Special issues in AIPS analysis of JVN/VERA data

Hiroshi Imai (Kagoshima University, Japan)
Version 6 on 6 January 2013

This manual can be downloaded from the URL:
http://milkyway.sci.kagoshima-u.ac.jp/~imai/VERA-AIPS-analysis.pdf .

Contents

1 Introduction

1.1 About this guide

When we make very long baseline interferometry (VLBI) data analysis with the Astronomical Imaeg Processing System (AIPS) developed by the National Radio Astronomy Observatory (NRAO), at first we shall read the AIPS Cook Book (mainly Chapters 9 and related subsections in other chapters) as well as the data analysis recipe found in the VLBA web page. Note that there have been many significant changes in the names of input parameters, *adverbs*, in the AIPS tasks and meanings of the set adverb values even if the same adverb names have appeared. This version of the guide is based on the latest AIPS version, `31DEC13`, therefore it is strongly recommended that the reader should install this AIPS version. The author also has provided the similar text document (*AIPS Data Analysis Training – Step-by-step recipe –*, it can now be downloaded from `http://milkyway.sci.kagoshima-u.ac.jp/~imai/aips_practice.pdf`. They describe only the general sequences of procedures for VLBI data analysis. Therefore, it is difficult or impossible to determine suitable values of the individual adverbs, only with reading them. Most of Ph. D. and Ms. theses also show similar descriptions. The difference is often only written languages, in Japan the procedures is only translated in Japanese. On the other hand, no document or guide for VLBI data analysis has described about suitable values of AIPS adverbs or any issues about trouble shooting and checking lists in data analysis. The author was asked to describe data analysis procedures for users of the VLBI Exploration of Radio Astrometry (VERA) and Japanese VLBI network (JVN, combination of VERA and other telescopes such as the NRO 45m and NICT 34m telescopes) and beginners of VLBI data analysis. He at first thinks why he was asked to do so even if there have already existed so many guides of VLBI data analysis for them, some of which are released as "manuals". It was easy to find out that none of the users has satisfied with the existing guides because of the reasons described above. Then the author has prepared this guide of VLBI data analysis by watching from view points of the users. The descriptions in the guide concentrate on the points of view as follows. All of the issues are customized for JVN/VERA data.

- How to choose suitable values of AIPS adverbs in individual AIPS.

- How to determine the order of processing tasks.

- How to check the quality, effectiveness of individual AIPS tasks.

- Difference between VLBA/EVN and JVN/VERA data analysis.

- Suitable strategy of a JVN/VERA observation for smooth data analysis.

- How to save time for VLBI data analysis.

1.2 Usage of this guide

This guide briefly describe typical sequences of procedures of data analysis with AIPS in several flow charts. Most of explanations of the AIPS tasks will be skipped, only special issues for the JVN/VERA data analysis are described for some tasks. For this policy, at first, the reader has to accept assumptions adopted in this guide as follows.

- The user already has some experiences to use not only UNIX/LINUX but also AIPS. Therefore he/she has already known a normal sequence of data analysis with AIPS.

- The user already has some experiences to make analysis of spectral line (maser source) data.

- The user already has some experience to make VLBI observations and to prepare observation command files (druge files of PC-SCHED, keyin or VEX files of NRAO's SCHED, or VEX files of VERA's `vs`).

- The user wants to know appropriate values of adverbs in AIPS tasks, the special analysis sequence for JVN/VERA observations.

- The user can specify appropriate values of the adverbs in AIPS tasks, which are not described in this text. This implicitly means that normally used values shall be specified in such adverbs.

Then he/she has to attempt to obtain empirical results of data analysis to find out how generally or explicitly this guide is describing individual issues for leading him/her to get, with shorter time consumption, source images that are scientifically meaningful.

2 Reading FITS data created by the Mitaka FX correlator

2.1 Loading FITS data obtained from JVN/VERA and the Mitaka FX Correlator

The FITS data are shipped via a DAT tape (DDS2) or a DVD disk. Some FITS data are also transpoted via `ftp` directly onto a hard disk drive (HDD). They are directly loaded on AIPS with the task `FITLD`.

Note that, for a pure VERA observation, the FITLDed data correlated after around 2004 September have extension tables `TY` and `GC`, which can soon be used in the amplitude calobration (see Sect. 5.3).

Figure 1 describes how to process the AIPS tasks for loading the JVN/VERA FITS data. Notice that they cannot be concatenated into one FITLDed file with this task, but with the task `DBCON`. When multiple FITS files exist on a DAT tape, each of them should be separately loaded by improving the adverbs `NFILE`, `INFILE`, and `NCOUNT=1`.

No special notice except for above issue is commented in adverbs in `FITLD`. The defaults values can be used in the all adverbs. When concatenating more than one FITS files, two ore more `TY` and `GC` tables are appended, respectively, which should be identical. One of the extension tables is necessary for the amplitude calibration.

2.2 Concatenating DIR2000 14+1 IF data for the VERA B-beam (VERA7 mode)

When a VLBI observation is made using the DIR2000 recording system with the digital filter unit modes `VERA7`, `VERA7MM`, there are one IF channel and 15 IF channels from the beam-A and Beam-B receiving systems, respectively. In practice, there exist three FITS files, two of which are obtained from the beam-B system but have different IF channel numbers (1 and 15 IF channels) with different numbers of spectral channels. As shown in the left branch of process in Figure 1. They can be concatenated to synthesize a 15 IF-channles data.The task `AVSPC` is used to unify the number of spectral channels to the smaller one in the combined The task `VBGLU` combines the two data with a common spectral channels.

Note that when this procedure is made, the gain (`GC`) and T$_{sys}$ (`TY`) tables are invalid. The user should create these tables by hand with the task `ANTAB`. This file concatenation is recommended when using the digital filter unie mode `VERA7MM` because reference frequency of the separated one-IF data from the Beam-B corresponds to that of the Beam-A and because the calibration solutions (`SN` tables) produced from the Beam-B are kept being valid when applying to the Beam-A.

2.3 Sorting visibility in time-baseline order: `MSORT`

It is recommended to perform the task `MSORT` even if the analysis is well processed without this task. When using `MSORT`, a new `NX` and `CL` tables should be created. Note that when setting the adverb `CPARM` in `INDXR`, the longest scan duration (<80 min, the recording length of a DIR2000 tape), and an accumulation period adopted in the data correlation (usually 1/60 min=1 sec). See also Figure 1.
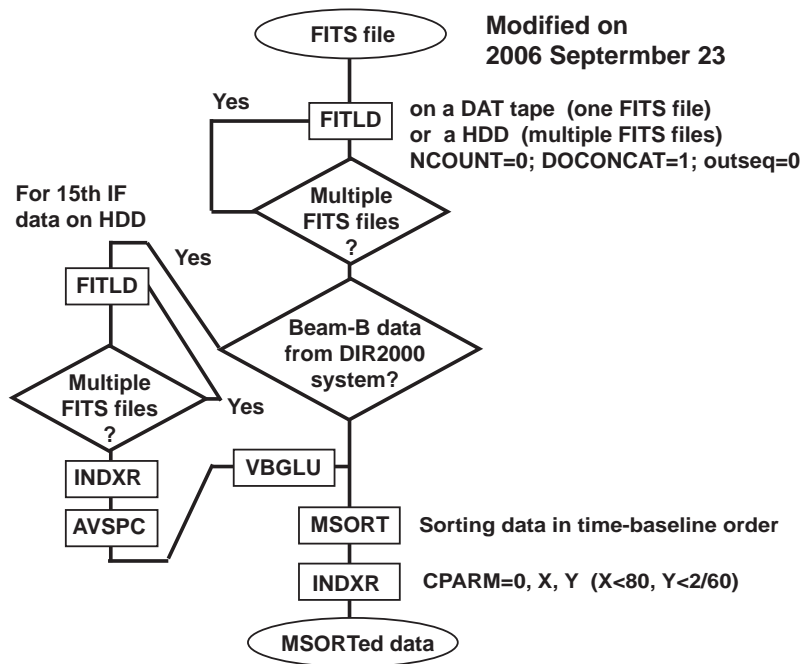
Figure 1: Flow chart of the part reading FITS data.

3   Correcting source coordinates (for VERA DIR2000 data)

Before August 2005, there was a bug in the program to make a FITS file from the data of the Mitaka FX correlator (CODA file system), which puts a wrong coordinate when the original coordinate (R.A. or decl.) that includes a zero character such as $+19°15'05''.12$. At the same time, the original coordinate equinox is missing. This error causes *fatal* problems in the tasks APCAL (gain calibration), CVEL (velocity tracking), FRMAP (fringe-rate mapping), and others in which such an error has not recognized yet.

The analyst can see the coordinates and equinox by print the source table SU with the task PRTAB. Here the row number of the source with wrong coordinate information shall be confirmed. The original coordinate and equinox should be inserted in the column *apparent coordinate (R.A. or decl.)*, and the keyword EPOCH in an SU table with the task TABED. An example is described as follows.

```
****** Corrections of coordinates for 3C273 and its equinox *******
*Row#6 3C273: correct coordinates (J2000.0):
*        R.A.=12h29m06.699729s decl.=+02d03'08.59819"
* in degree >>> 187.2779155 deg, +2.052388386 deg
task 'tabed'
indisk 1; getn 21;outdisk 1; geto 21
inext 'su'; inver 1; outver 1;
optype 'repl';
bcount 6;ecount 6
aparm 11 0 0 1; keyvalue 187.277, 9.155e-4 ; go;wait
aparm 12 0 0 1; keyvalue  2.0523, 8.8386e-5; go;wait
aparm 13 0 0 1; keyvalue  2.0e+3, 0.0;       go;wait
```

If necessary, the equinox shown in the data header, whose contents are seen with the verb IMHEADER, shall be edited with the task TABED as follows.

```
task'tabed'
optype 'key'; keyword 'epoch'; keystrng ''; keyvalue 2.0e+3, 0; aparm 0 0 0 2 0
clro; inext 'an'; inver 1; outver 1
go
```

4 Velocity tracking for JVN/VERA data

4.1 Redefine the correlator name in UV data

AIPS correctly performs the velocity tracking for data correlated in as the same manner as that done by the Socorro FX correlator. The Mitak FX correlator performs in as the same manner as the Socorro FX correlator. Therefore, the velocity tracking by AIPS is valid for JVN/VERA data by redefining the used correlater for the data. This can be made by editing the information of used correlator (by setting `Receiver=VLBA`) in the data header using the task `TABED` as follows.

```
task'tabed'
inext 'an'; inver 1; optype 'key'; keyword 'arrnam'; keystrng 'vlba'; aparm 0 0 0 3 0
go
```

The result shall be checked by the verb `IMHEADER`.

4.2 Trial velocity tracking

The tasks `SETJY` and `CVEL` shall be made at least twice for JVN/VERA data. A data analyst may not know exact allocation of local-standard-of-rest (LSR) velocities for the observed maser source or an LSR velocity that corresponds to the IF band center. This situation always occurs because a local frequency in the observation can be set in an 1 MHz step, and a sky frequency coverage of each IF channel can be set in an accuracy of 1 MHz (13.4 km s^{-1} at 22.2 GHz).

The analysis shall use a trial LSR velocity in the task `SETJY` then perform `CVEL`. Since the version `31DEC13`, `OPTYPE='VCAL'` should be specified. When running `CVEL`,the program messages in the message server tell by how many spectral channels the spectra are shifted for velocity tracking. See an example shown as follows, only important message lines appear. The *average shift* as well as the parameters set in the tasks `TABED` and `SETJY` are what the analyst shall check here.

```
virgo > CVEL 1: Array name in AN table is VLBA
virgo > CVEL 1: Will assume this is data from the VLBA correlator
virgo > CVEL 1: and that it is all fringe-rotated to Earth Center
virgo > CVEL 1: Velocity and frequency information for IRAS1629
virgo > CVEL 1: Velocity type is LSR
virgo > CVEL 1: Velocity definition is RADIO
virgo > CVEL 1: Rest frequencies for each IF:
virgo > CVEL 1:        IF:   1 Rest freq. =     22235.080078 MHz
virgo > CVEL 1: Reference channel for velocity =     1.00
virgo > CVEL 1: New velocity at reference channel for each IF (km/s):
virgo > CVEL 1:        IF:   1 New velocity =    52.0034 km/s
virgo > CVEL 1: Using CL table   1 to obtain time dependent freq offsets
virgo > CVEL 1: Scan    3 Source IRAS1629   0/ 20 19  1 -   0/ 20 41  0 Shifting
virgo > CVEL 1:       Ant:   1 IF#:  1 Average shift =       0.06221
virgo > CVEL 1:       Ant:   2 IF#:  1 Average shift =       0.06507
virgo > CVEL 1:       Ant:   3 IF#:  1 Average shift =       0.06476
virgo > CVEL 1:       Ant:   4 IF#:  1 Average shift =       0.06476
virgo > CVEL 1: Scan    4 Source IRAS1629   0/ 20 41  1 -   0/ 20 48 59 Shifting
virgo > CVEL 1:       Ant:   1 IF#:  1 Average shift =       0.05352
virgo > CVEL 1:       Ant:   2 IF#:  1 Average shift =       0.05352
virgo > CVEL 1:       Ant:   3 IF#:  1 Average shift =       0.05352
virgo > CVEL 1:       Ant:   4 IF#:  1 Average shift =       0.05352
...
...
...
virgo > CVEL 1: Scan   28 Source IRAS1629   1/  1 26  1 -   1/  1 40 59 Shifting
virgo > CVEL 1:       Ant:   1 IF#:  1 Average shift =      -0.16183
virgo > CVEL 1:       Ant:   2 IF#:  1 Average shift =      -0.16183
virgo > CVEL 1:       Ant:   3 IF#:  1 Average shift =      -0.16183
virgo > CVEL 1:       Ant:   4 IF#:  1 Average shift =      -0.16183
virgo > CVEL 1: NX table not copied since some fully flagged data deleted, rerun
virgo >          INDXR
```

If the shift is so large, a large fraction of data at the band edge are missing. In the second trial, the analysts improves either the adverb `SYSVEL` or `APARM(1)` to reduce the shift in the task `SETJY`. When improving `APARM(1)`, the adverb value should be increased by the value displayed in the program message. When improving `SYSVEL`, the adverb value should be increased by a velocity increment (should be negative) multiplied by the value displayed in the program message. For the author's opinion, the channel shift shall be by less than 2–3 channels.

