AIPS automatic pipelines for JVN/VERA

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URL: http://astro.sci.kagoshima-u.ac.jp/omodaka-nishio/member/imai/pipelines.html

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Contents

1 Motivation

1.1 Back ground

Reduction of VLBI data, especially for spectral line sources and high precision astrometry and polarimetry, is still a hard work. Comparing with data reduction of other observational instruments, this is a big disadvantage in astronomy and few people have tackled to such a "masochistic work" in the world [2]. This situation has recently changed by running AIPS automatically using "pipelines". A pipeline is a sequence of AIPS tasks and modules to control a pass of the tasks. The grammar of a pipeline script is quite simple such as program languages of FORTRAN, BASIC and so on. For example, data reduction of the TX Cam SiO masers (up to 75 observing epochs) [1] has been automatically made using Diamond's pipeline script. Based on this script, EVN automatic pipeline has also been developed [3]. The EVN pipeline has been released not only for personal data reduction but also for providing several services for EVN users. VLBA data have also been reduced in the similar pipeline process.

The pipeline scripts for VERA/JVN have also been developed to meet request from VERA; the VERA project has to release observational results *every few days* because observations will be done in almost the same rate and their scientific goals should be achieved within one decade. These should be supposed taking into account that at least a few years have been consumed to publish a scientific paper since a few of VLBI observations were made.

1.2 Functions of the pipeline

The AIPS pipeline has several functions useful not only to VLBI users but also to VLBI network operators and organizers as follows.

- Creating fundamental extension tables (SN, CL, FG, BP, TY, GC) for users.
- Making fundamental plots for data checking.
- Checking data quality and reliability of the VLBI network.
- Quick looking preliminary images of targets and calibrators.
- Introducing VLBI images to VLBI beginners (e.g. bachelor students).
- Automatic data reduction (in advanced use).

1.3 Current status of the JVN/VERA pipelines

Figure 1 presents the current data reduction flow using the JVN/VERA pipelines. There are another *sub-pipelines* such as `MPLOT` (only for finding spectral channels for self maser calibration). Individual *sub-pipelines* described in the figures automatically process a series of AIPS tasks. By the end of February 2009, interactive steps that previously existed and described as follows are improved so that they are able to automatically processing now.

- A sequence of the tasks `FILTD`, `DBCON`, and `MSORT` in the case in which the raw FITS data is separated into a few segments of FITS files. They are now automatically processed in the pipeline `JNET`. Data obtained from VERA B-beam system are split into two FITS files to have different IF channels, but they are also automatically concatenated in the pipeline.
- Velocity-averaged intensity maps and velocity-moment maps can be automatically created.
- Astrometric calibration procedures for VERA (`TBIN` for reading VERA calibration files and `DELZN` for estimating/correcting residuals of atmospheric zenith delays). item Atmospheric zenith delay residual offsets are supported with iterative procedures using `ZCOR`.
- Other useful sub-pipelines are created, such as `IMGSAV` to save many files into FITS files and `FRMAP2` to continuously process fringe-rate mapping without any erratic interaction.

However there still exist interactive steps in the flow as follows.

- Velocity tracking using thetasks `SETJY` and `CVEL`.
- Interactive data flagging using `IBLED`. The analyst mush select the phase-reference velocity channel and split it into a separate single source file using the task `SPLIT`. Then the single source files should be converted into a multiple-sources file using the task `MULTI`. The task `INDXR` is also necessary.
- Splitting velocity channels to make image cubes before the pipeline `MMAP`. To use the sub-pipelines `PKFND` and `MIFT`, image cubes should be prepared by using the task `IMAGR`.
- Making fringe-rate maps using the task `FRMAP`, which covers wider fields-of-view than those covered by the pipelines `MMAP`, `PKFND` and `MFIT`.
- After performing the tasks and pipelines, `FRMAP`, `MFIT`, `PKFND`, `MMAP`, FORTRAN programs developed by the author automatically collect physical parameters of maser emission.
- Other procedures for VERA astrometry, especially when applying calibration solutions from one beam data to another beam data.

1.4 Future development in pipeline

- Phase-referencing with dual-beam system for astrometry.
- Estimating and correcting differential atmospheric zenith delays via investigating image coherence.
- Precise calibration for polarimetry and VERA astrometry
- Automatic flagging of bad data, maybe that is attached in the present pipelines. item The current development of pipeline scripts should move to using ParselTongue developed at JIVE.

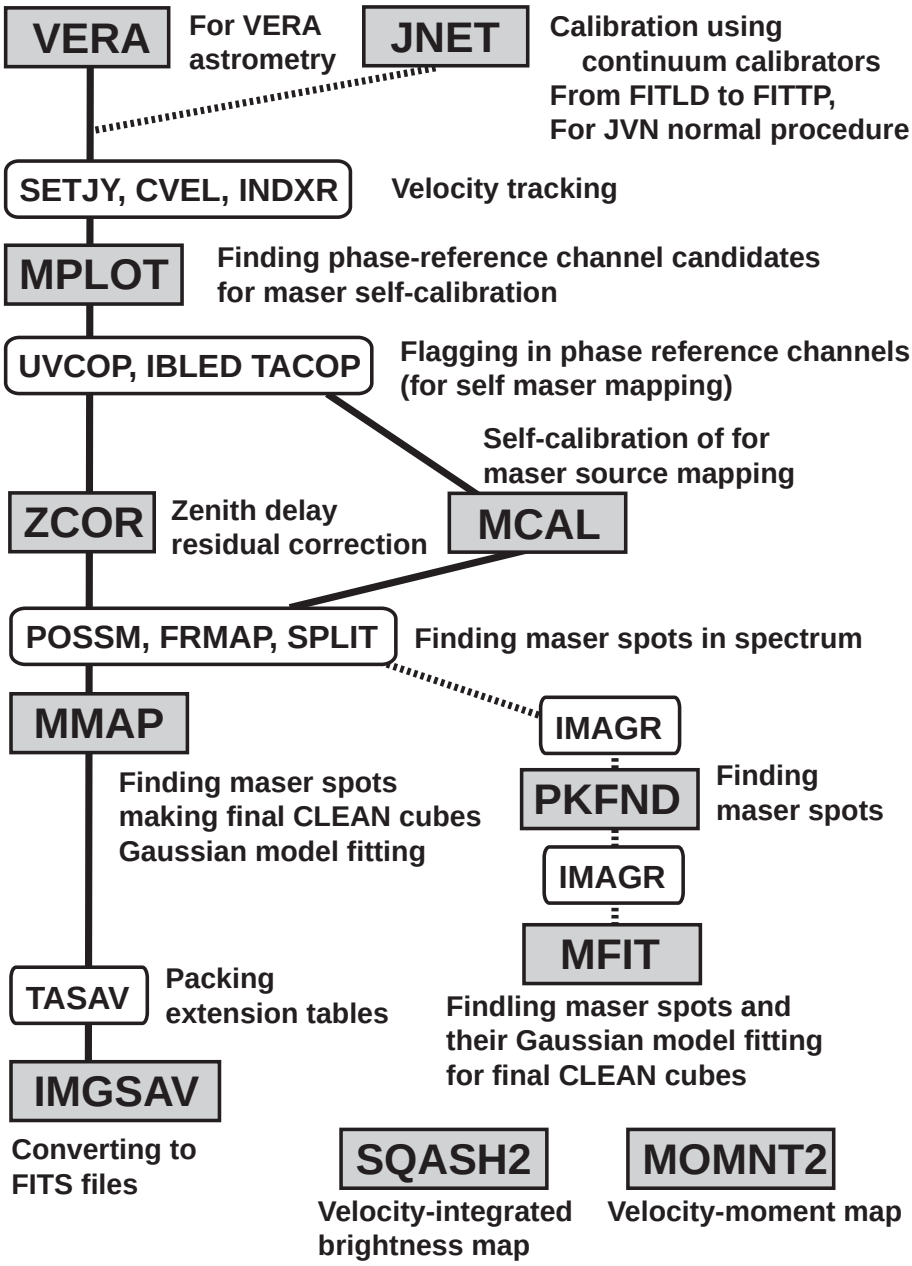

Figure 1: Global flow chart for the spectral-line VLBI data analysis using the pipelines. A grey block is a sub-pipeline that automatically and successively process AIPS tasks.

2 JNET: Full pipeline for continuum sources

Overview

This pipeline is used for quickly reducing data of mainly continuum sources.

The data are calibrated in standard manner, data flagging, clock parameter calibration and bandpass calibration as well as self-calibration. Several fundamental plots are created to check data quality and source properties. This pipeline may also be used as full data reduction for continuum sources. Extension tables are saved in FITS file. Figure 3 describes a flow of the pipeline.

