

# CTIOPI Photometry Reduction User Guide

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## Revision History

1. 04/20/03 by Wei-Chun Jao — Remarks section added.
2. 08/05/03 by Wei-Chun Jao — New evalfit.pl script released to match CTIOPI/SMARTS photometry catalogue.
3. 08/07/03 by John Subasavage — Cosmic ray section added, grammar corrections.
4. 08/28/03 by Wei-Chun Jao — New standard.pl script released.
5. 04/17/08 by Jen Winters — Fixairmass and setairmass tasks added, grammar corrections.
6. 05/09/12 by Jen Winters — Clarification, reorganizing, grammar corrections.
7. 04/26/13 by John Lurie — Revised aperture sizes for aperture correction.  
Also,  $\text{RMS} < 0.02$  for fitparams (Section 3.7).
8. 05/31/18 by Michele Silverstein — Update for post-Torrent, re-organization of sections, clarification of aperture corrections, hints for managing/moving around data.
9. 01/29/23 by Eliot Vrijmoet — clarification throughout, in particular on required files, standard star procedures, and aperture corrections.

## 1. Before Starting

Before starting to reduce photometry, you might need to know a little background (i.e., extinction, airmass, transformation equation, etc.). **Astronomical Photometry** by A. Henden and R. Kaitchuck is a good introductory book for those who want to get a first look at photometry. Users should also be familiar with IRAF. A couple of user guides can be found on IRAF’s website (<http://iraf.noao.edu/docs/photom.html>):

- **A User’s Guide to Stellar CCD Photometry with IRAF**
- **A User’s Guide to CCD Reductions with IRAF**

This manual will skip these introductory parts and start with the processed data (the data that have already been bias-subtracted and flat-fielded). Please read **Astrometry: Slurping Data from CTIO** on the RECONS Data Reduction page to learn how to process the raw data.

Have ready all the finder charts for the standard stars and science targets. You may also want the observing log (if available) and the airmass table, which is a bird’s eye view of all the objects observed in that night.

## 2. Organize Your Processed Data

Navigate to the photometry data folder: `/nfs/recons3/phot.0.9m/YYYY.MMDD` (where `YYYY.MMDD` is the night when the data were taken, for example: `2019.0820`). This folder should include `*.o.fits` files and the `*.headers.long` and `*.headers.short` files.

Open IRAF and load packages **daophot**, **photcal**, **redpi** before you begin anything<sup>1</sup>.

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<sup>1</sup>Patterson, R. J., *et al.* (1998) found no significant difference between IRAF/APPHOT and IRAF/DAOPHOT, although **APPHOT** is claimed for aperture photometry.

***FOR PRE-TORRENT DATA USING ARCON READOUT (pre ~May 2016):***

The new (not so new anymore) TCS does not communicate effectively with the telescope, and thus, the airmass is not accurate. This package will correct the airmass. Run **files \*.o.fits >> listfile** in IRAF. You also need to create a file called *coords* that contains the coordinates for each object. You can get these from the most recent photometry observing list posted on the protected page. The format for *coords* is as follows (note that you need the colons and only one space between the RA and DEC):

11:56:06.1 –48:39:46.0

Make sure that *listfile* and *coords* have the same number of lines or else it will crash. Then, run **fixairmass**.

***FOR ALL DATA:***

At the terminal, run **ls \*.o.fits >> listfile** to generate a list containing the file names.

Next, you will need to fix the headers. Load the **astutil** task in IRAF. Edit **setairmass** parameters for the correct observatory site (see Fig. 1). Then run **setairmass** to calculate the airmass at the middle of the exposure. This task adds a new header keyword, *utmiddle*, to header of each image. If the task is successful, it outputs one line per image to the IRAF terminal. It will *not* work if any of the following headers are missing: *date-obs*, *RA*, *ST*, *epoch*, or *airmass*. In that case you will need to add those header-keywords back to the header using the **hedit** task, then try **setairmass** again.

Create two directories: *standard* and *science*. Then sort the data into those directories depending on whether each image is a standard star or science star. That information can be found in the “short headers” file (e.g., *2018.0531.09.headers.short*) or by entering **imhead \*.fits** in IRAF; each image title will be *STAR at FILTER for phot* (science star) or *STAR at FILTER for stand* (standard star). Keep in mind that tired observers sometimes

mistype star names or the stand/phot labels. You can check the photometry observing list to verify which stars are standards.

One way to sort the files is to make a copy of the short headers file and edit that copy to create a bash script. For example, enter `cp 2018.0531.09.headers.short movestuff` to make a copy called *movestuff*, then edit its lines to match this format:

```
mv 20180531.09.051.o.fits standard
mv 20180531.09.052.o.fits standard
mv 20180531.09.053.o.fits science
```

Depending on whether each frame belongs in *standard* or *science*. If there is no header file in your directory, you can make one yourself by typing `imhead *.o.fits >> movestuff`. However, this would not be useful as a check to make sure all the photometry frames successfully made it to the directory.

You can then type `bash movestuff` in your terminal (or `!bash movestuff` from IRAF) to sort the files into their respective directories.

### 3. Standard Stars

The basic steps for reducing uncrowded standard star fields are:

1. Choose which frames to use and determine their average FWHM.
2. Remove cosmic rays.
3. Determine the aperture size you wish to use (typically 7"). This aperture will be applied to all the standard stars from all the nights for all filters. Edit the **datapars**, **centerpars**, **fitskypars** and **photpars** task parameters in the **phot** task.
4. Use the **redpi/apercorr** task to tag the standard stars so that the instrumental magnitudes can be calculated.

5. Organize the standard star configuration file and collect your standard stars' *VRI* instrumental magnitudes.
6. Apply transformation equations to get apparent magnitudes for the standard stars.

### 3.1. Determine FWHM for the Night and Choose Frames for Reduction

Enter **!ds9 &** to start ds9 from IRAF. You will use ds9 to view images and make sure things are going as planned! Before examining the data, you may need to change the setting for a radial plot using imexam. Type **epar rimexam** in IRAF, set *rplot* to 20, then enter **ctrl+d** to save and exit the settings menu. Finally, create a notes file for yourself (and anyone else who looks at these data) using this line in IRAF: **hselect \*.o.fits '\$I, RA, UTMIDDLE, AIRMASS, FILTER2, OBJECT' >> NOTES.txt**

Now you are ready to check the images. Run **displayexam listfile** to examine each image in *listfile* and note any potential problems affecting the circled stars in each standard star finder chart. These problems include: saturated stars, cosmic rays on the star's PSF, bad pixels on the star's PSF, and overlapping PSFs from neighbor stars (contamination). If a star in a frame has any of these issues, write it down in your notes file. Noting saturation is particularly important because the photometry of saturated stars cannot be determined, and in those cases iraf won't alert you with "INDEF" in the data file.

While you check the frames, you may want to note their FWHM, so you can determine the average seeing (FWHM) for this night's data. This average FWHM will be entered later into the **phot** task. You can also get this information from the observing log, if it is available. When you work with the science stars later in this process, you can assume their FWHM matches this average from the standard stars, because the science frames are sandwiched between the standard star frames.