Also, if an `NX` table is missing in the CVELed data, the task `INDXR` should be performed.

5 Calibration for visibility amplitude

Figure 2 describes an analysis flow for visibility amplitude calibration. The next subsections describe some details of individual AIPS tasks for the calibration.

5.1 `ACCOR`: calibration for correlator sampling bias

The correlation coefficients should be normalized in the correlator output. However, data obtained from the Mitaka FX correlator has correlation coefficients by a factor of 3–4 larger than the normalized ones. Therefore this correction is necessary for JVN/VERA data. A solution interval (the adverb `SOLINT`) of the taks `ACCOR` shall be 10–30 min. because of smooth time variation of the correction factors (within 2–3% within the time interval).

5.2 `BPASS`: Calibration for bandpass characteristics <u>amplitudes</u>

This calibration is necessary for data obtained from all of JVN stations no matter which data transmission and backend systems are equipped. This step shall be done after the calibration with `ACCOR` for any further amplitude calibration. For pure VERA observations *for maser source spectroscopy*, information on only bandpass characteristics amplitudes is necessary because a slope of bandpass characteristics phases is flat in an IF channel (with a typical bandwidth of 16 MHz) whose data are digitally sampled in a much wide bandwidth (256–512 MHz). On the other hand, complex band pass characteristics is still necessary for calibrating wide-band image synthesis of continuum sources [5].

In the task `BPASS`, the adverb `BPASSPRM(1)=1` is adopted. Scans of continuum emission calibrators (or a blank sky) shall be selected in the adverb `CALSOUR`. The adverb `SOLINT=-1` (to obtain one solution for the whole observation) may be adopted because the characteristics seems stable during several hours.

5.3 Using the `TY` and `GC` tables attached in a FITS file

As mentioned in Sect.2.1, `TY` and `GC` tables are associated with the FITLDed data for a pure VERA observation. They are used in the task `APCAL` to create an `SN` table.

5.4 Making the `TY` and `GC` tables based on observation log files

If the data are obtained from JVN, `TY` and `GC` tables associated with the FITLDed data are incomplete, T_{sys} and gain information from non-VERA stations are missing. These information shall be recorded either in the observation logs updated in `hotaka: /mmmYYYY`, where mmm and YYYY are three first characters and the year of the observation date, or repots from the telescope operators. They should be prepared in a text file that has a format accepted by the task `ANTAB` described as follows as an example. The text file consists of gain and T_{sys} information to create both `GC` and `TY` tables. An example of the text file format is described as follows. Note that, when applying the file to the beam-B data (having 15 IF channels), the adverb `INDEX` shall be specified as that shown in the example.

```
!--- Gains (Degree per flux unit (DPFU), K/Jy) ------
GAIN NOBEYA45 ALTAZ DPFU=0.362 FREQ=21530,22630 POLY=  1.000 /
GAIN KASHIM34 ALTAZ DPFU=0.115 FREQ=21530,22630 POLY=  1.000 /
!
TSYS KASHIM34 INDEX='L1:15' FT = 1.0 TIMEOFF=0 /
 84 08:28.8    127.873
 84 09:32.7    135.054
 84 10:37.7    133.914
 84 11:41.7    137.764
 84 12:49.4    152.337
/
TSYS NOBEYA45 INDEX='L1' FT = 1.0 TIMEOFF=0 /
 84 08:30.0    120.0
/
```

Note that the new data loaded by `ANTAB` can be appended to the extension tables that already exist in the FITLDed data. Notice that <u>the adverb `OFFSET` in `ANTAB` should have a large value</u> to add T_{sys} values that were obtained out of the actual duration of the observation.

If the analyst wants to remake `GC` and `TY` tables for all of the participating telescopes, he/she is recommended to contact either the VERA contact personnel or the author. The original T_{sys} data from VERA

telescopes are available in the directory, `mtksp1:home/work1/analyfiles/Tsys/`[project code]/ [station code].Table 1 lists of *density per flux unit* (DPFU, K Jy^{-1}) values of the JVN telescopes.

Table 1: Current DPFUs for JVN stations (1 November 2005).

Band	MIZNAO20	IRIKI	OGASA20	ISHIGAKI	NOBEYA45	KASHIM34	MIZNAO10	KAGOSIMA
K	0.057	0.061	0.051	0.048	0.054	0.052	0.049	0.046
Q	0.054	0.052	0.049	0.046	0.34[1]	0.15[2]	0.012[2]	N/A

[1] Deguchi et al. , PASJ 56, 765-802 (2004).
[2] Assuming a telescope aperture efficiency of 20%.
[3] Assuming a telescope aperture efficiency of 30%.

5.5   Calibration with *the template spectrum method*

This method uses total-power spectra of a target bright maser emission to relatively compare gains among the participating telescopes during a VLBI observation, which are reflected in apparent total-power spectrum amplitudes of the maser emission. It makes very accurate amplitude calibration (relative uncertainty less than 1-2%) possible, taking into account not only time variation of T_{sys} but also antenna gain variation due to deformation of the main/sub-reflectors, antenna pointing errors, and optical depths of the sky. In particular, this method is useful for estimating gains of the telescopes whose T_{sys} data or antenna gains during the VLBI observation are missing. However, this method is invalid for the maser sources that are too weak (<300 Jy for H_2O maser emission observed with a VERA telescope) to obtain accurate measured amplitudes or indicate intraday flux variation (because this method assumes a constant flux of the emission during the observation).

To perform this method, the following three calibration steps are necessary (see Figure 2).

- The sampling bias correction with the task `ACCOR` (see sect. 5.1).

- Calibration for bandpass characteristics amplitudes with the task `BPASS`(see sect. 5.2).

- Velocity tracking for the maser source (see sect. 4).

An example of AIPS inputs for the method is shown as follows. This example used the total-power spectra shown in Figure 3. The calibration solutions (gains) obtained from this example was shown in the right panel of Figure 4.

```
task'split'
source 'IRAS1629' ''                      % Specifying the maser source.
docal 1;gainuse 2;doband 1;bpver 1        % using ACCOR and BPASS solutions.
bchan 1;echan 0
aparm 0 0 0 0 2 0                         % Copying only auto-correlation data.
indisk 1;getn 25;outdisk 1;              % Specifying a UV data.
timer 0 18 40 0 0 18 45 0;outclass 'temp';go;wait   % Splitting a template spectrum.
timer 0;outclass 'all'; go;wait          % Copying the whole auto-correlated data.


task 'acfit'
indisk 1;getn 28     % Specifying the whole auto-correlated data.
in2disk 1;get2n 22   % Specifying the template spectrum.
timer 0
calsour 'IRAS1629' ''
antennas 0
refant 1     % The reference antenna should have a good sensitivity and known system temperature and antenna gain.
docal=-1;doband=-1
bchan 227; echan 233      % Covering only spectral channels having bright maser emission.
aparm 1 1 1/0.057 0 % Linear fitting for emission-free baselines, specifying a inverse of DPFU of the reference antenna.
bparm 10 200 250 400 ;cparm 10 200 250 400     % Specifying spectral channel coverage of the emission-free baselines.
xparm 182 0;yparm 0       % Specifying a system noise temperature of the reference antenna
in the period when the template spectrum is obtained.
solint 0.25        % Specifying a short time interval to trace quick gain variation.
snver 1            % The SN table should be copied later to the original UV data.
go
```

