Faint Object Classification and Analysis System
Standard Test Image Results

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ABSTRACT

A set of standard test images has been analyzed using the Faint Object Classification and Analysis System (FOCAS). This paper presents an outline of the FOCAS software and algorithms followed by a summary of the results and a description of the archive containing the detail analysis. The archive is available on magnetic tape. The detailed results may be used to verify current and future distributions of FOCAS and to compare against other image analysis systems which produce similar measurements.

1. Introduction

The Faint Object Classification and Analysis System (FOCAS) is a set of programs for creating and manipulating catalogs of objects from digital astronomical images. The catalogs are created by an automatic threshold detector where the threshold is measured relative to a simultaneously determined background. The manipulation of catalogs includes the separation of merged objects, the measurement of various position, shape, and photometric parameters, the astronomical classification of the objects, matching of different catalogs of the same field, interactive display and review, and analysis operations using various tools and user written procedures.

FOCAS may be used on any type of astronomical image data but it was primarily designed for the optimal detection of small faint objects and their classification as stars, galaxies, or noise. It is largely automated for the measurement of large numbers of objects for various statistical studies. It was not intended for very crowded stellar fields where point spread function fitting methods are more appropriate, or for large bright objects where surface brightness methods apply.

Version 1 of this system was developed by John Jarvis and J. A. Tyson [1] beginning in 1978 for use with digitized NOAO 4m photographic data. F. Valdes has since generalized the package to be easily used with any digitized images and improved or replaced most of the algorithms in Versions 2 and 3. This work was done first at A. T. & T. Bell Laboratories and then at the National Optical Astronomy Observatories. The system used in this paper is version 3.2.

The purpose of this paper is to present the results obtained for a set of standard test images collected and distributed for a Two-Dimensional Photometry Systems and Test Images Workshop (ESO/ECF, April 1989). A number of tables and figures summarize the results. However, the most important aspect of this analysis is the detailed archived results which is available upon request. This paper describes the contents of this archive (currently on magnetic

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† Operated by the Association of Universities for Research in Astronomy under contract with the National Science Foundation.

tape). This archive is intended to be used to verify any current and future distributions of the FOCAS package and to allow detailed comparison with other similar systems.

This paper begins with a brief summary of the FOCAS software and algorithms. A more detailed (and partially out of date) description is given in [2]. A summary of the test image analysis, including the hardware and general processing steps, is presented next. A set of tables, figures, and plates are used to present some of the specific results. Finally, the detailed archive is described in sufficient detail that others may use this information to make careful comparison with other FOCAS packages or from other image analysis systems.

2. The Software

FOCAS is a complete image processing system in that it provides tools for reading and writing images to FITS format, simple image arithmetic and header editing, graphics for line and column plots and histograms, image display, etc. However, the capabilities are not as well developed as in larger image processing systems such as IRAF†. In a recent development FOCAS now allows use of the IRAF image format, the IRAF developed image display server for Sun Workstations, and the FOCAS commands may be defined within the IRAF command environment. This allows use of the more powerful IRAF image processing capabilities with the FOCAS catalog system. The plates and figures were prepared using IRAF facilities. The general FOCAS image processing commands are not discussed in this paper.

The FOCAS software is a mixture of C source code and UNIX/CSH command scripts. The scripting capability is an example of FOCAS as an image processing system using UNIX as the command environment. Though the C source is fairly portable, the dependence on UNIX command scripts, and a catalog analysis structure which greatly benefits from pipes, really means that FOCAS is essentially a UNIX system. Until recently little effort had been made to use FOCAS on other than VAXes running BSD UNIX and using an IIS for image display. FOCAS is now moving increasingly toward other machines; Alliants, ISI, and Suns in particular. With the IRAF/IMTOOL display server FOCAS is well suited to a Sun Workstation environment.

The command environment is either UNIX or IRAF. In either case the system consists of a large set of programs (nearly 100) which take command line arguments and possibly read and write data to the standard input and output streams. The commands can be divided into two general types. The basic catalog processing generally consists of a command with the catalog name as the only argument or the main argument with additional flags and options. This is a very simple command structure.

The analysis commands are more often stream oriented in which one command reads a catalog or text from the standard input and writes an modified catalog or text to the standard output. This allows connecting commands with pipes to form a wide variety of operations. Typically one begins with input from a catalog into a filter program which produces a filtered catalog as it's output. The output of the filter is piped into a program which extracts selected parameters for each object and prints the values as text. Then a calculator type program might be used to read the text values and do some type of operation and print the results as output. Finally, the text stream might be used to generate a histogram, some type of averages, or a plot. There are a number of general utilities to do filtering and calculations which can be plugged into the data stream to do sophisticated analysis. Even more sophisticated analysis may be done using these tools in UNIX command scripts with other general UNIX tools. I have found this stream approach to catalog database analysis to be a very flexible and powerful one. All the data for the tables and graphs presented in this paper were generated in this fashion.

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† Image Reduction and Analysis Facility distributed by the National Optical Astronomy Observatories.

3. Algorithms

A more complete description of the algorithms and data formats used by FOCAS is given in [2]. This section very briefly outlines the important algorithms.

3.1. Detection

The detection of objects in an image consists of simultaneously tracking the sky background and collecting and merging adjacent pixels which are some fraction of the sky sigma above and below the mean background. This is done line by line with a user specified convolution function applied first. The image convolution is the primary reason that FOCAS is a faint object system; objects may be found only a few percent above sky with a threshold of about 0.3 of the pixel to pixel sky noise. The line by line, single pass method was originally required when computer memory was small but is still an important factor which allows arbitrarily large images to be processed.

