Data Processing in DES

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http://data.darkenergysurvey.org/fnalmisc/talk/detrend.p

Basic Signal-to-Noise calculation in astronomy:

Assuming a perfect atmosphere (fixed PSF of p arcsec FWHM), perfect telescope of mirror diameter A, perfect instrument of efficiency, q, to detect photons, what is the accuracy (S/N) to which a star of magnitude,m (in a perfect filter),in a sky background of sb mag/arcsec /arcsec, observed for exposure time t,in a filter W angstroms wide, can be measured and with what
accuracy can a position of the star be measured?

Rule of thumb: A V=0^{th} magnitude star gives
off ~1000 photon/cm/cm/s/Angstrom in the optical.

First the photometry S/N estimate:
Let's take A=4m, p=1'', q=13%, m=23rd magnitude, sb=22 mag/arcsec^2

One can estimate how many counts from the star (signal) and the background (noise) one gets:

Basic Signal-to-Noise calculation in astronomy:

Diameter of telescope mirror: A   (i.e. CTIO 4m)

Efficiency of instrument: q (typically 13%, mirror, lenses, CCD chip)

Point Spreading in the atmosph. (typically 1'', in space: diffraction limit)

Flux from object: ~1000 photons/s/cm/cm/Angstrom for Vega (V=0)

Exposure time: t(seconds)

Filter width W (1000 Angstroms for a broad band V filter)

Flux from sky (sky noise) or instrument (read noise), perhaps 22nd mag per square arcsec on dark sky. Read noise can be 6 counts/pixel typically less than sky noise unless exposure time very short.

Rule of thumb: A V=0th magnitude star gives off ~1000 photons/cm/cm/s/Angstrom.

First the photometry S/N estimate:
Let's take A=4m, p=1'', q=13%, m=21rd magnitude, sb=22 mag/arcsec^2 t=100s,
Signal = 10^(0-23)/2.5*1000*400*400*0.75*100*0.13*1000 ~1000 'counts'
Sky = 10^(0-22)/2.5*1000*400*400*0.75*100*0.13*1000 ~ 2500 'counts'

Noise = sqrt(sky+signal) [This is standard formula for Poisson noise]

Signal/Noise = 1000/Sqrt(3500) = 16.9

sigma(MAG) = 1.0857*(Noise/Signal) = 1.0857/16.9= 0.064 magnitudes

i.e. Should be able to measure a 23rd mag star to an accuracy of about 6%

Suppose you make a coadd of 10 individual exposures of the same 23rd magnitude star.

What should be the magnitude and error of the combined coadd image of that star?

Again, Poisson statistics rule, and thus
The error on a set of 10 measurements is 1/sqrt(10) times the
Error on a single measurement, thus the magnitude error
For a ‘stack of 10 coadd’ should be about 0.316 times that on
A single measurement,
In our case:

N=1: (mag,error) = (23, 0.064 mags)

N=10: (mag,error) ~ (23, 0.02 mags)

Similarly, the detection limit improves when you have a coadd.

Detection Limit:

If the 10-sigma (magerr ~ 0.1 mag) detection limit in a single image is mag=24 then one can ask:

What is the 10-sigma detection limit for a stack of 100 images?

The answer changes depending if you are ‘sky background’ limited or not, but assuming you are:

The average signal roughly stays the same, but the noise goes down by sqrt(100) = 10, therefore, the signal can drop by a factor of 10 to get the same signal to noise. Dropping the signal by a factor of 10 means that the magnitude increases by 2.5*log10(10) = 2.5 mags, thus the 10-sigma limit for a stack of 100 images in this case is 24+2.5=26.5th magnitude.

Astrometric accuracy theoretical limit:

One should be able to measure a star position to an accuracy of about 1/100th of a pixel, assuming the resolution is somewhat (x4) oversampled. I.E. if pixel size is 0.263'' then an individual star position (FWHM =1'') should be measurable to about 0.0026'' = 3 milliarcsec. ** This is a rough guess **

One mumbles words like 'how well can one do a centroid' of a Gaussian distribution of FWHM = x'' on a grid of pixel size y''/pixel? estimates range from 1/400th of a pixel to 1/20th of a pixel. 1/100th of a pixel is a good number to aim for, rarely achieved. The best methods to achieve close to it are to, again, use 'matched filter' techniques, convolving the stellar profile with a Gaussian or a Quartic distribution to smooth noise and measuring the centroid of the convolved distribution.

These estimates for photometric and astrometric theoretical accuracy are then kept in mind as we process the real, often far from ideal, data….

Data Processing Pipelines in DES:

0. Calibration Generation (Flat, Bias, Sky, response,bad pixels)
1. Single Epoch ‘detrending’ processing
2. Photometric Calibration – using multiple detection of the same objects
3. Coadd – combine single epoch exposures

The aim of data processing is to get as close as possible to the theoretical limits for photometric and astrometric accuracy and minimize unflagged artifacts.

There are absolute limits in addition to relative limits. We won’t discuss the absolute limits here much, mostly the relative.

