Data Reduction Workshop
Imaging & Photometry

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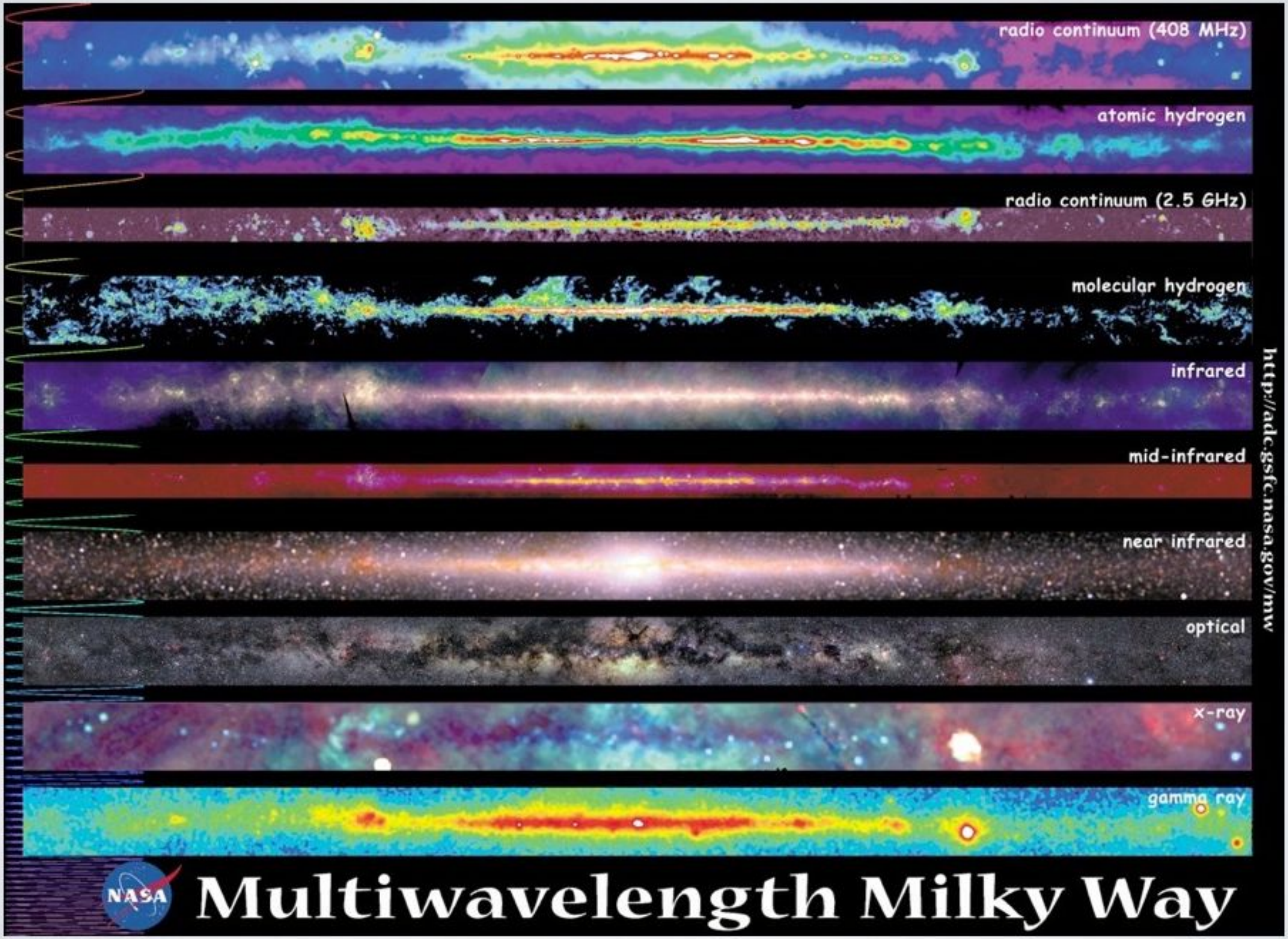
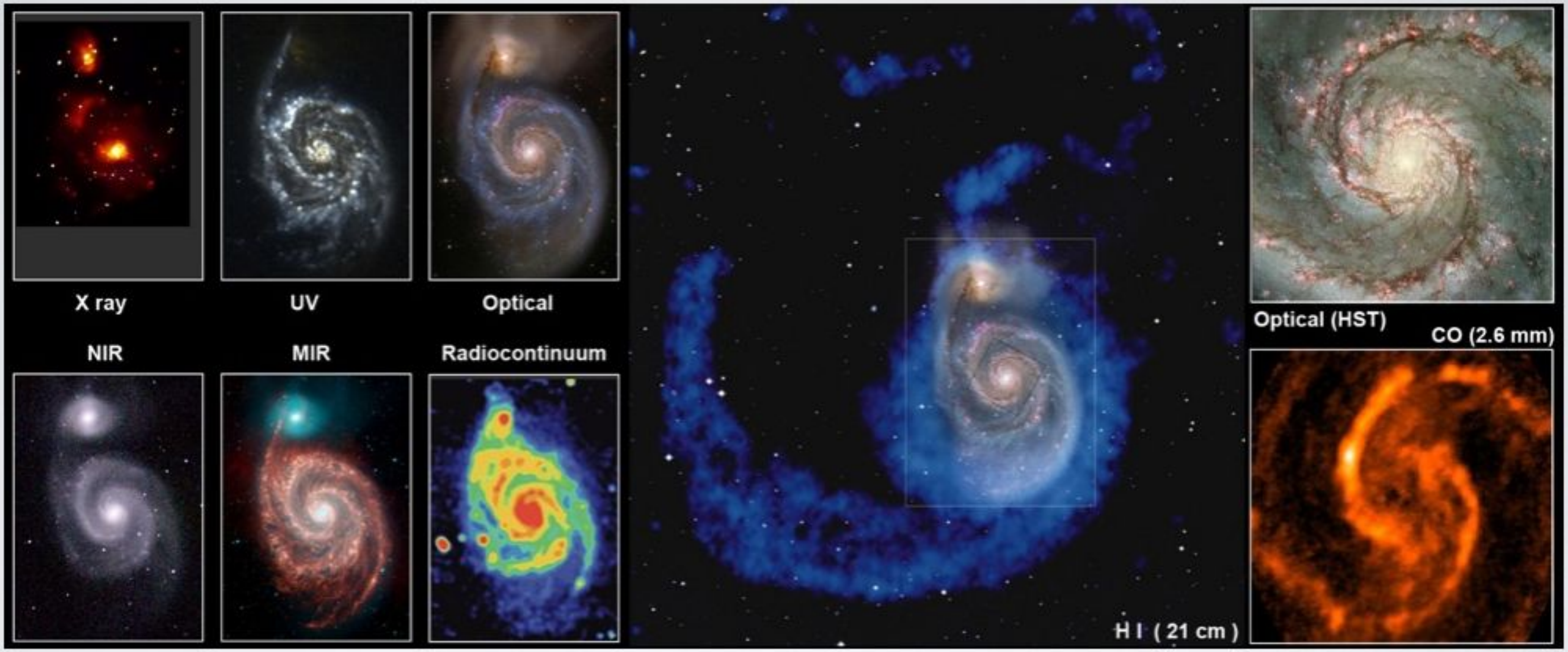
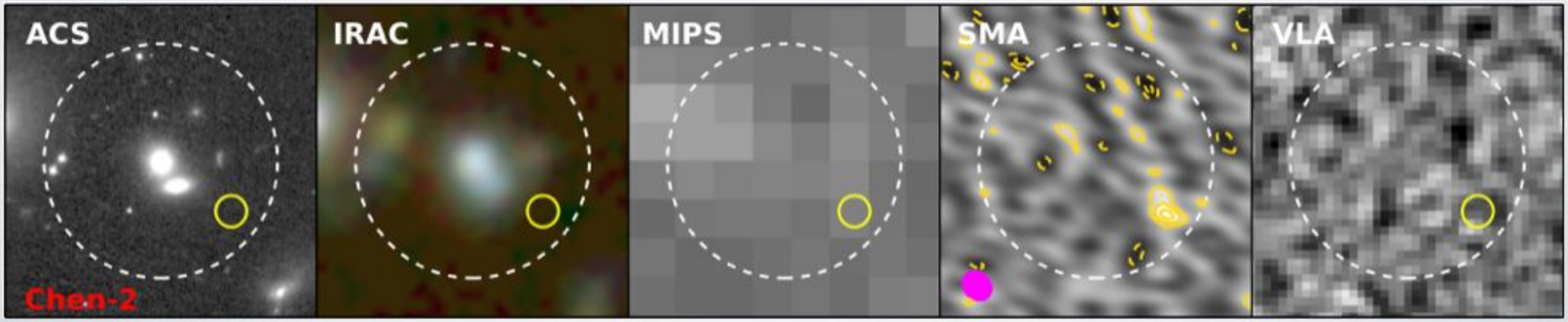
Images at different wavelengths...

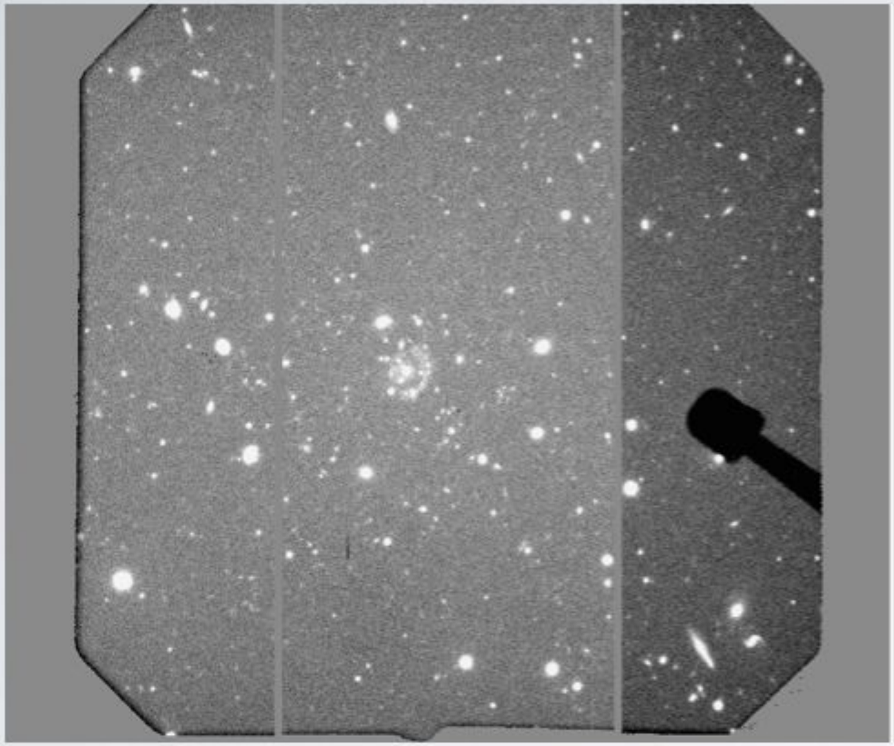


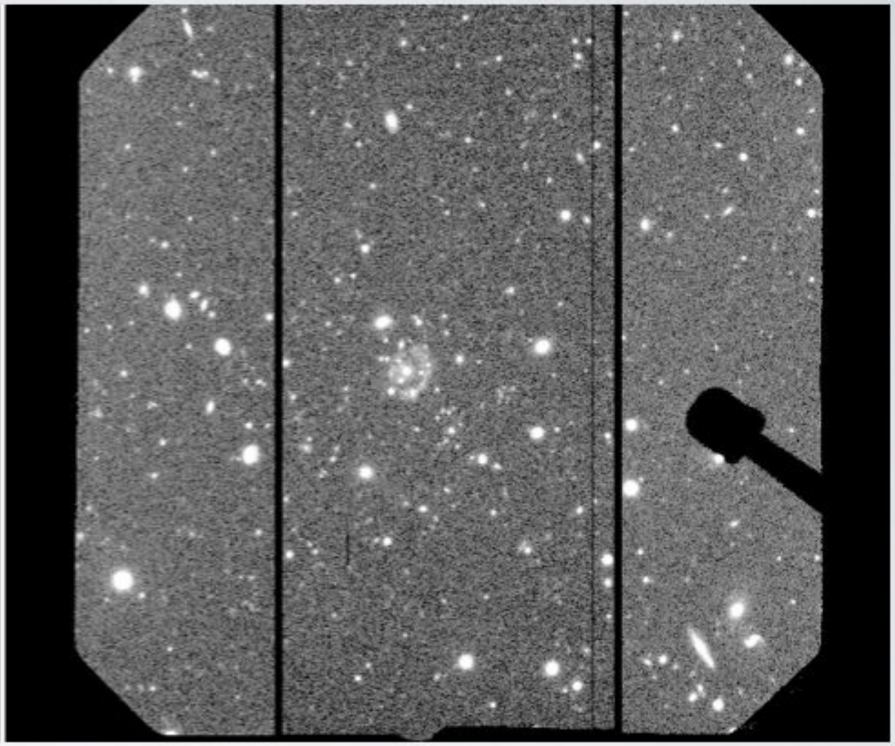
Images at different wavelengths...

