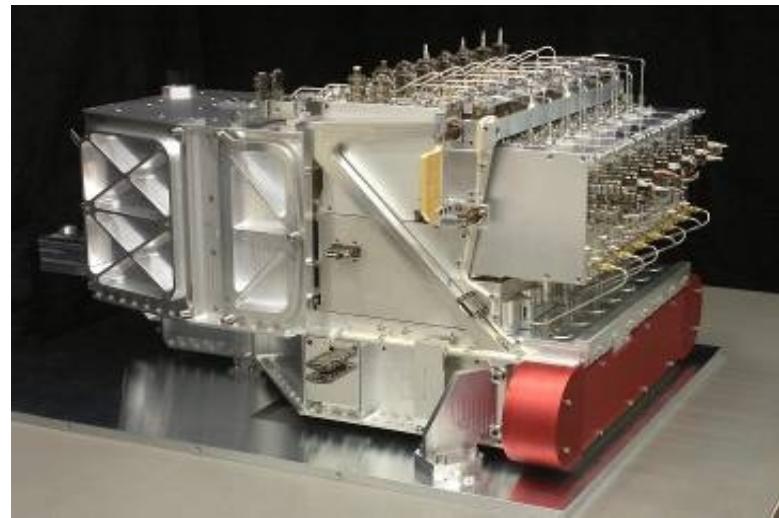
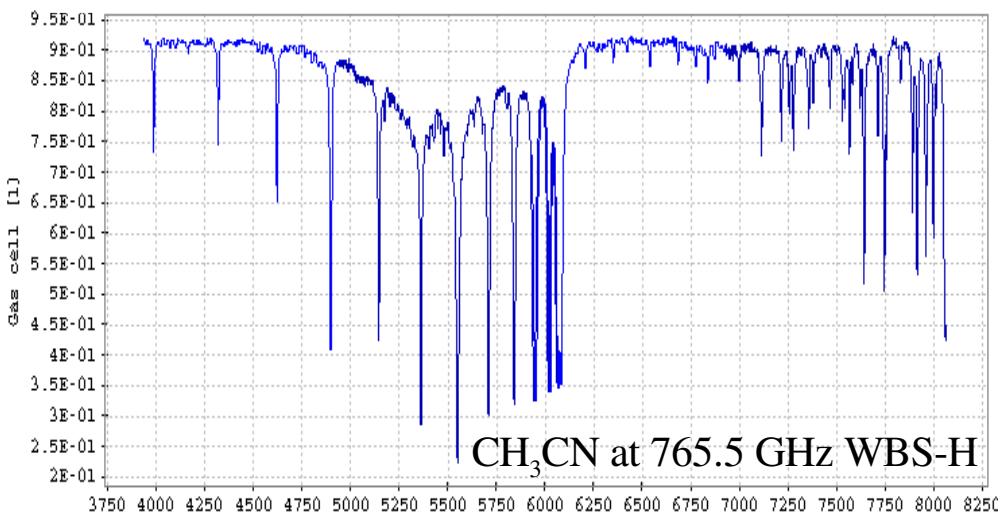


HIFI Pipelines and Data Products

Adwin Boogert, NHSC/IPAC, Pasadena, CA, USA

Thanks to: Pat Morris, Carolyn McCoey, Jesus Martin-Pintado,
Colin Borys, Russ Shipman, Steve Lord





Menu

- HIFI Instrument and AOTs
 - HIFI Pipeline Structure (see also posters!)
 - HIFI Level 0 → 1 Processing:
 - Standard Product Generation (SPG; 'lights out')
 - Interactively
 - HIFI Level 1 → 2 Processing:
 - Flagging Bad Data
 - Deconvolution Double Side Band Spectra
 - Standing Wave Removal
 - Map Making
 - ...
 - HIFI Data Products

HIFI: most powerful and versatile heterodyne instrument in space for observing molecular and atomic lines in FIR/submm at ultra-high spectral resolutions

- Single pixel on the sky

7 dual-polarization mixer bands

- 5 x 2 SIS mixers:
480-1250 GHz, IF 4-8 GHz
- 2 x 2 HEB mixers:
1410-1910 GHz, IF 2.4-4.8 GHz

14 LO sub-bands

LO source unit in common

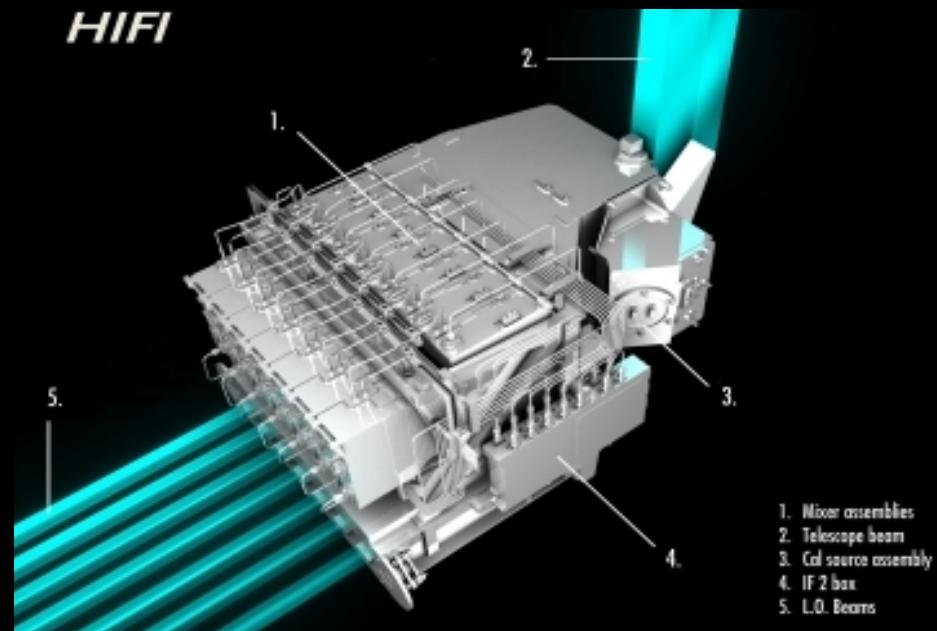
LO multiplier chains

2 spectrometers

- Auto-correlator (HRS)
- Acousto-optical (WBS)

IF bandwidth/resolution

- 2.4 and 4 GHz (in 2 polarizations)
- 0.14, 0.28, 0.5, and 1 MHz
- Velocity discrimination 0.1-1 km/s



Angular Resolution (w/ telescope):

11''.3 (high-freq. end) to 40'' (low-freq. end)

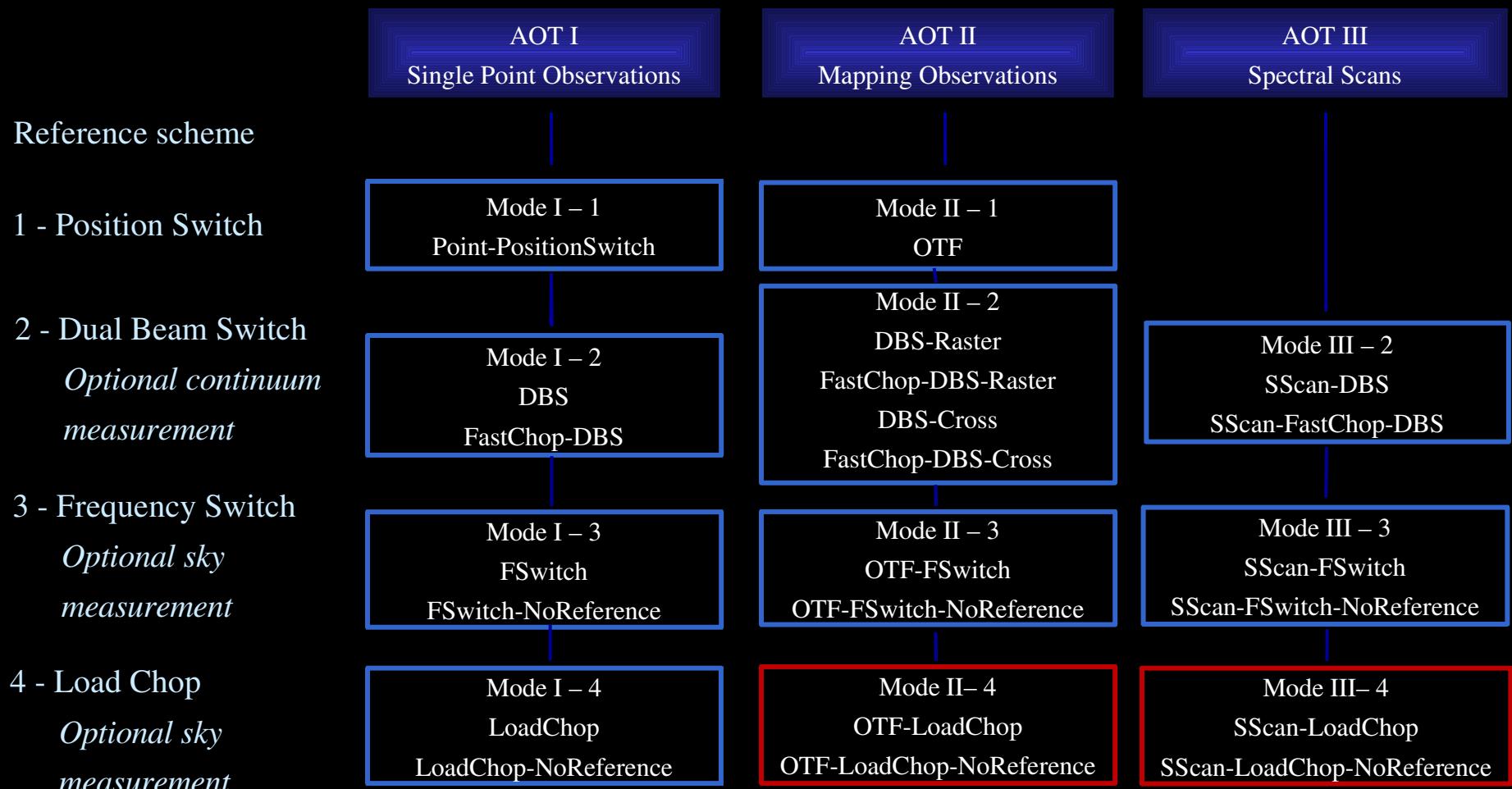
Sensitivity

Near-quantum noise limit sensitivity

Calibration Accuracy

10% radiometric baseline, 3% goal

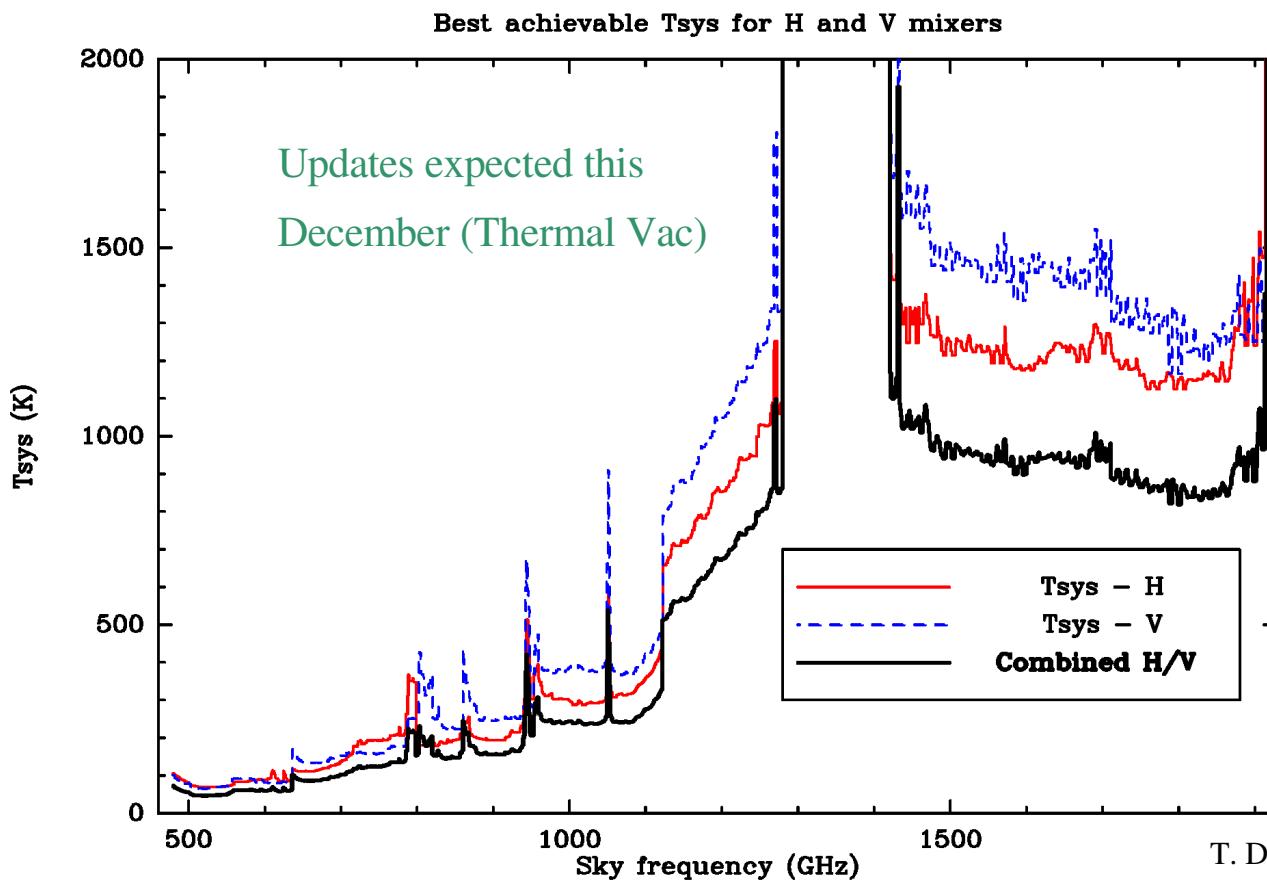
AOT Schemes



Load-Chop modes for OTF Maps and SScans being tested, as Fswitch alternative.

See HIFI Observers' Manual: http://herschel.esac.esa.int/Docs/HIFI/html/hifi_om.html

Latest Performances (June '08)



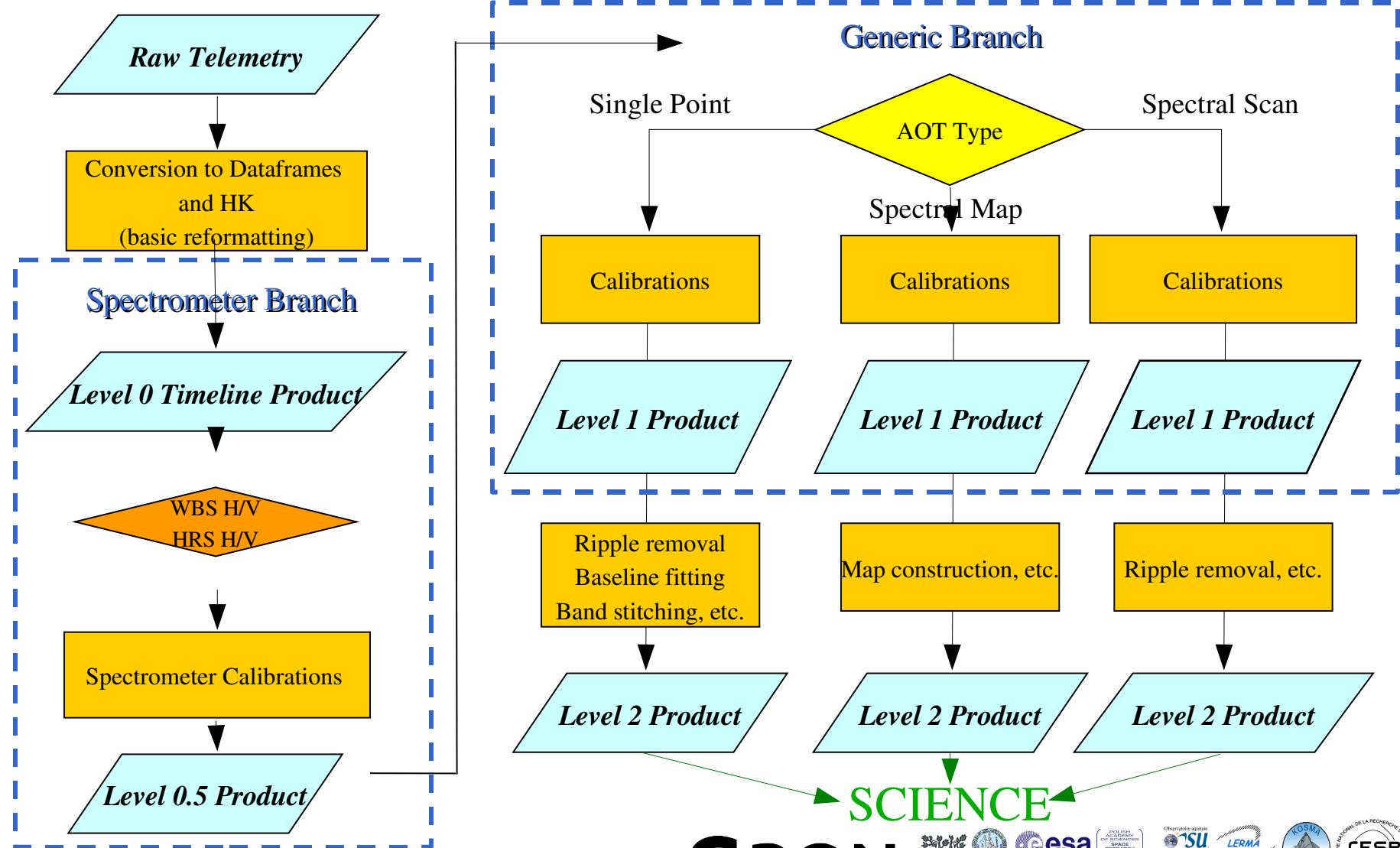
T. De Graauw, D. Teyssier, et al.
SPIE 2008 / Marseille

