An Introduction to JCMT Heterodyne Data Reduction

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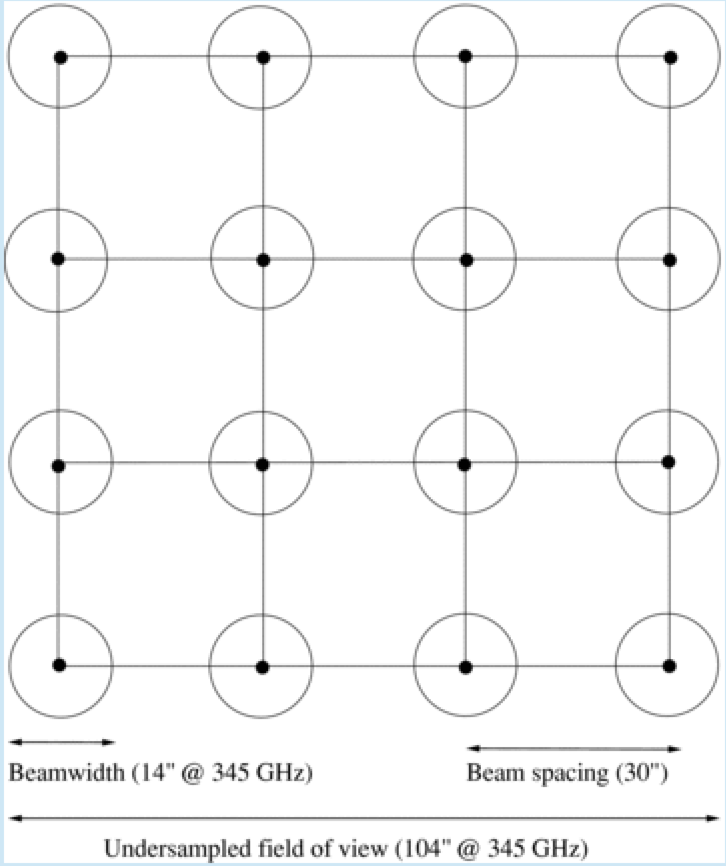
JCMT Heterodyne Instruments:

- RxA3(m) – Single pixel receiver 230 GHz
- HARP – 16 pixel 345 GHz array receiver
- ACSIS multi-channel digital spectrometer

How to reduce the raw data obtained from CADC:

- Observing modes
- Data files
- Pipeline reduction
- Recipes
- Inspecting the results with GAIA and SPLAT

HETERODYNE OBSERVING MODES



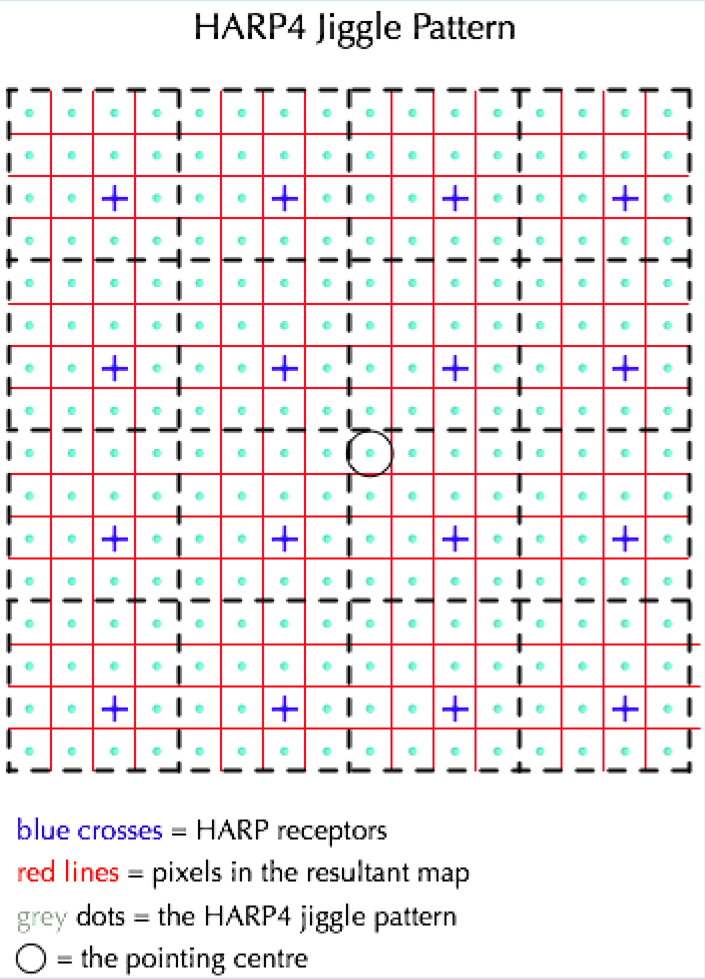
HARP array

Stare (also called grid) - single position integration:
1 pixel (RxA3)
16 pixels (HARP) receptors H00 - H15

Jiggle-map (mostly used for HARP):

- moves secondary mirror to fill in the 30” spacing between HARP receptors to make a 2'x2' map.

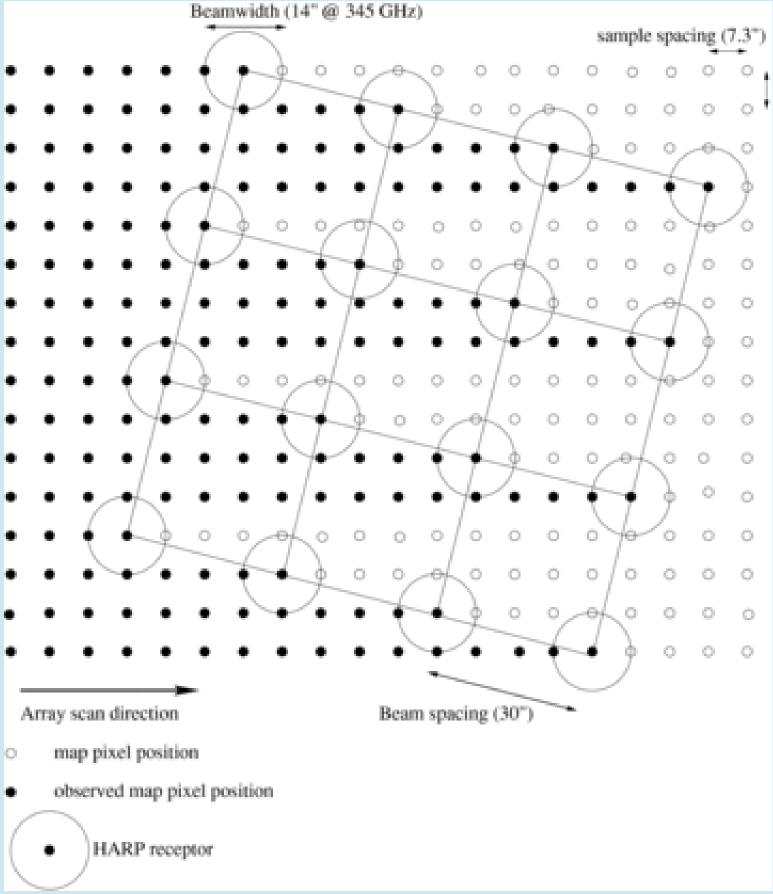
- Two main spacings: HARP4 – 4x4 jiggle, undersampled. 7.25” pixels
  HARP5 – 5x5 jiggle, oversampled, 6” pixels



Raster:

- Scan or 'on-the-fly' technique.

