A Method of Measuring High Delta m Doubles

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Abstract: This paper describes a method of precisely measuring theta and rho for pairs in which the difference in stellar magnitude (delta m) is in the range of 8 to 12 . The instrumentation takes the form of a stellar coronagraph where, in this design, a highly attenuating foil strip is substituted for the normal opaque occultor, thus giving a sharp, well exposed and well defined position for the bright primary, along with faint and sometimes numerous components lying clear of the foil. Many WDS listed high dm components are unconfirmed providing an additional challenge in their recovery. Although many components are optical, good measures of these objects can be of some value in various proper motion studies. The instruments optical/mechanical design is described in sufficient detail such that other observers may assemble a similar device from their optics collection. CCD images of a few program stars are also shown.

Introduction

Measuring high delta m pairs with a CCD detector presents special difficulties due to detector saturation. Even in the case of wide pairs, where the faint secondary is well imaged outside this saturated region, calculating the centroid of the overexposed primary is practically hopeless. As similar but increasingly closer pairs are imaged, there comes a separation where the faint component is impossibly buried in the "glare" of the primary, just as in visual work, only worse! Overcoming this limitation has fascinated the writer for years and recently, spurred on by a challenge of Brian Mason's, some progress was made in this area with the recovery and measurement of Burnham's faint "C" & "D" components of Polaris. These results were reported in the Spring 2006 issue of this journal. The instrumentation described here moves away from the somewhat makeshift arrangement used in the Polaris measures and, instead, follows along the lines of a true stellar coronagraph. In this report the word "occultor" is usually used when referring to the highly attenuating foil strip.

Sources of Scattered Light

Light is scattered passing through the atmosphere and again in the telescope optics. Depending on sky conditions, one or the other can be the dominant contributor. Sky transparency, as with a solar coronagraph, governs the strength of atmospherically scattered light. Atmospheric dust, haze, mist, fog, ice crystals and forest fire smoke produce an aureole or light glow around each star image. Typically this aureole extends only a short angular distance from the star, fading asymptotically away and typically going below the detection threshold (for the required program exposures) within a few arc minutes. In very clear conditions at high altitude sites, this attendant glow is very weak with a total integrated brightness perhaps one or two millionths of the observed star. With just the slightest haze, the atmospheric scatter begins to compete with the telescope's optical scatter. Determining the exact level or strength of instrumental scatter is not straightforward but needless to say systems with a minimum number of surfaces are favored. It is assumed by the writer that, on the clearest nights, the observed aureole surrounding a bright occulted star in the LSO telescope images is primarily instrumental in nature. In any case, the scatter clearly originates before the occultor and coronagraph lenses as can be seen by the blackness of the field covered by the occultor (see Figure 1).

The effects of this surrounding diffuse glow become apparent when detecting and measuring close-in faint components of the brightest primaries. The harmfulness of this glow can be reduced by digitally dividing an image of the program star by a control star of similar brightness and sky location. Here the control star (which can be the program star itself) must be positioned behind the occultor in nearly the same frame position as the program star (a slight displacement is required to extract the attenuated primary). Field information common to both images is thus subtracted out by division, the same as in the normal process of flat fielding an image. Esthetically, the results are hardly pleasing as artifacts from imperfect registration always remain, however, from a scientific viewpoint, beneficial canceling of the scattered light is achieved. Thankfully, most high delta m measures do not require this extremely sensitive and tedious operation.

