Reducing EVN spectral line data

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This guide takes the user through the necessary AIPS tasks required to calibrate and image and OH maser spectral line data using the EVN. This guide uses data from experiment EB063C, which performs spectral line mapping of the OH maser transition at 1665 MHz.

```
************************ START LOADING DATA AND CALIBRATION FILES FROM THE EVN PIPELINE
First, load the data.The data set comprises 252 FITS_IDI files, this number of files is specified
    with 'ncount' and concatenated using 'doconcat'

*******
*FITLD
*******
task 'fitld'
outdisk 2
datain 'DATA:eb063c_1_1.IDI
digicor -1

ncount 252
doconcat 1

go; wait; recat; pcat

JIVE processes all EVN experiments using the EVN data reduction and verification pipeline,
    written in ParselTongue.  Calibration files produced by the pipeline comprise:

    CL2:  Station based gains (ANTAB), parallactic angle corrections and XXX.
    BP1:  Complex bandpass corrections.
    FG1:  Flags for times when stations are off-source before/after scans.

    These tables are contained in the 'TASAV' FITS file which can be downloaded from the archive
    along with the UVFITS data.  We must also load the TASAV files using FITLD.


*******
*FITLD
*******
tget fitld
default
outdisk 2
datain 'DATA:eb063c.tasav.FITS
go; wait

Copy these tables into the UVDATA catalog number.

*******
*TACOP Copy them into our getn
*******
default tacop
indisk 2; outdisk 2
getn 2; geto 1
ncount 1

inext 'cl'
inver 2
go; wait; imh

inext 'bp'
invers 1;
go; wait; imh

inext 'fg'
invers 1;
go; wait; imh

*************************** END LOADING DATA AND CALIBRATION FILES FROM THE EVN PIPELINE
```

```
******************************************************************* START INSPECTING DATA
```

AIPS provides various ways to inspect our data, both graphically and using text.LISTR shows the chronology and durations of the observed scans, in addition to some source information.

```
*******
*LISTR
*******
default listr;
indisk 2
getn 1; opty 'scan'; go; wait
```

PRTAN provides information on the participating stations and ends with a list of stations and their coordinates.

```
*******
*PRTAN
*******
task 'prtan';
default ;
indisk 2; getn 1;
go;wait

Array= EVN Freq= 1661.990000 MHz Ref.date= 03-NOV-2017

Ant 1 = JB BX= -133034.3218 BY= -2124622.3388 BZ= 861061.9175
Ant 2 = WB BX= 182985.7739 BY= -1618807.1813 BZ= 839697.5754
Ant 3 = EF BX= 381230.3278 BY= -1687917.8952 BZ= 675206.8671
Ant 4 = MC BX= 971522.9715 BY= -1541655.2404 BZ= 224335.2584
Ant 5 = O8 BX= -67433.2338 BY= -1150670.7545 BZ= 1124440.0679
Ant 6 = T6 BX= -3286880.0616 BY= 5466695.5804 BZ= -950556.6815
Ant 7 = TR BX= 427097.1726 BY= -854597.3535 BZ= 851812.7402
Ant 8 = SV BX= -170480.3392 BY= -90407.9728 BZ= 1304745.0026
Ant 9 = BD BX= -2014294.3451 BY= 3735670.9015 BZ= 762446.6996
Ant 10 = ZC BX= 1225851.1137 BY= 811784.0313 BZ= 166690.8920
Ant 11 = HH BX= 2415861.7905 BY= -374955.7108 BZ= -6993920.8520
Ant 12 = IR BX= 67573.1516 BY= -570516.0660 BZ= 1134040.5130
```

POSSM is used to look at the amplitudes and phases as a function of frequency. Here we can see RFI and maser emission from our target. RFI can be identified as line-like spikes seen in continuum source scans.In preparation for POSSM, input the rest-frequency of the maser into the source table (SU table) so that POSSM can plot velocity as on the x-axis.

```
*******
*SETJY For the 1665 MHz line
*******
default setjy
indisk 2; getn 1
sources= 'G045.47+0.07''
restfreq 1.665E+09 401800
veltyp 'lsr'; veldef 'radio'; optype 'vcal'
go; wait


*******
*POSSM
*******
tget possm;
default ;
indisk 2; getn 1;

solint 1; aparm (9)=1; dotv 1; nplots 9
bchan 0; echan 0
docal -1; doband -1; flagver 1

baseline 3
stokes 'half'

source 'J2202+4216'
tvinit; go; wait
* Take notice of RFI channels

source 'G045.47+0.07'
tvinit; go; wait
* Take notice of maser channels
```

