

Cold IRAC Aperture Photometry from Individual BCDs for Point Sources with Stellar Spectral Energy Distributions

*[distilled by DWH from the Spitzer Heritage Archive (online) IRAC Instrument Handbook v1.0
(03/29/2010) and Hora et al. 2008, PASP, 120, 1233]*

1) Apply the array-location-dependent photometry correction to the BCDs by **multiplying** with the appropriate correction image, “ch[1-4]_photcorr_rj.fits”. The correction images are available at

<http://ssc.spitzer.caltech.edu/irac/locationcolor/>

This corrects the BCDs for the pixel area difference over the field-of-view (FOV), the changing effective wavelength over the FOV, and any extended/point-source illumination differences. In principle, this correction is only valid for stars of the same spectral type (K2) as used to derive the correction images; however, the color term for the correction is very small, so it can be applied for all stellar sources.

2) Obtain the background-subtracted flux (surface brightness in MJy/sr integrated over the photometry aperture) for the target(s) in each BCD using the IRAF task NOAO.DIGIPHOT.APPHOT.PHOT. Discussion of the task parameters and sample parameter files for all relevant IRAF tasks in the NOAO.DIGIPHOT.APPHOT hierarchy follows...

CENTERPARS: For channels 1 and 2, there is a pixel-phase correction that requires knowing the exact pixel position of the peak of the stellar profile. For channel 1, use the best-known celestial coordinates of the target(s) as initial input and centroid the photometry aperture on the target. For channel 2, use the average position (in celestial coordinates) determined from the channel 1 photometry (see item #3 below for the procedure used to determine the average channel 1 coordinates) as initial input and centroid the photometry aperture on the target. For channels 3 and 4, use the average position (in celestial coordinates) determined from the channel 1 BCDs with **no** additional aperture centroiding.

CENTERPARS Parameters for Channels 1 and 2

```
(calgorithm = "centroid") Centering algorithm
  (cbox = 3.)           Centering box width in scale units
(cthreshold = 0.)      Centering threshold in sigma above background
(minsnratio = 1.)      Minimum signal-to-noise ratio for centering
  (cmaxiter = 10)       Maximum number of iterations for centering
  (maxshift = 1.)       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.)         Rejection limit in sigma
  (mkcenter = no)      Mark the computed center on display?
  (mode = "ql")
```

CENTERPARS Parameters for Channels 3 and 4

```
(calgorithm = "none") Centering algorithm
  (cbox = 0.)           Centering box width in scale units
(cthreshold = 0.)      Centering threshold in sigma above background
(minsnratio = 1.)      Minimum signal-to-noise ratio for centering
  (cmaxiter = 10)       Maximum number of iterations for centering
  (maxshift = 1.)       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.)         Rejection limit in sigma
  (mkcenter = no)      Mark the computed center on display?
```

```
(mode = "q1")
```

DATAPARS: To facilitate use of the IDL routine READSPIT to process the photometry, it is helpful to set several of the BCD image header keywords to be transferred into the PHOT output files.

DATAPARS Parameters for All Channels

```
(scale = 1.)           Image scale in units per pixel
(fwhmpsf = 2.5)       FWHM of the PSF in scale units
(emission = yes)      Features are positive?
(sigma = INDEF)       Standard deviation of background in counts
(datamin = INDEF)     Minimum good data value
(datamax = INDEF)     Maximum good data value
(noise = "poisson")   Noise model
(ccdread = "")        CCD readout noise image header keyword
(gain = "")           CCD gain image header keyword
(readnoise = 0.)      CCD readout noise in electrons
(epadu = 1.)          Gain in electrons per count
(exposure = "framtime") Exposure time image header keyword
(airmass = "")        Airmass image header keyword
(filter = "chnlnum")  Filter image header keyword
(obstime = "utcs_obs") Time of observation image header keyword
(itime = 1.)          Exposure time
(xairmass = INDEF)    Airmass
(ifilter = "")         Filter
(otime = "")          Time of observation
(mode = "")
```

FINDPARS: This parameter file is not used by PHOT.

FITSKYPARS: The “mean” sky-fitting algorithm is used because it is recommended in regions with few background counts, and because the “centroid” method (which is recommended for most applications of PHOT and basically performs a weighted average of the sky histogram in which the average is performed over the histogram bin values weighted by the number of pixels in each bin) devolves to the “mean” method for sky histograms with increasingly small bin size. The background annulus radii values in particular should not be changed, since they determine, in part, the aperture correction that is used.