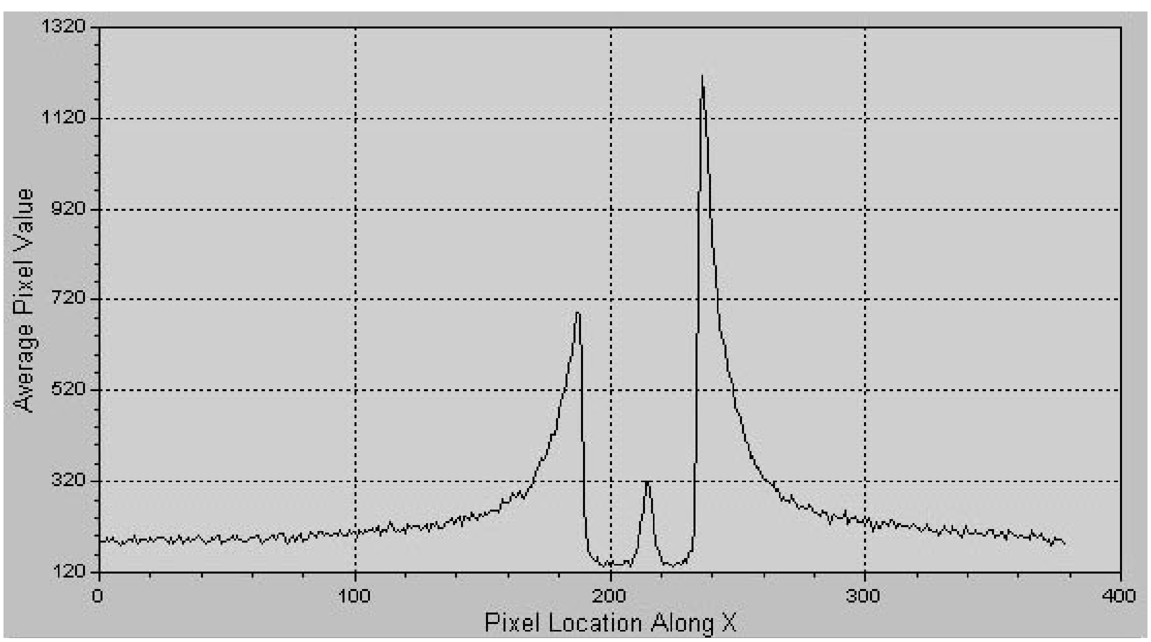

Figure 1: This graph shows a line intensity scan perpendicular to the occulting strip and through the occulted image of Spica. The sharp, highly attenuated image of the primary is clearly seen thus permitting accurate centroid determination. Scattered light outside the occultor tapers away to near sky background levels. Figure 5 shows the CCD image used for the scan and includes additional details.

The Tailpiece Coronagraph

The instrument is located at the final focus of the writer's 9-inch Schupmann medial telescope. It consists of a 24-mm focal length microscope eyepiece used as a magnifying relay providing an effective system focal length of 164.8-inches. The relay lens is mounted approximately midway inside an old empty Barlow tube into which the ST-7 CCD is plugged. In the initial design the attenuating "occultor" was taped to a thin support window at the entrance to the tube, the occultor and stars alike focused on the CCD via the relay lens set. The occultor is a 1-mm wide strip cut with a razor blade from a sheet of 1Baader solar film. It extends well outside the CCD field in the long dimension and subtends 40 seconds of arc in width. The film (foil) employed is designed for visual solar work and attenuates the light by 10 magnitudes or 10,000 times in intensity. Because the film is extremely thin, just a few ten thousandths of an inch, the focus for the occulted star and the unocculted star (s) are, for practical purposes, identical and all sharply imaged.

First Star Tests and Design Refinements

Imaging tests of the device were very encouraging until calibrations to determine the effective focal length were begun. A 38 arc seconds pair (STF 5 app) was chosen to obtain an initial calibration and to also determine if the magnification or plate scale was uniform throughout the field. It became apparent almost immediately that there was significant field distortion, as the separation values varied about 0.6 arcseconds, center to edge, of the 5.7 x 3.8 arcminute field. Optical distortion in any relay system can be reduced to

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near zero if a pupil is imaged at an appropriate place within its lens elements. This is done by providing a field lens at the first focus of the relay. This field lens images the Schupmann corrector of the author's telescope, itself an intermediate pupil, onto the relay elements. A plano convex field lens at that location would, as with the previous window, provide a convenient mounting surface for the foil strip against its plano surface. The price one pays for correcting distortion is an increase in field curvature, the field lens here adding to that of the relay lens.

The optical system was first ray traced in OSLO (a free downloadable student ray trace program) without a field lens confirming the distortion observation, the trace predicting about 2% distortion at the field edge. Next a field lens was entered in the optical prescription and located at the first focus such that the plano surface faced the incoming light. This is important so that the occultor, which is simply Scotch taped to the plano surface, blocks all the relay elements, including the field lens itself, of bright light. The convex curvature of the field lens was varied using OSLO's slide-bar feature until the distortion went to near zero (less than 0.05 %). This placed the pupil nearly coincident, but just 1mm skyward of the last element's surface at the chosen relay magnification of 1.65, thus providing an accessible location for the possible inclusion of a Lyot stop. A Lyot stop is a circular aperture located at a pupil after an occultor and blocks the bright diffraction ring originating at the telescope's aperture. In operation this stop reduces and defines the final or effective aperture.

