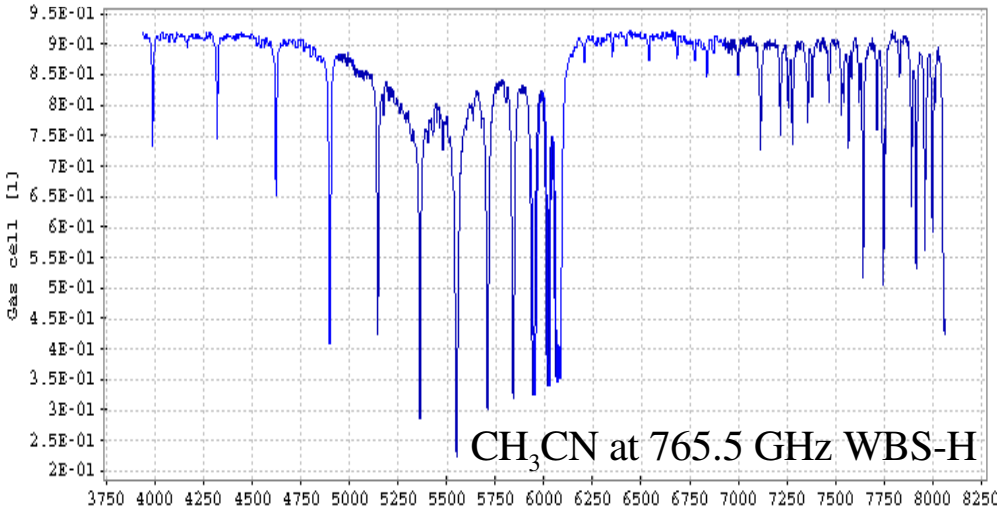
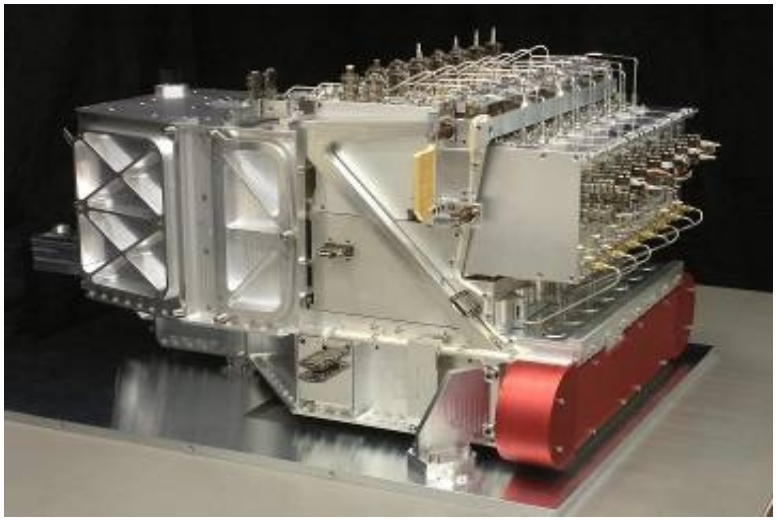
HIFI Pipelines and Data Products

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

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





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Menu

- HIFI Instrument and AOTs
- HIFI Pipeline Structure (see also posters!)
- HIFI Level 0 → 1 Processing:
  - **S**tandard **P**roduct **G**eneration (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

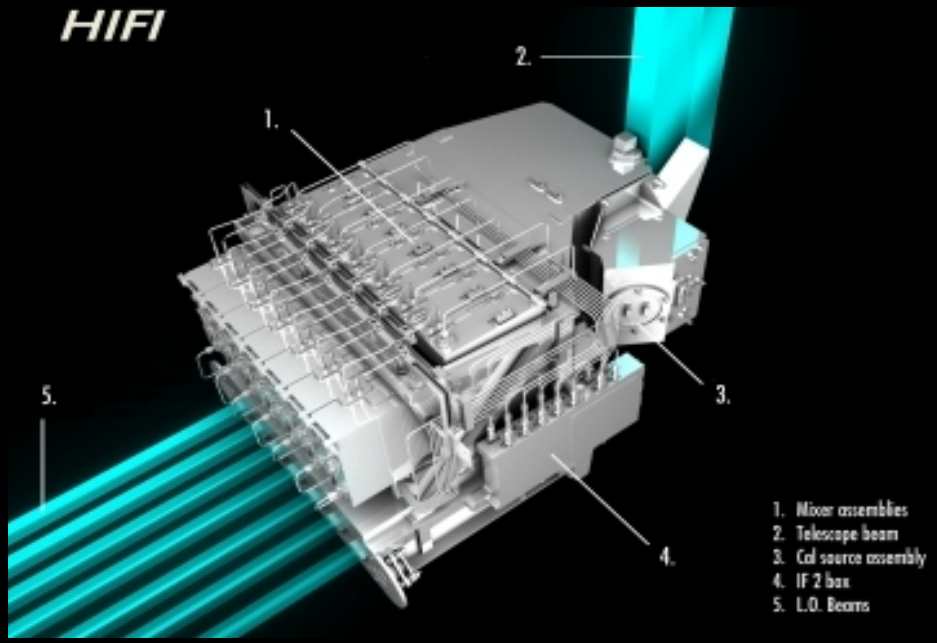
LO source unit in common
LO multiplier chains

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

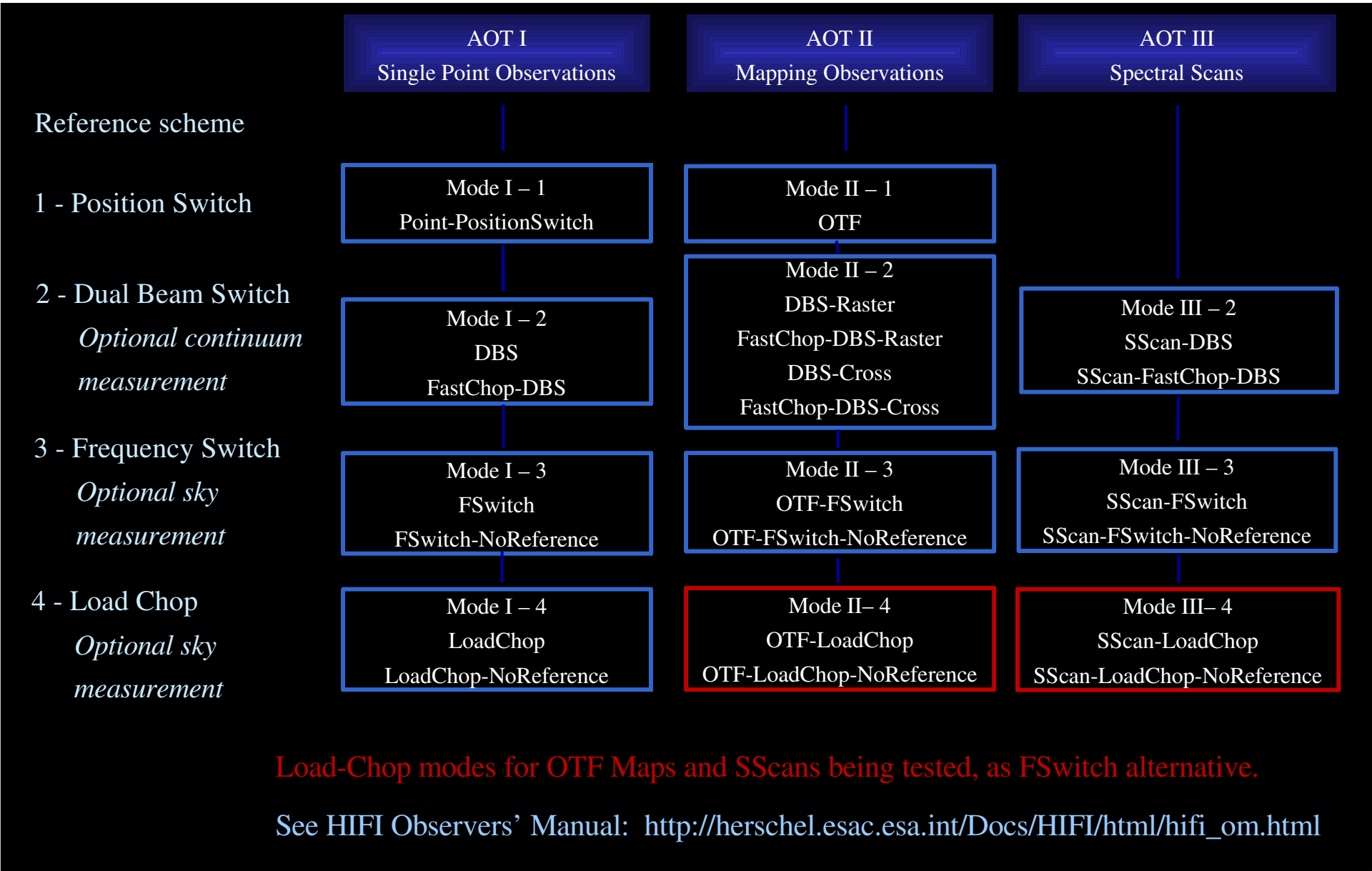
Near-quantum noise limit sensitivity

Calibration Accuracy

10% radiometric baseline, 3% goal

Handy summary: http://www.ipac.caltech.edu/Herschel/hifi/hifi_flyer_13_may_2008.pdf