Figure 4 shows gains obtained from the same VLBI data but in two methods (the normal method using T_{sys} data and the template spectrum method). The results of two methods are almost identical within the expected accuracy mentioned above, except for quick variation of the gains seen in the IRIKI station due to possibly strong winds.
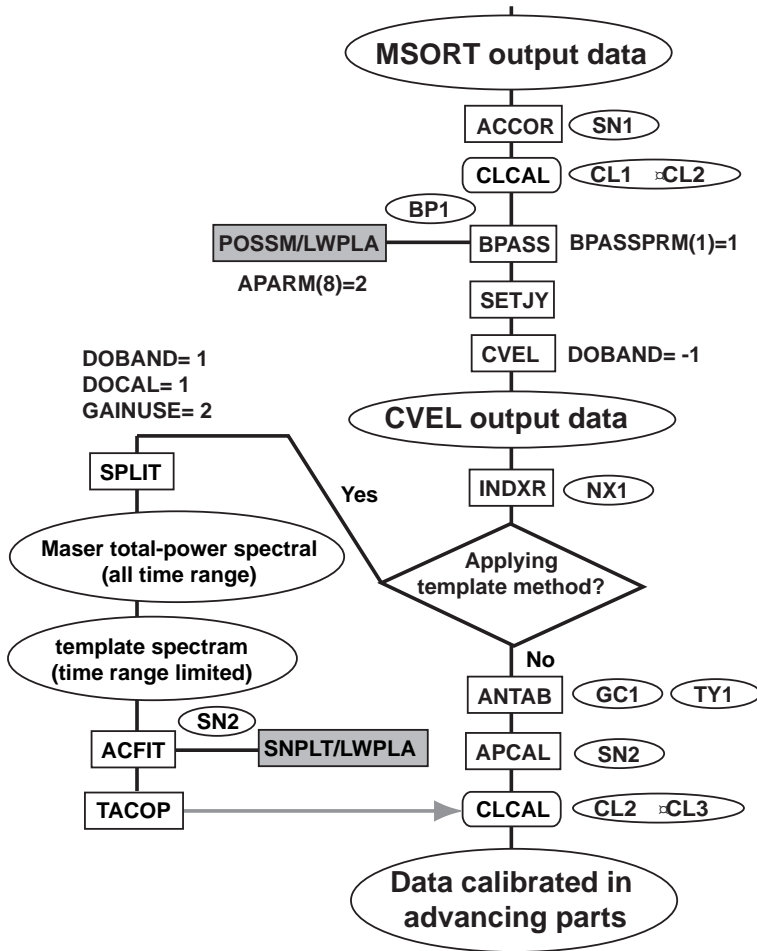
Figure 2: Flow chart of the part for visibility amplitude calibration, including template spectrum method, and velocity tracking. Note that, for JVN/VERA data, it is recommended to perform bandpass calibration *after the velocity tracking* even if spectral channels of CVELed data do not match those in the bandpass characteristics table (BP. A channel shift in the velocity tracking is less than a spectral channel spacing (see an example of the CVEL result)
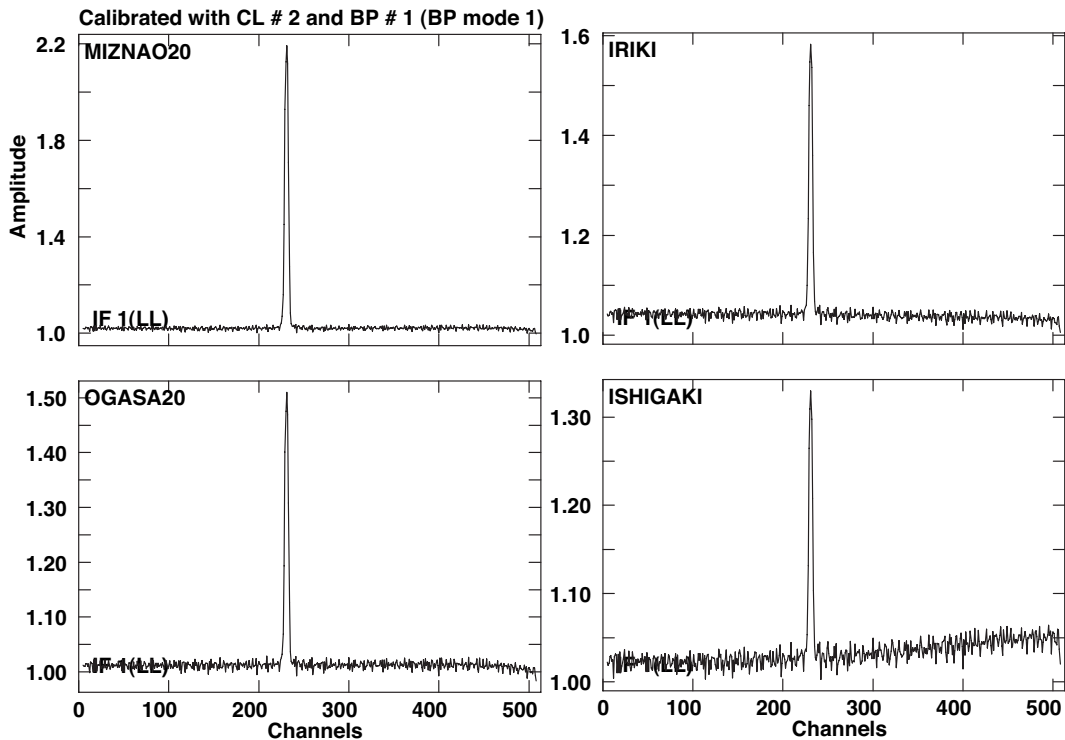
Figure 3: Total-power spectra used in the template spectrum method. Only calibration with the tasks ACCOR (see sect. 5.1) and BPASS (for only amplitudes) are applied.
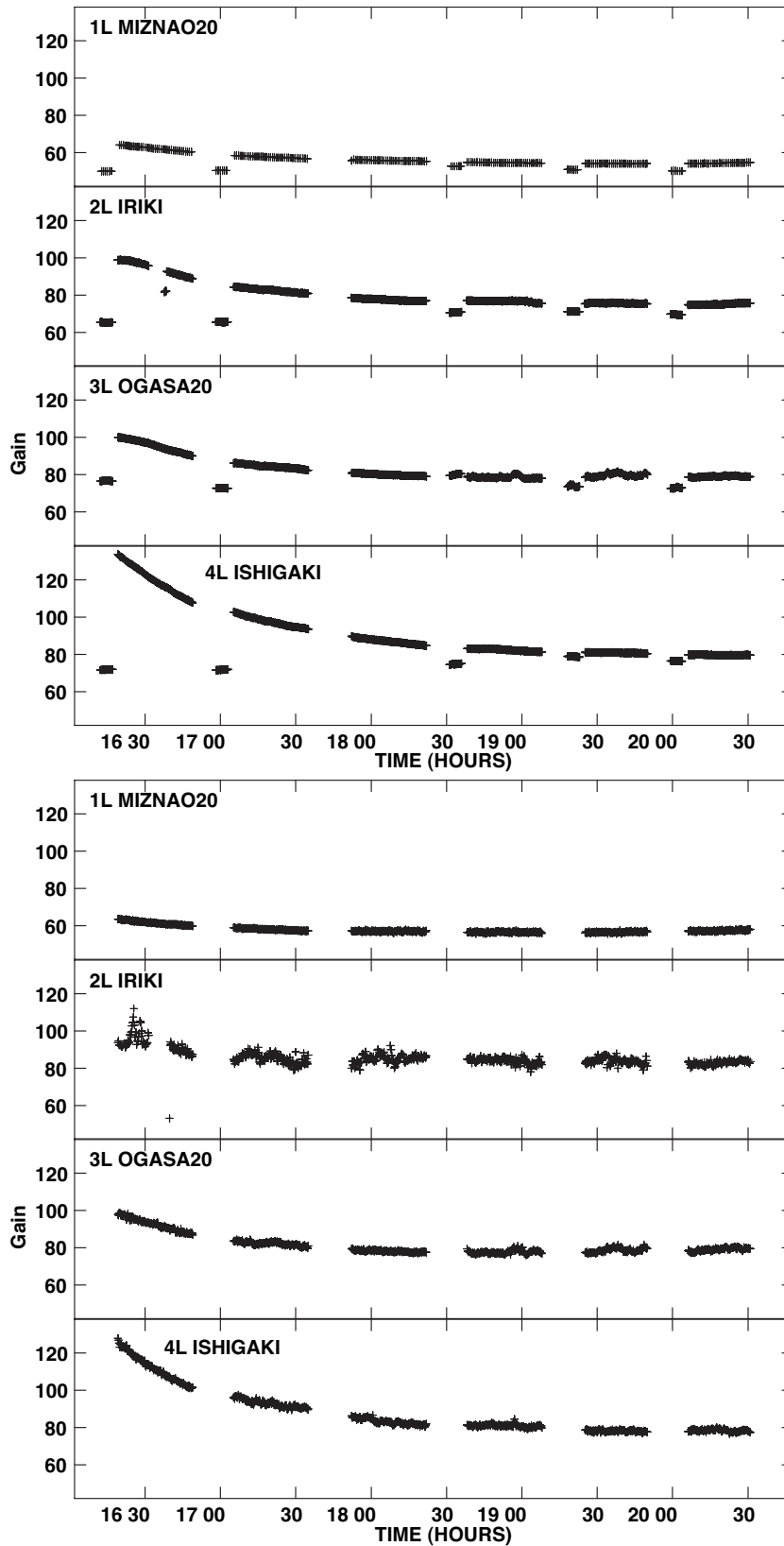
Figure 4: Comparison of two amplitude calibration method.*Left*: Gains obtained through the tasks `ANTAB`, `APCAL`, including scans on the H_2O maser source IRAS16293−2422 and the continuum calibrators. *Right*:same but through the task `ACFIT`, including only scans on the maser source. The adverb `SOLINT=0.25` was adopted.

6 Astrometric corrections with AIPS

All of the astrometric corrections described as follows are necessary to perform VLBI astrometry in 10-μas level precision. In the future coming soon, most of the corrections, except for the correction for unexpected atmospheric zenith delays, will have already been applied to the VERA FITS data received by an analyst. The efforts to achieve this stage and the current status of this issue are described by the developing group of VERA analyzing software.

The astrometric corrections shall be made BEFORE any phase calibrations such as fringe fitting and self-calibration because they are independently performed for each observed source.

6.1 Recalculating (u,v,w) values and remaking delay tracking

The task to perform this has not yet provided in the current version of AIPS, instead some astronomers in the world have independently developed it including as precise geometrical, astrophysical, and geophysical models as possible. The detail of this task for JVN/VERA data is described by the developing group of VERA analyzing software.

There are two paths for this corrections for VERA/JVN data. The first is reproducing FITS data, in which (u,v,w) values are improved and the delay re-tracking is performed. The second is producing a text file that contain solutions for the delay re-trracking in AIPS and that is read in AIPS with the task `TBIN`. In the second, antenna and source coordinates shall be improved by editing `AN` and `SU` tables with the task `TABED`.

6.2 Correction of source coordinates and antenna locations

Residual delays due to offsets of source coordinates and antenna locations are improved with the task `CLCOR` by setting the adverb `OPCODE='ANTP'`. In this task, `AN` and `SU` tables are modified in the same tables, while a new `CL` table is created.

6.3 Parallactic angle correction

Time variation of a *parallactic angle* of a source (see, TMS Figure 4.3 in p.88) occurs for the receiving system mounted in an azimath-elevation mounted telescope and generates a phase rotation. This phase rotation can be corrected with the task `CLCOR` with the adverbs `OPCODE='PANG'` and `CLCORPRM(1)=0`. Figure 5 shows phase correction solutions obtained with this task. Notice that this correction is unnecessary for VERA telescopes performing a dual-beam observation because the field rotator fixes the parallactic angle. This correction is essential only when both of VERA non-VERA telescopes participate in the same differential VLBI observation.

6.4 Correction of residual zenith delays

Usually a residual delay due to an unestimated atmospheric delay still remain after the corrections described above. It is proportional to an unestimated zenith delay multiplied by a depth of the atmosphere between a telescope and the observed source, or $\sec(Z)$, where Z is the zenith angle of the observed source. If a modeled value of the unestimated zenith delay is provided in a text file, the task `CLCOR` can read the text file and perform correction for the zenith delay with the adverb `OPCODE='ATMO'`. The accepted format of the text file is found by typing `HELP CLCOR` and by looking at the explanation of the adverb `INFILE`.

The task `TECOR` performs a similar correction but only for the contribution from the ionosphere. Data of the total electron contents (TEC) can be downloaded from the URL: `ftp://cddisa.gsfc.nasa.gov/%2Fgps/products/ionex/` and read in AIPS by specifying the adverb `INFILE`. The dispersive delays are corrected in the updated `CL` table. Note that the adverb `INFILE` accepts only a combination of an environment variable specified before starting AIPS (e.g. `FITS:` and the variables specified by the analyst) and file names of the data (e.g., `XXXXDDD0.YYi`, where `XXX` is the code of the ionosphere model, e.g. `codg`, `DDD` the day of the year, `YY` last two digits of the A.D. year). This task will not used if the FITS data are corrected by the procedure mentioned in Sect. 6.1.
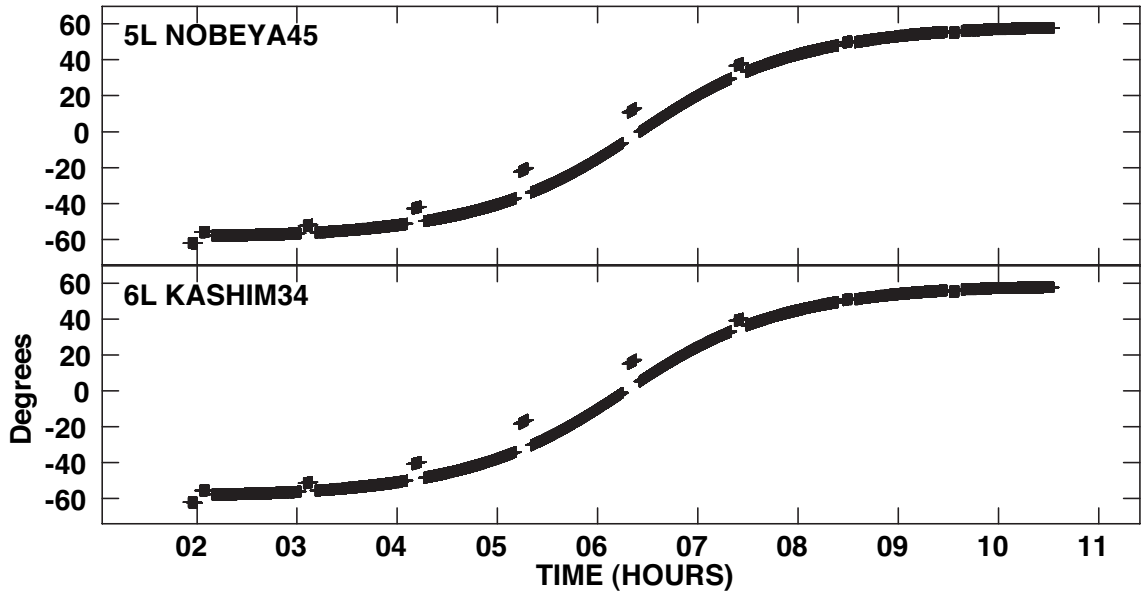
Figure 5: Phase correction solutions for the parallactic angle correction. The observed source are located around decl.~20°. This correction should be applied to only the data from the NRO 45m and NICT 34m telescopes by specifying the adverb ANTENNAS=5,6.

6.5   Direct estimate of residual zenith delays

Residual zenith delays that cannot be modeled in data correlation in practice may be directly measured by a geodetic VLBI observation. The geodetic VLBI observation observes several times as many quasars for geodetic VLBI as possible within 24 hours. Even for estimating only the residual zenith delays, it takes at least 30–40 min. To obtain group delays with an accuracy better than 0.1 ns, A frequency setup with a wide effective bandwidth (>200 MHz) shall be adopted, which is quite different from those adopted in astronomical, especially ,spectral line VLBI observations.

In contrary, even if the method is still in development, the VERA dual-beam observations enables us to perform both astronomical and geodetic VLBI observations with the same frequency setup during the single observation. The VERA digital filter unit mode VERA7 has a 16-MHz IF channel for the A-beam to scan a maser source and 15 16-MHz IF channels for the B-beam to scan a continuum source. An effective bandwidth of 240 MHz is obtained with the mode VERA7. Figure 7 shows an example of delay solutions obtained by such fringe fitting. Furthermore, a great advantage for the estimate of the residual zenith delays is expected from VERA observations. Because continuum reference sources are always scanned with the B-beam together with the adjacent target sources in different zenith angles. Therefore, many data sets of residual group delays can be obtained, which improve an accuracy of the estimated residual zenith delays.

Residual zenith delays as well as clock delay offsets are estimated with the task DELZN on basis of group delays (OPTYPE='MDEL') in an SN table obtained in fringe fitting (see Sect. 7.1. The obtained solutions shall be applied to the CL table that has been updated by calibration for visibility (amplitude) calibration and used for fringe fitting. This application shall be made with the task CLCOR with the adverb OPCODE='ATMO'. Usually, a new CL table shall be created in the task DELZN with the adverb APARM(4)=1. In this case, calibration for both clock parameters and residual zenith delays are performed. An output text file created by the task DELZN shall be read by specifying the adverb INFILE in the task CLCOR.

