VISUAL MEASURES OF BRIGHT CEPHEIDS
A VARIABLE STARS SOUTH PROJECT

Summary: **This project aims to determine seasonal or yearly epochs of maximum and combine them with historical data to allow period changes since discovery to be studied. To do this it will improve the standard of visual measures of selected bright southern Cepheid stars by the use of improved observing methods and modern sequences determined to an accuracy of 0.01 magnitudes. There will be a limited number of observers and the first results will be presented at the NACAA Conference in Easter 2010, also at the RASNZ Annual Conference in May, 2010. All substantial contributors will be co-authors.**

1.0 Introduction: Many Cepheids have been observed for over a century. Observing began visually, then photography was used to supplement this, now photoelectric photometry and CCD photometry are used to determine their behaviour with more accuracy. But these latter two techniques have limitations in that there are other demanding targets and they are, in many cases, unsuited to bright targets. So we continue to rely rather heavily upon visual measures.

Visual measures quite obviously are not as accurate as electronic ones. The eye is a great multi-purpose instrument but its flexibility limits its ability to compete with specialised devices. So visual measures have tended to be directed toward observations of longer period, large amplitude Miras where accuracy of 0.1 to 0.3 is good enough. As a result, the visual observing world has become stereotyped, with sequences to 0.1 magnitudes and reporting of measures to the nearest 0.1. It was not always like this. In the nineteenth century several observers were reporting to 0.05 or even more precisely, but the accepted—and demonstrably incorrect—wisdom that 0.1 was the limit has prevailed. It is amusing to see in the International Database that some of these measures were rounded off to match the system!

In the 1960s visual observing of Flare Stars showed that better was possible. More recently observers such as Sebastian Otero have worked on low amplitude, bright variables and shown that a precision improvement of two to four times the accepted standards is possible with care and good sequences. One of the goals of this project is to apply such techniques to a group of bright Cepheids.

The charts will be specialised and concentrate upon the target stars alone. This will ignore the other variable stars on the chart. Historically the goal seems to have been to measure as much as possible, with often three or four variables and sequences on a single chart. This sort of 'mass production' is, no doubt, good for overall numbers but appears to have reflected upon accuracy. Thus the charts in use will be clear and simple, with only the necessary comparisons and major stars labelled. Magnitudes are from Project Pluto's Guide 8. This uses transformed Hipparcos values which do not match the standard system exactly, but are homogeneous and within 0.03 in almost all case, usually better.

Participants are expected to send monthly reports of their measures to the analysts, Ranald McIntosh and Stan Walker. These will also be stored in the VSS records and reviews and progress reports put on the website. Information required is Star, JD, magnitude, and a note if the magnitude is considered unreliable. Observing methods are discussed in Section 3.0.

2.0 A Case Study - l Carinae: (Lower-case letter "l") This star was first observed by Alexander Roberts in South Africa on 7 April, 1891. On that date he estimated its magnitude at 4.46, using a much less accurate sequence than we now have available. The 75 measures made during the first season are shown below, folded to the ephemeris JD 2411800 + 35.52 days.

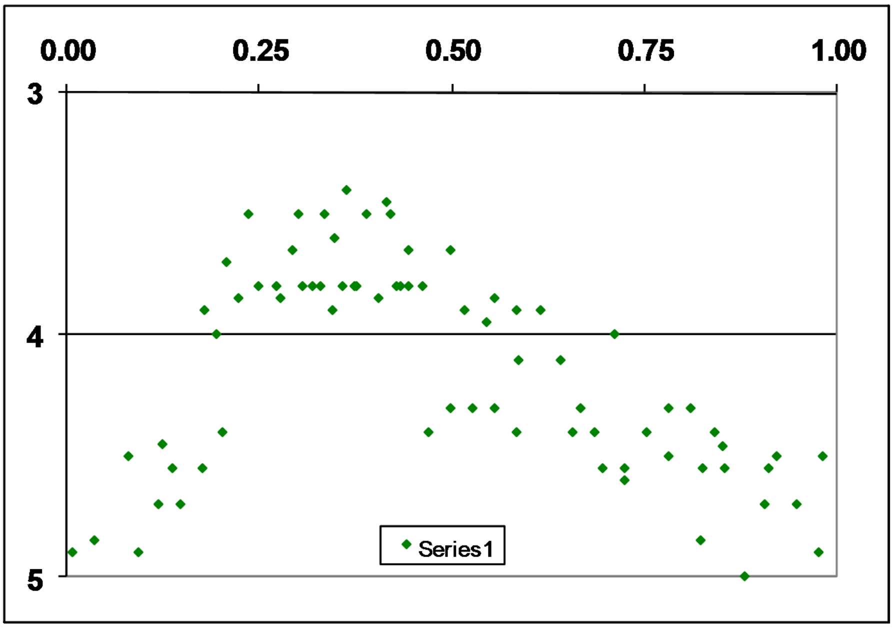

Figure 1: Visual observations of l Carinae by Alexander Roberts of South Africa in 1891 phased to the light elements JD2418800 + 35.52 days.

