

# Stellar Photometry

IDL photometry routines

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University of Rochester

# Stellar photometry

User guides for IDL photometry routines:

ATV Aperture photometry

XStarFinder PSF-fitter /  
deconvolver for  
photometry in  
crowded fields

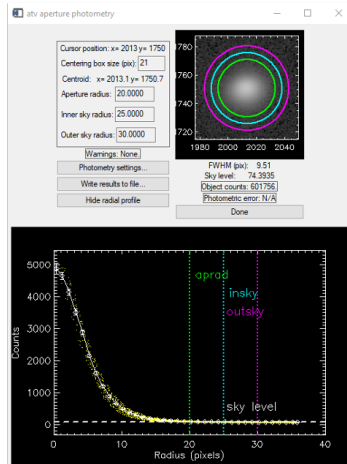


*M15, LRGB, from Mees*

# 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**.

1. Add the DNs from each pixel within
  - ▶ An aperture centered on the star, with an aperture radius large enough to contain all of the stellar flux
  - ▶ An annulus centered on the star that contains nothing but background emission.
2. Multiply the annulus DNs by the ratio of number of pixels in the aperture and annulus, and subtract this from the aperture DNs.
  - ▶ Note that this automatically happens in ATV.



# For calibration stars and uncrowded fields

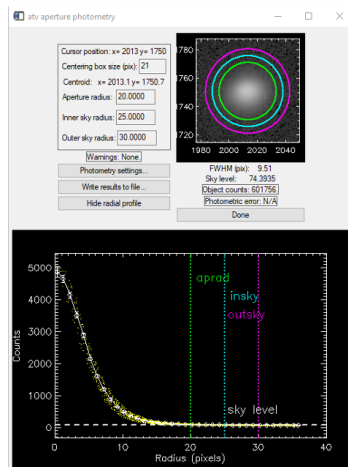
- ▶ If the target is a calibration star, this is one measurement of the flux density-to-DN conversion ratio,  $C$ , as discussed in Lesson 4:

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

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

- ▶ If not, its magnitude in that filter is

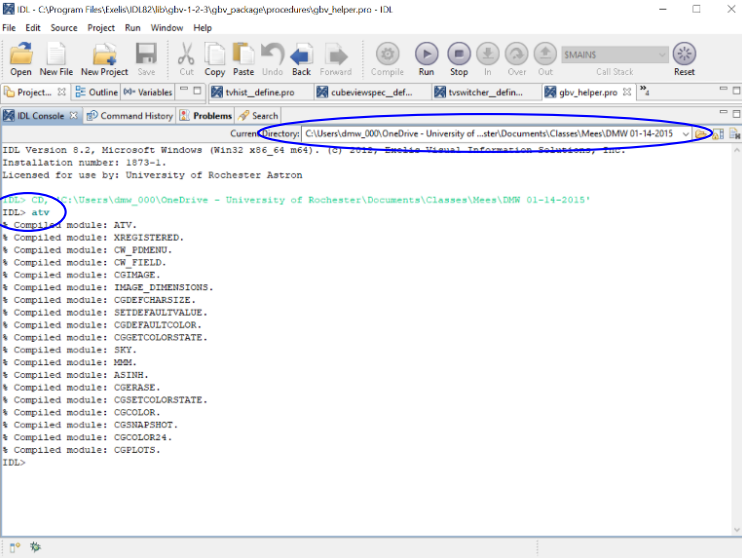
$$m = 2.5 \log \left( \frac{F_0}{C(DN_{\text{aperture}} - DN_{\text{sky}})} \right)$$



# Typical aperture photometry tool: ATV

ATV is a widely-used IDL application for browsing images and performing aperture photometry. Here is a basic step-by-step guide:

1. Start IDL
2. Browse to the directory containing the data.
3. Type `atv` <enter> at the IDL> prompt.
4. This will produce the main ATV window (on right).