The background sky is binned eight pixels per sky point along a line. Each pixel which is not accepted as part of an object is added into the nearest and two adjacent sky bins using fractional weights. The fractional weights control how fast the sky may change as the image is processed. A useful analogy for this algorithm is that of a "leaky memory". Though the background sky changes a small amount in each line the sky values are recorded as an image every eight lines to give a sky image at one-eighth resolution. This detection sky is primarily for inspection and is not used for the photometry. The sky image can also be used to produce a sky subtracted image by expanding it back to the original image dimensions and subtracting.

The poorest aspect of the sky tracking is that it requires the initial lines and estimate of sky be good. The initial lines are iteratively cleaned to estimate the first background line and sigma of sky. For difficult cases one may specify the sky sigma and initial sky explicitly.

The sky sigma is assumed constant over the image and is used to define the detection level relative to sky based on user specified detection thresholds. There are independent detection thresholds above and below sky so that "dark" objects can be found and excluded from the background.

After no further connecting pixels (in eight directions) are found for an object the object must have a user specified minimum area to be recorded. An object is entered in the catalog at this point with some basic information (i.e. object number, average x and y, and area) and the detailed shape of the isophote is recorded in an area description file.

3.2. Photometric Sky

One option the user has is to specify a constant sky value for all objects. However, generally a local sky is determined for each objects as follows. A square annular aperture around the detection isophote with a minimum separation from the object isophote (default 5 pixels) is defined. A histogram is computed and the mode is determined within the aperture. The histogram is then truncated at two times the sky sigma from the mode and the mean is computed. Both the mode and the mean are recorded with the mean being the default sky value.

The mode may be used as the sky value but this is a noisy estimate. A better approach is to correct the mean value for bias in the sky histogram due to faint objects in the sky aperture. This correction consists of computing the average difference between the mean and mode estimates and subtracting this single value from all the mean sky estimates. This is the method used for the test images.

3.3. Photometry, Astrometry, and Shapes

Most of the cataloged parameters except for the classification parameters are set in an evaluation step. In principle one can use the catalog to drive any evaluation routine one likes. The one used in FOCAS is relatively simple. The luminosity and object center parameters are summarized as follows (the others are not described here). There are four luminosity parameters; a core magnitude, an aperture magnitude, an isophotal magnitude, and a total magitude.

The core magnitude is the brightest three by three pixel sum with center within the detection isophote. This center is the default coordinate parameter though the unweighted and weighted centroids are also computed and recorded. The aperture magnitude is a circle with a user specified radius. No partial pixels are used so the actual shape is not a perfect circle but it is a constant shape. The isophotal magnitude is the flux within the detection isophote. The total magnitude is the flux within a region obtained by expanding the detection isophote to an defined area increase (default a factor of 2). It is not really a "total" magnitude but this is the name given to this magnitude.

3.4. Splitting

Except in uncrowded data many detection isophotes contain many objects. In more crowded areas in order to reach a faint detection threshold large groupings of objects are often found. To separate these merged objects a splitting program is used. The splitting begins with the minimum value in the original isophote and successively increases this level in steps of 0.2 of the sky sigma. At each new level the pixels above this level are examined to see if there is more than one region of adjacent pixels; i.e. regions separated by pixels below the current splitting level. As with the original detection any piece must have at least the minimum area. If two or more objects are found then the parent object is flagged as multiple and the new objects are evaluated and added to the catalog. The original objects are not thrown away though the user may later filter the catalog if desired. Each new object is then split until no pixels remain above some value. Objects which do not split are flagged as single objects. Thus, there can be any number of splitting "generations".

Objects may not be split by this algorithm primarily because at the point where pixels separate (if they do at all) the number of remaining pixels falls below the minimum area. Thus there are cases where the eye can identify merged objects but the automated algorithm cannot. However, this algorithm does work exceptionally well as the test image results show. The test images are, for the most part, fairly challenging crowded fields.

The evaluation of the split object parameters differs in some respects. The sky value for a split object is inherited from the original detection and so will be lower than might be found locally. Of course all the magnitudes will then be brighter than might be found by local methods. The core and aperture magnitudes will be affected by light from the neighboring objects. The isophotal magnitude will be within a brighter and smaller isophote and so different objects will not have consistent isophotal magnitudes. In an attempt to provide a reasonable estimate of a split objects luminosity the total magnitude is not evaluated directly. Instead the total luminosity of the parent object is divided between the daughter objects in proportion to the isophotal luminosities.

FOCAS does not attempt to deconvolve objects since it is used in fields containing an arbitrary mixture of stars and galaxies. For largely stellar fields a point spread function deconvolution method would clearly be more appropriate.

3.5. Classification

The classification algorithm is described in [3]. The idea is that a template point spread function is defined. There is no restriction on the shape; i.e. it is an average of stellar images rather than a function. A set of alternate templates is then formed by changing the spatial scale of the PSF to broader and narrower profiles. An additional set of templates is formed consisting of two components, one with scale 1 (the PSF) and one with scale 2 (a broader component).

