# 7 ANALYZING IMAGES

In order to obtain useful astronomical information from the data, software exists for the analysis of images, combining of images, estimating of errors, etc. Only a few of the programs are described here; the others should be self-explanatory using the HELP and INPUTS files for the tasks listed in Chapter 13. A complete list of software in $\mathcal{AIPS}$ for the analysis of images may also be obtained at your terminal by typing ABOUT ANALYSIS $^{C}_{R}$.

## 7.1 Combining two images (COMB)

The task COMB is a general purpose program for combining two images, pixel by pixel, to obtain a third image. Many options are available and, as a first example, we illustrate inputs to subtract a continuum image from a spectral line image cube.

### 7.1.1 Subtracting a continuum image from an image cube

A common method to obtain a spectral data cube containing only line signal without any continuum emission is to create a line-free continuum image $C$, and subtract it from the data cube $L$. For a more general discussion and alternative methods see § 8.3. COMB can be used to this purpose as follows:

| | |
|---|---|
| > TASK 'COMB' ; INP $^{C}_{R}$ | to review the required inputs. |
| > INDI 0 ; MCAT $^{C}_{R}$ | to help you find the catalog numbers of $C$ and $L$. |
| > INDI *n1* ; GETN *ctn1* $^{C}_{R}$ | to select the $L$ image cube from disk *n1* catalog slot *ctn1*. |
| > IN2D *n2* ; GET2N *ctn2* $^{C}_{R}$ | to select the $C$ image from disk *n2* catalog slot *ctn2*. |
| > OUTN '*xxxx*' $^{C}_{R}$ | to specify *xxxx* for the name of the continuum-free image cube. |
| > OUTC '*ccc*' $^{C}_{R}$ | to specify *ccc* for the class of the continuum-free image cube, *e.g.*, LCUBE. |
| > OPCODE 'SUM' $^{C}_{R}$ | to select the addition algorithm. |
| > APARM 1, -1 $^{C}_{R}$ | to specify that we want $+1 \times L - 1 \times C$. |
| > GO $^{C}_{R}$ | to compute the continuum-free, line-only output cube. |

Once COMB task has terminated with the message COMB: APPEARS TO END SUCCESSFULLY, you should find the requested image in your catalog:

| | |
|---|---|
| > MCAT $^{C}_{R}$ | to list the images in your catalog. |

### 7.1.2 Polarized intensity and position angle images

As a second example, we derive the polarization intensity and angle from the Q and U Stokes parameter images. To compute a polarized intensity image, enter:

| | |
|---|---|
| > TASK 'COMB' ; INP $^{C}_{R}$ | to review the required inputs. |
| > INDI 0 ; MCAT $^{C}_{R}$ | to help you find the catalog numbers of the Q and U images that you want to combine. |
| > INDI *n1* ; GETN *ctn1* $^{C}_{R}$ | to select the Q image from disk *n1* catalog slot *ctn1*. |
| > IN2D *n2* ; GET2N *ctn2* $^{C}_{R}$ | to select the U image from disk *n2* catalog slot *ctn2*. |
| > OUTN '*xxxx*' $^{C}_{R}$ | to specify *xxxx* for the name of the polarized intensity image. |

> OUTC '*ccc*' $^{C}_{R}$ — to specify *ccc* for the class of the polarized intensity image, *e.g.*, PCLN.

> OPCODE 'POLC' $^{C}_{R}$ — to select the $\sqrt{Q^2 + U^2}$ algorithm with correction for noise.

> BPARM *ns1* , *ns2* $^{C}_{R}$ — to specify the noise levels of the 2 images.

> GO $^{C}_{R}$ — to compute the corrected, polarized intensity image.

*AIPS* will write the message `TASK COMB BEGINS` followed by a listing of the `POL. INTENSITY` algorithm. While it is running, you can prepare the inputs to make a polarization position angle image. Type:

> OUTN '*yyyyy*' $^{C}_{R}$ — to specify *yyyyy* for the name of the polarization angle image.

> OUTC '*ddd*' $^{C}_{R}$ — to specify *ddd* for the class of the polarization angle image, *e.g.*, PSIMAP, CHICLN.

> OPCODE 'POLA' $^{C}_{R}$ — to select the $\frac{1}{2}\tan^{-1}\left(\frac{U}{Q}\right)$ algorithm.

Once `COMB` has finished, enter:

> GO $^{C}_{R}$ — to compute the polarization angle image.

### 7.1.3 Other image combination options

`COMB` may also be used to rescale images, and to compute spectral indices, optical depths, etc. Type:

> HELP COMB $^{C}_{R}$ — to review the available options.

The `OPCODE` options are:

| | | |
|---|---|---|
| 'SUM ' | Addition | $a_1 M_1 + a_2 M_2 + a_3$ |
| 'MEAN' | Average | $a_1 M_1 + a_2 M_2$ except $M_j$ where $M_i$ blanked |
| 'MULT' | Multiplication | $a_1 M_1 M_2 + a_2$ |
| 'DIV ' | Division | $a_1 M_1 / M_2 + a_2$ |
| 'SPIX' | Spectral Index | $a_1 \ln(M_1/M_2) / \ln(\nu_1/\nu_2) + a_2$ where $M_1 > a_3$ and $M_2 > a_4$ |
| 'OPTD' | Opacity | $a_1 \ln(a_3 M_1/M_2 + a_4) + a_2$ where $M_1 > a_5$ and $M_2 > a_6$ |
| 'POLI' | RMS sum | $a_1\sqrt{M_1^2 + M_2^2} + a_2$ |
| 'POLC' | RMS sum | $a_1 C(M_1, M_2)\sqrt{M_1^2 + M_2^2} + a_2$ where $C$ is a noise-based correction for Ricean bias |
| 'POLA' | Arctangent | $a_1 \tan^{-1}(M_2/M_1) + a_2$ where $\sqrt{M_1^2 + M_2^2} > a_3$ |
| 'REAL' | Real part | $a_1 M_1 \cos(a_2 M_2) + a_3$ |
| 'IMAG' | Imaginary part | $a_1 M_1 \sin(a_2 M_2) + a_3$ |
| 'RM ' | Rotation measure | $a_1 RM(M_1, M_2) + a_2$ |
| 'CLIP' | Clipping | $M_1$ except blanked where $a_1 > M_2 > a_2$ or $a_2 > a_1 > M_2$ or $M_2 > a_2 > a_1$ |

where the $a_i$ are user-adjustable parameters — specified by `APARM` — and $M_1$ and $M_2$ are the images selected by `INNAME`, *etc.* and by `IN2NAME`, *etc.*, respectively. `COMB` may be instructed to write an image of the estimated noise in the combination in addition to the direct result of the combination. These noise images may be used as inputs to `COMB` and, *e.g.*,`BLANK` to control later computations.

### 7.1.4 Considerations in image combination

For some applications of COMB, undefined pixel values may occur. For example, if the spectral index is being calculated and the intensity level on either image is negative, the index is undefined. In this case, the pixel value is given a number which is interpreted as undefined or "blanked." Blanking also arises naturally in operations of division, opacity, polarization angle, and clipping and, of course, the input images may themselves be blanked. In addition, the output image can be blanked (set BPARM(4) = 0) whenever either $M_1$ <APARM(9) or $M_2$ <APARM(10). Alternatively, blanking may be done on the basis of the estimated noise (set BPARM(4) = 1) or signal-to-noise ratio (set BPARM(4) = 2) in the combination. See HELP COMB $^{C}_{R}$ for a description of these options and certain limitations in their use. With APARM(8) = 1 $^{C}_{R}$, the user may specify that all undefined pixels are to be assigned an apparently valid value of zero, rather than the "magic" undefined-pixel value. Alternatively, the task REMAG can be used to replace blanked pixels in the output image with a user-specified value.

When combining two or more images, COMB, PCNTR, *et al.* must decide which pixels in the 2nd image go with which pixels in the 1st image. The user input parameter DOALIGN controls this process. A value of 1 requires the two headers to be correct and sufficiently similar that an alignment by coordinate value is possible. A value of −2 tells the programs to ignore the headers and align by pixel number. Enter HELP DOALIGN $^{C}_{R}$ for details and intermediate options. In some cases, the images may have been created on different grids which are correctly described in the headers. The observations, for example, could have differed in the phase reference position or projective geometry used or the imaging could have been done with different axis increments. Such images should *not* be combined directly. Instead, the header of one should be used as a template for re-gridding the other. Task HGEOM provides this service with up to 7th-order polynomial interpolation. See § 7.6.1 and type EXPLAIN HGEOM $^{C}_{R}$ for more information.

## 7.2 Combining more than two images (SUMIM)

The task SUMIM is used to sum or average any number of images. Since *AIPS* has only a limited number of adverbs of the kind INNAME, IN2NAME, etc., SUMIM requires that all input images have identical INNAME and INCLASS. The input images are then specified by INSEQ (the sequence number of the *first* input image), IN2SEQ (the sequence number of the *last* input image), and IN3SEQ (the increment in sequence number). All input images have to reside on the *same* disk.

| | |
|---|---|
| > TASK 'SUMIM' ; INP $^{C}_{R}$ | to review the required inputs. |
| > INDI 0 ; MCAT $^{C}_{R}$ | to help you find the catalog number of the first input image. |
| > INDI *n* ; GETN *ctn* $^{C}_{R}$ | to select the first input image from disk *n* catalog slot *ctn*. |
| > IN2SEQ *s* $^{C}_{R}$ | to specify the sequence number of the last image to be included. |
| > IN3SEQ 0 | to specify the increment in sequence number (= 1). |
| > OUTN '*xxxx*' $^{C}_{R}$ | to specify *xxxx* for the name of the output image. |
| > OUTC '*ccc*' $^{C}_{R}$ | to specify *ccc* for the class of the output image. |
| > FACTOR *f* $^{C}_{R}$ | to specify the factor with which to multiply each image before adding. $f = 1$ leads to summation, $f = 0$ defaults to the inverse of the number of input images (average) |
| > GO $^{C}_{R}$ | to start SUMIM. |

This is a very noisy way to make a line-sum image. For more serious work, use BLANK (§ 7.4) and XMOM (§ 8.6) instead.

## 7.3 Image statistics and flux integration (IMEAN, IMSTAT, TVSTAT, BLSUM)

The task **IMEAN** is used to determine the statistics of the image over a specified rectangular area. It derives the minimum and maximum value and location, the rms, the average value and, if the image has been Cleaned, an approximate flux density within the area. A typical run might be:

| | |
|---|---|
| > TASK 'IMEAN' ; INP $^{C}_{R}$ | to list the input parameters. |
| > INDI *n* ; GETN *ctn* $^{C}_{R}$ | to select the image file from disk *n* catalog slot *ctn*. |
| > BLC *n1, n2* ; TRC *m1, m2* $^{C}_{R}$ | to set the window from (*n1,n2*) to (*m1,m2*) — or use **TVWIN** with the cursor on the TV. |
| > DOHIST TRUE $^{C}_{R}$ | to make a plot file of the pixel histogram. |
| > PIXRANGE *x1, x2* $^{C}_{R}$ | to set the range of the histogram from *x1* to *x2*. |
| > NBOXES *n* $^{C}_{R}$ | to set the number of boxes in the histogram. |
| > GO $^{C}_{R}$ | to run the task. |

**IMEAN** attempts to determine the true noise of the image by fitting the peak of the histogram and reports both that result and the one found by including all pixels within the window. The adverbs **PIXSTD** gives **IMEAN** help in determining which values to use for the true noise fit.

