Lecture 6

October 11, 2018

Lab 4 and Data Calibration

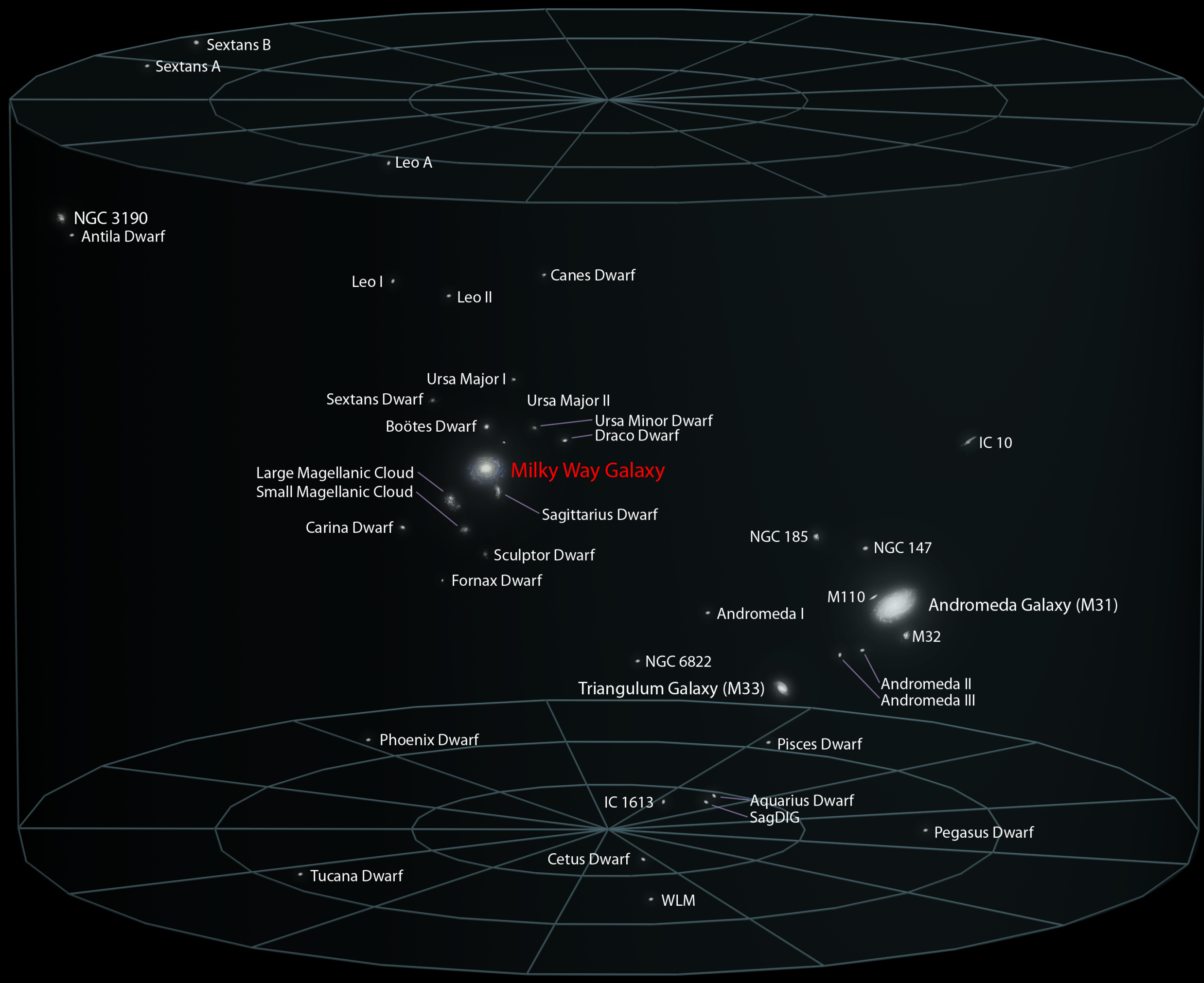
News

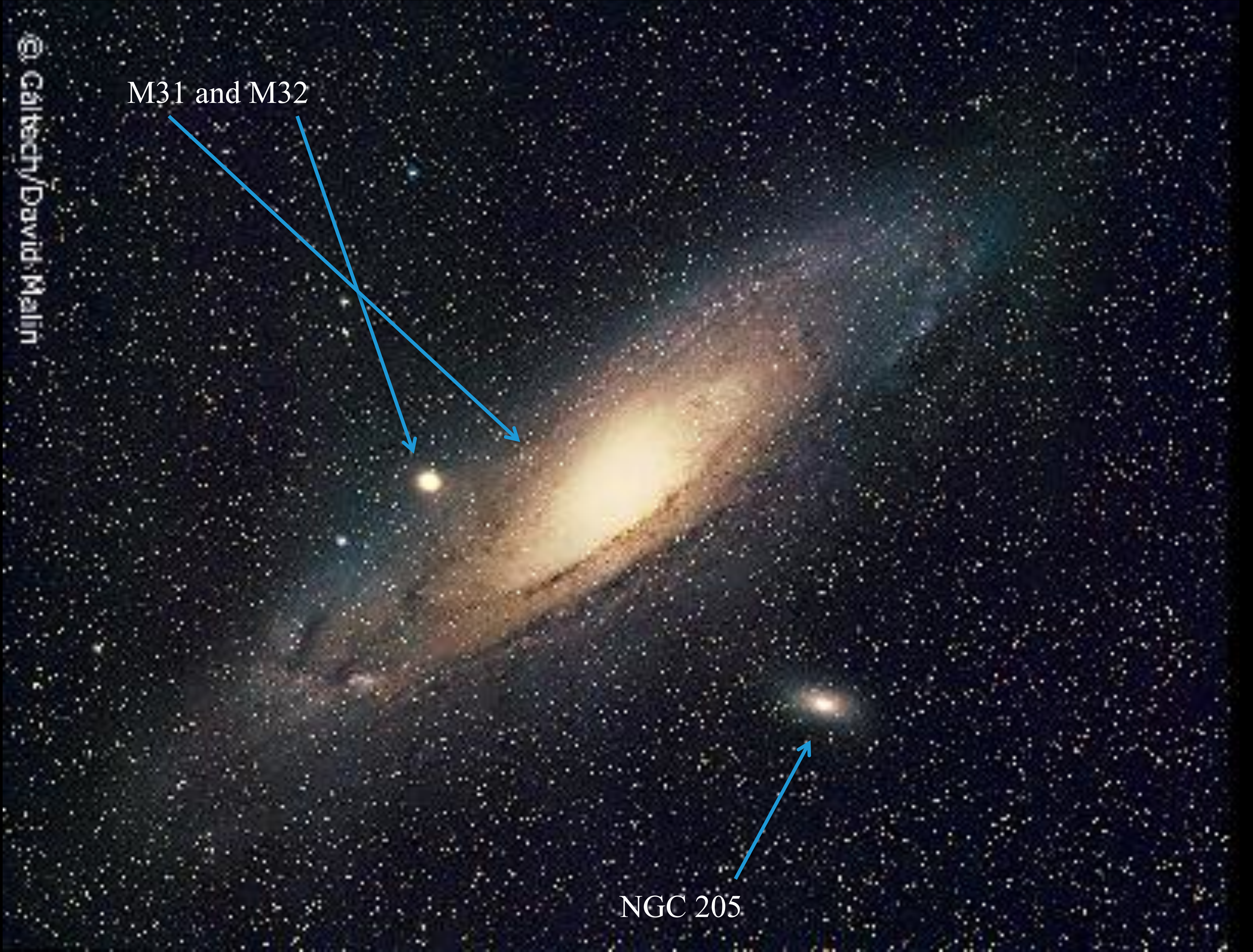
- Lab 2
  - Due today.
- Lab 3
  - Due today.
- Lab 4
  - Imaging the galaxies M31, M32, and M33.
  - Observing starts tomorrow (October 12).
  - Due October 25 (tentatively)

Galaxy & Stellar Photometry in Images

- Lab 4: Photometry of M31, M32, and M33
  - Measure the projected shape and radial profiles.
  - Observe in both the B and V filter to get colors, B−V, which reflect changing stellar populations.
- Lab 5: Measuring the Transit of an Exoplanet
  - Determines the radius of the planet (and it's orbital period if observe multiple transits).
- The basic method for both labs is to measure the brightnesses of galaxies/stars in images.
  - Will perform differential photometry by using stars in the field with known magnitudes.

Local Galactic Group




M31 and M32
NGC 205
© Caltech/David Malin


M32
NGC 206
(richest OB associaton)

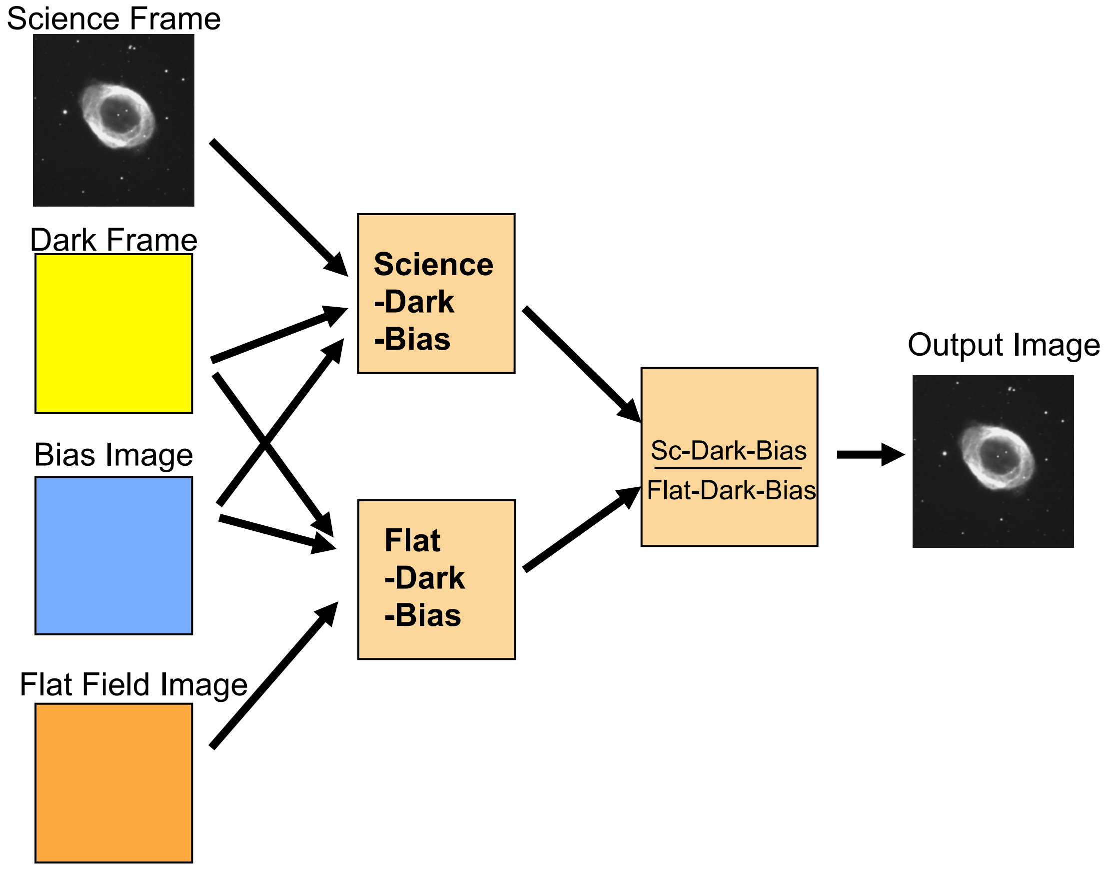
M33

Photometry in Images

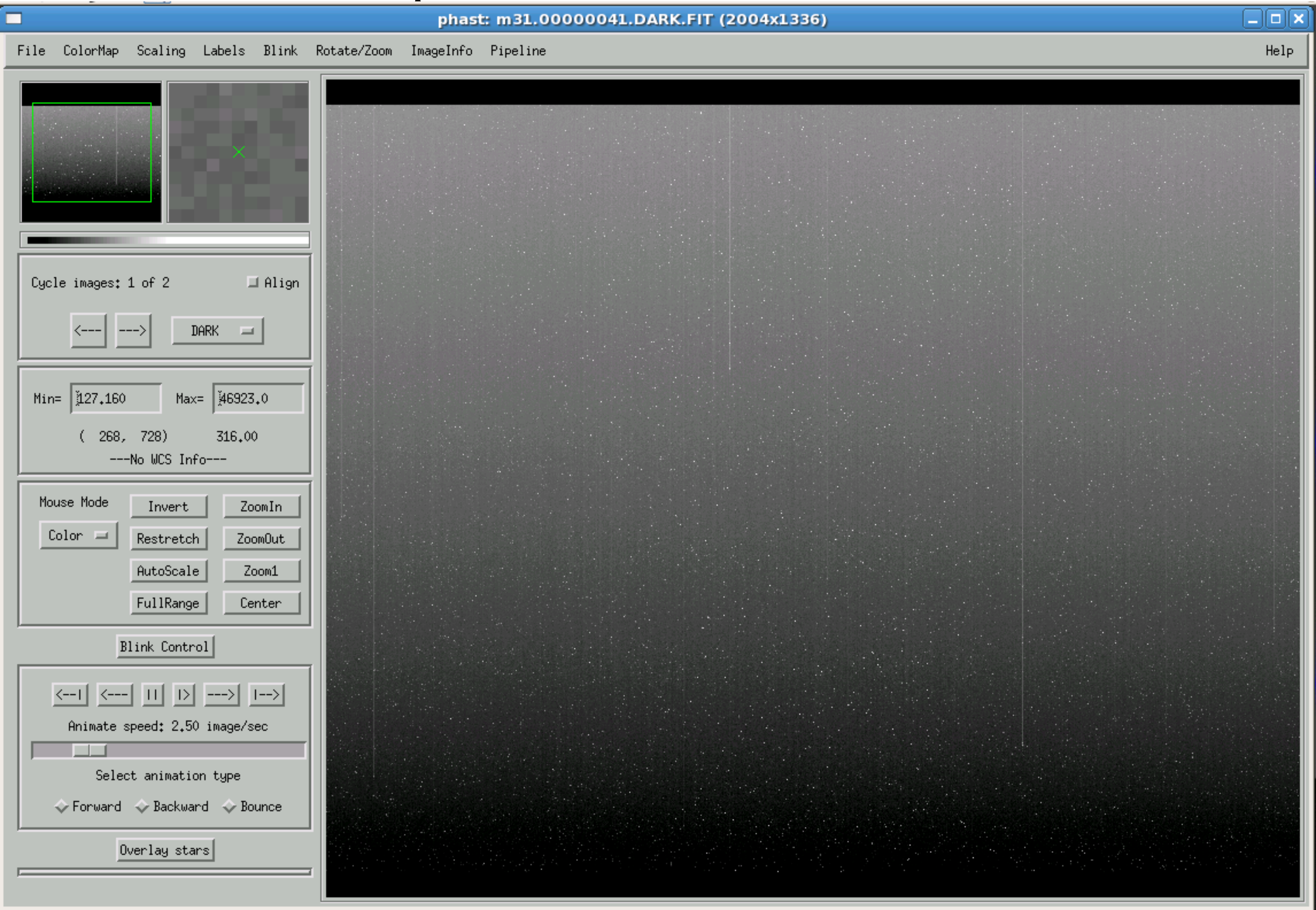
- Correct the image to a uniform, linear response.
  - Dark current and bias level subtraction either
    - done at the telescope with *autodark* subtraction or
    - done by taking separate dark images and subtracting them from the science images later.
  - Need to create an average image of a uniformly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

