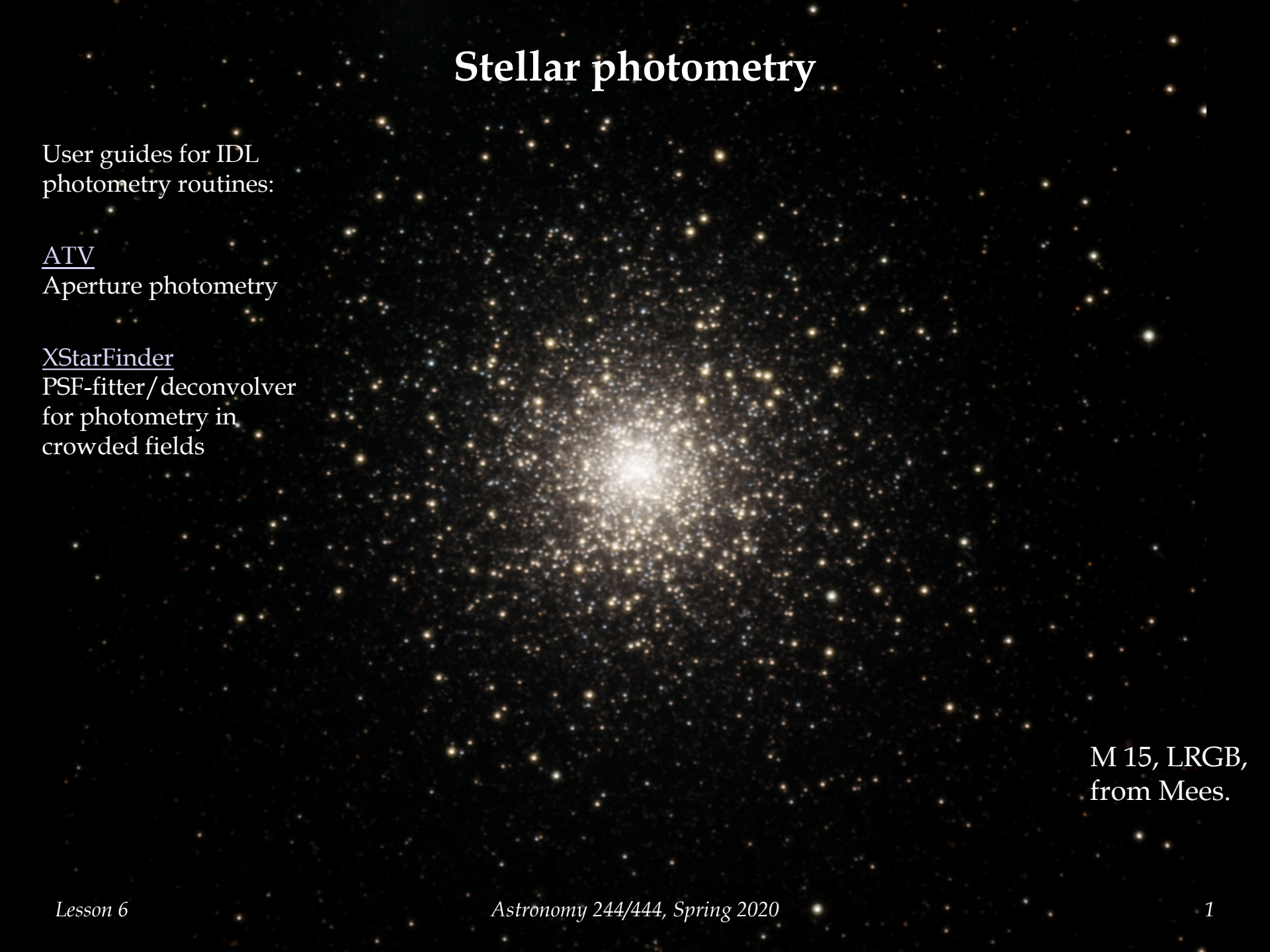
Stellar photometry

User guides for IDL photometry routines:

ATV
Aperture photometry

XStarFinder
PSF-fitter/deconvolver for photometry in crowded fields

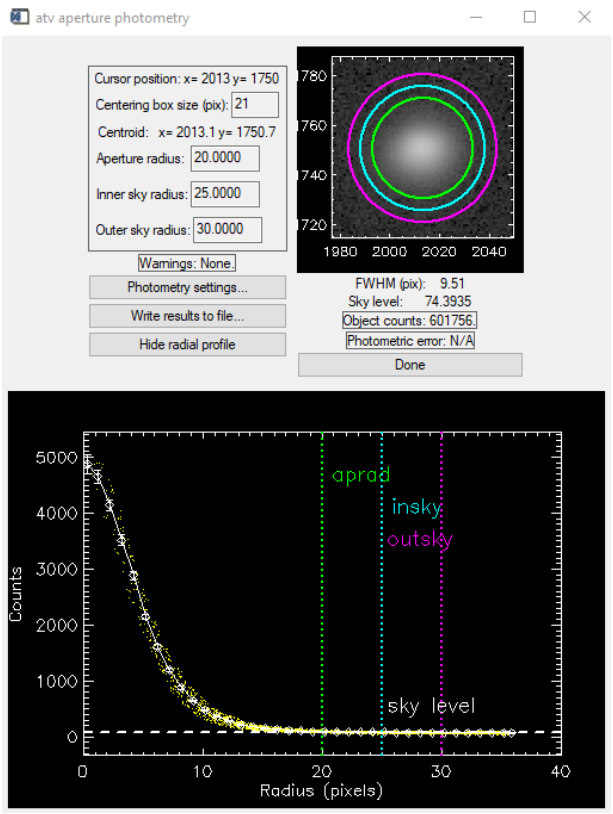


M 15, LRGB, from Mees.

For calibration stars and uncrowded fields

If stars in an image are not very close together, most of us will measure the stellar fluxes or magnitudes using **aperture photometry**.

- Add the DNs from each pixel within
  - an aperture centered on the star, with aperture radius large enough to contain all the stellar flux, and
  - within an annulus centered on the star that contains nothing but background emission.
- Multiply the annulus DNs by ratio of number of pixels in aperture and annulus, and subtract from aperture DNs.
  - This is automatic, in ATV.



