## (1) Open MIR/IDL

\$ idl

## (2) Read the data into MIR

Read in only the 240GHz to ensure there's sufficient memory for processing. It is always advisable to process each receiver separately.

scaled by any rebin factor.

IDL> readdata, dir='mir2018bin4', rx='240'

View a summary of the data.

IDL> select

### (3) Flag pointing data

Pointing data will have an integration time < 6 seconds. It used to be sufficient to select scans that were shorter than this using dat\_filter and then flag them.

IDL> result=dat\_filter(s\_f, '"integ" lt "6"', /reset)

IDL> flag, /flag

Since mid 2019, the potential science scan length has been considerably shortened, meaning it is not reliable to blindly flag the pointing scans in newer data based on scan length. Instead a pointing flag has been implemented, and dat\_filter can be used like so.

IDL> result=dat\_filter(s\_f,'"pointing" lt "1"',/reset) IDL> flag, /flag

see if any pointings need flagging and what the scan lengths are.

If you are unsure, try flagging by pointing option first. If this does not return any results examine your data to

Afterwards, you must re-select only the positive weighted (unflagged data). Some scans will have been flagged during the observation (e.g. while the antennas are switching sources) so this will exclude them also.

IDL> select,/pos,/res

(4) Inspect the data visually

## Plot the pseudo-continuum channel [1]. This is an average of the spectral channels across all baselines for

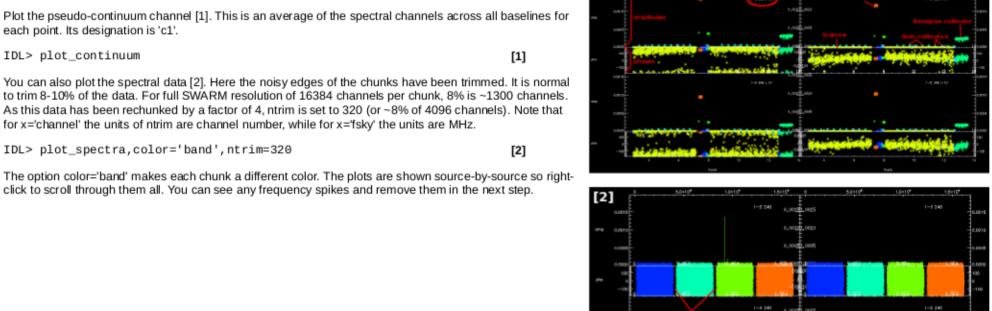
each point. Its designation is 'c1'.

IDL> plot\_continuum

[1] You can also plot the spectral data [2]. Here the noisy edges of the chunks have been trimmed. It is normal to trim 8-10% of the data. For full SWARM resolution of 16384 channels per chunk, 8% is ~1300 channels. As this data has been rechunked by a factor of 4, ntrim is set to 320 (or ~8% of 4096 channels). Note that

for x='channel' the units of ntrim are channel number, while for x='fsky' the units are MHz. IDL> plot\_spectra,color='band',ntrim=320

click to scroll through them all. You can see any frequency spikes and remove them in the next step.



#### (5) Check for spikes The MIR task, uti\_checkspike, will identify and optionally fix spikes in the frequency data. Alternatively, this

flat spectral signature.

can be done manually which is more labor intensive but may be faster. This example runs a couple of loops of uti\_checkspike, then manually removes a remaining spike.

For uti\_checkspike a source must be specified. This source will be used as a template to identify the spike positions. As such, choose a source like a gain calibrator quasar, or the bandpass calibrator, which has a

IDL> uti\_checkspike, source='3c84', ntrim=320, /fix The /fix option applies the corrections for each spike identified. When a channel is flagged, it is flagged for all sources. By default the spectra are averaged over all baselines, but the option /baseline finds the spikes

in each baseline independently. Be warned the /baseline option takes a long time to complete, and with the very high resolution of SWARM it is often not necessary to worry about losing the occasional channel.

