PRELIMINARY RESULTS OF APPLE VALLEY VIDEO CAMERA SENSITIVITY TESTS

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Note for Revision A: On pages 3 and 7 qualifications are mentioned regarding the performance of the Watec 902H2 Ultimate video camera. October 17 images obtained by Terry Redding indicate that it is to be expected that this camera is indeed more sensitive than shown here, the difference being better use of the camera controls. Quantitative data are not yet available, but it is believed that new data for this camera will show it, in Figures 2 through 5, to be one of the most sensitive cameras. The present data for this camera, files a9-H and b9-H, fall near the middle of the sensitivity range.

INTRODUCTION

In conjunction with the IOTA annual meeting, on Saturday evening, September 13, 2008, about 15 of the meeting attendees gathered in the parking lot of the Lewis Center in Apple Valley, California to obtain video recordings of M11, the Wild Duck Cluster. The purpose was to obtain data that would allow a determination of the relative sensitivity of many video cameras. Two SCTs were used with a total of 13 video cameras to obtain 22 recordings. Data obtained using the 8-inch SCT were designated 'a' series data; data obtained using the 10-inch SCT were designated 'b' series data. A two-second sample of each recording was later used with Limovie, obtaining over 150 amplitude determinations of individual stars. Some of those were repeats; the final data set has 116 amplitude values. This is a preliminary report of the results of those tests.

A third set of data was obtained at the same time, but using several small telescopes with two video cameras. Those data, referred to as the 'c' series, have not yet been analyzed.

The sections that follow will cover a list of equipment tested, a description of the camera models, plots of the amplitude data, and summary results.

A more comprehensive final report is planned, adding representative video images, making the plots more presentable, and describing more details of the tests and analysis.

EQUIPMENT TESTED

Six basic video camera types were tested, and one of those was also used with a Collins I*3 image intensifier. All of the tests were identified with a letter followed by a one or two digit number, such as a3 and a12 in the 'a' series (using an 8-inch SCT), and b5 and b8 in the 'b' series (using a 10-inch SCT). The 'a' and 'b' series were redundant in the sense that, hopefully, either series would by itself give the answers desired. Meade f/3.3 focal reducers were used on both SCTs for all tests. Table I lists all of the cameras, and associates each with a particular data record.

Incidental to the basic objectives, the separation of two of the brighter stars was measured for each record. That confirmed that the cameras fell into two general categories with respect to their ability to image a large field. It is assumed that this difference was entirely dependent on whether a one-third-inch or one-half-inch CCD was used. For reference, Table II gives the nominal field-of-view obtained with each of these video cameras, in both the 'a' and 'b' test series. The actual field-of-view obtained with the various video cameras having a given size CCD chip varied by a few percent. That variation would have been reduced, or eliminated, if the distance from the focal reducer to the CCD plane had been held constant.

TABLE I
Identification of video cameras used with each experiment

'a' Series experiment name	'b' Series exeriment name	Video camera model	Camera owner
a19-802	b17-802	Watec 802	D. Breit
a3-164a	b3-164a	PC164C	W. Morgan
	b5-164c	PC164C-Bumgarner modified	R. Nolthenius
	b18-164c	PC164C-Bumgarner modified	R. Nolthenius
a18-164d		PC164C	S. Degenhardt
a13-EXa	b16-EXa	PC164CEX	M. Collins
a12-EXb	b13-EXb	PC164CEX	D. Falla
a6-XXa		PC164CEX-2	W. Morgan
a7-XXb		PC164CEX-2	T. Redding
	b8-XXc	PC164CEX-2	R. Nolthenius
a8-XXd		PC164CEX-2	S. Degenhardt
a9-H	b9-H	Watec 902H2 Ultimate	T. Redding
a16-M	b12-M	Matrix	K. Young
a17-III	b14-III	PC164CEX-2 with Collins I*3	D. Dunham
	b15-III	PC164CEX-2 with Collins I*3	D. Dunham

Notes:
'a' Series experiments were with an 8-inch SCT
'b' Series experiments were with a 10-inch SCT
Experiment names:
the prefix identifies a particular video record
the suffix identifies the specific video camera used
b18-164c was a repeat of b5-164c, one hour ten minutes later
b15-III was a repeat of b14-III after adjusting intensifier/camera

TABLE II
Approximate field-of-view obtained

	- - - - - - - - - Field-of-view - - - - - - - - - - - (arcminutes, Horizontal x Vertical)		
Test series	one-third-inch	one-half-inch	Collins I*3
'a' series (8-inch SCT)	20 x 15	26 x 20	36 x 25
'b' series (10-inch SCT)	15 x 11	19 x 14	28 x 20

Comments:
One-third-inch cameras: PC164C; PC164CEX; PC164CEX-2
One-half-inch cameras: Watec 802; Matrix; Watec 902H2 Ultimate
The Collins I*3 was used with a PC64CEX-2. It is not known whether using a Watec camera with it would increase its field-of-view.