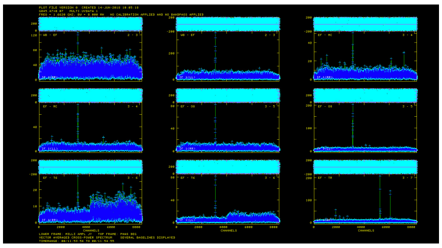

Figure 1: Dynamic spectrum of the water maser emission in S255IR-SMA1 in 2010 from

POSSM is also useful to determine appropriate band-edge ranges to flag.

```
*******
*POSSM Autos, find band edges for flagging
*******
tget possm;
default ;
indisk 2; getn 1; docal -1;
doband -1;
solint 1; aparm (9)=1; dotv 1; nplots 9
bchan 0; echan 0

baseline 0
stokes 'half'

aparm(8)=1

source 'J2202+4216'
tvinit; go; wait
* takes a few seconds
```

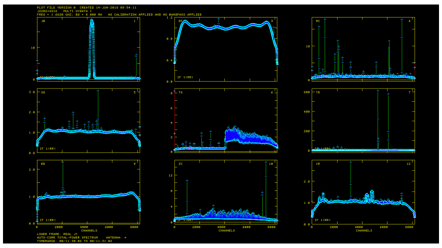

Figure 2: Dynamic spectrum of the water maser emission in S255IR-SMA1 in 2010 from

```
****************************************************************** END INSPECTING DATA
```

```
****************************************************************** START FLAGGING DATA
```

All data (especially L-band) should be carefully flagged to ensure that data represent the signal of our targets, rather than being strongly infuelnced by the RFI in the data and other instrumental / observational defects. Flagging can be done in the time and frequency domain, and also by text commands.In each flagging round we begin by duplicating the current flag table, and adding new flags to the new table.

```
default tacop; indisk 2; outdisk 2; getn 1; inext 'fg'; invers 2; outvers 3; go
* FG1: OFF-SOURCE TIMES, FROM TASAV
```

UVFLG - useful for flagging whole stations, time ranges and channel ranges without plotting to the TV.

```
******  Totally flagging T6, Tr, Wb, Ir
```

```
*UVFLG  based on station feedback and cases of bad bandpass.
******
tget uvflg
default
indisk 2; outdisk 2; getn 1
antennas 6,7,11,12
opcode 'flag'
outfgver 2
go; wait
* FG2: (OFF SOURCE) + (PROBLEMATIC STATIONS)


default tacop; indisk 2; outdisk 2; getn 1; inext 'fg'; invers 2; outvers 3; go
******
*UVFLG   Band edges
******
tget uvflg
default
indisk 2; outdisk 2; getn 1
opcode 'flag'
outfgver 3

******* 10% BAND EDGES
bchan 1; echan 819
go; wait
bchan 7373; echan 8192
go; wait
********
* FG3: (OFF SOURCE) + (PROBLEMATIC STATIONS) + (BandEdges)
```

SPFLG - Very useful graphical flagging task that allows the user to flag a dynamic spectrum of the selected data. It is particularly useful for flagging RFI and identifying weak maser emission. It can be used on auto- or -cross correlation data, the latter can require considerable loading time.

```
default tacop; indisk 2; outdisk 2; getn 1; inext 'fg'; invers 3; outvers 4; go
******   Flagging RFI via interactive clip
*SPFLG   Only flag continuum sources
******
tget spflg
default
indisk 2; getn 1
flagver 4; outfgver 4
doband 1; bpver 1;
dotv 1
stokes 'half'

dparm(6)=30
dparam(2)=2

sources= '-G045.47+0.07''

go; wait
* FG4: (OFF SOURCE) + (PROBLEMATIC STATIONS) + (BandEdges) + (RFI)




*******  Check bandpass and RFI
*POSSM   Cross Correlation; Compare before and after flags
*******
tget possm;
default ;
indisk 2; getn 1; docal -1;
doband 1; bpver 1;
solint 1; aparm (9)=1; dotv 1; nplots 9
bchan 0; echan 0;

baseline 3; stokes 'rr'
source 'J2202+4216'
```

```
flagver -1
tvinit; go; wait

flagver 4
tvinit; go; wait
```