HIFI Pipeline Concept

Processing HIFI observations similar to ground-based telescopes with heterodynes,
e.g., @ CSO, JCMT, IRAM, KOSMA

- **Spectrometer Pipeline (level 0 → 0.5):** initial processing backends
 - AOT mode independent
 - Each spectrometer and polarization separately: WBS-H, WBS-V, HRS-H, HRS-V
 - *Users can run automatically and interactively, changing options, but unlikely need to*
- **Generic Pipeline (level 0.5 → 1):** applying AOT mode-specific calibrations
 - Spectrometer independent
 - Intensity calibration using Hot/Cold loads
 - Reference spectrum subtraction (on-off sky DBS, position switch, freq. throw, load)
 - *Users can run automatically and interactively, changing options, but unlikely need to*
- **Extended Pipeline (level 1 → 2):** remove additional instrumental effects
 - e.g. Standing waves, Baseline offset and slope, Sideband convolution
 - *Most interactive step for users*

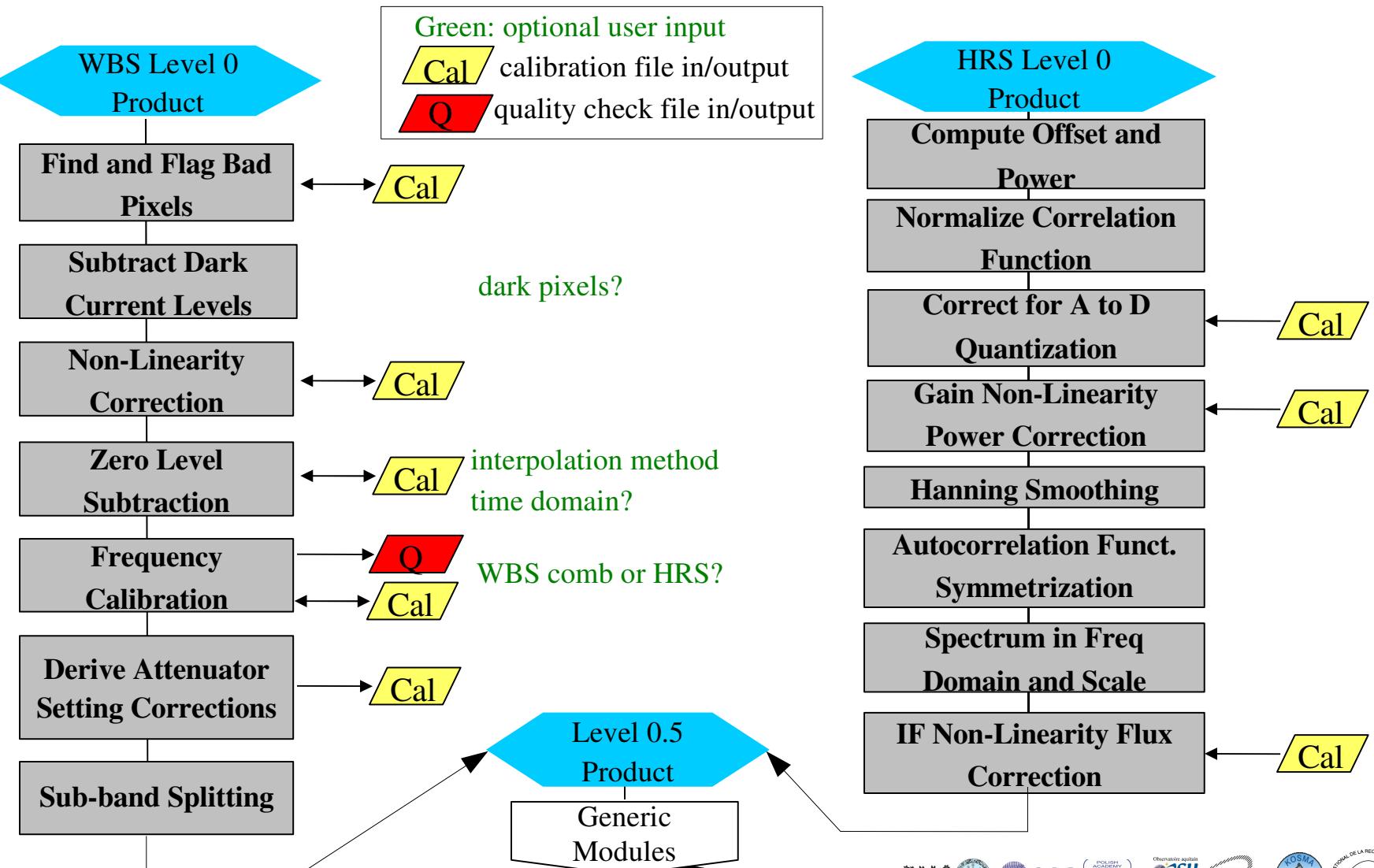
Overall Pipeline Structure



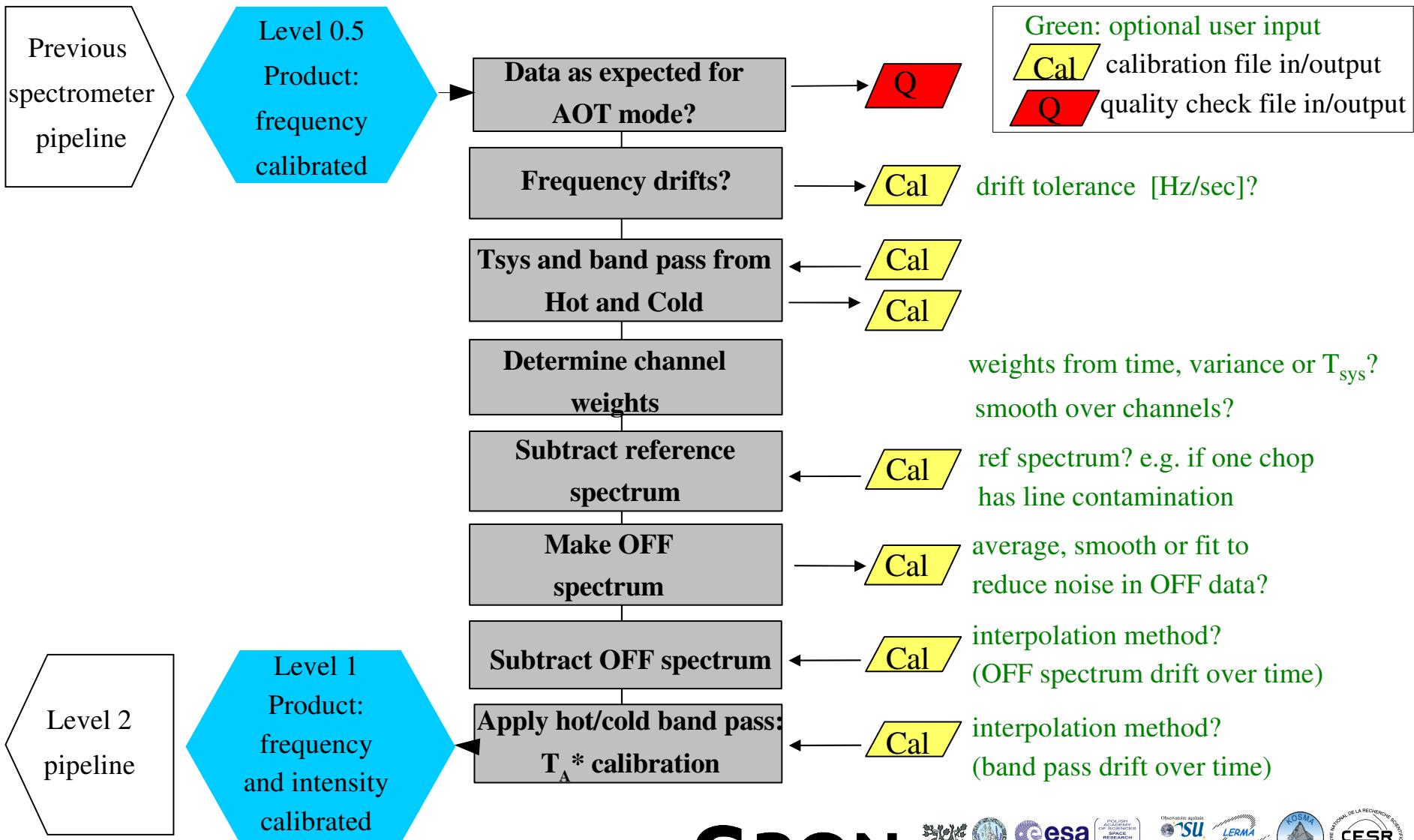
HIFI Pipelines and Data Products

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Spectrometer Pipelines (Level 0 → 0.5)



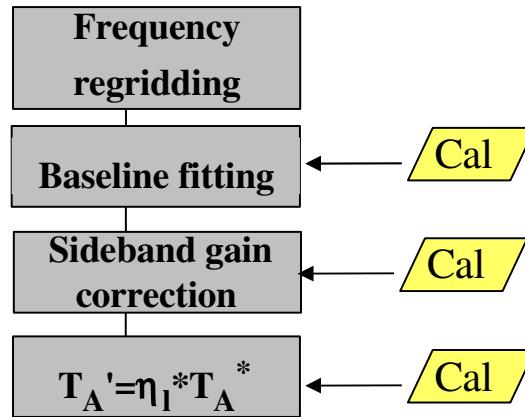
Generic Pipeline (Level 0.5 → 1)



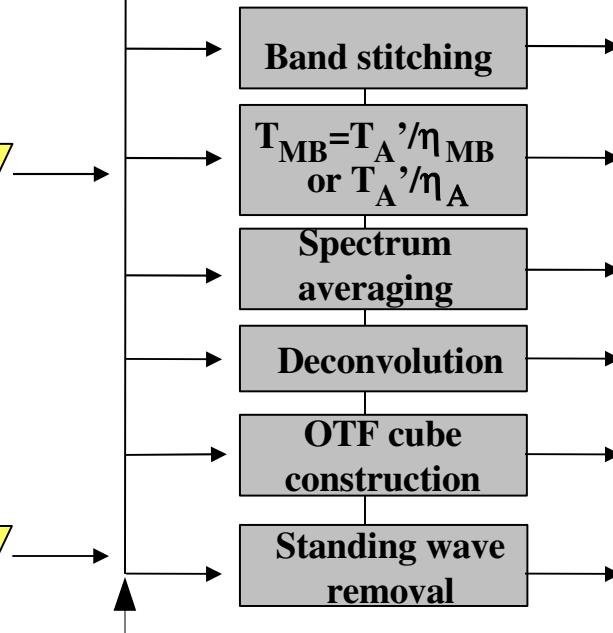
Extended Pipeline (Level 1 → 2)

Previous spectrometer and generic pipelines

Level 1 Product



freq. grid, resolution?
interpolation method?
model to fit?



sideband to correct?

Green: optional user input
Cal calibration file in/output

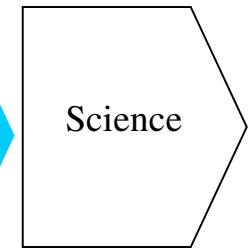
point source or extended source calibration?

Cal

Level 2 processing is most user-interaction. Several steps are optional.

Cal

Level 2 Product



How to Run these Pipelines?

Pipeline definition

Pipeline "How To"

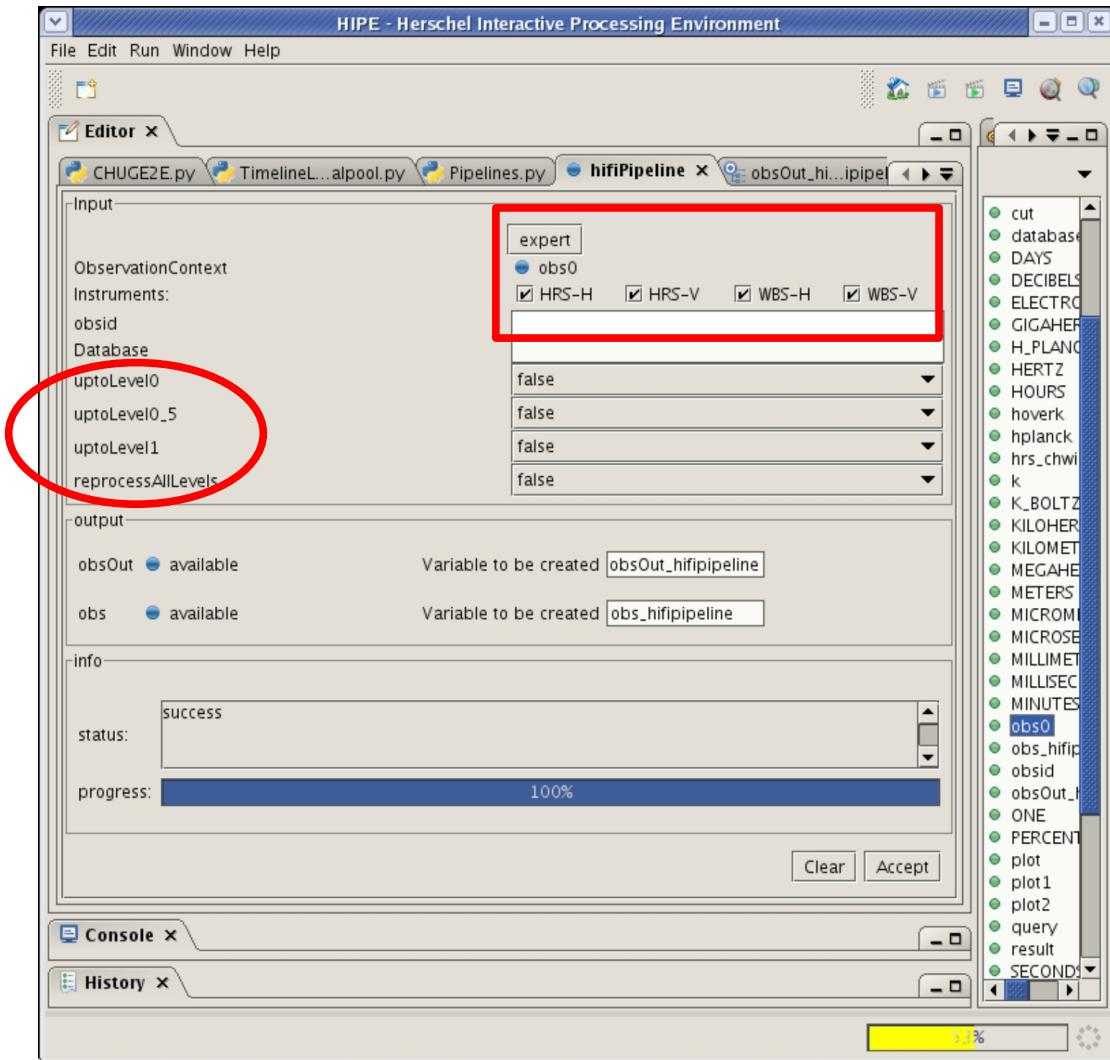
The screenshot shows a Mozilla Firefox browser window displaying the HCSS Help System. The left sidebar contains a table of contents for 'Pipeline definition' and 'Pipeline "How To"'. The 'Pipeline definition' section includes links for HIFI Frequently Asked Questions, Definition of Hifi Pipeline (with a red oval around it), Introduction, HRS Pipeline, WBS Pipeline, Generic Pipeline, HIFI Release notes for HCSS/HIFI 0.6.2 (DP 12.3), HIFI Documentation, A Basic Developer's Manual, and HIFI User's Manual. The 'Pipeline "How To"' section includes links for Java/Output of Spectra, Running the HIFI pipeline (with a red oval around it), How to run the HIFI pipeline in HIPE (with a red oval around it), How to run the HIFI pipeline from the command line, Viewing Spectra, Fitting Spectra, Mathematical Operations on Spectra, Spectral Viewing, Fitting and Operations Using ClassLib, HIFI Housekeeping, Handling On-The-Fly Maps, Sideband Deconvolution, Advanced User, and User's Reference Manual.

