White Balancing RGB Filters with a G2V Star

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Why White Balance?

Because "true color" requires balanced RGB signal-to-noise ratios

- Non-flat CCD quantum efficiency (QE) curves result in uneven RGB filter responses to white light, unless the RGB filter transmittances are specifically tailored to a chip's QE curve
- Uneven RGB responses mean imbalanced signal-to-noise ratios (SNRs) from white-light sources when equal exposure times are used for RGB data acquisition
- "Truer," more esthetic RGB color composites derive from balanced RGB SNRs, so we need a method to determine RGB exposure times which provide that balance

Balanced RGB SNRs are important! Following are RGB composites of globular cluster M56 made from an imaging system where R:G:B transmittance = 0.6 : 1.0 : 0.75; that is, 5 units of red, 3 units of green, and 4 units of blue are required for white balance.

<u>NOTE</u>: All layers in each image were stretched equally, with a gamma of 10. Backgrounds were balanced.

R:G:B = 2:3:4 minutes

Low red SNR results in stars that are too cyan

R:G:B = 4:3:2 minutes

Low blue SNR results in stars that are too red/yellow

R:G:B = 5:3:4 minutes

Balanced SNR star color is "true"

Applying a simple pixel value multiplier to a layer to offset its low QE position in the R:G:B ratio does not change the SNR deficit:

R:G:B = 2:3:4

R:G:B = 2:3:4, R x 2.5

Nonlinear stretches of gamma=10 were applied to all layers of each image. Backgrounds were equalized.

Balanced SNRs are key to a white-balanced result

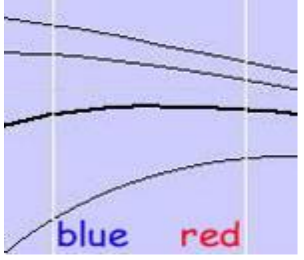
Why use G2V Stars for White Balancing?

1. Our sun is a G2V star and is our reference for white light

2. Although the sun is often seen as a yellow star, this is primarily due to atmospheric extinction, which scatters blue wavelengths more than red wavelengths, making the sun look yellow to red, depending on the sun's altitude, atmospheric contaminants, and water vapor content

3. The sun's black-body radiation curve does peak in the light-yellow (which is why it is called a yellow star in astronomy), but it best represents an even distribution of wavelengths across the visible spectrum:

G2



"The vertical lines represent the range of visible light, from blue and violet (on the left) to red (on the right). The curves, from lowest to highest, represent temperatures of 3000, 5780, 12000 and 24000 Kelvins. Cooler bodies radiate more in the red and infrared, and hotter bodies in the violet and ultraviolet."

Graph and caption from: http://cseligman.com/text/sun/blackbody.htm

Although there are relatively small percentage differences in the R:G:B ratios derived from extinction-corrected photometry of stars with photospheric temperatures from about 4500K to 8000K, a G2 star is the best standard for our purposes.

Acquiring and applying proper G2 calibration data for RGB filters is quick and easy with the following procedure:

1. Use a sky that is nicely transparent. Seeing isn't critical, but steady transparency is!

This

Not this

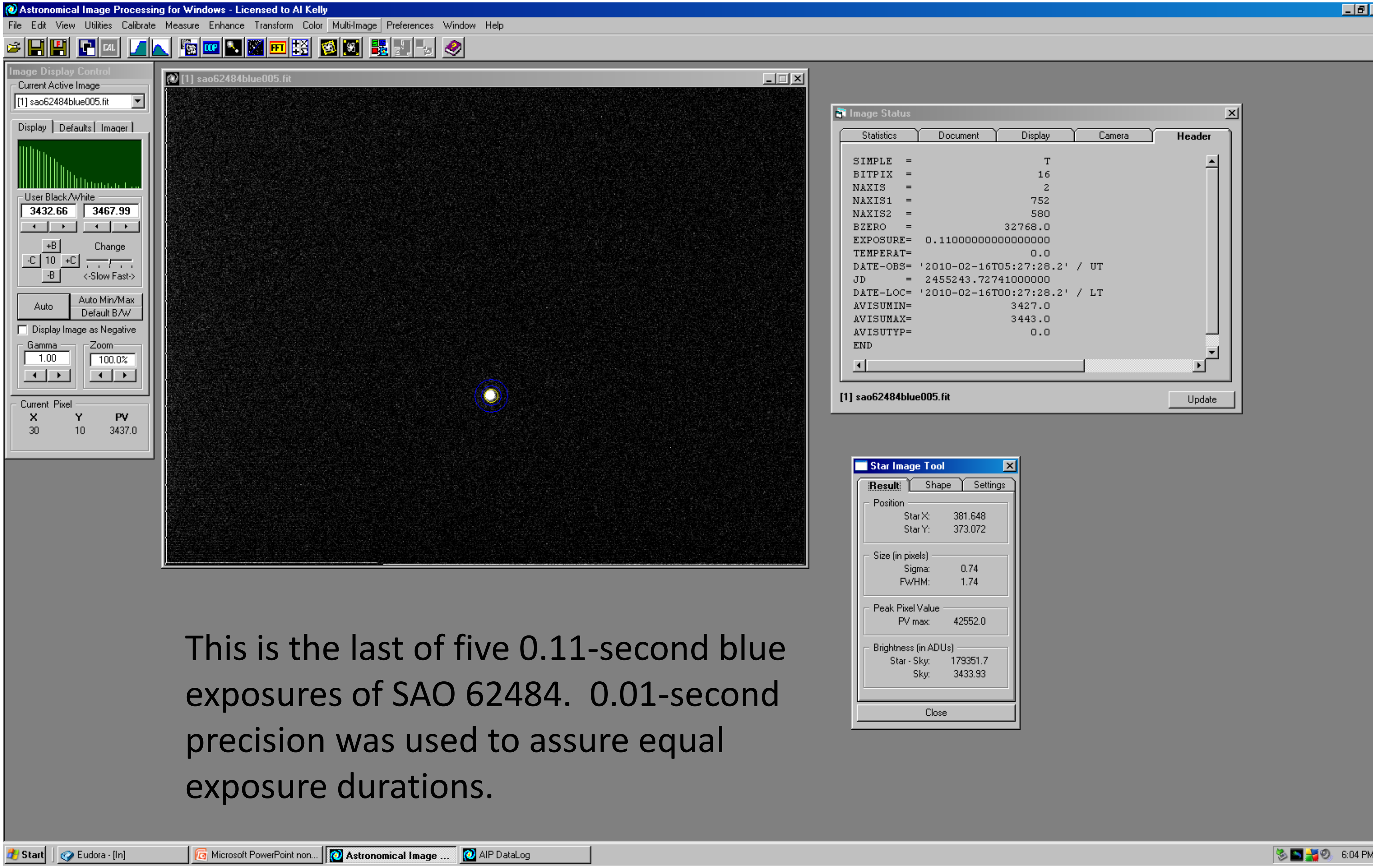
2. Select a G2 star with a low zenith angle; that is, high in the sky, at least 50 degrees or so above the horizon. Although extinction corrections can be made for stars at any zenith angle, it is best to keep visibility good and corrections small

Example	Solar	Analog	Stars	
Right Ascension	**Declination**	**Magnitude**	**Spectral Type**	**Name**
00h 18m 40s	-08° 03' 04"	6.5	G3	SAO 128690
00h 22m 52s	-12° 12' 34"	6.4	G2.5	9 Cet
01h 41m 47s	+42° 36' 48"	5.0	G1.5	SAO 37434
01h 53m 18s	+00° 22' 25"	9.7	G5	SAO 110202
03h 19m 02s	-02° 50' 36"	7.1	G1.5	SAO 130415
04h 26m 40s	+16° 44' 49"	8.1	G2	SAO 93936
06h 24m 44s	-28° 46' 48"	6.4	G2	SAO 171711
08h 54m 18s	-05° 26' 04"	6.0	G2	SAO 136389
10h 01m 01s	+31° 55' 25"	5.4	G3	20 LMi
11h 18m 11s	+31° 31' 45"	4.9	G2	Xi UMa
13h 38m 42s	-01° 14' 14"	10.0	G5	SAO 139464
15h 37m 18s	-00° 09' 50"	8.4	G3	SAO 121093
15h 44m 02s	+02° 30' 54"	5.9	G2.5	Psi Ser
15h 53m 12s	+13° 11' 48"	6.1	G1	39 Ser
16h 07m 04s	-14° 04' 16"	6.3	G2	SAO 159706
16h 15m 37s	-08° 22' 10"	5.5	G2	18 Sco
19h 41m 49s	+50° 31' 31"	6.0	G1.5	16 Cyg A
19h 41m 52s	+50° 31' 03"	6.2	G3	16 Cyg B
20h 43m 12s	+00° 26' 15"	10.0	G2	SAO 126133
21h 42m 27s	+00° 26' 20"	9.1	G5	SAO 127005
23h 12m 39s	+02° 41' 10"	7.7	G1	SAO 128034