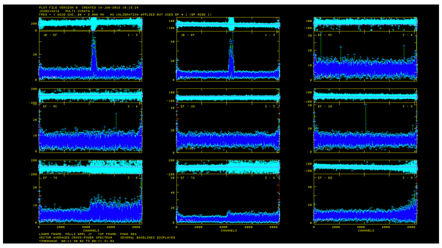

Figure 3: Dynamic spectrum of the water maser emission in S255IR-SMA1 in 2010 from

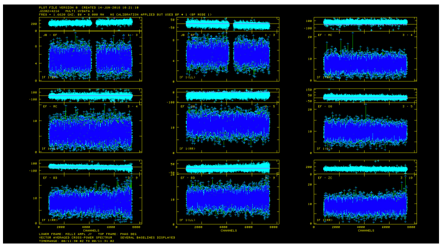

Figure 4: Dynamic spectrum of the water maser emission in S255IR-SMA1 in 2010 from

```
******************************************************************* END FLAGGING DATA
```

In the majority of spectral line experiments, much of the neccessarry calibration is based on the continuum sources and is subsequently applied to the spectral line data. Since continuum data sets do not require the high spectral resolution of maser data sets it is useful to split out the continuum sources using the full bandwidth and some frequency averaging to reduce the file size (and thus speed up data reduction). Furthermore, spectral line emission rarely fills the entire frequency band - thus it may also be possible to split out the spectral line sources including only the desired channel range.Indeed, some observers request two correlator passes: one with wide-band and low spectral resolution for continuum sources and one with narrow-band and high spectral resolution for spectral line sources. In the case of EB063C the data comprise of one 16 MHz band with 8192 channels, thus we produce a ‘continuum’ data set of 16 MHz with 64 channels, and a ‘line’ data set of 100 channels (XXX km/s) centered on the maser emission.

```
******************************************************* START AVERAGING CONT. DATA SET

*******  Averaging down by 128 to get a 64 ch 'continuum' data set
*AVSPC   Applying CL2, BP1 and FG4
*******
tget avspc
default
indisk 2; outdisk 2; getn 2;
doacor 1
avoption 'subs'; channel 128

docal 1; gainuse 2
doband 1; bpver 1
flagver 4
outname 'C2B1F4

sources 'J1800+3848''OQ208''J2202+4216''
go; wait; pcat
```

```
*******  Check bandpass and delays after averaging
*POSSM
*******
tget possm;
default ;
indisk 2; getn 2
aparm (9)=1; dotv 1; nplots 9
doband -1; docal -1
bchan 0; echan 0

stokes 'half'
aparm(8)=1

* Fix the time and y-axis scales
aparm 0, 2 0 1, -180, 180

solint 5;

source 'J2202+4216'
go; wait
```