0. Calibration Generation:

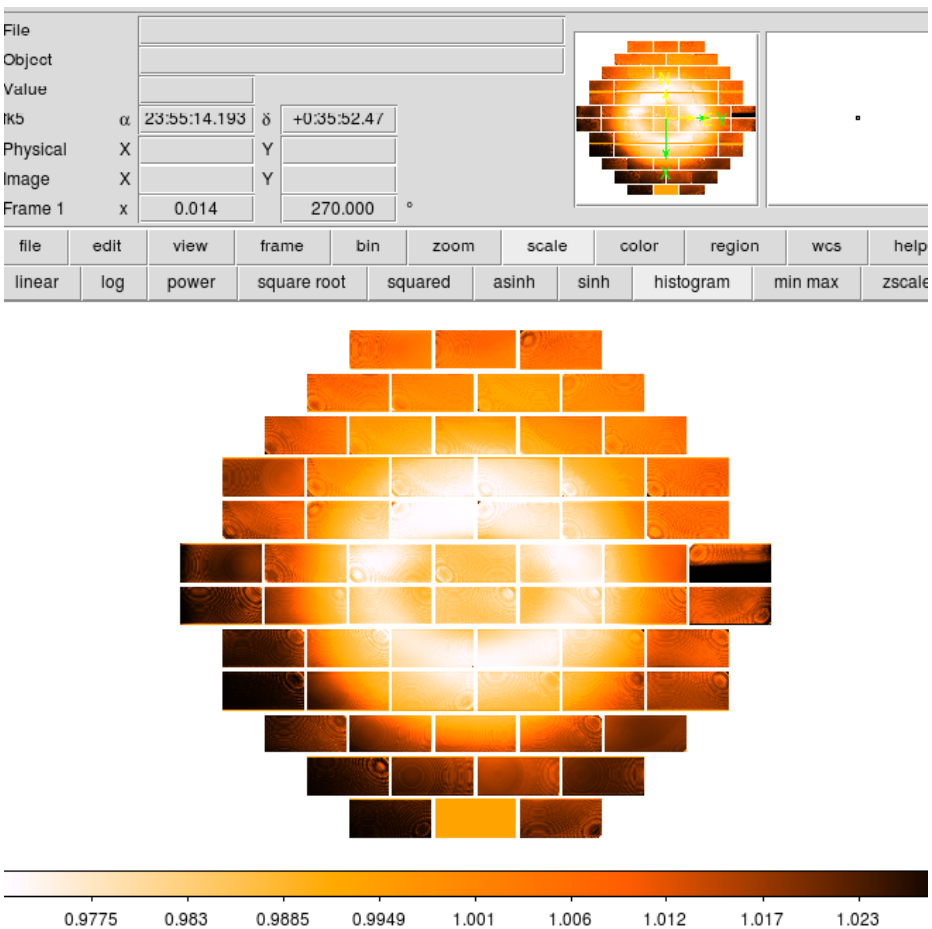
A. Bias
B. Dome Flat
C. Bad Pixel Mask
D. (Additive) Sky background Template
E. (Multiplicitive) Star Flats

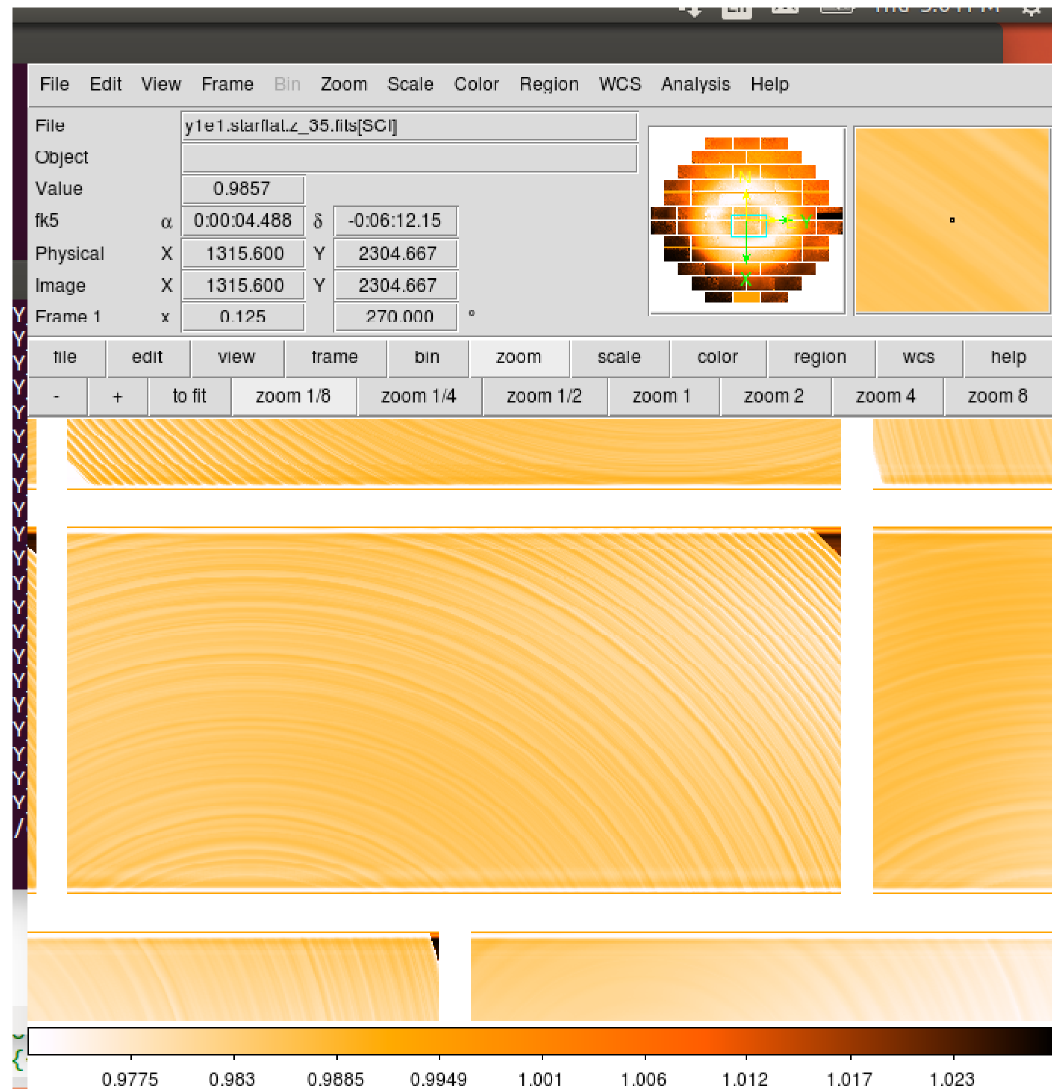
F. Non-linearity
G. Gain/Read-noise per chip maps
H. Cross-talk correction matrix
I. Brighter-Fatter correction matrix

J. Camera Geometry (Distortion and Scale, chip position)

Sample flat field and starflat correction image.