HARP: array rotated at 14.04 deg to scan direction, with 7.3” pixels often repeated with 90 deg rotation to create 'basket-weave' maps



ACSIS spectrometer options:

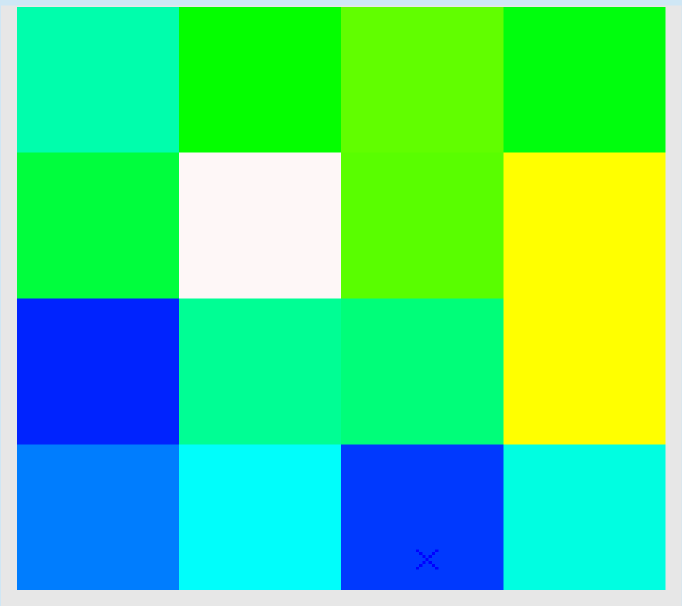
- 250 MHz bandwidth; spectral resolution 0.0305 MHz
- 1000 MHz bandwidth; spectral resolution 0.488 MHz
- 1 - 4 subbands (RxA3)
- 1 - 2 subbands (HARP) (for 2 subbands resolution 0.061/0.977 MHz)

e.g. for simultaneous observations of $C^{18}O$ and ^{13}CO

for 420 MHz (2x250) and 1800 MHz (2x1000) modes the two subbands have to be merged in the reduction

Example: G34.3 integrated intensity images

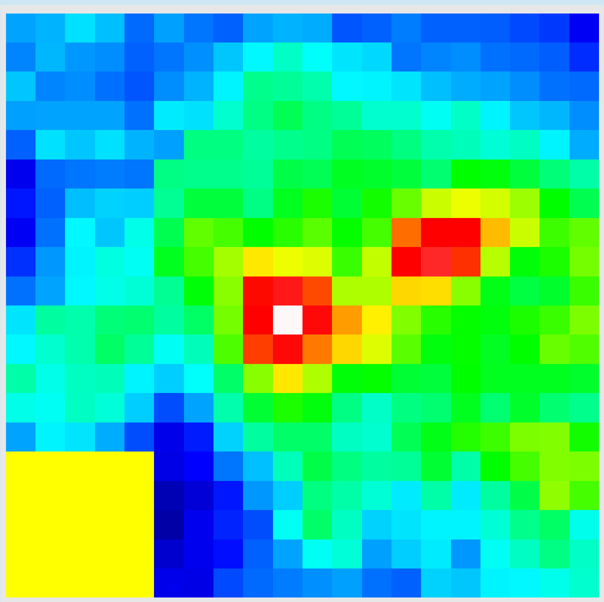
HARP Stare



2 arcmin

30” pixels

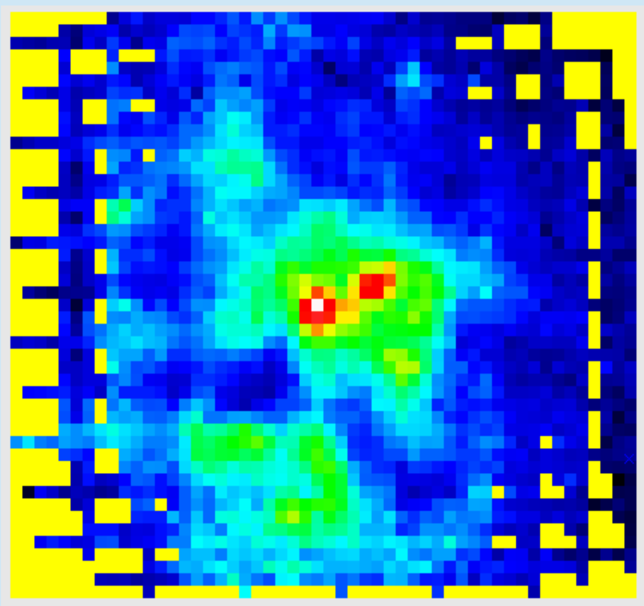
HARP Jiggle-map



2 arcmin

6” pixels

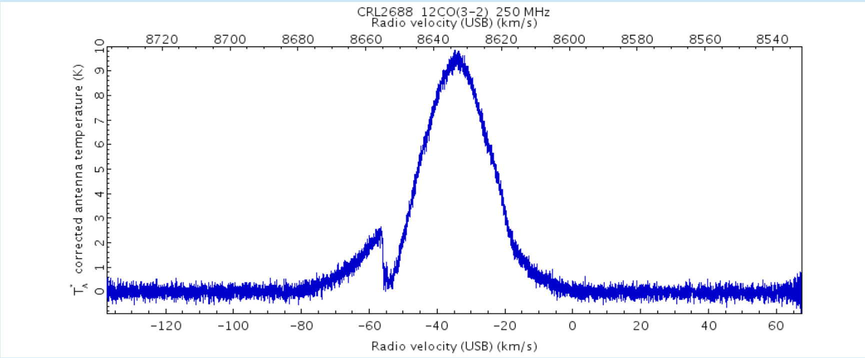
HARP Raster map



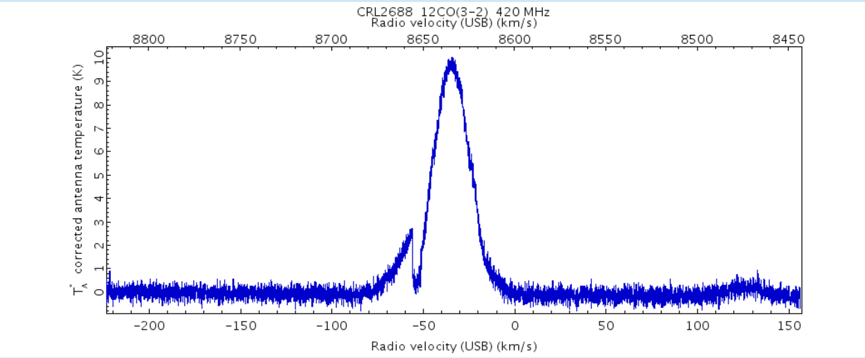
6 arcmin

7.25” pixels

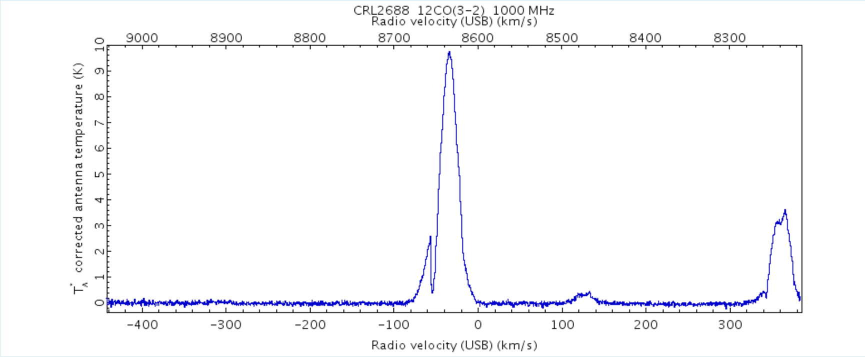
CRL2688 ACSIS examples (HARP)



