# PHOTOELECTRIC PHOTOMETRY OF TX PSC, ALPHA HER A, OMICRON CET, AND RT CYG

**Richard P. Wasatonic**
170 Hillside Drive
Coopersburg, PA 18036

*Presented at the 85th AAVSO Annual Meeting, November 2, 1996*

**Abstract**

Photoelectric observations at 5500Å have been conducted on the Lb carbon star TX Psc as part of the AAVSO Small Amplitude Red Variable program; the observed light curve from 1990 through 1995 indicates a semiregular variation with a cycle length of approximately 220 days, rather than complete irregularity. Photoelectric (V) observations were also made on the SRc variable alpha Her A; a beat period of 377 days with an amplitude of 0.8 magnitude was found. The Mira-type variables o Cet and RT Cyg have recently been observed in V and three narrow-band filters in the near infrared. Results from the first two months of observations are shown.

## 1. TX Piscium

Since 1990, the carbon star TX Piscium (HD 223075, SAO 120026, 19 Psc) has been observed photoelectrically by the author to search for periodicities and amplitude ranges as part of the AAVSO Small Amplitude Red Variable (SARV) program. TX Psc is one of the brightest carbon stars, and its spectral type is usually given as N0 or C6,2. Most of the work done on this star has been spectroscopic in nature, with little time devoted to characterizing its photometric properties. Thus it seemed a good candidate for sustained, long-term monitoring to ascertain any variability features.

All observations by the author were taken with a silicon PIN photodiode SSP-3 photometer that was mated to a 20-cm Schmidt-Cassegrain (SCT) reflector fitted with a Schott V filter. Standard photometric observations involving sky, comparison star, and check star measurements were done, and reduction techniques included heliocentric light time corrections and atmospheric extinction corrections. Transformation to the UBV system was done via the red-blue star pair method described in Hall and Genet (1982). The comparison star used was HD 223719 (V = 5.55, B-V = 1.53, K4 II), and the check star was HD 222368 (V = 4.13, B-V = 0.51, F7 V); there was no appreciable variation between these two stars. Standard error for all observations averaged about 10 millimagnitudes.

It has been proposed that TX Psc, as an optically variable carbon star, is in a post-Mira evolutionary phase, in which a circumstellar shell has become detached from the star (Judge and Stencel 1991). Heske *et al.* (1989) speculate that the circumstellar shell is clumpy in nature, and that mass loss is asymmetric, caused by pulsational properties of semiregular (SR) variables. This is one basis for a possible variability type re-classification.

The resultant light curve from all observations up to and including the 1996 season is shown in Figure 1a, with the tabulated data in Table 1. Note the semiregular light variations from 1990 to 1995, with a well-defined periodicity of approximately 220 days. This feature is in contrast to the current Lb irregular giant classification for TX Psc. Following the 1994 observing season, the author suggested that the classification of TX Psc be changed from Lb to SRa or SRb (Wasatonic 1995).

However, the observations from 1996 indicate that a re-classification of the

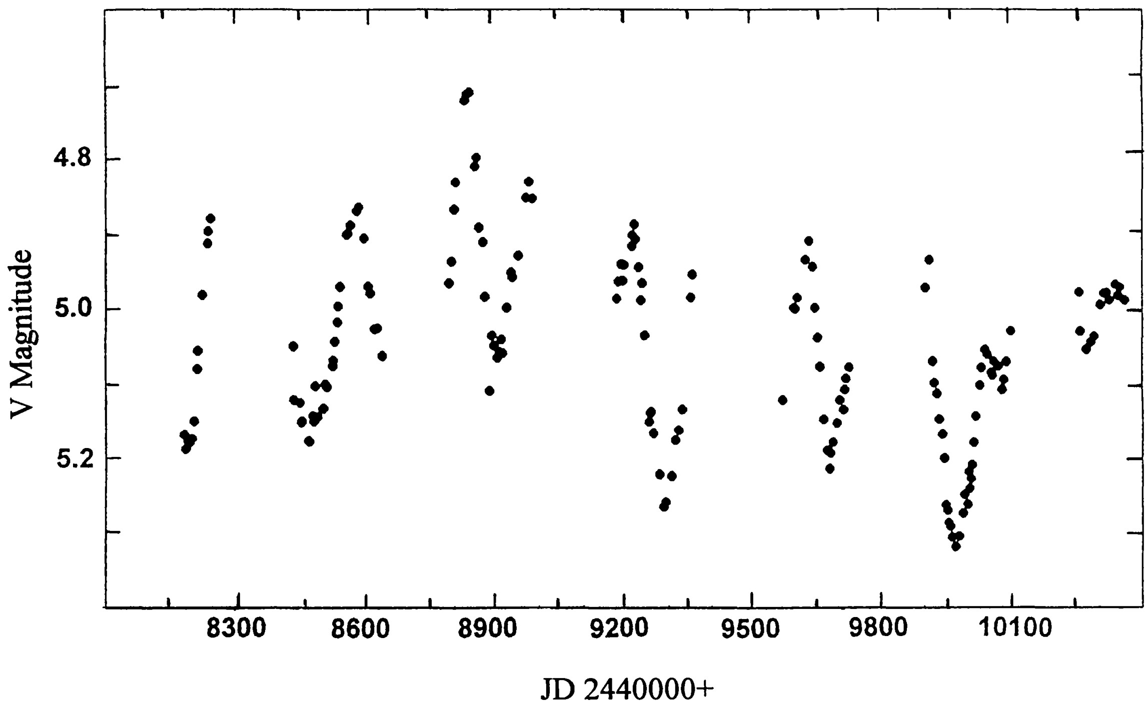


Figure 1a. TX Psc 1990–96 V light curve. Note the semiregular variations in brightness levels with an approximate 220-day period.

