Lecture 5

October 4, 2018

CCD's, Observing and Image Analysis

News

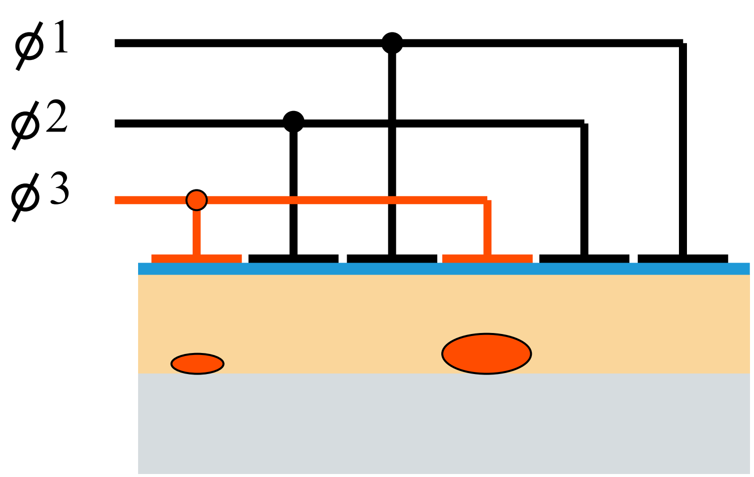
- I still want everyone to complete Lab 2, since that is where you learn how to operate the telescope.
  - Nearly everyone has finished the observing; talk to me if you have not.
  - Lab 2 is now due October 11.

- Lab 3 made available last Tuesday.
  Due: October 11.
  - "Cloudy lab" data is part of this lab. Start working on these data, if you have them.
  - I have made M39 and two asteroid images available in /home/ph344/lab3.

Charge Transfer in a CCD 1.

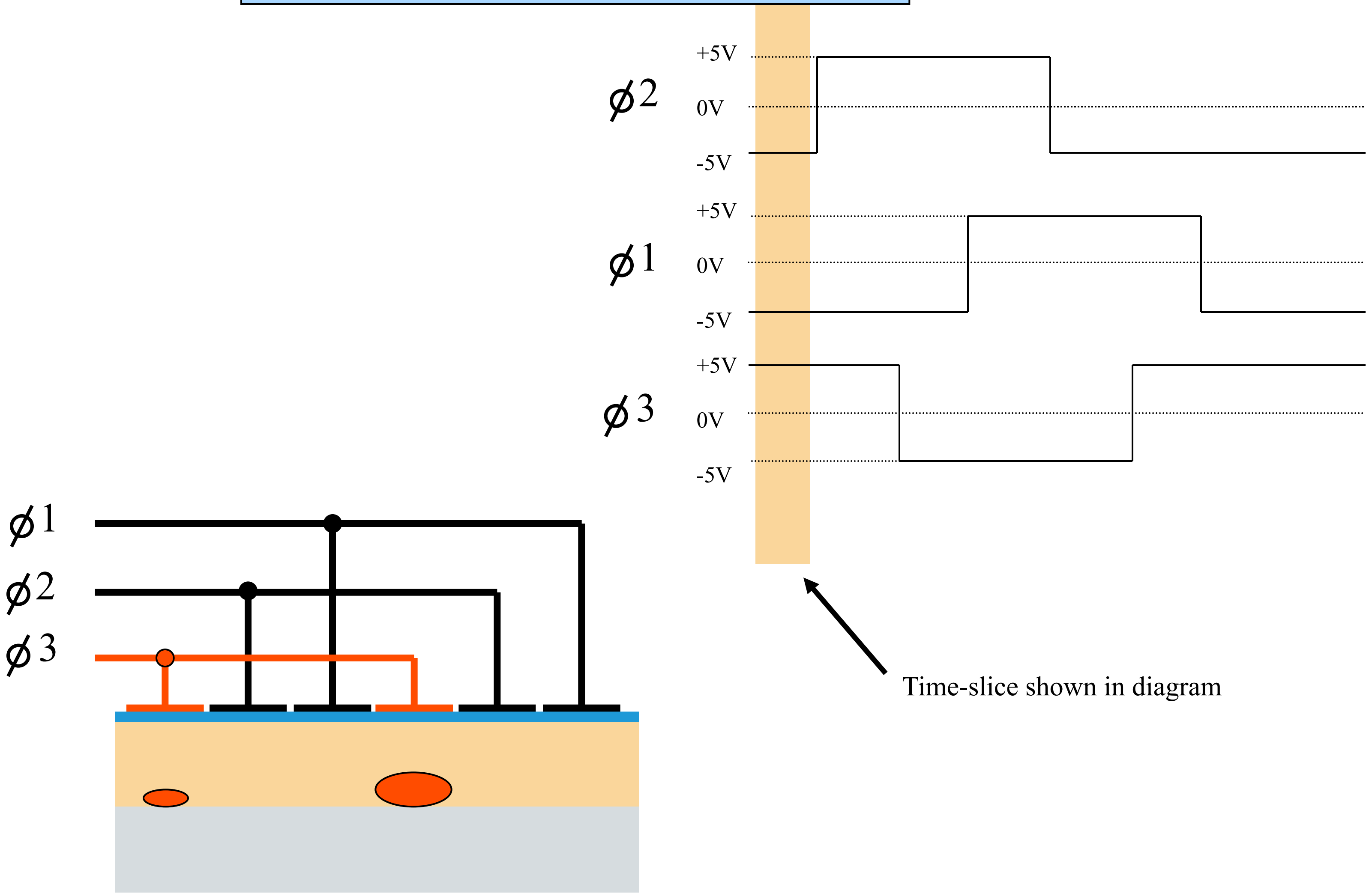
In the following few slides, the implementation of the 'conveyor belts' as actual electronic structures is explained.

The charge is moved along these conveyor belts by modulating the voltages on the electrodes positioned on the surface of the CCD. In the following illustrations, electrodes color coded red are held at a positive potential, those colored black are held at a negative potential.

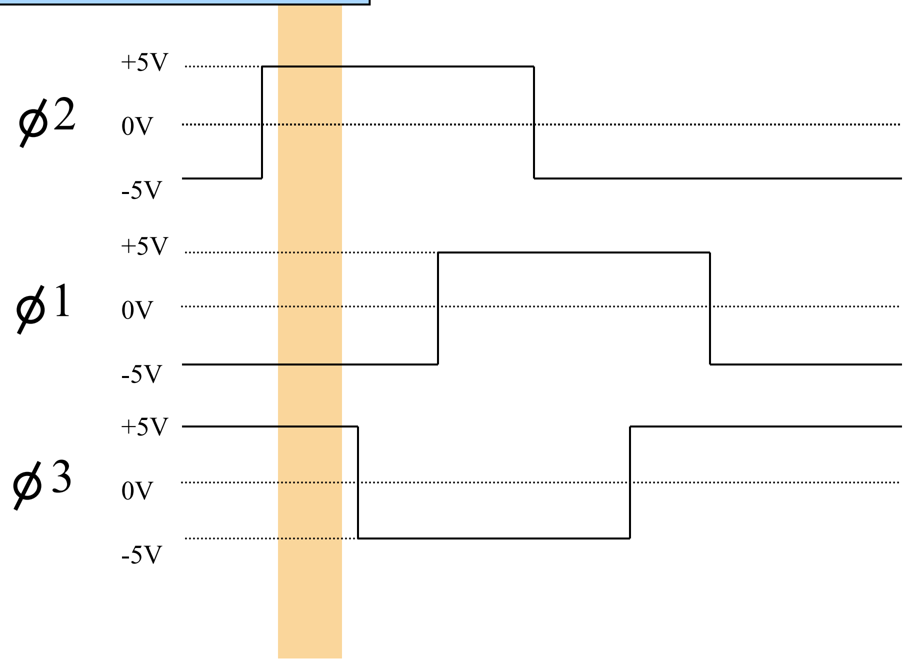


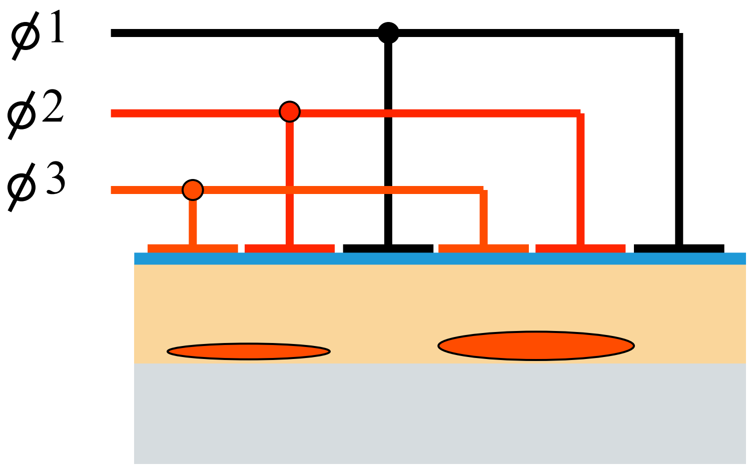
Slides from Simon Tulloch

Charge Transfer in a CCD 2.

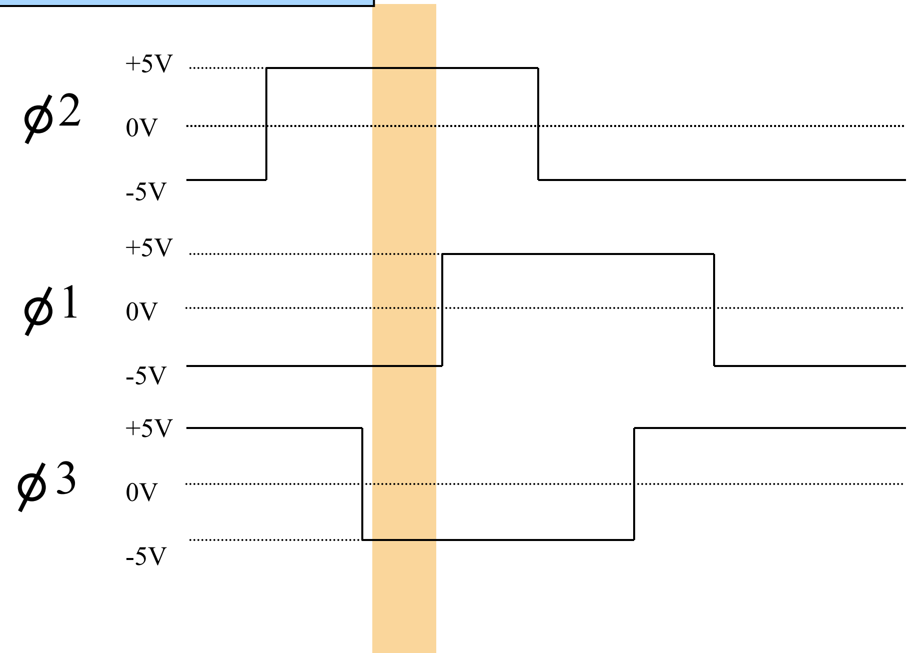


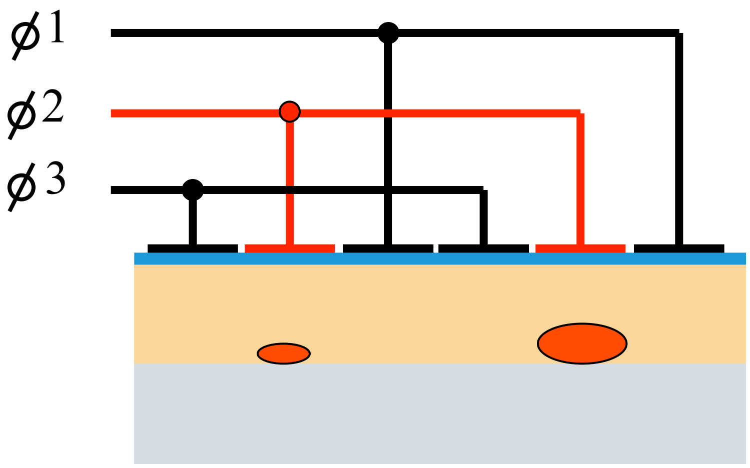
Charge Transfer in a CCD 3.



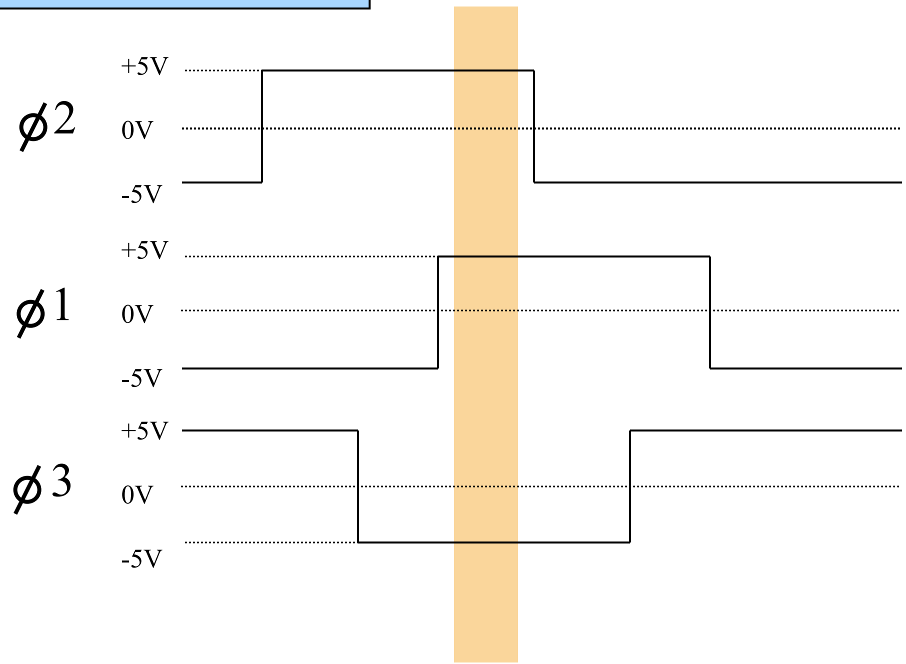


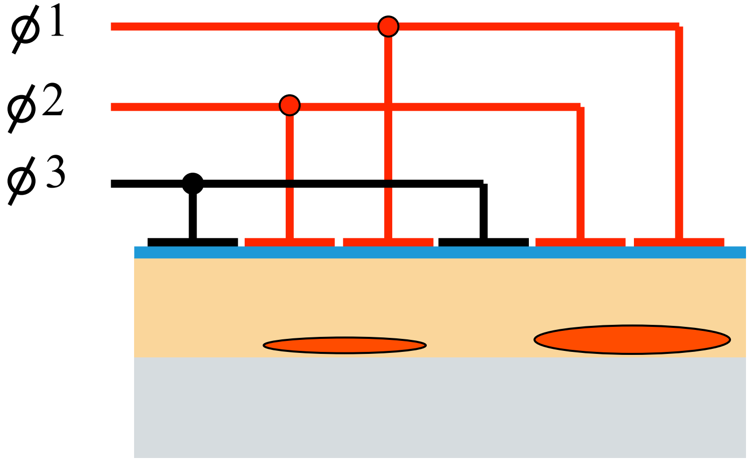
Charge Transfer in a CCD 4.



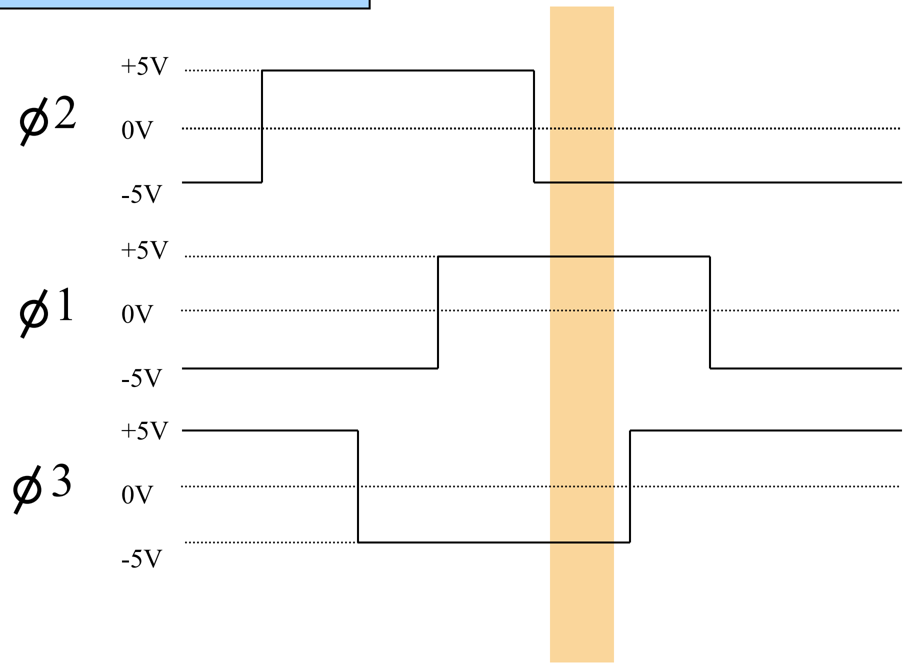


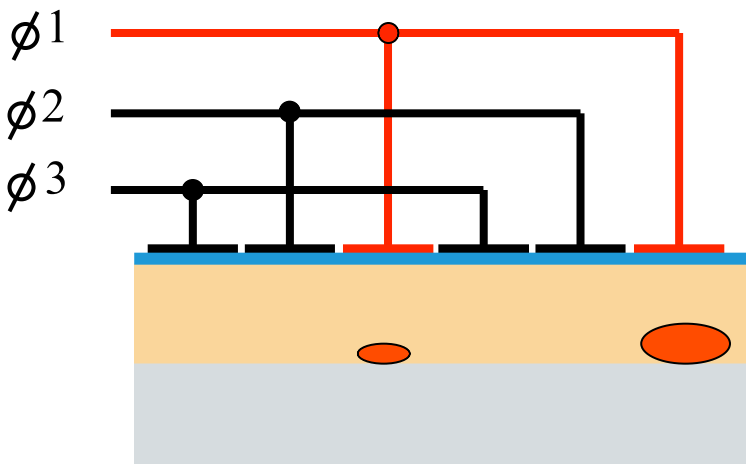
Charge Transfer in a CCD 5.





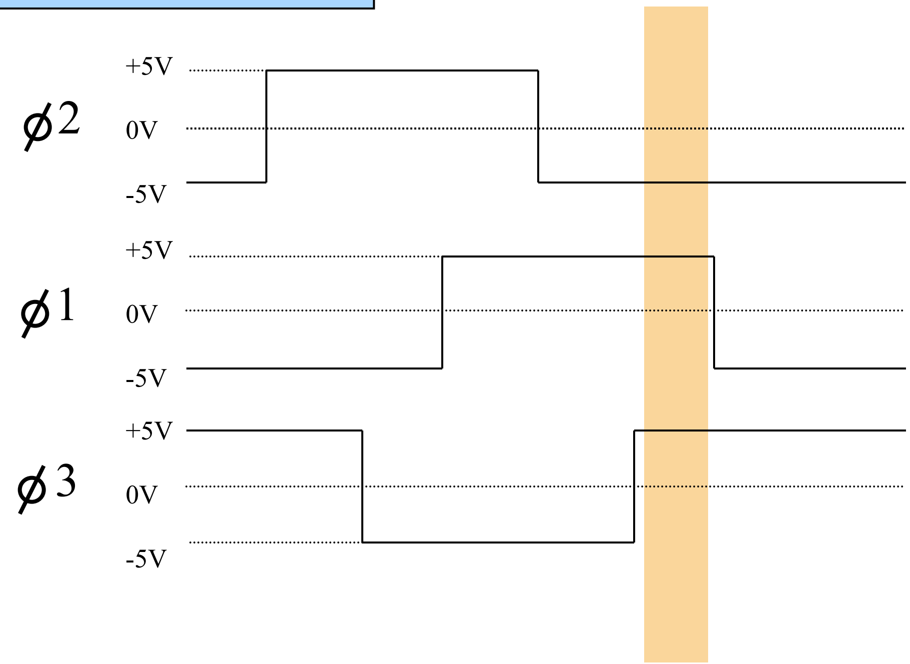
Charge Transfer in a CCD 6.

