Photometry Using IRAF

Lisa A. Wells

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This document is an overview for those users wishing to do photometry in IRAF. This is not meant to be a reduction manual or a cookbook; other documents exist for this purpose. It is assumed that the user has had some experience with IRAF and understands the basic concepts of the IRAF command language (CL). It is also assumed that the user understands the basic principles involved with doing photometry. The tasks mentioned in this document are based on IRAF Version 2.10.3 and associated releases of add-on packages.

Contents

1 Introduction

Photometry may be performed within IRAF a number of ways so this document provides information to help the user choose the tasks best suited to his/her needs. This is not a reduction manual or a cookbook; other documents exist that provide step by step instructions (see Appendix C and the on-line help pages for the various tasks). The user should have experience using IRAF and understand the basic concepts of the IRAF CL, since details about IRAF itself will not be presented in this manual. It is also assumed that the user understands the basic principles involved with doing photometry (see Section 2). The tasks mentioned in this document are based on IRAF Version 2.10.3 and associated releases of add-on packages.

Before beginning any photometric calculation, the images must be processed through flat-field correction, (and de-fringing performed if necessary). Illumination corrections may also be required for some cases. Details on these steps are discussed in the manual by Phil Massey, *A User's Guide to CCD Reductions with IRAF*, listed in Appendix C.

This document concentrates on CCD photometry of images containing stellar-like objects, although photometry of diffuse objects such as galaxies is also discussed. We begin with an introduction to photometric methods in Section 2. The tasks in IRAF which perform the necessary operations are listed in Section 3, and Sections 4, 5, 6, and 7 detail the main tasks and packages available. Section 8 provides information on adding artificial stars to an image to check the completeness and limiting magnitude (see the paper by Harris 1990, referenced in the next section. Section 9 directs the user to tasks which will help in the determination of aperture corrections for all the images in a data set. The transformation of instrumental to standard magnitudes is discussed in Section 10. Section 11 talks about the Faint Object Classification and Analysis System (FOCAS). Information about the photometry tasks in the add-on packages CTIO and STSDAS is given in Appendices A and B, respectively. Appendix C lists other useful documentation available.

2 Photometry Methods

There are many techniques involved in doing aperture photometry, and these methods vary from one astronomer to another. Some observers use large apertures for their measurements to account for seeing, tracking, and focus variations, while others use small apertures and apply aperture corrections. The sky algorithm used may vary according to the chip characteristics and the data. There are a number of ways to do the standard calibration so be sure to observe standards in a way that is compatible with the calibration package.

Some references on the theory and techniques of aperture photometry are:

- Golay, M., 1974, *Introduction to Astronomical Photometry*, D. Reidel Publishing, Dordrecht-Holland.

- Hardie, Robert H., 1962, in *Stars and Stellar Systems*, Vol. 2, *Astronomical Techniques*, ed. W. A. Hiltner, University of Chicago Press, 178.

- Harris, W. E., 1990, PASP, **102**, 949.

- Harris, W. E., FitzGerald, M. P., and Reed, B. C., 1981, PASP, **93**, 507.

- Howell, S. B., 1989, PASP, **101**, 616.

- Howell, S. B. (ed.), 1991, Astronomical CCD Observing and Reduction Techniques, ASP Conf. Series, Vol. 23.

- Philip, A. G. Davis (ed.), 1979, *Problems of Calibration of Multicolor Photometric Systems*, Dudley Observatory, Schenectady, New York.

- Stetson, P. B., 1987, PASP, **99**, 191.

- Stetson, P. B., 1990, PASP, **102**, 932.

- Stetson, P. B., and Harris, W. E., 1988, AJ, **96**, 909.

The basic principle of aperture photometry is to sum up the observed flux within a given radius from the center of an object, then subtract the total contribution of the sky background within the same region, leaving only the flux from the object to calculate an instrumental magnitude. The aperture size is important since seeing, tracking, and focus errors affect the amount of flux within the stellar profile. The noise grows linearly with radius as the stellar flux trails off in the wings of the profile. Increasing the size of the aperture will increase the poisson shot noise of the background sky and any flat-field errors that may be nearby. The signal-to-noise ratio of the flux measurement reaches a maximum at an intermediate aperture radius shown by Howell (1989, referenced above). The use of a smaller radius introduces the problem that the fraction of the total flux measured will vary for objects of different flux from image to image. Aperture corrections must be used in this latter case (see Section 9).