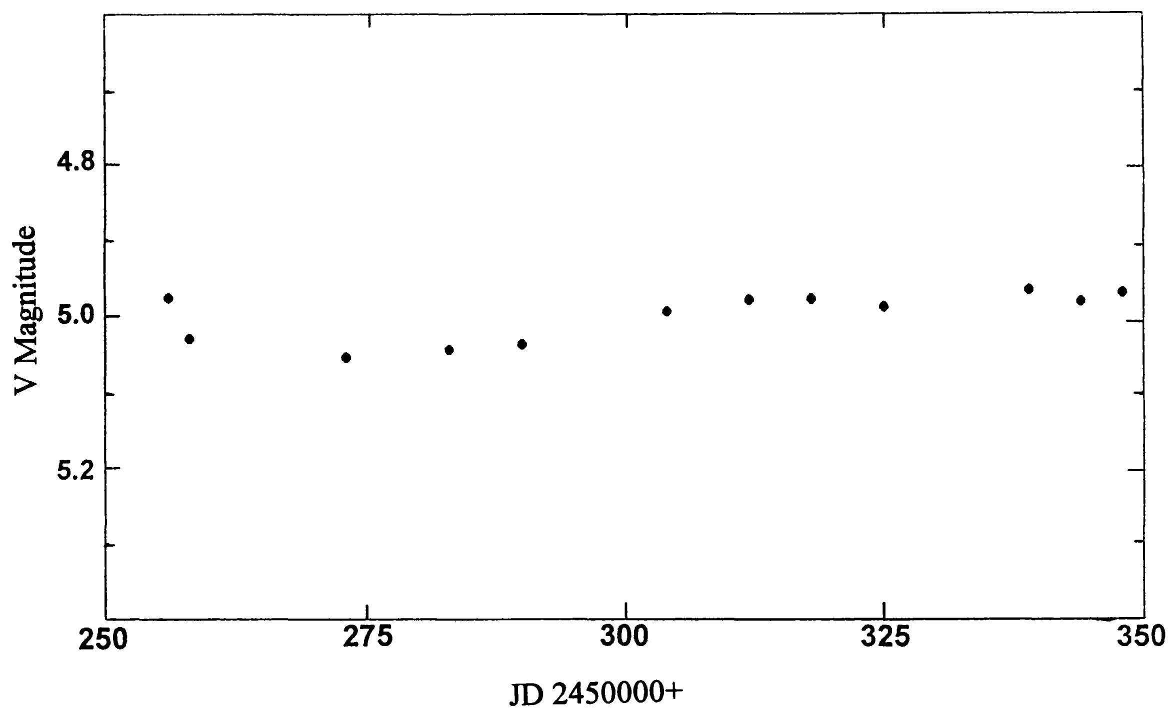


Figure 1b. TX Psc 1996 V light curve. The brightness variations are less than those of previous years.

Table 1. TX Psc V magnitudes.

| *JD 2440000+* | *V* | *JD 2440000+* | *V* | *JD 2440000+* | *V* | *JD 2440000+* | *V* |
|---|---|---|---|---|---|---|---|
| 8180.55 | 5.17 | 8613.46 | 4.98 | 9242.63 | 4.99 | 9928.80 | 5.11 |
| 8184.55 | 5.19 | 8622.47 | 5.03 | 9245.63 | 4.96 | 9933.79 | 5.15 |
| 8189.51 | 5.18 | 8628.48 | 5.03 | 9250.64 | 5.03 | 9940.71 | 5.17 |
| 8191.56 | 5.18 | 8641.47 | 5.06 | 9261.62 | 5.15 | 9945.72 | 5.20 |
| 8193.55 | 5.18 | 8795.85 | 4.96 | 9264.60 | 5.14 | 9949.68 | 5.26 |
| 8197.54 | 5.17 | 8801.82 | 4.94 | 9265.60 | 5.14 | 9953.76 | 5.27 |
| 8202.50 | 5.15 | 8808.82 | 4.87 | 9271.57 | 5.17 | 9956.67 | 5.29 |
| 8211.51 | 5.08 | 8819.84 | 4.83 | 9285.63 | 5.22 | 9960.72 | 5.29 |
| 8213.53 | 5.06 | 8832.74 | 4.72 | 9295.60 | 5.26 | 9963.68 | 5.31 |
| 8222.47 | 4.98 | 8836.75 | 4.71 | 9300.49 | 5.26 | 9971.61 | 5.32 |
| 8234.46 | 4.19 | 8842.72 | 4.71 | 9313.46 | 5.22 | 9979.58 | 5.30 |
| 8235.47 | 4.90 | 8855.70 | 4.81 | 9322.47 | 5.17 | 9988.58 | 5.27 |
| 8240.48 | 4.88 | 8859.71 | 4.80 | 9330.46 | 5.16 | 9992.56 | 5.24 |
| 8434.86 | 5.12 | 8865.66 | 4.89 | 9338.48 | 5.13 | 9999.54 | 5.26 |
| 8435.82 | 5.05 | 8875.64 | 4.91 | 9358.46 | 4.98 | 10001.59 | 5.22 |
| 8449.82 | 5.12 | 8880.62 | 4.98 | 9562.46 | 4.95 | 10003.55 | 5.24 |
| 8452.81 | 5.15 | 8889.67 | 5.02 | 9571.73 | 5.12 | 10006.56 | 5.23 |
| 8454.81 | 5.15 | 8895.59 | 5.04 | 9598.68 | 5.00 | 10009.54 | 5.21 |
| 8469.80 | 5.18 | 8901.60 | 5.05 | 9601.67 | 5.00 | 10013.53 | 5.18 |
| 8471.76 | 5.18 | 8909.56 | 5.06 | 9606.64 | 4.98 | 10017.52 | 5.14 |
| 8479.75 | 5.14 | 8913.56 | 5.06 | 9625.62 | 4.93 | 10026.50 | 5.10 |
| 8481.81 | 5.15 | 8918.53 | 5.04 | 9633.61 | 4.91 | 10030.55 | 5.08 |
| 8485.72 | 5.10 | 8921.53 | 5.05 | 9641.54 | 4.94 | 10038.58 | 5.06 |
| 8490.68 | 5.14 | 8930.52 | 5.00 | 9647.55 | 5.00 | 10044.46 | 5.06 |
| 8501.68 | 5.13 | 8939.52 | 5.00 | 9654.51 | 5.04 | 10056.53 | 5.09 |
| 8503.69 | 5.13 | 8940.48 | 4.95 | 9659.57 | 5.08 | 10059.47 | 5.07 |
| 8508.67 | 5.10 | 8943.48 | 4.96 | 9667.57 | 5.15 | 10069.45 | 5.08 |
| 8512.64 | 5.10 | 8957.48 | 4.93 | 9676.48 | 5.19 | 10078.45 | 5.11 |
| 8526.59 | 5.08 | 8975.53 | 4.85 | 9681.48 | 5.21 | 10081.45 | 5.09 |
| 8527.61 | 5.07 | 8981.48 | 4.83 | 9683.47 | 5.19 | 10088.46 | 5.07 |
| 8531.62 | 5.04 | 8990.48 | 4.85 | 9689.47 | 5.18 | 10098.46 | 5.03 |
| 8536.59 | 5.02 | 9185.84 | 4.99 | 9698.48 | 5.15 | 10258.85 | 4.98 |
| 8538.59 | 5.00 | 9189.50 | 4.96 | 9705.46 | 5.12 | 10260.84 | 5.03 |
| 8543.56 | 4.97 | 9196.76 | 4.94 | 9713.46 | 5.13 | 10275.85 | 5.05 |
| 8558.58 | 4.90 | 9199.82 | 4.96 | 9716.46 | 5.11 | 10285.76 | 5.05 |
| 8560.52 | 4.90 | 9202.74 | 4.94 | 9719.47 | 5.09 | 10292.76 | 5.04 |
| 8566.53 | 4.89 | 9221.83 | 4.92 | 9726.46 | 5.08 | 10306.72 | 4.99 |
| 8581.55 | 4.87 | 9222.76 | 4.90 | 9901.81 | 4.97 | 10314.75 | 4.98 |
| 8585.51 | 4.86 | 9226.71 | 4.89 | 9911.85 | 4.94 | 10320.74 | 4.98 |
| 8598.46 | 4.91 | 9229.66 | 4.94 | 9918.84 | 5.07 | 10327.65 | 4.99 |
| 8608.46 | 4.97 | 9236.64 | 4.94 | 9922.78 | 5.10 | 10341.67 | 4.98 |
| | | | | | | 10346.69 | 4.98 |

variability type may not be appropriate. Figure 1b is the V light curve for the 1996 season alone, and it can be seen that the star's semiregular variation has at least temporarily ceased, and that the star has basically remained close to V magnitude 5.0 throughout the entire season. The light curve is somewhat reminiscent of Z Cam standstills, and continual observations are now deemed necessary to ascertain whether or not this "standstill" is only a temporary feature of an otherwise semiregular pulsating star.