FITSKYPARS Parameters for All Channels

```
(salgorithm = "mean") Sky fitting algorithm
(annulus = 3.)        Inner radius of sky annulus in scale unit
(dannulus = 4.)       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 iterations
(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 = 0.1)       Binsize of histogram in sky sigma
(smooth = no)         Boxcar smooth the histogram
(rgrow = 0.)          Region growing radius in scale units
(mksky = no)          Mark sky annuli on the display
(mode = "q1")
```

PHOTPARS: The only important parameter in this task is the aperture radius, which should not be changed from 3 pixels, which is required in order to match the aperture correction.

PHOTPARS Parameters for All Channels

```
(weighting = "constant") Photometric weighting scheme for wphot
(apertures = "3.")      List of aperture radii in scale units
(zmag = 25.)           Zero point of magnitude scale
(mkapert = no)         Draw apertures on the display
```

```
(mode = "ql")
```

PHOT: The file “infiles” contains a list of the input BCDs. The file “coords” contains the celestial coordinates of the target(s) in decimal degrees. It is vital that the “wcsin” parameter be set to “world” in order for the task to interpret the input coordinates correctly.

PHOT Parameters for All Channels

| | |
|--------------------------|---|
| image = "@infiles" | The input image(s) |
| skyfile = "" | The input sky file(s) |
| (coords = ".././coords") | The input coordinate files(s) |
| (output = "default") | The output photometry file(s) |
| (plotfile = "") | The output plots metacode file |
| (datapars = "") | Data dependent parameters |
| (centerpars = "") | Centering parameters |
| (fitskypars = "") | Sky fitting parameters |
| (photpars = "") | Photometry parameters |
| (interactive = no) | Interactive mode? |
| (radplots = no) | Plot the radial profiles in interactive m |
| (icommands = "") | Image cursor: [x y wcs] key [cmd] |
| (gcommands = "") | Graphics cursor: [x y wcs] key [cmd] |
| (wcsin = "world") | The input coordinate system |
| (wcsout =)_.wcsout) | The output coordinate system |
| (cache =)_.cache) | Cache the input image pixels in memory? |
| (verify =)_.verify) | Verify critical parameters in non-interactive mode? |
| (update =)_.update) | Update critical parameters in non-interactive mode? |
| (verbose =)_.verbose) | Print messages in non-interactive mode? |
| (graphics =)_.graphics) | Graphics device |
| (display =)_.display) | Display device |
| (mode = "ql") | |

3) The average channel 1 celestial coordinates are determined as follows. First, use the IRAF task NOAO.DIGIPHOT.PTOOLS.TXDUMP to create an output file for each “*.mag.1” photometry output file that lists the (x,y) pixel coordinates of the target. Typically, constructing a cl script file is the easiest way to do this for multiple BCDs (then use the command “cl < txdump.cl” in IRAF to execute the script). Next, use the IRAF task IMAGES.IMCOORDS.WCSCTRAN to convert the files of pixel coordinates into files of celestial coordinates for the target, using the wcs solutions contained in the input BCD image headers. The input parameters to WCSCTRAN are the list of pixel coordinate files obtained from TXDUMP (input = “@coopixfiles”), a list of output file names for the celestial coordinates files (output = “@coofiles”), and the list of filenames for the corresponding BCDs containing the plate solutions (image = “@infiles”) – see below for the full listing of WCSCTRAN parameters. Finally, compute the average of the channel 1 celestial coordinates.

Sample TXDUMP Script file (“txdump.cl”)

```
txdump {bcd01}.mag.1 xcenter,ycenter yes > {bcd01}.coopix
txdump {bcd02}.mag.1 xcenter,ycenter yes > {bcd02}.coopix
txdump {bcd03}.mag.1 xcenter,ycenter yes > {bcd03}.coopix
...
```

WCSCTRAN Parameters

| | |
|-----------------------------|---|
| input = "@coopixfiles" | The input coordinate files |
| output = "@coofiles" | The output coordinate files |
| image = "@infiles" | The input images |
| inwcs = "logical" | The input coordinate system |
| outwcs = "world" | The output coordinate system |
| (columns = "1 2 3 4 5 6 7") | List of input file columns |
| (units = "") | List of input coordinate units |
| (formats = "%11.7f") | List of output coordinate formats |
| (min_sigdigit = 9) | Minimum precision of output coordinates |
| (verbose = yes) | Write comments to the output file ? |
| (mode = "ql") | |

4) Apply the integrated surface brightness-to-flux density conversion (in practice, this step – along with averaging of photometry from multiple BCDs – is accomplished by the IDL routine READSPIT).

$$F_{\nu} [\text{mJy}] = \frac{(1000)(2.350443 \times 10^{-5})(a_{cor})(pix_size^2)(FLUX)}{(\phi_{cor})(K)}$$

- $F_{\nu} [\text{mJy}]$ is the flux density in units of mJy.
- The factor 1000 is the conversion from units of Jy to mJy.
- The factor 2.350443×10^{-5} is the conversion from MJy/sr to Jy/arcsec².
- a_{cor} is the aperture correction from Table 4.7 in the SHA IRAC Instrument Handbook (v1.0):

