# WFCAM Catalogues

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## Changes

Version 4:
The main changes from the previous versions of this document are: a slightly refined set of radii for the larger aperture sizes (the previous ones extended to an optimistically large final aperture which was similar size to the the background following algorithm ie. too big); a hopefully clearer definition of the aperture radii used; renaming and redefinition of the radius of the FWHM total flux estimator to avoid confusion with the aperture 3 flux; additional descriptions of further header content mostly relating to derived Data Quality Control (DQC) information; and addition of the extra parameters summarising the photometric quality of the night. Finally a note has been added describing the user-selectable parameters that determine how the cataloguing software is run.

Version 5:
Added a note describing the initial contents of parameter #55.

## Preamble

The derived object catalogues are stored in multi-extension FITS files as FITS binary tables, one for each image extension with a dummy primary header unit. Each catalogue header contains a copy of the relevant telescope FITS header content in addition to detector-specific information.

Each detected object has an attached set of descriptors, forming the columns of the binary table and summarising derived position, shape and intensity information. During further processing stages ancilliary information such as the sky properties, seeing and so on are derived from the catalogues and stored in the FITS headers attached to each catalogue extension.

The catalogue format was derived from similar APM/SuperCOSMOS/INT WFC/CIRSI analysis which produced 32 4-byte parameters per detected object. This has been enhanced for WFCAM to an 80 4-byte parameter set to include extra parameters for flux estimation and error estimates.

The following tables cover the WFCAM standard and further processing pipeline output catalogues, where for simplicity all derived parameters are stored as floating point numbers even though some of them are more naturally integers.

**Columns content description**

| No. | Name | Description |
|---|---|---|
| 1 | Seq. no. | running number for ease of reference, in strict order of image detections |
| 2 | Isophotal flux | standard definition of summed flux within detection isophote, apart from |
| | | detection filter is used to define pixel connectivity and hence which |
| | | pixels to include. This helps to reduce edge effects for all isophotally |
| | | derived parameters. |
| 3 | X coord | intensity–weighted isophotal centre–of–gravity in X |
| 4 | Error in X | estimate of centroid error |
| 5 | Y coord | intensity–weighted isophotal centre–of–gravity in Y |
| 6 | Error in Y | estimate of centroid error |
| | | |
| 7 | Gaussian sigma | these are derived from the three general intensity–weighted second moments |
| 8 | Ellipticity | the equivalence between them and a generalised elliptical Gaussian |
| 9 | Position angle | distribution is used to derive Gaussian sigma $= (\sigma_a^2 + \sigma_b^2)^{1/2}$ |
| | | ellipticity $= 1.0 - \sigma_a/\sigma_b$ |
| | | position angle = angle of ellipse major axis wrt x axis |
| | | |
| 10 | Areal profile 1 | number of pixels above a series of threshold levels relative to local sky. |
| 11 | Areal profile 2 | levels are set at T, 2T, 4T, 8T . . . 128T where T is the threshold. These |
| 12 | Areal profile 3 | can be thought of as a sort of poor man's radial profile. Note that for now |
| 13 | Areal profile 4 | deblended, *i.e.* overlapping images, only the first areal profile is computed |
| 14 | Areal profile 5 | and the rest are set to –1 flagging the difficulty of computing accurate |
| 15 | Areal profile 6 | profiles. |
| 16 | Areal profile 7 | |
| 17 | Areal profile 8 | for blended images this parameter is used to flag the start of the sequence |
| | | of the deblended components by setting the first in the sequence to 0 |
| | | |
| 18 | Peak height | in counts relative to local value of sky - also zeroth order aperture flux |
| 19 | Error in pkht | |
| | | |
| 20 | Aperture flux 1 | These are a series of different radii soft-edged apertures designed to |
| | | adequately sample the curve-of-growth of the majority of images and to |
| | | provide fixed-sized aperture fluxes for all images. The scale size for |
| | | these apertures is selected by defining a scale radius $\approx$<FWHM> |
| | | for site+instrument. In the case of WFCAM this "core" radius (rcore) has |
| | | been fixed at 1.0 arcsec for convenience in inter-comparison with other |
| | | datasets. A 1.0 arcsec radius is equivalent to 2.5 pixels for non-interleaved |
| | | data, 5.0 pixels for 2x2 interleaved data, and 7.5 pixels for 3x3 interleaved |
| | | data. In $\approx$1 arcsec seeing an rcore-radius aperture contains roughly |
| | | 2/3 of the total flux of stellar images. [In general the rcore parameter |
| | | is user specifiable and hence is recorded in the output catalogue FITS |
| | | header.] |
| | | The aperture fluxes are sky-corrected integrals (summations) with a |
| | | soft-edge (ie. pro-rata flux division for boundary pixels). However, |