If the user is interested in applying an extinction correction to the data then extinction stars need to be observed and reduced along with the object data. The extinction stars should be observed at airmasses corresponding to the range in airmass of the program objects (a range of not less than 0.5 magnitudes in extinction is suggested) so that a good airmass correction can be determined and applied to the data. Color and zero point corrections are often applied to the instrumental magnitudes as well to put them on the standard system defined by a set of observed standard stars (these same standard stars can also be used as the extinction stars). These stars should be chosen prior to observing so that their colors bracket those of the program objects (a good rule of thumb is to have at least a 0.5 magnitude range in the colors of the standards to determine reasonable calibrations). (See Section 10 for details.).

IRAF currently provides a means of creating polygonal and elliptical aperture lists for use with specific tasks. Elliptical apertures may also be used to perform isophotal surface photometry on galaxies. The next section briefly describes the many options.

3   What Tasks Are Available?

Performing photometry on a large number of images is a time consuming process. Knowing what tasks are available can help determine what method is best for a given data set. Aperture photometry is done using the following tasks in IRAF:

- **imexamine** - single aperture photometry using the image display.

- **qphot** - interactive or batch mode multi-aperture photometry for a list of stars with an abbreviated parameter list.

- **phot** - interactive or batch mode multi-aperture photometry for a list of stars with many more parameter choices than the previous task.

- **polyphot** - interactive or batch mode single aperture photometry for a list of polygonal regions.

- **wphot** - interactive or batch mode multi-aperture photometry for a list of stars with weighting.

The above tasks work well on uncrowded fields—for crowded field photometry point spread function (PSF) fitting is used. The following tasks are available.

- **peak** - fit the PSF to single stars.

- **nstar** - fit the PSF to groups of stars simultaneously.

- **allstar** - group and fit the PSF to multiple stars simultaneously.

These all require a point spread function which is fit to the stars in the field. This is described in more detail later. Two add-on packages contain tasks which may be useful as well:

- **sphot** - single aperture stellar photometry using the algorithms from the old NOAO LSI-11 mountain code. (CTIO package)

- **ellipse** - fit elliptical isophotes to objects given primary ellipse parameters. (STSDAS.ISOPHOTE package)

The tasks **imexamine**, **qphot**, or **sphot** may be used to do quick look photometry. **Qphot**, **phot**, **polyphot**, **wphot**, and those tasks in the DAOPHOT package are used for doing photometry of a large number or complex set of data frames. An uncluttered image which has only a few objects of interest should be processed with the APPHOT package which contains the tasks **qphot**, **phot**, **polyphot**, and **wphot**. Crowded field photometry is normally done with the DAOPHOT package which contains the tasks **peak**, **nstar**, and **allstar**. Isophotal photometry of galaxies is possible with the task **ellipse**.

4   Quick Look Photometry: imexamine

Imexamine is a general purpose task used to interactively examine many different aspects of images and includes aperture photometry. The parameters directly relating to the photometry calculation are in the *rimexam* hidden parameter set (called a *pset* [1]) which

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[1] *Psets* are parameter sets within parameter sets. Psets provide a way to group a long list of parameters into smaller, more manageable parameter lists that can then be shared by several tasks in a package.

is described in more detail in the help page for **imexamine**. Only one aperture size may be specified in the parameters; a preferred radius may be chosen using the radial profile or line/column plotting options in the task.

The photometry measurement may be done with the **a** cursor keystroke. The output consists of the x-y coordinates, magnitude, flux, number of pixels within the aperture, mean background, r (FWHM), e, pa (in degrees between -90 and +90 with 0 along the x axis), gaussian peak, and gaussian FWHM. If a quantity is numerically undefined then INDEF is printed. A radial profile plot is obtained using the **r** cursor keystroke. The output produced is the same as that for the **a** command above.

Error analysis for the computed magnitudes is not performed, and the output file must be specified and the logging option turned on in order to save the output values. The background fitting and photometry techniques used are not intended for optimal astronomical photometry. The format of the output file is not compatible with the PHOTCAL package which computes the transformation from instrumental to standard magnitudes. See the help page of **imexamine** for more information.