CAMERA DESCRIPTIONS

Watec 802. This is an older model video camera that turned out to be the least sensitive one for which data were obtained. (One PC23C was used briefly, but it was so insensitive that no useful recording could be obtained for the star field being used.) The apparent sensitivity of all other cameras will be given relative to the Watec 802.

PC164C. This is the model that represented a major breakthrough in sensitivity over the PC23C, the most commonly used video camera at that time (circa 2002?). Three of these cameras were used in these tests, with somewhat variable results.

PC164CEX. This model was introduced about three years ago as a higher resolution alternative to the PC164C. Two of these units were tested. The one purchased in 2005 is significantly less sensitive than the one purchased early in 2008.

PC164CEX-2. This model first became available in early 2008, and these tests showed it to be the most sensitive of the camera-only units. Three units were tested, and they gave nearly identical results.

Watec 902H2 Ultimate. A number of persons have praised the sensitivity and versatility of this camera model. Although it is believed that at least three of these were available during the test session, somehow test data were obtained using only one. When it was first placed on the 8-inch SCT, only a few of the very brightest stars appeared in the image. After a search for a miniature screwdriver and someone familiar with the camera, some adjustments were made and the image improved markedly. The question remains, however, as to whether this was a fair test of its capability.

Matrix. I am not familiar with this camera, provided by Karen Young. It has the significant benefit of using a one-half-inch CCD chip (as do the two Watec models tested).

Collins I*3 with PC164CEX-2. This image-intensified system was much more sensitive than any of the others, and it produced the widest field-of-view. It is also much more expensive than any of the others, and bulky, and needs careful adjustment. It appears that most of the star images are saturated and only stars of magnitude 10.4 or fainter were processed with Limovie. Comparison with the camera-only tests was difficult, and perhaps the numerical value assigned to its relative sensitivity is not valid. But there is no question that it is more sensitive: it is believed that stars of magnitude 14 can be identified in the record. Question: is the sensitivity of this system tied to the sensitivity of the video camera used?

PLOTTED DATA

Typically three seconds of video data from near the middle of each test were transferred to a computer using Movie Maker. Those files were run through Virtual Dub, edited to about two seconds (actually 59 to 61 frames), and then saved in a form acceptable to Limovie. Each data record was run repeatedly to obtain two-second samples of the brightness of several stars, the results were saved as csv files, and Excel was used to obtain an averaged amplitude value for each star. Each of those averages will be referred to as the Limovie amplitude — for a given star, in a given test.

No brightness or contrast enhancements were used.

The number of stars tracked for a given test varied from 3 to 8. The ‘a’ series, because of its larger field-of-view, generally used more stars than the ‘b’ series, and, similarly, more stars were tracked for tests using the more sensitive video cameras. Although 20 seconds or more of data are available for each test, to this point only a single two-second sample from near the middle of the record has been examined.

The statistical variation of the 60-odd sums that make up each Limovie average can be used to improve the confidence in the results, but that refinement will be deferred.

To illustrate the analysis process, Figure 1 is a Limovie plot of the amplitudes produced by measurements of four stars from test b16. Fifty-nine frames were used with each star, so 59 amplitudes are plotted for each star. For the data shown in Figure 1, the Limovie amplitudes obtained (via Excel) were 884, 630, 241 and 116. These are four of the 116 data points retained for plotting. The signal-to-noise ratio typically became marginal at around 100 to 200 counts. The largest Limovie amplitude obtained with any of the camera-only units was 3104 in the 'a' series, and 4176 in the 'b' series.

