MAOPhot 1.1.8

Welcome to MAOPhot 1.1.8, a PSF Photometry tool using Astropy 7.1.1 and Photutils 2.3.0

1.1.8 Changes

1) Intermediate results display qfit metrics
2) Button-2 click centers image
3) Button-1 + Shift drags image
4) Mouse wheel zooms image in and out
5) Added View-->Invert; this inverts image
6) Added Effective PSF-->Load… and Effective PSF-->Save As…
7) ENSEMBLE calculated for Single Image Photometry
8) ENSEMBLE outliers displayed for Single Image Photometry
9) Replace IRAFStarFinder with DAOStarFinder
10) SourceGrouper is used in IterativePSFPhotometry
11) In APASS DR10, remove any entries with Johnson (V) > maglimit until cgi-bin/apass_dr10_download.pl is fixed
12) Added Moffat with beta parameter as option for PSF model
13) Added option to generate residual image
14) MAOPhot 1.1.7 has been merged into MAOPhot 1.1.8

Introduction

Aperture photometry and Point Spread Function (PSF) photometry are two widely used methods for measuring the magnitude of stars or other stellar objects. Here's how they differ:

1. Aperture Photometry

a. Definition:

- Aperture photometry involves summing the light within a circular (or elliptical) aperture centered on the star and subtracting the background light estimated from an annulus around the aperture.

b. Advantages:

- Simple and straight forward to implement

- Works well for isolated stars with little contamination from nearby stars or artifacts

c. Disadvantages:

- Less effective in crowded fields, where light from nearby stars may contaminate the aperture
- Accuracy depends on the choice of aperture size; a large aperture captures more light but also more background noise, while a small aperture might miss some of the star's light
- When stars are blended, it is obviously impossible simply to sum the CCD data numbers corresponding to the image of each star and then to subtract an allowance for the diffuse sky emission (Stetson 1986)

d. Usage:

- Suitable for relatively uncrowded fields and for stars with a relatively high signal-to-noise ratio (SNR)

2. PSF Photometry

a. Definition:

- PSF photometry models the star's light distribution as a mathematical function called the Point Spread Function (PSF), which describes how the star's light spreads across the detector. The PSF is then fitted to the star to determine its total flux, accounting for overlaps with nearby stars.
- If nature has attempted to confuse us by blending the light of two or more stars, we retaliate by fitting a model in which two or more of the expected stellar profiles are superimposed: each model stellar profile is shifted in χ and y and scaled in intensity, and one or more parameters describing the local distribution of diffuse sky light are varied, until a satisfactory fit of the overall model to the image data is achieved (Stetson 1986).

b. Advantages:

- Excellent for crowded fields, as it can deconvolve the light from overlapping stars
- Provides more precise measurements, especially in dense star clusters or regions with significant background contamination
- The PSF model can be a simple analytic function (e.g., 2D Gaussian or Moffat profile) or a more complex model derived from a 2D PSF image

c. Disadvantages:

- More computationally intensive and requires accurate modeling of the PSF
- Sensitive to systematic errors if the PSF model does not accurately represent the actual star profiles

d. Usage:

- Ideal for dense stellar fields, such as globular clusters or the cores of galaxies

About MAOPhot

This program was derived from "MetroPSF" by Maxym Usatov. It has been renamed and extended to produce AAVSO reports exclusively and to facilitate generating an effective PSF for PSF photometry.

MAOPhot calculates stellar magnitudes from FITS formatted digital photographs using PSF photometry. It produces an extended AAVSO (American Association of Variable Star Observers) report (https://www.aavso.org/aavso-extended-file-format) which can be submitted to AAVSO using their online tool WebObs (https://www.aavso.org/webobs).

MAOPhot uses PSF (point spread function) photometry exclusively.

MAOPhot is written in Python using Astropy (a common core package for astronomy). MAOPhot also uses Photutils. See "PSF Photometry" which describes many of the classes and methods used in MAOPhot:
https://photutils.readthedocs.io/en/stable/user_guide/psf.html

Key Features

MAOPhot has been redesigned for AAVSO reporting only and includes, but is not limited to, the following enhancements:

- Uses Astropy 7.1.1 and Photutils 2.3.0
- Generation of an Effective PSF model (EPSF model) following the prescription of Anderson and King (2000; PASP 112, 1360), with the ability to create a 'rejection list' of stars that the user can select that will not be part of the EPSF model generated
- Option to use a Circular Gaussian PRF (Pixel Response Function) as a model
- Option to use a Moffat PSF model
- Uses **Iterative PSF Photometry** - an iterative version of PSF Photometry (IterativePSFPhotometry class from Photutils) where new sources are detected in

the residual image after the fit sources are subtracted. This is particularly useful for crowded fields where faint sources are very close to bright sources and may not be detected in the first pass