| | | |
|---|---|---|
| | | for overlapping images they are more subtle than this since they are in practice simultaneously fitted top-hat functions, to minimise the effects of crowding. Images external to the blend are also flagged and not included in the large radius summations. |
| 21 | Error in flux | |
| 22 | Aperture flux 2 | |
| 23 | Error in flux | |
| 24 | Aperture flux 3 | Recommended if a single number is required to represent the flux for ALL |
| 25 | Error in flux | images - this aperture has a radius of rcore. |
| 26 | Aperture flux 4 | |
| 27 | Error in flux | Starting with parameter 20 the radii are: $1/2\times$ rcore, $1/\sqrt{2}\times$ rcore, rcore, $\sqrt{2}\times$ rcore, $2\times$ rcore, $2\sqrt{2}\times$ rcore, $4\times$ rcore, $5\times$ rcore, $6\times$ rcore, $7\times$ rcore, |
| 28 | Aperture flux 5 | $8\times$ rcore, $10\times$ rcore, $12\times$ rcore |
| 29 | Error in flux | |
| 30 | Aperture flux 6 | Note $4\times$ rcore, ensures $\sim 99\%$ of PSF flux |
| 31 | Error in flux | |
| 32 | Aperture flux 7 | extras for generalised galaxy photometry further spaced |
| 33 | Error in flux | |
| 34 | Aperture flux 8 | in radius to ensure reasonable sampling further out. |
| 35 | Error in flux | |
| 36 | Aperture flux 9 | |
| 37 | Error in flux | |
| 38 | Aperture flux 10 | Note these are all corrected for pixels from overlapping neighbouring images |
| 39 | Error in flux | |
| 40 | Aperture flux 11 | |
| 41 | Error in flux | |
| 42 | Aperture flux 12 | |
| 43 | Error in flux | |
| 44 | Aperture flux 13 | The biggest with radius $12\times$ rcore ie. $\approx$24 arcsec diameter |
| 45 | Error in flux | The aperture fluxes can be combined with later-derived aperture corrections for general purpose photometry and together with parameter 18 (the peak flux) give a simple curve–of–growth measurement which forms the basis of the morphological classification scheme |
| 46 | Petrosian radius | $r_p$ as defined in Yasuda et al. 2001 AJ 112 1104 |
| 47 | Kron radius | $r_k$ as defined in Bertin and Arnouts 1996 A&A Supp 117 393 |
| 48 | Hall radius | $r_h$ image scale radius eg. Hall & Mackay 1984 MNRAS 210 979 |
| 49 | Petrosian flux | flux within circular aperture to $k \times r_p$ ; $k = 2$ |
| 50 | Error in flux | |
| 51 | Kron flux | flux within circular aperture to $k \times r_k$ ; $k = 2$ |
| 52 | Error in flux | |
| 53 | Hall flux | flux within circular aperture to $k \times r_h$ ; $k = 5$; alternative total flux |
| 54 | Error in flux | |

