DETECTION OF DOUBLE STARS WITH THE TWO-COLOR REFRACTOMETER

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ABSTRACT

Attempts to detect double stars are being made with the Two-Color Refractometer (TCR). The refractometer is an instrument developed by the Quantum Electronics Group of the University of Maryland to measure atmospheric refraction.

During check-out observations using the U.S. Naval Observatory's (USNO's) 24" reflecting telescope, the refractometer is being used to detect the astrometric separation of the ultraviolet and red photocenters of the combined light from a double star, differentially referenced to nearby stars. The refractometer contains two dispersive wedges which null the incoming dispersion; the positions of the wedges then provide a measure of the dispersion of the incoming light. The angular part of this measure immediately gives the position angle of the double. The angular distance between the two components of the pair is a combined function of the measured quantity and of the magnitude and color differences of the components of the double star, and is therefore obtainable only with additional information.

INTRODUCTION--THE TWO-COLOR REFRACTOMETER

In contrast to the previous papers in this session, we have no observations to present at this time. Instead we are presenting a promising new technique and instrument for the detection of double stars. The Two-Color Refractometer, under development by the Quantum Electronics Group of the University of Maryland, is currently undergoing a series of check-out and shake-down observations using the 24-inch telescope at the U.S. Naval Observatory. During the course of these observations we have become aware of its potential for the detection of double stars.

A brief description of the design and operation of the refractometer will introduce the method we propose to use in the detection of double stars. This refractometer does not measure the refraction directly, but instead measures the dispersion of light in a star image. The dispersion is determined by measuring the difference in position between the photocenters of red and ultraviolet images of the star.

The heart of the refractometer is a four-quadrant photon-counting detector. This type of detector excels in determining when an image falling on it is centered. Also, with lower accuracy, it can be used to determine the amount and direction of offset of an image. Offsets

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of the images produce error signals which are used to control various servo loops which drive the images toward the center.

The mean offset of the images is used for guiding the telescope and for driving guiding mirrors in the instrument. The difference in position of the red and ultraviolet photocenters is used to drive wedges which produce an adjustable dispersion to cancel the dispersion of the incoming light, thereby causing the red and ultraviolet photocenters to be simultaneously centered on the quadrant photo-detector. The instrument is primarily a nulling instrument and the output consists of the angular positions of the two wedges, allowing derivation of the angle and amount of dispersion which was necessary to superimpose the red and ultraviolet photocenters of the images.

Figure 1 shows the layout of the Two-Color Refractometer. Tracing the light path to the right from the quadrant photo-sensor, we first find the neutral density (ND) filter wheel, which is used to optimize the count rate for the proper operation of other system components and servo loops. Next we find a beam extraction mirror, which allows the observer to acquire a star and focus the image. Beyond this are found the guiding mirrors, which operate in perpendicular directions.

The next object is the color filter wheel, which spins at 3600 rpm. This allows a sample of the red and ultraviolet images to be taken every 2.4 milliseconds, before the atmosphere changes. Finally we find the dispersive non-deviating wedges, which introduce the dispersion necessary to cancel the incoming dispersion. The entire instrument is intended to be used with a small reflecting telescope, which should contain no refractive elements since they could introduce sizeable instrumental dispersion.