For calibration stars and uncrowded fields (continued)

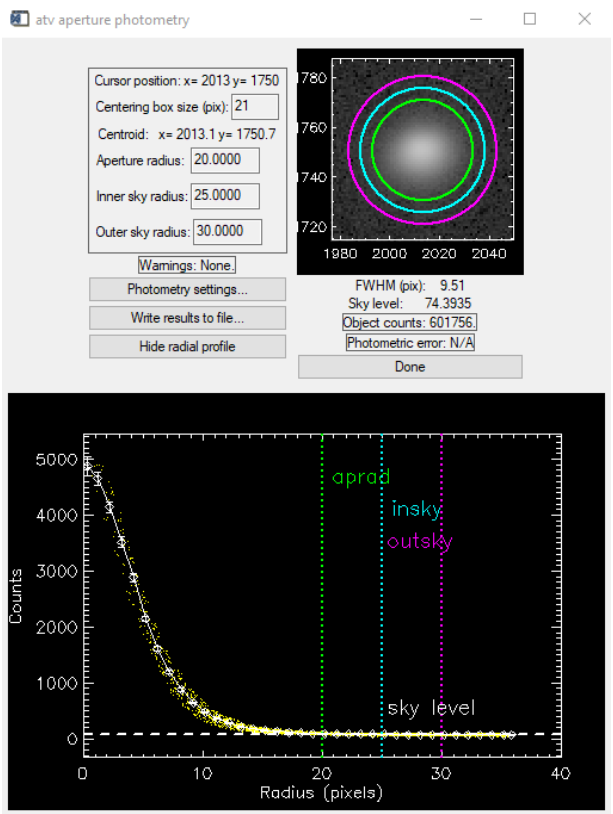
- If the target is a calibration star, this is one measurement of the flux density-to-DN conversion ratio, C: as discussed in Lesson 2:

$$C = \frac{F}{DN_{\text{aperture}} - DN_{\text{sky}}} = \frac{10^{-m/2.5} F_0}{DN_{\text{aperture}} - DN_{\text{sky}}}$$

  where m is the star's magnitude in the filter that's in use, and F_0 the zero-magnitude flux density in that filter, corrected for atmospheric extinction (Lesson 2, page 27).

- If not, its magnitude in that filter is

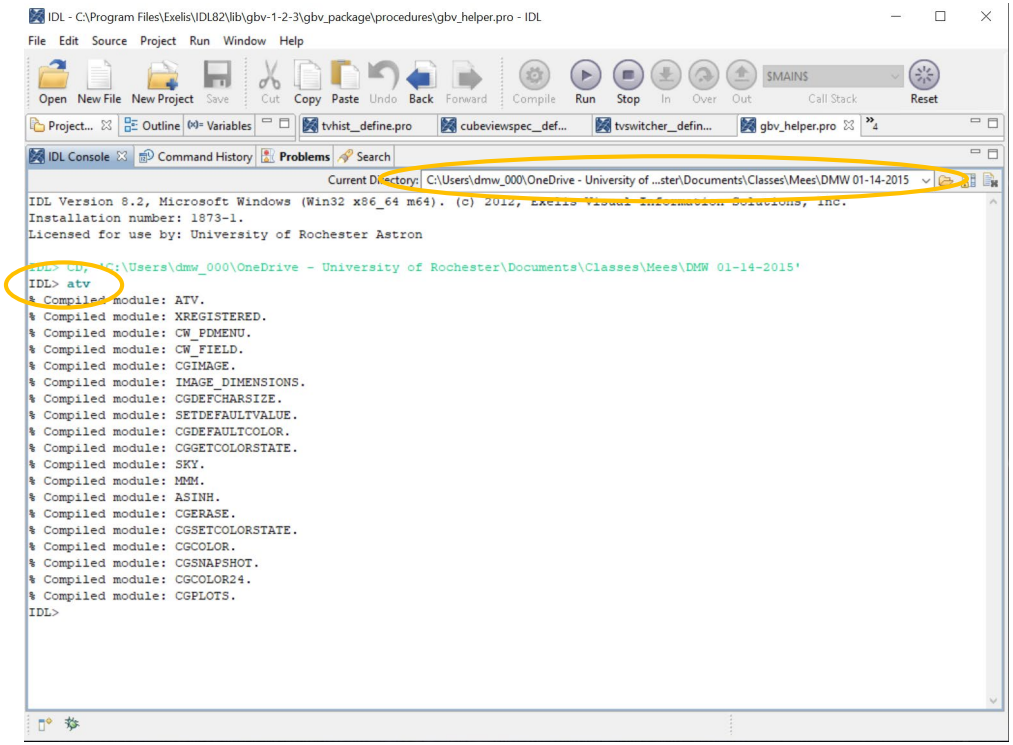
$$m = 2.5 \log\left(F_0 \Big/ C\left[DN_{\text{aperture}} - DN_{\text{sky}} \right] \right) \quad .$$



Typical aperture photometry tool: ATV

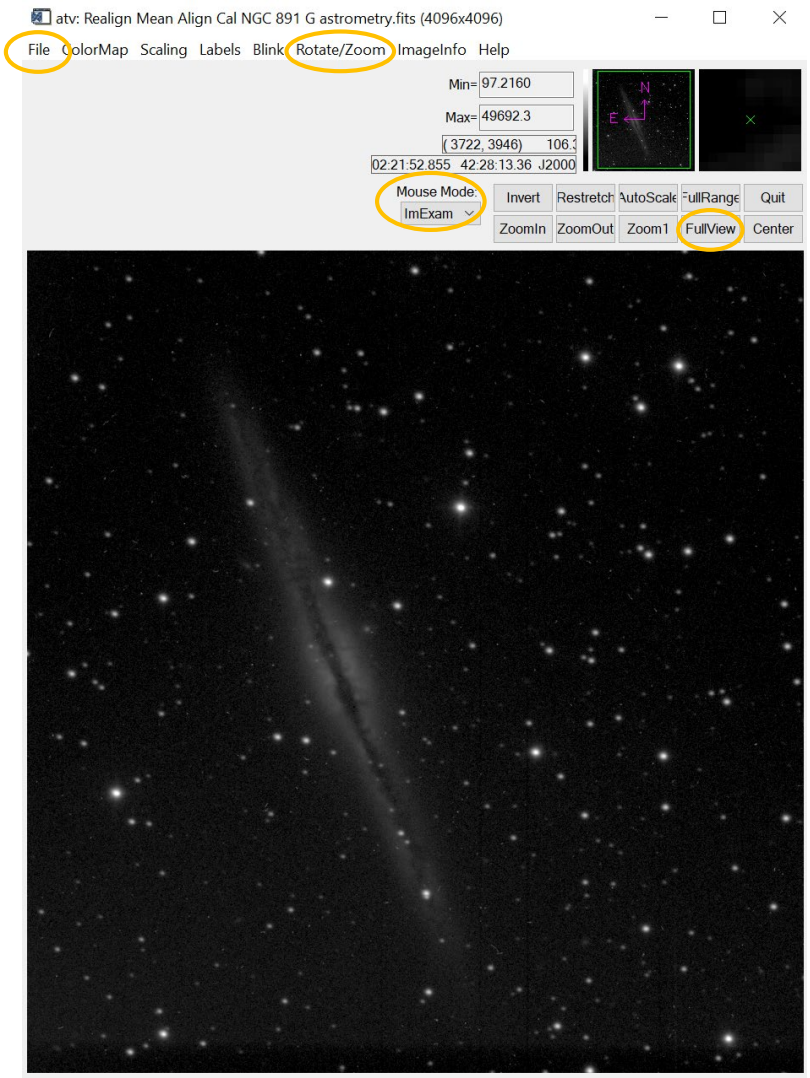
ATV, written by Aaron Barth, is a widely-used IDL application for browsing images and performing aperture photometry. Here's a basic step-by-step guide.

