1983JAVSO..12...58C

A SPECTRAL CATALOGUE OF SOUTHERN HEMISPHERE MIRA VARIABLE STARS

RICHARD A. CROWE
David Dunlap Observatory
Department of Astronomy
University of Toronto
Toronto, Ontario M5S 1A1
Canada

Abstract

The catalogue of Keenan, Garrison, and Deutsch (1974) has been extended by the addition of 483 blue spectrograms of 72 Southern Hemisphere Mira variables. About 190 direct and image-tube plates at a dispersion of 120 Å/mm were obtained in Chile between 1977 and 1982. Along with the spectral types and photographic magnitudes, emission ratios Hδ λ4101/Hγ λ4340/Hβ λ4861 and eye-estimated intensities of the absorption lines CaI λ4226, CrI λ4254, and SrII λ4077 have been tabulated. Spectral intensity tracings and magnitude-phase diagrams are displayed for a few of the best-studied Miras in the Southern Hemisphere program.

* * * * *

1. Introduction

Over the past five years, I have been using AAVSO phases of Mira variables in order to plan my observing program as part of my preparation of an extension of the catalogue of Keenan, Garrison, and Deutsch (1974) (hereafter KGD) with the addition of 483 blue spectrograms of 72 Southern Hemisphere Mira variables. These spectrograms were obtained on direct and image-tube plates between 1977 and 1982 with the University of Toronto's 24-inch telescope at Las Campanas Observatory in Chile. Most of the 190 plates were photographed at a dispersion of 120 Å/mm, but a small number of them were taken at a scale of 67 Å/mm. Along with the spectral types and blue magnitudes, eye-estimated intensities of some important absorption lines of calcium (Ca), chromium (Cr), and strontium (Sr) have been tabulated. In addition, relative strengths of hydrogen emission lines (of the Balmer series) and of metallic iron (Fe) and magnesium (Mg) emission lines have been estimated whenever visible. Here, I will focus my attention on a few Miras which have been particularly well-studied due to adequate phase coverage. This coverage was the result of the work of those dedicated AAVSO observers who contributed to the light curves and who thus helped me plan my observing more efficiently.

2. Criteria for Classification

The temperature classification of M stars is based on the relative strengths of titanium oxide (TiO) bands; the cooler the star, the stronger the bands. Because the temperature of a Mira variable changes over the course of a cycle, the TiO bands vary in strength; therefore, the spectral type varies also (an "earlier" type refers to a higher temperature). In addition, there are effects which can distort spectral type estimates based on absolute strengths. The most important of these effects is the so-called line-weakening phenomenon in Miras, which is especially pronounced in the older generation (Population II) group with periods from 140-250 days, or earlier than type M5e at maximum light (Garrison 1972). The difference in these stars relative to non-variable M giants of the same spectral type is an apparent weakening of strong absorption lines and TiO bands. This situation may lead one to assign a type that is too early, unless band ratios are used. The weakening is also present in those younger (Population I) Miras (P>250 days) later than type M5 at maximum light, but here the phenomenon is more complex and cannot be entirely explained by abundance effects (Garrison 1972). For spectral types later than M8, the classification becomes difficult, since there are no non-variable standards! There is an added complication at faint phases in that the spectrum takes on a "washed-out" appearance, with loss of contrast in the TiO bands and a "blurring" of the atomic lines (they become shallower and wider). This condition has been referred to as "veiling" by many investigators (Garrison 1972); it may be produced by the formation of high-level atmospheric clouds which vary in thickness, density, and level. The apparent weakening of strong TiO bands may again lead to the assignment of a spectral type which is too early.

3. Representative Spectral Changes

Illustrations of the spectra of six Mira variables as well as a complete list of the stars studied in my Southern Hemisphere program are given in Crowe (1984). Phases were determined from observational data sent to me by the AAVSO Director, J. A. Mattei (1984). Spectral types and absorption line strengths were estimated from the spectrograms. The intensities of the hydrogen emission lines and of the post-maximum metallic emission lines were determined from intensity tracings produced by scanning direct plates on the PDS microdensitometer at the David Dunlap Observatory. It is thought that the hydrogen emission is produced by atmospheric material which has been excited to high temperature by the passage of a shock wave. The metallic Fe emission is probably produced by a process called fluorescence, in which pre-shock (unshocked) gas is excited by ultraviolet photons emerging from layers which have already been shocked (cf. Willson 1976; Barnes and Willson 1980). The Mg emission is thought to be a consequence of the dissociation of magnesium hydride (MgH) molecules in shocked regions (Merrill 1940).