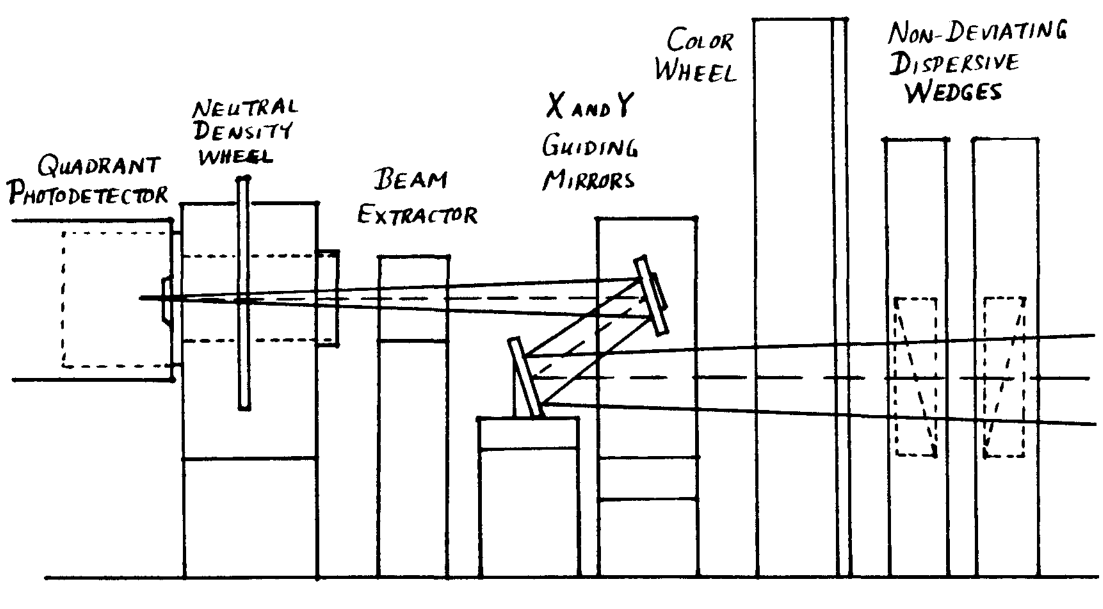

Figure 1.

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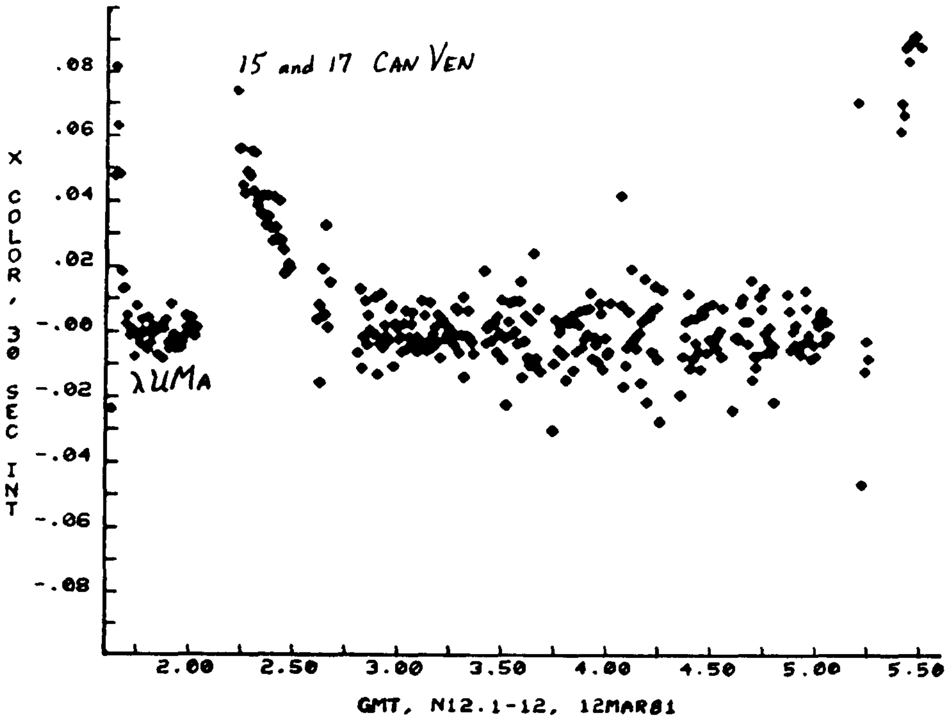

Figure 2.

The following figures present the results of a typical observing run. Figure 2 displays the X component of residual dispersion as detected by the quadrant photo-detector as a function of time. In operation, this quantity should be nulled to guarantee that the wedge positions indicate the appropriate amount of dispersion has been introduced. The first set of observations are of Lambda UMa, followed by a series switching between 15 and 17 Can Ven. The entire series stretches over a period of 4 hours. Each point represents one 30 second observation. Since the data is recorded in digital form on magnetic tape, it can be further smoothed and analyzed at a later time.