The maximum V amplitude range observed from 1990 to 1996 is 0.55 magnitude, slightly higher than the average seasonal range of 0.33 magnitude. Note that in 1992 the average brightness of the star increased, but in the following years it returned to "normal." It remains to be seen whether or not the 1992 event was transient or if it is part of a very much longer cycle superimposed over the seasonal variations. The 0.55 magnitude amplitude is near the 0.50 magnitude range reported by Mitton and MacRobert (1989), but slightly lower than the 0.8 magnitude amplitude reported by both Drake *et al.* (1991) and Judge and Stencel (1991).

In conclusion, at this time it is uncertain as to whether or not the classification of TX Psc should be changed from its current Lb classification to that of an SRa- or SRb-type variable. Prior to the 1996 observing season, the generated light curve exhibited semiregular variations characteristic of SR variables, but the apparent non-variability in 1996 cannot be ignored in proposing the re-classification.

## 2. Alpha Herculis A

In support of observational studies done by Smith, Patten, and Goldberg (1989), photoelectric (V) observations were made of the bright SRc supergiant alpha Herculis A since 1993. The alpha Her star system is a visual binary that consists of a variable M5Ib-II primary (alpha Her A, HD 156014, HR 6406) and a less luminous secondary (alpha Her B, HD 156015, HR 6407), which is itself a spectroscopic binary. Previous analyses by Smith, Patten, and Goldberg (1989), using AAVSO data from the past 60 years, indicated that alpha Her A is a semiregular variable star with both short-term (~100 days) and long-term (several years) brightness variations.

Radial velocity (RV) studies have been made on alpha Her A at the McMath telescope on Kitt Peak (Smith, Patten, and Goldberg 1989). Their work has indicated a probable fundamental pulsational period of $350 \pm 40$ days. Because no systematic photometric study had been made of the star, photometric (V) observations were started to correlate the RV measurements with the photometric results. These observations have continued to the present, and, based on the results discussed below, further observations will be necessary.

Figure 2 is the V light curve of alpha Her A from 1993 through 1996 obtained by the author; these data are tabulated in Table 2. The observations were made in conjunction with V-band Automated Photometric Telescope (APT) data obtained by the Four College Consortium Phoenix-10 telescope on Mt. Hopkins in Arizona. The Schmidt-Cassegrain telescope extended the APT observing season on both ends by two to three months, and helped to produce a more complete light curve. The common comparison star was HD 154595 (V = 4.91, B-V = 1.02, A4 IV), and the common check star was HD 154143 (V = 4.98, B-V = 1.60, M3 III). As with the TX Psc observations, standard methods of observing and data reduction techniques were employed.

Perhaps the most striking feature of the light curve itself is the relatively large light variation that seems to occur at an interval of about 373 days. Following this large "pulse" is a series of smaller variations that gradually "damp" out. Additionally, there has been an overall decrease in stellar brightness of about 0.3 magnitude from 1990 to 1996. This could be related to the long-term variations seen in earlier V

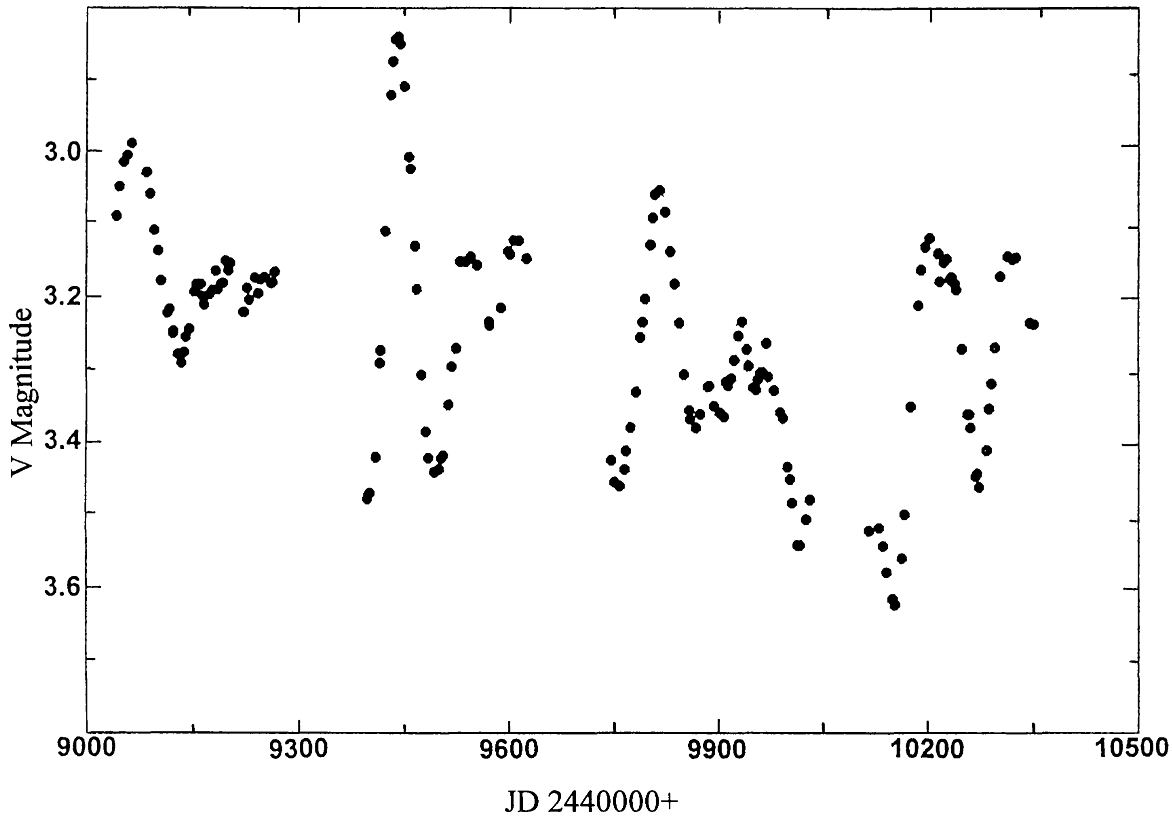


Figure 2. Alpha Her A 1993-96 V light curve, characterized by a large brightness variation that occurs approximately every 373 days and then slowly "damps" out to a series of smaller variations.

estimates. The overall light curve is rather complex, and the future behavior of the system is somewhat unpredictable.