An example of the results of the task DELZN will soon be seen here in this text.

7 Fringe fitting for JVN/VERA data

There are several special issues in fringe fitting (the task FRING) described as follows. Other adverbs that do not appear in these issues are not explained here because they do not affect fringe fitting solutions so severely.

7.1 Solving multi-band delay solutions for VERA DIR2000 data

VERA DIR2000 data have a good advantage to detect a weak continuum emission source with a wide effective bandwidth. In the case of the digital filer unit mode VERA7, 15 IF channels with a band width of 16 MHz are used and the local frequency increases by 16 MHz in the IF channel order. The effective bandwidth is 240 MHz. This advantage is realized by looking at an example shown in Figures 6 and 7.

Usually, to obtain a multi-band delay, at first, a single band delay for each IF channel shall be obtained and a phase offset shall be calibrated using phase-calibration tones in the single-band fringe fitting. These are necessary because the individual IF channels are expected to have different instrumental delays causing different single-band delays and phase offsets in the backend system, in which digital sampling is made at the final step of the signal flow before recording the signals onto recording media (e.g. magnetic tapes).

In contrary, the VERA data acquisition system digitalizes the received signals passing through an electrically common signal path before splitting them into multiple IF channels with the digital filter unit that conserves an instrumental delay of the original signals. Therefore, these IF channels shall have a common group delay and phase offsets each of which corresponds to the group delay multiplied by the difference between the local frequency and that of a reference IF channel. In this situation, it is possible to obtain a multi-band delay in the single step of fringe-fitting.

To perform the multi-band fringe-fitting described above in AIPS, the adverb APARM(5)=1 shall be adopted in the task FRING. This means that an effective band width is a bandwidth per IF channel (usually 16 MHz) multiplied by the number of IF channels. Such extension of an effective band width enables the VERA system to have much higher sensitivity for continuum emission sources.

7.2 Fringe fitting for the differential VLBI technique

To perform astrometry or long-term integration on basis the differential VLBI technique (using the VERA dual-beam system), an interval of fringe-fitting solutions (SOLINT in the task FRING) should be carefully specified.

The solution interval here roughly corresponds to a coherence time, during which a fringe phase shifts by one cycle (360°) or less. A typical fringe rate residual in a short time scale (within a coherence time, 2–3 min) is less than 5 mHz in a JVN/VERA observation (see Figure 8). This makes a phase shift by one cycle within 200 s. If a phase shift is larger than one cycle, it is possible to occur $2\pi - n$ radian ambiguity in connection of calibrating phases between phase offset solutions. Therefore, it is recommended to set the solution interval shorter than this duration, say 2 min.

In addition, it is important to obtain as many solutions as possible to avoid loss of visibility data after flagging for visibilities without calibration solutions. An accuracy of fringe rate solutions enough to avoid $2\pi - n$ radian uncertainty is necessary when connecting calibrating phases between phase offset solutions separated by the solution interval. For these reasons, a typical solution interval of fringe fitting is 1–2 min for JVN/VERA data.

Since the AIPS version 15DEC05, the adverb SOLSUB can be used to set a time interval of fringe fitting solution shorter than an integration time set by the adverb SOLINT. SOLSUB shall be shorter than unity for this purpose. This enables us to obtain better fringe fitting solutions achieved by a longer integration time with a shorter time interval of the solutions.

7.3 Fringe fitting for a maser source

For phase calibration of a line spectrum (maser) source, fringe-fitting and following self-calibration are made using data in *reference velocity channels*, which are selected on basis of the criteria of detected maser emission in the channels shown as follows in order of priority.

- The maser emission is bright enough to be detected with all baselines.

No calibration applied and no bandpass applied

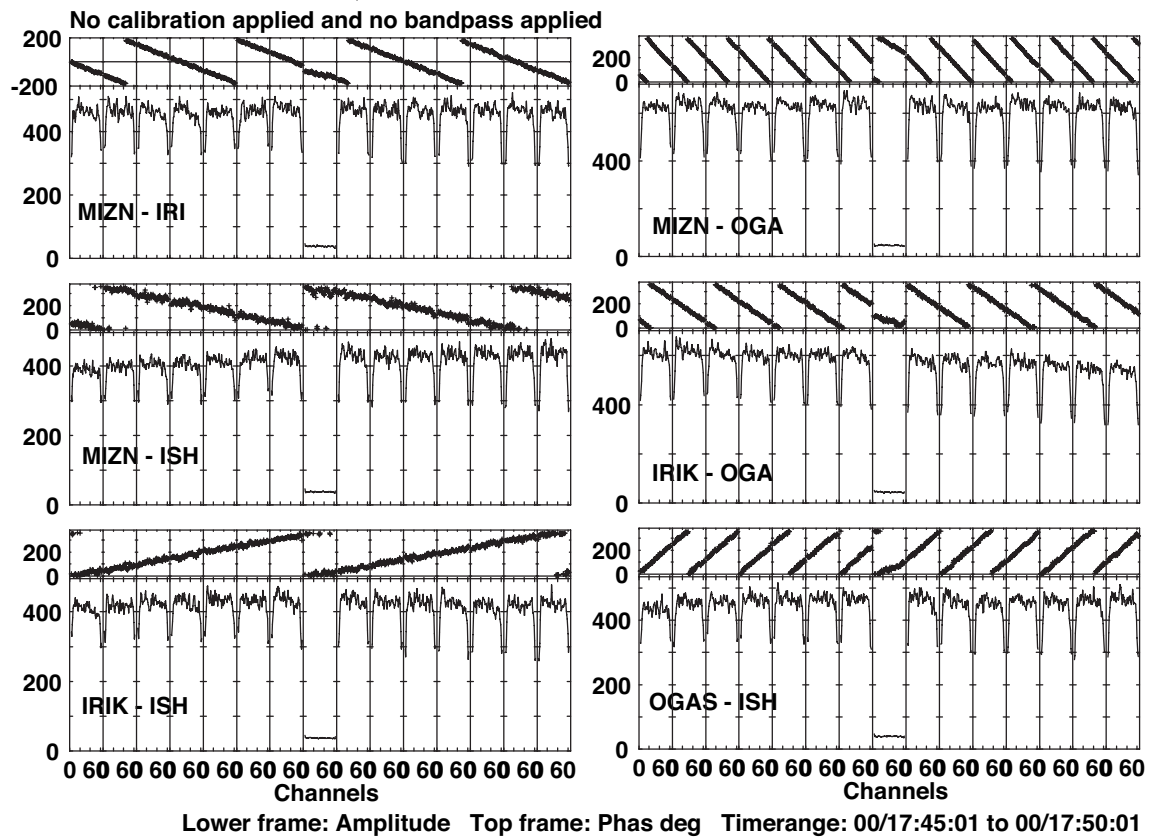Lower frame: Amplitude   Top frame: Phas deg   Timerange: 00/17:45:01 to 00/17:50:01

Figure 6: Row data obtained with the VERA DIR2000 system for the continuum emission source 3C273B. Fringe phases in all of the 15 IF channels are aligned along a single gradient. Because the eighth IF channel has a bandwidth of 8 MHz, the phase gradient looks different from that in other IF channels even if it is actually as the same as that in other IF channels. The eighth IF channel also has different fringe amplitudes, but which are calibrated with the task `ACCOR` to have as the same amplitudes as those in other IF channels.
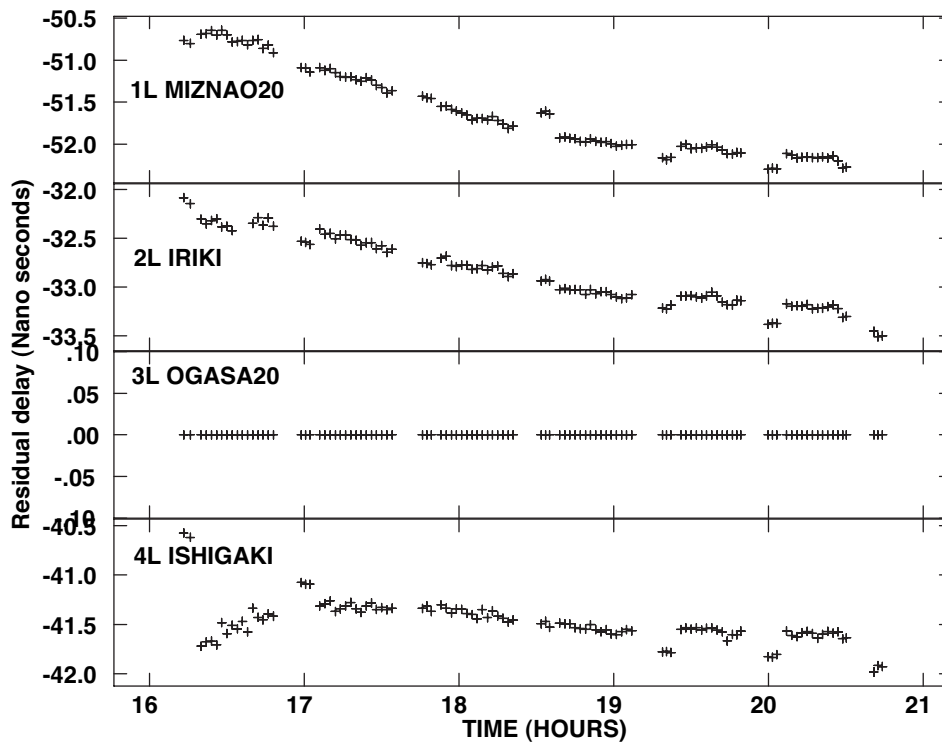

Figure 7: Group delay solutions of fringe fitting, which are made with the data obtained from the VERA beam-B receiving system with 15 16-MHz IF channels. The continuum source observed was J1625−2527 with a flux density of about 2 Jy.
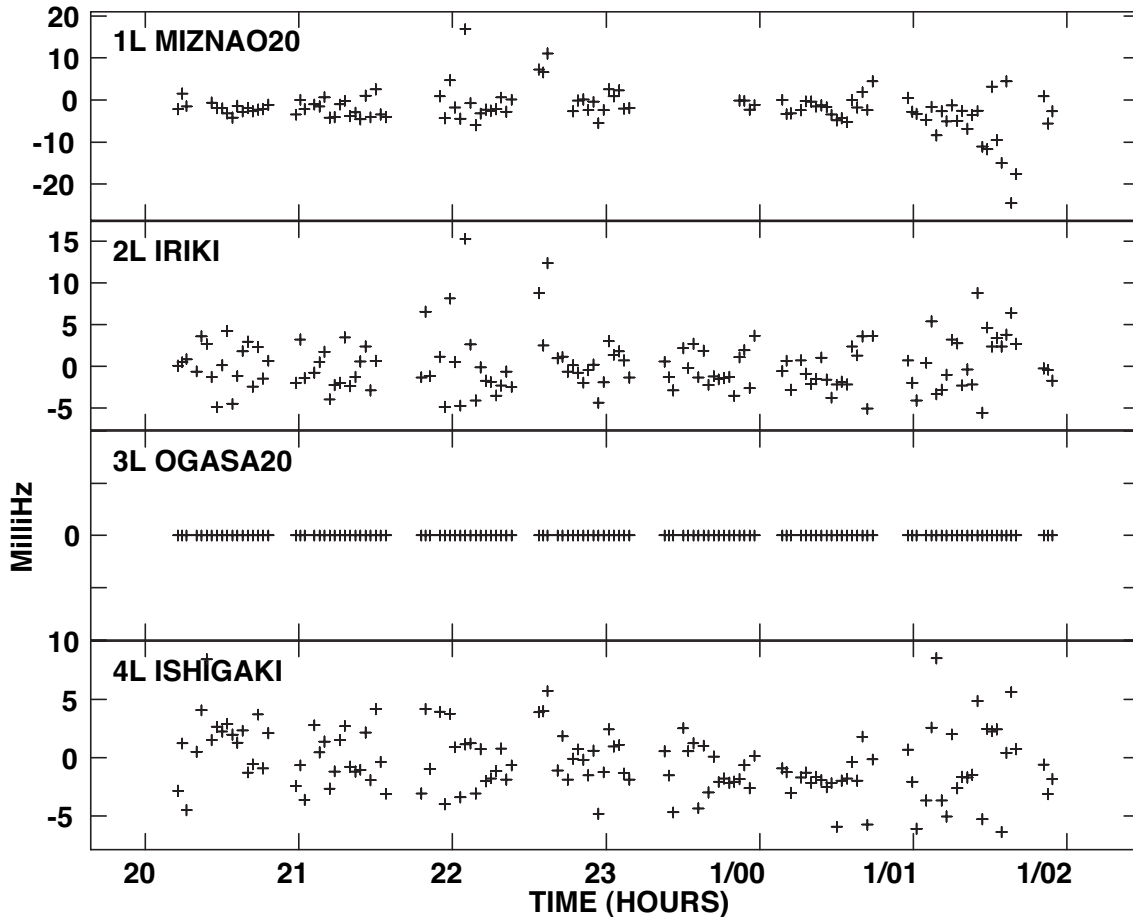
Figure 8: Rates in fringe-fitting solutions for a continuum calibrator observed with the VERA B-beam and recorded their signal with the DIR2000 recorder. The VERA observatin was made in 3 February 2004. A solution interval of 2 min was adopted.