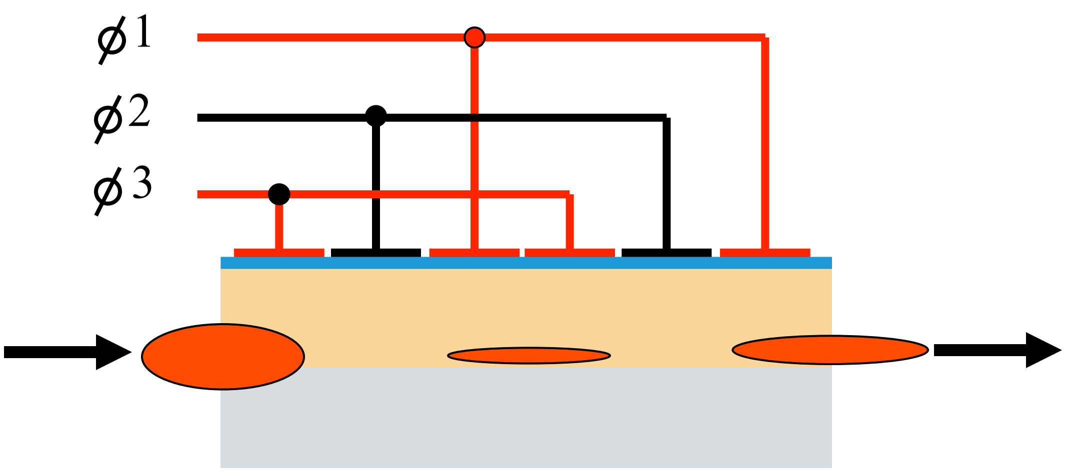




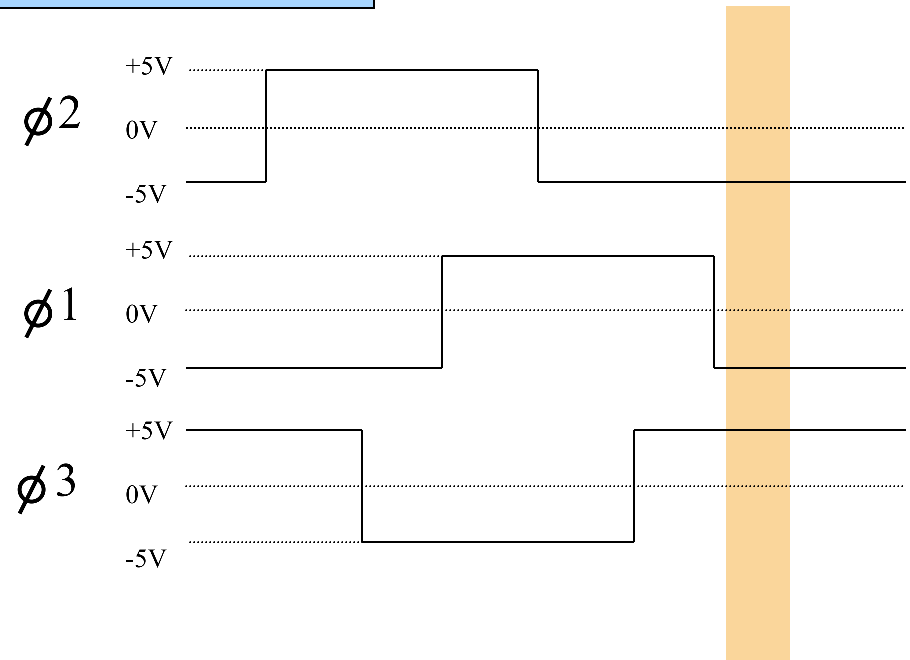
Charge Transfer in a CCD 7.

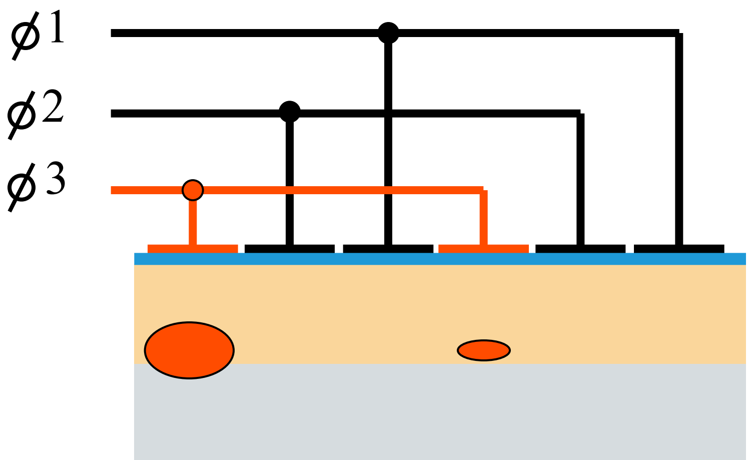
Charge packet from subsequent pixel enters from left as first pixel exits to the right.





Charge Transfer in a CCD 8.



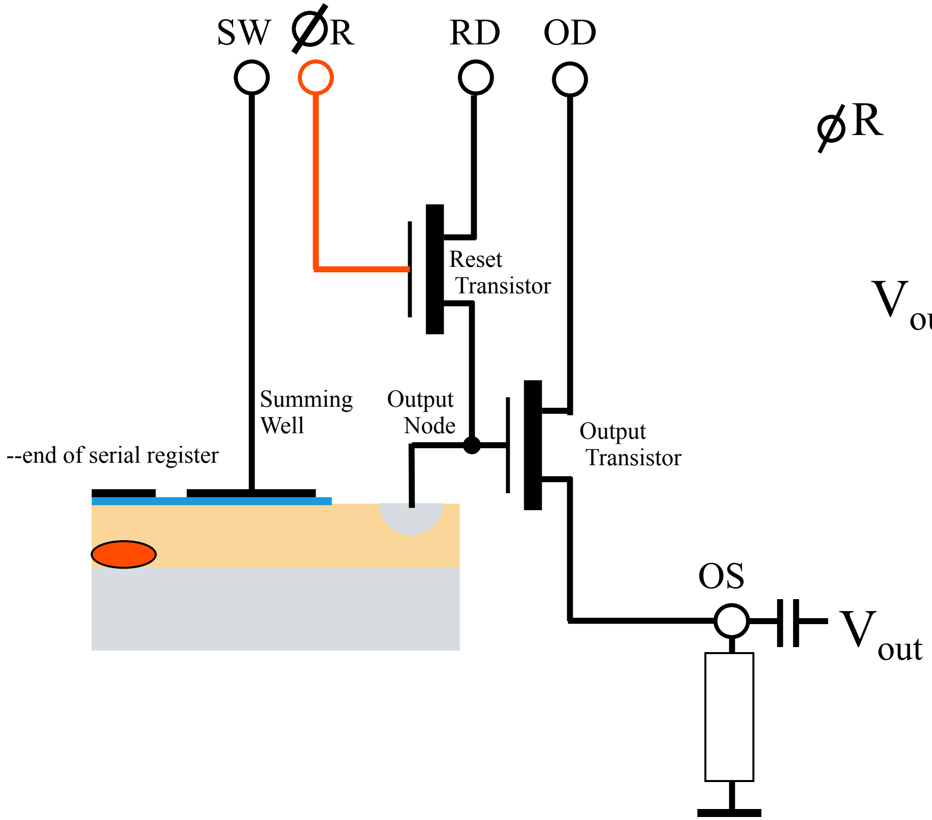


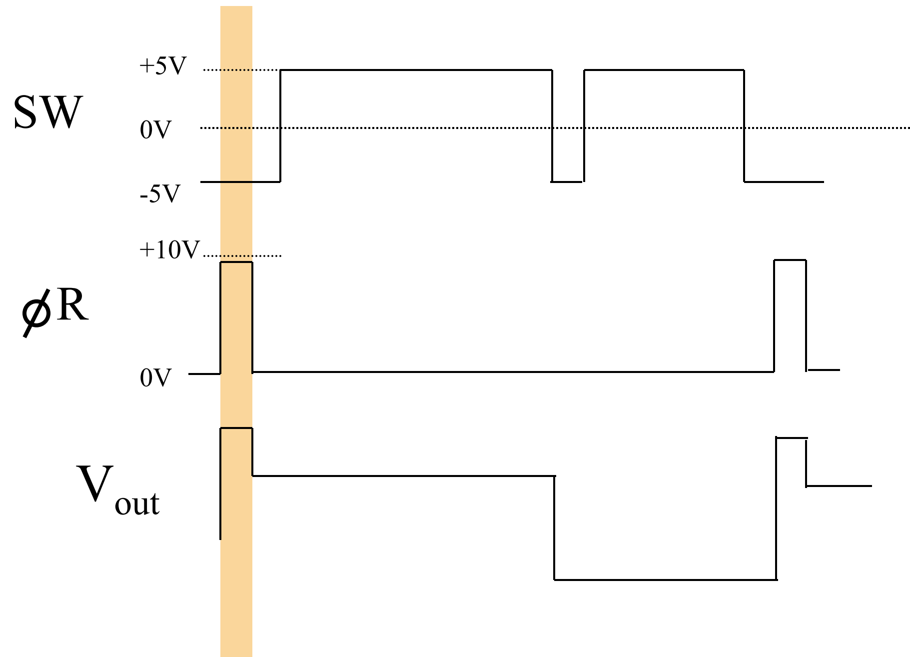
Charge transfer efficiency needs to be very high (~0.99999) because the charge is transferred 1000's of times.

On-Chip Amplifier 1.

The on-chip amplifier measures each charge packet as it pops out the end of the serial register.

RD and OD are held at constant voltages



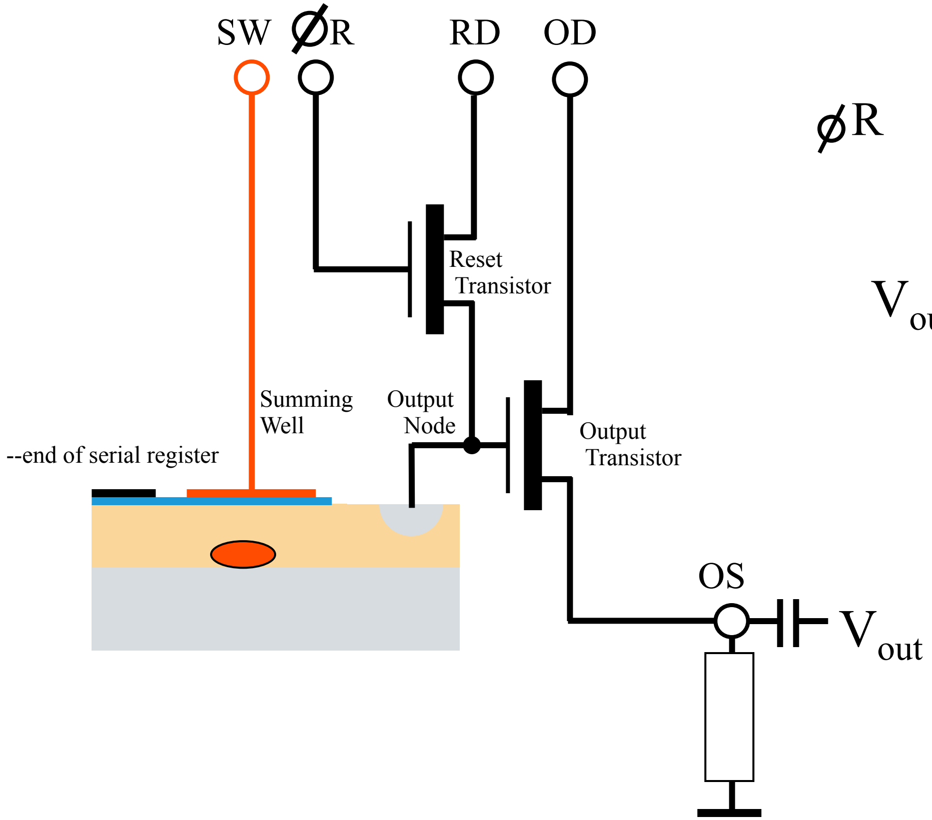


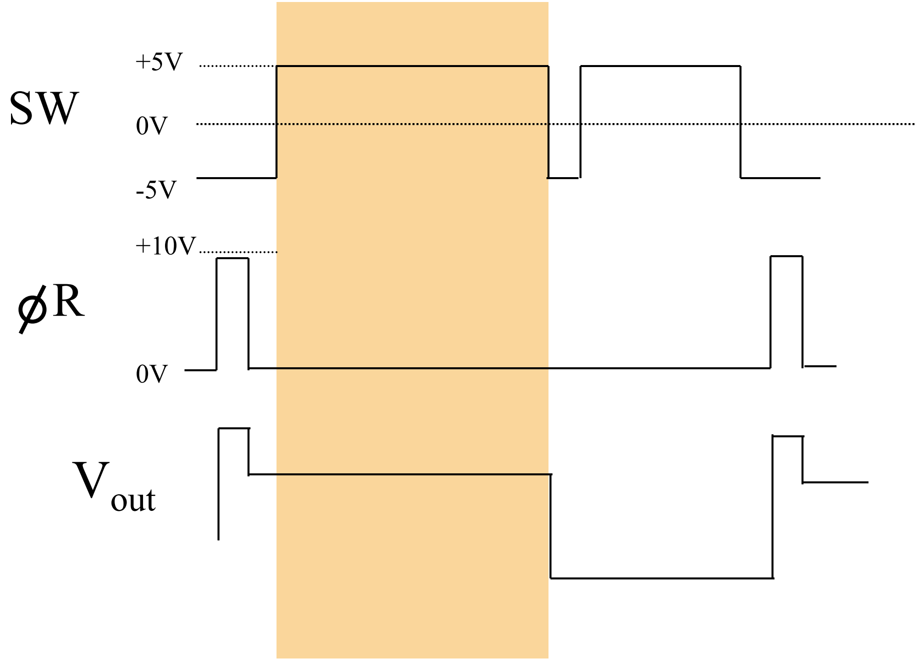
(The graphs above show the signal waveforms)

The measurement process begins with a reset of the ‘output node’. This removes the charge remaining from the previous pixel. The output node is in fact a tiny capacitor (< 0.1pF).

On-Chip Amplifier 2.

The charge is then transferred onto the Summing Well. V_{out} is now at the 'Reference level'

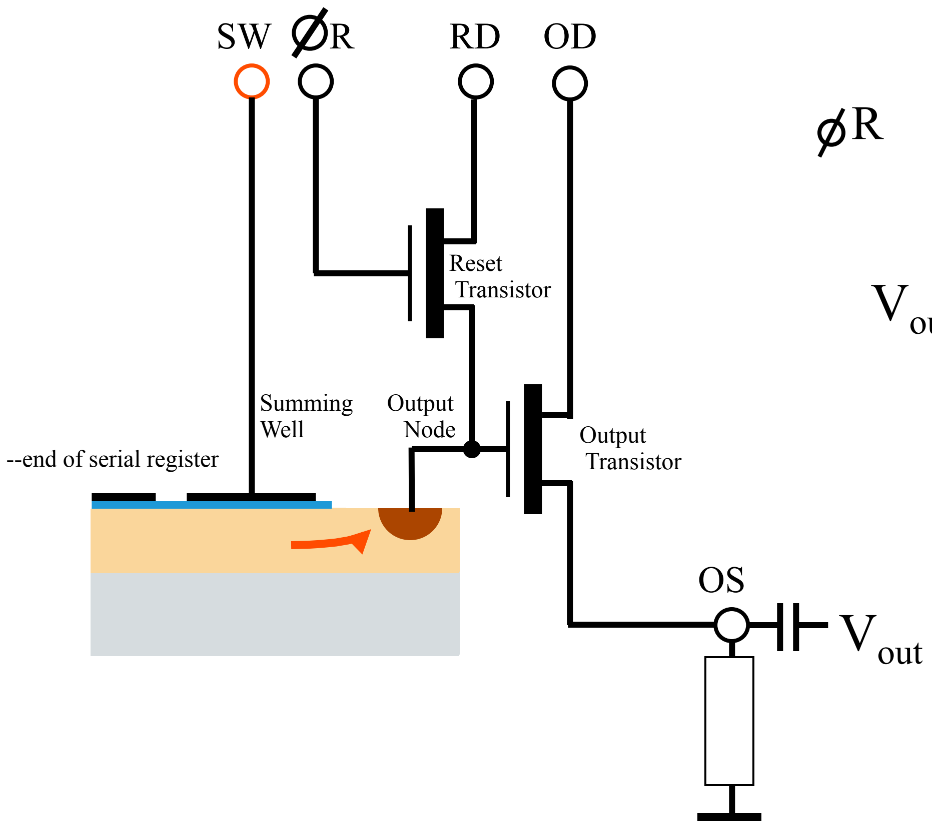


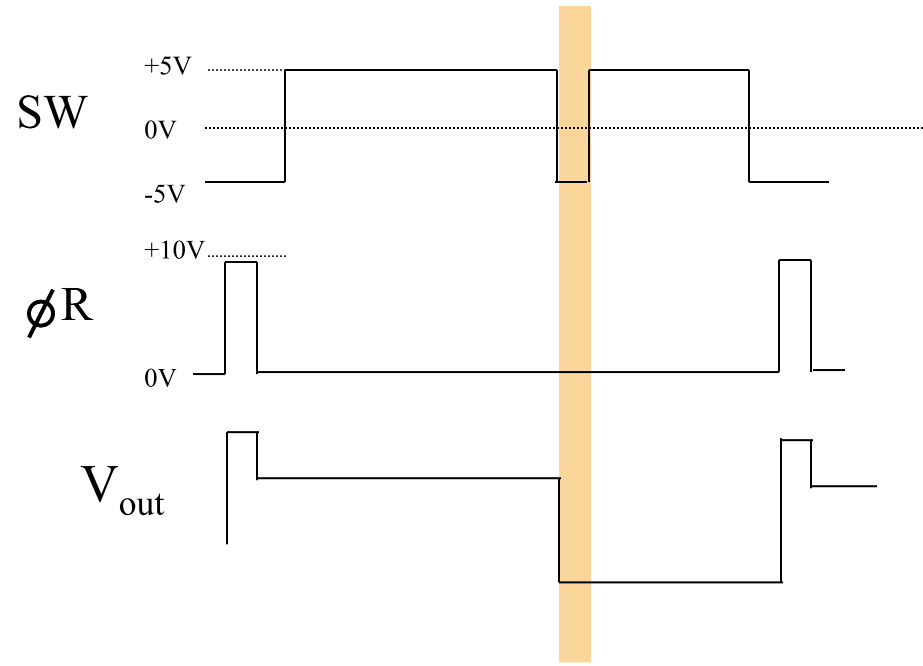


There is now a wait of up to a few tens of microseconds while external circuitry measures this 'reference' level.

On-Chip Amplifier 3.