- Start IDL. 
- Browse to the directory containing the data.
- Type atv <enter> at the IDL> prompt.
- This produces the main ATV window (next page).



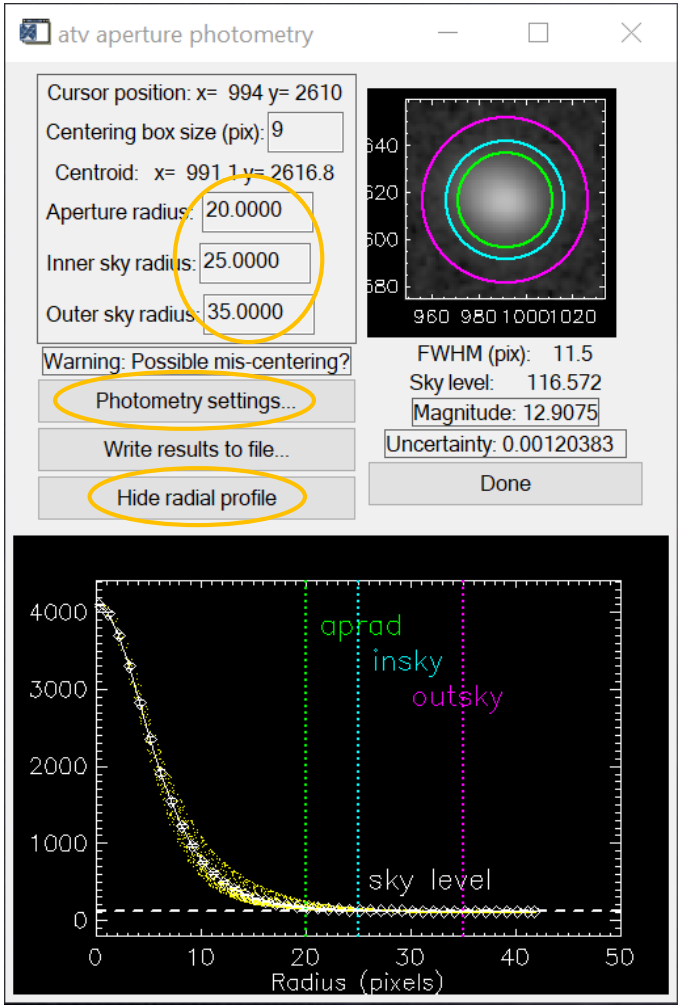
ATV (continued)

- File > ReadFits to open image
  - We presume this image is calibrated and normalized
- FullView button to see whole image
- Rotate/Zoom > Invert Y to make it right side up, if it's a Mees image
- Mouse Mode > ImExam to start photometry mode
- Click a star. This brings up the atv aperture photometry window.



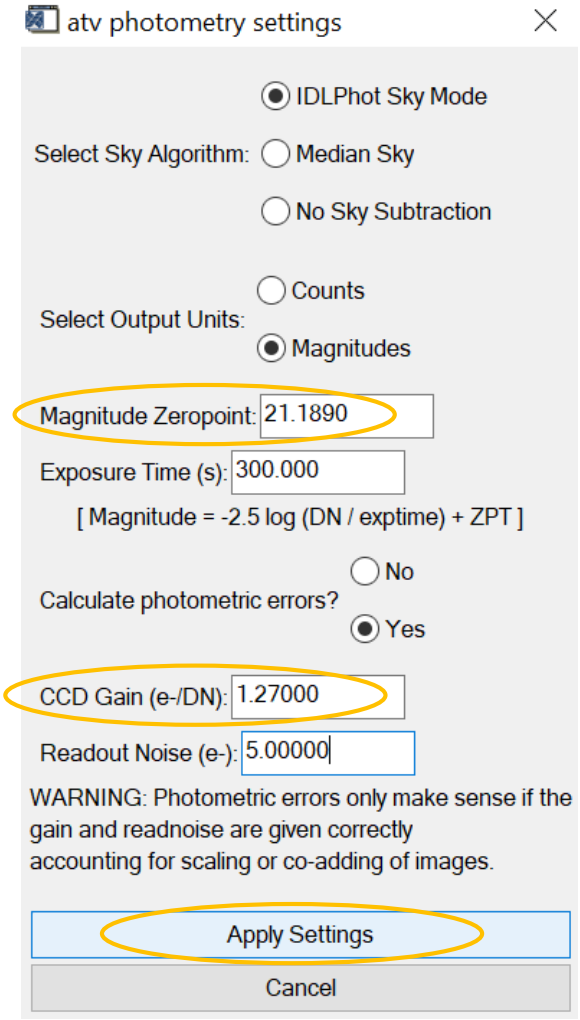
ATV (continued)

- Click Show radial profile to see the whole window.
- Adjust the settings:
  - Aperture radius, inner and outer sky radius, so that aperture contains stellar flux and annulus is unlikely to contain other stars.
  - <Enter> after changing each parameter.
- Photometry settings... button brings up a dialogue by that name, with parameters to set.