- PSF Photometry using an ensemble of comparison stars or a single comp star
- Generation of Two-Color Photometry (B, V), (V, R) or (V, I), and Single Image Photometry reports in AAVSO extended format
- Use of telescope Transformation Coefficients (needed for Two Color Photometry)
- User can specify check star and list of comp stars
- Manually select a star for measurement
- Intermediate results are saved as .csv files
- Optionally enter an AAVSO Chart ID when retrieving comparison star data

Photutils Integration

MAOPhot leverages several key Photutils classes:

- **PSFPhotometry**: Provides a flexible framework for PSF photometry workflow that can find sources, group overlapping sources, fit the PSF model, and subtract fit PSF models from the image
- **IterativePSFPhotometry**: Iteratively calls PSFPhotometry to detect new sources in the residual image after subtracting fitted sources - essential for crowded field photometry
- **DAOStarFinder**: Implements the DAOFIND algorithm (Stetson 1987) to detect stars by searching for local density maxima. The Gaussian kernel is defined by FWHM, ratio, theta, and sigma_radius parameters. DAOStarFinder finds object centroids by fitting the marginal x and y 1D distributions of the Gaussian kernel to the marginal x and y distributions of the input data image
- **LocalBackground & MMMBackground**: Used for local background estimation around each source before PSF fitting

System Requirements

1. MAOPhot runs on Windows 10 or 11
2. 8 GB of memory and 1 GB storage

Installation

1. Go to https://github.com/petefleurant/PSF-Photometry/releases

    a. Under MAOPhot 1.1.8, scroll down to Assets

    b. Download file "MAOPhot_SETUP.exe" (override any download warnings)

2. Execute MAOPhot_SETUP.exe on your local machine

    a. You may encounter a warning as shown in the following illustration (Windows 11)

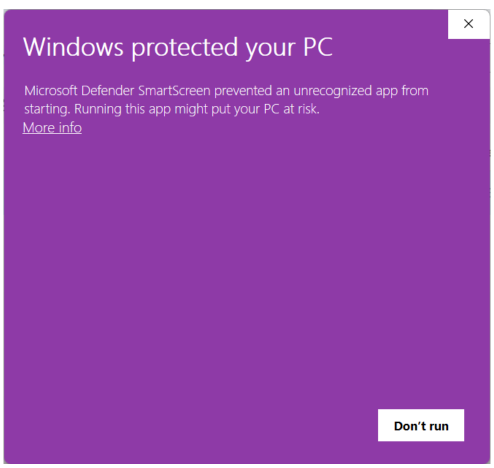
    b. Select More Info, then Run

    c. Allow "Unknown Publisher to make changes to your device"

    d. Accept License agreement (MIT License that comes with most Python applications)