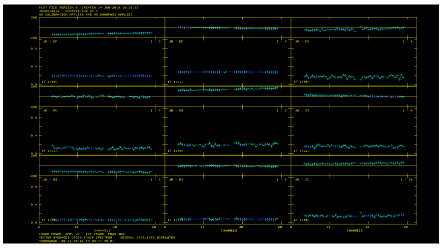

Figure 5: Dynamic spectrum of the water maser emission in S255IR-SMA1 in 2010 from

```
****************************************************** END AVERAGING CONT. DATA SET



****************************************************** START SPLITTING LINE DATA SET
*******
*POSSM Cross Correlation; Maser, find emission range
*******
tget possm;
default ;
indisk 2; getn 1;
aparm (9)=1; dotv 1; nplots 9
stokes 'half'
source 'G045.47+0.07'

baseline 3
solint 1;

doband 1; bpver 1
docal 1; gainuse 2
flagver 3

bchan 3000
echan 3200

tvinit; go; wait

* Maser is at 65-70 km/s.  I'll SPLIT 55 to 75 km/s
    * This range is 3050 to 3150


*******  Maser SPLIT and MULTI
*SPLIT
*******
default split
indisk 2; outdisk 2; getn 1

doband 1; bpver 1
```

```
docal 1; gainuse 2
flagver 3

outclass 'Line
sources= 'G045.47+0.07''
bchan 3050; echan 3149

go; wait; recat; pcat
AIPS 1: 31 63 G045.47+0.07.Line . 1 UV 10-MAY-18 19:12:18

*******
*MULTI
*******
tget multi
default
indisk 2; outdisk 2;
aparm(1)=0.1
getn 31;
sources= 'G045.47+0.07''
go; wait; recat; pcat

AIPS 1: 32 63 G045.47+0.07.MULTI . 1 UV 10-MAY-18 19:14:29


*******
*SETJY For the 1665 MHz line
*******
default setjy
indisk 2; getn 32
sources= 'G045.47+0.07''
restfreq 1.665E+09 401800
veltyp 'lsr'
veldef 'radio'
optype 'vcal'
go; wait



******* CHECK THE LINE DATA
*POSSM
*******
tget possm;
default ;
indisk 2; getn 31;
aparm (9)=1; dotv 1; nplots 9
stokes 'half'
source 'G045.47+0.07'

baseline 3
solint 1;

bchan 0
echan 0

tvinit; go; wait
* Brightest maser in channel 39
```

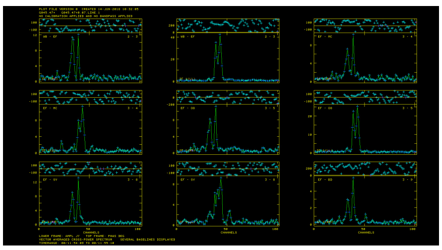

Figure 6: Dynamic spectrum of the water maser emission in S255IR-SMA1 in 2010 from

```
********************************************************* END SPLITTING LINE DATA SET
```

```
******************************************************************* START FRING: DELAY
```
Delays must be obtained using continuum sources and is therefore carried out on the continuum data set. The spectral line data set also required delay calibration - therefore the solutions obtained for continuum sources are copied and applied to the spectral line data.NOTE: that if we wish to apply FRING solutions for the continuum sources to themselves for imaging we desire a short solution interval (less than the coheerence time) and inclusion of PHASE and RATE, however the DELAY solutions that we wish to apply to the maser should not contain this information; one solution per continuum source scan is sufficient, and we discard PHASEs and RATEs. As such, we run FRING twice - one time for each of these different purposes.

```
*******
*FRING
*******
tget fring;
default;
indisk 2; getn 2; docal 0; gainuse 0; refant 3;
calsour 'J2202+4216''J1800+3848''OQ208''
bchan 0; echan 0
aparm 2,-1,0,0,0,0,3
dparm 1,0,0,2

solint 1; solsub 0;
go; wait; imh
* CREATING SN1: TO BE APPLIED TO CONTINUUM SOURCES

solint 10; solsub 0;
go; wait; imh
* CREATING SN2: TO BE APPLIED TO SPECTRAL LINE SOURCES
```

```
*******  Check if solutions are smooth in the time domain
*SNPLT
*******
tget snplt
default;
indisk 2; getn 2;
tvinit; dotv 1; nplots 8
do3col 1
opcode 'ALST'

* SN1: short solint for cont. sources
inext 'SN'; invers 1;

optype 'DELA'
go; wait
```

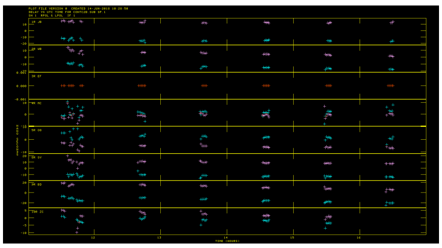

Figure 7: Dynamic spectrum of the water maser emission in S255IR-SMA1 in 2010 from

```
* SN1: long solint for line sources
inext 'SN'; invers 2;

optype 'DELA'
go; wait
```