The screenshot shows the IDL software interface. The title bar reads "IDL - C:\Program Files\Exelis\IDL82\lib\gbv-1-2-3\gbv\_package\procedures\gbv\_helper.pro - IDL". The menu bar includes File, Edit, Source, Project, Run, Window, and Help. The toolbar contains icons for Open, New File, New Project, Save, Cut, Copy, Paste, Undo, Back, Forward, Compile, Run, Stop, In, Over, Out, Call Stack, and Reset. The Project pane shows "Project: tvhstst\_define.pro", "cubeviewspec\_def...", "tvswitcher\_defin...", and "gbv\_helper.pro". The IDL Console pane shows the following text:

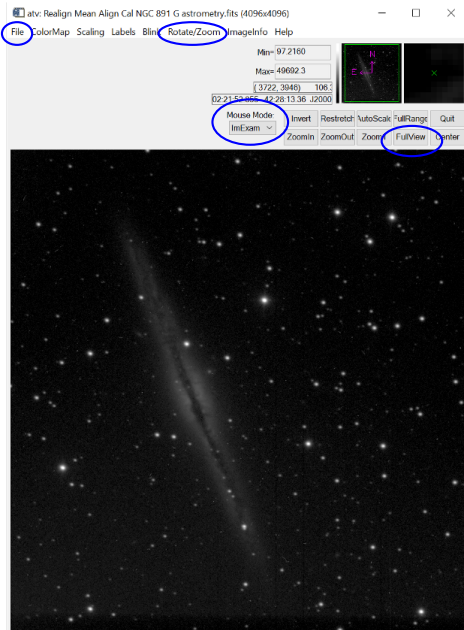
```
Current Directory: C:\Users\dmw_000\OneDrive - University of Rochester\Documents\Classes\Mees\DMW 01-14-2015
IDL Version 8.2, Microsoft Windows (Win32 x86_64 m64). (c) 2012, Exelis Visual Information Solutions, Inc.
Installation number: 1873-1.
Licensed for use by: University of Rochester Astron

IDL> CD, C:\Users\dmw_000\OneDrive - University of Rochester\Documents\Classes\Mees\DMW 01-14-2015
IDL> atv
% Compiled module: ATV.
% Compiled module: XREGISTERED.
% Compiled module: CW_PDMENU.
% Compiled module: CW_FIELD.
% Compiled module: CGIMAGE.
% Compiled module: IMAGE_DIMENSIONS.
% Compiled module: CGDEFCHARSIZE.
% Compiled module: SETDEFAULTVALUE.
% Compiled module: CGDEFAULTCOLOR.
% Compiled module: CGGETCOLORSTATE.
% Compiled module: SKY.
% Compiled module: MMM.
% Compiled module: ASINH.
% Compiled module: CGERASE.
% Compiled module: CGSETCOLORSTATE.
% Compiled module: CGCOLOR.
% Compiled module: CGSNAPSHOT.
% Compiled module: CGCOLOR24.
% Compiled module: CGPLOTS.
IDL>
```

Red circles highlight the "Current Directory" path and the `atv` command in the IDL Console.

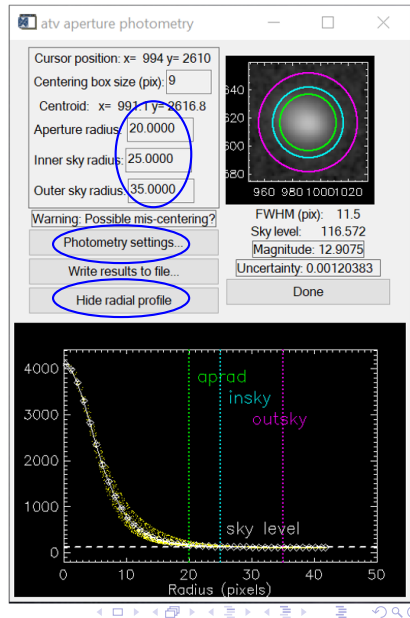
# Typical aperture photometry tool: ATV

5. File > ReadFits to open image
  - ▶ This image should already be calibrated and normalized.
6. FullView button to see the entire image.
7. Rotate/Zoom > Invert Y to make it right side up, if it is a Mees image.
8. Mouse Mode > ImExam to start photometry mode.
9. Click a star. This brings up the atv aperture photometry window.