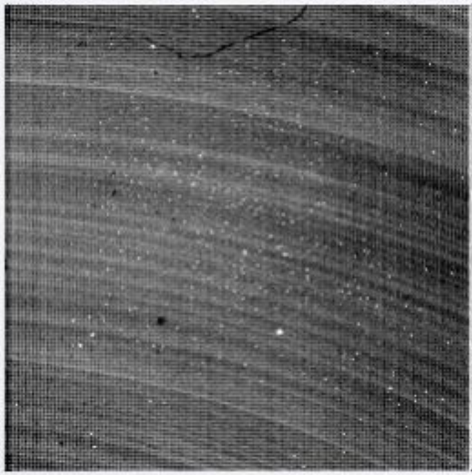


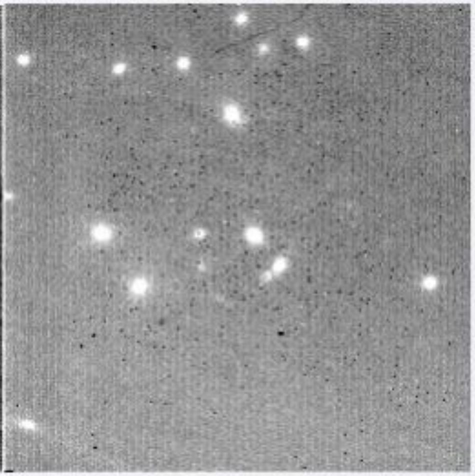


However, the raw data are always not as pretty







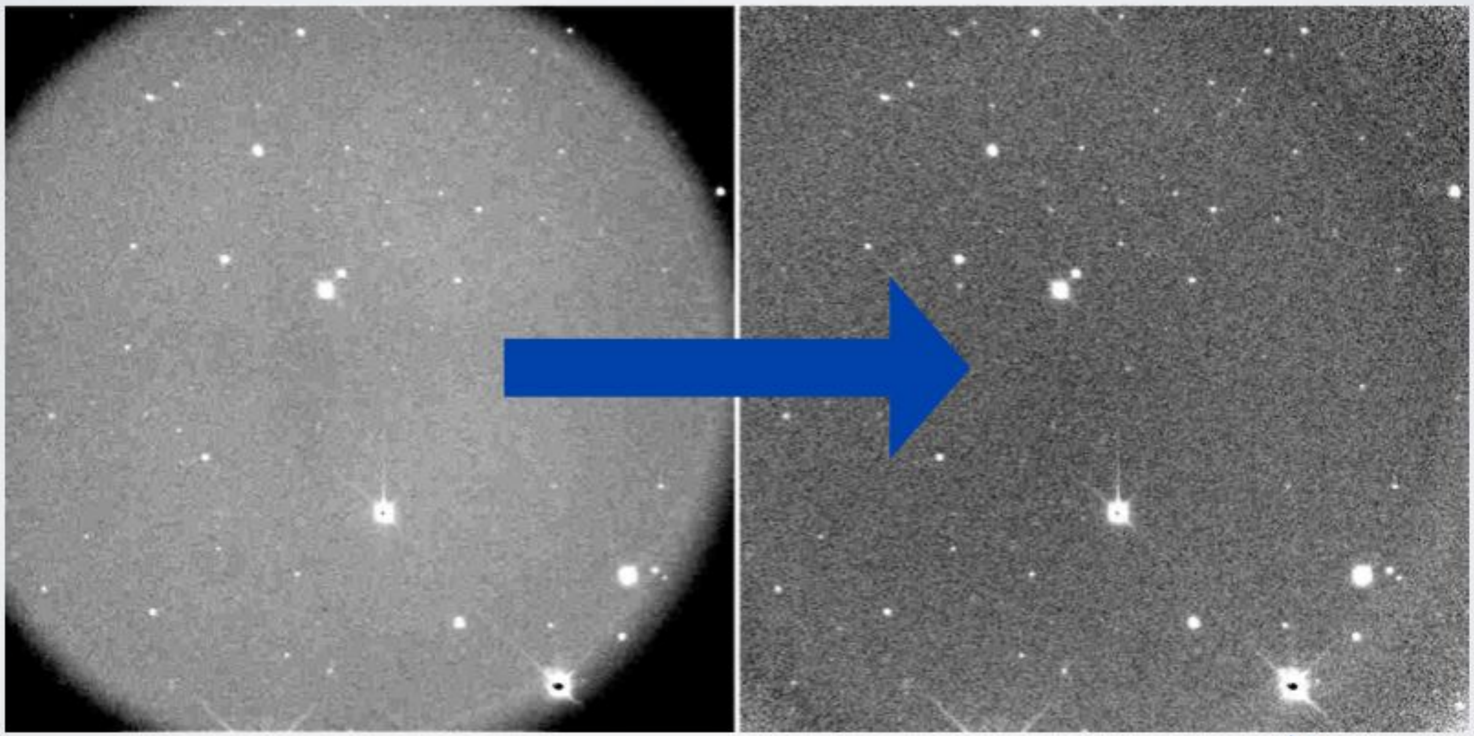


Why?

"The total amount of energy from outside the solar system ever received by all the radio telescopes on the planet Earth is less than the energy of a single snowflake striking the ground"

-Carl Sagan

- Raw images are dominated by sky background and instrumental noises/ effects
- Objects of interest are usually faint and require many exposures to detect
- Need to reduce and combine raw data into one final science image



Goal: Learn how to *in principle* do 

Why do we learn how to reduce data when there are usually pipelines available?

Pipelines may not work properly.....

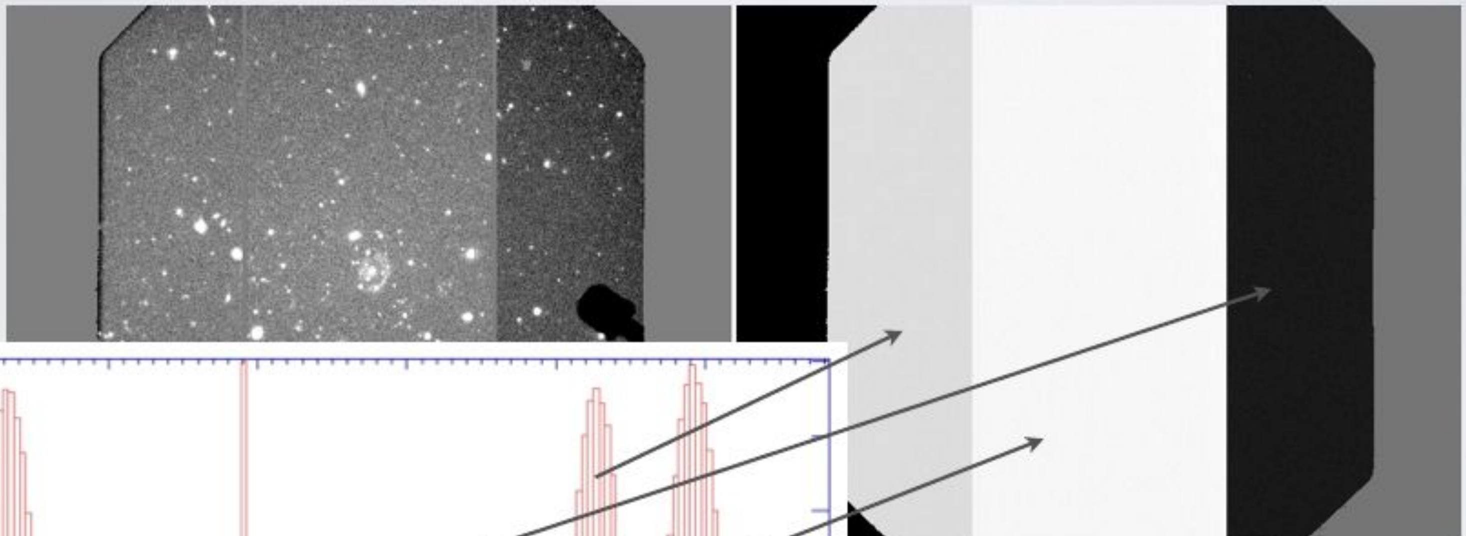
Are data in different wavelengths all reduced in the same way?

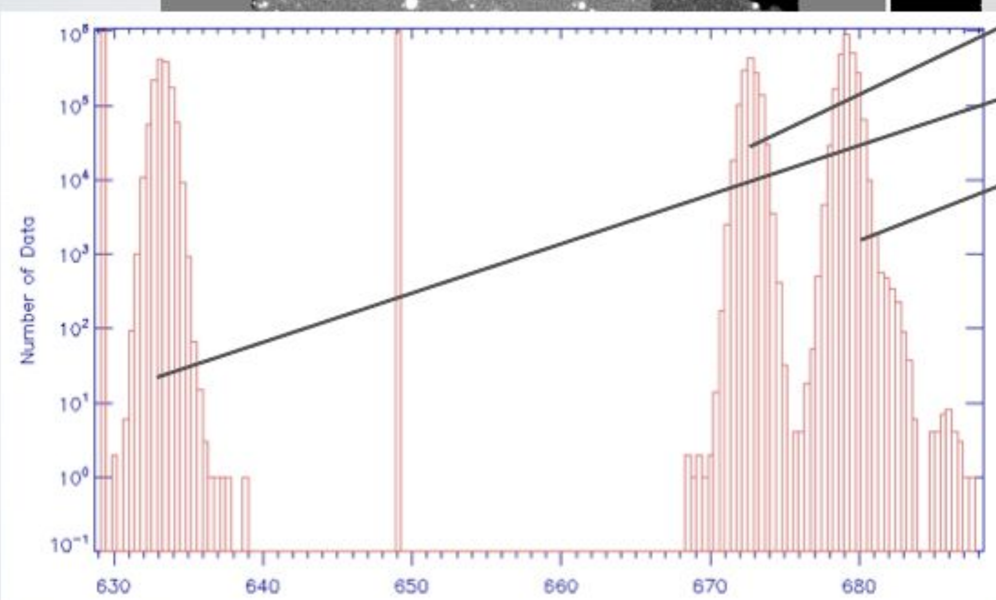
No, but the concepts are similar.....

Instrumental noises / effects :

Bias:

An offset to keep the signals positive.





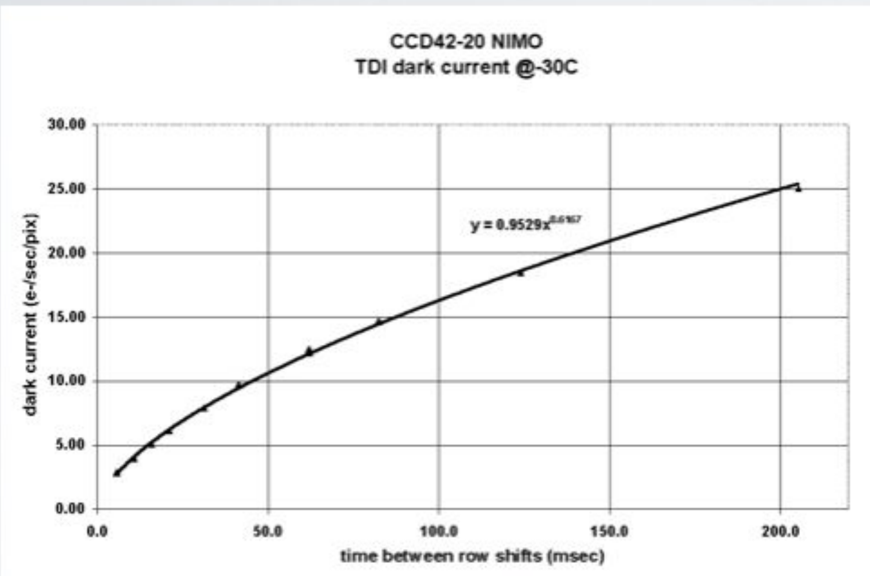
Extra noises:

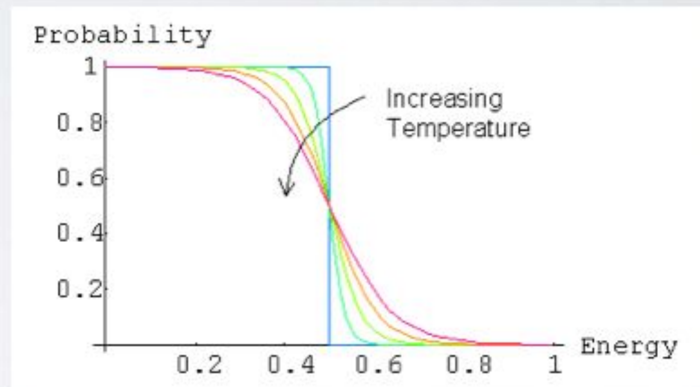
1. analog to digital conversion
2. spurious electrons (in certain type of CCD)

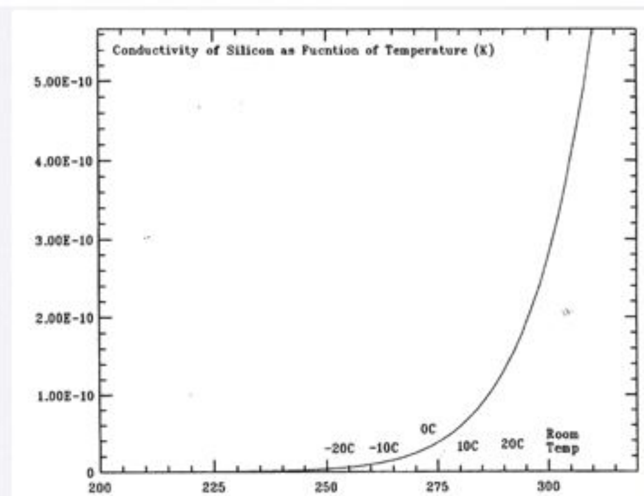
Instrumental noises / effects :

Dark:

Thermal signals from the detector, highly temperature dependent, non-negligible in NIR.



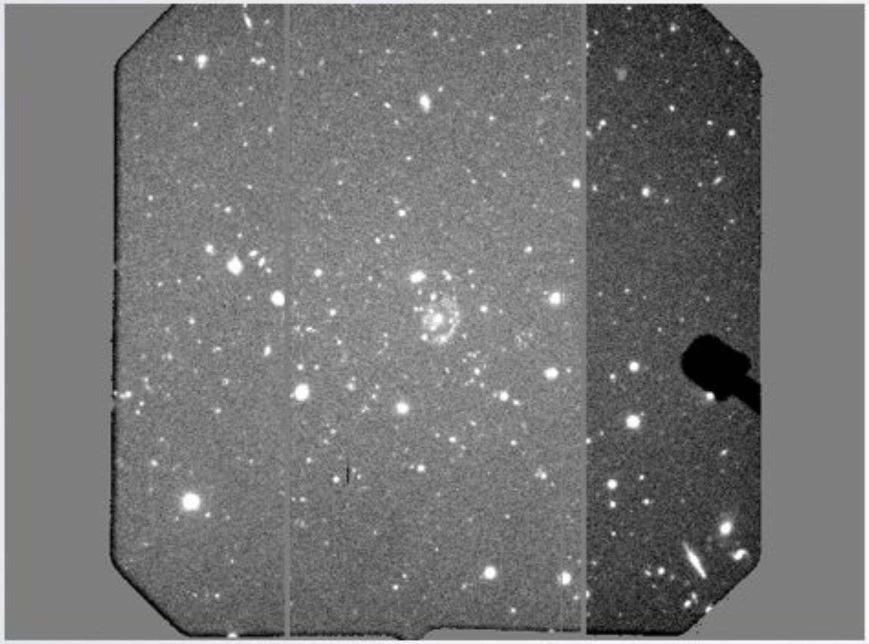


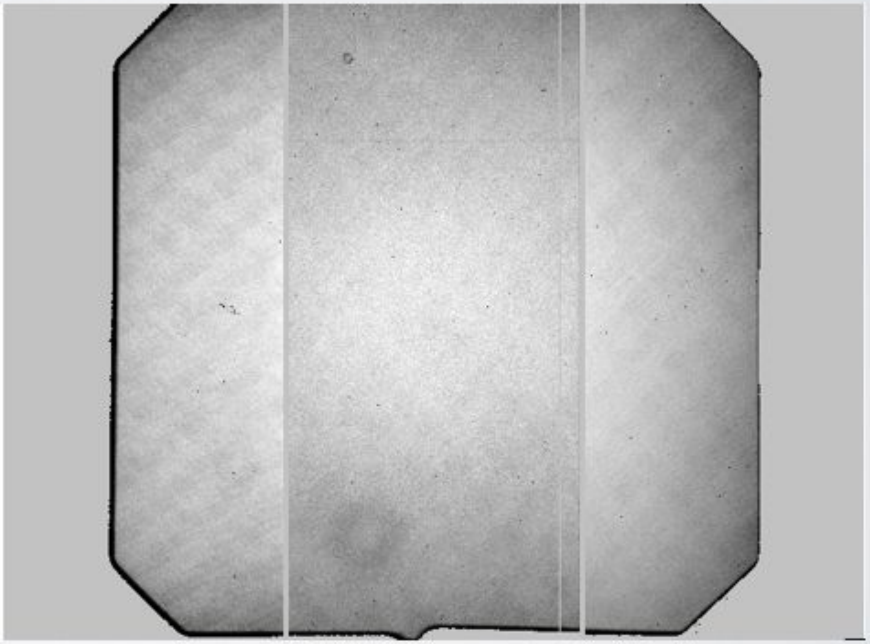


Instrumental noises / effects :

Flat-field:

Non-uniformity of the quantum efficiency across the whole detector.