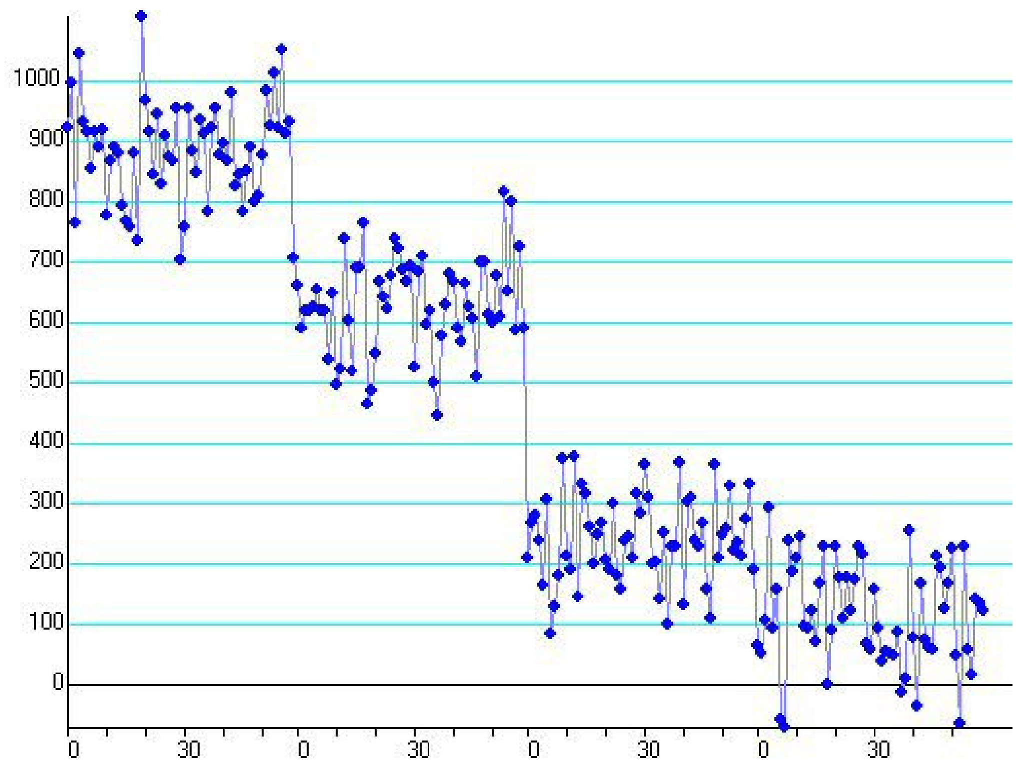


Figure 1. Limovie plot of amplitudes measured for four stars in test a16. The identical 59 frames were used for each of the four amplitude determinations.

Since star magnitudes are on a logarithmic scale, it is appropriate to also plot the measured amplitudes on a logarithmic scale. If the base 10 logarithm of the Limovie amplitude is used, the plotted amplitude information would fall in the range of two to 3.5. It was chosen instead to use 2.512 times the base 10 logarithm, which places the amplitude values in the range of five to nine, and each ordinate unit can be considered to be equivalent to a change of one magnitude. For convenience I will call this quantity the "Limovie magnitude," and abbreviate that to LM.

> LM is defined as being 2.512 times the base 10 logarithm of the Limovie amplitude obtained from a video record for a given star.

This is equivalent to assuming that a given recording system will produce 2.5 times as many counts from one star as it will from another star that is exactly one magnitude fainter. Of more interest to this study is the corollary, the assumption that, for a given star, two systems that produce Limovie counts in the ratio of 2.5:1 differ in sensitivity by one magnitude.

Figures 2 and 3 show all of the amplitude data for the ‘a’ and ‘b’ series, respectively. Note first that the results are better-behaved for the brighter stars. It is assumed that this is because noise problems begin to interfere strongly above magnitude 11 or 12. It is further assumed, then, that valid results will be obtained if comparisons are based primarily on data from the brighter stars.

Figure 2. Star brightness determinations from Limovie analysis of ‘a’ series experiments. The abscissa is the listed red magnitudes for the various stars. The eleven different video cameras used can be identified by cross-referencing the legend and Table I.