HCSS Help System - Mozilla Firefox
 File Edit View History Bookmarks Tools Help
 http://127.0.0.1:41705/index.jsp?mark=null
 Red Hat, Inc. Red Hat Network Support Shop Products Training
 TOC Search
 3.1. How to run the HIFI pipeline in HIPE
 3.1.1. Running the Pipeline
 1. Select the Hifi Pipeline from either the HIPE Window menu (under Show View), if you already have data for processing loaded into the session. Otherwise, double-click on the hifipipeline task under the Hifi Category in the Tasks pane.

The HIPE software interface is shown. The 'File' menu is open, and 'Show View' is selected. In the 'Tasks' pane, the 'Hifi Pipeline' task is highlighted. Other tasks listed include Classes, Console, Data Access, Editor, Herschel Login, Herschel Science Archive, History, Log, Navigator, Packages, Tasks, Variables, and Welcome. The 'Console' pane at the bottom shows the text 'IA>>'. The 'Input' and 'Output' panes show various parameters and status information.

- Pipelines generate level 0, 0.5, 1, and 2 products that can be retrieved from Herschel archive, **including all calibration products**.
- Observers have all software and can run pipelines on lap/desktop: automatically, interactively, or with own algorithms.
- Level 2 processing especially interactive, some steps are optional.
- Extensive help on running pipeline available in HIPE, written in 'how-to' fashion.
- *See demos this afternoon by Carolyn McCoey (level 0 → 1 pipelines) and Steve Lord (level 2 deconvolution tool)*

HIPE: Running Pipeline 'Lights Off'

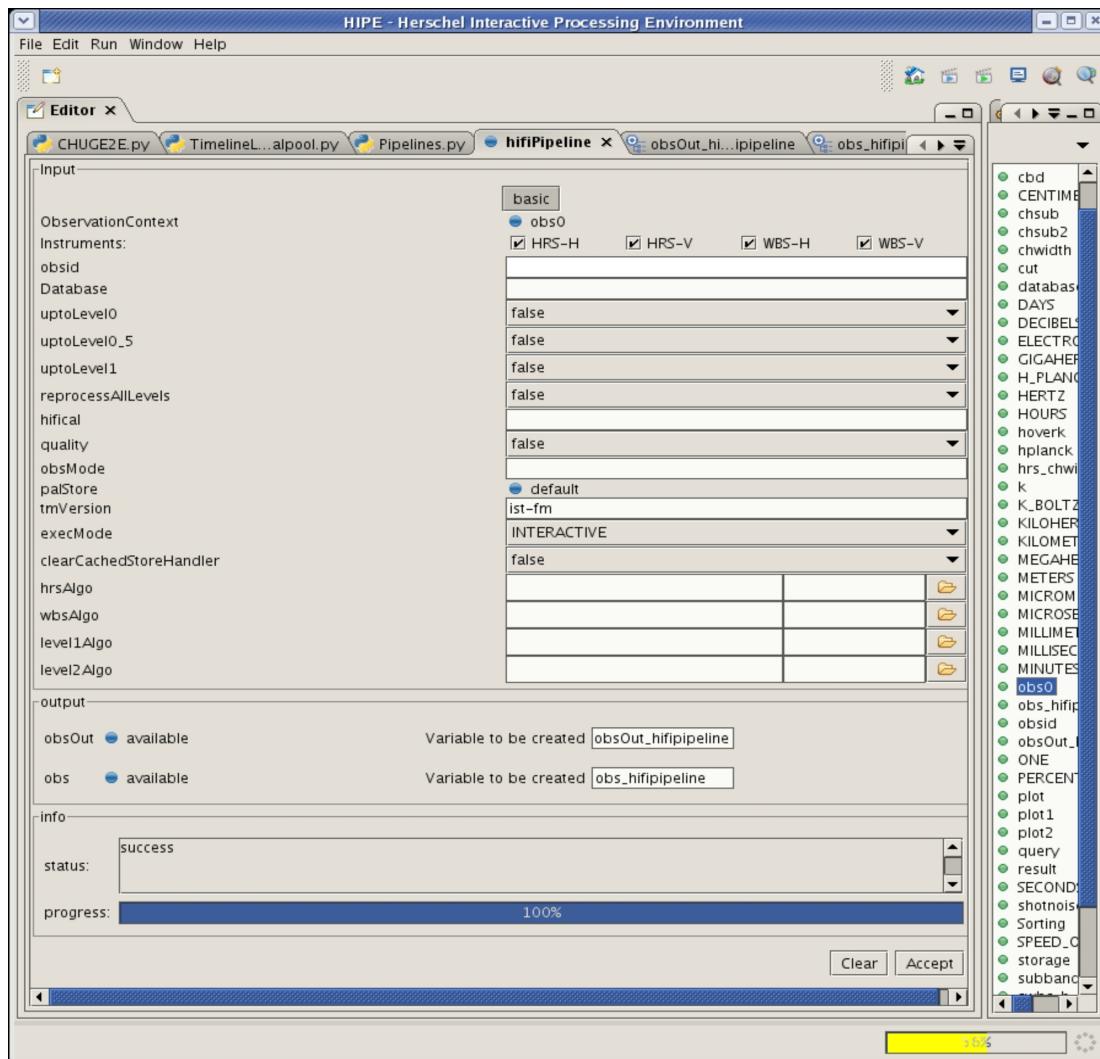


Basic HIFI SPG pipeline form
 (selected with [window->Show](#)
[View->HifiPipeline](#) and click on
[hifiPipeline](#) in Tasks pane).

Data to be processed previously
 retrieved from *Herschel Science
 Archive* is dragged and dropped
 from ObservationContext in
Variables pane on right.

Click on '[Accept](#)' to run all pipelines
 or selection thereof.

HIPE: Running Pipeline 'Lights Off'

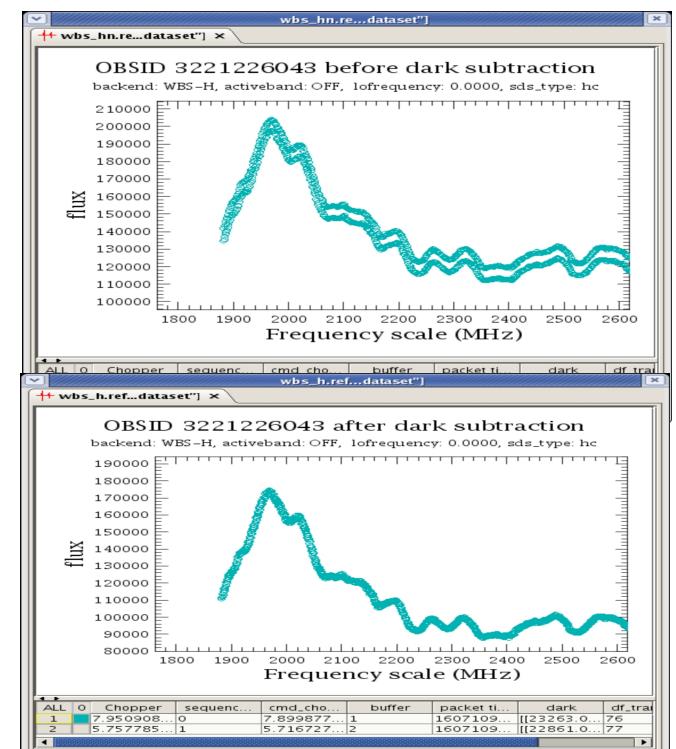
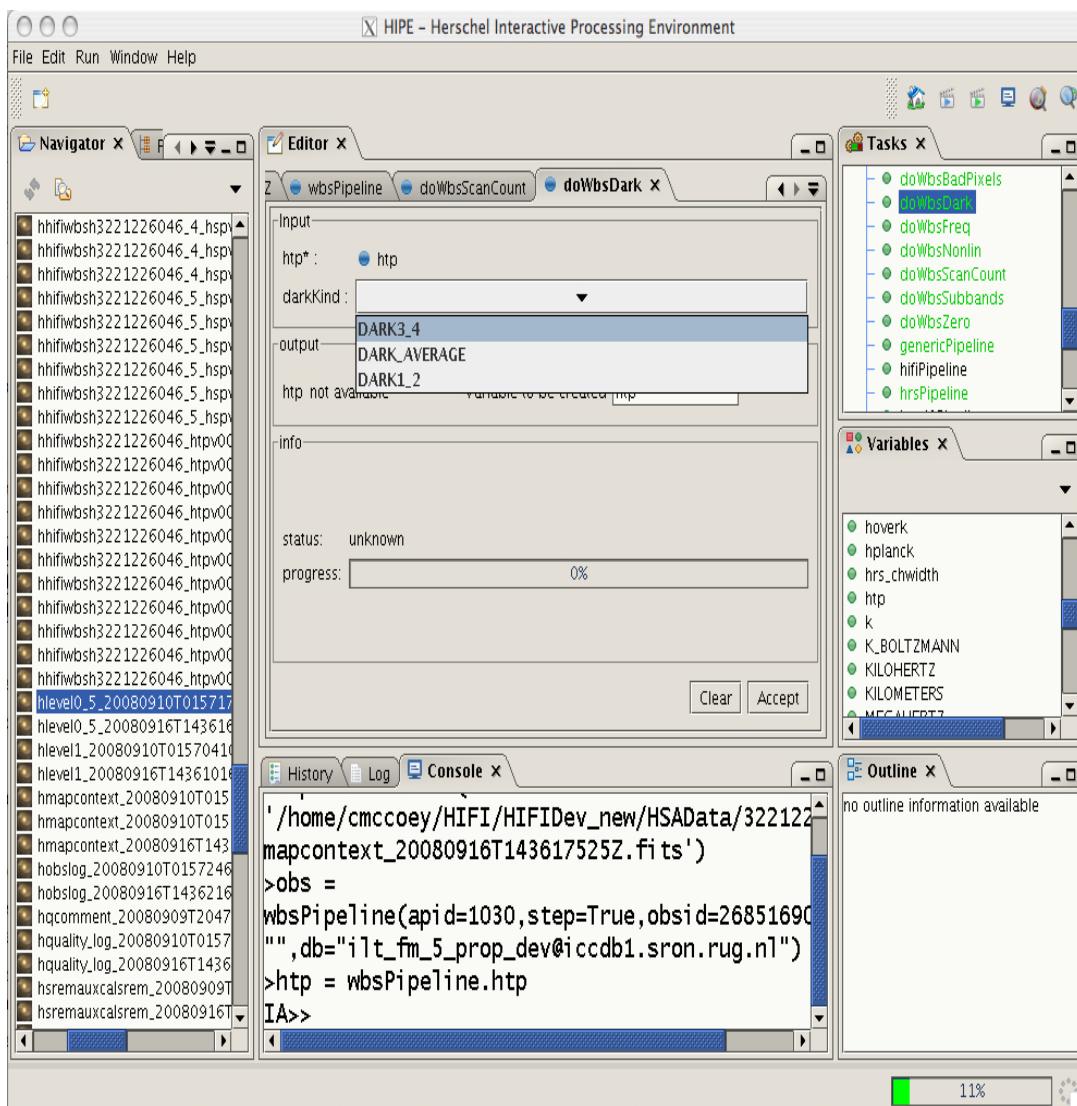


Expert HIFI SPG pipeline form offers possibility of **user-defined pipeline algorithms** (written in jython).

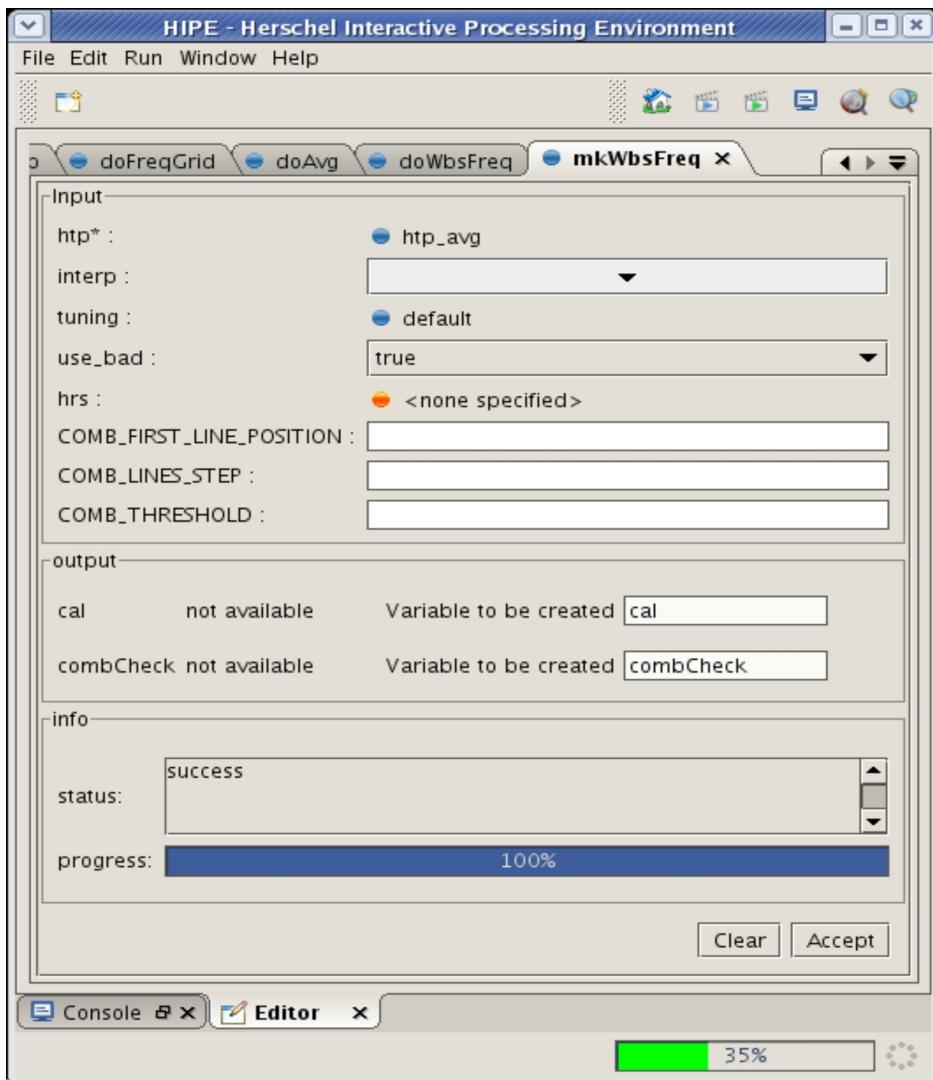
HIPE: Interactive Pipeline

Both spectrometer and generic pipelines can be run **step-by-step**. Allows for modification of parameters by user, though rarely necessary.