A plano convex lens of 45 mm FL was found that closely matched that of the prescription. It was mounted in the same threaded cell that previously held the window and which screws into the nose of the old Barlow tube. Adding the field lens steepened the field curvature (Petzval radius) from 35.8 mm to 25.8 mm, just barely acceptable for maintaining focus across the ST-7 chip at the working f-ratio of 18. The microscope eyepiece is held in the tube with setscrews through the side of the tube. Figures 2, 3, and 4 show photographs of the device.

Final Star Tests

First an observing run was made, again on STF 5 app, to verify the ray trace work and to get an initial measure of the telescope's effective focal length. The results of this test were very encouraging with distortion now greatly reduced. Measured separations of STF 5 app for 3 field positions gave the following results: Field center 37.989" sd = 0.065", 50% field 37.987 sd =0.069", and field edge 38.025" sd = 0.081". The field positions measured are located along the wide axis of the CCD. The effective FL based on this double was determined to be 164.8 inches. Next an independent measurement of EFL was performed with a coarse objective grating which closely confirmed the value, the grating being the final arbiter.

Figure 2: Coronograph tube

Figure 3: Closeup of Occulting Strip Taped to Field Lens.

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Figure 4: Coronagraph Attached to ST-7 CCD.

Operational Bounds

In order to set up an observing program, it was necessary to determine the faintest primary that could be reliably imaged through the foil optical attenuator. Past experience at LSO showed that a 30 second exposure is just about the limit before image motion and, to some extent, atmospheric blurring becomes ruinous to faint double star work (this limit is somewhat extended at higher declinations). Given this, a few 30 second test exposures showed that primaries no fainter than 4.5 magnitude could be usefully imaged through the foil in 3x3 binned mode and that primaries around 3.5 are well imaged in full resolution (no binning) on perfect nights. Experience with the finished system shows 2x2 binning the more usual for most work. The magnitude limit for secondaries fall out of the 30 second limit and run roughly in the range of magnitude 14 to 16. Component separation limits are, of course, delta m dependent.

Based on the above constraints along with limiting the observations to declinations between the pole and minus 15 degrees, Brian Mason generated an observing list of about 222 objects. This list forms the basis of LSO's high delta m observing program.

First Impressions

Not surprisingly, a great number of unlisted stars are found around many of the primaries. As CCD's are red sensitive and as no optical (bandpass) filtering is employed for most of this work, red stars are detected which appear brighter than the WDS listed components. My rule on this is simple, if a star as close or closer and similarly bright as the listed closest program star is discovered, then I will assign it a designation. CCD images are always available to investigators for further study in any case.

Operational Procedure

The program stars are all bright and easy to find using the handy *Norton's Star Atlas* or similar charts. This is quite a relaxing change from recent work on faint doubles such as Stein's photographic pairs! Once the primary is roughly centered using a special cross hair eyepiece, the remaining task is to rotate the coronagraph tube so that the last measured position angle is approximately perpendicular to the long axis of the occulting strip. Often the faint companion can be visually spotted at this point. Next the bright primary is centered behind the "occultor" and the CCD installed. Usually the faint companion(s) show well with a 10 second exposure and, for the brighter primaries, is the most often used exposure time.

Sample Images

The following sample images are unfiltered, the bandwidth determined primarily by the ST-7 CCD color response. This favors the red region tending to accentuate K and M stars. The images are oriented with north up and east to the left.

In Figure 5 we see the occulted image of Spica, the primary of BUP 150 AB. This 10 second exposure in 2x2 binned mode through a thick atmosphere easily captures the 12th magnitude "B" component seen in upper left. A very faint closer star is also just revealed. Note the CCD "burn-in" spot where Spica was inadvertently exposed outside of the occultor. These desensitized spots disappear by the next night.

Figure 6 shows Gamma Draco and some of Burnham's many faint components, a few of which lie well outside the field.

Lastly, the star Vega is seen in Figure 7. The STF component "D" is, interestingly, measured from "C"

