Introduction to Photometry with HST

This is an unofficial document for internal RIAB training purposes only

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Revision History

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You will be using images of the globlular cluster NGC6791 taken with ACS/WFC using two broadband filters. You will perform aperture photometry on these images and produce a color magnitude diagram of the cluster. Here is an outline of the procedure followed by a few explicit instructions on how to perform the tasks necessary to complete this exercise.

1. Convert your images from counts per second to counts and add sky that was removed by AstroDrizzle
2. Use one of your images to find stars and define a source catalog
3. Use catalog to perform aperture photometry on your images
4. Extract photometry information from daophot output files
5. Determine aperture corrections for each frame
6. Apply aperture corrections and produce final catalog in STMag
7. Make CMD of globular cluster in F606W-F814W vs F814W

1 Making a counts image

You will be using the DAOPHOT package within IRAF. The tasks in this package assume that the images you will be using are in counts and that the sky is part of the image. AstroDrizzle products are in counts/second and do not contain sky. We will modify our images so they comply with what DAOPHOT expects. To start navigate to the directory containing your ***drc_sci.fits** images and start Pyraf and then load the DAOPHOT package:

```
avila@avila: phot > pyraf
setting terminal type to xterm...

    NOAO/IRAFNET PC-IRAF Revision 2.14 Fri Nov 30 15:27:05 MST 2007
    This is the RELEASED version of IRAF V2.14 supporting PC systems.


  Welcome to IRAF.  To list the available commands, type ? or ??.  To get
  detailed information about a command, type `help <command>'.  To run  a
  command  or  load  a  package,  type  its name.   Type  `bye' to exit a
  package, or `logout' to get out  of the CL.    Type `news' to find  out
  what is new in the version of the system you are using.

  Visit http://iraf.net if you have questions or to report problems.

  The following commands or packages are currently defined:



                    IIIII    RRRR     AAA    FFFFF   XX  XX
                      I      R   R   A   A   F        X  X
```

```
                    I      RRRR    AAAAA   FFF       XX
                    I      R  R    A   A   F        X  X
                  IIIII    R   R   A   A   F       XX   XX


IRAFX Prepared 2012-08-16

clpackage/:
 apropos        fitsutil/      mscred/        salt/          user/
 cirred         gemini/        nmisc/         softools/      utilities/
 clpackage/     gmisc/         noao/          stecf/         wcstools/
 color/         images/        obsolete/      stlocal/       xdimsum/
 ctio/          iuetools/      plot/          stsdas/
 dataio/        language/      proto/         system/
 dbms/          lists/         rvsao/         tables/
PyRAF 2.1.dev Copyright (c) 2002 AURA
Python 2.7.1 Copyright (c) 2001-2010 Python Software Foundation.
Python/CL command line wrapper
  .help describes executive commands
--> digiphot
digiphot/:
 apphot/        daophot/       photcal/       ptools/
--> daophot
daophot/:
 addstar        daotest        nstar          pexamine       psf
 allstar        datapars@      pcalc          pfmerge        psort
 centerpars@    findpars@      pconcat        phot           pstselect
 daoedit        fitskypars@    pconvert       photpars@      seepsf
 daofind        group          pdump          prenumber      setimpars
 daopars@       grpselect      peak           pselect        substar
-->
```

You will be using the PyFits package to manipulate your images so import that:

```
--> import pyfits
-->
```

The 0th extension of drizzled images contains your image header and science data. The first extension contains the header information from all the images you used to create your drizzled image. The header of the input images is contained in the form of a table. We need all this information so we will load it all to memory:

```
--> f = pyfits.open('f606w_drc_sci.fits')  #open fits file
--> fdata = f[0].data       #reads 0th extension data into variable fdata
--> fheader = f[0].header   #reads 0th extension header into variable fheader
--> ftable= f[1].data       #reads 1st extension data into variable ftable
```

```
--> f.close()              #closes image
-->
```

Now let's look for some information we need, namely the total exposure time (texptime) in this image and how much sky was subtracted from each image (mdrizsky). Take note of the different syntax used to query headers and tables:

```
--> fheader['texptime']
7024.0
--> ftable.field('mdrizsky')
array([ 85.60038757,  85.60038757,  90.88925171,  90.88925171,
        97.06797791,  97.06797791,  91.16620636,  91.16620636,
        95.353508   ,  95.353508   ,  96.62722015,  96.62722015])
-->
```