Example: WBS dark subtraction: even and odd channels have different dark levels



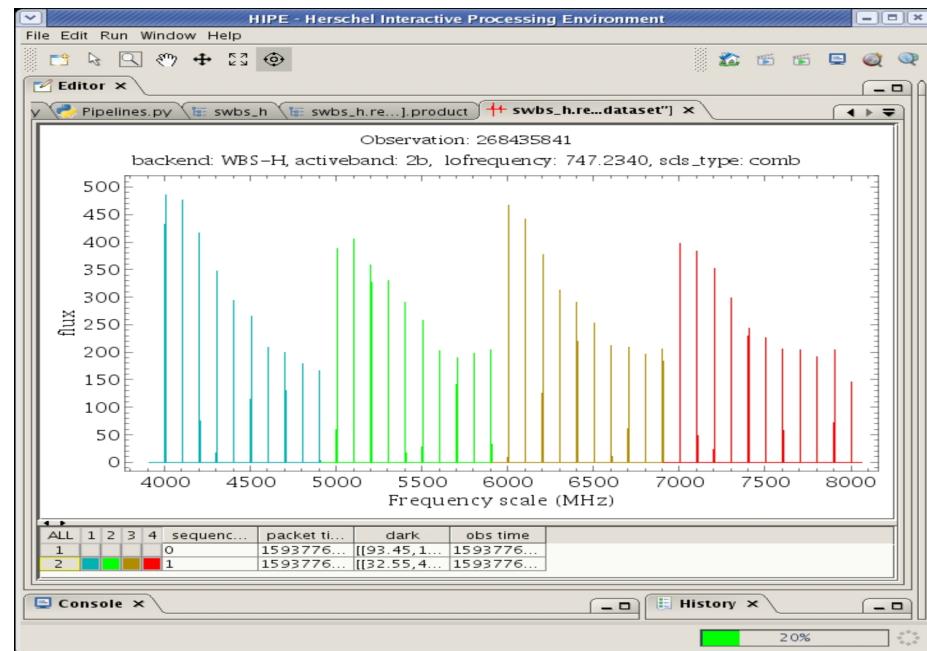
HIPE: Interactive Pipeline



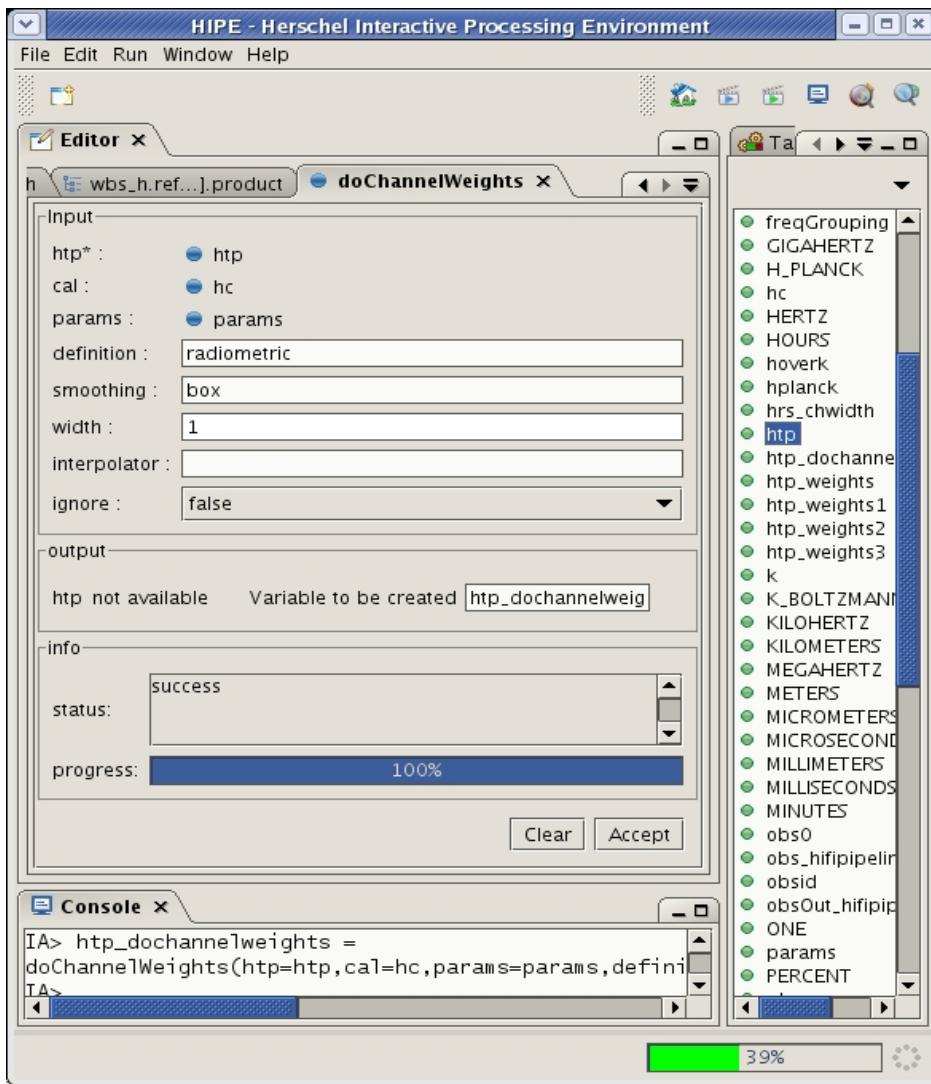
WBS frequency calibration on **comb spectrum**, fitting Gaussians. Initial values from Cal file or user input.

If comb spectrum fit fails, equally good solution can be obtained using simultaneous HRS spectrum.

Note: although user can intervene using HIPE form, pipeline will likely work fine in 99.9% of cases.



HIPE: Interactive Pipeline



- Generic pipeline somewhat more interactive than Spectrometer pipelines, although defaults will work well for almost all observations.
 - Example doChannelWeights():
 - Weight per channel can be calculated by entering in definition box:
 - 'integrTime': integration time
 - 'variance': variance in moving window
 - 'radiometric': integration time/ T_{sys}^2
 - Result can be smoothed as function of channel using box car or Gaussian convolution.
 - Note command-line equivalent in console window.

Level 1 → 2 Processing

Additional processing needed prior to science analysis (level 2):

- Bad channel flagging and interpolation (*in development*)
- Frequency regridding (*available*)
- Band stitching (*in development*)
- Baseline fitting and subtraction (*available*)
- Residual standing wave removal (*in development*)
- Averaging spectra (*available*)
- Coupling correction point and extended sources (*in development*)
- Dual sideband deconvolution of spectral scans (*available*)
- Sideband gain correction (*in development*)
- Producing cubes of OTF maps (*available*)

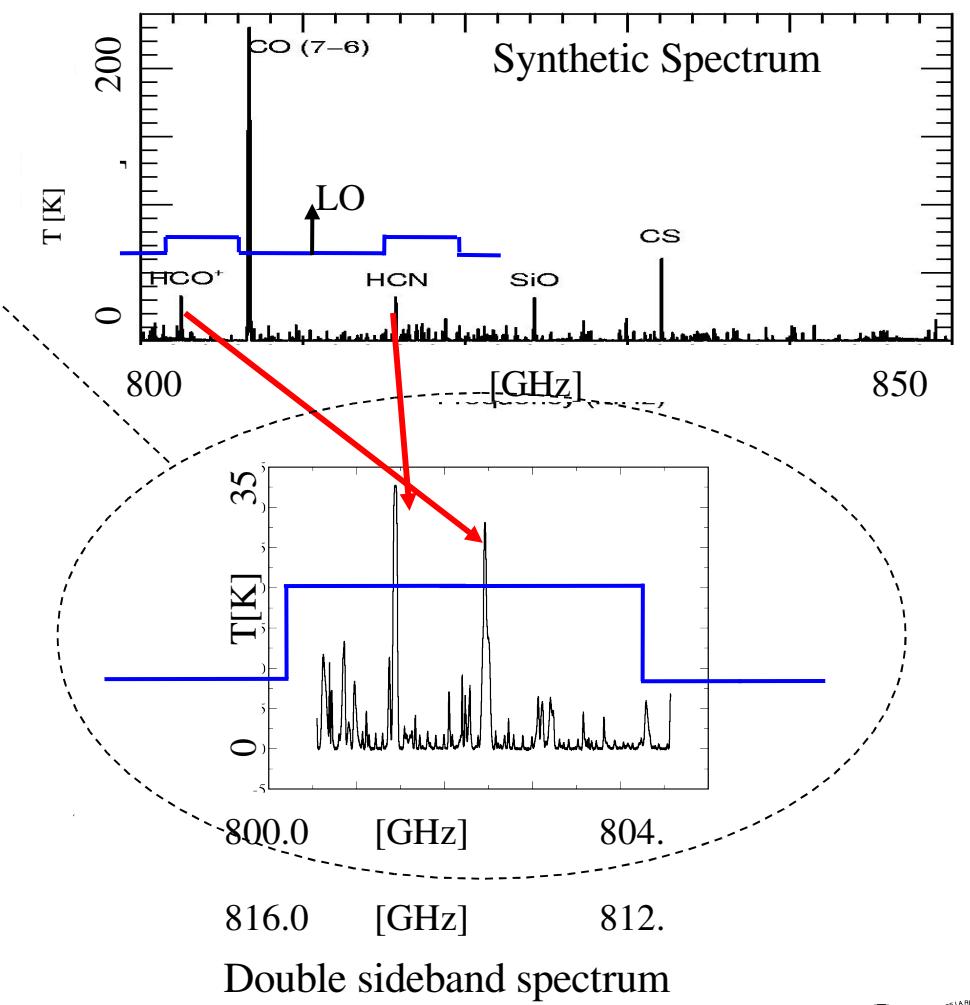
Level 1 → 2: Sideband Deconvolution

At any given LO frequency, two sidebands of 4 GHz IF coverage each (2.4 GHz bands 6+7), separated by 8-16 (4.8-9.6) GHz in sky frequencies are overlaid on top of each other in DSB spectrum, with mirrored freq. scales.

Sideband deconvolution especially important to spectrally complex regions.

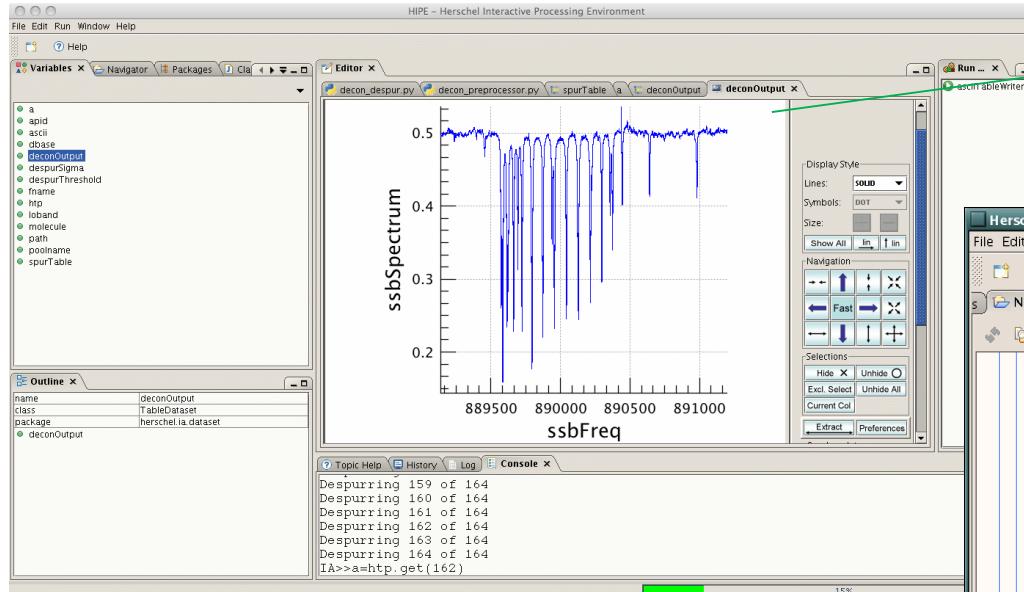
HIPE deconvolution tool based on Comito & Schilke (2002) algorithm in X-CLASS for deconvolving ground-based observations.

See demo Steve Lord this afternoon



Level 1 → 2: Sideband Deconvolution

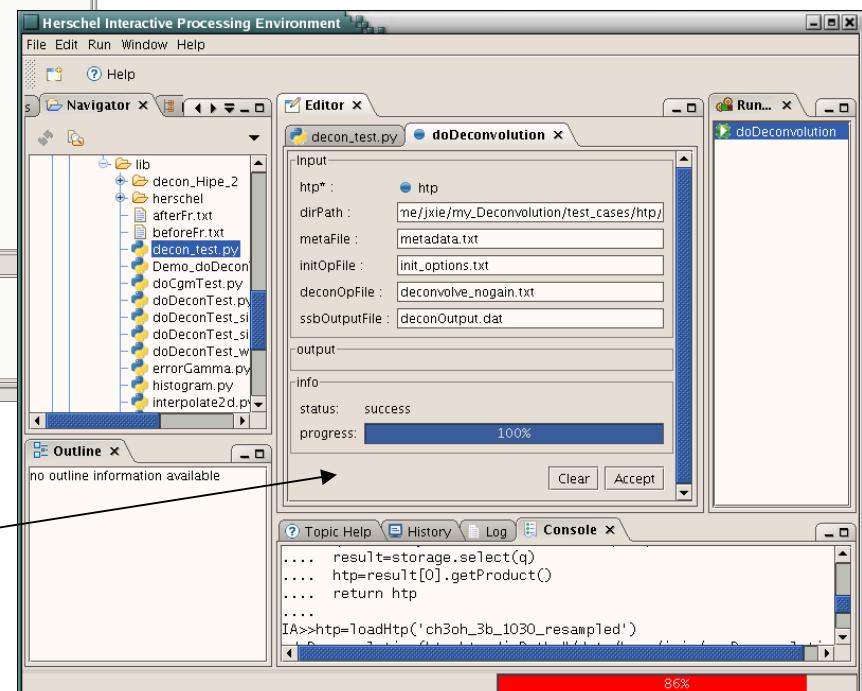
Deconvolved (SSB) result, methanol with HIFI in the lab, viewed in HIPE with TablePlotter.



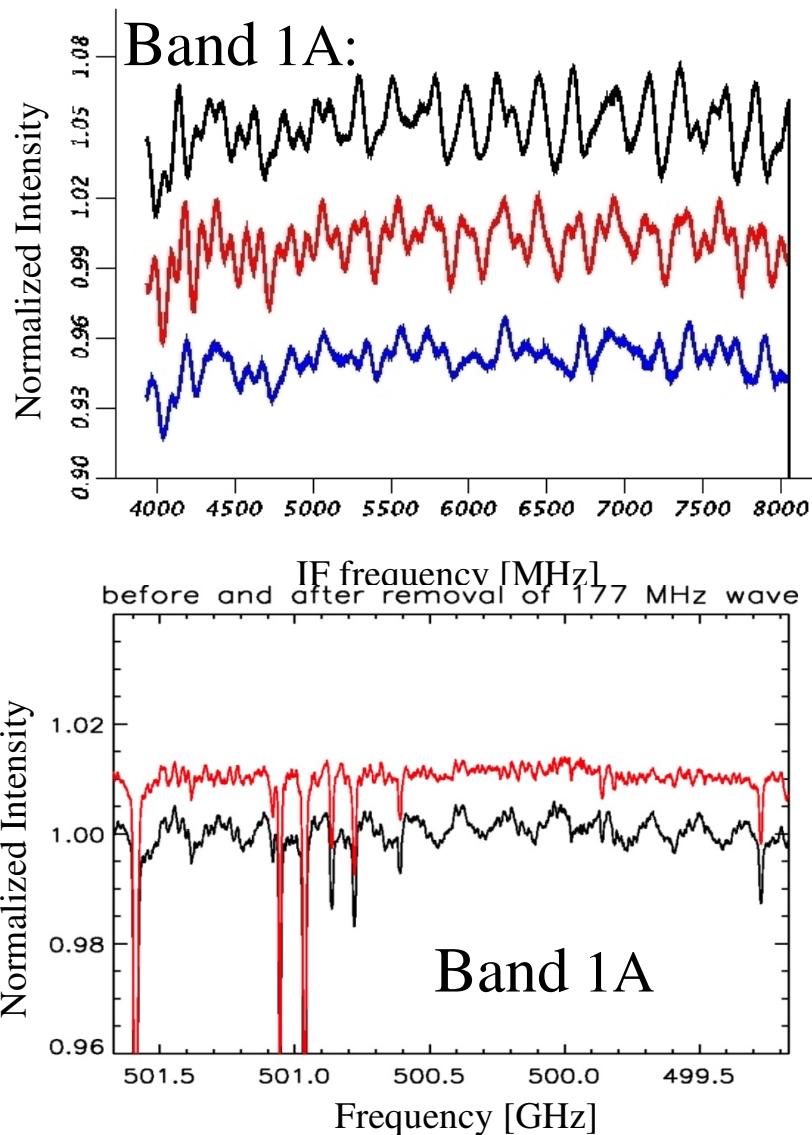
HIPE GUI frontend (beta) for decon tool
I/O and hooks to view intermediate results, fit
statistics