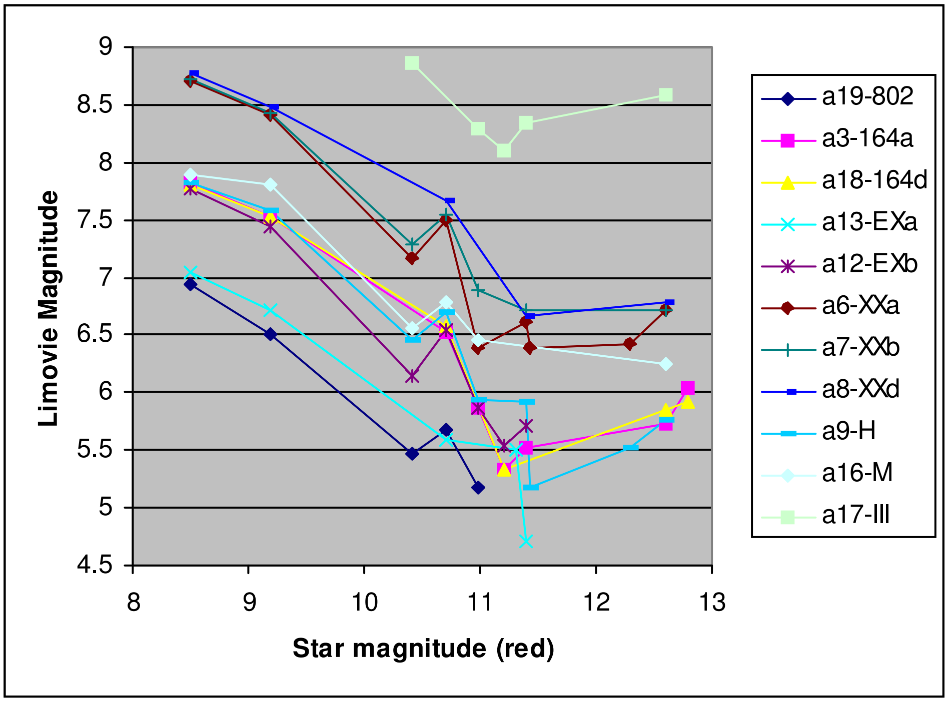
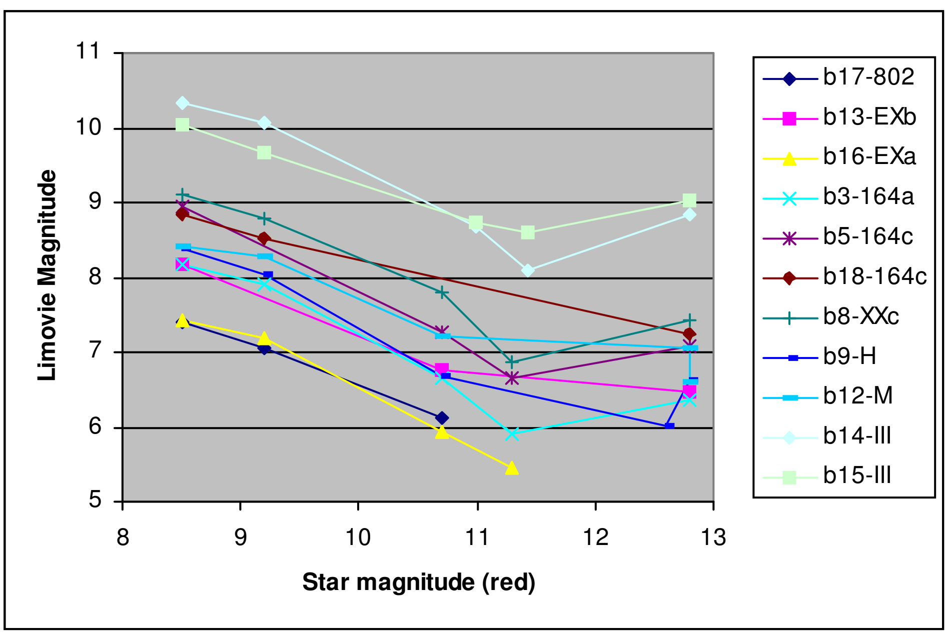


Figure 3. Star brightness determinations from Limovie analysis of ‘b’ series experiments. The abscissa is the listed red magnitudes for the various stars. The nine different video cameras used can be identified by cross-referencing the legend and Table I. Test b18 was a repeat of test b5. Test b15 was a repeat of test b14.



