Rev. Mexicana Astron. Astrof., **14**, 362-366 (1987)

NEW M-TYPE SUPERGIANTS IN THE SOUTHERN MILKY WAY

R. F. Wing *

Astronomy Department, Ohio State University
Columbus, Ohio, U.S.A.

D. J. MacConnell *

Computer Sciences Corporation, Space Telescope Science Institute
Baltimore, Maryland, U.S.A.

and

E. Costa *

Departamento de Astronomía, Universidad de Chile
Santiago, Chile

RESUMEN. Una búsqueda infraroja con prisma objetivo ha encontrado un número grande de posibles supergigantes de tipo tardío a lo largo del plano galáctico austral. Las observaciones subsecuentes con fotometría de bandas estrechas y con espectroscopía CCD han confirmado que más de 100 de los candidatos son verdaderamente supergigantes de tipo K o M, incrementando substancialmente la cuenta de tales estrellas conocidas en esta parte del cielo. Debido a que las distancias pueden ser estimadas para estas estrellas en base de los datos espectroscópicos y fotométricos, las nuevas supergigantes deben ayudar a mejorar nuestro conocimiento de la estructura espiral en esta parte de la Galaxia.

ABSTRACT. An infrared objective-prism survey of the southern Milky Way from longitude 210° to 320° has revealed a large number of likely supergiants of late type. Follow-up observations by narrow-band photometry and CCD spectroscopy have confirmed that more than 100 of the candidate stars are indeed supergiants of types K and M, increasing very substantially the number of such stars known in this part of the sky. Since distances can be estimated for these stars from the spectroscopic and photometric data, the new supergiants should help to improve our knowledge of the spiral-arm structure of this part of the Galaxy.

Key words: STARS-LATE TYPE -- STARS-SUPERGIANTS -- GALAXY-STRUCTURE

I. INTRODUCTION

Our knowledge of the spiral-arm structure of our Galaxy has been obtained primarily from optical observations of early-type supergiants and H II regions, and from radio observations of the 21-cm line of neutral hydrogen and millimeter transitions of carbon monoxide. Because of the scarcity of supergiants and the difficulty of assigning distances to gas clouds, the picture is far from complete.

* Visiting Astronomer, Cerro Tololo Inter-American Observatory, National Optical Astronomy Observatories, operated by the Association of Universities for Research in Astronomy, Inc., under contract with the National Science Foundation.

Late-type supergiants offer the possibility of bringing this picture into sharper focus because they are reasonably numerous, young enough to be confined to the spiral arms, and bright enough to be seen in distant parts of the Galaxy, especially when infrared observations are used. Unfortunately, previous surveys for late-type supergiants have not reached very faint magnitudes in the southern hemisphere, and consequently our knowledge of the spiral structure interior to the Sun's position in the Galaxy is particularly sketchy.

This paper is a progress report on a project directed at discovering new late-type supergiants in the southern Milky Way and obtaining the spectroscopic and photometric observations needed to determine their distances. Already we have found more than 100 new supergiants of late type, more than doubling the number known in the regions surveyed.

II. OUTLINE OF OBSERVING PROGRAM

Three kinds of observations are used in this project:

1) Objective-prism spectra obtained with the Curtis Schmidt telescope at Cerro Tololo Inter-American Observatory (CTIO) are used to identify possible late-type supergiants. These unwidened spectra have a dispersion of 3400 Å/mm at the A-band and are recorded on I-N plates, covering the near-infrared region from 6800 to 8800 Å and reaching stars as faint as $I = 13$.

2) Narrow-band photometry of stars selected from the Schmidt plates is being obtained with the CTIO 0.9-m, 1.0-m, and 1.5-m telescopes. We are using a set of eight interference filters which measure molecular bands and continuum points between 7100 and 11000 Å (Wing 1971); the detector is a Varian VPM159A photomultiplier. This photometry provides not only magnitudes and colors but also the spectral information needed for two-dimensional classifications of M stars.

3) CCD spectra are also being obtained for as many of the candidate stars as possible with the CTIO 1.0-m telescope. Two different dispersions are used, again in the near infrared. A number of sample spectra are shown elsewhere in this volume (MacConnell, Wing, and Costa 1987).

The objective-prism survey has been carried out entirely by MacConnell and is described in MacConnell et al. (1986, 1987). All three authors have been engaged in the collection and reduction of the follow-up observations.

It is noteworthy that the whole project can be carried out at CTIO with telescopes of the one-meter class. We have been able to detect late-type supergiants at great distances -- and in large numbers -- because they are very bright in the infrared and the dispersion of our survey plates is extremely low. The follow-up photometry, with bands narrow enough for spectral classification, can be done with small telescopes because of the great sensitivity of the Varian cell, which exceeds that of an S-1 cell by a factor of 40 at 10000 Å. It is likewise the sensitivity of the CCD detector that makes our spectroscopy program possible. We are indeed fortunate that all the needed instrumentation is available on the smaller telescopes at CTIO; if any part of the project required the use of the 4-m telescope it is unlikely that sufficient observing time could be made available to complete the work. We have also benefited from the fact that dark skies are not needed since all of our observing is done in the near infrared.