The process later will be easier if each field has only *complete* sets of  $V$ ,  $R$ , and  $I$  images. If a field was observed one extra time in only one filter, you should choose the best image from the two duplicates, and delete the worse image from *listfile*. For example, if a field was observed in  $V$ ,  $R$  and two times in  $I$ , choose the best of the two  $I$ -band images, and delete the other one from *listfile*. On the other hand, multiple full sets of  $VRI$  are fine: for example, if a field is observed in  $V$ ,  $V$ ,  $R$ ,  $R$ ,  $I$ , and  $I$ , now you have two full sets of  $VRI$  and you will have two sets of photometry results calculated from IRAF. If you delete any lines from *listfile* during this process, please note that action clearly in your notes file.

As you examine the stars in each frame, you should note whether any stars have flux beyond the standard 7" radius aperture — if they do, note the maximum aperture that could be used for that frame without (1) light spilling out from the target star or (2) light from a neighboring source sneaking into and contaminating the target's aperture. Stars that need a smaller aperture to contain their PSF or avoid contamination will need you to compute an “aperture correction” later. This is not typical for standard stars, but science stars in crowded fields often require them.

### 3.2. Remove Cosmic Rays

It is always better to remove a cosmic ray rather than apply an aperture correction to avoid it. This is done with the IRAF command **cosmicrays** in package **imred.crutil**. Using the default parameter values first is fine to see if it does the job. Often, this command will have to be run a few times to remove the cosmic ray of concern. You should always name the output image *test.o.fits*. That way, if something goes wrong, you don't have to go back and reprocess the raw frame. When you have removed the cosmic ray to your satisfaction, you can rename *test.o.fits* to the star image. If you choose to review parameters interactively, you can delete specific points by placing the cursor over the

point and pressing *d*. Repeat this process until the cosmic ray is completely removed or until its peak flux is no more than 1% of that of the science star. See the help page by typing *help cosmicrays* for information on parameter tweaking. A bad pixel map (located at */nfs/recons3/phot.0.9m/default*) is needed to remove bad columns, but we do not usually do that correction.

Another tool that can be used is the **epix** command. Copy the image to a *test.o.fits* file to use this command, and when confident with the changes, copy the modified *test.o.fits* back to the original file name. If you know the pixel coordinates of the cosmic ray (check using a surface plot, the *e* key in **imexam**), then you can enter those coordinates when you run **epix**, and then replace the number of counts value for that pixel with the median that **epix** reported for that region.

### 3.3. Determine the Aperture Size

The aperture size is key to aperture photometry reductions. If you haven't already, you need to select a "suitable" aperture size to cover the brightness profile. Most of the standard stars we choose at CTIO are Landolt (1992) standard stars which are now included in the 2003 Astronomical Almanac. The aperture size he uses is 7" in radius (14" in diameter). Therefore, the aperture size we choose should not be less than 7" in radius. However, it highly depends on the FWHM of your images. Usually, if an image has a FWHM < 4 pixels in radius, the aperture size will be 12 to 15 pixels in radius according to IRAF manuals.

To check an aperture size's suitability, make sure all the flux from the stars land within the aperture. Do a radial plot (hit *r* in *imexam*) to show how far the light extends from the center of the star in pixels on the x-axis. The curve should be flat for at least ~5 pixels from the edge of the chosen aperture. If there is contaminating flux from another source



within the aperture, an aperture correction will be needed, as discussed in Section 4.2.

### 3.4. Modify Parameters in PHOT Task

The main IRAF task to finish this aperture photometry is **phot**. This task has been included in **redpi/apercorr option 3** task. **phot** is a task with other tasks (**datapars**, **centerpars**, **fitskypars** and **hotpars**) nestled inside.

When you load the **redpi/apercorr** task, there will be 4 options. Select **option 4** for standard stars because standards are usually in uncrowded fields where no aperture correction necessary, unless some bonehead has positioned a star too close to the bad column. After choosing option 4, you will need to modify the following parameters in each task by scrolling down (using the up and down arrow keys) to each and typing *:e*.

#### 3.4.1. *hotpars*

This task specifies the size of the aperture. It is 7" in radius in Fig. 1. If *mkapert* is set to "yes", it will indicate the aperture size on the radial plot while you tag the stars. This is helpful to see whether any contamination will fall within the aperture.

#### 3.4.2. *datapars*

Fig. 2 shows the parameter examples for this task. The key parameter is *fwhmpsf* because it will be different from night to night. Set *fwhmpsf* to the average FWHM (in arcsec) of all the standard star images. Compute this value by multiplying the FWHM in pixels (the units in IRAF's radial plot) by the CTIO 0.9m plate scale: 0.401"/pixel. The other parameters refer to instrument properties and will not change from night to night.

### 3.4.3. *centerpars*

This task will determine the centering algorithm while we tag the stars. Set the *algorithm* to “centroid” (see Fig. 2). The other parameter needing modification from night to night is *cbox*. Usually it is two times *fwhmpsf* (still in units of arcsec).

### 3.4.4. *fitskypars*

The background noise will affect the quality of aperture photometry. You will need to select the size of the sky and sky annulus to calculate the background noise. Currently, we choose a radius of 20” with a 3” annulus width as shown in Fig. 2. Set *mksky* to “yes” to have the sky annulus drawn on the radial plot as you tag each star. (very useful)

## 3.5. Tag standard stars to generate mag.1 files

After you modify all the above parameters, press **ctrl+d** to save and quit. Then the **apercorr** task will automatically display each image listed in *listfile*. For each image, move the cursor onto the image and tag the stars you need using the spacebar. Please make sure to tag the stars in a consistent order from filter to filter, as shown in their finder charts. With each tag, a radial plot will appear with the aperture and sky annulus sizes marked. A new file *\*.mag.1* will be generated after you type *q* to quit the tagging sequence.

Once this step is complete, double check everything is a-ok by entering into the terminal **grep ‘INDEF’ \*.o.mag.1**. If this command produces output, that means there was an issue with tagging, and you should check the *\*.o.mag.1* file it named to see the error code and which star it affects. (At the bottom of the file, each star has a block of several lines. Look for “INDEF” at the end of one of those blocks. For ex., *INDEF 305 BadPixels*)

Various issues have different solutions. Good luck. If your error is *BadPixels*, here are some suggestions:

- It is never a bad idea to check which pixel(s) is/are bad. If it's smack in the center of the star or on the PSF tail, you usually cannot get good photometry of that star in that frame. The **epix** task cannot be used to fix the bad pixel.
- If a bad pixel or cosmic ray is near the edge of the 7" aperture, and surrounding pixels are all very similar in value, then you may try **epix** to change the pixel value.
- Sometimes it works if you decrease the *sigma* and/or *datamin* parameters in *datapars*.

When you've done what you can to fix the affected frames and/or parameters, it's time to re-tag those frames! To do that, you first must rename or delete the *\*.o.mag.1* files with errors. If a file of the same name exists, *apercorr* will crash. Once you've done this, make a file *listfile.retag* listing only files that need re-tagging, then run **apercorr** again (as you did before). Don't forget to specify your new file *listfile.retag* (instead of *listfile*) at the prompt.

