HIFI Spectral Maps

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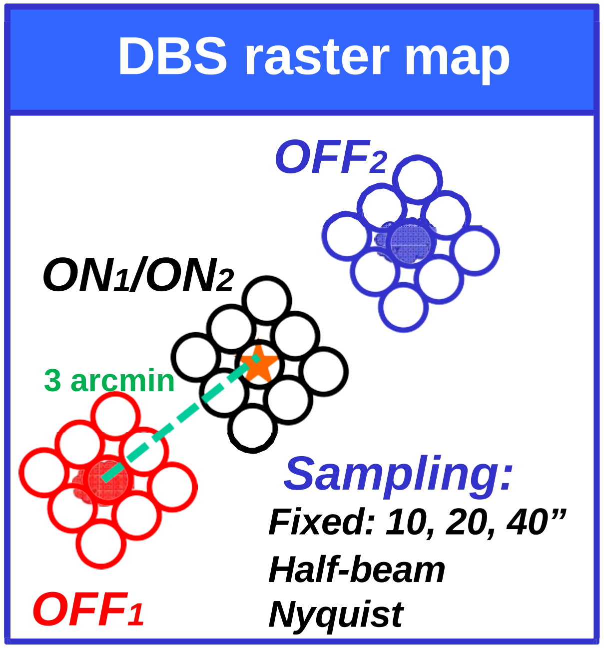
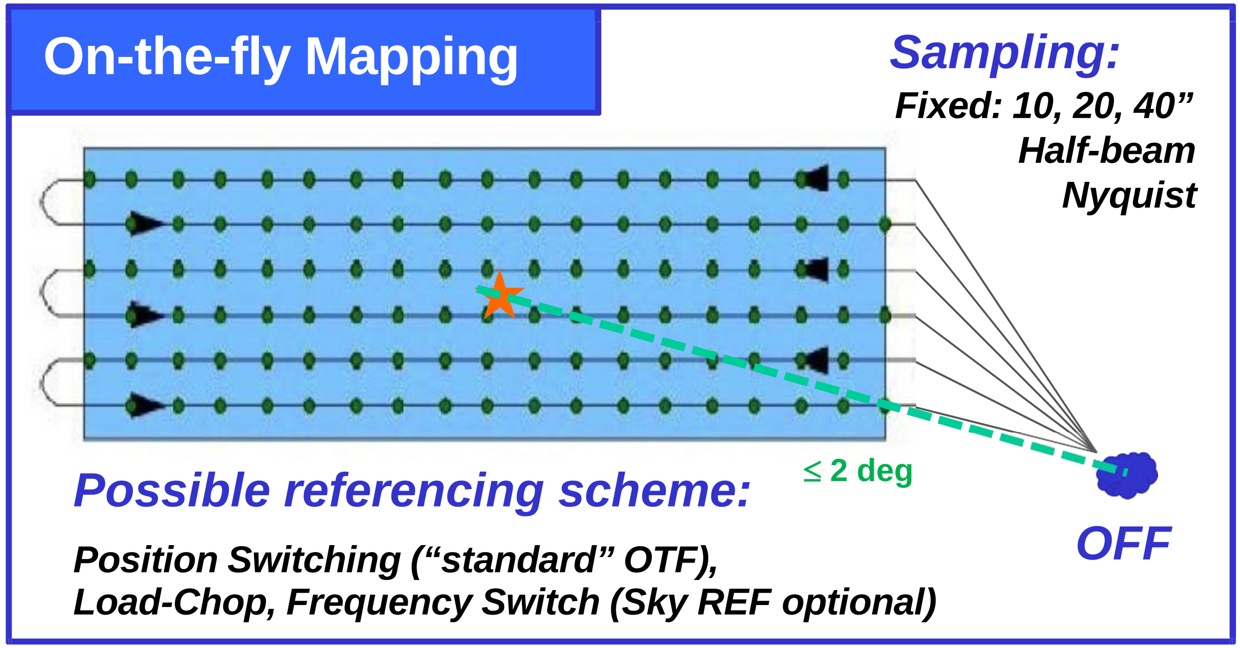
Topics

- Familiarity with HIFI's mapping modes
- Inspection
- Cleaning the input spectra (baselines)
- Regridding
- Cube toolbox
- Image analysis
- Line fitting with the spectrum fitter tool

The Mapping AOTs schematically

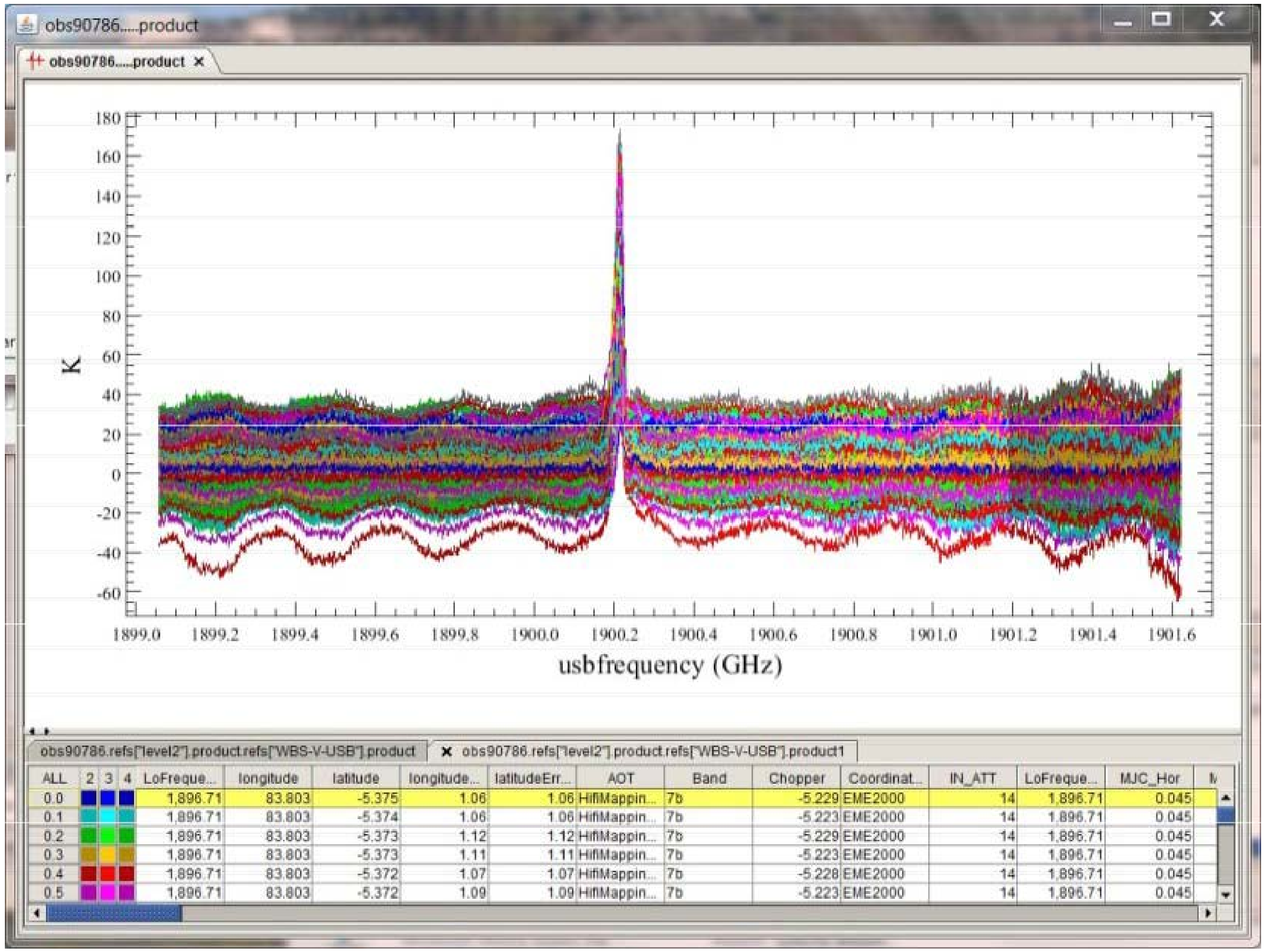




The main purpose of the OFF positions is to provide baseline removal of drift + standing waves.