The statistics will appear in the *AIPS* window. For a hard copy type:

| | |
|---|---|
| > PRTASK 'IMEAN' ; PRTMSG $^{C}_{R}$ | with **PRIO** $\leq 5$. |

To see the histogram of the intensities, an example of which is shown in §6.3.2.3, type one of:

| | |
|---|---|
| > GO TKPL $^{C}_{R}$ | to display the histogram in the TEK window. |
| > GO LWPLA $^{C}_{R}$ | to display the histogram on a PostScript printer. |

The verbs **TVSTAT** and **IMSTAT** provide similar functions to **IMEAN** without the histogram and true rms options. Both return their results as **AIPS** parameters **PIXAVG** (mean), **PIXSTD** (rms), **PIXVAL** (maximum), **PIXXY** (pixel position of the maximum), **PIX2VAL** (minimum), **PIX2XY** (pixel position of the minimum). **IMSTAT** uses the same file name, **BLC**, and **TRC** parameters as **IMEAN** and is useful to prepare the initial rms guess for that task. **TVSTAT**, however, works on the image plane currently displayed on the TV and is not limited to a single rectangular area. Instead, the TV cursor is used to mark one or more polygonal regions over which the function is to be performed. Type EXPLAIN TVSTAT $^{C}_{R}$ for a description of its operation.

The interactive task **BLSUM** employs a method similar to that of **TVSTAT**. The TV cursor is used to mark a region of interest in a "blotch" image. Then **BLSUM** finds the flux in that region not only in the blotch image but also in each plane (separately) of a second image. More than one region of interest may be done in any given execution of the task. In spectral-line problems, the blotch image is often the continuum or the line sum while the second image is the full "cube" in almost any transposition. However, numerous continuum applications also exist (*e.g.*, polarization, comparison across frequency). Type EXPLAIN BLSUM $^{C}_{R}$ for a description of the operation.

## 7.4 Blanking of images

In order to determine accurate flux values in images, or moments of velocity profiles, it is desirable to restrict the integrations to pixels that contain emission, or, in other words, to exclude pixels that contribute only noise. If this is not done, the inclusion of noisy pixels will increase the rms in the derived integrated value to an unacceptable extent. The task **BLANK** gives the user the opportunity to replace pixels containing pure noise with values that *AIPS* and its tasks interpret as *undefined*. The decision whether a certain pixel contains pure noise, or carries some emission, can be made subjectively (using the TV) or in a more objective fashion

(see below for an example). In all cases, **BLANK** creates an output image which is a copy of the input image with some pixels replaced by undefined values, or — if the user specifies it — by zero values.

The most straightforward use of **BLANK** is to apply a cutoff to the input image, e.g. let **BLANK** replace with an undefined value every pixel in the input image that lies below a specified. *e.g.*, $3\sigma$ noise level. This effectively removes almost all noisy pixels. The disadvantage is that this method also removes any *signal* below the $3\sigma$ noise level. Since a substantial fraction of the total flux may be "hidden" in pixels below $3\sigma$, this method prevents an accurate total flux determination.

A better way to perform the blanking is one which is not based on the pixel values in the input image itself, but on those in a *second* input image. Typically this is a convolved (spatially and/or in velocity) version of the input image, which has a higher signal to noise for extended emission than the input image. In the example given here we have the input image $I_1$ of full spatial resolution, and a convolved version of this input image $I_2$ with a linear beam size roughly twice full resolution. Careful inspection of this second image has shown that there are no outlying noise peaks below $f$ mJy/beam. **BLANK** is then run as follows:

| | |
|---|---|
| > TASK 'BLANK' ; INP $^{C}_{R}$ | to review the required inputs. |
| > INDI 0 ; MCAT $^{C}_{R}$ | to help you find the catalog numbers of $I_1$ and $I_2$. |
| > INDI *n1* ; GETN *ctn1* $^{C}_{R}$ | to select $I_1$ from disk *n1* catalog slot *ctn1*. |
| > IN2D *n2* ; GET2N *ctn2* $^{C}_{R}$ | to select $I_2$ form disk *n2* catalog slot *ctn2*. |
| > OUTN '*xxxx*' $^{C}_{R}$ | to specify *xxxx* for the name of the blanked output image. |
| > OUTC '*ccc*' $^{C}_{R}$ | to specify *ccc* for the class of the blanked output image. |
| > OPCODE 'IN2C' $^{C}_{R}$ | to specify that the blanking is performed using pixel values in a *second* input image. |
| > DPARM(3) $-f$; DPARM(4) $f$ $^{C}_{R}$ | to specify that all pixels with fluxes in the second input image in the interval $(-f, f)$ should be blanked. |
| > GO $^{C}_{R}$ | to compute the blanked output image. |

The task **REMAG** can be used to replace blanked pixels by a value to be specified by the user.