Spectral intensity tracings for a few representative stars over the wavelength range λ4000 - λ4400 are shown in Figures 1 and 2. These spectra are rectified; that is, the continuum level is set to 1. The continuum is established by choosing points of highest intensity where emission is absent in the spectrum. At these wavelengths, photons suffer relatively little absorption on their way out of the atmospheric layers. The emission line intensities are then calculated as a multiple of this continuum level. Due to variability and changing velocity gradients of 20-70 km/sec in the Mira atmospheres, the selected continuum points change with each spectrum!

The tracings show that there are enormous changes in the Ca λ4226 line and in the hydrogen emission lines, Hδ λ4101 and Hγ λ4340. As a shock wave emerges from the lower atmosphere during the approach to maximum light, the hydrogen emission strengthens and the neutral atomic zero-volt lines (such as Ca λ4226 and Cr λ4254) weaken. However, as the shock builds in intensity on the rising branch, Hγ increases in strength relative to Hδ. This relative increase occurs because Hγ is in a region of the spectrum more heavily obscured by TiO, which implies that the absorption layer lies above the emission layer (Merrill 1940). The Ca λ4226 line becomes much narrower and shallower as the star brightens and as the H lines strengthen. See the tracings of R Horologii in Figure 1a. This change could be due both to an increase in the temperature and to the presence of the velocity gradient (Yamashita et al. 1981). In some stars, there is quite a difference in the Ca and Cr absorption line strengths between one cycle and the next, even if observed at the same phase. This difference may be seen in S Carinae, which is quite obviously a Population II Mira variable. The spectrum at most phases is noticeably lacking in TiO absorption, and the Ca λ4226 line is all but absent at maximum light. Note that at phase -32 days, we observe a strong-line cycle, while at phase -24 days the star is in a weak-line cycle. R Centauri is a fine example of a double-maximum Mira variable (max I - max II is 210 days; max II - max I is 336 days). The tracings clearly show that significant H emission appears only at max I, with a subsequent rapid diminishing of emission strength. The post-maximum spectra of R Carinae show the presence of the metallic Fe emission lines in anti-phase with the H emission lines. As the post-shock gas cools and radiates energy, ultraviolet photons excite iron atoms lying above the shock. As the H emission disappears, the iron then de-excites, generating metallic emission.

To supplement this work, diagrams of blue magnitude as a function of phase are given in Figures 3, 4, and 5 for a few of the Southern Hemisphere Miras. Different symbols refer to different cycles. Visual magnitudes were taken from AAVSO observational data (Mattei 1984). In each case, a **B-V** correction was applied to the visual magnitude by using exposure time ratios relative to standard stars previously observed with the 24-inch spectrograph. R Horologii, shown in Figure 3a, displays a very rapid rise toward the maximum, which is expected for those Miras having OH (hydroxyl) emission arising from a circumstellar envelope (Willson 1983). On the other hand, T Columbae and R Carinae, which are not OH Miras, have less sharply peaked light curves. See Figures 3b and 4a. The Population II Mira variable S Carinae shows little magnitude variation from one cycle to the next. See Figure 4b. R Centauri appears to be slightly brighter at max II (+225 days) than at max I, in accordance with previous observations (AAVSO 1983). See Figure 5a. Figure 5b is a magnitude-phase diagram of AS Puppis, a Southern Hemisphere Mira which has been rarely observed (other examples include RV Puppis and XZ Centauri). In these stars, as in all Miras, the Ca line strength is weakest when the star is brightest.

4. Acknowledgements

I would like to once again thank the large body of dedicated AAVSO observers that has made the completion of this work possible, as well as the Director and her staff for providing encouragement. In practice, one can never obtain enough observations of Mira variables (especially of the southern stars) and so I encourage everybody to keep monitoring them - your contribution is very important!

REFERENCES

American Association of Variable Star Observers. 1983, *Report No. 38*.

Barnes, T. G. and Willson, L. A. 1980, *Journ. Amer. Assoc. Var. Star Obs. 9*, 3.

Crowe, R. A. 1984, *Journ. Roy. Astron. Soc. Canada*, in press.

Garrison, R. F. 1972, *Journ. Amer. Assoc. Var. Star Obs. 1*, 39.