5   Aperture Photometry: The APPHOT Package

The APPHOT package, used for doing photometry in uncrowded fields, is a subpackage of NOAO.DIGIPHOT and includes tasks to locate and compute the center of objects, fit the sky, perform aperture photometry, and inspect the output files. All the tasks may be run interactively by marking objects one at a time or they may be run in batch mode by supplying a list of objects. Lists of objects may be obtained using the task **daofind** or simply marked and saved in a file with the task **rimcursor**. The output format of all the photometry tasks in this package are compatible with the PHOTCAL package which performs the photometric transformation. Many aperture sizes may be specified (except in **polyphot**), and the read noise and gain of the CCD are used to compute the magnitude errors for the following tasks:

- **qphot** - measure magnitudes for a list of stars using an abbreviated input parameter list.

- **phot** - measure magnitudes for a list of stars using an extensive input parameter list.

- **wphot** - measure magnitudes for a list of stars with weighting.

- **polyphot** - measure magnitudes inside a list of polygonal regions.

The task **qphot** is considered a "quick" photometry task and has a limited parameter list which is a subset to the more detailed parameter list for the task **phot**. The user is queried for all the vital parameters when running this task. The default setting for the centering algorithm is *centroid*, and *mode* is used for the sky fitting algorithm. **Qphot** is often the task of choice for the novice user.

The **phot** task has many parameters which should be specified, however the user is not queried for them as in **qphot**. The pset parameter files **datapars**, **centerpars**, **fitskypars**, and **photpars** should be checked and set accordingly. These may be edited

individually or from the main parameter list of the task by moving to the named parameter set and typing a **:e** for edit. This task gives the user a higher level of customization in performing photometry. There are many options for the centering and sky fitting algorithms which must be specified unless the defaults are satisfactory.

Aperture photometry using a weighted profile is done using **wphot**. The possible options are *constant*, *cone*, and *gaussian* fitted weights, using the same pset parameter files as those for **phot**. **Qphot**, **phot**, and **wphot** all allow more than one aperture radius to be defined and calculated.

Only one polygonal aperture may be defined in **polyphot** unless input files are used to specify several apertures per object. The task **polymark** may be used to create this input file. A task found in the STSDAS.ANALYSIS.ISOPHOTE package called **elapert** may also be used to create a list of elliptical apertures to feed **polyphot** (see Appendix B). The pset parameter files **datapars**, **centerpars**, **fitskypars**, and **polypars** are used in the running of **polyphot**.

Separate tasks for calculating the centers of objects - **center**; fitting the background sky - **fitsky**; and plotting the radial profiles of objects - **radprof**; are found in this package. **Txdump** and the interactive task **pexamine** may be used to pull out important values from the large tables created by these tasks. See the task help pages for more information.

6 Crowded Field Photometry and PSF Fitting: The DAOPHOT Package

The problems involving crowded field photometry were addressed many years ago by Peter Stetson at the Dominion Astrophysical Observatory (DAO) in a FORTRAN software package called DAOPHOT. This has been incorporated into IRAF as a subpackage within NOAO.DIGIPHOT. The *DAOPHOT I* algorithms are installed in IRAF Version 2.10.2 and previous releases, while the *DAOPHOT II* algorithms have been installed in IRAF Version 2.10.3. The DAOPHOT II version of the DAOPHOT package is also available as an add-on package to IRAF 2.10.2.

The DAOPHOT package is used for locating objects, fitting point spread functions, subtracting stars, and performing photometry in a crowded field such as a globular cluster. The output format of all the photometry tasks in this package are compatible with the reformatting task in the PHOTCAL package which creates a properly formatted table for input to the transformation tasks. Many aperture sizes may be specified, and the read noise and gain of the CCD are used to compute the errors. The main tasks are:

- **daofind** - find stars in an image using the DAO algorithm.

- **phot** - compute sky values and initial magnitudes for a list of stars.

- **psf** - compute the point spread function.

- **peak** - fit the PSF to single stars.

- **nstar** - fit the PSF to predefined groups of stars.

- **allstar** - group and fit PSF to multiple stars simultaneously.

- **substar** - subtract the fitted stars from the original image.

These are listed in the order one would run through the process of fitting the stars and deleting them from an image.