### 3.6. Make Observation Files

The instrumental magnitude for each standard star has been calculated and listed in each *\*.mag.1* file. Before assembling them into a master file, you need to use the **mkimsets** task to sort these images (see Fig. 3). The output file should be named "standard.imsets", which stands for "standard fields image sets". The first column indicates the ID of each field, and the second, third, and fourth columns are *V*, *R*, and *I* filters, respectively. In Fig. 3 you can see that standard field 1 was observed one time in the *V* and *R* filters, but twice in the *I* filter (1004 and 1005). Standard field 2 was observed twice in each.

When running the **mkimsets** task you will be entering the star names corresponding to each set of images. These star names **must exactly match** the ones used in the Landolt

standards table (*landvri.dat*, containing the known magnitudes of each standard star). Copy that table now from */nfs/recons3/phot.0.9m/default/landvri.dat* to your current directory. Then open *landvri.dat*, locate the standards for your current reduction night, and note how each of those stars is named (consider writing them down).

Once you have checked the names and task settings, go ahead and run **mkimsets**. There will be several steps that require your input. When it is done, you should have an output file called *standard.imsets*.

### 3.7. Make Master List of Instrumental Magnitudes (*VRI* Table for Standards)

The next step will be to extract all the instrumental magnitudes in *\*.mag.1* into a master file. The task to be used is **mknoobsfile**, as shown in Fig. 3. If you computed an aperture correction for any frames, be sure to include that filename (usually “aperture.corr”) under the *apercors* parameter.

The output file *standard.obs* is the master list of instrumental magnitudes of all the standard stars you tagged. If there are three stars in a field, they will be labeled in sequential order: 1, 2, and 3. After it finishes, please open *standard.obs* to check the filter orders (should be ov, r, then i) and check that the file matches the format shown in Fig. 3. Note that sometimes the program will pick up additional “nonsense” stars in these images; these will correspond to lines that just have “INDEF” for all their values. Eliminate those excess lines from *standard.obs* and, if necessary, rearrange the lines so the *V*, *R*, and *I* measurements for each star are grouped together.

### 3.8. Make Configuration File

Next, you must create a configuration file (as shown in Fig. 4) to define the transformation equation for the photometry. More detail on this equation is in Section 5. As of August 2018, these configuration files have been pre-made for several years. Simply copy the *standard.cfg* file from */nfs/recons3/phot.0.9m/default/* to the current directory.

If you only have *VR*, *RI*, and/or *VI* filters (instead of a full *VRI* set) for any number of standard star visits, you can use the *standardvr.cfg*, *standardri.cfg*, or *standardvi.cfg* file(s). If you are doing a photometry reduction with any filters other than the usual *ov*, *r*, *i* filters, you will need to either find or create a different configuration file.

If you have not already done so, copy *landvri.dat* from */nfs/recons3/phot.0.9m/default/* to the current directory. Then verify that all stars listed in your *standard.obs* file are listed **identically** to how they appear in *landvri.dat*. The next steps will not work if the star IDs do not match Landolt’s table!

### 3.9. Fit the Transformation Equations for Standard Stars

The last task to use in this standard star data reduction is **fitparams**, shown in Fig. 5. Basically, the task will apply the method of least-squares to the transformation equations to calculate apparent magnitudes for the standard stars and also to determine the transformation equation coefficients (listed in the output file *standard.coeff*) so that we can apply those coefficients to our science stars.

This task will plot a residual and tell you if the solution converges or not. If the RMS is higher than 0.02 or if the fit does not converge in one filter, delete a couple of high residual stars and then fit again (shown in Fig. 7). Please read the help manual of **fitparam** task for more details. You may quit this task after each filter’s fittings converge with  $\text{RMS} < 0.02$ .

Run **fitparam** now. Here are some commands to use to adjust the fit (remember the goal is a residual  $< 0.02$ ):

- d — delete a point
- u — undelete a point
- r — re-run the fit
- q — quit and move on to the next filter

If the solution converges the first time, there will be three main blocks in the output *standard.coeff* file. If not, some extra blocks with “diverge” will be noted in this file. The last three blocks in this file indicate the final coefficient results for this transformation. If you run into any issues, the *logfile* that is produced during this procedure is often a good source of information. New data is appended every time **fitparam** is run.

Concerning results:

- Stars with residuals far from all the other stars’ residuals. There may be some issue with the data taken during that epoch, or perhaps something went wrong with that star earlier in the reduction.
- Issues with red standards — there are usually not many observations of red standards, but the ones we get are important. Try and revisit...?

The output of **fitparams** is the file *standard.coeff*, which contains the transformation equation coefficients. You will need the file later when you reduce the science stars’ data.

### 3.10. Final Standards Step: Create the Photometry Catalog File

Finally, we must prepare the standard star results for the photometry catalog. Make a backup of *standard.imsets* (**cp standard.imsets standard.imsets.backup**). Then open

*standard.imsets* and remove the first two blank lines. Make one line for each visit of each object, repeating file names for images with multiple objects.

For example, standard star LSE-44 has 7 stars, so should have 7 identical lines, with the only difference being that each line has a different object name (LSE-44A, LSE-44B, etc.). The names must be in the order that you tagged the stars. Make sure to leave a space on either side of the “:” symbol. The first three lines for LSE-44 would then look like this:

```
LSE-44A : 20180823.09.074.o 20180823.09.075.o 20180823.076.o
LSE-44B : 20180823.09.074.o 20180823.09.075.o 20180823.076.o
LSE-44C : 20180823.09.074.o 20180823.09.075.o 20180823.076.o
```

Note that these are all from the same “standard visit”; each row uses the same frames, but has a different name for each object.

To generate the photometry catalogue entries for CTIOPI, you must run a perl script: `perl ~/bin/standard.pl`. This script uses the files *standard.imsets* and *standard.obs* as input, and creates a file *standard.catalog* (as shown in Fig. 6). Run this script now. **THIS SCRIPT WILL NOT CALCULATE THE EXTINCTION CURVE. IT GENERATES THE CATALOGUE ONLY.**

If you excluded any images from the standard star data reduction (check your *NOTES.txt* file), **PLEASE MANUALLY ADD THOSE BAD IMAGES INTO THE CATALOGUE FILE.** List them with the extension “.ext” instead of “.o”.

Now you have finished processing the standard stars and have gotten the transformation coefficients. Next, continue to work on the science stars.

#### 4. Science Stars

Science star fields are usually more crowded than the standard star fields. However, our CTIO images are far less crowded than those in globular clusters. The necessity of aperture correction strongly depends on the fields. Determining aperture size is more of an art than a science. The larger the aperture, the larger the error from the sky subtraction and the more cosmic rays included. Therefore, a correct “aperture size” is the one which is large enough to include most of the flux from a star. Theoretically, a star’s flux will not increase after a critical aperture size.

An aperture correction is a magnitude correction from a small size to a larger critical aperture size. Basically, if there are no extra objects within the  $7''$  radius (no “contamination”), the regular aperture photometry without aperture correction should work — otherwise, an aperture correction is necessary. Note that if you can apply a  $7''$  or larger radius aperture to an object, do not apply a smaller aperture size to it. No correction is better than any correction.