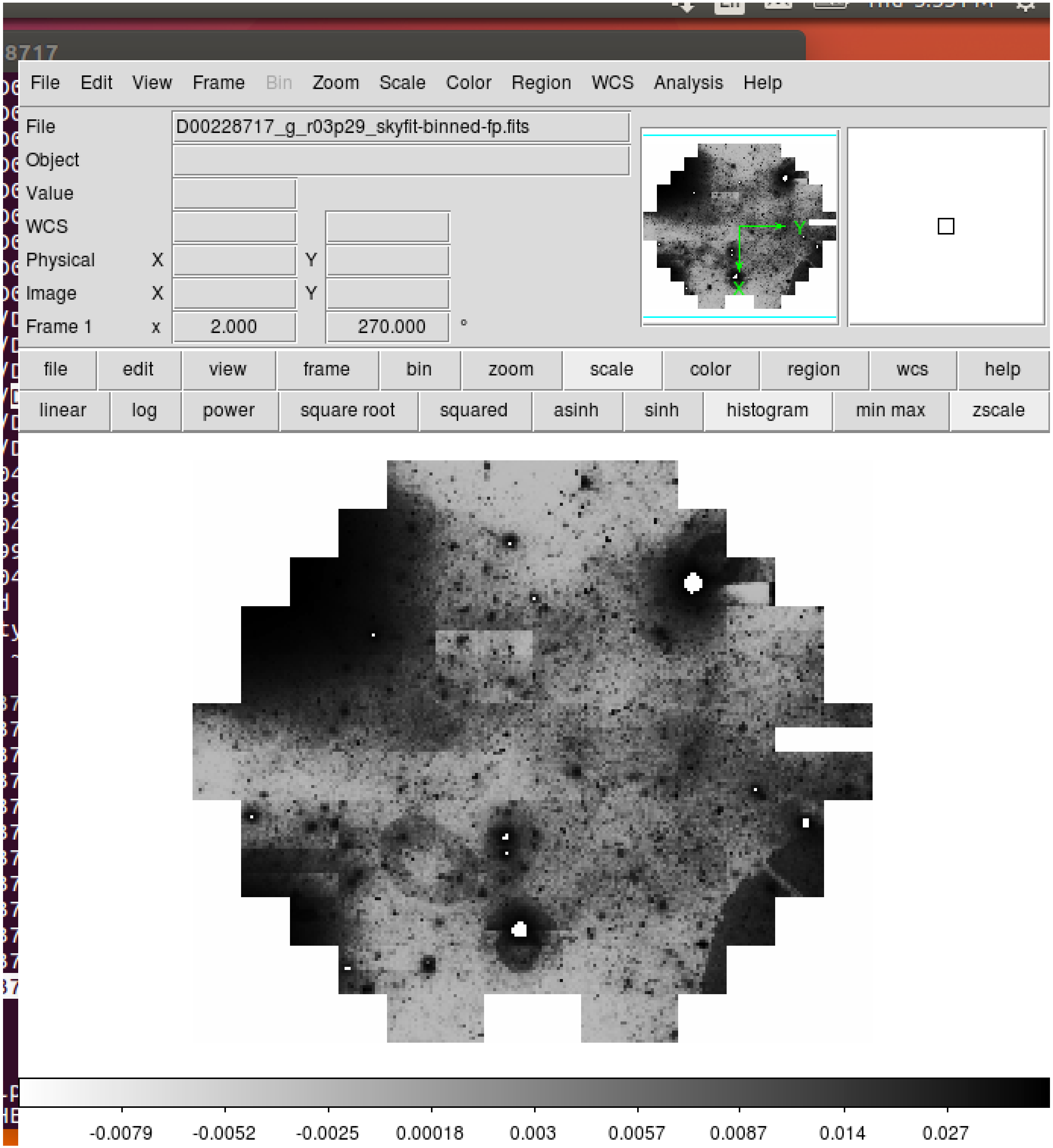
The range of values from 0.97 to 1.03 gives the
Amount by which the response varies across the field depending on where the star lands,
The amount of counts detected varies by +/- 3%.
The ‘Tree Rings’ are an effect due to deep well CCDs.