CCD calibration

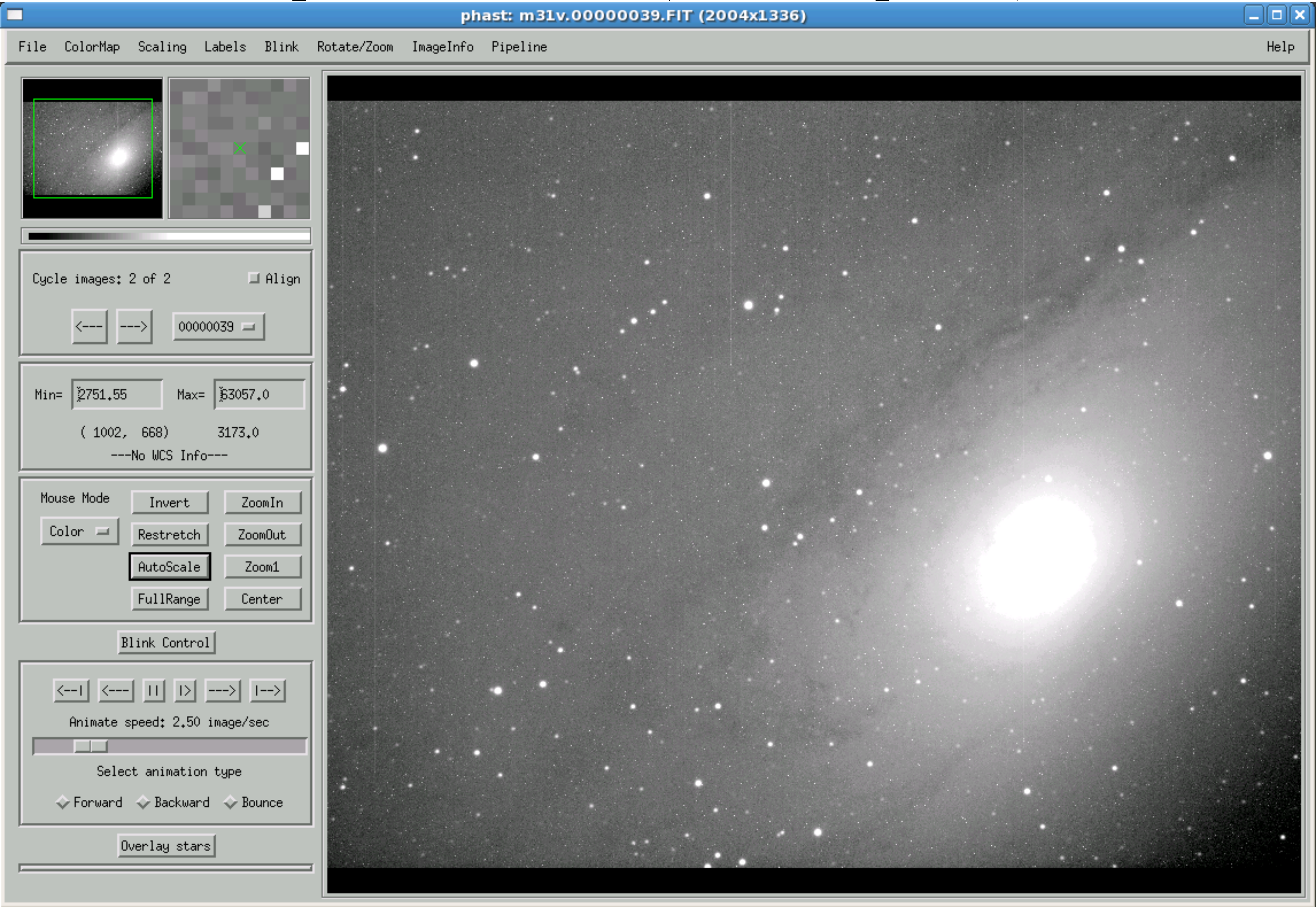
If there is significant dark current present:



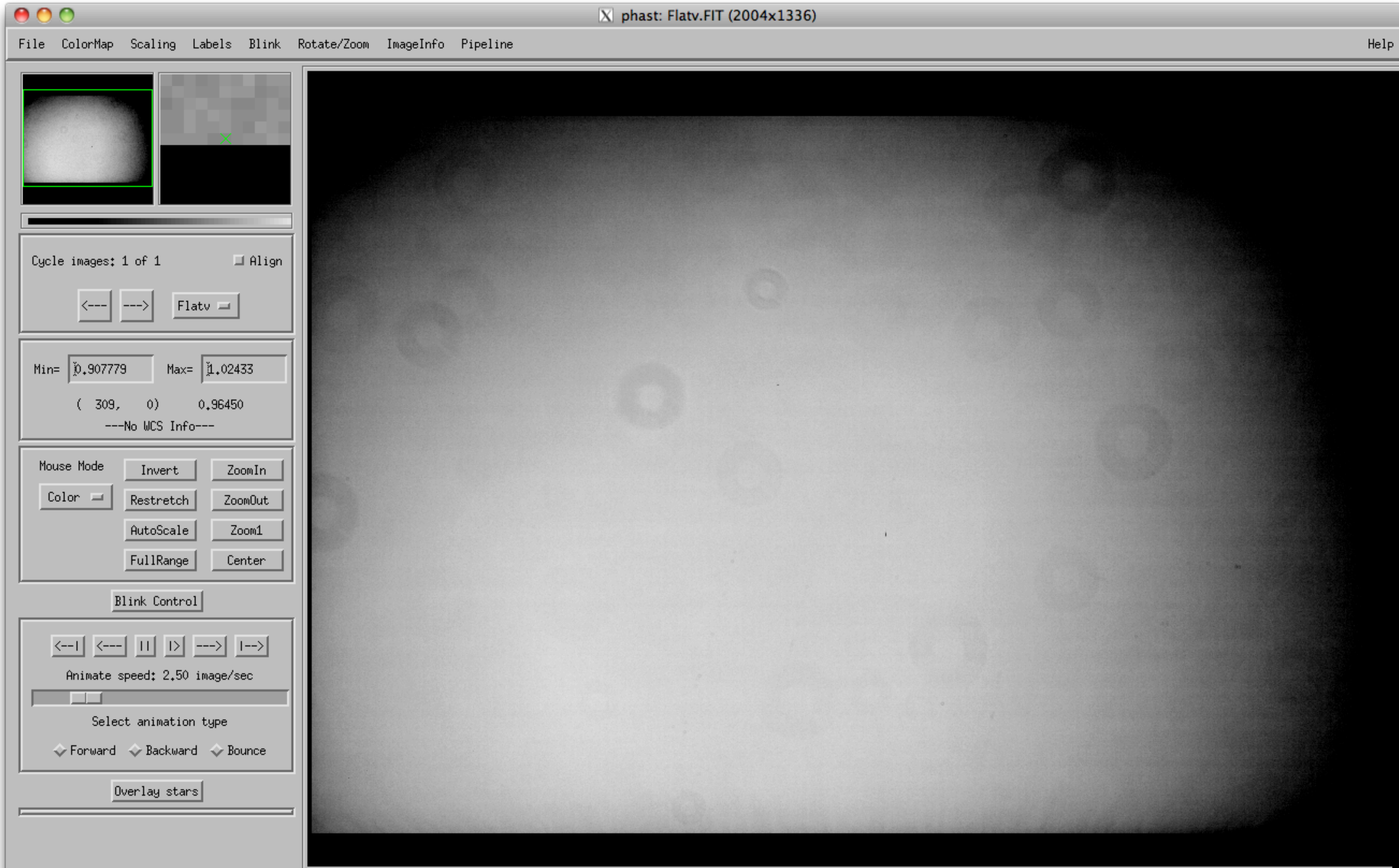
A 300 s dark exposure.



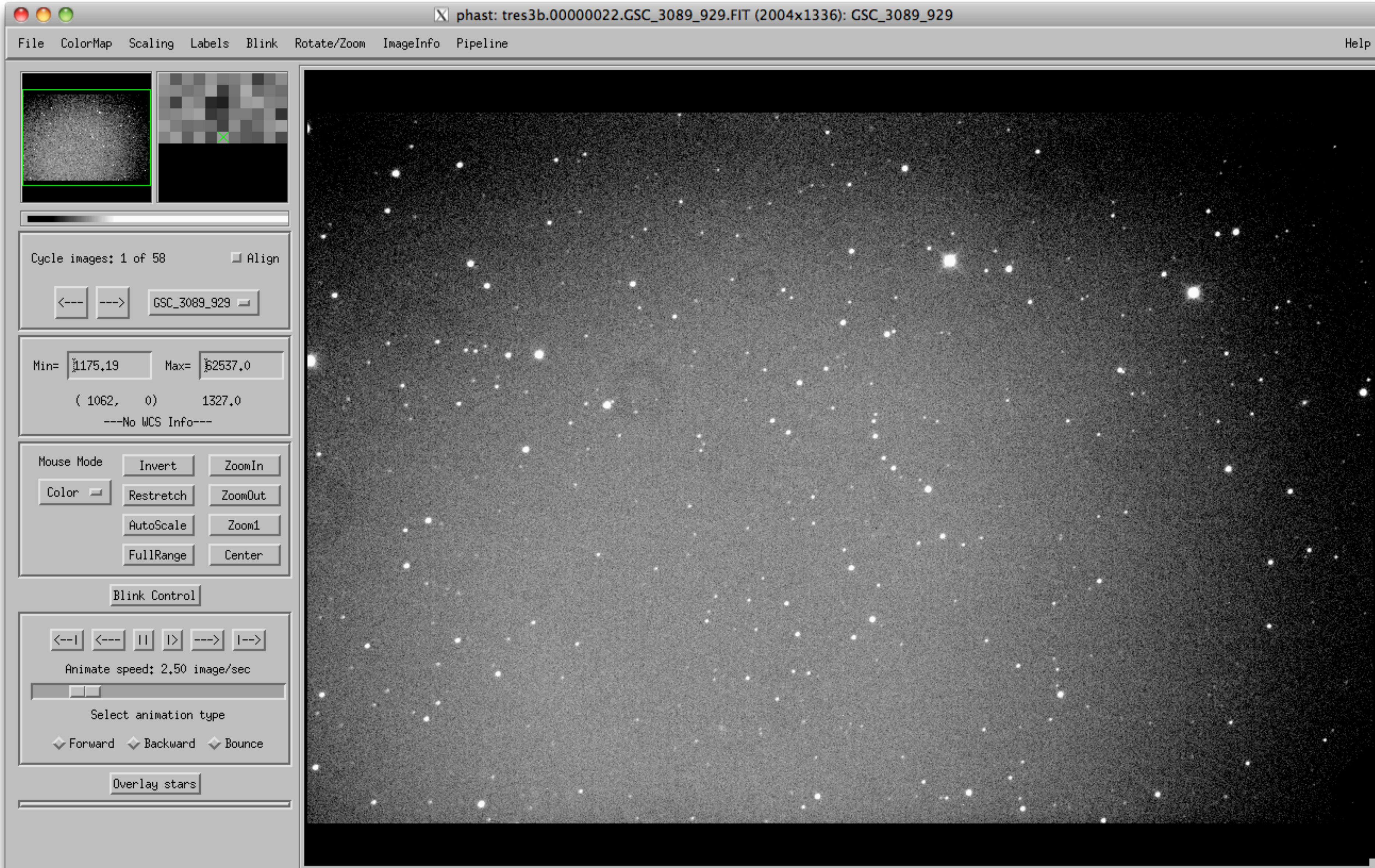
A 300 s exposure of M31 (note hot pixels).



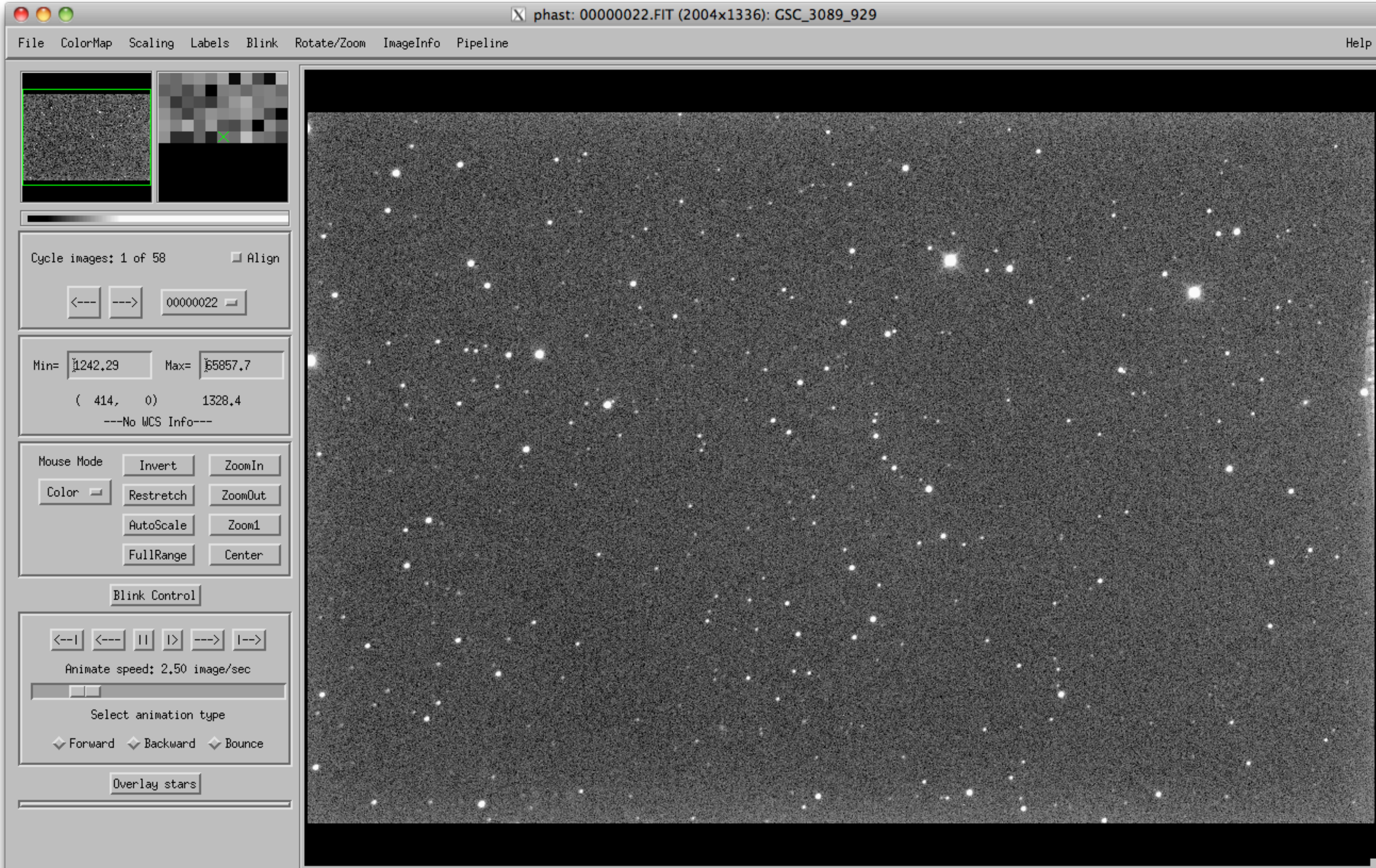
The flatfield produced by the median of dome exposures.



Raw image (autodark subtracted)