- The maser spots are located as close to the delay-tracking center in the correlation as possible or within 2–3″from the delay-tracking center. It is necessary to avoid using data that are affected by time-integration smearing (phase-smearing by phase rotation during an accumulation period of the correlation).

- The maser emission is compact or have simple spatial structure so that the phase variation with time and baseline length is well resolved into phase variations due to the well-known structure and due to residual delays.

In order to confirm the criteria mentioned above, the tasks POSSM, VPLOT and CLPLT shall be used. POSSM used to find a flux density and structure variation along velocity channels. The latter is indicated by phase variation along the velocity channels. Velocity channels that have an enough flux density and a constant residual phases are suitable for the reference channels.
VPLOT is used to find time variation of correlated amplitude, which indicates compactness and degree of complication of the spatial structure. Roughly constant amplitudes indicate the existence of a compact maser spot.
In VPLOT, only amplitude information is valid, while in the task CLPLOT, closure phases plotted directly indicates the information on the spatial structure. Roughly constant closure phases indicate the existence of a maser spot with a simple structure.

7.4 Selecting the first and second reference antennas

A reference antenna for fringe fitting shall be specified in the adverb `REFANT` in the task `FRING`. The reference antenna selected shall have the best sensitivity and performance to avoid missing fringe fitting solutions when good visibility data from the antenna are missing. If *the second reference antenna* is specified in the adverb `SEARCH` with setting the adverb `APARM(9)=1`, the second antenna is used as a reference antenna instead of the first reference antenna specified in the adverb `REFANT` when valid solutions from the first one are missing. For data analysis of a JVN/VERA observation, such second reference antenna is dispensable.

7.5 Solutions from poor signal-to-noise ratio

It is frequently seen for JVN/VERA data that a signal-to-noise ratio cutoff (the adverb `APARM(7)` is set to a lower value (3–5) to save visibility from flagging due to missing of fringe fitting solutions. In that case, the obtained solutions shall be carefully examined. Valid solutions are scattered within 2–3 nsec in group delay (for a 16 MHz band width) and 5 mHz in fringe rate (see e.g. Figure 8).The solutions scattered over such delay/rate criteria should be interactively flagged out by using the task `SNEDT`.

7.6 Applying a fringe-fitting solution to a calibration table

To connect phase offset solutions of fringe fitting, the $2\pi - n$ radian ambiguity shall be solved by using fringe rate solutions. It is made when the solution (`SN` table in the task `FRING`) is applied to a new `CL` table in the task `CLCAL` with setting the adverb `INTERPOL='AMBG'`.

7.7 Bug in the task `CLCAL` (`VERSION=31DEC05`) for fringe-fitting solutions

Many users analyzing VERA data have reported that the task `CLCAL` makes wrong performance so that the visibility calibration made with the created `CL` table creates visibilities that have unbelievable, extremely high amplitude (MJy or GJy!). They appear all spectral channels. This bug occurs in the AIPS version `31DEC05`. It is strongly recommended to use other AIPS version for only this procedure. If the above version alone is available in the AIPS computer, these odd visibilities shall be manually flagged with the task `IBLED`.

8   Making a complex bandpass characteristics table

8.1   Obtaining a complex bandpass characteristics

A complex bandpass characteristics solution can be obtained by using long scans on very bright continuum emission sources and by fully integrating then for the whole observation. For VERA observations that consist of 20m dish–20m dish baselines, scans of continuum sources brighter than 2 Jy for as long as 30 min in total are necessary. This is usually made by setting the adverb `SOLINT=-1` when using the task `BPASS`. However, when some scans on the bright calibrators are missing for some reason, this setting fails to obtain the bandpass solution for the whole observation. It is recommended, therefore, to set `SOLINT` to a large positive value.

8.2   For pure VERA observations

Figure 9 presents an example of the complex bandpass characteristics solution obtained from a JVN observation. For VERA stations, the bandpass characteristics phases are perfectly flat in an IF channel, while they have a slope within 30°for other stations. The latter stations are still using the analog IF filter that introduces such phase slopes. Thus, the complex bandpass solutions are necessay only for a JVN observations including non-VERA stations.
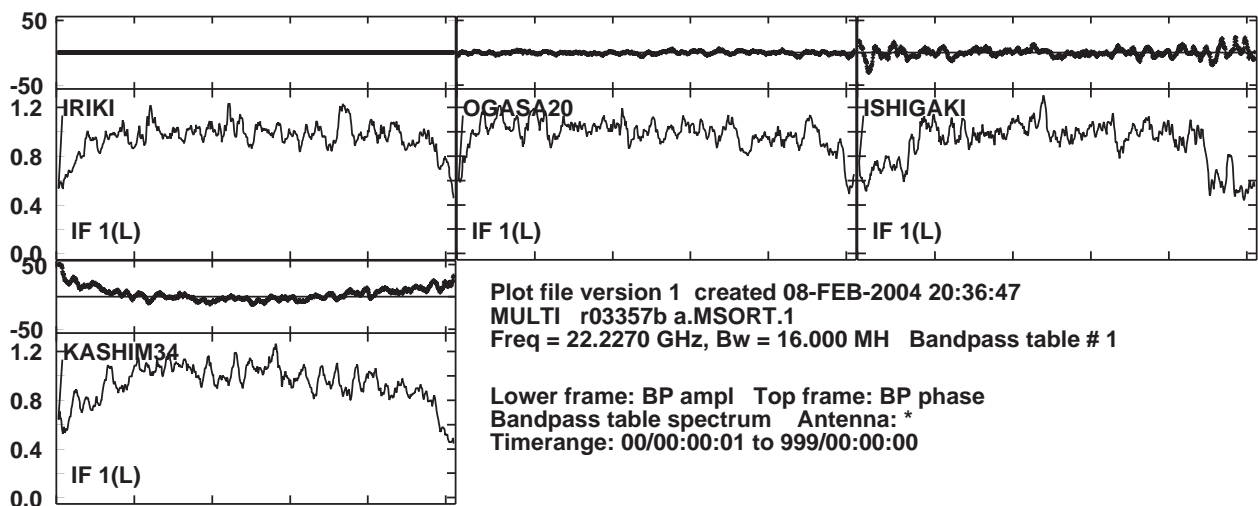

Figure 9: Bandpass characteristics obtained with the task `BPASS` and plotted with the task `POSSM` (`APARM(8)=2`). Only the Kashima station has a slope of bandpass phases because an analogue base band filter (the Nittuki sampler interface in the VSOP terminal) is used. Other VERA stations have the wide-band samplers and the digital base band filters. The bandpass solution for ISHIGAKI is noisy and invalid for calibration unless the solution is smoothed (by setting, e.g. `SMOOTH=3,16`).

9 Notes of self-calibration and imaging for JVN/VERA data

9.1 Self-calibration

Figure 10 shows a typical flow for self-calibration and hybrid mapping. The general procedure of the self-calibration/hybrid mapping is well described in the text *AIPS Data Analysis Training*. There are additional notes of self-calibration for JVN/VERA data as follows.

- Closure phases and amplitudes are calculated to calculate a suitable visibility model for a brightness model, which shall be obtained by previous trial in the CLEAN imaging with the task `IMAGR`. To obtain such closures, the adverb `APARM(1)=3` and `APARM(1)=4` shall be specified for closure phases and amplitudes, respectively, in the task `CALIB`. However, if the VLBI observation consists of smaller number of telescopes, `APARM(1)=2` shall be specified to avoid missing visibilities by flagging.

- A better image can be obtained by specifying CLEAN box around true source emission. For VERA observations, deep valleys next to the true emission always exist in the dirty image. The CLEAN boxes should avoid such valleys to prevent the process from soon finding negative CLEAN components.

- A better image can be obtained by specifying a shorter solution interval with the adverb `SOLINT` in the task `CALIB`, which enables to remove fringe-phase fluctuation on a short time scale. The image quality is significantly improved at the final stage that adopts amplitude/phase solutions (the adverbs `SOLTYPE=L1`, `SOLMODE='A&P'`). However, there is a trade off between better solutions in this stage and more flagged visibilities. An image based on this calibration shall be carefully examined on basis of an obtained dynamic range of the image.

- The adverb `SOLSUB` is available sinece the AIPS version `15DEC05` (see Sect. 7.2). This is useful especially when obtaining phase/amplitude calibration solutions at the final stage of self-calibration.

9.2 An image dynamic range

A dynamic range on an image is defined by a ratio of the largest intensity on the image with respect to 1-$sigma$ noise intensity level. This is controlled by the (u,v) coverage of the VLBI observation. For VERA observations made by four telescopes in Japan, the best dynamic range on an image is empirically estimated to be about 400 (Sakakibara et al. 2004). For the best configuration, which consists of VERA stations as well as the Usuda 64m, Gifu 11m, Yamacughi 32m, and Tsukuba 32m telescopes, a dynamic range achieved to 1700 (Sudoh et al. 2005).

9.3 An image cube for a maser source

Even if the self-calibration has been made deeply, it is a tough work to obtain images with a high dynamic range in individual velocity channels of an image cube. A high dynamic range image can be obtained by using CLEAN box well defined for each of velocity channel, which is very tough or impossible at present especially when there are many maser spots in a wide field and many velocity channels. CLEAN imaging with automatic assigning of CLEAN boxes will be a future issue in the development of data analysis scheme for maser sources.
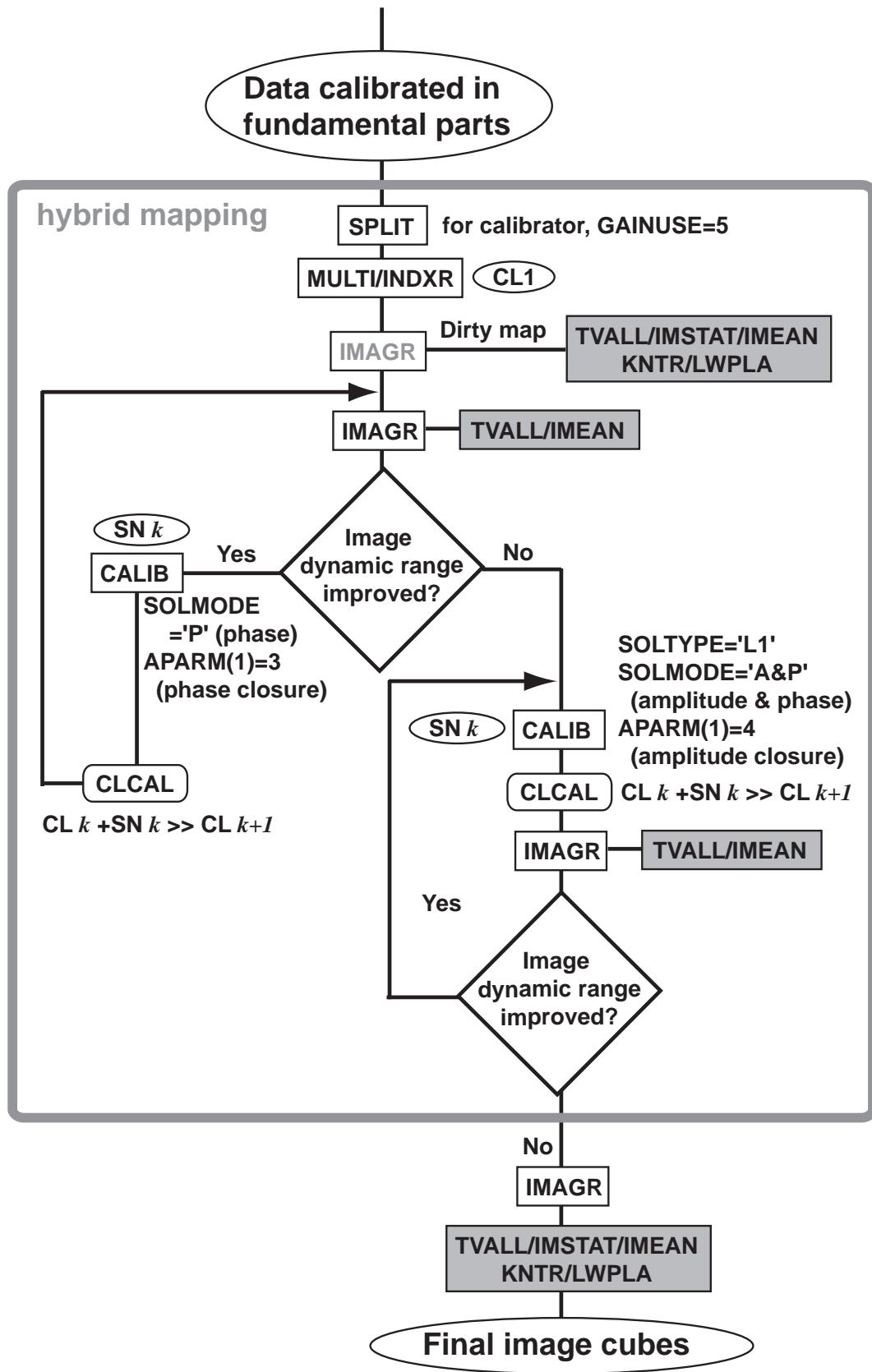
Figure 10: Flow chart of the part that describes the hybrid mapping.