Ways to measure them :

Bias:

Obtain by reading-out the CCD with a zero-second exposure.

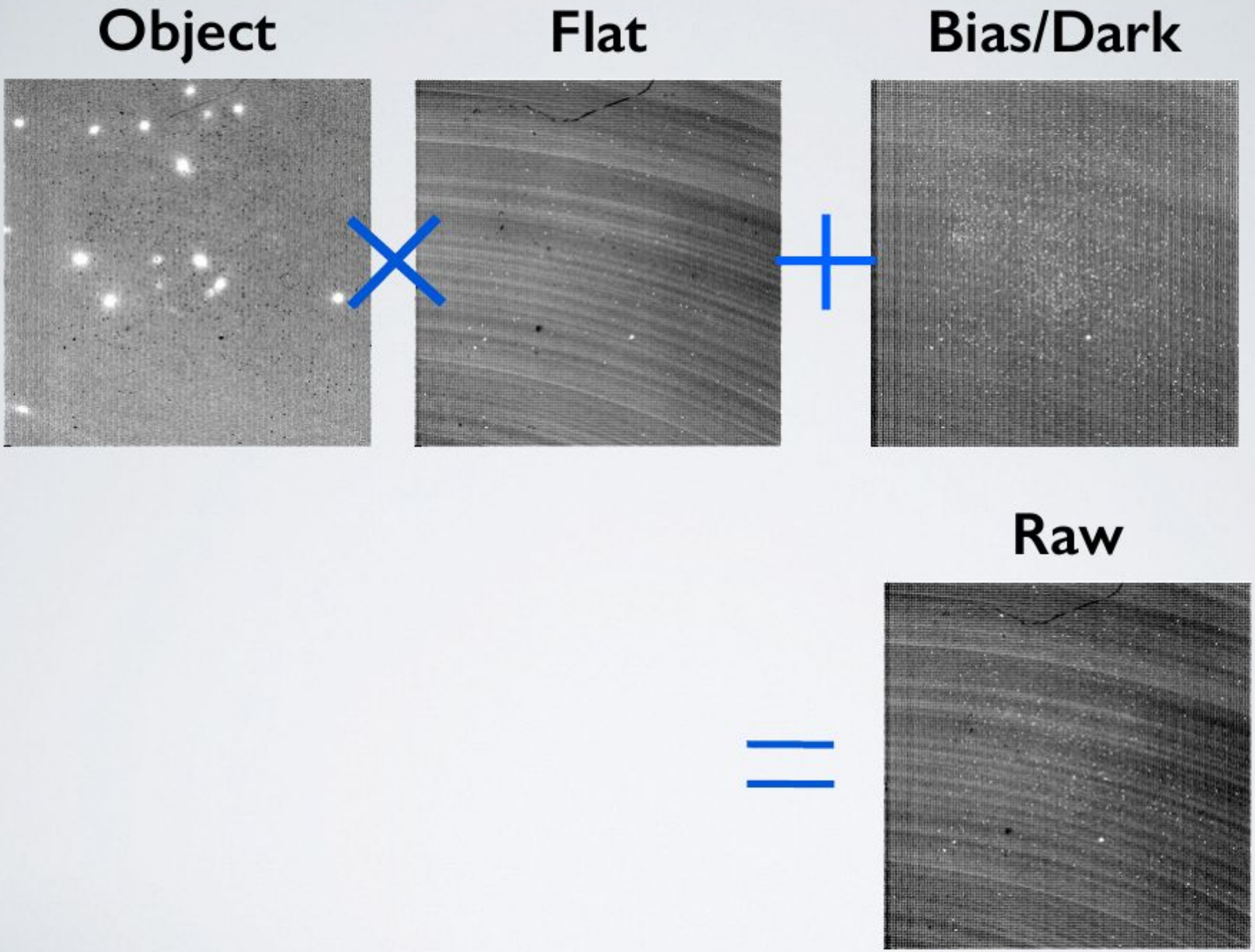
Dark:

Exposures taken with the shutter closed (dark!), with the same exposure time and temperature as the science images.

Flat-field:

Exposures of a uniformly illuminated source. Type of flatfields: Dome, Twilight, Sky

NOTE: Often will have several exposures for each effect, and they can be averaged together to make a more robust master


Object
Flat
Bias/Dark
Raw

Fundamental Steps :

1. Subtract bias / dark

2. Flat-fielding

3. Co-add all "reduced" frames into one final image

4. Calibrate astrometry and flux using references such as standard stars, and update FITS header.

Calibrations

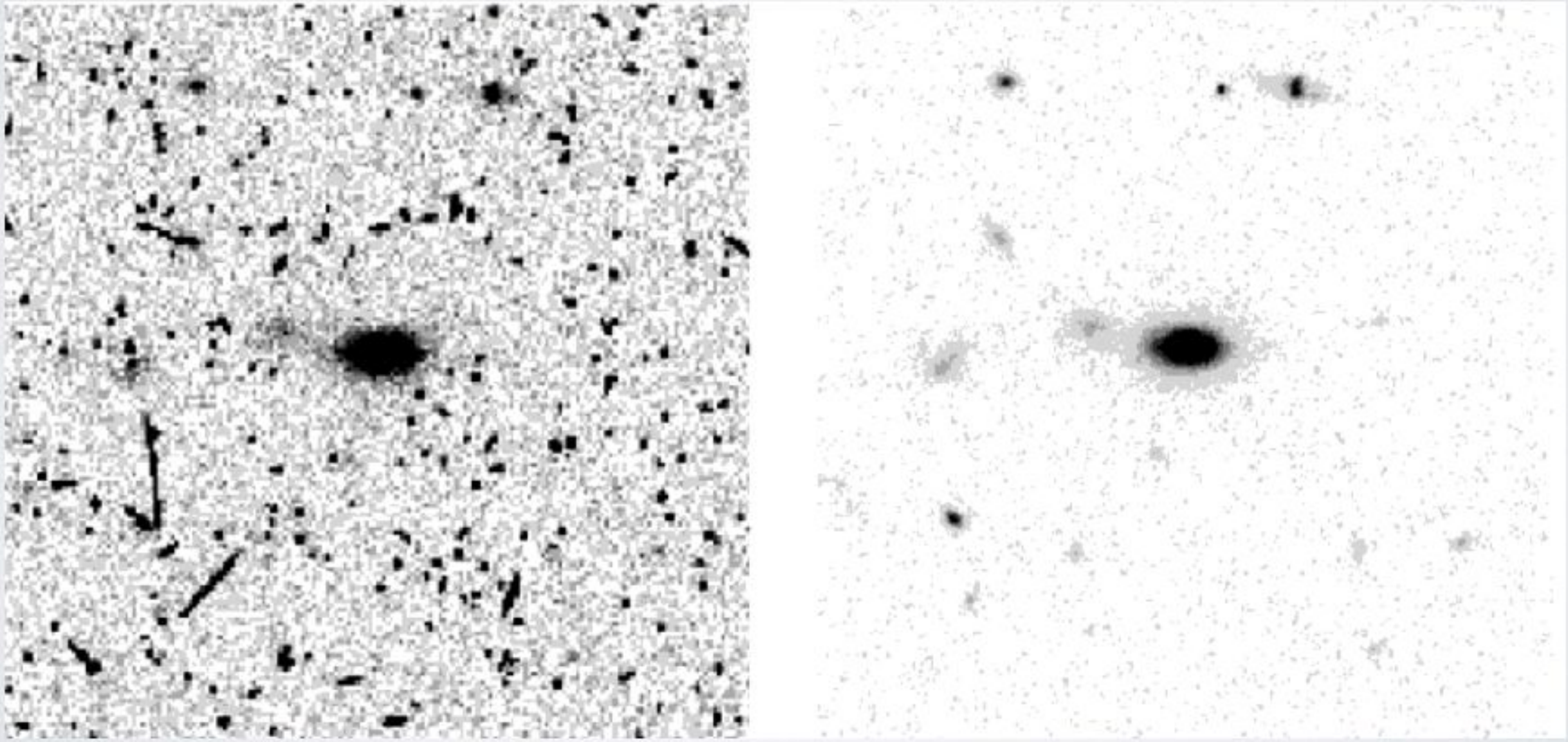
Flux:

The digital values of the reduced images are usually arbitrary. Need to convert those values to physically meaningful values, again using bright referencing objects with known fluxes and that are observed by the same instrument.

Other issues

Cosmic rays:

Comic rays often appear on images taken by the space telescopes. Need to be removed.



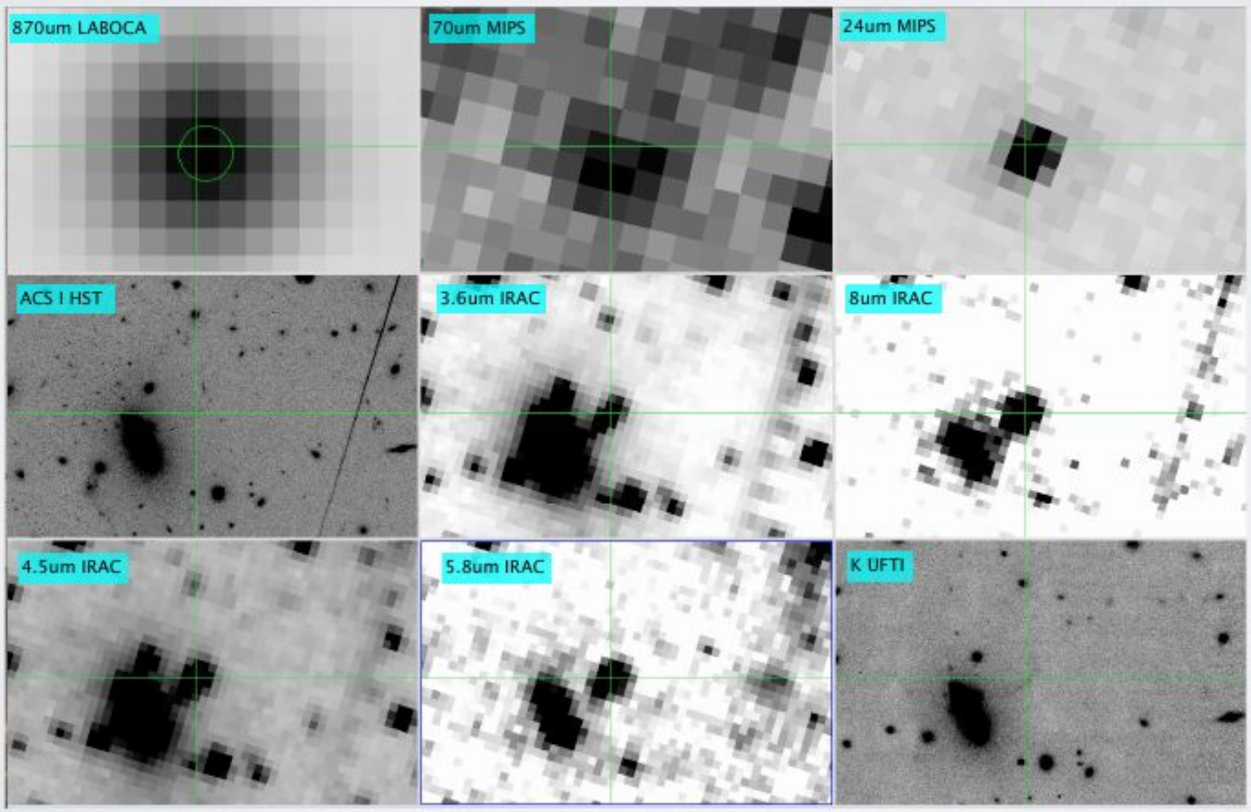
Your toolkit

1. Fundamentally, we're dealing with arithmetic operations on 2D arrays. Use your favorite computer language (IDL, Python, C, IRAF, etc) to manipulate them. Choice is yours.

2. Some invaluable tools: SExtractor (object extraction and photometry), SWarp (image co-add and re-sampling), WCSTools (manipulate/fit astrometry)

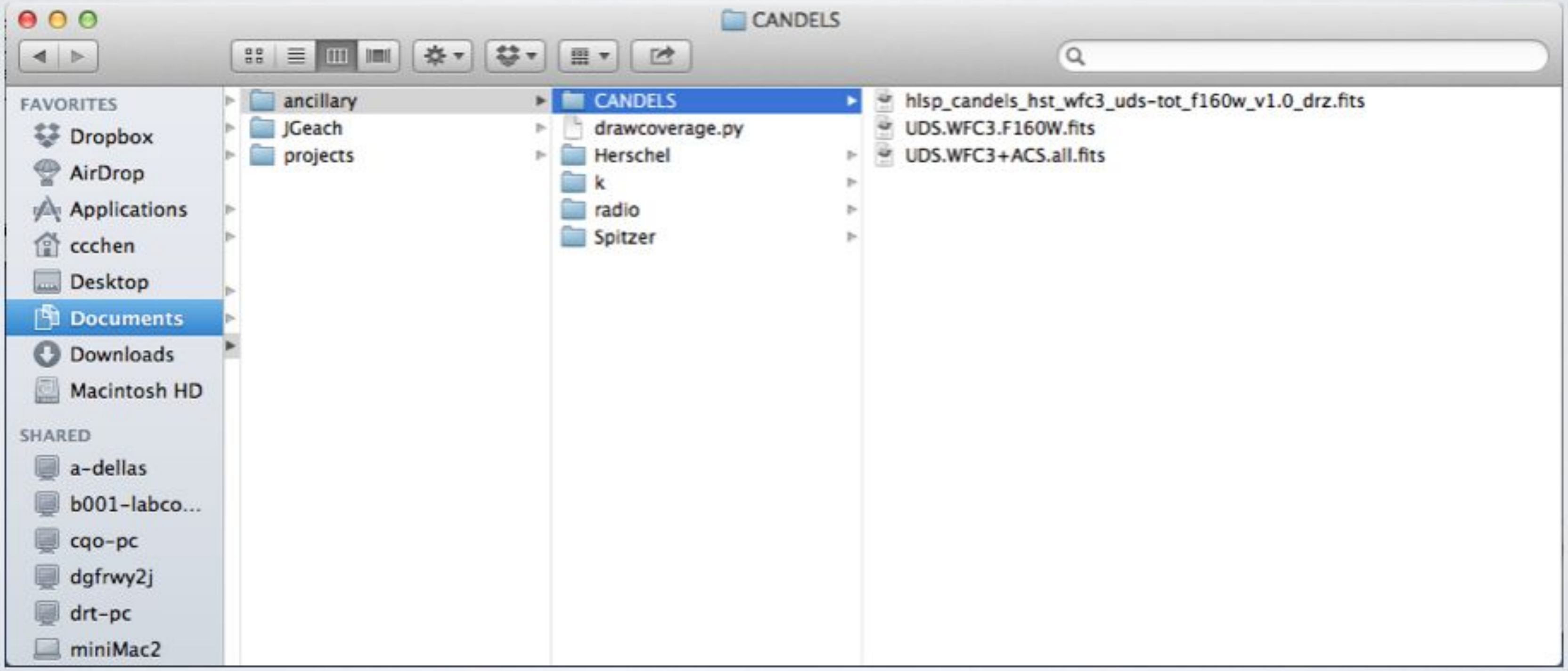
Your toolkit

3. Viewing Tools: ds9, Gaia (for example, ds9 can load many images on different pixel scale and align them).



Things that will help you

1. Naming convention : often a good idea to re-name the cryptically named raw files to something useful describing what the frame is (e.g., r102914.fits becomes object_K_10s.fits).