For each object the best fitting template based on Bayesian maximum likelihood using the known noise properties is found. The scale factor (with 1 being the original PSF) and component fraction (with 0 for pure PSF and 1 for pure broad component) form the classification parameters. A set of classification rules then assign astronomical classifications based on the magnitude, scale, and fraction.

For example if objects have scales of .72, .98, 1.62, 3 they would be classified as noise (n), star (s), galaxy (g), and galaxy (g). The two component templates might be divided as greater than 80% stellar being fuzzy star (sf) and less as galaxy (g). The classification parameters are recorded in the catalog and the classification rules are in the catalog header. The rules can be changed later if desired.

3.6. Matching

Catalogs of different images of the same field can be combined to form a *matched* catalog. This is described further below. The matching algorithm is simply a minimum distance after transforming the image coordinates to a common coordinate system. Because of different numbers of objects, different seeing, and different splittings, there will be a combination of matched and unmatched objects. The user can then select objects based on any combination of matching and nonmatching as well as all the filtering parameters for each object.

A variant processing technique when there are multiple fields detects the objects on a combined frame and then does the photometry on the individual images using the isophotes from the combined frame. In the results described in this paper each image was treated independently. Thus, in cases where matching fields are available the magnitudes are taken from somewhat different apertures.

4. Standard Test Image Analysis

A set of standard test images was collected and distributed for analysis by a number of image processing systems with the results presented at the Two-Dimensional Photometry Systems and Test Images Workshop (ESO/ECF, April 1989). These images are described in more detail in the workshop proceedings [4]. Table 1 summarizes the images.

Table 1: Standard Test Images

ID	Title	Size	Processed	Plate
sgp0001	S. Gal. Pole J	234x441	Y	1
sgp0002	S. Gal. Pole R	234x441	Y	2
gal0001	Gal. Cl. 0637-53	320x503	Y	3
gal0002	Gal. Cl. 0637-53	264x427	Y	4
gal0003	SA68 Test Field 1	1000x1000	Y	5
gal0004	SA68 Test Field 2	1000x1000	Y	6
for0001	Fornax V	320x513	Y	7
for0002	Fornax B	326x513	Y	8
ngc0001	NGC 3210 V long	321x507	Y	9
ngc0002	NGC 3210 V short	322x508	Y	10
com0001	NGC 4874 Coma	500x500	Y	11
tuc0001	47 Tuc Centre V	337x520	N	
tuc0002	47 Tuc Centre B	337x520	N	
tuc0003	47 Tuc Field V	436x277	Y	12
tuc0004	47 Tuc Field B	435x276	Y	13
neb0001	Veil Nebula	512x512	N	
neb0002	Veil Nebula	512x512	N	

The indicated images were processed by FOCAS and the results are summarized in this paper and archived for detailed reference. The globular cluster center and veil nebula images were not analyzed. FOCAS is not a croweded stellar field system though it does work on moderately crowded field such as the outer globular cluster field. Though in some cases there was a temptation to use some additional image processing from IRAF all the operation were performed solely with the tools provided by FOCAS. Also there is no interactive editing of the catalogs except in selecting objects to form the point spread function and to define the coordinate translation between matching images.

The processing was performed on a Sun-4/280 with 16 Mb of memory. The machine typically had half a dozen users. The processing was fast enough for all fields to be considered interactive; 5 to 10 minutes for the noninteractive steps.

Plates 1-13 are Postscript finding charts produced by FOCAS using the IMTOOL image display system on the Sun Workstation. The isophotes are those determined by FOCAS after separating merged objects. Only a selection of all objects is generally shown.

Though there are many image processing, catalog processing, and analysis commands the basic core of the system is a few catalog processing commands. Catalog processing begins with creating an empty catalog with some of the header parameters set. Apart from this step the processing is almost entirely driven by parameters in the catalog header. The same program is used to modify header parameters at any point.

All images were processed with the following basic steps where *image* is replaced by the appropriate image name:

```
setcat image.cat
detect image.cat
sky image.cat
skycorrect image.cat
evaluate image.cat
splits image.cat 1000
setpsf image.cat <image.psf
resolution image.cat H
```

The differences between fields occurs in the parameters used during the initialization of the catalog, possibly trimming and flattening the field as described below, possibly restricting the initial guess at sky in the detection step, and the point spread function used for classification.

One interactive step was selecting objects to form the point spread function (PSF) for classification. This was done using the interactive **review** program and flagging stellar objects with the attention flag. The derived PSF is in the catalog and also contained in a text file so that the classification can be reproduced using the same PSF without requiring identifying the stars used. There is a noninteractive, heuristic program which is useful when there are many stellar objects. This was used in one field.

Some fields with strong sky gradients were first flattened. This was done by using the same detection operation but with higher thresholds. This detects everything but the faintest objects and the sky tracking algorithm produces a smoothed, low resolution image of the background. The faint objects do not affect the mean sky significantly because of the "leaky memory" sky tracking and the objects are generally much smaller than the scale at which the sky is determined. The background sky image is expanded to the original image size using linear interpolation, thereby smoothing further, and subtracted. This procedure works extremely well as seen in the Coma cluster field.

Those fields with overlapping frames were matched to create a FOCAS *matched* catalog. There are three steps required. First the interactive **review** program is used to identify a number of matching objects as reference objects. The reference coordinate is entered for each reference object. Generally this is the detection coordinate from one image. This operation is easily done because **review** loads multiple catalogs and lets the user rapidly switch between any catalog and any object and select matching objects with the image display cursor.