The star magnitudes used on the abscissa are red magnitudes, obtained for me by Scotty Degenhardt, with the assistance of Steve Preston. There is one exception: for star GSC5126-3292 I chose to use the visual magnitude, 11.43. The red magnitude found by Scotty was 10.448 and by Steve was 10.40. Using either of the red magnitudes in my plots produced a major discontinuity; using the visual magnitude did not. The reader may claim that this is arbitrarily fudging the data, but my counter claim is that since the interest is in relative sensitivity, it doesn't matter what magnitude is assigned to any given star. The choice is whether each record using the particular star will have a distracting jog, or not have a distracting jog. A similar problem arose with another star, TYC5126-3280-1, listed as visual magnitude 10.71 and red magnitude 10.70. In Figure 2 it is the star that causes a bump above the general trend for several of the records – but it bumps up by about the same amount every time it is used. The real difference in my choice of use for the two stars is that the first one (3292) seemed to be a full magnitude out of line compared with stars listed as being less than a tenth magnitude different, and the second one (3280) seemed to be one-third magnitude out of line compared with stars listed as being about one-third magnitude different. For the moment I will explain away this problem by claiming that, although the spectral response of our video systems is better in the red, and using red magnitudes of stars is therefore a sensible choice, it is not a totally reliable way to predict system response for a particular star. (A further note: of the 17 stars used at some point in this study, the difference in visual and red magnitude was 0.2 or less for 12 of them, and in the range of 0.28 to 0.39 for three more. If visual magnitudes had been used for all stars, the plots would still look very much like Figures 2 and 3.)

Ideally the slope of the results from any one camera would be negative one, i.e., a one magnitude decrease in measured brightness (an LM decrease of one, on the ordinate) would correspond to a one magnitude increase in published star magnitude (on the abscissa). The observed slope seems to be closer to -0.8, but nevertheless I will compare the sensitivity of one camera versus another by looking at the ordinate difference at a given abscissa, i.e., the comparison will be of LM difference at each published star brightness.

The result of this comparison is Figures 4 and 5, the data from Figures 2 and 3, respectively, after LM values for the Watec 802 have been subtracted from the LM values of all of the other recording systems.

Figure 4. Relative sensitivity of ten video cameras from the 'a' series tests, which used an 8-inch SCT. All sensitivities are referenced to test a19, which used a Watec 802. Results for test a17 are off scale to the top: 3.38 magnitudes at Rmag = 10.4 and 3.11 magnitudes at Rmag = 11.0.

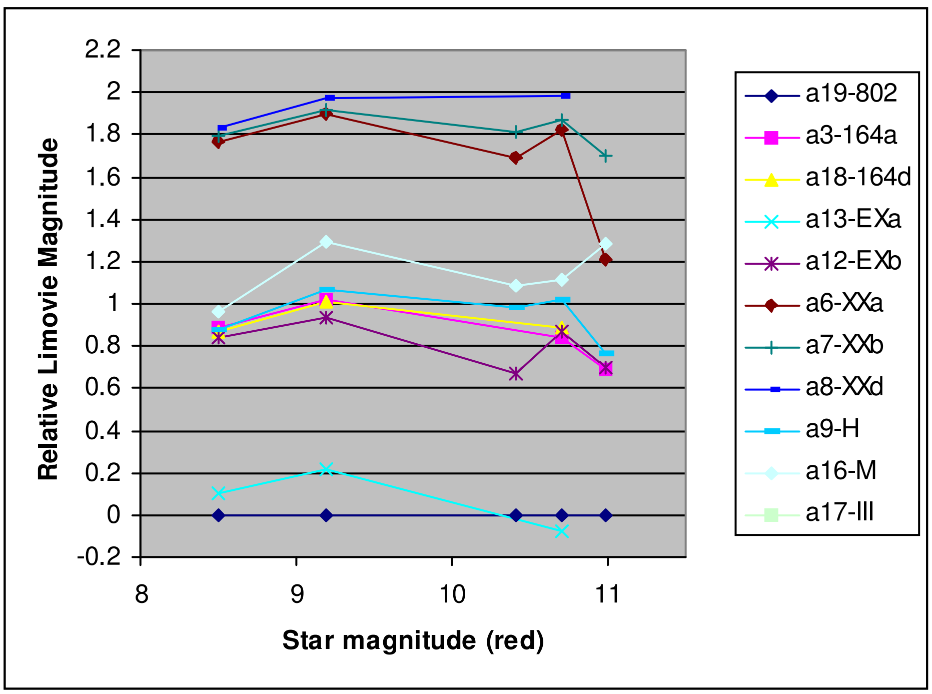
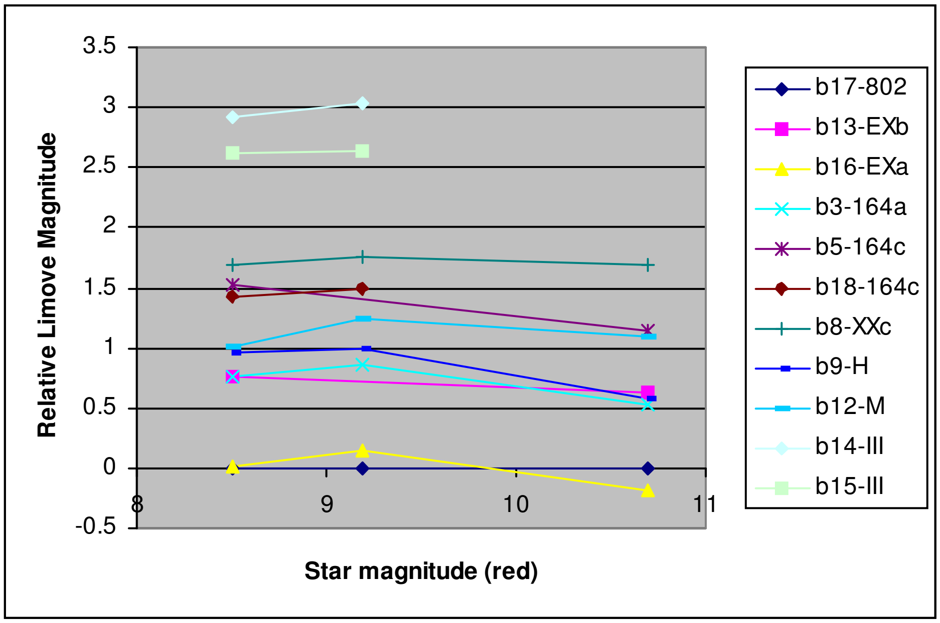