The *AIPS* TV display may be used to do a more subjective blanking with this task. Set OPCODE 'TVCU' $^{C}_{R}$ to display the image, one plane at a time in any transposition. You will be prompted to set "blotch" regions (much like **TVSTAT** and **BLSUM**) to define the areas to be blanked. This is one method for having different regions of signal at different spectral channels. There are also four windowing methods for blanking spectral-line cubes which have been transposed to have the frequency axis be first. In these methods, a window (range of spectral channels) about the peak signal in each spectrum is retained.

## 7.5 Fitting of images

There are three programs which estimate the position and intensity of a component on a two-dimensional image. The simplest and fastest method is the verb **MAXFIT**. This fits a two-dimensional parabola to the maximum within a few pixels of an image position, and gives the peak and its position. The tasks **IMFIT** and **JMFIT** are similar and fit an image subsection with up to four Gaussian components with error estimates. Task **SAD** attempts to automate the process of finding and fitting Gaussian components in an image. In one dimension, the task **SLFIT** fits Gaussian components to slice data and the task **XGAUS** fits Gaussian components to each row of an image.

### 7.5.1 Parabolic fit to maximum (MAXFIT)

MAXFIT's speed makes it useful for simple regions. Type:

> EXPLAIN MAXFIT $^{C}_{R}$ to get a good explanation of the algorithm.

The inputs should be self-explanatory. The IMSIZE parameter can be important in crowded fields. MAXFIT can be used conveniently by first displaying the image on the TV and then typing:

> IMXY ; MAXFIT $^{C}_{R}$

First the cursor will appear on the TV. Move it close to a maximum, press the left mouse button, and hit button A, B, C, or D. The fit will appear in your *AIPS* window.

### 7.5.2 Two-dimensional Gaussian fitting (IMFIT)

A more sophisticated least-squares fit of an image is obtained with IMFIT, which fits an image with up to four Gaussian components and attempts to derive error estimates. A linear or curved, two-dimensional "baseline" may also be fitted. A sample set-up is as follows:

| | |
|---|---|
| > TASK 'IMFIT' ; INP $^{C}_{R}$ | to list the input parameters. |
| > INDI *n* ; GETN *ctn* $^{C}_{R}$ | to select the image from disk *n* catalog slot *ctn*. |
| > BLC *n1*, *n2* ; TRC *m1*, *m2* $^{C}_{R}$ | to set the area to be fitted as (*n1*,*n2*) to (*m1*,*m2*) — or use TVWIN with the cursor on the TV. |
| > NGAUSS 2 $^{C}_{R}$ | to set the number of components to be fitted to 2. |
| > CTYPE 1, 1 $^{C}_{R}$ | to have both components be Gaussians. |
| > GMAX 0.34 0.20 $^{C}_{R}$ | to give estimates of peak intensity in Jy. |
| > GPOS 200, 100, 210, 110 $^{C}_{R}$ | to give estimates of the pixel locations of each component. |
| > GWID 6 4 20 6 4 20 $^{C}_{R}$ | to give estimates of component sizes in pixels. In this case, each component has a FWHM of 6 by 4 pixels with the major axis at position angle 20 degrees. |
| > DOWID FALSE $^{C}_{R}$ | to hold all of the widths constant in the fitting process (if required). |
| > INP $^{C}_{R}$ | to review inputs. |
| > GO $^{C}_{R}$ | to run the task. |

To save execution time, include as small an area as possible in the fit. In some cases, it is useful to hold some of the parameters constant, particularly when fitting a complex clump of emission with several components. The parameters can interact. Error estimates are given for each component. IMFIT will sometimes fail to converge in complicated regions. When this happens, you might try using the task JMFIT, which is very similar in function, but uses a different mathematical method to minimize the rms and to estimate the errors. Comparison of the results of IMFIT and JMFIT will sometimes be instructive. It is wise to treat the results of MAXFIT, IMFIT and JMFIT with considerable caution, particularly the estimates of the errors in the component widths after deconvolution.

Use RUN INPFIT $^{C}_{R}$ (see § 12.2.1) to obtain a procedure which will help to supply input parameters to IMFIT. This RUN file loads a procedure called INPFIT into AIPS. To invoke it, load the image which you want to fit onto the TV with TVALL and type INPFIT ( 3 ) $^{C}_{R}$ to specify three components. The procedure will prompt you to set the desired sub-image window with the TV cursor (it uses verb TVWINDOW) and then to point the TV cursor at the peaks of each of the Gaussians, click the left mouse button when the cursor is correctly placed, and push button A, B, C, or D. The inputs GMAX, GPOS, BLC, and TRC are set in this way.

### 7.5.3 Gaussian fits to slices (SLFIT)

You can generate a one-dimensional slice (profile) through any plane (characterized by the first two coordinates) of an image file using the *AIPS* task **SLICE**. The output file is appended to the image file as an **SL** extension file. Slices are computed along lines in the two-dimensional image joining any valid pair of points selected by **BLC** and **TRC**. The set of software dealing with slice file analysis and display can be obtained on your terminal by typing ABOUT ONED $^{C}_{R}$. The list is also given in Chapter 13.

To generate a slice:

> TASK 'SLICE' ; INP $^{C}_{R}$ to review the inputs to **SLICE**.

Use **INDISK** and **GETNAME** to select the input image. The beginning (**BLC**) and ending (**TRC**) points for the slice can be specified conveniently using the TV cursor if the image to be sliced is first displayed on the TV with **TVLOD** or **TVALL**. To set these points with the TV, type:

> TVSLICE $^{C}_{R}$

then set the TV cursor to the desired beginning point for the slice, press the left mouse button, and repeat for the ending point for the slice. Note that, for slices, **BLC** need not be below or to the left of **TRC**. Finally:

> GO $^{C}_{R}$ to generate the slice file.