Table 4.7: IRAC aperture corrections.

| Radius on source (native pixels) | Background annulus (native pixels) | Aperture correction | | | |
|-------------------------------------|---------------------------------------|---------------------|-------------------|-------------------|-------------------|
| | | 3.6 μm | 4.5 μm | 5.8 μm | 8.0 μm |
| infinite | N/A | 0.994 | 0.937 | 0.772 | 0.737 |
| 10 | 12-20 | 1.000 | 1.000 | 1.000 | 1.000 |
| 5 | 12-20 | 1.049 | 1.050 | 1.058 | 1.068 |
| 5 | 5-10 | 1.061 | 1.064 | 1.067 | 1.089 |
| 3 | 12-20 | 1.112 | 1.113 | 1.125 | 1.218 |
| 3 | 3-7 | 1.124 | 1.127 | 1.143 | 1.234 |
| 2 | 12-20 | 1.205 | 1.221 | 1.363 | 1.571 |
| 2 | 2-6 | 1.213 | 1.234 | 1.379 | 1.584 |

- pix_size^2 is the area of the pixels, in arcsec², for a given channel. If the BCD images have been multiplied by the corresponding array-location-dependent photometric correction images, then the pixel sizes are as given below. When performing calculations, square the tabulated pixel sizes (which are given exactly) instead of using the squared values listed below (which are rounded).

| | | | | |
|--------------------------------------|---------|---------|---------|---------|
| IRAC channel | 1 (3.6) | 2 (4.5) | 3 (5.8) | 4 (8.0) |
| pix_size (arcsec) | 1.221 | 1.213 | 1.222 | 1.220 |
| pix_size^2 (arcsec ²) | 1.491 | 1.471 | 1.493 | 1.488 |

- $FLUX$ is the summed value of the background-subtracted pixels in a specified aperture around a target in an array-location (and pixel size) corrected BCD image. By default, the pixels are calibrated to units of surface brightness (MJy/sr).

- ϕ_{cor} is the pixel-phase-dependent photometric correction (which accounts for the offset of the PRF peak from the center of a pixel). For channels 3 and 4, $\phi_{cor} = 1$. For channels 1 and 2, the correction is

$$\phi_{cor} = 1 + A \left(\frac{1}{\sqrt{2\pi}} - p \right),$$

where $A = 0.0535$ or 0.0309 for channel 1 or 2, respectively, and $p = \sqrt{(x - x_0)^2 + (y - y_0)^2}$ is the offset of the centroid of the point source (x, y) from the integer pixel numbers (x_0, y_0) of the pixel containing the centroid. Note that the center of a pixel is defined with integer coordinates, so pixel (n, m) actually extends from $(n-0.5)$ to $(n+0.5)$ and $(m-0.5)$ to $(m+0.5)$. Thus, to determine which integer pixel numbers (x_0, y_0) to use, round the centroid pixel coordinates (x, y) to the nearest integer (i.e., if the fractional part of x or y is > 0.5 , then round up; if the fractional part is < 0.5 , then round down).

- K is the color correction factor, whose value depends on the spectral shape of the target. For a wide variety of spectral shapes, the color correction is less than 3% if the flux densities are always plotted against the nominal IRAC channel wavelengths (λ_0):

| | | | | |
|-----------------------|---------|---------|---------|---------|
| IRAC channel | 1 (3.6) | 2 (4.5) | 3 (5.8) | 4 (8.0) |
| λ_0 (microns) | 3.550 | 4.493 | 5.731 | 7.872 |

In this case, it is assumed that $K = 1$ for all channels and target types. Color corrections for blackbody spectra with temperatures of 5000 K and cooler, as well as power law spectra ($F_\nu \propto \nu^\alpha$), are available in the SHA IRAC Instrument Handbook.

5) Calculate the total uncertainty on the average photometry as the sum in quadrature of 3% for the absolute gain calibration (systematic error), 1% for repeatability (systematic error), 3% for the absolute flux calibration of the calibration stars (systematic error), 1% for the color correction for stars with spectral energy distributions similar to CV secondary stars (systematic error; upper limits from the SHA IRAC Instrument Handbook v1.0), and some estimate of the intrinsic scatter (random error). For the last term, the field-scatter flux density term from the V592 Cas data set (see Hoard et al. 2009, ApJ, 693, 236) can be used, which is the average (rounded to the nearest 0.5%) of all points within $\pm N\%$ of the target flux density, where N is the smallest integer ($N \geq 10$) that yields at least 10 points from the V592 Cas field data. This can be accomplished using the IDL routine FINDERR.