A guide to solving and coadding DoublePrime images

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1 Obtaining basic WCS solutions

WCS meta data is not written to the Double-Prime image headers. Accurate WCS meta data can be obtained with use of Hogg & Lang's Astrometry.net "astromerty-engine" [1] for which the only required input is the raw image. A simple example can be run from the command line on astronomy department network computers as follows

```
>  /opt/astrometry/solve-field file-name -o base-name -p --scale-low 0.5 \
   -\u2013scale-high 0.6 --scale-units app --sextractor-path /usr/bin/sextractor
```

where file-name is the name of the fits image file you want to solve and base-name is your chosen name (minus extension) given to the various output files that the `solve- field` task produces. For a detailed description of all the possible output files see [1]. The most important output will be base-name.wcs, which is a new image header containing the solved wcs and can be copied to file-name. It is also possible to have `solve-field` output a copy of the old image containing the new wcs header.

The `solve-field` task has considerably more options than those used in the simple example above. For a full list type

```
>  /opt/astrometry/solve-field
```

at the command line.

2 Compatibility with Astromatic.net

`solve-field` provides the non-linear conversion from image to sky coordinates as a SIP (Simple Image Polynomial) projection. Unfortunately, we have found that the commonly used Astromatic.net software suite [2], which includes `sextractor`, does not handle the SIP projection.

A reliable work around is to run the Astrometry.net solve-field package with the -T option invoked. This will force the solver to bypass the SIP computation step and return an unrefined TAN solution. This solution can then be fine-tuned by the Astromatic.net package `scamp` (see below).

In order to then refine this solution using `scamp` you will need to generate a source catalog of your image with positional information based on the TAN solution you just generated. You must do this using the Astromatic.net package `sextractor`. A short example is given below, however before you start it should be noted that for optimal performance `sextractor` should be configured according to the specific needs of your program. It is highly recommended that you consult the manual and configure `sextractor` before you begin see [2].

`sextractor` is configured via a configuration file. In order to generate a default configuration file type the following at the command line

```
> ur_forget
> sex -d > default.conf
```

For this example change the following lines in default.conf as follows (read the `sextractor` manual to find out what each of these configuration parameters does.)

```
CATALOG_NAME     test.cat      >  # CATALOG_NAME  test.cat
CATALOG_TYPE     ASCII_HEAD    >  CATALOG_TYPE     FITS_LDAC
DETECT_THRESH    1.5           >  DETECT_THRESH    3.0
ANALYSIS_THRESH  1.5           >  ANALYSIS_THRESH  3.0
FILTER           Y             >  FILTER           N
SATUR_LEVEL      50000.0       >  SATUR_LEVEL      60000.0
PIXEL_SCALE      1.0           >  PIXEL_SCALE      0.0
```

`sextractor` can write out a vast number of parameters to the source catalog. In order to tell `sextractor` which parameters you want written to your catalog type

```
> sex -dp > default.param
```

open the file default.param and uncomment the parameters you wish to be written out. `scamp` requires the following at a minimum

```
NUMBER
FLUX_AUTO
FLUXERR_AUTO
ALPHA_J2000
DELTA_J2000
XWIN_IMAGE
YWIN_IMAGE
ERRAWIN_IMAGE
ERRBWIN_IMAGE
ERRTHETAWIN_IMAGE
FLAGS
FLAGS_WEIGHT
```

then on the command line issue the following

```
> sex file-name -c default.conf -CATALOG_NAME catalog-name
```

where catalog-name is your desired output catalog name.

After this step you are then ready to pass this catalog to `scamp`. `scamp` will read the astronomical source positions from the catalog and then try to match them to a remote reference catalog such as SDSS or 2MASS (a local reference catalog can also be used). Once the matching is complete `scamp` will generate a set of interpolating polynomials that best describe the projection of your source positions on to the matched sources in the reference catalog. In the example below we use the TPV projection.