Objects are automatically found using **daofind** which searches for local maxima above a given background level, computes shape characteristics, and writes these to an output list. The x and y centroids are computed from the best fitting Gaussian function. Only two pset parameter files are involved here, **datapars** and **findpars**. A magnitude is computed from the peak density in the convolved image. Once positions are obtained, they are input to **phot** (described above in Section 5) to calculate sky values and magnitudes for given aperture sizes.

A number of well sampled stars in uncluttered regions of the image are used to compute the point spread function (PSF) of the image. Stars are selected using the task **pstselect** and input to the task **psf**, or selected interactively while running **psf**. The output **psf** image is fit to groups of stars in the image with **nstar** or **allstar**, and subtracted from the image using **substar**. Finding a good PSF for an image is an iterative process, particularly if there are non-linearities or focus problems across the detector. Step by step instructions on the procedure are found in the help page for the **psf** task.

The task **daoedit** allows the user to modify the various psets used in the package interactively. The package also contains a wide selection of tasks to review and edit the output files created by the tasks mentioned above. Stars may be added to images also using **addstar** (see Section 8). See Appendix C for a listing of other documents available to assist the user with this complex package.

7   Surface Photometry

IRAF has limited capabilities in performing surface photometry at this time, but a package will be added to IRAF in the future. Normally some aperture shape such as an ellipse is fit to a low surface brightness object such as a galaxy to determine the luminosity profile and shape characteristics. Sources for surface photometry methods are:

- de Vaucouleurs, G., 1979, *International Conf. on Photometry, Kinematics and Dynamics of Galaxies*, ed. Evans, Univ. of Texas, 1. (Historical Review)

- Jones, W. B., *et al.*, 1967, Pub. Dept. of Astro., Univ. Texas, Series II, Vol 1, No. 8.

- Sedmac, G., Capaccioli, M., and Allen, R. J., (eds), 1979, *International Workshop on Image Processing in Astronomy*, Proceedings of the 5th Colloquium on Astrophysics, Trieste, 1.

The task **pvector** may be used in a round about way to perform surface photometry by making a cut across an object. An arbitrary vector may be plotted or output to an image or text file specified by the parameter *out_type* and named by *vec_output*. *Width* specifies the number of pixels perpendicular to the vector to average, and the *boundary* condition for averaged cuts (if the extraction process tries to exceed the image boundary)

is used. The object coordinates, vector angle, and length are also input parameters. It is left as an exercise for the user to decide how this information should be used.

The computing group at STScI has developed an elliptical aperture fitting routine to perform isophotal photometry (see Appendix B).

8 Photometric Testing

Statistical testing may be done to determine the limiting magnitude for an image (defined as the level at which the completeness of detection drops to 50% (Harris 1990, see reference in Section 2). Creating or adding objects and noise to an image to calculate statistical completeness is possible in IRAF. The DAOPHOT package contains a task called **addstar**. The input is taken from a list of positions and magnitudes or added uniformly as specified by the magnitude limit parameters. The input file may be a simple text file, a DAOPHOT/APPHOT database file, or an STSDAS binary table file. A PSF image is also used for the profiles of the added stars and the number of stars to be added must be specified. The output image names may be given by a root name to avoid overwriting existing images.

The ARTDATA package is home to other tasks which may be used to add artificial stars, galaxies, or noise to an image:

- **mknoise** - make/add noise and cosmic rays to 1D/2D images.

- **mkobjects** - make/add artificial stars and galaxies to 2D images.

Other tasks in this package help in making lists of positions for the fake stars - **starlist** and galaxies - **gallist**. These tasks require a choice of spatial distributions and luminosity functions, and use a random number generator to create coordinates for the objects. Galaxy morphology must also be specified in **gallist**. These lists are then input to the **mkobjects** task. The task **mkexamples** creates the specified image type as an example for the user. Check the help pages for these tasks for more information.

9 Aperture Corrections: apfile and mkapfile

Apfile and **mkapfile**, found in the DIGIPHOT.PHOTCAL package, are used to plot the curve of growth of the objects in a magnitude file and compute the aperture correction between the desired apertures using the daogrow algorithm (Stetson 1990, see Section 2). **Apfile** and **mkapfile** are identical in function and differ only in that **mkapfile** reads in its data from a multi-aperture list photometry file produced by the **qphot** or **phot** tasks, and **apfile** reads in its data from a simple multi-column text file containing the same information.