The next step is to determine a transformation matrix between the detection coordinates and the reference coordinates. The transformation can be entered manually but normally it is determined from the reference objects. This is done for each catalog and the catalog reference coordinates are then computed for every object. The last step is to match the objects in the catalog. Below are the basic steps used for two images.

```
review image1.cat image2.cat
setcat image1.cat
setcat image2.cat
match field.mcat image1.cat image2.cat
```

In the following sections a brief discussion of each image is presented. The magnitudes are all instrumental magnitudes with a zero point of 30; i.e. 30 - 2.5 log (luminosity), where the luminosity is the sum of the sky subtracted pixel values. FOCAS does provide conversion to a magnitude based on reference objects by changing the magnitude zero point in the catalog header.

4.1. SGP0001 and SGP0002

Processing this field required no special steps. The two catalogs from the two fields were matched to produce a matched catalog. Table 2 gives the number counts for objects classified as star or galaxy as a function of the total magnitude. Columns 2-5 are relative to J magnitudes and columns 6-9 are in R magnitudes. Columns 3 and 7 give the counts of stars and galaxies found and matched in both fields. Figure 1 shows a color magnitude diagram of stars and galaxies combined. One feature of this diagram is the blue trend in the colors of fainter galaxies. The red trend at the faintest magnitudes is a result of the magnitude limits of the images as indicated.

4.2. GAL0001 and GAL0002

These images are of the galaxy cluster 0637-53. GAL0001 is a single 15 minute exposure and GAL0002 the sum of six 15 minute exposures through a Gunn r filter. The center of the brightest object in GAL0002 was replaced to eliminate a wrapping of the 16 bit integer. Apart from that there were no special steps required. Table 3 presents the number counts for the two fields in the same format described previously. Figure 2 shows the magnitude difference between the two fields as a function of magnitude in GAL0002 with a line indicating the expected difference based on the exposure times. The total magnitude is more sensitive to problems in splitting than the small aperture core magnitude.

4.3. GAL0003 and GAL0004

These fields of SA68 (0015+15) are portions of a good digitized Kitt Peak 4-meter IIIa-J photographic plate. The digitized values have been linearized. This is the type of data for which the first version of FOCAS was developed. There were no special steps required to process these fields. Table 4 give the number counts for the two fields.

4.4. FOR0001 and FOR0002

These images are V and B exposures of a region in Fornax. They are averages of 3 exposures of 30 minutes (V) and 45 minutes (B). The V image was trimmed of columns 1 to 2 and 308 to 320 as well as the last line. The B image was trimmed of columns 1 to 2 and 308 to 326 and lines 1 to 15 and 513. The trimmed images are stored in the FOCAS archive. In addition each field was flattened as described earlier. The rest of the processing was normal. Table 5 presents the number counts in the same format as described for table 2. Figure 3 presents a color-magnitude diagram for the matched objects using the total magnitude and the core magnitude. A feature in this diagram is a clumping near a V instrumental magnitude of 22. This must be the cluster population. This diagram also shows a bluing trend in the faint background galaxy population.

4.5. NGC0001 and NGC0002

The images are 10 minute and 1 minute V exposures of a field in NGC 3210. The first 50 columns of these images were trimmed before processing. Because this is a stellar field classification is not really necessary, but for the sake of evaluating the classifier the classification was done. Because there are many bright stellar objects the point spread function was automatically determined by taking objects in a range of magnitudes and a range of first radial moment sizes. Because the image sizes were quite small a template size smaller than normal was used. Note that the brightest and saturated objects were consistently misclassified as galaxies. By setting an appropriate saturation level these objects can be correctly classified though this was not done here.

Table 6 gives the number counts for the two fields in the same format as table 2. Figure 4 presents the total and core magitude differences as a function of the total and core magnitude of the longer exposure. The solid line is the expected difference.

4.6. COM0001

The image is a high resolution (0.11 arc second per pixel), actively guided (ISIS system), image of a region around the Coma cluster galaxy NGC 4874. The purpose of this field is to find and measure the globular cluster population. Since the FOCAS detection and classification works better and smaller scales the image was first block averaged by a factor of 3. The detection program was run with a high threshold and rapid sky tracking to produce a sky image at a scale 8 times smaller. This smooth low resolution sky image was then expanded back to the original full size (a factor of 24) and subtracted. This step was repeated to further improve the field flattening and elimination of the bright parent galaxy. After this second iteration the image was again block average by a factor of 3 and this is the final image used. This image has the large scale background removed and has 0.33 arc second pixels.

The rest of the processing was then normal except, since there were a small number of objects and no reliable star for use in the point spread function, the smallest objects were used and the point spread function was radially averaged to reduce noise. Table 7 gives the number counts in this field.

4.7. TUC0003 and TUC0004

These V and B images are of a field away from the center of the globular cluster 47 Tuc. The bad edges were trimmed. The images were flattened using the technique described earlier. The processing was normal. Because this is a stellar field classification is not really necessary, but for the sake of evaluating the classifier the classification was done. A transformation from the B image coordinates to the V image coordinates was determined and the catalogs were matched. Table 8 gives the number counts in the same format as table 2. Figure 5 shows a color-magnitude diagram for the matched objects using total and core magnitudes. The stellar sequence is clearly visible. The fixed aperture core magnitude is clearly better at reducing photometry errors from crowding and splitting.