Like `sextarctor`, `scamp` requires a configuration file. To dump the default configuratin file do

```
> scamp -d > default.conf
```

The default configuration file should usually be fine to start with but as always we recommend reading the manual to determine how best to configure `scamp` to your own needs [2]. A few parameters worth changing are shown below.

```
ASTREF_CATALOG     2MASS      or SDSS-R9
ASTREF_BAND        J          or r
ASTREFMAG_LIMITS   13.0,17.0 or 15.0,19.0
PROJECTION_TYPE    TPV
MERGEDOUTCAT_TYPE NONE
FULLOUTCAT_TYPE    NONE
MOSAIC_TYPE        LOOSE # This is a good choice for a first pass
SOLVE_PHOTOM       N
CHECKPLOT_DEV      NULL  # check plots are not supported on astro computers
CHECKPLOT_TYPE     NONE
```

then to run `scamp`

```
> scamp catalog-name -c default.conf
```

This will produce a text file with a .head extension, which will contain your solved wcs meta-data. Among the terminal output you should see the following header line

```
instruments   pos.angle   scale   cont.   shift   cont.
```

below this line you should see a list of measurements from the matching process (see the manual). In general a successful WCS solution should have `cont > 2` however it is a good idea to check the solution via other means. Usually this can be done via the check plots option in `scamp`, however this is not supported on the astro network computers. Instead run your image through `sextractor` again, this time ensure your .head file is named file-name.head and the entries ALPHA_J2000 and DELTA_J2000 are uncommented in default.param.

`sextractor` will now read the wcs-meta data and output celestial coordinates for detections to the output catalog. Match your new catalog to an on-line reference catalog such as SDSS or 2MASS using e.g. Topcat, CDS etc. and determine whether the match residuals are small enough for your application.

It is possible to further refine your wcs solution by running `scamp` a 2nd, 3rd... time. To do this you will need to rename your file-name.head files to catalog-name.ahead. On each iteration use the output .head file from the last run as the input .ahead file on the current run. You can now generate accurate wcs solutions that are compatible with astromatic software suite.

3 Image stacking

If stacking of multiple dithered exposures is required then a final image re-sampling step will be necessary. Double Prime suffers from a small amount of pincushion distortion, which is inherent in the design of the four-element prime-focus corrector. The nominal plate scale at the center of the field is 0."581/pixel but drops to near 0."566/pixel at the corners of the usable field. Before stacking dithered images it is necessary to re-sample each frame on to a uniform plate scale. For this we recommend the use of Astromatic.net `swarp`, which will handle both the re-sampling and stacking steps once the TPV WCS solution described above has been computed.

`swarp` can also be configured

```
> swarp catalog-name -c default.conf
```

but should run reasonably well out the box. Again read the manual for best results. A few configuration parameters you may want to consider changing are

```
IMAGEOUT_NAME      file-name.coadd.fits  # name your coadded image output filename
WEIGHTOUT_NAME     file-name.weight.fits # scamp outputs a weight map, name it here
WEIGHT_TYPE                              # if your input images have weight maps tell sw
                                           what units they are in
CELESTIAL_TYPE     EQUITORIAL
PROJECTION_TYPE    TPV
COMBINE_TYPE       WEIGHTED              # tell swarp what algorithm to use to combine y
                                           images, many options here so read the manual
```

To run `scamp` you need all your .head files from the last step in the same directory as all your image files. If your image filenames are e.g. file-name-1, file-name-2... your .head files should be named file-name-1.head file-name-2.head...

Then run `swarp`

```
> swarp file-name-1 file-name-2... -c swarp.conf
```

TIP: Note for all the astromatic software, you can override configuration parameters on the command line. This can be done by specifying the parameter at the end of the your command e.g.

```
> swarp file-name-1 file-name-2... -c swarp.conf -IMAGEOUT_NAME mycoadd.fits
```

This is also useful for scripting if you have a lot of processing to do e.g. consider reading hundreds of input and output files from a list called file.list as follows

```
#!/bin/bash
while read f1 f2 f3 out; do
    swarp $f1 $f2 $f3 -c swarp.conf -IMAGEOUT_NAME $out
done < file.list
```

[1] http://astrometry.net/
[2] http://www.astromatic.net/