Figure 5. Relative sensitivity of nine video cameras as tested using a 10-inch SCT. All sensitivities are referenced to test b17, which used a Watec 802.



SUMMARY RESULTS

Figures 4 and 5 have the results of all of these experiments in a fairly concise form, but it is still a little difficult to grasp what it all means, especially because I have not yet taken the time to tidy up the plots by using more readily distinguishable line styles. A summary of the content of Figures 4 and 5 is therefore given in Table III.

The self-consistency between the 'a' and 'b' series is judged to be very good. The biggest difference appears to be for the PC164C, but, although three of these cameras were tested, somehow none of them was used in both series. The apparent difference may or may not be real.

The two PC164CEX units appear to be consistently different from each other, and it is plausible that the difference is due to production changes over a span of nearly three years. The significance of that result is minimized by the fact that the PC164CEX has effectively been replaced by the PC164CEX-2, which seems to be the most sensitive video camera tested here.

As a last comment, my pre-conceived notion was that the Watec 902H2 Ultimate would be the best performer. This was based on the various comments that have been posted by users over the past year and more. The rather average sensitivity result found here is somewhat offset by the capability of that camera to image a relatively large field-of-view (because of its one-half-inch CCD), and to exercise various gain and gamma controls. Unfortunately, only one unit was included in these experiments, so high priority should be placed on obtaining further data with this model. The added controls may actually be a penalty if the adjustment process requires special expertise.

TABLE III
Relative sensitivity of various video cameras, as determined experimentally on September 13, 2008

Video camera model	Increased sensitivity (magnitudes) 'a' Series	'b' Series	Notes
Watec 802 (reference)	0	0	a
PC164C	0.9		
PC164C-Bumgarner modified		1.4	b
PC164C-Bumgarner modified		1.4	b
PC164C	0.9		
PC164CEX	0.1	0	c
PC164CEX	0.8	0.7	d
PC164CEX-2	1.8		
PC164CEX-2	1.8		
PC164CEX-2		1.7	
PC164CEX-2	1.9		
Watec 902H2 Ultimate	1.0	0.9	e
Matrix	1.1	1.1	
PC164CEX-2 with Collins I*3	3.2	2.9	f
PC164CEX-2 with Collins I*3		2.6	f

Notes:

a There were many hot pixels, but data analysis was not compromised. Most cameras had few hot pixels.

b This camera was used twice in the ‘b’ series, with an hour between the tests.

c This camera was purchased in 2005.

d This camera was purchased in January 2008.