10   Special issues in the differential VLBI technique with VERA

The differential VLBI technique is widely used for high precision VLBI astrometry between adjacent two sources and for performing long-term coherent integration to detect fainter sources. This technique assumes a common instrumental delay and an atmospheric delay residual between two sources in each of antenna stations. In this case, residual fringe phases seen in one source are referred as the sum of the instrumental delays and atmospheric delays in order to compensate fringe phases seen in another. This is so-called *phase referencing*. The assumption of a common instrumental delay mentioned above is valid when the two sources are observed using the same receiving system in the technique such as the antenna fast-switching observation with a switching period shorter than a coherence time (a few minutes at the 22 GHz band). The assumption of a common atmospheric delay residual is valid for the two sources whose separation is within a few degrees at the 22 GHz band. However, even if these assumptions are actually valid, a difference of zenith angles of the two sources provides a phase difference due to the residual zenith delay as described in Sect. 6.4.

In the next subsections, AIPS data analysis for the differential VLBI technique performed with VERA and JVN is described. Figure 11 presents the whole flow of data analysis for VERA astrometry.
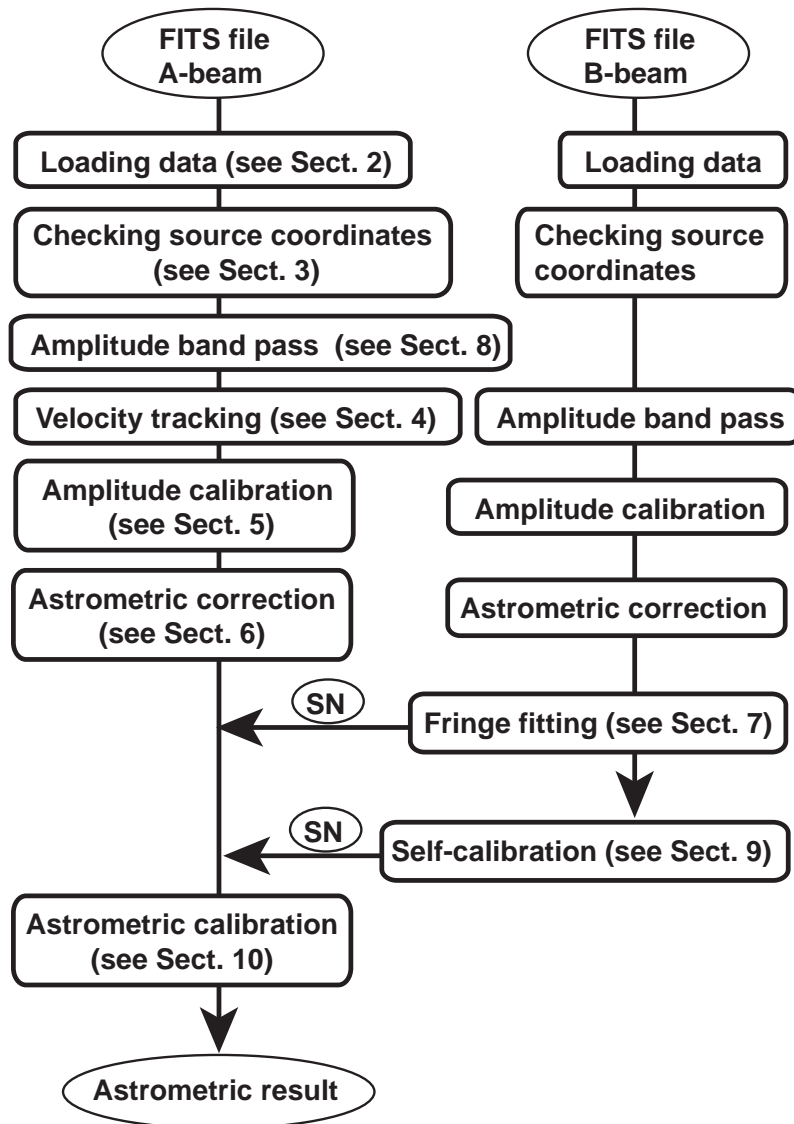

Figure 11: Flowchart of data analysis for VERA astrometry. In this flowchart, the target source and calibrator are observed with the beam-A and beam-B systems, respectively.

10.1 Preparing solution (SN) tables obtained from phase calibrations

Solution (SN) tables for the phase referencing technique shall be obtained by fringe fitting and self-calibration performed for *the calibrators*. Here *the calibrator* means the source whose visibilities provide such SN tables for calibrating the visibilities of other sources, or *the target sources*. It is a normal that a calibrator is an extragalactic continuum source as fringe phase and position reference while a target source is a source whose coordinates may be precisely detected or whose faint emission is tried to be detected. In some case, for example, when a position reference source is too faint while a target source is enough bright to provide referenced fringe phases, SN tables shall be provided by the target source. This is termed *inverse phase referencing technique* (see Sect. 10.3).

It should be noticed that data of a calibrator and a target source should have a common number of IF channels when applying an SN table from the former to the latter data. Alternately, the SN table should be applied to the IF channel whose local frequency is equal or closest to that in the data providing the SN table. Figure 12 describes how to copy an SN table from the data of a calibrator to those of a target, which depends on the numbers of IF channels in these data. It is assumed that data with multiple IF channels are obtained from a continuum emission source, while the data with one IF channel is obtained from a bright continuum or maser source.

10.2 Instrumental delay calibration for data from the VERA dual beams

VERA introduces artificial noise emission sources in the antenna system, whose generated noise is received by two independent receiving systems (or the dual receiving systems, beam-A and beam-B) and correlated in real time to find an instrumental delay difference (including delay difference coming from the optics of the VERA antenna) between the two systems. The correlated data are used to generate text files that are read in AIPS with the task TBIN to create an SN table. Usually TBIN shall be executed after all of phase calibrations such as fringe fitting and self-calibration.

The text files are provided together with FITS files. The name of the text file has a form of [project code].[Beam]-NO[file #].[MINUS or PLUS].TBIN. Here project code is the code assigned for the JVN/VERA observation (e.g. r05084a), Beam one-alphabetical code of the receiving system (A or B). MINUS and PLUS indicates that the visibilities in the specified beam have *positive* and *negative* instrumental phase/delay offsets that were measured with respect to those in other beam, respectively, Because the phase/delay offsets of the target-beam visibilities shall be measured with respect to the reference-beam ones and they still remain even after all of calibration procedures in the reference-beam, they shall be either subtracted from the visibilities in the target beam or added to those in the reference beam. with the task CLCAL. In the usual case, the text file named [project code].[Target source beam]-NO[file #].[PLUS].TBIN shall be applied to the data of the target source.

10.3 Inverse phase-referencing technique

If a continuum reference source observed with the beam-B system is too faint to be used as fringe-phase reference, one of bright maser spots shall be used as phase and position reference. Figure 13 shows the flowchart of data reduction in this *inverse* phase-referencing technique. For applying this technique, another brighter quasar (or fringe finder) should be observed in the beam-B. Fringe fitting for calibrating large (common) group delay residuals shall be perfomed for this bright source. Its solutions shall be applied to the both A- and B-beams. The upgrade of the complex gains (CL table) should be made in the perfectly equal manner between the beam-A and beam-B gains. The calibration for the dual-beam instrumental delays (see Sect. 10.2) should be applied in the beam-A before performing fringe-fitting and self-calibration in the beam-A using a spectral channel including a bright maser spot. For copying these solutions (SN tables) into the beam-B, The beam-B data shall be compressed in to one IF channel (see (c) of Figure 12). The derived position offset of the quasar corresponds to the inverse of the maser spot position offset (see Figure 14).
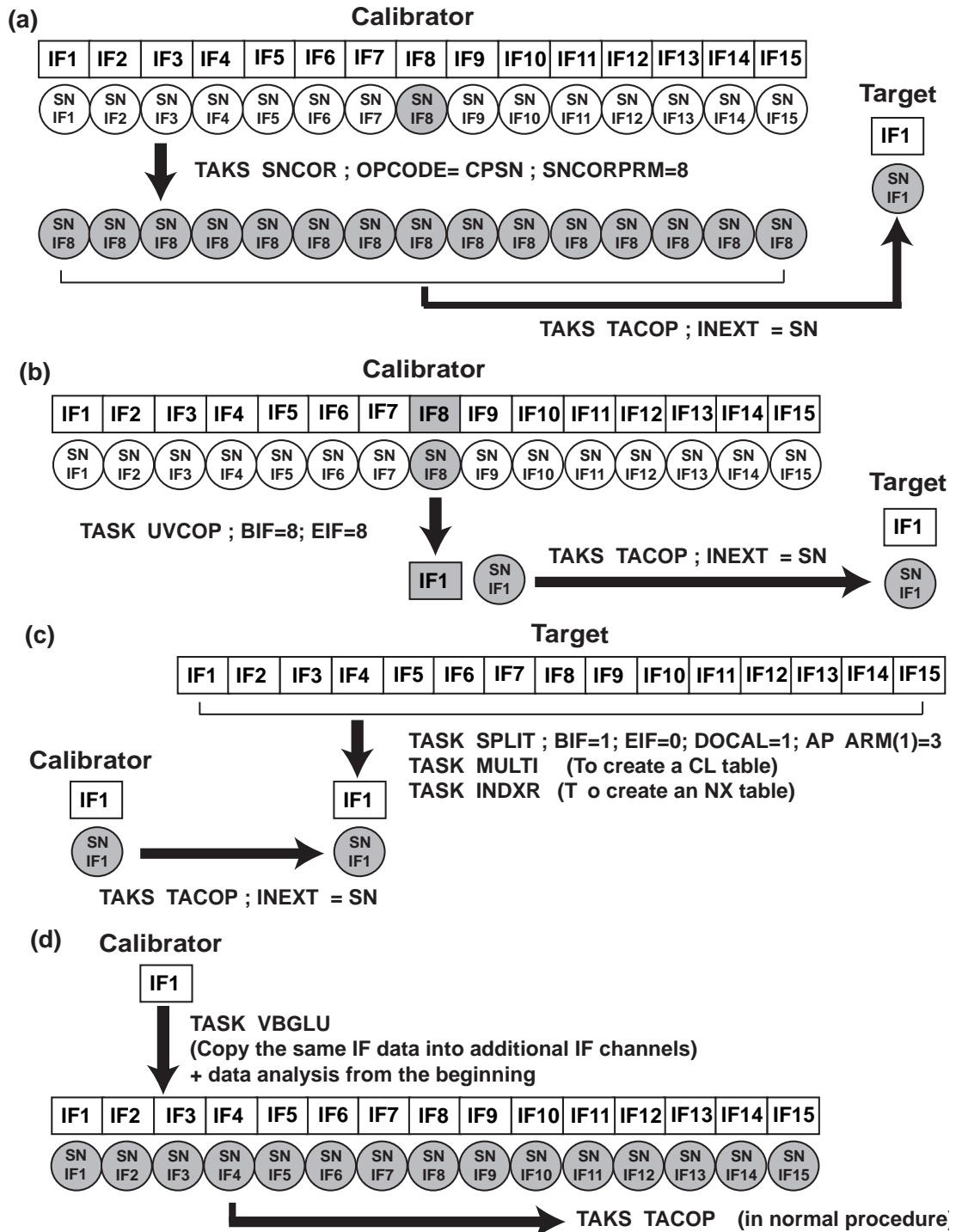
Figure 12: Procedures to copy an SN table between data with different numbers of IF channels. (a): In the case where the calibrator data have multiple IF channels while the target data have one IF channel. IF8 in the calibrator contains calibration solutions at the frequency closest to the data in the target. In the task TACOP, solutions in all of the 15 IF channels are copied, but only those in IF1 shall be used for calibration.(b): Same as (a), but this uses another procedure for SN copy. (c): In the case where the calibrator data have one IF channel while the target data have multiple IF channels. When combining the multiple IF channel with the task SPLIT, phase gradients along frequency shall be calibrated (DOCAL=1). (d): Same as (c) but this prepares 15 IF channels each of which has as the same data as IF1 data for the calibrator.
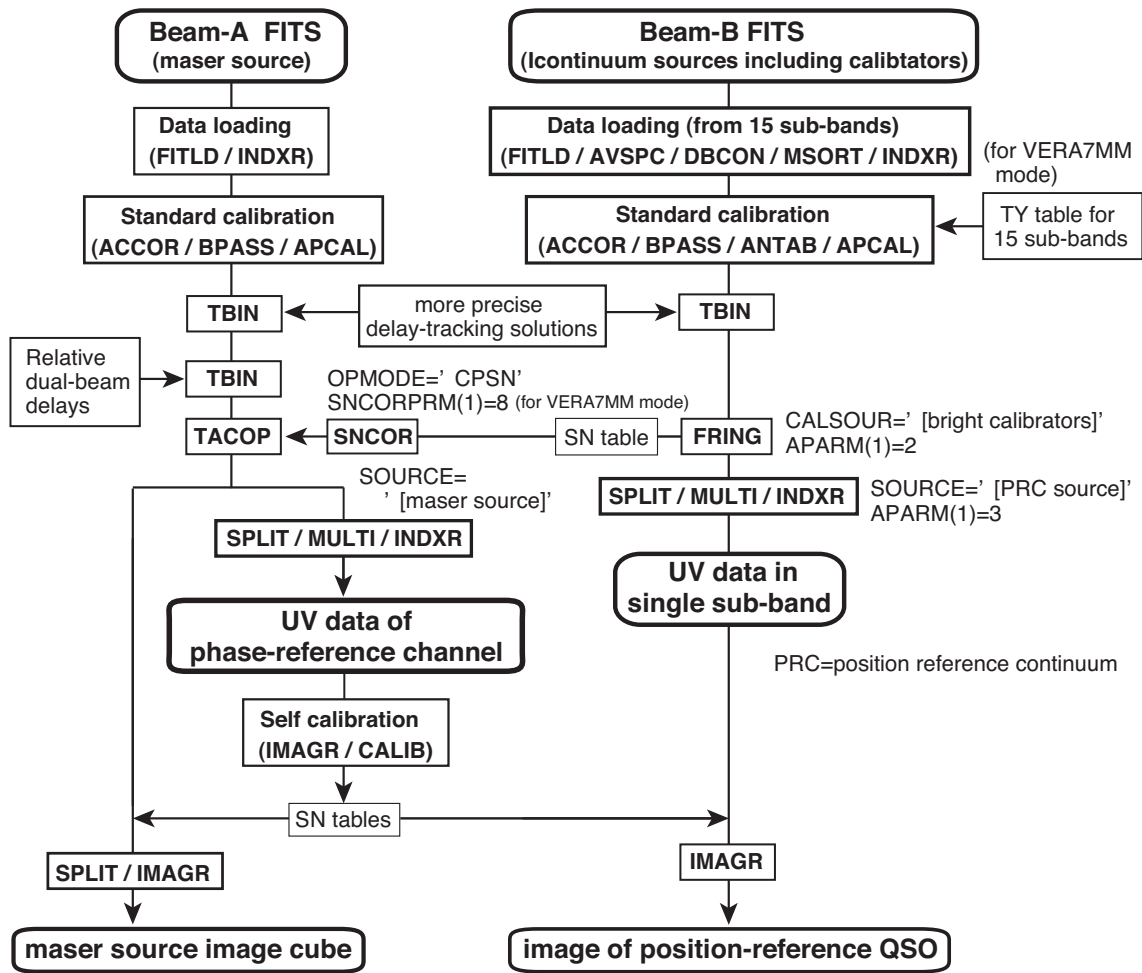
Figure 13: Same as Figure 11 but for the case of the *inverse* phase-referencing technique. The original figure was cited from Imai et al.(2012) [2].
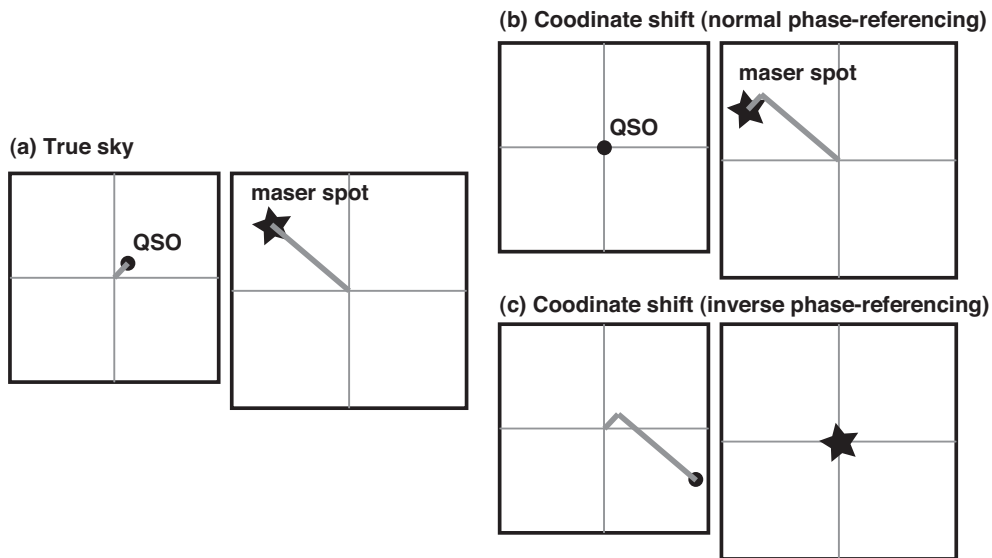