1. The OFFs may sometimes be contaminated with line emission (most often CO and [CII], sometimes others because of the fixed DBS throw). *You can check for this in the data --- response calibrated OFF spectra part of the data tree in HIPE ≥ 13.*

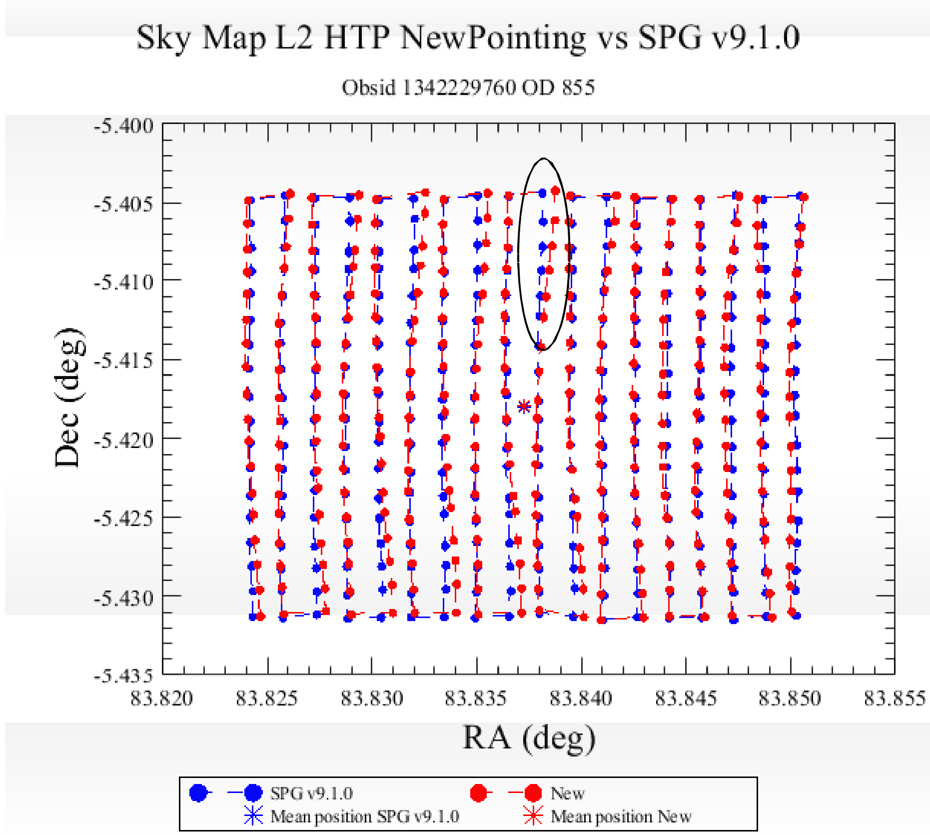
2. The OFFs may sometimes not fully correct the ripples, due to short Allan times (rapid drift cross-over from radiometric noise).



C^+ + 1900 GHz + continuum + drift

Effects of imperfect line scanning on OTF maps

- Drift and slew effects (over- / under-shoot after slews) producing departures along the intended scan path.

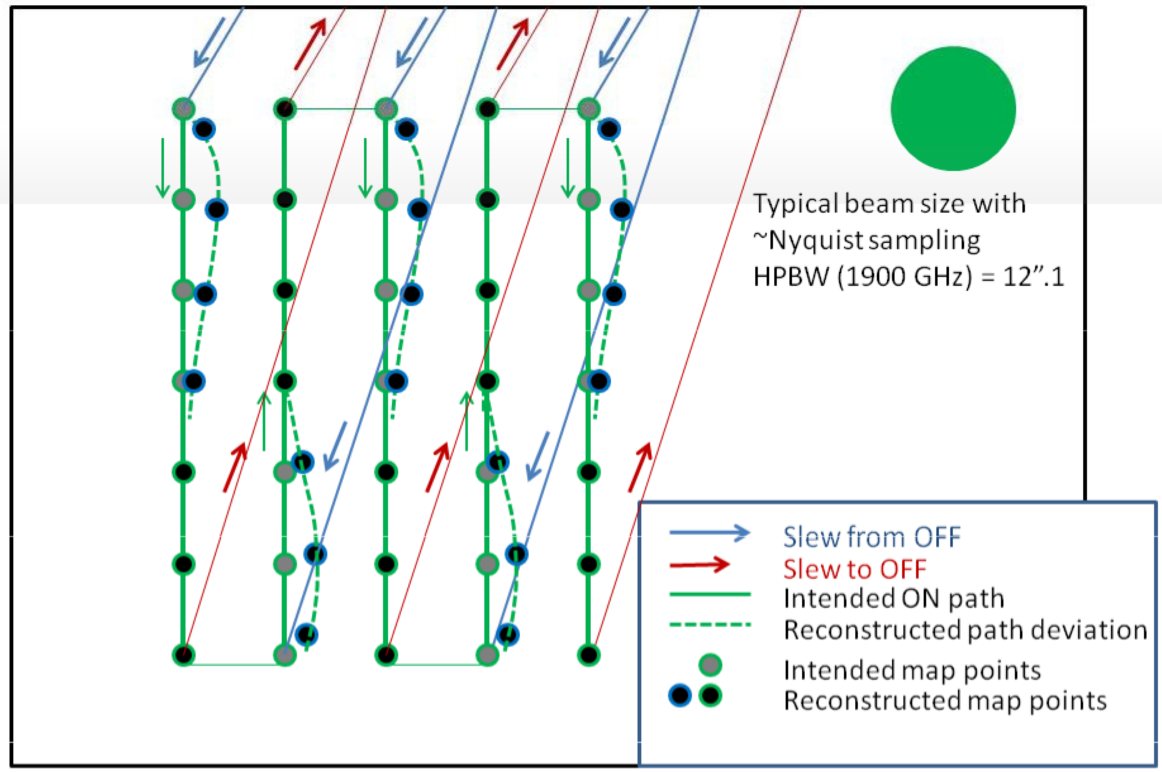


- Improvements in pointing reconstruction, better jitter characterizations, provide more reliable WCS in gridded cubes.

Our current picture

The “zig-zag” has components of slewing errors (not due to timing errors in HIFI).

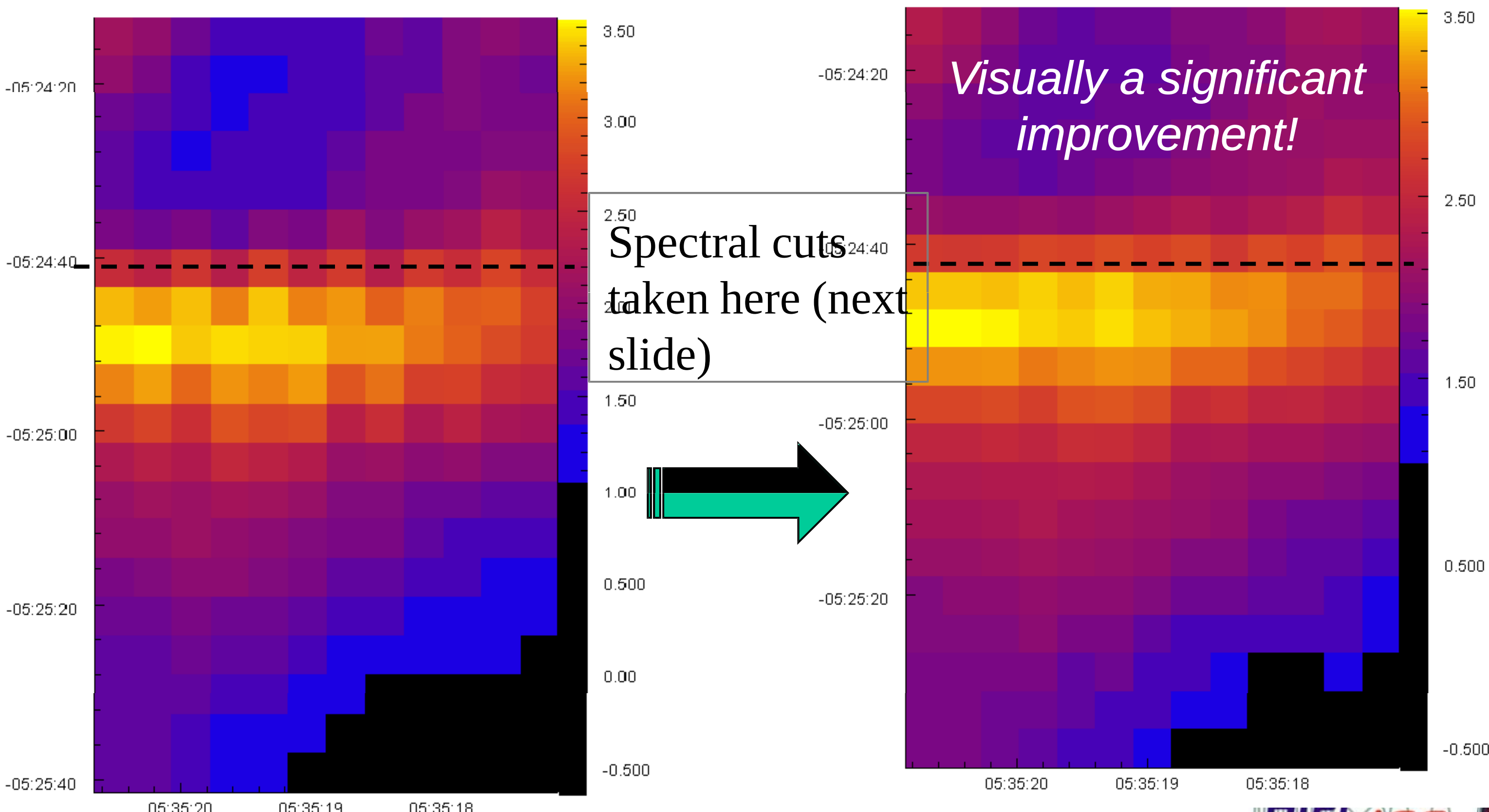
Errors are projected in both α and δ.