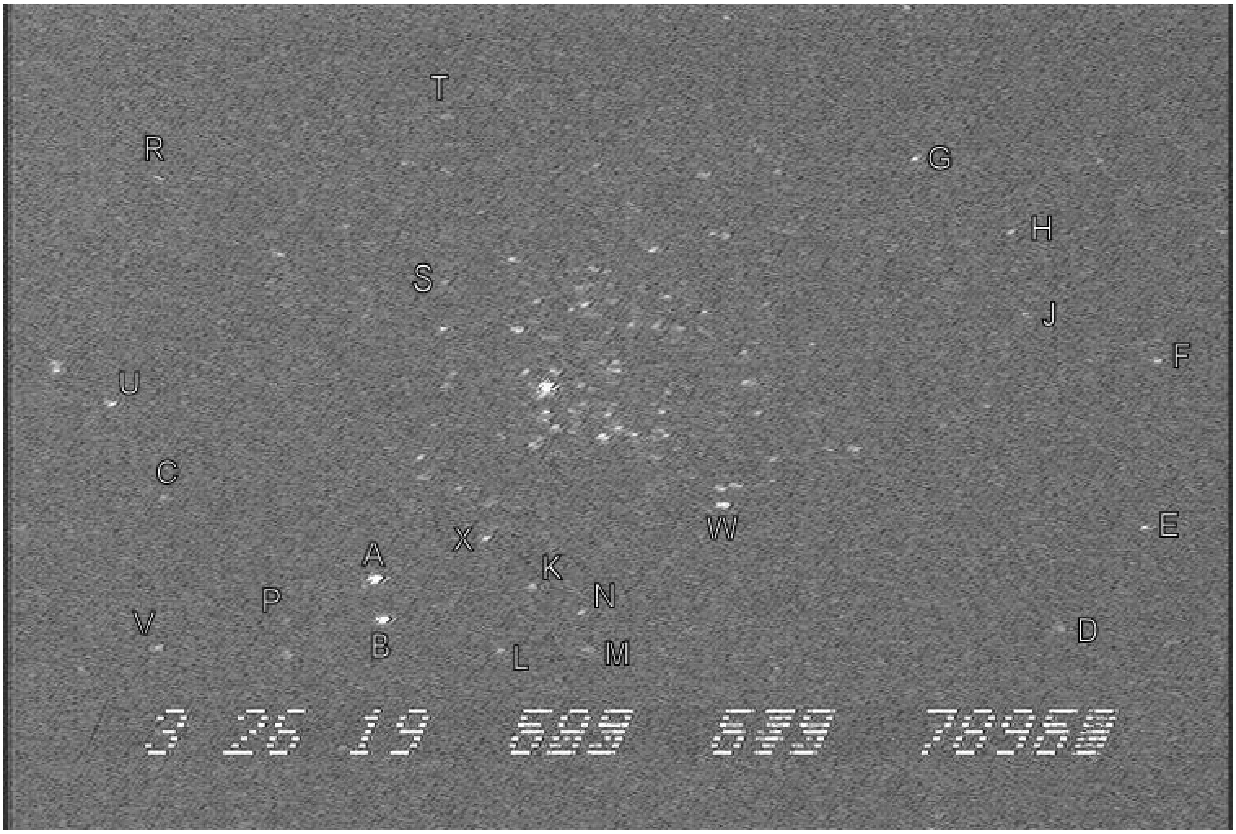
e Adjustments prior to the ‘a’ series test greatly improved the performance. The ‘b’ series test was later. It is plausible that further adjustments could have been beneficial.

f The two ‘b’ series tests were two minutes apart, with adjustments in between. Note that the adjustment procedure actually penalized the performance slightly.

FUTURE EXPERIMENTS

The basic procedure described in this report can be used by anyone to compare the sensitivities of two or more cameras. This need not be done under any particular conditions of sky quality or elevation, though noting unusual circumstances would be appropriate. The target need not be a star cluster or Messier object, either. The target should have, within the camera f-o-v, a minimum of three stars spanning more than one magnitude in brightness that are also within the detectable range of the least sensitive camera. Anyone who uses Limovie can then analyze their own data, or I will be willing to assist with that. Data obtained in this way by individuals can then be accumulated to expand on the experiments reported here. It is my intent to test my own video cameras this way in the near future, and perhaps the results of those experiments will encourage others to do similar testing.

APPENDIX A
M11 star map used for these experiments



Shown above is the star map used in analyzing the experimental data. This was made by first creating a five-frame moving average from several seconds of the test a6 record, then capturing a single frame from that averaged file. Brightness and contrast were then increased a lot with a photo editor, and letters were placed by many of the stars.