The charge is then transferred onto the output node. V_{out} now steps down to the 'Signal level'

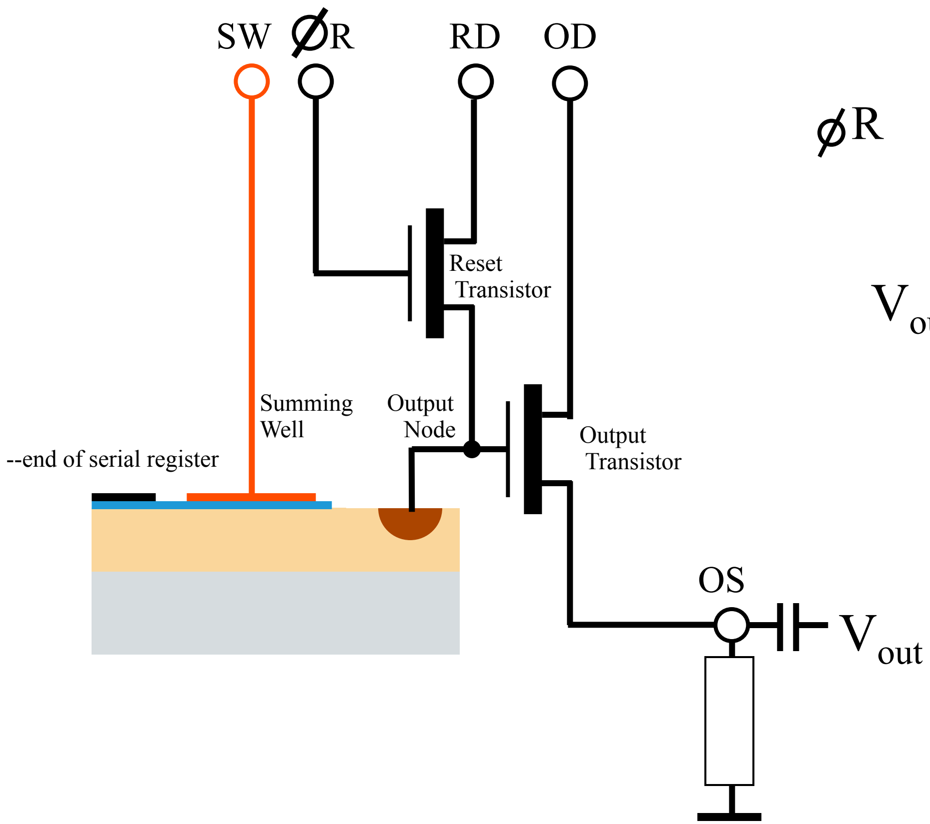


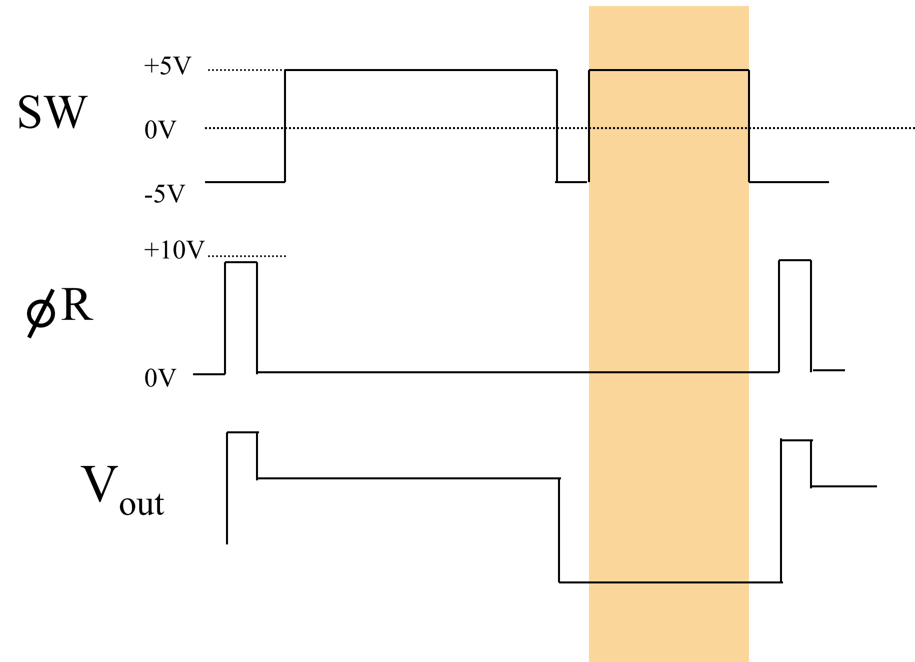


This action is known as the 'charge dump'. The voltage step in V_{out} is as much as several μV for each electron contained in the charge packet.

On-Chip Amplifier 4.

V_{out} is now sampled by external circuitry for up to a few tens of microseconds.



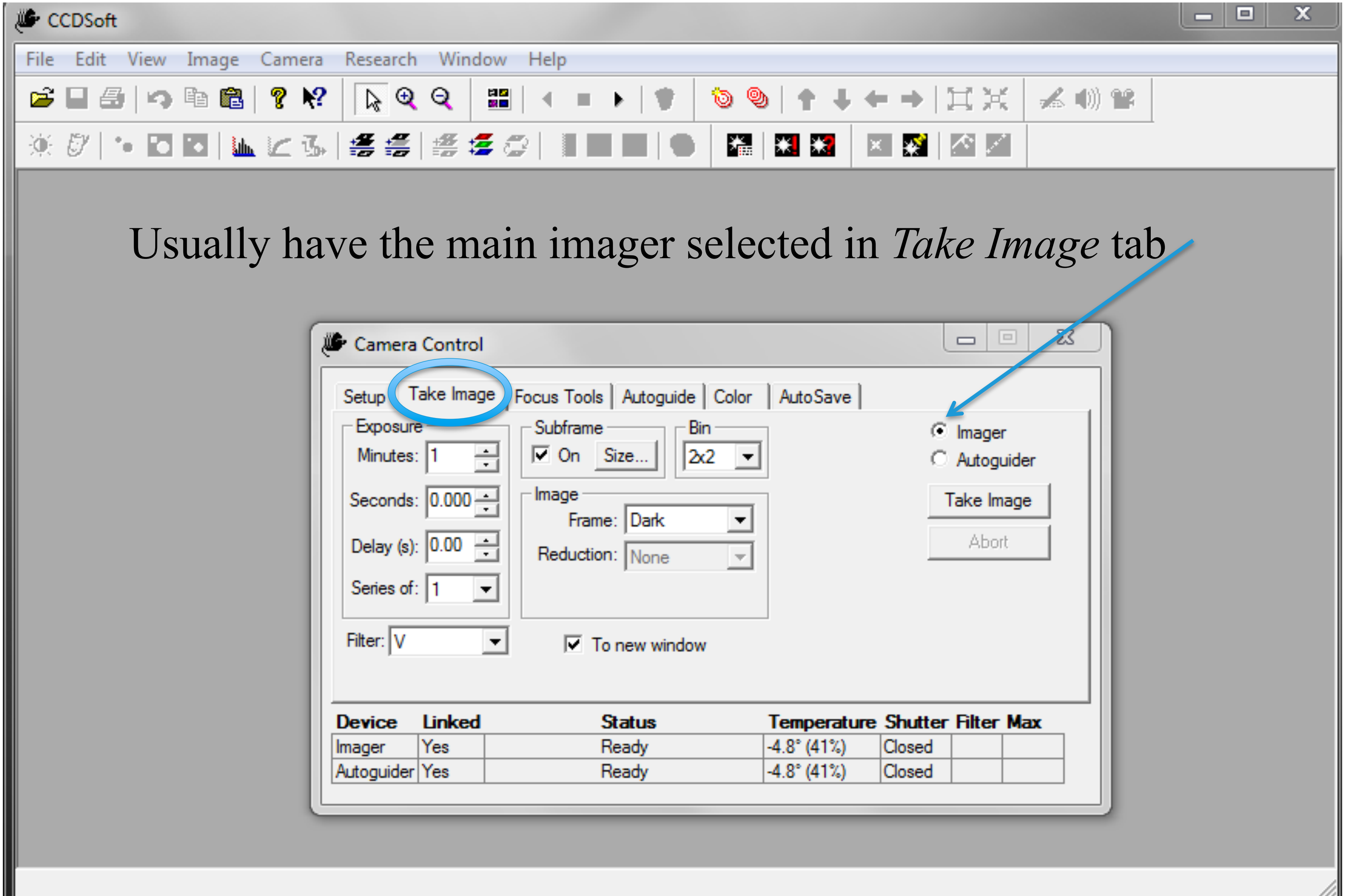


The value of (sample level - reference level) will be proportional to the size of the input charge packet.

Low-noise readout is SLOW. A full-frame readout of our CCD takes about 26 seconds.

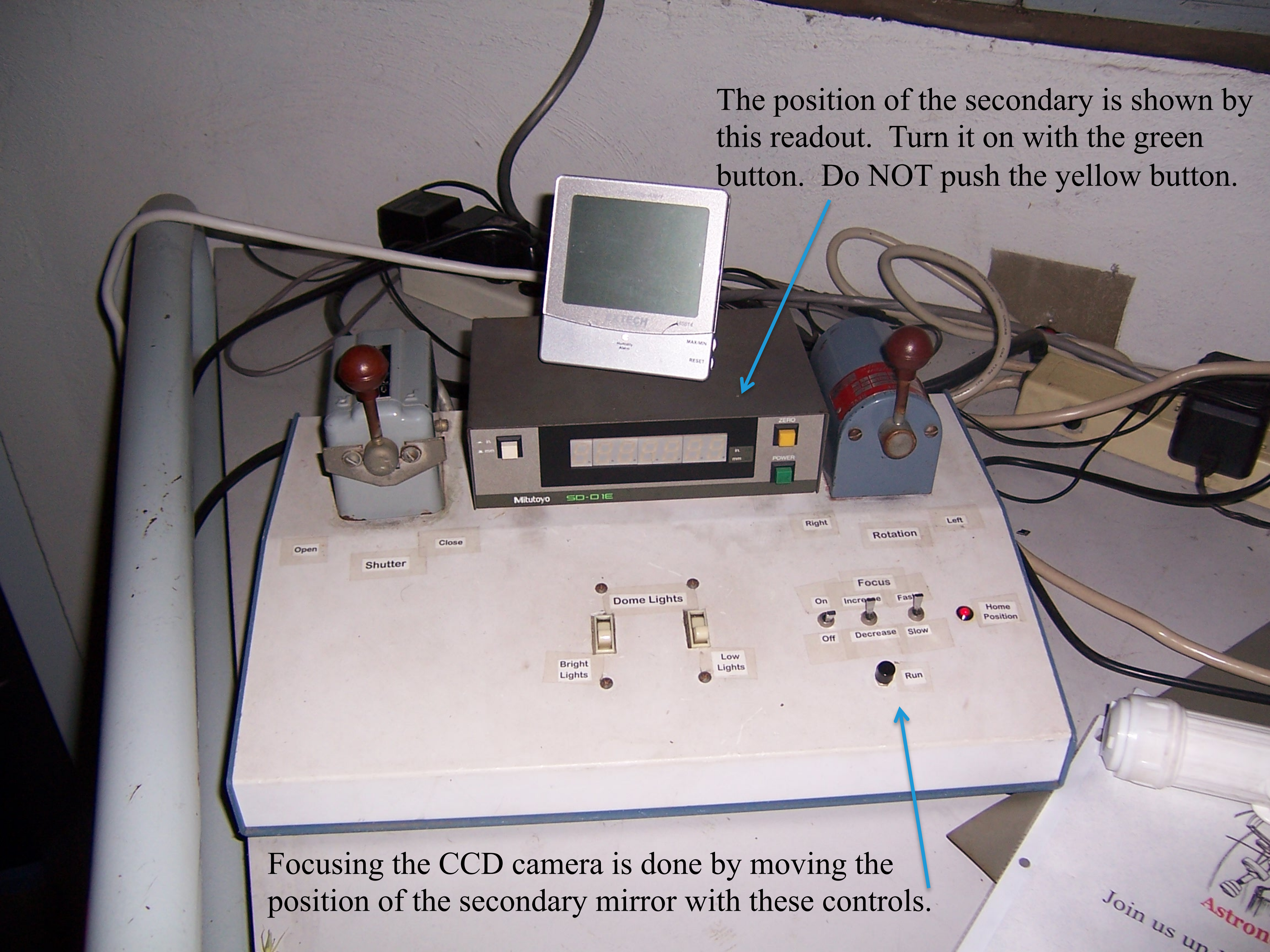
CCD Camera Control

Usually have the main imager selected in *Take Image* tab



Focusing the CCD

- We focus the telescope on the CCD by moving the secondary mirror.
  - Controls are on the observing panel.
  - Mirror position is shown on the display above the panel (turn on with the green power button).
    - Don't push the yellow "zero" button.



The position of the secondary is shown by this readout. Turn it on with the green button. Do NOT push the yellow button.

Focusing the CCD camera is done by moving the position of the secondary mirror with these controls.

Focusing the CCD

- We focus the telescope on the CCD by moving the secondary mirror.
  - Controls are on the observing panel.
  - Mirror position is shown on the display above the panel (turn on with the green power button).
    - Don’t push the yellow “zero” button.
  - Be careful not to use saturated images to determine the focus.
  - Best focus will be around 2.40 mm, and the value increases by about 0.100 mm for every 5 C *decrease* in temperature.

Sequence of 7 images spaced by 0.05 mm in mirror position.

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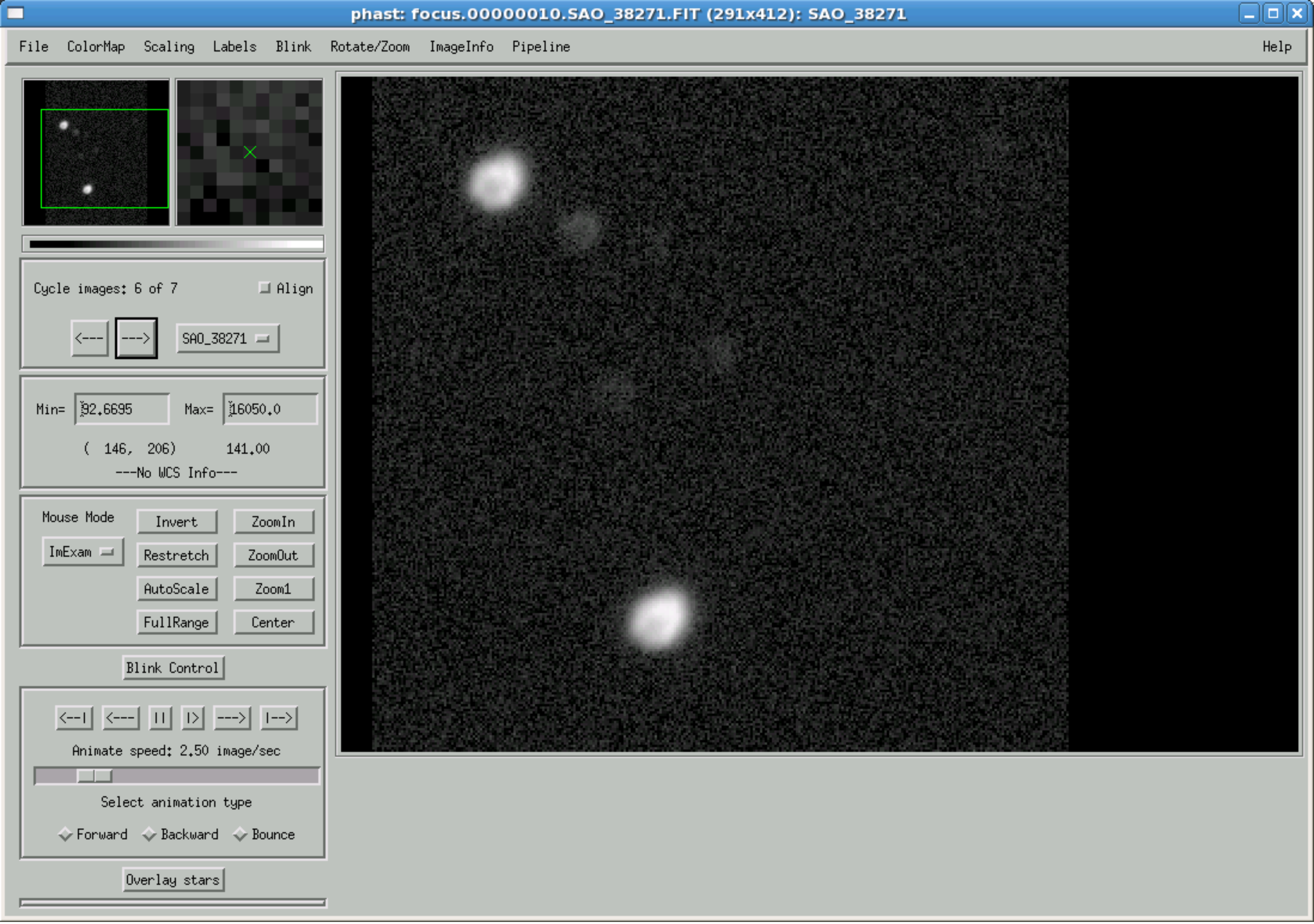
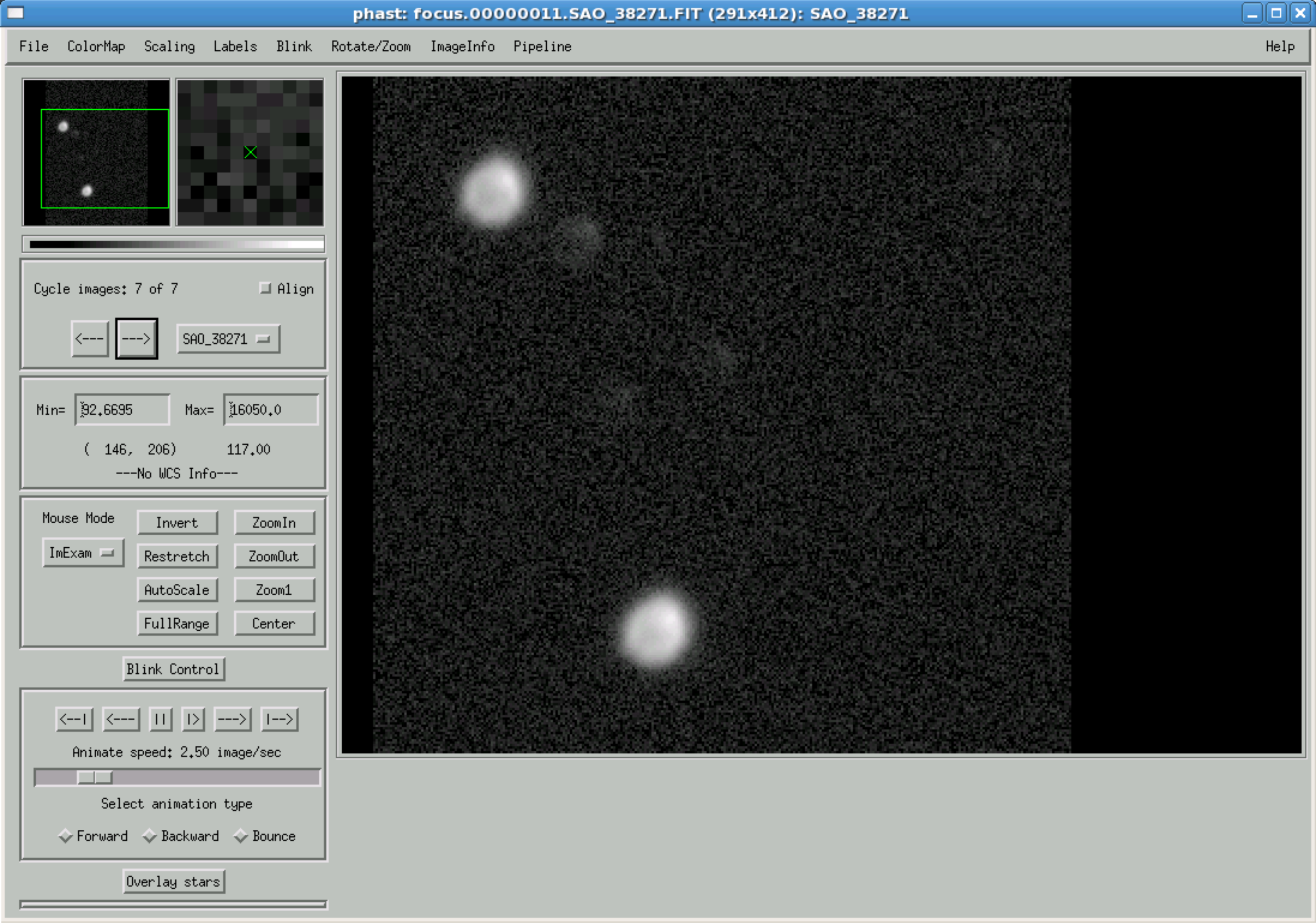