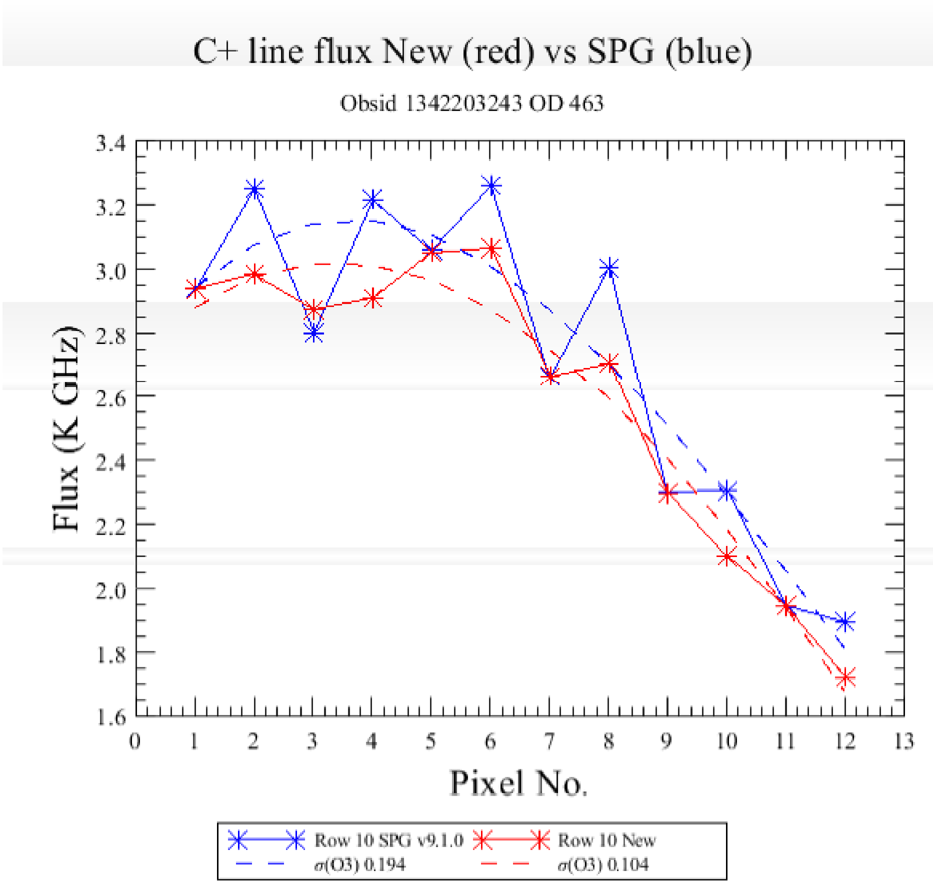
The deviations are clearly correlated with the slews from OFF,
Looks like slew → deceleration → scan transition bugs.

Impact of the anomalous line scanning

- The consequence is that sampling requested in HSpot is not perfect.
- New pointing reconstruction available in HIPE 13 for re-assignment of attitudes, will reduce “zig-zag” pattern noise. will exhibit a form of “zig-zag”



The new pointing history reduces the zig-zag



C+ line fluxes in spectra extracted from the cube in a slice across the Orion Bar.

Red is based on New pointing and shows ~2x lower noise around an approximating (3rd order) fit to the flux gradient across the PDR.

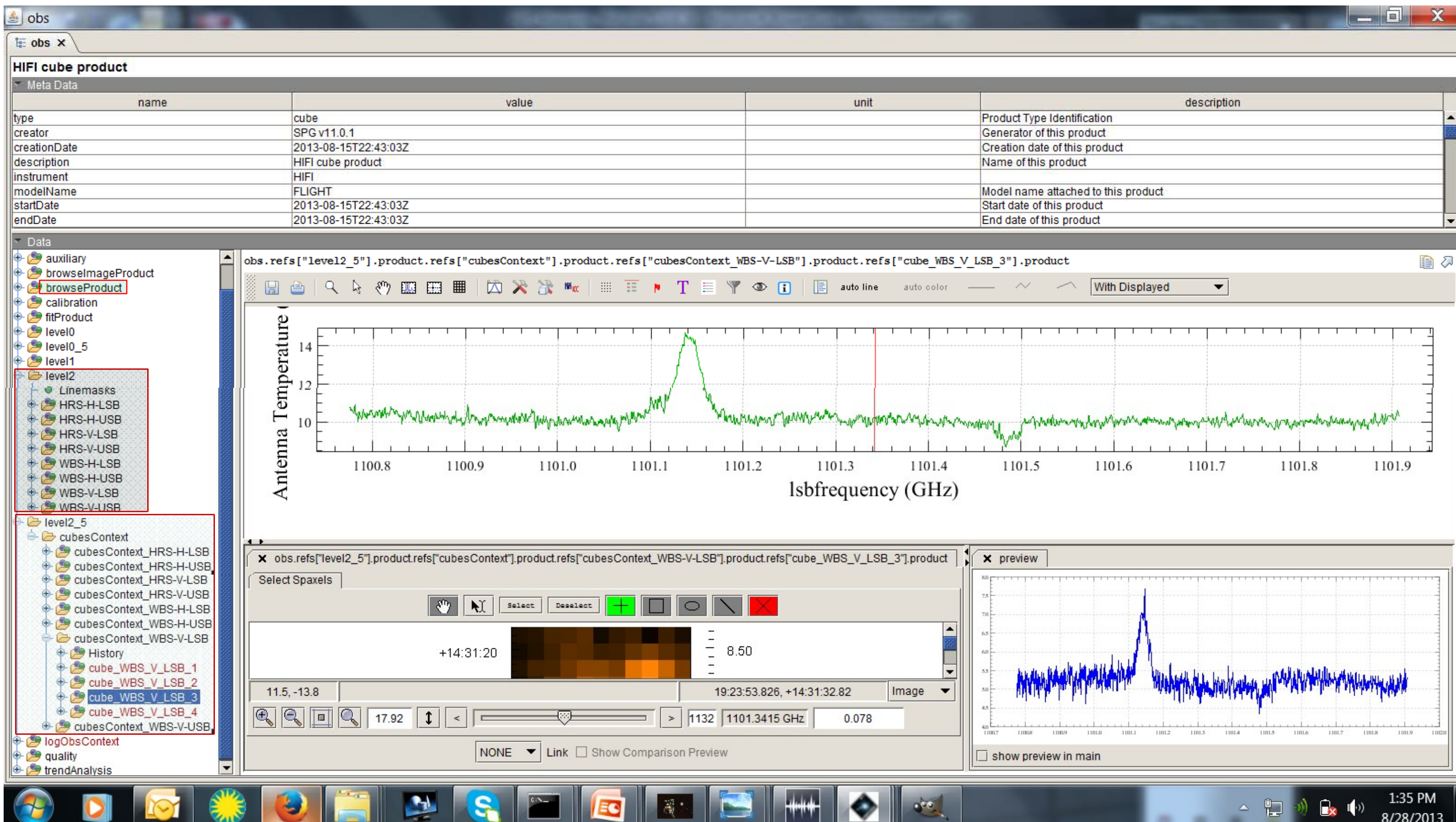
Browsing Map Products

- This is a tour. A detailed set of tutorials using HIPE will be given in NHSC's workshop for newcomers in October.