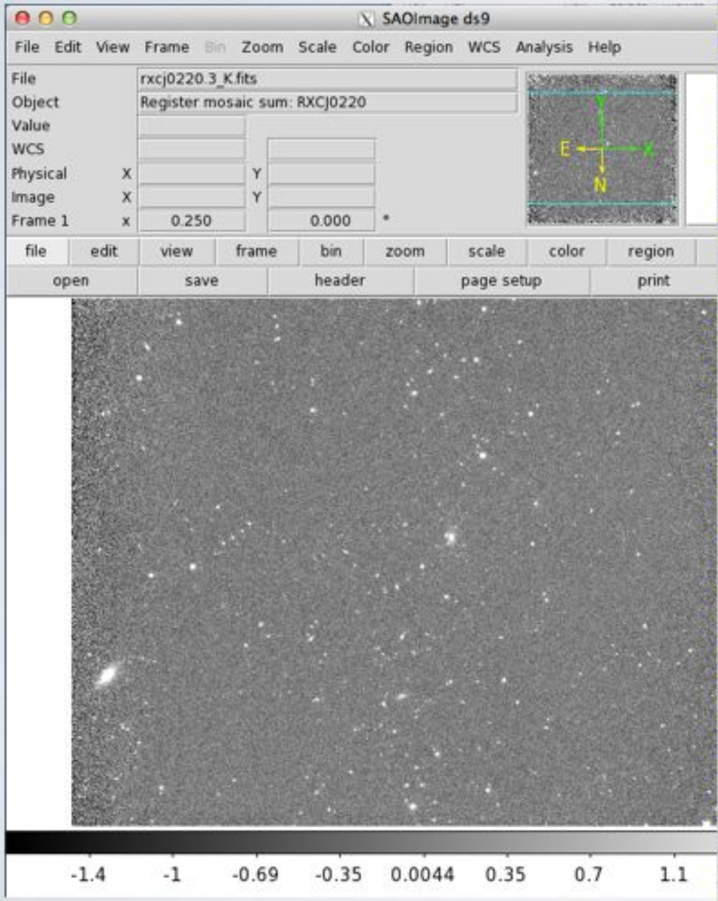


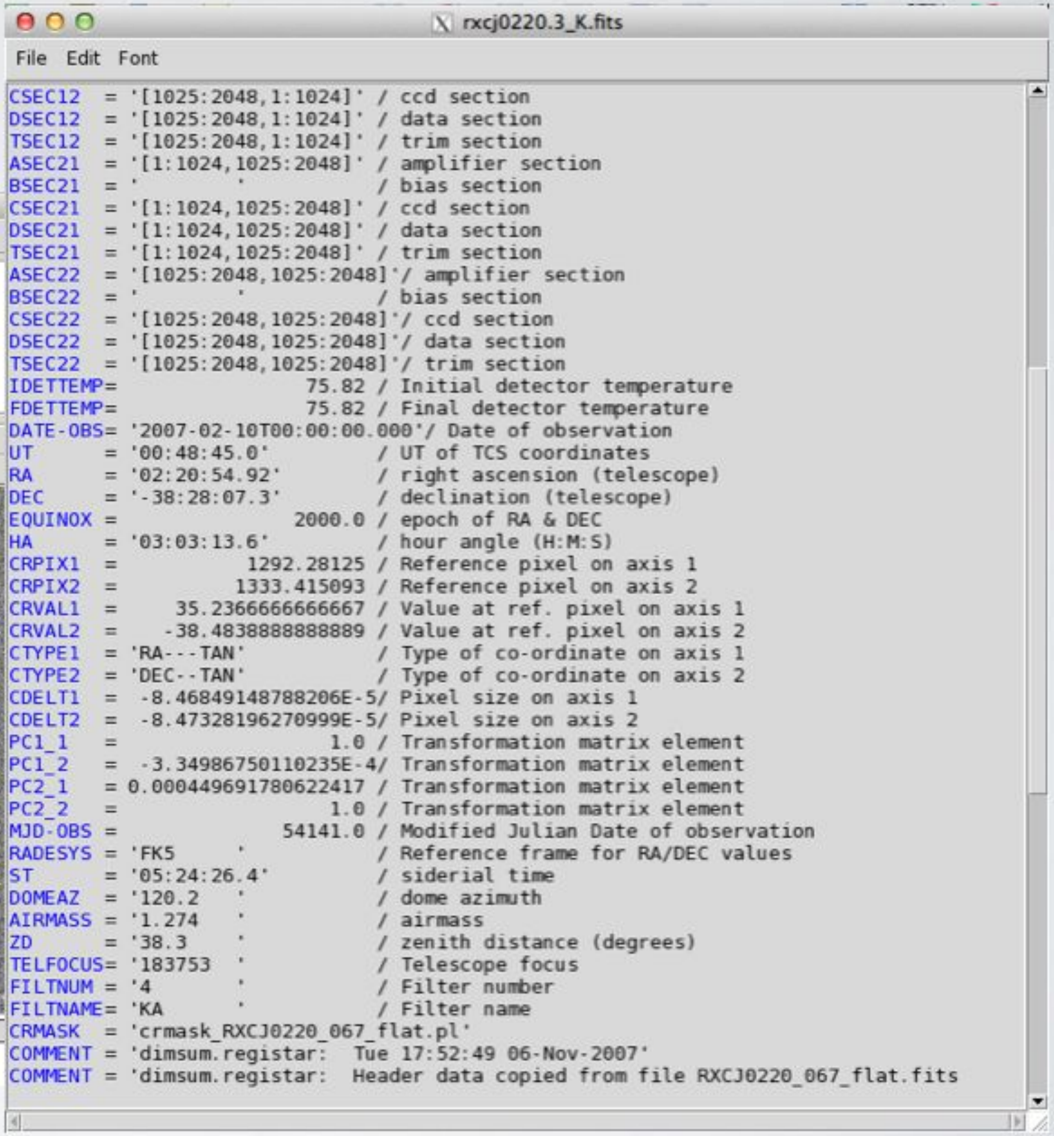
Things that will help you

2. Flexible Image Transfer System (FITS) file format : Consists of 'header' containing meta-data (most important being world-coordinate system: WCS) and a binary array containing image data. FITS can also support multiple extensions (beware the hidden extension) and some catalogues come in FITS table format.

Hint: Information for sensible re-naming can be found in the header

FITS Header


SAOImage ds9
File Edit View Frame Bin Zoom Scale Color Region WCS Analysis Help
File rxcj0220.3_K.fits
Object Register mosaic sum: RXCJ0220
Value
WCS
Physical X Y
Image X Y
Frame 1 x 0.250 0.000 °
file edit view frame bin zoom scale color region
open save header page setup print
E X N Y
-1.4 -1 -0.69 -0.35 0.0044 0.35 0.7 1.1


rxcj0220.3_K.fits
File Edit Font
CSEC12 = '[1025:2048,1:1024]' / ccd section
DSEC12 = '[1025:2048,1:1024]' / data section
TSEC12 = '[1025:2048,1:1024]' / trim section
ASEC21 = '[1:1024,1025:2048]' / amplifier section
BSEC21 = ' ' / bias section
CSEC21 = '[1:1024,1025:2048]' / ccd section
DSEC21 = '[1:1024,1025:2048]' / data section
TSEC21 = '[1:1024,1025:2048]' / trim section
ASEC22 = '[1025:2048,1025:2048]'/ amplifier section
BSEC22 = ' ' / bias section
CSEC22 = '[1025:2048,1025:2048]'/ ccd section
DSEC22 = '[1025:2048,1025:2048]'/ data section
TSEC22 = '[1025:2048,1025:2048]'/ trim section
IDETTEMP= 75.82 / Initial detector temperature
FDETTEMP= 75.82 / Final detector temperature
DATE-OBS= '2007-02-10T00:00:00.000'/ Date of observation
UT = '00:48:45.0' / UT of TCS coordinates
RA = '02:20:54.92' / right ascension (telescope)
DEC = '-38:28:07.3' / declination (telescope)
EQUINOX = 2000.0 / epoch of RA & DEC
HA = '03:03:13.6' / hour angle (H:M:S)
CRPIX1 = 1292.28125 / Reference pixel on axis 1
CRPIX2 = 1333.415093 / Reference pixel on axis 2
CRVAL1 = 35.2366666666667 / Value at ref. pixel on axis 1
CRVAL2 = -38.4838888888889 / Value at ref. pixel on axis 2
CTYPE1 = 'RA---TAN' / Type of co-ordinate on axis 1
CTYPE2 = 'DEC--TAN' / Type of co-ordinate on axis 2
CDELT1 = -8.46849148788206E-5/ Pixel size on axis 1
CDELT2 = -8.47328196270999E-5/ Pixel size on axis 2
PC1_1 = 1.0 / Transformation matrix element
PC1_2 = -3.34986750110235E-4/ Transformation matrix element
PC2_1 = 0.000449691780622417 / Transformation matrix element
PC2_2 = 1.0 / Transformation matrix element
MJD-OBS = 54141.0 / Modified Julian Date of observation
RADESYS = 'FK5 ' / Reference frame for RA/DEC values
ST = '05:24:26.4' / siderial time
DOMEAZ = '120.2 ' / dome azimuth
AIRMASS = '1.274 ' / airmass
ZD = '38.3 ' / zenith distance (degrees)
TELFOCUS= '183753 ' / Telescope focus
FILTNUM = '4 ' / Filter number
FILTNAME= 'KA ' / Filter name
CRMASK = 'crmask_RXCJ0220_067_flat.pl'
COMMENT = 'dimsum.registar: Tue 17:52:49 06-Nov-2007'
COMMENT = 'dimsum.registar: Header data copied from file RXCJ0220_067_flat.fits

Workshop

Two main datasets:

1. Optical Imaging Data: GMOS B-band imaging of cluster RXJC0220.9-3839 (@0220/optical/)

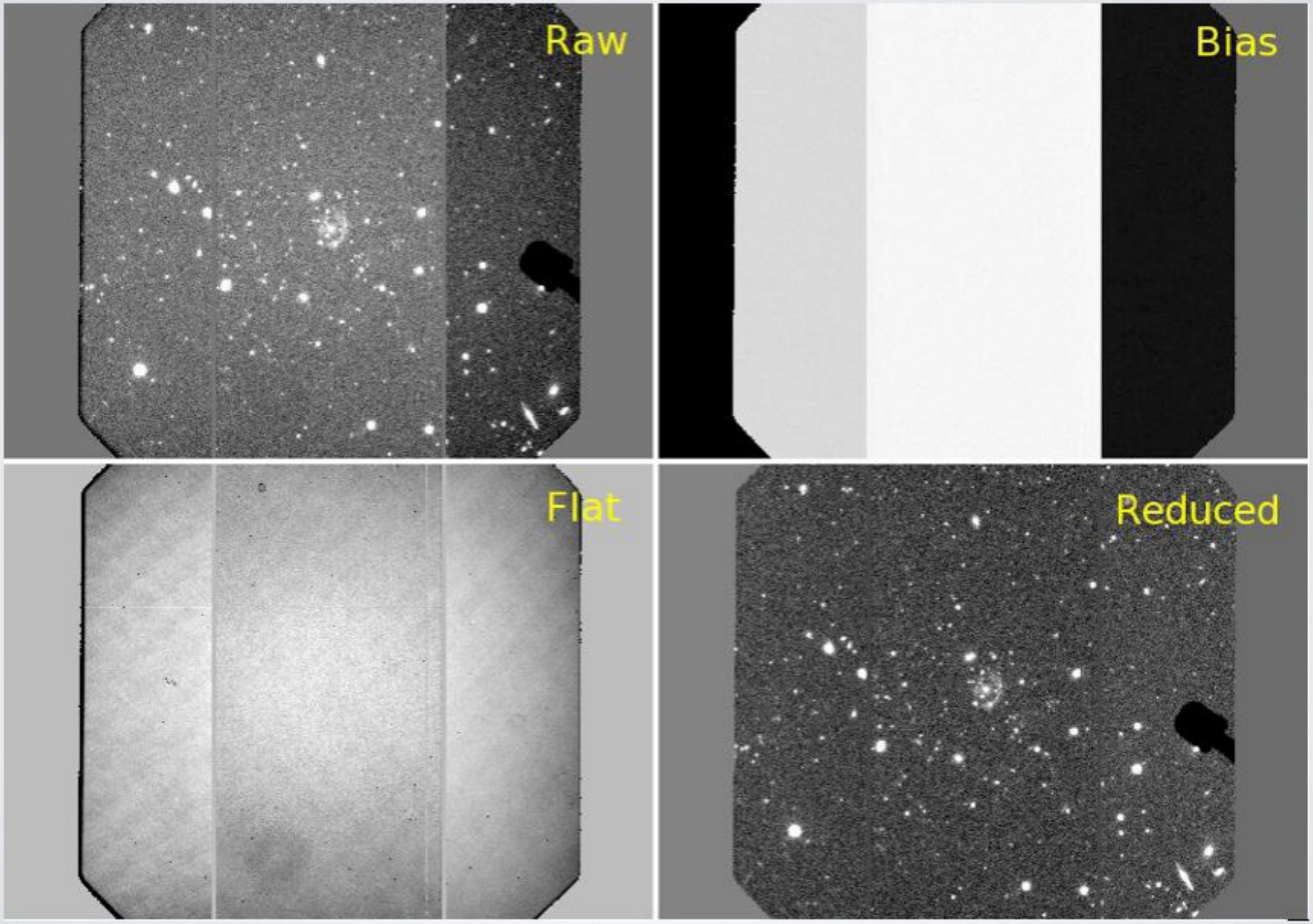
2. Near-IR imaging Data: a gravitationally lensed galaxy in Cl2243 with NIRC on Keck (@NIR/)