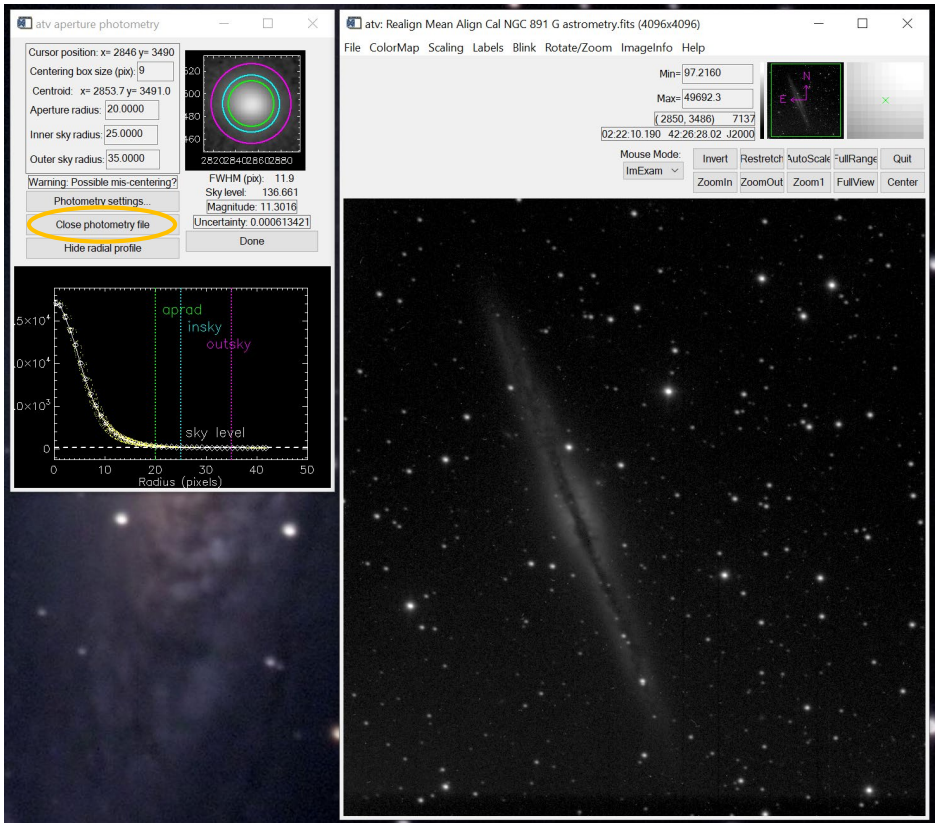
ATV (continued)

- Choose your favorite among counts (DN) and magnitudes. I usually choose counts.
- If you want magnitudes, set the Magnitude Zeropoint, according to the DN/exposure time for zero magnitude (from your flux calibration) and the formula in this window.
- If you want photometric errors displayed, enter
  - the CCD Gain (1.27 e/DN; see Lesson 1)
  - the applicable noise in the image, e.g. from the CCDStack Info window
- It is very easy to underestimate noise. You will ordinarily deserve to get 0.05 mag, or as small as 0.01 mag with great effort.



ATV (continued)

- If you want the counts or magnitudes of several stars in the image, click Write results to file in the atv aperture photometry window.
- Then click away on those stars in the image, also pushing the Close photometry file when you're done.



x	y	r	insky	outsky	sky	mag	err	fwhm
989.9	2616.9	20.0	25.0	35.0	116.801	12.9054	0.00120174	11.84
856.7	2347.8	20.0	25.0	35.0	123.923	12.0863	0.000832432	11.42
1397.1	1689.7	20.0	25.0	35.0	124.359	12.8910	0.00117970	11.57
1532.1	1670.8	20.0	25.0	35.0	125.657	12.9645	0.00128254	13.97
2264.9	2778.2	20.0	25.0	35.0	216.200	9.98286	0.000395364	13.70
2853.7	3491.0	20.0	25.0	35.0	136.661	11.3016	0.000613421	11.92

Other aperture photometry programs

This process can be automated, using routines in or descended from the Goddard Space Flight Center Astronomy Library:

- astrolib, for IDL (at right)
- photutils within astropy or astroconda, for python
- All based on DAOPHOT, a well tested set of routines written and maintained by Peter Stetson, and often used with IRAF.
- Dangerous to automate, without some experience on your images with aperture photometry by hand using the likes of ATV.