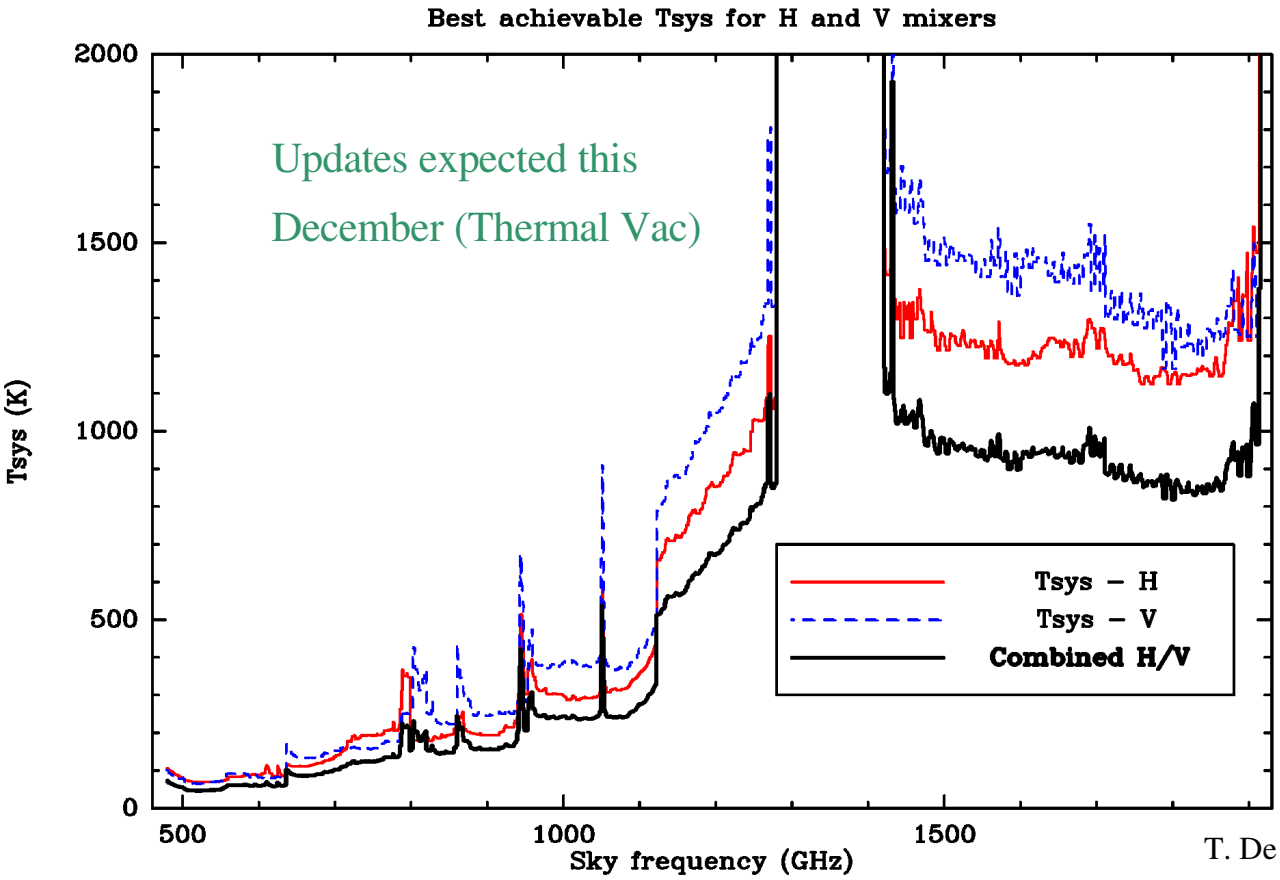
AOT Schemes



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

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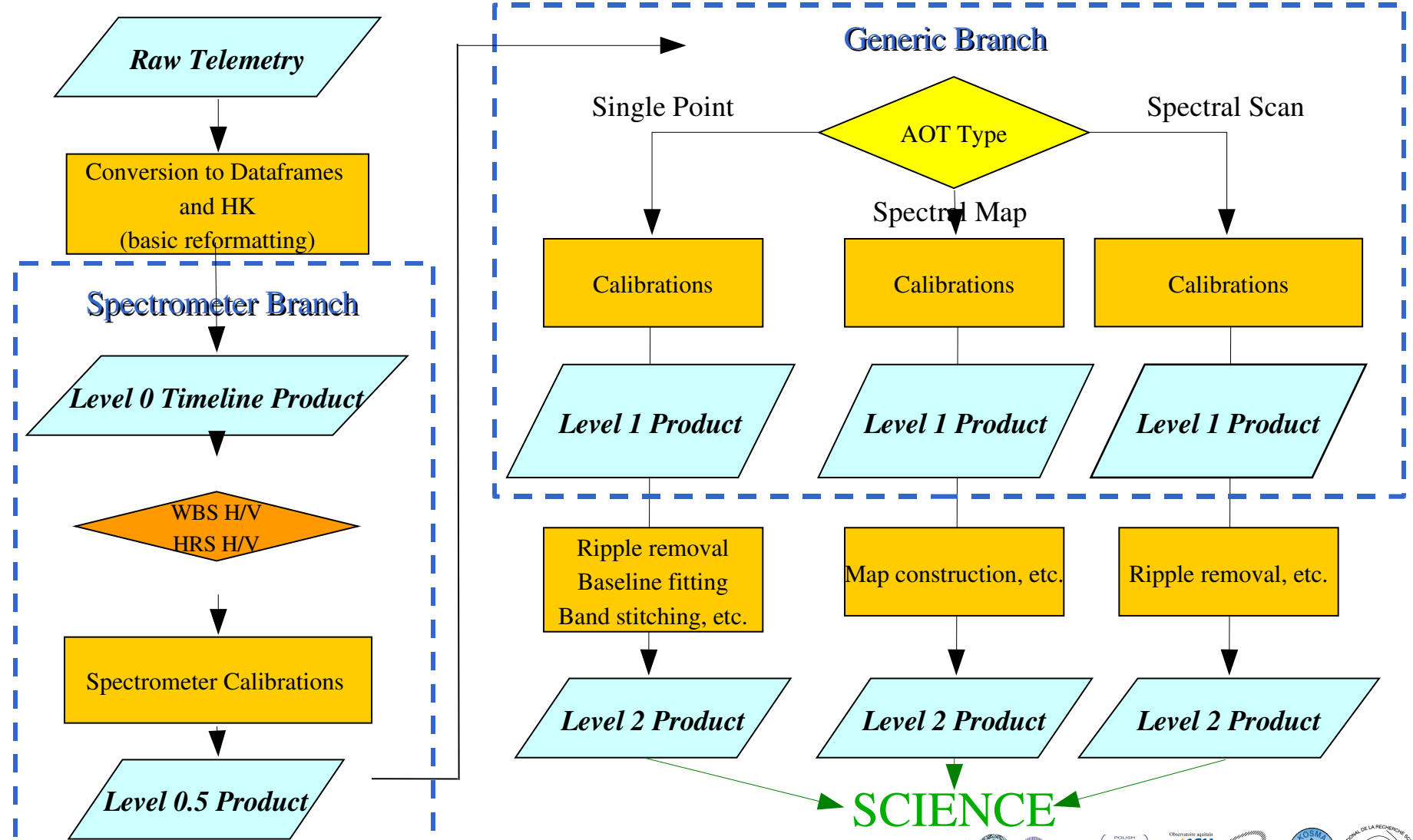
HIFI Pipeline Concept

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



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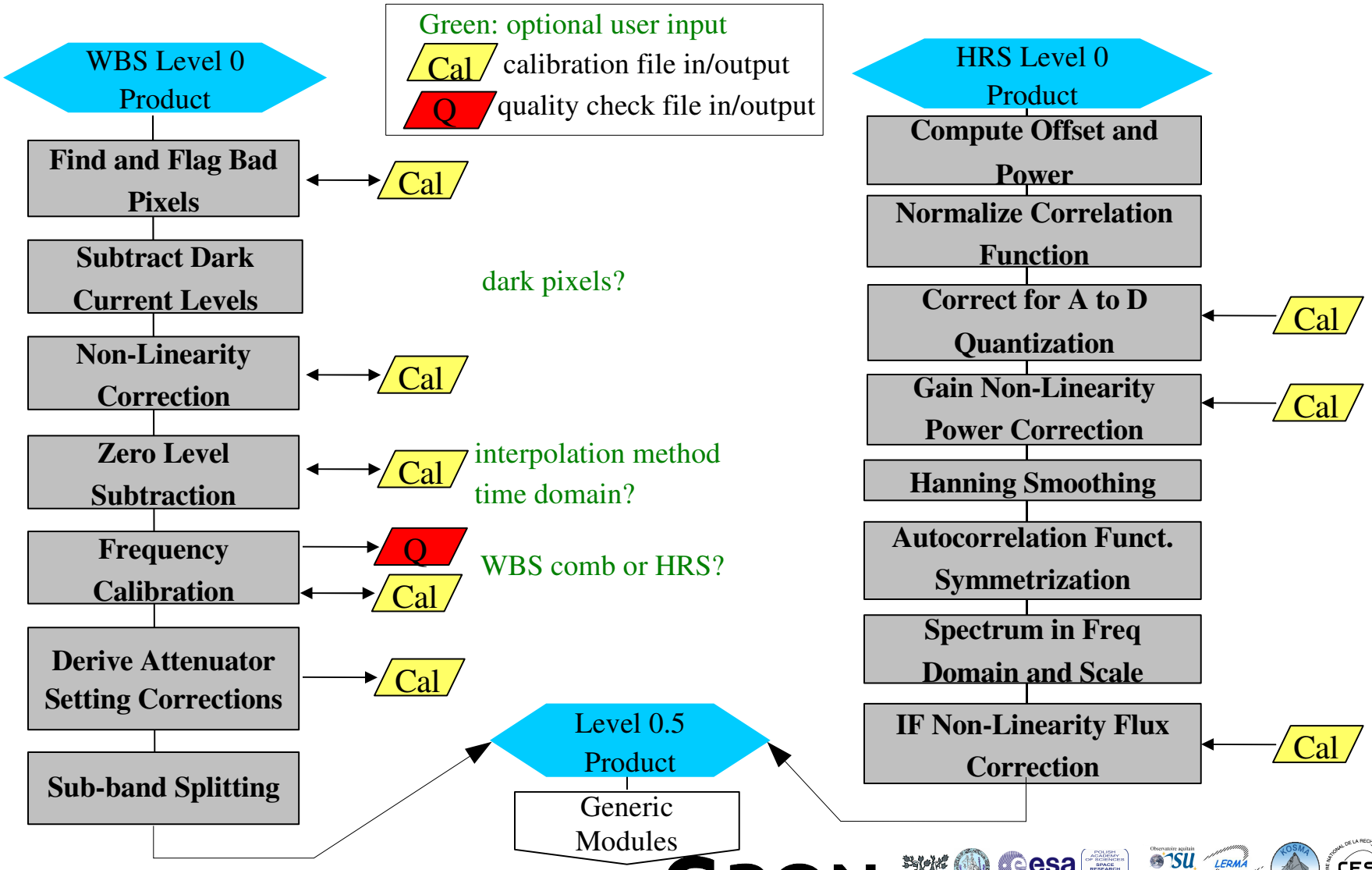
Spectrometer Pipelines (Level 0 → 0.5)