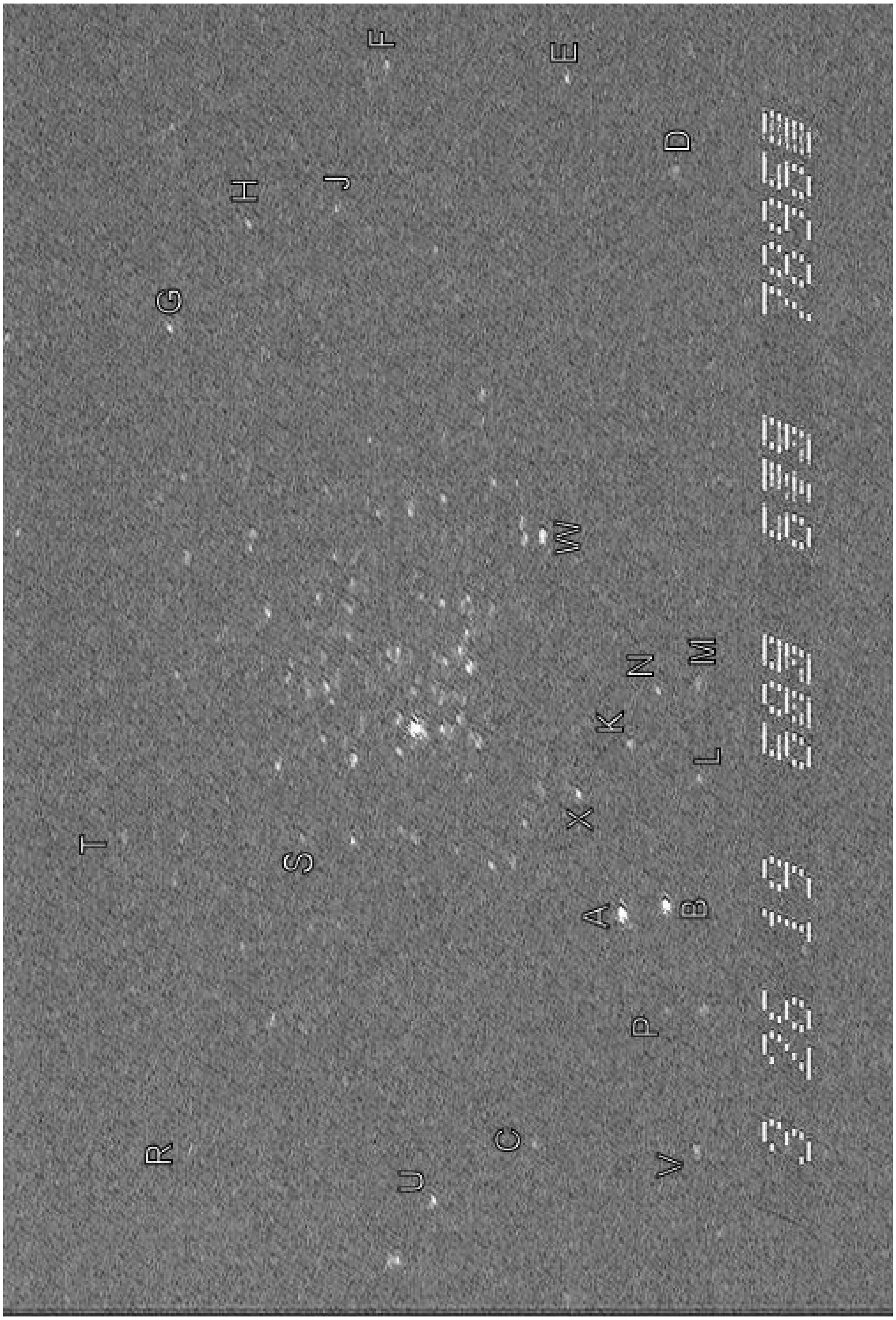
(The quality of this image suffered greatly when it was reduced to fit within the width of the page, so it was rotated and inserted again on the next page, at full size.)

Stars A, B and W were used most. The ‘sunlit limb’ mode of Limovie was used to get information from star W, and a few others, in order to avoid stars close by. In some of the records stars U, C and V were off scale to the left, and in a few star B was down in the timing display. Hot pixels on the Watec 802 image far outnumbered the stars detected, but it was still possible to obtain Limovie amplitudes for several stars.

In general the images were very dark, with each star appearing like a point. The major exception was the image produced by the image-intensified system: its background was much, much brighter than in the enhanced image above, and each star was a circle with significant diameter.

Analysis would be simpler if fewer stars were present, but it is important to have several stars appear in the image.

APPENDIX A (concluded)
M11 star map used for these experiments



This is the same M11 star map shown on the previous page, but this copy is at full size.