Extinction Correction Factors

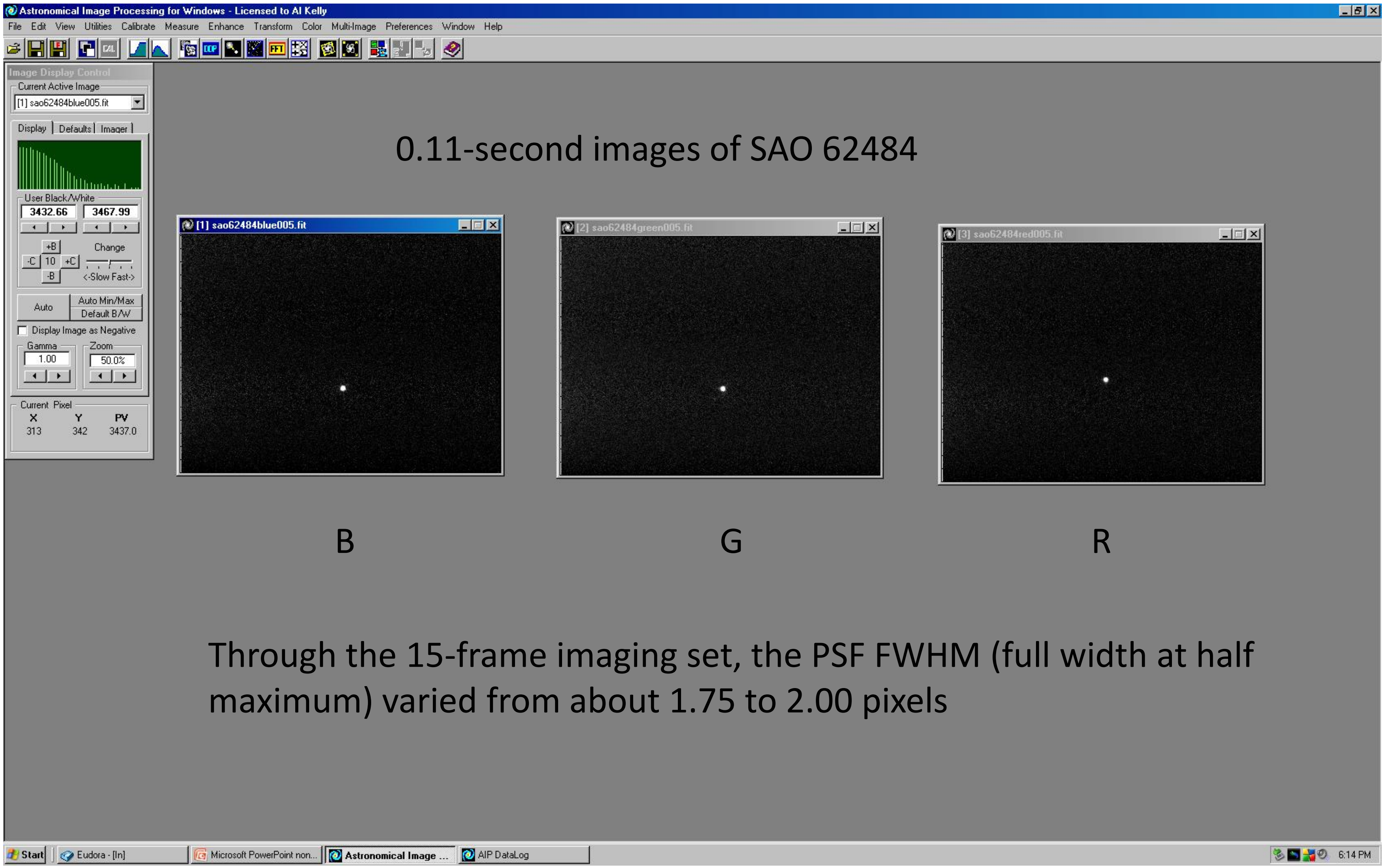
EL	ZA	Air Mass	Rxc	Gxc	Bxc
90	00	1.000	1.000	1.000	1.000
80	10	1.015	1.001	1.002	1.003
70	20	1.064	1.005	1.010	1.014
60	30	1.155	1.013	1.025	1.035
55	35	1.221	1.018	1.036	1.050
50	40	1.305	1.025	1.050	1.070
45	45	1.414	1.034	1.068	1.097
40	50	1.555	1.046	1.092	1.132
35	55	1.743	1.063	1.125	1.180
30	60	2.000	1.085	1.172	1.249
25	65	2.365	1.118	1.242	1.356
20	70	2.923	1.170	1.356	1.535
15	75	3.862	1.263	1.574	1.892

3. Make several short, equal-duration exposures through each filter, making sure that no pixel saturation occurs (same as in taking flats)