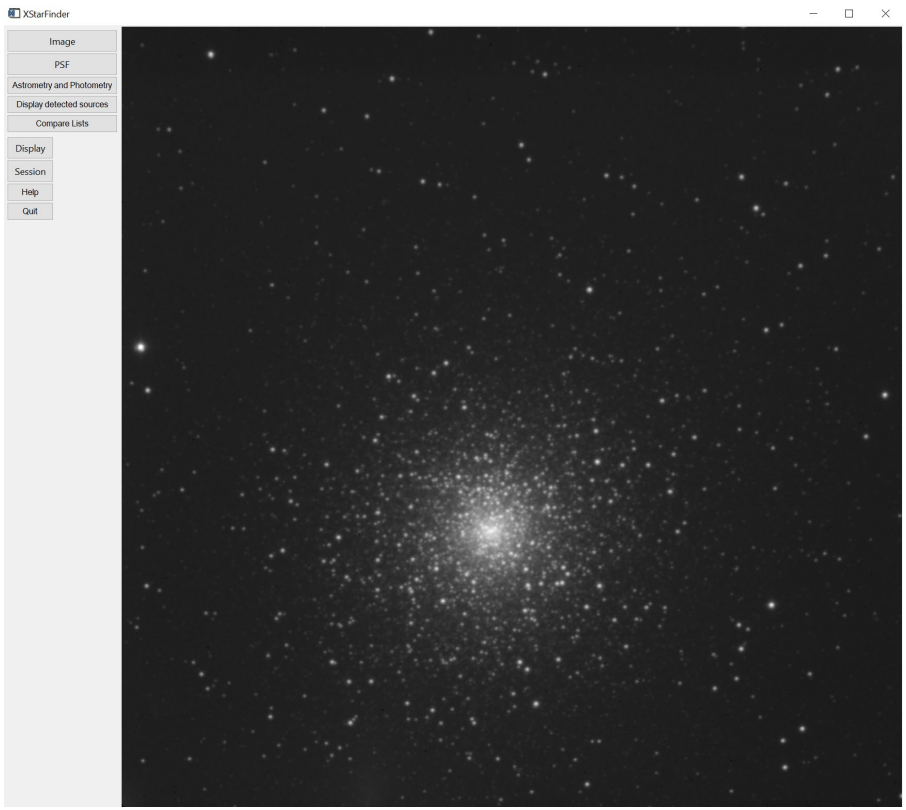
DAOPHOT-Type Photometry Procedures

- README
- APER Circular APERture photometry
- CNTRD Obtain the centroid of a star by locating where derivatives go to zero
- DAOERF Calculate the intensity, (and optionally, the derivatives) of a bivariate Gaussian, integrated over pixels. Called by DAO_VALUE
- DAO_VALUE Obtain the value of a DAOPHOT PSF function at a given set of points
- FIND FIND point sources within an image
- GCNTRD Determine centroid by Gaussian fits to the marginal X,Y distributions
- GETPSF Obtain a PSF (Gaussian + residuals) from isolated stars.
- GROUP Place stars with non-overlapping PSF's in distinct groups
- MMM (Mean, Median, Mode) sophisticated sky background computation
- NSTAR Simultaneous PSF fitting of a group of stars
- PIXWT() Compute the area of a circle-rectangle overlap (called by APER)
- PKFIT Fit a Gaussian + residuals to a isolated star (called by GETPSF)
- RDPSF Read a PSF file that was created by GETPSF into an IDL array.
- RINTER Cubic Interpolation at a set of reference points, optionally obtain derivatives. (in /image)
- SKY Compute image sky level using MMM
- SRCOR Correlate the source positions in two different lists
- SUBSTAR Subtract a scaled PSF at specified star positions
- T_APER Driver procedure for APER with I/O to a disk FITS ASCII table
- T_FIND Driver procedure for FIND with I/O to a disk FITS ASCII table
- T_GROUP Driver procedure for GROUP with I/O to a disk FITS ASCII table
- T_GETPSF Driver procedure for GETPSF with I/O to a disk FITS ASCII table
- T_NSTAR Driver procedure for NSTAR with I/O to a disk FITS ASCII table
- T_SUBSTAR Driver procedure for SUBSTAR with I/O to a disk FITS ASCII table

For crowded fields

If there are many stars in the image; if they are crowded in parts; and if the stellar images are well sampled; **automated PSF photometry** is best:

- Supply or calculate a PSF for the image.
- Find all the stars in the image above some threshold.
- Iteratively remove all the stars by CLEAN-like PSF subtraction; record centroids and total DNs for each.
- Check DNs on isolated stars with aperture photometry.

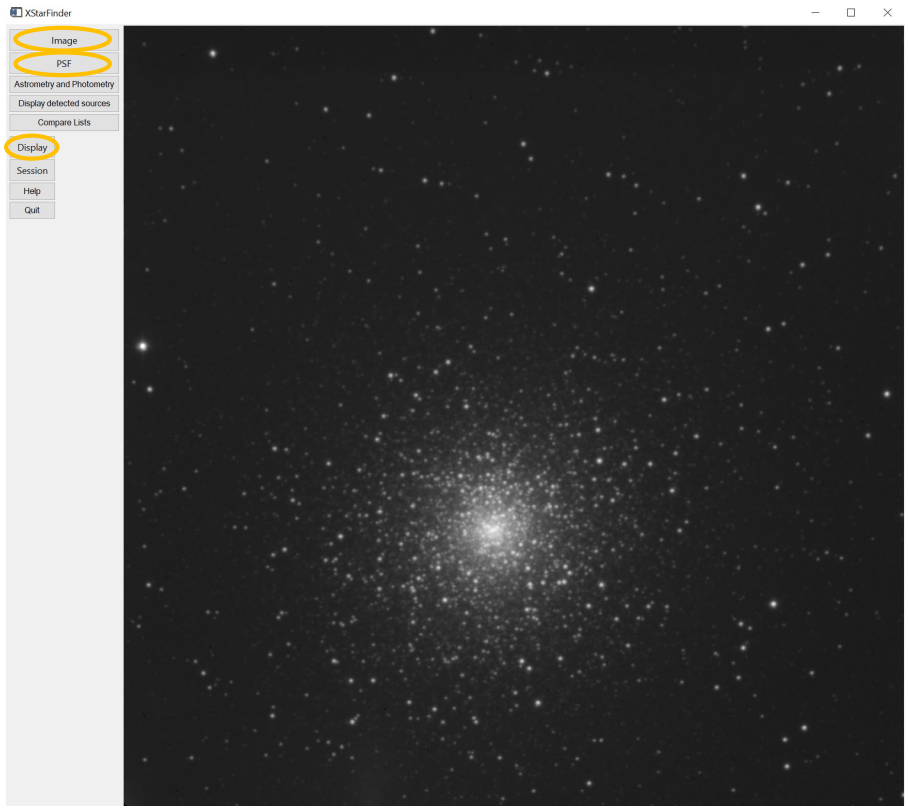


M 15, on a not-so-great night in October 2016.

Typical PSF photometry tool: XStarFinder

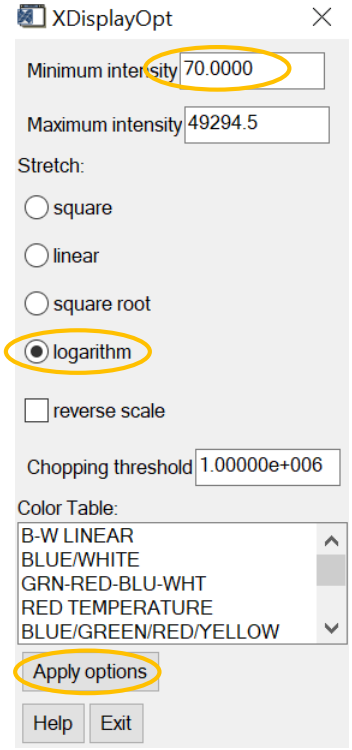
XStarFinder is an IDL routine for PSF fitting and photometry, in crowded fields of both the diffraction-limited (AO) and the seeing-limited sort. To use it,