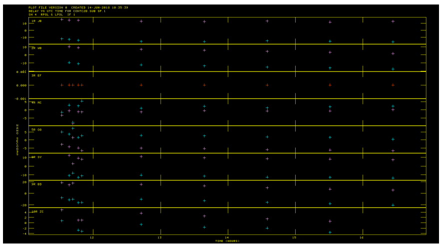

Figure 8: Dynamic spectrum of the water maser emission in S255IR-SMA1 in 2010 from

```
*******  Apply continuum source solutions to themselves
*CLCAL
*******
tget clcal;
default;
indisk 2 ;getn 2; snver 2; gainver 1; gainuse 2; refant 3
interpol 'ambg';
OPCODE ='cali'

SOURCES = 'J1800+3848''
CALSOUR = 'J1800+3848''
go; wait; imh

SOURCES = 'OQ208''
CALSOUR = 'OQ208''
go; wait; imh

SOURCES = 'J2202+4216''
CALSOUR = 'J2202+4216''
go; wait; imh

* CL2: FOR IMAGING CONT. SOURCES

****************************************************************** END FRING: DELAY



*********************************************** START CHECKING REUSLT FOR CONT. SOURCES
*******
*SPLIT
*******
tget split
default
indisk 2; outdisk 2; getn 2;
docal 1; gainuse 2; flagver 1
bchan 0; echan 0
aparm(1)=2

source 'J2202+4216''
go; wait; pcat

* Create new SPLIT
AIPS 1: 7 63 J2202+4216 .VLBACP. 1 UV 09-MAY-18 22:59:25

*******  RadPlot: to identify stations needing better gain corrections
*UVPLT
*******
tget uvplt
indisk 2; getn 2
docal 1; gainuse 3
stokes 'I'

sources 'J2202+4216'
go; wait
```

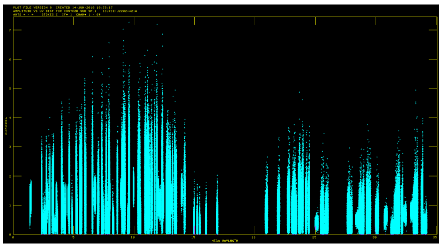

Figure 9: Dynamic spectrum of the water maser emission in S255IR-SMA1 in 2010 from

```
*******
*IMAGR TEST imaging, just to see if flagging and FRING were okay
*******
tget imagr
default
indisk 2; outdisk 2; getn 2
bpver 0;
dotv 1; nchav 0; niter 500
minpatch 128; onebeam -1; maxpixel 0
bchan 0; echan 0;
nchav 64
chinc 64
docal 1; gainuse 3

cellsize 0.001 0.001
imsize 256 256

Stokes 'I'
UVWTFN 'NA'
baseline 0
antennas 0

source 'J2202+4216''
go; wait; recat; pcat
AIPS 1: 5 63 contC2B .IBM001. 1 MA 09-MAY-18 18:09:27
AIPS 1: 6 63 contC2B .ICL001. 1 MA 09-MAY-18 18:09:27
```

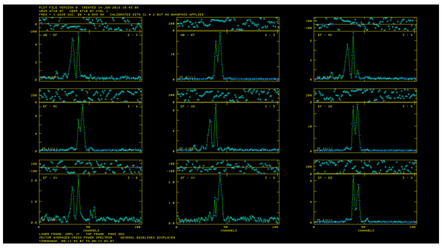

Figure 10: Dynamic spectrum of the water maser emission in S255IR-SMA1 in 2010 from

```
*********************************************** END CHECKING REUSLT FOR CONT. SOURCES
```

If the flagging and calibration done up to this point are satisfactory the FRING DELAY solutions (SN2) can be applied to the spectra line data set.

```
************************** START COPY FRING DELAY SOLUTIONS TO SPECTRAL LINE DATA SET
*******
*TACOP
*******
default tacop
indisk 2; outdisk 2; getn 2; geton 3;
inext 'sn'; invers 2; outvers 1; ncount 1; go


* Zero the PHASE and RATE solutions
```

```
default sncor
indisk 2; getn 33; snver 1
OPCODE 'ZPHS'; go; wait; imh
OPCODE 'ZRAT'; go; wait; imh


*******  Check that DELAYs are smooth and PHASE and RATE are zero
*SNPLT
*******
tget snplt
default;
indisk 2; getn 3;
tvinit; dotv 1; nplots 8
inext 'SN'; invers 1;

do3col 1
opcode 'ALST'

optype 'DELA'; go; wait

optype 'PHAS'; go; wait

optype 'RATE'; go; wait


*******
*CLCAL
*******
tget clcal;
default;
indisk 2 ;getn 3;
snver 1; gainver 1; gainuse 2; refant 3

OPCODE ='cali'; interpol '2pt'
CALSOUR = ''; source '''

go; wait; imh
* CL2: FRING DELAY SOLUTIONS FROM CONT. DATA SET



*******  Check maser coheerence before / after DELAY corrections
*POSSM
*******
tget possm;
default ;
indisk 2; getn 3;
aparm (9)=1; dotv 1; nplots 9; tvinit;
stokes 'half'
baseline 3

bchan 0; echan 0
solint 10;
source 'G045.47+0.07'

docal 1; gainuse 1; go; wait

docal 1; gainuse 2; go; wait
```