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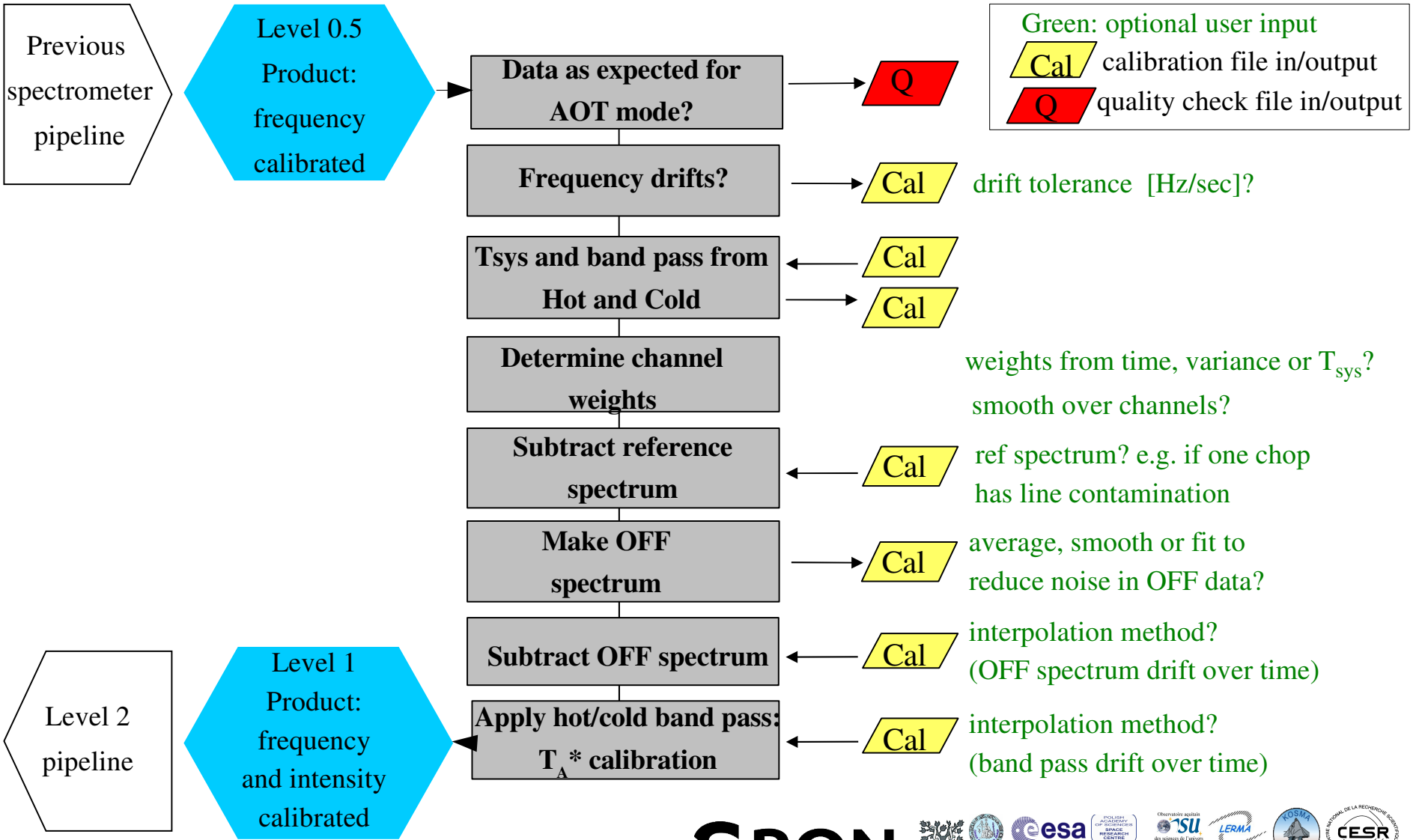
Generic Pipeline (Level 0.5 → 1)



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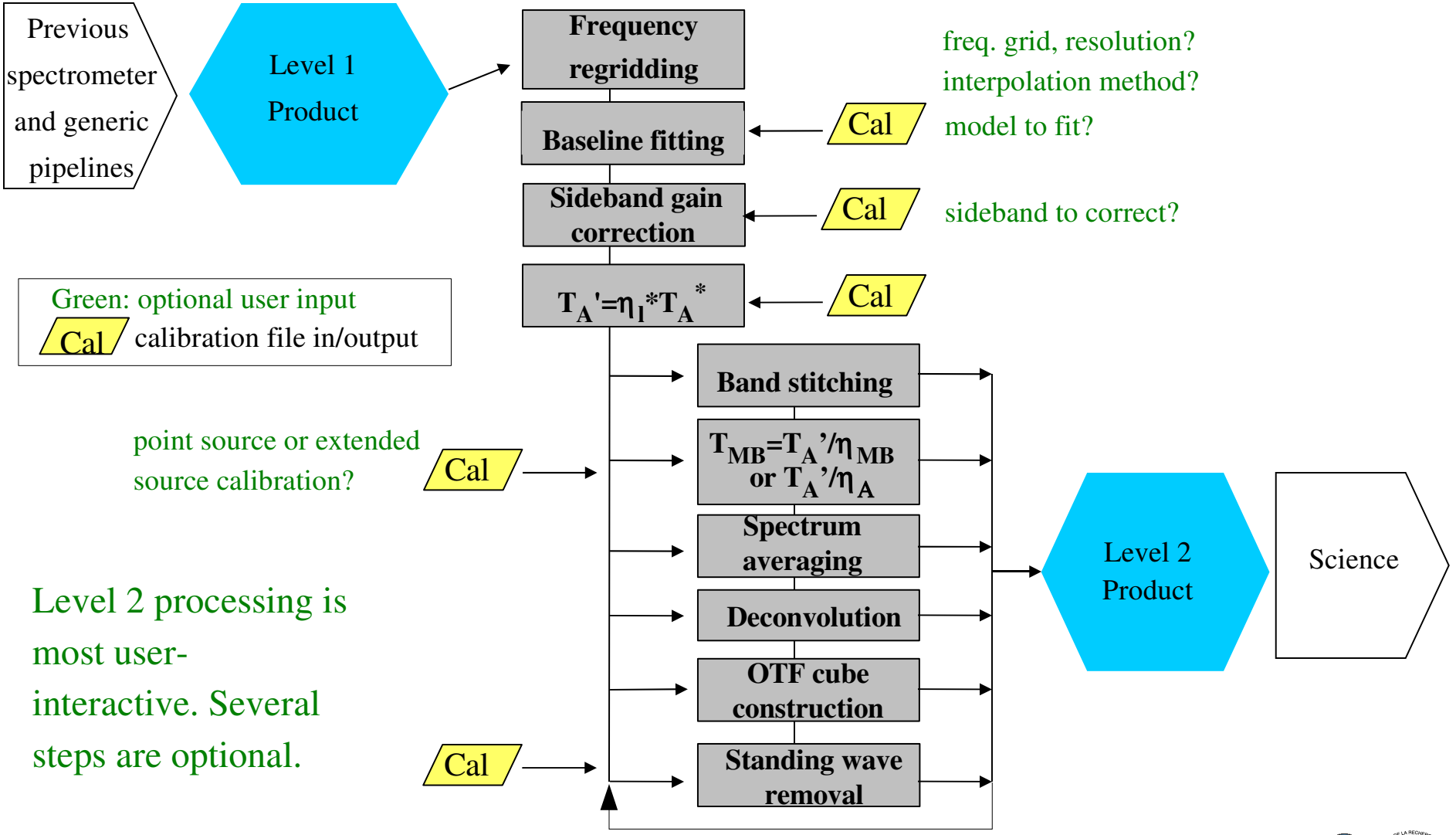
Extended Pipeline (Level 1 → 2)



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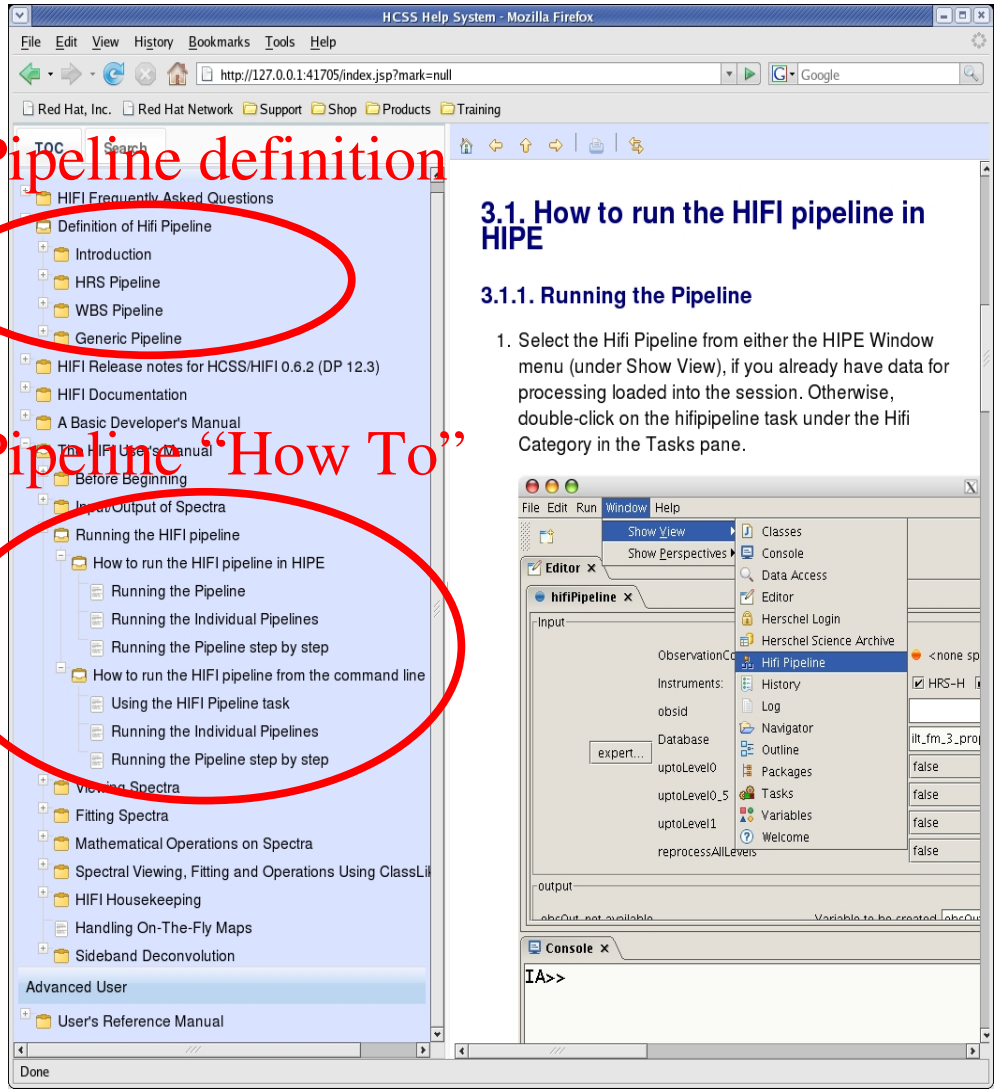
How to Run these Pipelines?