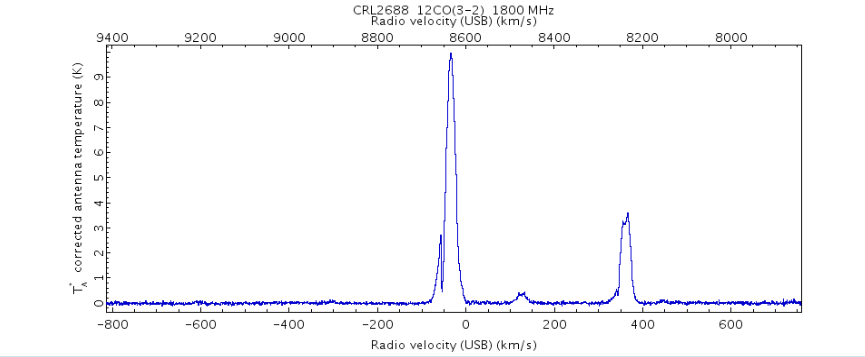
250 MHz (0.0305 MHz)



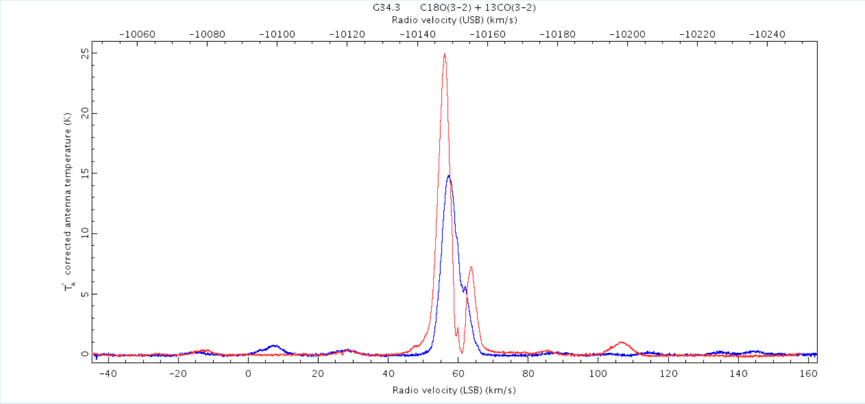
420 MHz (0.061 MHz)



1000 MHz (0.488 MHz)



1800 MHz (0.977 MHz)



G34.3 2x250 MHz (0.061 MHz)
$^{13}CO(3-2)+C^{18}O(3-2)$

Filenames

One subband:
a20140201_00006_01_0001.sdf

Two subbands:
a20140201_00006_01_0001.sdf
a20140201_00006_02_0001.sdf

Large maps:
a20140201_00006_01_0001.sdf
a20140201_00006_01_0002.sdf
etc

a (ACSIS)
UT-date
Scan number
Subband number
File number

Easiest is to make a text file myfiles.list with a list of file names to be reduced.

Files are cubes with dimensions Velocity/Receptor/Time, viewable with GAIA.

How to reduce

Quick, using SMURF:
> smurf
> makecube in=^myfiles.list out=fileout.sdf autogrid
(results in a raw cube with default pixels, no processing)
Further reduction with KAPPA commands (and/or via GAIA is possible, but not easy)

Better use

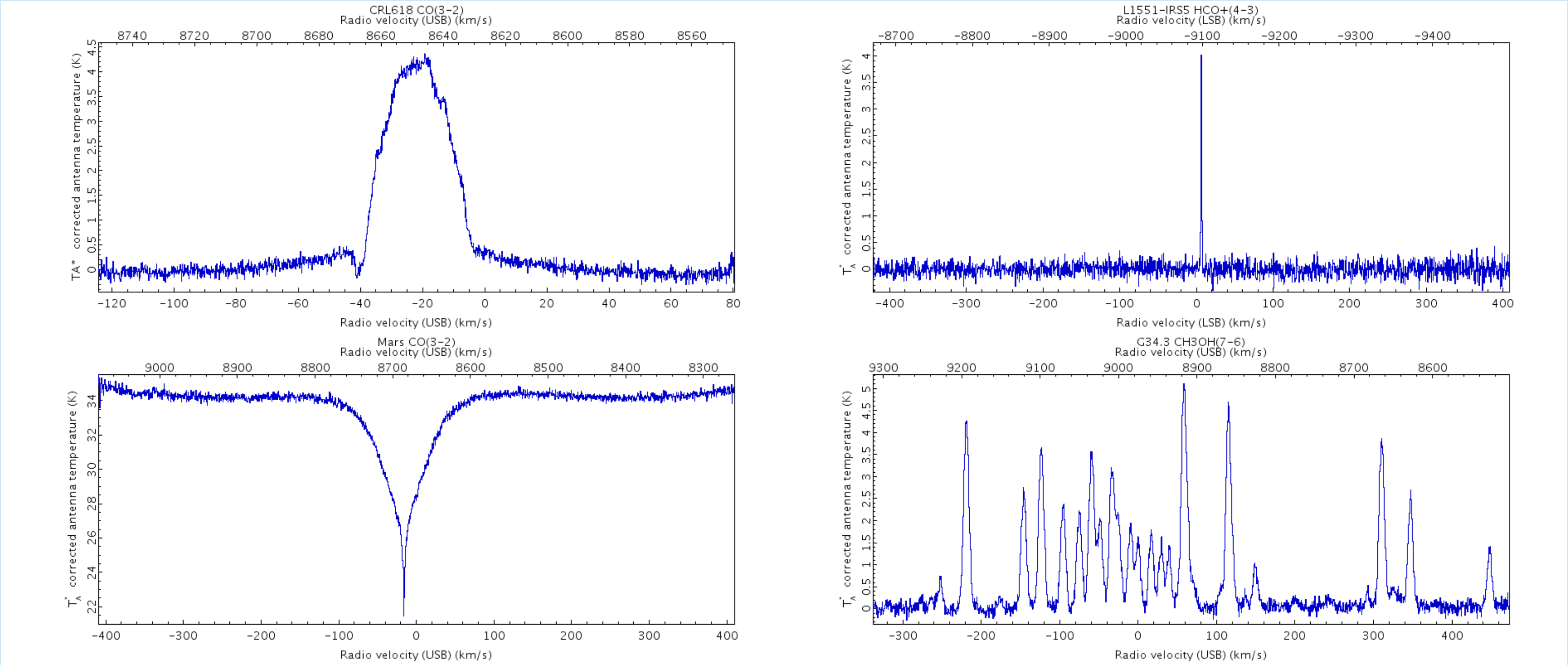
ORAC-DR pipeline

ORAC-DR uses recipes describing what to do with the data.