5. FOCAS Analysis Archive

The most valuable aspect of the FOCAS standard test image analysis is the detailed archive of the results. It serves three purposes, to allow comparison with current and future FOCAS distributions, comparison with other image processing systems, and as examples for presentation and use of FOCAS. This section describes the contents of this archive which is currently available on magnetic tape. Table 9 describes the contents of the archive.

This paper is included in TROFF format using the MS macros since it documents the archive. The ultimate description of the system used to process the standard test images is the source code. This is also included.

The basic data are the images. The images are included in machine independent FITS format. Because the archive tape is a mixture of different types of files I suggest reading the files

Table 9: Contents of FOCAS Standard Test Image Archive

Description	Files	Type	Format
This paper	1	ascii	TROFF MS macros
Catalog headers	13	ascii	Free format
Catalog data	13	ascii	Free format
Images	13	binary	FITS
FOCAS processing	1	ascii	UNIX TAR
FOCAS source	1	ascii	UNIX TAR

directly to disk and reading the images with a FITS reader (including the FOCAS fits reader) from the disk files.

The basic FOCAS data files are the images, the catalogs (single and matched), and the area or isophote descriptions. The processing is preserved in a UNIX tar file. The contents of the file is the directory shown in Table 10. The images as FITS format files are also found here with the "fits" extension. The catalogs and area descriptions are integer binary files in machine adaptable format meaning that they should be directly readable by FOCAS on machines having different byte orders and floating point formats. The matched catalogs are not machine independent but they can be readily reproduced by the FOCAS match program.

Table 10: FOCAS Test Images Processing Directory

com0001.ar	for0002.psf	gal0003.fits	ngc0002.cat	tuc.mcat
com0001.cat	for0002.run	gal0003.psf	ngc0002.fits	tuc0003.ar
com0001.fits	gal.mcat	gal0003.run	ngc0002.psf	tuc0003.cat
com0001.psf	gal0001.ar	gal0004.ar	ngc0002.run	tuc0003.fits
com0001.run	gal0001.cat	gal0004.cat	sgp.mcat	tuc0003.psf
focas.ms	gal0001.fits	gal0004.fits	sgp0001.ar	tuc0003.run
for.mcat	gal0001.psf	gal0004.psf	sgp0001.cat	tuc0004.ar
for0001.ar	gal0001.run	gal0004.run	sgp0001.fits	tuc0004.cat
for0001.cat	gal0002.ar	ngc.mcat	sgp0001.psf	tuc0004.fits
for0001.fits	gal0002.cat	ngc0001.ar	sgp0001.run	tuc0004.psf
for0001.psf	gal0002.fits	ngc0001.cat	sgp0002.ar	tuc0004.run
for0001.run	gal0002.psf	ngc0001.fits	sgp0002.cat	
for0002.ar	gal0002.run	ngc0001.psf	sgp0002.fits	
for0002.cat	gal0003.ar	ngc0001.run	sgp0002.psf	
for0002.fits	gal0003.cat	ngc0002.ar	sgp0002.run	

Each image has a UNIX script with the extension "run". This is an important feature of the archive in that it allows anyone to reproduce the processing at a future date for comparison with the results obtained by the author. The files with the "psf" extension are the external text representation of the point spread function generated by the **template** program after selecting template stars interactively. This file is read by the processing script to reproduce the classification with the same PSF without requiring knowing which stars were used. *Note that if one wants to run the processing script the original catalogs and area files will be destroyed unless one copies them first.*

For comparisons with other image processing systems and on machines without the FOCAS software the catalogs are included in a ascii text representation. FOCAS catalogs consist of a header containing processing and history information and a large number of object records containing 40 parameters. The catalog header was produced by the **info** command. Table 11 shows the catalog header information for the NGC V field.

Table 11: Sample ASCII FOCAS Catalog Header

```
Catalog: ngc0002.cat
```

```
Number of objects: Total = 1885
Field image file: ngc0002
Field name: N3201,V,1 F2,CL
Field epoch:
Field passband: V
Field coordinates: 0 0
Image exposure or integration: 60
Observer: Ortolani
Origin: ESO
Field size: 271 507
Field scan origin: 52 1
Field corners in reference coordinates:
 (69, 1.00002) (339, 1.00005) (69, 507) (339, 507)
Magnitude zero point: 30.000000
Catalog magnitude limit: 100.00
Radius of fixed circular aperture: 5.000000
Sigma of sky: 9
Sigma above sky for detection: 2.500000
Sigma below sky for detection: 100.000000
Minimum area for detection: 6
Significance for evaluation and splitting: -100
Area file:   ngc0002.ar

Comments:

Mon Apr  3 10:44:52 1989: setcat ngc0002.cat
Mon Apr  3 10:44:53 1989: detect ngc0002.cat 0 1000 129 137
 sky: pts =  200 avg = -0.087478 sigma = 1.42302
 threshold above = 3.55756 threshold below = 142.302

Mon Apr  3 10:44:59 1989: sky ngc0002.cat
Mon Apr  3 10:45:10 1989: sky -3 -1.03959 ngc0002.cat
Mon Apr  3 10:45:11 1989: evaluate ngc0002.cat
Mon Apr  3 10:45:41 1989: splits ngc0002.cat 1000
Mon Apr  3 10:54:36 1989: setcat ngc0002.cat
Mon Apr  3 10:54:40 1989: resolution ngc0002.cat H
Mon Apr  3 11:09:39 1989: filter I ignre
Mon Apr  3 11:10:26 1989: setcat ngc0002.cat

Detection filter

  Builtin filter
    0     1     2     1     0
    1     2     3     2     1
    2     3     4     3     2
    1     2     3     2     1
    0     1     2     1     0

Transformation matrix

            1            0           17
 1.34689e-07            1  8.79065e-06
            0            0            0
```

```
Instrumental intensity relation:

  Linear

Point spread function template

  3   6   8   6   3
  6  26  50  26   6
  8  50 100  50   8
  6  26  50  26   6
  3   6   8   6   3

Classification rules:

  0.00 100.00   0.10   0.70   0.00   1.00    n
  0.00 100.00   0.71   1.20   0.00   1.00    s
  0.00 100.00   1.21 100.00   0.80   1.00    g
  0.00 100.00   1.21 100.00   0.00   0.75   sf
```