- 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)*

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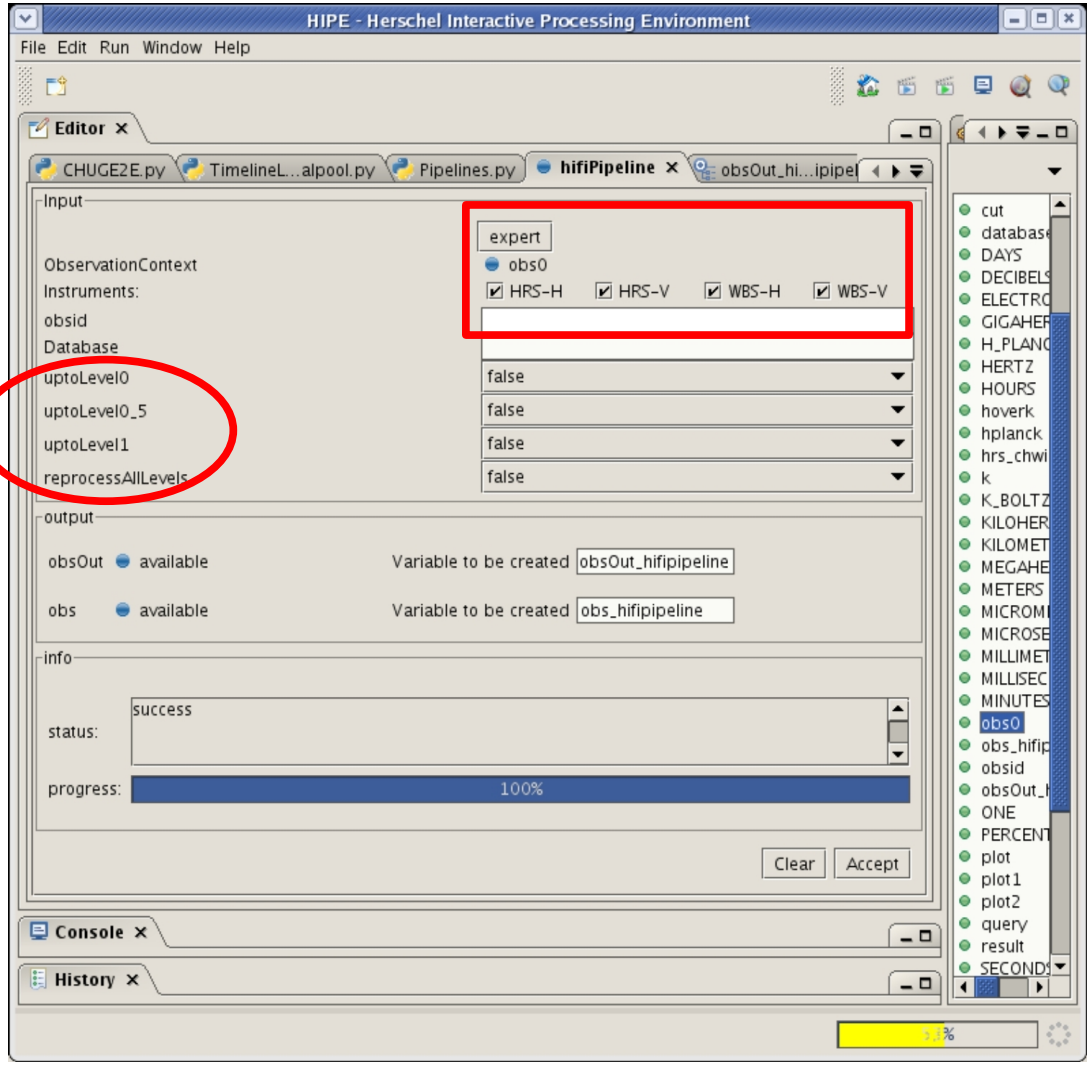
HIPE: Running Pipeline 'Lights Off'



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.

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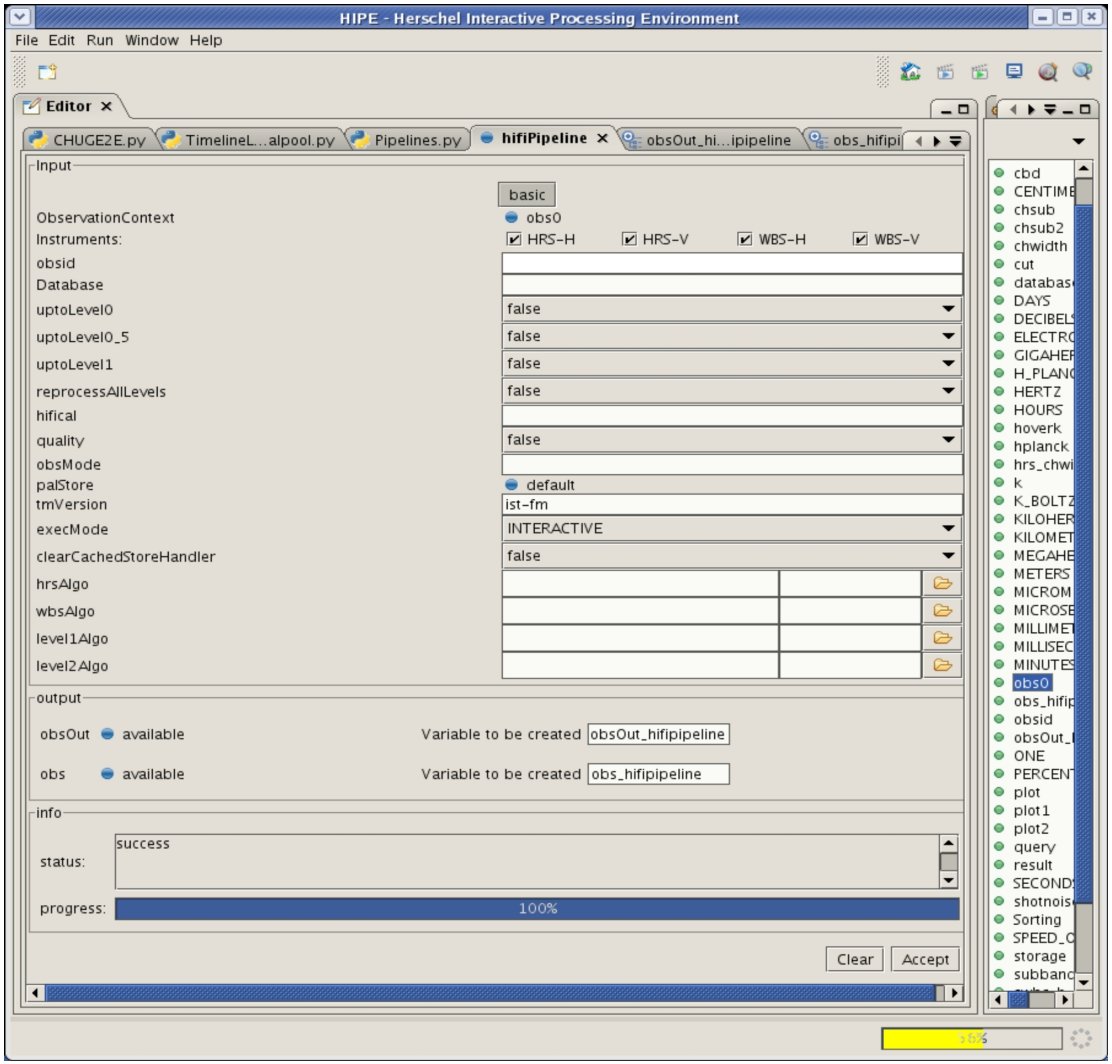
HIPE: Running Pipeline 'Lights Off'



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

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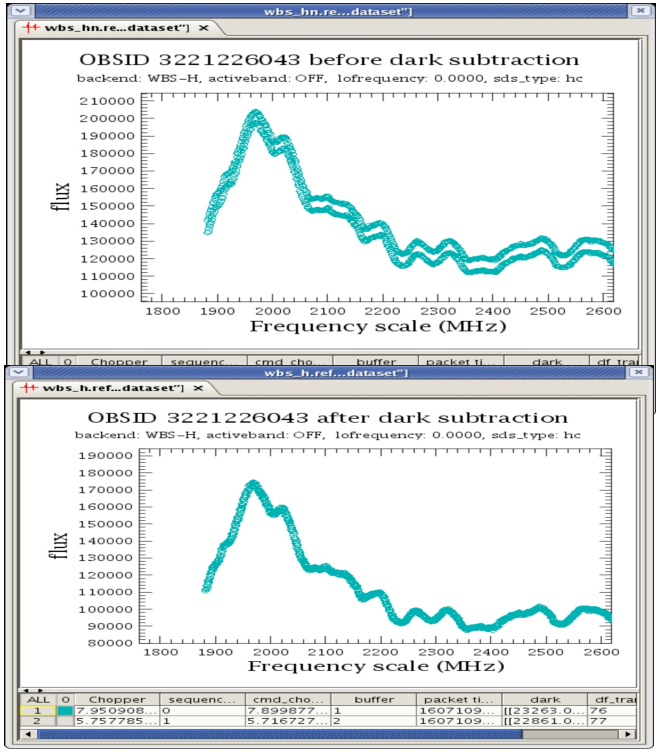
HIPE: Interactive Pipeline

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



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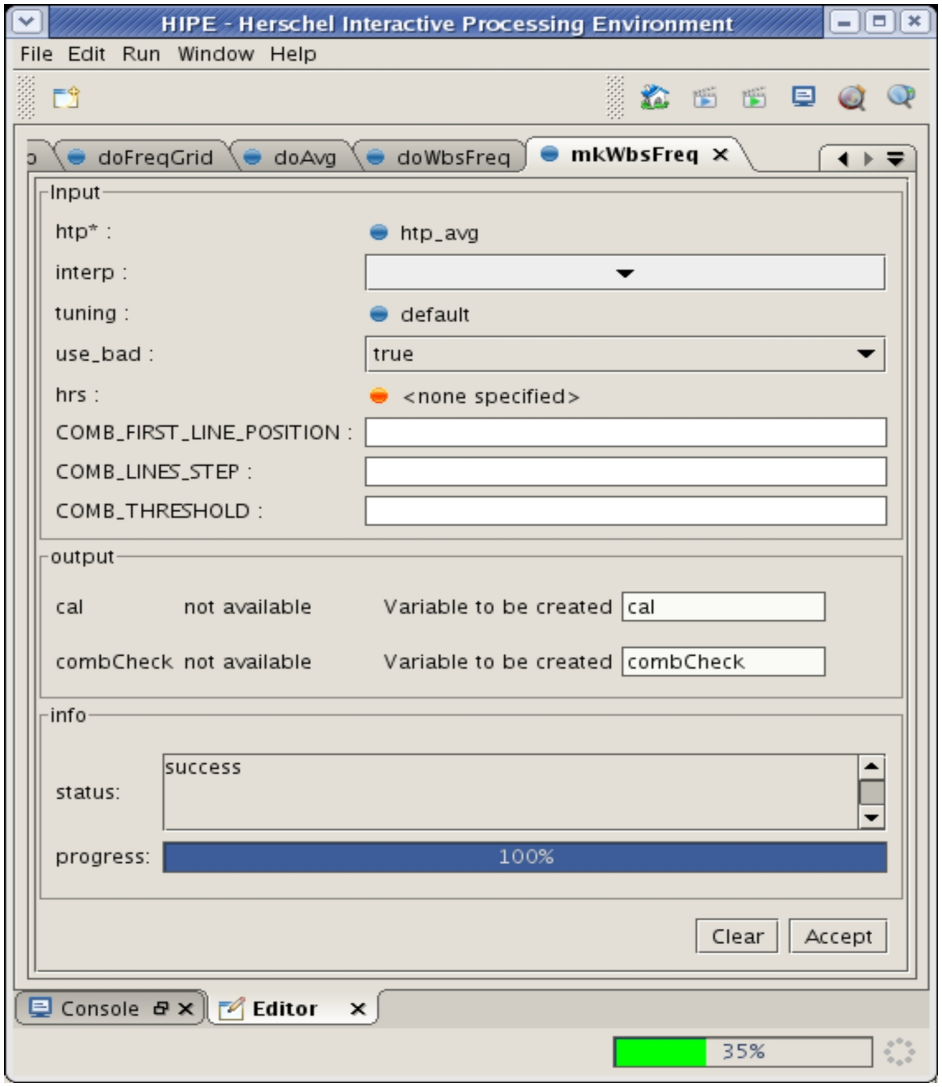
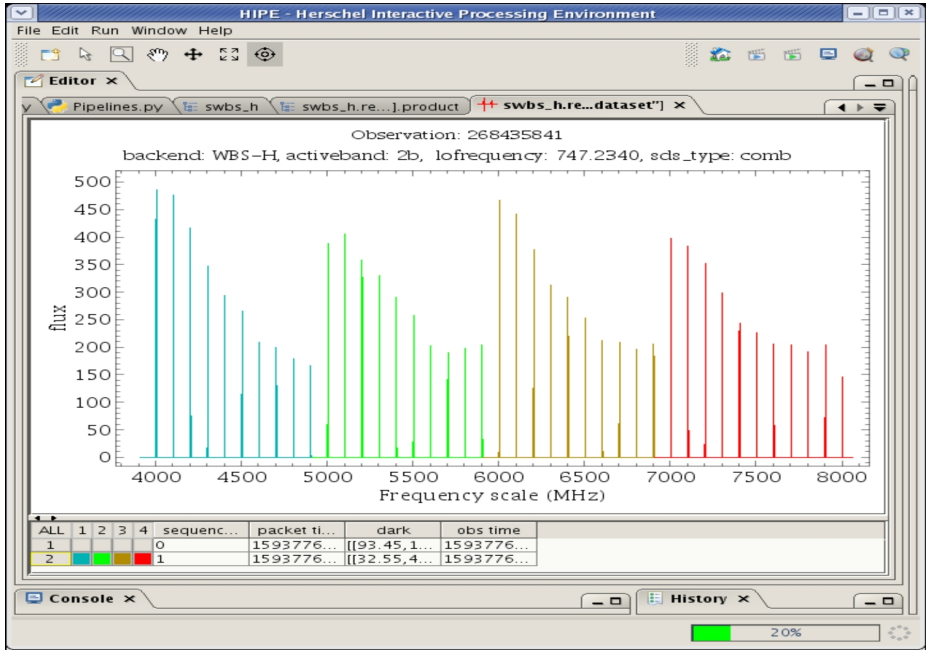
HIPE: Interactive Pipeline