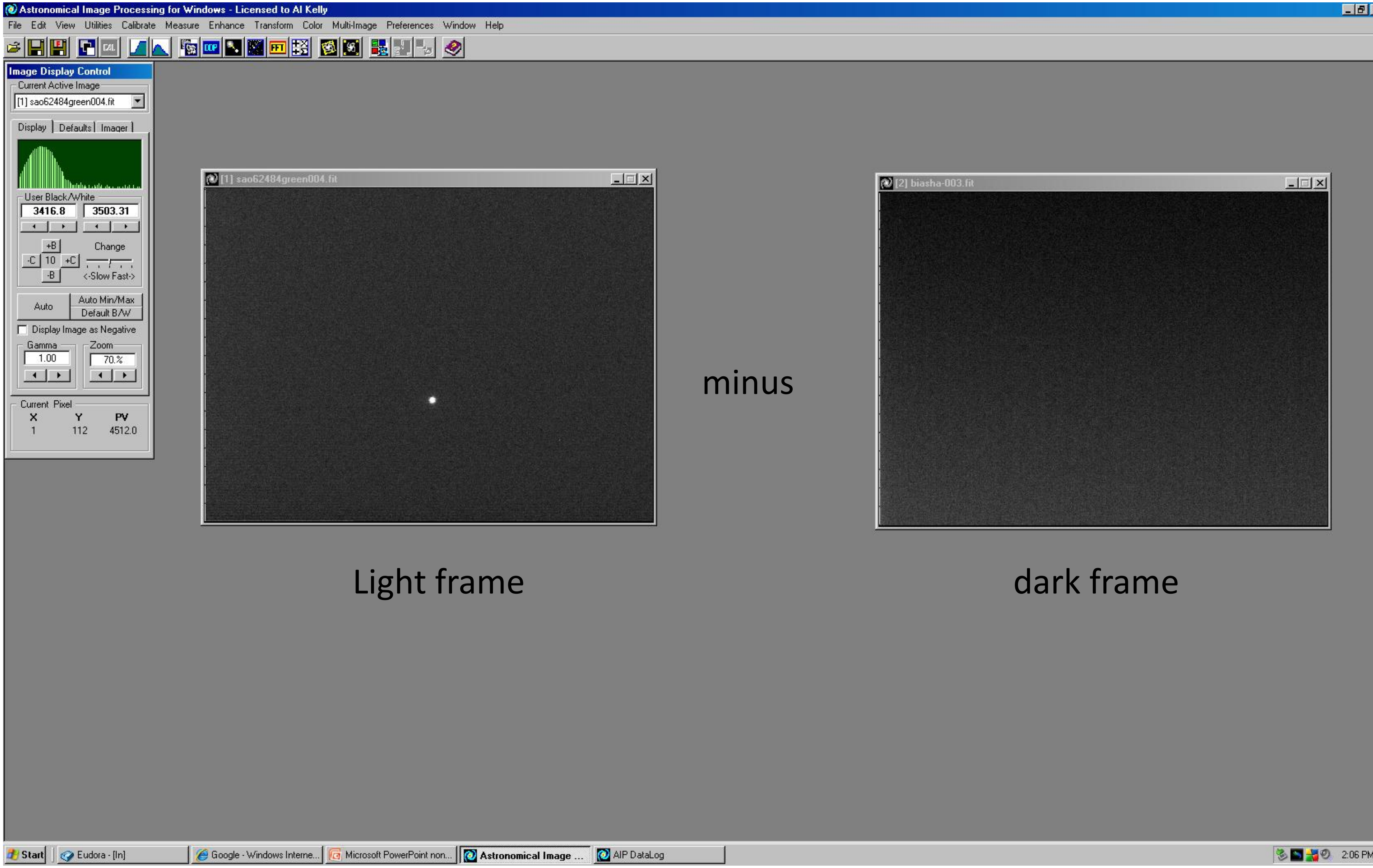


This is the last of five 0.11-second blue exposures of SAO 62484. 0.01-second precision was used to assure equal exposure durations.