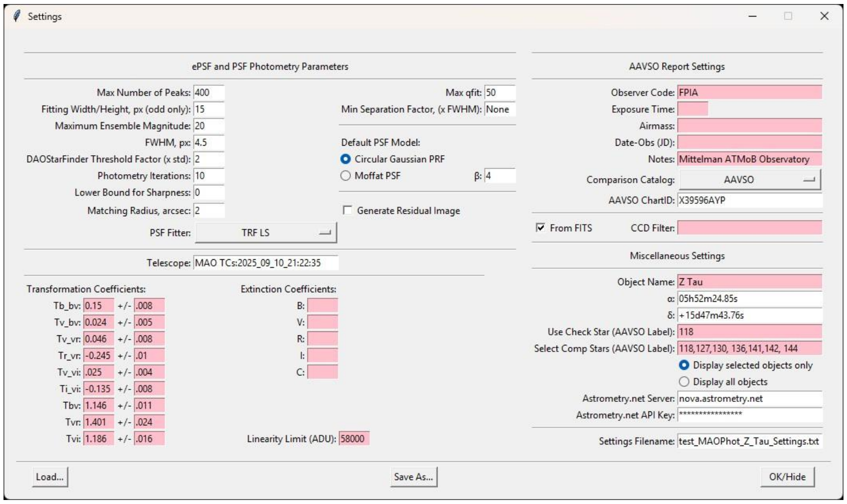
    e. Select Destination Directory

    f. Proceed to install MAOPhot

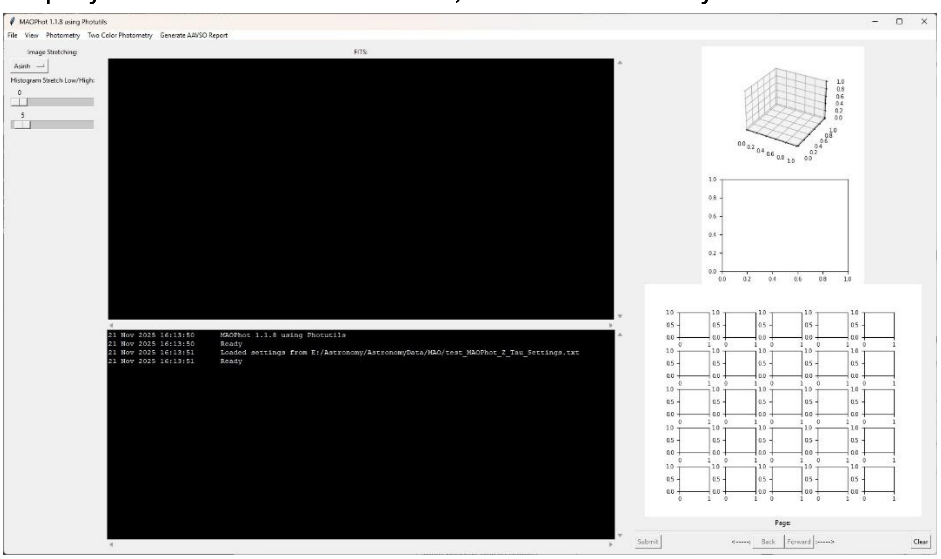


3. Launch MAOPhot.exe. The following 2 windows should appear:

    - **Settings window**: Contains important parameters for PSF Photometry, telescope specifications, and location where variable object, comp, and check stars are specified



    - **Main Window**: Contains stretching tools for the images on the left, the image display and console in the center, and the PSF analysis section on the right



Single Image Photometry Workflow

General Workflow for Single Image Photometry and AAVSO report generation using example "2022 8 1 V1117 Her (Example)"

1) Prepare master images

The master should be calibrated in proper FITS format. It should be cropped such that no 'black' or zero value ADU exists at the edges. The image need not be plate solved, but RA and DEC values should exist for proper plate solving in MAOPhot (see below for Astrometry.net server settings). The fit files *V1117Her_B.fit* and *V1117Her_V.fit* in the 2022 8 1 V1117 Her example are already cropped and plate solved.

2) Launch MAOPhot

Run the following command in the working directory:

MAOPhot.exe

3) Fill in recommended settings values

a. Use 'Load...' to load an existing set of settings (e.g., 2022 8 1 V1117 Her (Example)\V1117 Her Settings.txt)

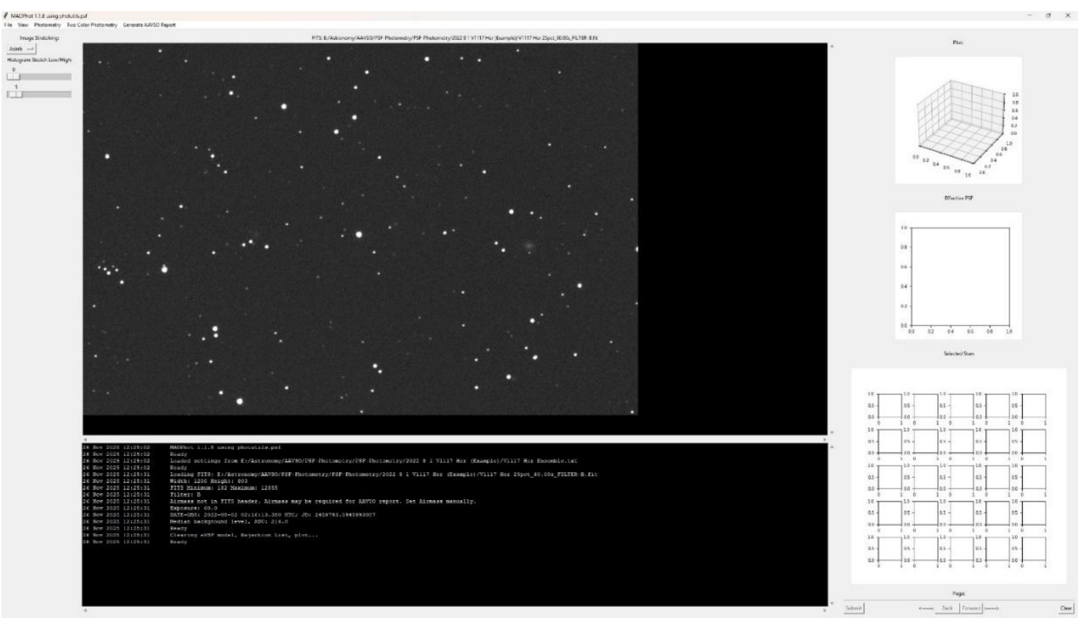
d. Close the Settings Window by clicking OK