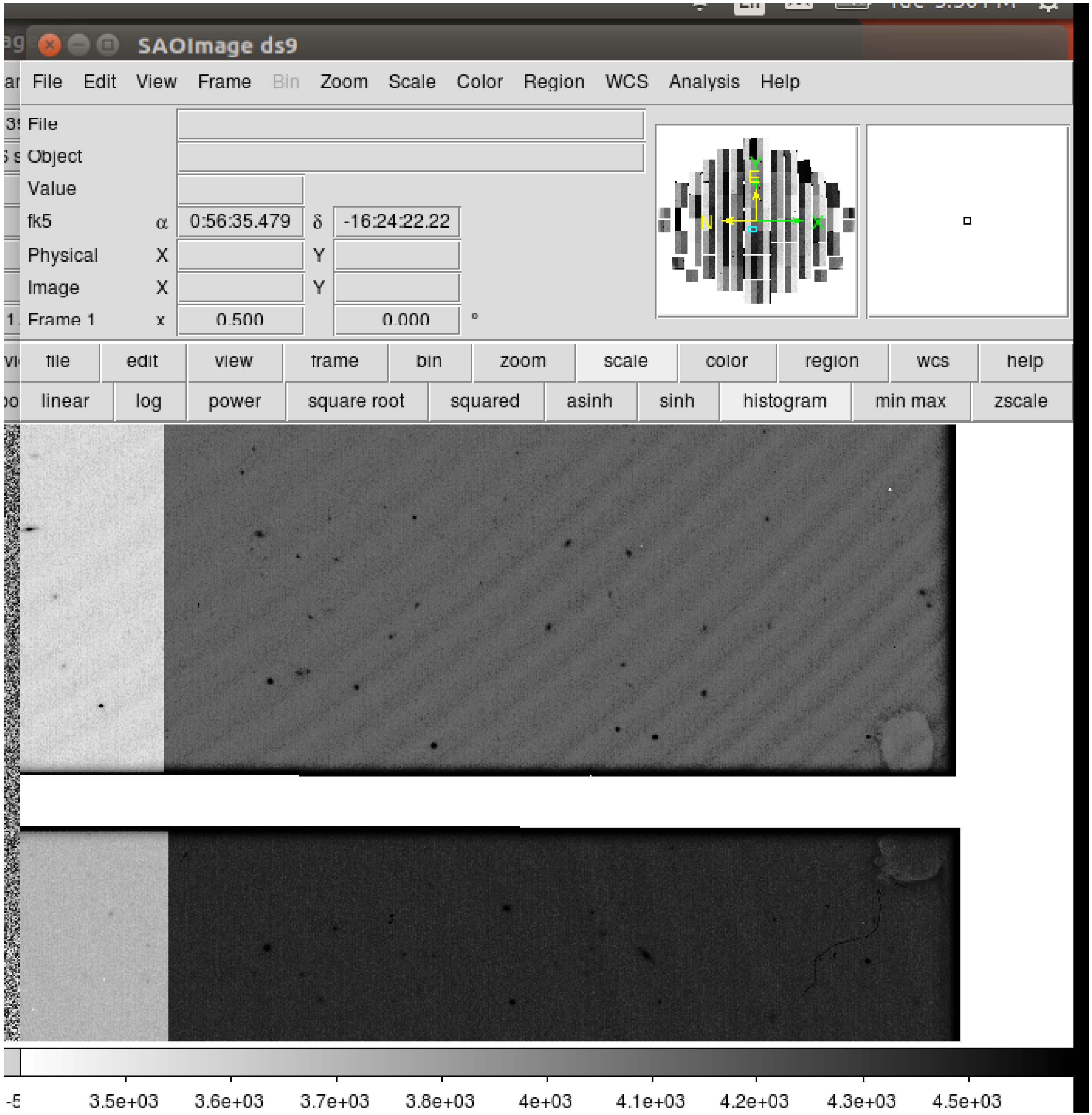




This is a ‘sky template Residual’, it is also about 3%.

This is ADDITIVE, Unlike the Starflat which is MULTIPLICITIVE.




SAOImage ds9
File Edit View Frame Bin Zoom Scale Color Region WCS Analysis Help
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linear log power square root squared asinh sinh histogram min max zscale
3.5e+03 3.6e+03 3.7e+03 3.8e+03 4e+03 4.1e+03 4.2e+03 4.3e+03 4.5e+03

1. Single Epoch:

Detrending:
A. Crosstalk removal (mostly left-right amp crosstalk, about 1 part in 1000). 0.H,J
B. Overscan and Bias removal 0.A
C. Bad pixel masking (image specific mask) 0.C
D. Pupil Correction (additive, includes fringe) 0.D
E. Non-linearity correction 0.F,I
F. Flat Fielding (small pixel-scale multiplicitive) 0.B
G. Generate weight plane (1/counts = inv var)
H. Illumination Correction (large scale multiplicitive) 0.E

Astrometric Solution:
I. Detect bright stars, match to external star catalog
100-200 mas (2MASS) 10-20 mas (GAIA) 0.J
PSFEX:
J. Select bright, unsaturated stars generate PSF model

1. Single Epoch (continued):

Cataloging:

K. Object detection (convolve frame with PSF, find peaks above threshold)

L. Fit PSF to each peak, if good fit, it's a star (to first order,all stars look just the PSF, only the amplitude (magnitude) changes).