Flattened image = (science − dark)/flat

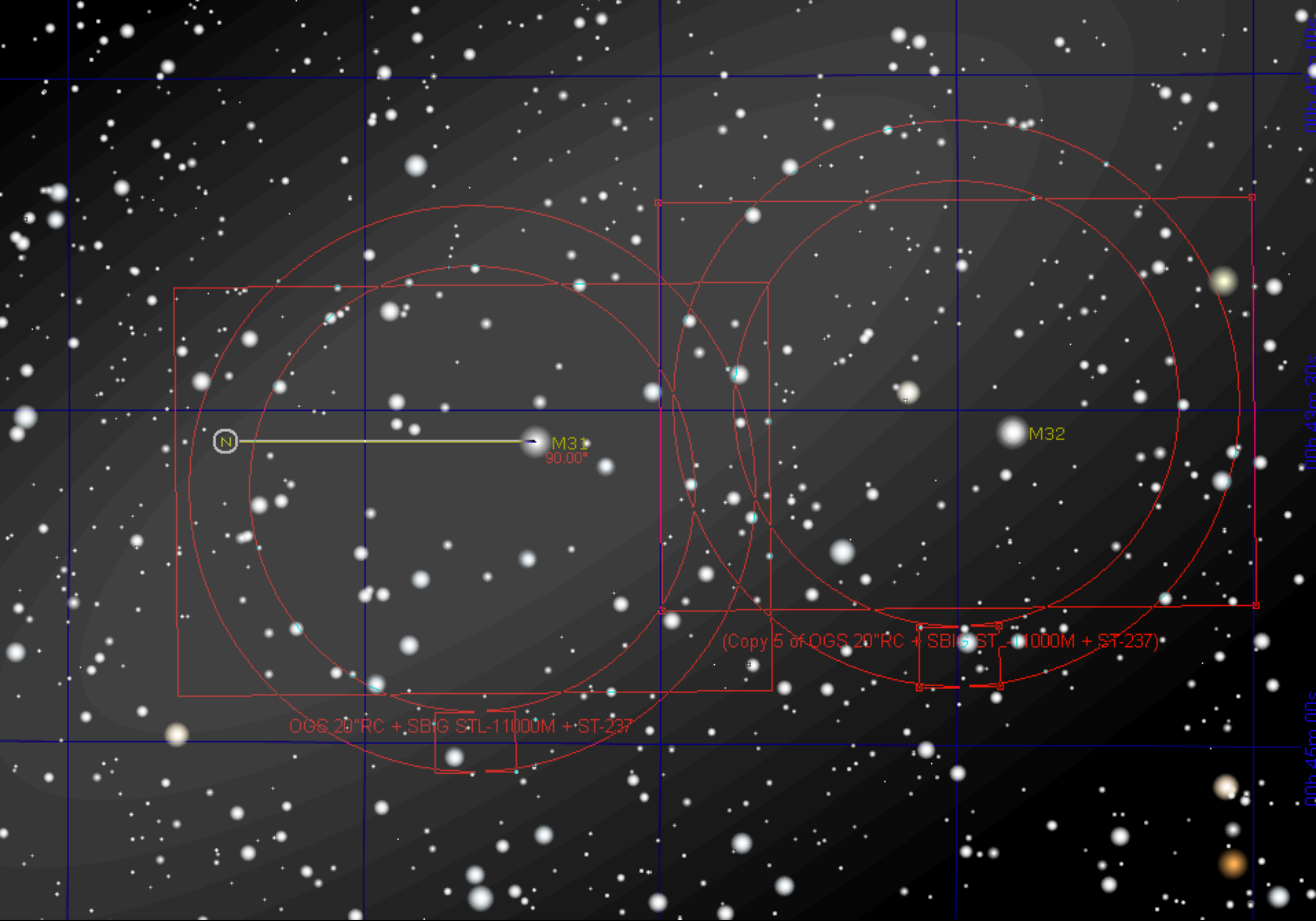


Galaxy & Stellar Photometry in Images

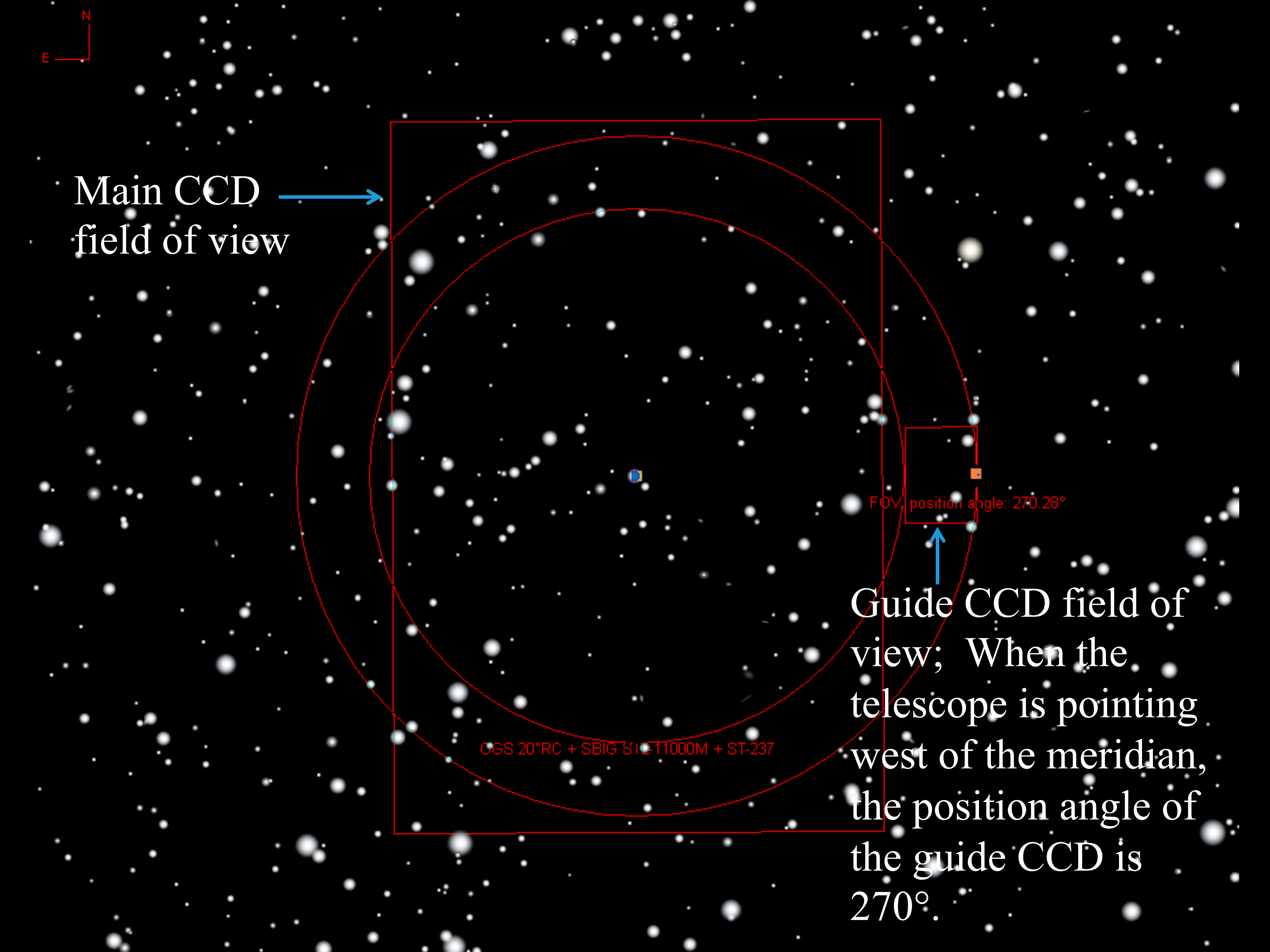
- Lab 4: Photometry of M31, M32, and M33
  - Measure the projected shape and radial profiles.
  - Observe in both the B and V filter to get colors, B−V, which reflect changing stellar populations.
- Lab 5: Measuring the Transit of an Exoplanet
  - Determines the radius of the planet (and it's orbital period if observe multiple transits).
- The basic method for both labs is to measure the brightnesses of galaxies/stars in images.
  - **Will perform differential photometry by using stars in the field with known magnitudes.**

Observing for Labs 4 and 5

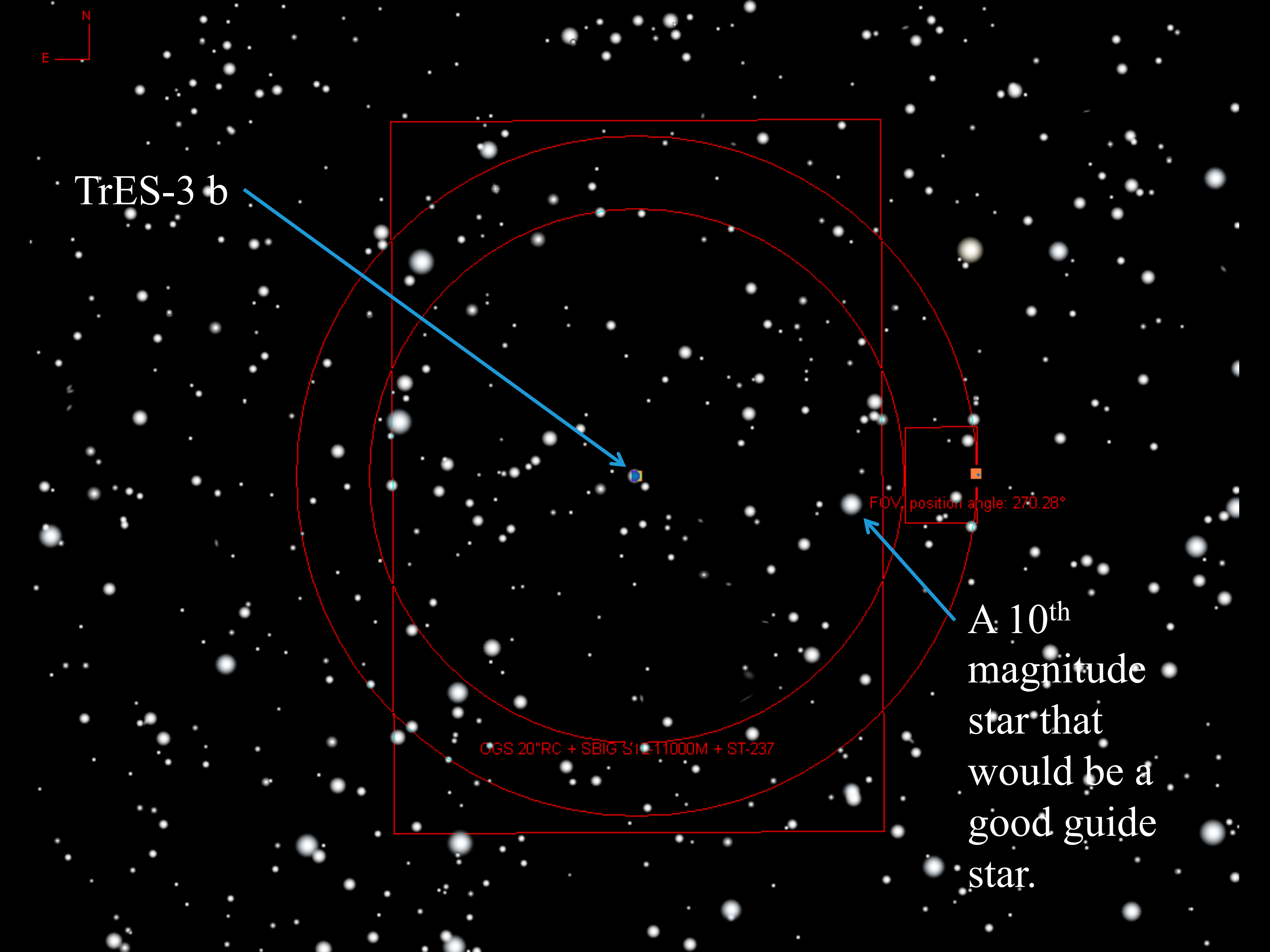
- Initial planning:
  - Decide whether will be observing M31east or west of the meridian.
  - Use The Sky to identify a good “guide star”: – preferrably 10th magnitude or brighter.
  - Plan how to get the guide star onto the small field of view of the guide CCD.

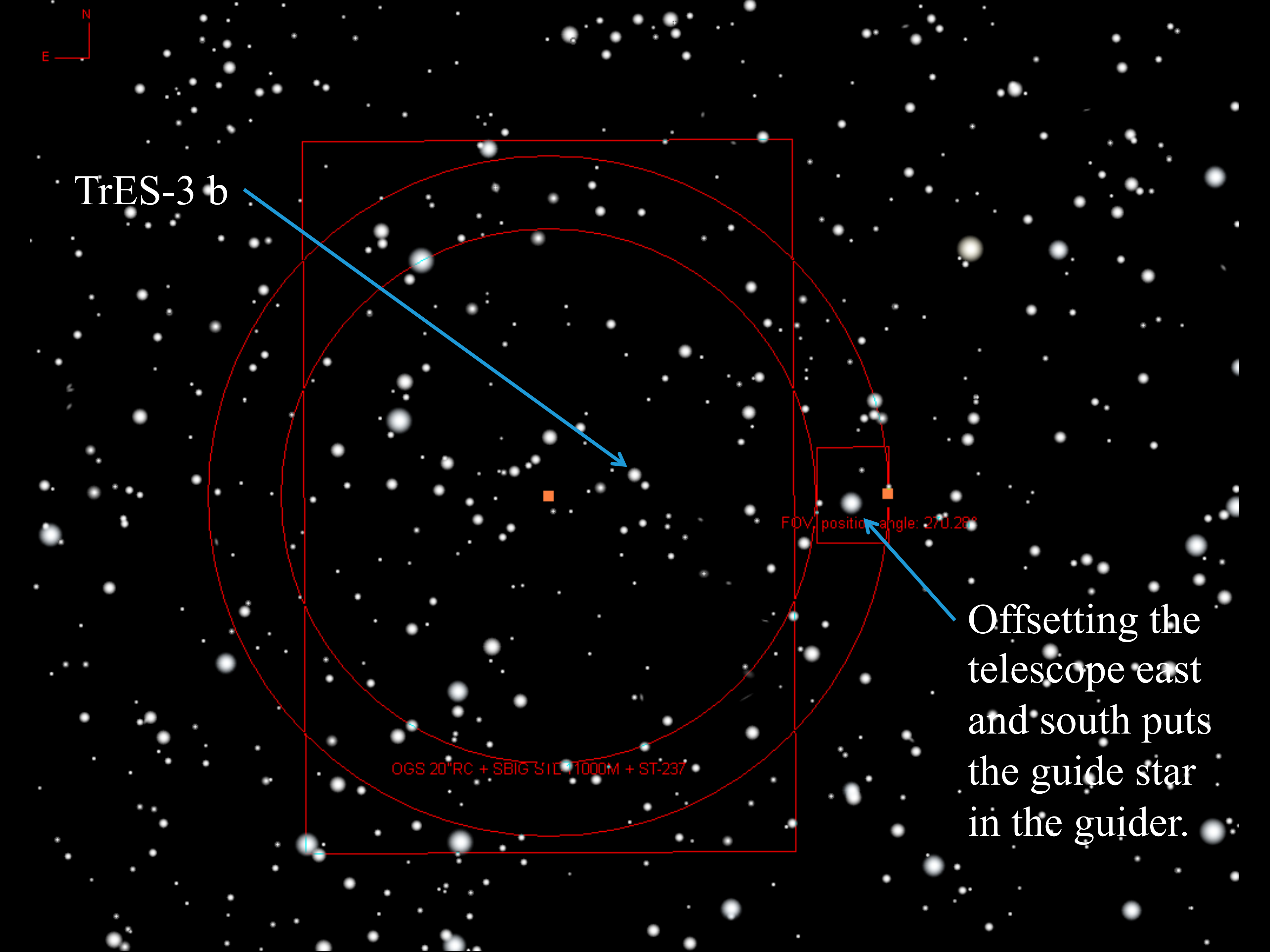


M31
90.00°
N
M32
OGS 20"RC + SBIG STL-11000M + ST-237
(Copy 5 of OGS 20"RC + SBIG ST - 11000M + ST-237)
00h 42m 00s
00h 43m 30s
00h 45m 00s


N
E
Main CCD field of view
CGS 20"RC + SBIG STL-11000M + ST-237
FOV position angle: 270.28°
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°.

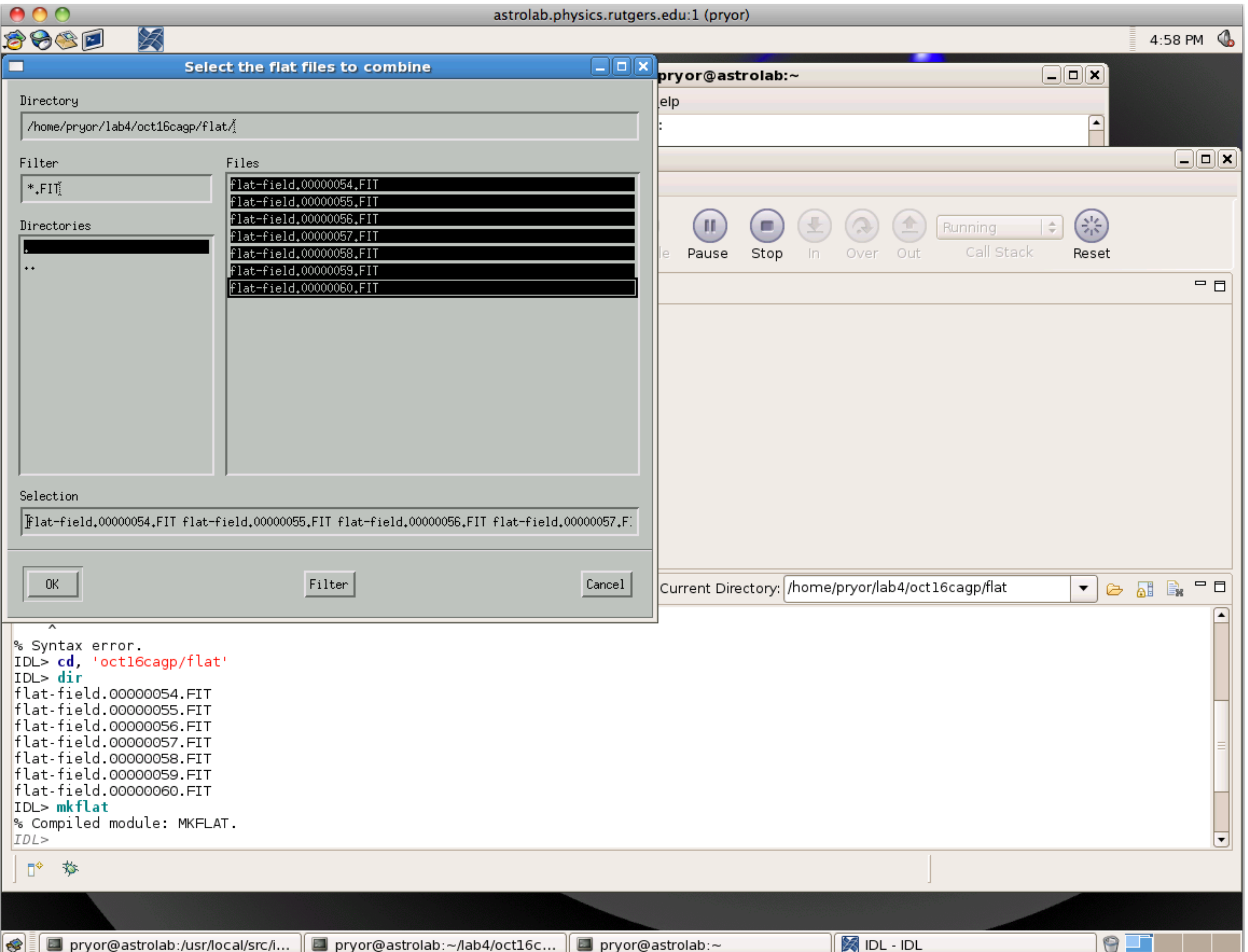

N
E
TrES-3 b
FOV position angle: 270.28°
OGS 20"RC + SBIG STL-11000M + ST-237
A 10th magnitude star that would be a good guide star.


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

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.