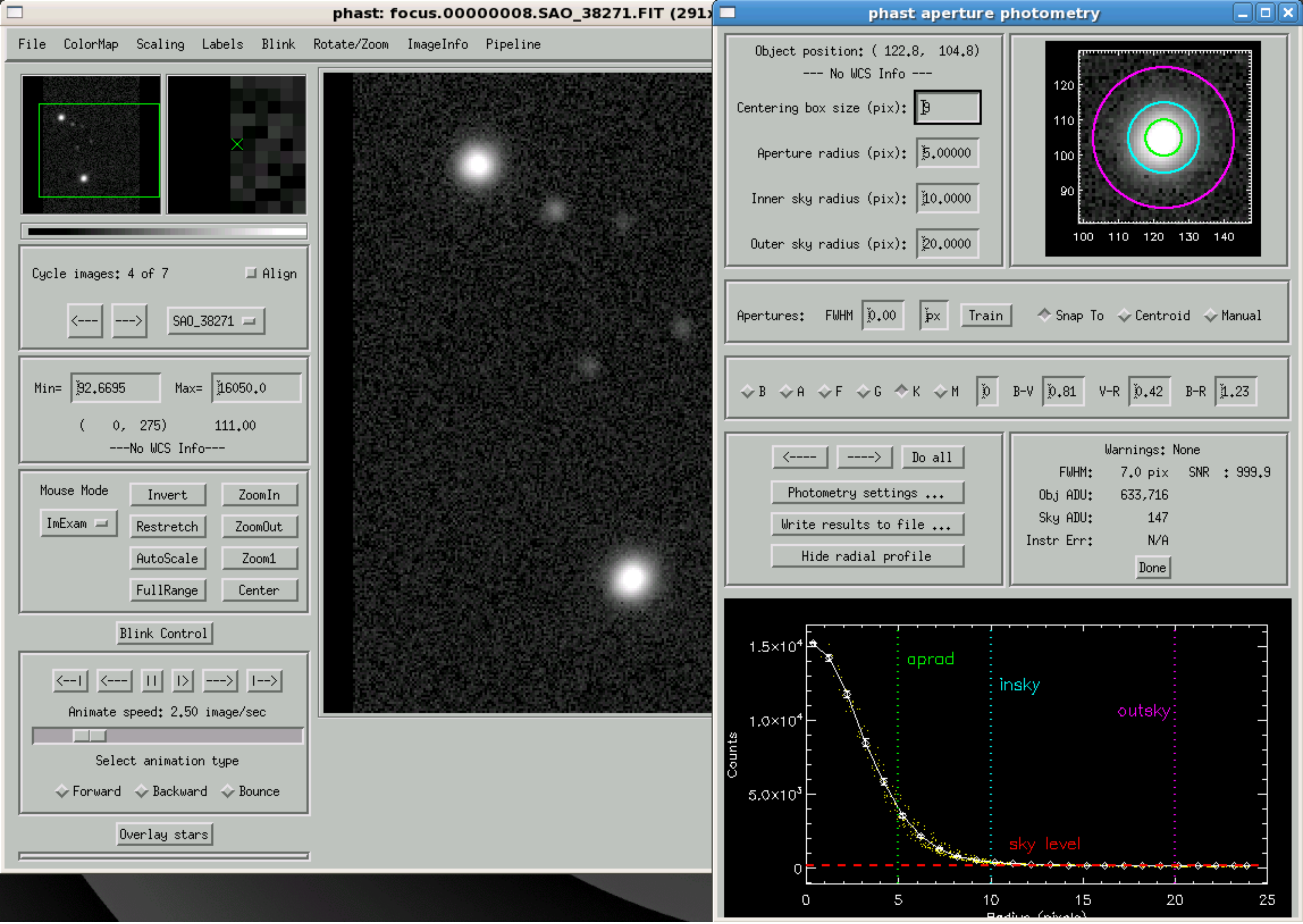
Sequence of 7 images spaced by 0.05 mm in mirror position.



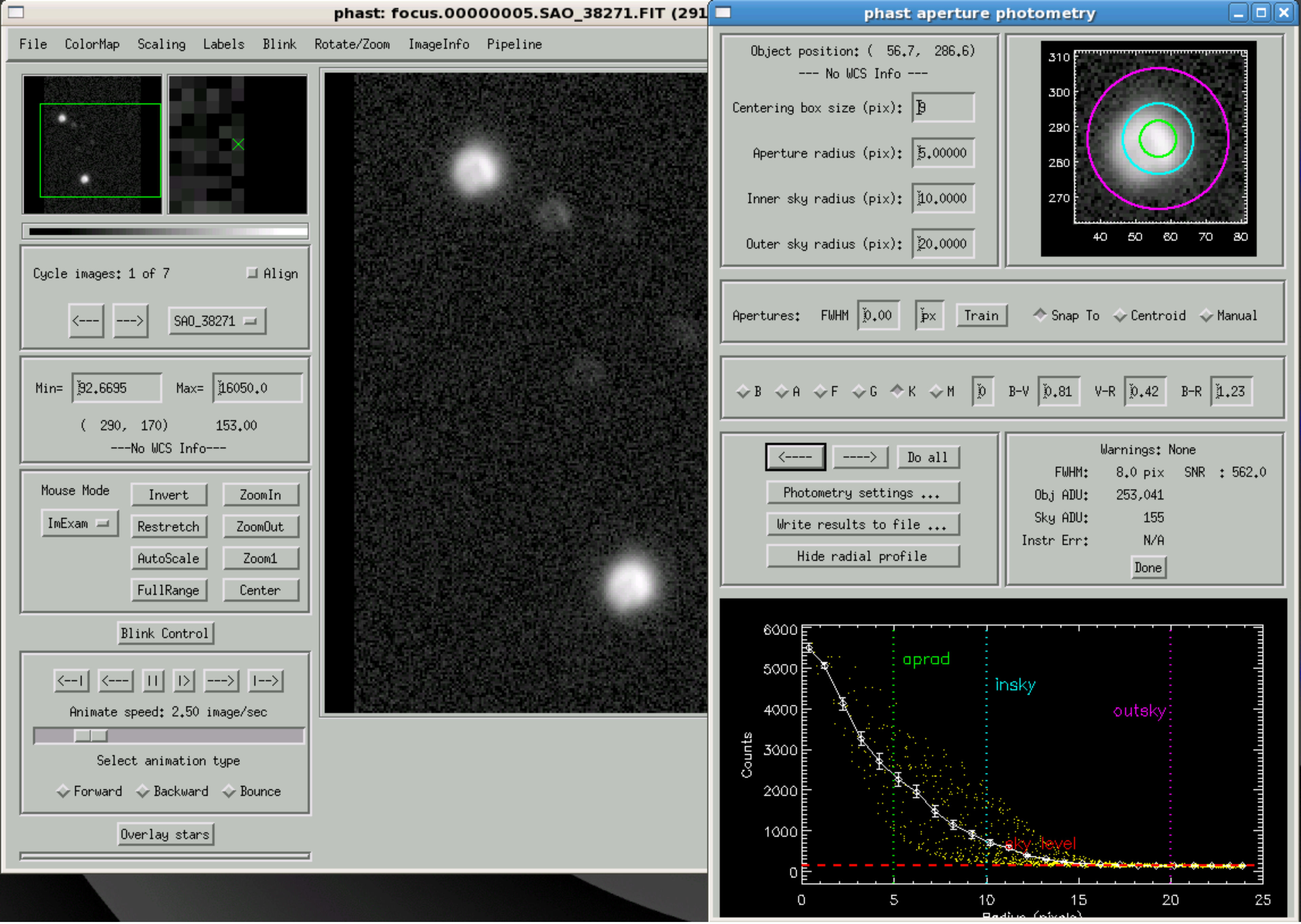
Sequence of 7 images spaced by 0.05 mm in mirror position.

Focusing the CCD

- Use RUPhAst and its aperture photometry tool (p key or left-mouse-button) to measure the full-width at half-maximum (FWHM) of stellar images.
  - RUPhAst fits a gaussian to the profile of the star to determine the FWHM.
  - Smallest FWHM is the best focus.
    - But should also visually assess the quality of the fit to the profile.
    - Subsequent slides show a good and a bad focus that had similar derived FWHM's.

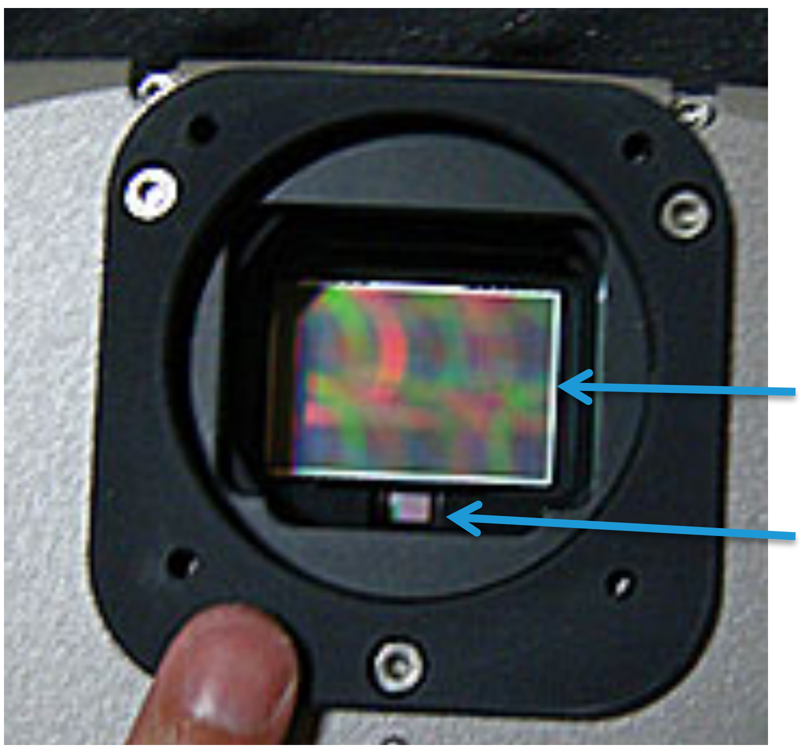


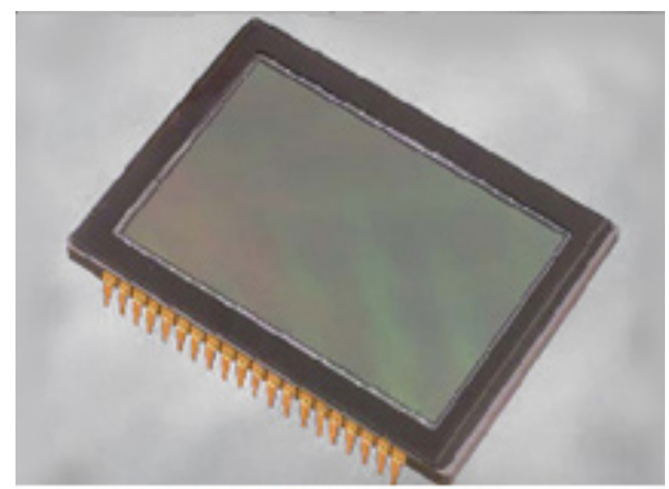
phast: focus.00000008.SAO_38271.FIT (291x
File
ColorMap
Scaling
Labels
Blink
Rotate/Zoom
ImageInfo
Pipeline
Cycle images: 4 of 7
Align
<---
--->
SAO_38271
Min=
92.6695
Max=
16050.0
(0, 275) 111.00
---No WCS Info---
Mouse Mode
ImExam
Invert
ZoomIn
Restretch
ZoomOut
AutoScale
Zoom1
FullRange
Center
Blink Control
Animate speed: 2.50 image/sec
Select animation type
Forward
Backward
Bounce
Overlay stars
phast aperture photometry
Object position: (122.8, 104.8)
--- No WCS Info ---
Centering box size (pix):
9
Aperture radius (pix):
5.00000
Inner sky radius (pix):
10.0000
Outer sky radius (pix):
20.0000
120
110
100
90
100 110 120 130 140
Apertures:
FWHM
0.00
px
Train
Snap To
Centroid
Manual
B
A
F
G
K
M
0
B-V
0.81
V-R
0.42
B-R
1.23
<----
---->
Do all
Photometry settings ...
Write results to file ...
Hide radial profile
Warnings: None
FWHM: 7.0 pix
SNR : 999.9
Obj ADU: 633,716
Sky ADU: 147
Instr Err: N/A
Done
1.5×10⁴
1.0×10⁴
5.0×10³
0
Counts
aprad
insky
outsky
sky level
0
5
10
15
20
25

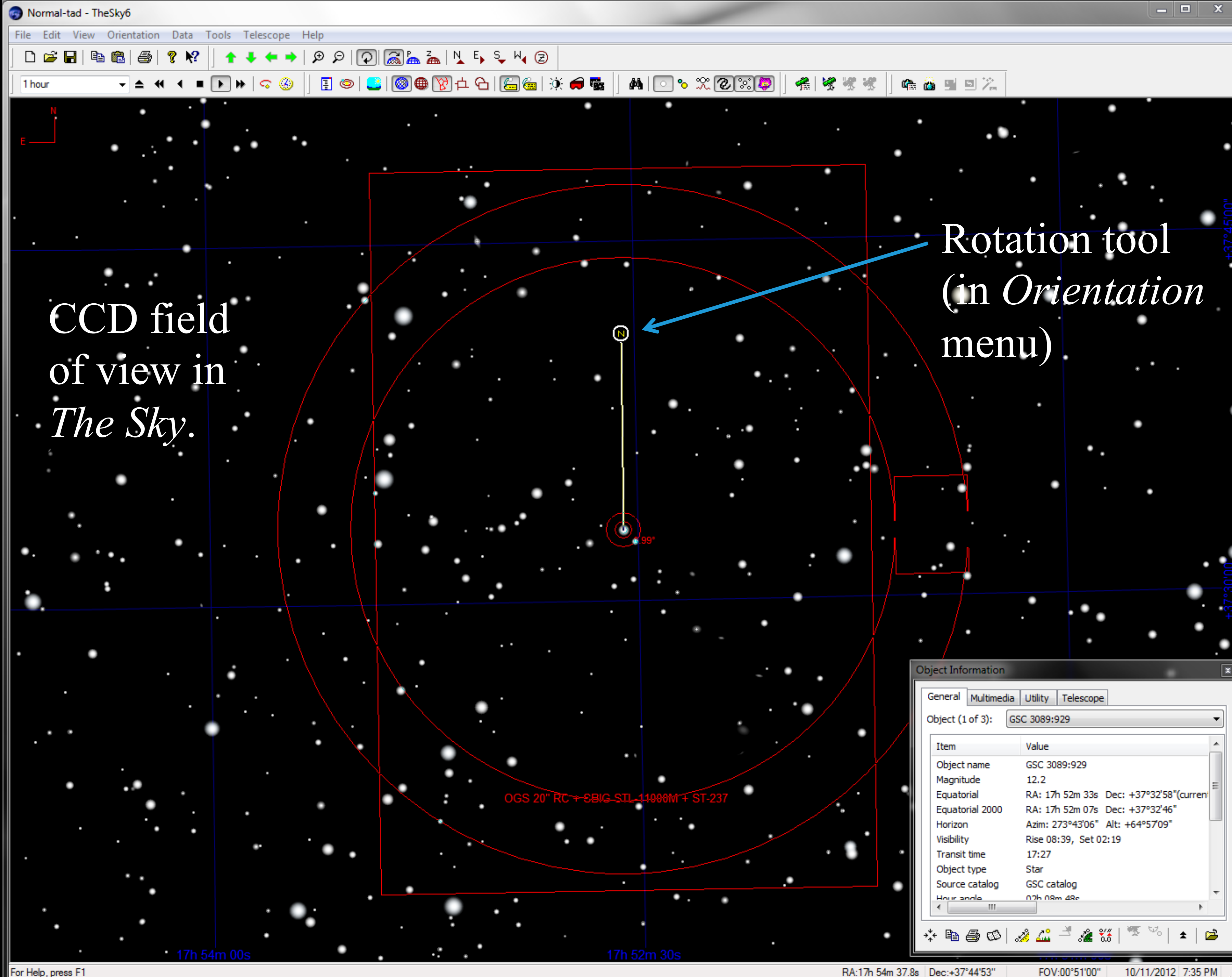

phast: focus.00000005.SAO_38271.FIT (291
File ColorMap Scaling Labels Blink Rotate/Zoom ImageInfo Pipeline
Cycle images: 1 of 7
Align
<--- --->
SAO_38271
Min= 92.6695 Max= 16050.0
(290, 170) 153.00
---No WCS Info---
Mouse Mode
ImExam
Invert ZoomIn
Restretch ZoomOut
AutoScale Zoom1
FullRange Center
Blink Control
Animate speed: 2.50 image/sec
Select animation type
Forward Backward Bounce
Overlay stars
phast aperture photometry
Object position: (56.7, 286.6)
--- No WCS Info ---
Centering box size (pix): 9
Aperture radius (pix): 5.00000
Inner sky radius (pix): 10.0000
Outer sky radius (pix): 20.0000
Apertures: FWHM 0.00 px Train Snap To Centroid Manual
B A F G K M 0 B-V 0.81 V-R 0.42 B-R 1.23
<---- ----> Do all
Photometry settings ...
Write results to file ...
Hide radial profile
Warnings: None
FWHM: 8.0 pix SNR : 562.0
Obj ADU: 253,041
Sky ADU: 155
Instr Err: N/A
Done
aprad
insky
outsky
sky level
Counts
Radius (pixels)