# Typical aperture photometry tool: ATV

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



## Typical aperture photometry tool: ATV

13. Choose your favorite among the counts (DN) and magnitudes. I normally choose counts.
14. 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.
15. If you want photometric errors displayed, enter
  - ▶ the CCD gain ( $1.35 e^- / \text{DN}$ ; see Lesson 1)
  - ▶ the system's read noise ( $9 e^-$  for  $1 \times 1$  binning,  $4.5 e^-$  for  $2 \times 2$  binning; see Lesson 1)
16. 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 photometry settings

IDLPhot Sky Mode

Select Sky Algorithm:  Median Sky  
 No Sky Subtraction

Select Output Units:  Counts  
 Magnitudes

Magnitude Zeropoint: 21.1890

Exposure Time (s): 300.000  
[ Magnitude = -2.5 log (DN / exptime) + ZPT ]

Calculate photometric errors?  No  
 Yes

CCD Gain (e-/DN): 1.35000

Readout Noise (e-): 9.00000

WARNING: Photometric errors only make sense if the gain and readnoise are given correctly accounting for scaling or co-adding of images.

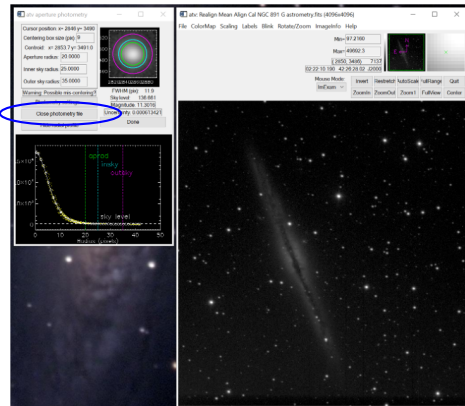
Apply Settings

Cancel



# Typical aperture photometry tool: ATV

- 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 on all of those stars in the image. Click on the Close photometry file button when you are finished.



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
- ▶ `photutils` within `astropy` or `astroconda`, for python

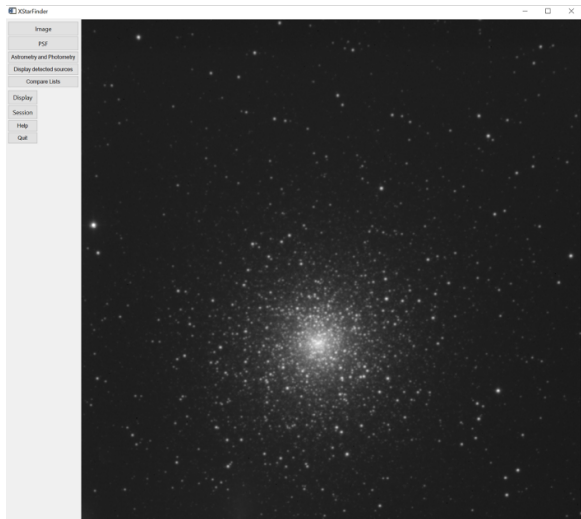
All of these are based on `DAOPHOT`, a well-tested set of routines written and maintained by [Peter Stetson](#), and often used with IRAF.

It is dangerous to automate this process, though, especially without some experience on your images with aperture photometry by hand using the likes of ATV.

## 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 of the stars in the image above some threshold.
- ▶ Iteratively remove all of the stars by CLEAN-like PSF subtraction. Record centroids and total DNs for each star.
- ▶ Check the DNs on isolated stars with aperture photometry.

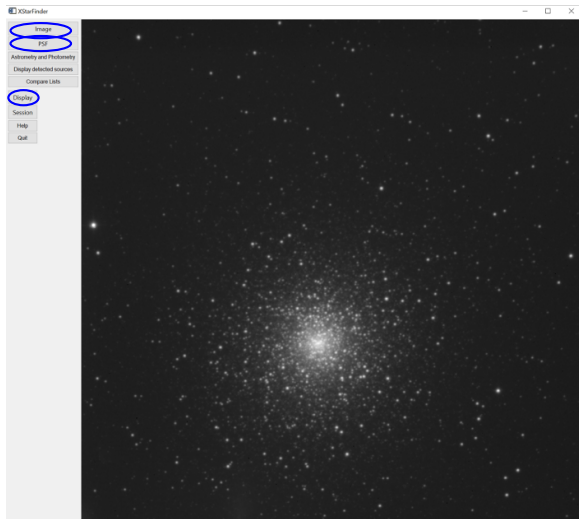


*M 15, on a not-so-great night in October 2016*

# 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,

1. Start IDL (if you have not yet done so)
2. Browse to the directory containing the data
3. Type `xstarfinder` <enter> at the IDL> prompt.
4. This produces the main XStarFinder window.
5. Push the Image button to load a calibrated image.