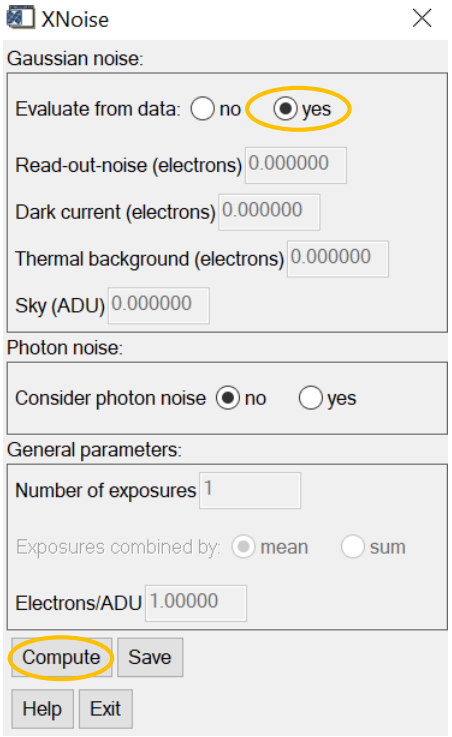
- start IDL, if you haven't already done so.
- Browse to the directory containing the data.
- Type xstarfinder <enter> at the IDL> prompt.
- This produces the main XStarFinder window.



XStarFinder (continued)

- Push the Image button and load a calibrated image (previous pages)
- Under Display > Options, adjust the scale and stretch so that you can see all your stars.
  - Image will be mirror inverted (north down), as in ATV. No Invert Y function this time though.
- Under Image > Noise > Compute, choose Evaluate from data and push the Compute button.



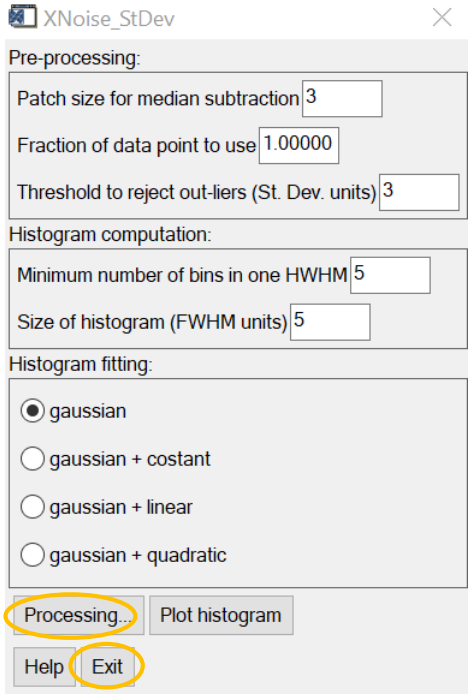


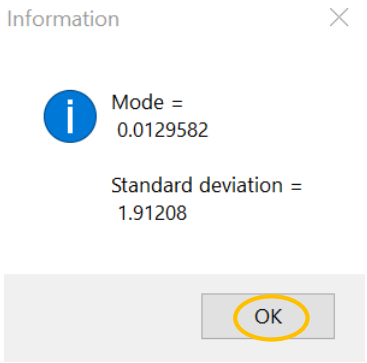
XStarFinder (continued)

- Push OK on the next window to bring up the XNoise_StDev window. Accept the defaults and push Processing... .

- An information window appears with the grand-total noise result. Push OK, Exit, Exit to get out of the noise-calculation process.

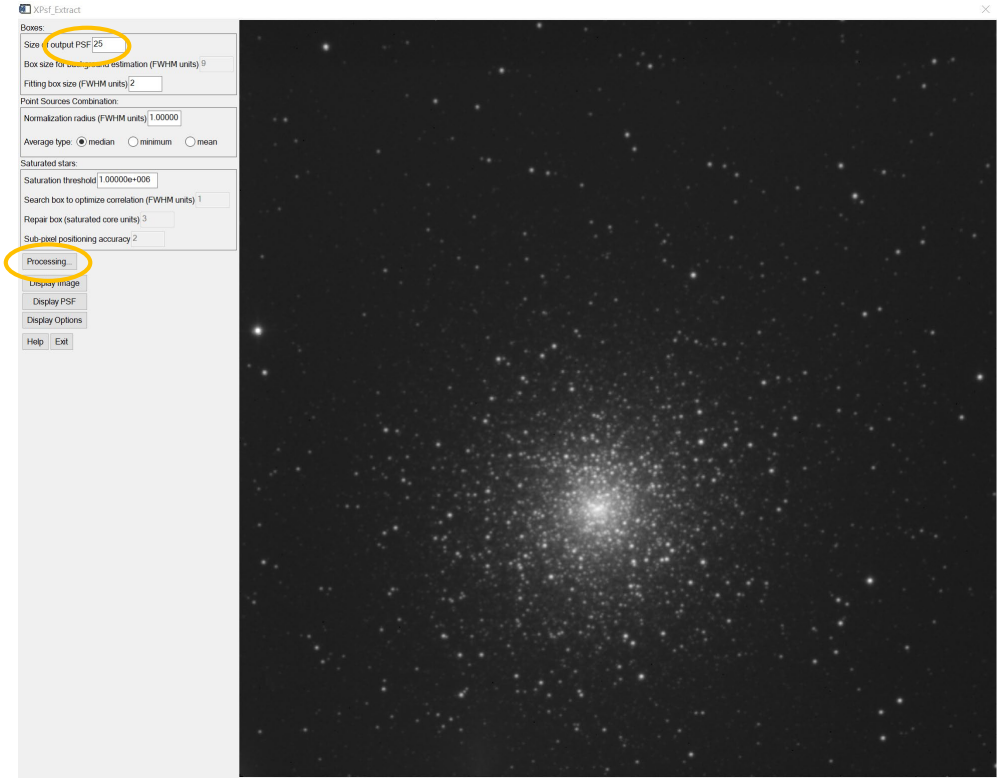
- Next, define the point spread function to use to deconvolve the image. Choose PSF > Extract from image to get the XPsf_Extract window (next page).