Another option is threshold; this is the rms threshold above which a spike is identified. This is 10 by default by can be changed using threshold=X. Checking the spectral plots again show some spikes remaining [3]. IDL> plot\_spectra,ntrim=320 [3][4]

Repeatedly run uti\_checkspike so it iterates down [4]. The default threshold over which emission qualifies

Some small spikes remain which can be fixed by hand. First you must select the chunk in which the spike

as a spike is 10-sigma. This can be changed with the option threshold=x.

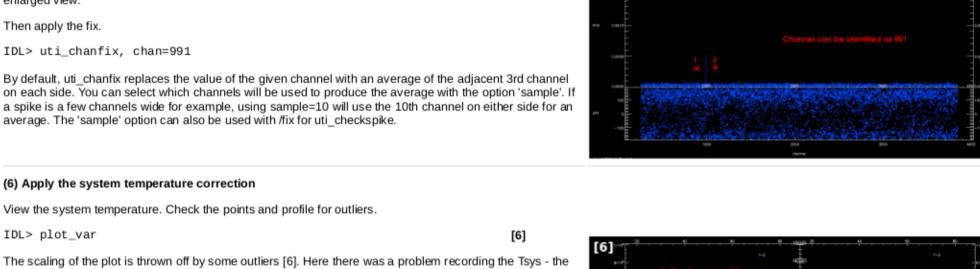
falls; in this case chunk s3. This must be done to ensure it plots the correct channel numbers on the x-axis. IDL> select,/p,/re,band='s3',sideband='l' IDL> plot\_spectra,ntrim=320

By repeatedly zooming in on the first panel (left-click on the panel, then left-click on ether side of the area to be enlarged), the channel containing the spike can be identified as 991 [5]. Right-click to exit from the enlarged view.

Then apply the fix. IDL> uti\_chanfix, chan=991

By default, uti\_chanfix replaces the value of the given channel with an average of the adjacent 3rd channel on each side. You can select which channels will be used to produce the average with the option 'sample'. If

(6) Apply the system temperature correction



[4]

[5]

data itself are unaffected. Check underlying causes by looking at the observing report to see if any issues were reported.

View the system temperature. Check the points and profile for outliers.

average. The 'sample' option can also be used with /fix for uti\_checkspike.

To re-scale the y-axis select data with the range of Tsys to be plotted (here <1000K); then plot that subset [7]. Now points that are offset from the standard curve become visible. Remember to re-select all the data afterwards.

IDL> result=dat\_filter(s\_f, ' "tssb" gt "1000" and "wt" gt "0"',/reset)

IDL> plot\_var IDL> select,/pos,/re All these points can be fixed using the MIR task uti\_tsys\_fix. This refits the Tsys for points below 'high=X', and above 'low=Y'. It then replaces any points that differ from the re-fitted curve by more than 'loose=Z'.

IDL> uti\_tsys\_fix, high=500,loose=100,/refit Checking the result shows a few Uranus points which could not be fit to the curve.

In this case there is the option to replace the system temperature for the entire antenna with those from a

IDL> tsys\_ant IDL> tsys\_replace ;x=3

;y=6 IDL> tsys\_bsl

With the system temperature plots looking normal the correction can be applied. IDL> apply\_tsys Then regenerate the continuum channel.

IDL> plot\_var

IDL> uti\_avgband

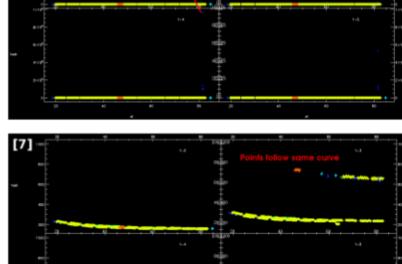
Enter source and new cal code. eg: 3C273 YES

or hit Return if all the sources are correctly specified

different antenna - in this case replacing antenna 3 with 6.