Keenan, P. C., Garrison, R. F., and Deutsch, A. J. 1974, *Astrophys. Journ. Suppl. 28*, 271.

Mattei, J. A. 1984, AAVSO observations, private communication.

Merrill, P. W. 1940, *The Spectra of Long Period Variable Stars*, University of Chicago Press, Chicago.

Willson, L. A. 1976, *Astrophys. Journ. 205*, 172.

_______________ 1983, *Journ. Amer. Assoc. Var. Star Obs.*, this volume.

Yamashita, Y., Maehara, H., and Norimoto, Y. 1981, *Ann. Tokyo Astron. Obs. 18*, 142.

1983JAVSO..12...58C

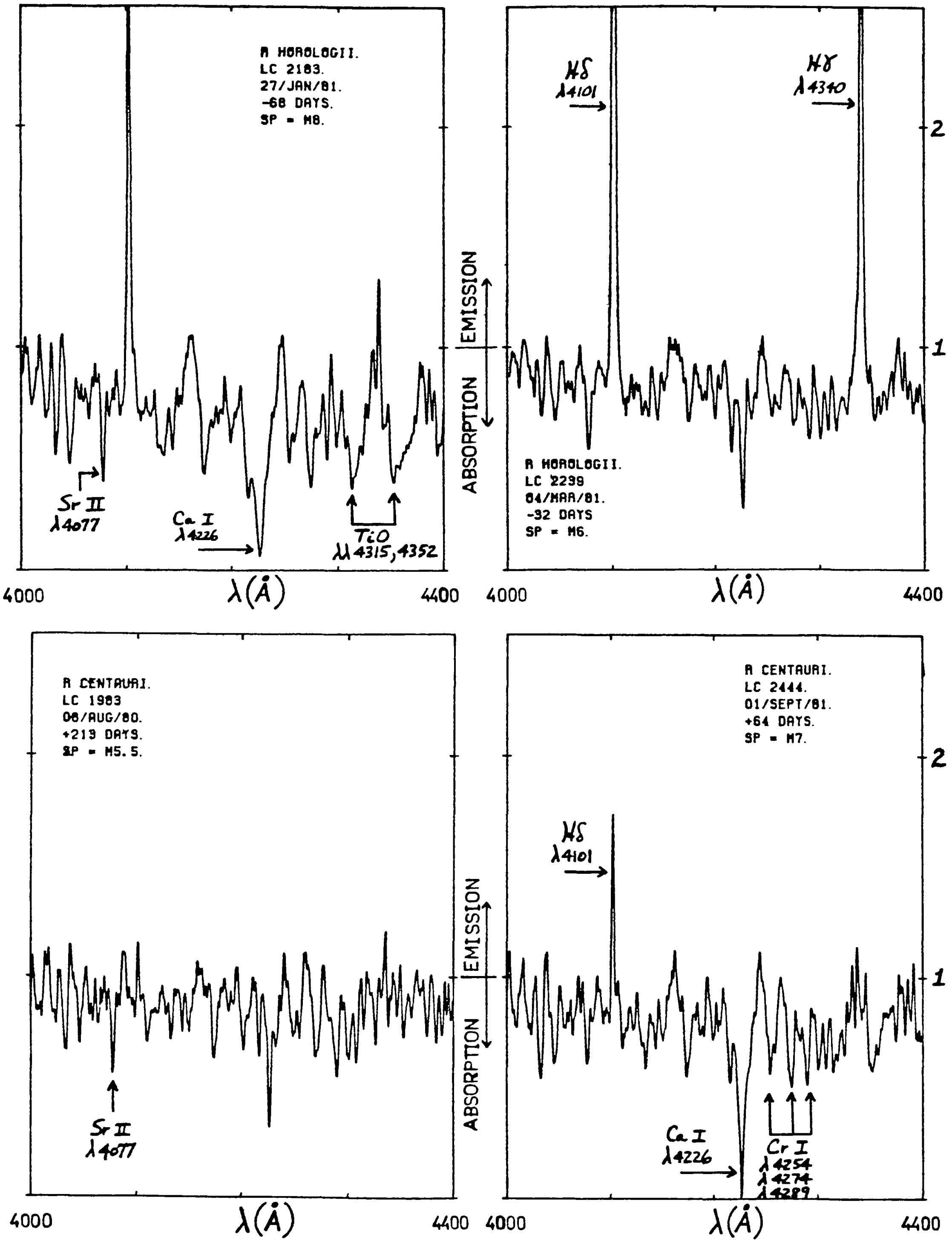


Figure 1. Rectified spectral intensity tracings covering the wavelength range λ4000 to λ4400 for a) R Horologii and b) R Centauri at two different phases. The continuum level has been set to 1.0 so that an intensity greater than 1 is emission, and an intensity less than 1 is absorption. Important spectral features are marked. Note the enormous changes in the H emission lines and in the CaI λ4226 line as R Horologii approaches maximum light. R Centauri, a double-peaked Mira variable, only shows significant H emission close to maximum I (+64 days), even though it has a later spectral type (M7) at this phase. The dates of observation and the Las Campanas plate numbers are also given.