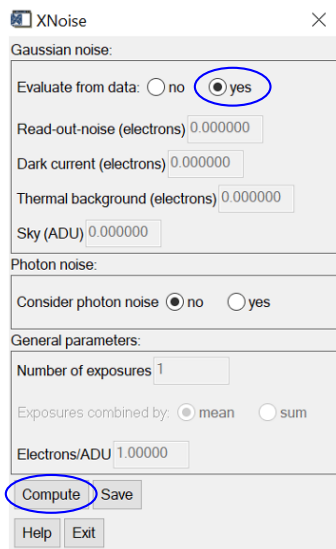
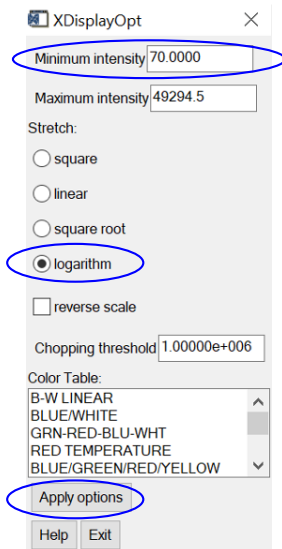
*M 15, on a not-so-great night in October 2016*

# Typical PSF photometry tool: XStarFinder

6. Under Display > Options, adjust the scale and stretch of your image so that you can see all of your stars.

- ▶ The image will be mirror inverted (North down), as in ATV. Unfortunately, there is no Invert Y function this time.

7. Under Image > Noise > Compute, choose Evaluate from data and click the Compute button.



## Typical PSF photometry tool: XStarFinder

- Click OK on the next window to bring up the XNoise\_StDev window. Accept the defaults and click Processing...
- An information window appears with the grand-total noise result. Click OK, Exit, Exit to get out of the noise-calculation process.
- Define the point spread function (PSF) to use to deconvolve the image. Choose PSF > Extract from image to get the XPsf\_Extract window.

The screenshot shows the XNoise\_StDev window with the following settings:

- Pre-processing:**
  - Patch size for median subtraction: 3
  - Fraction of data point to use: 1.00000
  - Threshold to reject out-liers (St. Dev. units): 3
- Histogram computation:**
  - Minimum number of bins in one HWHM: 5
  - Size of histogram (FWHM units): 5
- Histogram fitting:**
  - gaussian
  - gaussian + costant
  - gaussian + linear
  - gaussian + quadratic

Buttons at the bottom of the XNoise\_StDev window include Processing... (circled in blue), Plot histogram, Help (circled in blue), and Exit.

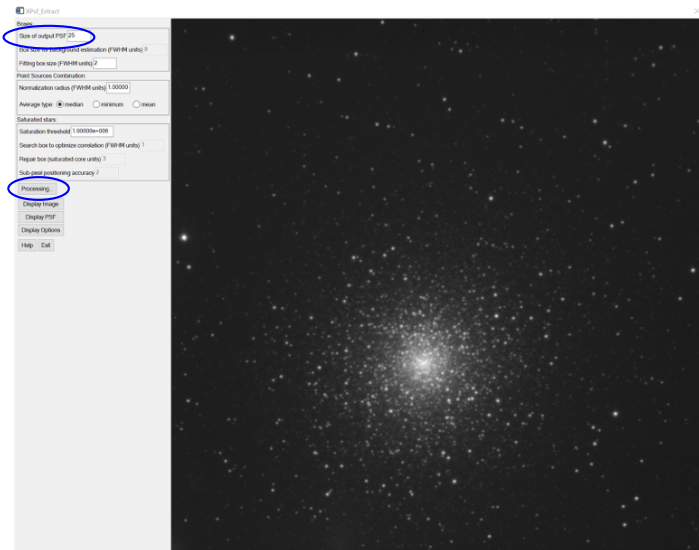
The Information window on the right displays the following data:

- Mode = 0.0129582
- Standard deviation = 1.91208

The OK button in the Information window is circled in blue.