Apply the phase based bandpass first. For SWARM data use either no or minimal smoothing as there is a lot of detailed structure in the baseline. Note that the pass\_cal command treats each sideband (and

(7) Perform bandpass calibration



#### receiver) independently. IDL> pass\_cal,cal\_type='pha',preavg=8, smoothing=1, ntrim=320, tel\_bsl='telescope', refant=4

Check: Found a total of

tel\_bsl='telescope', refant=4

name: 3c279

Set which sources will be used as calibrators and set the calibrator fluxes The flux should be in Jy at the frequency of the observation These are the sources and their current passband codes name: 0449+113 passband cal: NO

[8]

[9]

[10]

[11]

[11]

6 different sources in the data set.

passband cal: NO name: Science name: 0510+180 passband cal: NO passband cal: YES name: 3c84 name: uranus passband cal: NO

passband cal: YES

At this stage there is the option to accept the sources it suggests or add/remove any. Usually the bandpass calibrator(s) is identified as such in the software (and listed as YES) but not always. Add or remove sources by typing 3C273 YES or 0449+113 NO.

Once it has generated a solution it will create a plot of the fits [8]. Right-click through the solutions for each baseline. After exiting the plot window it will prompt to apply the suggested solution to all other sources.

If pass\_cal fails reporting insufficient flux, try adding more sources to the list (if suitable ones are available),

or increasing the 'preavg' value to boost the signal-to-noise. Next repeat the process in the same way for amplitude [9]. IDL> pass\_cal,cal\_type='amp',preavg=8, smoothing=1, ntrim=320,

Note the ntrim and preavg values have been scaled to account for this data having been rebinned by 4. For unbinned data use 1300 and 32 respectively. (8) Save the data

Select all unflagged data, regenerate the continuum and save in MIR format. It is important to save the

dataset before starting flux measurement as the phases will be irreversibly disrupted.

# IDL> mir\_save, 'mir2018\_rx240.mir' (9) Flux measurement

a phase of ±180°.

/preavg,/non\_point

IDL> plot\_continuum,x='int'

lower).

IDL> select,/p,/re IDL> uti\_avgband

Do this section separately for each receiver and sideband. They will each have different scaling factors. Select all the calibrator sources and one of the sidebands.

The /non-point option takes into account the size of planets, on some baselines resolved planets may have

IDL> gain\_cal,cal\_type='pha',/connect, tel\_bsl='telescope', refant=4,

IDL> select,/p,/re, band='c1', source='['0449+113', '0510+180', '3c84', '3c279', 'uranus'] Apply the gain\_cal in phase first with the /connect option to force the phases to zero for every scan [10].

Make sure the data have been saved!

/non\_point : all yes Next run amplitude based gain\_cal [11]. Here, only say YES to the flux calibrator (usually a planet). Using

required to make the flux calibrator match its expected flux.

within an hour or two of the flux calibrator (here the first 200 scans).

Scalar Average or Vector Average ? [S ]:

Nscans

122

Flags

For comparison here are the result for scalar average.

IDL> result=dat\_filter(s\_f,'"el" ge "40" and "el" le "50"')

: all no : uranus yes Note: the task sma\_flux\_cal performs a similar task to the amplitude gain calibration above.

Now measure the resulting fluxes of the gain calibrators. The conditions (pointing/opacity/system) should be

the /non-point option it will retrieve its flux. Note that if your flux calibrator is not a planet or moon, you can provide the flux when prompted - e.g. mwc39a yes 1.8. This command will scale every source by the level

IDL> gain\_cal, cal\_type='amp',x='hours',poly=0,tel\_bsl='telescope',refant=4,

as similar as possible between the flux calibrator used to scale the data in the previous step, and the gain calibrator whose flux you are now calculating. To achieve this there are a couple of options available. Either select only scans taken close in time to the flux calibrator, or select only scans taken at a similar elevation. Sometimes only one of these options is available to you. The pointing model is less reliable at very high and low elevations so it always worth removing any elevation extremes (<30° and >70°).