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.



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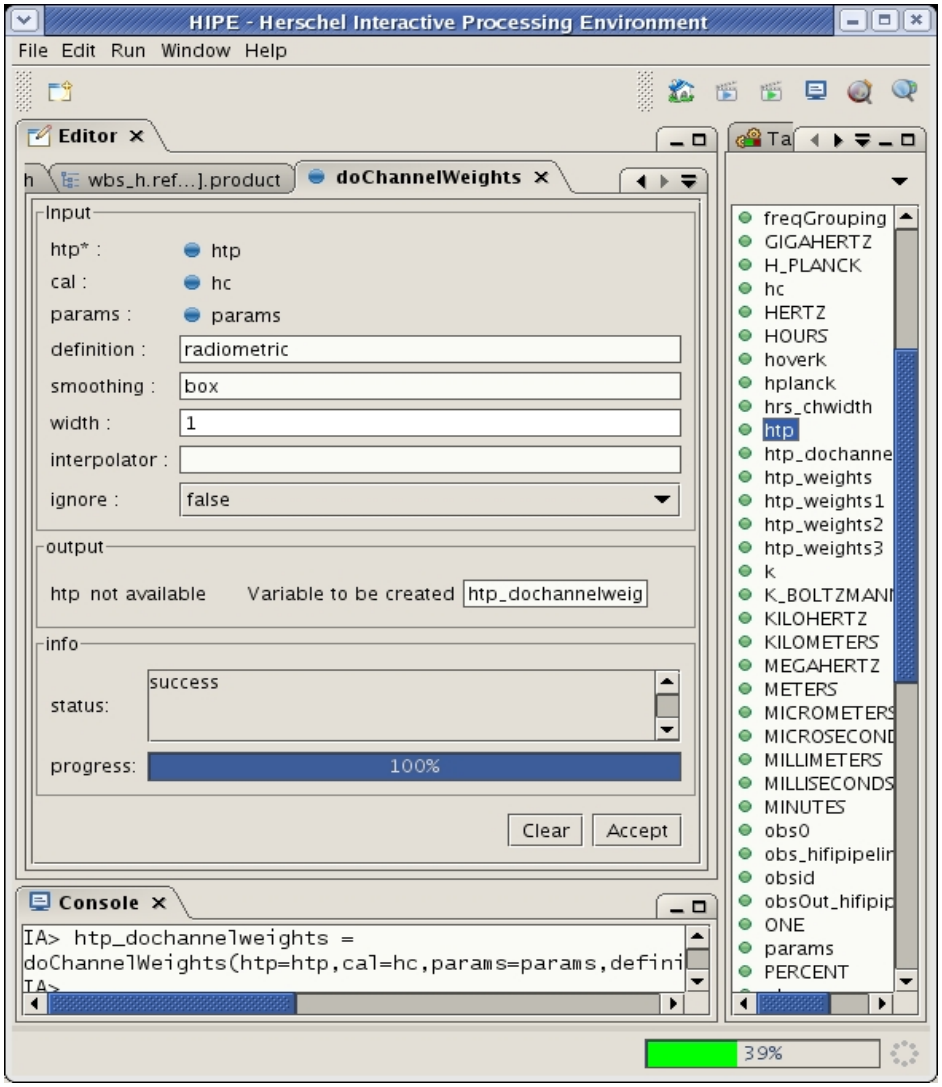
HIPE: Interactive Pipeline



- 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^2_{sys}

- 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*)

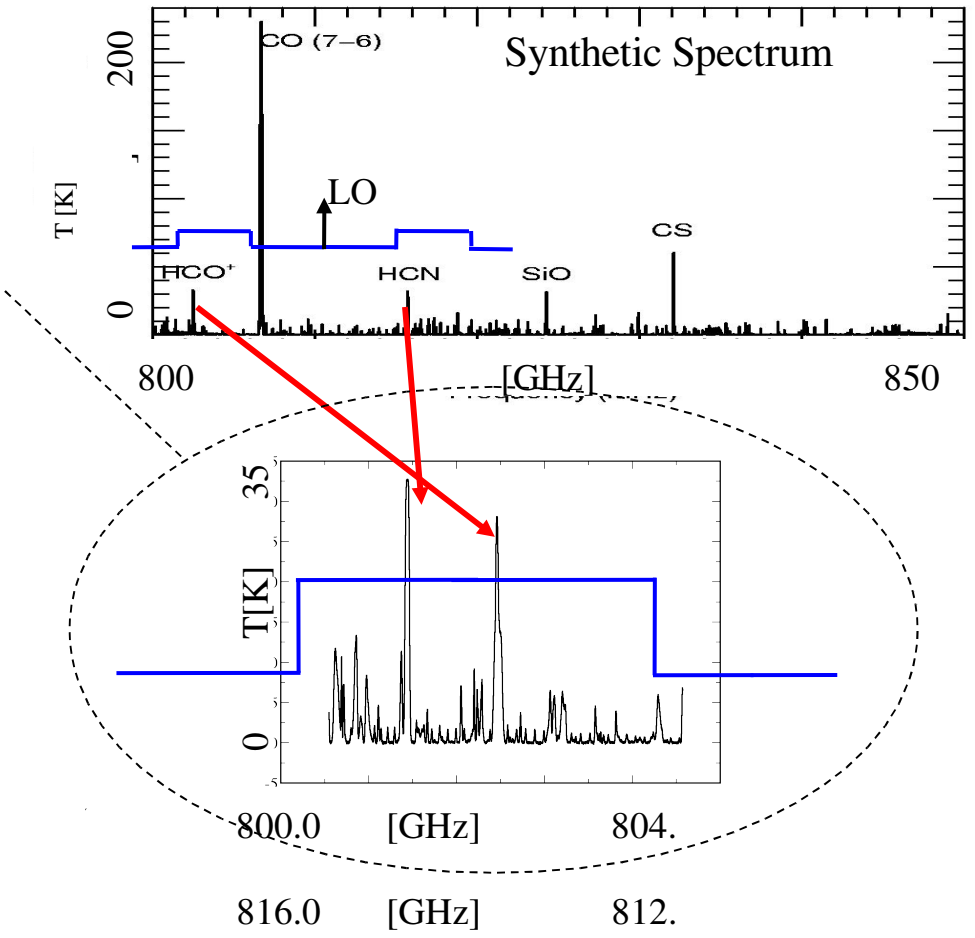
Level 1 → 2: Sideband Deconvolution

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



Double sideband spectrum

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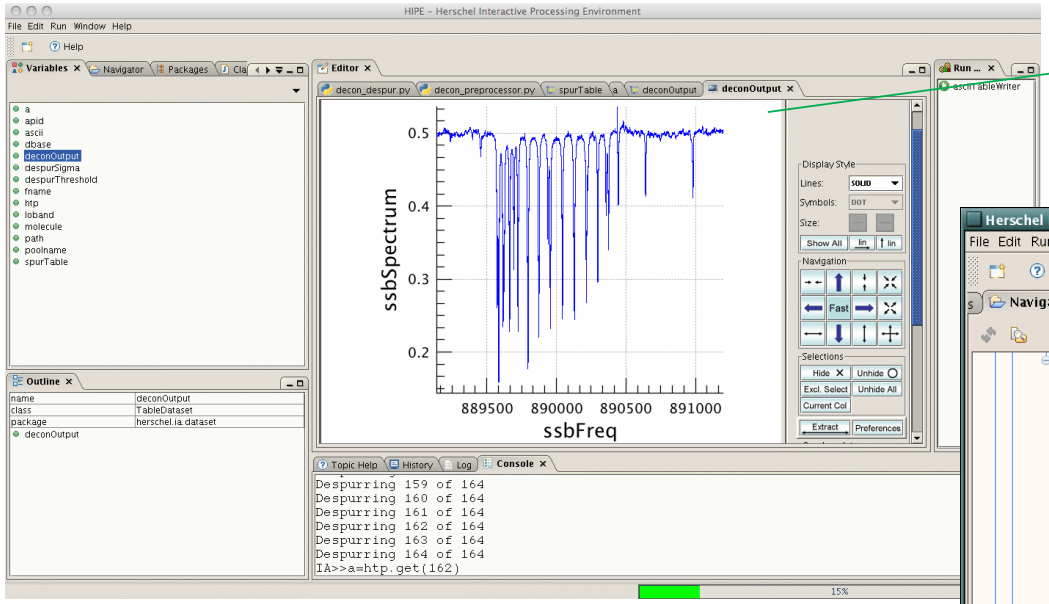
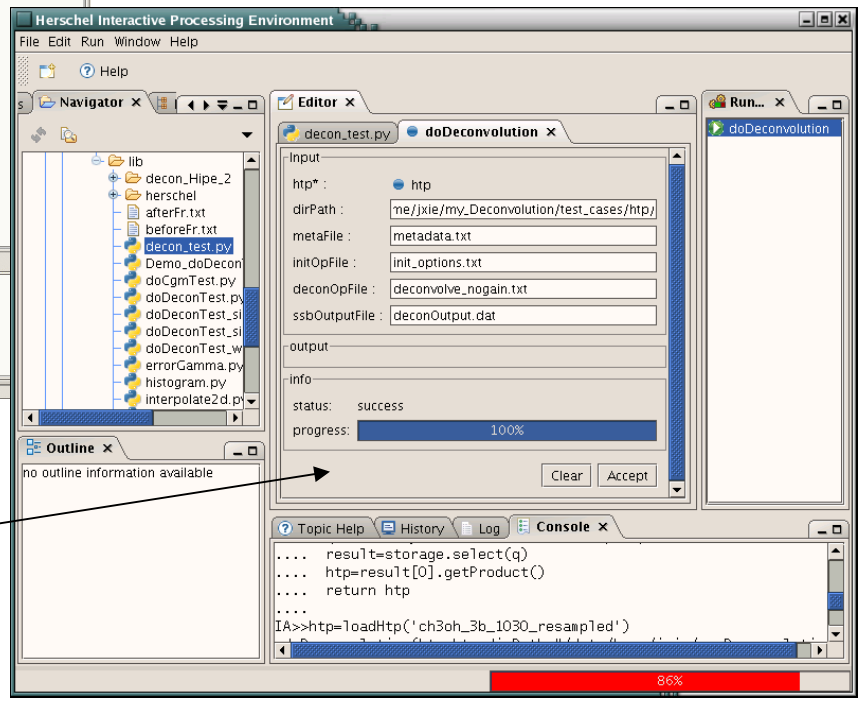
Level 1 → 2: Sideband Deconvolution