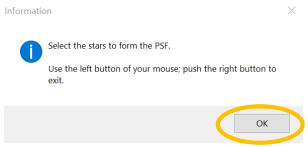




XStarFinder (continued)

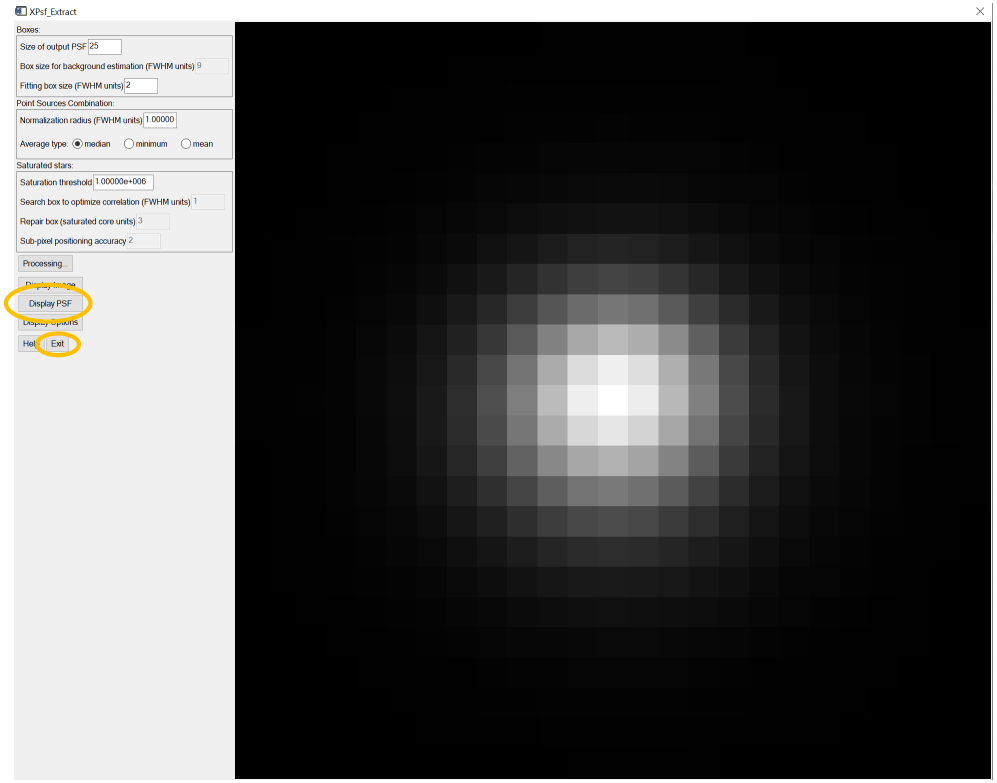
- Set output PSF to be about 25; otherwise accept defaults.
- Press Processing…, then OK on the next window.
- Left-click on 5-10 relatively bright and isolated stars; right-click when you're done choosing.
- Then you'll be asked to confirm (Yes) or reject (No) your choices. Reject any that don't look like the others, e.g. are not round.





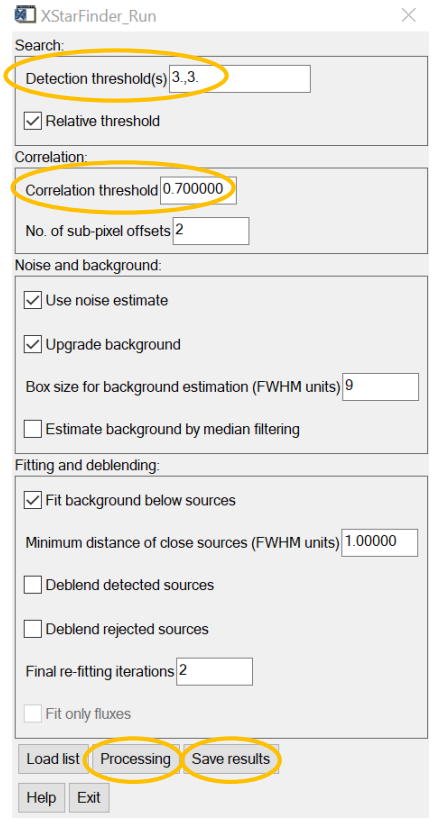
XStarFinder (continued)

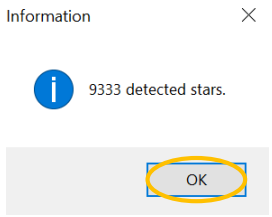
- You should have no secondary sources nearby, so say No to the next window.
- OK when done.
- Non-rejected stellar profiles are averaged to produce the PSF. Choose Display PSF to see what you got.
- Exit. You'll be asked if you want to save the PSF stars. Do so if you have more images, aligned with this one, to process. (PSF > Load gets them back.)



XStarFinder (continued)

- Now you're back on the main XStarFinder window. Choose Astrometry and Photometry to bring up the XStarFinder_Run window.
  - This is the part that does the PSF fitting and subtraction.
- Accept defaults and push Processing...
- Might take 2-4 minutes; will iterate according to number in Final re-fitting iterations box.
- When done you get an info box that says how many stars got found.





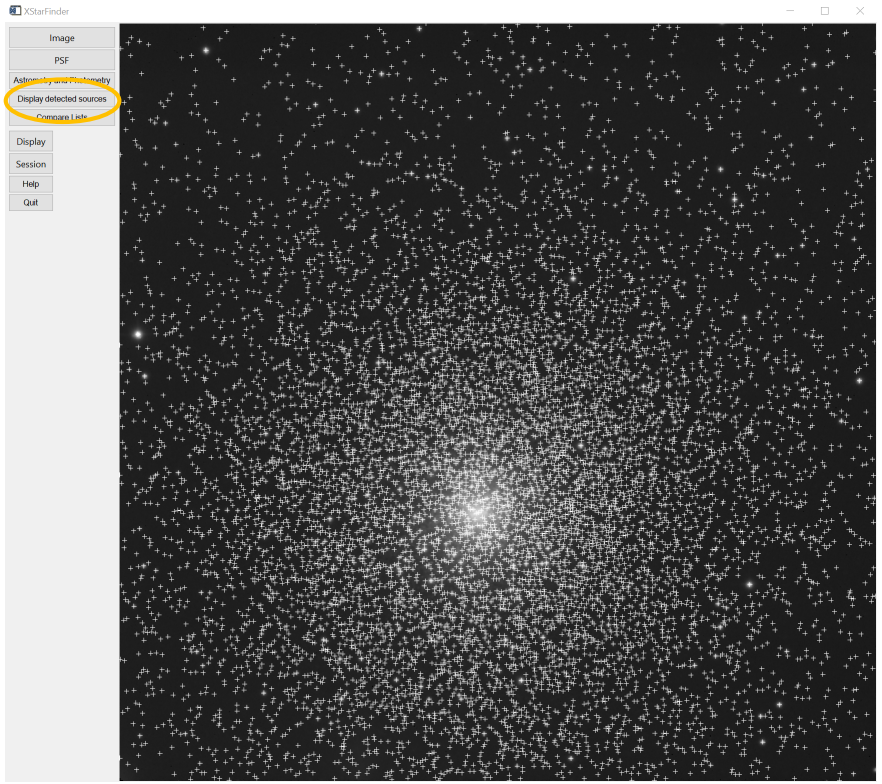
XStarFinder (continued)

- Reduce Detection threshold and/or Correlation threshold if you think you deserved to find more stars.