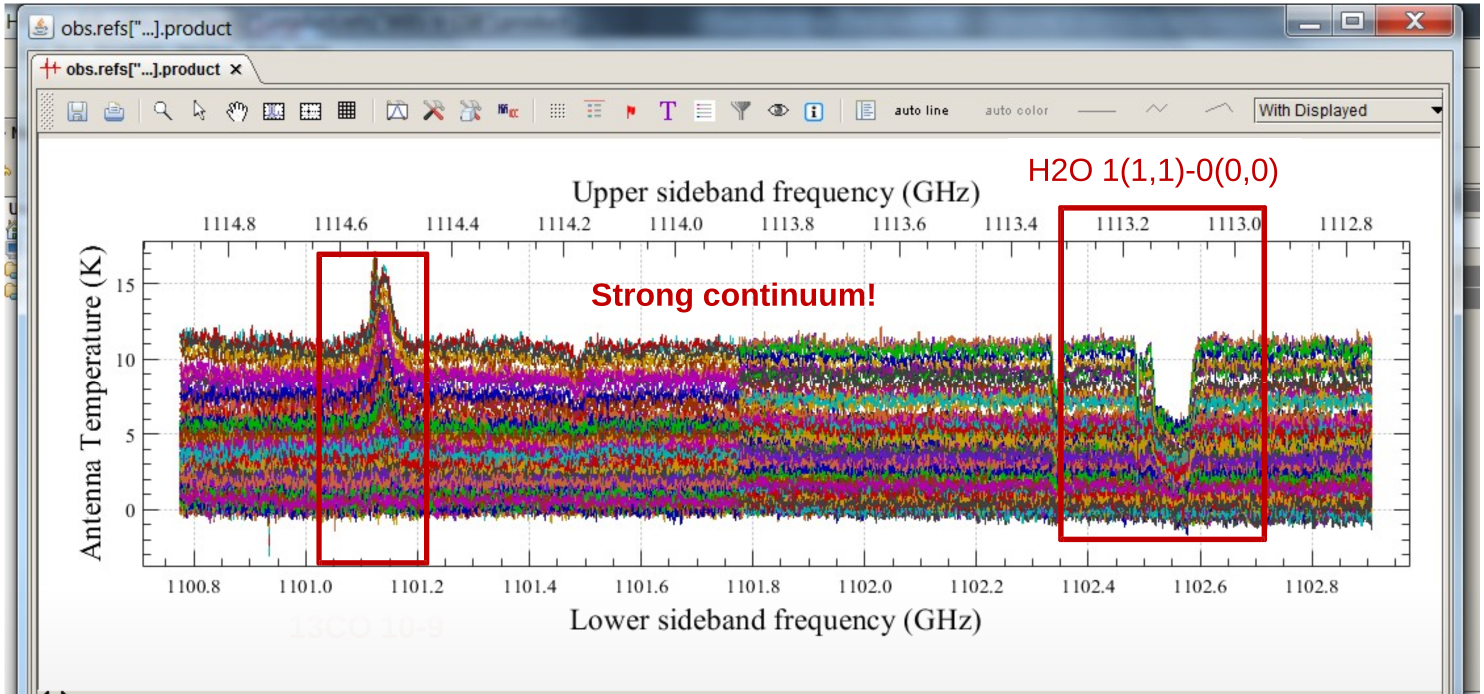
- Today:
  1. Load a H_2O and ^{13}CO OTF map of massive SFR W51.
  2. Inspect metadata for the map layout on the sky, noise performance parameters.
  3. Visually ID "artifacts" in the Level 2 spectra.
  4. More discussion of artifacts (ripples).
  5. Regrid into spectral cubes.
  6. Show the Cube Spectrum Analysis Toolbox (CSAT)
  7. Highlight some image analysis tools.

2. Browsing the data

- Familiarizing with the data tree for a spectral map, inspection of the Level 2 HTPs in Spectrum Explorer (for data quality / artifacts), and locating the metadata that describe the map pattern and expected noise.



2. HTP inspection



DataTree | obs.refs["level2"].product.refs["WBS-V-LSB"].product

ALL	1	2	3	4	LoFreque...	longitude	latitude	longitude...	latitudeErr...	Band_ATT	Chopper	IN_ATT	LOF_code	LoFreque...	MJC_Hor	MJC_Ver	bac
0					1,107.831	290.90947	14.49601	1.54	1.54	[6,4,6,0]	-5.463	12	[30688,92...	1,107.81	0.032	0.03	[5,0,0,
1					1,107.831	290.90963	14.49676	1.79	1.79	[6,4,6,0]	-5.463	12	[30688,92...	1,107.81	0.032	0.03	[5,0,0,
2					1,107.831	290.90980	14.49750	1.81	1.81	[6,4,6,0]	-5.463	12	[30688,92...	1,107.81	0.032	0.03	[5,0,0,
3					1,107.831	290.90990	14.49815	1.81	1.81	[6,4,6,0]	-5.463	12	[30688,92...	1,107.81	0.032	0.03	[5,0,0,
4					1,107.831	290.90995	14.49880	1.52	1.52	[6,4,6,0]	-5.462	12	[30688,92...	1,107.81	0.032	0.03	[5,0,0,
5					1,107.831	290.90997	14.49945	1.55	1.55	[6,4,6,0]	-5.462	12	[30688,92...	1,107.81	0.032	0.03	[5,0,0,
6					1,107.831	290.90994	14.50013	1.57	1.57	[6,4,6,0]	-5.463	12	[30688,92...	1,107.81	0.032	0.03	[5,0,0,
7					1,107.831	290.90989	14.50082	1.53	1.53	[6,4,6,0]	-5.463	12	[30688,92...	1,107.81	0.032	0.03	[5,0,0,
8					1,107.831	290.90985	14.50151	1.51	1.51	[6,4,6,0]	-5.463	12	[30688,92...	1,107.81	0.032	0.03	[5,0,0,
9					1,107.831	290.90982	14.50211	1.56	1.56	[6,4,6,0]	-5.463	12	[30688,92...	1,107.81	0.032	0.03	[5,0,0,
10					1,107.831	290.90980	14.50274	1.56	1.56	[6,4,6,0]	-5.463	12	[30688,92...	1,107.81	0.032	0.03	[5,0,0,
11					1,107.831	290.90982	14.50342	1.54	1.54	[6,4,6,0]	-5.463	12	[30688,92...	1,107.81	0.032	0.03	[5,0,0,
12					1,107.831	290.90981	14.50412	1.54	1.54	[6,4,6,0]	-5.462	12	[30688,92...	1,107.81	0.032	0.03	[5,0,0,
13					1,107.831	290.90979	14.50474	1.47	1.47	[6,4,6,0]	-5.463	12	[30688,92...	1,107.81	0.032	0.03	[5,0,0,
14					1,107.831	290.90976	14.50538	1.33	1.33	[6,4,6,0]	-5.462	12	[30688,92...	1,107.81	0.032	0.03	[5,0,0,

2. Important metadata

obs.refs["**auxiliary**"].product.refs["**HifiUplinkProduct**"].product["**HifiUplinkParameters**"]

obs.refs["...ameters"]

obs.refs["...ameters"]

HifiUplinkParameters

Meta Data

None

Table Data

Index	name	value	unit	type	description
0	mapLines	11		java.lang.Long	Number of map lines
1	mapLineStep	9.0	arcsec	java.lang.Double	Map line spacing
2	mapReadouts	11		java.lang.Long	Number of readouts per line
3	mapReadoutSep	9.6	arcsec	java.lang.Double	Line readout spacing
4	noiseMinUsb	UNKNOWN	K	UNKNOWN	Predicted SSB Noise USB at minimum bandwidth
5	noiseMaxUsb	UNKNOWN	K	UNKNOWN	Predicted SSB Noise USB at maximum bandwidth
6	noiseMinLsb	UNKNOWN	K	UNKNOWN	Predicted SSB Noise LSB at minimum bandwidth
7	noiseMaxLsb	UNKNOWN	K	UNKNOWN	Predicted SSB Noise LSB at maximum bandwidth
8	noiseMinWidth	UNKNOWN	MHz	UNKNOWN	Minimum bandwidth for noise predictions
9	noiseMaxWidth	UNKNOWN	MHz	UNKNOWN	Maximum bandwidth for noise predictions
10	tmbReference	789.0	K	java.lang.Double	Temperature (main beam) at noise reference frequency
11	noiseRefFrequency	1108.0	GHz	java.lang.Double	Noise reference frequency
12	observingTime	3091	s	java.lang.Long	Observing time
13	offTime	471.6	s	java.lang.Double	Off source time
14	overheadTime	702.8	s	java.lang.Double	Overhead
15	totTimeEfficiency	77.3	%	java.lang.Double	Total time efficiency
16	totNoiseEfficiency	44.2	%	java.lang.Double	Total noise efficiency
17	driftNoiseContrib	9.0	%	java.lang.Double	Drift noise contribution
18	refSelected	true		java.lang.Boolean	Sky reference selected
19	fe_lof_0	1107.898	GHz	java.lang.Double	LO frequency selected
20	oneGHzReference	true		java.lang.Boolean	One GHz noise estimation bandwidth
21	hrsModeH	Nominal		java.lang.String	HRS resolution mode H
22	flyRefOffsetDec	0.0	arcmin	java.lang.Double	Sky reference offset declination
23	frame	heliocentric		java.lang.String	Redshift velocity frame
24	spectrometer	both		java.lang.String	Spectrometers used
25	dec	14.510694444444445	degrees	java.lang.Double	Target declination J2000.0
26	fe_eff_res_max_0	0.3	GHz or km/s	java.lang.Double	Maximum width spectral resolution at noise goal
27	redshiftType	radio		java.lang.String	Redshift type
28	flyRefOffset	true		java.lang.Boolean	Sky reference offset is relative
29	resolutionMhz	false		java.lang.Boolean	Resolution width units (true = MHz, false = km/s)
30	ra	290.922875	degrees	java.lang.Double	Target right ascension J2000.0
31	decoff	14.5106782913208	degrees	java.lang.Double	Sky reference OFF declination J2000.0
32	fe_eff_res_min_0	0.3	GHz or km/s	java.lang.Double	Minumum width spectral resolution at noise goal
33	goalTime	2800	s	java.lang.Long	Goal observing time
34	flyNyquistSel	true		java.lang.Boolean	Spectral Map Nyquist sampling requested
35	raoff	291.0089416503906	degrees	java.lang.Double	Sky reference OFF right ascension J2000.0
36	redshift	59.5	redshift or km/s	java.lang.Double	Redshift value (km/s if redshiftType is optical or radio)
37	doingTime	true		java.lang.Boolean	Time estimation is based on observing time or rms noise goal
38	flyY	1.5	arcmin	java.lang.Double	Spectral map scan length requested
39	band	4b		java.lang.String	HIFI band
40	goalNoise	0.1	K	java.lang.Double	Goal rms basline noise