Notice there are 12 values for mdrizsky even though there were only 6 images in your stack. This is a 'feature' of AstroDrizzle which tells you how much sky was subtracted from each chip in your stack. Anyway, sum up your values and divide by two to figure out the total amount of sky. Remember that when the sky was subtracted your images still had their original plate scale (0.05"/pix), but your drizzled images have smaller pixels. You need to rescale your sky to the new plate scale to ensure your total sky flux is conserved throughout the image. The formula to compute your final image looks like this:

$$f606_{cts} \quad = \quad f606_{cps} \times exptime + \frac{\sum mdrizsky}{2} \times rescale^2 \tag{1}$$

where $rescale = 0.03/0.05$. In the command line type

```
--> f606cts = fdata*7024. + 556.7*0.6*0.6   #See how easy things are with pyfits?
-->
```

Now write out your data to a FITS file, including the header, and you're done:

```
--> pyfits.writeto('f606w_cts.fits',f606cts,header=fheader)
-->
```

2 Defining a source catalog

Use the DAOFIND task to find stars in one of your images. First of all, make sure to run the "unlearn" command on DAOFIND to reset everything to the default values. After that change the following parameters and execute the task. Remember that some parameters are found by pushing the **PSET datapars** and **PSET findpars** buttons and that you must save the values in each window when you edit them:

- image = f606w_cts
- output = starlist

- fwhmpsf = (measure the psf of a few stars in your image and use 2× that value)
- sigma = (use imexam to determine the sky standard deviation in your image)
- readnoise = (ACS rdnoise is 5.5e-, but that value needs to be rescaled to the plate scale of your image, see equation 2)
- itime = 7024.

The read-noise in each image is 5.2 electrons, but you need to rescale that to the new pixel size and take into account that there are 6 images in your stack. To figure out your new read-noise use this equation:

$$new\_rdnoise \;=\; \sqrt{nframes \times (old\_rdnoise \times rescale)^2} \tag{2}$$

Finally use the PHOT task to perform aperture photometry. Your **PSET datapars** parameters should carry over from the FIND task but you need to edit other settings:

- image = f606w_cts
- coords = starlist
- output = f606w.raw
- calgorithm = centroid
- salgorithm = median
- annulus = 17.
- dannulus = 3.
- apertures = 5.,16.666
- zmag = (the appropriate zeropoint for each filter)

This will run for some time but when it is finished you will have a file in your directory called **f606w.raw**.