Example of running mkflatru

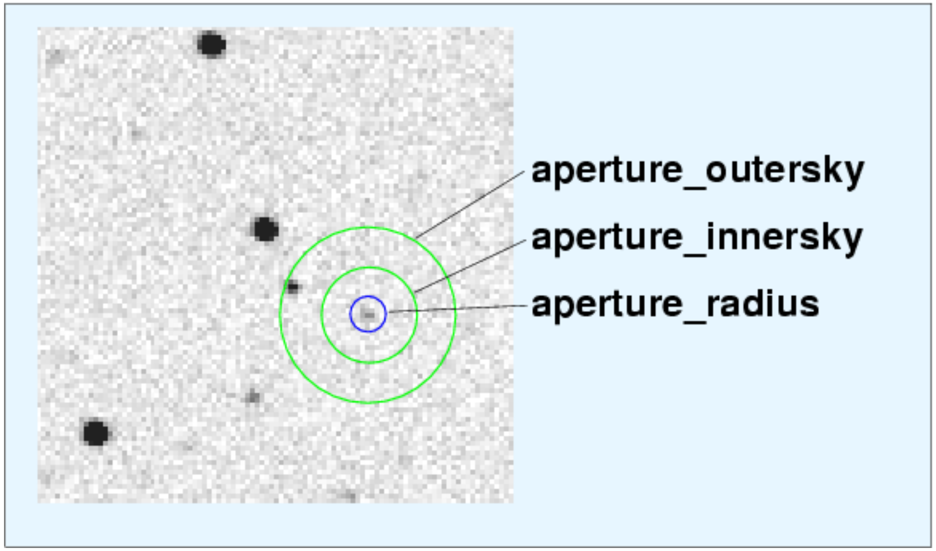


Mkflatru:

1) Finds an average value for every input image.
2) Divides the image by its average.
3) Takes the median of the stack of images.
4) Saves the result in a file.

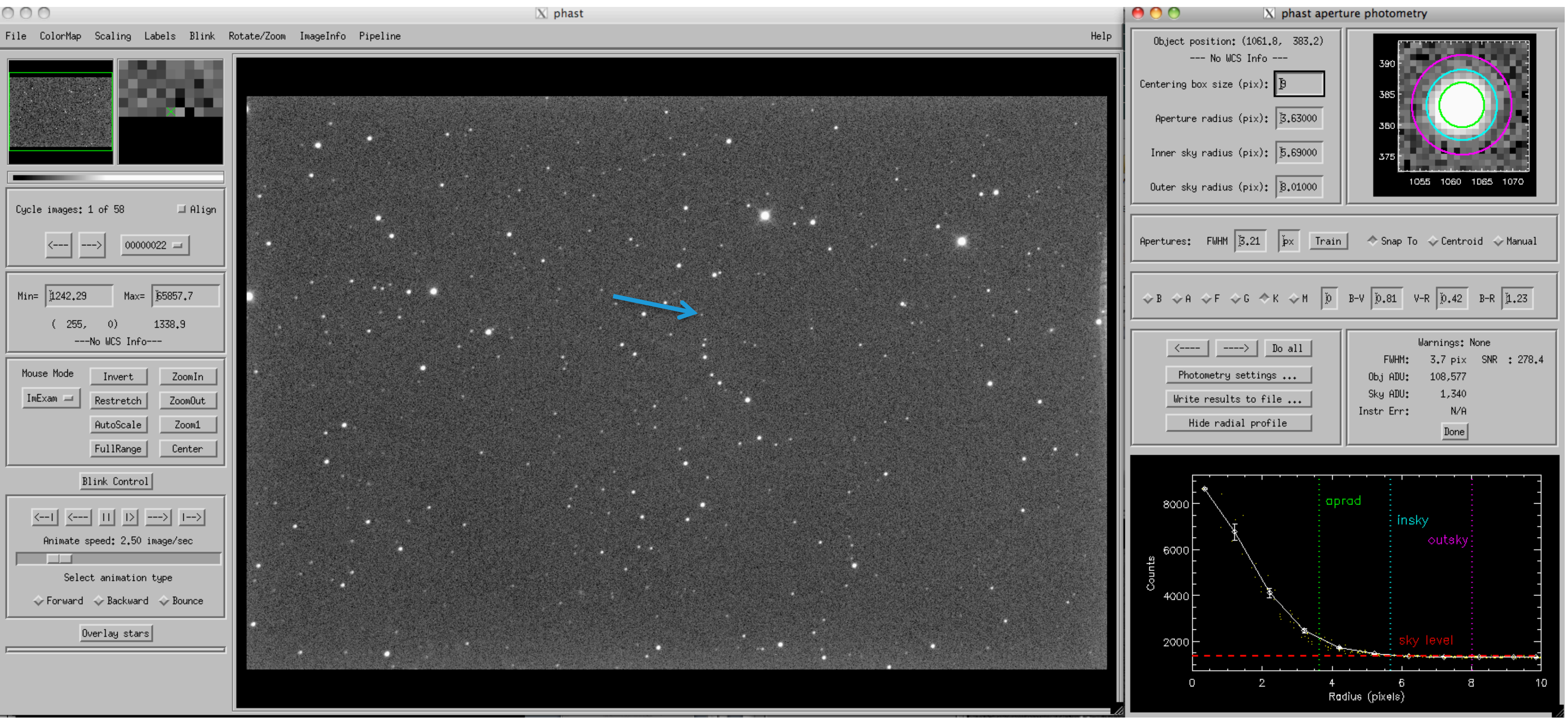
Measuring Stellar Brightness

- 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?

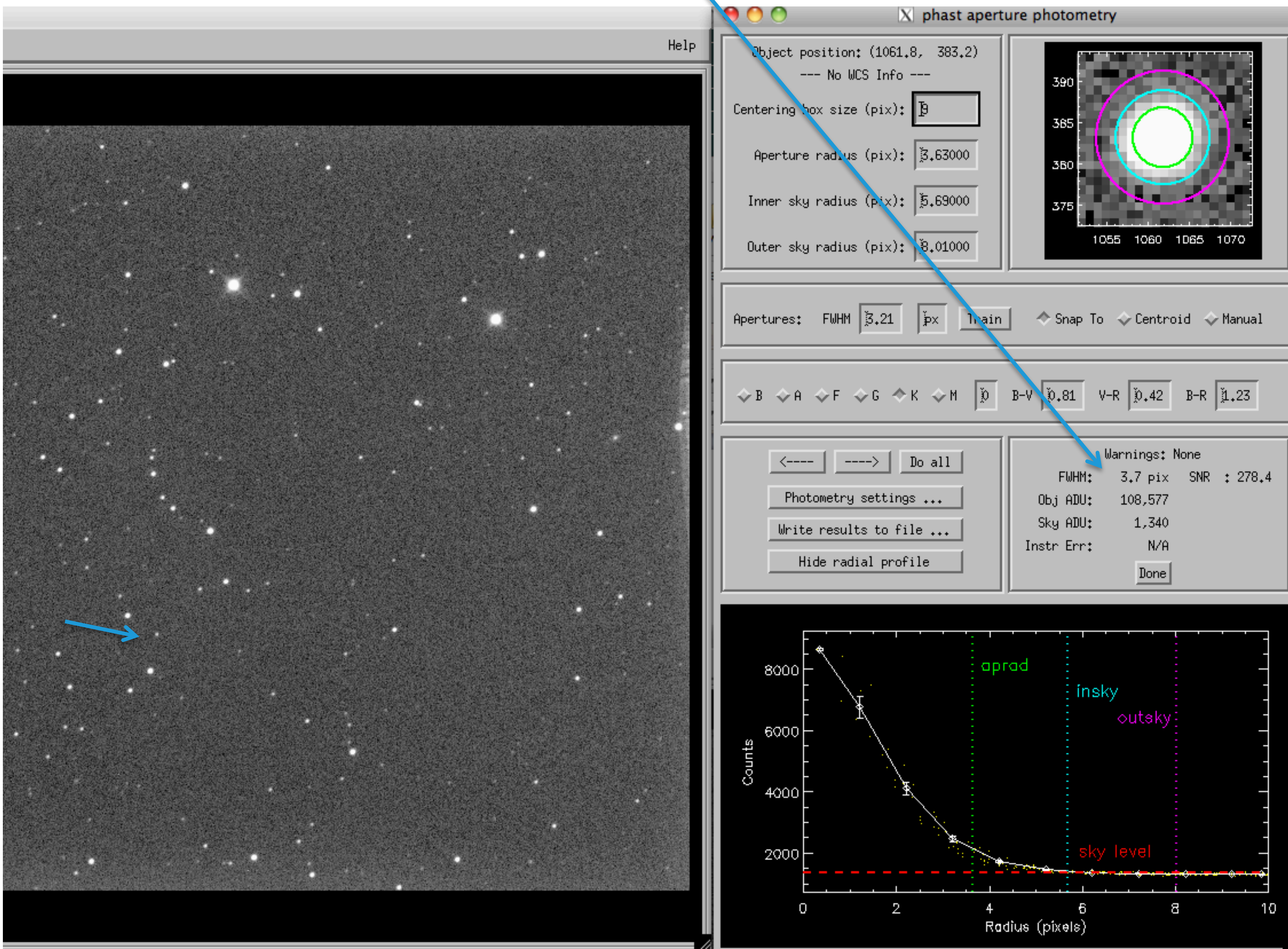


Measuring the brightness of an individual star with RUPhAst using aperture photometry.

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



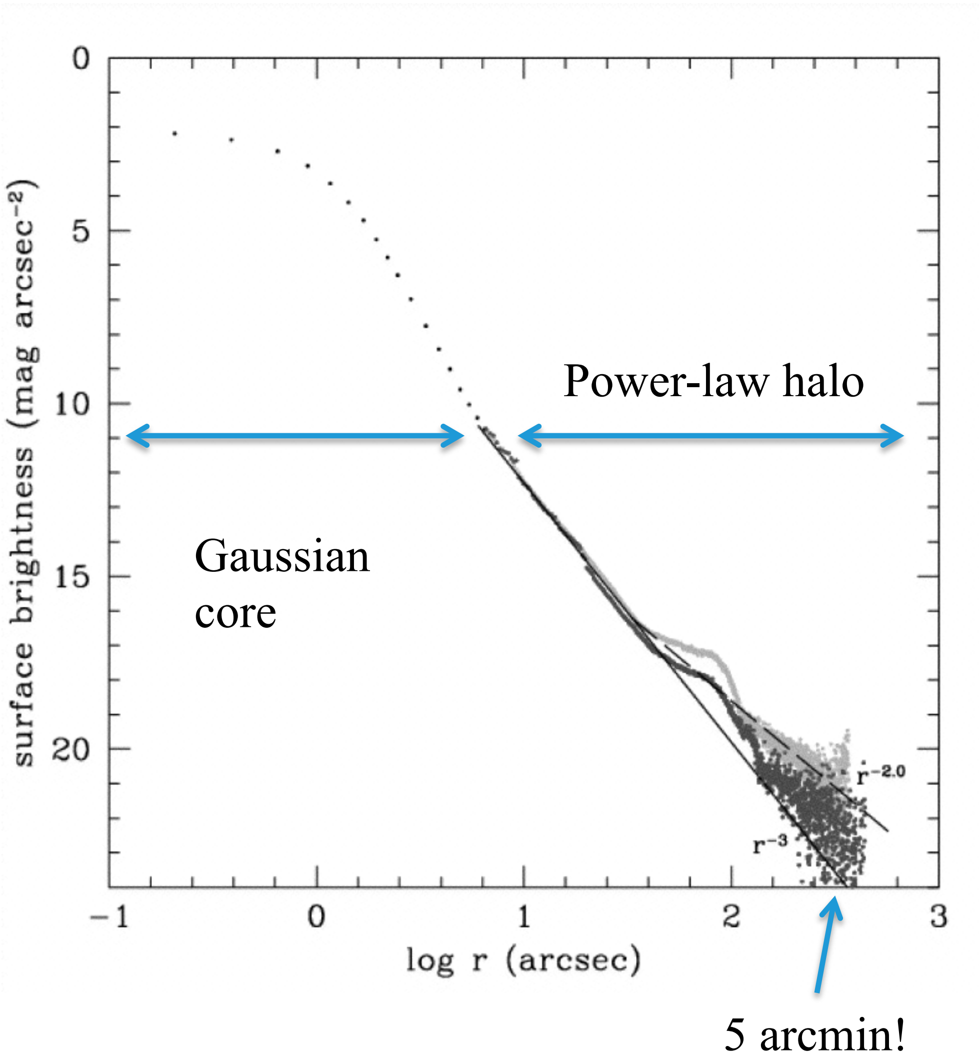
Note the FWHM of the stellar images. Decide on the aperture size.



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.

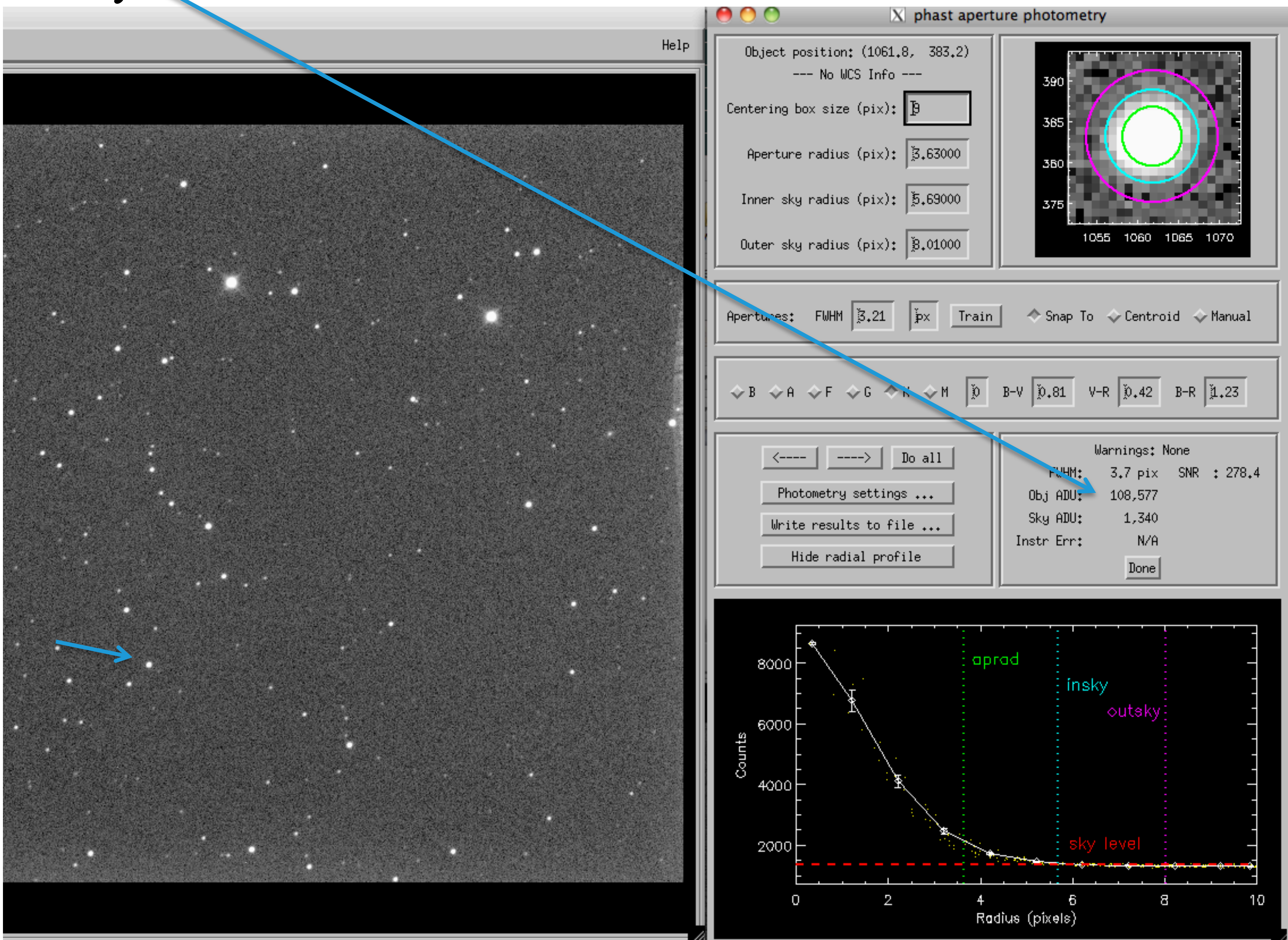
- Shape of a stellar image – the "point spread function" (PSF)



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.