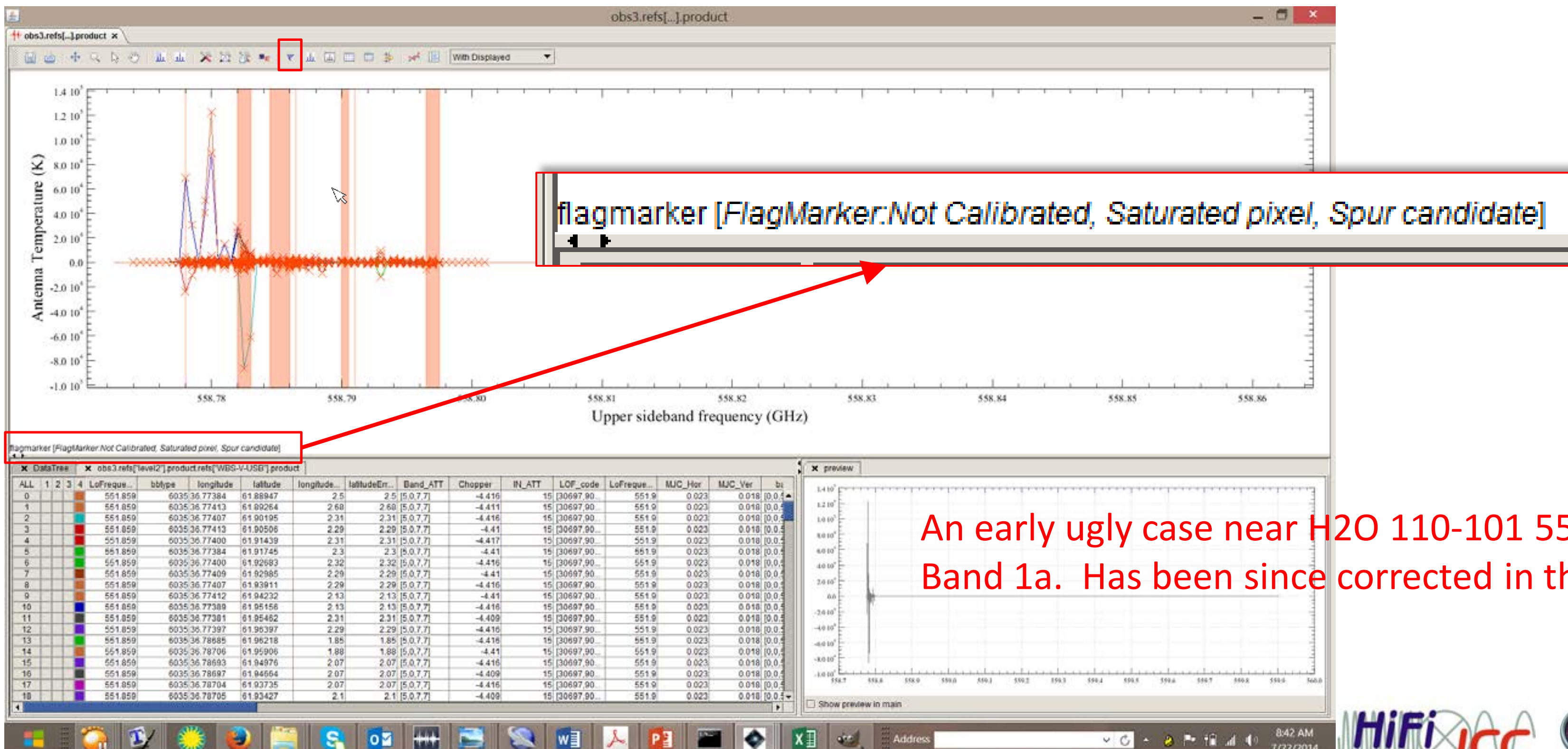
Selected key parameters are also stored in the observation context header.

Esp. for advanced searches in the HSA.

3. Artifacts in Maps

- Many maps are well-behaved. Some cases (treatable) that may come up:

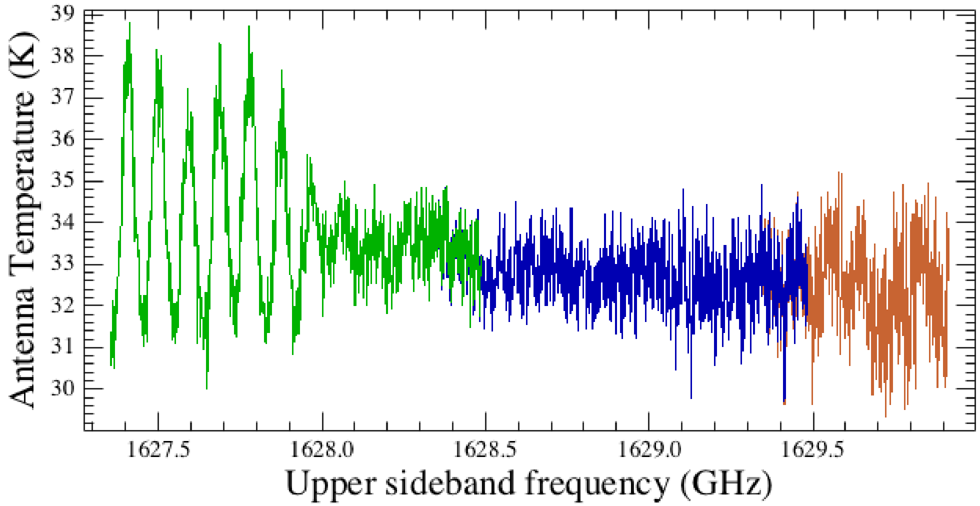
1. Spurs or spurious response.
    - Cataloged and visualizable in HSpot. Some are mission phase dependent.
    - Some unruly but important LO freqs were stabilized by tuning mixer currents, gains.
    - Normally avoided during observation planning of the selected LO setting, unless the feature was not known at the time, or the user had no options (or simply missed the warning).
    - <u>Mitigations</u>: these regions are masked out during ripple fitting + correction. However only saturated IF frequencies are avoided during map (*spatial*) convolution.



An early ugly case near H2O 110-101 557 GHz Band 1a. Has been since corrected in the instrument.

3. Artifacts in Maps – cont'd

2. Sub-band resonances.
    - Also cataloged, visualizable in HSpot. These are more common in the HEB bands 6 and (less frequently) 7.

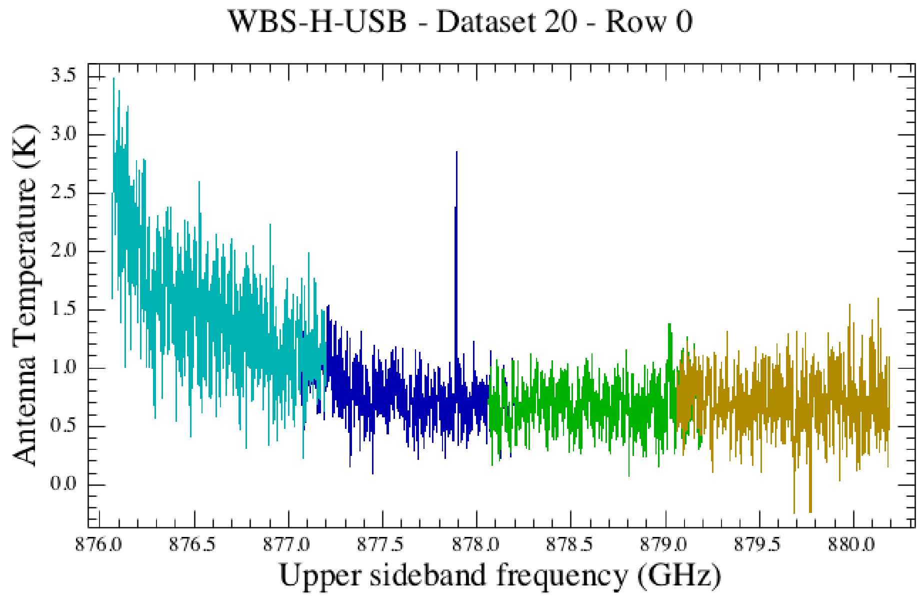


- Band 6 isolated ripple usually in last 600-700 MHz of IF (sub-band 4).
- Mostly in 6b but also exists in upper end of 6a and lower end of 7a.

- Mitigations: might be treatable with the hebCorrection task --- under investigation.

