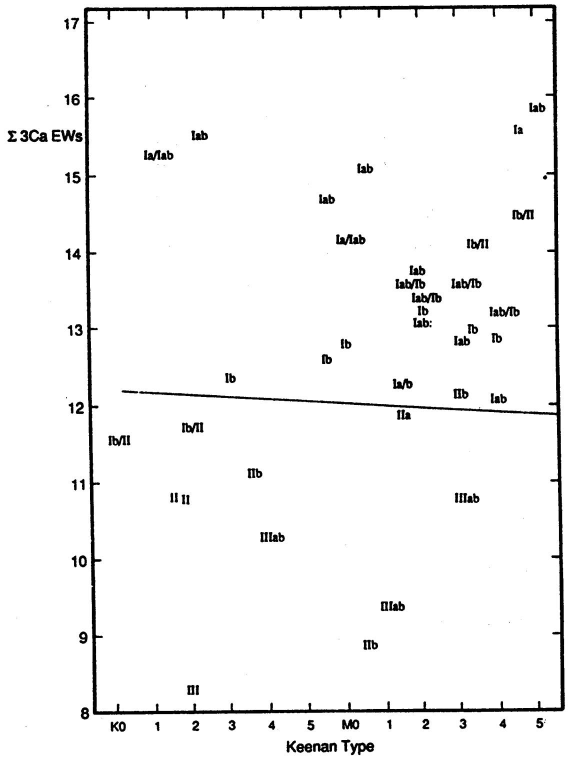



Fig. 4b. Same as Figure 4a for the 1.4 A/pixel spectra.

tinguishing those known previously from the ones discovered in this study, and two things are evident; 1) we have more than doubled the number of late supergiants and 2) the new ones are fainter and presumably more distant than those in the literature. The visual magnitude estimates were made from short-exposure, direct plates taken with the Curtis Schmidt camera. Table 1 summarizes the numerical results in the areas surveyed; the numbers in parentheses give the number of known supergiants refound in the survey, and the figures in the final columns give the percentages of stars in the three magnitude ranges for the new ones discovered in this

TABLE 1. Numbers of Late Supergiants in the areas surveyed

| Sector | No. known | No. this survey | % V<8 | % 8<V<12 | % V>12 |
|---|---|---|---|---|---|
| 208<l<248 | 10 ( 3) | 31 | 3 | 94 | 3 |
| 288<l<328 | 47 (11) | 32 | 0 | 44 | 56 |

survey. It is noteworthy that the majority of stars in the higher-longitude sector are fainter than V=12. These statistics clearly have to do with the facts of galactic structure where, in the lower-longitude sector, we may be seeing the extension of the relatively-nearby Perseus arm whereas in the higher-longitude region, we are looking to large distances tangential to the Carina arm. There seems to be little support from the present data, however, for the fainter stars having smaller values of latitude than the brighter ones as might be expected if we were observing a single, flattened population at varying distances. The sudden drop in new supergiants with l>240 and l>310 in Figs. 1a, 1b may be mostly due to observational selection since we have not yet observed all high-priority candidates in those regions.

Finally, we note that all but ten of the new stars are in the IRAS Point Source Catalogue and that many of those brighter than V=10 are also in an unpublished list of Sanduleak and/or in the survey of Albers (1974). We will soon publish the details of the stars' positions, reddening estimates, etc. elsewhere.

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