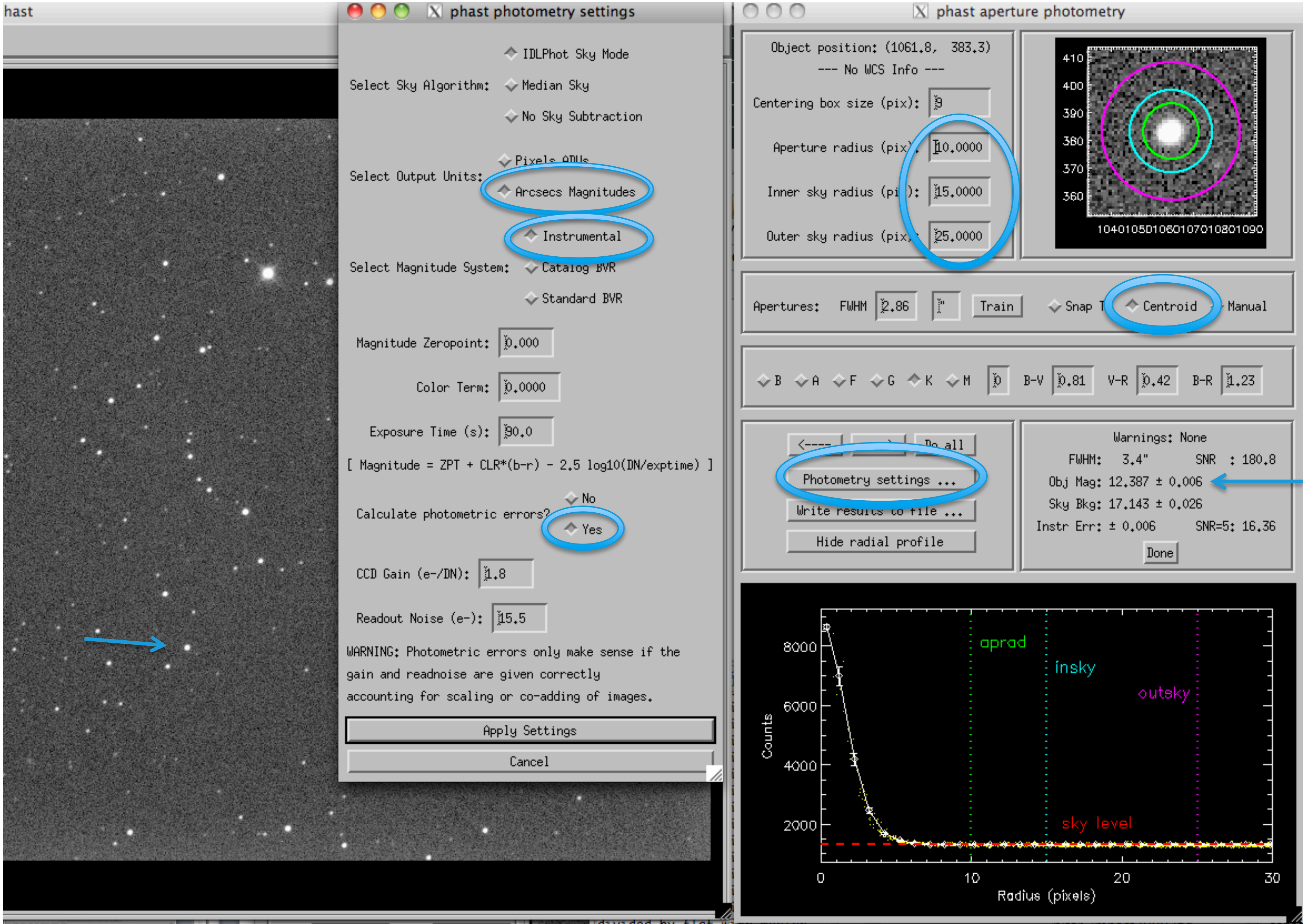
Default PhAst photometry just gives counts in aperture and no uncertainty.



Measuring Stellar Brightness

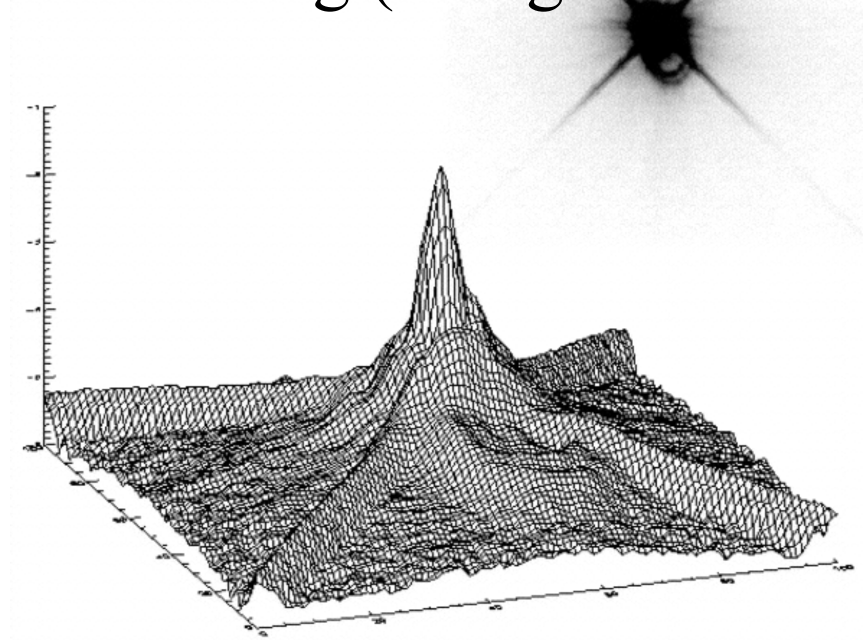
- RUPhAst aperture photometry measures (x,y) position, “object counts” (*c*), “sky level” (*s* in counts/pixel), and exposure time (*t* in seconds, from the image header).
  - Can only measure *non-saturated* stars.
- Calculates instrumental magnitudes using
  - $m_{inst} = 20.3 - 2.5 \log_{10}(c/t)$
  - $\sigma_m = 1.086\ (\sigma_c/c) = 1.086((c\ g + N_p s\ g + N_p\ r^2)^{1/2}/(g\ c))$
    - g = gain = 0.80 electrons/ADU
    - r = read noise = 15.5 electrons/pixel

Change the photometry settings and the apertures.



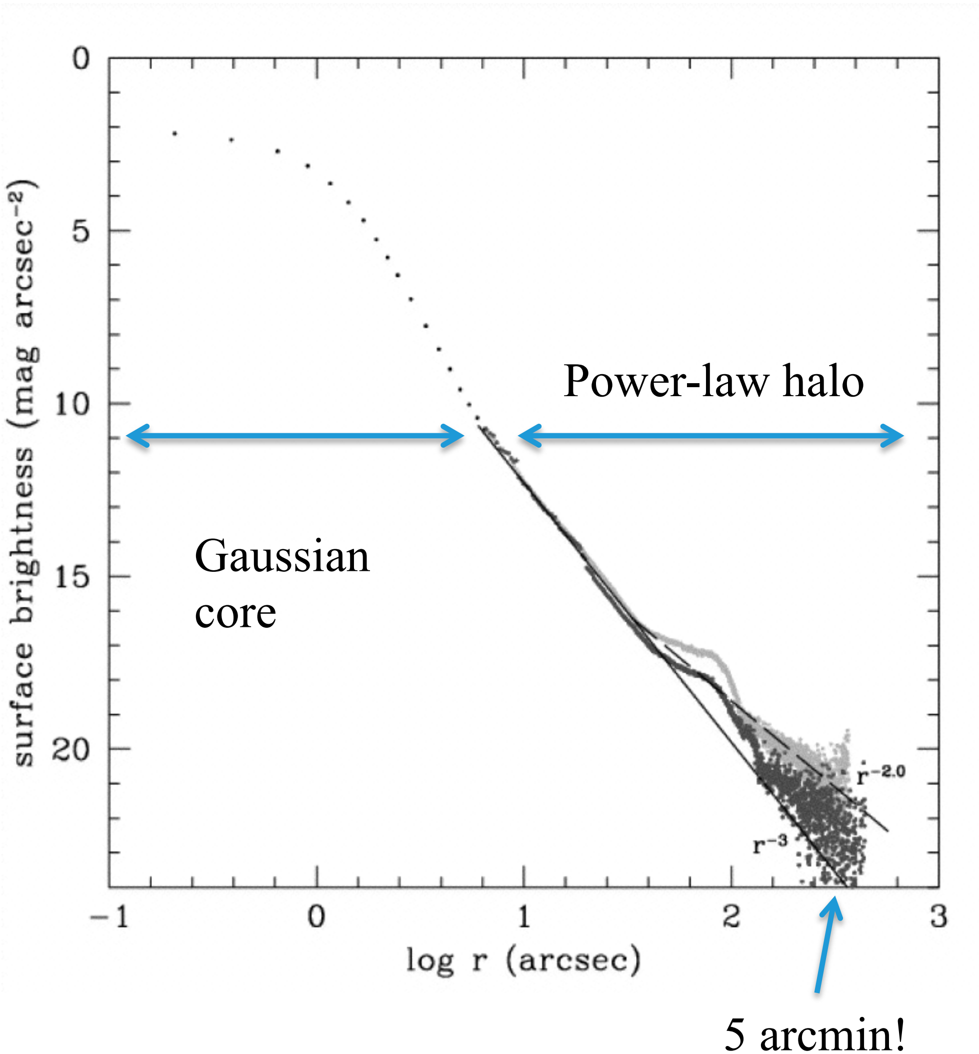
Measuring Stellar Brightness

- 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)

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



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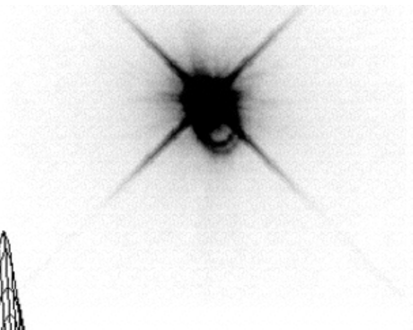
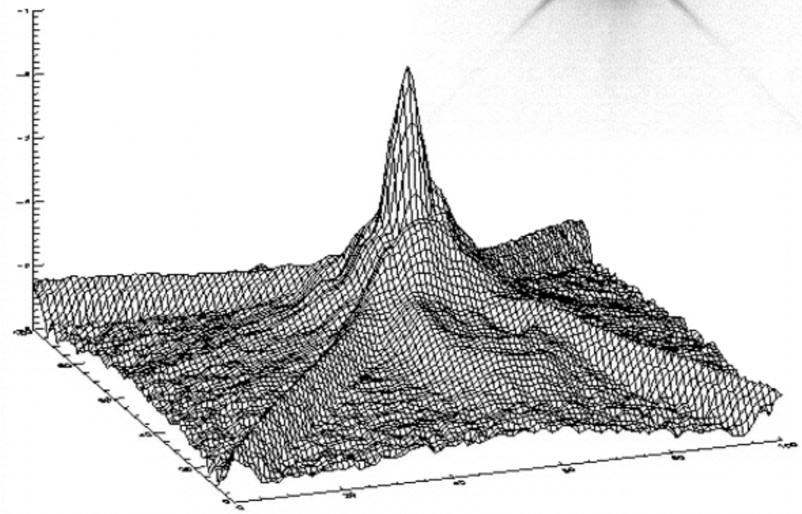
Measuring Stellar Brightness

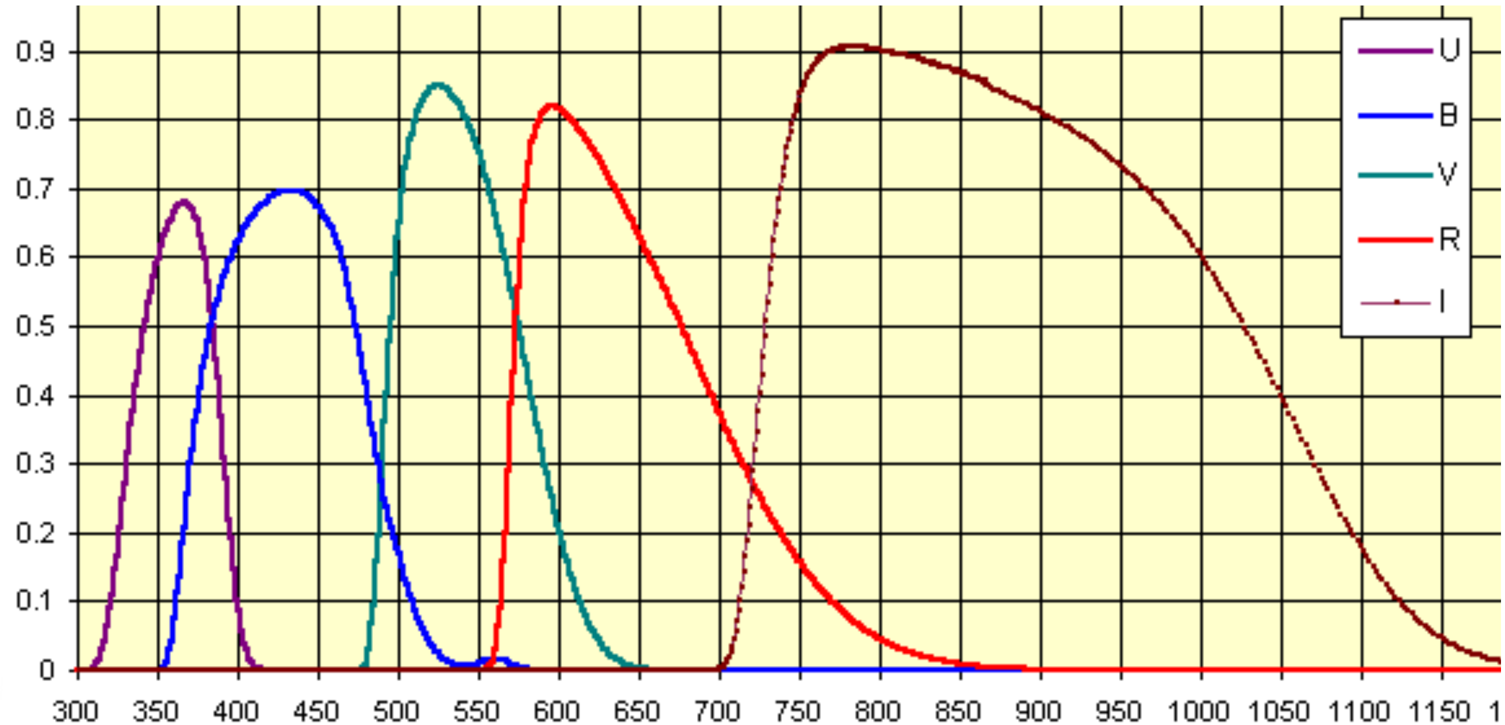
- PSF-fitting method:
  - Fit a functional form for the PSF plus a constant sky to the pixel values. Volume under the function is a measure of the stellar brightness.
  - Bright pixels in the core have the highest weight in the fit ➔ better S/N.
  - Can measure overlapping stars by simultaneously fitting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