The output file of corrections named by the *apercors* parameter from these tasks is input directly to the **mknobsfile** or **mkobsfile** tasks for formatting into a file acceptable by the transformation fitting tasks. An optional output file containing the magnitudes for objects in the image corrected to the large aperture radius specified in the task may be saved by specifying the parameter *magfile*. This is input to the **obsfile** task to be formatted into a file acceptable by the transformation fitting tasks. The user may keep

track of the session by saving the log and plot files. See the help pages of these tasks for more information.

10 Photometric Transformations: The PHOTCAL Package

PHOTCAL is found in the NOAO.DIGIPHOT package and performs the transformation of instrumental to standard magnitudes by solving for color and extinction terms in the transformation equations. The output files from the photometry tasks in IRAF must be fed to one of the preprocessor tasks, **mknobsfile**, **mkobsfile**, or **obsfile**, which creates a properly formatted table for input to the transformation tasks; this file is called the **observations** file. The first two of these tasks prepares an observation file from the APPHOT or DAOPHOT output photometry files, while the **obsfile** task takes the input from a multi-column text file. An **imsets** file, which associates the different filter frames taken of the same object, is required as input to **mknobsfile** and **mkobsfile** as well.

A **configuration** file is needed to define the formats of the input tables and the transformation equations. Help is obtained by typing **phelp config**. Before performing the coefficient fit, the **configuration** file may be checked using **chkconfig**, and a **catalog** file will need to be created for the standard stars using the **mkcatalog** task. Some catalogs of standards are available in the *photcal$catalogs* directory. The fitting is done by the task **fitparams** which outputs the extinction and color coefficients for a given night using the calibration standards. The coefficients are then used to compute the magnitudes for the program objects in the following tasks:

- **evalfit** - compute the standard indices by evaluating the fit.

- **invertfit** - compute the standard indices by inverting the fit.

The main difference between these tasks is the form of the transformation equations specified in the configuration file. See the help pages on these tasks for more information. Type **phelp pcintro** for details about the package.

As mentioned in Section 2 getting sufficient observations for the airmass and transformations calculations are an important part of this process. The extinction stars should bracket your program objects in airmass with a minimum delta airmass of 0.5 magnitudes. The standard stars should bracket your program objects in color with a minimum range of 0.5 magnitudes as well. The extinction stars can be the same or different stars than the standards.

11 Faint Object Classification: The FOCAS Package

FOCAS stands for Faint Object Classification and Analysis System. This is an add-on package for UNIX versions of IRAF and is available by anonymous ftp to *iraf.noao.edu* (140.252.1.1) within the *iraf.old* directory. FOCAS is a versatile set of tasks which will

detect objects, catalog, classify, determine shape parameters, and perform photometry and astrometry on an image. The main tasks within this package are:

- **setcat** - create and initialize a catalog.

- **detect** - detect the objects.

- **sky** - evaluate the local sky in an annulus around the object.

- **evaluate** - all the photometry, astrometry shape computations.

- **splits** - separates merged objects.

- **resolution** - classify the objects.

The photometry performed uses two fixed apertures, one of which is set by the user, and two isophotal photometry measurements. The detection isophotes can be any shape, however partial pixel sampling is not done. The shape information consists of intensity-weighted moments over the detection isophote, and separation into noise, stars and galaxies is done based on the relative scales of the light distribution.

A   The Add-on CTIO Package Photometry Tasks

The add-on CTIO package in IRAF includes several useful tasks, **growthcurve** and **sphot**. This package is not included in the general release of IRAF but may be acquired by anonymous ftp to *iraf.noao.edu* (140.252.1.1) in a file called *ctio.tar.Z* in the *iraf.old* directory. The installation instructions are found in the *readme.ctio* file. This is an older version but the photometry tasks have not been modified. The latest version is available from *pgigoux@noao.edu*.

The input for the task **growthcurve** is the output file from the photometry tasks in the APPHOT and DAOPHOT packages, where many concentric apertures were measured for one or more isolated stars in an image. The observed differences between the successive apertures for each star are calculated. An aperture correction to the smallest aperture is computed by summing up the individual average magnitude differences between two specified apertures. An output file is automatically written to store the corrected magnitudes for objects in the image.