4) Open the FITS file

'File->Open...' (e.g., 2022 8 1 V1117 Her (Example)\V1117Her_B.fit)

a. Image Stretching uses Asinh by default. Adjust stretch if necessary. (This is only a screen stretch; it does not affect the file.)

'Photometry->Iterative PSF Photometry' can optionally be executed after an image is loaded with the default PSF Model chosen, either Circular Gaussian PRF or Moffat PSF.



Use mouse wheel to Zoom In (roll wheel up) or Zoom Out (roll wheel down).

Center image by clicking on center button (or mouse wheel)

5) [Optional] Find Peaks

'Photometry->Find Peaks' for generation of Effective PSF model.

a. MAOPhot uses DAOStarFinder to search for peaks in the image and removes any over the Linearity Limit, any that are close to the edge, and any that have close companions. It also removes any that the user has specified previously.

b. Example output: 186 peaks were found, 5 peaks on edge were removed, and 10 with close companions were removed. The user specified a 'Max Num of Peaks' of 50; so, from what is left, the 50 brightest peaks will be used.

c. The 50 remaining peaks are shown on the right side. The user can select any to be further rejected. The user pages through and inspects for any peaks not desired for the generation of the ePSF model. To reject stars, click on one or more of them, then submit. To undo a rejection, just click on it again.

6) [Optional] Create Effective PSF

'Photometry->Create Effective PSF'

a. Watch the progress bar in the output console (console that first appeared after invoking MAOPhot.exe) b. [Optional] Select more stars to be rejected (see step 5):

- Select stars NOT well isolated from their neighbors (most are done automatically)
- [Optional] Save rejection list (Photometry-> Save rejection list)
- Then select 'Photometry->Create Effective PSF' again and repeat if necessary
- Inspect "Effective PSF Plot" for a "reasonable" looking PSF

Note: The ePSF model is built following Anderson and King (2000; PASP 112, 1360). The maximum number of iterations is hardcoded at 50. Any two peaks within an aperture width/height are rejected.

7) [Optional] Load Rejection List

'Photometry->Load Rejection List...'

After loading, select 'Photometry->Create Effective PSF' again

8) Perform Iterative PSF Photometry

If no Effective PSF was created, then model defaults to either Circular Gaussian PRF or Moffat PSF. Select corresponding radio button in Settings (‘File→Edit Settings…’)

'Photometry->Iterative PSF Photometry'

a. Watch the progress bar in the output console

b. After this completes, the photometry is saved to a CSV (comma-separated values) file that can be inspected in Excel or some other editor. In this example, the file saved is: *V1117Her_B.fit.csv*. This is referred to as the photometry file.

About Iterative PSF Photometry: This uses the IterativePSFPhotometry class from Photutils, which is particularly useful for crowded fields. After the initial PSF fits are subtracted from the image, new sources are detected in the residual image. The iterative process continues until no additional sources are detected or a maximum number of iterations is reached.

9) [Optional] Solve Image

'Photometry->Solve Image' (example files for Z Tau and V1117 Her already have WCS data)

a. 'Photometry->Solve Image' to plate solve if the FITS file does not contain WCS Header data

b. [Optional] After solving, 'File->Save' or 'File->Save As...' to save WCS data in the FITS file

Note: If your input file image already has WCS Header data, there is no need to "Solve Image"

After Solve Image, it is recommended to save the image with the WCS data. Use File->Save or File→Save As… to save the fit file.

10) Get Comparison Stars

'Photometry->Get Comparison Stars' [WCS Header data required]

a. Here, MAOPhot finds objects by querying AAVSO and VizieR servers.

b. The photometry file is updated with the objects found, associating the object, comp, and check stars with their photometry data.