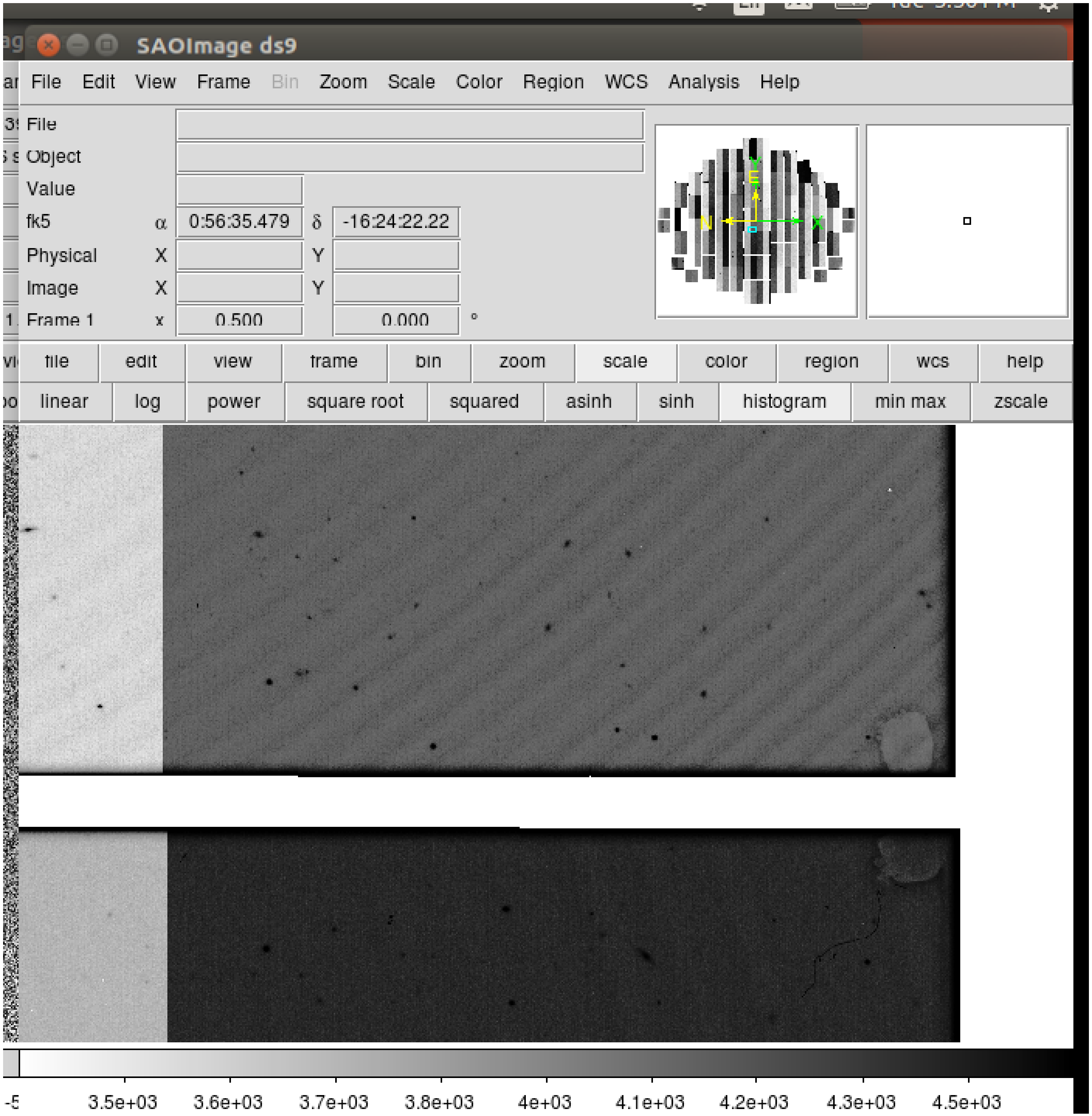
M. Fit model ellipsoid (convolved with PSF) to all objects (x,y,theta,a,b,height). (Galaxies are broader than stars, and have a variety of shapes and sizes, thus: higher errors)

N. Measure catalog parameters (position, flux,shape)

O. Use mask plane and weight plane to flag artifacts

P. Use information about fullwell to find saturated objects

Q. Use information about PSF width to find Cosmic rays


SAOImage ds9
File Edit View Frame Bin Zoom Scale Color Region WCS Analysis Help
File
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Physical X Y
Image X Y
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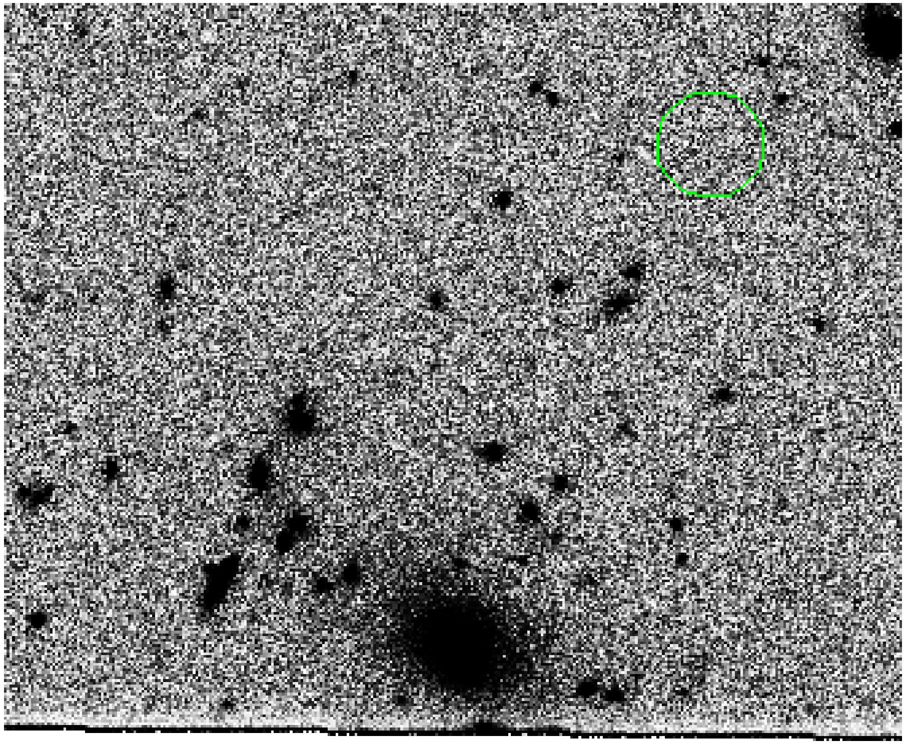
linear log power square root squared asinh sinh histogram min max zscale
3.5e+03 3.6e+03 3.7e+03 3.8e+03 4e+03 4.1e+03 4.2e+03 4.3e+03 4.5e+03



After ‘detrending’, the background (except the edge – which is masked), is very uniform, with the sky noise visible as ‘Poisson noise’.

Objects (Galaxies and Stars) are clearly visible as dark ellipses, and it matters little where an object falls on the field (counts are the same within 1%).

Defects are minimized (again, excepting the edge).