4. Focus is not critical, but keep star point spread functions (PSFs) relatively consistent



5. Calibrate the images to remove bias and hot pixels

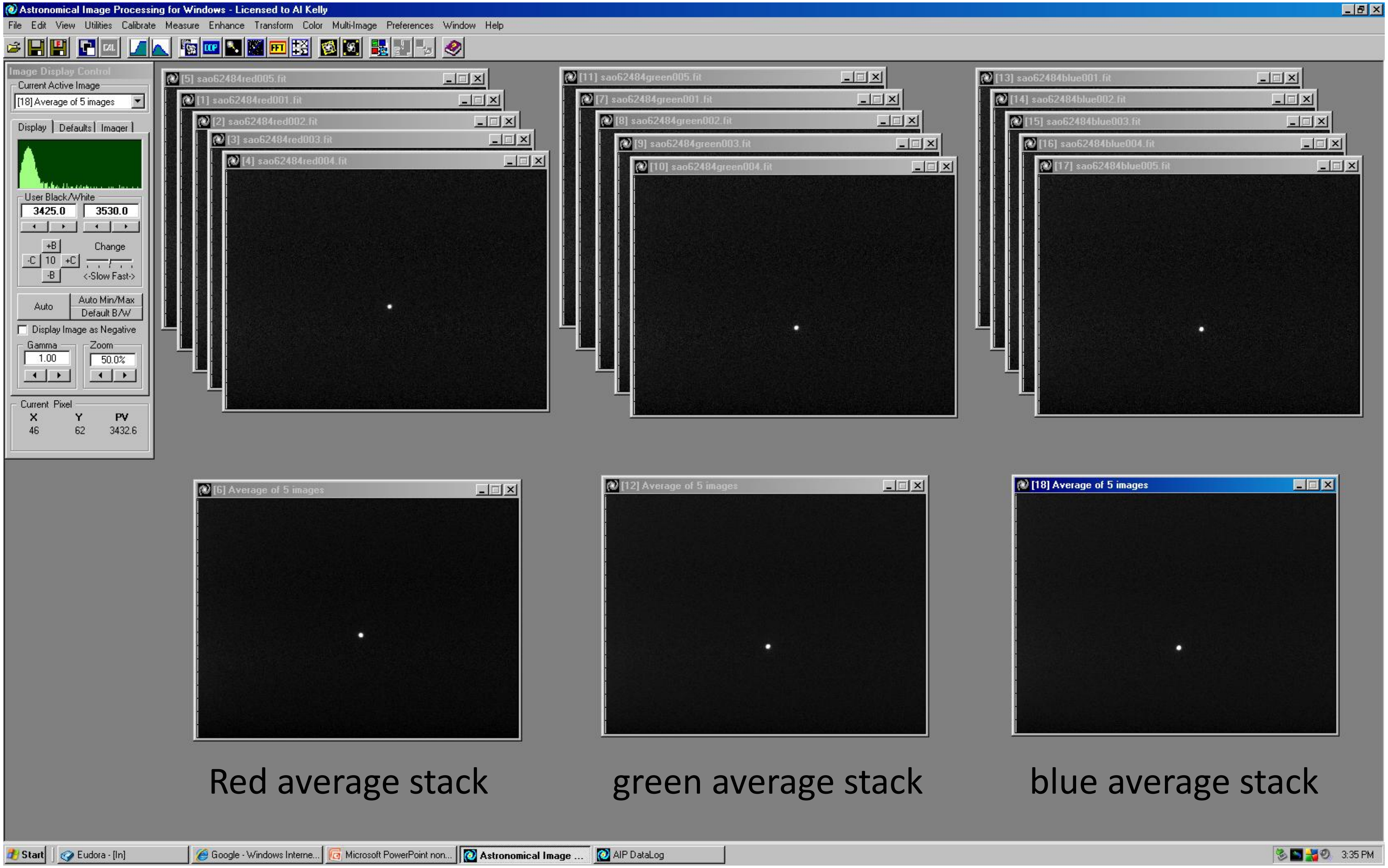


minus

Light frame

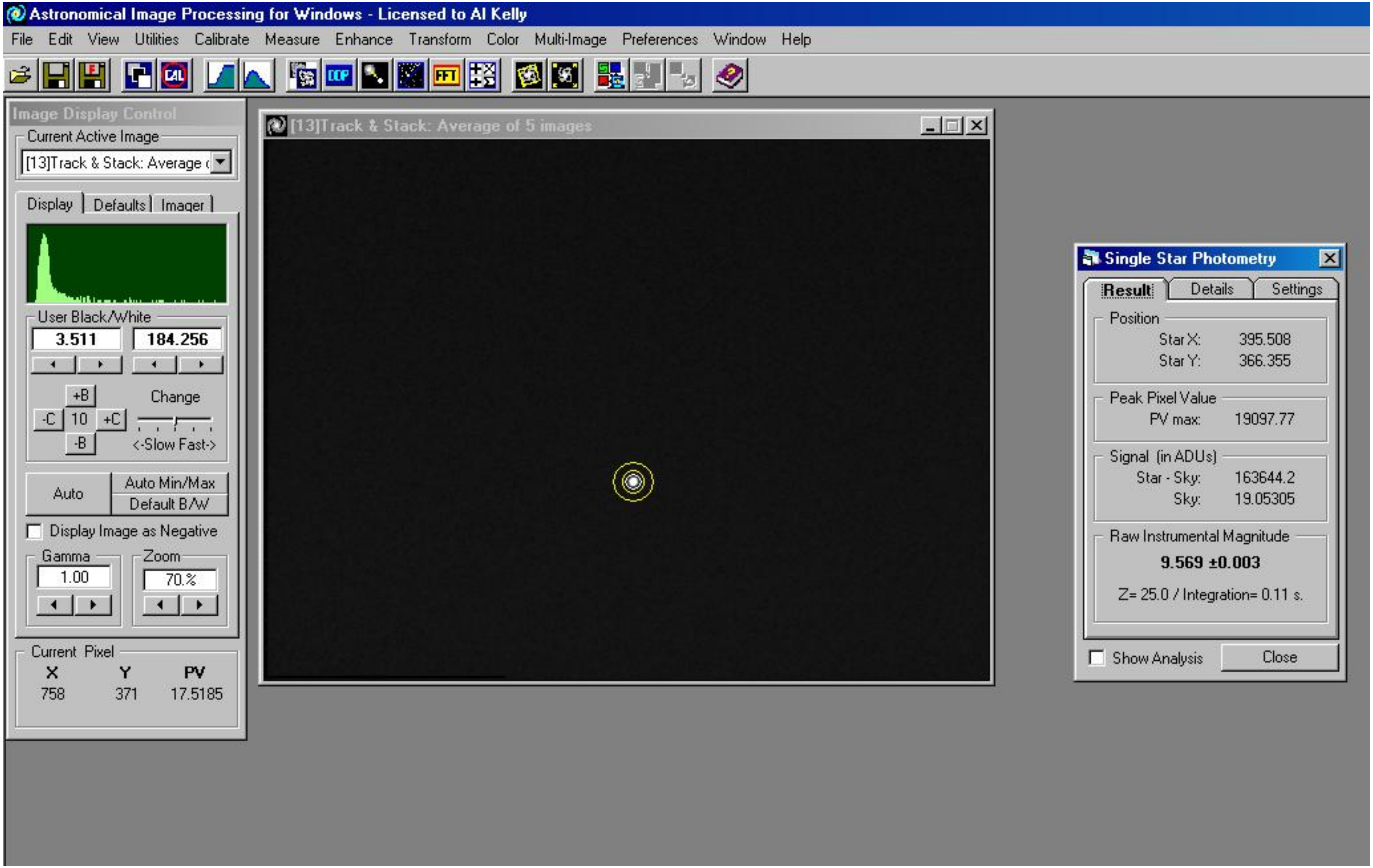
dark frame

6. Carefully register the images and create averaged RGB stacks for photometric sampling

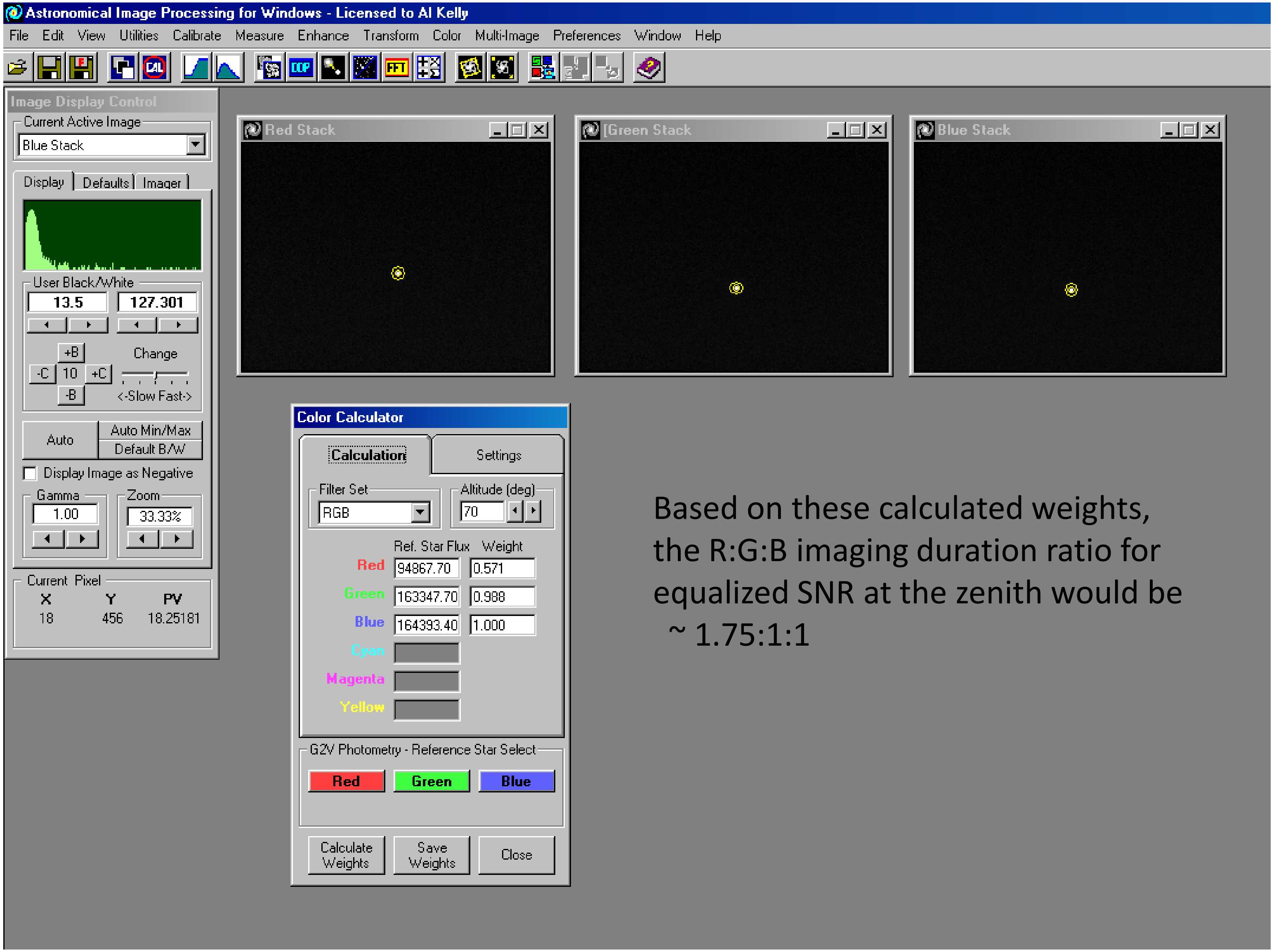


Red average stack green average stack blue average stack

7. Determine the photometric flux for the target star in the RGB stacks



8. Correct the flux for extinction and calculate the R:G:B sensitivity ratio



Based on these calculated weights, the R:G:B imaging duration ratio for equalized SNR at the zenith would be ~ 1.75:1:1