In analyzing the light curve, it was seen that the primary maximum occurs at the 373 $\pm$ 30 day interval, which is consistent with the reported spectroscopic period of 350 $\pm$ 40 days from Smith, Patten, and Goldberg (1989), based on their RV observations. To characterize more possible periods quantitatively, a Discrete Fourier Transform (DFT), using a program published by Sinnot (1988), was applied. Figure 3 shows the results of the DFT in which two significant periods were found in the data, at 127 and 95 days. The routine, however, did not find the 373-day cycle that was ascertained from inspection of the light curve, and it was subsequently discovered that the 373-day cycle is very close to the 377-day beat cycle of the 127- and 95-day periods. These periods could be caused by shocks in the star's atmosphere generated by pulsations, as noted both by Bowen (1992) and Smith *et al.* (1995). The 194-day cycle detected by the DFT is thought to be an alias. The growth and decay of supergranulation on or near the surface of the star could account for the long-term 0.3 magnitude decline in brightness.

Figure 4 is the V light curve from the 1996 observing season alone, and is an expanded view of the 1996 portion of the curve presented in Figure 2. Note that following the primary maximum, the secondary maximum, usually 0.2 magnitude fainter than the primary, reached almost the same magnitude as the primary and that overall there is less "damping" of the light oscillations than in previous years. This was not expected, and clearly exemplifies the unpredictability of the star and the need

Table 2. Alpha Her A visual magnitudes.

| *JD 2440000+* | *V* | *JD 2440000+* | *V* | *JD 2440000+* | *V* | *JD 2440000+* | *V* |
|---|---|---|---|---|---|---|---|
| 9043.89 | 3.09 | 9400.87 | 3.47 | 9787.87 | 3.26 | 10031.45 | 3.48 |
| 9047.90 | 3.05 | 9402.87 | 3.47 | 9790.85 | 3.24 | 10116.93 | 3.52 |
| 9052.97 | 3.02 | 9410.87 | 3.42 | 9794.92 | 3.20 | 10130.94 | 3.52 |
| 9057.74 | 3.01 | 9416.85 | 3.29 | 9801.84 | 3.13 | 10136.92 | 3.54 |
| 9065.42 | 2.99 | 9417.86 | 3.27 | 9805.85 | 3.09 | 10141.96 | 3.58 |
| 9085.12 | 3.03 | 9423.85 | 3.11 | 9808.88 | 3.06 | 10150.83 | 3.62 |
| 9090.81 | 3.06 | 9431.81 | 2.92 | 9815.82 | 3.05 | 10153.91 | 3.62 |
| 9096.74 | 3.11 | 9434.83 | 2.88 | 9823.77 | 3.08 | 10163.91 | 3.56 |
| 9101.73 | 3.14 | 9437.81 | 2.84 | 9830.85 | 3.14 | 10167.82 | 3.50 |
| 9105.32 | 3.18 | 9441.81 | 2.84 | 9836.73 | 3.18 | 10175.79 | 3.35 |
| 9114.54 | 3.22 | 9444.78 | 2.85 | 9843.71 | 3.24 | 10186.75 | 3.21 |
| 9117.72 | 3.22 | 9450.77 | 2.91 | 9850.81 | 3.31 | 10190.72 | 3.16 |
| 9122.28 | 3.25 | 9457.76 | 3.01 | 9857.68 | 3.36 | 10196.73 | 3.13 |
| 9123.67 | 3.25 | 9459.79 | 3.03 | 9859.67 | 3.37 | 10202.86 | 3.12 |
| 9129.72 | 3.28 | 9465.75 | 3.13 | 9867.83 | 3.38 | 10214.67 | 3.14 |
| 9134.64 | 3.29 | 9468.76 | 3.19 | 9873.63 | 3.36 | 10216.71 | 3.18 |
| 9138.65 | 3.28 | 9475.76 | 3.31 | 9884.63 | 3.32 | 10222.65 | 3.15 |
| 9140.64 | 3.26 | 9481.73 | 3.39 | 9886.61 | 3.32 | 10224.64 | 3.15 |
| 9145.65 | 3.25 | 9485.67 | 3.42 | 9893.60 | 3.35 | 10226.65 | 3.15 |
| 9152.63 | 3.19 | 9494.65 | 3.44 | 9901.58 | 3.36 | 10231.62 | 3.18 |
| 9155.67 | 3.18 | 9500.68 | 3.44 | 9907.58 | 3.37 | 10233.61 | 3.17 |
| 9161.87 | 3.18 | 9503.65 | 3.42 | 9910.66 | 3.32 | 10238.61 | 3.18 |
| 9163.61 | 3.20 | 9506.61 | 3.42 | 9913.58 | 3.32 | 10240.62 | 3.19 |
| 9166.59 | 3.21 | 9513.61 | 3.35 | 9918.58 | 3.31 | 10248.59 | 3.27 |
| 9173.58 | 3.20 | 9518.61 | 3.30 | 9922.60 | 3.29 | 10256.57 | 3.36 |
| 9178.58 | 3.19 | 9524.61 | 3.27 | 9928.59 | 3.25 | 10258.58 | 3.36 |
| 9182.60 | 3.17 | 9530.62 | 3.15 | 9933.61 | 3.23 | 10260.62 | 3.38 |
| 9185.59 | 3.19 | 9538.65 | 3.10 | 9940.58 | 3.27 | 10268.61 | 3.44 |
| 9189.59 | 3.18 | 9545.58 | 3.15 | 9943.55 | 3.29 | 10270.62 | 3.44 |
| 9192.58 | 3.18 | 9554.58 | 3.16 | 9949.55 | 3.32 | 10273.60 | 3.46 |
| 9196.58 | 3.15 | 9571.59 | 3.24 | 9953.55 | 3.33 | 10283.63 | 3.41 |
| 9199.58 | 3.17 | 9572.57 | 3.24 | 9956.53 | 3.31 | 10286.58 | 3.35 |
| 9202.58 | 3.16 | 9588.56 | 3.22 | 9960.54 | 3.30 | 10290.73 | 3.32 |
| 9221.58 | 3.22 | 9598.57 | 3.14 | 9963.55 | 3.20 | 10295.58 | 3.27 |
| 9222.57 | 3.22 | 9601.52 | 3.14 | 9968.53 | 3.26 | 10302.63 | 3.17 |
| 9226.56 | 3.19 | 9606.53 | 3.12 | 9971.53 | 3.31 | 10312.54 | 3.15 |
| 9229.55 | 3.21 | 9614.51 | 3.12 | 9979.51 | 3.33 | 10319.55 | 3.15 |
| 9237.53 | 3.18 | 9625.52 | 3.15 | 9988.49 | 3.36 | 10324.55 | 3.15 |
| 9242.52 | 3.20 | 9746.93 | 3.42 | 9992.49 | 3.37 | 10344.52 | 3.24 |
| 9245.52 | 3.18 | 9751.91 | 3.46 | 9999.48 | 3.43 | 10350.53 | 3.24 |
| 9250.53 | 3.17 | 9758.93 | 3.46 | 10003.48 | 3.45 | | |
| 9259.50 | 3.18 | 9765.90 | 3.44 | 10006.49 | 3.48 | | |
| 9262.50 | 3.18 | 9767.84 | 3.41 | 10013.47 | 3.54 | | |
| 9265.50 | 3.17 | 9773.89 | 3.38 | 10017.47 | 3.54 | | |
| 9398.88 | 3.48 | 9781.90 | 3.31 | 10026.46 | 3.51 | | |