Further details of the objective-prism survey and the spectroscopic follow-up observations are given in our display presentation (MacConnell et al. 1987). Below we discuss the photometry program and the results obtained from it to date.

III. THE EIGHT-COLOR PHOTOMETRY

The filters of this system have widths of 40-70 Å at half-power and were chosen (Wing 1971) to provide explicit measures of the band strengths of TiO, VO, and CN. The VO bands appear only at the late M subtypes, but the other two molecules are present in nearly all stars later than about type K3. Since the TiO bands are sensitive to temperature and quite insensitive to luminosity, while the reverse is true for CN, the measures of TiO and CN can be used effectively for the two-dimensional classification of M and late K stars (White and Wing 1978; Wing and White 1978).

Other quantities provided by the photometry are the apparent magnitude at 10400 Å, designated I(104), and the observed color. Of the several ways available to express a star's color, the magnitude difference m(7540)-m(10540) is the one least affected by blanketing in M stars earlier than M7.

In principle, the eight-color photometry provides all the information needed to assign distances to late K and M supergiants. In particular, the reddening can be measured and allowed for because the band-strength indices used for classification are defined as depressions at specific wavelengths and hence are independent of the reddening. However, quite a bit of calibration work needs to be done before we can derive distances with confidence, and we do not yet know how accurate our results will be. We need to establish -- through observations of supergiants in clusters and associations of known distance and reddening -- the absolute magnitudes M(104) at 10400 Å and intrinsic colors m(7540)-m(10540) of the supergiants as a function of their two-dimensional classifications. Preliminary calibrations are available from observations in h and χ Persei (Warner and Wing 1977), but further work is needed before the full potential of the eight-color system can be realized.

Given the calibrations mentioned above, the procedure for determining the distances of individual stars from eight-color measurements of I(104), m(7540-m(10540), TiO, and CN is the following: (1) look up the intrinsic color corresponding to the observed TiO index (this may also depend slightly on the luminosity class, as indicated by the CN index); (2) determine the color excess from comparison of the observed and intrinsic color; (3) use a mean interstellar reddening law to determine the absorption at 10400 Å from the color excess, and correct the I(104) magnitude for absorption; (4) assign an absolute magnitude M(104) on the basis of the CN index (this may also depend slightly on the spectral type); and (5) calculate the distance from this absolute magnitude and the corrected apparent magnitude.

The main problems with this method of determining distances revolve about the measurement and use of the CN index. For one thing, the (0,0) band of CN is difficult to measure accurately because of rapidly decreasing detector sensitivity near 11000 Å, while all the CN bands of shorter wavelength are contaminated by TiO absorption. Also, the relation between CN strength and absolute magnitude must have some intrinsic scatter due to composition differences among stars; indeed, giant stars of type S may have CN strengths similar to those of much more luminous M supergiants. For these reasons we have decided not to rely entirely upon the photometry but to obtain spectroscopic observations as well for as many stars as possible. The spectra allow us to recognize various kinds of peculiarities and to assign luminosity classes on the basis of the infrared triplet of Ca II. At this point we don't know whether CN or Ca II is the more reliable luminosity indicator, but at any rate we will soon have the data needed to examine the correlation between the two.

IV. STATUS OF THE PHOTOMETRIC OBSERVING PROGRAM

Since March 1984, when we started collecting eight-color photometry for stars marked on the objective-prism plates, we have obtained 640 observations of 385 different stars. The observations have been reduced, and spectral classifications derived, at the Ohio State University. In general, classifications of the same star on different nights are in good agreement, although we have noted several discordant luminosity classes, which are harder to measure than the temperature classes. These follow-up observations have been concentrated in the two intervals of galactic longitude described by MacConnell et al. (1987).

Since the 385 stars observed to date represent only a small fraction (less than 20%) of the candidate stars marked in these longitude intervals, it would be premature to draw conclusions about galactic structure at this time. We can, however, usefully inquire as to the fraction of candidate stars that are confirmed as supergiants by the eight-color photometry. The results are shown in Table 1. The largest proportion of stars (51%) are of luminosity classes II and III, and although many of them appear to be somewhat more luminous than typical giants, they cannot be considered supergiants. On the other hand, 117 stars have been confirmed as supergiants, most of them new (these include 13 stars of spectral type earlier than K4). When this figure is compared to the 58 stars previously known to be late-type supergiants in the regions surveyed (as confirmed by slit spectroscopy), it is clear that our technique is very successful in increasing the number of such stars available for galactic-structure studies.

The 64 stars listed as "uncertain" include border-line cases whose CN indices are close to the rather arbitrarily chosen border between luminosity classes Ib and II, as well as stars with discordant data on different nights. All these stars will be observed again if possible. A few stars in the sample have been found to be mild cases of S and C stars.