9. Use the calculated ratio to guide the amount of total exposure time required through each filter for white-balanced color composites

KEEP IN MIND:

Ratio numbers within ~5% are close enough For SNR balancing purposes.

When imaging far from the zenith, make adjustments to your RGB imaging times to maintain relatively equal SNRs*. For example, imaging at 35 degrees above the horizon means that the calculated R:G:B imaging times of 1.75:1:1 are closer to 1.6:1:1.*

Either imaging method is valid: 1) making equal numbers of unequal R:G:B subexposure durations or 2) making unequal numbers of equal R:G:B subexposure durations. The latter may be easier.

Extinction Correction Factors

EL	ZA	Air Mass	Rxc	Gxc	Bxc
90	00	1.000	1.000	1.000	1.000
80	10	1.015	1.001	1.002	1.003
70	20	1.064	1.005	1.010	1.014
60	30	1.155	1.013	1.025	1.035
55	35	1.221	1.018	1.036	1.050
50	40	1.305	1.025	1.050	1.070
45	45	1.414	1.034	1.068	1.097
40	50	1.555	1.046	1.092	1.132
35	55	1.743	1.063	1.125	1.180
30	60	2.000	1.085	1.172	1.249
25	65	2.365	1.118	1.242	1.356
20	70	2.923	1.170	1.356	1.535
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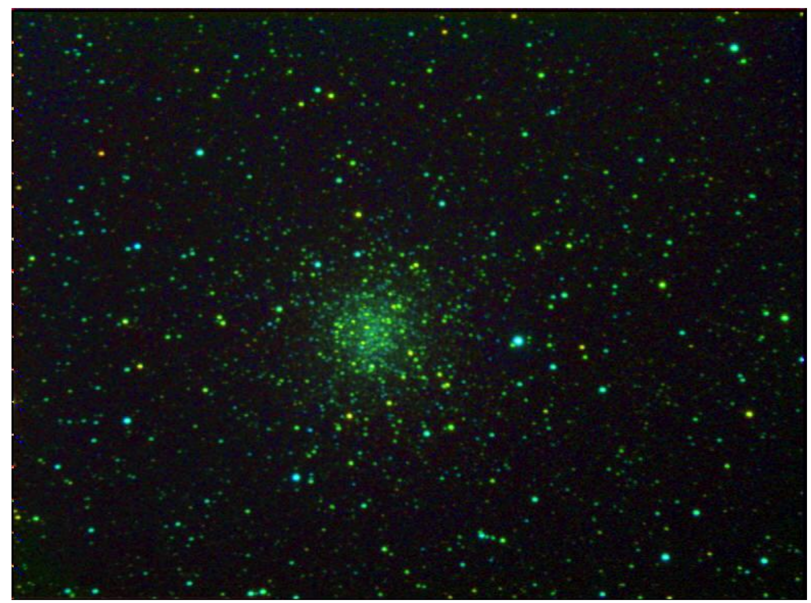
The importance of equalized nonlinear stretching and background neutralization

When RGB exposures of white-balanced durations are combined, “true color” composites will naturally fall out….right?   WRONG!