Ancillary datasets:

3. Pre-reduced NIR Imaging Data: J/K-band imaging of cluster RXJC0220.9-3839 (@0220/NIR)

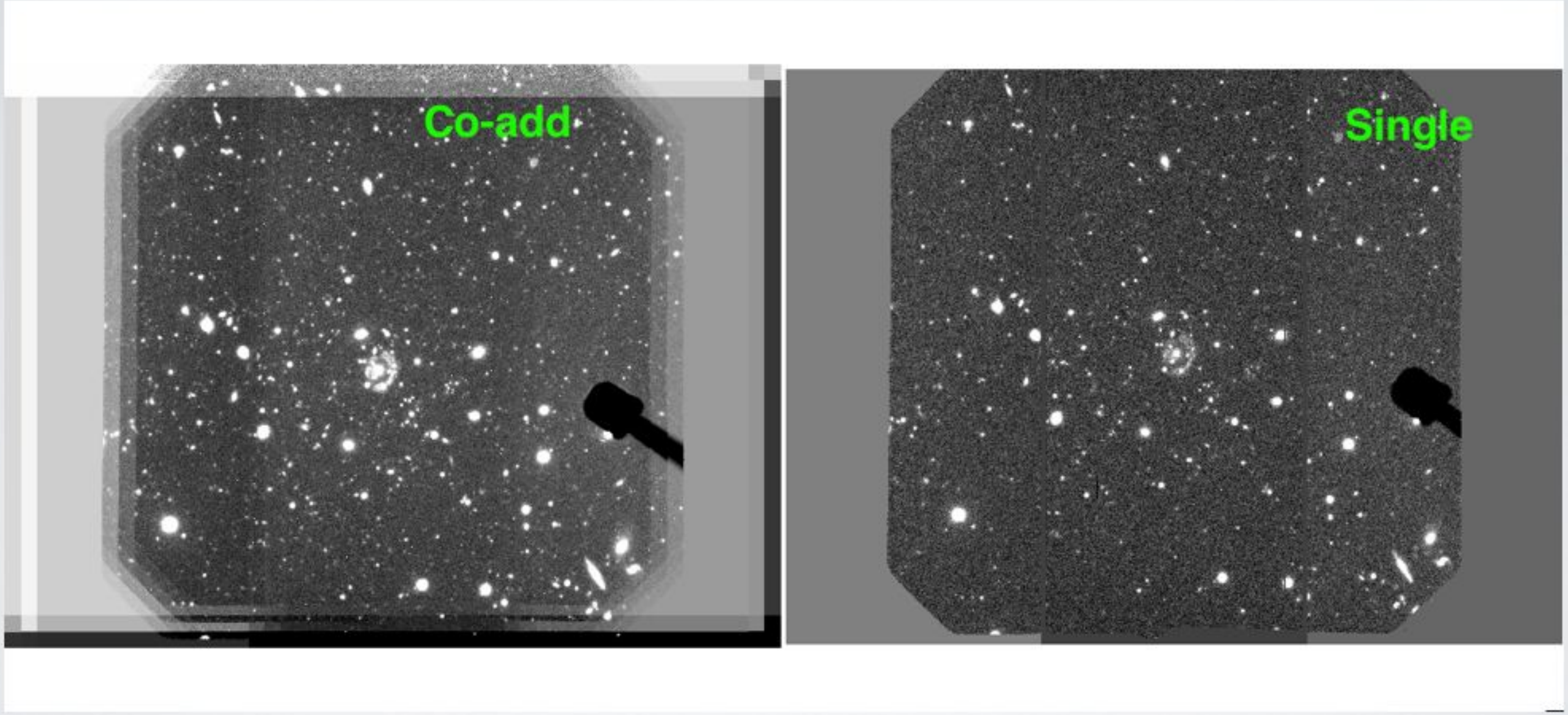
Workshop

Task 1: Reduce raw data



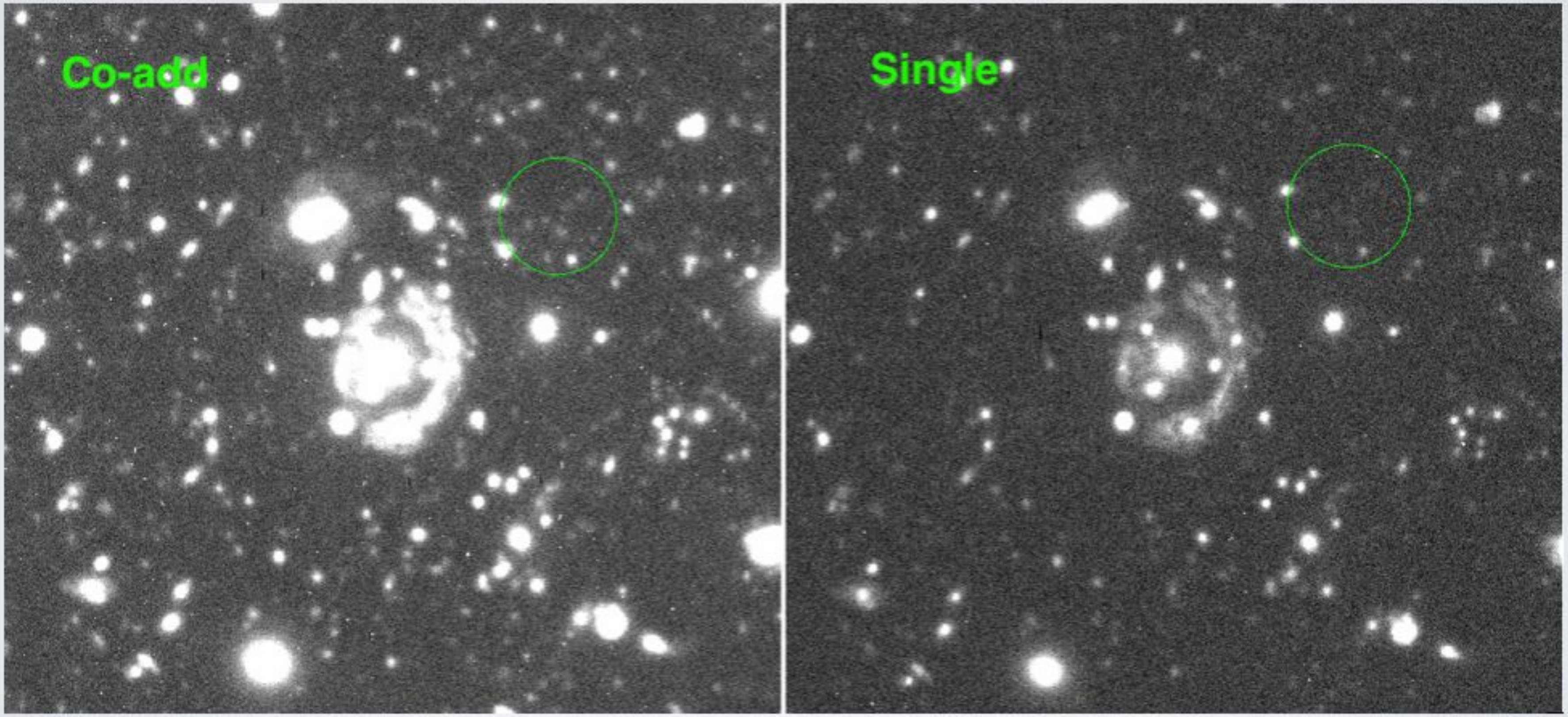
Workshop

Task 2: Co-add reduced frames



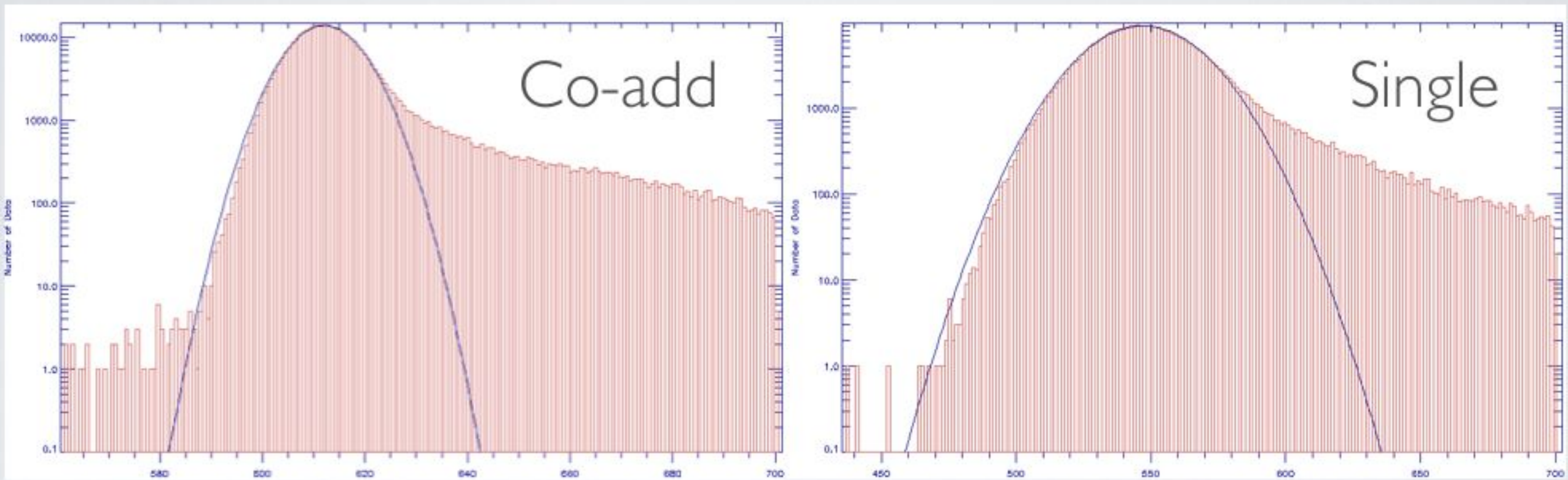
Workshop

Co-adding makes deeper images



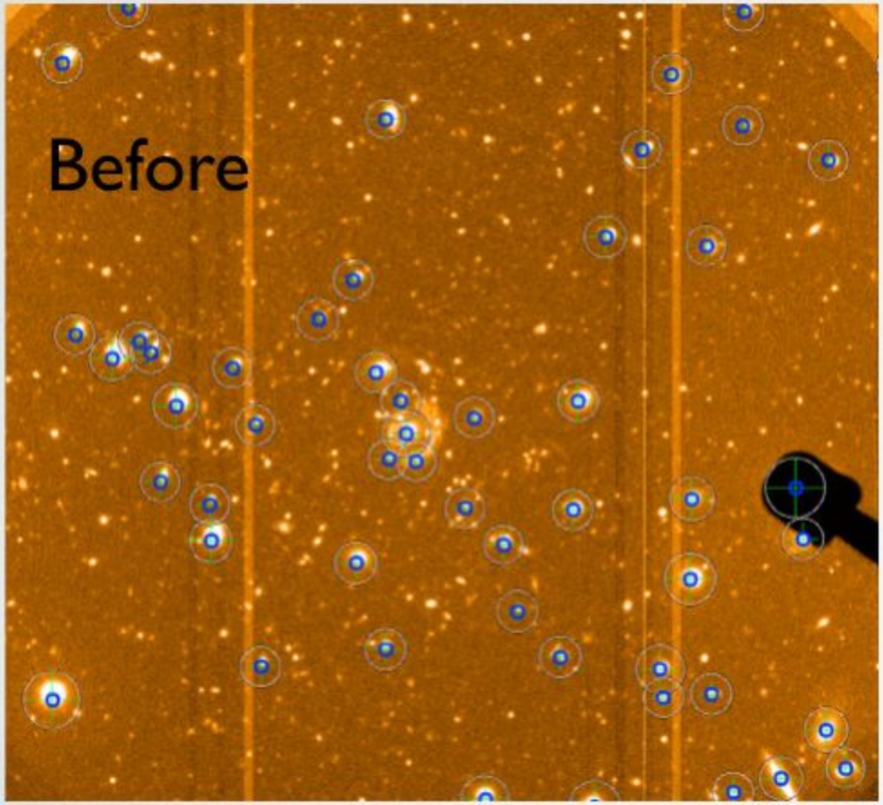
Workshop

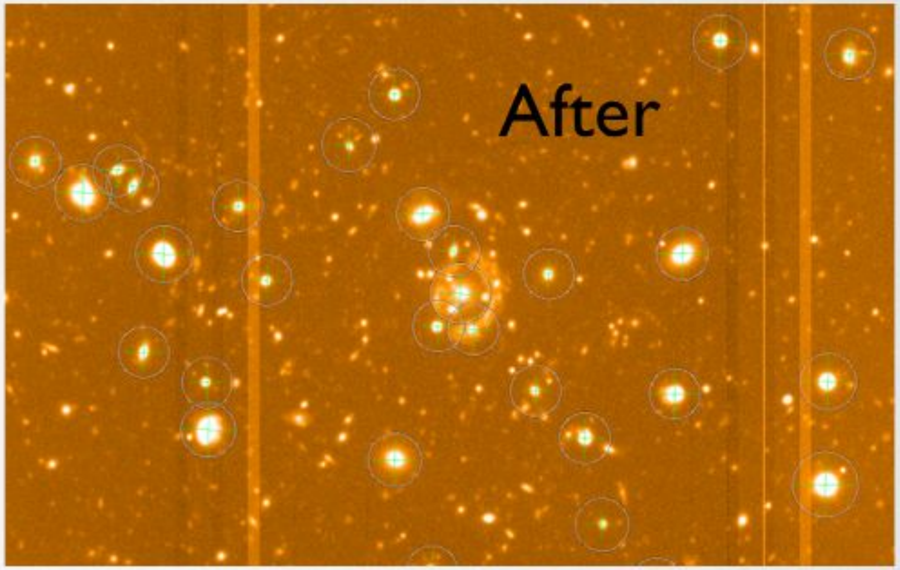
Co-adding makes deeper images