Quite obviously the comparison star sequence differs from that of today, but the light curve is recognisable and an epoch of maximum could be obtained from this.

There are 22000+ measures in the International Database but few are this good!

L Carinae was also observed photoelectrically from the Auckland Observatory during the interval 1981-90 and other observers have published p/e measures. These are shown in Figures 2 and 3, the first measures from Auckland alone showing a light curve obviously including some small period changes, the second showing a major change in period about 1964.

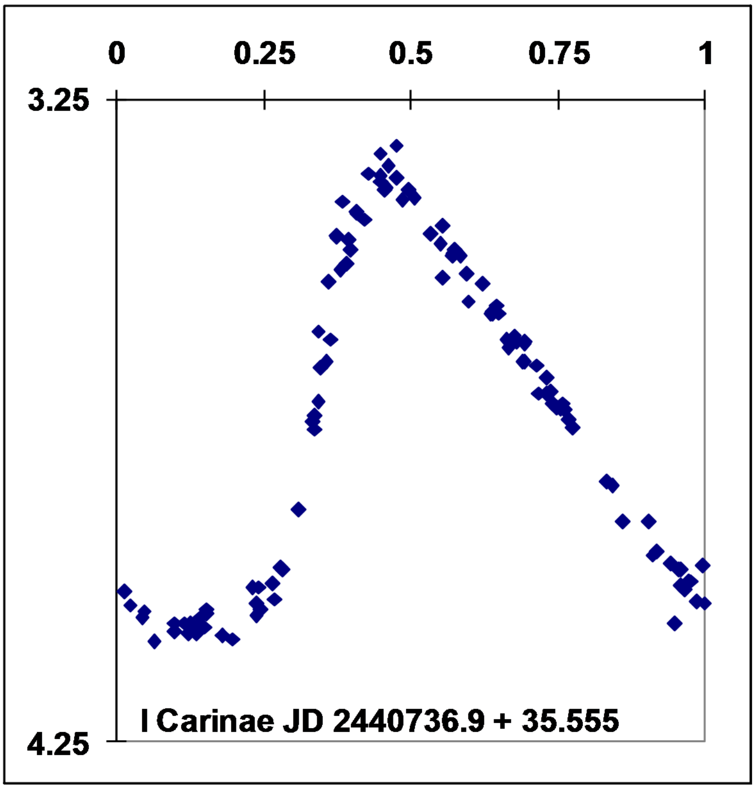

Figure 2: Observations of l Carinae at Auckland Observatory 1981-90 and the Milton Road Observatory 1991-96 Accuracy is +/-0.005, better than the size of the data points.

The scatter in the diagram results from a continuing change in period over the interval of 15 years

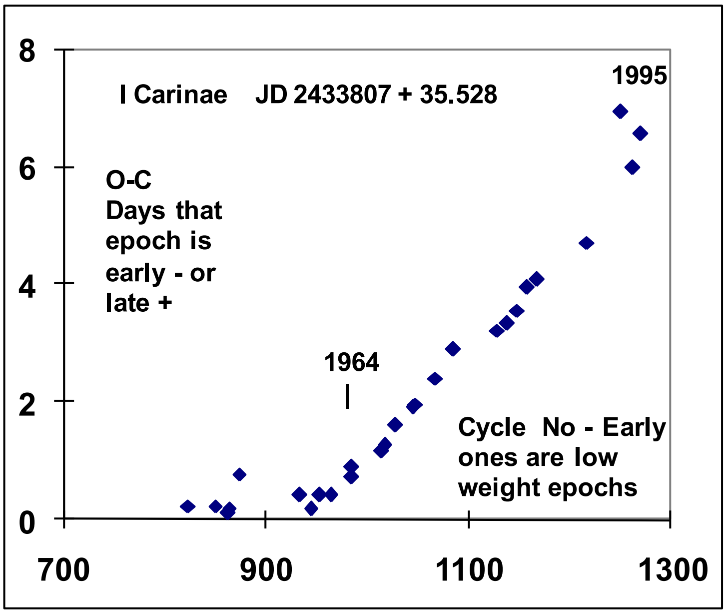

Figure 3: All published pe epochs to 1996 showing a major period change in 1964 and some other smaller fluctuations.

The period seems to be continually increasing as values quoted by some observers in the 2000s are longer still.

The long period Cepheids are noted for period changes but as explained in the text, some are not easy objects because of their brightness.

3.0 What Level of Accuracy is Needed? Here it depends upon the star. But many Cepheids with periods of 15 days or longer show quite detectable period changes over a few years. So we can be updating epochs at the same time as we are extending the future database. Let's look at an example.

Applying some crude rounding to the light curve of l Carinae it can be assigned an amplitude of one magnitude, or 10 tenths, a rise time of 20% of a cycle, a decline of 60% and a flat minimum of 20%, spread over a 35 day interval. The average amplitude of the selected targets is just over one magnitude.