The basic steps of the reduction procedure for science stars are:

1. **imexam** every science image to ensure that none are saturated and determine which images require an aperture correction. Note any cosmic rays for removal, if necessary.
2. Edit all parameters in **phot**.
3. If an image needs an aperture correction, tag 3 or 4 isolated field stars.
4. Calculate the amount of correction based on these isolated stars.
5. Tag your science stars with selected aperture size.
6. Generate the science star configuration file and collect your science stars’ *VRI* instrumental magnitudes.
7. Based on the transformation equation coefficients from standard stars, calculate apparent magnitudes.



#### 4.1. Examine Science Images

If you have not done so already, navigate out of the *standard* folder and into the night's *science* folder. As you did for the standard stars, you may want to have a *NOTES.txt* file for these science star images. Make this file using this IRAF command: **hselect \*.o.fits '\$I, RA, UTMIDDLE, AIRMASS, FILTER2, OBJECT' >> NOTES.txt**

Understanding the quality of your science images is important because you need to apply the right method to process your precious data. Run the **redpi/displayexam** task in IRAF to examine each image. For each science star in each image, determine if an aperture correction is necessary and make a note of any cosmic rays within a 7" radius. Note these things in your *NOTES.txt* file. After you have checked each image, go back and fix any cosmic rays or bad pixels that are not directly on the science stars' PSFs (see Section 3.2)

#### 4.2. Making an Aperture Correction

Sometimes no aperture correction is needed on any science star in a night of photometry. If that is the case, shout "Hooray" and skip to the section **Get Instrumental Magnitudes for Science Stars** (Section 4.3). However, we are not usually that lucky, so if you *do* need to make an aperture correction, continue on to the next section.

**Note:** The following instructions will apply the aperture correction to *every* tagged star in the specified frames. If a frame has more than one science star and you only want to apply the correction to one (or a few) of those stars, then execute the aperture correction in a subdirectory. Create a directory within the *science* folder, copy only the relevant frames into that subdirectory, and follow these instructions through **mknoobsfile**. Then reconcile the aperture-corrected *science.obs* file with the main directory's *science.obs* before proceeding to **evalfit**.

#### 4.2.1. Tag Isolated Stars in a Crowded Field

As a first step it is important to decide the aperture size you plan to correct *from*. For example, you may need an aperture of size 4" to avoid contamination from another nearby source. Keep in mind that the flux from a star reaches pretty far into the tail of the radial plot, so don't use an aperture that goes right up to what *appears* to be the edge of the contaminating flux — try to go a couple arcseconds smaller with your aperture.

You will need to execute a separate aperture correction for each different aperture size. Group your correction-needing frames according to the size of each correction: e.g., make a *listfile.3* file that lists frames needing 3", a *listfile.3.5* file for those needing 3.5", etc.

For each frame needing a correction, you must choose 3–5 stars in the field that do *not* have any contamination or anomalies within 7". Choose stars with peak counts  $\geq 10,000$  for best results. You can do this using **displayexam** in iraf to cycle through the list of frames needing one correction (e.g., *listfile.5* for 5"), and marking the isolated stars you plan to use. (go to **Edit** then **Regions** in ds9, then click on the image to draw circles)

When you have chosen your isolated stars for each frame, **redpi/apercorr** and choose **option 1**. It will allow you to edit the parameters of the **phot** task (explained in Section 3.4). Most parameters should not change from when you did standard stars, but for **photpars** you must choose a large variety of aperture sizes spanning from *smaller* than your new small aperture up to the standard 7" radius. For example, if I want to use a 5" aperture, I might list: 2, 2.5, 3, 3.5, 4, 4.5, 5, 5.5, 6, 6.5, 7, 7.5 for *apertures*. Upon saving, the task will present you with each image in your list, where you should tag the 3–5 isolated stars you chose earlier. These stars *do not* need to be tagged in the same order or even be the same stars in each filter, but you must tag the same *number* of stars in each filter. The new generated file is called *\*.aper.1*.

#### 4.2.2. Apply Aperture Correction

After the isolated stars are all tagged, run **redpi/apercorr** and select **option 2** to calculate the correction. The actual task behind the curtain is **mkapfile** (shown in Fig. 5). The script will initially present you with an epar of the **mkapfile** parameters.

You need to change the parameters to match the list of apertures you gave earlier during option 1. On some scratch paper, make a table like this:

index	1	2	3	4	5	6	7	8	9	10	11
radius size (arcsec)	2	2.5	3	3.5	4	4.5	5	5.5	6	6.5	7

Edit the parameter *naperts* to the total number of apertures you want to extract — in the example above, that is “11”. The *smallap* parameter indicates the index of the small aperture you would like to apply, and *largeap* indicates the index of the aperture to correct to. Use the table you wrote above to determine these indices. For example, to apply a 5” aperture, change *smallap* to “7” (because 5” here is index 7), and set *largeap* to “11” (for 7”). The result will be a correction *from* a 5” aperture *to* a 7” aperture.

When you save and exit the parameters, the task will show a curve of growth for every *\*.aper.1* file. This curve plots magnitude within each aperture vs. aperture size. If you tagged  $\gtrsim 5$  stars, you can delete any bad points here with *d* and then re-fit the curve.

When you exit, the program makes the output file *aperture.corr*. This file contains the image name in column 1, the aperture correction computed from *smallap* to *largeap* in column 2, and the estimated error in the aperture correction in column 3. If you are computing multiple different aperture sizes for the same night (for example, some stars need 3” and some need 5”), rename each *aperture.corr* file as you go (to *aperture.corr.3*, *aperture.corr.5*, etc.), then concatenate them into one single *aperture.corr* file when you are done computing all corrections. In that single final file, create a 4th column and enter

the aperture radius in arcsec for each image. A # must precede this column so it does not affect the calculation to come later. For example:

```
20030101.09.101.o -0.01218093 8.684811E-4 #5"
20030101.09.112.o -0.08370557 0.004138806 #3"
```

### 4.3. Get Instrumental Magnitudes for Science Stars

You will need to do this procedure once for each different aperture size you want to use. Prepare a list of frames for each aperture. For example, if you computed aperture corrections for some stars at 3", some at 5", and you intend to use the standard 7" for the rest, then have files *listfile.3*, *listfile.5*, and *listfile.7*.

This step is similar to the standard star tagging procedure. Load the task **redpi/apercorr** and choose **option 3**. This option will let you edit **phot** parameters, where you only need to adjust the *apertures* parameter. The correct aperture size is the same as the *smallap* (in arcsec) which you used in the aperture correction. If no aperture correction was needed, this is just the 7" radius that you used when you tagged the standard stars. Again, when tagging fields with more than one science star, **the tagging order should be the same for all filters**. The output file for each frame is called *\*.mag.1*.

### 4.4. Make Science Star Observation Files and VRI Magnitude Files

You do **not** need to do these next steps separately for each aperture! That is because you have one file (*aperture.corr*) containing all your aperture corrections and specifying to which frames each correction applies.