> *For convenience, the qfit for each found object is displayed. This should be examined for high qfit values. “qfit” is a quality-of-fit metric defined as the sum of the absolute value of the fit residuals divided by*

the fit flux. qfit is zero for sources that are perfectly fit by the PSF model.

c. Once this is done, the user can repeat steps 1 through 10 for another filter or immediately proceed to generate an AAVSO report for this single image. (Transformation coefficients would not be able to be applied in this case.)

11) Generate AAVSO Report

'Generate AAVSO Report->Single Image Photometry'

a. Select the <fits filename>.csv file that was generated by step 10 (e.g., V1117Her_B.fit.csv)

b. An AAVSO report is generated in the subdirectory aavso_reports/ (e.g., 2022 8 1 V1117 Her (Example)/aavso_reports/AAVSO V1117Her_V V1117 Her_single.txt)

Example Single Image Photometry AAVSO Report:

```
#TYPE=Extended
#OBSCODE=ZZZZ
#SOFTWARE=Self-developed; MAOPhot 1.1.8 using photutils.psf
#DELIM=,
#DATE=JD
#OBSTYPE=CCD
#NAME,DATE,MAG,MERR,FILT,TRANS,MTYPE,CNAME,CMAG,KNAME,KMAG,AMASS,GROUP,CHART,NOTES
V1117 Her,2459793.58430,12.964,0.016,V,NO,STD,ENSEMBLE,na,123,13.198,na,na,X27876MZ,Mittelman ATMoB
Observatory|KMAGINS=8.838|KMAGSTD=13.198|KREFERR=0.016|KREFMAG=13.217|KRA=249.68025|KDEC=9.81633|VM
AGINS=-9.073
```

Single Image Photometry does not utilize Transformation coefficients

Two Color Photometry Workflow

General Workflow for Two Color Photometry and AAVSO report generation using example "2022 8 1 V1117 Her (Example)"

Execute steps 1 through 10 above for the B master (if not done already) and then the V master images. Skip step 11.

Then continue with step 12:

12) Perform Two Color Photometry

'Two Color Photometry->(B-V)'

a. Select the 2 CSV files that were generated in step 10 (1 for B and 1 for V; e.g., V1117Her_B.fit.csv and V1117Her_V.fit.csv)

- When the file selection dialog appears, it will specify the files needed using the default file names

b. The output displays the "Two Color Photometry" results

c. This data is saved in a "Master-Report": e.g., V1117 Her-B-V-Master-Report.csv

d. Note that the column "outlier". If there was a comp star that was an outlier, it would be indicated there. MAOPhot checks values outside the IQR (interquartile range) to detect outliers.

e. If any outliers (comparison stars) were indicated, delete them from 'Select Comp Stars (AAVSO Label)' in the Settings if desired, then select 'Generate AAVSO Report->Two Color Photometry->(B-V)' again.

13) Generate AAVSO Report

'Generate AAVSO Report->Two Color Photometry->(B-V)'

a. Select the "Master-Report" CSV file that was generated in step 12 (e.g., V1117 Her-B-V-Master-Report.csv)

- When the file selection dialog appears, it will specify the file needed using the default file names

b. An AAVSO report is generated in the subdirectory (e.g., 2022 8 1 V1117 Her (Example)/aavso_reports/AAVSO V1117Her_V V1117 Her.txt)

Example Two Color Photometry AAVSO Report:

```
#TYPE=Extended
#OBSCODE=ZZZZ
#SOFTWARE=Self-developed; MAOPhot 1.1.8 using photutils.psf
#DELIM=,
#DATE=JD
#OBSTYPE=CCD
#NAME,DATE,MAG,MERR,FILT,TRANS,MTYPE,CNAME,CMAG,KNAME,KMAG,AMASS,GROUP,CHART,NOTES
V1117 Her,2459793.59495,12.949,0.015,B,YES,STD,ENSEMBLE,na,123,13.204,na,na,X27876MZ,Mittelman ATMoB Observatory|KMAGINS=-8.838|KMAGSTD=13.204|KREFMAG=13.217|Tbv=1.182|TbvErr=0.01|VMAGINS=-9.073
```

V1117 Her,2459793.58465,12.6,0.023,V,YES,STD,ENSEMBLE,na,123,12.318,na,na,X27876MZ,Mittelman ATMoB Observatory|KMAGINS=-9.723|KMAGSTD=12.318|KREFMAG=12.287|Tv_bv=-0.115|Tv_bvErr=0.008|VMAGINS=-9.503

More about Two Color Photometry

MAOPhot mimics VPhot's "Two Color Photometry" (for this discussion we use B and V).