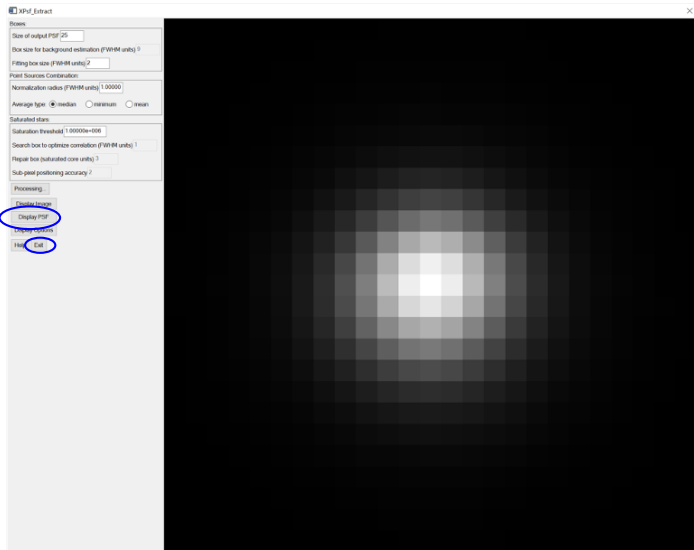
# Typical PSF photometry tool: XStarFinder

11. Set output PSF to be about 25; otherwise, accept the default settings.
12. Click Processing . . . , then OK on the next window.
13. Left-click on 5–10 relatively bright, isolated stars. Right-click when you are finished.
14. You will then be asked to confirm (Yes) or reject (No) your choices. Reject any that do not look like the others, e.g. are not round.



# Typical PSF photometry tool: XStarFinder

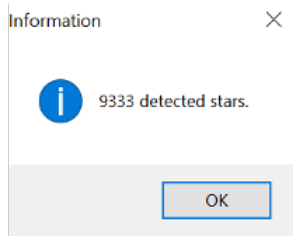
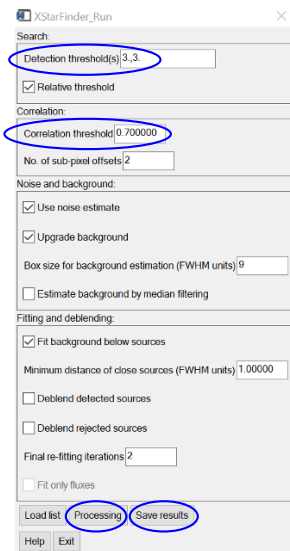
15. You should have no secondary sources nearby, so say No in the next window.
16. OK when done.
17. Non-rejected stellar profiles are averaged to produce the PSF. Choose Display PSF to see what you got.
18. Exit. You will be asked if you want to save the PSF stars. Do so if you have more images aligned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





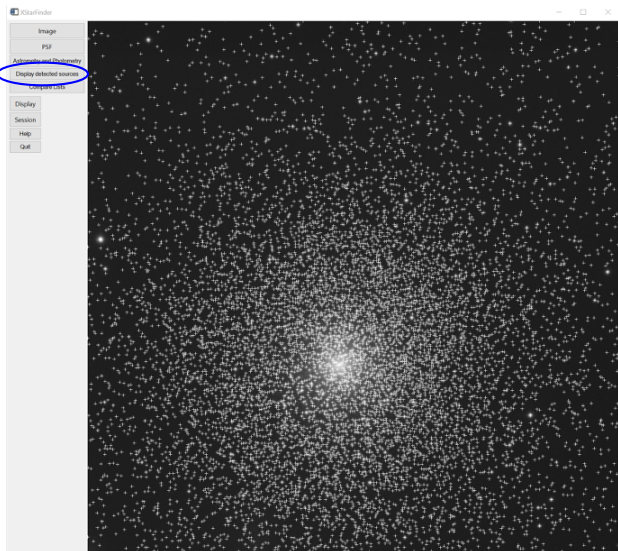
# Typical PSF photometry tool: XStarFinder

19. You should now be 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.
20. Accept the defaults and click Processing...
21. This will likely take a few (2–4) minutes; it will iterate according to the number in the Final refitting iterations box.
22. When finished, you will get an information box that says how many stars were found.



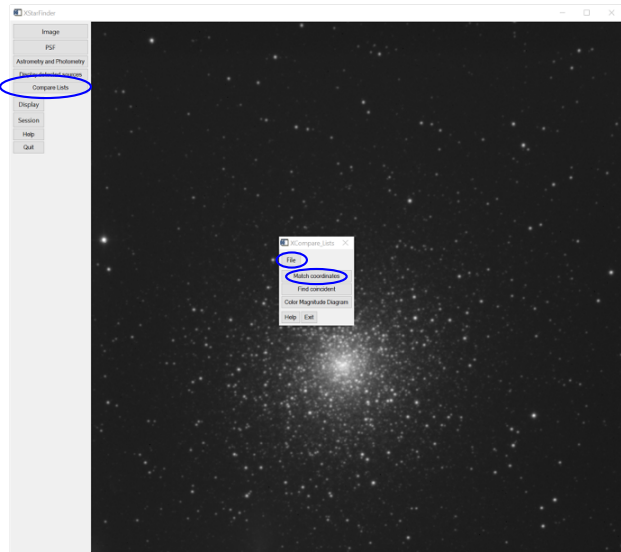
## Typical PSF photometry tool: XStarFinder