TABLE 1

RESULTS FROM PHOTOMETRY PROGRAM

	n	%
Confirmed supergiants . . .	117	30.4
Class II and III giants . . .	197	51.2
Uncertain (need more data) . .	64	16.6
S and C stars	7	1.8
	385	100.0

An interesting preliminary result is that the success rate in confirming candidates as supergiants is distinctly different in different longitude intervals. In the Puppis-Monoceros region, where we see an arm that is quite close to the Sun, we have many bright candidates and nearly all of the ones tested to date have proved to be supergiants. On the other hand, in the Carina region the spiral arm is more distant, the candidates fainter, and only about one-quarter of them prove to be supergiants, the remainder being inter-arm giants lying at various distances along the line of sight.

V. DISCUSSION

If our overall success rate -- about 1 in 3 -- of confirming supergiants seems low, it should be pointed out that the survey spectra are of such small scale that they provide very little spectral information. Indeed, stars earlier than about type M3 show no trace of TiO absorption (or other features) on the survey plates, and they are marked as candidates purely on the basis of their red color which causes the unwidened spectrum to have a tapered appearance. Since redness is often enhanced by interstellar reddening, and since reddening tends to be much greater for distant supergiants than for giants of the same magnitude, a substantial number of the candidate stars do turn out to be supergiants. If our survey plates had higher dispersion, we might more often be able to recognize and exclude the ordinary giants, thus reducing the number of follow-up observations needed, but we would then have a brighter limiting magnitude and would not reach the most distant -- and therefore most interesting -- of the supergiants.

The ordinary giants found in this study are not without interest. Since distances and reddening values can be determined for them in the same manner as for the supergiants, the inclusion of inter-arm giants will allow us to give a more complete account of the distribution of interstellar dust in the Galaxy.

We have been greatly encouraged by our success in finding new supergiants of late type, but a good deal of observing remains to be done to complete the project. We only hope that the CTIO telescope allocation committee will not lose patience with us.

We are grateful to the staff of Cerro Tololo Inter-American Observatory for help in obtaining the observations discussed here, and to Mr. Rob Landis for help in reducing them.

REFERENCES

MacConnell, D.J., Wing, R.F., and Costa, E. 1986, in IAU Symposium No. 116: Luminous Stars and Associations in Galaxies, ed. C.W.H. de Loore, A.J. Willis, and P. Laskarides (Dordrecht: D. Reidel), p. 123.

MacConnell, D.J., Wing, R.F., and Costa, E. 1987, Rev. Mex. Astron. y Astrof. (this vol.), p. .

Warner, J.W., and Wing, R.F. 1977, Astrophys. J. 218, 105.

White, N.M., and Wing, R.F. 1978, Astrophys. J. 222, 209.

Wing, R.F. 1971, in Proc. Conf. on Late-Type Stars, ed. G.W. Lockwood and H.M. Dyck (Tucson: KPNO Contr. No. 554), p. 145.

Wing, R.F., and White, N.M. 1978, in IAU Symposium No. 80: The HR Diagram, ed. A.G.D. Philip and D.S. Hayes (Dordrecht: D. Reidel), p. 451.

DISCUSSION

SERRANO: How large are the variations in CN strength due to differences in chemical composition? Do they affect the luminosity classes?

WING: Unfortunately, there is almost no limit to the changes in CN strength that can be caused by abundance differences: carbon stars have stronger CN than M stars of any luminosity. But evidently this is not a serious problem among the M supergiants, since for MK standard stars the luminosities determined from CN agree well with spectroscopic luminosities from atomic line ratios. This is a more serious problem for the class III giants, which have a wider range of population type.

FUENMAYOR: To which luminosity classes do the new carbon stars belong?

WING: We do not have a way to judge the luminosities of individual carbon stars. Their CN strengths are sensitive to the CNO abundances, and we do not even know if they show a luminosity effect at all. We cannot determine their reddening, either.

TAPIA: Do you have plans for extending the photometric studies of your sample to the two-micron or even the three-micron region? That would be important, for example by providing better calibrations of the CO and H_2O narrow-band indices.

WING: No, we have no such plans. It would take a great deal of telescope time to measure CO and H_2O indices in this large sample of faint stars. But we have found that most of our program stars are contained in the IRAS point-source catalogue, and we do intend to study the far-infrared colors of these stars as a function of our classifications.

FIRMANI: In terms of the galactocentric distance do you confirm the anti-correlation between the upper luminosity limit of the supergiant branch with the number of late nitrogen Wolf-Rayet stars?

WING: I do not have an answer to your question, but I should think that the larger sample of cool supergiants will be helpful for examining any such correlation.

MacCONNELL: Our survey is now reaching into the interior of the solar circle where we are beginning to find new red supergiants. I think the WR/M_{sg} anti-correlation will look very different when we are finished.

Edgardo Costa H.: Departamento de Astronomía, Universidad de Chile, Casilla 36-D, Santiago, Chile.
Darrell Jack MacConnell: Astronomy Programs, Computer Sciences Corporation, Space Telescope Science Institute, 3700 San Martin Drive, Baltimore, MD 21218, U.S.A.
Robert F. Wing: Astronomy Department, Ohio State University, 174 West 18th Avenue, Columbus, OH 43210, U.S.A.