See spreadsheet: ProcessingMaoImages_202281V1117Her.xlsx - It includes formulas to generate "two color photometry". (See https://github.com/petefleurant/PSF-Photometry)

Error Estimation

MAOPhot mimics VPhot when calculating error estimation.

From VPhot documentation:

For ensemble solutions with more than two comp stars:

- The magnitude is estimated as the average of the individual comp stars' estimates [of the check star]
- The error is taken as the standard deviation of this sample

For one or two comp stars:

- The error estimate is based on the SNR of each measurement (the target measurement and the comp stars' measurements)
- The standard error of a measurement is defined as: 2.5 * np.log10(1 + 1 / SNR)
- The errors are added in quadrature

Menu Functionality

File Menu

- **File->Open**: Load a FITS file into MAOPhot for analysis
- **File->Save**: Save loaded FITS file
- **File->Save As...**: Save loaded FITS file to a file
- **File->Edit Settings...**: Display 'Settings' window
- **File->Exit**: Exit application

View Menu

- **View->Zoom In**: Zoom in by +0.5 scale increments (mouse wheel up)
- **View->Zoom Out**: Zoom out by -0.5 scale increments(mouse wheel down)

- **View->100% Zoom**: Zoom to normal scale
- **Invert**: inverts loaded image
- **View->Refresh**: used if the setting "Display selected objects only" has changed

Photometry Menu

- **Photometry->Find Peaks**: Uses DAOStarFinder to search for peaks in the image that will be used for effective PSF (ePSF) model generation. It discards any peaks over the Linearity Limit, any that are close to the edge, and any that have close companions. It also discards any that the user has specified previously.
- **Effective PSF→Create**: Analyzes the image and generates an ePSF model following the prescription of Anderson and King (2000; PASP 112, 1360). Maximum number of iterations is hardcoded at 50. Any two peaks within an aperture width/height are rejected. If a rejection list has been loaded, then peaks in the list are also rejected.
- **Effective PSF→Load...**: Load a saved ePSF file
- **Effective PSF→Save As...**: Save the loaded ePSF to a file
- **Effective PSF→Clear**: Clears psf model, rejection lists, and plot
- **Photometry->Load Rejection List...**: Loads a previously saved rejection list
- **Photometry->Save Rejection List...**: After running "Photometry->Find Peaks", the user can select peaks to be rejected by mouse-clicking on them in the "Selected Stars" area. When user clicks on a peak to be rejected, the word "Rejected" appears over that selection. The user can page through the list of peaks and reject (and undo a rejection). When the Submit button is clicked, the peaks rejected will not be used in the next "Photometry->Create Effective PSF". Once the rejected peaks are submitted, they can be saved using "Photometry->Save Rejection List..."
- **Photometry->Iterative PSF Photometry**: Executes the iterative version of PSF Photometry using Photutils' IterativePSFPhotometry class, where new sources are detected in the residual image after the fit sources are subtracted. This is essential for crowded field photometry.
- **Photometry->Solve Image**: Uses Astrometry.net server to add WCS Header information
- **Photometry->Get Comparison Stars**: Queries AAVSO and VizieR for VSX objects and comparison stars in the field

Two Color Photometry Menu

- **Two Color Photometry->(B,V)**: Executes two color photometry for B and V
- **Two Color Photometry->(V,R)**: Executes two color photometry for V and R
- **Two Color Photometry->(V,I)**: Executes two color photometry for V and I

Generate AAVSO Report Menu

- **Generate AAVSO Report->Single Image Photometry**: Generates an AAVSO report in extended format for a single filter
- **Generate AAVSO Report->Two Color Photometry->(B,V)**: Generates an AAVSO report in extended format for 2 filters (B,V). The data is transformed.
- **Generate AAVSO Report->Two Color Photometry->(V,R)**: Generates an AAVSO report in extended format for 2 filters (V,R). The data is transformed.
- **Generate AAVSO Report->Two Color Photometry->(V,I)**: Generates an AAVSO report in extended format for 2 filters (V,I). The data is transformed.