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



More pretty examples of real HIFI data in the Supplemental Slides



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

See demo Steve Lord this afternoon

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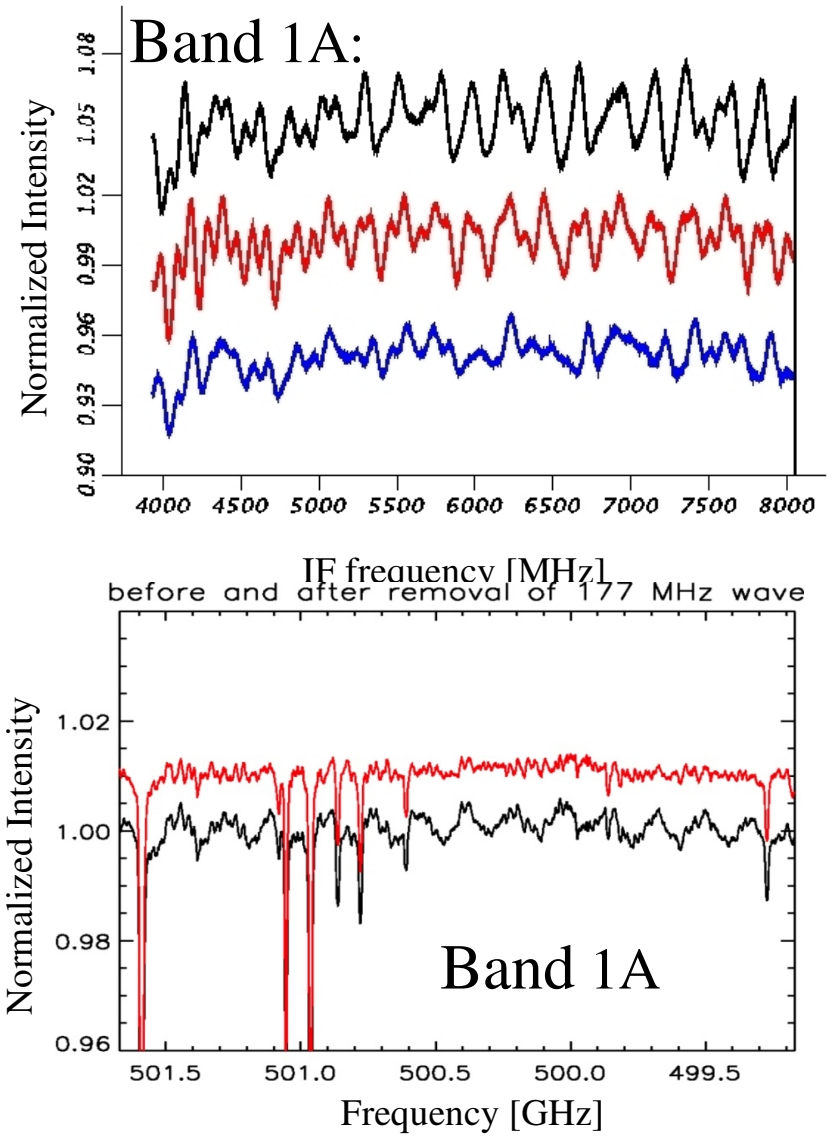
Level 1 → 2: Standing Waves Removal



•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.

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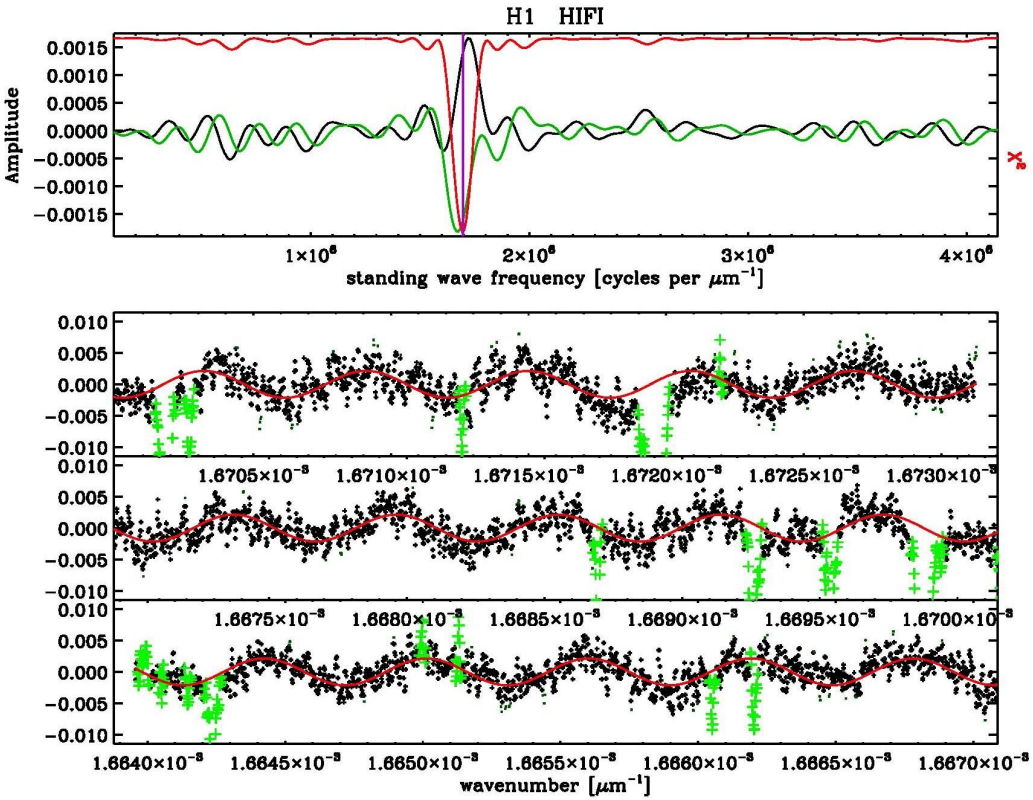
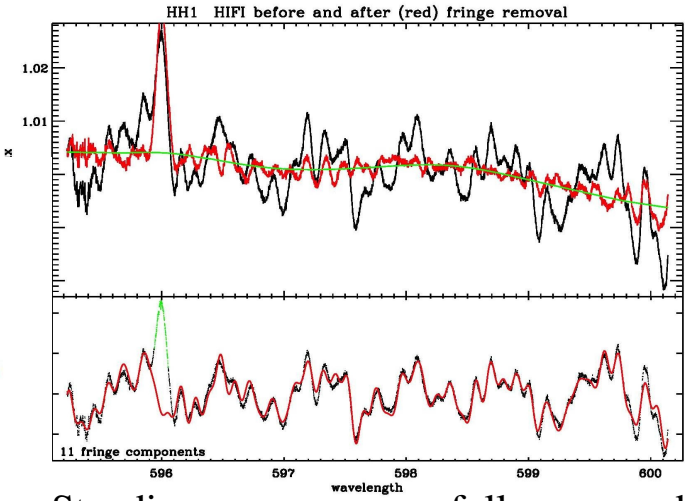
Level 1 → 2: Standing Waves Removal

'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.

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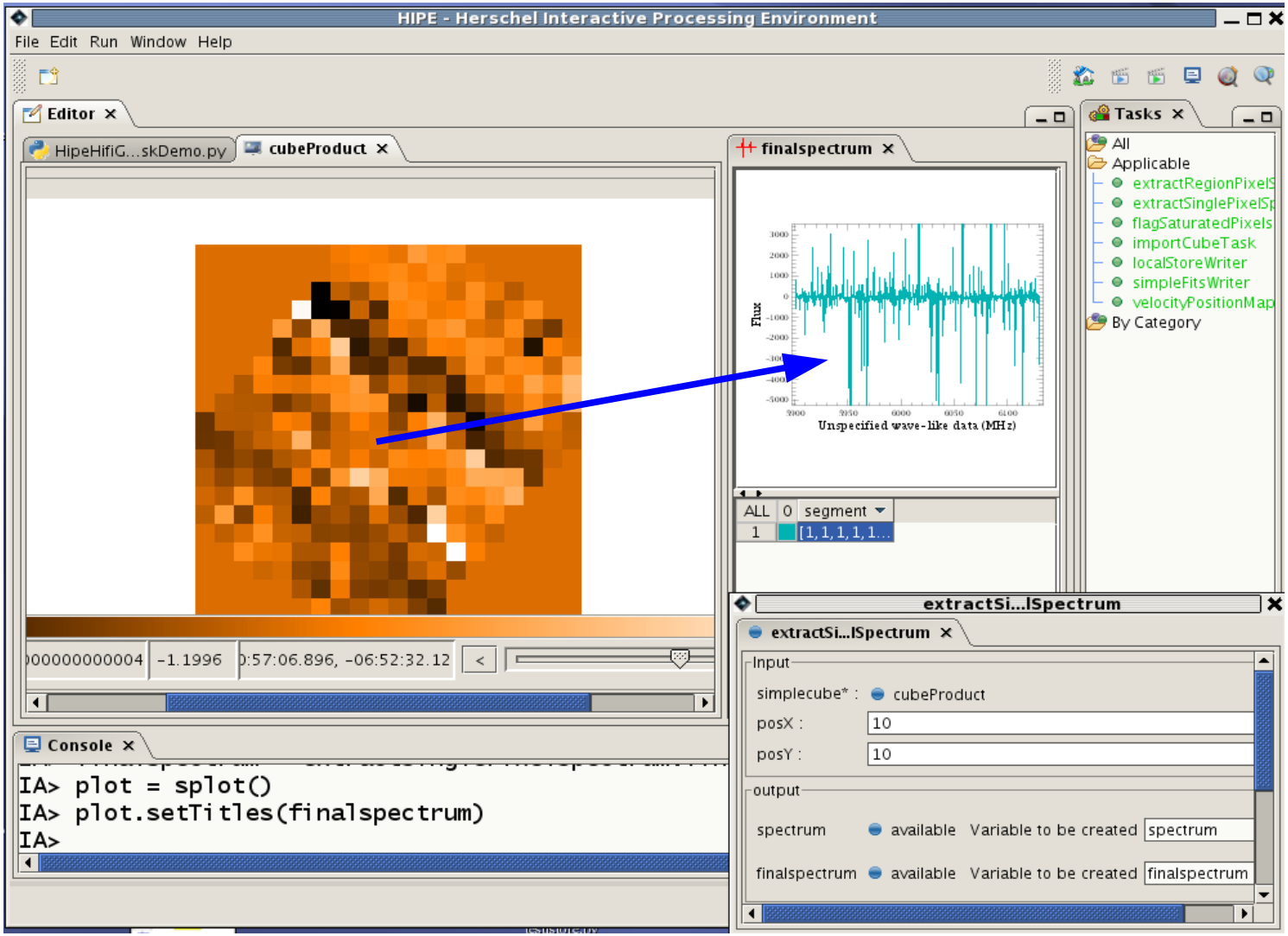
Level 1 → 2: Map Making