See demo Steve Lord this afternoon

More pretty examples of real HIFI data in the Supplemental Slides



Level 1 → 2: Standing Waves Removal



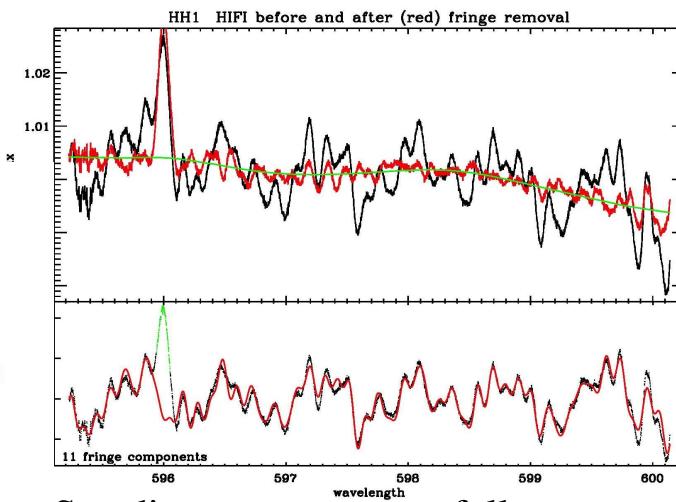
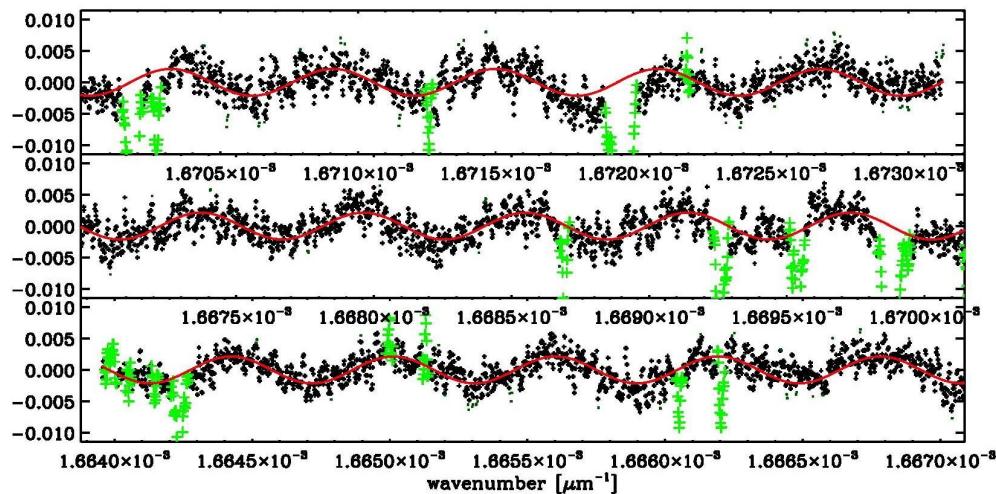
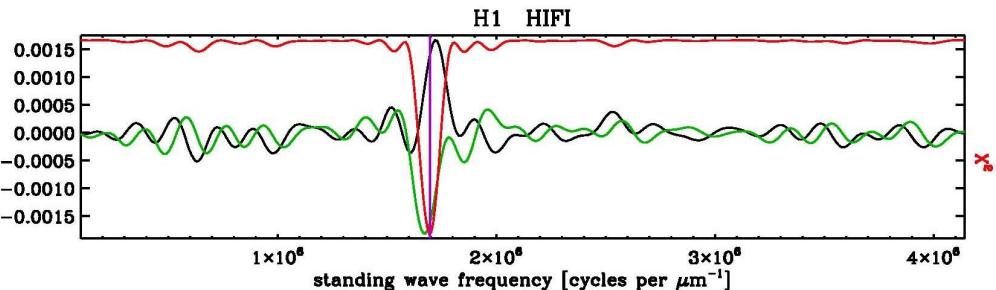
HIFI Pipelines and Data Products

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- Standing wave removal needed for all HIFI AOTs, either as a residual (e.g. chopped/nodded spectra) or if OFF sky not taken with FSwitch or LoadChop modes.
- Robust sine wave fitting routine for ISO/SWS and Spitzer/IRS defringing available in IDL. Fits multiple sine waves, using Bayesian statistics. Little user interaction. Contains line blanking routine.
- Tool being developed in HIPE. May be used for PACS and SPIRE spectra as well.

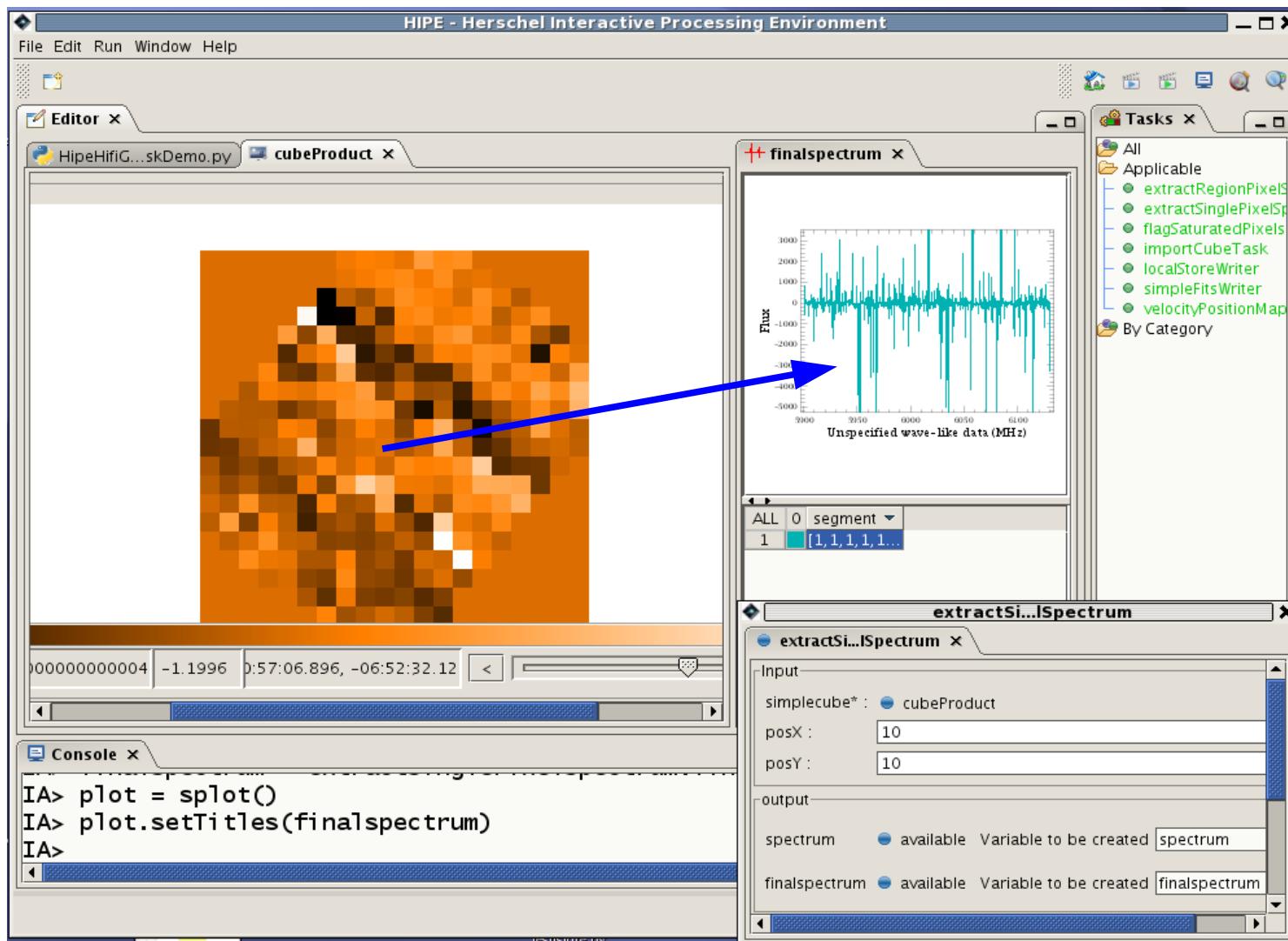
Level 1 → 2: Standing Waves Removal

'Fringes'-diagnostic plot --- χ^2 vs frequency,
with clear minimum (red)



- Standing waves successfully removed in gas cell spectra. (residual) standing wave patterns likely different in space. However, **algorithm very flexible!** Initial guesses easily adjusted.
- Bands 6+7 non-optical standing waves, non-sinusoidal. **Strength and shape power-dependent**. Well reproduced in laboratory spectra with similar power: **remove empirically**.

Level 1 → 2: Map Making



Level 2 pipeline produces data cubes of OTF maps, which can be displayed in HIPE.

Level 1 → 2: Masking Bad Data

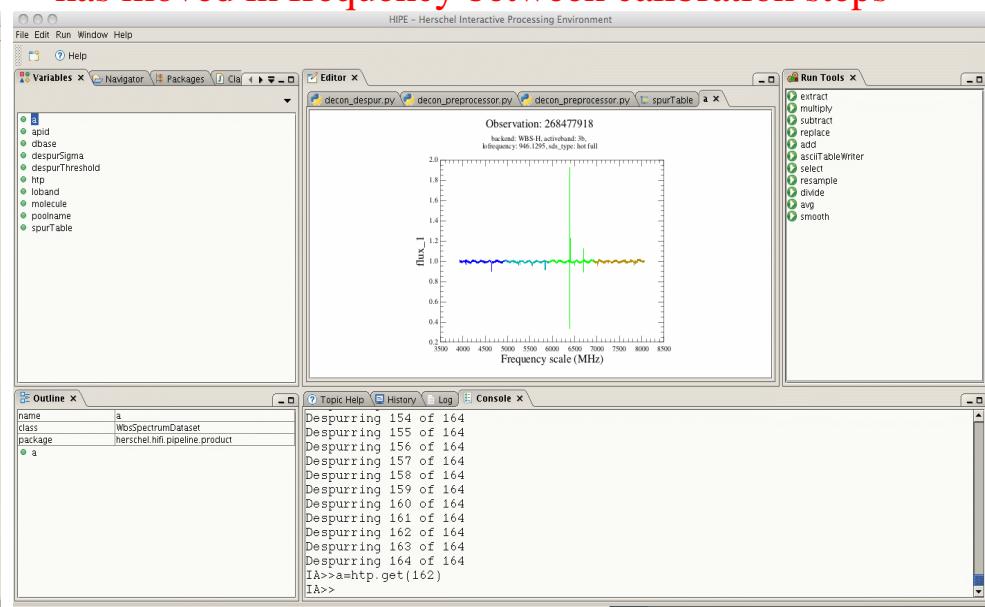
- Spurious response ('spurs') in some LO chains observed, arising from strong harmonics or oscillations in bias circuitry.
- Spurs may affect hot/cold calibrations, deconvolution solution, and spectral lines.
- Spur detector will be included in pipeline, but user may also flag spectral ranges

Spur list generated by prototype spur detector

The screenshot shows the HIPE environment with several windows open:

- Variables**: Shows variables like apid, dbase, despurSigma, despurThreshold, hpc, loband, molecule, poolname, and spurTable.
- Editor**: Displays a table titled "spurTable" with columns: Index, index, LOIM4Q, F1NH3, sinc, width [...], and Type. The data includes rows for indices 0 to 9, with various values for each column.
- Run Tools**: Shows a list of tools: extract, multiply, subtract, replace, add, asciitableWriter, select, resample, divide, avg, and smooth.

Different spur types, e.g. up/down type, where spur has moved in frequency between calibration steps



Level 2 data ALL instrument signatures removed. Science analysis tools available for HIFI users:

HIPE has Spectrum Toolbox of Astrolib-like applications for

- Conveniently displaying maps, spectral scans: *See Russ Shipman presentation tomorrow*
- Gaussian, polynomial fitting (and more functions), interactively and in scripts

Line intensity and shape fitting (outside HIPE):

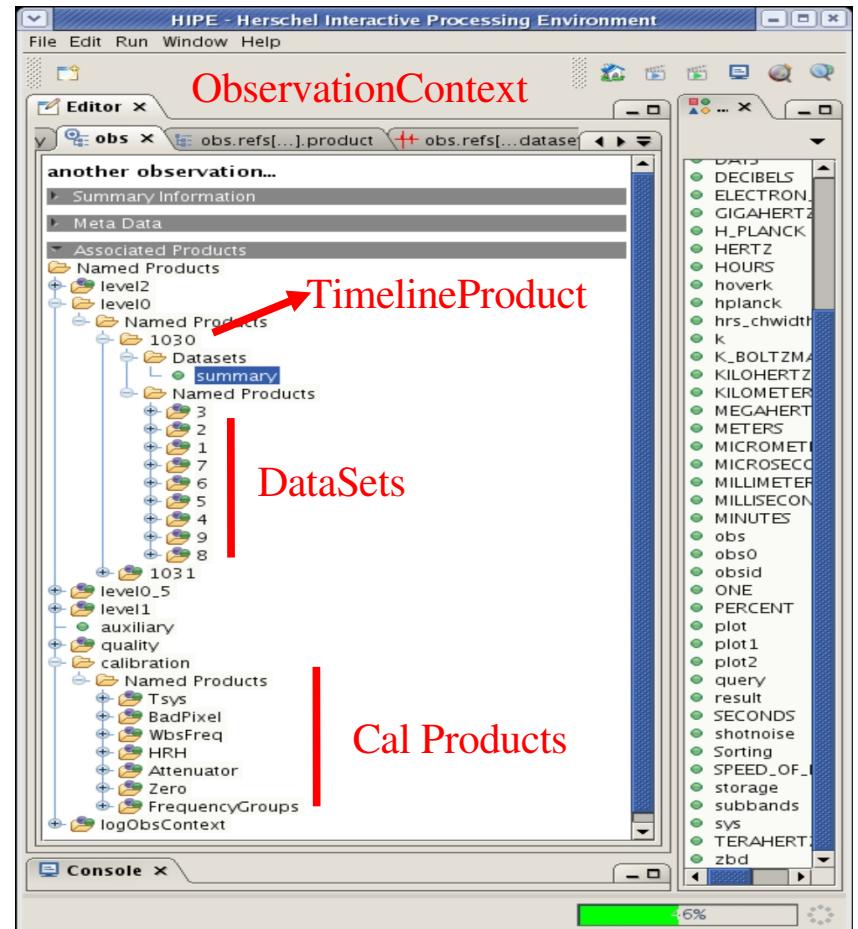
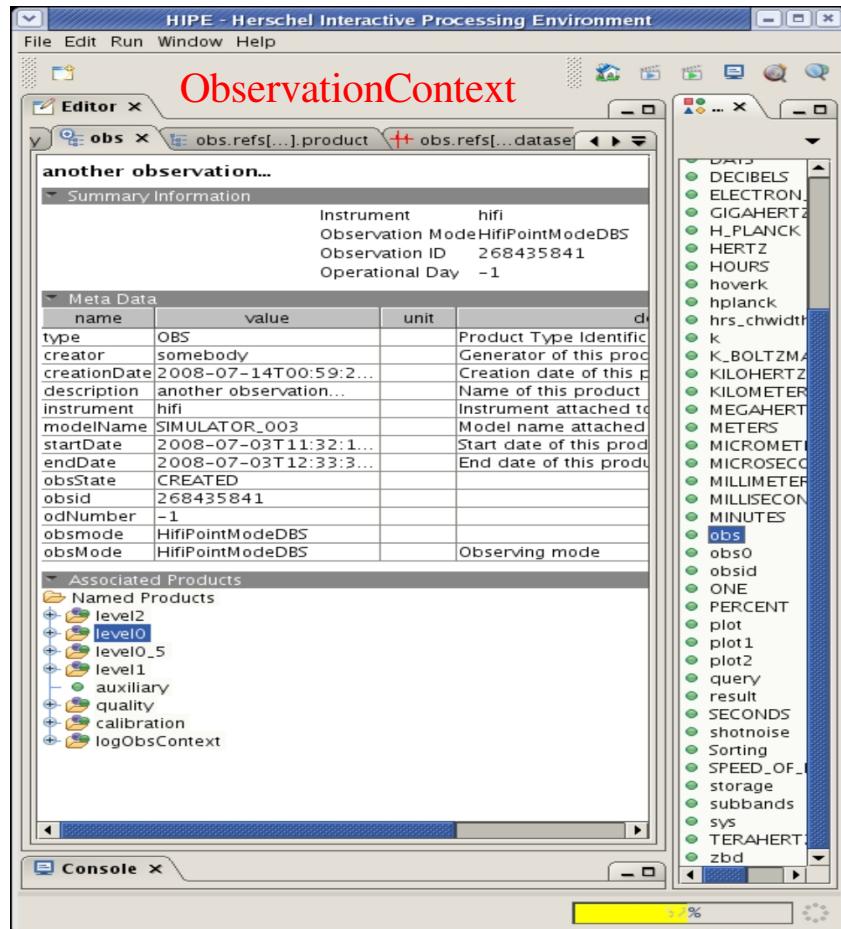
- CASSIS <http://cassis.cesr.fr/> (might be called within HIPE)
- MASSA <http://www.damir.iem.csic.es/mediawiki-1.12.0/index.php/Portada#MASSA>

Imaging tool (in HIPE) MADCUBA:

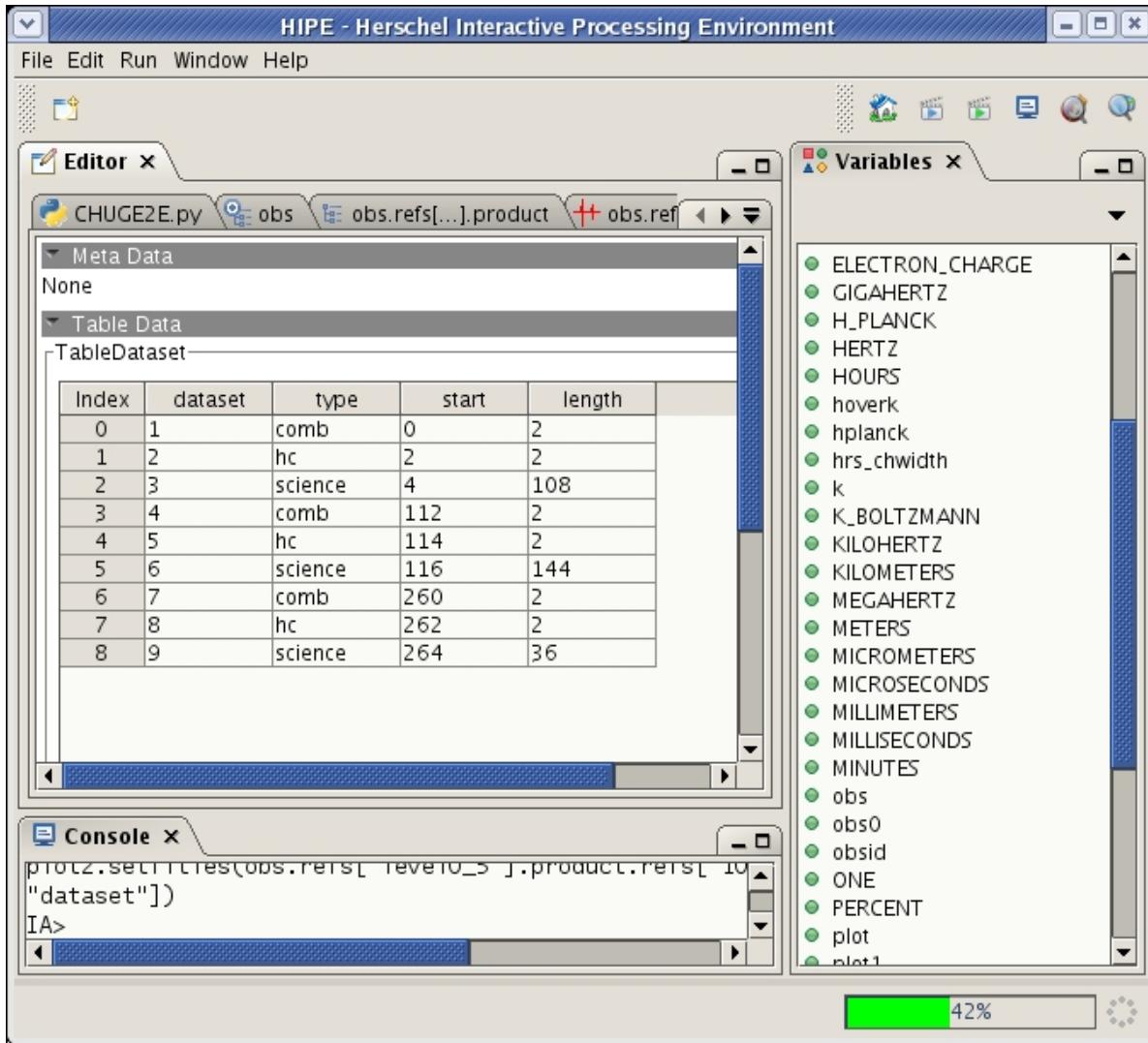
- <http://www.damir.iem.csic.es/mediawiki1.12.0/index.php/Portada>
- Regrid irregularly spaced data (time, position) to a regular grid
- Production monochromatic images, and cube of images.
- Different interpolation methods depending on desired spatial scale:
 - Nearest Neighbor (coarse but fast)
 - Linear Interpolation with windowing, with selective distance weighting and filtering

HIFI Data Products: ObservationContext

Pipelines produce “ObservationContext”, wrapping products of various pipeline levels, calibration files and meta data with observing mode, time, pointing, spacecraft velocity etc.:



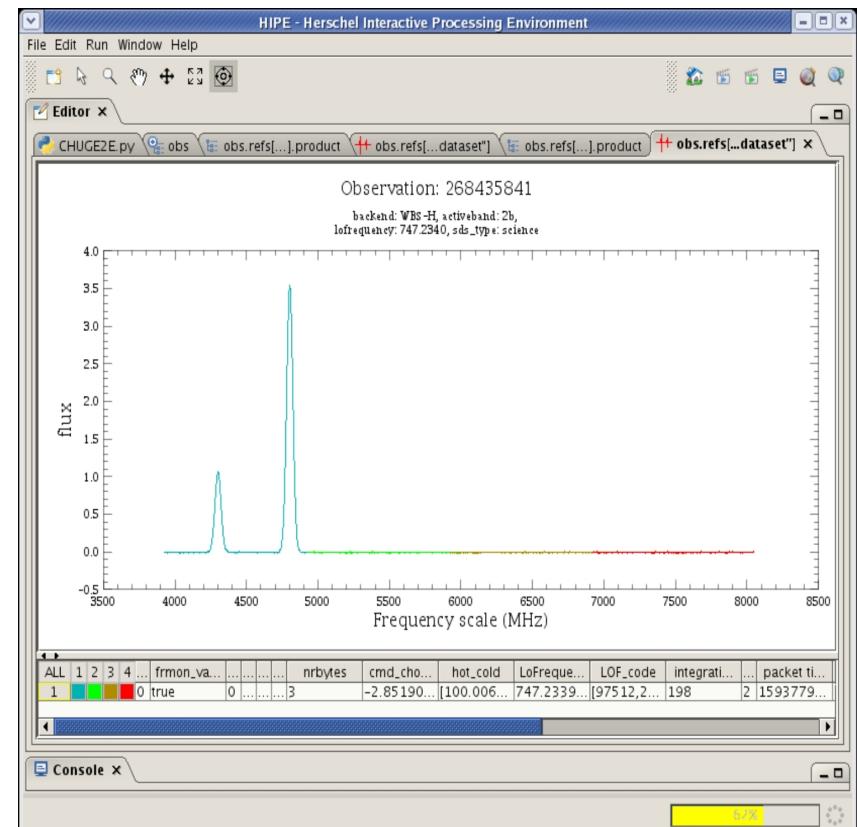
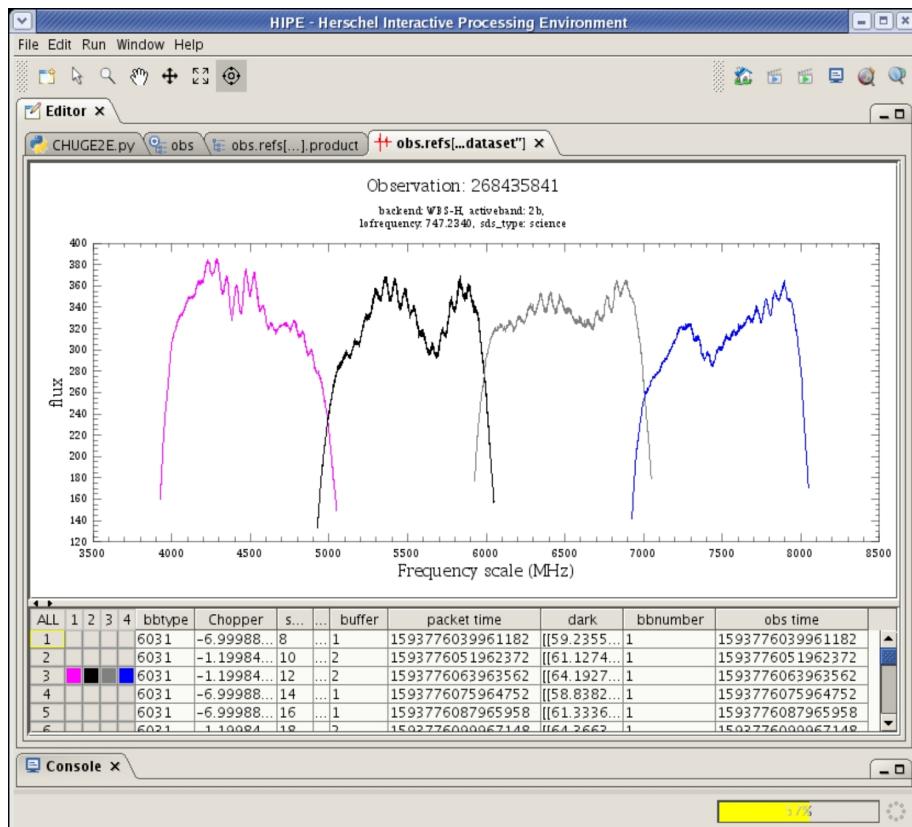
HIFI Data Products: TimelineProduct



- TimelineProduct is the fundamental container of spectra and metadata in ObservationContext
- At level 0 contains all observed spectra in time sequence including hot and cold loads, combs, on and off integrations
- At level 1 TimelineProduct cleaned from calibration data, and only science spectra remaining

HIFI Data Products: TimelineProduct

Individual integrations stored in TimelineProduct and user can list and view them in HIPE in several ways (*see presentation by Russ Shipman tomorrow*).
Level 0.5 on-source **Level 2**



Conclusions

- HIFI healthy, thermal vacuum (cold LO!) tests ongoing this and next week
- Pipelines in place, have been (and are being) extensively tested against various simulator and real-instrument data from various campaigns. Much effort going into level 2 software development.
- Pipelines can be run 'lights out' and interactively, step-by-step by users. User interaction most needed in level 1 → 2 pipeline.
- See pipeline and deconvolution demos this afternoon.

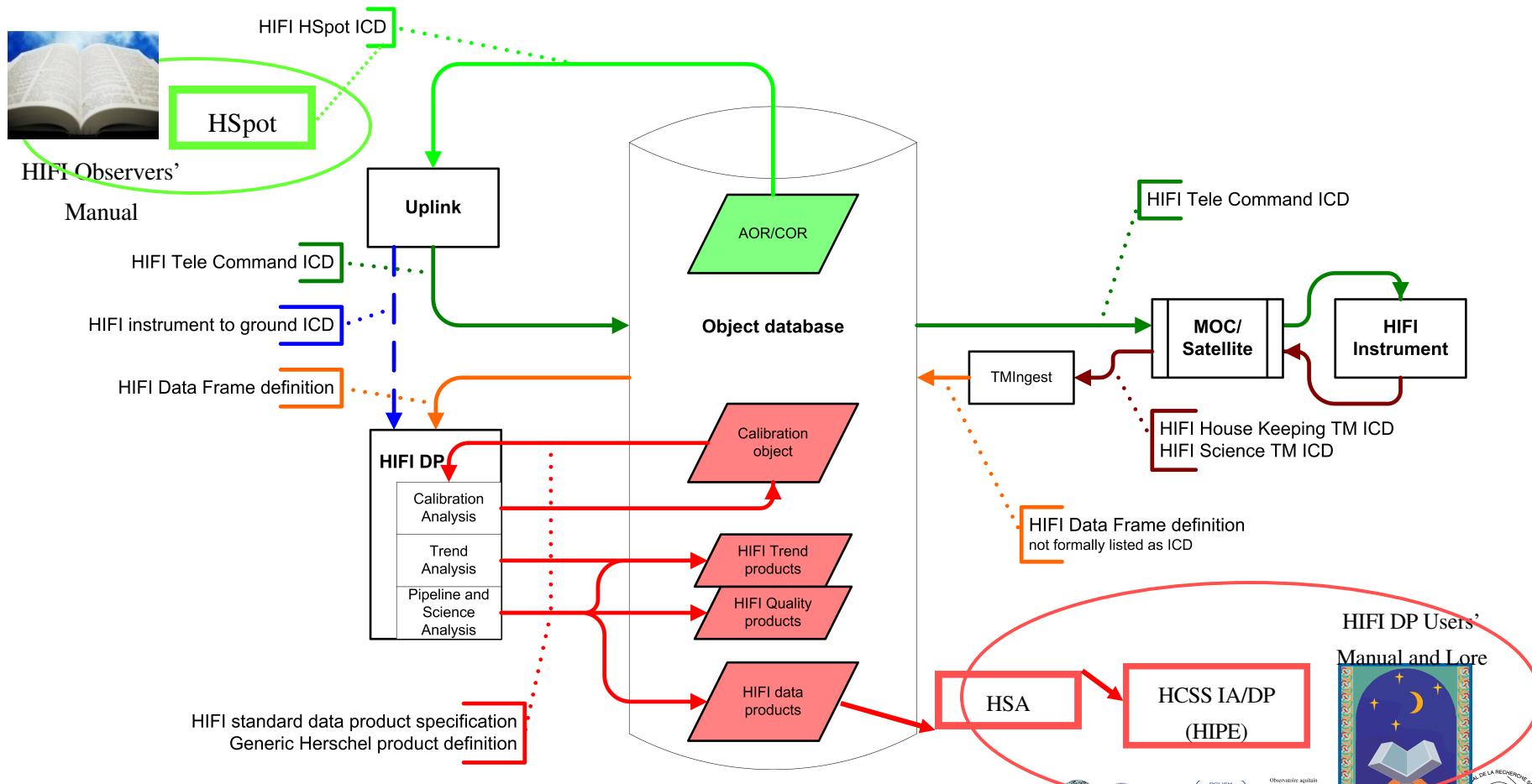
Supplemental Slides

Backup slides

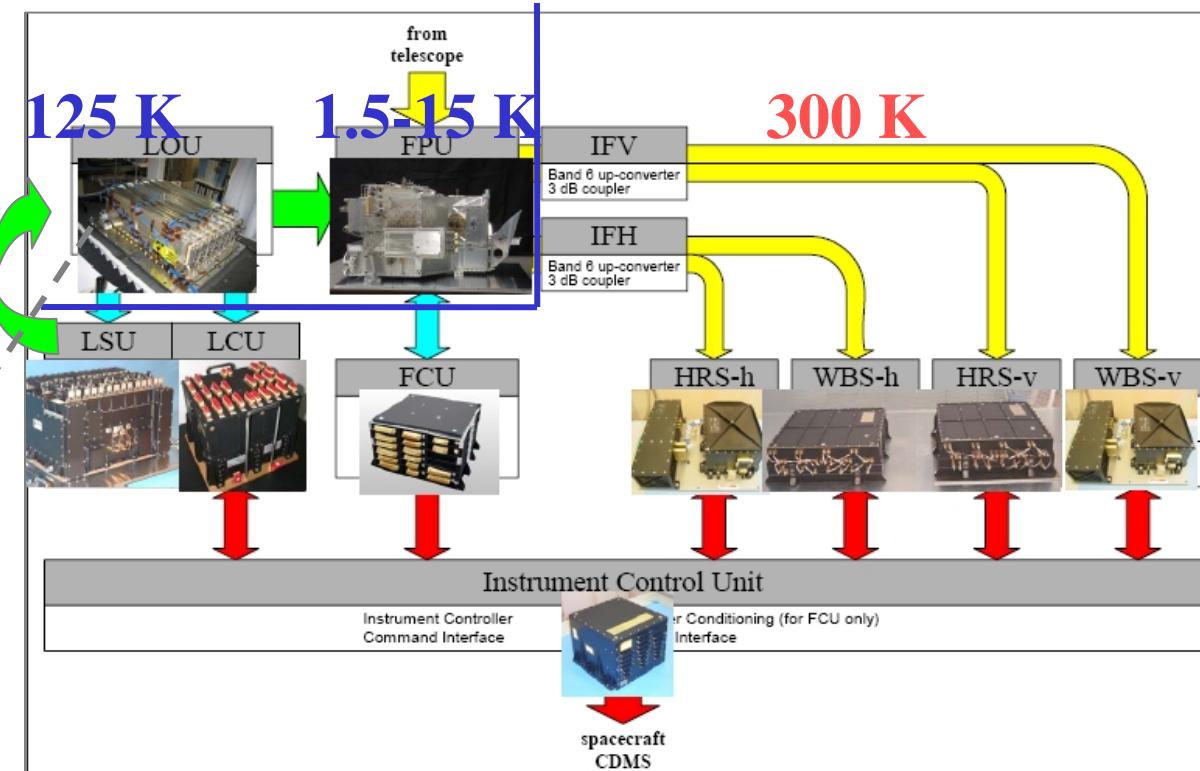
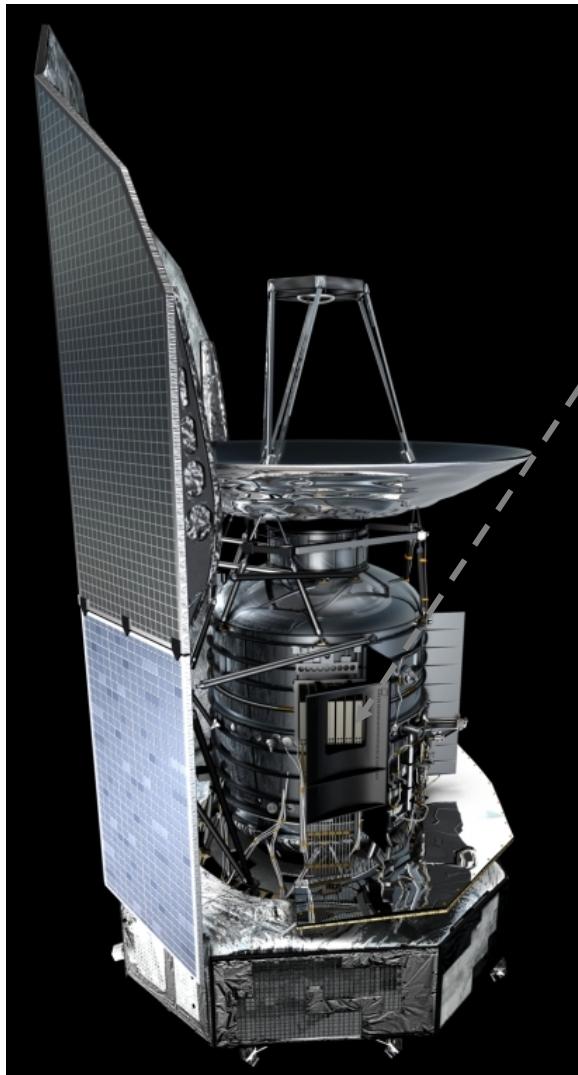
HIFI Data Interfaces

HIFI ICC data interface definitions
(P. Roelfsema, HIFI PM)

Where are Users?