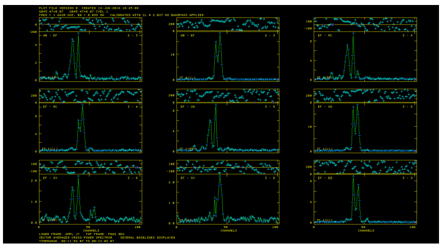

Figure 11: Dynamic spectrum of the water maser emission in S255IR-SMA1 in 2010 from

```
*************************** END COPY FRING DELAY SOLUTIONS TO SPECTRAL LINE DATA SET
```

DELAY solutions have been applied to the spectral line data however the PHASE and RATE (phase fluctuations as a function of time) are still uncalibrated. PHASE fluctuations are dominated by atmospheric effects such as the troposphere and ionosphere. Before completing calibration of spectral line data these fluctuations must be measured and their effects removed from the data, again using FRING.

```
************************************ FRING: PHASE AND RATE FOR SPECTRAL LINE DATA SET
```

Before fringe fitting in the time domain the data should be flagged also in the time domain. The task IBLED is suitable for this.

```
******
*IBLED
******
tget ibled
default
indisk 2; outdisk 2; getn 3
docalib 1; gainuse 3
flagver 1; outfgver 2
source 'G045.47+0.07'
bchan 39; echan 39
tvinit; go; wait


*******
*FRING of the maser
*******
default fring
indisk 2; getn 3
aparm 3, 0, -1, 0
dparm 2 0 100 0

docalib 1; gainuse 3; FLAGVER 2
refant 3

calsour 'G045.47+0.07''
bchan 39; echan 39

solint 1; go; wait
*SN3 - solint 1

solint 30/60; go; wait
*SN4 - solint 30/60
```

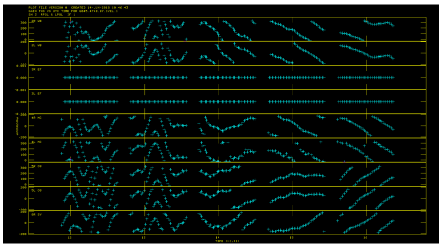

Figure 12: Dynamic spectrum of the water maser emission in S255IR-SMA1 in 2010 from

* Pick the SN table that has clear, connected phase vs time
    * This SN table shouldnt have valid delays so, clip delays

```
*******
*sncor
*******
default sncor
indisk 2; getn 33; snver 4
OPCODE 'CLPD';
SNCORPRM(1) = -1.0E-3
SNCORPRM(2) = 1.0E-3
go; wait; imh

*****Manually flag some rates
tget snedt
default
indisk 2; getn 3
inext 'sn'; inver 4
dotv 1
dodelay 1
go; wait
* makes SN5
```

```
*******
*CLCAL
*******
tget clcal;
default;
indisk 2 ;getn 33; refant 3

interpol 'ambg';
OPCODE ='CALI'

calsour 'G045.47+0.07''
SOURCES 'G045.47+0.07''

snver 5; gainver 3; gainuse 4;
go; wait; imh
* Creating CL4
```

Check the spectral line data at each stage of calibration by applying the various flag, bandpass and calibration tables, in series, and compare the results.

```
*******
*POSSM
*******
tget possm;
default ;
indisk 2; getn 33;
aparm (9)=1; dotv 1; nplots 9
stokes 'half'
source 'G045.47+0.07'

baseline 3
solint 30;

bchan 0
echan 0

aparm 0 1 0 15, -180, 180
docal 1;

grchan 1
gainuse 1
tvinit; go; wait

grchan 2; bchan 2
gainuse 2
go; wait

grchan 3; bchan 3
gainuse 3
go; wait

grchan 4; bchan 4
gainuse 4
go; wait
```