Type of recipe depends on the kind of spectra expected in the source.

REDUCE_SCIENCE (default = REDUCE_SCIENCE_GRADIENT)
REDUCE_SCIENCE_NARROWLINE
REDUCE_SCIENCE_BROADLINE
REDUCE_SCIENCE_GRADIENT
REDUCE_SCIENCE_LINEFOREST
REDUCE_SCIENCE_CONTINUUM
REDUCE_SCIENCE_STANDARD
REDUCE_SCIENCE_FSW (more listed in Sun260)

Default recipe for observation written to FITS header via JCMTOT:
>kappa
>fitslist a20140201_00006_01_0001.sdf | grep ORAC
> RECIPE = 'REDUCE_SCIENCE'   / ORAC-DR recipe



Examples of typical spectra for broadline, narrowline, continuum, lineforest recipes
Narrowline: linewidth < 8 km/s
Gradient: 8 km/s < linewidth < 40 km/s
Broadline: linewidth > 40 km/s   (but those limits are not well-defined)

Recipe	Description of emission	Baseline method
Narrowline	One or more narrow lines are expected across the band. Select this recipe if the expected lines are less than about 8 km/s wide.	Smoothing: Spatial = 5x5 pixels Frequency = 10 channels
Broadline	This recipe is designed for wide lines that extend over a large fraction of the band. The line is typically too weak to see in a single observation so a pre-determined baseline window and linear baselines are used.	Uses the outer 10% of each end of the spectra to fit a first-order polynomial.
Gradient	Typically one moderately wide line is expected, for which the center velocity varies significantly across the field. The expected lines should be wider than about 8 km/s and probably not wider than 20% of the available bandwidth.	Smoothing: Spatial = 3x3 pixels Frequency = 25 channels
Lineforest	A forest of lines is expected across the band. Optionally separate moments map for each line are created.	Smoothing: Spatial = none Frequency = 10 channels

Example:

REDUCE_SCIENCE_NARROWLINE – what is it doing – see Sun260:

This recipe is used for advanced narrow-line ACSIS data processing.

- Creates a spatial cube from the raw time series data.
- Working on the raw time series data, it subtracts a median time-series signal, thresholds the data,
- Trims the ends of the frequency range to remove high-noise regions.
- Receptors with non-linear baselines and spectra affected by transient high-frequency noise may be rejected.

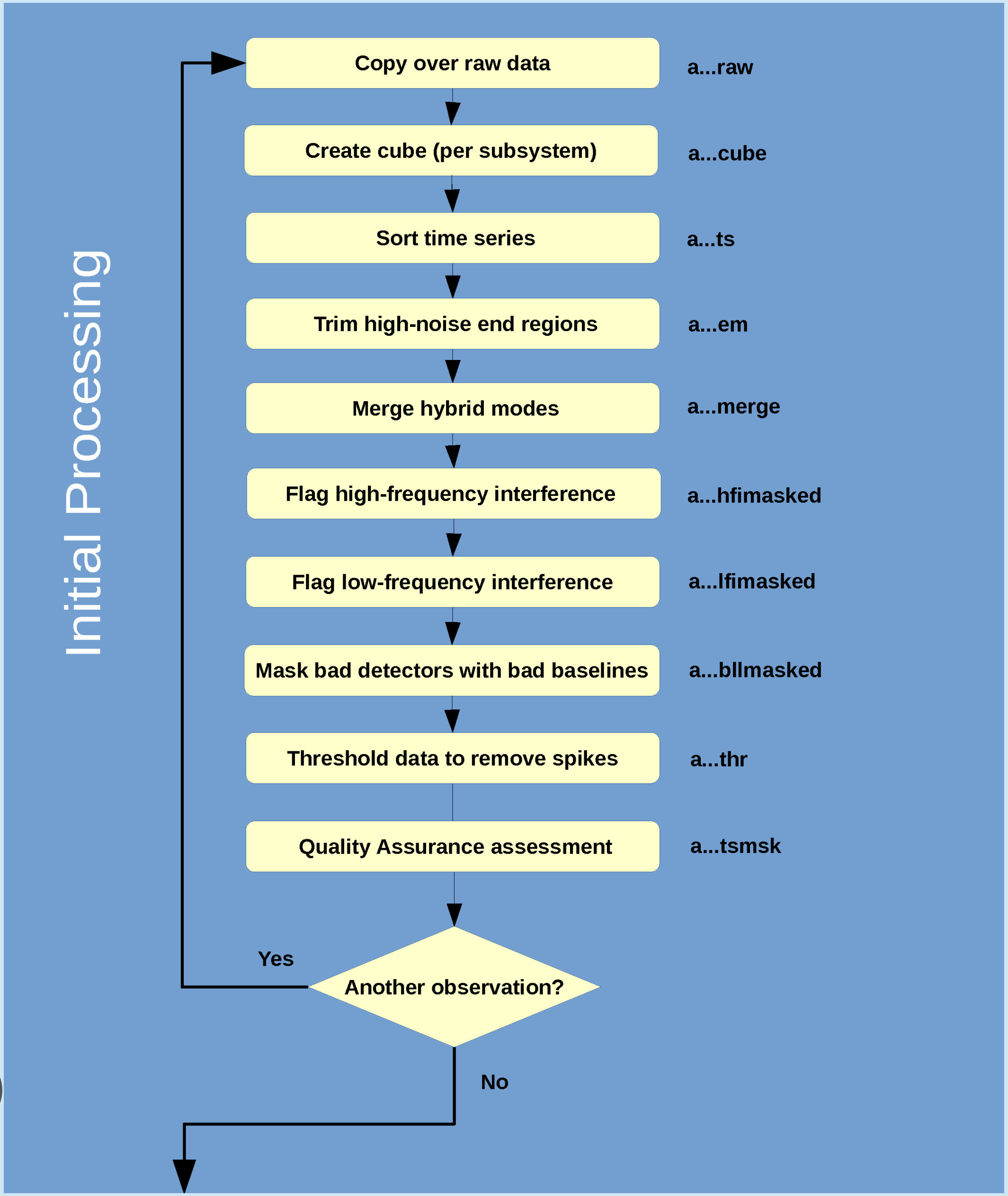
- After the time-series manipulation has been done to every member of the current group, every member is run through MAKECUBE to create a group spatial cube.
- This cube then has its baseline removed through a smoothing process, and moments maps are created.

- A baseline mask formed from the group cube is run through UNMAKECUBE to form baseline masks for the input time-series data, which are then baselined.
- The baselined time-series data are then run through MAKECUBE to create observation cubes, from which moments maps are created.