Instrument Subsystems



HIFI Pipelines and Data Products

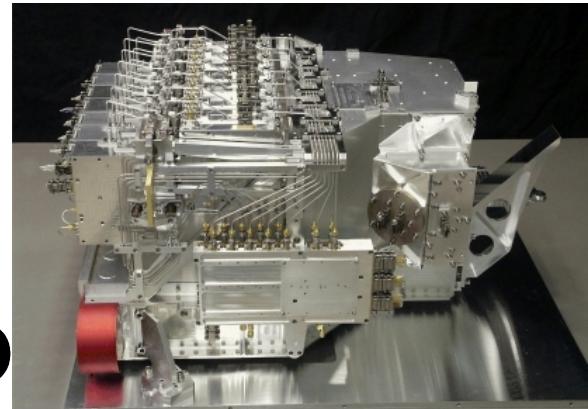
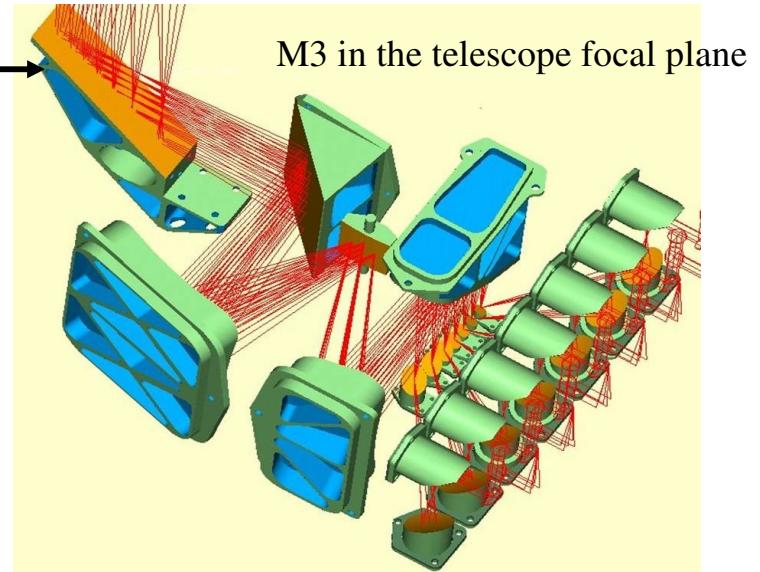
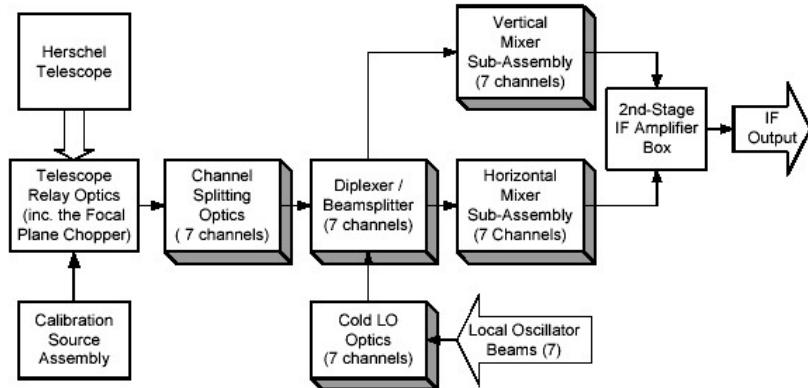
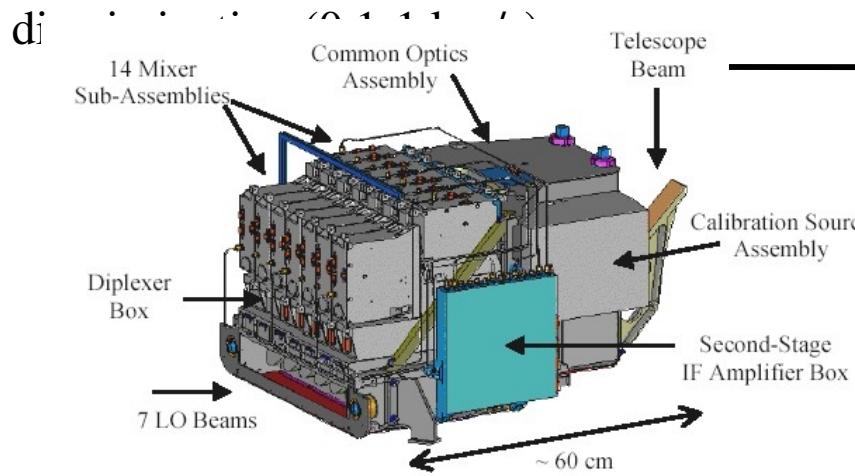
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S RON
Netherlands Institute for Space Research



HIFI Layout and Optics

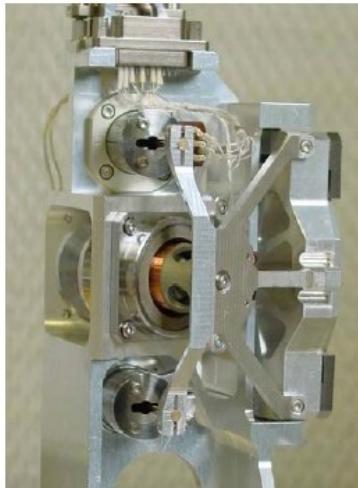
HIFI is aimed at the cool and cold Universe of Molecules (120 species known), neutral and ionic lines occurring at TeraHerz (10^{12} Hz) frequencies with very high velocity



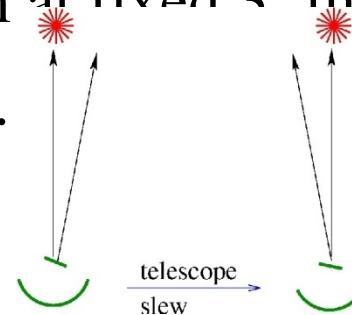
Chopper Mechanism

So-called M6 mirror, workhorse of Dual Beam Switching and Load Chop
Observing Modes to

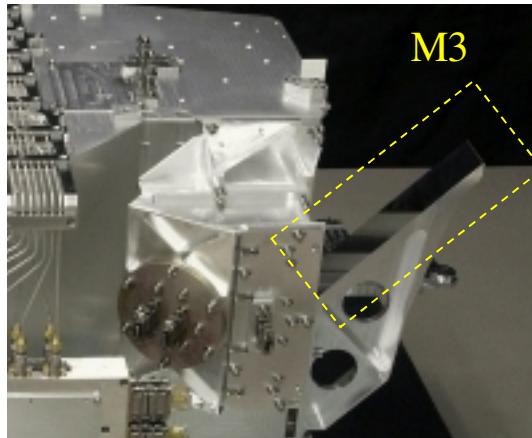
- Equivalently chop the telescope secondary to move the beam on the sky
- Redirect the instrument's optical beam to internal hot (100 K) and cold (10 K)
Chopping of the telescope



beam at fixed 3' throw, up to
5 Hz.



HIFI on the “sky”

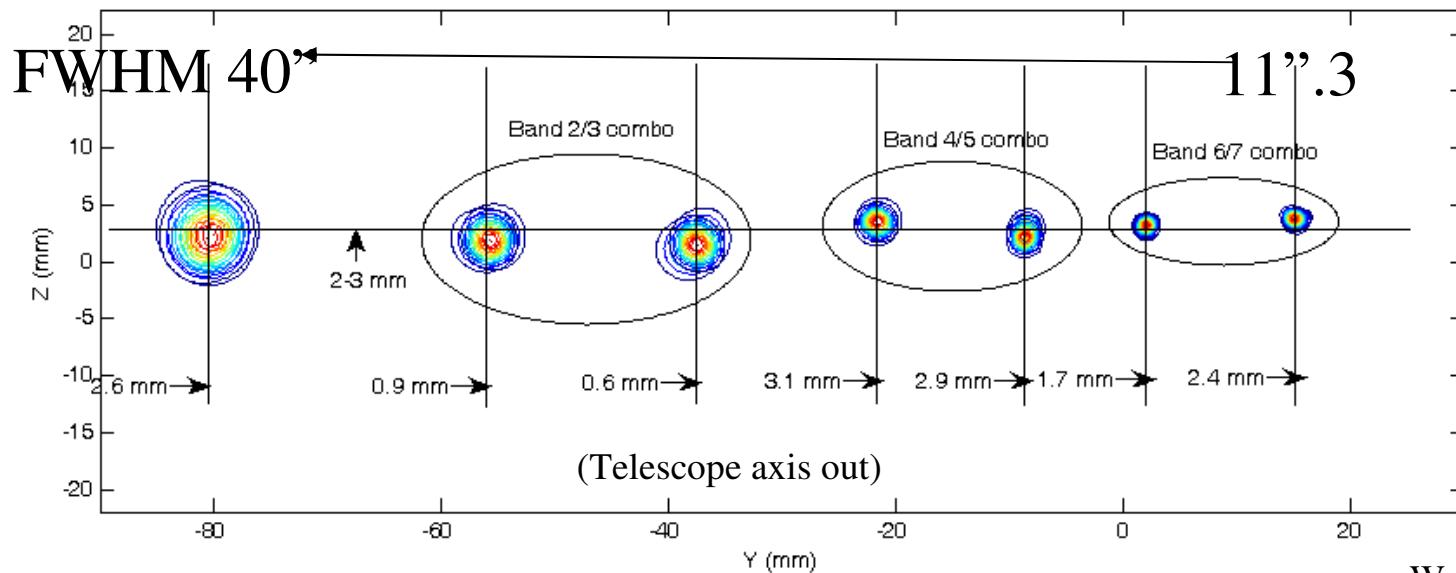


Beams optically re-imaged
(simulating telescope M2) at
SRON.



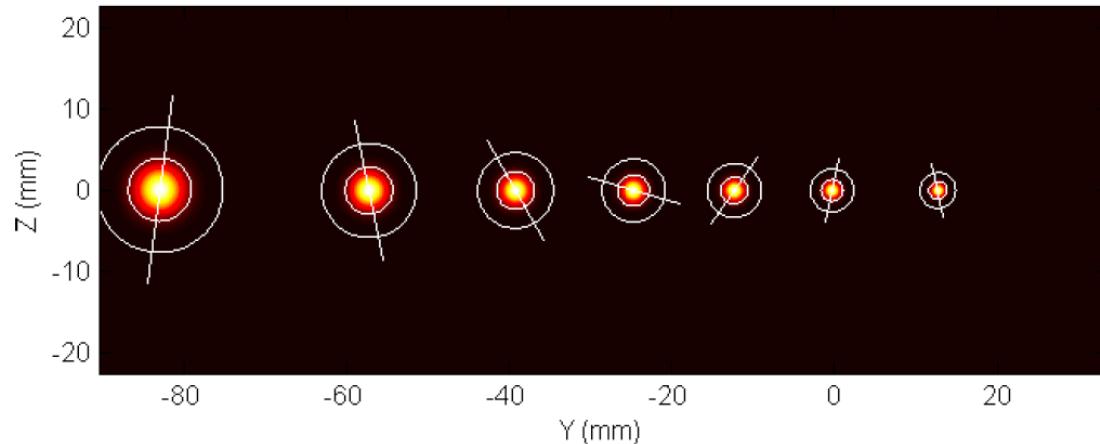
Beams sizes / waist properties
are nominal.

Measured focal plane spots projected on M3



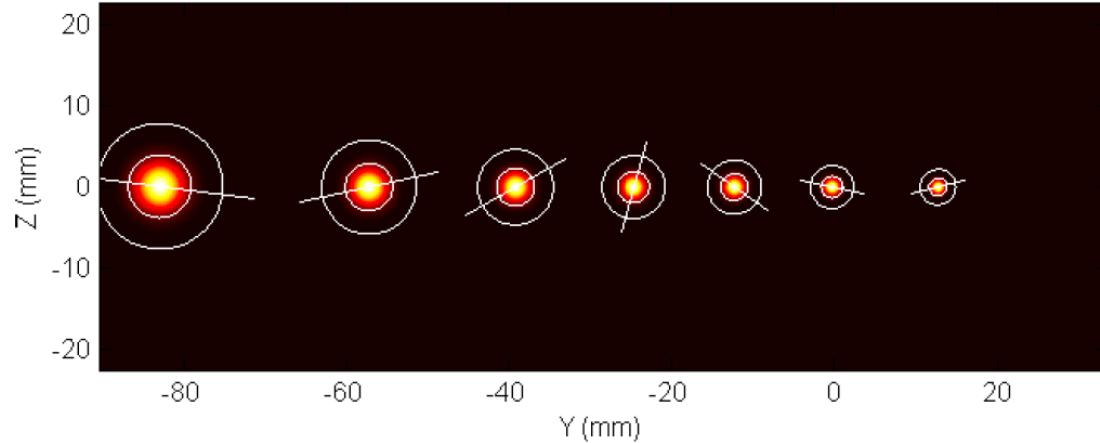
H and V Polarized Mixer Beams

MSA-H polarisation orientation in FP



Band	$\theta_x(^{\circ})$ MSA-H	$\theta_x(^{\circ})$ MSA-V
1	82.5	-7.5
2	-78.2	11.8
3	-59.8	30.2
4	-15.3	74.7
5	54.8	-35.2
6L	77.5	-12.5
6H	-77.0	13.0

MSA-V polarisation orientation in FP

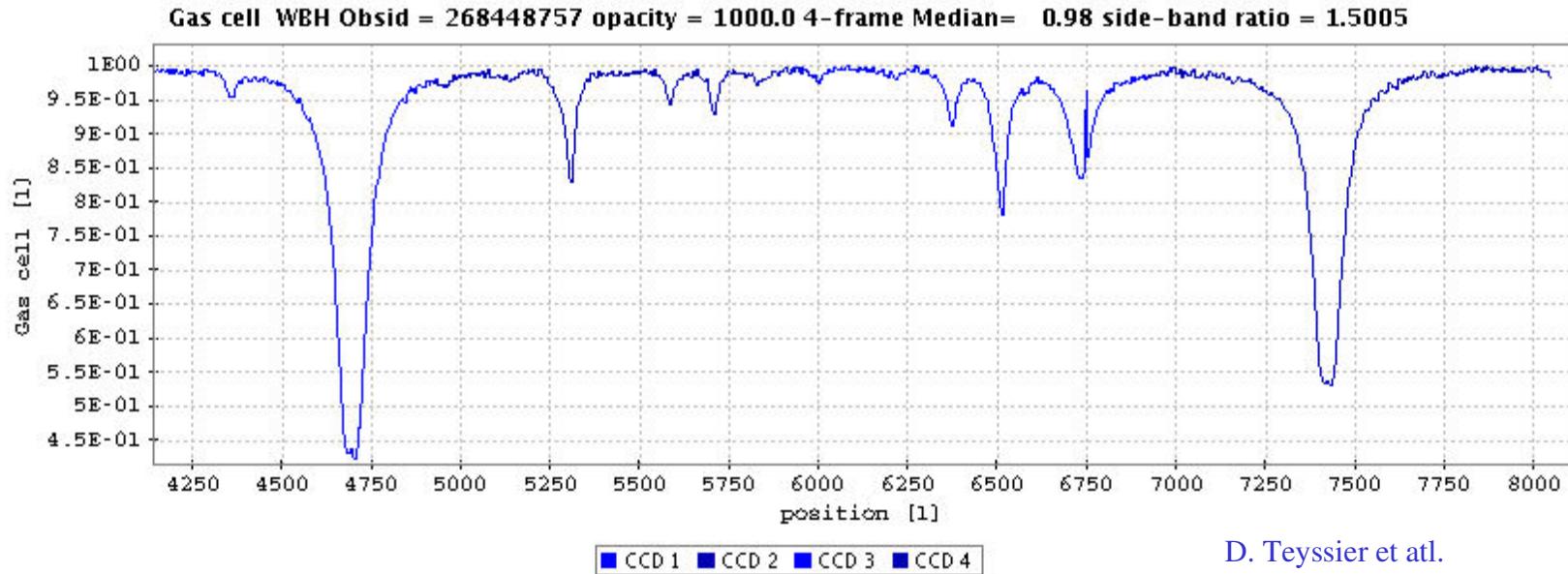


H and V polarizations are well aligned orthogonally. Some deviations from linearity in the optics chain, losses are very small.