For object at (ra,dec) = (342.1869-44.5354)
Flux=19161 cnts, Fluxerr=1256 cnts
MAGERR_AUTO = 0.071
MAG_AUTO=20.683

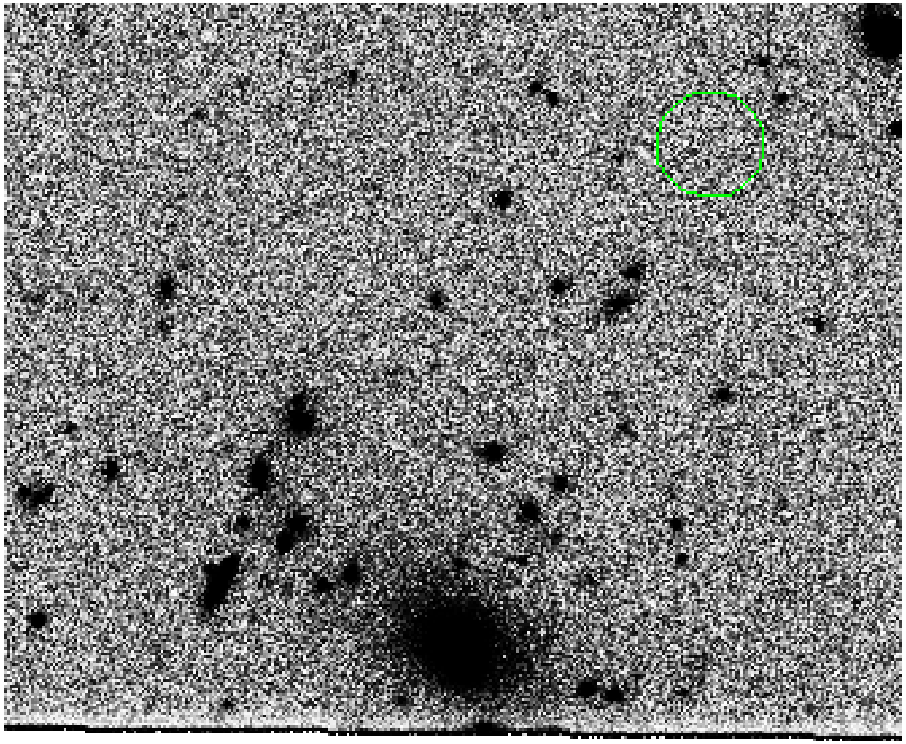
2. Coadd:

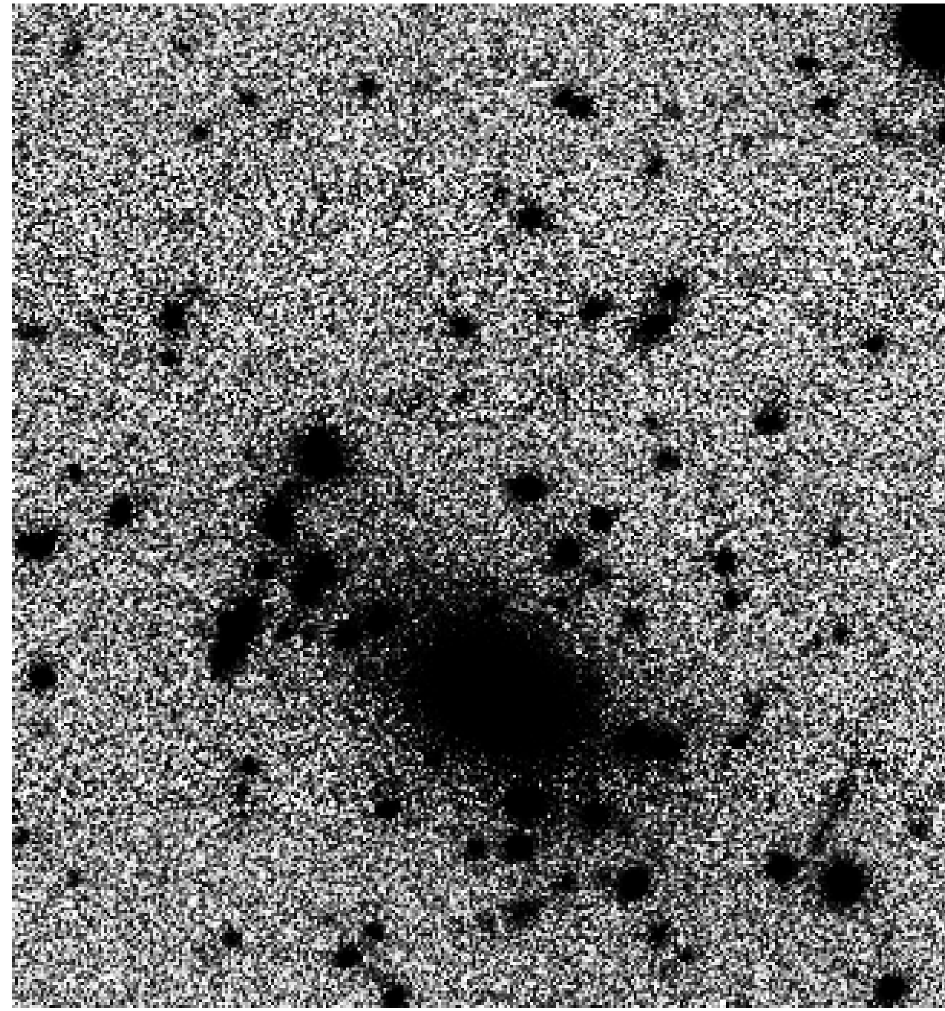
Decide on Tile to generate, for instance DES0102-4914
Tile Center (RA,DEC) = (01:02:00, -49:14:00)
Tile Size (10000x10000) pixels (0.72 x 0.72) deg^2
0.263''/pixel (match to single epoch)