Notice in the second set of observations that the residual dispersion was not at first nulled. The non-zero value was used as a signal to drive the wedges to null the residual dispersion. Notice that in succesive observations the residual is quickly reduced. In this case, the last bit of the residual is not removed for some time. These residuals must be checked in the course of the data analysis to assure that the system was able to null the dispersion.

Figure 3 shows the magnitude of the dispersion produced by the wedges as a function of time. The numbers shown at the left are related to a refraction interpretation of the data. Each small division is approximately 0.1 seconds of arc of dispersion, according to our current calibration. Notice that the RMS error is 0.01 arc-seconds for 10 minutes of observation.

The change in the dispersion between observations of Lambda UMa and 15 and 17 Can Ven is due to a large change in zenith distance as the telescope was moved to the new stars. Slight gaps appear in the data where the telescope was moved between 15 and 17 Can Ven.

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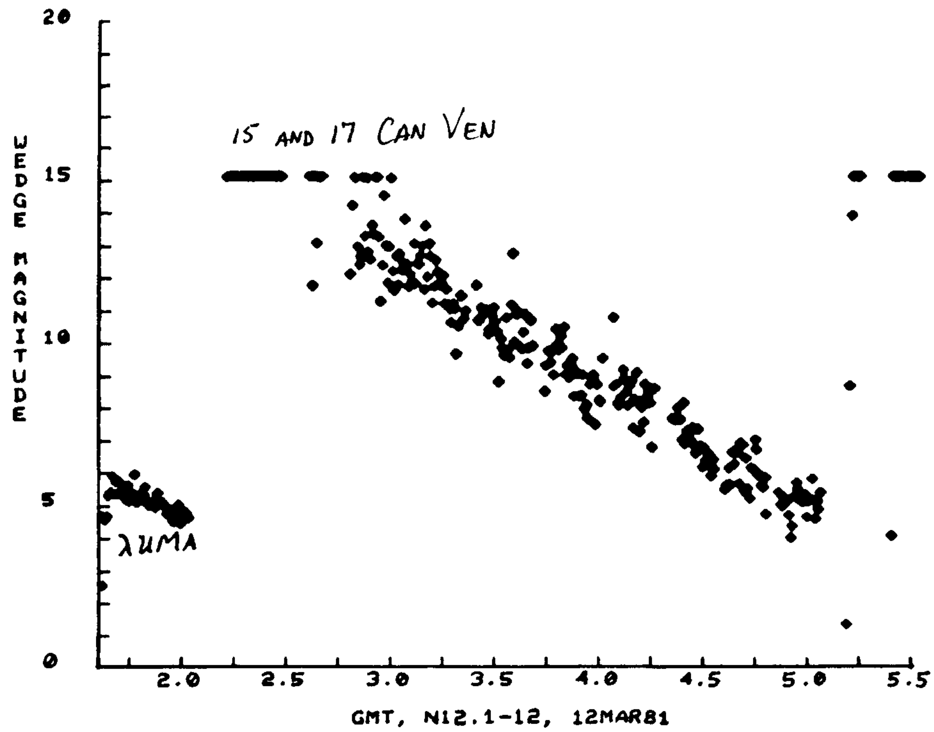

Figure 3.

The general downward slope of the dispersion for 15 and 17 Can Ven is consistent with the decreasing atmospheric dispersion due to the decrease of zenith distance of the star with time. At the beginning of the observation of 15 and 17 Can Ven, the maximum dispersion produced by the wedges was insufficient to cancel the dispersion produced by the atmosphere when the star was at an hour angle of four hours east. Thus the residuals in Figure 2 were non-zero until the zenith distance was reduced sufficiently for the atmospheric dispersion to be cancelled by the wedges.

Because 15 and 17 Can Ven are only 209 arc-seconds apart in the sky, the difference in atmospheric refraction of their light is very small. Therefore they show similar atmospheric dispersion as a function of time.

The stars 15 and 17 Can Ven are sixth magnitude giant stars of spectral types B7 and F0, respectively. The absence of changes in the dispersion when switching between these stars indicates the measured dispersion for single stars is independent of the colors of the stars, as required for measurement of atmospheric dispersion by this method.