H and V beams are separated on the sky by up to few arcsec; each are acquired and combined in the automated pipeline.

W. Jellema

FM Spectral Performance Tests with the gas cell

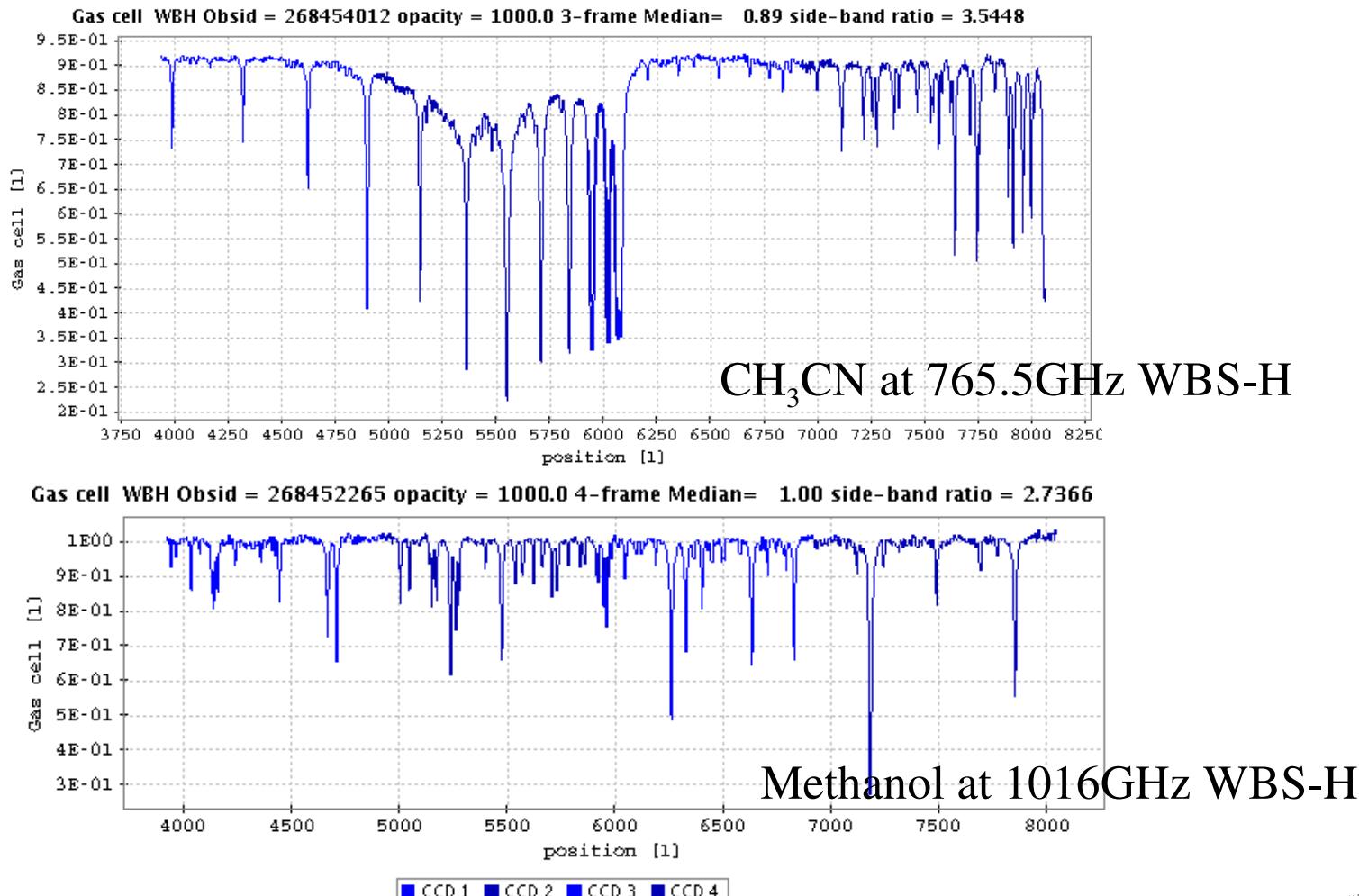


OCS in the cell, LO is at ~564GHz, picking up simultaneously the J=46-45 and 47-46 transitions in each side-band (OCS has transitions every 12GHz, so it is a dual side-band ratio measurement in one go. In the middle of the IF are all the isotopes and some vibrational transitions. S/N > 100, Tsys ~ 70K. The apparent side-band ratio = 1.5, but requires correction for baseline, some known LO ripple issues etc. Sideband ratio is

HIFI Pipelines and Data Products
closer to 1.1 or less.
Herschel-PPW-1.1 - ESAC Madrid

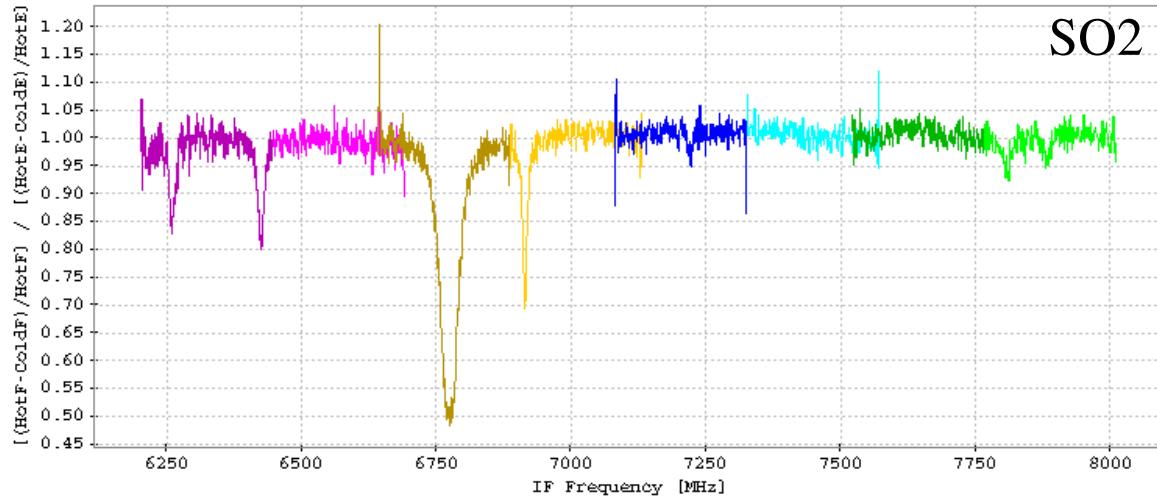
Herschel DP Workshop – ESAC, Madrid, E, 2008 Dec 4 - page 36

Acetonitrile, Methanol



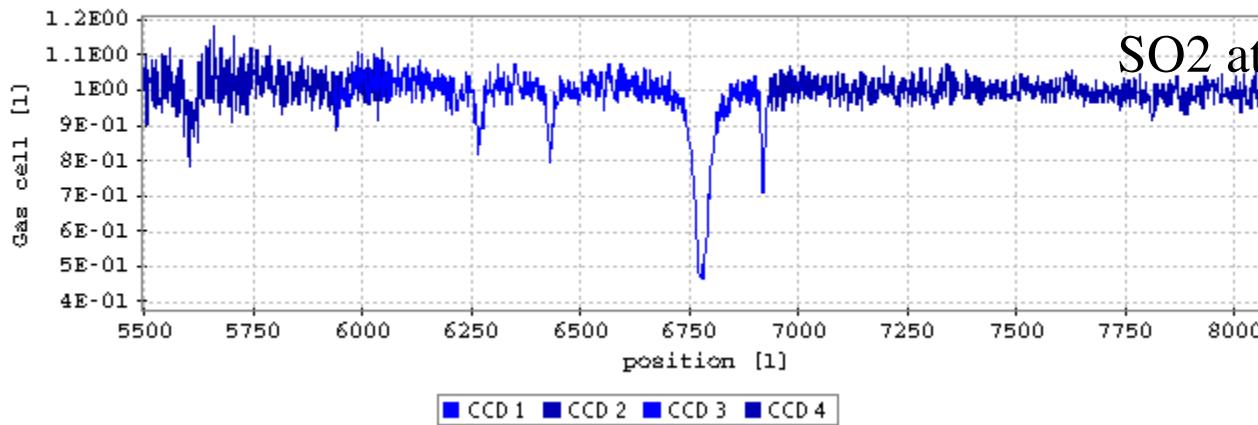
SO with HRS and WBS

Gas Cell HRH obsid=268455122 bpid=3415-1 time=2007-01-25T18:07:48 frame=18 HotE=4 HotF=4 ColdE=4
ColdF=4 ratio=1.08



SO2 at 1696.5GHz HRS-H
(2.4 GHz IF)

Gas cell WBH Obsid = 268455122 opacity = 1000.0 4-frame Median= 0.97 side-band ratio =
20.3910



SO2 at 1696.5GHz WBS-H

HIPE: Running Pipeline 'Lights Off'

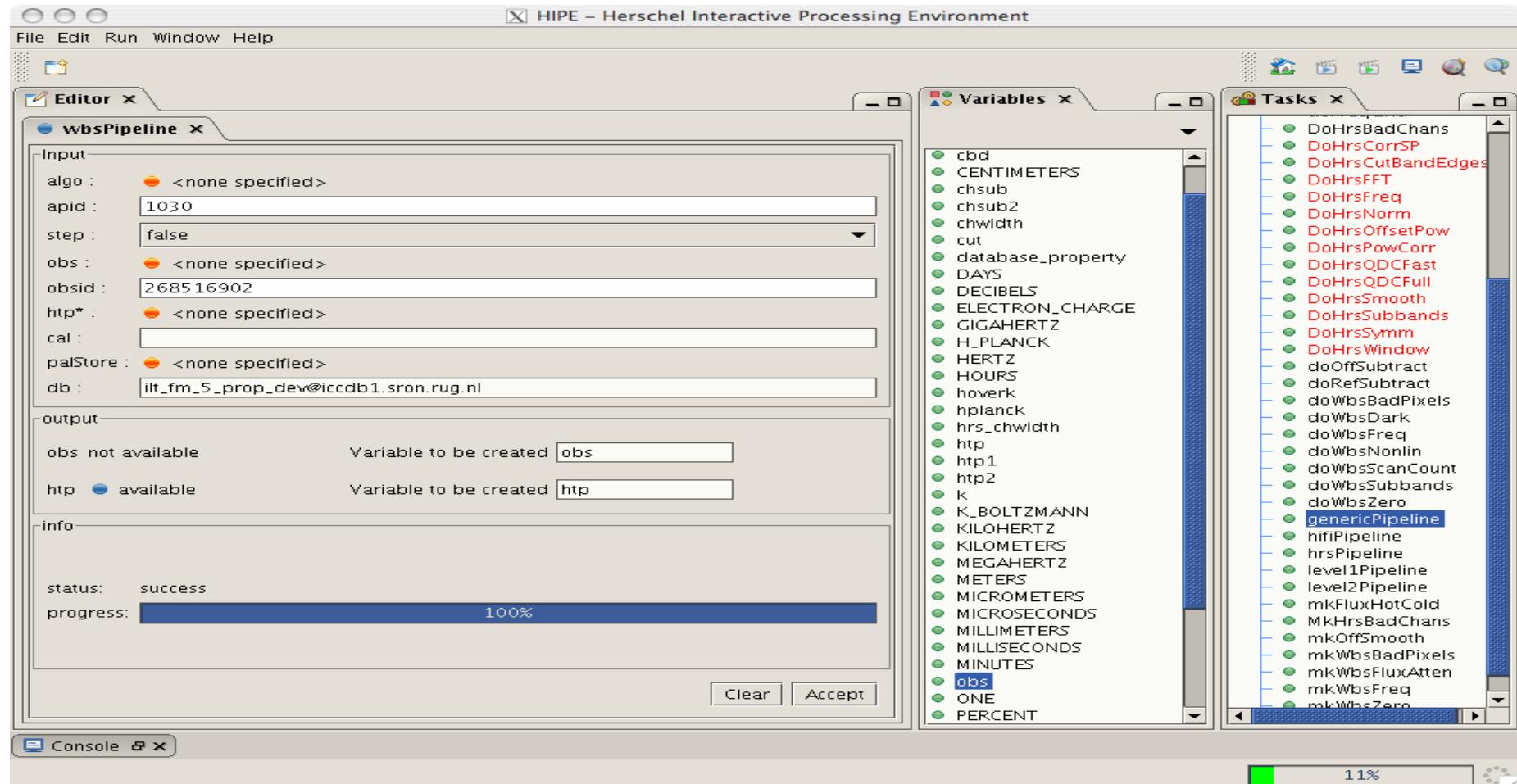
The screenshot shows the HIPE software interface with several windows open:

- File Edit Run Window Help**: The main menu bar.
- Editor x**: A window showing the "hifiPipeline" project structure under "Input". It includes sections for ObservationContext, Instruments (HRS-H, HRS-V, WBS-H, WBS-V), and various configuration parameters like "ilt_fm_3_prop@iccdb.sron.rug.nl" and "false".
- Variables x**: A list of variables with green circular icons next to them, such as ANGSTROMS, ASTRONOMICAL_UNITS, cbd, CENTIMETERS, chsub, chsub2, chwidth, cut, database_property, DAYS, DECIBELS, ELECTRON_CHARGE, GIGAHERTZ, H_PLANCK, HERTZ, HOURS, hoverk, hplanck, hrs_chwidth, K, K_BOLTZMANN, KILOHERTZ, KILOMETERS, MEGAHERTZ, METERS, MICROMETERS, MICROSECONDS, MILLIMETERS, MILLISECONDS, MINUTES, ONE, PERCENT, SECONDS, and shotnoise.
- Tasks x**: A list of tasks with green circular icons, including DoHrsBadChans, DoHrsCorrSP, DoHrsCutBandEdges, DoHrsFFT, DoHrsFreq, DoHrsNorm, DoHrsOffsetPow, DoHrsPowCorr, DoHrsQDCFast, DoHrsQDCFull, DoHrsSmooth, DoHrsSubbands, DoHrsSymm, DoHrsWindow, doOffSubtract, doRefSubtract, doWbsBadPixels, doWbsDark, doWbsFreq, doWbsNonlin, doWbsScanCount, doWbsSubbands, doWbsZero, genericPipeline, hifiPipeline, hrsPipeline, level1Pipeline, level2Pipeline, mkFluxHotCold, MkHrsBadChans, mkOffSmooth, mkWbsBadPixels, mkWbsFluxAtten, mkWbsFreq, mkWbsZero, and whsPipeline.
- Console x**: A window showing the command "IA>>".

Start automated HIFI pipeline task ('SPG'): [window->Show View->HifiPipeline](#) and click on

hifiPipeline in Tasks on right pane

HIFI Pipelines and Data Products



Spectrometer and generic pipelines can be run separately (not sure if showing this makes sense, as level 0.5 of the pipeline task shown before does the same thing)