CCD Camera Guiding

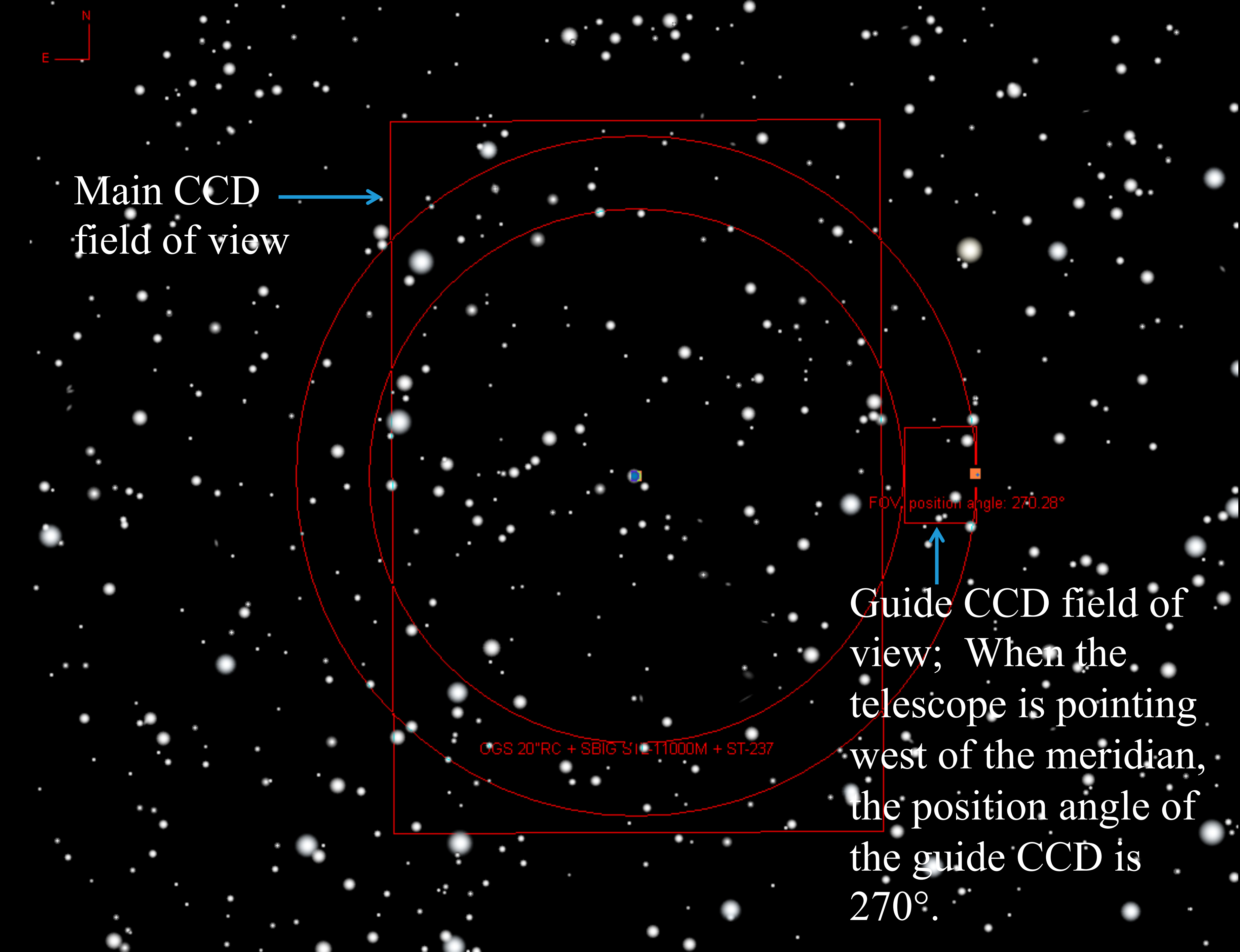
- Contains two CCDs
  - 4008 x 2672 pixels main imager
  - 680 x 500 pixels guide imager



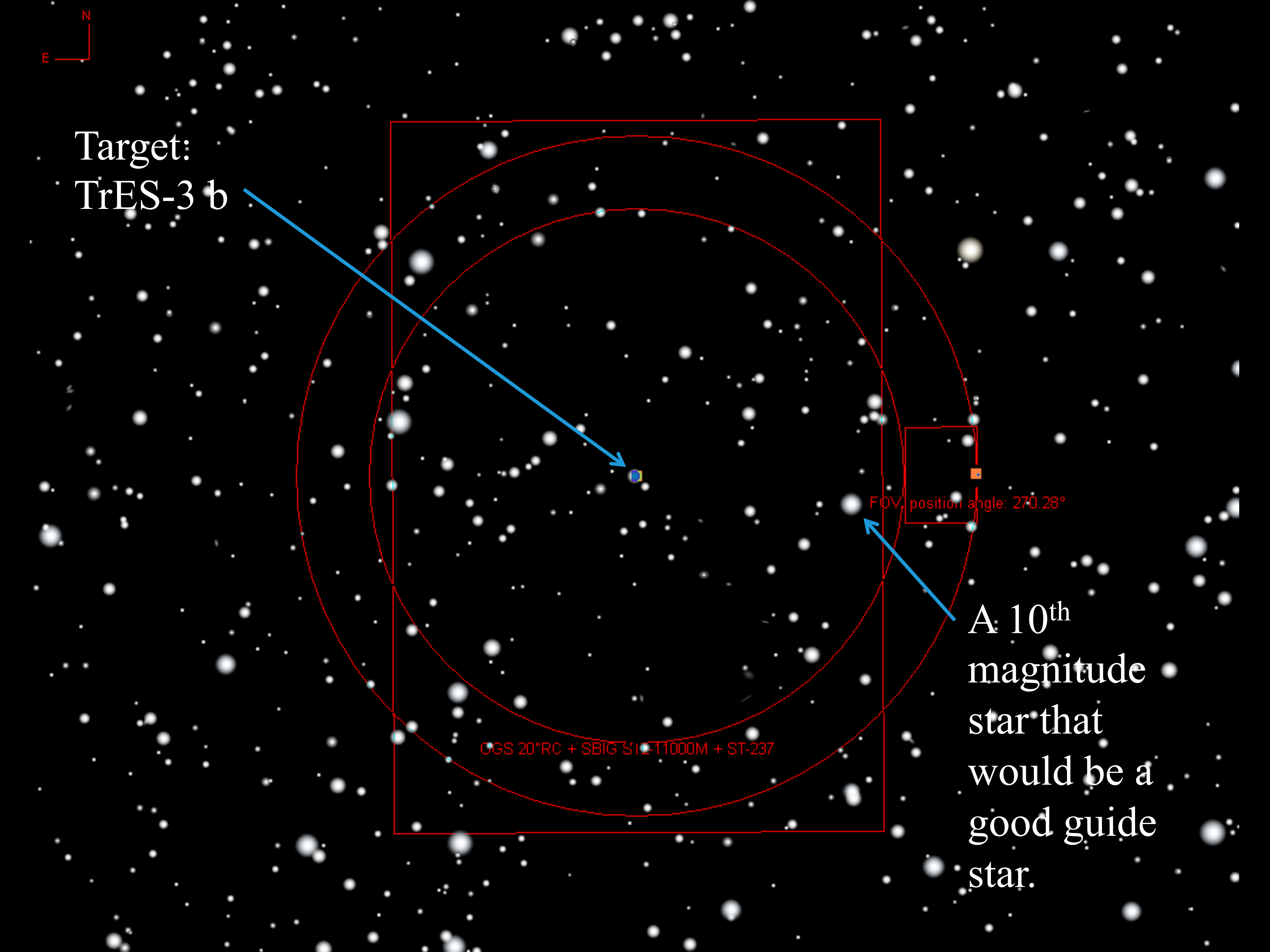




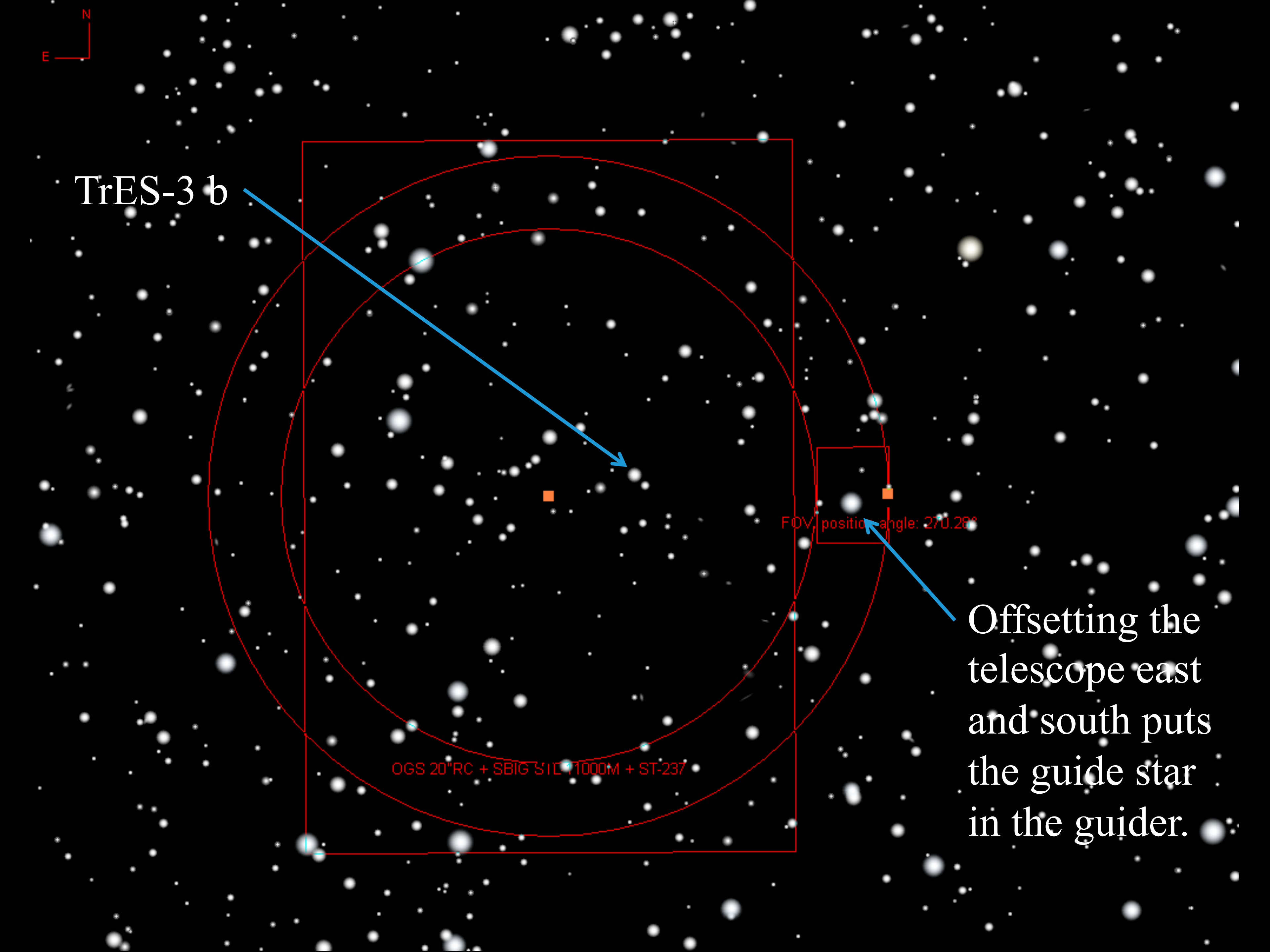
CCD field of view in *The Sky*.
Rotation tool (in *Orientation* menu)
Normal-tad - TheSky6
File Edit View Orientation Data Tools Telescope Help
1 hour
OGS 20" RC + SBIG STL-11000M + ST-237
17h 54m 00s
17h 52m 30s
+37°45'00"
+37°30'00"
Object Information
General Multimedia Utility Telescope
Object (1 of 3): GSC 3089:929
Item Value
Object name GSC 3089:929
Magnitude 12.2
Equatorial RA: 17h 52m 33s Dec: +37°32'58"(curren
Equatorial 2000 RA: 17h 52m 07s Dec: +37°32'46"
Horizon Azim: 273°43'06" Alt: +64°57'09"
Visibility Rise 08:39, Set 02:19
Transit time 17:27
Object type Star
Source catalog GSC catalog
For Help, press F1
RA:17h 54m 37.8s Dec:+37°44'53"
FOV:00°51'00"
10/11/2012 7:35 PM


N
E
Main CCD field of view
FOV position angle: 270.28°
OGS 20"RC + SBIG STL-11000M + ST-237
Guide CCD field of view; When the telescope is pointing west of the meridian, the position angle of the guide CCD is 270°.

When the telescope is pointing east of the meridian, the position angle of the guide CCD is 90°.

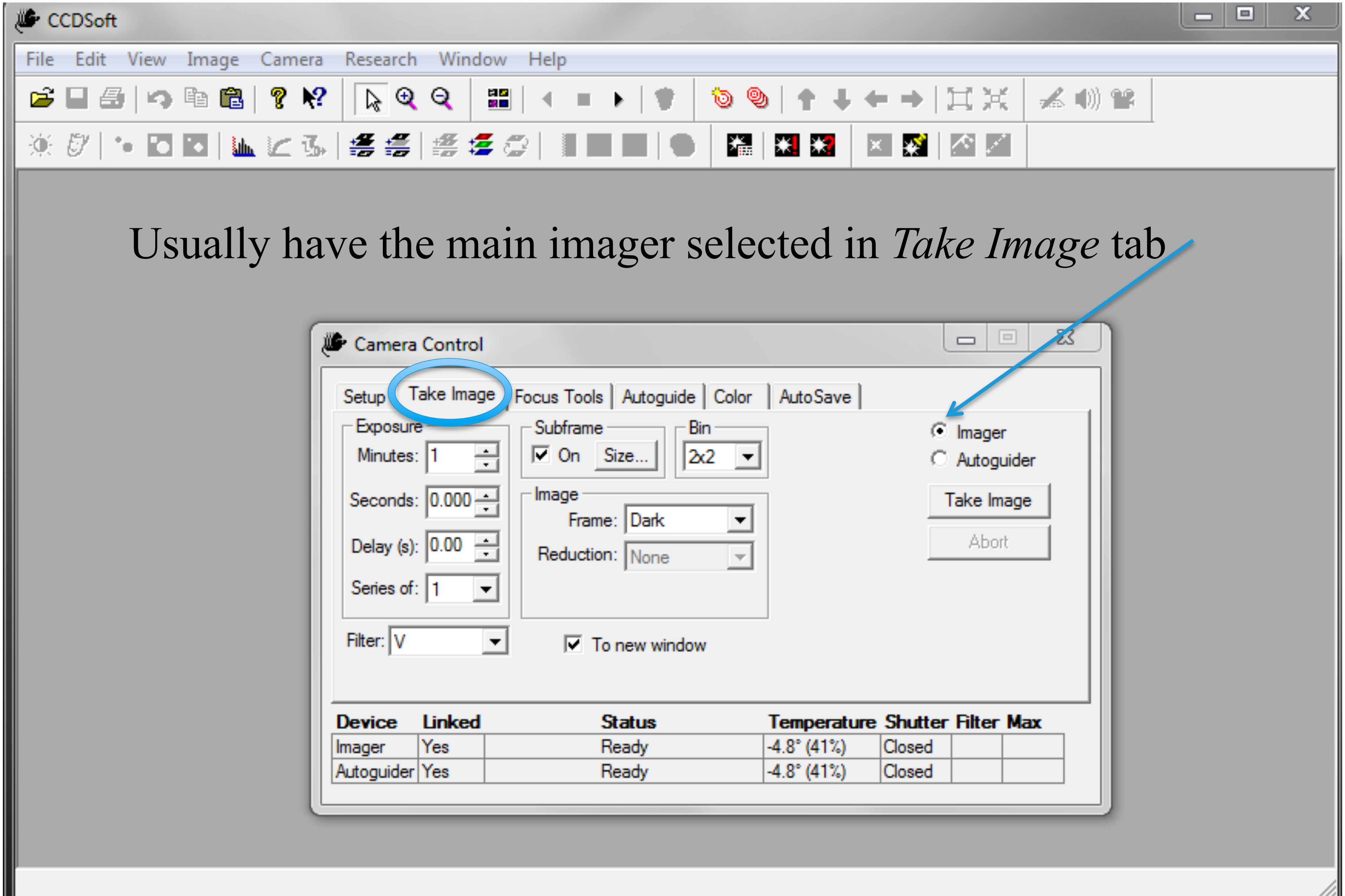


N
E
Target:
TrES-3 b
FOV, position angle: 270.28°
CGS 20"RC + SBIG STL-11000M + ST-237
A 10th magnitude star that would be a good guide star.


N
E
TrES-3 b
FOV, positio angle: 270.28
OGS 20"RC + SBIG STL 11000M + ST-237
Offsetting the telescope east and south puts the guide star in the guider.