- Save results or you'll have to do the last step over again; then Exit to return to the XStarFinder window.

- Display > Select data > Detected sources shows what it says.

    - Note that there will often be regions so crowded that point sources can't be extracted.



XStarFinder (continued)

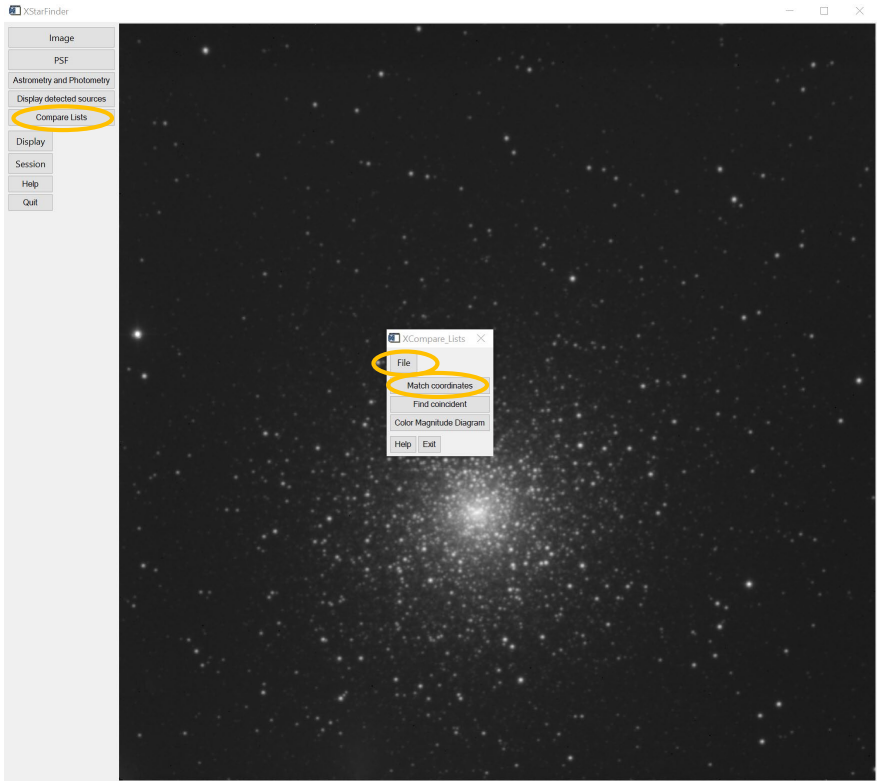
- Once you have extracted the stars from all your images, choose Compare Lists.

- Can load two lists (File) and Match coordinates between them.

  - Easiest if you've aligned the images as carefully as you can.

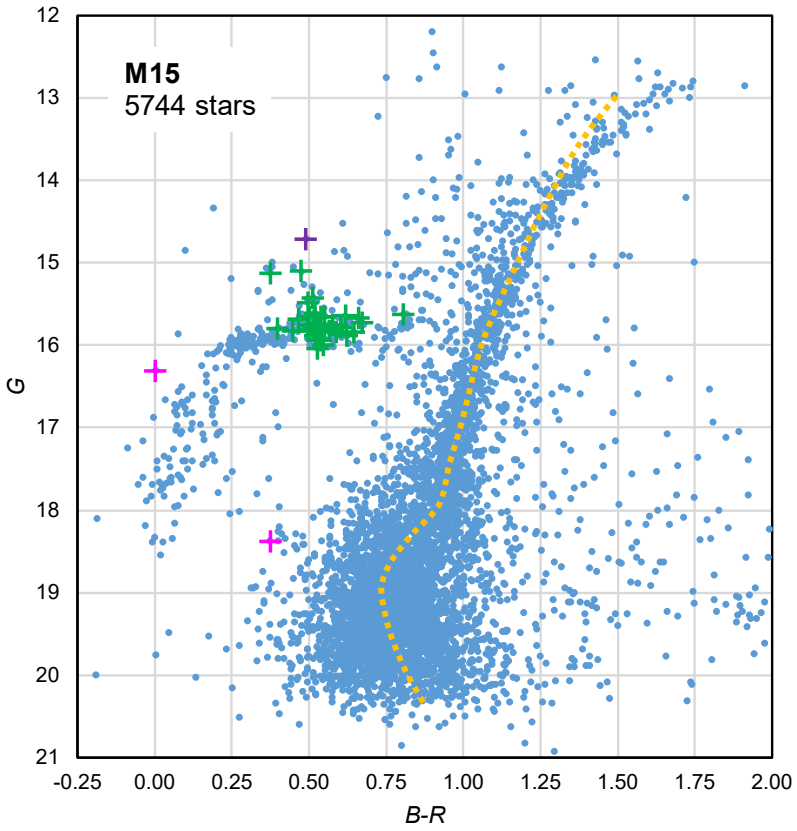
- With our filters it's best to plot HR diagrams as G *vs*. B-R, so you'll need to identify stars in common in all three images.

  - Can do this by using Match coordinates cyclically among the three.



XStarFinder (continued)

- Almost done. Now convert the DNs in your list to fluxes, using your flux calibration in each filter.
- Or better yet convert them to magnitudes, assuming that you have observed a star cluster and want to plot its HR diagram.



Other PSF-photometry programs

- DAOPHOT is really a hybrid of star search, aperture photometry, PSF fitting, and precision photometry.
  - All work under IDL or python.
  - Only downside *vis-à-vis* XStarFinder is that the latter has a graphical user interface, and so is newbie-friendlier.
- Source Extractor (a.k.a. SExtractor) can pull stars out from moderately crowded fields or (better) from within bright nebulosity.
  - Not what SExtractor is for though. Precision of photometry better in DAOPHOT and XStarFinder.

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