Slice files may be output as ASCII text files using the **OUTFILE** adverb. Slice files are archived in your disk catalog as **SL** extensions to the image file from which they were derived. Running **SLICE** again with new parameters does not overwrite the slice file, but makes another with a higher "version" number. To review and/or delete slice files, follow the instructions for **EXTLIST** and **EXTDEST** of plot files in § 6.3 above, but use INEXT 'SL' $^{C}_{R}$ in place of INEXT 'PL' $^{C}_{R}$.

When **SLICE** has terminated, the file may be plotted in the TEK window on your workstation using:

> INP TKSLICE $^{C}_{R}$ to review the inputs to verb **TKSLICE**.

> INEXT 'SL' ; EXTL $^{C}_{R}$ to find the intensity range and number of points in the interpolated slice.

The default scales will plot all slice points on a vertical scale from the slice minimum to the slice maximum. You can alter the part of the slice that is plotted and the vertical scale by specifying, for example:

> BDROP 100 ; EDROP 225 $^{C}_{R}$ to drop 100 points from the beginning and 225 points from the end of the plotted portion of the slice.

> PIXRANGE -0.001 0.004 $^{C}_{R}$ to set the range of the vertical axis to be −1 to 4 mJy/beam.

> TKSLICE $^{C}_{R}$ to plot the slice in the TEK window.

Note: several slices may be put on one TEK plot. Use TKASLICE $^{C}_{R}$ for the additional ones.

Slice files may be converted into plot files by:

> GO SL2PL $^{C}_{R}$

The resulting plot files may then be output by:

> GO LWPLA $^{C}_{R}$ to display the plot file on a PostScript printer.

> GO TKPL $^{C}_{R}$ to display the plot file in the TEK window.

> GO TVPL $^{C}_{R}$ to display the plot file on a TV graphics plane.

The task **SLFIT** fits Gaussian components to one-dimensional data in slice files. Assuming that the usual **GETNAME** step has been done, a typical session would go like:

> INEXT 'SL'; EXTL $^{C}_{R}$ to list the parameters of the slice files.

> INVERS $m$ $^{C}_{R}$ to select the $m^{\text{th}}$ file for analysis.

> TKSLICE $^{C}_{R}$ to plot the slice in the TEK window.

> EDROP 840 ; BDROP 700 $^{C}_{R}$ to select a subsection to fit.

> TKSLICE $^{C}_{R}$ to re-plot just the subsection.

> NGAUSS 2 $^{C}_{R}$ to fit 2 Gaussians.

> TKSET $^{C}_{R}$

This verb will prompt you to `POSITION CURSOR AT CENTER & HEIGHT OF GAUSSIAN COMP 1`. Move the cursor to the requested position and click the left mouse button. Then you are asked to `POSITION CURSOR AT HALFWIDTH OF GAUSSIAN COMP 1`. Move the cursor to the half-intensity point of the component and click the left mouse button. Continue until all components have been entered. Then type:

> TKAGUESS $^{C}_{R}$ to plot the guess on top of the slice plot.

If everything looks ok, then:

> GO SLFIT $^{C}_{R}$ to run the task.

When the task gets an answer, the solution will be displayed as *AIPS* messages, recorded in the message file, and recorded in the slice file itself. To get a hard copy of the results:

> PRTASK 'SLFIT' ; PRTMSG $^{C}_{R}$ to print the message file.

and, to display the results in the TEK window, enter:

> TKSLICE $^{C}_{R}$ to re-plot the slice.

> TKAMODEL $^{C}_{R}$ to add the model results to the plot.

> TKARESID $^{C}_{R}$ to add the residuals (data – model) to the plot.

To get a higher quality plot of the results, an example of which is shown in § 6.3.2.1, type:

> DORES TRUE ; DOMOD TRUE $^{C}_{R}$ to request the model and the residuals.

> DOSLICE FALSE $^{C}_{R}$ to leave the slice data out of the plot.

> TASK 'SL2PL' ; GO ; WAIT $^{C}_{R}$ to make a plot file and wait for it to be complete.

### 7.5.4 Other one-dimensional Gaussian fits (XGAUS)

`XGAUS` is an interactive task which can fit up to four Gaussians and a linear baseline to each row of an image. It writes its results as a set of $n-1$ dimensional image files. Although `XGAUS` was designed for use primarily on transposed spectral-line cubes (see § 8.5.2), it has a wide variety of other applications. The interaction is optional and uses the TEK window on your workstation. The data, initial guess, model fit, and the residual for each row may be plotted on the TEK screen. If the number of Gaussians being fit is larger than one, you may choose for each row to enter a revised initial guess using the cursor in the TEK window. This process is similar to that of `TKSET` described above (§ 7.5.3). This task has too many options to do them justice here. Enter EXPLAIN XGAUS $^{C}_{R}$ for details.

### 7.5.5 Source recognition and fitting (SAD)

The task `SAD` (§ 10.4.4) attempts to find all sources in a sub-image whose peaks are brighter than a given level. It searches the sub-image specified by `BLC` and `TRC` for all points above this level and merges such points in contiguous "islands." For each island, initial estimates of the strength, size, and number of components are generated. Then the fitting algorithm used in `JMFIT` is called to determine the least square Gaussian fit. Solutions which fail to meet certain criteria can be retried as two components and, if they still fail, rejected. `SAD` is a task with many adverbs, a full description of which would be beyond the scope of this *CookBook*. Enter EXPLAIN SAD $^{C}_{R}$ for a full description of this task and its parameters. `SAD` produces a Model-Fit extension file which may be converted to a stars file (§ 6.3.2) with `MF2ST` or printed (§ 10.4.4) with `MFPRT`.