| | | |
|---|---|---|
| 55 | Error bit flag | bit pattern listing various processing error flags<br>initially set to the no. of bad pixels within aperture of radius “rcore”<br>- note this can be fractional due to soft-edged apertures |
| 56 | Sky level | local interpolated sky level from background tracker |
| 57 | Sky rms | local estimate of variation in sky level around image |
| 58 | Child/parent | flag for parent or part of deblended deconstruct<br>(redundant since only deblended images are kept) |
| | | **The following are accreted after standard catalog generation** |
| 59 | RA | RA and Dec explicitly put in columns for overlay programs that cannot, |
| 60 | Dec | in general, understand astrometric solution coefficients – note r*4<br>storage precision accurate only to $\approx$ 50mas. Astrometry can<br>be derived more precisely from WCS in header and XY in parameters 5 & 6 |
| 61 | Classification | Flag indicating most probable morphological classification:<br>eg. –1 stellar, +1 non–stellar, 0 noise, –2 borderline stellar, –9 saturated |
| 62 | Statistic | An equivalent N(0,1) measure of how stellar–like an image is, used in<br>deriving parameter 61 in a ‘necessary but not sufficient’ sense.<br>Derived mainly from the curve-of-growth of flux using the well-defined<br>stellar locus as a function of magnitude as a benchmark<br>(see Irwin et al. 1994 SPIE 5493 411 for more details). |
| | | **From the further processing pipeline after deriving a suitable PSF** |
| 63 | PSF flux | fitted flux from PSF |
| 64 | Error in flux | |
| 65 | X coord | updated PSF-fitted X centre |
| 66 | Error in X coord | |
| 67 | Y coord | updated PSF-fitted Y centre |
| 68 | Error in Y coord | |
| 69 | PSF fit $\chi^2$ | standard normalised variance of fit |
| 70 | $\nu_{PSF}$ | no. of degrees of freedom for PSF fit |
| 71 | 1D Sersic flux | fitted flux for Sersic profile |
| 72 | Scale length | scale factor of fit |
| 73 | Power index | power law index of fit |
| 74 | Error in fit | standard normalised variance of fit |
| 75 | $\nu_{S1}$ | no. of degrees of freedom for 1D Sersic fit |
| 76 | 2D Sersic flux | fitted flux for PSF-deconvolved 2D Sersic fit |
| 77 | Scale length | scale factor of fit |
| 78 | Power index | power law index of fit |
| 79 | Error in fit | standard normalised variance of fit |
| 80 | $\nu_{S2}$ | no. of degrees of freedom for 1D Sersic fit |

[For numerical stability the Sersic fits will use the previously derived x-y coordinates]

Note:- a more formal mathematical definition of many of these parameters, together with a corresponding definition of the image processing steps is given in the VDFS Data Reduction Library Design document VIS-SPE-IOA-20000-0010, and references therein, available on http://www.ast.cam.ac.uk/vdfs/docs/. Although this particular document is specific to VISTA, the formalism is generally applicable and the processing steps and catalogue parameters are expected to be almost identical.

## Derived catalogue FITS header contents

Examples of extra FITS header items derived from the catalogues, or during catalogue creation, or specifying user-selectable input parameters, one set for each extension.

```
SKYLEVEL=             91.82     / Median sky brightness (counts/pixel)
```

An automatic 2D background-following algorithm is used to track and "remove" slowly varying background features such as image gradients etc.. The default scale size for background tracking (NBSIZE) is currently set to 64 pixels, coupled with a smidge of non-linear filtering this gives a background tracking scale of order 100 pixels. (A bilinear interpolator is used to generate pixel resolution background maps internally).

```
SKYNOISE=              6.06     / Pixel noise at sky level (counts)
```

Robust MAD estimator for noise scaled to equivalent Gaussian rms value ie. = MAD x 1.48 after removing large scale sky background variations. MAD = Median of the Absolute Deviations about the median

```
THRESHOL=              9.09     / Isophotal analysis threshold (counts)
```