Select set of overlapping expnum/ccdnums from 1.H

Astrometrically re-register expnum/ccdnums (optional)1.I

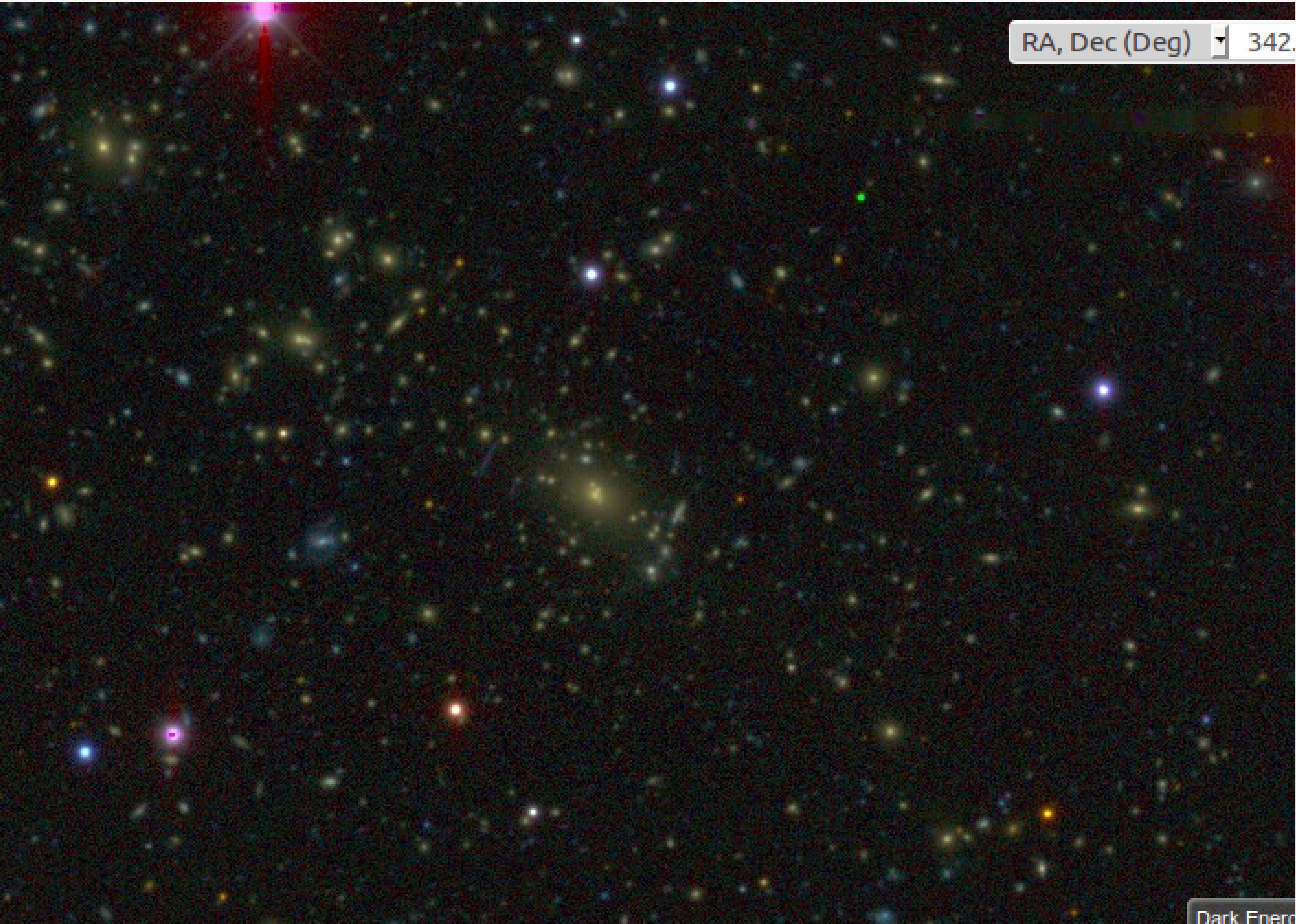
Combine all expnum/ccdnums with common filter,
Variance weight by weight plane (essentially 1/sky counts).
Construct 'detection image' as sum across bands.
Run Object detection step on the detection image to obtain catalog of coadd objects.
For each coadd object for each filter:
Measure on the individual color filter coadds the coadd object parameters (ra,dec,magnitude,shape,flags)





For object at (ra,dec) = (342.1869-44.5354)
Flux=19161 cnts, Fluxerr=1256 cnts
MAGERR_AUTO = 0.071
MAG_AUTO=20.683

Coadd mag from N=4 expnum
20.654+-0.050
Nominally error from 4 expnums should
Go down by sqrt(4) = 2, in this case
It only goes down by 0.07/0.05 = 1.4


RA, Dec (Deg)
342.

http://data.darkenergysurvey.org/aux/releasenotes/DESDMrelease.html

Link for This Talk:

http://data.darkenergysurvey.org/fnalmisc/talk/
detrend.pdf

Easyaccess queries:
Start at:

cosmology.illinois.edu

DESDM file tree

Single Epoch:

https://desar2.cosmology.illinois.edu/DESFiles/desarchive/OPS/finalcut/Y2A1/

Coadd:

https://desar2.cosmology.illinois.edu/DESFiles/desarchive/OPS/multiepoch/Y3A1/

Select some parameters for a set of objects or coadd_objects:

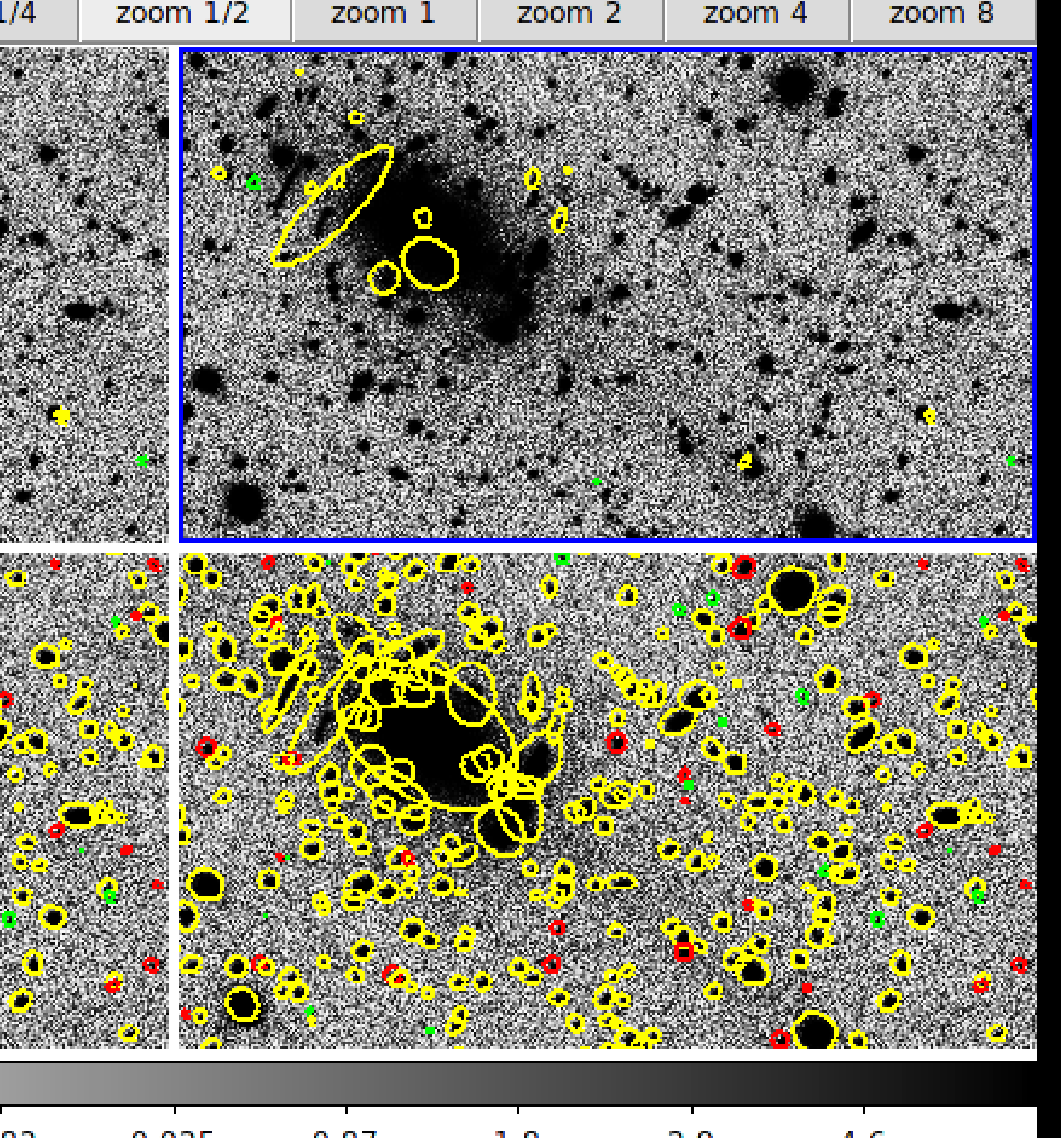
Select id,alphawin_j2000,deltawin_j2000,mag_auto,magerr_auto,spread_model,
band,flags,imaflags_iso,a_image,b_image,theta_image from
coadd_object@desoper Where alphawin_j2000 between 30 and 30.1 and
deltawin_j2000 between -45 and -44.9;
> saveobjects.csv

This query needs post-processing, to join together objects with the same id.

We recommend waiting for the so-called: ‘COADD_SUMMARY’ table to
be instantiated (a couple of weeks from now). This will be in the dessci database,
with a table name like:

Y3A1_COADD_OBJECT_SUMMARY@DESSCI

Here, objects will be joined across filter, columns like MAG_AUTO_G-MAG_AUTO_R as
gmr_auto will be available for selection. Stay tuned (announcement will
be sent to des@fnal.gov mailing list).



Top: missed objects

Yellow: spread_model > 0.003 (extended =galaxy)

Red:-0.003< spread_model < 0.003 (stellar=star,qso)

Green: spread_model< -0.003 (cosmic ray, very faint object (indeterminate star/galaxy type)

Ellipses come from a_image, b_image, theta_image params In database.

Bottom: detected objects in catalog

Sample Problem set (with answers – please check!):

Q1. What's the S/N for a 1 hour spectrum at resolution 1 Angstrom for a 23rd magnitude star through a 1'' slit onto 1''/pixel on a 4m telescope? How long must one exposure to reach S/N = 10? Efficency of system = 2%, same 22nd mag/arcsec^2 sky.

A1: S/N ~ 1.1, 100 hours to reach S/N=10; spectrographs have lower efficency and W ~ 1 vs. 1000

Q2. If a single exposure reaches a 5-sigma sky-limited limiting magnitude of mag=23rd in 90 seconds, how many 90s exposures must one coadd to reach a 10-sigma limiting magnitude of 24th mag?

A2:N=10 exposures: 2.5x to reach fainter limit, 4x to reach higher S/N sigma at new limit

Q3. If the PSF/seeing/diffraction limit of your instrument is 0.1'' (space telescope) instead of 1'', and the pixel size of your detector is also 0.1'' pixels or smaller, what is the typical magnitude error in space and on the ground for a sky-limited 100s V-band observation of a 24th magnitude star? Assume the mirror has A=2.5m, the sky is the same 22 mag/sq. arcsec in space and on the ground and the detector efficiency is 13%.

A3:S/N~5(gnd), S/N~12(space), much less sky under your star image in space.