(at the moment the description of the broadline recipe is incomplete)

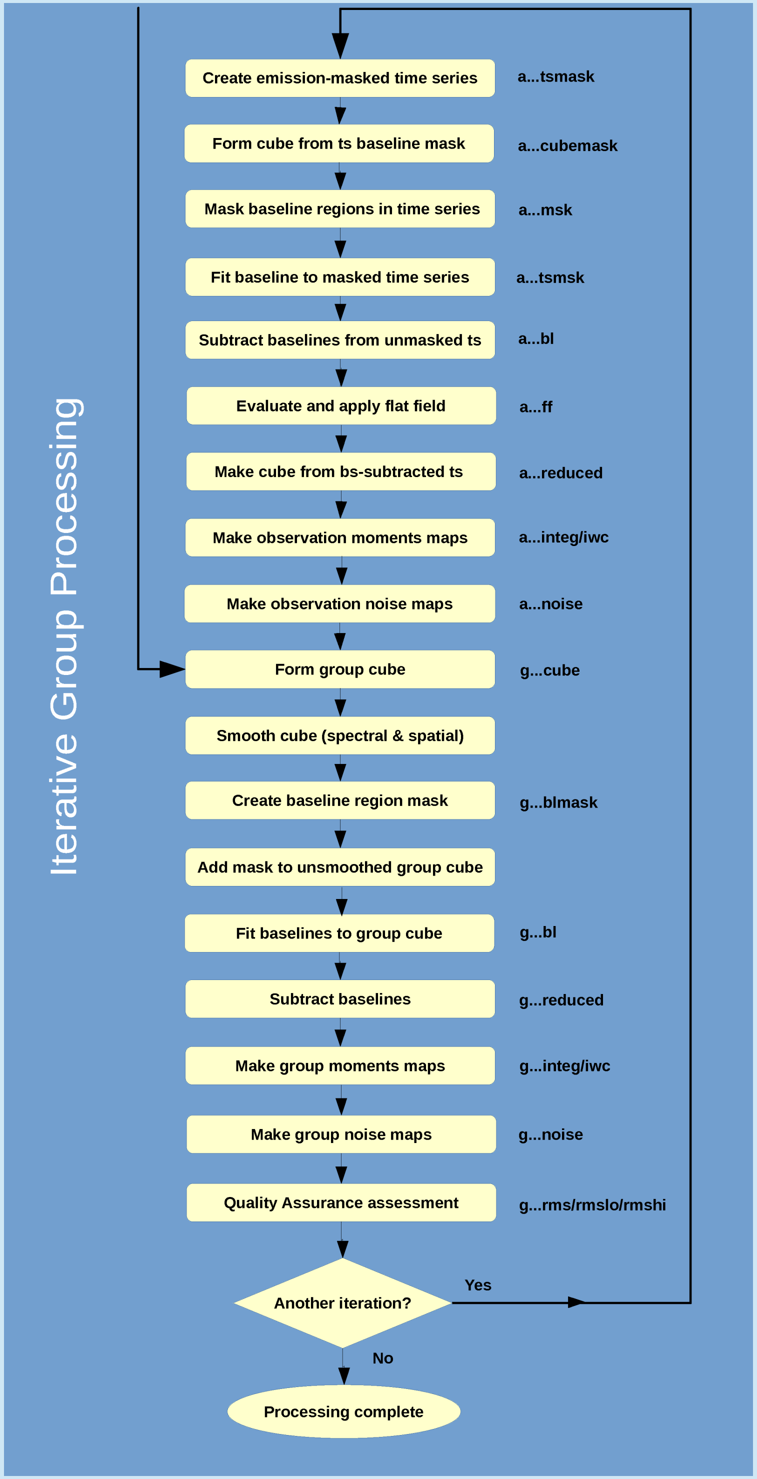
The pipeline

- oracdr_acsis
- oracdr -help
- setenv ORAC_DATA_IN (pwd)
- oracdr -file myfiles.lst
- (will use recipe from header)



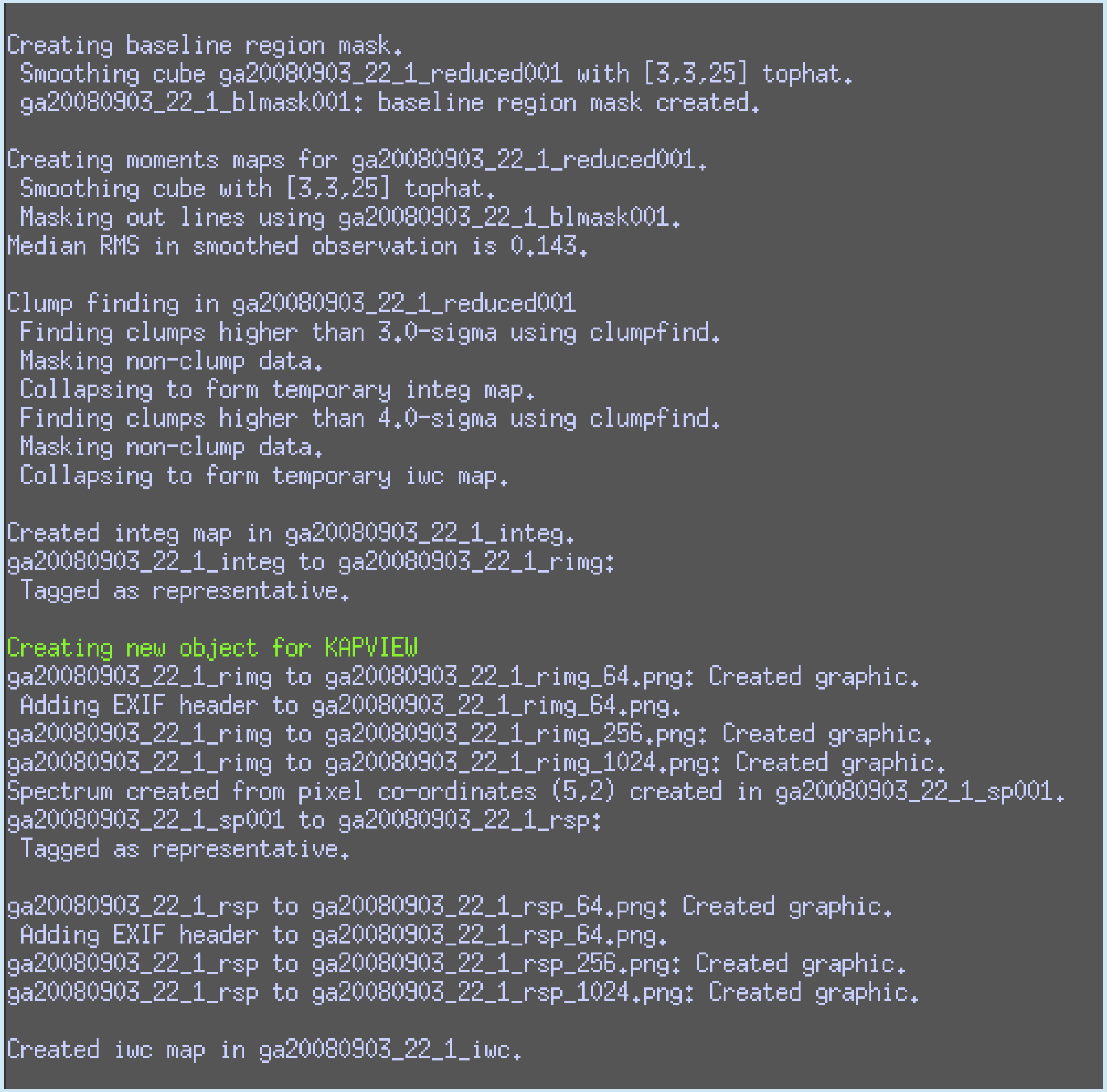
(continuation)