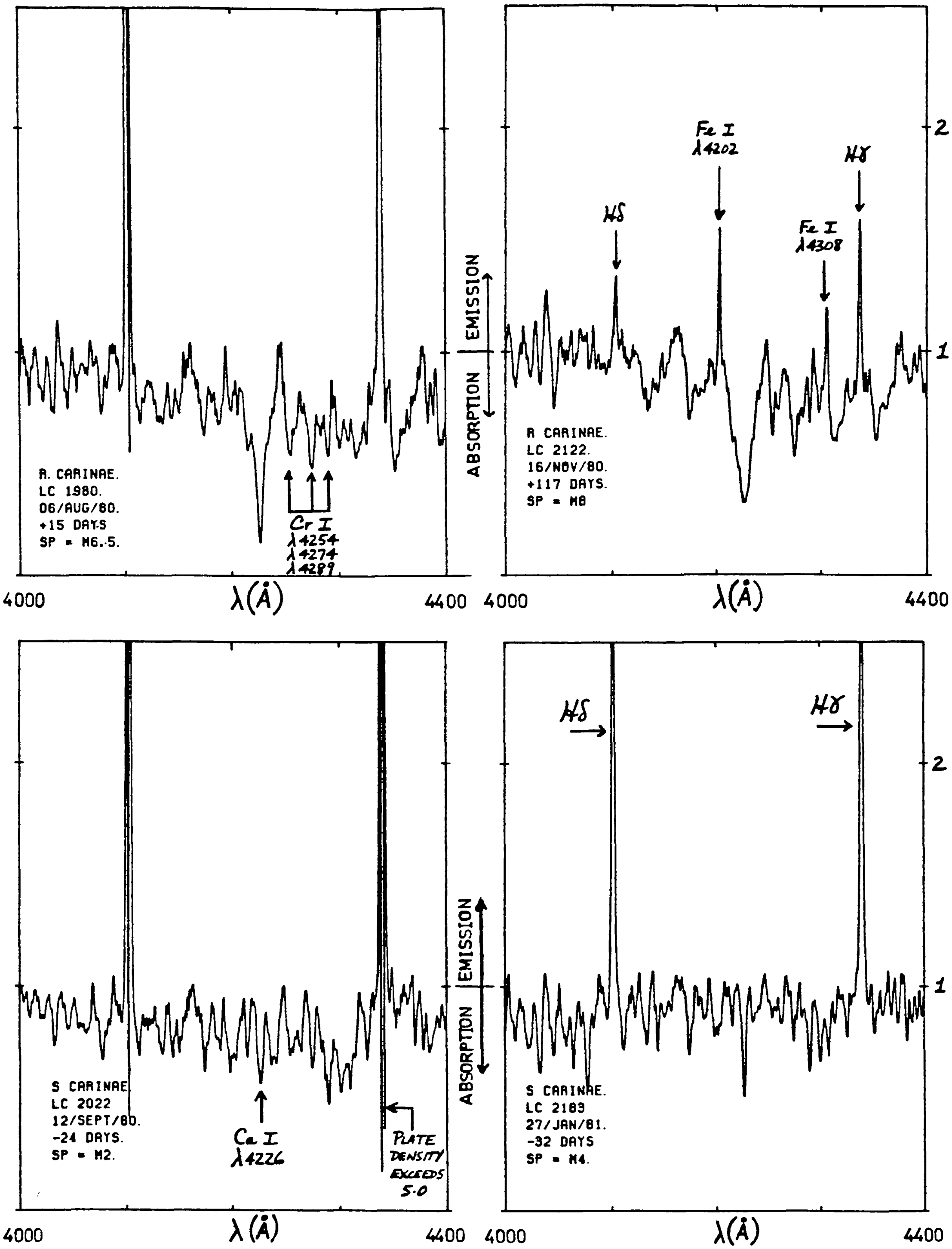


Figure 2. Rectified spectral intensity tracings covering the wavelength range λ4000 to λ4400 for a) R Carinae and b) S Carinae at two different phases. The post-maximum spectrum at +117 days of R Carinae shows that metallic emission appears in anti-phase with the H emission lines. At phase -24 days, S Carinae is in a weak absorption-line cycle, while at -32 days it is in a strong absorption-line cycle. Note that the CaI λ4226 line appears to be weaker when the H emission lines are stronger. A spike at the emission peak indicates that the intensity in the line exceeds a value of 10 relative to the continuum.