Run the **mkimsets** task just as you did for standard stars. Make sure to change the output file to "science.imsets". After this file is generated, remove the top two blank lines.

Next, use **mknoobsfile** to generate a list of instrumental magnitudes. Edit the parameters first to specify “science.imsets” for the *imsets* parameter, and “science.obs” for *observation* (the output file). And if you want to apply your aperture corrections, specify “aperture.corr” for *apercors* (otherwise leave that parameter blank).

## 4.5. Calculate Apparent Magnitude

There are two ways to calculate the apparent magnitude. One is with **evalfit**, an iraf standard task, and the other is with **evalfit.pl** which is a perl script. The latter produces an output consistent with the CTIOPI photometry catalogue and is preferred.

For both tasks, you will need to copy the *standard.coeff* file from the standard star directory to your current directory. You will also need to copy *science.obs* and *science.cfg* (which is the same as *standard.cfg*, therefore science and standard stars will have the same transformation equation) from */nfs/recons3/phot.0.9m/default/* to your current directory.

### 4.5.1. iraf evalfit task

Before using this iraf task, copy the *standard.coeff*, *science.obs*, and *science.cfg* files as instructed above. No modification to *standard.coeff* is necessary in this case. An example parameter for **evalfit** is shown in Fig. 5. The output file is called *evalfit.out*. The S/N magnitude error is also printed in this file. More error discussion can be found in Section 5.

### 4.5.2. perl script

Before using this script, copy the *standard.coeff*, *science.obs*, and *science.cfg* files as instructed above. In this case, you need to also modify the *standard.coeff* file by leaving

only the last block of converged *VRI* results in the file. No divergent result can exist.

The output file that was created by **mkimsets** must be called “science.imsets” for this script to work. Also, in the case where a series of frames were taken of a double star (with a separate photometry measurement for each??), you must insert an extra line for the second star which has the same frame name as the first star. For example,

```
LHS300AB : 20030101.09.101.o 20030101.09.102.o 20030101.09.103.o
```

should be modified to look as follows:

```
LHS300A : 20030101.09.101.o 20030101.09.102.o 20030101.09.103.o
```

```
LHS300B : 20030101.09.101.o 20030101.09.102.o 20030101.09.103.o
```

This perl script is called **evalfit.pl**. Have a copy of it under your bin directory, because the date/format perl module is called, logon **penston**. Type **perl ~/bin/evalfit.pl** to execute it. This perl script is only applied for a second-order transformation equation as shown in Section 5.

The output file *science.ans* is shown in Fig. 6. This file includes the standard star error as well as other important parameters such as airmass. More discussion about magnitude error can be found in Section 5. This file needs to be manually edited to include the **diameter** (not radius!) of the aperture size you used for each field. For example, if you used the standard 7" radius, you will enter 14" for that image.

As you did for the standards, if you excluded any images from the science reduction (check your *NOTES.txt* file), **PLEASE MANUALLY ADD THOSE BAD IMAGES INTO THE CATALOGUE FILE**. List their extension as “.ext” instead of “.o”.

## 5. Transformation Equations

The transformation equations for apparent magnitude  $V(RI)_c$  are as follows:

$$V = m_V + a_1 + a_2X + a_3(m_V - m_I) + a_4(m_V - m_I)X \quad (1)$$

$$R = m_R + b_1 + b_2X + b_3(m_R - m_I) + b_4(m_R - m_I)X \quad (2)$$

$$I = m_I + c_1 + c_2X + c_3(m_R - m_I) + c_4(m_R - m_I)X \quad (3)$$

where  $V$ ,  $R$ , and  $I$  are the apparent magnitudes for standard stars,  $m_{VRI}$  is the instrumental magnitude from iraf,  $a_1$  to  $a_4$  are the transformation coefficients (same for  $b_i$  and  $c_i$ ), and  $X$  is the airmass.

The method of least-squares is performed by the **fitparam** task to calculate the transformation coefficients based on the standard star observations. This task calculates not only the transformation coefficients but also the so-called “external error” or “standard star error”. This standard deviation error can be found in the **fitparam** output *logfile*.

Another magnitude error is the “internal error” or “night-to-night error”, which is the error from the repeated observation of the same object. The smallest error is called the “photon error” which indicates the signal-to-noise ratio received by the detector. This error is printed in the output file of the **evalfit IRAF** task. Because of the large signal-to-noise ratio, this error is usually very small.

## 6. Remarks About Sky Subtraction

When subtracting the sky background, you must choose an inner radius for the sky annulus and a width for that annulus. The example given here uses the **noao.digiphot.daophot.phot** task applied to the standard star field SA98. The seeing on that night (14 NOV 2001) was 1.4”, or 3.5 pixels. The parameter file for the task **fitskypars** is shown in Fig. 2 (the numbers for the parameters *annulus* and *dannulus* are in arcsec). Mean sky counts for two example inner radii for the sky annulus (10” and 20”) are

shown in Table 1. In both cases the width is  $3''$ .

star	$10''$ (radius)	$20''$ (radius)	note
SA98–650	58.33632	57.91608	
SA98–670	63.51149	58.55741	
SA98–676	60.38068	58.39950	mix with SA98–675
SA98–675	61.22947	58.12084	mix with SA98–676

Two things can be seen in these results: (1) the  $20''$  inner annulus radius has lower counts (and lower standard deviations, not shown) than the  $10''$  radius — the smaller radius may include counts from the wings of the star, indicating that a larger sky annulus radius is preferred, and (2) even when a nearby star is within the sky annulus width (e.g., SA–676 and SA98–675), the mean sky counts are not affected.



```
-----  
-setairmass-  
-----  
    images = "@listfile"      Input images  
(observatory = "CTIO")      Observatory for images  
    (intype = "beginning")   Input keyword time stamp  
    (outtype = "effective")  Output airmass time stamp\n  
    (date = "date-obs")      Observation date keyword  
    (exposure = "exptime")  Exposure time keyword (seconds)  
    (airmass = "airmass")   Airmass keyword (output)  
    (utmiddle = "utmiddle") Mid-observation UT keyword (output)\n  
    (show = yes)            Print the airmasses and mid-UT?  
    (update = yes)         Update the image header?  
    (override = yes)       Override previous assignments?  
    (mode = "ql")  
  
-----  
-task=phot-  
-----  
    image = ""              Input image(s)  
    coords = ""            Input coordinate list(s) (default: image.coo.?)  
    output = ""            " Output photometry file(s) (default: image  
    skyfile = ""          Input sky value file(s)  
    (plotfile = "")       Output plot metacode file  
    (datapars = "")      Data dependent parameters  
    (centerpars = "")    Centering parameters  
    (fitskypars = "")    Sky fitting parameters  
    (photpars = "")      Photometry parameters  
(interactive = yes)     Interactive mode ?  
    (radplots = yes)     Plot the radial profiles?  
    (verify = )_.verify) Verify critical phot parameters ?  
    (update = )_.update) Update critical phot parameters ?  
    (verbose = )_.verbose) Print phot messages ?  
    (graphics = )_.graphics) Graphics device  
    (display = )_.display) Display device  
    (icommands = "")     Image cursor: [x y wcs] key [cmd]  
    (gcommands = "")     Graphics cursor: [x y wcs] key [cmd]  
    (mode = "ql")  
  
-----  
-photpars-  
-----  
(weighting = "constant")  Photometric weighting scheme  
    (apertures = "7")      List of aperture radii in scale units  
    (zmag = 25.)          Zero point of magnitude scale  
    (mkapert = yes)       Draw apertures on the display  
    (mode = "ql")
```