# 7.6 Image analysis

Image analysis is a very broad subject covering essentially all that *AIPS* does or would like to do plus specialized programs designed to analyze a user's particular image in the light of his favorite astrophysical theories. *AIPS* provides some general programs to perform geometric conversions, image filtering or enhancement, and model fitting and subtraction. These are the subjects of the following sections. Specialized programs for spectral-line, VLBI, and single-dish data reduction are described in Chapter 8, Chapter 9, and Chapter 10, respectively. Chapter 11 of *Synthesis Imaging in Radio Astronomy*[1] *Synthesis Imaging in Radio Astronomy*, A collection of Lectures form the Third NRAO Synthesis Imaging Summer School, eds. R. A. Perley, F. R. Schwab and A. H. Bridle, Astronomical Society of the Pacific Conference Series Volume 6 (1989) covers the topic of image analysis in more detail.

## 7.6.1 Geometric conversions

The units of the geometry of an image are described in its header by the coordinate reference values, reference pixels, axis increments, axis dimensions, and axis types. The types of coordinates (celestial, galactic, etc.) and the type of tangent-plane projection (SIN from the VLA, TAN from optical telescopes, ARC from Schmidt telescopes, NCP from the WSRT) are specified in the *AIPS* headers by character strings. See *AIPS* Memo No. 27 for details of these projections. A "geometric conversion" is an alteration of one or more of these geometry parameters while maintaining the correctness of both the header and the image data. The *AIPS* tasks which do this interpolate the data from the pixel positions in the input image to the desired pixel positions in the output image.

The simplest geometric conversion is a re-gridding of the data with new axis increments and dimensions with no change in the type of projection or coordinates. The task `LGEOM` performs this basic function and also allows rotation of the image. One use of this task is to obtain smoother displays by re-gridding a sub-image onto a finer grid. To rotate and blow up the inner portion of a $512^2$ image, enter:

| | |
|---|---|
| > TASK 'LGEOM' ; INP $^{C}_{R}$ | to review the inputs. |
| > INDISK *n* ; GETN *ctn* $^{C}_{R}$ | to select the image. |
| > BLC 150 ; TRC 350 $^{C}_{R}$ | to select only the inner portion of the image area. |
| > IMSIZE 800 $^{C}_{R}$ | to get an $800^2$ output image. This will allow the sub-image to be blown up by a factor of 3 and rotated without having the corners "falling" off the edges of the output image. |
| > APARM 0 $^{C}_{R}$ | to reset all parameters to defaults. |
| > APARM(3) = 30 $^{C}_{R}$ | to rotate the image 30 deg counterclockwise (East from North usually). |
| > APARM(4) = 3 $^{C}_{R}$ | to blow up the scale (axis increments) by a factor of 3. |
| > APARM(6) = 1 $^{C}_{R}$ | to use cubic polynomial interpolation. |
| > INP $^{C}_{R}$ | to check the inputs. |
| > GO $^{C}_{R}$ | to run the program. |

`LGEOM` allows shifts of the image center, an additional scaling of the $y$ axis relative to the $x$ axis, and polynomial interpolations of up to $7^{\text{th}}$ order. Type EXPLAIN LGEOM $^{C}_{R}$ for more information and advice.

A much more general geometric transformation is performed by `HGEOM`, which converts one image into the geometry of a second image. The type of projection, the axis increments, the rotation, and the coordinate reference values and locations of one image are converted to those of a second image. `HGEOM` should be used before comparing images (with `COMB`, `KNTR`, `PCNTR`, `BLANK`, `TVBLINK`, etc.) made with different geometries, *i.e.*, radio and optical images in different types of projection or VLA images taken with different phase

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reference positions. Use EXPLAIN HGEOM $^{C}_{R}$ to obtain the details and useful advice. SKYVE regrids images from the Digital Sky Survey (optical DSS) into coordinates recognized by *AIPS*.

A potentially very powerful transformation is performed by PGEOM. In its basic mode, it converts between rectangular and polar coordinates. An example of this operation is illustrated in § 7.6.6. However, PGEOM can also "de-project" elliptical objects to correct for their inclination and "unwrap" spiral objects. Type EXPLAIN PGEOM $^{C}_{R}$ for information.

### 7.6.2 Mathematical operations on a single image

The task MATHS allows the user to do a mathematical operation on a single image on a pixel by pixel basis. Currently supported mathematical operators are: SIN, COS, TAN, ASIN, ACOS, ATAN, LOG, LOGN, ALOG, EXP, POLY, POWR, and MOD. An example of MATHS follows, in which the output image (OUT) is computed in terms of the natural logarithm of the input image (IN) as follows: OUT = 4 + 2 × (log(3 × IN) − 1)

| | |
|---|---|
| > TASK 'MATHS' ; INP $^{C}_{R}$ | to review the required inputs. |
| > INDI 0 ; MCAT $^{C}_{R}$ | to help you find the catalog number of the input image. |
| > INDI *n* ; GETN *ctn* $^{C}_{R}$ | to specify the image, on disk *n* catalog slot *ctn* as the input. |
| > OUTN '*xxxxx*' $^{C}_{R}$ | to choose *xxxxx* as the name for the output image. |
| > OUTC '*ccc*' $^{C}_{R}$ | to choose *ccc* as the class for the output image. |
| > OPCODE 'LOGN' $^{C}_{R}$ | to specify the operation to be performed (a natural logarithm). |
| > CPARM 4 , 2 , 3 , -1 $^{C}_{R}$ | to specify the coefficients. |
| > GO $^{C}_{R}$ | to start MATHS. |

Undefined output pixels (in the current example, all pixels in the input image ≤ 0) are either blanked (CPARM(6) ≤ 0) or put to zero (CPARM(6) > 0). Type EXPLAIN MATHS $^{C}_{R}$ for further information on the available operators and the meaning of CPARM for any particular operator.