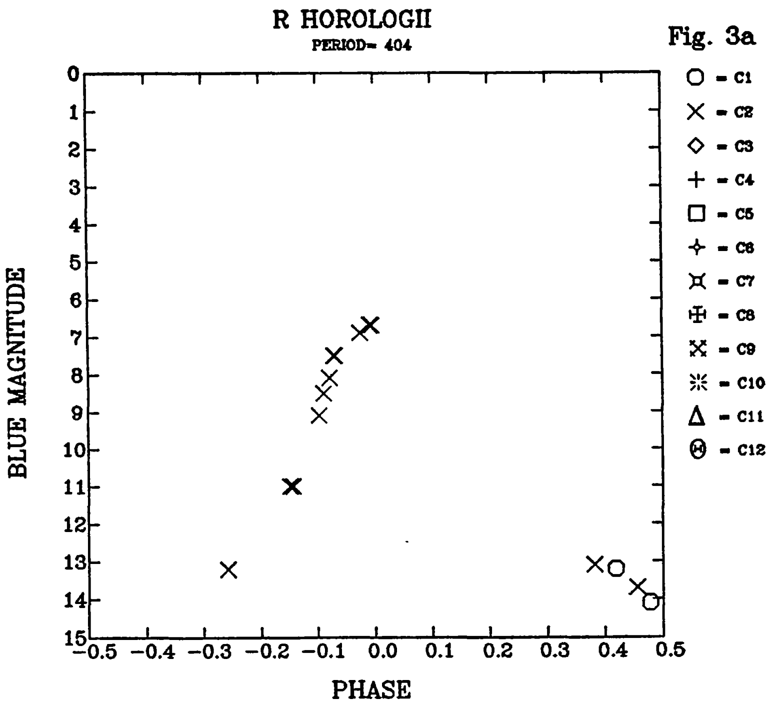


Fig. 3a

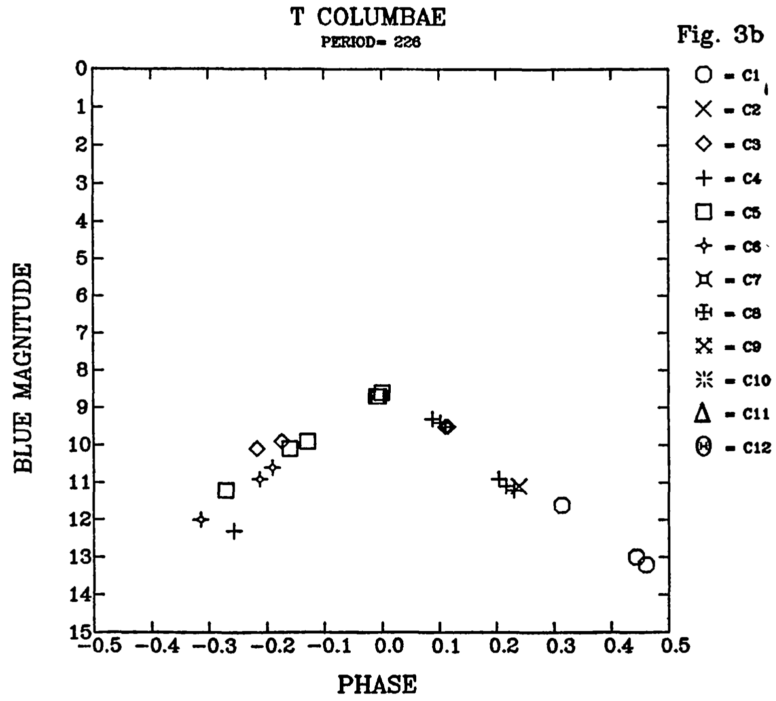


Fig. 3b

Figure 3. Magnitude-phase diagram for two Mira variables in the Southern Hemisphere program, a) R Horologii and b) T Columbae. The visual magnitudes were first determined from AAVSO observational data (Mattei 1984). Blue magnitudes were obtained in each case by applying a **B-V** correction to the visual magnitude, using as a guide exposure time ratios relative to standard stars previously observed with the 24-inch spectrograph. Each symbol refers to a different cycle, but not every star was observed through 10 or more cycles. Note the short rise time for R Horologii, a star that is also an OH maser emission source. This short rise time is expected since the star is known to have a circumstellar shell. T Columbae, on the other hand, is not an OH Mira, and shows a much less sharply peaked light curve.