User-selectable parameter, the default is to set this to 1.5 skynoise as a compromise between detecting close to the limit of the data and not being swamped by spurious sources. It is possible to push the data limit fainter but at the expense of a large increase in spurious sources. LSBG detection requires a more subtle add-on to the catalogue and could be added given suitable demand.

```
MINPIX  =                 4     / Minimum size for images (pixels)
```

User-selectable parameter, in conjunction with the threshold above this determines how deep and how small "real" images can be. This default precludes many of the few pixel-hit cosmic rays from being considered since "real" images must have 4 contiguous simply-connected pixels in the union of the detection filter and data domains. For more details on image detection and parametersiation see the papers in http://www.ast.cam.ac.uk/vdfs/publications.html .

```
CROWDED =                    1     / Crowded field analysis flag (0 none, 1 active)
```

User-selectable parameter, detection algorithm tried to disentangle overlapping images or images supperposed on the "slowly" varying background of other large images (default) otherwise just straighforward isophotal detection.

```
RCORE   =                 3.50     / Core radius for default profile fit (pixels)
```

User-selectable parameter, aperture flux designed to match median seeing of survey data. It is straighforward to show that if rcore = FWHM then for typical profiles encountered the rcore flux estimate has between 80-90% of the accuracy of an idealised perfectly known PSF model method.

```
OPTFILT =                 2.0      / FWHM of Gaussian detection filter (pixels)
```

User-selectable parameter, should be chosen to match the average FWHM of stellar images in the data. This defines the Gaussian matched detection filter to use.

```
SEEING  =                 2.95     / Average FWHM (pixels)
```

An average realistic FWHM estimated directly from the stellar images on the frame. Mutiply by pixel scale size to convert to arcsec (eg. *0.400 WFCAM; *0.333 INT WFC).

```
ELLIPTIC=                 0.04     / Average stellar ellipticity (1-b/a)
```

A direct estimate of the average stellar ellipticity, useful for spotting trailed frames usw.. Should not average much above 0.15 for "normal" frames.

```
CLASSIFD=                        T / Classified
```

Has image morphological classifier been run ? if so an object classification flag and a stellarness index is included in the binary table columns.

```
SATURATE=              41593.8     / Average saturation level in frame
```

An estimate directly from saturated images on the frame at what level image saturation occurs, including sky. This varies from detector to detector depending on the relative gains applied to bring them to a uniform flatfield reponse etc..

Photometric Information

```
APCORPK =              2.812     / Stellar aperture correction - peak height
APCOR1  =              0.635     / Stellar aperture correction - core1 flux
APCOR2  =              0.114     / Stellar aperture correction - core2 flux
APCOR3  =              0.028     / Stellar aperture correction - core3 flux
APCOR4  =              0.000     / Stellar aperture correction - core4 flux
APCOR5  =              0.000     / Stellar aperture correction - core5 flux
APCOR6  =              0.000     / Stellar aperture correction - core6 flux
APCOR7  =              0.000     / Stellar aperture correction - core7 flux
```

Aperture corrections in magnitudes needed to correct the assorted aperture-like measures produced in the catalogues onto the equivalent of a total flux stellar system. These constitute the components of a curve-of-growth analysis contained within the catalogues with radii defined in the previous table; t o be used in the sense that

$$corrected\ photometry = 2.5 * log10(flux) + apcor \tag{1}$$

They also work well as a first order seeing correction for faint galaxies. Larger aperture corrections are not included.

The remaining information necessary for photometric calibration may also be included in the following keywords:-

```
PERCORR =               -0.006  / Sky calibration correction (mags)
```

this is a correction based on the median dark sky recorded in science frames compared to the median for all the detectors and as such is an ancillary correction to the gain correction derived from the flatfield (usually twilight flats) data. This correction is to be used in the same sense as before in that

$$corrected\ photometry = 2.5 * log10(flux) + apcor + percorr \tag{2}$$

```
MAGZPT  =                22.10  / Photometric ZP (mags) for default extinction
```