This shows the workflow for the narrowline and gradient recipes.



```
Quality assurance with masking
---------------------------------------------

Retrieving Tsys values from a20080903_00022_01_thr001.
 Tsys for entire array:   1032.63 K
 Tsys values for each receptor:
      H00      H02      H04      H05      H06      H08      H09      H10      H11
 1057.305 1233.972  862.486  795.125  977.215  841.287 1740.310  974.778  979.218
      H12      H13      H15
 1012.982  902.390 1014.460

Calculating RMS values for a20080903_00022_01_thr001.
 RMS for entire array:      4.16 K
 RMS values for each receptor:
      H00      H02      H04      H05      H06      H08      H09      H10      H11
    3.035    3.635    2.553    2.155    2.571    2.505   10.831    2.652    2.946
      H12      H13      H15
    2.827    2.561    2.942

QA results for CO 3-2:
 Time-series QA  passed  for Telescope.
  RMS statistics: minimum: 2.15 maximum: 3.63 mean: 2.76
  Tsys statistics: minimum: 795.13 maximum: 1740.31 mean: 1032.63
  QA note:
   Receptor-to-receptor RMS value test passed after removing receptor H09

Using Telescope results to mask out receptors H09
a20080903_00022_01_thr001 to a20080903_00022_01_rmsk001:
 Masked receptor H09.
```

Calculates T_{sys} and RMS for all receptors and compares to quality assurance Parameters set by the pipeline.



Baselines, finds emission regions using clumpfind, and creates moments maps, velocity maps, and integrated intensity images.

```
Create noise maps
--------------------------

Creating noise map for ga20080903_22_1_reduced001.
 Using variance array in ga20080903_22_1_reduced001 to create temporary noise map.
Created noise map in ga20080903_22_1_noise.

Checking RMS spatial uniformity for ga20080903_22_1_noise.
 Using central 50% of map.
 minimum: 1.21 maximum: 2.56 mean: 1.65
 Number of pixels used:   420
 Number of bad pixels:      0
 Percentage bad: 0.00%

 Spatial RMS uniformity  passed  for Telescope for ga20080903_22_1_noise.
 QA based on bad pixels in final map  passed  for Telescope for ga20080903_22_1_noise.

Checking RMS uniformity for ga20080903_22_1_reduced001.
 Masking out lines using ga20080903_22_1_blmask001.
 RMS map from lower 10% of frequency range created in ga20080903_22_1_rmslo.
 RMS map from upper 10% of frequency range created in ga20080903_22_1_rmshi.
 Median RMS in lower 10%: 1.9199K
 Median RMS in upper 10%: 1.4993K
 Percentage difference: 28.06%
 Frequency RMS uniformity  passed  for Telescope for current map.
```

Produces noise map and applies any QA rms tests.

List of output files (default output)

.oracdr_*.log	ORAC-DR log file
a20140103_00043_01_cube001.sdf	Raw (unbaselined) cube
a20140103_00043_01_integ.sdf	Integrated intensity image
a20140103_00043_01_rimg*.sdf	Representative image (same as integ file), used to form rimg PNG
a20140103_00043_01_sp001.sdf	Spectrum taken from position of peak intensity in the integ file
a20140103_00043_01_rsp*.sdf	Representative spectrum (same as sp001), used to form rsp PNG
a20140103_00043_01_iwc.sdf	Intensity weighted co-ordinate image
a20140103_00043_01_noise.sdf	Noise map
a20140103_00043_01_reduced001.sdf	Final baselined trimmed cube of the 1st (of n) file.
a20140103_00043_01_rmslo.sdf	Low-frequency noise
a20140103_00043_01_rmshi.sdf	High-frequency noise
log.qa	Quality assurance reports
log.noisestats	Noise statistics for each observation and group
log.group	The files contibuting to each group
ga20140103_43_1_reduced001.sdf	Combined baselined cube
ga20140103_43_1_integ.sdf	Combined integrated intensity image
etc	

(ORAC_KEEP=1 more intermediate files)

Options for non-standard Quality Assurance or Recipes

Setting Quality Assurance parameters:

Make file myqa.par with e.g.

```
[default]
GOODRECEP = 10
TSYSBAD = 600
RMSVAR_MAP = 0.05
```

Use option
oracdr -cal qaparams=myqa.par

Changing Recipe parameters:

Make file myparams.ini with e.g.

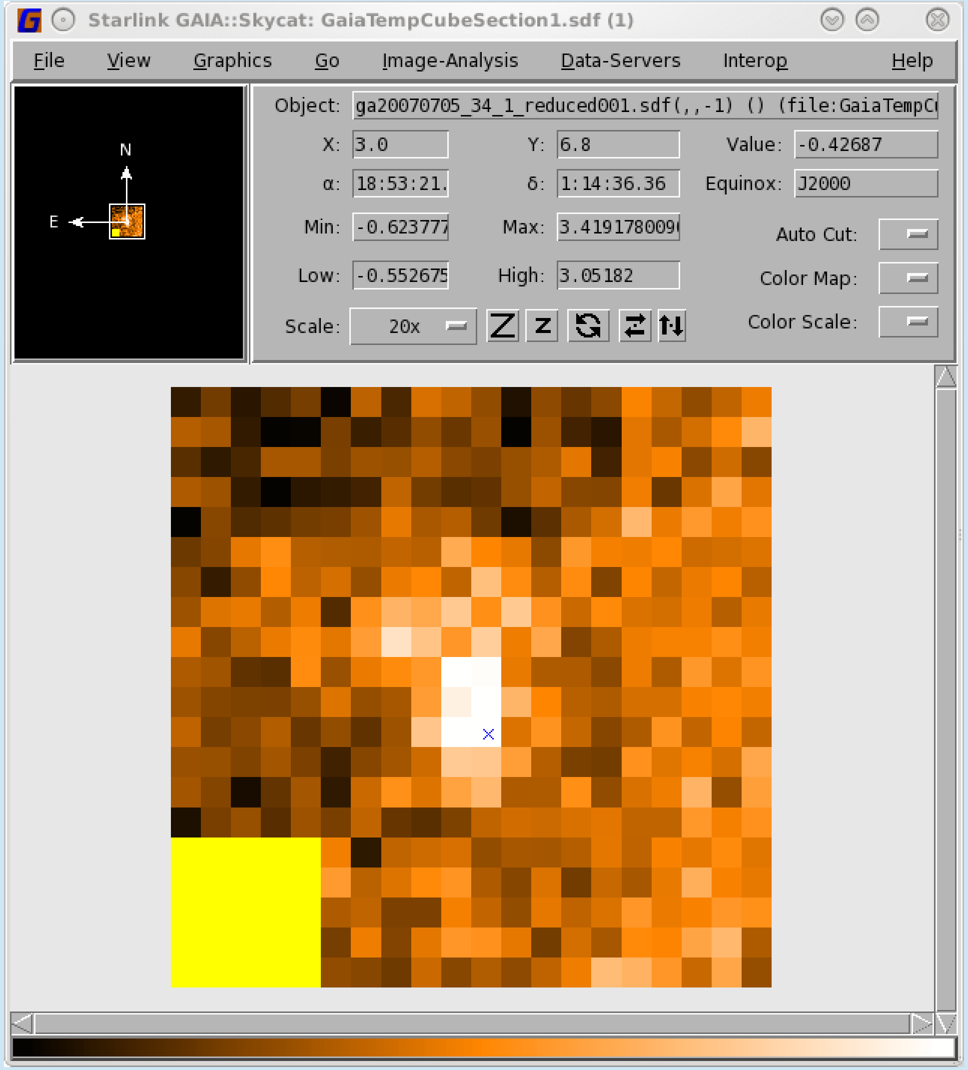
```
[REDUCE_SCIENCE_NARROWLINE]
TRIM_PERCENTAGE = 3.5
REBIN = 5
PIXEL_SCALE = 8
```