The catalog header contains a wealth of information. The first part contains some documentary information as well as the important processing parameters of the sky sigma, detection thresholds, and minimum area for an object. The comments are mostly processing history. The complete command line is recorded with a date and time. Note that since much of the processing was done together the times give a feel for the real time needed. The bigger time intervals are for the interactive selection of PSF stars. The **setcat** commands are to initialize the catalog, enter the PSF, and set the reference coordinate transformation. The sky information was produced by **detect** and the **filter** command is the result of **review** for reasons not worth going into.

The detection convolution filter is given next. The *builtin filter* is a particularly efficient filter though any user filter might be used. The *transformation matrix* is used to set the reference coordinates, usually for matching catalogs of the same field. In the example the transformation is simply a shift of 17 pixels. The *point spread function template* used for classification is given with the center normalized to 100 though internally it is stored with greater precision. Finally the *classification rules* are given. These consist of a magnitude range, a template scale factor range, a composite fraction range, and the classification string. For the meaning of these parameters relative to classification see [3]. Note that the rules shown differ from the defaults.

The object information is dumped into an ascii format with the **catdump** program. All the object information contained in the catalog is given except the offset into the area description file. Table 12 shows the first object from the catalog "sgp0001.cat" and the symbolic name of each field. Table 13 gives a brief description of each value. For more description see [2].

The object record illustrated has been tabulated while the tape records are simply separated by a space or a new line. This free format is used to save space since card image format is many times bigger.

Table 12: Sample ASCII Catalog Object Entry

1	0	g	-B----S--E	2314.34
68	4.63765	10	23	9.43671
3.33333	2.5	36	4	36
4	89.5894	6.78845	74.9304	227.629
167.52	25.0941	37.6096	3.59462	4.44267
.59107	-.531971	1.8588	14.4907	43.0699
37.7	3.8	4.1	.6	-.1
2315	36	4	2	.75

entnum	subent	class	eflgs	sbr
nsbr	ssbr	area	tarea	ispht
xavg	yavg	xc	yc	ra
dec	Li	sLi	Lc	Lfca
Ltotal	mag	icx	icy	ixx
iyy	ixy	ir1	ir3	ir4
cx	cy	xx	yy	xy
r1	fitxc	fityc	scale	frac

Table 13: FOCAS Catalog Object Entry Parameters

entnum	detection number
subent	split number
class	classification
eflgs	object flags
sbr	sky brightness
nsbr	number of sky pixels
ssbr	sky sigma
area	isophotal area
tarea	total area
ispht	isophote brightness
xavg	average x width
yavg	average y width
xc	x position
yc	y position
ra	transformed x coordinate
dec	transformed y coordinate
Li	isophotal luminosity
sLi	sigma of isophotal luminosity
Lc	core luminosity (central 9x9 square)
Lfca	aperture luminosity (radius in catalog header)
Ltotal	total luminosity
mag	isophotal magnitude (zero point in catalog header)
icx	x intensity weighted centroid
icy	y intensity weighted centroid
ixx	xx intensity weighted second moment
iyy	yy intensity weighted second moment
ixy	xy intensity weighted second moment
ir1	intensity weighted first moment radius
ir3	intensity weighted third moment radius
ir4	intensity weighted fourth moment radius
cx	x unweighted centroid
cy	y unweighted centroid

xx	xx unweighted second moment
yy	yy unweighted second moment
xy	xy unweighted second moment
r1	unweighted first moment radius
fitxc	x template center
fityc	y template center
scale	resolution scale
frac	resolution fraction

References

[1] Jarvis, J. F. and Tyson, J. A., **Astron. J. 86**, 476, 1981.

[2] Valdes, Francisco, *Faint Object Classification and Analysis System*, Central Computer Services, National Optical Astronomy Observatories, P.O. Box 26732, Tucson, AZ, 85725, USA.

[3] Valdes, Francisco, *The Resolution Classifier*, in **Instrumentation in Astronomy IV, S.P.I.E. Proceedings, Vol. 331, 1982.**

[4] **Proceedings of the ESO Data Analysis Workshop**, to be published.