### 7.6.3 Primary beam correction

PBCOR allows correction for the attenuation due to the shape of the primary beam. Its use is straightforward:

| | |
|---|---|
| > TASK 'PBCOR' ; INP $^{C}_{R}$ | to review the required inputs. |
| > INDI 0 ; MCAT $^{C}_{R}$ | to help you find the catalog number of the input image |
| > INDI *n* ; GETN *ctn* $^{C}_{R}$ | to select the input image from disk *n* catalog slot *ctn*. |
| > OUTN '*xxxxx*' $^{C}_{R}$ | to specify *xxxxx* for the name of the output image. |
| > OUTC '*ccc*' $^{C}_{R}$ | to specify *ccc* for the class of the output image |
| > DPARM 0 $^{C}_{R}$ | to use the header pointing position and VLA beam parameters. |
| > GO $^{C}_{R}$ | to start PBCOR. |

The default behavior of DPARM is to use the position in the header as pointing position, and use the empirically determined shape of the VLA primary beam; PBCOR will scale the primary beam shape according to the frequency provided in the image header. All these defaults can be overridden by specifying particular values of DPARM.

An image of the primary beam may be generated with the task PATGN using OPCODE 'BEAM' $^{C}_{R}$ with other adverbs to give the frequency, cell size, image size, and, optionally, the parameters of the beam shape.

### 7.6.4 Filtering

For our purposes here, we can define "filtering" as applying an operator to an image in order to enhance some aspects of the image. The operators can be linear or nonlinear and do, in general, destroy some of the information content of the output image. As a result, users should be cautious about summing fluxes or fitting models in filtered images. (Technically, these remarks can also be made about Clean and self-calibration.) However, filtered images may bring out important aspects of the data and often make excellent, if unfamiliar-looking, displays of particular aspects.

`NINER` produces an image by applying an operator to each cell of an image and its 8 nearest cells. The task offers three nonlinear operators which enhance edges (regions of high gradient in any direction). It also offers linear convolutions with a $3 \times 3$ kernel which can be provided by the user or chosen from a variety of built-in kernels. Among the latter are kernels to enhance point sources and kernels to measure gradients in any of 8 directions. The `'SOBL'` edge-enhancement filter can bring out jets, wisps, and points in the data, while the gradient convolutions produce images which resemble a landscape viewed from above with illumination at some glancing angle (as when viewing the Moon). Both are very effective when displayed on the TV or by the `KNTR` / `LWPLA` combination (see § 7.6.6). Enter EXPLAIN NINER $^{C}_{R}$ for additional information.

`MWFLT`, at present, applies any one of four non-linear, low-pass filters to the input image. Each filter is applied in a user-specified window surrounding each input pixel. One of the operators is a "normalization" filter designed to reduce the dynamic range required for the image while bringing out weaker features. The others produce, at each pixel, the weighted sum of the input and the median, the "alpha-trimmed" mean, or the alpha-trimmed mode of the data in the window surrounding the pixel. These last filters can be turned into high-pass filters by subtracting the output of `MWFLT` from the input with `COMB`. Type EXPLAIN MWFLT $^{C}_{R}$ for further information.

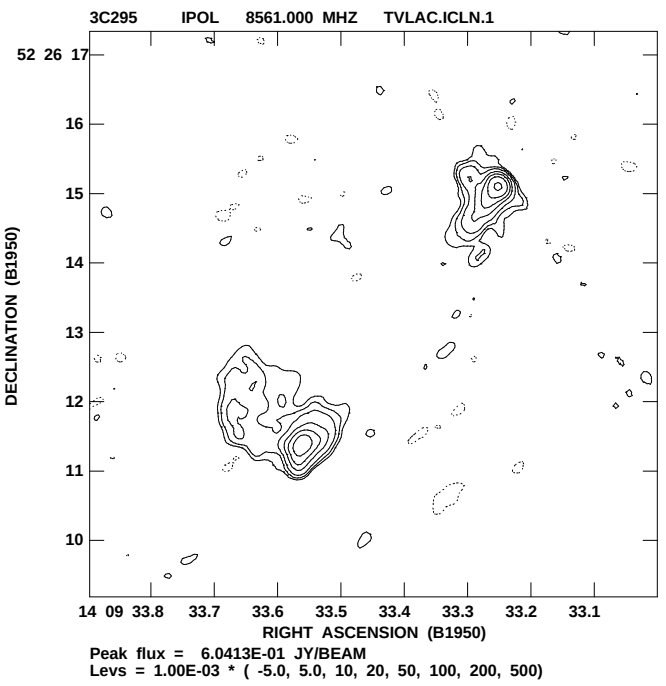
Histogram equalization provides another form of non-linear filtering. `HISEQ` converts the intensities of the full input image to make an output image with a nearly flat histogram. This magnifies small differences in the heavily occupied parts of the histogram (usually noise) and diminishes large differences in the less occupied parts (often real signal). `AHIST` does an "adaptive" histogram equalization on each pixel using a rectangualr window centered on that pixel. This will magnify small differences in a more local sense, bringing out structures in smooth areas of different brightness. Although both tasks magnify noise, they are likely to ellucidate real structures in large areas of nearly constant brightness.