Quick look photometry may be done using **sphot**, which was taken from the NOAO mountain photometry program written in FORTH for the LSI-11s. This does not run from the *display* window, but requires coordinates from a file or entered interactively from the keyboard. Only one aperture size may be specified and though errors are calculated, the output format is not compatible with the input formats for the PHOTCAL package. Therefore **sphot** is not suggested for use in performing final calibrations.

B   Surface Photometry: The STSDAS ISOPHOTE Add-on Package

STSDAS is the add-on package developed at STScI and is available by anonymous ftp to stsci.edu (130.167.1.2), as is the user documentation (see Appendix C). The subpackage

ISOPHOTE is the only source currently in IRAF for doing surface photometry on non-stellar objects. A user defined ellipse is fit to a galaxy image using the task **ellipse**. The approximate center of the galaxy to be fit, ellipticity, and position angle specified by the user may be tested with several runs of the fit. The output from this task takes several forms, either STSDAS table format or a set of four text files with all the calculated parameters. These values may be checked using the many graphics tasks also found in this package:

- **isoimap** - graph ellipses superposed over the gray-scale image display.

- **isomap** - graph ellipses superposed over image contours.

- **isopall** - graph summary of all results from isophotal analysis.

- **isoplot** - graph results of isophotal analysis.

The input format for these tasks is the STSDAS table generated by the task **ellipse**. Any two parameters from that table may be plotted against each other using the task **isoplot**. The ellipses themselves may be plotted over the displayed image or a contour plot of the image. A 2-D image containing a noiseless photometric model of a source image from the results of isophotal analysis is created using the task **bmodel**. A list of elliptical apertures may be created using the task **elapert** which is then input to the **polyphot** task in APPHOT. See the help pages for all these tasks for more information.

C   Other Useful Documentation

On-line help pages are available for all the tasks mentioned in this document using **help** or **phelp**. More information on topics covered in this manual may be found in the following documentation, accessed by anonymous ftp to **iraf.noao.edu** or 140.252.1.1:

- **Photometry in IRAF**, by Lisa Wells, February 1994 (this manual). (iraf/docs/photom.ps.Z)

- **A Beginner's Guide to Using IRAF**[draft], by Jeannette Barnes, August 1993. (pub/beguide.ps.Z)

- **A User's Guide to CCD Reductions with IRAF**, by Philip Massey, June 1992. (iraf/docs/ccduser2.ps.Z)

- **A User's Guide to Stellar CCD Photometry with IRAF**, by Phillip Massey and Lindsey E. Davis, April 1992. (iraf/docs/daophot2.ps.Z)

- **Specifications for the Aperture Photometry Package**, by Lindsey Davis, May 1989. (iraf/docs/apspec.ps.Z)

- **A User's Guide to the IRAF Apphot Package**, by Lindsey Davis, May 1989. (iraf/docs/apuser.ps.Z)

- **A Reference Guide to the IRAF/DAOPHOT Package**, by Lindsey E. Davis, January 1994. (iraf/docs/daorefman.ps.Z)

- **FOCAS User's Guide**, by Francisco Valdes, September 1993. (iraf/docs/focas/focasguide.ps.Z)

- **Faint Object Classification and Analysis System: Standard Test Image Results**, by Francisco Valdes, April 1989. (iraf/docs/focas/standards.ps.Z)

The following documentation is accessed by anonymous ftp to **stsci.edu** or 130.167.1.2:

- **STSDAS Users Guide**, Nov 1991. (documents/stsdas-docs/user/UserGuide/UserGuide_12.ps)

- **STSDAS Calibration Guide**. (documents/stsdas-docs/user/CalibrationGuide/CalibGuide_12.ps)

- **Quick Reference Cards for IRAF and STSDAS**.
  (documents/stsdas-docs/user/UserQuickRef.ps)

The following source may also be helpful:

- Davis, L. E. & Gigoux, P. 1993, *PHOTCAL: The IRAF Photometric Calibration Package*, eds., Worrall, D. M., Biemesderfer, C., and Barnes, J., ASP Conf. Series Vol. 52, 479.