Number Count Tables:

Table 2: Number Counts for SGP Field

Total Magitude	SGP0001 Ntotal	SGP0001 Nmatch	SGP0001 Nstar	SGP0001 Ngalaxy	SGP0002 Ntotal	SGP0002 Nmatch	SGP0002 Nstar	SGP0002 Ngalaxy
17.00	1	1	1	0	1	1	1	0
17.50	1	1	1	0	0	0	0	0
18.00	0	0	0	0	1	1	1	0
18.50	0	0	0	0	0	0	0	0
19.00	1	1	1	0	0	0	0	0
19.50	1	1	1	0	1	1	1	0
20.00	2	2	0	2	5	5	1	4
20.50	7	7	2	5	4	4	2	2
21.00	18	17	4	14	4	4	2	2
21.50	40	40	7	33	16	16	4	12
22.00	34	35	6	28	25	24	4	21
22.50	82	77	12	70	36	36	5	31
23.00	116	113	16	100	63	62	9	54
23.50	142	124	35	107	105	98	5	100
24.00	155	116	48	107	188	159	11	177
24.50	159	89	56	103	186	127	10	176
25.00	133	58	62	71	226	110	26	200
25.50	66	19	31	35	136	51	37	99
26.00	13	1	7	6	34	14	12	22
26.50	3	1	2	1	1	0	0	1

Table 3: Number Counts for Galaxy Cluster Field

Total Magitude	GAL0001 Ntotal	GAL0001 Nmatch	GAL0001 Nstar	GAL0001 Ngalaxy	GAL0002 Ntotal	GAL0002 Nmatch	GAL0002 Nstar	GAL0002 Ngalaxy
16.00	1	1	1	0	2	2	1	1
16.50	0	0	0	0	1	1	0	1
17.00	0	0	0	0	4	4	4	0
17.50	1	1	1	0	3	3	1	2
18.00	1	1	1	0	8	8	2	6
18.50	5	3	3	2	7	7	2	5
19.00	3	3	3	0	13	13	2	11
19.50	2	2	1	1	16	15	2	14
20.00	11	9	2	9	22	19	3	19
20.50	10	5	2	8	15	15	1	14
21.00	18	13	4	14	22	18	0	22
21.50	16	14	2	14	36	17	2	34
22.00	22	19	2	20	41	8	4	37
22.50	23	14	3	20	89	6	12	77
23.00	28	18	1	27	106	6	31	75
23.50	44	25	11	33	67	0	20	47
24.00	38	11	15	23	6	0	4	2
24.50	14	5	8	6	1	0	0	1
25.00	1	0	0	1	0	0	0	0
25.50	0	0	0	0	1	0	0	1

Table 4: Number Counts for SA68 Fields

Total Magitude	GAL0003			GAL0004		
	Ntotal	Nstar	Ngalaxy	Ntotal	Nstar	Ngalaxy
16.00	1	0	1	1	0	1
16.50	2	0	2	0	0	0
17.00	0	0	0	0	0	0
17.50	1	0	1	4	0	4
18.00	5	0	5	1	0	1
18.50	7	0	7	6	0	6
19.00	1	0	1	3	0	3
19.50	7	5	2	2	2	0
20.00	3	0	3	2	2	0
20.50	6	3	3	5	2	3
21.00	14	4	10	13	4	9
21.50	23	10	13	12	2	10
22.00	34	4	30	28	4	24
22.50	52	5	47	49	11	38
23.00	104	4	100	74	2	72
23.50	197	13	184	172	20	152
24.00	284	61	223	277	55	222
24.50	261	95	166	270	109	161
25.00	51	27	24	62	44	18
25.50	9	6	3	9	7	2
26.00	1	1	0	0	0	0

Table 5: Number Counts for Fornax Field

Total Magitude	FOR0001				FOR0002			
	Ntotal	Nmatch	Nstar	Ngalaxy	Ntotal	Nmatch	Nstar	Ngalaxy
16.00	1	1	0	1	0	0	0	0
16.50	0	0	0	0	0	0	0	0
17.00	3	3	0	3	1	1	1	0
17.50	10	7	0	10	0	0	0	0
18.00	5	0	0	5	1	1	1	0
18.50	8	1	1	7	2	1	1	1
19.00	5	5	5	0	2	2	2	0
19.50	9	9	8	1	0	0	0	0
20.00	18	18	13	5	9	9	6	3
20.50	21	20	14	7	15	14	9	6
21.00	51	51	26	25	30	30	12	18
21.50	86	82	34	52	62	58	14	48
22.00	93	88	48	45	89	87	13	76
22.50	59	49	25	34	90	86	29	61
23.00	68	59	20	48	66	61	13	53
23.50	124	93	31	93	100	84	24	76
24.00	166	113	67	99	122	101	37	85
24.50	170	81	90	80	111	88	51	60
25.00	152	46	84	68	98	77	51	47
25.50	65	24	25	40	55	38	28	27
26.00	7	0	3	4	18	10	8	10
26.50	2	0	1	1	1	0	1	0

Table 6: Number Counts for NGC 3210 Field

Total Magitude	NGC0001 Ntotal	NGC0001 Nmatch	NGC0001 Nstar	NGC0001 Ngalaxy	NGC0002 Ntotal	NGC0002 Nmatch	NGC0002 Nstar	NGC0002 Ngalaxy
16.00	11	10	0	11	2	1	0	2
16.50	20	18	2	18	2	2	0	2
17.00	43	41	6	37	10	9	2	8
17.50	77	75	59	18	7	5	7	0
18.00	74	70	65	9	10	10	10	0
18.50	92	85	80	12	8	7	6	2
19.00	105	92	94	11	21	19	19	2
19.50	94	90	84	10	35	35	32	3
20.00	95	87	72	23	61	57	59	2
20.50	112	99	92	20	79	70	69	10
21.00	116	98	84	32	83	77	76	7
21.50	112	95	69	43	112	96	102	10
22.00	103	70	71	32	113	99	104	9
22.50	111	35	68	43	92	80	72	20
23.00	73	13	35	38	112	101	95	17
23.50	12	1	4	8	113	101	91	22
24.00	0	0	0	0	100	89	69	31
24.50	1	1	1	0	108	84	67	41
25.00	0	0	0	0	62	41	39	23
25.50	0	0	0	0	19	9	10	9
26.00	0	0	0	0	2	1	1	1