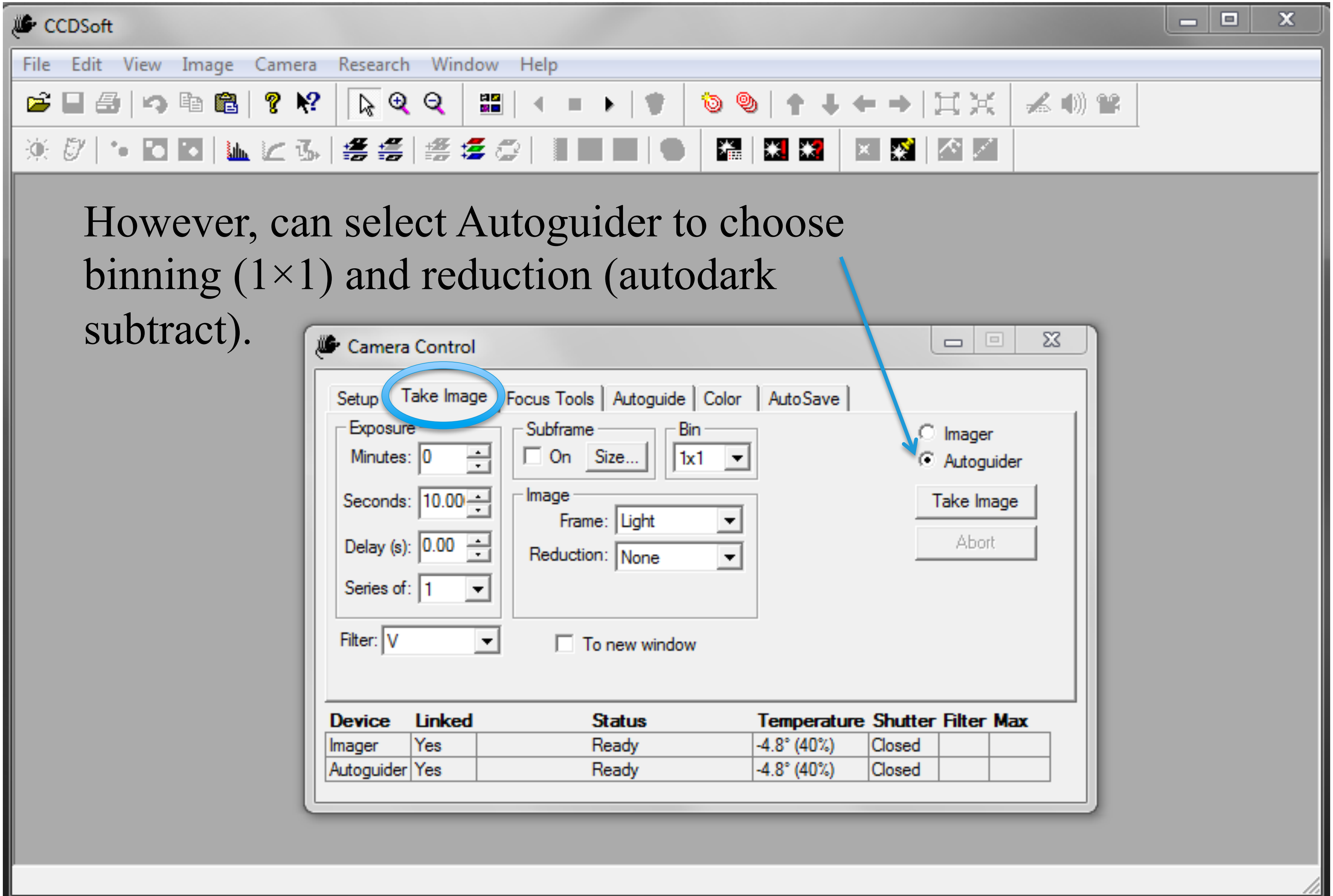
Guider Setup

Usually have the main imager selected in *Take Image* tab

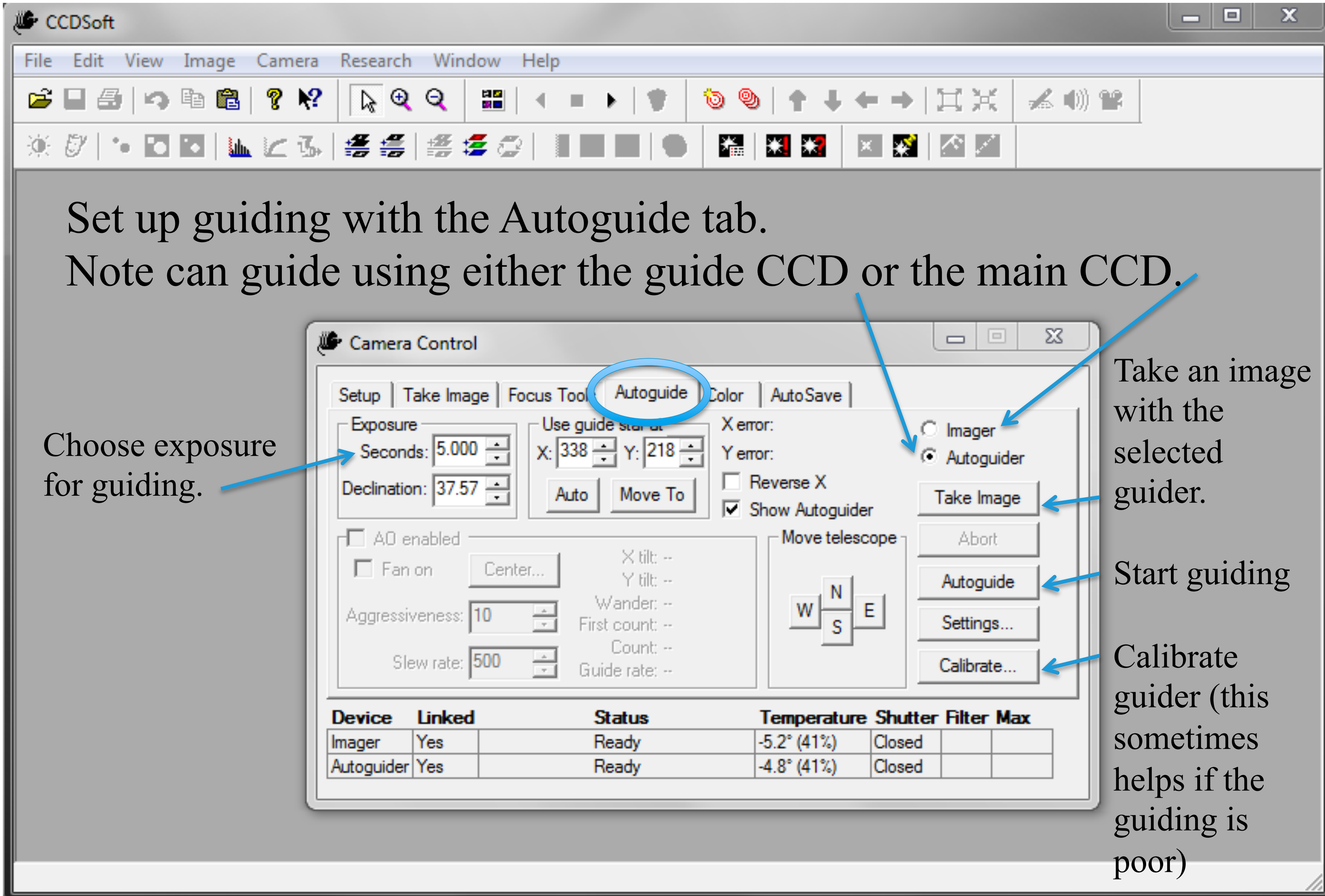


Guider Setup

However, can select Autoguider to choose binning (1×1) and reduction (autodark subtract).



Guider Setup



Set up guiding with the Autoguide tab.

Note can guide using either the guide CCD or the main CCD.

Choose exposure for guiding.

Take an image with the selected guider.

Start guiding

Calibrate guider (this sometimes helps if the guiding is poor)

- Select the Autoguide tab and take a test exposure of a few seconds.
- Click in the displayed image to select a guide star. White box flashes and coordinates appear in the tab.
- Start guiding with Autoguide button (will hear clicks of corrections being made).

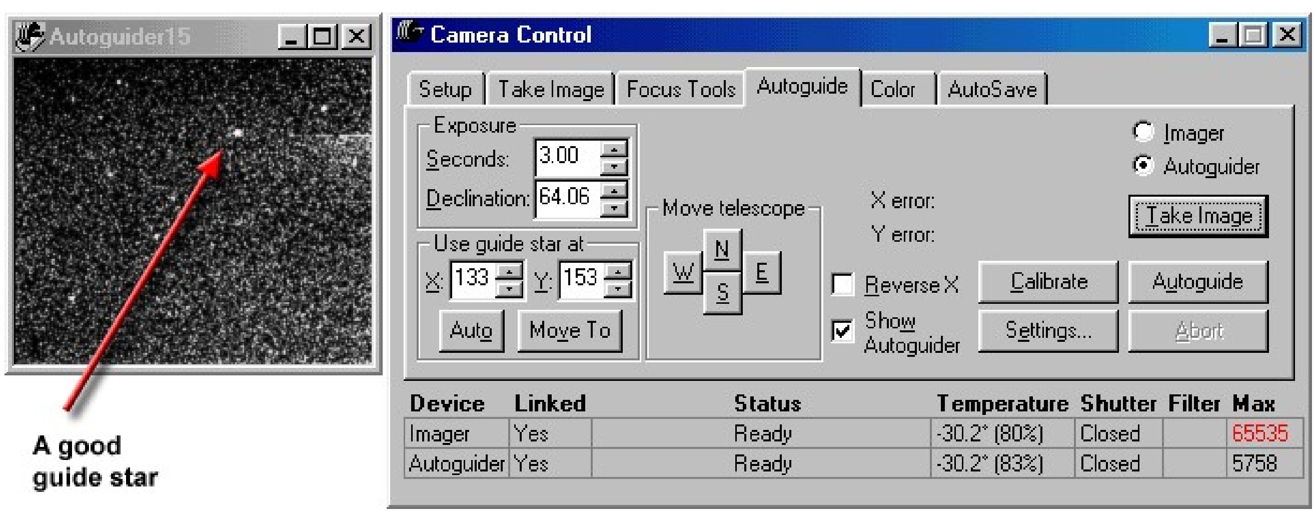
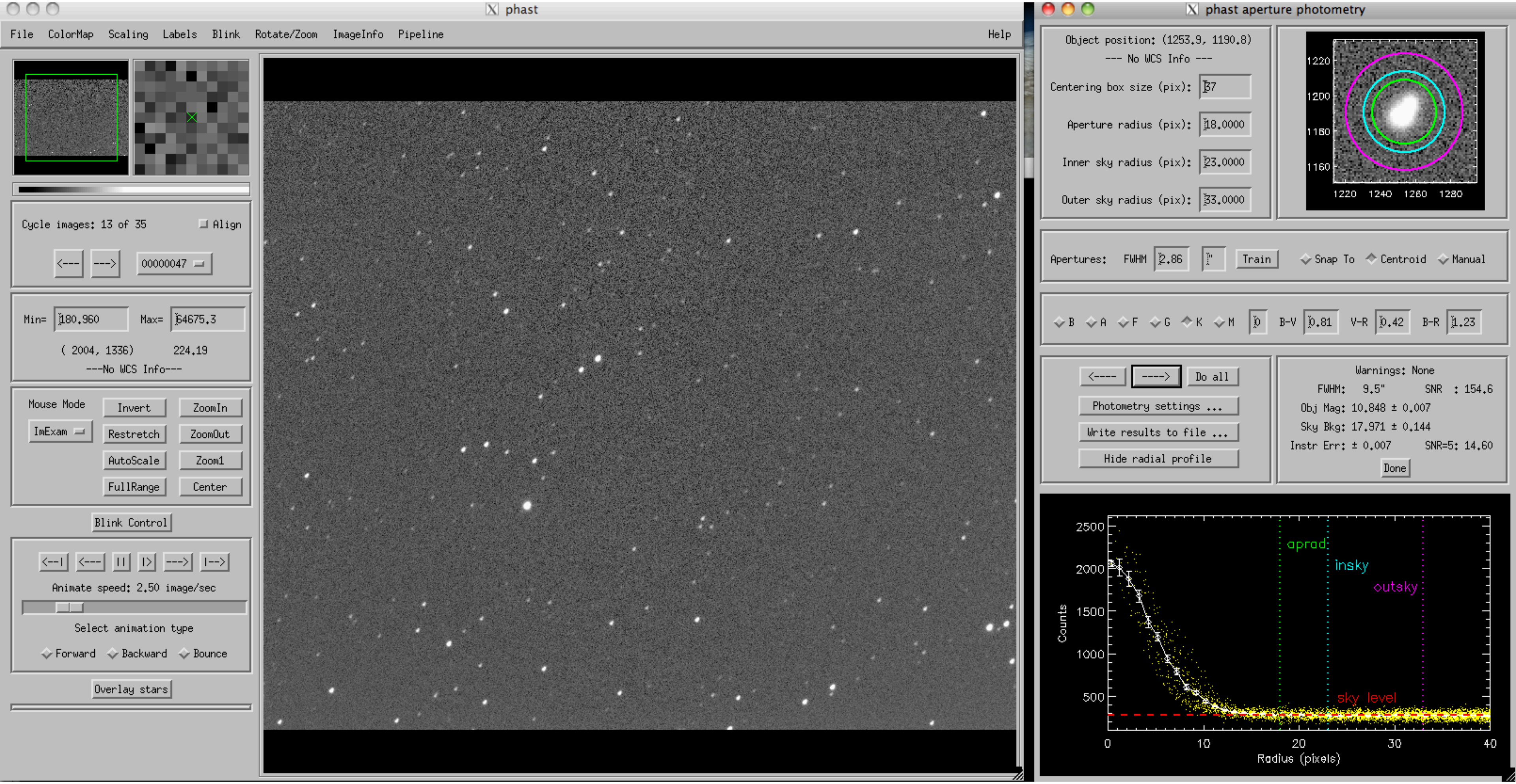


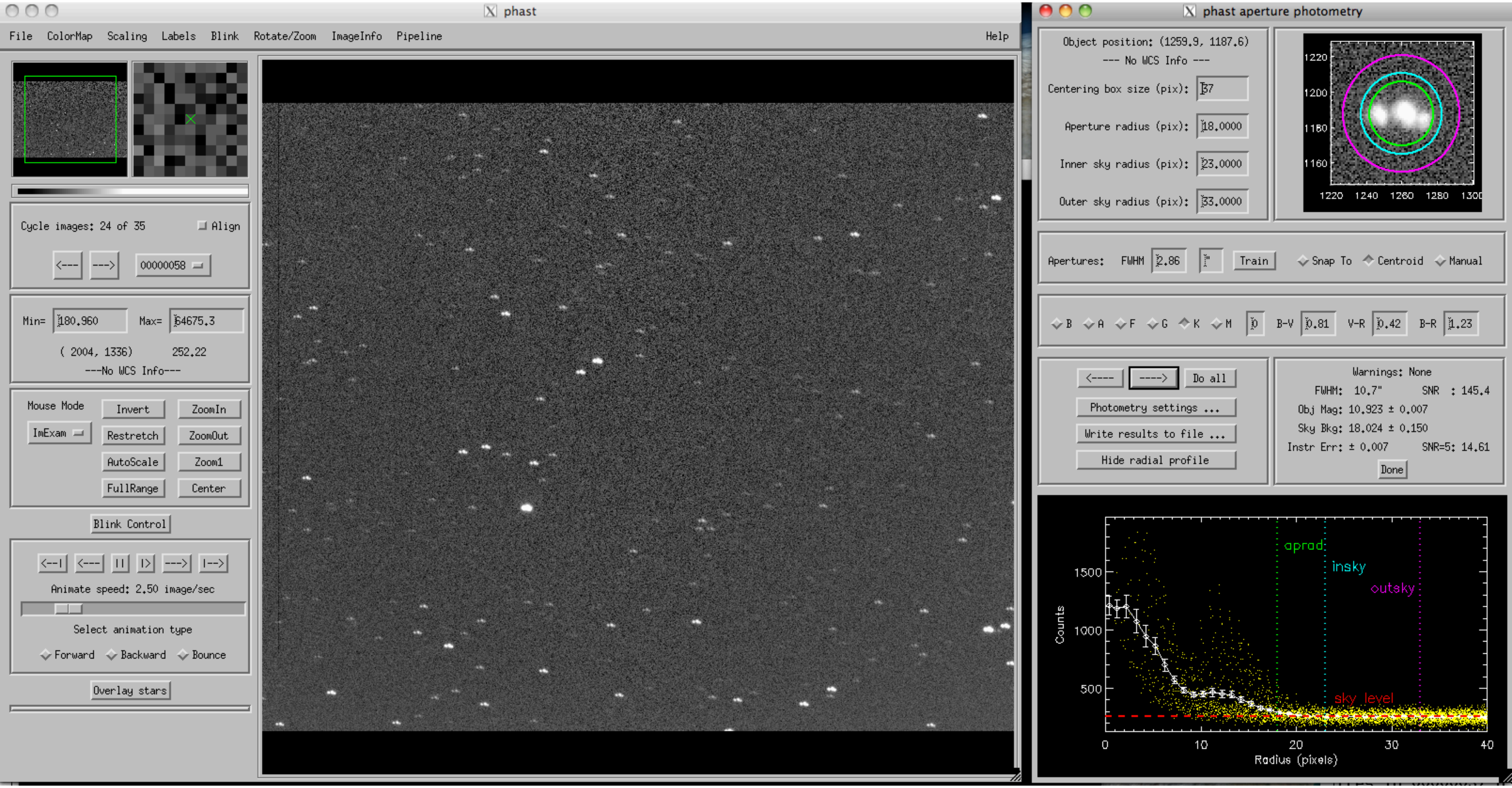
Figure 2: An autoguide image taken for reference. Note that there is one star significantly brighter than the others; this is a good choice for a guide star.

Guider Problems



Over-correcting by the guider can cause the telescope to oscillate back and forth. These images can still be useful if use a big aperture.

Guider Problems

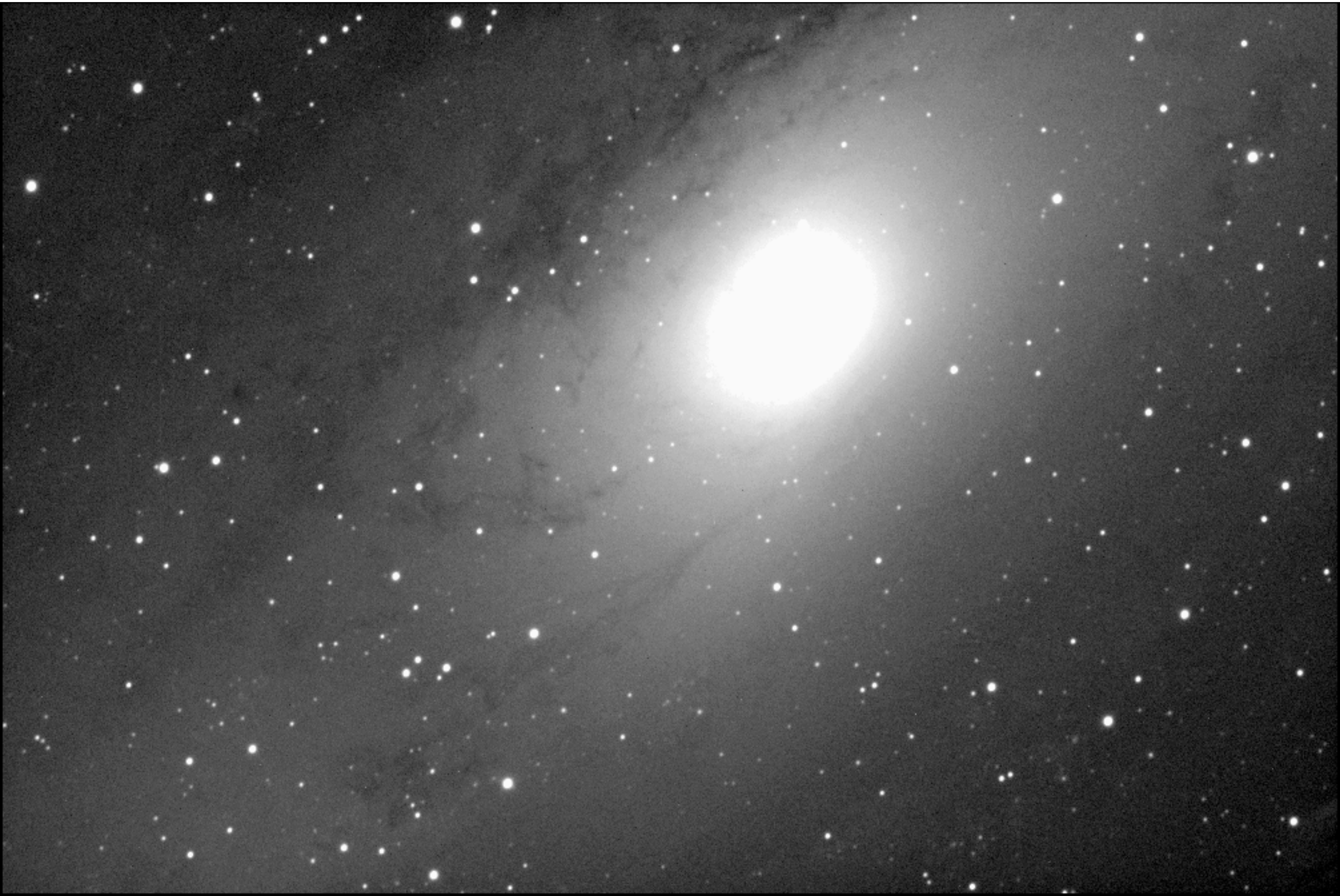


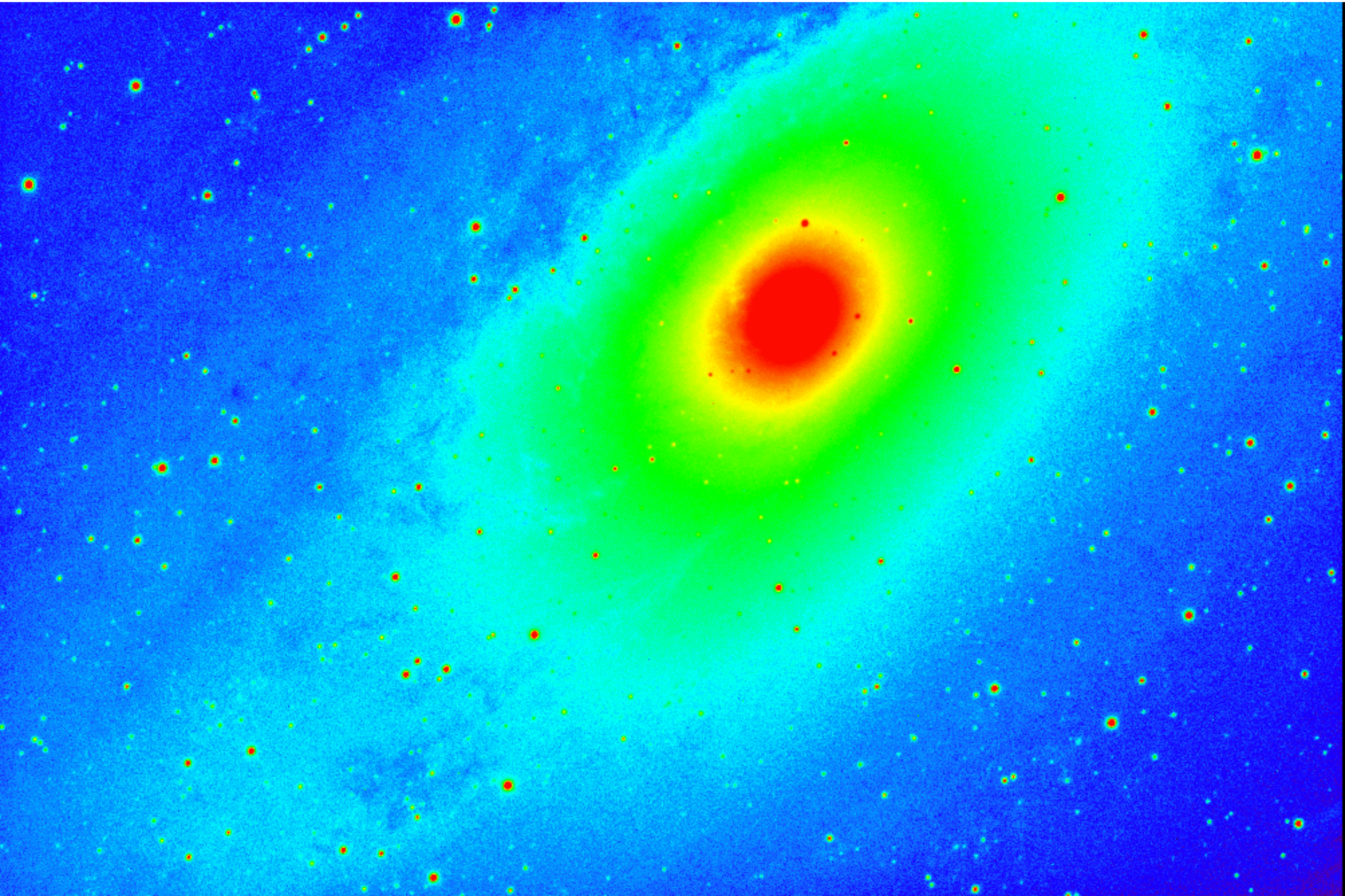
Really bad guiding. Waiting a few correction cycles for the guiding to settle down before starting an exposure can help. If the problem persists, try doing a guider calibration.