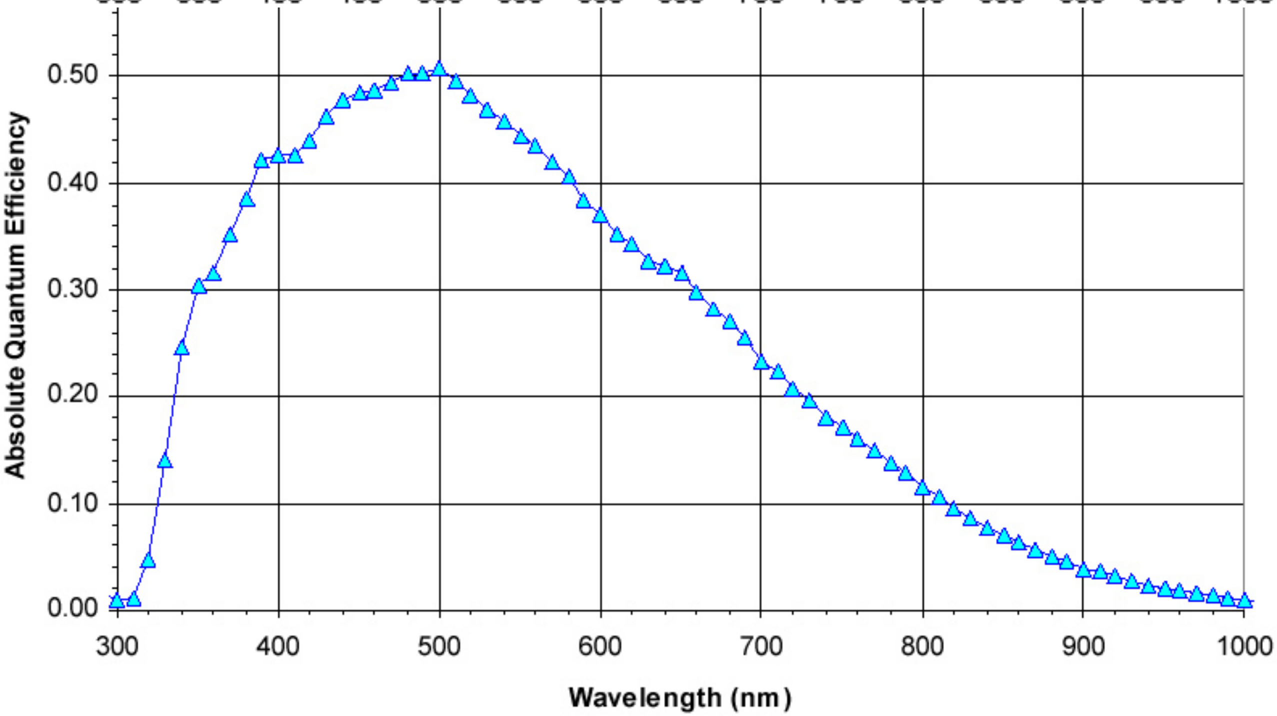




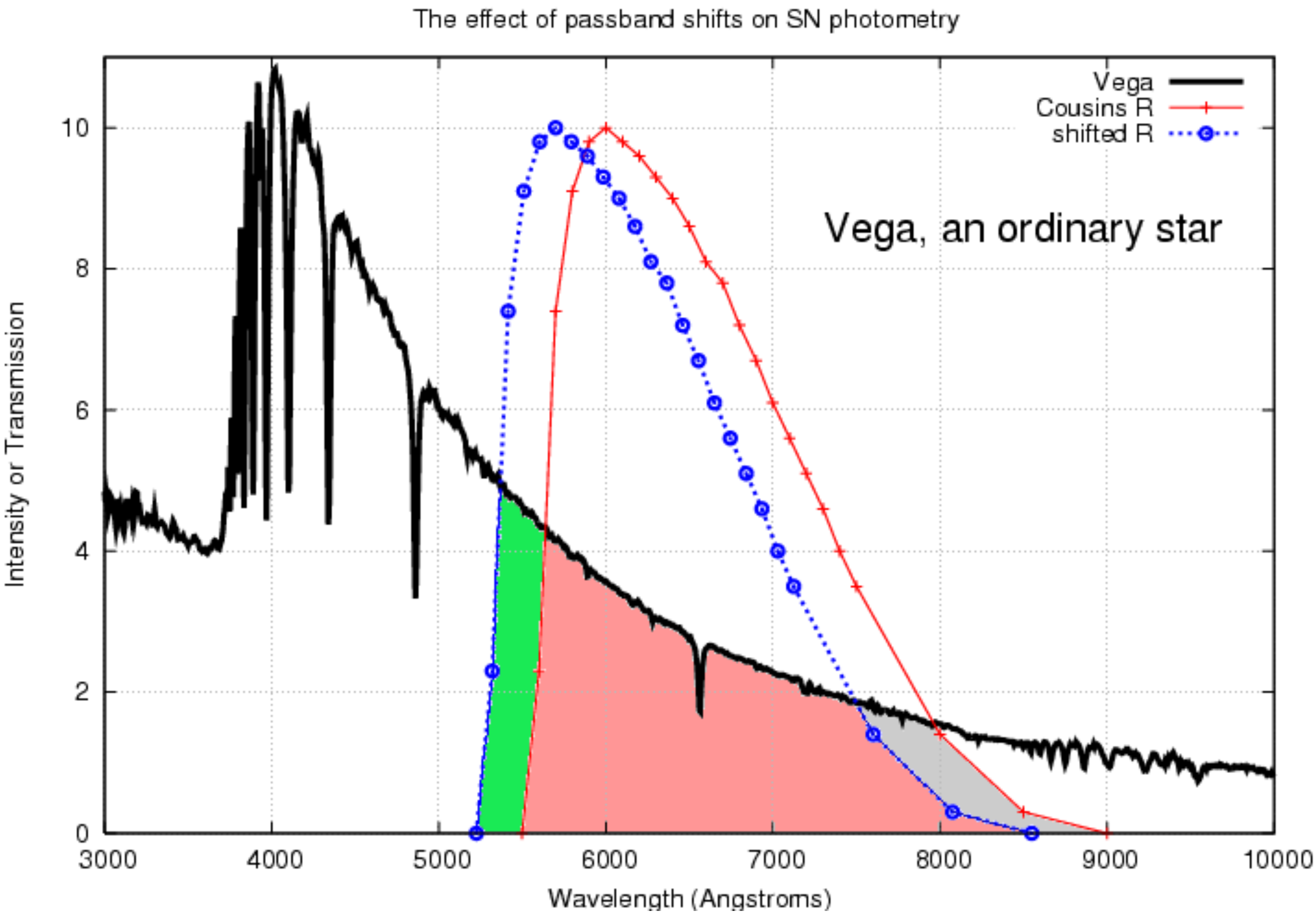
Transformation to Standard Magnitudes

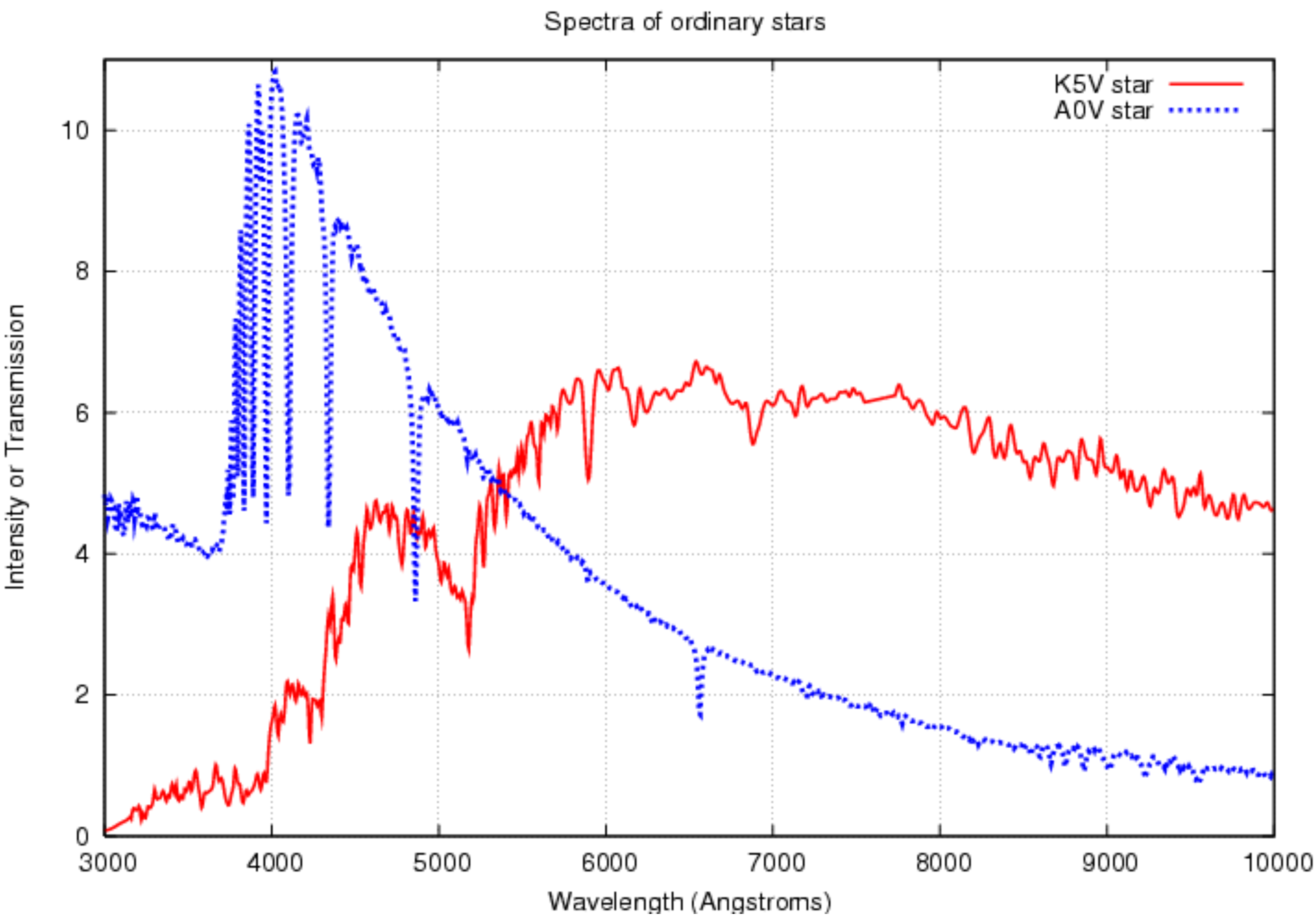
- The simplest transformation would be a simple additive correction, like that for atmospheric extinction, to account for the efficiency of the telescope and detector.
- However, the passbands defined by our filters and the spectral response of the CCD do not exactly match that of the standard system (which was defined by a 1P21 photomultiplier tube that is no longer made).
  - As the following figures illustrate, the shift in the passband causes the correction to depend on the temperature of the star.





The quantum efficiency of the CCD is varying significantly across the V and B bands.


The effect of passband shifts on SN photometry
Vega
Cousins R
shifted R
Vega, an ordinary star
Intensity or Transmission
Wavelength (Angstroms)
0
2
4
6
8
10
3000
4000
5000
6000
7000
8000
9000
10000



The effect of a shifted passband will be different for hot and cool stars.

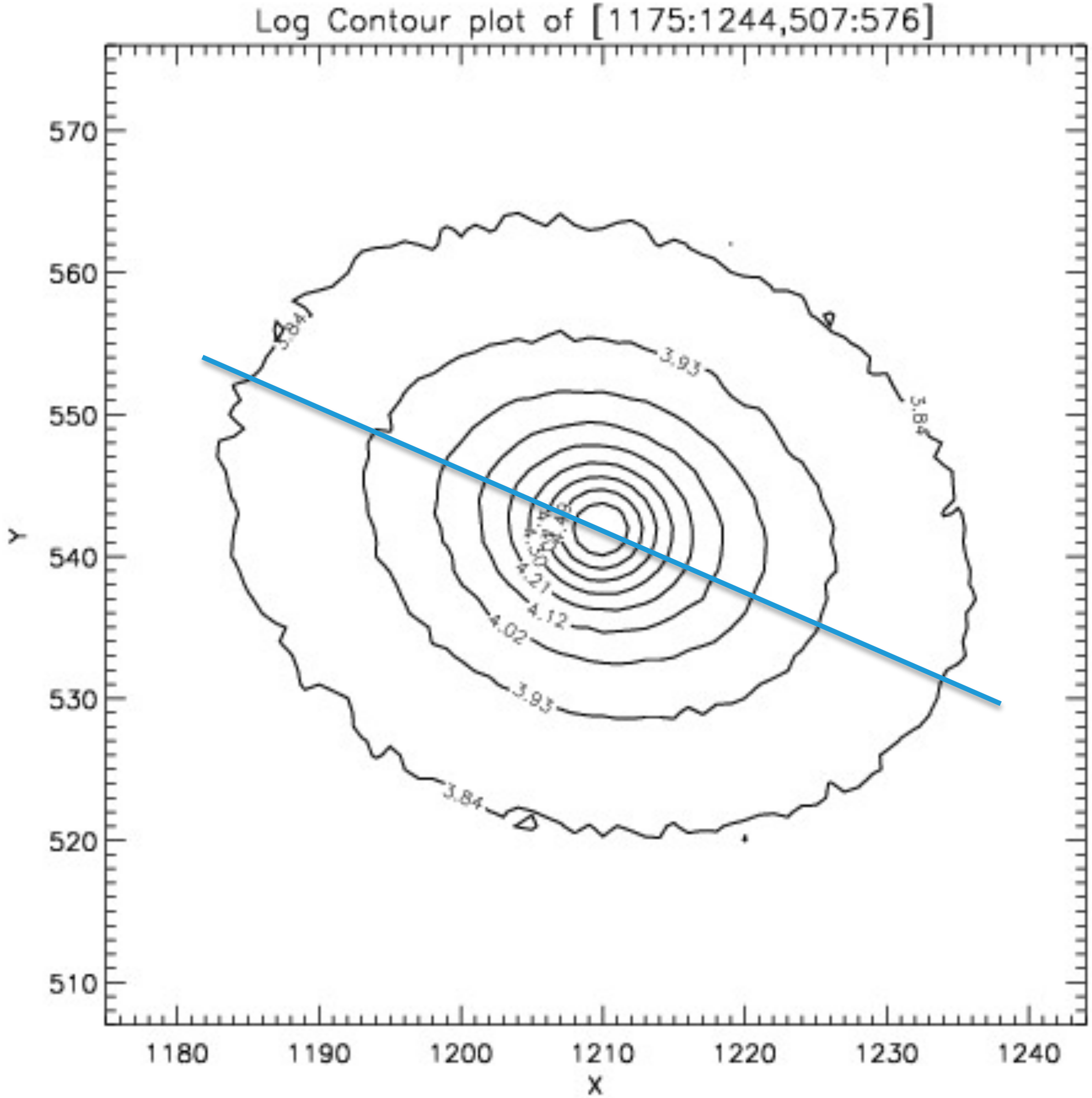
Lab 4: Galaxy Surface Photometry

- Galaxies are not resolved into stars (certainly not in our telescope!)
  - So measure amount of light per area (mag/sq arcmin)
- Measure projected shape of light distribution.
  - Shape is elliptical to first order.
    - "Disky" and "boxy" departures from ellipses are seen.
  - Ellipticity and position angle of major axis can vary with radius.
    - Ellipticity: $\varepsilon = 1 - b/a$; b=minor axis, a=major axis
    - Position angle: angle from North to major axis (measured positive through east).


Linear Scaling

M32 V

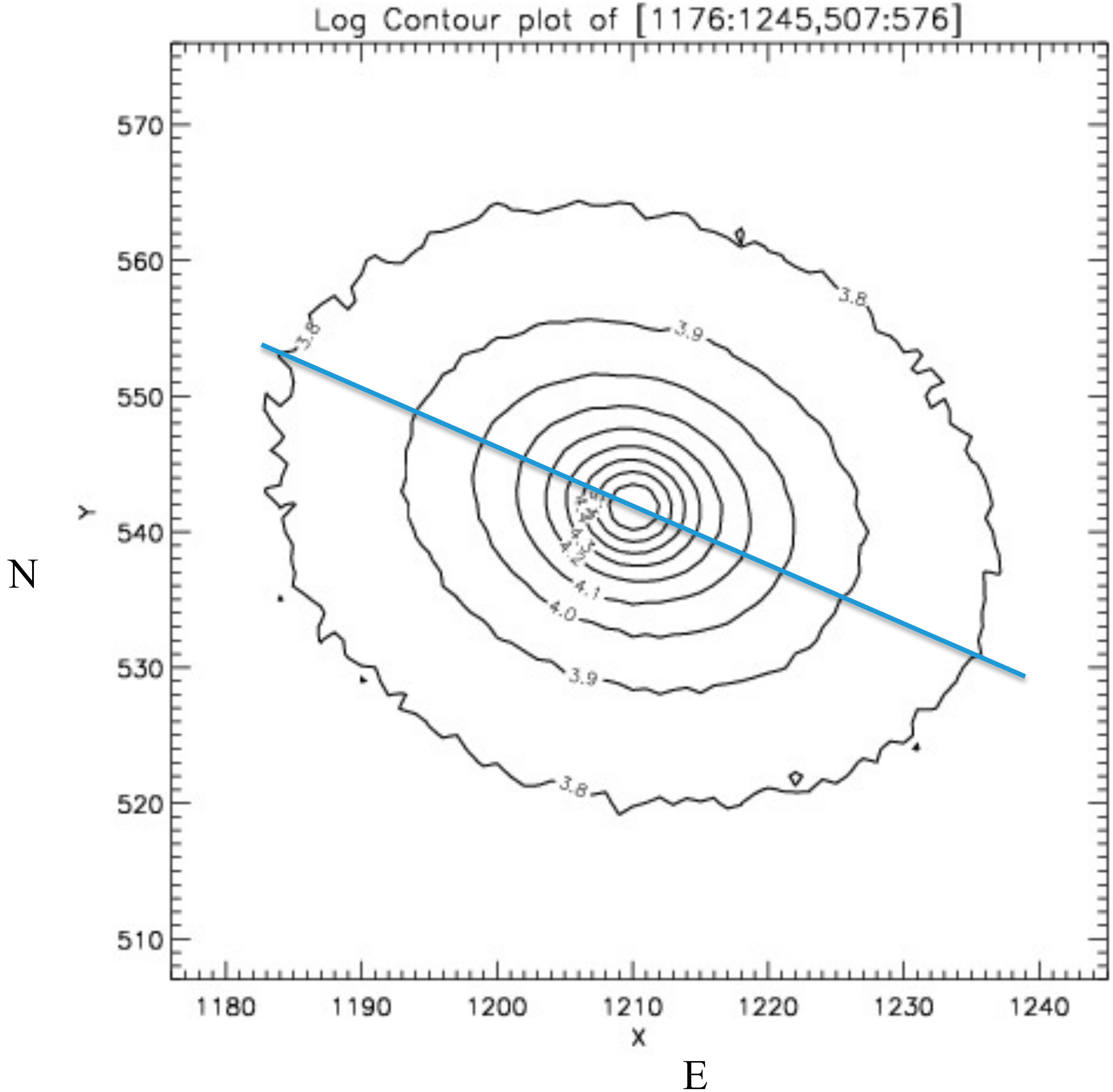
N



E

Logarithmically spaced contours (select log scaling in RUPhAst)