List of Parameters in Settings Window

Parameter	**Description**	**Units**	**Required***
Max Number of Peaks	The maximum number of peaks that is initially displayed in the Selected Stars area after Photometry->Find Peaks is executed	integer	
Fitting Width/Height	Rectangular shape around the center of a star that will be used to define the PSF-fitting region (odd number)	pixels	
Maximum Ensemble Magnitude	Magnitude limit used when fetching comp stars	magnitude	
FWHM	PSF Photometry searches for peaks with similar FWHM. This parameter is used by DAOStarFinder to define the Gaussian kernel.	pixels	

Parameter	Description	Units	Required*
DAOStarFinder Threshold Factor	The absolute image value above which to select sources, in terms of multiples of standard deviation	float	
Photometry Iterations	Number of iterations to perform in Iteratively Subtracted PSF Photometry	integer	
Lower Bound for Sharpness	The lower bound on sharpness for DAOStarFinder detection. (Upper bound is fixed at 1.0)	float	
Matching Radius	Tolerance between image coordinate and catalog; if within tolerance, then a match is made	arcsecs	
PSF Fitter	Type of fitter used in Iterative PSF Photometry: **TRF LS**: Trust Region Reflective algorithm and least squares statistic (common) **Sequential LS Programming**: Sequential Least Squares Programming (SLSQP) optimization algorithm and least squares statistic (used when fields are crowded) **Simplex LS**: Simplex algorithm and least squares statistic (for noisy images)	list selection	
Max qfit	MAOPhot discards any PSF fit with qfit > "Max qfit" qfit is a quality-of-fit metric defined as the sum of the absolute value of the fit residuals divided by the fit flux. qfit is zero for sources that are perfectly fit by the PSF	float	
Min Separation Factor (x fitting radius)	Min Separation Factor × (fitting radius) This sets the minimum separation distance (in pixels) such that any two sources separated by	float	

Parameter	Description	Units	Required*
	less than this distance will be placed in the same group. Stars in a group are fitted simultaneously. min_separation value, which is the minimum distance (in pixels) that two sources must be separated by to be considered in different groups. If two stars' PSFs overlap within the fitting box, they need to be grouped (i.e., their separation should be less than ‘min_separation’ = Min Separation Factor x fitting radius) so they're fitted simultaneously. Otherwise, you get contamination and poor PSF fitting, (high qfit values).		
Default PSF Model			
Circular Gaussian PRF	This model is evaluated by integrating the 2D Gaussian over the input coordinate pixels and is equivalent to assuming the PSF is 2D Gaussian at a *sub-pixel* level. Because it is integrated over pixels, this model is considered a PRF instead of a PSF.	Radio button	
Moffat PSF	This model is evaluated by sampling the 2D Moffat function at the input coordinates. The Moffat profile is normalized such that the analytical integral over the entire 2D plane is equal to the total flux.	Radio Button	
beta	The asymptotic power-law slope of the Moffat profile wings at large radial distances. Larger values provide less flux in the profile wings. For	float	

Parameter	Description	Units	Required*
	large beta, this profile approaches a Gaussian profile. beta must be greater than 1. If beta is set to 1, then the Moffat profile is a Lorentz function, whose integral is infinite. For this normalized model, if beta is set to 1, then the profile will be zero everywhere. (try 1.7)		
Generate Residual Image	If checked, a residual image is generated in the working directory when IterativePSFPhotometry completes. A residual image indicates how well the psf model has fit the peaks. The residual image shows what's left after subtracting the fitted PSF models from your original image.	Checkbox	
Telescope	Name of telescope; for reference only (OPTIONAL, not used)	string	
Tbv	Transformation Coefficient	float	yes
Tb_bv	Transformation Coefficient	float	yes
Tv_bv	Transformation Coefficient	float	yes
Tvr	Transformation Coefficient	float	yes
Tv_vr	Transformation Coefficient	float	yes
Tr_vr	Transformation Coefficient	float	yes
Tvi	Transformation Coefficient	float	yes
Tv_vi	Transformation Coefficient	float	yes
Ti_vi	Transformation Coefficient	float	yes
Extinction Coefficients	B, V, R, I, C (Not used)		