Figure 14: Shifts of coordinates in two cases of phase-referencing astrometry. (a) True positions of a QSO and a maser spot on a common reference frame, which has two reference points (map origins) corresponding to the phase-tracking centers of the two sources. (b) Shift of coordinates in the case of the normal phase-referencing method in which the visibilities of the QSO are self-calibrated. (c) Same as (b) but the case of the *inverse* phase-referencing method in which the visibilities of the maser spot are self-calibrated.

11 Fringe-rate mapping

The AIPS task `FRMAP` performs the *multiple-points* fringe-rate mapping (see Walker 1981 and type `EXPLAIN FRMAP` in detail). Fringe-rate mapping is frequently used in data analysis of JVN/VERA observations for the purposes described as follows. Here examples of suitable sets of adverbs in the task `FRMAP` are also shown.

11.1 An example of the result of the task `FRMAP`

Figure 15 shows an example of a fringe rate map obtained with the data of a VERA observation that observed the bright H_2O maser emission in IRAS16293−2422. To make this plot, the adverbs shown as follows are specified in the task `FRMAP`.

```
SOURCES   'IRAS1629'     % Maser source name.
UVRANG    0              % UV range limit is useful when making wide-field maps.
TIMERANG  0 20 20 00 1 01 54 00
          % They shall be explicitly specified to use more good maser data.
BCHAN 235; ECHAN 236     % Averaging two velocity channels to detect weaker maser spots.
CHANNEL=-1               % No channel for phase reference in the mapping is specified.
ANTENNAS 0; BASELINE 0   % All antennas shall be used for JVN/VERA data.
DOCALIB  1; GAINUSE  15
          % CL table version updated with fringe-fitting and self-calibration  solutions.
FLAGVER  0               % The highest flag table version is selected.
DOBAND  1; BPVER   1     % Complex or scalar (amplitude) BP table is applied.
APARM(1)  2              %  Tell the accumulation period.
APARM(3)  2              % Two velocity channels are averaged.
APARM(4) 50; APARM(5) 100
      % R.A.(MILLISECOND) and decl. (milli-arcsecond) steps of a map grid to find
      %  maser spots.
      % A larger grid has a higher possibility to find a true spot, but obtains
      %  less spots in a spot-crowded region.
APARM(6) 700; APARM(7) 1000
      % Half widths of a map on the sky in unit of MILLISECOND and milli-arcsecond,
      % smaller than 200 grids.
BPARM(1) 7        % Threshold (in sigmas) in detection maxima in fringe spectrum.
BPARM(2) 35
      % Time interval between beginnings of interval of averaging (min),
      % longer than one tenth of the whole time range specified in TIMER.
BPARM(3) 8   % Interval of averaging in unit of minute.
          % A longer interval provides higher sensitivity, but a smaller field-of-view.
          % BPARM(3) > 10 is usually impossible.
BPARM(6) 0.2 % 0< BPARM(6) < 1.0 is valid.
          % A smaller value allows a smaller line (drawn on the map) number density
          %  as a true emission candidate.
```

In this example, locations of maser spots are calculated with respect to *the reference spot* located at the map origin. The reference spot is included in *the reference velocity channel* whose visibility phases have been referred for fringe fitting and self-calibration. Therefore the absolute coordinates of the spots are missing. Note that the adverb `CHANNEL` is used to specify the reference velocity channel when uncalibrated visibilities are used for the mapping. The default `CHANNEL=0` means the value (BCHAN+ECHAN)/2, so it never be used. It should be noticed that the estimated locations of maser spots are expressed in unit of MILLISECOND (milli-arcsecond dividided by the declination value) and milli-arcsecond in R.A. and decl. directions, respectively.

Fringe-rate mapping in the above case may be valid for maser features that are detected within a few times as long as a coherence time (*sim*10 min). For VERA observations, it corresponds to a maser spot with a flux density higher than 10–20 Jy.
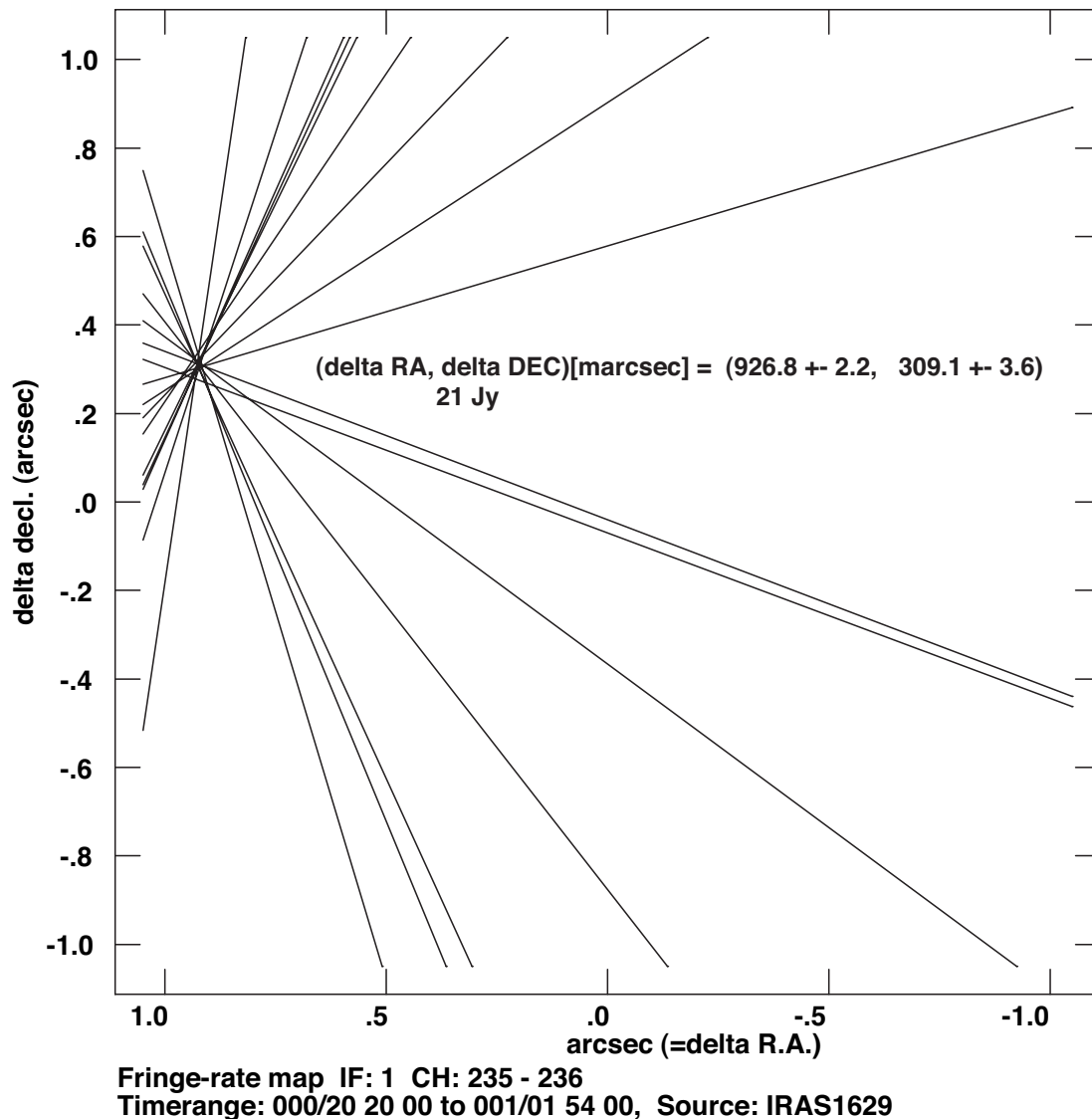
Figure 15: Fringe rate map for an H_2O maser spot in IRAS16293−2422. The adverbs input for making this plot are described in the main text (Sect.11.1). Note that the coordinates in this plot is ΔR.A. (roughly R.A. offset divided by the source declination angle) and Δdecl., not normal offsets.