3 Extract photometry from DAOPHOT files

All the photometry information you need is in this file which looks like this:

```
--> !more f606w.raw
#K IRAF       = NOAO/IRAFV2.14EXPORT    version    %-23s
#K USER       = avila                   name       %-23s
#K HOST       = Tac-OSX04.local         computer   %-23s
#K DATE       = 2012-08-20              yyy-mm-dd  %-23s
#K TIME       = 20:15:05                hh:mm:ss   %-23s
#K PACKAGE    = apphot                  name       %-23s
#K TASK       = phot                    name       %-23s
```

```
#
#K SCALE      = 1.                       units      %-23.7g
#K FWHMPSF    = 2.6                      scaleunit  %-23.7g
#K EMISSION   = yes                      switch     %-23b
#K DATAMIN    = INDEF                    counts     %-23.7g
#K DATAMAX    = 9000000.                 counts     %-23.7g
#K EXPOSURE   = ""                       keyword    %-23s
#K AIRMASS    = ""                       keyword    %-23s
#K FILTER     = ""                       keyword    %-23s
#K OBSTIME    = ""                       keyword    %-23s
#
#K NOISE      = poisson                  model      %-23s
#K SIGMA      = 13.                      counts     %-23.7g
#K GAIN       = ""                       keyword    %-23s
#K EPADU      = 1.                       e-/adu     %-23.7g
#K CCDREAD    = ""                       keyword    %-23s
#K READNOISE  = 7.3                      e-         %-23.7g
#
#K CALGORITHM = centroid                 algorithm  %-23s
#K CBOXWIDTH  = 5.                       scaleunit  %-23.7g
#K CTHRESHOLD = 0.                       sigma      %-23.7g
#K MINSNRATIO = 1.                       number     %-23.7g
#K CMAXITER   = 10                       number     %-23d
#K MAXSHIFT   = 1.                       scaleunit  %-23.7g
#K CLEAN      = no                       scaleunit  %-23b
#K RCLEAN     = 1.                       scaleunit  %-23.7g
#K RCLIP      = 2.                       scaleunit  %-23.7g
#K KCLEAN     = 3.                       sigma      %-23.7g
#
#K SALGORITHM = median                   algorithm  %-23s
#K ANNULUS    = 10.                      scaleunit  %-23.7g
#K DANNULUS   = 3.                       scaleunit  %-23.7g
#K SKYVALUE   = 0.                       counts     %-23.7g
#K KHIST      = 3.                       sigma      %-23.7g
#K BINSIZE    = 0.1                      sigma      %-23.7g
#K SMOOTH     = no                       switch     %-23b
#K SMAXITER   = 10                       number     %-23d
#K SLOCLIP    = 0.                       percent    %-23.7g
#K SHICLIP    = 0.                       percent    %-23.7g
#K SNREJECT   = 50                       number     %-23d
#K SLOREJECT  = 3.                       sigma      %-23.7g
#K SHIREJECT  = 3.                       sigma      %-23.7g
#K RGROW      = 0.                       scaleunit  %-23.7g
#
#K WEIGHTING  = constant                 model      %-23s
#K APERTURES  = 3.,10.,16.666            scaleunit  %-23s
```

```
#K ZMAG       = 26.678                  zeropoint  %-23.7g
#
#N IMAGE               XINIT     YINIT     ID    COORDS                 LID    \
#U imagename           pixels    pixels    ##    filename               ##     \
#F %-23s               %-10.3f   %-10.3f   %-6d  %-23s                  %-6d
#
#N XCENTER    YCENTER    XSHIFT  YSHIFT  XERR    YERR            CIER CERROR   \
#U pixels     pixels     pixels  pixels  pixels  pixels          ##   cerrors  \
#F %-14.3f    %-11.3f    %-8.3f  %-8.3f  %-8.3f  %-15.3f         %-5d %-9s
#
#N MSKY           STDEV          SSKEW          NSKY   NSREJ     SIER SERROR   \
#U counts         counts         counts         npix   npix      ##   serrors  \
#F %-18.7g        %-15.7g        %-15.7g        %-7d   %-9d      %-5d %-9s
#
#N ITIME          XAIRMASS       IFILTER                 OTIME                  \
#U timeunit       number         name                    timeunit               \
#F %-18.7g        %-15.7g        %-23s                   %-23s
#
#N RAPERT   SUM           AREA       FLUX          MAG    MERR   PIER PERROR   \
#U scale    counts        pixels     counts        mag    mag    ##   perrors  \
#F %-12.2f  %-14.7g       %-11.7g    %-14.7g       %-7.3f %-6.3f %-5d %-9s
#
f606w_cts.fits         6505.001  269.006   1     starlist                 1      \
   6505.000   269.018    -0.001  0.012   0.001   0.001          0    NoError   \
   200.4136       20.16031       18.36138       168    44       0    NoError   \
   7024.          INDEF          INDEF                   INDEF                   \
   3.00     1226540.      28.38765   1220851.      21.078 0.001 0    NoError  *\
   10.00    1353694.      314.7326   1290617.      21.017 0.001 0    NoError  *\
   16.67    1479307.      872.9724   1304351.      21.006 0.002 0    NoError  *
f606w_cts.fits         6420.338  271.456   2     starlist                 2      \
   6420.557   271.464    0.219   0.008   0.021   0.014          0    NoError   \
   200.4137       0.             0.             102    118      0    NoError   \
   7024.          INDEF          INDEF                   INDEF                   \
   3.00     10795.87      28.33908   5116.329      27.022 0.015 0    NoError  *\
   10.00    82445.52      314.1608   19483.4       25.570 0.008 0    NoError  *\
   16.67    223457.9      872.4777   48601.5       24.578 0.005 0    NoError  *
```