Derived detector zero-point in the sense of what magnitude object gives a total (corrected) flux of 1 count/s. These ZPs are appropriate for generating magnitudes in the natural detector+filter system based on Vega, see http://www.ast.cam.ac.uk/vdfs/docs/reports/ for more details on colour equations etc.. The ZPs have been derived from a robust average of all photometric standards observed on any particular set of frames, corrected for airmass but assuming the default extinction values listed later. For other airmass or other values of the extinction use

$$ZP \Rightarrow ZP - [sec(z) - 1] * extinct + extinct\ default - extinct \tag{3}$$

You can then make use of any of the assorted flux estimators to produce magnitudes via

$$Mag = ZP - 2.5 * log10(flux/exptime) - apcor - percorr \tag{4}$$

Note that for the so-called total and isophotal flux options it is not possible to have a single-valued aperture correction

```
MAGZRR  =                   0.15  / Photometric ZP error (mags)
```

error in the zero point. If good photometric night this error will be at the level of a few percent. Values of 0.05 and above indicate correspondingly non-photometric night and worse.

```
EXTINCT =                   0.05  / Default extinction in passband
```

for WFCAM these are currently set to a constant clear night level, which within the current measuring error is the same for all passbands. Note that the frame-by-frame derived ZP from 2MASS automatically corrects for extinction variations, assuming they are uniform across the field of view.

To compute approximate errors in the fluxes you can also use the following:-

$$error^2 = flux/gain + npixels * skynoise^2 \tag{5}$$

where npixels is either the effective area ie. $\pi * rcore^2$ for the "core" measures or the no. of pixels above the detection isophote ie. areal profile1; gain is the final overall detector system gain. (see http://www.ast.cam.ac.uk/vdfs/docs/reports/sv for values); flux is whichever measure you are using but note that for "total" this formula is not accurate since "total" fluxes are derived using a rather convoluted curve-of-growth technique; average skynoise can be obtained from the catalogue fits header.

```
NUMZPT  =                    623  / Number of standards used
```

the actual number of standards used in the photometric calibration for the pointing

```
NIGHTZPT=                  22.85  / Average photometric ZP (mags) for night
```

a robust estimate of the average ZP in a particualar passband for the night

```
NIGHTZRR=                   0.26  / Photometric ZP sigma for night (mags)
```

a robust estimate of the scatter in this ZP to give an indication of how photometric or otherwise the night was (0.03 or better is good; worse than 0.05 is usually indicative that the majority of the night was non-photometric; the example above says you should have gone to bed early).

Astrometric Information

For a description of the World Coordinate System (WCS) see Calabretta & Greisen 2002 A&A 395 1077 and Greisen & Calabretta 2002 A&A 395 1061.

```
CTYPE1  = 'RA---ZPN'           / Zenithal polynomial projection
CTYPE2  = 'DEC--ZPN'           / Zenithal polynomial projection

CRPIX1  =              2999.40 / Reference pixel X on axis 1
CRPIX2  =              -940.32 / Reference pixel Y on axis 2

CRVAL1  =         112.45449231 / [deg] Right ascension at the reference pixel
CRVAL2  =          30.07196251 / [deg] Declination at the reference pixel
CRUNIT1 = 'deg     '           / Unit of right ascension co-ordinates
CRUNIT2 = 'deg     '           / Unit of declination co-ordinates

CD1_1   =      -7.11999928E-08 / Transformation matrix element
CD1_2   =       1.11427136E-04 / Transformation matrix element
CD2_1   =       1.11433289E-04 / Transformation matrix element
CD2_2   =      -1.73270884E-07 / Transformation matrix element

PV2_1   =                  1.0 / Pol.coeff. for pixel -> celestial coord
PV2_3   =                -50.0 / Pol.coeff. for pixel -> celestial coord
PROJP1  =                  1.0 / Old style ZPN projection keyword r term
PROJP3  =                -50.0 / Old style ZPN projection keyword r**3 term

NUMBRMS =                   87 / Number of standards used
STDCRMS =                0.089 / Astrometric fit error (arcsec)
```