11.2 For estimating an absolute coordinates

With the task `FRMAP`, rough absolute coordinates of a source (not only maser but also continuum emission source) can be obtained. For this purpose, the visibilities that are calibrated for only clock parameters (residual fringe rates obtained from scans on continuum calibrators). Figure 16 shows the estimate of the absolute coordinate of as the same H_2O maser spot as that shown in the previous section and Figure 15. The position accuracy is much worse than that obtained by the method described in the previous section because the calculated fringe rates are fluctuated due to the atmosphere. However, the accuracy is sufficient for defining the delay-tracing center in the data correlation to avoid the *time-integration smearing*. A position offset of a delay-tracking center with respect to the position of a maser spot selected as position reference shall be within 1″ for JVN/VERA data. It is recommended to ask data re-correlation if provided data has a much larger offset of the delay-tracking center with respect to the position of the position-reference spot than the offset criterion mentioned above (e.g. offset larger than 10″) and if the tapes containing recorded signals have not been degaussed yet.
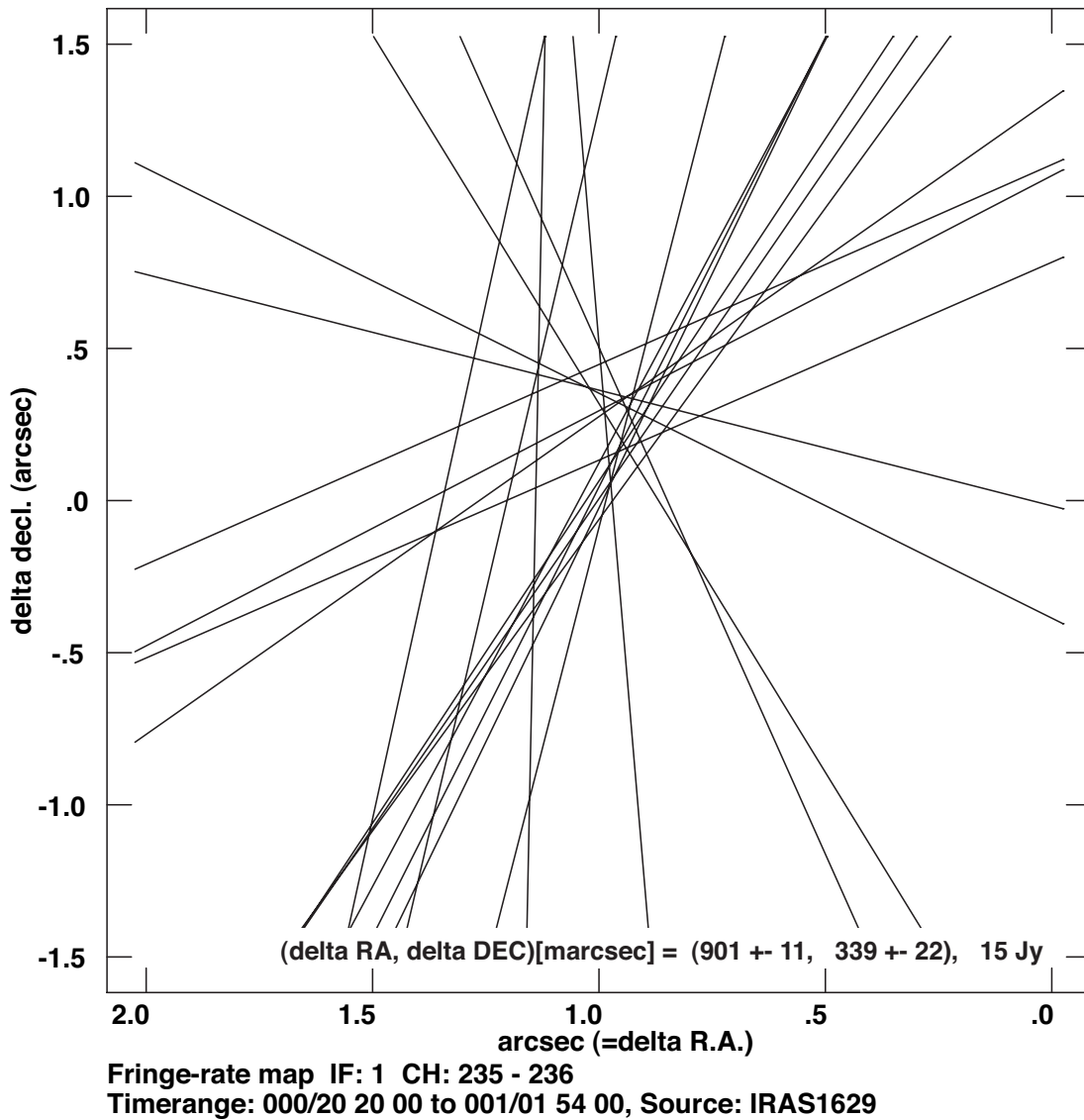
Figure 16: Same as Figure 15, but this is made for estimating absolute coordinates of the same maser spot. The map origin is located at the delay-tracking center in the data correlation.

11.3 For creating a rough-accurately wide-field maser map

For most of JVN/VERA observations for the Galactic H_2O maser sources in star-forming regions, it is necessary to make rough-accurately wide-field maser maps to find true distribution sizes of maser spots. In this case, data in many velocity channels shall be mapped with fringe-rate mapping. In practice, it is difficult or impossible to make maps for all specified velocity channels in only one process of the task FRMAP. This is because the task may be aborted when no maser spot candidate is found in one of the velocity channels. To automatically process all of the velocity channels, the following script may be useful.

```
    task 'frmap';dowait=1
    dotv=-1; i=5; j=500; for k=i to j;bchan=k;echan=k
    bchan=I; echan=I; outfile 'OUTDIR:MAP'//char(i)//'.txt';go;clrstat;end
% Specify a directory as the environment variable OUTDIR before stating AIPS.
```

Although many output text files are generated with this script, they can be edited into one summary file using an editor software or a UNIX shell script.

12 AIPS pipeline: automatic spectral data analysis

A pipelines for data analysis is a sequence of the analysis procedures, which is well defined from the beginning to the end of the data analysis so that all analysts using the pipeline can obtain almost the same analyzed results. A pipeline is used for several purpose in data analysis, not only to obtain a preliminary result but also to repeat the same procedures but with different parameters in the used adverbs for investigating the dependence of analyzed results on the input parameters.

AIPS pipelines for data of JVN/VERA observations have been developed by the author and are now available to users of JVN and VERA. The manual and the scripts of the pipelines shall be downloaded from the following URL:

`http://milkyway.sci.kagoshima-u.ac.jp/~imai/AIPS-analysis.html`.

Figure 17 shows prepared pipelines for data of JVN and VERA. The pipeline for astrometric calibration is now in construction.

Since 2010, the pipeline scripts running on the ParselTongue platform (developed in the Joint Institute for VLBI in Europe) are available from the VCON Wiki Page:

`http://milkyway.sci.kagoshima-u.ac.jp/groups/vcon_lib/wiki/9fbfd/Data_Analysis.html`.

The ParselTongue scripts are Python scripts. They have some extension of functions from previous POPS scripts described in this text and Figure 17 (JVN instead of JNET, MCAL, MMAP). **The author strongly recommend to use the former rather than the latter old scripts**.
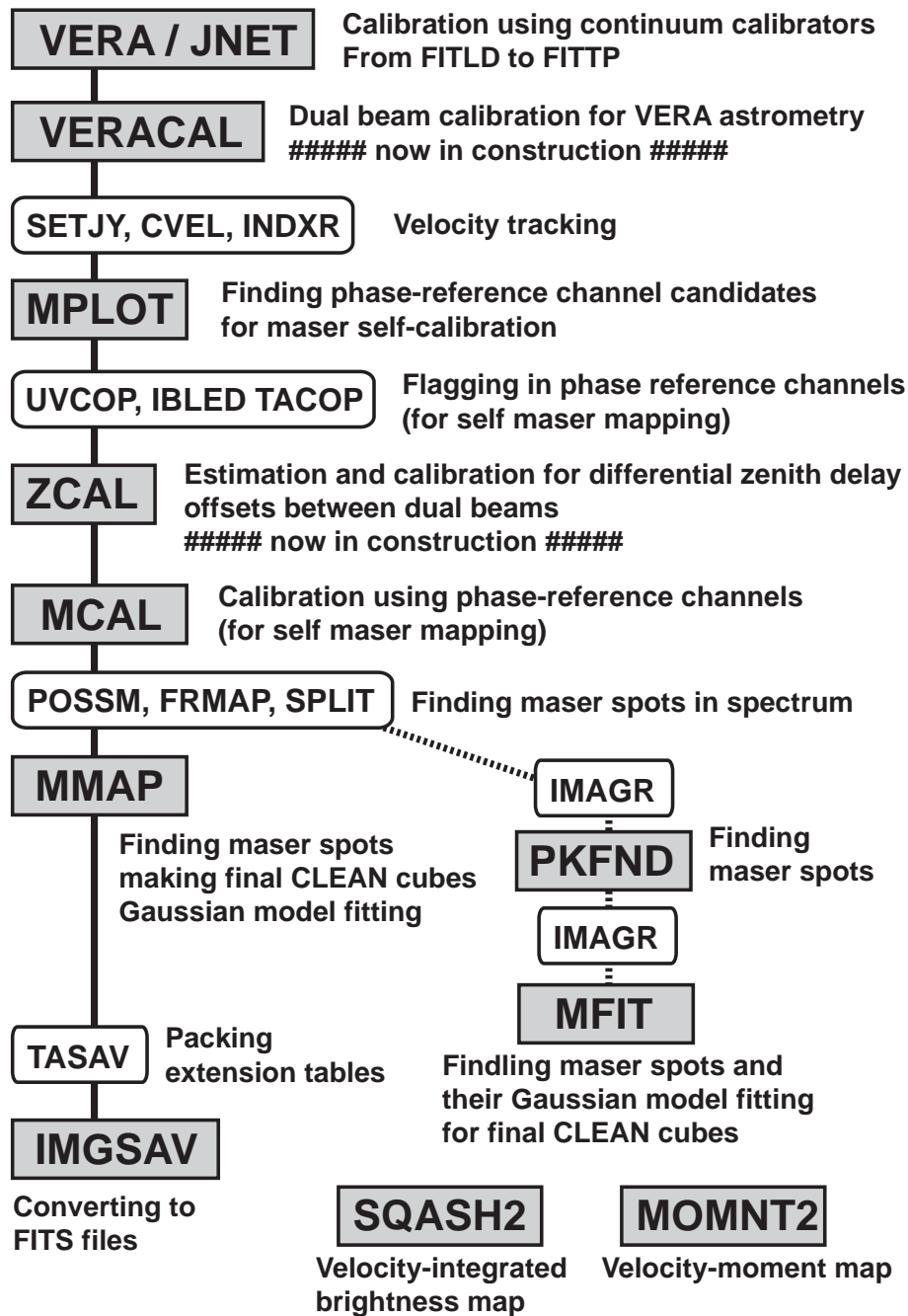
Figure 17: Global flow chart for data analysis using the pipelines for JVN and VERA. A grey block is a sub-pipeline that automatically and successively process AIPS tasks.

This list of references are usefully to deeply understand the principle of VLBI and analysis of VLBI data.

References

[1] NRAO,*AIPS Cook Book*
see `http://www.aips.nrao.edu/cook.html`

[2] Imai, H., et al., 2012, PASJ, 64, 142

[3] Imai, H., 2004, *AIPS Data Analysis Training - Step-by-step recipe –*,
`http://milkyway.sci.kagoshima-u.ac.jp/~imai/aips_practice.pdf`

[4] Imai, H., 2004, *AIPS automatic pipelines for JVN/VERA*,
`http://http://milkyway.sci.kagoshima-u.ac.jp/~imai/pipelines.pdf`

[5] Petrov, L., et al., 2007, AJ, 133, 2487

[6] Thompson, R. A., Moran, J. M., & Swenson Jr., G. W., 2001, *Interferometry and Synthesis in Radio Astronomy, 2nd Edition*, Willy-Interscience (TMS)

[7] Walker, R. C., 1981, Astron. J., 86, 1323

[8] Zensus, J. A., Diamond, P. J., & Napier, P. J., eds., 1995, *Verl Long Baseline Interferometry and the VLBA*

A   Update log of this document

- 6 February 2013: 7the version. minor update, compatible to AIPS version 31DEC13.

- 15 February 2011: 5th version. Changing the URL links. Set. 2.2 was updated. In Sect. 12, the ParselTongue scripts are explained. In Sect. 10.3, the section "Finding contributions from unestimated residual zenith delays in an astrometric result" was replaced by the section "Inverse phase-referencing technique".

- 22 June 2010: 4th version. Correction in Sect. 10.2.

- 15 November 2005: 2nd version.
  Adding topics in Sect. 5.4, 10.2, and DELZN 6.5

- 28 December 2005: 3rd version. Modified Sect. 2.2 and 3.
  A bug in `CLCAL` (`VERSION=31DEC05`) for fringe-fitting solutions was reported (in Sect. 7.7.

- 2 November 2005: 1st version.