Workshop

Task 3: Calibrate Astrometry

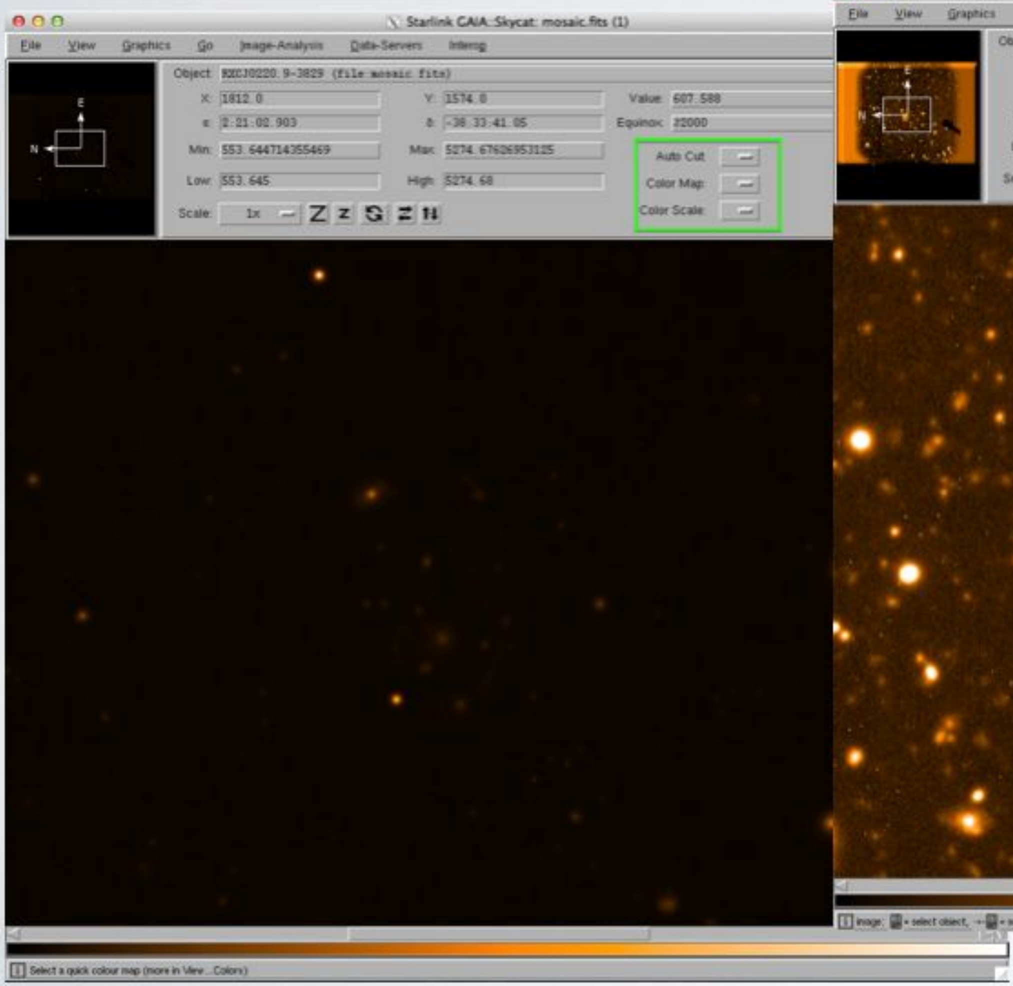


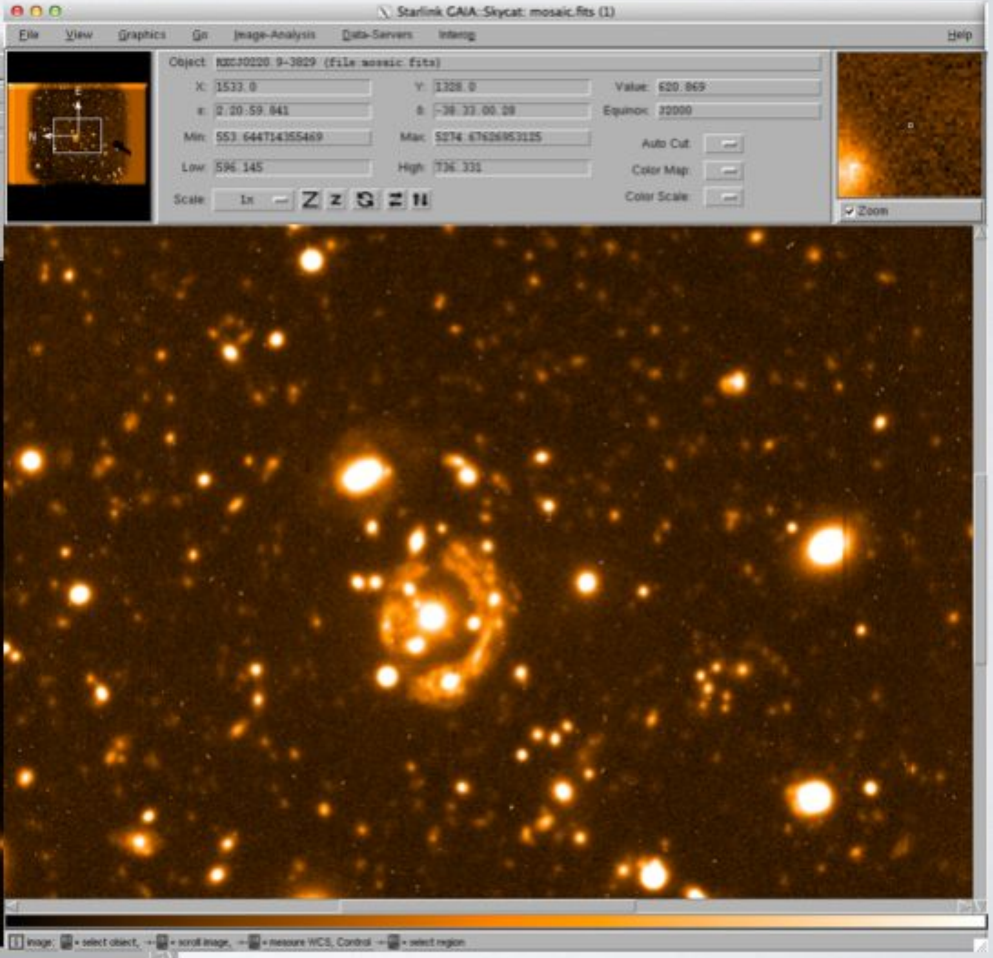


Workshop

Task 3: Calibrate Astrometry

Step 1: Open Co-add image in Gaia, adjust to your favorite colors and scales

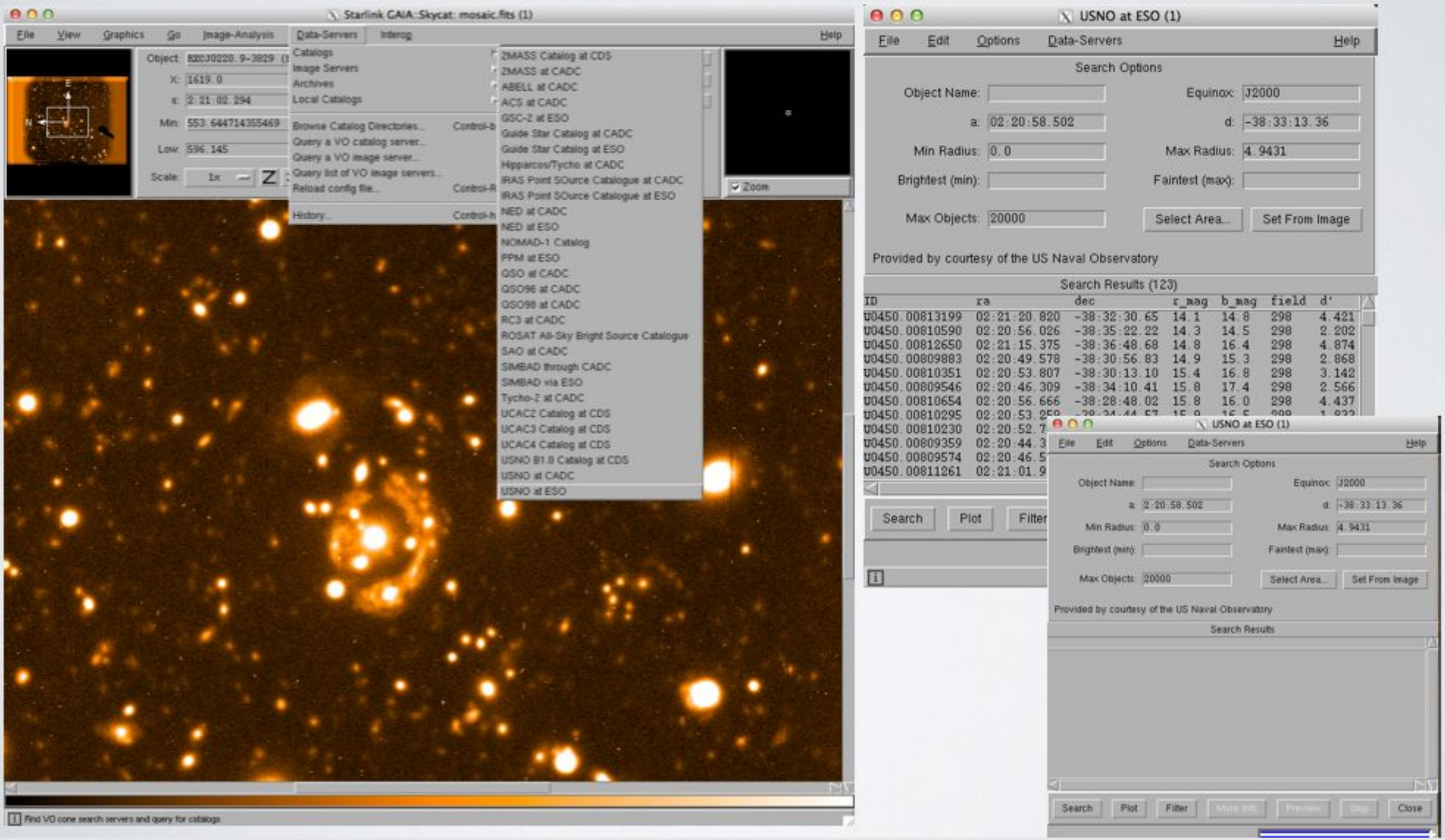




Workshop

Task 3: Calibrate Astrometry

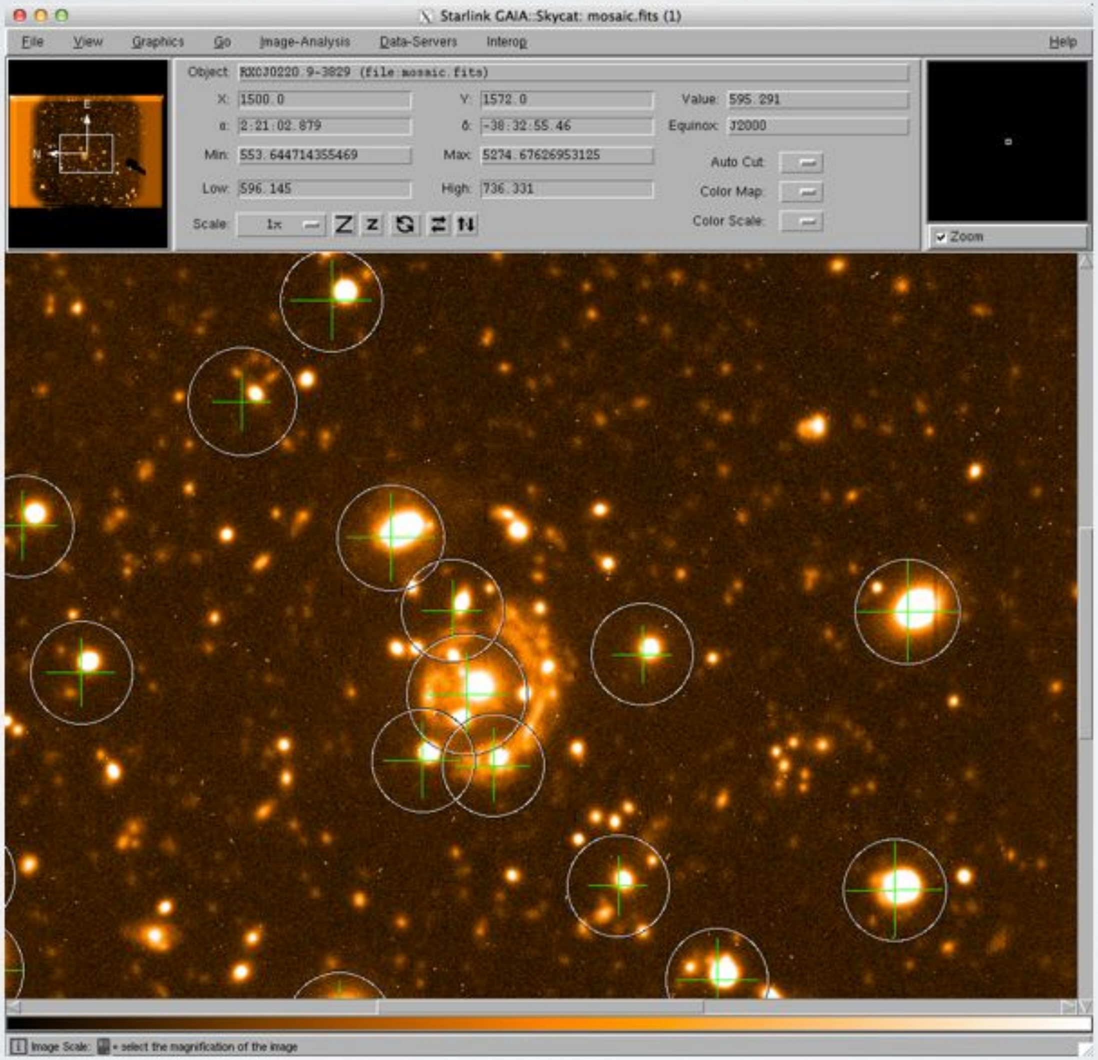
Step 2: Go to Data-Servers, Catalogs, bright object catalog USNO at ESO, search