Necessary item

- JNET.001: copy it to RUN directory in AIPS.
- JNET.HLP: copy it to HELP directory in AIPS.
- *expname*.uvflg: Flag file prepared on basis of observation logs.
- *expname*.chflag: Flag file for band-edge flagging.
- *expname*.antab: File containing Tsys and antenna-gain values. This file can be created by using the module "veratsys" (see section A).
- Creating directories for putting calibration files mentioned above and for containing plot files.
- FITS files on a DAT tape or a hard disk drive, otherwise an AIPS UV file.
- Schedule file that is used for selecting sources pipelined.

Usage

Type `RUN JNET`, then input necessary parameters specified as follows. Usage in detail can be seen by typing `HELP JNET`.

Outputs

- Output text files from `PRTAN, LISTR, DTSUM`.
- Uncalibrated visibilities, total-power and cross-power spectra and channel-integrated visibilities against time.
- Tsys and antenna gain plots.
- Fringe fitting solutions (SNR, phase, delay, rate).
- Bandpass characteristics (total-power and cross-power spectra).
- Calibrated visibilities of individual sources, cross-power spectra, channel-integrated visibilities against time.
- Dirty maps and CLEANed maps for individual sources. The latter is a result of self-calibration.
- Text files of phase and amplitude-phase solutions of the self-calibration for individual sources.
- Closure phases after subtracting source models.
- FITS file including extension tables.
- History text file.

```
*** Input adverbs *************** Meaning ********
TMASK=      -3                    Specifies all tasks after UVFLG.
VARRAY     'jnet'                 Specifies "JNET" (single beam) or "VERA" (dual beams).
NSRC        2                     Number of sources pipelined.
SRCLST     '0212+735' '3C84'      Name of sources pipelined.
CALSRCLST  '0212+735' '3C84'      Name of calibrators (should be included in SRCLST as well).
NBPASS       2                    Number of bandpass calibrators.
BPASSLST   '0212+735' '3C84'      Name of bandpass calibrators.
NPAIRS       0                    Number of source pairs in phase-referencing.
PREFLST    ' '                    Name of source pairs in phase-referencing.
INTAPE       1                    "INTAPE" in FITLD.
FITSFILE   ' '                    FITS file name in FITLD.
TECORFILE  ' '                    Name header of TEC correction files.
NTECOR       0                    Number of TEC correction files.
INDI         2                    "INDISK" in all tasks.
IN2D         2                    Should be same as INDISK in the present version.
REFANT       1                    "REFANT" in FRING, BPASS and CALIB.
REFAN2       2                    "SEARCH" in FRING (secondary reference antennae).
PLOTREF      1                    "REFANT" in POSSM, VPLOT, CLPLT and UVPLT.
OINT         1                    "DPARM(4)" in FRING (typically 1 second).
SOLCAL       6                    "SOLINT" in FRING (typically 5 minutes).
PLOTAVG      0.25                 "SOLINT" in VPLOT (typically 0.05-0.5 minuts).
SCITER       2                    Number of iterations in self-calibration.
NIF          1                    The number of IF channels.
NCHAN        128                  The number of spectral channels per IF.
POLS       'LL'                   Circular polarization selection.
CPOLS        0                    Specifies no plots for cross-hand circular polarization data.
DIR      ' '                      Directory including calibration files.
DIR2     'OUT:                    Directory putting plot files.
DOEDIT       0                    Specifies no flagging of bad data before self-calibration.
DELCH        0                    Doing band-edge flagging.
EXPNAME  'j03079a                 Experiment name, put on the top of plot files.
OBSBAND  'K'                      Observation cord.
DOPRINT=     -2                   Making PostScript files of plots.
***** End ***************************
```

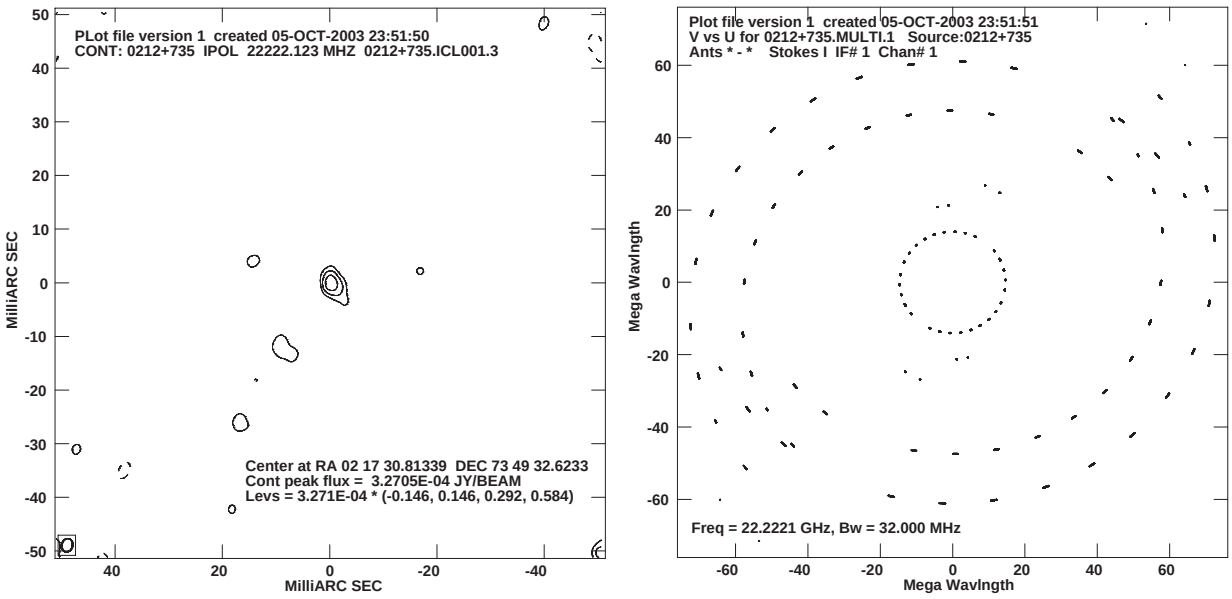

Figure 2: JVAS 0212+735 that was pipelined with JNET. This source was observed with 4 stations of JVN as a clock-parameter calibrator. *Left:* CLEANed image after self-calibration with SCITER=2. *Right:* UV-plane coverage.

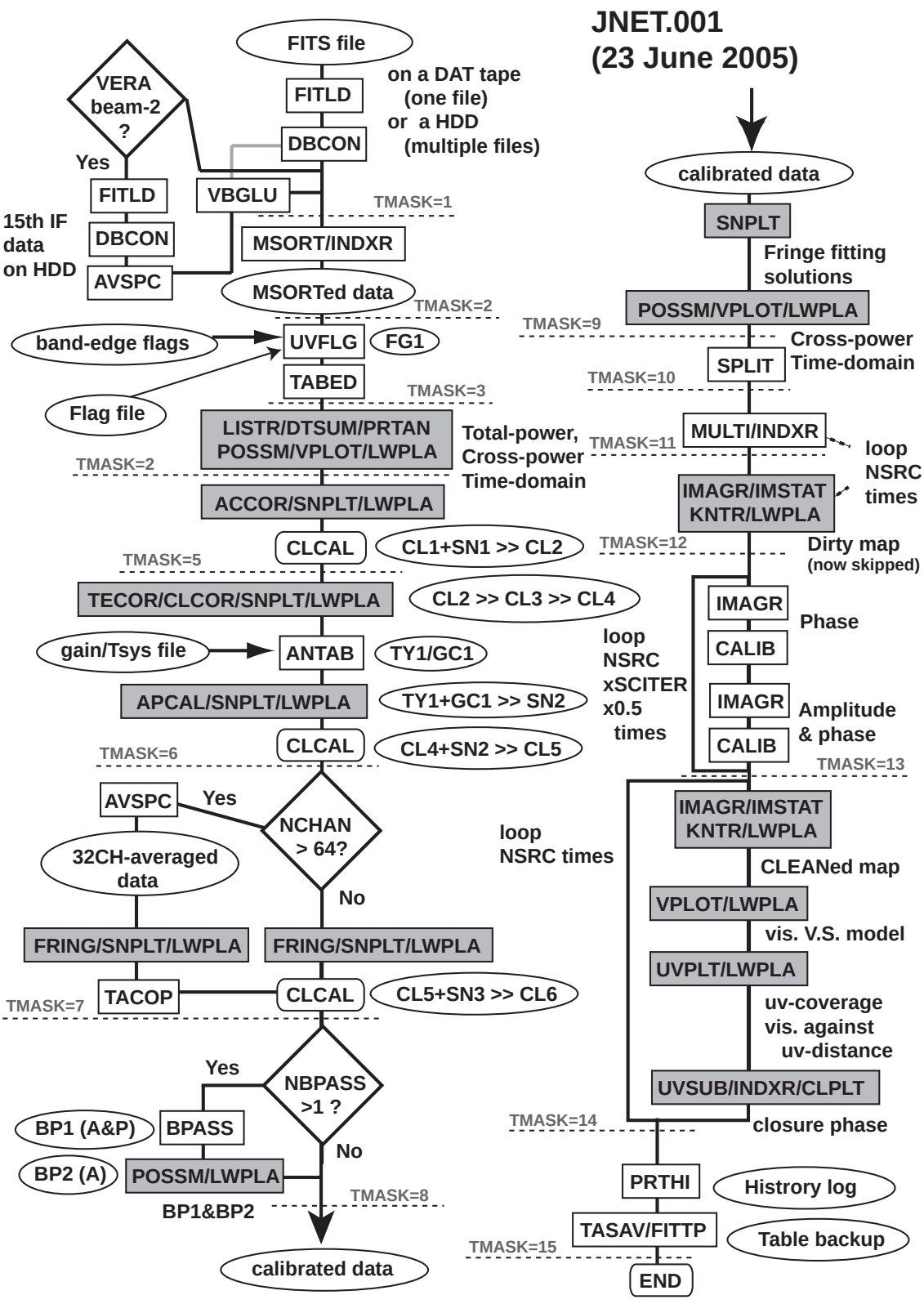

Figure 3: Flow chart of the pipeline JNET.