Fig. 1.— parameter examples for **setairmass**, **phot** and **photpars**.

```

-----
-datapars-
-----
      (scale = 0.401)      Image scale in units per pixel
      (fwhmpsf = 1.3)     FWHM of the PSF in scale units
      (emission = yes)    Features are positive ?
      (sigma = 5.)        Standard deviation of background in counts
      (datamin = -4.)     Minimum good data value
      (datamax = 65535.)  Maximum good data value
      (noise = "poisson") Noise model
      (ccdread = "gtron21") CCD readout noise image header keyword
      (gain = "gtgain21") CCD gain image header keyword
      (readnoise = 4.7)   CCD readout noise in electrons
      (epadu = 3.1)       Gain in electrons per count
      (exposure = "exptime") Exposure time image header keyword
      (airmass = "airmass") Airmass image header keyword
      (filter = "filter2") Filter image header keyword
      (obstime = "utmiddle") Time of observation image header keyword
      (itime = 20.)       Exposure time
      (xairmass = 1.2660490274429) Airmass
      (ifilter = "diar")  Filter
      (otime = "4:50:29.7") Time of observation
      (mode = "ql")
-----
-centerpars-
-----
      (calgorithm = "centroid") Centering algorithm
      (cbox = 2.6)         Centering box width in scale units
      (cthreshold = 0.)    Centering threshold in sigma above background
      (minsnratio = 1.)    Minimum signal-to-noise ratio for centering alg
      (cmaxiter = 10)      Maximum iterations for centering algorithm
      (maxshift = 4.)      Maximum center shift in scale units
      (clean = no)         Symmetry clean before centering
      (rclean = 1.)        Cleaning radius in scale units
      (rclip = 2.)         Clipping radius in scale units
      (kclean = 3.)        K-sigma rejection criterion in skysigma
      (mkcenter = no)      Mark the computed center
      (mode = "ql")
-----
-fitskypars-
-----
      (salgorithm = "mode") Sky fitting algorithm
      (annulus = 20.)      Inner radius of sky annulus in scale units
      (dannulus = 3.)     Width of sky annulus in scale units
      (skyvalue = 0.)      User sky value
      (smaxiter = 10)      Maximum number of sky fitting iterations
      (sloclip = 0.)       Lower clipping factor in percent
      (shiclip = 0.)       Upper clipping factor in percent
      (snreject = 50)      Maximum number of sky fitting rejection iterati
      (sloreject = 3.)     Lower K-sigma rejection limit in sky sigma
      (shireject = 3.)     Upper K-sigma rejection limit in sky sigma
      (khist = 3.)         Half width of histogram in sky sigma
      (binsize = 0.10000000149012) Binsize of histogram in sky sigma
      (smooth = no)        Boxcar smooth the histogram
      (rgrow = 0.)         Region growing radius in scale units
      (mksky = yes)        Mark sky annuli on the display
      (mode = "ql")

```

Fig. 2.— parameter examples for **datapars**, **centerpars** and **fitskypars**. Note that after May 2016, the values should be different: *readnoise* is 12 and *epadu* (gain) is 3.

```

-----
-mkimsets-
-----
    imlist = "*.o.mag.1"      The input image list
    idfilters = "v,r,i"      The list of filter ids
    imsets = "standard.imsets" The output image set file
    (imobsparams = "")       The output image observing parameters file
    (input = "photfiles")    The source of the input image list
    (filter = )              The filter keyword
    (fields = "")            Additional image list fields
    (sort = "")              The image list field to be sorted on
    (edit = yes)             Edit the input image list before grouping
    (rename = yes)           Prompt the user for image set names
    (review = yes)           Review the image set file with the editor
    (list = "")
    (mode = "ql")

-----
standard.imsets example:
-----

field1 : dec02s.1001.o dec02s.1003.o dec02s.1004.o
field1 : dec02s.1001.o dec02s.1003.o dec02s.1005.o
field2 : dec02s.1009.o dec02s.1011.o dec02s.1010.o
field2 : dec02s.1012.o dec02s.1013.o dec02s.1014.o

-----
-mknobsfile-
-----

photfiles = "*.o.mag.1"      The input list of APPHOT/DAOPHOT databases
    idfilters = "v,r,i"      The list of filter ids
    imsets = "standard.imsets" The input image set file
    observations = "standard.obs" The output observations file
    (obsparams = "")         The input observing parameters file
    (obscolumns = " ")       The format of obsparams
    (minmagerr = 0.001)      The minimum error magnitude
    (shifts = "")            The input x and y coordinate shifts file
    (apercors = "")          The input aperture corrections file
    (aperture = 1)           The aperture number of the extracted magnitude
    (tolerance = 5.)          The tolerance in pixels for position matching
    (allfilters = no)         Output only objects matched in all filters
    (verify = yes)           Verify interactive user input ?
    (verbose = yes)          Print status, warning and error messages ?
    (mode = "ql")

-----
standard.obs example:
-----

field1-1      v      5:59:25.5  1.512  607.395  749.645  16.147  0.001
*             r      6:01:47.8  1.526  607.467  748.719  14.937  0.001
*             i      6:03:35.7  1.537  609.185  748.972  14.170  0.001
field1-2      v      5:59:25.5  1.512  543.660  558.728  17.673  0.003
*             r      6:01:47.8  1.526  543.682  557.738  17.036  0.003
*             i      6:03:35.7  1.537  545.469  558.193  17.288  0.005
field1-3      v      5:59:25.5  1.512  967.006  226.776  16.597  0.001
*             r      6:01:47.8  1.526  967.282  225.602  16.247  0.002
*             i      6:03:35.7  1.537  968.751  226.254  16.706  0.003

-----
example file of landvri.dat
-----

field1-1      10:54:05.0 -00:50:15.0      8.754      8.240      7.756
field1-2      10:53:52.0 -00:50:40.0      9.246      8.698      8.201
field1-3      10:48:13.0 -11:20:12.0     15.600     13.400     11.180
field2-1      04:02:40.9 -44:45:09.0     13.097     12.658     12.274
field2-2      04:02:31.8 -44:47:08.0     14.090     13.778     13.452
field2-3      04:02:44.0 -44:47:00.0     15.751     15.239     14.793