In this mode of operation, we expect to reach a precision of 1 milli-second of arc for 10 to 20 minutes of observations; this translates to a precision in the measurement of refraction to about 0.03 seconds of arc.

DETECTION OF DOUBLE STARS

Up to this point we have commented on the reaction of the refractometer to dispersion produced by atmospheric refraction, but it also responds to the color differences of close double stars. If, when attempting to measure refraction with this refractometer, we found ourselves observing a close pair of stars of different colors instead of a single star, we might get quite unexpected results. If one star produced pure red light and the other pure ultraviolet, there would be an intrinsic separation of the red and ultraviolet photocenters due to the apparent angular separation of the stars. In this pure case, the apparent separation due to color would be equal to the apparent angular separation; with all realistic star colors, the apparent separation due to color would be less than the apparent angular separation.

More exactly, the separation 'c' of the red and ultraviolet photocenters would be related to 'rho', the apparent angular separation, by the equations shown in Figure 4. The subscripts 'A' and 'B' refer

$$\begin{aligned} c/\mathrm{rho} &= r_B/(r_A + r_B) - u_B/(u_A + u_B) \\ &= (1 + 10^{0.4\ \delta R})^{-1} - (1 + 10^{0.4\ \delta U})^{-1} \\ &= (1 + 10^{0.4\ \delta V}\ 10^{-0.4\ \delta(V-R)})^{-1} - (1 + 10^{0.4\ \delta V}\ 10^{-0.4\ \delta(U-V)})^{-1} \end{aligned}$$

Figure 4.

to the two stars in question, and the symbols 'r' and 'u' refer to the red and ultraviolet bandpasses in which they are observed. The bandpasses we have used are not exactly equivalent to the standard 'R' and 'U', since we have picked optimum bandpasses for doing refractometry rather than photometry. Although they are close enough to the photometric bandpasses for the purpose of illustration of expected results, calibration must be done before exact interpretation of our results can be made.

The maximum theoretical value of c/rho we have found for a possible pair of stars is 0.90. This is abnormally high; for usual giant pairs we would expect about 0.3. For a pair of stars with the magnitude-color relationship of the main sequence Table 1 gives the expected ratio of c to rho as a function of the magnitude difference of the stars. With this relationship, if there is no magnitude difference there is no color difference. The ratio of c to rho increases rapidly to a maximum of 0.10 at a delta V of 1.5 magnitudes, then decreases slowly to 0.01 at a delta V of 5.5. For a 14th magnitude star, using a moderate-size telescope, one hour of observation would give a resolution of 0.1 arc-second in the determination of c.

We have now discussed both the dispersion due to atmospheric refraction and the apparent intrinsic dispersion due to a double star. The simplest way to remove the atmospheric component of dispersion is

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MAIN SEQUENCE APPROXIMATION

delta V	c/rho	delta V	c/rho
0.0	.00	1.0	.09
0.1	.01	1.5	.10
0.2	.02	2.0	.09
0.3	.03	2.5	.08
0.4	.04	3.0	.06
0.5	.05	3.5	.04
0.6	.06	4.0	.03
0.7	.07	4.5	.02
0.8	.07	5.0	.02
0.9	.08	5.5	.01

Table 1.

to alternately observe a suspected double star and a very close-by reference star. For this combination, the atmospheric component of the dispersion should be changing in the same way with time for both the reference and suspected double star and any intrinsic dispersion should appear as a constant difference in the measured dispersion. Figure 5 shows the right ascension component of the wedge color for alternate observations of Beta Cygni A and B. Figure 6 shows the declination component. This is the type of signal we expect to get from a close double star referenced to a nearby single star. Although the signal is very close to what we expect from Beta Cyg, instrumental