3 VERA: Full pipeline for VERA astrometry analysis

Overview

This pipeline is similar to JNET (see section 2), but better customized to quickly reducing data for VERA astrometry. This assumes that the data are obtained from only VERA telescopes. Solutions of delay re-tracking and differential instrumental delays between the VERA's dual beams are introduced. In addition, residuals of atmospheric zenith delays are estimated and removed. Figure 4 describes a flow of the pipeline.

Necessary item

- VERA.001: copy it to RUN directory in AIPS.
- VERA.HLP: copy it to HELP directory in AIPS.
- *expname*.uvflg: Flag file prepared on basis of observation logs.
- *expname*.chflag: Flag file for band-edge flagging.
- *expname*.antab: File containing Tsys and antenna-gain values (if DOANTAB=-1).
- Creating directories for putting calibration files mentioned above and for containing plot files.
- FITS files on a hard disk drive. The name should be changed as shown in the example of the input adverbs.
- A solution file of the delay-retracking.
- Solution files for differential instrumental delays between the VERA's dual beams.
- Schedule file that is used for selecting sources pipelined.

Usage

Type `RUN VERA`, then input necessary parameters specified as follows. Usage in detail can be seen by typing `HELP VERA`.

Outputs

- Output text files from `PRTAN, LISTR, DTSUM`.
- Uncalibrated visibilities, total-power and cross-power spectra and channel-integrated visibilities against time.
- Bandpass characteristics (total-power spectrum).
- Tsys and antenna gain plots.
- Solutions of delay tracking, dual beam calibration, and fringe fitting (SNR, phase, delay, rate).
- Solution of DELZN (text file, zenith delay and clock parameter plots).
- Calibrated visibilities of individual sources, cross-power spectra, channel-integrated visibilities against time.
- Dirty maps and CLEANed maps for individual sources (PS and FITS files). The latter is a result of self-calibration.
- Text files of phase and amplitude-phase solutions of the self-calibration for individual sources.
- Closure phases after subtracting source models.
- FITS file including extension tables.
- History text file.

```
*** Input adverbs *************** Meaning ********
TMASK=      -3                    Specifies all tasks after UVFLG.
NSRC         2                    Number of sources pipelined.
SRCLST     '0212+735' '3C84'      Name of sources pipelined.
CALSRCLST  '0212+735' '3C84'      Name of calibrators (should be included in SRCLST as well).
DELZNLST   '0212+735' '3C84'      Name of calibrators for DELZN
NPAIRS       0                    Number of source pairs in phase-referencing.
PREFLST    ' '                    Name of source pairs in phase-referencing.
INTAPE       1                    "INTAPE" in FITLD.
FITSFILE   'FITS:r06143c/R06143C.B32.FITS     FITS file name in FITLD (***.FITS).
FITSFILE2  'FITS:r06143c/R06143C.B512.FITS    FITS file name of 2nd VERA B-beam data.
NFITS        2                    Number of FITS files.
DOANTAB      1                    Reading Tsys and gain curve data from a text.
DELAYFILE   'R06143C.A-2006-08-18-APPLY2A-SN.TXT       File name of the delay tracking solutions.
BEAMFILE(1)    'R06143C.A-NO1.PLUS.TBIN.1111       File name of the differential beam delay solutions.
BEAMFILE(2)    'R06143C.A-NO2.PLUS.TBIN.1111       Number of the BEAMFILE names should be the same as NFITS.
INDI         2                    "INDISK" in all tasks.
IN2D         2                    Should be same as INDISK in the present version.
REFANT       1                    "REFANT" in FRING, BPASS and CALIB.
REFAN2       2                    "SEARCH" in FRING (secondary reference antennae).
PLOTREF      1                    "REFANT" in POSSM, VPLOT, CLPLT and UVPLT.
OINT         1                    "DPARM(4)" in FRING (typically 1 second).
SOLCAL       6                    "SOLINT" in FRING (typically 5 minutes).
SSUB2        2                    "SOLSUB" in FRING (typically 5 minutes).
SNRCUT       6                    SNR cut off of "FRING".
PLOTAVG      0.25                 "SOLINT" in VPLOT (typically 0.05-0.5 minuts).
SCITER       2                    Number of iterations in self-calibration.
POLS       'LL'                   Circular polarization selection.
CPOLS        0                    Specifies no plots for cross-hand circular polarization data.
DIR     'IN:r06143c/              Directory including calibration files.
DIR2    'OUT:r06143c/             Directory putting plot files.
DOEDIT       0                    Specifies no flagging of bad data before self-calibration.
DELCH        0                    Doing band-edge flagging.
EXPNAME  'r06143c                 Experiment name, put on the top of plot files.
OBSBAND  'K'                      Observation cord.
DOPRINT=     -2                   Making PostScript files of plots.
***** End ***************************
```

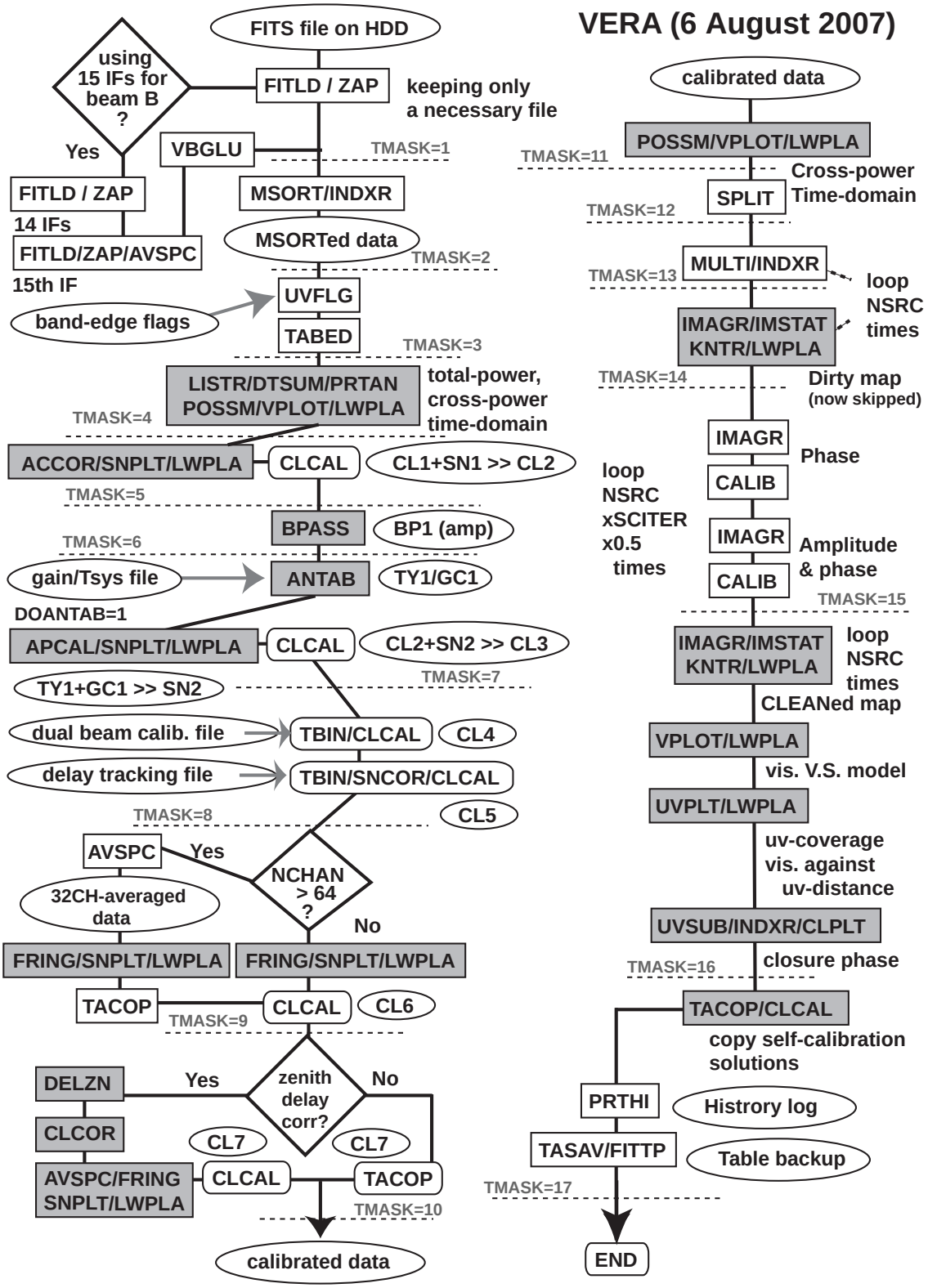

Figure 4: Flow chart of the pipeline `VERA`.