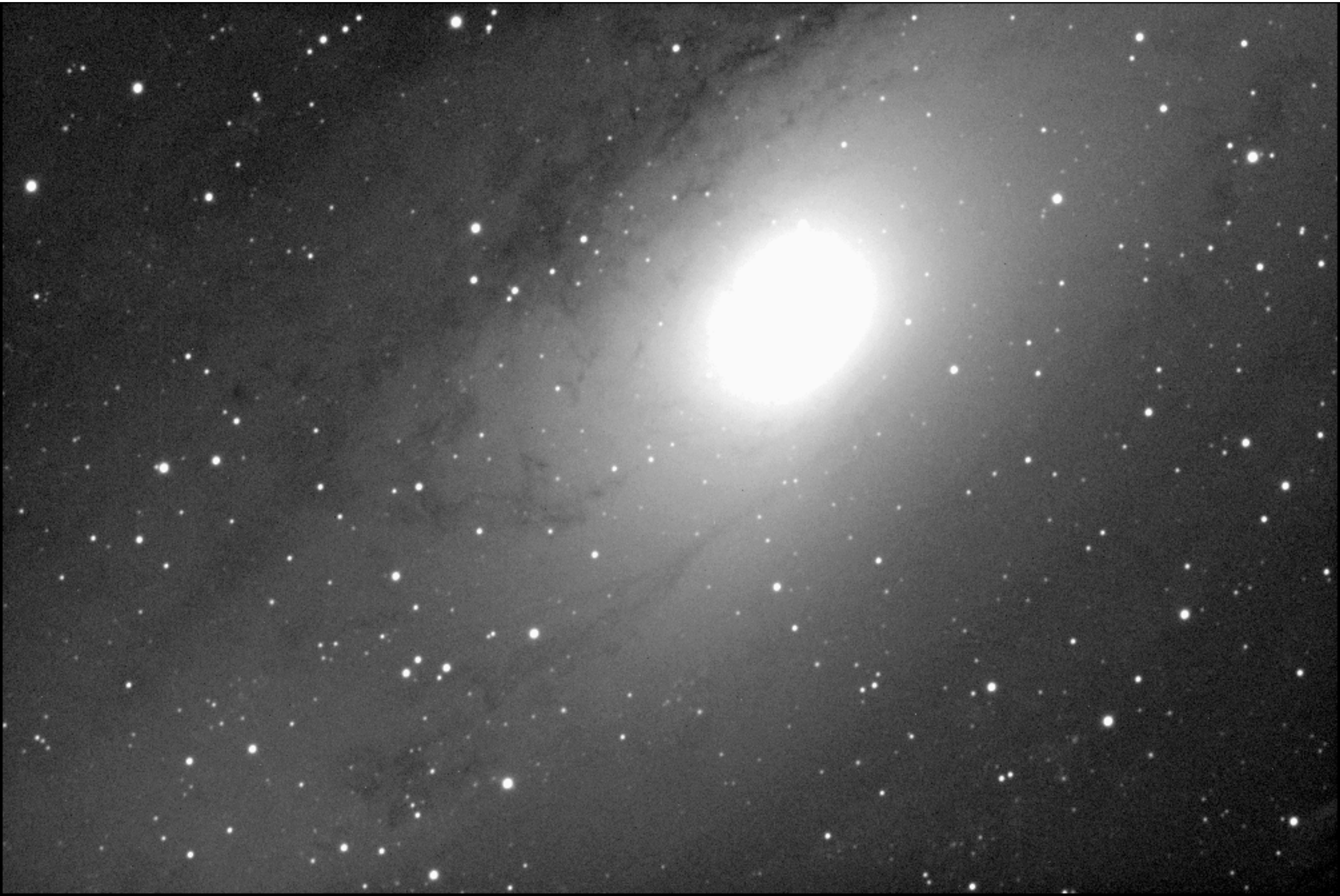
Information in Astronomical Images

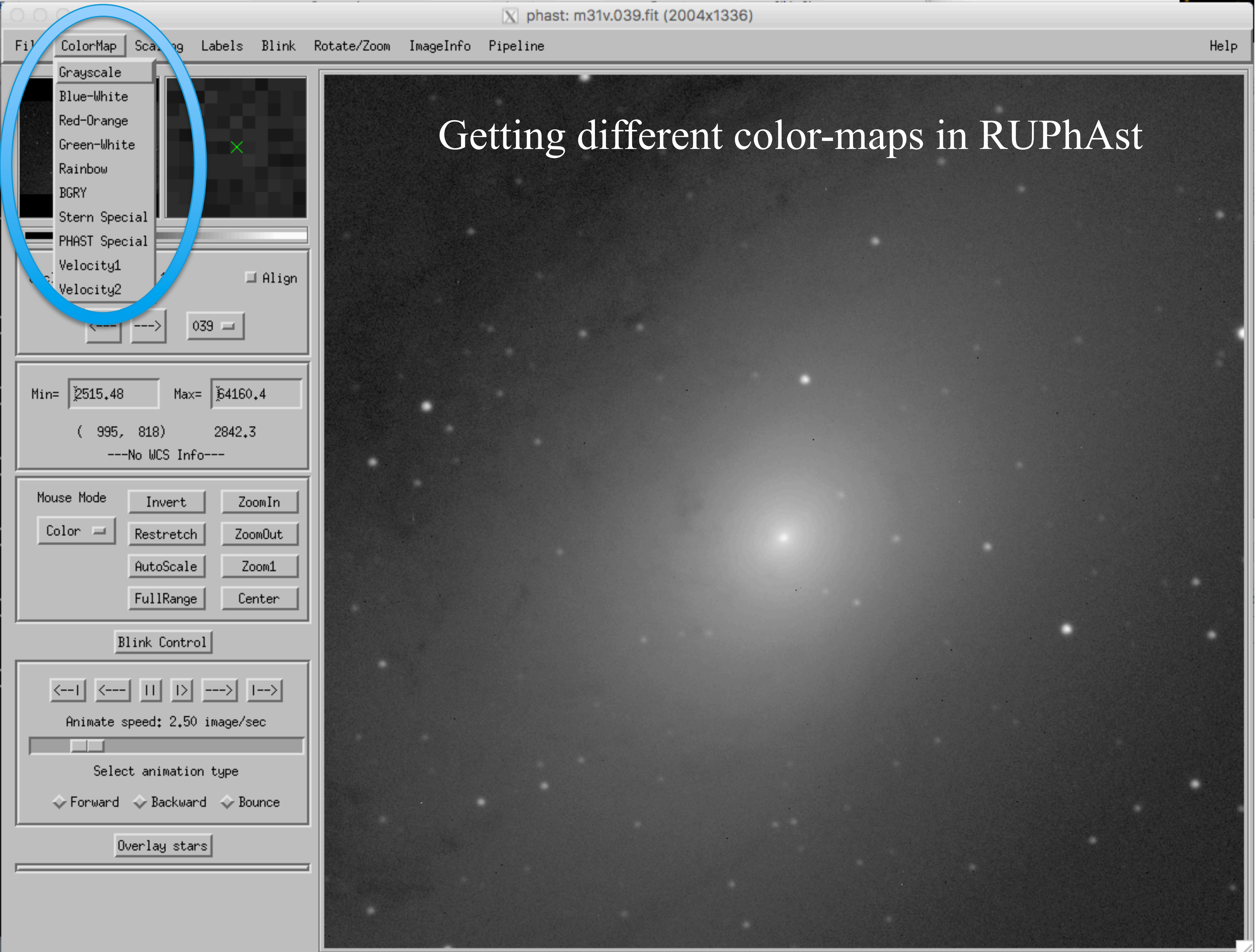
- There is more information in images from CCD detectors than can be easily displayed.
  - Dynamic range: saturation/(read noise) = (64,000 ADU × 1.8 e-/ADU)/(15.5 e^-) = 7400
    - Can extend this with multiple exposure times.
  - Displays can produce only a limited number of (linear) brightness levels (100?).
  - The eye is also sensitive to only a limited number of (logarithmically spaced) levels.
    - Has a dynamic range of about 10^6 (or more?), but this is not available simultaneously due to adaption.
    - At one time can get about $10^{4.5}$.

display.

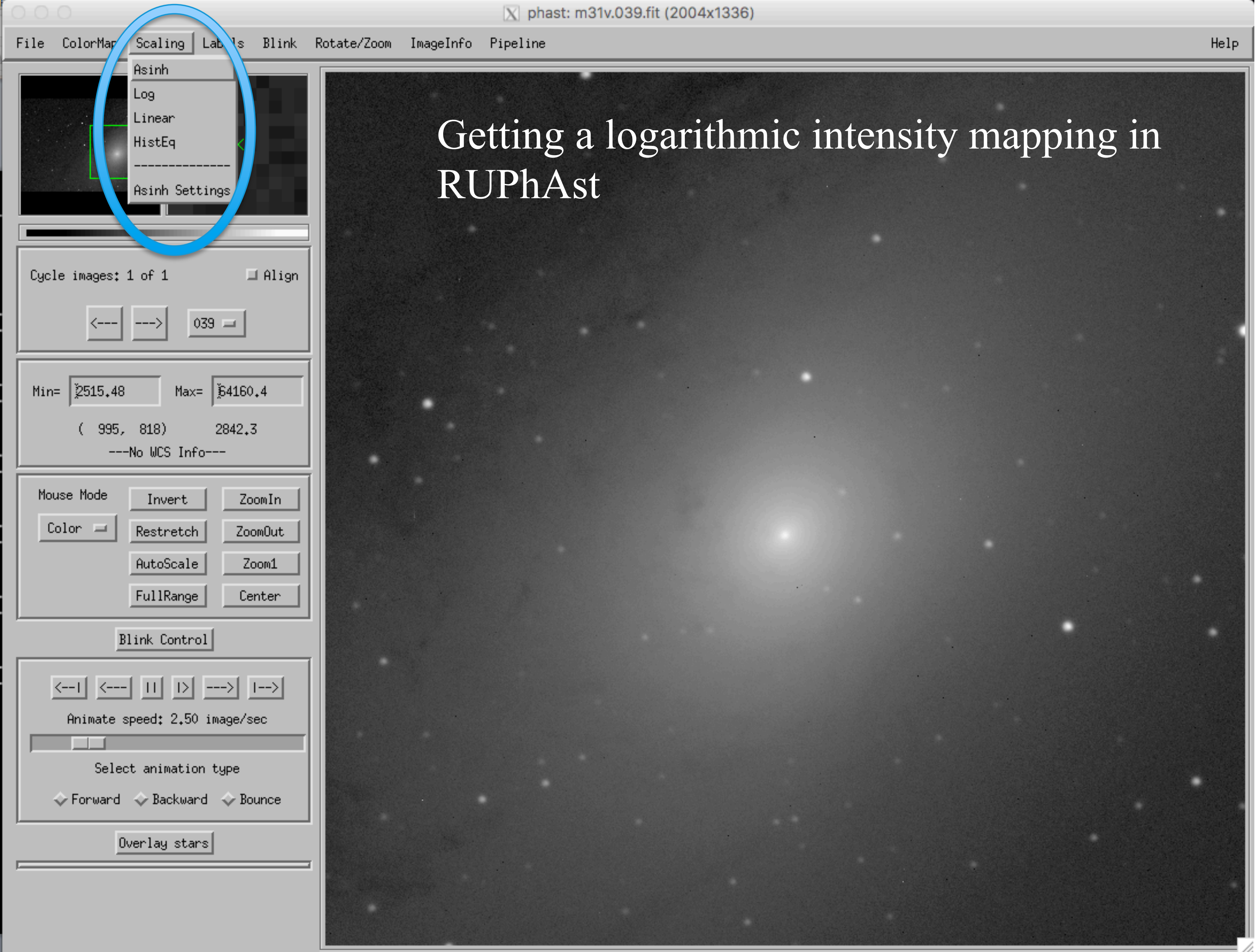




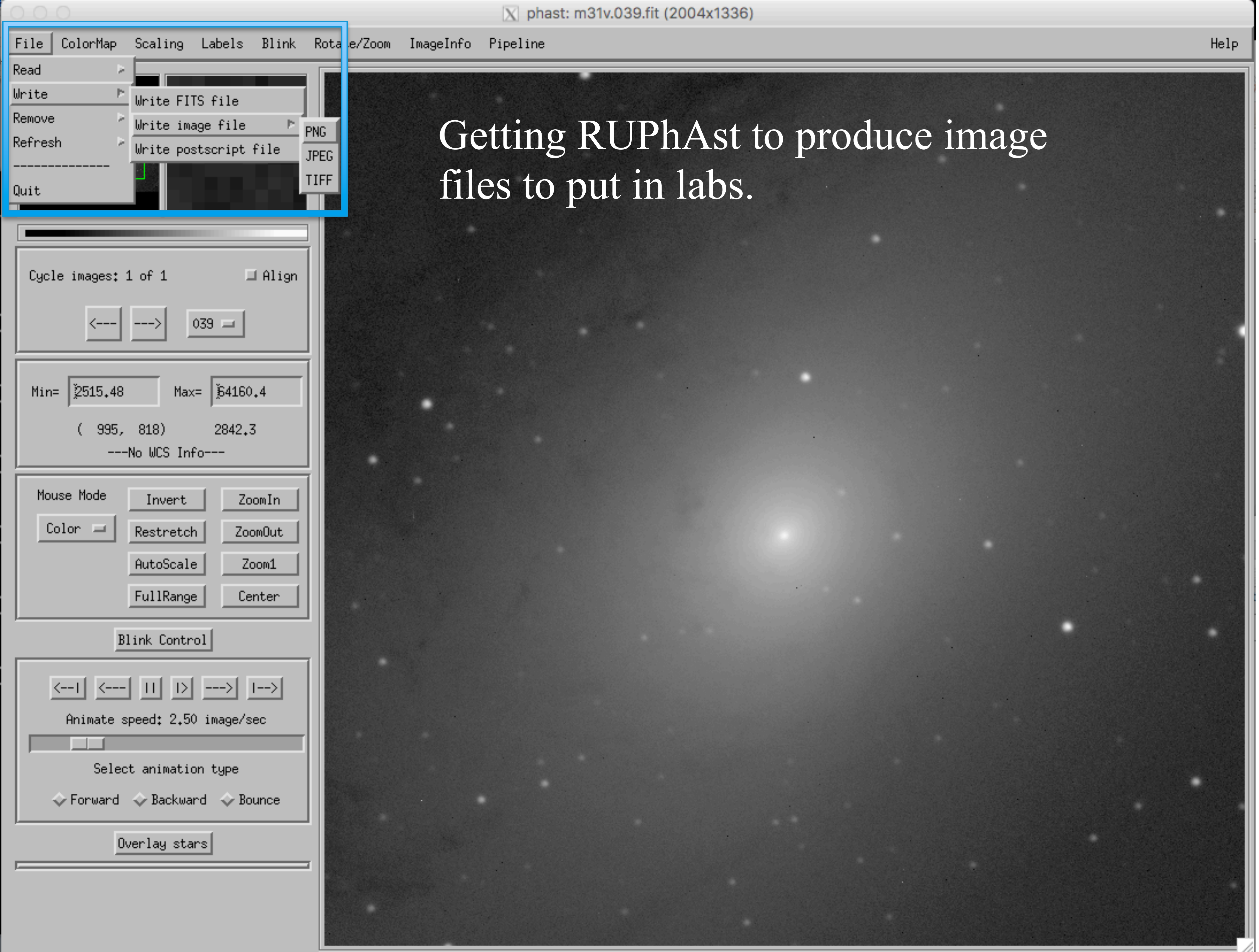


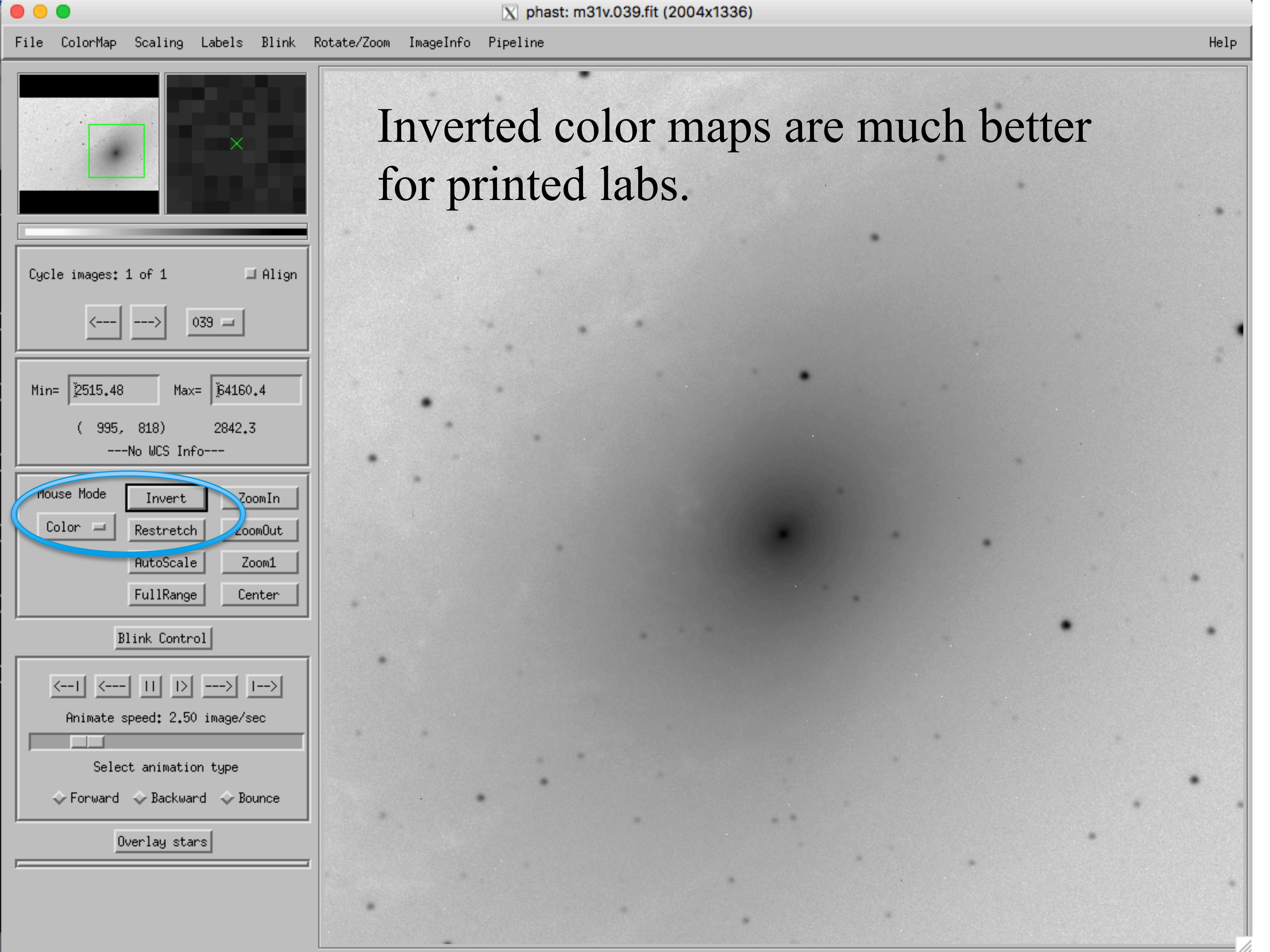

phast: m31v.039.fit (2004x1336)
ColorMap
Labels
Blink
Rotate/Zoom
ImageInfo
Pipeline
Help
Grayscale
Blue-White
Red-Orange
Green-White
Rainbow
BGRY
Stern Special
PHAST Special
Velocity1
Velocity2
Align
039
Min= 2515.48
Max= 64160.4
(995, 818) 2842.3
---No WCS Info---
Mouse Mode
Color
Invert
ZoomIn
Restretch
ZoomOut
AutoScale
Zoom1
FullRange
Center
Blink Control
Animate speed: 2.50 image/sec
Select animation type
Forward
Backward
Bounce
Overlay stars
Getting different color-maps in RUPhAst

Getting a logarithmic intensity mapping in RUPhAst



Getting RUPhAst to produce image files to put in labs.