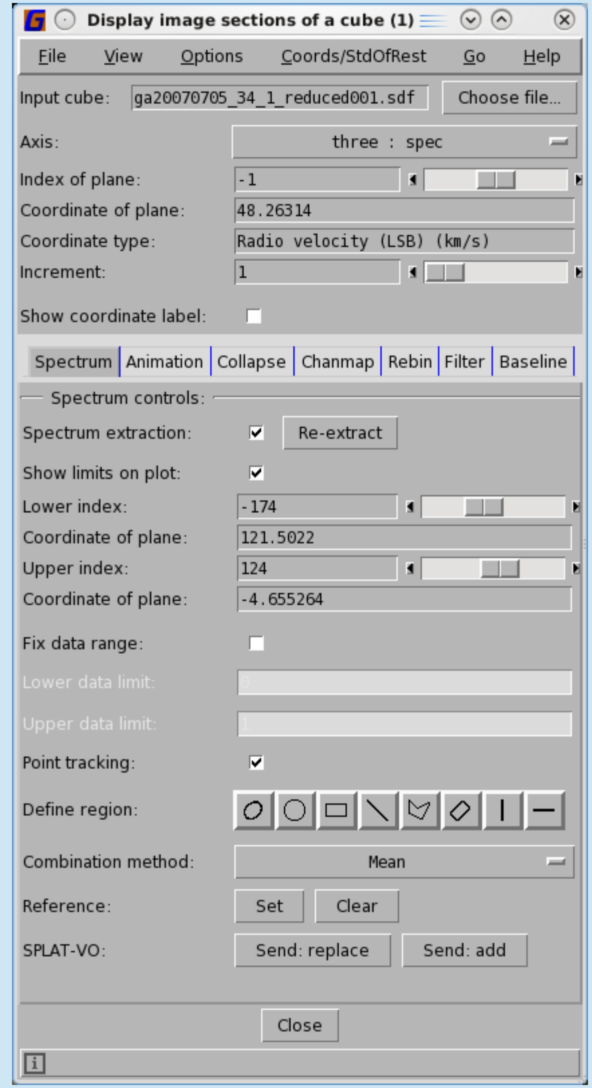
Use option
oracdr -recpars myparams.ini

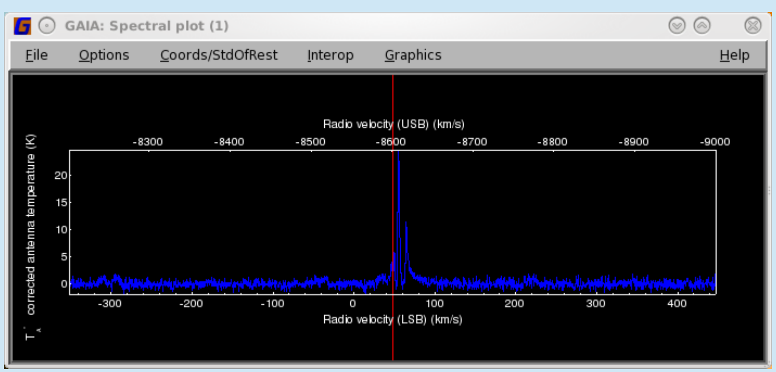
(or – copy recipe to your workspace and edit it; use setenv ORAC_RECIPE_DIR)