IDL> select,int=[0,200],band='c1',source='-Sci',sideband='u',/pos,/res To chose scans that are at a similar elevation use the result command (note that 'select' is just a wrapper for 'result=dat\_filter'). Do not use the /reset option here or you will lose any previous selections (calibrators only, upper sideband, first 200 integrations).

Now measure the calibrated flux with flux\_measure. It will return either vector or scalar values for each source included in the selection. (Vector terms adjust for phase noise so the amplitudes will be slightly

To choose scans close in time first plot the continuum with x as integration number, then select integration

IDL> flux\_measure % Compiled module: FLUX\_MEASURE. % Compiled module: SMA\_FLUX\_MEASURE. 13806 passed in list

SNR

307

meantime

8.02

REAL

0.3791

[14]

0510+180 81 1.4371 406 8.07 1.4371 8.7523 644 7.93 8.7523 3c84 14 3c279 98 6.9313 503 13.18 6.9313

Flux(Jy)

0.3791

Scalar average: Flux(Jy) meantime Source Flags Nscans SNR REAL 0449+113 122 0.3836 313 8.02 0.3791 0510+180 81 1.4383 407 8.07 1.4371 3c84 14 8.7524 644 7.93 8.7523 3c279 98 6.9338 508 13.18 6.9313

Now repeat for the lower sideband. (10) Gain calibration on the restored data

calibration.

the amplitude gain calibration step [11].

to 0 for the selected gain calibrators.

: 0449+113 yes 0.3791

Vector average:

Source

0449+113

IDL> mir\_restore, 'mir2018\_rx240.mir' IDL> select,/p,/re Select just the science and gain calibrator sources along with the sideband you are going to apply the corrections to first. IDL> select,/pos,/res,source=['Sci', '0449','0510'],sideband='u'

refant=4 : 0449+113 yes : 0510+180 yes

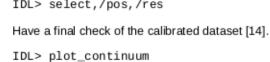
Next apply the amplitude based gain calibration - this time supply the fluxes reported by flux\_measure [13]. This will scale the amplitudes of all the sources selected by the scaling factor determined from the real flux of the gain calibrators. IDL> gain\_cal,cal\_type='amp', x='hours', smoothing=0.6,/preavg, tel\_bsl='telescope',refant=4 [13]

0510+180 ves 1.4371 Now select the lower sideband data and re-run the gain\_cal task to apply those corrections.

(10) Apply the Doppler tracking error fix Data taken between April 4th, 2011 and April 3rd, 2019 were affected by an error related to Dopplertracking of data, which will affect spectral line measurements of features smaller than 1 km/sec in width. The effect is extremely small for most tracks, however the MIR task 'uti\_hayshft\_fix' can be used to make

IDL> uti\_hayshft\_fix (11) Save the calibrated data

Reselect all the data IDL> select,/pos,/res



the correction.

Then save the data in MIR format.

IDL> autofits, source='Science'

IDL> mir\_save, "mir2018\_rx240\_cal", /new Export continuum and spectral data to MIRIAD.

IDL> select,/pos,/re IDL> idl2miriad, dir='Science\_cont\_240u.uv', source='Science', sideband='u', /cont IDL> idl2miriad,dir='Science\_line\_240u.uv',source='Science',sideband='u'
IDL> idl2miriad,dir='Science\_cont\_240l.uv',source='Science',sideband='l',/cont
IDL> idl2miriad,dir='Science\_line\_240l.uv',source='Science',sideband='l'

Save the data in uvfits format to be read by CASA. IDL> select,/p,/re

IMAG 0.0001 -0.0001 -0.0001 -0.0021 IMAG 0.0001 -0.0001 -0.0001 -0.0021 If the flux calibrator is included in the list you will see the scalar value for it will be the flux it was scaled to in 12 With known fluxes for the gain calibrators, restore the previously saved file and perform time based gain Apply the phase based gain\_cal using /preavg and /connect [12]. The /connect option forces all the phases IDL> gain\_cal,cal\_type='pha',x='hours',/connect,/preavg, tel\_bsl='telescope', 13

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