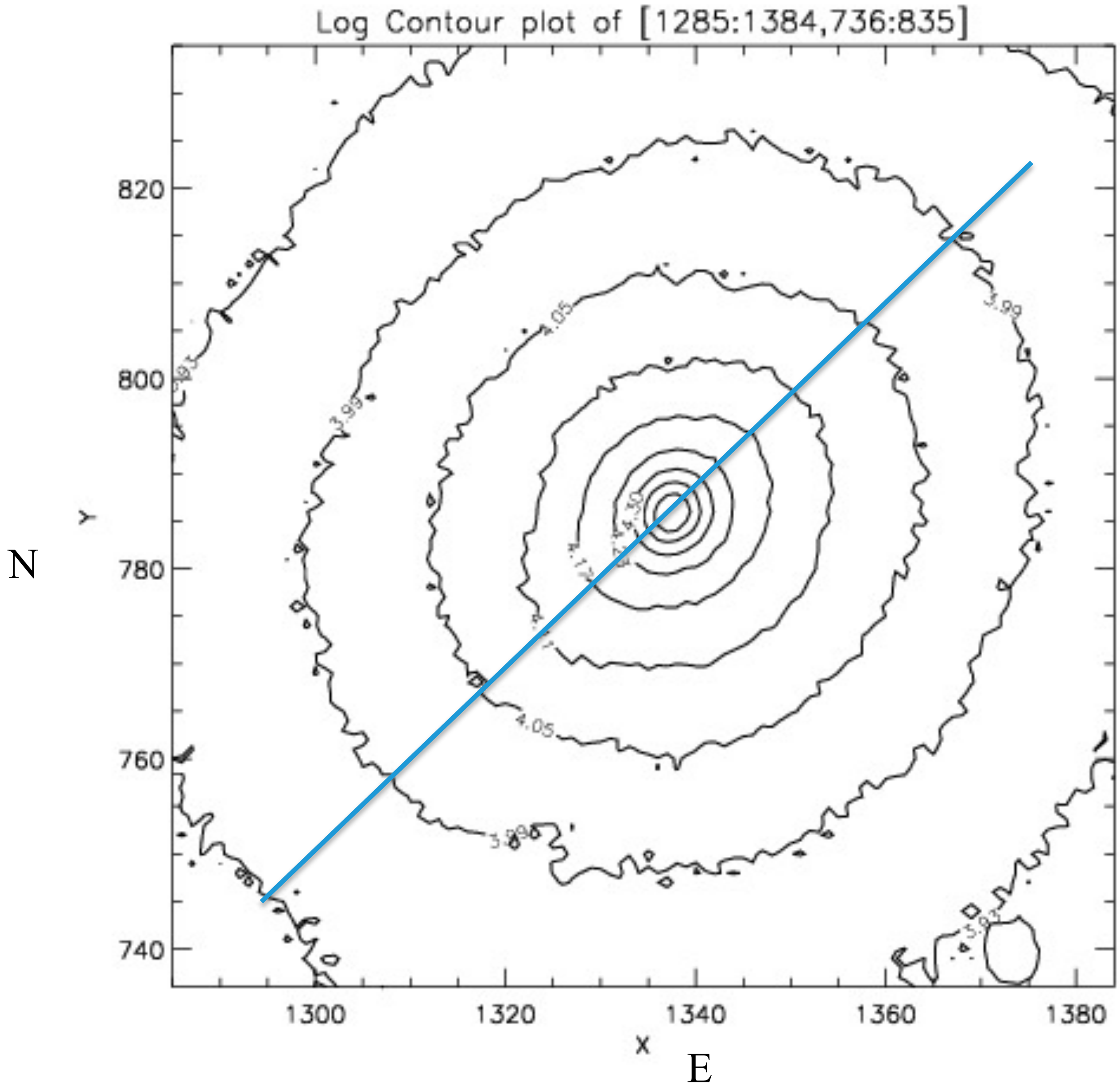
M32 R



Logarithmically spaced contours (select log scaling in RUPhAst)

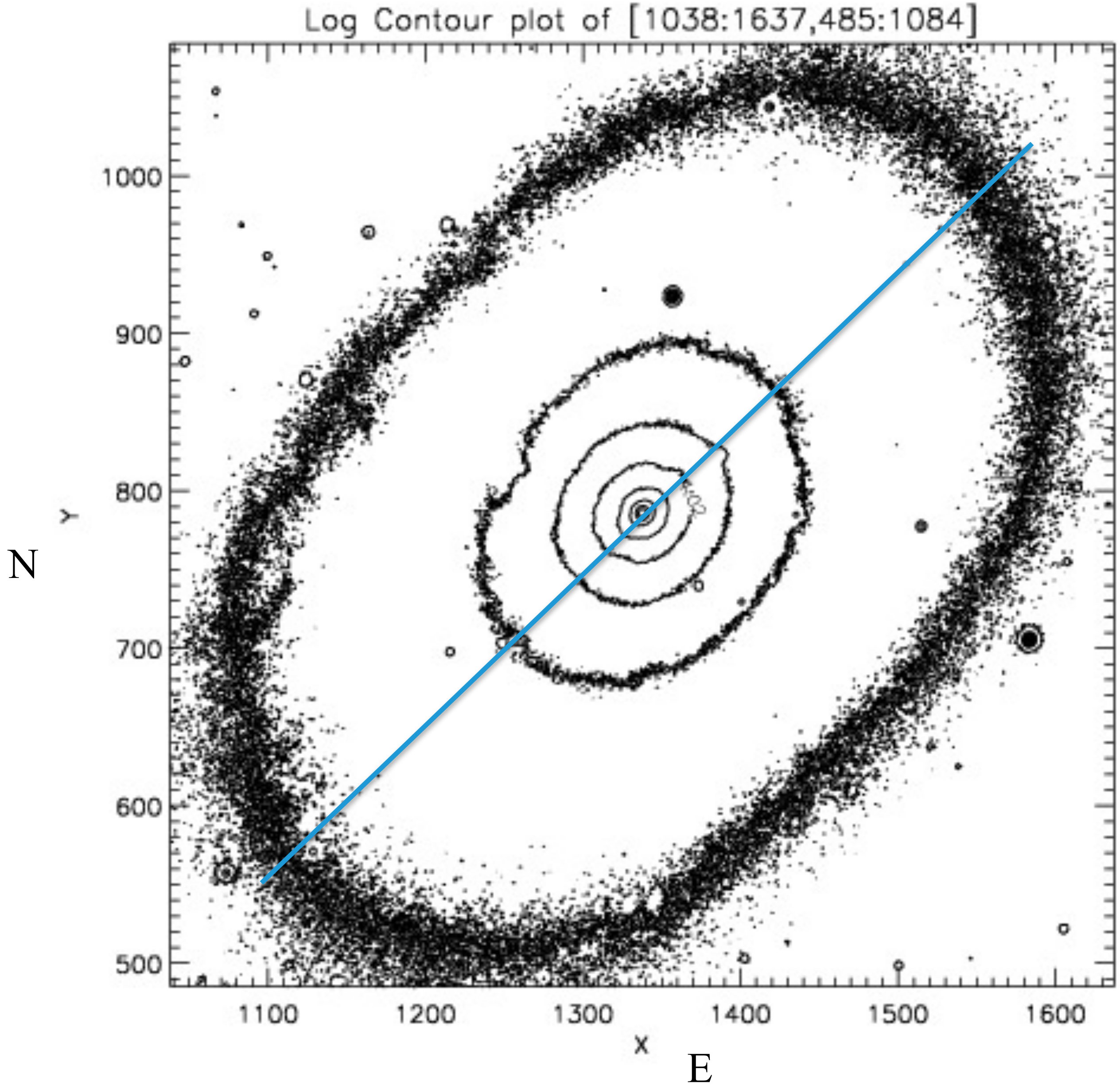
Log Scaling

M31 V



Logarithmically spaced contours (select log scaling in RUPhAst)

M31 V



Logarithmically spaced contours (select log scaling in RUPhAst)

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- Measure projected shape of light distribution.
  - Shape is elliptical to first order.
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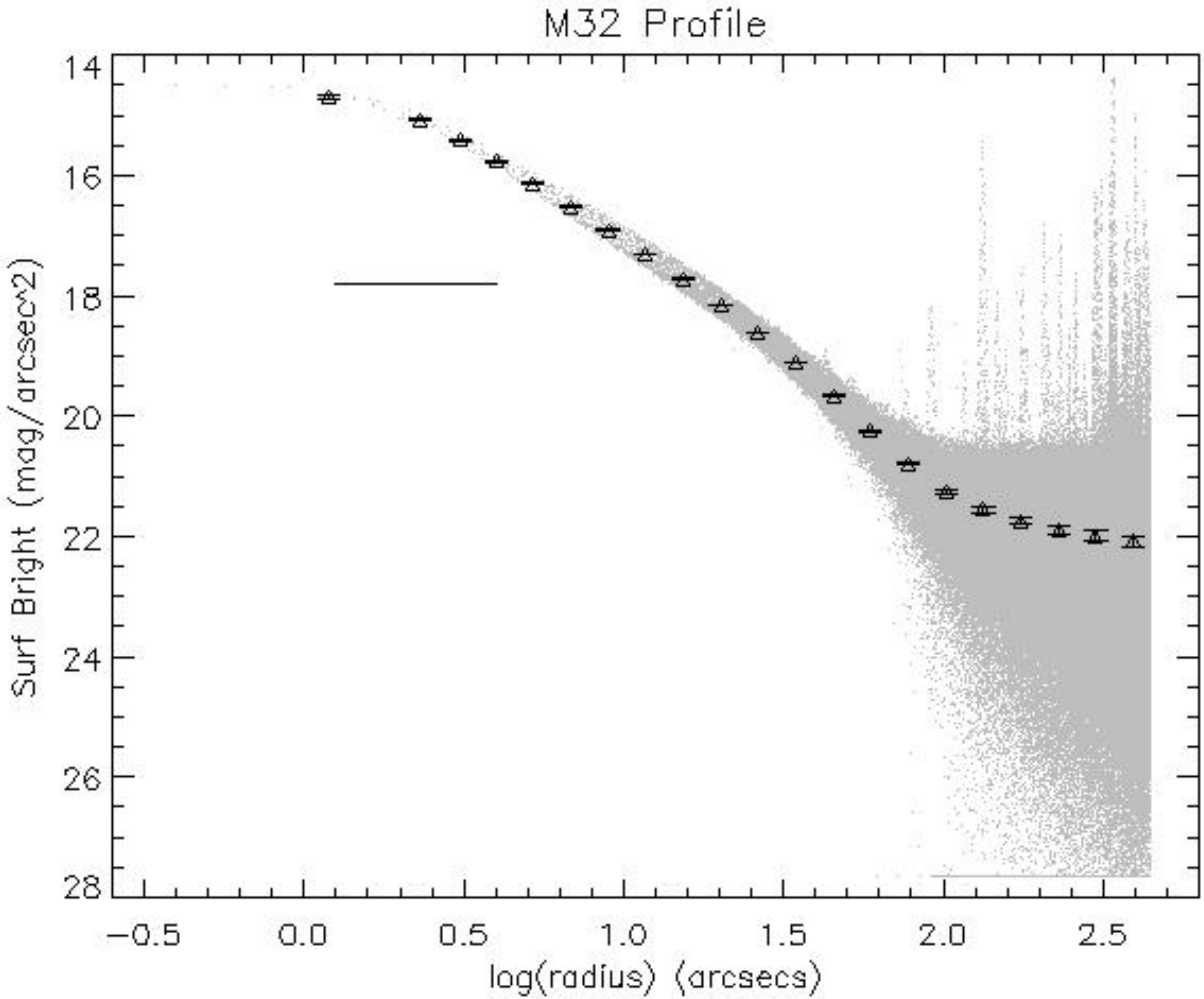
  - Ellipticity and position angle of major axis can vary with radius.
    - Ellipticity: $\varepsilon = 1 - b/a$; b=minor axis, a=major axis
    - Position angle: angle from North to major axis (measured positive through east).

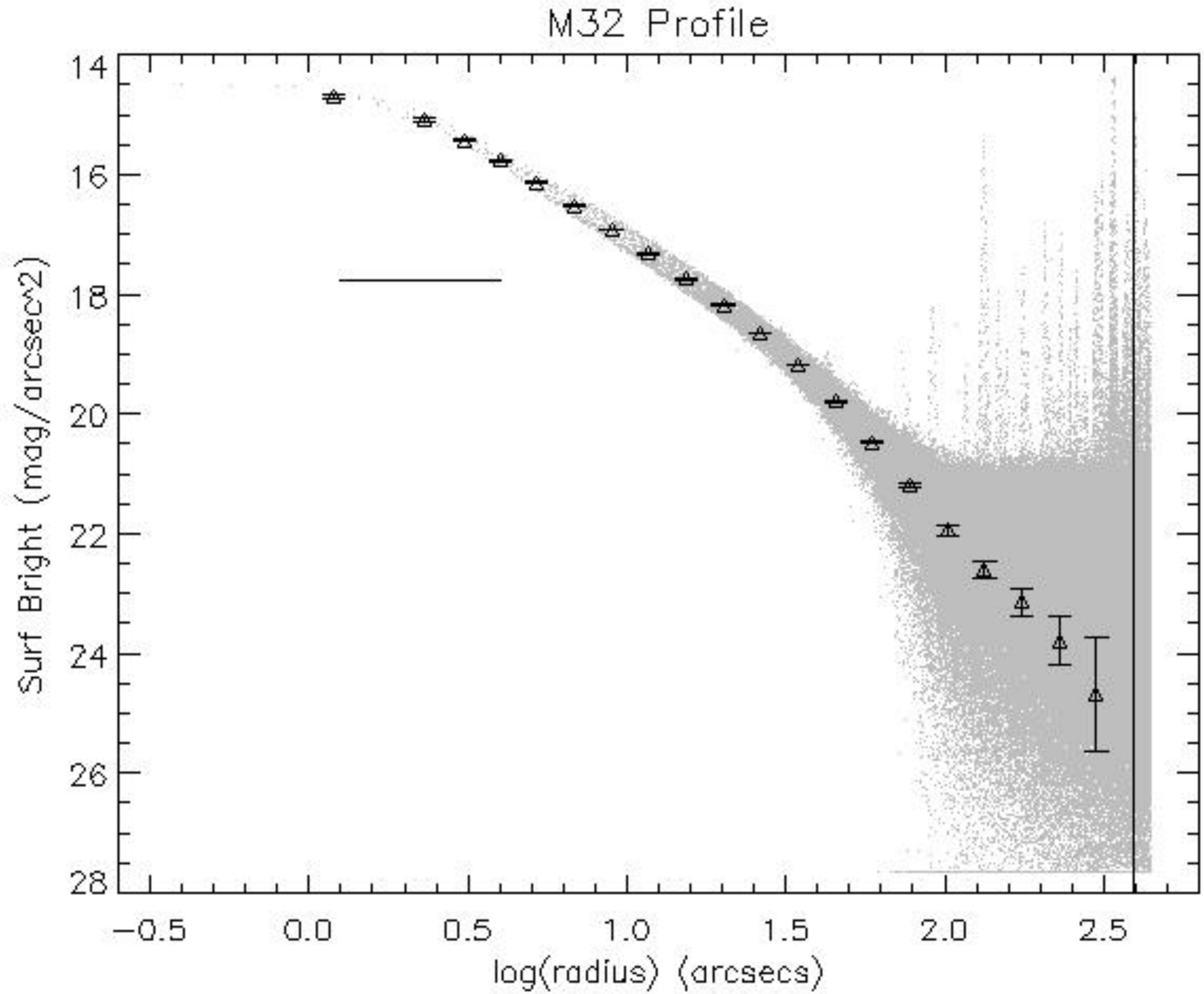
Lab 4: Galaxy Surface Photometry

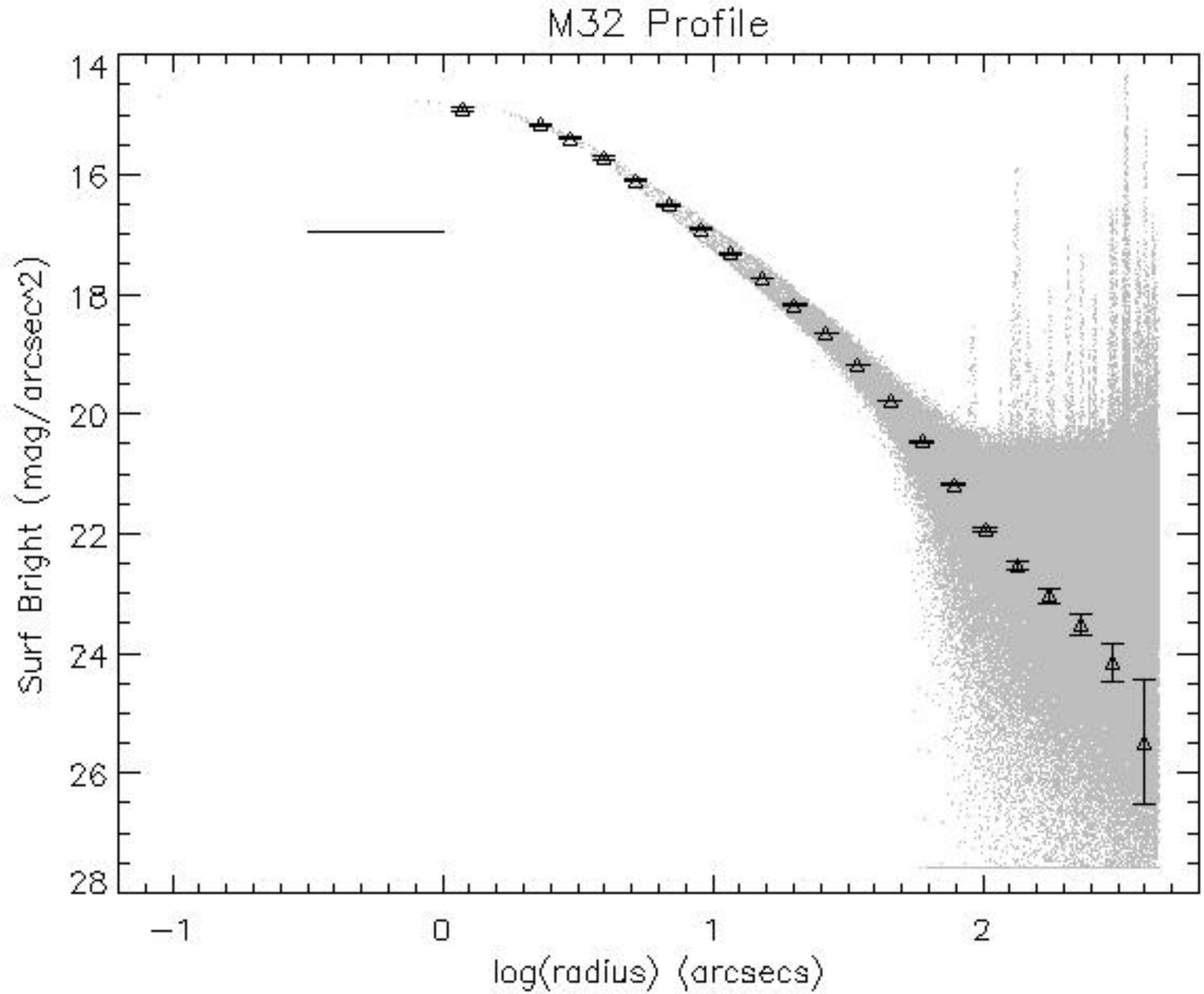
- Galaxies are not resolved into stars (certainly not in our telescope!)
  - So measure amount of light per area (mag/sq arcmin)
- Measure radial profile of light distribution.
  - Ideally on ellipsoidal contours
    - Galsbmag_ru uses circular apertures.
  - Choosing a local "sky" level is critical since galaxy profiles quickly become fainter than it.
    - galsbmag_ru, img, xcen, ycen, rmax, sky, skyunc, img_scale, m_1,title