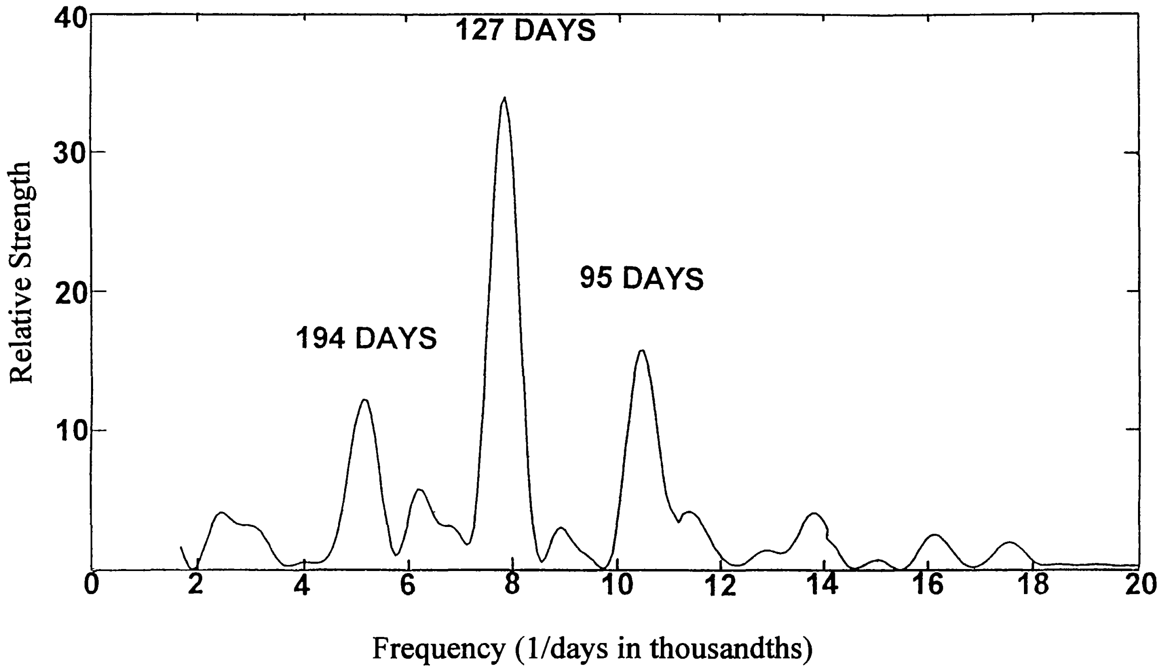


Figure 3. Discrete Fourier Transform of the alpha Her A light curve. Note the detected periods at frequencies of 0.0052, 0.0079, and 0.0105 (194, 127, and 95 days, respectively).

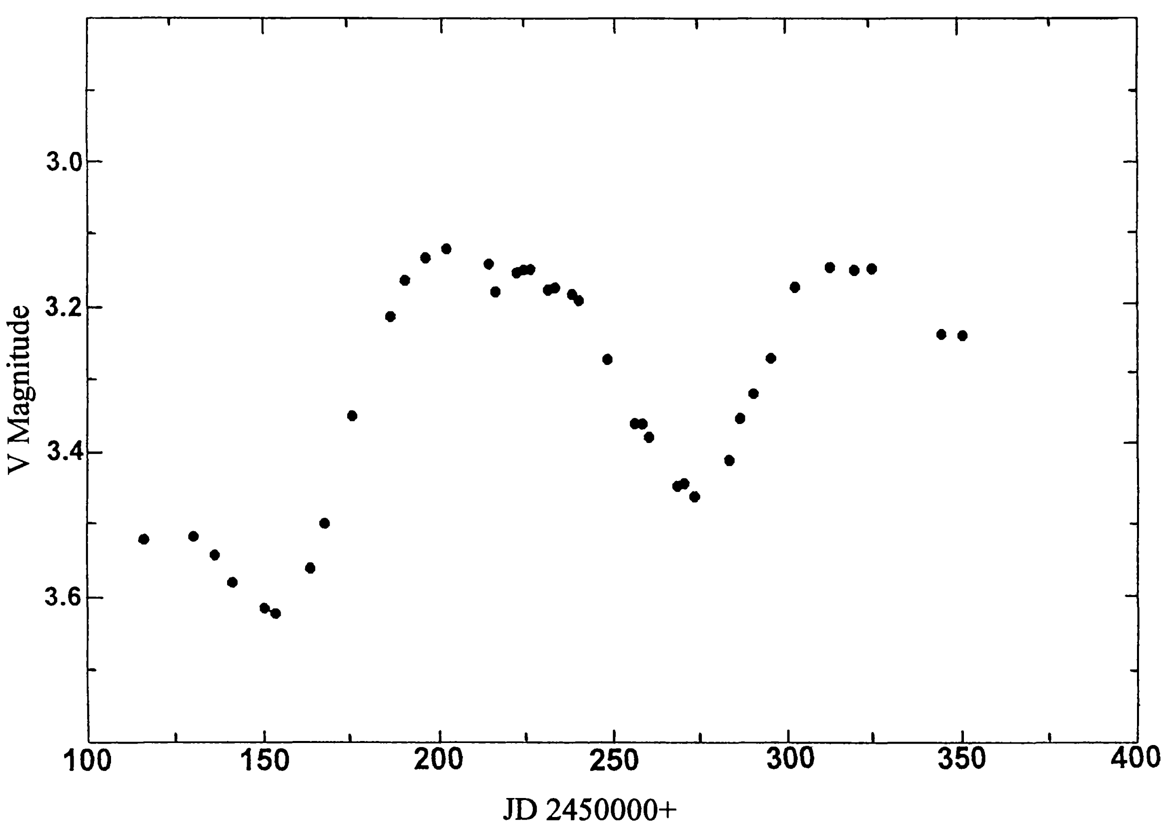


Figure 4: Alpha Her A 1996 V light curve. The damping effects observed in previous years are still present, but are not as apparent as before.

Table 3. Three-color filter characteristics (adapted from Wing 1992).

| *Filter* | *Region Measured* | *Central Wavelength* | *Bandpass (FWHM)* |
|---|---|---|---|
| A | TiO band | 7190 Å | 110 Å |
| B | Continuum | 7540 | 110 |
| C | Continuum | 10240 | 420 |

for further investigation.

## 3. Omicron Ceti and RT Cygni Visual and Infrared observations

Photoelectric observations in both the Visual and near-IR of the Mira-type variables omicron Ceti (HD 14386, Mira) and RT Cygni (HD 186686) were recently started in an attempt to generate light curves and note any characteristic differences that could arise due to the observations being done at widely varying wavelengths. This work has been done only during the past 2–3 months, and hence is preliminary at best. However, it has served as a excellent indicator that very useful scientific data can be obtained in a field of variable star research in which, to date, relatively little work has been done on a continual, long-term basis. The idea behind the observations is that while there is a wealth of visual observations of Mira-type variables, the stars themselves radiate mostly in the IR, with their energy maxima between 1 and 2 micrometers (Wing 1986). Hence it is thought that it would be beneficial to monitor selected Miras photometrically using specialized IR filters, to start characterizing their photometric properties in this part of the spectrum.