4 MPLOT: Sub-pipeline for finding reference velocity channel candidates

Overview

This pipeline is used for finding suitable velocity channels as phase-reference channels. To find such channels, flux density, phase variation along time and frequency should be investigated in velocity channels with maser emission. This pipeline automatically creates necessary plots. for this purpose. AIPS UV data are recommended to be calibrated with `CVEL`, `FRING` (with continuum calibrators), `BPASS` and `ANTAB/APCAL`. Figure 5 describes a flow of the pipeline.

Necessary item

- Calibrated AIPS UV data.
- MPLOT.001: copy it to RUN directory in AIPS.
- MPLOT.HLP: copy it to HELP directory in AIPS.
- Creating directories for putting plot files.

Usage

Type `RUN MPLOT`, then input necessary parameters specified as follows. Usage in detail can be seen by typing `HELP MPLOT`.

Outputs

- Output PostScript files from `POSSM` (cross-power spectra).
- Output PostScript files from `VPLOT`, in which individual channels are plotted separately.

```
*** Input adverbs ************** Meaning ********
MSOURCE    'LKHA234'              Specify a maser source to be plotted.
INDI          1                   "INDISK" in all tasks.
PLOTREF       1                   "REFANT" in the tasks "POSSM" and "VPLOT".
POSSMAVG      6                   "SOLINT" (min) in the task "POSSM".
VPLOTAVG      1                   "VPLOT" (min) in the task "POSSM".
BIF           1                   IF containing reference cannel candidates.
BCHANM        381                 Begin channel of plots.
ECHANM        440                 End channel of plots.
POLS       'LL'                   Circular polarization selection.
GAINUSE       3                   CL tables used in data calibration.
DOBAND        1                   Apply band pass table.
BPVER         1                   BP version to apply.
DIR2       'OUT:/j03056/          Directory to put plot files (PostScript).
EXPNAME    'j03056b               Experiment name, put on the top of plot files.
***** End *****
```

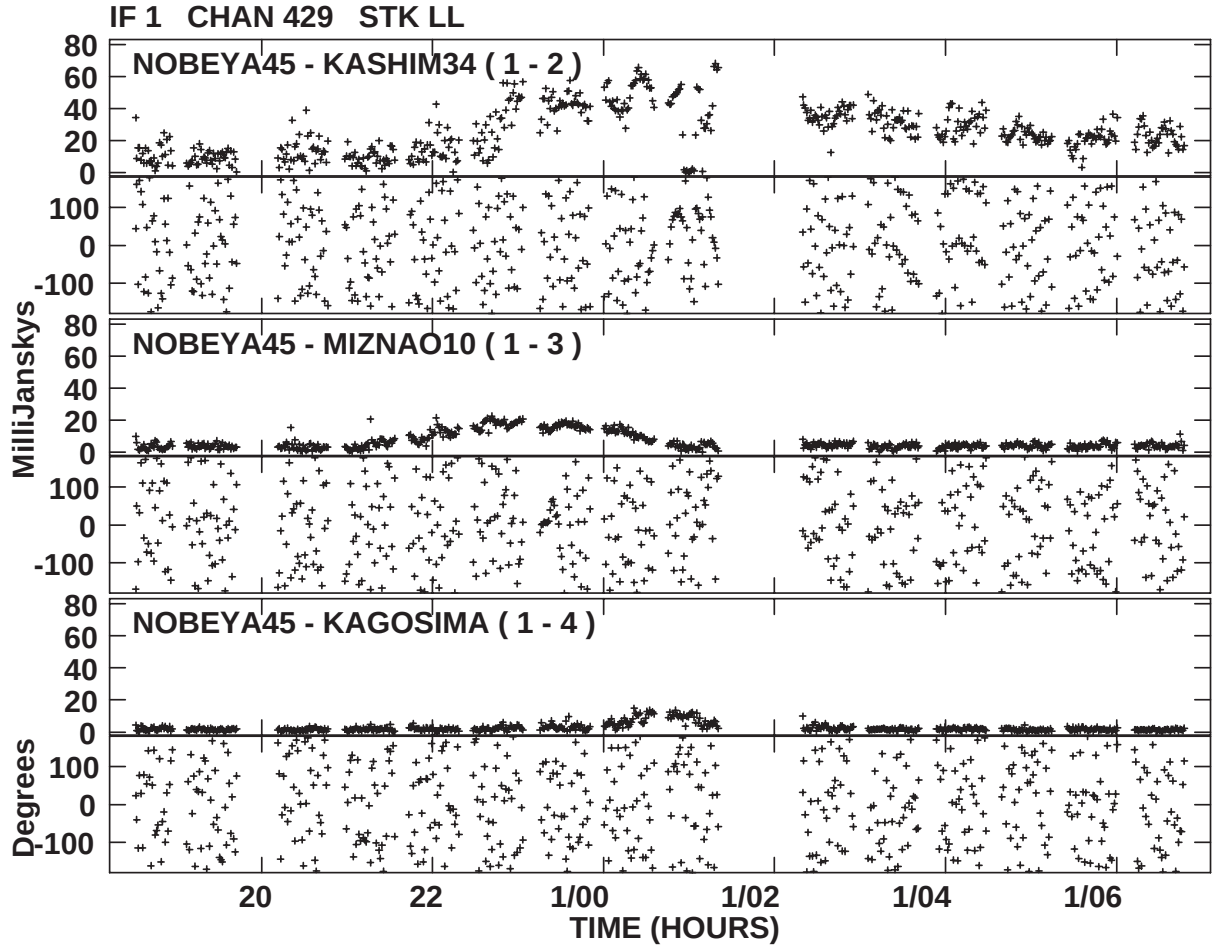

Figure 5: Temporary variation in visibility amplitudes and phases in `MPLOT`. One of the phase-reference velocity channel candidates is selected in this diagram. The reference channel candidates were selected in H_2O maser emission in LkHα234.

5 MCAL: Sub-pipeline for calibrating maser source data

Overview

This pipeline is used for calibrating maser data using selected phase-reference velocity channels throughout fringe fitting (FRING) and self-calibration (CALIB/IMAGR). The reference channel should contain maser emission suitable for procedures mentioned above. In fringe fitting with FRING, only residual rate and phase solutions are calculated. Solution (SN) tables are corrected so that they can be applied to all of IF channels in the UV data. The size of maser maps in CLEAN is controlled by users to find multiple maser spots in a wider field. Figure 6 describes a flow of the pipeline.

Necessary item

- MCAL.001: copy it to RUN directory in AIPS.
- MCAL.HLP: copy it to HELP directory in AIPS.
- An AIPS UV file that has already been calibrated with the following procedures.
  - Calibrated with continuum calibrators with ANTAB, APCAL, FRING and , BPASS.
  - Velocity tracked with SETJY and CVEL.
  - Flagged with , e.g., UVFLG and IBLED.

Usage

Type RUN MCAL, then input necessary parameters specified as follows. Usage in detail can be seen by typing HELP MCAL.