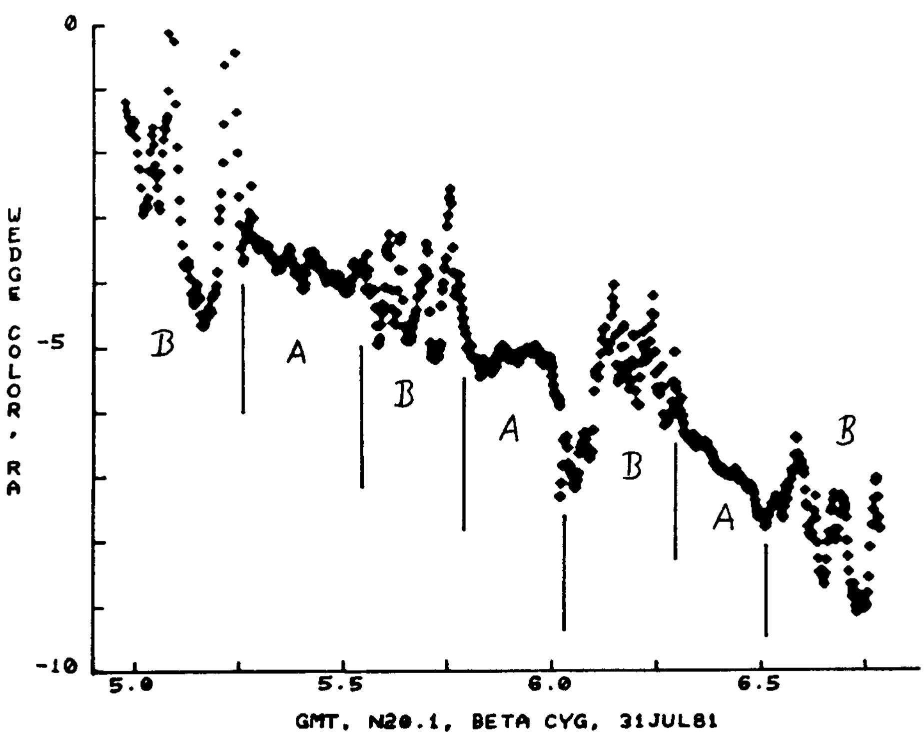

Figure 5.

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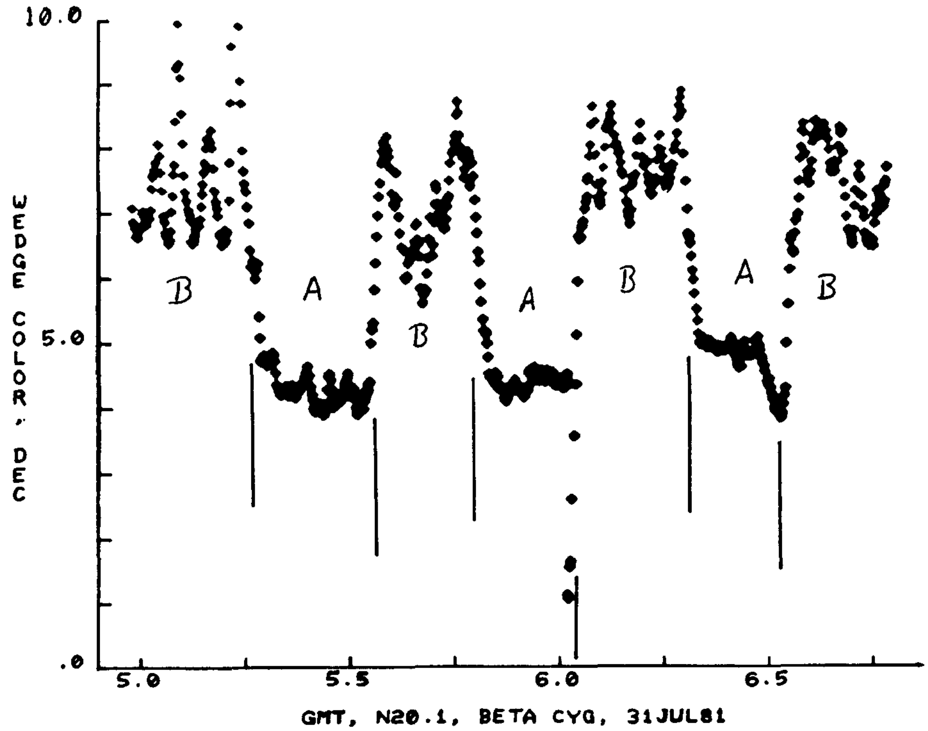

Figure 6.

problems have not been entirely eliminated from this data, so we do not yet consider this to be a reliable observation.