Table 7: Number Counts for NGC 4874 - Coma Field

Total Magitude	COM0001 Ntotal	COM0001 Nstar	COM0001 Ngalaxy
20.00	1	0	1
20.50	2	0	2
21.00	4	0	4
21.50	9	4	5
22.00	9	6	3
22.50	15	12	3
23.00	20	16	4
23.50	5	3	2
24.00	3	2	1

Table 8: Number Counts for 47 Tuc Field

Total	TUC0003				TUC0004			
Magitude	Ntotal	Nmatch	Nstar	Ngalaxy	Ntotal	Nmatch	Nstar	Ngalaxy
17.00	1	1	0	1	0	0	0	0
17.50	1	1	0	1	2	2	2	0
18.00	2	2	2	0	2	2	1	1
18.50	17	17	14	3	14	14	13	1
19.00	15	15	15	0	19	17	18	1
19.50	28	28	28	0	24	23	23	1
20.00	28	28	28	0	25	24	25	0
20.50	37	37	35	2	31	32	31	0
21.00	42	40	38	4	37	36	35	2
21.50	33	32	30	3	29	27	27	2
22.00	36	34	32	4	25	24	20	5
22.50	40	34	32	8	34	33	33	1
23.00	46	41	37	9	44	44	38	6
23.50	59	48	53	6	42	40	32	10
24.00	62	48	55	7	69	55	55	14
24.50	65	36	50	15	63	52	50	13
25.00	44	21	34	10	39	23	27	12
25.50	21	4	14	7	25	14	17	8
26.00	8	1	5	3	15	4	9	6
26.50	0	0	0	0	4	2	1	3

Figures

Figure 1: Color-Magnitude Diagrams for matched stars and galaxies in the SGP field. The line is at a constant R magnitude of 26. a) instrumental J and R total magnitudes, b) instrumental J and R core magnitudes.

Figure 2: Magnitude Difference Diagrams for matched stars and galaxies in the galaxy cluster field 0637-53. Magnitude 1 is the longer exposure and the constant line is the expected magnitude difference based on the ratio of exposure times. a) instrumental total magnitudes, b) instrumental core magnitudes.

Figure 3: Color-Magnitude Diagrams for matched stars and galaxies in the Fornax field. The line is at a constant B magnitude of 26. a) instrumental B and V total magnitudes, b) instrumental B and V core magnitudes.

Figure 4: Magnitude Difference Diagrams for matched stars and galaxies in the NGC 3210. Magnitude 1 is the longer exposure and the constant line is the expected magnitude difference based on the ratio of exposure times. a) instrumental total magnitudes, b) instrumental core magnitudes.

Figure 5: Color-Magnitude Diagrams for matched stars and galaxies in the 47 Tucana field. The line is at a constant B magnitude of 26. a) instrumental B and V total magnitudes, b) instrumental B and V core magnitudes.

Plates

Plate 1: Finding chart for image SGP0001. Objects classified as star or galaxy, brighter than 25 isophotal instrumental magnitude, and matching an object in SGP0002.

Plate 2: Finding chart for image SGP0002. Objects classified as star or galaxy, brighter than 25 isophotal instrumental magnitude, and matching an object in SGP0001.

Plate 3: Finding chart for image GAL0001. All objects classified as star or galaxy.

Plate 4: Finding chart for image GAL0002. Objects classified as star or galaxy, brighter than 23.5 isophotal instrumental magnitude, and having a core significance greater than 2.

Plate 5: Finding chart for image GAL0003. Objects classified as star or galaxy, brighter than 24.5 isophotal instrumental magnitude, and having a core significance greater than 3.

Plate 6: Finding chart for image GAL0004. Objects classified as star or galaxy, brighter than 24.5 isophotal instrumental magnitude, and having a core significance greater than 3.

Plate 7: Finding chart for image FOR0001. Objects classified as star or galaxy, brighter than 25 isophotal instrumental magnitude, and matching an object in FOR0002.

Plate 8: Finding chart for image FOR0002. Objects classified as star or galaxy, brighter than 25 isophotal instrumental magnitude, and matching an object in FOR0001.

Plate 9: Finding chart for image NGC0001. Objects classified as star or galaxy, brighter than 23 isophotal instrumental magnitude.

Plate 10: Finding chart for image NGC0002. Objects classified as star or galaxy, brighter than 25 isophotal instrumental magnitude.

Plate 11: Finding chart for image COM0001. Objects classified as star or galaxy, brighter than 24 isophotal instrumental magnitude.

Plate 12: Finding chart for image TUC0001. Objects classified as star or galaxy, brighter than 25 isophotal instrumental magnitude, and matching an object in TUC0002.

Plate 13: Finding chart for image TUC0002. Objects classified as star or galaxy, brighter than 25 isophotal instrumental magnitude, and matching an object in TUC0001.