```

Fig. 3.— parameters for **mkimsets**, and the output file format.

```
# Declare the standards catalog variables
catalog
v      4          # the V magnitude
r      5          # the R magnitude
i      6          # the I magnitude

# Declare the observations file variables
observations
Tv     3          # time of observation in filter V
Xv     4          # airmass in filter V
xv     5          # x coordinate in filter V
yv     6          # y coordinate in filter V
mv     7          # instrumental magnitude in filter V
error(mv) 8       # magnitude error in filter V

Tr     10         # time of observation in filter R
Xr     11         # airmass in filter R
xr     12         # x coordinate in filter R
yr     13         # y coordinate in filter R
mr     14         # instrumental magnitude in filter R
error(mr) 15     # magnitude error in filter R

Ti     17         # time of observation in filter I
Xi     18         # airmass in filter I
xi     19         # x coordinate in filter I
yi     20         # y coordinate in filter I
mi     21         # instrumental magnitude in filter I
error(mi) 22     # magnitude error in filter I

# Sample transformation section for the Landolt UBVRI system
transformation

set rv = v-mv
set rr = r-mr
set ri = i-mi
set vr = mv-mr
set vi = mv-mi
set dri = mr-mi

fit v1=0.0, v2=0.0, v3=0.0, v4=0.0
VFIT: v = mv + v1 +v2*Xv + v3*(mv-mi) + v4*(mv-mi)*Xv

fit r1=0.0, r2=0.0, r3=0.0,r4=0.0
RFIT: r = mr + r1 +r2*Xr + r3*(mr-mi) + r4*(mr-mi)*Xr

fit i1=0.03, i2=0.02, i3=0.04, i4=0.03
IFIT: i = mi + i1 +i2*Xi + i3*(mr-mi) + i4*(mr-mi)*Xi
```

Fig. 4.— standard star configuration example.

```

-----
-fitparam-
-----
observations = "standard.obs"      List of observations files
catalogs     = "landvri.dat"      List of standard catalog files
config       = "standard.cfg"    Configuration file
parameters   = "standard.coeff"  Output parameters file
(weighting   = "photometric")    Weighting type (uniform,photometric,equations)
(addscatter  = yes)              Add a scatter term to the weights ?
(tolerance   = 1.0000000000000E-7) Fit convergence tolerance
(maxiter     = 30)              Maximum number of fit iterations
(nreject     = 3)              Number of rejection iterations
(low_reject  = 3.)             Low sigma rejection factor
(high_reject = 3.)             High sigma rejection factor
(grow        = 0.)             Rejection growing radius
(interactive = yes)            Solve fit interactively ?
(logfile     = "logfile")      Output log file
(log_unmatch = yes)            Log any unmatched stars ?
(log_fit     = yes)            Log the fit parameters and statistics ?
(log_results = yes)            Log the results ?
(catdir      = " ")            The standard star catalog directory
(graphics    = "stdgraph")     Output graphics device
(cursor      = " ")            Graphics cursor input
(mode        = "ql")

-----
-mkapfile-
-----
photfiles    = "*.aper.1"       The input list of APPHOT/DAOPHOT databases
naperts      = 14               The number of apertures to extract
apercors     = "aperture.corr"  The output aperture corrections file
(smallap     = 5)              The first aperture for the correction
(largeap     = 9)              The last aperture for the correction
(magfile     = " ")            The optional output best magnitudes file
(logfile     = " ")            The optional output log file
(plotfile    = " ")            The optional output plot file
(obsparams   = " ")            The observing parameters file
(obscolumns  = "2 3 4 5")      The observing parameters file format
(append      = no)             Open log and plot files in append mode
(maglim      = 0.1)            The maximum permitted magnitude error
(nparams     = 5)              Number of cog model parameters to fit
(swings      = 1.2)            The power law slope of the stellar wings
(pwings      = 0.1)            The fraction of the total power in the stellar
(pgauss      = 0.5)            The fraction of the core power in the gaussian
(rgescale    = 0.9)            The exponential / gaussian radial scales
(xwings      = 0.)             The extinction coefficient
(interactive  = yes)            Do the fit interactively ?
(verify      = no)             Verify interactive user input ?
(gcommands   = " ")            The graphics cursor
(graphics    = "stdgraph")     The graphics device
(mode        = "ql")

-----
-evalfit-
-----
observations = "science.obs"    List of observations files
config       = "science.cfg"    Configuration file
parameters   = "standard.coeff" Fitted parameters file
calib        = "evalfit.out"    Output calibrated standard indices file
(catalogs    = " ")            List of standard catalog files
(errors      = "obsererrors")   Error computation type (undefined,obsererrors,equ
(objects     = "program")       Objects to be fit (all,program,standards)
(print       = " ")            Optional list of variables to print
(format      = " ")            Optional output format string
(append      = no)             Append output to an existing file ?
(catdir      = ".catdir")      The standard star catalog directory
(mode        = "al")

```

Fig. 5.— parameter examples for fitparam, mkapfile and evalfit.