Parameter	Description	Units	Required*
AAVSO Observer Code	Entered into the report under #OBSCODE	string	yes
Exposure Time	Exposure time is usually found in FITS header; used to calculate instrumental magnitude	float	yes
Airmass	Found in FITS header	float	
Date-Obs	Entered into report; usually found in FITS header	JD	yes
Notes	Entered into report under notes	string	yes
Comparison Catalog	**AAVSO**: Use comp stars found in AAVSO Variable Star Database **Gaia DR2**: Use objects from I/345 Gaia DR2 (Gaia Collaboration, 2018) **APASS DR9**: Use objects from II/336 AAVSO Photometric All Sky Survey (APASS) DR9 (Henden+, 2016) (R and I filters are Sloan). Comp names have a 'B' (e.g., 113B_2) **APASS DR10**: Use objects from AAVSO Photometric All Sky Survey (APASS) DR10 (R and I filters are Sloan). Comp names have an 'A' (e.g., 113A_2)	list selection	
AAVSO ChartID	Specific chartID to be used (e.g., X28484CPQ) (optional)	string	
From FITS	If checked, the CCD Filter value is obtained from the FILTER value in the loaded FITS file header. If unchecked, the user can override the FITS header value by entering it into CCD Filter.	checkbox	
CCD Filter	Filter used for image; usually found in FITS header	string	yes

Parameter	Description	Units	Required*
Object Name	Variable star name to be measured	string	yes
α	RA of Object specified by Object Name	hmsdms	
δ	Dec of Object specified by Object Name	hmsdms	
Use Check Star	KNAME	AAVSO label	yes
Select Comp Stars	Comma-separated list of AAVSO labels specifying comp stars to be used in measurement; if more than 1, then "ENSEMBLE" keyword is entered into report	AAVSO labels	yes
Display selected objects only	Display only objects listed in Comp Stars, Check Star, and Object Name	Radio Button	
Display all objects	Display all objects found by Astrometry.net (redundant ones have .0, .1, etc. appended to name)	Radio Button	
Astrometry.net Server	URL of Astrometry.net server (e.g., nova.astrometry.net or a local one)	string	
Astrometry.net API Key	To use astroquery.astrometry.net, you will need to set up an account at astrometry.net and get your API key. The API key is available under your profile at astrometry.net when you are logged in. Copy the key and insert it into this field.	string	
Settings File Name	Name of file containing loaded Settings (Not used to load settings. Use "Load..." button)	String	

*Required: These settings are directly inserted into the AAVSO Report; most are automatically filled in from the FITS header (Only some TCs are inserted into AAVSO Report)

Definitions

Term	Definition
IRAF	IRAF is a general Image Reduction and Analysis Facility providing a wide range of image processing tools for the user. IRAF is a product of the National Optical Astronomy Observatories and was developed for the astronomical community, although researchers in other scientific fields have found IRAF to be useful for general image processing. (see https://iraf-community.github.io/)

Technical Notes

Optimization Algorithms: gtol and xtol

In optimization algorithms used in statistics and numerical computing, **gtol (gradient tolerance)** and **xtol (step tolerance)** are termination conditions that determine when an algorithm should stop iterating.

1. gtol (Gradient Tolerance)

- **Definition**: The optimization stops when the gradient (first derivative) of the objective function is small.
- **Interpretation**: The gradient represents the rate of change of the function. A small gradient means the function has reached a local minimum (or is very close to it).
- **Usage**: If $||\nabla f(x)|| < gtol$, the algorithm stops.
- **Common in**: Newton methods, Quasi-Newton methods (e.g., BFGS, L-BFGS), and Conjugate Gradient.
- **Example**: If gtol = 1e-6, the optimizer stops when the gradient norm is smaller than 0.000001.

2. xtol (Step Tolerance)

- **Definition**: The optimization stops when the change in the parameter values (x) is very small.
- **Interpretation**: If the steps taken in each iteration become very small, the algorithm assumes convergence.
- **Usage**: If $||x_{new} - x_{old}|| < xtol$, the algorithm stops.
- **Common in**: Trust-region and Line Search methods.
- **Example**: If xtol = 1e-8, the optimizer stops when the parameter updates are smaller than 0.00000001.

Key Differences

Termination Condition	Meaning	Stops when...	Typical Use
gtol	Gradient tolerance	The gradient is small (function slope is near 0)	Gradient-based methods (e.g., BFGS, CG)
xtol	Step tolerance	The parameter change is small	Trust-region & Line Search

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Additional Resources

Documentation Links

- **Photutils PSF Photometry Guide**: https://photutils.readthedocs.io/en/stable/user_guide/psf.html
- **Astropy Modeling and Fitting**: https://docs.astropy.org/en/stable/modeling/
- **AAVSO Extended Format**: https://www.aavso.org/aavso-extended-file-format
- **AAVSO WebObs**: https://www.aavso.org/webobs
- **Astrometry.net**: https://nova.astrometry.net/

GitHub Repository

- **MAOPhot Source Code**: https://github.com/petefleurant/PSF-Photometry

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