What can be learned from observing Miras in the IR? If relatively narrow bandpasses are used, filters can be designed to measure the strength of molecular absorption bands, which are indicative of the temperature in the star's upper atmosphere. Filters can also be chosen to avoid the molecular absorption, and then one can measure the slope of the spectral continuum, which is indicative of the temperature deeper in the photosphere. From the infrared continuum light curve and the temperature variations, one can calculate the change in size of the star's emitting surface. This is the photometric method of estimating radius changes.

The three IR filters used to monitor the Miras are a subset of Wing's larger 8-color system (MacConnell, Wing, and Costa 1992) The characteristics of these filters are given in Table 3, which is adapted from Wing (1992). It should be noted that the central wavelength for the C filter is 10240Å, which is significantly different from the 10400Å wavelength of filter 5 of the 8-color system. However, a color term was used in determining the transformation coefficient, and hence all computed magnitudes have been transformed from the instrumental system of filter C to that of filter 5 of the 8-color system. This transformation can permit direct comparisons with the large amount of data already available on the 8-color system, including the light curves of

Table 4. V and IR magnitudes of o Cet.

| *JD 2450000+* | *V* | *A* | *B* | *C* |
|---|---|---|---|---|
| 312.28 | 7.35 | 3.84 | 1.45 | -0.38 |
| 318.29 | 7.66 | 3.97 | 1.52 | -0.28 |
| 339.23 | 8.03 | 4.36 | 1.89 | -0.17 |
| 358.19 | 8.28 | 4.77 | 2.26 | -0.32 |
| 366.17 | 8.43 | 4.80 | 2.28 | -0.29 |

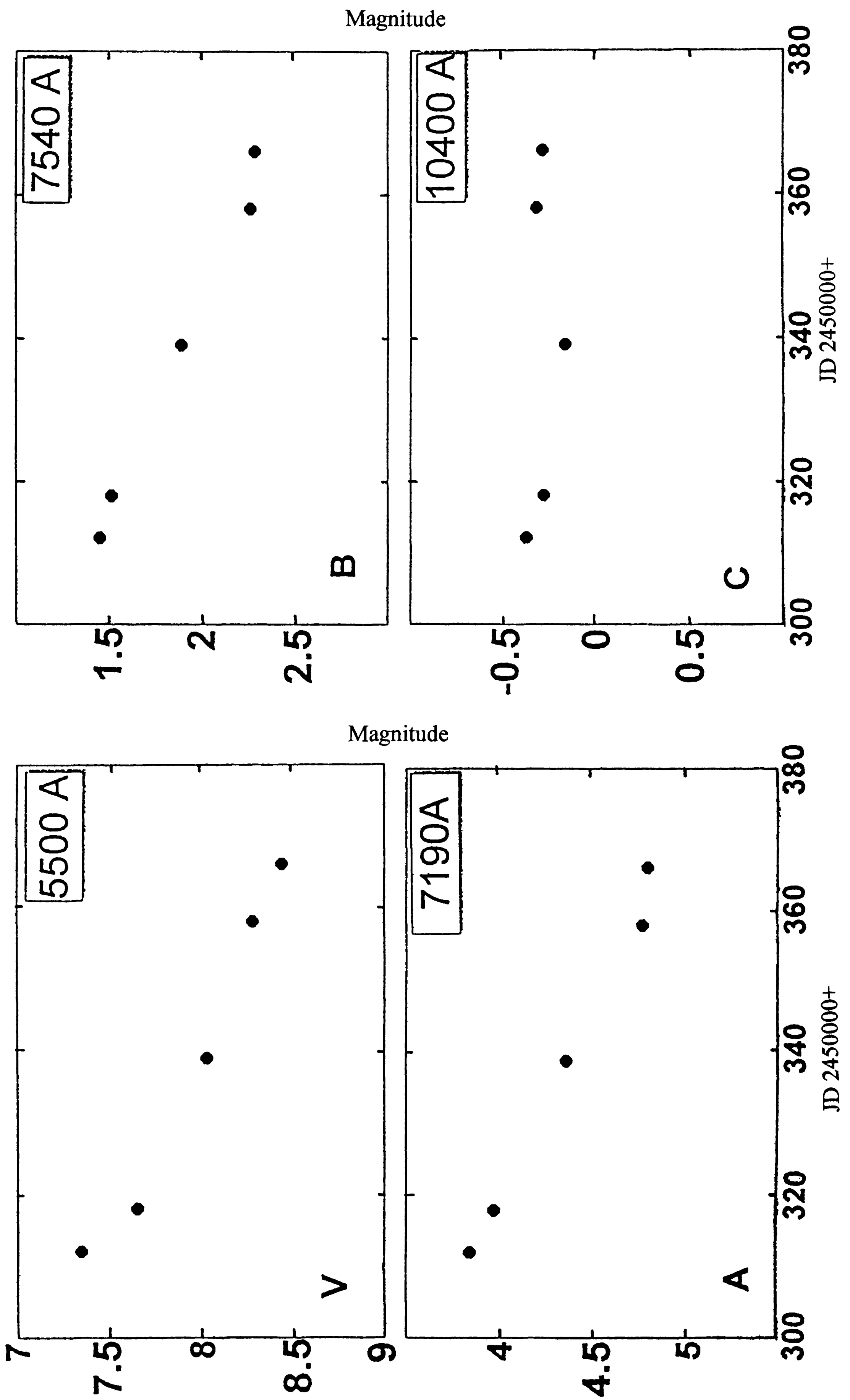


Figure 5. o Cet (Mira) 1996 V and IR light curves. Note how the magnitude drop diminishes toward the IR.