3. Artifacts in Maps – cont'd

3. Baseline distortions.
   - Generally at unstable LO frequencies, but not accompanied by large increases in noise. Thus line information is still usable.



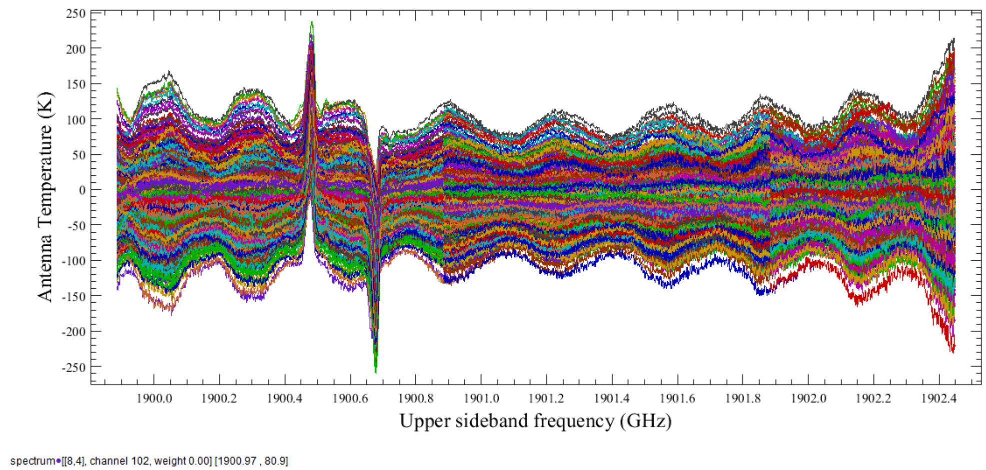
- Typically in the diplexer bands (3, 4, 6, 7).

- <u>Mitigations</u>: treatable with baseline fitting (fitBaseline task), but information on the continuum (if present) is likely to be lost.

3. Artifacts in Maps – cont'd

4. Residual standing waves + drift.

- More typical in bands, ranges, or at specific LO frequencies with instabilities or short Allan times.



Band 7b, [CII] OTF map (frequency switching)

Note ripple amplitude increases with offset, phase reversal.

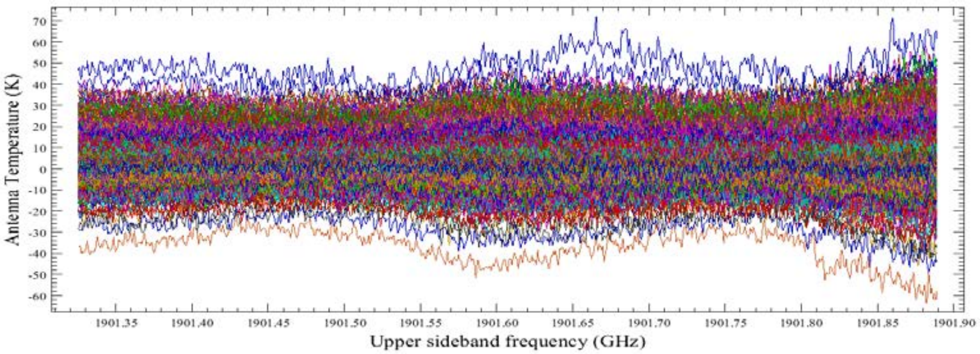
- Map observing mode dependence is mainly in total power (OTF), if OFF calibration timing (sky and/or internal load measurements) do not well-match drift timescales.
- Also DBS Raster, if fast chop option was not used where high drift noise was expected.

- Mitigations: treatable with fitHifiFringe (sine waves, OK for optical standing waves), and **hebCorrection task** (non-sinusoidal electrical standing waves in Bands 6, 7) →