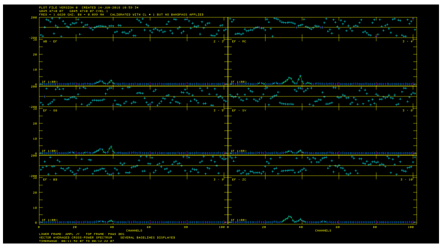

Figure 13: Dynamic spectrum of the water maser emission in S255IR-SMA1 in 2010 from Dynamic spectrum of the water maser emission in S255IR-SMA1 in 2010 from Dynamic spectrum of the water maser emission in S255IR-SMA1 in 2010 from Dynamic spectrum of the water maser emission in S255IR-SMA1 in 2010 from

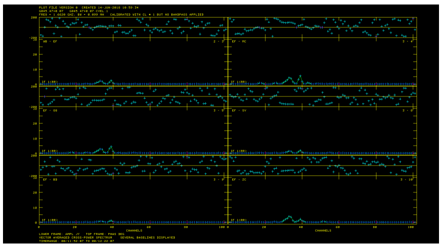

Figure 14: Dynamic spectrum of the water maser emission in S255IR-SMA1 in 2010 fromDynamic spectrum of the water maser emission in S255IR-SMA1 in 2010 from Dynamic spectrum of the water maser emission in S255IR-SMA1 in 2010 from Dynamic spectrum of the water maser emission in S255IR-SMA1 in 2010 from

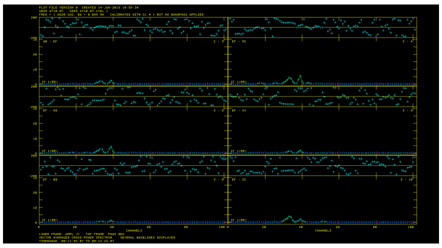

Figure 15: Dynamic spectrum of the water maser emission in S255IR-SMA1 in 2010 fromDynamic spectrum of the water maser emission in S255IR-SMA1 in 2010 from Dynamic spectrum of the water maser emission in S255IR-SMA1 in 2010 from Dynamic spectrum of the water maser emission in S255IR-SMA1 in 2010 from

```
***************************
If satisfied, the final calibration procedure is to correct spectral line data for the effects of
    earth rotation, which causes a small drift in the observed frequency of the spectral line
    emission.  This is corrected with the task CVEL


*******
*CVEL
*******
default cvel
indisk 2; getn 3
outdisk 2
flagver -1

freqid 1
veltyp 'lsr
veldef 'radio
aparm(10)=1 $_Earth center
aparm(4)=1
```

```
sources 'G045.47+0.07''

go; wait; recat; pcat
AIPS 1: 33 63 G045.47+0.07.CVEL . 1 UV 10-MAY-18 19:14:29
```

The final step is to produce an image cube from the calibrated spectral line data set. All calibration tables created up to this point are applied at this stage.

```
*******
*IMAGR
*******
tget imagr
default
indisk 2; outdisk 2;
bpver 0;
nchav 0; niter 500
minpatch 128; onebeam -1; maxpixel 0

Stokes 'I'
UVWTFN 'NA'

cellsize 0.002 0.002
imsize 2048 2048

source 'G045.47+'
getn 57

docal 1; gainuse 2

dotv -1

bchan 0; echan 0

go; wait; recat; pcat
AIPS 1: 58 63 MasAll .IBM001. 1 MA 10-MAY-18 22:57:56
AIPS 1: 59 63 MasAll .ICL001. 1 MA 11-JUN-18 11:13:48
```

Sit back and admire a movie of your image cube.

```
getn 59; tvmovie
```

The guide presented here takes the user though the very most basic approach to EVN spectral line data reduction. More complex observing strategies require more sophisticated data reduction - for assistance in planning such observations, and in reducing the resulting data please <u>do not hesitate</u> to contact the JIVE support scientists. It is our pleasure to work with EVN users, new and old.

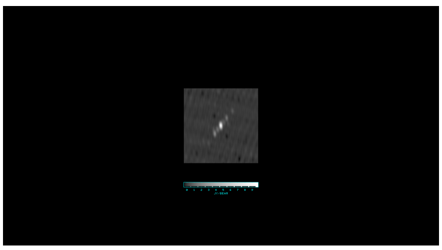

Figure 16: Dynamic spectrum of the water maser emission in S255IR-SMA1 in 2010 from