Outputs

- Fringe fitting solutions (SNR, rate).
- Calibrated visibilities of individual sources against time.
- Dirty maps and CLEANed maps for the calibrated maser source. The latter is a result of self-calibration.
- Text files of phase and amplitude-phase solutions of the self-calibration.
- Closure phases after subtracting a source model.
- The same AIPS UV file as the original one, but having SN and CL tables newly created.

```
*** Input adverbs *************** Meaning ********
TMASK         0                   Specifies all tasks in MCAL.
NSRC          1                   Number of sources pipelines.
SRCLST  'LKHA234' ' '             Name of sources pipelined.
CALSRC  'LKHA234'                 Name of the maser calibrator (should be included in SRCLST as well).
NPAIRS        0                   Number of source pairs in phase-referencing.
PREFLST ' '                       Name of source pairs in phase-referencing.
INDI          1                   "INDISK" in all tasks.
IN2D          2                   Should be same as INDISK in the present version.
REFANT        1                   "REFANT" in FRING, BPASS and CALIB.
REFAN2        2                   "SEARCH" in FRING (secondary reference antennae).
PLOTREF       1                   "REFANT" in POSSM, VPLOT, CLPLT and UVPLT.
REFIF         1                   IF channel containing the phase-reference velocity channels.
REFBCHAN      409                 Begin of the phase-reference velocity channels.
REFECHAN      411                 End of the phase-reference velocity channels.
BCL           5                   Used CL table (highest existing version).
BSN           5                   SN version for fringe fitting, followed by self-calibration solutions.
POLS       'LL'                   Circular polarization selection.
SOLCAL        3                   "SOLINT" in FRING (typically 5 minutes).
DOBAND        1                   Apply band pass table.
BPVER         1                   BP version to apply.
PLOTAVG       0.25                "SOLINT" in VPLOT (typically 0.05-0.5 minuts).
SCITER        4                   Number of iterations in self-calibration.
DIR2       'OUT:/j03056/          Directory to put plot and text files.
```

```
DOEDIT        0                  Specifies no flagging of bad data before self-calibration.
DELCH         0                  Doing band-edge flagging.
EXPNAME    'j03056b              Experiment name, put on the top of plot OBSBAND    'K'
WMAP       'W'                   Making wider maps with 4096 x 4096 pixels.
NBOXE           1                Number of CLEAN boxes in IMAGR.
CLBOXES          0               Four coordinates for each CLEAN box.
DOPRINT=      -2                 Making PostScript files of plots.

***** End *****
```

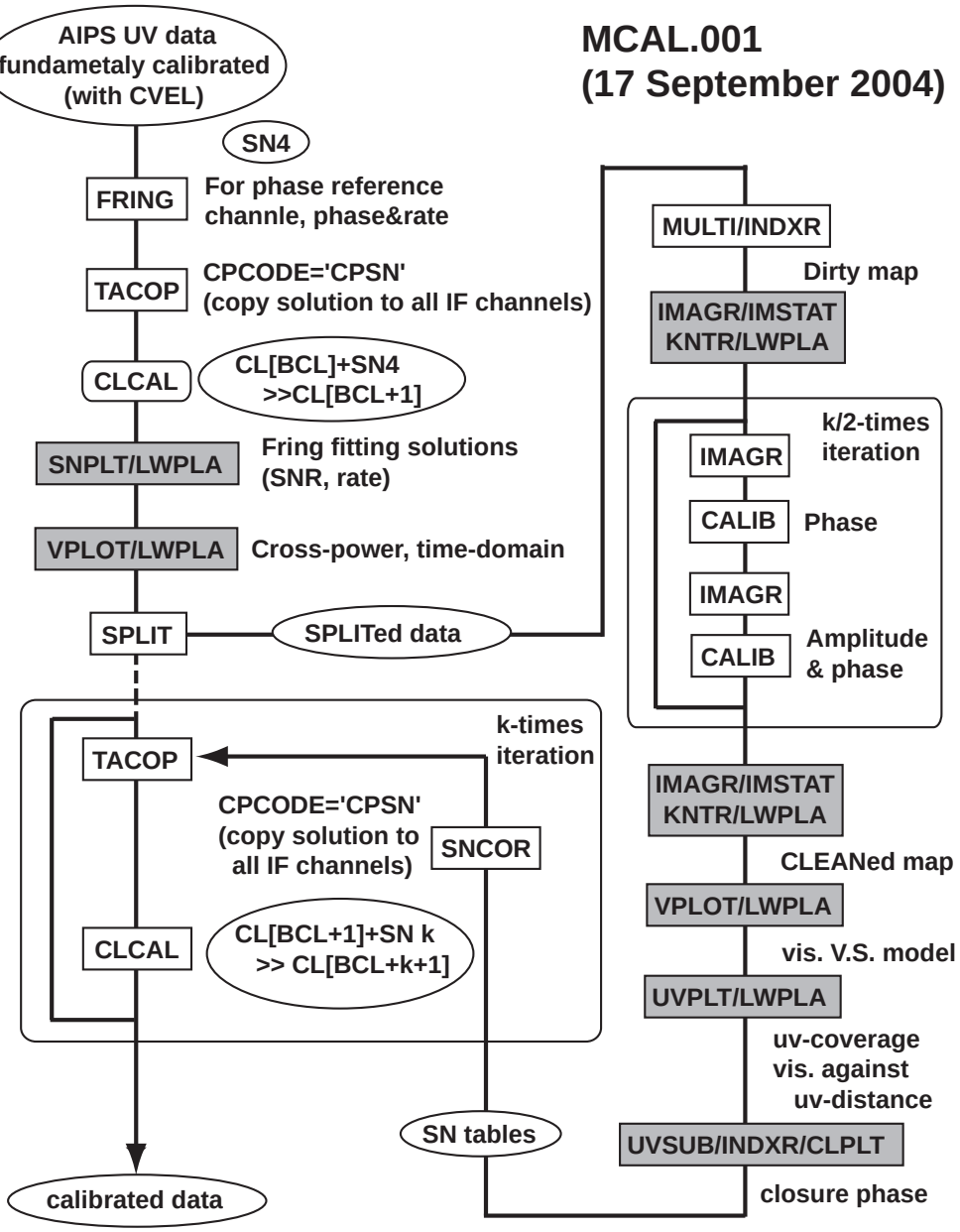

Figure 6: Flow chart of the pipeline MCAL.

6 ZCOR: Sub-pipeline supporting the atmospheric zenith delay residual offsets

Overview

This pipeline is used for finding zenith delay residual offsets at the individual VERA stations. Because VERA has only four telescopes located in relatively narrow region in the Earth, it is difficult to estimate these residuals using the geodetic VLBI observation mode in a short time span (<1 hour). Instead, the gimage optimization methodh has been applied in VERA astrometry [4] for the estimation. This is made by the package developed by A. Nakagawa and the author, they prepared programs to create TBIN files and a RUN script, respectively. The package is release in the same web page now. Here, the usage of the pipeline `ZCOR` is explained. The usage of the whole package is explained in the README file in the package.

`ZCOR` reads the TBIN files for zenith delay residual correction trials and creates images with trial corrections, then estimate a source peak brightness, an r.m.s image noise, and a signal-to-noise ratio of each of the trial maps. Finally, the best corrected image and SN tables are preserved. For maser source imaging, used spectral channels and a mapped field should be specified by using the pipeline `MPLOT` and by making a trial map.

Necessary item

- SPLITed AIPS UV data. The class name of the data should be 'SPLIT'.
- ZCOR.001: create it by running the zenith residual estimation package. When running the package, a file named as '[project code].zenith_run' is created. It should be moved to RUN directory in AIPS with changing its name to ZCOR.001.
- ZCOR.HLP: copy it to HELP directory in AIPS. item TBIN files created by the zenith residual estimation package. This should be put in the directory specified in the package execution. item Creating directories for putting plot files.

Usage

Type `RUN ZCOR`, then input necessary parameters specified as follows. Usage in detail can be seen by typing `HELP ZCOR`. Note that image parameters are fixed to be customized for VERA imaging. Also only one CLEAN box can be specified if necessary.

Outputs

- Output PostScript files from `SNPLT` (SN delay/phase solution).
- Output PostScript files from `KNTR` (best corrected image).
- Text file describing a peak brightness, an r.m.s. noise, and a signal-to-noise ratio of the trial images.

```
*** Input adverbs *************** Meaning ********
INNAME     IRAS1828      Input UV fil (name), should be single source (SPLITed) file.
INCLASS                  Input UV file (class).
INSEQ                    Input UV file (seq. #).
INDISK                   Disk drive# of input UV file.
BCHAN                    Begin ch# for IMAGR.
ECHAN                    End ch# for IMAGR.
RASHIFT                  RA shift in arcsecond.
DECSHIFT                 DEC shift in arcsecond.
CLBOX                    4 coordinates for each box.
***** End *****
```

7 PKFND: Sub-pipeline for finding emission peaks from an image cube

Overview

This pipeline is used for finding true maser spot candidates in a huge image cube, for which it is difficult to display the whole area of the image cube in the AIPS TV server at the same time. The AIPS task `IMEAN` makes image statistics, to find average and rms intensities as well as maximum and minimum intensities and their locations. In order to find `multiple` true maser spots in a huge image cube, however, it is insufficient to process the AIPS task `IMEAN` only once because it can find only one of the brightest peak in the cube. The image cube should be divided into individual velocity channels as well as several sub-fields. It is suitable for the size of a sub-field to set to that as same as or smaller than the size of the field of view of the AIPS TV server.

This sub-pipeline automatically performs above procedures and creates a text file including the image statistics information. Using other program provided separately, the text file can be edited to read only necessary parameters.