Log Scaling

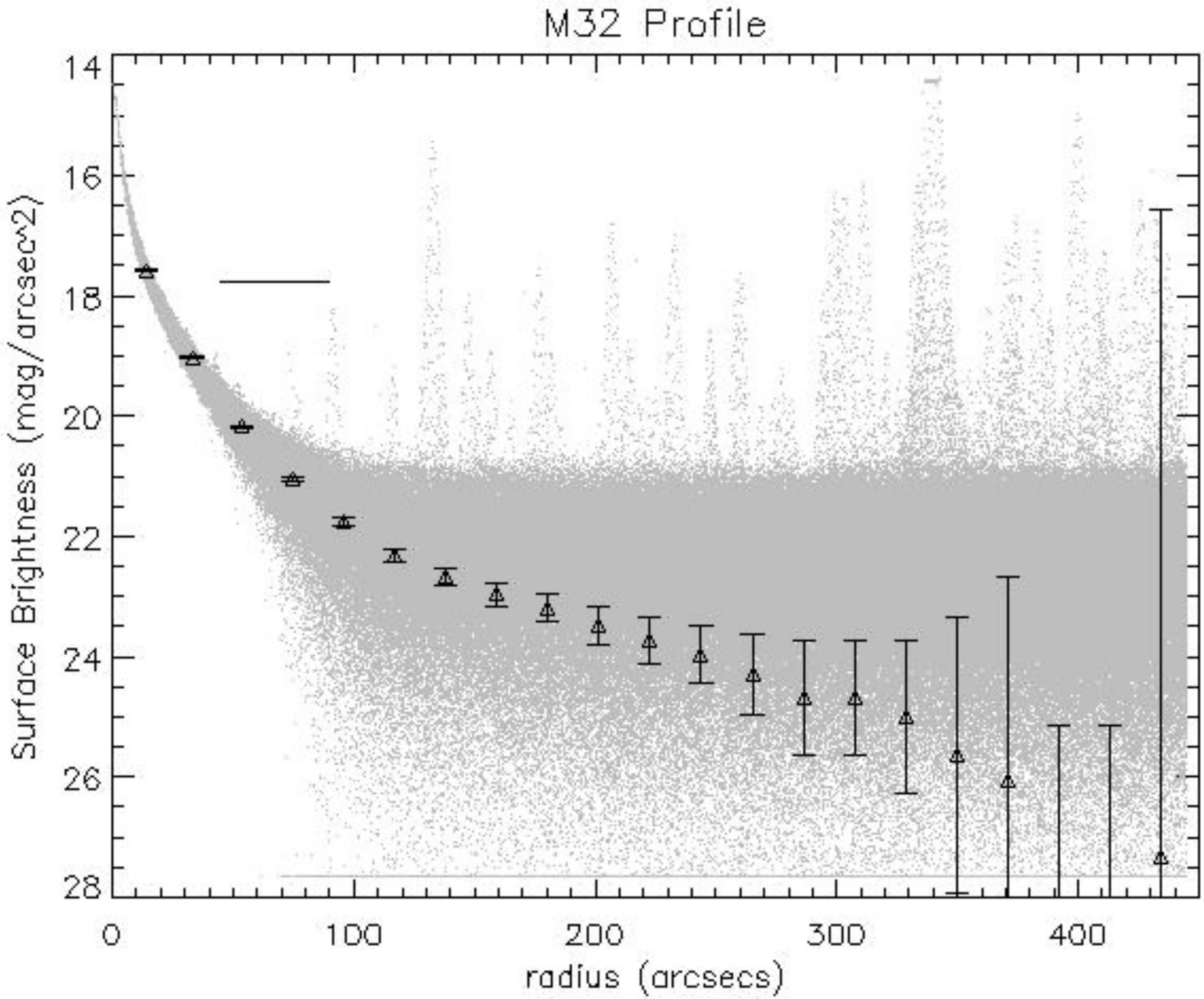


M32 Profile
Surf Bright (mag/arcsec^2)
log(radius) (arcsecs)
14
16
18
20
22
24
26
28
−0.5
0.0
0.5
1.0
1.5
2.0
2.5

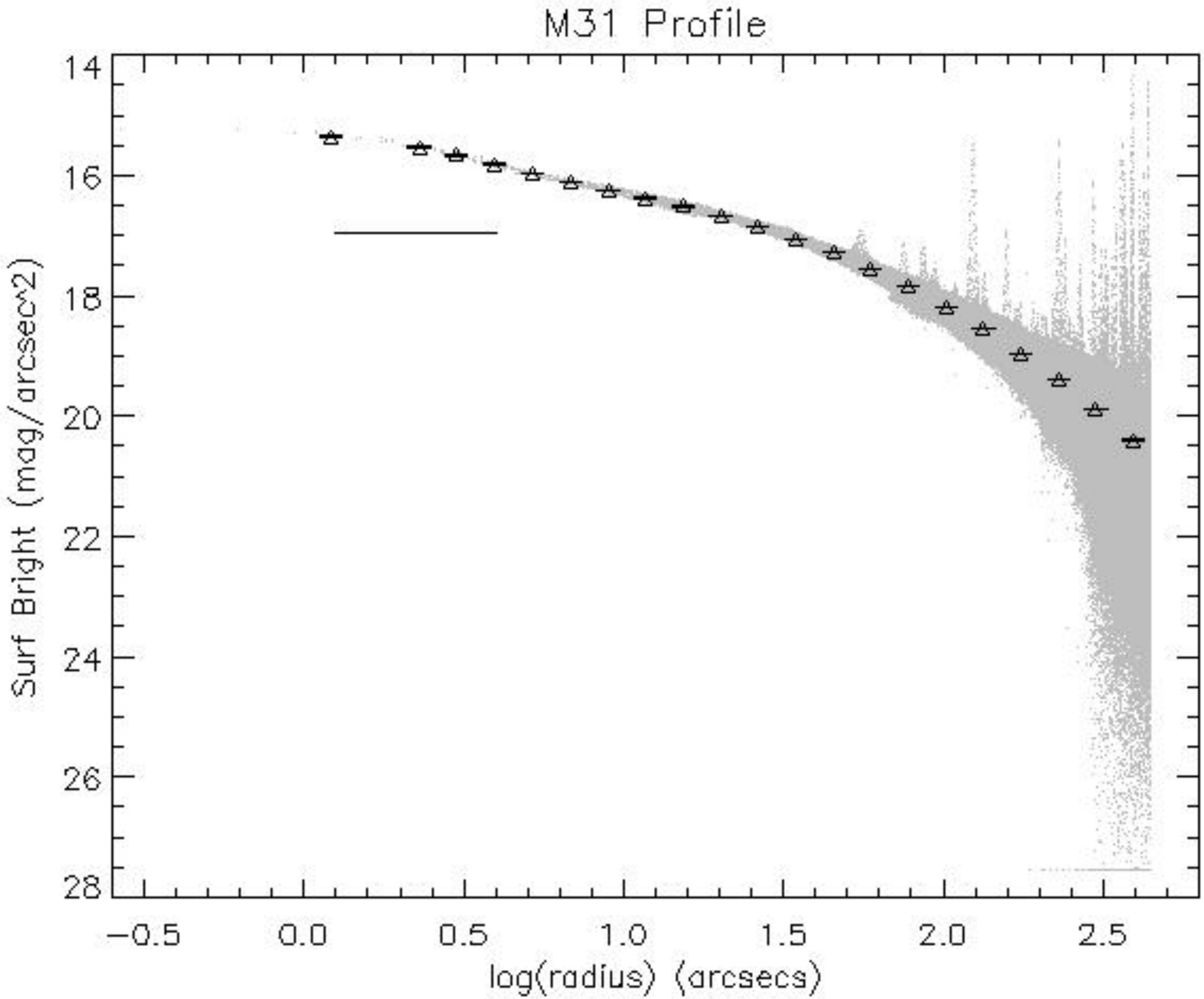

M32 Profile
Surf Bright (mag/arcsec^2)
log(radius) (arcsecs)
14
16
18
20
22
24
26
28
−0.5
0.0
0.5
1.0
1.5
2.0
2.5



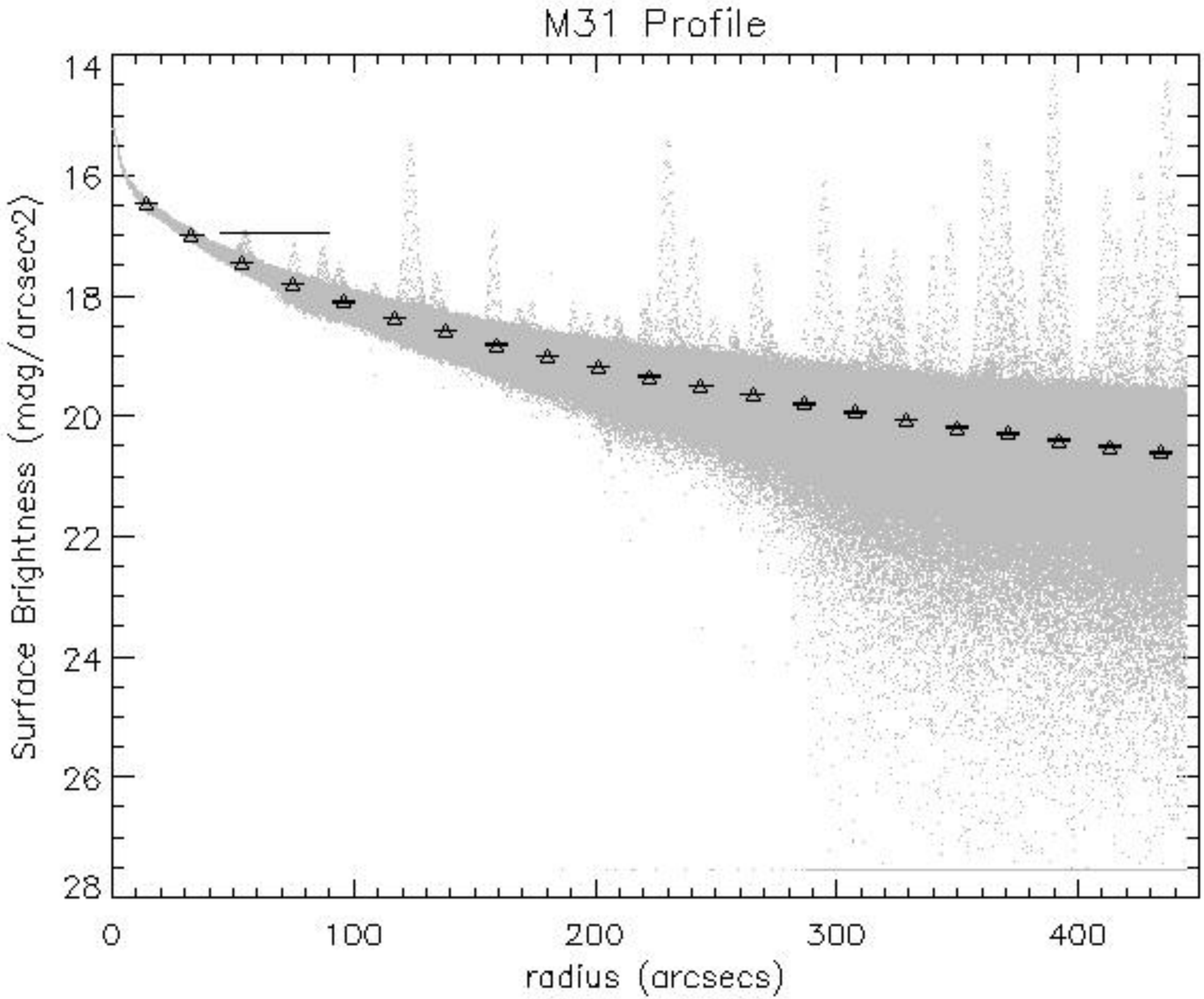
M32 Profile
Surf Bright (mag/arcsec^2)
log(radius) (arcsecs)
14
16
18
20
22
24
26
28
−1
0
1
2

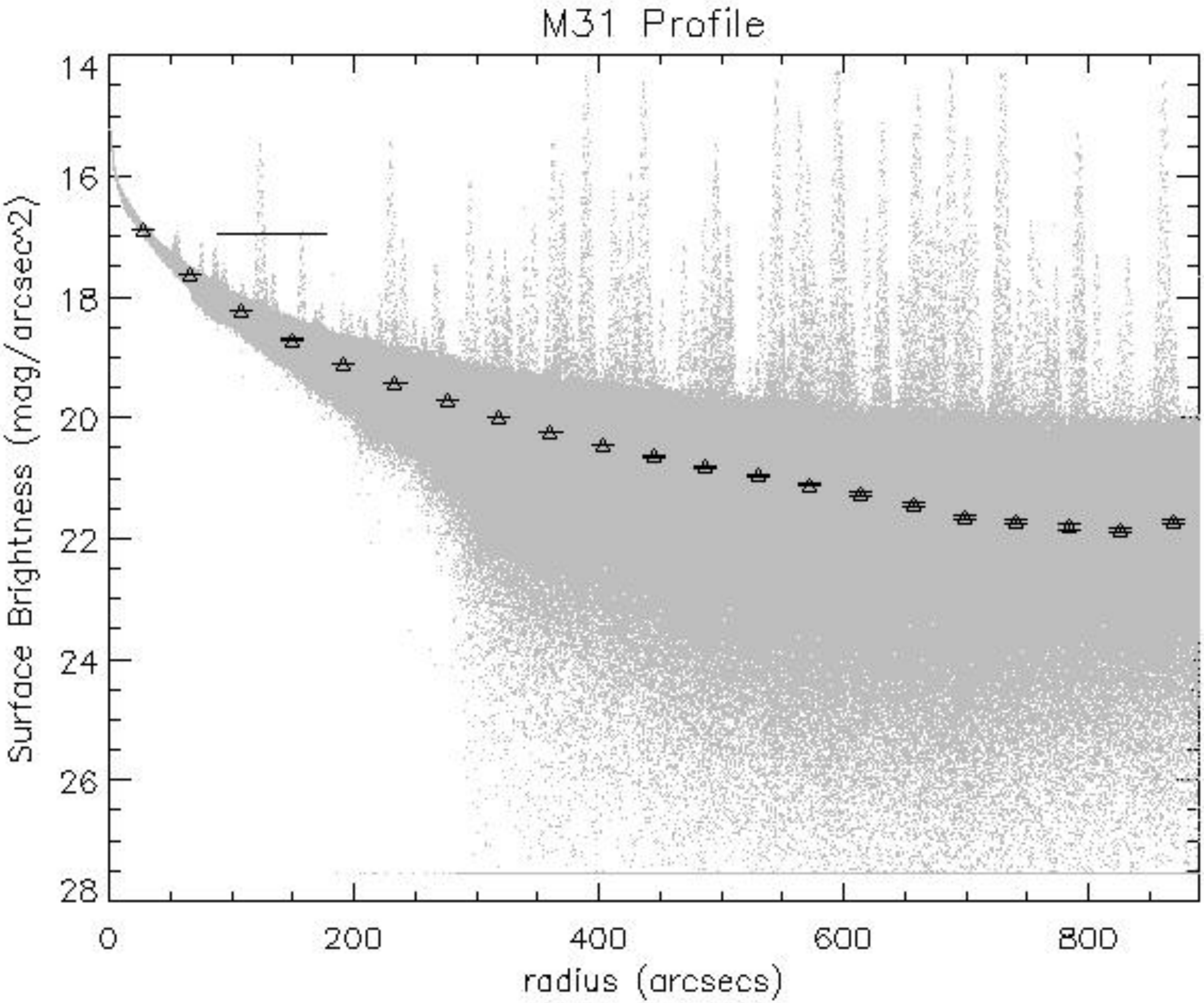

M32 Profile
Surface Brightness (mag/arcsec^2)
14
16
18
20
22
24
26
28
0
100
200
300
400
radius (arcsecs)

Log Scaling



M31 Profile
Surf Bright (mag/arcsec^2)
14
16
18
20
22
24
26
28
−0.5
0.0
0.5
1.0
1.5
2.0
2.5
log(radius) (arcsecs)


M31 Profile
Surface Brightness (mag/arcsec^2)
radius (arcsecs)
14
16
18
20
22
24
26
28
0
100
200
300
400



M31 Profile
Surface Brightness (mag/arcsec^2)
14
16
18
20
22
24
26
28
0
200
400
600
800
radius (arcsecs)