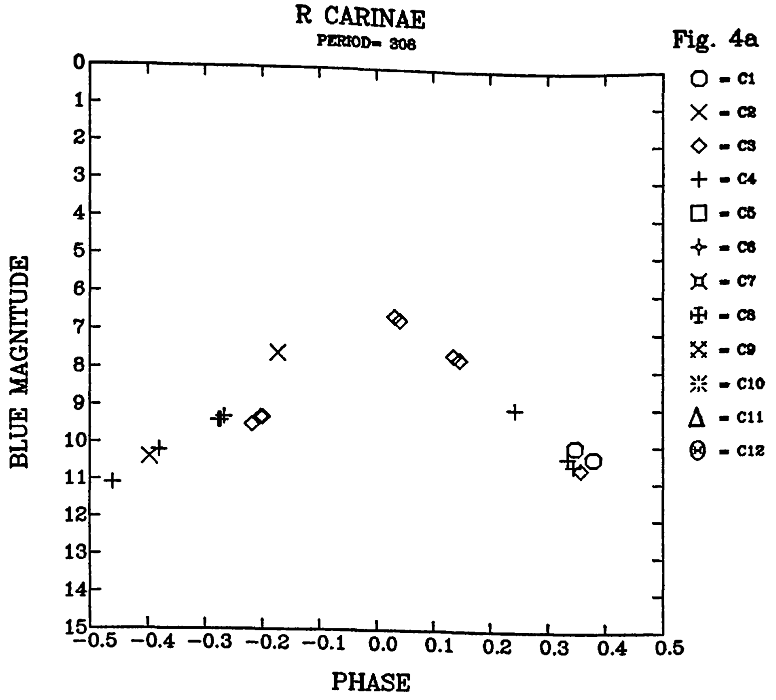


Fig. 4a

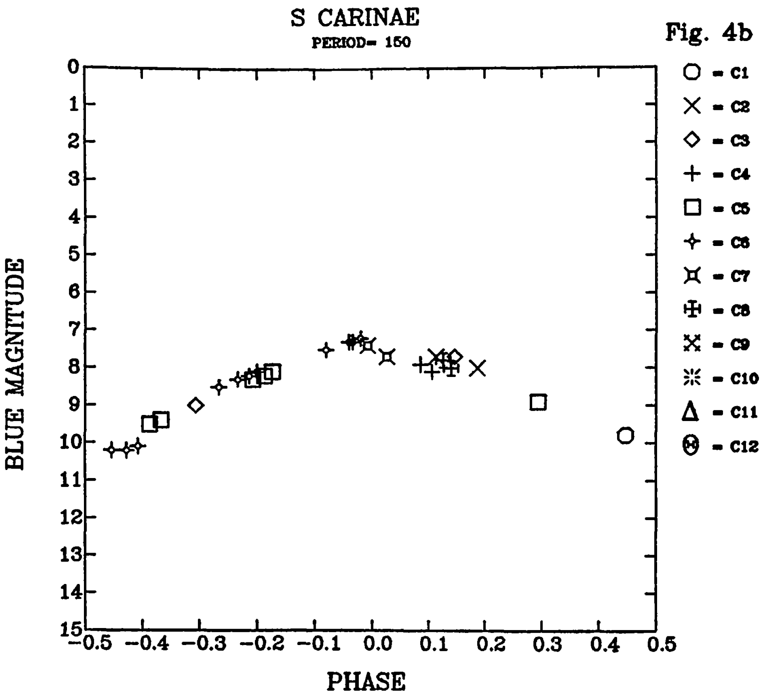
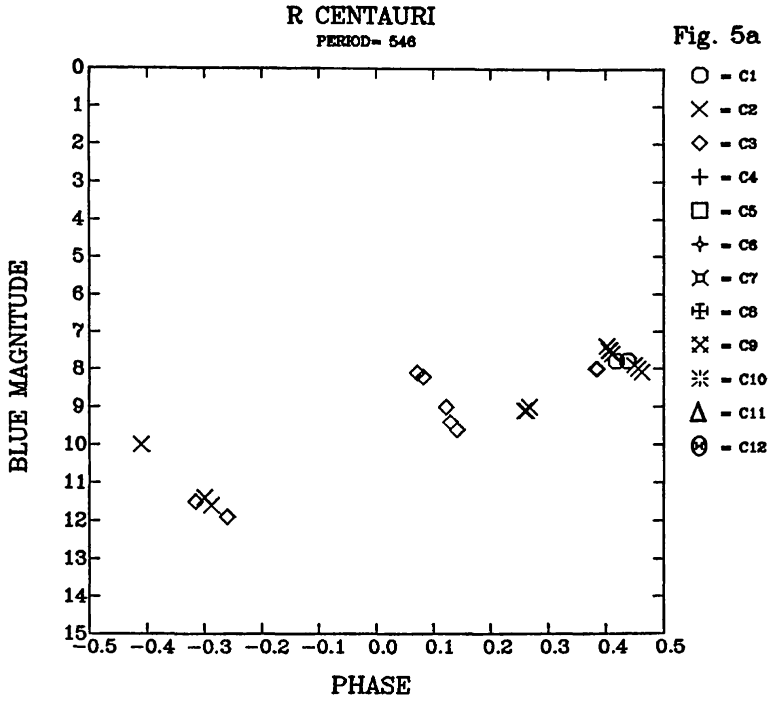


Fig. 4b

Figure 4. Magnitude-phase diagrams for two Mira variables in the Southern Hemisphere program, a) R Carinae and b) S Carinae. R Carinae, which always has a spectral type later than M5e at maximum light, shows a larger amplitude and significantly more cycle-to-cycle variation than S Carinae, which always has a spectral