Name	FILTER	FITS	AM	APER	MAG	SNerr	S*err	DATEreduce	WHO
LHS2621	v	20030329.09.096.o	1.587	----	16.187	0.006	0.013	2003-08-11	Subasavage
LHS2621	r	20030329.09.097.o	1.584	----	15.783	0.006	0.018	2003-08-11	Subasavage
LHS2621	i	20030329.09.098.o	1.581	----	15.445	0.010	0.017	2003-08-11	Subasavage
LHS2734A	v	20030329.09.104.o	1.094	----	16.126	0.006	0.013	2003-08-11	Subasavage
LHS2734A	r	20030329.09.103.o	1.103	----	15.322	0.004	0.018	2003-08-11	Subasavage
LHS2734A	i	20030329.09.102.o	1.112	----	14.593	0.004	0.017	2003-08-11	Subasavage
LHS2734B	v	20030329.09.104.o	1.094	----	18.827	0.057	0.013	2003-08-11	Subasavage
LHS2734B	r	20030329.09.103.o	1.103	----	17.893	0.031	0.018	2003-08-11	Subasavage
LHS2734B	i	20030329.09.102.o	1.112	----	16.743	0.025	0.017	2003-08-11	Subasavage
SCR1138-7721	v	20030329.09.131.o	1.538	----	14.767	0.004	0.013	2003-08-11	Subasavage
SCR1138-7721	r	20030329.09.132.o	1.542	----	13.201	0.001	0.018	2003-08-11	Subasavage
SCR1138-7721	i	20030329.09.133.o	1.547	----	11.250	0.001	0.017	2003-08-11	Subasavage
SCR1322-7254	v	20030329.09.144.o	1.387	----	15.322	0.003	0.013	2003-08-11	Subasavage
SCR1322-7254	r	20030329.09.145.o	1.390	----	14.122	0.002	0.018	2003-08-11	Subasavage
SCR1322-7254	i	20030329.09.146.o	1.392	----	12.594	0.002	0.017	2003-08-11	Subasavage
SCR1328-7253	v	20030329.09.149.o	1.399	----	16.895	0.006	0.013	2003-08-11	Subasavage
SCR1328-7253	r	20030329.09.148.o	1.396	----	15.645	0.004	0.018	2003-08-11	Subasavage
SCR1328-7253	i	20030329.09.147.o	1.393	----	13.994	0.003	0.017	2003-08-11	Subasavage
SCR1726-8433	v	20030329.09.150.o	1.757	----	14.254	0.002	0.013	2003-08-11	Subasavage
SCR1726-8433	r	20030329.09.151.o	1.755	----	13.004	0.001	0.018	2003-08-11	Subasavage
SCR1726-8433	i	20030329.09.152.o	1.753	----	11.415	0.001	0.017	2003-08-11	Subasavage
SCR1735-7020	v	20030329.09.170.o	1.333	----	99.999	0.005	0.013	2003-08-11	Subasavage
SCR1735-7020	r	20030329.09.169.o	1.337	----	99.999	0.004	0.018	2003-08-11	Subasavage
SCR1735-7020	i	20INDEF	0.000	----	99.999	0.000	0.017	2003-08-11	Subasavage
SCR2012-5956	v	20030329.09.191.o	1.287	----	16.063	0.011	0.013	2003-08-11	Subasavage
SCR2012-5956	r	20030329.09.192.o	1.280	----	15.484	0.008	0.018	2003-08-11	Subasavage
SCR2012-5956	i	20030329.09.193.o	1.275	----	15.035	0.012	0.017	2003-08-11	Subasavage
SCR2012-5956	i	20030329.09.194.o	xxxxx	xxx	xxxxxx	xxxxx	xxxxx	2003-08-11	Subasavage << bad image
-----									
E2_M	v	20030127.09.071.o	1.050					2003-08-28	jao
E2_M	r	20030127.09.072.o	1.055					2003-08-28	jao
E2_M	i	20030127.09.073.o	1.061					2003-08-28	jao
E2_O	v	20030127.09.071.o	1.050					2003-08-28	jao
E2_O	r	20030127.09.072.o	1.055					2003-08-28	jao
E2_O	i	20030127.09.073.o	1.061					2003-08-28	jao
E2_S	v	20030127.09.071.o	1.050					2003-08-28	jao
E2_S	r	20030127.09.072.o	1.055					2003-08-28	jao
E2_S	i	20030127.09.073.o	1.061					2003-08-28	jao
E2_I	v	20030127.09.071.o	1.050					2003-08-28	jao
E2_I	r	20030127.09.072.o	1.055					2003-08-28	jao
E2_I	i	20030127.09.073.o	1.061					2003-08-28	jao
E2_T	v	20030127.09.071.o	1.050					2003-08-28	jao
E2_T	r	20030127.09.072.o	1.055					2003-08-28	jao
E2_T	i	20030127.09.073.o	1.061					2003-08-28	jao
E2_T	i	20030127.09.074.o	xxxxx					2003-08-28	jao << bad image
98_675	v	20030127.09.124.o	1.412					2003-08-28	jao
98_675	r	20030127.09.123.o	1.402					2003-08-28	jao
98_675	i	20030127.09.122.o	1.388					2003-08-28	jao
98_676	v	20030127.09.124.o	1.412					2003-08-28	jao
98_676	r	20030127.09.123.o	1.402					2003-08-28	jao
98_676	i	20030127.09.122.o	1.388					2003-08-28	jao
98_682	v	20030127.09.124.o	1.412					2003-08-28	jao
98_682	r	20030127.09.123.o	1.402					2003-08-28	jao
98_682	i	20030127.09.122.o	1.388					2003-08-28	jao
98_685	v	20030127.09.124.o	1.412					2003-08-28	jao
98_685	r	20030127.09.123.o	1.402					2003-08-28	jao
98_685	i	20030127.09.122.o	1.388					2003-08-28	jao

Fig. 6.— example output file from `evalfit.pl` (top) and `standard.pl` (bottom) scripts.

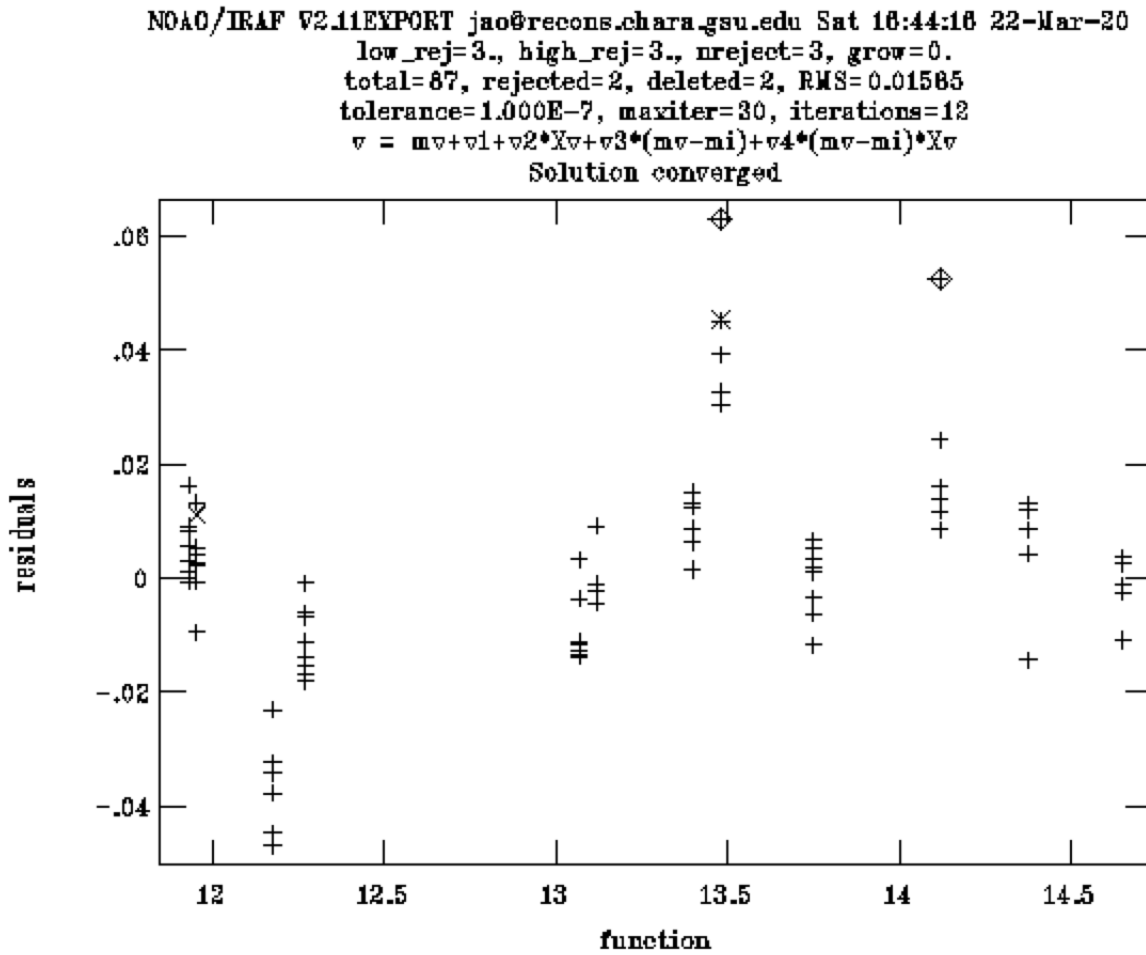


Fig. 7.— **fitparam** fitting plot example, and it shows that this solution is converged. Two diamonds indicate this task deleted data automatically and two crosses indicate they were deleted by users.