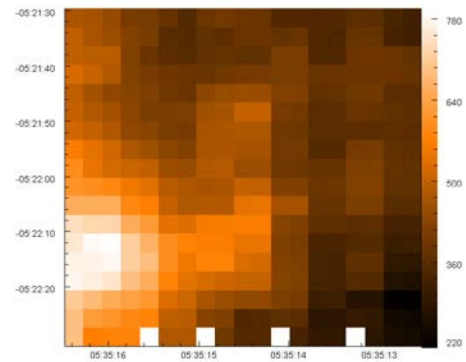
hebCorrection task

Level 2 WBS-V sub-band 2

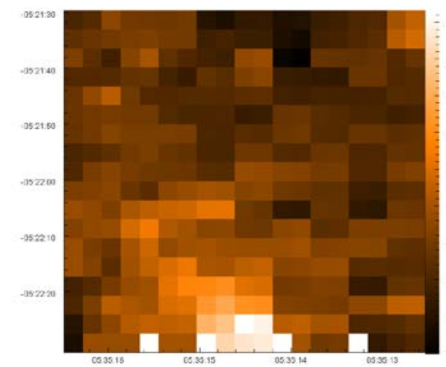
HSA/SPG 11.1



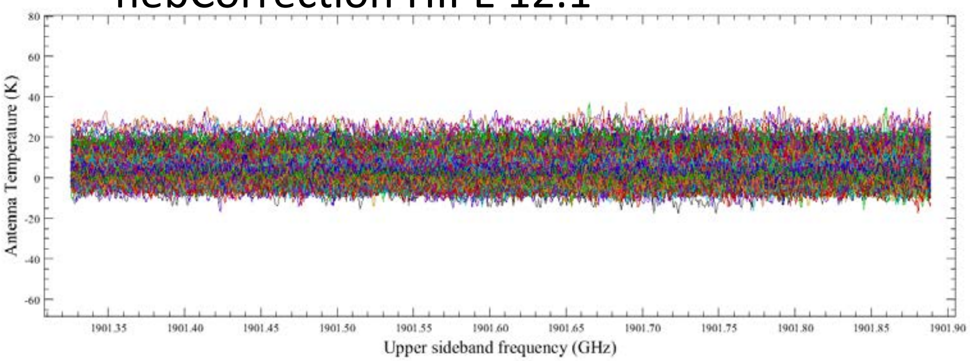
Integrated C+

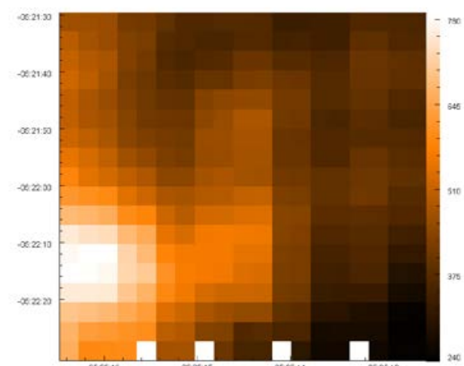


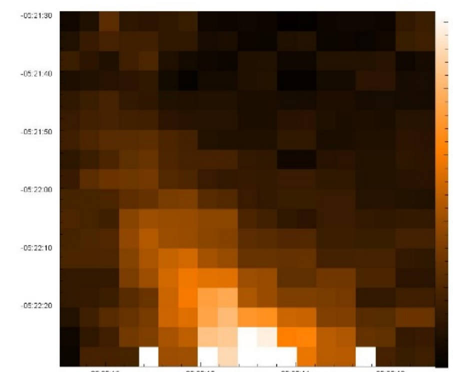
Integrated Continuum



hebCorrection HIPE 12.1



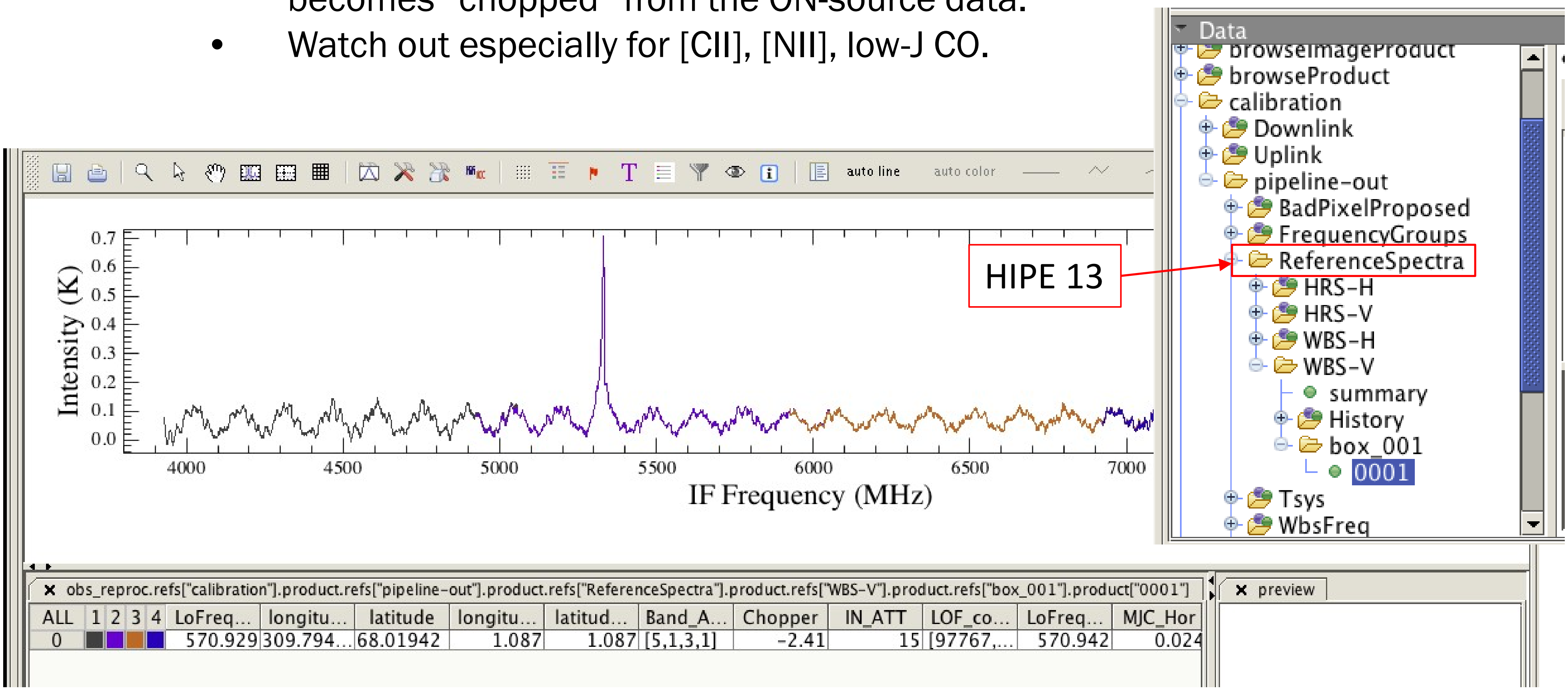




4. Other Non-Instrumental Effects

1. OFF-source (sky) contamination

- Observations using Position Switch (standard OTF, or in conjunction with either Load Chop or Frequency Switch), and DBS Raster (with 3 arcmin chop/nod to either side of the source) may sometimes pick up extended line emission, which becomes “chopped” from the ON-source data.
- Watch out especially for [CII], [NII], low-J CO.



4. Other Non-Instrumental Effects

2. Pointing pattern noise

   In OTF observations, this is the "zig-zag", caused by (a) problems with deceleration and transition to line-scanning; (b) low fidelity pointing reconstruction (deviations are smoothed over).

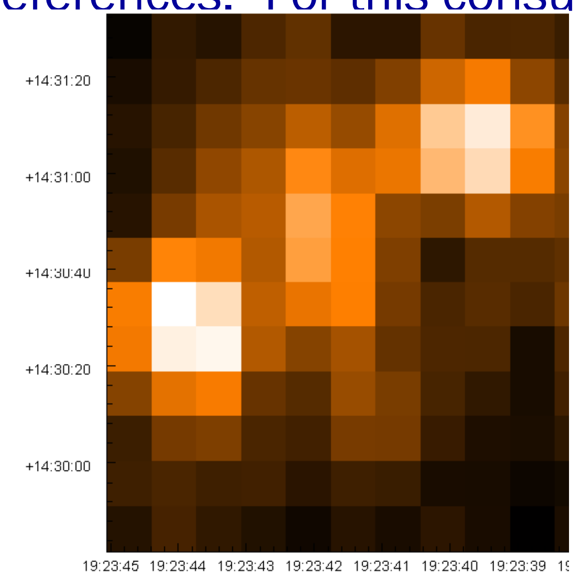
   Present to different degrees in other modes, easiest to visualize in maps.

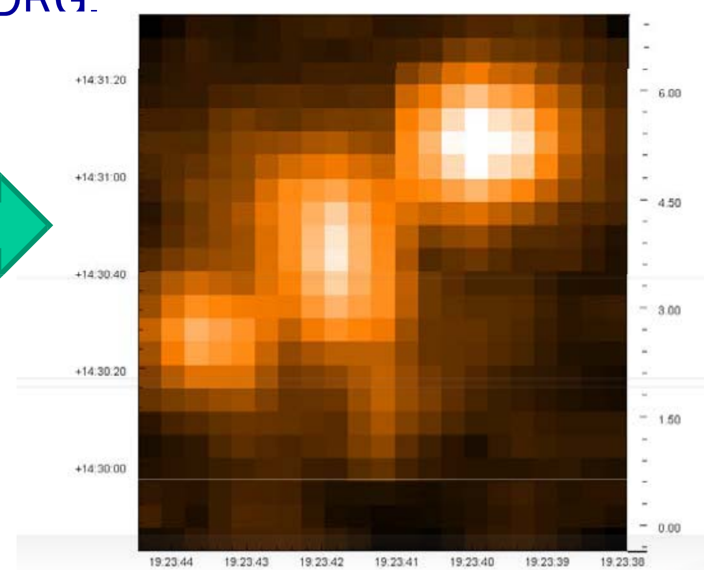
   Mitigation: New pointing reconstruction algorithm uses gyro-drift estimation much better, resolves pointing history to better accuracy. The deviations don't go away, but lower attitude *history* errors helps convolution.

   Better pointing products can be produced in HIPE 13, hopefully also in SPG 13/14 for the HSA.

5. Resample with doGridding

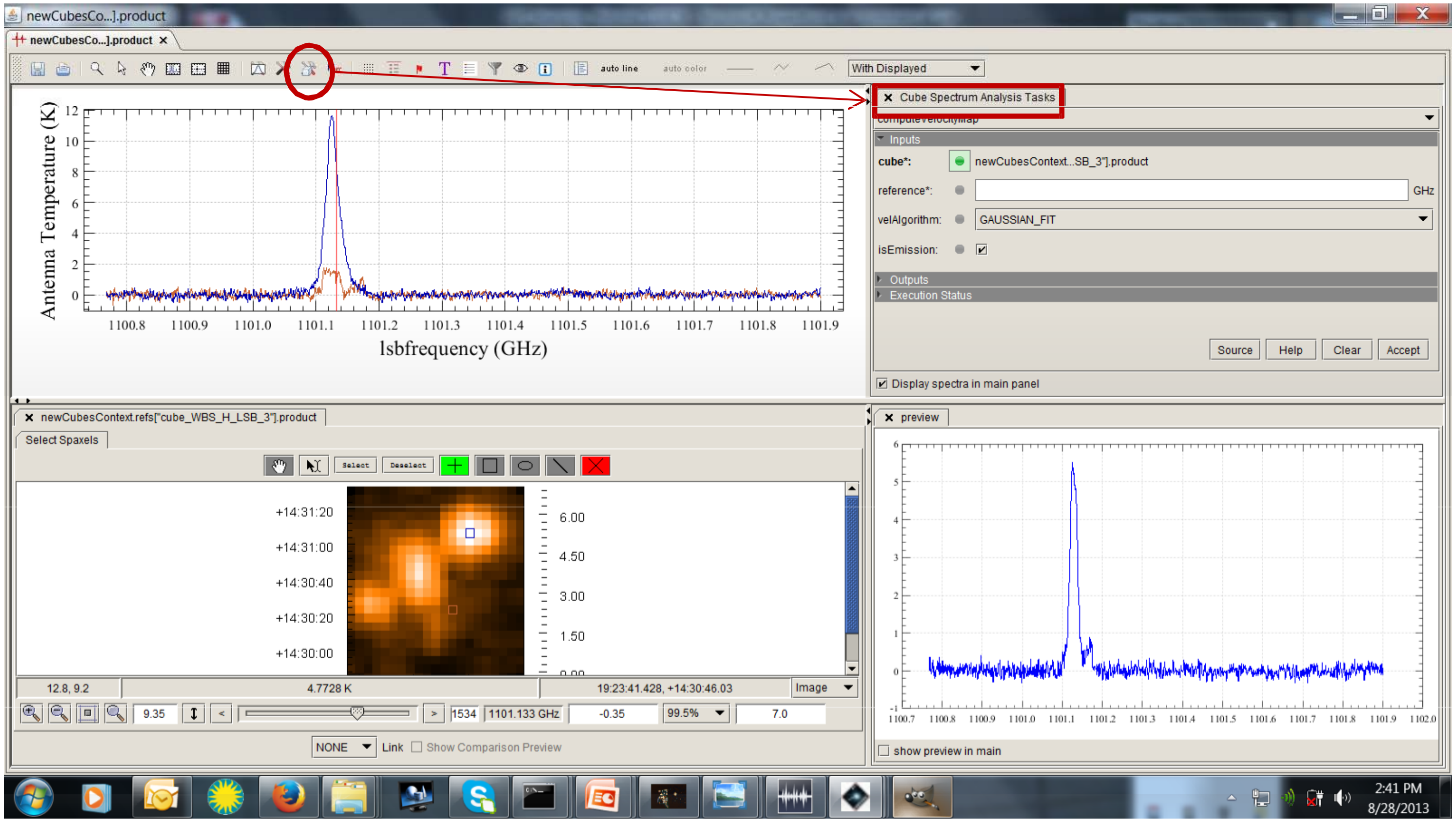
- S/N is good experiment with oversampling to ~2 x Nyquist.
  - Remember that structures are resolvable to at least ~1/10 the beam size when S/N is very high.
  - Noise is computed on a map point basis; does not take the convolution into account (thus generally better than predicted).
  - Changing the pixel scale is the most common application, and we do not do a complete experiment with all possible parameters, e.g. altering WCS references. For this consult the HIFI DRG.