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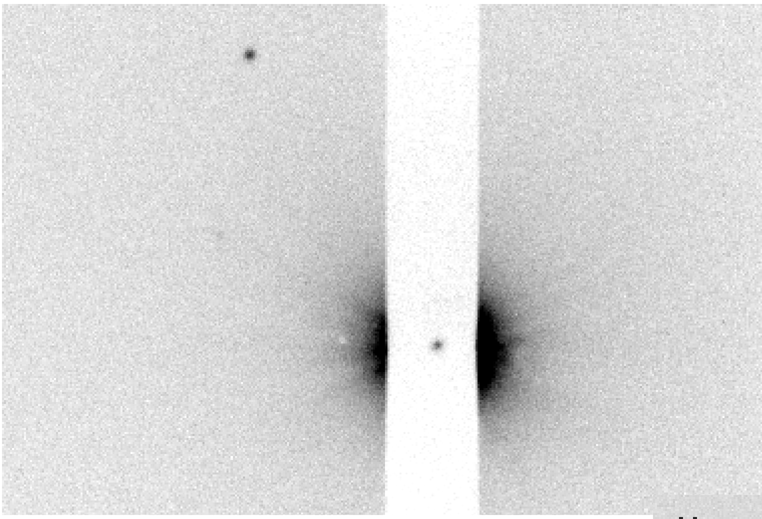

Figure 5: Spica, 10 sec exp, 2x2 binned.

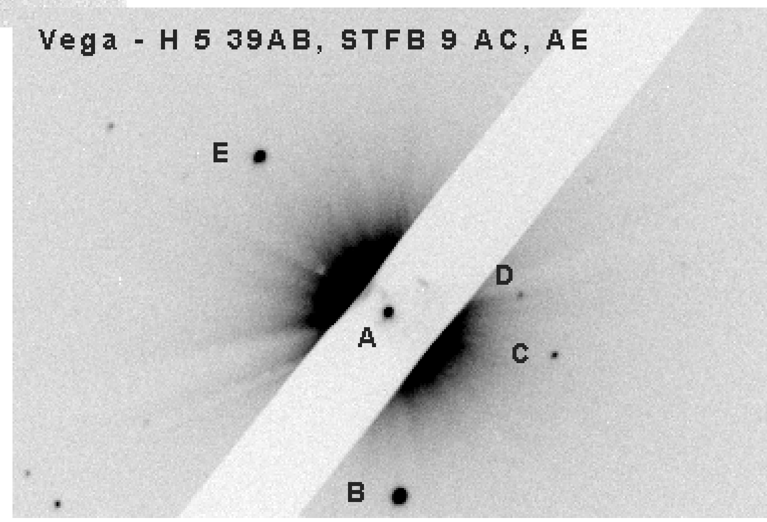

Figure 7: Vega, 20 sec exp, 2x2 binned.

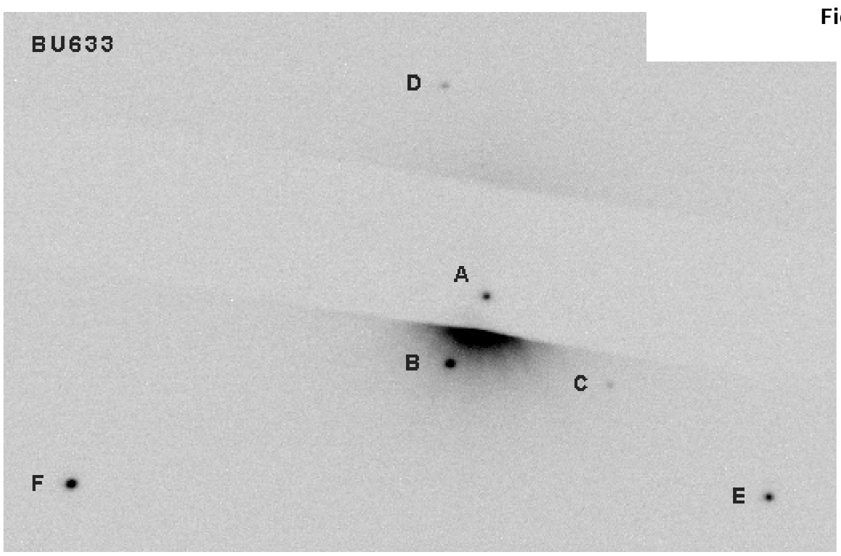

Figure 6: Gamma Draco, 10 sec exp, no binning, cropped.

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but not from "A". Note the closer faint unlisted component at the LSO measured values of 277 degrees and 29.27 arcseconds separation and the neat double at lower left.

Summary

A method of measuring high delta m pairs with a CCD sensor has been presented. The device implementation is described and sample images shown. The device is currently employed in an ongoing measurement program of these difficult stellar objects. Filters such as the Baader photographic foil of density 3.5 may be tried to cover an intermediate delta m range. Measurements of many of the program's high delta m doubles will be submitted to this journal in the near future.

References

Baader AstroSolar[tm] Density 5-Visual, Baader Planetarium, Mammendorf Germany. US-Canadian distributor: Astro-Physics, Inc. www.astro-physics.com