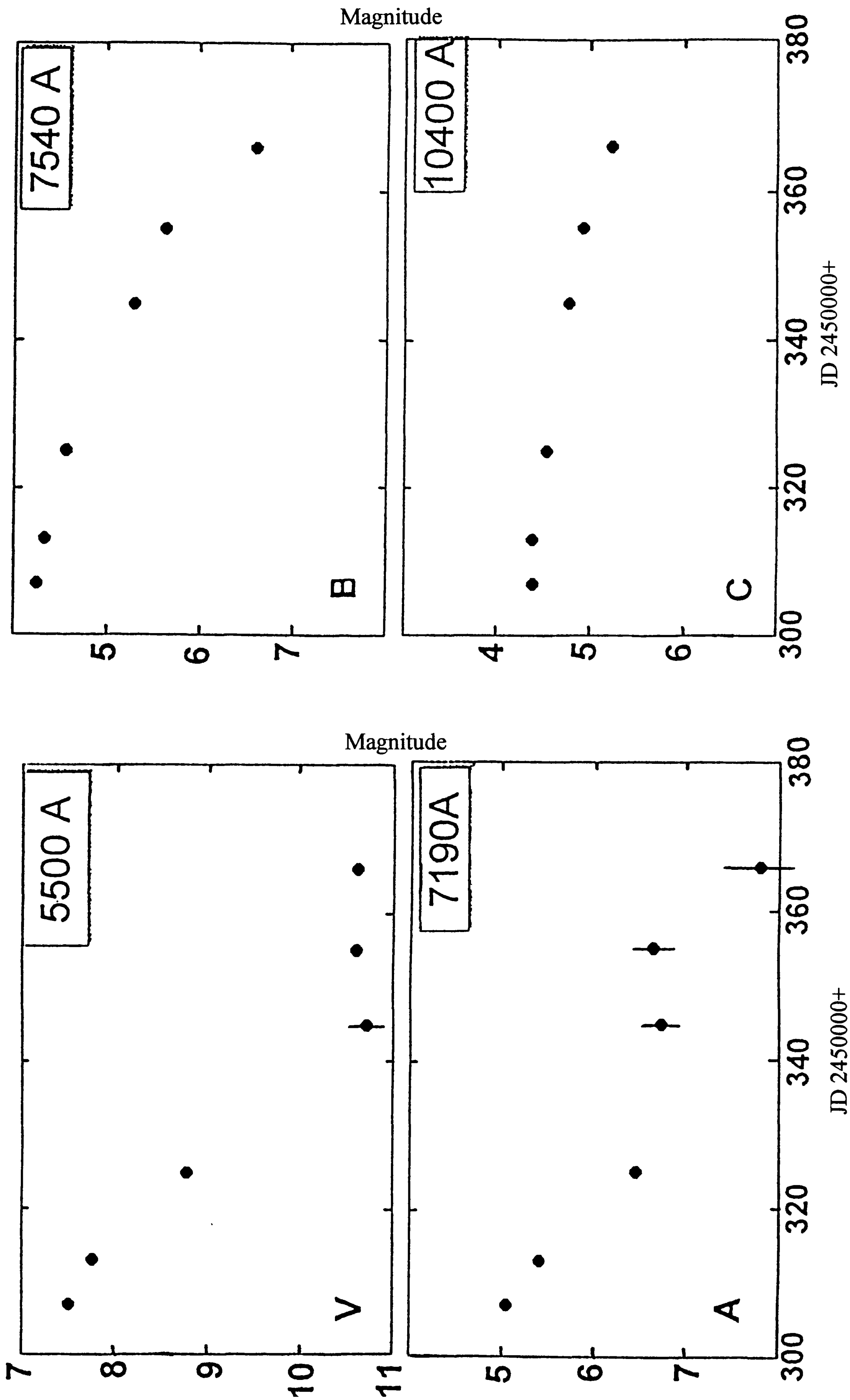


Figure 6. RT Cyg 1996 V and IR light curves. As with o Cet, there is a diminished magnitude drop toward the IR.

Table 5. V and IR magnitudes of RT Cyg.

| JD 2450000+ | V | A | B | C |
|---|---|---|---|---|
| 307.14 | 7.72 | 5.05 | 4.25 | 4.39 |
| 313.07 | 7.77 | 5.40 | 4.34 | 4.39 |
| 325.06 | 8.77 | 6.45 | 4.56 | 4.54 |
| 345.09 | 10.71 | 6.72 | 5.30 | 4.78 |
| 355.06 | 10.60 | 6.63 | 5.62 | 4.94 |
| 366.03 | 10.61 | 7.79 | 6.59 | 5.24 |

Miras published by Lockwood and Wing (1971).

In addition to obtaining standardized IR magnitudes using the Wing filter subset to generate light curves, spectral sub-type classification can be done on M-type stars up to M8, as the central wavelengths were chosen so that a titanium oxide (TiO) index could be calculated from the magnitudes (Wing 1992). For stars later than M8, the TiO index is made ineffective by the appearance of absorption by vanadium oxide (VO) in filter B, and an additional filter would be required for classification of the coolest stars (Wing 1986). The filters themselves were fitted into holders for use in the SSP-3, and hence no new specialized instrumentation had to be introduced to the photometer/telescope setup in order to conduct the observations.

Figures 5 and 6 show the results to date of observations conducted on o Cet and RT Cyg in the V and in the Wing 3-color system; these data are tabulated in Tables 4 and 5, respectively. These observations were taken from August to October 1996, and hence are just a small part of the entire pulsational cycles of these stars, as the periods for o Cet and RT Cyg are 332 and 190 days, respectively (Cooper and Walker 1989). Note that for o Cet the V magnitude drop was about one magnitude, while for RT Cyg the drop was slightly more than 3 magnitudes. It should be noted that the magnitude drops in filter C (the best infrared continuum point) are much less than the drops in V or in either of the other narrow-band filters, all of which are affected by molecular absorption. These values can be seen in Tables 4 and 5.

The V magnitude drops are indicative of atmospheric expansion and cooling that results in TiO formation that absorbs V radiation. However, in going from the visual region into the IR, the TiO absorption gradually becomes less, to the extent that at 10400Å, TiO formation and absorption play no part in the variations. At this wavelength, any variations are almost bolometric in nature, and are caused solely by temperature and diameter variations (Wing 1986). Hence, it can be seen from these few observations that the V, IR, and bolometric light curves are different. Only continued observations will enable complete light curves to be generated that will allow full cyclic, differing-wavelength comparisons to be made.

It was stated earlier that the 3-color system can be used to determine spectral sub-types from the calculated standardized magnitudes. In order to do this, a calibration had to be done to correlate the calculated TiO index for stars of known spectral sub-types; once a specific TiO index could be mapped to a spectral sub-type, a variable star spectral sub-type could then be classified simply by calculating the index from the 3-color magnitudes. To this end, K and M stars of known spectral sub-types (Wing 1978) were observed using the 3-color system, and the standardized magnitudes computed. The calculated magnitudes were then used in the defining TiO index relation:

$$\mathrm{TiO} = A - B - 0.13\,(B - C)\,, \qquad (1)$$

where A, B, and C are the standardized magnitudes obtained through the 7190Å,

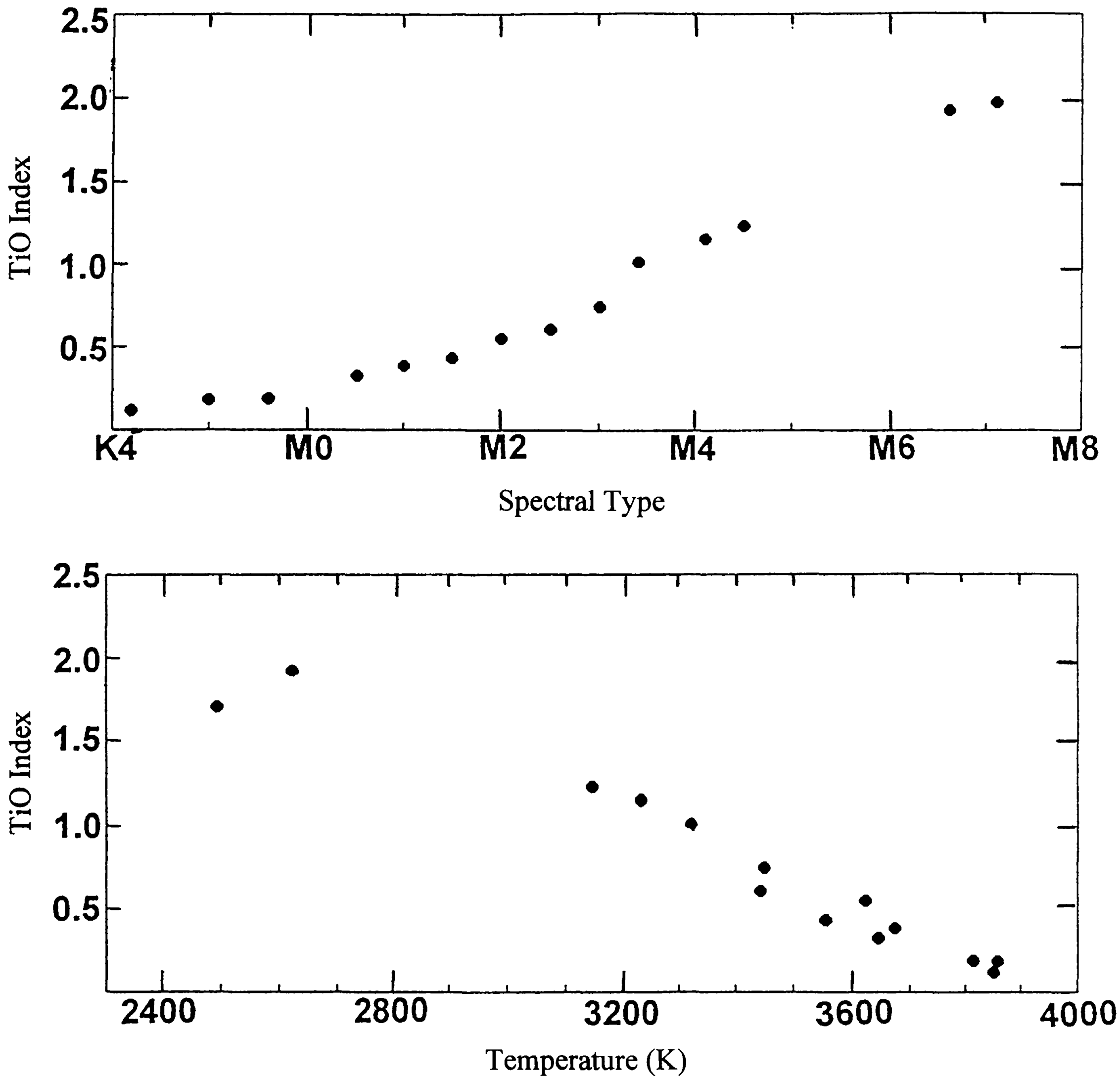


Figure 7. TiO calibration. The upper panel displays the calculated TiO index vs. spectral type; as the spectral type advances, the TiO index increases, indicating more atmospheric molecular formation. The lower panel displays the calculated TiO index vs. temperatures from Wing's 8-color system; at lower temperatures, the index rises, indicative of strengthening TiO formation.

7540Å, and 10240Å filters, respectively (Wing 1992). Results of this calibration can be seen in Figure 7, where the top portion plots the calculated TiO index vs. spectral sub-type and the bottom portion plots the calculated TiO index vs. color temperatures obtained from Wing's 8-color system (Wing 1978).

These temperatures were obtained by measuring fluxes with the 8-color system, and reducing the fluxes to an absolute scale by adopting the energy distribution for the star Vega. Molecular band strengths were measured by fitting a blackbody curve to the calibrated fluxes at the best continuum points and measuring the absorption, in magnitudes, at each filter relative to this curve. A second blackbody fit was then made, yielding the color temperature (Wing 1978).

It can be seen that the index starts to rise around M0 and levels out around M7;

again, this is indicative of later-type stars having more TiO due to cooler temperatures, to the point where VO becomes more prominent in the stellar atmosphere. It should be noted that this calibration is not yet complete, in that more stars of different spectral types need to be observed to fill in the existing gap between M4.5 and M6, and some stars need to be re-observed to reduce variability effects.

## 4. Future work

Continued observations of TX Psc, alpha Her A, o Cet, and RT Cyg, as well as new observations of other Miras and bright supergiants, are planned. Various criteria were taken into account in selecting the program stars, such as sky accessibility, visibility in the SSP-3 through the 20-cm SCT, spectral type, range, period, and the sensitivity of the SSP-3 itself. Further observing experience and scientific results will guide the selection of future program stars.

## 5. Acknowledgements

The author gratefully wishes to acknowledge Drs. Edward F. Guinan of Villanova University and Myron A. Smith of Computer Sciences Corporation for their guidance and support in conducting the observations and analyzing the alpha Her A results. Also, the author would like to thank Dr. Emilia Belserene for her assistance in translating the DFT program from BASIC to FORTRAN. Finally, the author gratefully acknowledges Dr. Robert F. Wing of The Ohio State University, who provided much valuable information and data needed to make the o Cet IR observations and analytical results possible.

## References

Bowen, G. 1992, *Instabilities in Evolved Supergiants*, ed. C. DeJager, N. Holland Publ., Amsterdam, 104.
Cooper, W. A., and Walker, E. N. 1989, in *Getting the Measures of the Stars*, ed. A. Hilger, IOP Publishing, Ltd., Bristol and Philadelphia, 265.
Drake, S. A., Linsky, J. L., Judge, P. G., and Elitzur, M. 1991, *Astron. J.*, **101**, 230.
Judge, P. G., and Stencel, R. E. 1991, *Astrophys. J.*, **371**, 357.
Hall, D. S., and Genet, R. M. 1982, in *Photoelectric Photometry of Variable Stars*, IAPPP, 13.
Heske, A., Te Lintel Heckkert, P., and Maloney, P. R. 1989, *Astron. Astrophys.*, **218**, L5.
Lockwood, G. W., and Wing, R. F. 1971, *Astrophys. J.*, **169**, 63.
MacConnell, D. M., Wing, R. F., and Costa, E. 1992, *Astron J.*, **104**, 821.
Mitton, J., and MacRobert, A. 1989, *Sky & Telescope*, **77**, 180.
Sinnot, R. W. 1988, *Sky & Telescope*, **76**, 3.
Smith, M. A., Patten, B. M., and Goldberg, L. 1989, *Astrophys. J.*, **98**, 2233.
Smith, M. A., Teays, T. F., Wasatonic, R. P., Taylor, L., Guinan, E. F., and Baliunas, S. 1995, in *Application of Stellar Pulsations*, eds. R.S. Stobie and A. Whitelock, ASP Conf. Series, No. 88, 403.
Wasatonic, R. 1995, *Inf. Bull. Var. Stars*, No. 4159.
Wing, R. F. 1978, *Spectral Classifications and Color Temperatures For 280 Bright Stars in the Range K4-M8*, Ohio State Univ. Dept. of Astron., Columbus.
Wing, R. F. 1986, in *The Study of Variable Stars Using Small Telescopes*, ed. John R. Percy, Cambridge Univ. Press, 127.
Wing, R. F. 1992, *J. Amer. Assoc. Var. Star Obs.*, **21**, 1.