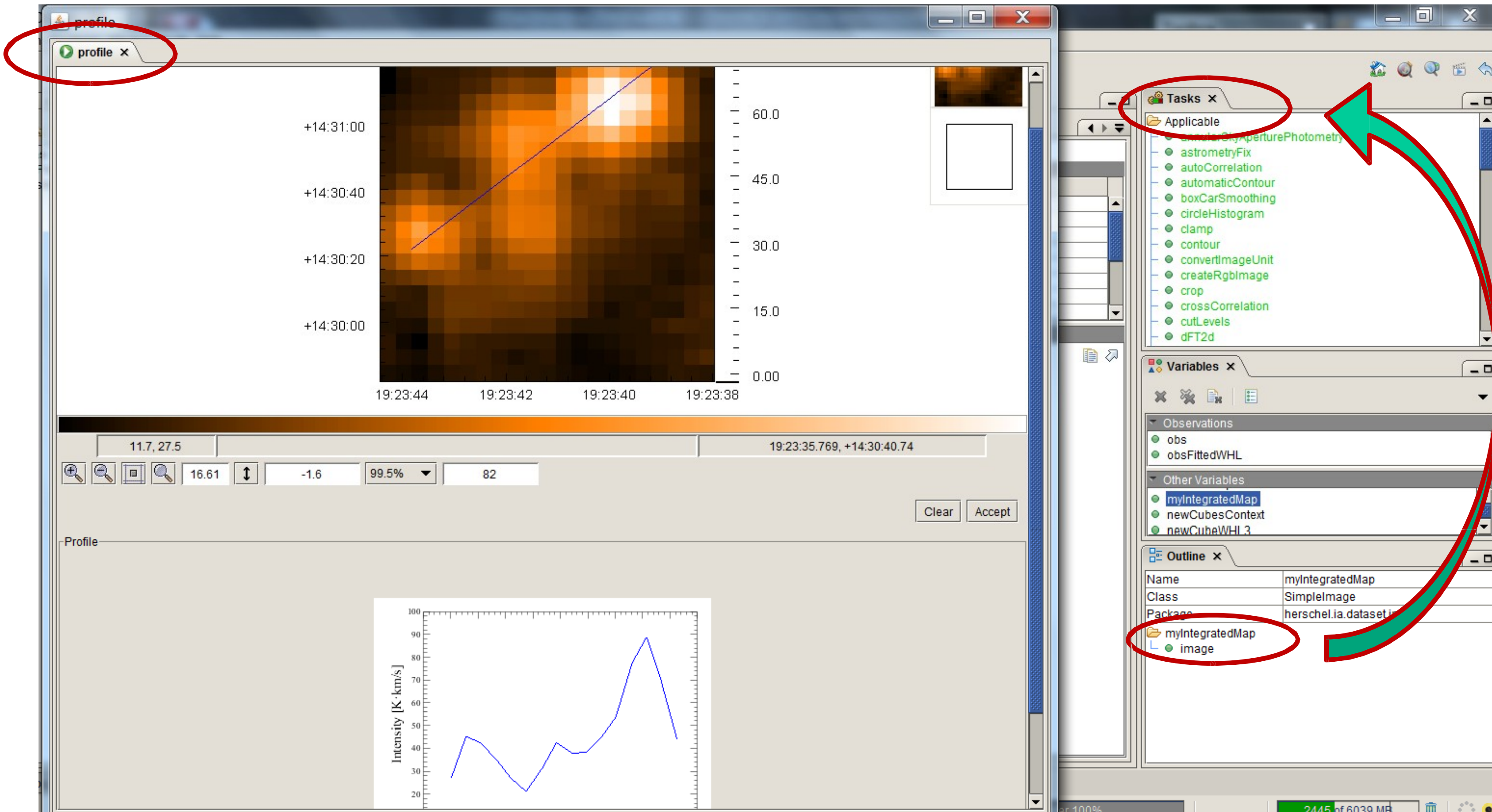
6. Cube Spectrum Analysis Toolbox (CSAT)

- Can extract spectra in various apertures, crop in frequency, create a PV map, convert the cube units (GHz to velocity), make a velocity map, and integrated intensity map. We can also subtract baselines in the CSAT (not as sophisticated as fitBaseline, but a good means to create a continuum map).

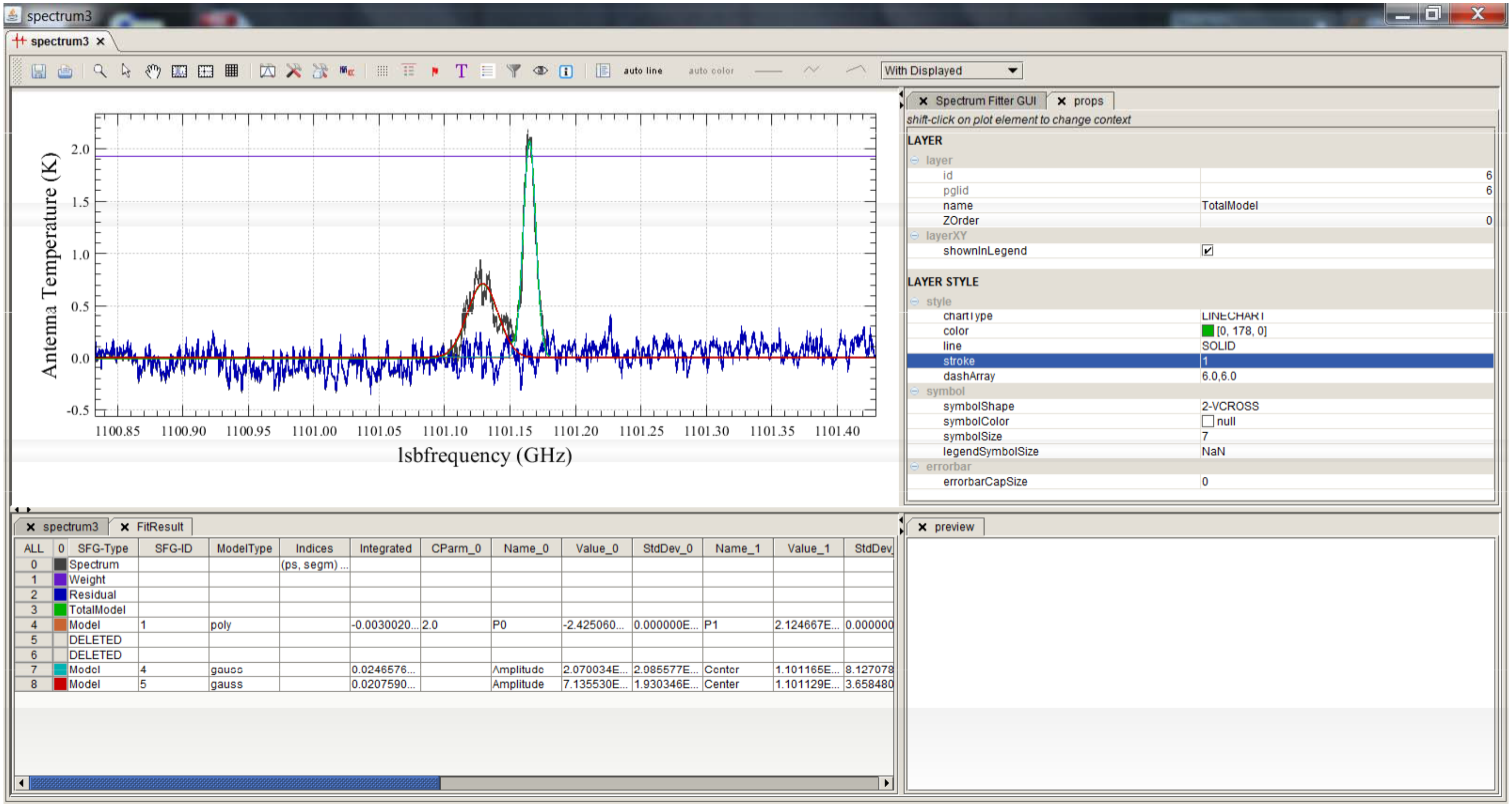


7. Image analysis

- Image analysis tools have been developed by PACS/SPIRE, usable on any HIFI 2D map image.
- Smoothing, contour overlays, source fitting, etc etc.



8. Line fitting: CSAT + Spectrum Fitter Toolbox (teaser)



Multi-component fitting can be done on individual spectra extracted from a cube, and applied to the entire cube if desired, creating products for each component.