Without equalized nonlinear stretching to balance the histograms and sky background neutralization, even RGBs with equal SNRs can produce ghastly results:

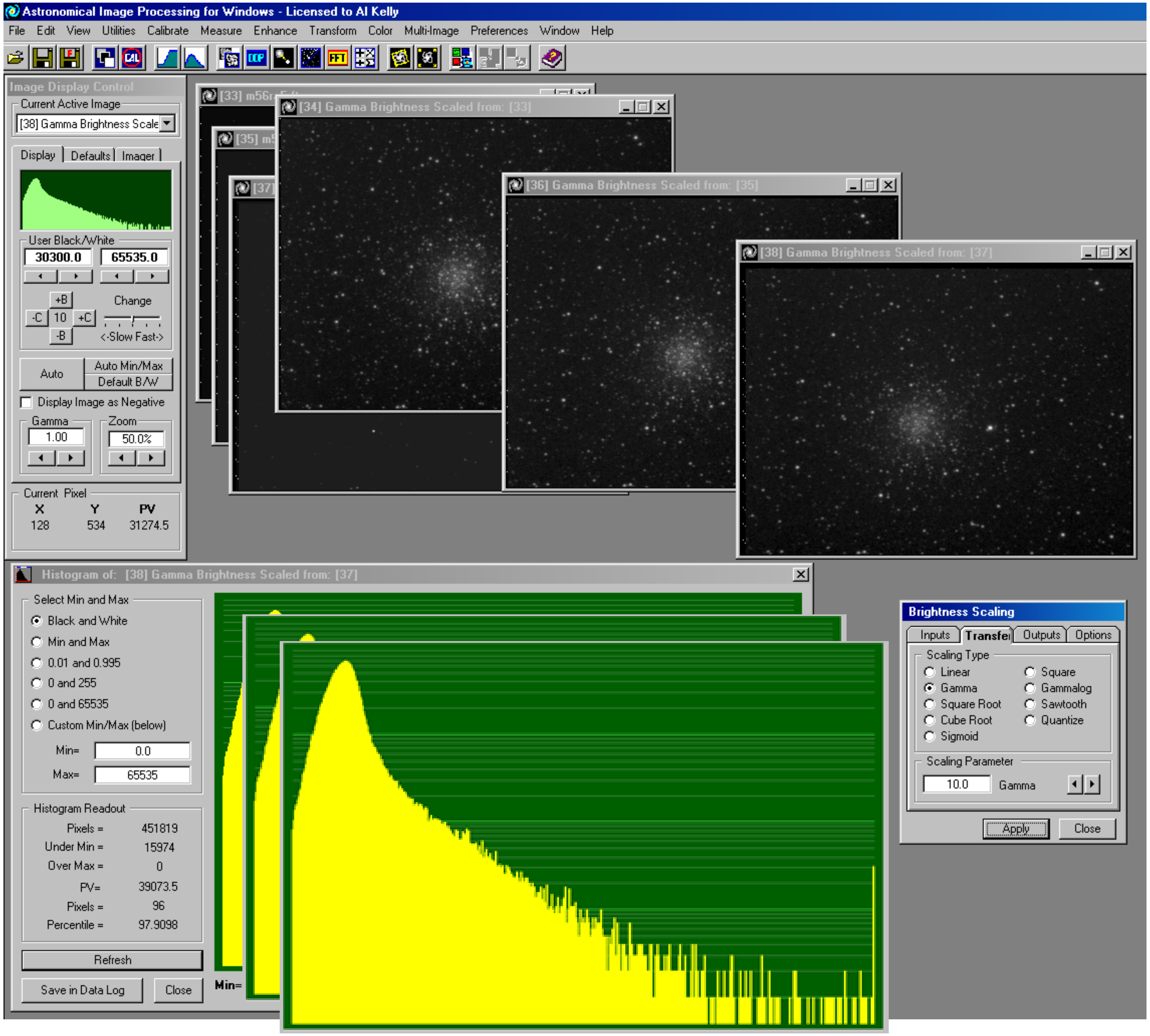
Red gamma10, green gamma10, blue gamma10



red gamma5, green gamma12, blue gamma8

M56 data with equal RGB SNRs -- R:G:B = 5:3:4

Equal nonlinear stretching and background neutralization of RGB frames with equal SNRs yields balanced histograms:



And true color results!