Workshop

Task 3: Calibrate Astrometry

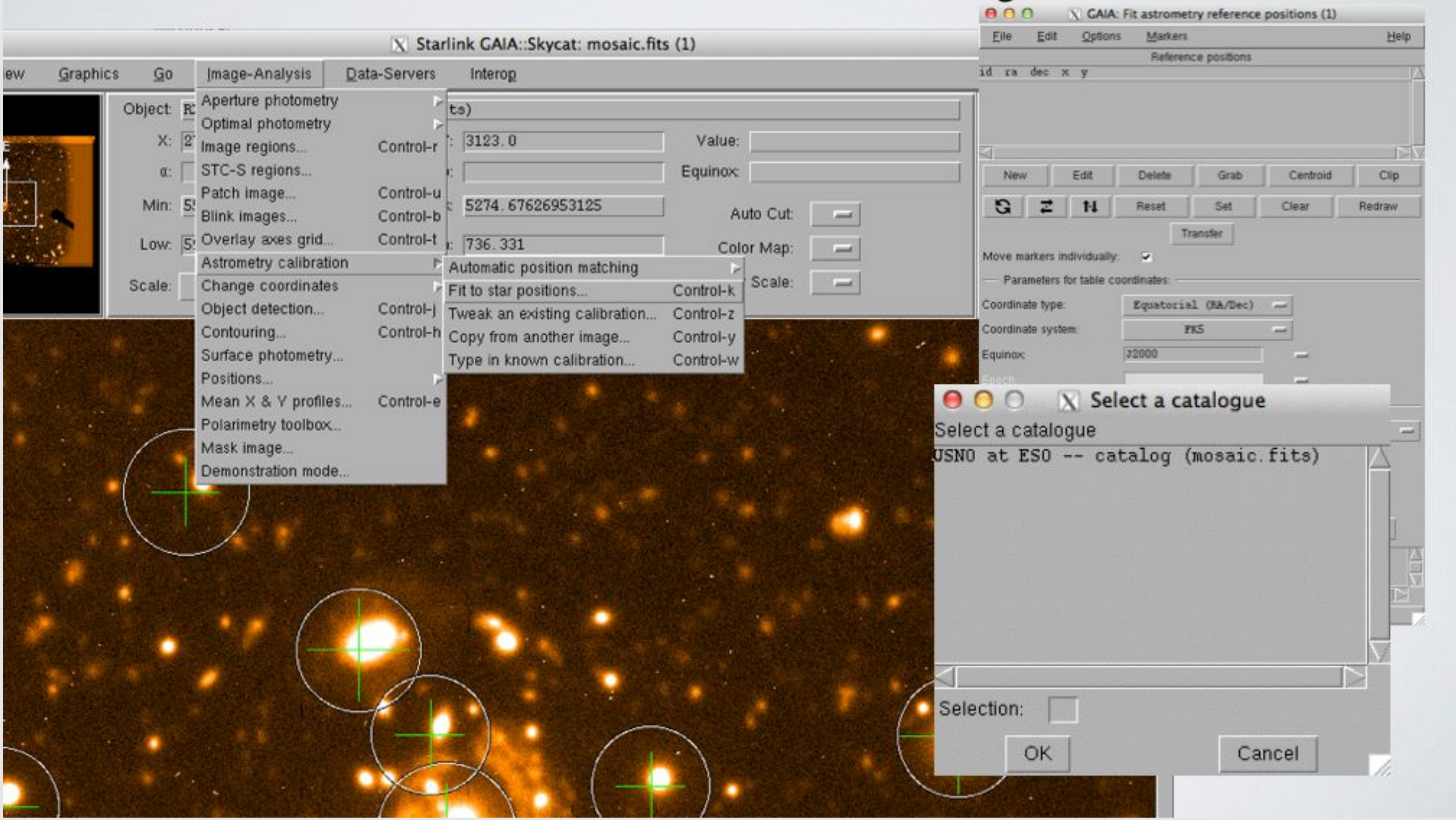
Step 2: Once click search, sources should appear, can see mismatched positions



Workshop

Task 3: Calibrate Astrometry

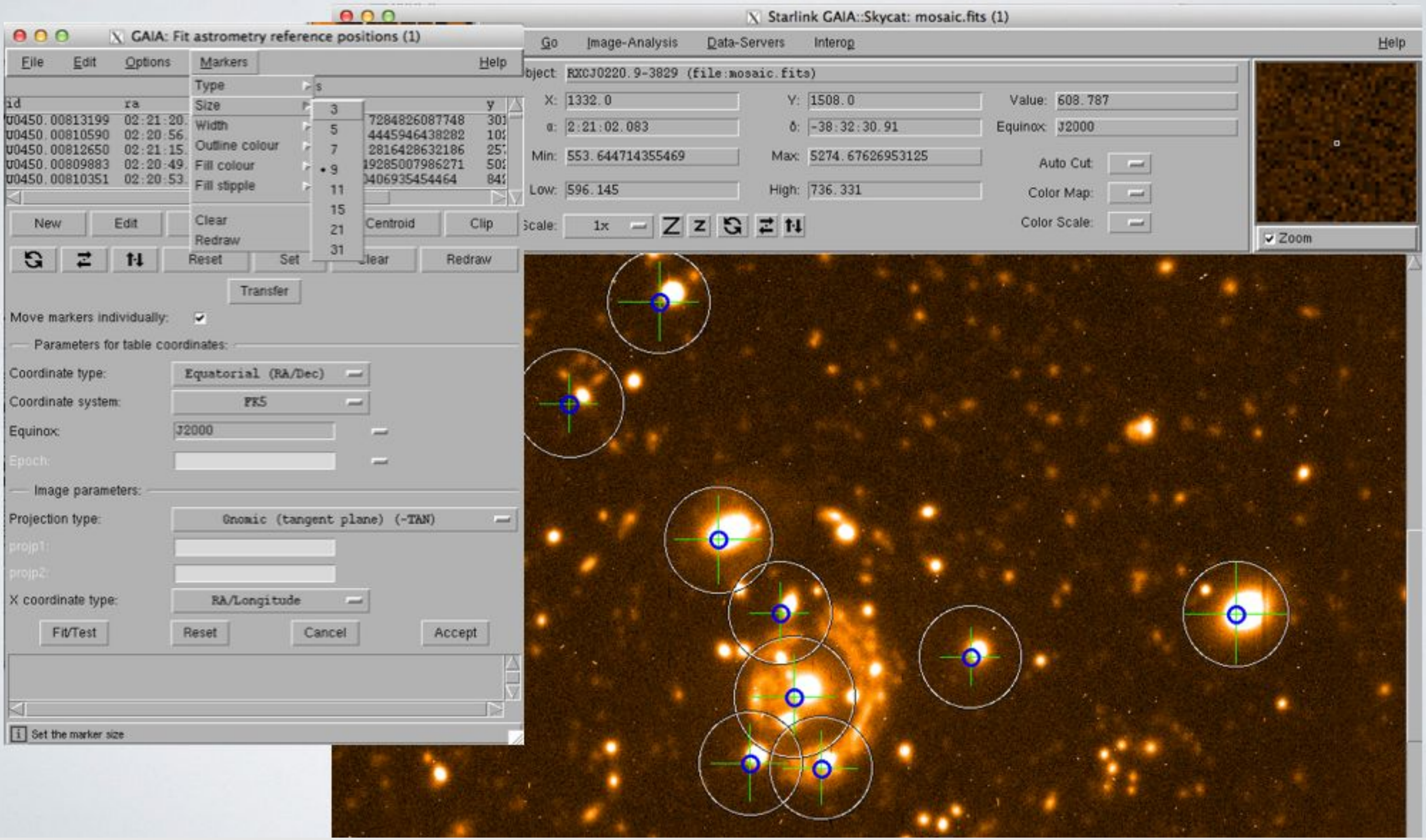
Step 3: Image-Analysis -> Astrometry calibration -> Fit to star positions -> Select the USNO at ESO catalog



Workshop

Task 3: Calibrate Astrometry

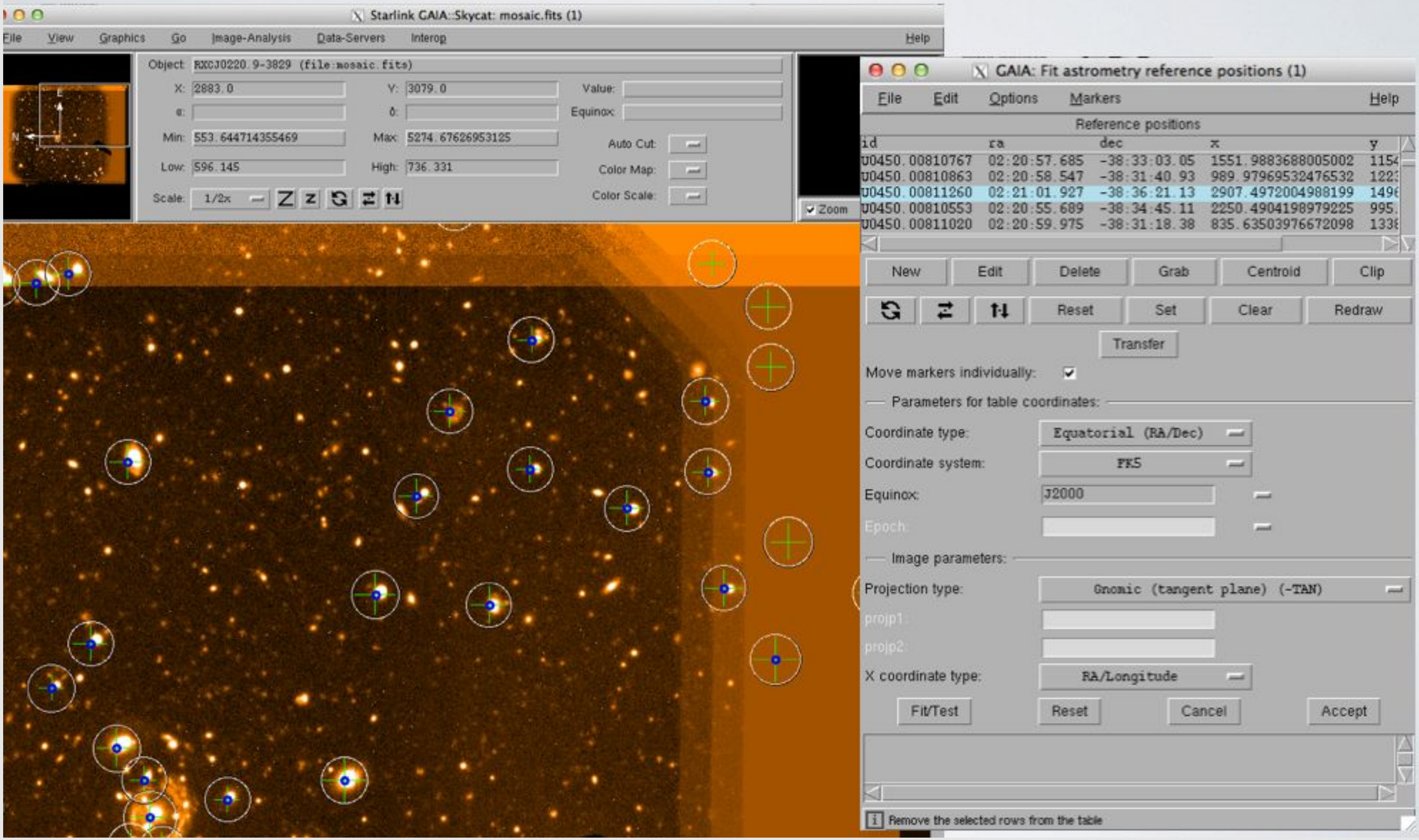
Step 4: Adjust the marker size and width



Workshop

Task 3: Calibrate Astrometry

Step 5: Clip objects outside the frame, extended objects, saturated stars

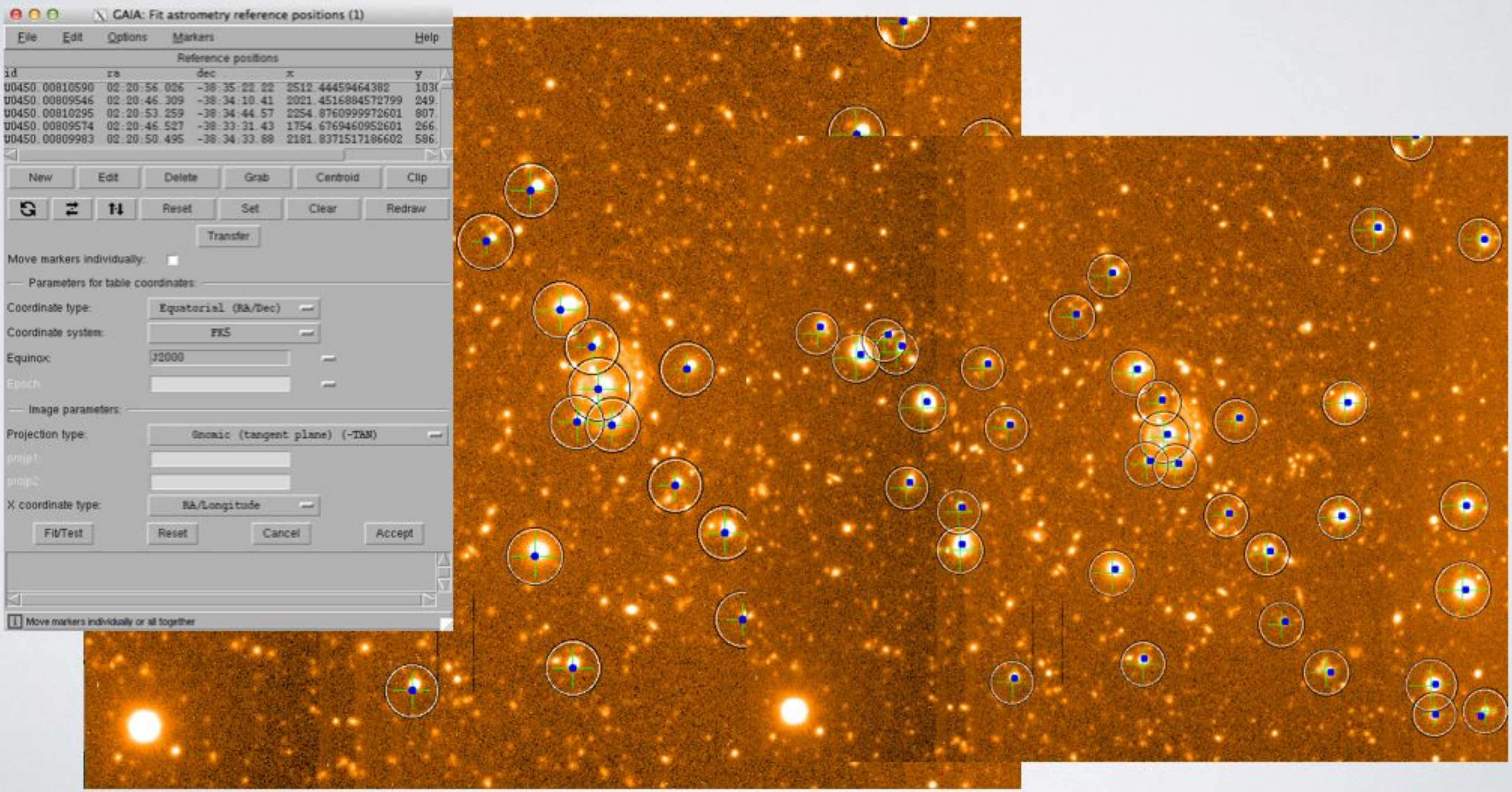


Workshop

Task 3: Calibrate Astrometry

Step 6: move markers to the right positions of the bright objects

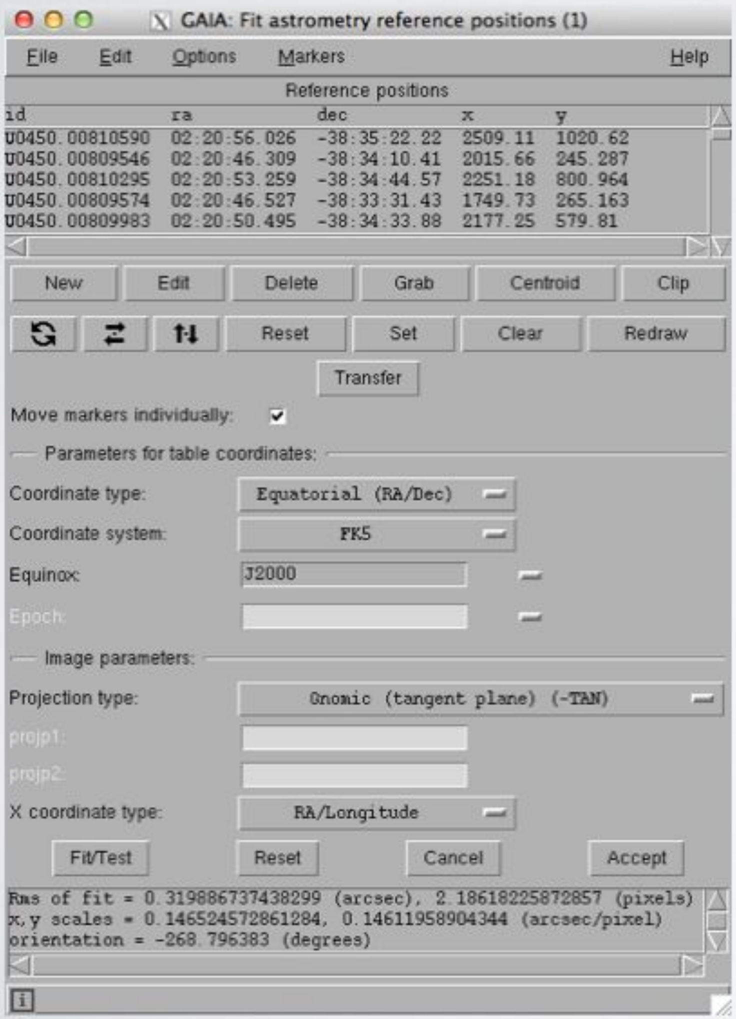
Hint: unclick Move markers individually to move all markers