type earlier than M5e at maximum light. See Figure 3 for more description of the plots.



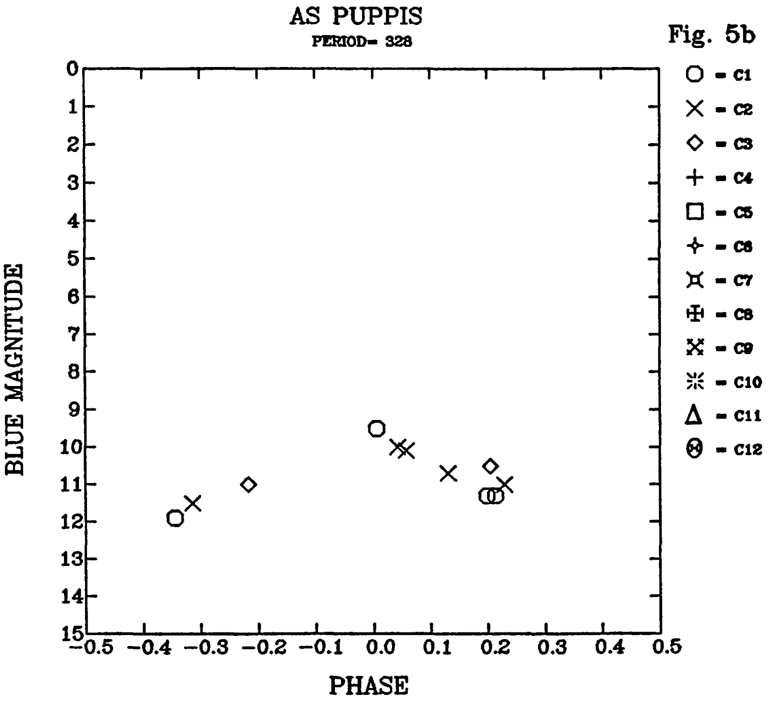


Figure 5. Magnitude-phase diagrams for two Mira variables in the Southern Hemisphere program, a) R Centauri and b) AS Puppis. The double-maximum variable R Centauri appears to be brighter at max II (phase +225 days) than at max I. AS Puppis has rarely been observed in the past. See Figure 3 for more description of the plots.