Necessary item

- PKFND.001: copy it to RUN directory in AIPS.
- PKFND.HLP: copy it to HELP directory in AIPS.
- An AIPS `IM` file that includes an image cube of a maser source.

Usage

Type `RUN PKFND`, then input necessary parameters specified as follows. Usage in detail can be seen by typing `HELP PKFND`.

Outputs

A text file specified in the adverb `OUTFILE` is created as an `IMEAN` output format, which contains the following parameters.

- Peak intensity in Jy/beam.
- Location of the pixel having the peak intensity, unit in pixel.
- R.M.S. noise level in Jy/beam.

The searched spots can be read and mapped by the FORTRAN programs *imeanget* and *imeanmap* developed by the author.

Figure 7 describes an image in one of velocity channels and adverbs used in `PKFND`.

```
*** Input adverbs *************** Meaning ********
INDISK        2       Disk number including the image cube.
INNAME  'L1287'      Name of the imag cube.
XG            500     Total grid number in X-axis for emission peak finding.
YG            500     Total grid number in Y-axis for emission peak finding.
XMG           167   Grid number of sub-field in X-axis for peak finding.
YMG           167   Grid number of sub-field in Y-axis for peak finding.
NEDGE         10    Grid number skipped at the bottom-left image edge.
NOVER         10    Grid number overlapped in adjacent sub-fields.
BVEL          1     Begin velocity channel for pea finding.
EVEL          0     End velocity channel for pea finding.
OUTFILE   'OUT:ei005c/ei005c_L1287_1.imean    Name of the output text file.
***** End *****
```

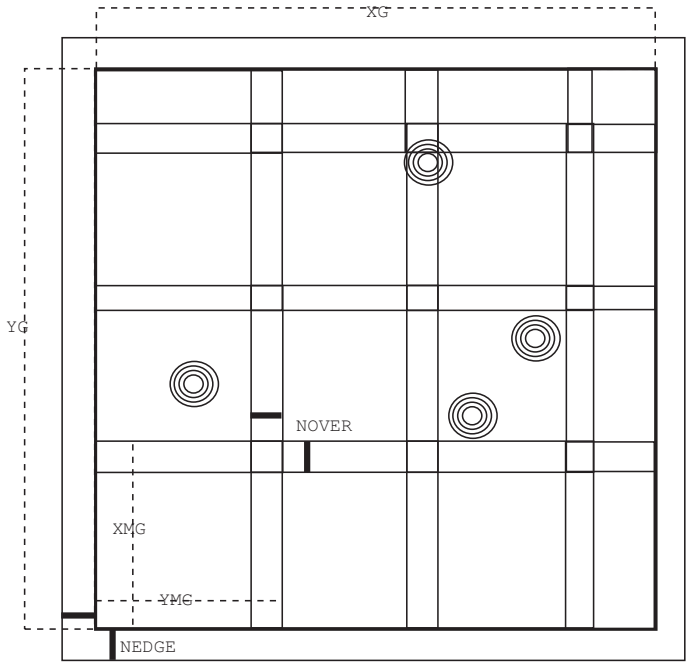

Figure 7: An image cube and adverbs used in the pipeline "PKFND". There are contours indicating emission peaks located in same/different sub-fields.

8 MFIT: Sub-pipeline for finding and Gaussian fitting for emission peaks

Overview

This pipeline is used for finding true maser spots in a huge image cube and for obtaining physical parameters of the found spots. The procedure of spot finding is as almost same as that in the sub-pipeline `PKFND`. `MFIT` also performs Gaussian fitting for the found spots using the AIPS task `SAD` (search and destroy). SAD automatically finds "islands" containing true maser emission, fits each of the islands with a Gaussian component, then subtracts it from the original image to find another emission peak. Because `SAD` should be carefully controlled with a signal-to-noise ratio cutoff and a peak intensity (to set search intensity criterion), `MFIT` automatically calculates an r.m.s. noise level in a sub-field using the verb `IMSTAT`. The calculation of an r.m.s. noise level is also performed without miscounting true spot emission as noise. To do it, one of the most suitable r.m.s noise levels obtained from all of the sub-fields is adopted, which may be selected from the sub-field which is far away from bright side lobes in the full image. The fitting results are stored in a text file.

To satisfactorily perform the sub-pipeline `MFIT`, it is recommend to perform the sub-pipeline `PKFND` to reduce areas to search maser emission. The task `SAD` picks up many possible "islands"; the number of the islands often exceeds the number limit (1000 in `MFIT`). In this case, true maser spots will be easily missed. It is recommended to reduce the image size smaller than 512×512 pixels. Note also that the printed coordinate values have digit numbers down to 0.00001 arcsec (10μas) then the lower digit numbers, which are available only with the task `JMFIT`, cannot be obtained.

The searched spots can be read and mapped by the FORTRAN program *csad*, *mfident*,respectively, developed by the author.

Necessary item

- MFIT.001: copy it to RUN directory in AIPS.
- MFIT.HLP: copy it to HELP directory in AIPS.
- An AIPS `IM` file that includes an image cube of a maser source.

Usage

Type `RUN MFIT`, then input necessary parameters specified as follows. Usage in detail can be seen by typing `HELP MFIT`.

Outputs

A text file specified in the adverb `OUTPRINT` (not `OUTFILE`) is created, which contains the following parameters.

- Peak intensity and flux density of a Gaussian component (errors in brackets) in Jy/beam and Jy.
- Location of the Gaussian compoent (X, Y) (errors in brackets) in arcsecond.
- Major and minor axis length of the Gaussian component (errors in brackets) in arcsecond as well as a position angle of the major axis in degree.
- R.M.S. noise level in Jy/beam expected in noise theory.

```
*** Input adverbs *************** Meaning ********
(same as adverbs PKFND mentioned above.)
OUTPRINT   'OUT:r03280a/r03280a_msad.txt   Name of the output text file.
SNRCUT     5                 SNR cutoff for true maser spot selection.
***** End *****
```

9 MMAP: Sub-pipeline for making multiple image cubes towards a wide-field maser source

Overview

This pipeline is used for automatically processing all of the following procedures.

(1) Making an image cube covering a wide field-of-view and a wide velocity range. At this procedure, larger cellsize and velocity channel width are used.

(2) Finding true maser spots in the above image cube. The finding strategy is almost same as that described in the sub-pipeline `PKFND`. Locations and velocities of the detected maser spots are recorded in a memory for the next step. Note that the momory space is so limited that we cannot analyse an image cube to have too many image pixels ($\geq$8192) and too many averaged velocity channels ($\geq$100).

(3) Creating image cubes containing the detected maser spots. Multiple fields-of-view are generated for successful CLEAN process. Therefore, there exist several segments of velocity ranges, each of which has different numbers of image cubes, and for each of which the task `IMAGR` runs.

(4) Finding true maser spots in the above image cube and applying Gaussian fitting for the maser spot brightness distributions. This process is as same as that in the sub-pipeline `MFIT`.

The searched spots can be read and mapped by the FORTRAN program *csad*, *mfident*, respectively, developed by the author.

Necessary item

- MMAP.001: copy it to RUN directory in AIPS.
- MMAP.HLP: copy it to HELP directory in AIPS.
- An AIPS `UV` file created by the task `SPLIT`. No calibration is applied in this pipeline.
- The text file `BOXES` in the directory `$AIPS_ROOT/FITS`. This describes default CLEAN boxes in all of the image cubes and has the following format.

```
001  10  10  4090  4090
002  10  10  4090  4090
003  10  10  4090  4090
004  10  10  4090  4090
005  10  10  4090  4090
006  10  10  4090  4090
007  10  10  4090  4090
008  10  10  4090  4090
009  10  10  4090  4090
010  10  10  4090  4090
```

  The first column indicates the image cube number, the second to fifth columns indicates four coordinates of each CLEAN box in each image cube.

Usage

Type `RUN MMAP`, then input necessary parameters specified as follows. Usage in detail can be seen by typing `HELP MMAP`. Please do not forget to put the text file `BOXES` in the directory `$AIPS_ROOT/FITS`. Note that `TMASK=-3` or `3` is valid only for XG, YG=XMG, YMG. To avoid an error called "array limit", the following verbs should be carefully specified as follows.

Both to cover a wide field of view and to have a suitable pixel size, set the verb `CELLFACT` to 2, 4, or 8 rather than increasing the value of adverb `XYG` (less than 4096 is suitable to finish the process within a reasonable duration). Note that it is better to set a pixel size used to make a trial wide-field image cube (`CELL1`$\times$`CELLFACT`) to smaller than a synthesized beam. To process more velocity channels at the same time, set the verb `CHAV` to 2, 4, or 8, depending on a velocity width of the detected maser emission. Note that a total number of averaged velocity channels [(`ECHANM-ECHANM`+1)/`CHAV`] should be smaller than 30 when using the widest but reasonable number of map pixels (2048×2048).