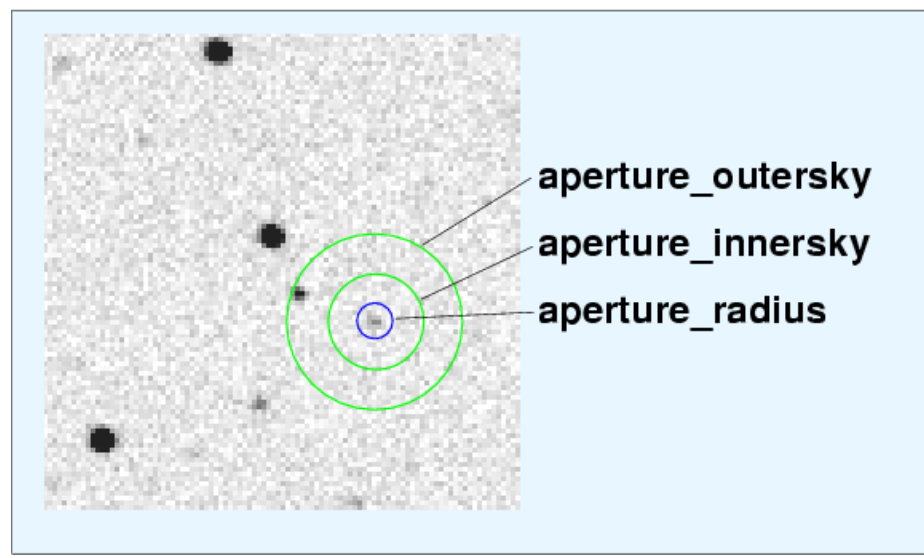

phast: m31v.039.fit (2004x1336)
File ColorMap Scaling Labels Blink Rotate/Zoom ImageInfo Pipeline Help
Inverted color maps are much better for printed labs.
Cycle images: 1 of 1
Align
<--- --->
039
Min= 2515.48
Max= 64160.4
(995, 818) 2842.3
---No WCS Info---
Mouse Mode
Color
Invert
Restretch
AutoScale
FullRange
ZoomIn
ZoomOut
Zoom1
Center
Blink Control
Animate speed: 2.50 image/sec
Select animation type
Forward
Backward
Bounce
Overlay stars

Stellar Photometry in Images

- Correct the image to a uniform, linear response.
  - Dark current and bias level subtraction either
    - done at the telescope with *autodark* subtraction or
    - done by taking separate dark images and subtracting them from the science images later.
  - Need to create an average image of a uniformly illuminated field ("flat field") and divide by it.
    - The mkflatru command.
- Identify your target and comparison stars.
- Measure the brightness of each star (all stars) in all of the images.

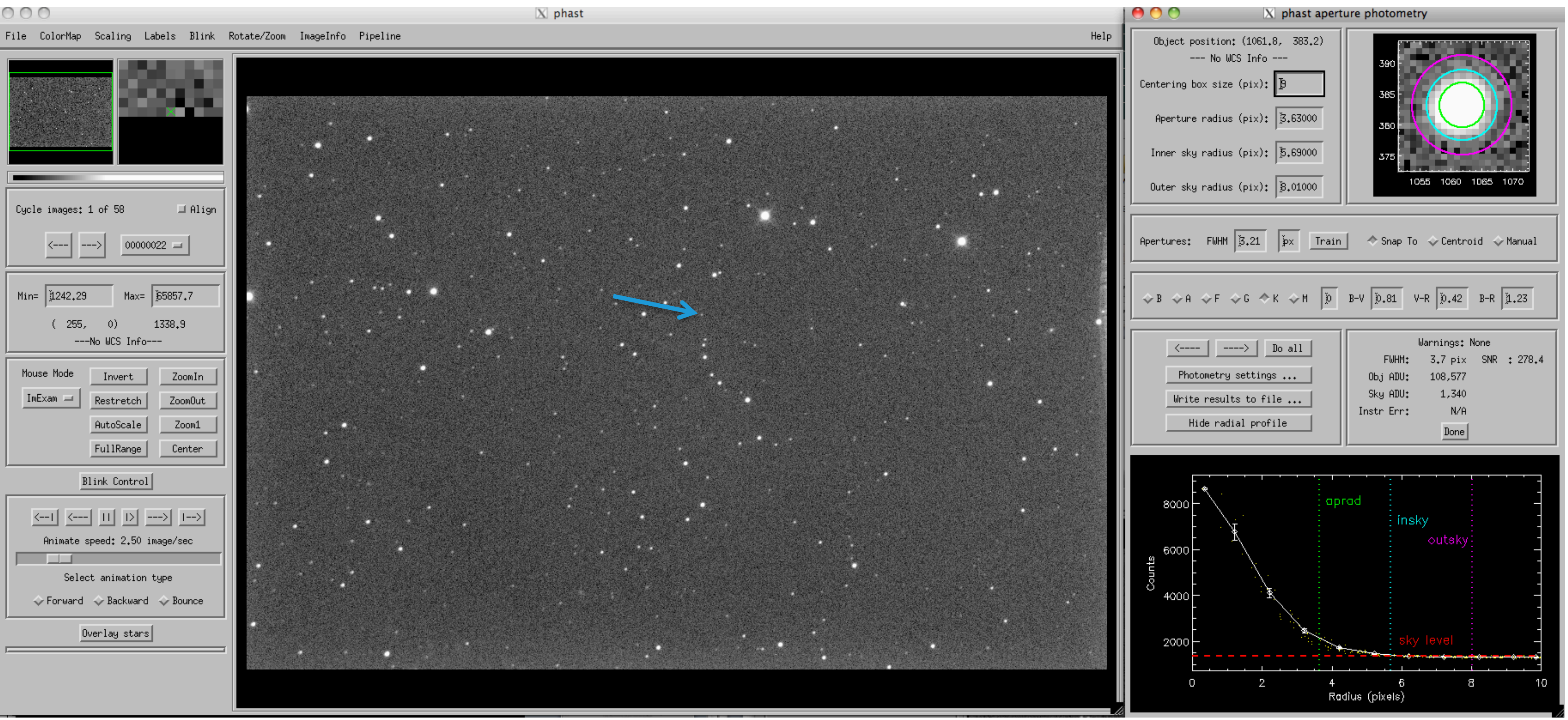
Measuring Stellar Brightness

- One Method: Aperture Photometry
  - Add up signal in pixels within a circular aperture centered on the star.
  - Subtract the contribution from the sky, estimated from pixels in a surrounding annulus.
    - Need a “robust” average sky value that removes the effect of any stars present.
  - (Relatively) simple.
  - How big to make the aperture?

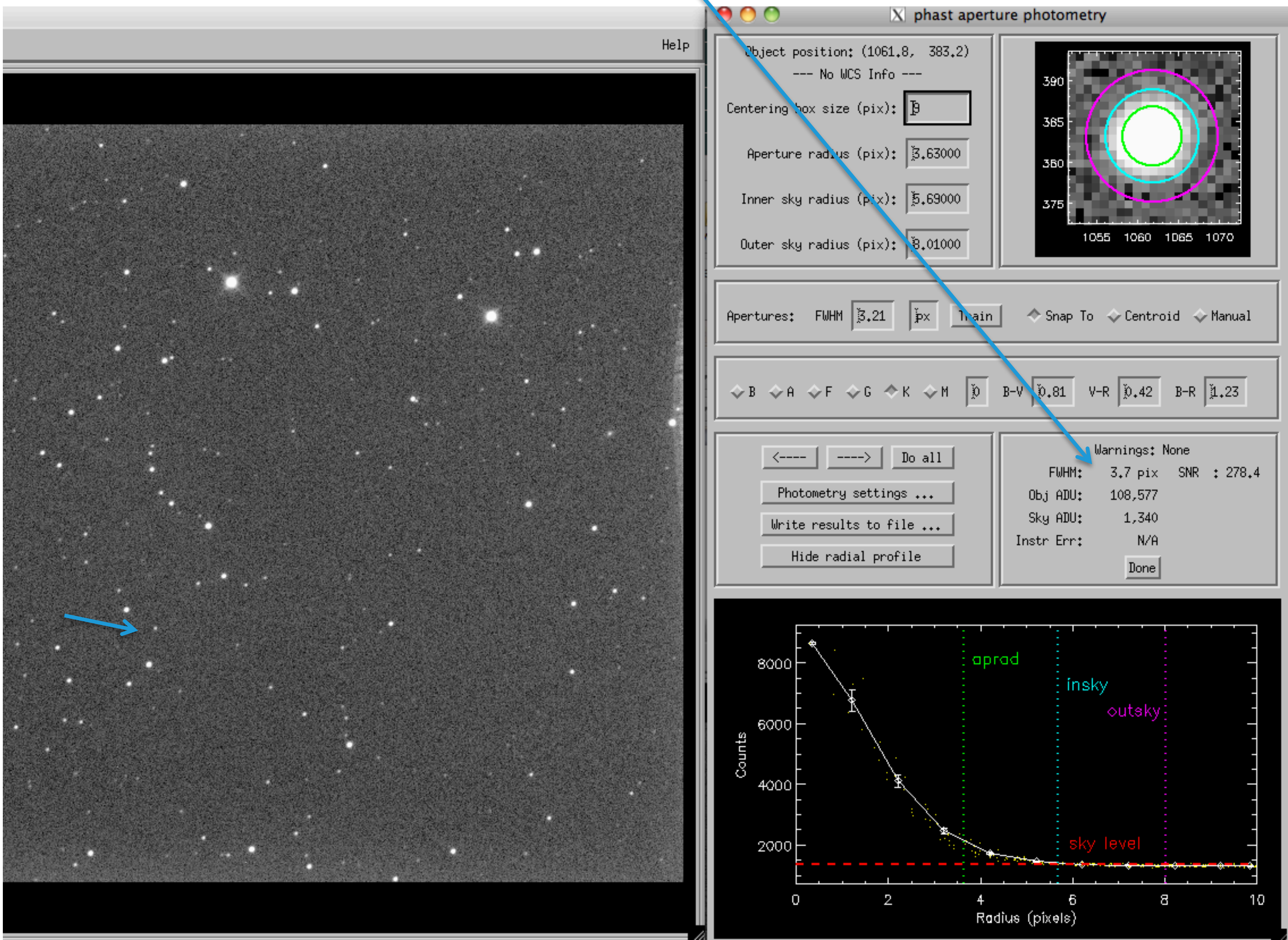


Measuring the brightness of an individual star with RUPhAst using aperture photometry.

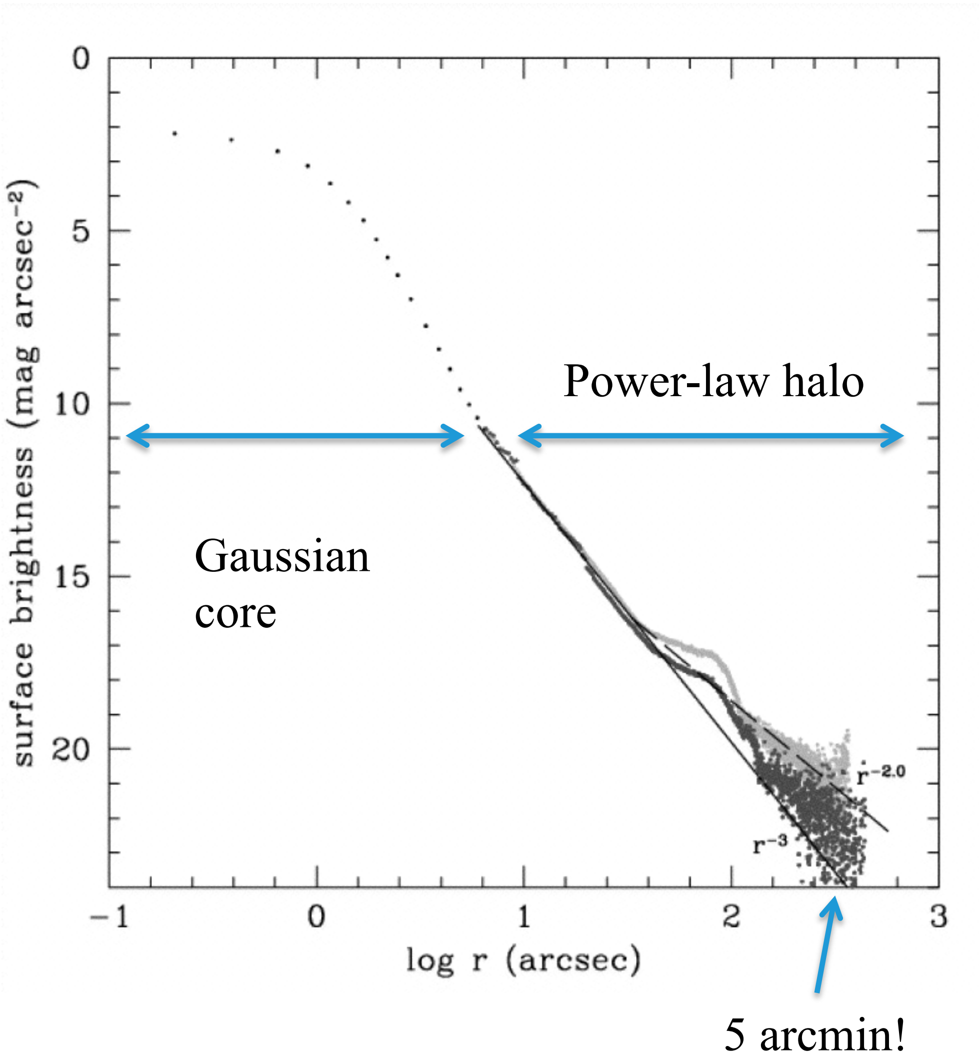
In ImExam mouse mode, left-click on your target star to bring up the aperture photometry window.



Note the FWHM of the stellar images. Decide on the aperture size.



- Shape of a stellar image – the "point spread function" (PSF)



The core is caused by a) the bending of light in the rapidly changing inhomogeneous atmosphere – seeing and b) quality of the optical system (how well it is focused, …). It often varies over a night and within an image.

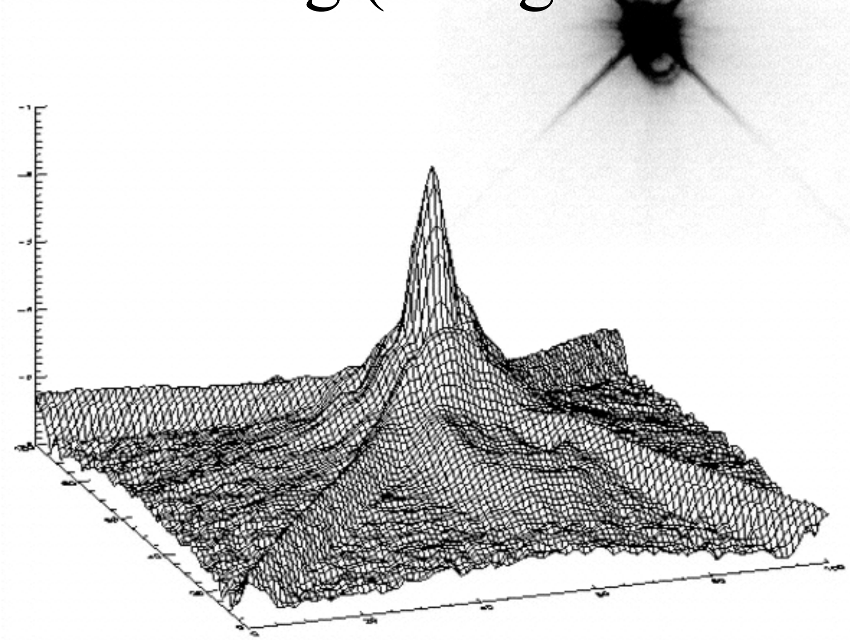
The origin of the halo is less well understood, but it is probably caused by diffraction from the telescope aperture and scattered light from dust and "micro-ripple" imperfections on surfaces of mirrors, filters, and other optical elements. The halo is constant at least over the several nights of an observing run.

Measuring Stellar Brightness

- Choosing an Aperture Size
  - Compromise on an intermediate size that contains a fixed fraction of the light.
    - This lab compares the brightness of stars in the same image (*differential photometry*), so a fixed fractional loss is OK as long as it is constant across the image.
  - Thus, the size needs to be bigger than the time- and spatially-variable core of the PSF.
  - Rule of thumb: aperture radius = 2 × FWHM of the stellar profile. In this lab, the stars are bright enough that noise from the sky is less important and can err on the side of even larger apertures.
    - Compensates for less-than-perfect guiding and variable PSF.

Measuring Stellar Brightness

- Another method of measuring stellar brightness uses the shape of a stellar image – the PSF
  - For space telescopes (such as HST), the core (and spikes) are mostly determined by diffraction due to the telescope aperture. This is less variable with time than seeing (though still affected by focus changes).



Stellar "point spread function" (PSF) for the Space Telescope Imaging Spectrograph (O'Dowd & Urry 2005)

Measuring Stellar Brightness

- PSF-fitting method:
  - Fit a functional form for the PSF plus a constant sky to the pixel values. Volume under the function is a measure of the stellar brightness.
  - Bright pixels in the core have the highest weight in the fit ➔ better S/N.
  - Can measure overlapping stars by simultaneously fitting two PSFs.
  - But greater complexity and higher computational cost.