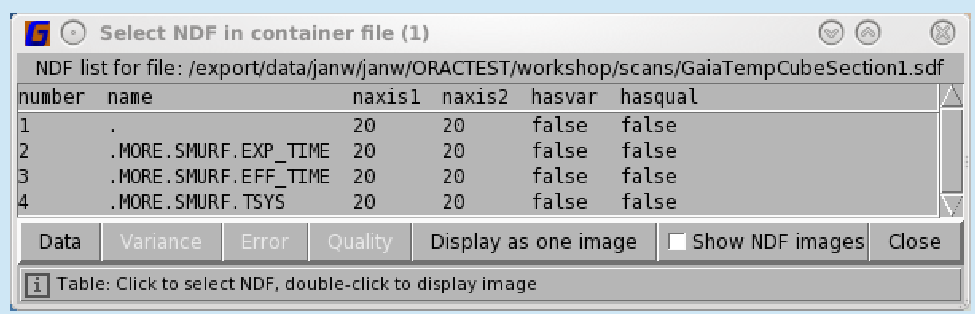
GAIA

Inspect cube or image



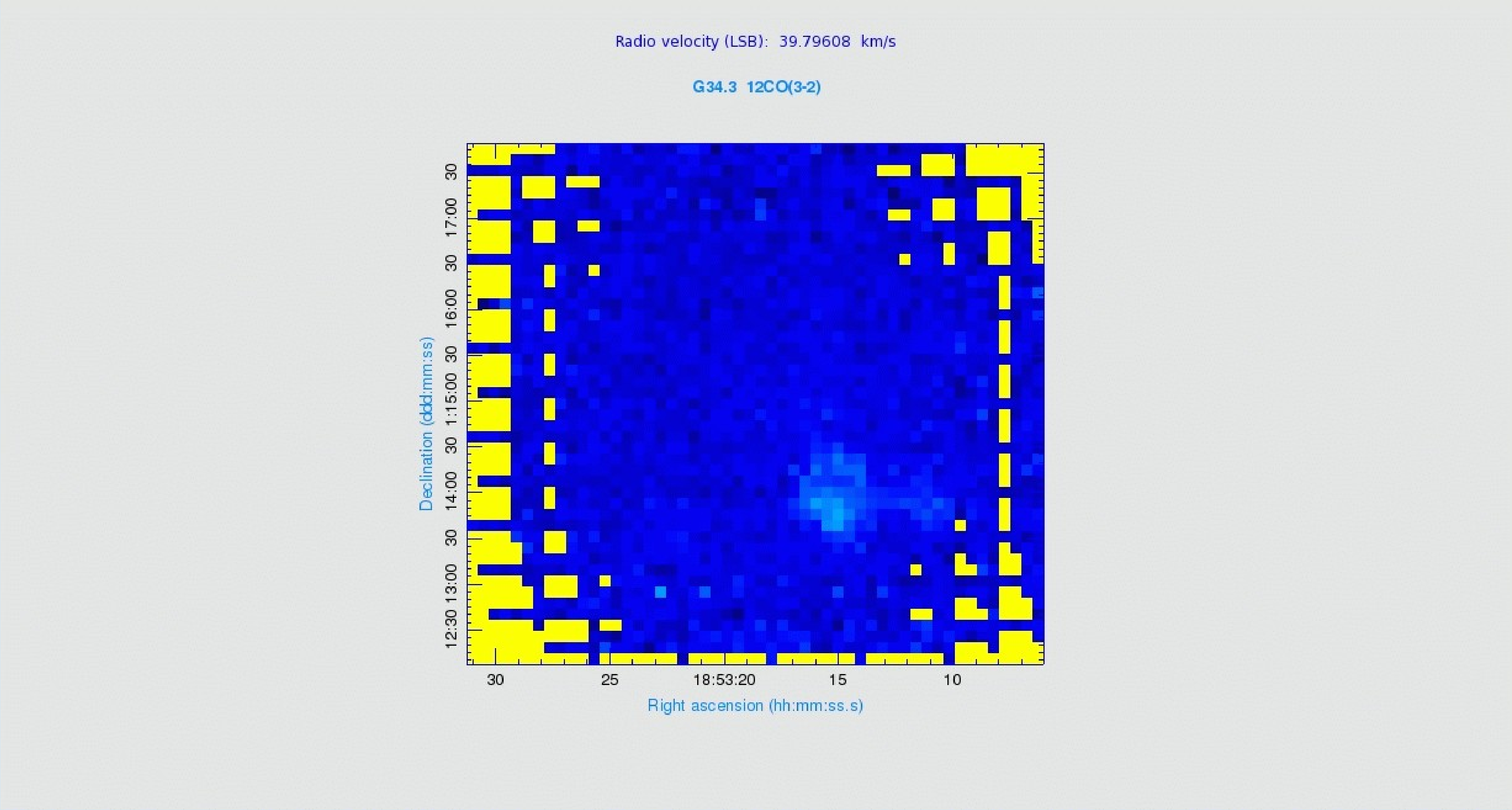


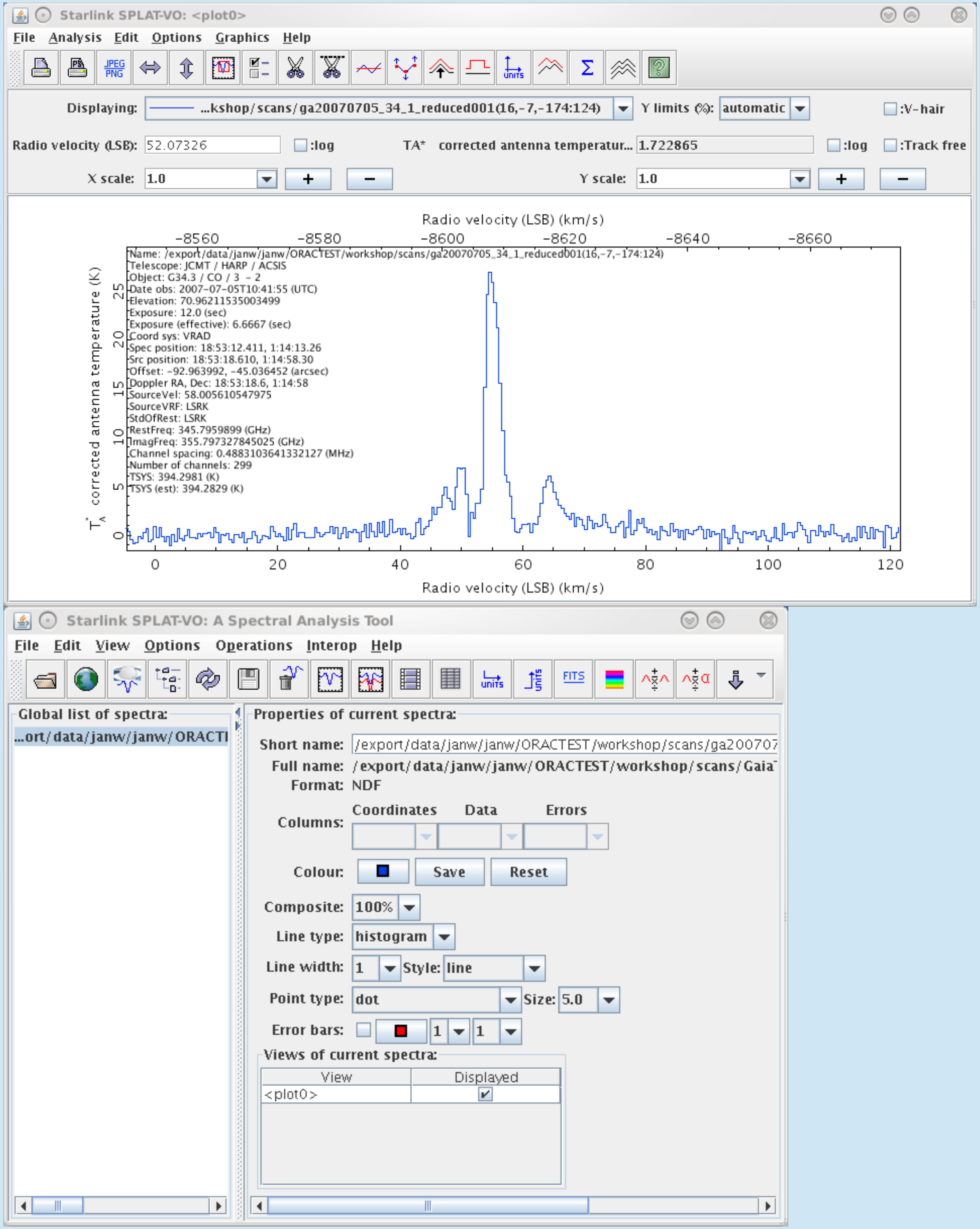




GAIA animation

similarly one can look for wings/outflows in position-velocity plots.





SPLAT – spectrum sent from GAIA via 'Send replace'.

Where to find help

Quick Guide (heterodyne):
http://www.eaobservatory.org/jcmt/instrumentation/heterodyne/data-reduction/reducing-acsis-data/

Heterodyne DR Cookbook
(Starlink Cookbook SC/20)
http://starlink.eao.hawaii.edu/devdocs/sc20.htx/sc20.html

ORAC-DR – Submm heterodyne pipeline data reducion User Guide
(Starlink User Note 260)
http://starlink.eao.hawaii.edu/devdocs/sun260.htx/sun260.html

Ask your Friend of Project

Send a mail to helpdesk@eaobservatory.org