Outputs

- Text files that contain the SAD outputs and are put in the directory specified in the adverb DIR2. The file names are automatically specified following the experiment code EXPNAME and the order of the velocity range segment.
- A wide-field image cube having a larger cell size and averaged velocity channels.
- Small-field image cubes are also created. It is recommended to save them for data analysis back up.

```
*** Input adverbs ************** Meaning ********
TMASK  0              Specifies all tasks in MMAP.
INDISK  2             Specifying the disk# 2.
INNAME  'W51M'        SPLITed file name (name)
INCLASS  'SPLIT'      SPLITed file name (class)
INSEQ  1              SPLITed file name (seq #)
DISK2   2             Output disk (OUTDISK)
BCHANM  101           Begin frequency channel of the image cubes
ECHANM  200           End frequency channel of the image cubes
IFM    1              Specifying IF channel #1.
SHIFT   1.0, -1.0     (X,Y) shift of map centers in arcsecond.
XYG   4096  4096      Grid number of searching field (X, Y)
XYMG  512   512       Grid number of final sub image cubes (X, Y). Set smaller for save the cubes in a reasonably small file size.
CELL1  0.0002  0.0002 Cellsize of final image cubes (X, Y).
CELLFACT  2           Extension factor of a cell  size for a first wide image cube(2,4, or 8 is suitable).
CHAV  4               Averaging spectral channel  number for a first wide image cube.
WTFN  'NA'            Naturally weighting visibility is adopted.
NEDGE  20             Grid number skipped at the bottom-left image edge.
NOVER  20             Grid number overlapped in adjacent sub-fields.
SNRCUT  7             SNR cutoff for true maser spot.
STOKES  'I'           Stokes parameter for imaging (I, Q, U, V).
EXPNAME  'r04202a'    Experiment name, used for output file name.
OBSBAND  'K'          Observing band only for setting the default grid size.
DIR2  'OUT:           Directory for SAD output files (assuming DOCRT=-1)
***** End *****
```

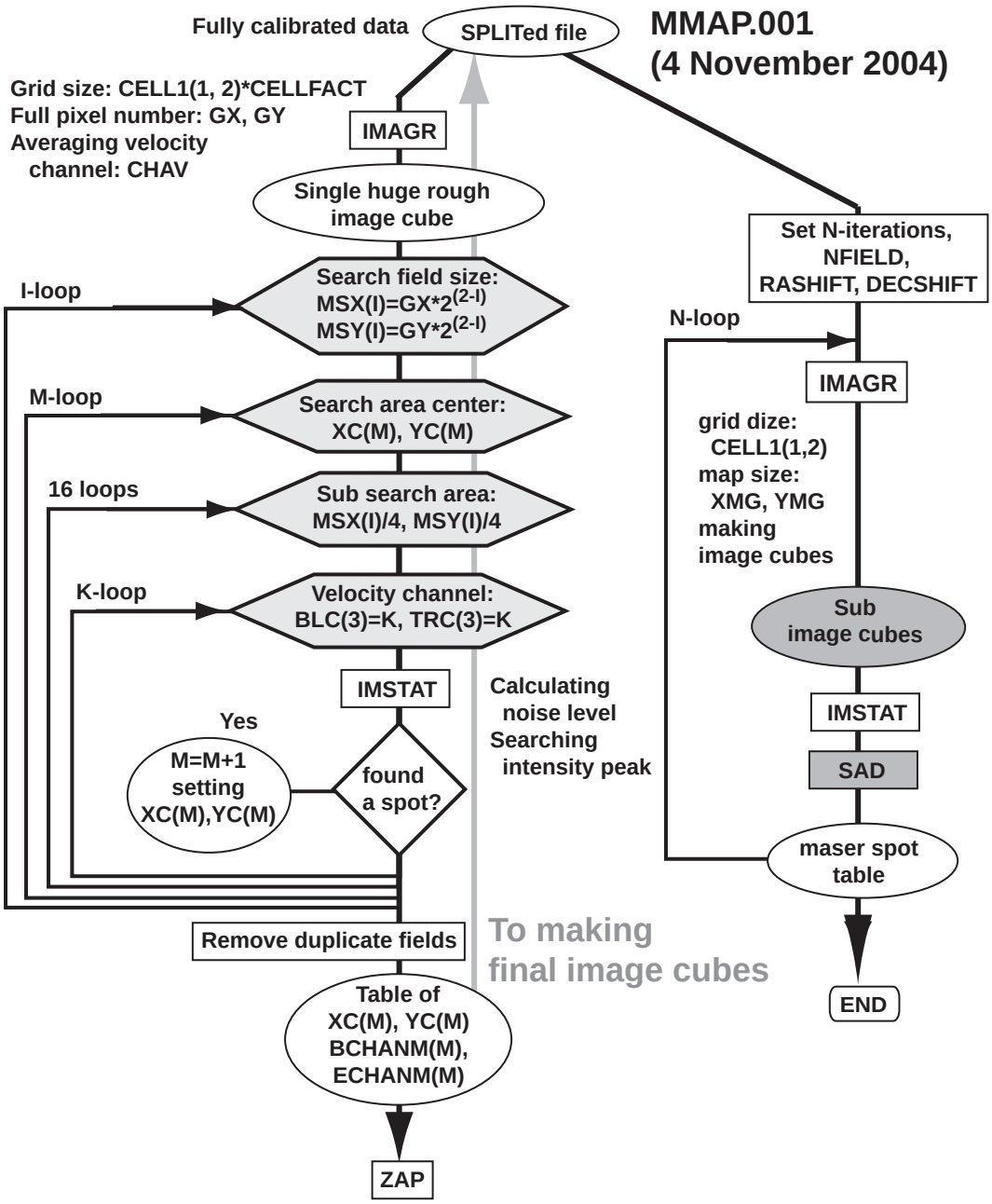

Figure 8: Flow chart of the pipeline `MMAP`.

10 SQASH2: Sub-pipeline for making a velocity-averaged intensity map from an image cube

Overview

This pipeline is used for automatically processing the all of the following procedures.

(1) Blanking unnecessary noise emission in the image cube with the task `BLANK`, which is made on basis of a noise criterion calculated by the verb `IMSTAT`.This calculation is separately performed in each of velocity channels because different velocity channels, especially when bright maser emission emission exists, have different noise level. Noise-blanked images are created for individual velocity channels.

(2) Creating a velocity-averaged intensity map from the noise-blanked images mentioned above with the task `SUMIM`.

(3) Drawing a contour map with the task `KNTR`, which is saved in a PostScript file with the task `LWPLA`. Contour levels are automatically specified on basesis of the maximum intensity in the map.

Necessary item

- SQASH2.001: copy it to RUN directory in AIPS.
- SQASH2.HLP: copy it to HELP directory in AIPS.
- An AIPS `IM` file created by the task `IMAGR`.

Usage

Type `RUN SQASH2`, then input necessary parameters specified as follows. Usage in detail can be seen by typing `HELP SQASH2`. Later you can recall the task `KNTR` and specify more suitable adverbs in the task to obtain a more preferable contour map.

Outputs

- A velocity-averaged intensity map, whose file name is automatically specified following the name of the `IM` file.
- A PostScript file of the created velocity-averaged intensity map.

```
*** Input adverbs *************** Meaning ********
INDISK  2             Specifying the disk# 2.
INNAME  'W51M'        IM file name (name)
INCLASS  'SPLIT'      IM file name (class)
INSEQ  1              IM file name (seq #)
XG    1024            Grid number of the drawing field (X)
YG    1024            Grid number of the drawing field (Y)
NEDGE  20             Grid number skipped at the bottom-left image edge.
BVEL    101           Begin velocity channel of the image cube
EVEL    200           End velocity channel of the image cube
SNRCUT  7             SNR cutoff for noise blanking
DIR2  'OUT:           Directory for SAD output files (assuming DOCRT=-1)
***** End *****
```