As you can see this photometry file contains a lot of information about the image and photometry parameters. Following the comments you can see the photometry information for each of the stars. Unfortunately it is not in a format that is easy for programming/plotting tools to read. Have no fear, txdump is here to help. txdump is a task in IRAF that can read DAOPHOT files and extract the columns you ask for. Let's extract the star positions and magnitudes for now.

```
--> txdump f606w.raw xcenter,ycenter,mag yes > f606w.phot
```

It's that easy. If you look at the first 10 lines of your **f606w.phot** file it should look like this:

```
--> !head f606w.phot
6505.000  269.018  21.078  21.017  21.006
6420.557  271.464  27.022  25.570  24.578
6457.000  272.500  27.802  26.979  25.991
6391.617  272.543  25.965  22.090  21.233
6306.500  274.499  24.918  24.742  24.490
6360.782  274.000  26.480  25.557  24.722
6504.341  274.001  24.954  21.021  21.021
6272.000  275.500  26.713  26.339  25.661
6224.496  276.500  26.568  25.257  24.230
6328.593  276.500  26.484  26.239  25.968
-->
```

The first two columns are the x and y positions of the stars. The next three columns are the magnitudes of the stars in your three apertures. There will be some bad measurements (INDEF) in your file. Use your favorite text editor or sed to change any "INDEF" to "99.999".

4 Aperture corrections

Now that you have your data in a usable format, use your favorite plotting tool to display Δmag vs mag_{r3}. Your plot should look something like figure 1.

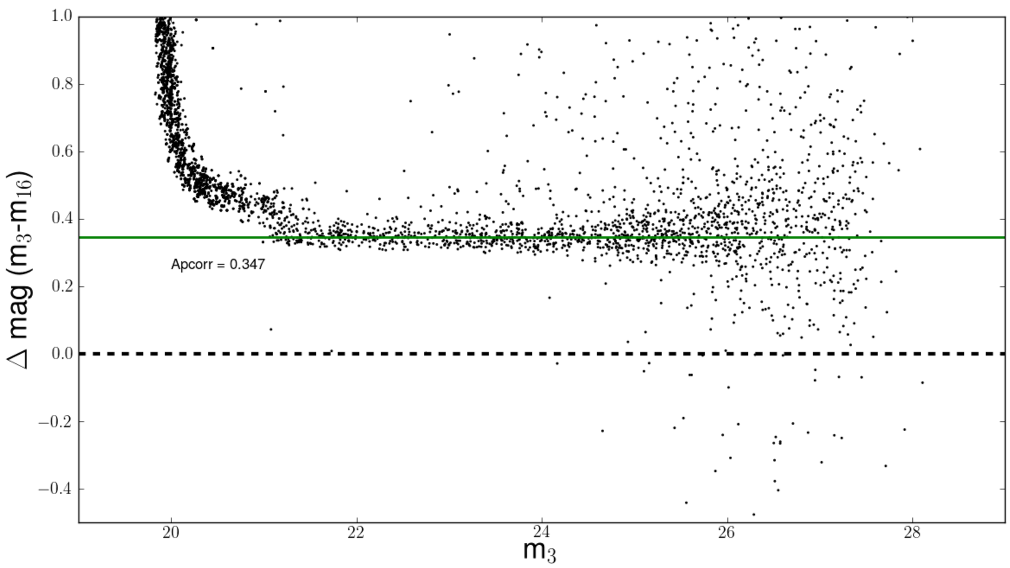

Figure 1: Aperture correction for F606W drizzled image.

Use the bright, unsaturated stars and your favorite estimator to find the value of the aperture correction (ac05) for this image. You can see where I've marked the aperture correction in my plot. Should the value of the aperture correction be negative or positive? When you apply the correction should it be added or subtracted?

For the encircled energy correction (AC05) look up the values in Table 5 of Sirianni et al (2005PASP..117.1049S).

You will need to repeat steps 1 – 5 for the F814W image.

Finally you will need to merge your two catalogs. The positions of your sources won't be exactly the same between the two catalogs so you will have to match the sources by position using some tool like tmatch or xyxymatch. Once you have your master catalog with all the stars and (corrected) magnitudes you can make your CMD.

Place your aperture correction plots and CMDs in your results folder so I can review your work.