Errors for the best visual measures are stated to be about +/- 0.1 magnitudes. More about this below. If this error is applied to our standard light curve any estimate might be +/- 0.7 days on the rise and +/- 2.1 days on the fall. Not very exciting. Statistically this error can be divided by the square root of the number of measures. So with 100 in a season errors change to 0.07 and 0.21 days—100 and 300 minutes. But even one reasonable measure would have found the O-C deviation of l Carinae. Some selection of measures is worthwhile—25% of measures near maximum or minimum are of lower weight in defining any particular epoch.

There will be more than one observer on each star so the numbers will be built up that way. Looking at the 8 initial longer period targets and expecting a six month season on each star five observers would—at a rate of two nights a week—build up an annual total of 250 measures on each of the eight stars. A divisor of 16 (square root of 250) is some improvement over 10—which is good enough—but this shows that abandoning observations during periods when the Moon was in the way would have little effect on the overall quality if this reduced the totals to 100 per star.

If the measures are then plotted we find a very messy light curve. But all the measures are then fitted to a mean light curve and the fit with the least sum of squares of deviations is determined to be the best fit. A fairly normal method and better than most for accuracy.

The visual accuracy figure of 0.1 has been built up with historical analyses of measures. It can probably be improved upon. Sebastian Otero has proven this possible and some emulation of his methods is indicated. Sequences are now far better and there seems no reason why these cannot be quoted to 0.05 or even 0.01 magnitudes. New charts will be issued with the magnitudes of the selected comparison stars shown to 0.01 values.

Attention to the observing method would certainly be worthwhile. Adapting the flare star technique to visual estimates of CVs in Auckland when we were monitoring orbital cycles of 100 minutes or so led to a considerable improvement in estimations. The concentration on numbers of measures has always been a negative factor in variable star observing. If we forget numbers and concentrate on quality things can be changed. Sebastian recommends that you initially determine roughly where, as compared to the sequence, the Cepheid's brightness is at the moment. Then spend a few minutes checking the values of the comparisons so that you have the correct 'feel' then spend a minute or so determining the value of the Cepheid on the night. Timing to the nearest minute is adquate.

If the accuracy can be refined to +/-0.05 this sees a doubling of the accuracy of the epochs, +/-0.03 a trebling—equivalent to 4 or 9 times the actual number of estimates each season!

All of this is somewhat exploratory but we'd appreciate visual volunteers. Data should be sent in monthly to the website and we will provide monthly reviews of progress, with publications once a year, the first aimed at the Easter, 2010, NACAA Conference.

4.0 Target Stars: Our targets are all stars which during all or most of their cycles are too bright for ASAS3. As far as we are aware, noone is doing photometry of these brighter objects—or if they are, it's merely casual visual measures which don't attain the precision which concentrated measures in the manner described would. There are 15 stars—8 with longer periods and 7 with much shorter periods. Some have been measured in Auckland photoelectrically—ones with good light curves are marked **, less well observed objects *.

Comparison stars are selected from Project Pluto's Guide comprises these stars. Whilst these magnitudes are satellite based and not transformed ideally to the standard UBV system or visual magnitudes they are generally within 0.03 magnitudes and are internally consistent. See visual targets or digital camera targets (latter not complete until November).

5.0 Analysis of Observations: Each season's measures will be analysed as a separate unit to produce one epoch for an O-C Diagram as shown in Figure 3 earlier. These will be added to the historical database, trends studied and, where appropriate, used to suggest further research patterns. With observing baselines of almost a century on average, this is obviously a long-term project - but it's made more valuable by the existence of this historical data.

The method begins by determining an average light curve from as many good quality measures as are available during an interval when the period was not changing. Even if the period does change during the interval it does not affect the determination enough to influence the results. Until we determine our own current mean light curves historical curves will be used. This is slightly less accurate as sequences differ in the visual and, if we use V light curves, there is a difference between V of the UBV system and v of visual.

Observed data are then cleaned of any obviously poor measures falling outside a predetermined deviation from the mean curve. The remaining data are then analysed by a method which plots them against the mean light curve by assigning each observation a phase based upon the present period. This makes 600 tests over an interval containing the expected mean epoch of maximum, and then narrows the interval in a succession of steps until no improvement is seen. The result is the seasonal epoch.

It might seem more appropriate to determine a period from the collected seasonal measures but this does not work in practice. Our expectations of l Carinae are that it will produce an epoch within +/- 200 minutes. This is 0.2777 days over 10 cycles at most. So a period of 35.555 days will come out at any value between 35.526 and 35.583 days. There are period changes but that in 1964 was from 35.528 to 35.555 days, rather less than 35.583-35.526+0.057, but clearly shown over a ten year interval. Our advantage is that we can use historical data to come to quick conclusions—even a month's measures will show if a star is running late or early.

Do not attempt to make heliocentric corrections. These will be added as necessary by the analysts. JD tables are available if needed. Finally, when everything is completed, the seasonal epochs will then be published to the historical database.