23. Reduce Detection threshold and/or Correlation threshold if you think that you deserve to find more stars.
24. Save results or you will have to do the last step over again; then Exit to return to the XStarFinder window.
25. Display > Select data > Detected sources shows what it says (example shown on the right).
  - ▶ Note that there will often be regions so crowded that point sources cannot be extracted.



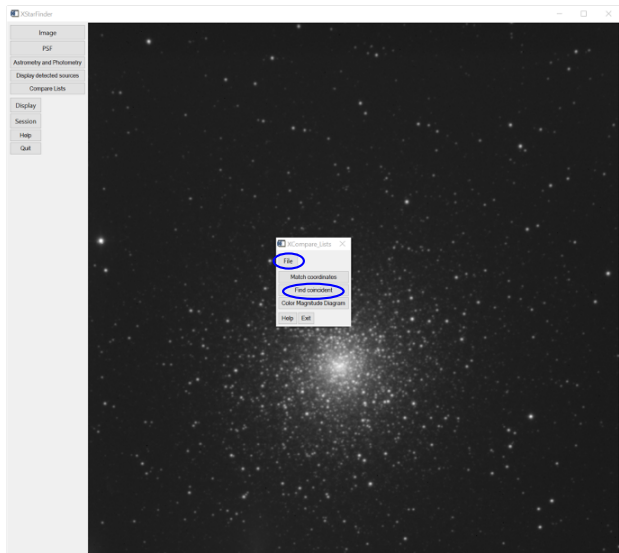
# Typical PSF photometry tool: XStarFinder

26. Once you have extracted the stars from all of your images, choose Compare lists.
27. You can then load two lists (Files) and Match coordinates between them. Accept the default values provided in the XMatch Coord window that pops up.
  - ▶ This is easiest if you have already aligned the images as carefully as you can.
  - ▶ Also load a “Reference list” (can be your PSF stars file).



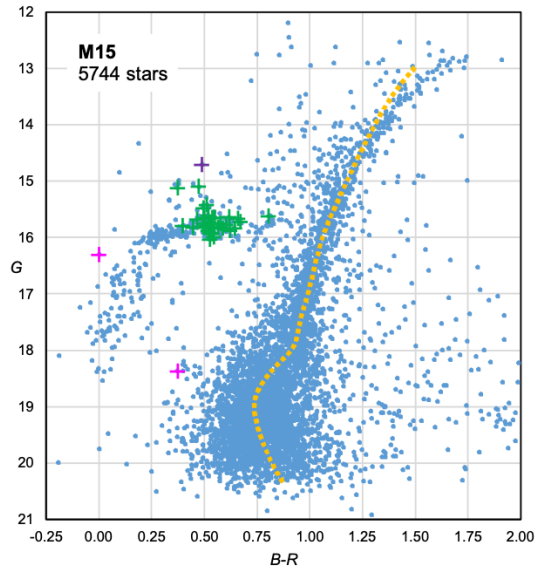
# Typical PSF photometry tool: XStarFinder

28. To acquire the subset of the two lists that appear in both, click the Find coincident button in the XMatch Coord window. Enter the width of the PSF (or your best estimate of it) in the Matching distance window that pops up.
29. Save the subset of each file that appears in both lists: File > Save for each list.



## Typical PSF photometry tool: XStarFinder

30. With our filters, it is best to plot the H-R diagrams as G v. B-R, so you will need to identify the stars in common in all three images.
- ▶ You can do this by using Match coordinates cyclically between the three.
31. Almost done. 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 H-R 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.
- ▶ When compared to XStarFinder, the only downside is that there is no GUI.

**Source Extractor** (a.k.a. **SExtractor**) can pull stars out from moderately crowded fields or (better) from within bright nebulosity.

- ▶ This is not what SExtractor was designed for, though. The precision of the photometry is better in DAOPHOT and XStarFinder.