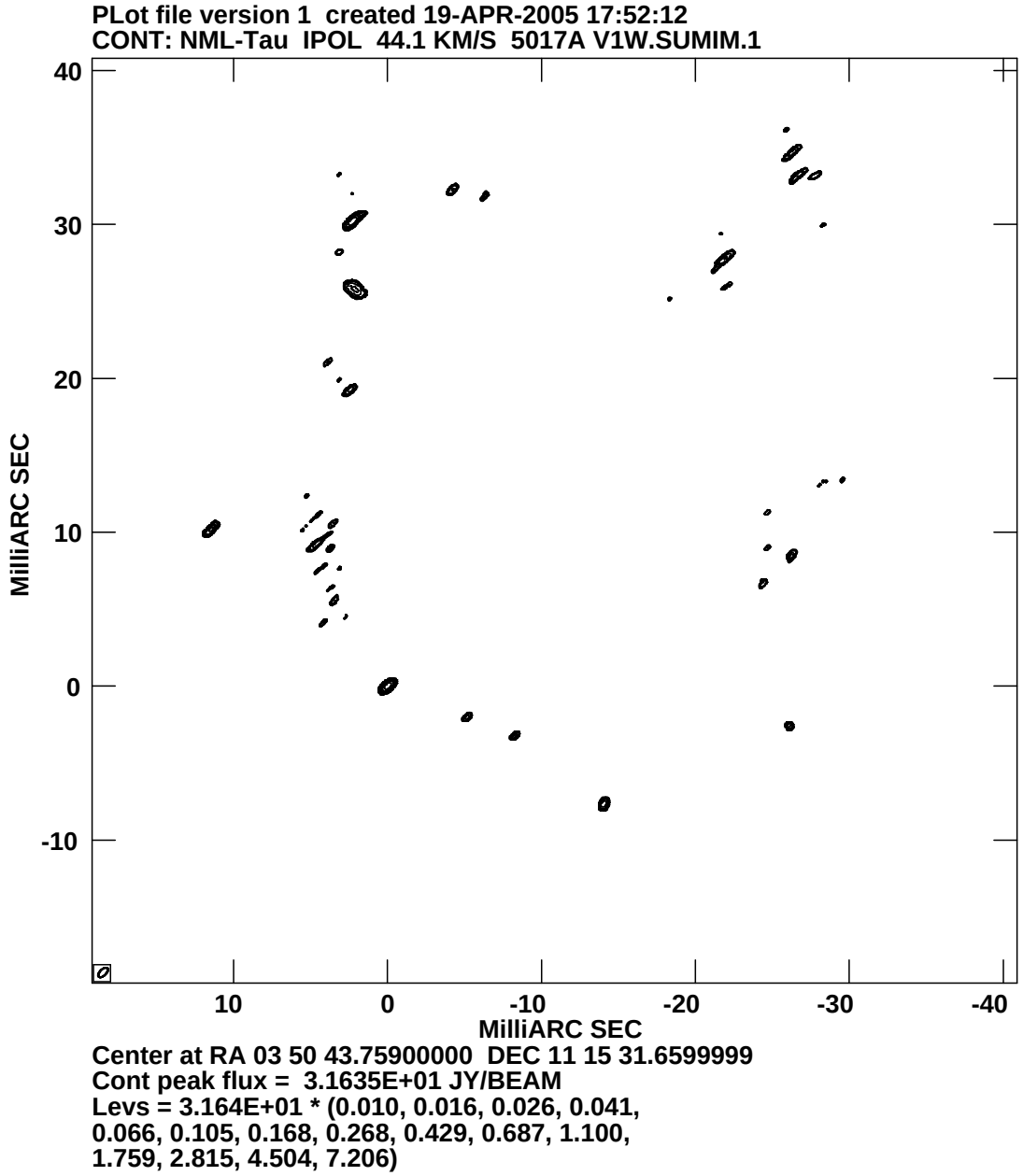

Figure 9: Velocity-averaged intensity map of the SiO v =1 J =1–0 maser emission in NML Tau obtained by SQASH2. The task KNTR was rerun to reduce a field size.

11 MOMNT2: Sub-pipeline for making a velocity (first)-moment map from an image cube

Overview

This pipeline is used for automatically processing the all of the following procedures.

(1) Blanking unnecessary noise emission in the image cube with the task `BLANK`, which is made on basis of a noise criterion calculated by the verb `IMSTAT`.This calculation is separately performed in each of velocity channels because different velocity channels, especially when bright maser emission emission exists, have different noise level. Noise-blanked images are created for individual velocity channels.

(2) Recreating an image cube with the task `MCUBE`.

(3) Rotating the axis definition with the task `TRANS` to make the task `MOMNT` avalialbe.

(4) Creating a velocity-moment image (`IM` file) with the task `MOMNT`.

Necessary item

- MOMNT2.001: copy it to RUN directory in AIPS.
- MOMNWT2.HLP: copy it to HELP directory in AIPS.
- An AIPS `IM` file created by the task `IMAGR`.

Usage

Type `RUN MOMNT2`, then input necessary parameters, which are the same as those described in the sub-pipeline `SQASH2`. Usage in detail can be seen by typing `HELP MOMNT2`. Later you can draw a velocity-moment map with the verbs `TVAL` and `TVLABEL`, and save (or copy) the color plot with the task `TVCPS`.

Outputs

A velocity-moment map (`IM` file) is created, whose file name is automatically specified following the name of the `IM` file.

12 IMGSAV: Sub-pipeline for converting AIPS to FITS data formats

Overview

This pipeline is very simple, but works for converting many AIPS files to FITS formats.

Necessary item

- IMGSAV.001: copy it to RUN directory in AIPS.
- AIPS `IM` and `UV` files to be converted to FITS files.

Usage

Type `RUN IMGSAV`, then input adverb `OUTD` to specify the directory for created FITS files. After specifying one of the FITS files, the type `IMGSAV`. By using the verbs `FOR`, `TO`, and `END` for creating a loop, many AIPS files can be successively converted to FITS formats.

Outputs

FITS files whose names are automatically specified on the basis of the file name, file class, and file sequential number.

A Other tools for VERA/JVN data analysis

They have been developed by H. Imai for quick data analysis of VERA/JVN data. In near future, NAOJ officially will release similar modules for users.

A.1 veratsys

This creates `.antab` file from observation logs. The parameter file "veratsys.prm" should be prepared. Usage of this parameter file is described in detail in itself. A user should provide an antenna gain file named "JNET_gain.txt" in the current (working) directory to create a gain curve (`GC`) table in AIPS. Since June 2004, both of two formats provided for VERA T_{sys} files are acceptable. A user should specify which beam is requested a `TY` table, either A- or B-beam.

A.2 noiseana

This creates `SN` input file from logs of the artificial noise source. The parameter file "noiseana.prm" should be prepared. Usage of this parameter file is described in detail in itself. A user should provide a VERA *calib*2*B* files and specify which beam is requested an `SN` table, either A- or B-beam. For A- and B-beams, signs of the calibrated residual delays, rates and phases are inversed and unchanged from those of the data originally provided. The `SN` table created should be applied to a `CL` table before processing *before fringe-fitting and self-calibration*. This is necessary when solutions of the fringe-fitting and self-calibration are copied from data in one beam, to which the `SN` table is applied, to those in other beam.

A.3 csad, mfident

csad reads a series of image header (csad.header) and a series of `SAD` outputs listed in the file csad.list. The third axis described in the image header should be "VELO-LSR", not "FREQ". To switch the axis information, execute the verb `ALTSWTCH`. Note that this correctly works only when the image cube is created from `UV` data created by the task `SPLIT`. In the sub-pipeline `MMAP`, `ALTSWTCH` is automatically performed.

mfident is used not only to collect the output of the program *csad* but also identify the same group of maser spots (velocity components), or a"maser feature" on basis of angular separations among maser spots. There are two criteria to perform the maser feature identification, 1st a radius within which more than two maser spots having the same LSR velocity are regarded as the same spots, 2nd a radius over which two maser spots belong to different maser features. The former and latter may be around 1/10 and 1/2 of a synthesized beam. A SNR cutoff (larger than 7 is recommended) should also be specified to reject dummy maser spots.

References

[1] Diamond, P. J., Kemball, A. J. 2003, ApJ 599, 1372

[2] Diamond, P. J. 1989, in *Very Long Baseline Interferometry*, ed. M. Felli, R. E. Spencer (Dordrecht: Kluwer), p. 231

[3] Reynolds, C., Paragi, Z., Garrett, M. A. 2002, in URSI General Assembly, Commission J (http://www.evlbi.org/pipeline/user_expts.html)

[4] Honma, M., Tamura, Y., Reid, M. J. 2008, PASJ, 60, 951

B About this document

- 10 February 2004: 1st version. FRCHK.
- 12 February 2004: 2nd version. modification in FRCHK and JNET.
- 9 March 2004: 3nd version. modification in FRCHK and JNET, addition of MPLOT and MCAL.
- 13 April 2004: 4th version. updating MCAL and JNET.
- 29 June 2004: 5th version. adding PKFND, MFIT. Modifying veratsys and noiseana.
- 24 August 2004: 6th version. modifying PKFND, MFIT.
- 19 November 2004 : 7th version. updating Chap.1, MPLOT, MCAL, MMAP.
- 7 June 2005 : 8th version. Adding SQASH2, MOMNT2.Slight modification.
- 8 June 2005 : 9th version. Updating explanation of sect. 1, 9, A
- 7 August 2007 : 10th version, omitting FRCHK, adding VERA, IMGSAV. Updating Chap. 1.
- 28 February 2009 : 11th version, adding ZCOR. Updating the whole description.