### 7.6.5 Modeling

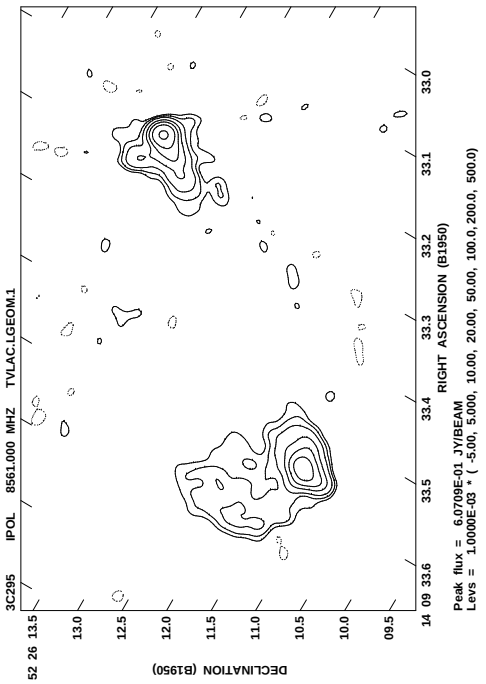
The addition of model data to an image or *uv* data set is often useful either to simplify later processing steps or to study processing steps using a "source" of known structure. For example, the removal of the response to an appropriate uniform disk from the *uv* data for a planet will leave Clean the task of deconvolving only the remaining fine-scale structure to which it is well suited. The removal of a few bright point sources of known position and strength may allow imaging with significant tapers in a numerically smaller field. The tasks `IMMOD` and `UVMOD` will add (or subtract) a point, Gaussian, disk, or rectangular source to the (scaled) input image or *uv* data, respectively. Both tasks can also add noise and both allow the original data to be replaced by the model. Type EXPLAIN IMMOD ; EXPLAIN UVMOD $^{C}_{R}$ for details.

The task `CCMOD` will create a clean-components file representing the chosen Gaussian or disk model. Clean may then be "restarted" with the model as its initial set of components. The task `UVFIT` may be useful for fitting Gaussian or uniform-sphere models to small ($< 2000$ visibility) *uv* data sets.

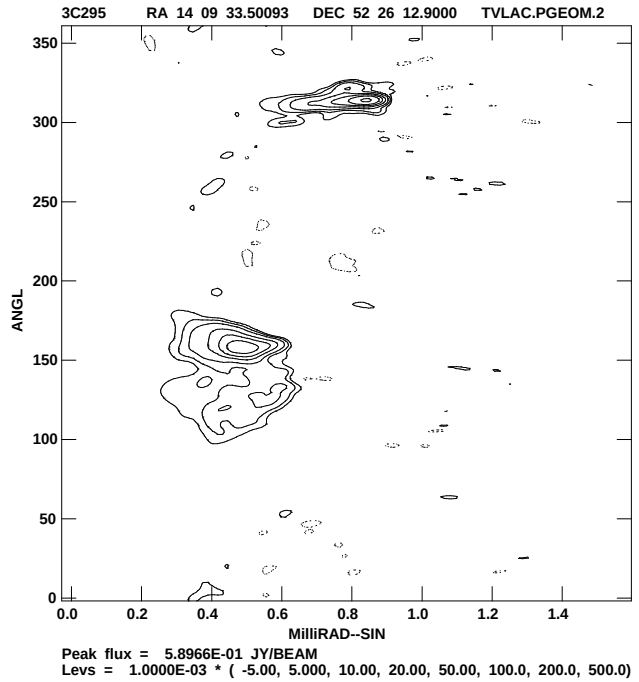
### 7.6.6 Examples



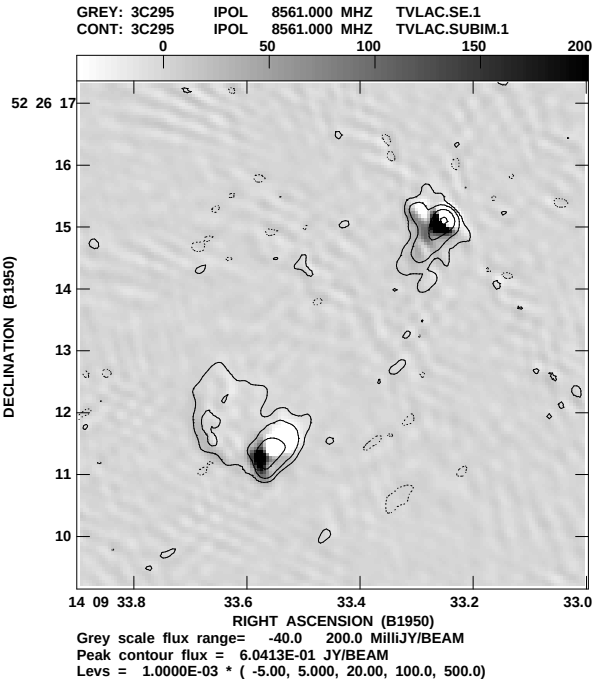

input image




`LGEOM` with rotation and interpolation




`PGEOM`




`NINER`: `'SE '` derivative

Figure 7.1: Geometric and other functions on an image.