Workshop

Task 3: Calibrate Astrometry

Step 7: Click Centroid, and Fit/Test, re-center and re-clip till the rms good

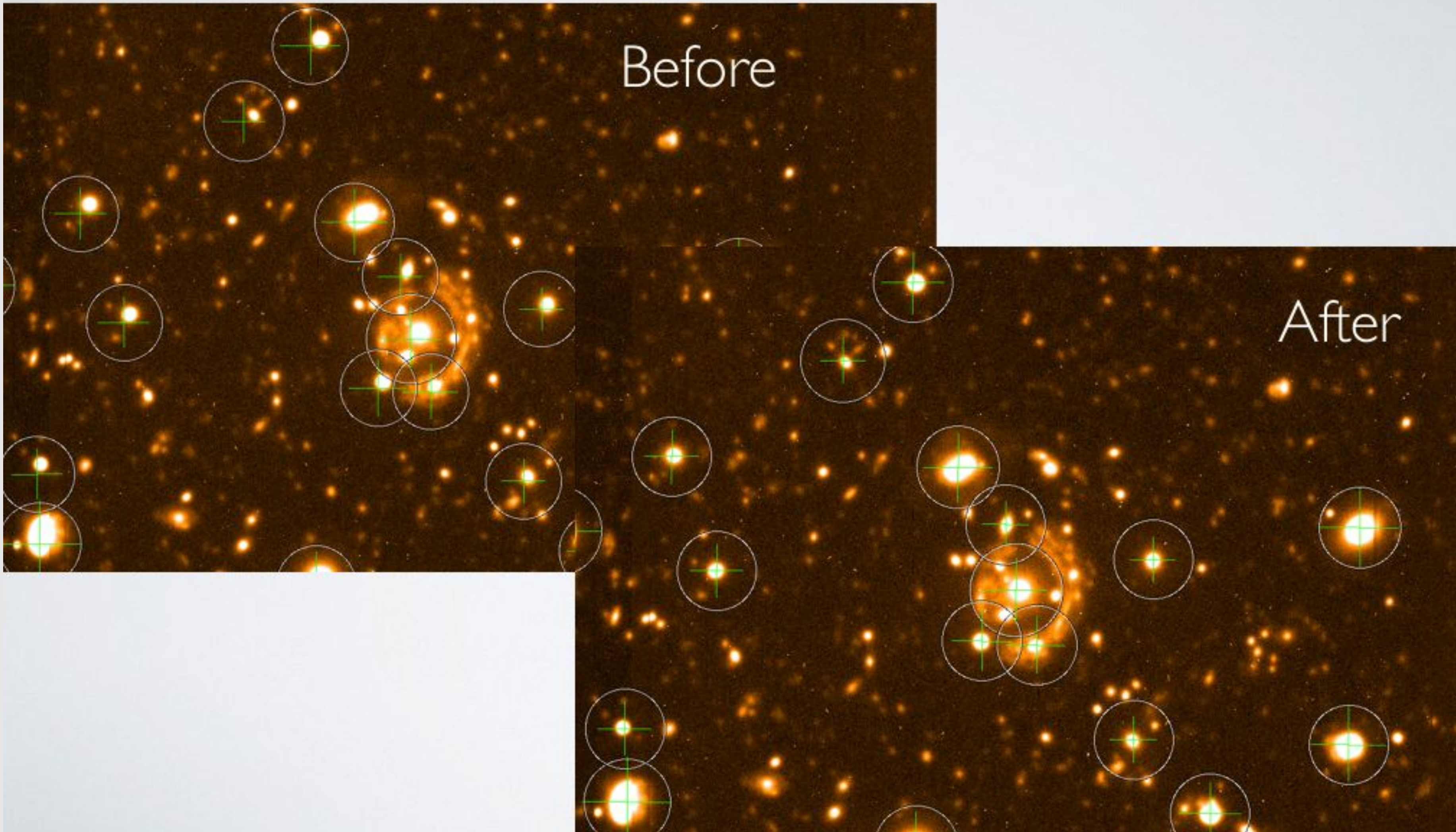


Hint: an rms of < 0.4” is acceptable in this data

Workshop

Task 3: Calibrate Astrometry

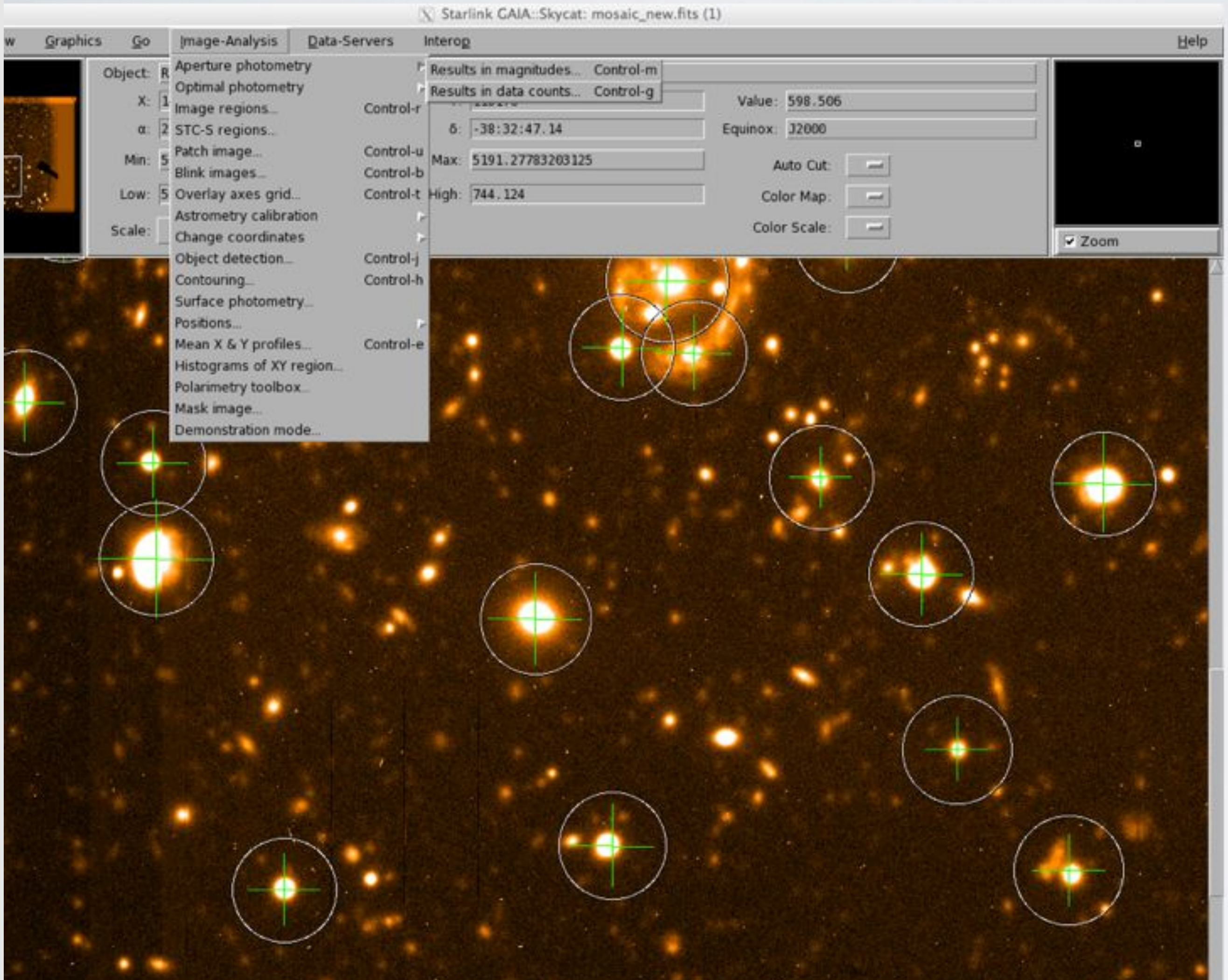
Step 8: when the fit is good, click Accept and save the image



Workshop

Task 4: Flux calibration

Step 1: Image Analysis -> Aperture Photometry -> Results in data counts



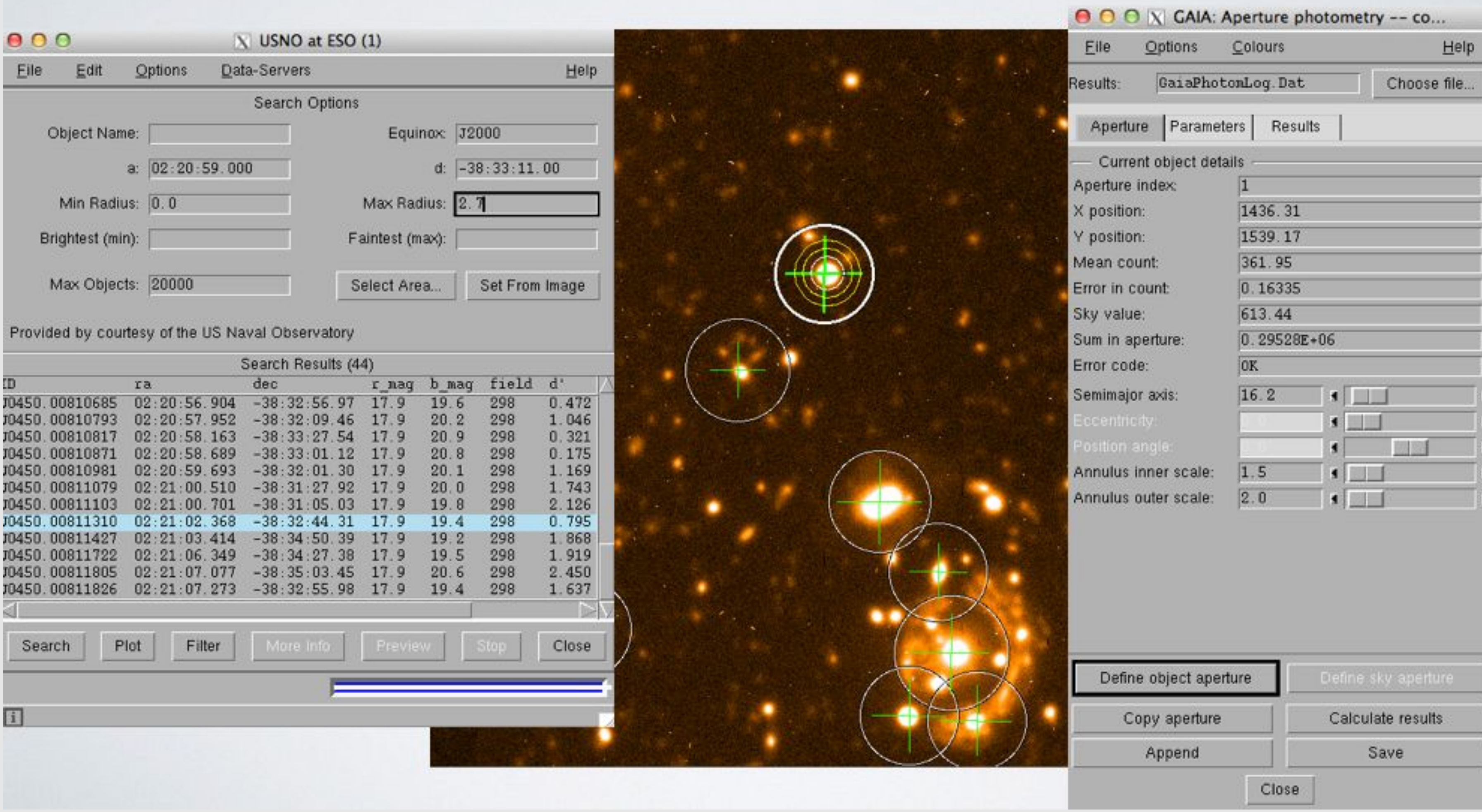
Hint:
Goal is to find the zero point (magnitude = Zpt - 2.5*log(flux))

Workshop

Task 4: Flux calibration

Step 2:Define an aperture by dragging the cursor -> Calculate results

Hint: Use the B-band magnitude from the catalog as the reference



Workshop

Task 5: Do some science

1. What is the pixel scale, in arcsecond/pixel, on the GMOS image?
2. What is the seeing (the FWHM of a point source in arcseconds) of the GMOS image?
3. What is the zero-point of the GMOS image?
4. What is the S/N and magnitude of the galaxy at 02:20:53.754 -38:32:45.48?
5. Make a histogram of the S/N of all the detected objects in the frame, as well as a histogram of the magnitudes. What is the 5-sigma limiting magnitude?

There are also reduced J/K-band images available in 0220/NIR/ directory

6. Align these images with the optical image and make a color image (Hint: use hastrom in IDL to align the images)
7. Run SExtractor in dual-mode and make a color-magnitude diagram on K vs J-K of all the detected objects. (Hint: see the SExtractor manual for dual-mode extraction)