To calibrate the instrument, we shall make observations of known double stars with well-determined parameters. As an illustration of the type of observation which can be made, Figure 7 shows a set of observations of Vega followed by alternating sets of observations of Epsilon 1 and Epsilon 2 Lyr. Epsilon 1 and Epsilon 2 Lyr are each double stars oriented nearly North-South and East-West. The angular separations are each about 2.5 arc-seconds, but all the stars are early A, so the colors are nearly the same. This gives us a good test for the instrument: a large, well-known rho combined with a small determinable color separation c. Unfortunately, in this case the colors have not been well-determined so far as we have found in the literature. Other close double stars will serve as better calibration standards.

When using the refractometer for measuring atmospheric dispersion, another method of detecting double stars is available. Over the course of a night, a number of program stars and stars of opportunity will be observed several times. Then the entire mass of data will be fit using a model with parameters which describe the refractive dispersion, the instrumental constants, contributions from anomalous refraction, and constant intrinsic color offsets from double stars. This type of program requires a fair amount of work in implementation, but is necessary if we are to remove the biases double stars would contribute to the determination of refraction. The alternative is to eliminate double stars from the refraction program. However, to the limits at which they affect our results, the double

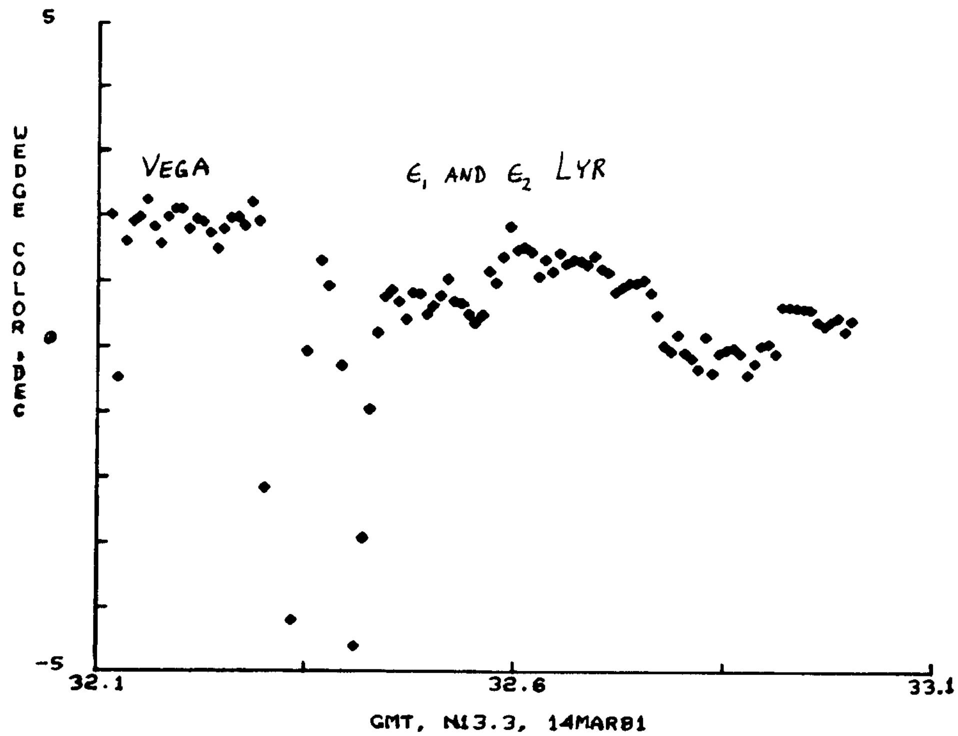

Figure 7.

stars are not known.

SUMMATION

Although the current observations reflect a number of instrumental and calibration difficulties, we expect that these will soon be surmounted, and that detection of double stars will soon be achieved.

We are developing a technique which may allow detection of bright double-stars with separations as small as 10 milli-seconds of arc. It may also allow detection of double stars with separations of less than an arc-second to beyond 14th magnitude using a moderate-size telescope.