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

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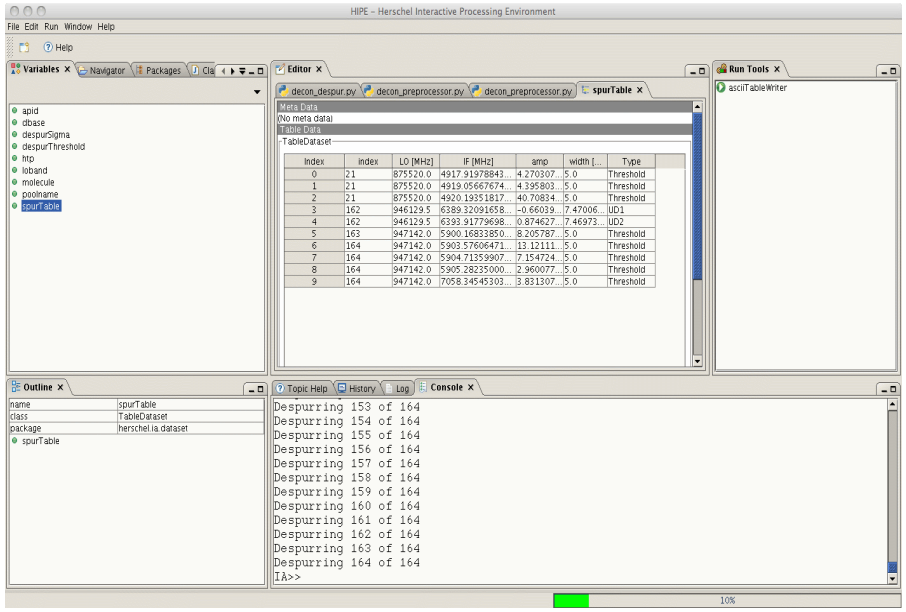
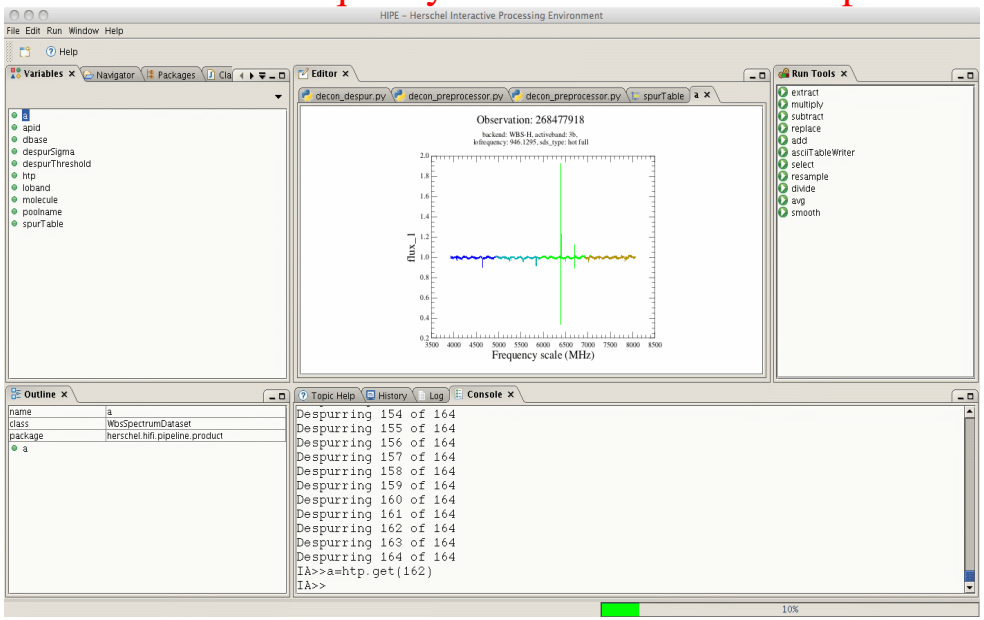
Level 1 → 2: Masking Bad Data

- 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



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



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Science Analysis Tools

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):

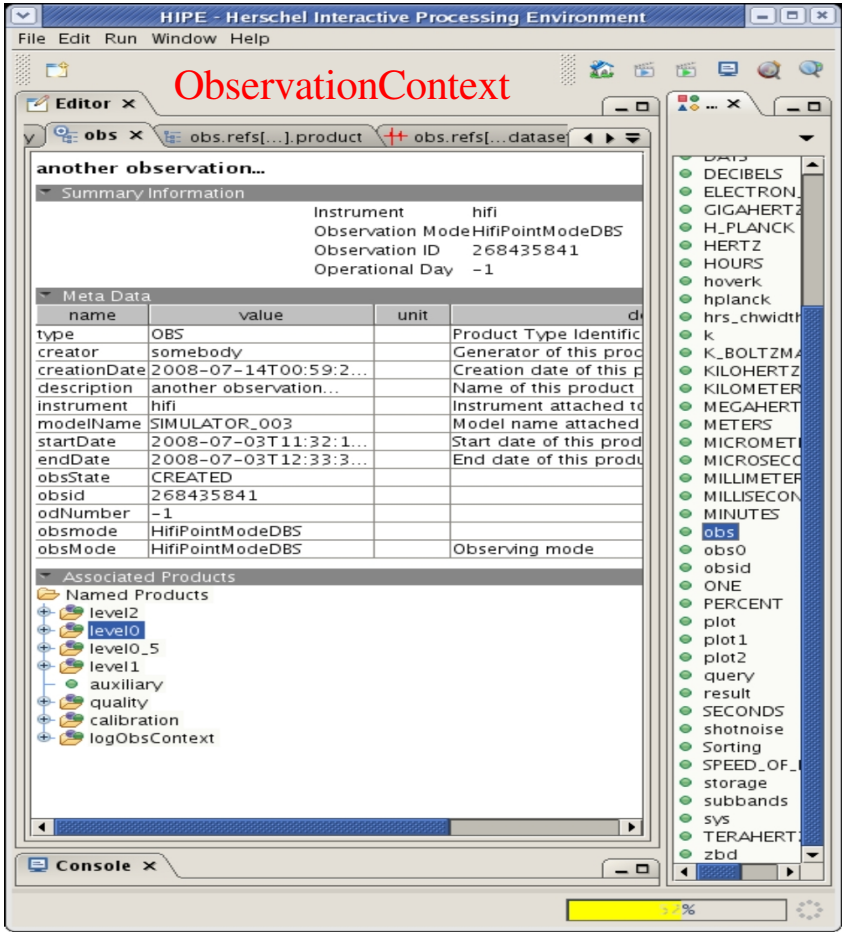
- CASSIS http://cassis.cesr.fr/ (might be called within HIPE)
- MASSA http://www.damir.iem.csic.es/mediawiki-1.12.0/index.php/Portada#MASSA

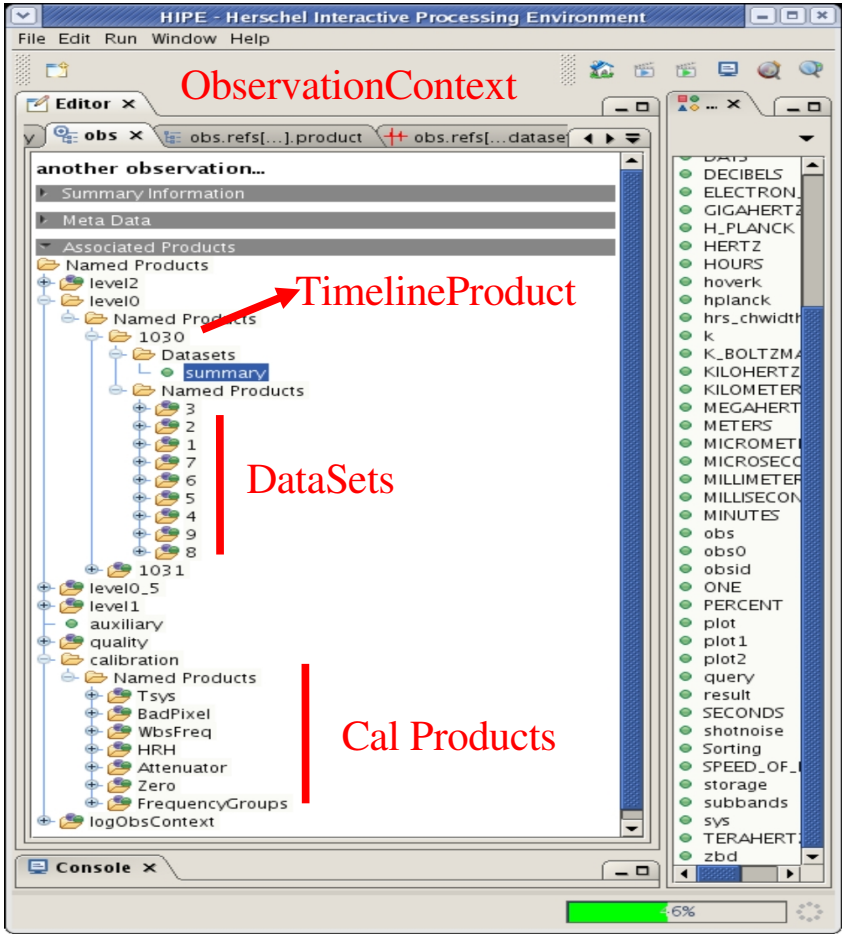
Imaging tool (in HIPE) MADCUBA:

- 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.:





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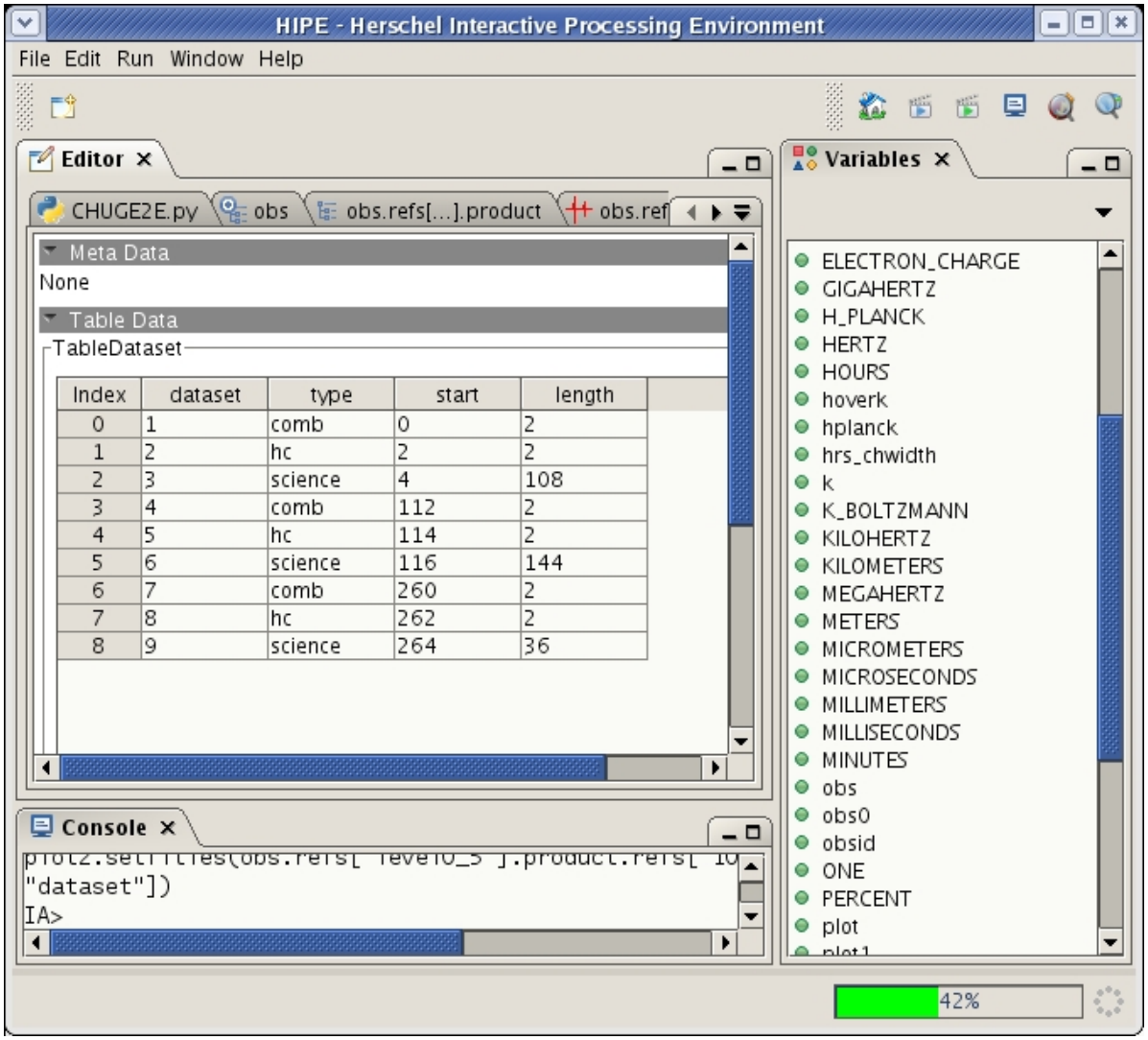
HIFI Data Products: TimelineProduct



- 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

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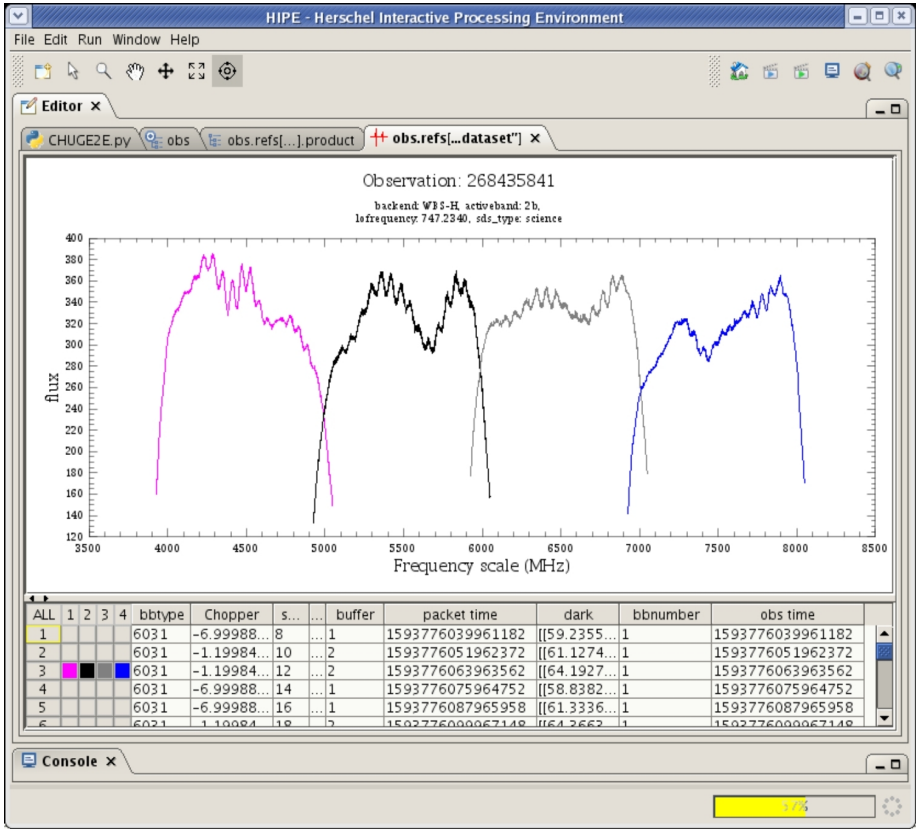
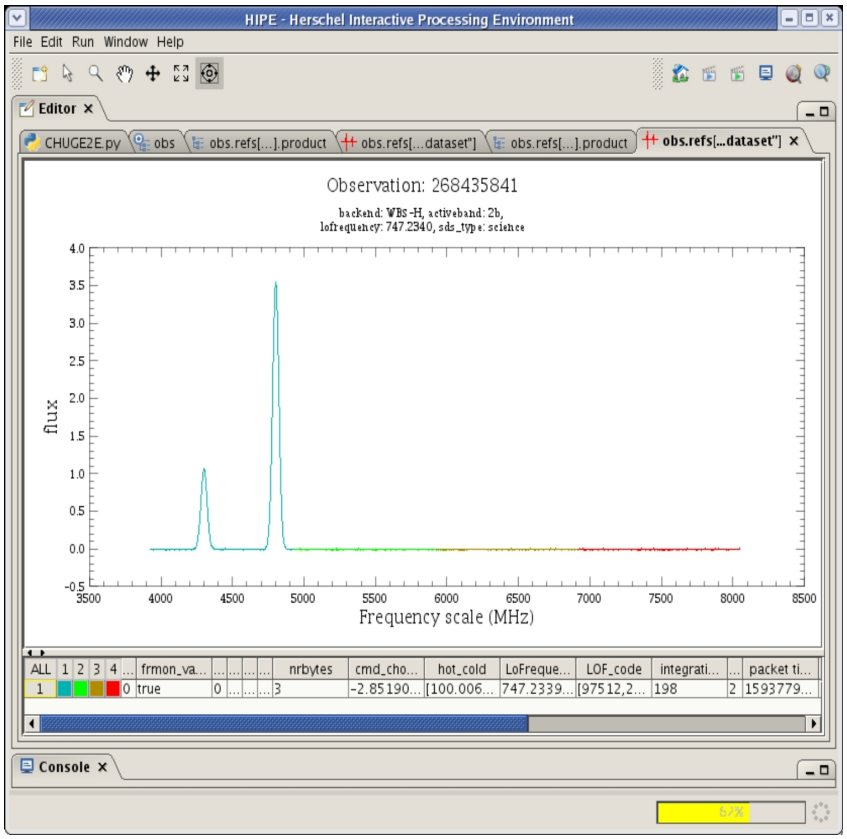
HIFI Data Products: TimelineProduct

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



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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?

HSpot

HIFI Observers' Manual

HIFI HSpot ICD

Uplink

HIFI Tele Command ICD

HIFI instrument to ground ICD

HIFI Data Frame definition

HIFI DP

Calibration Analysis

Trend Analysis

Pipeline and Science Analysis

HIFI standard data product specification
Generic Herschel product definition

AOR/COR

Object database

Calibration object

HIFI Trend products

HIFI Quality products

HIFI data products

HIFI Tele Command ICD

MOC/ Satellite

HIFI Instrument

TMIngest

HIFI House Keeping TM ICD
HIFI Science TM ICD

HIFI Data Frame definition
not formally listed as ICD

HSA

HCSS IA/DP
(HIPE)

HIFI DP Users' Manual and Lore

SRON
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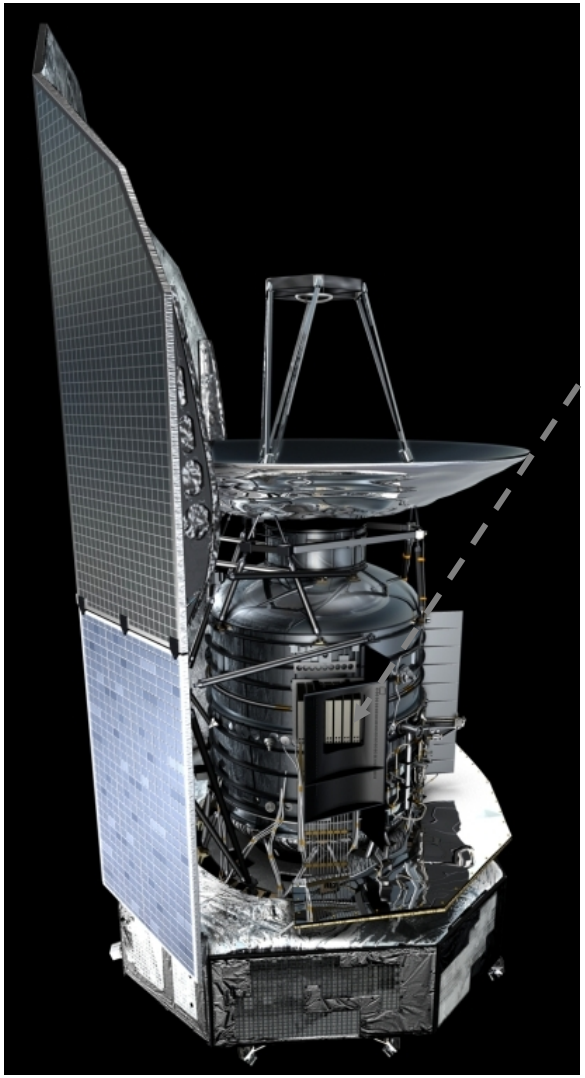
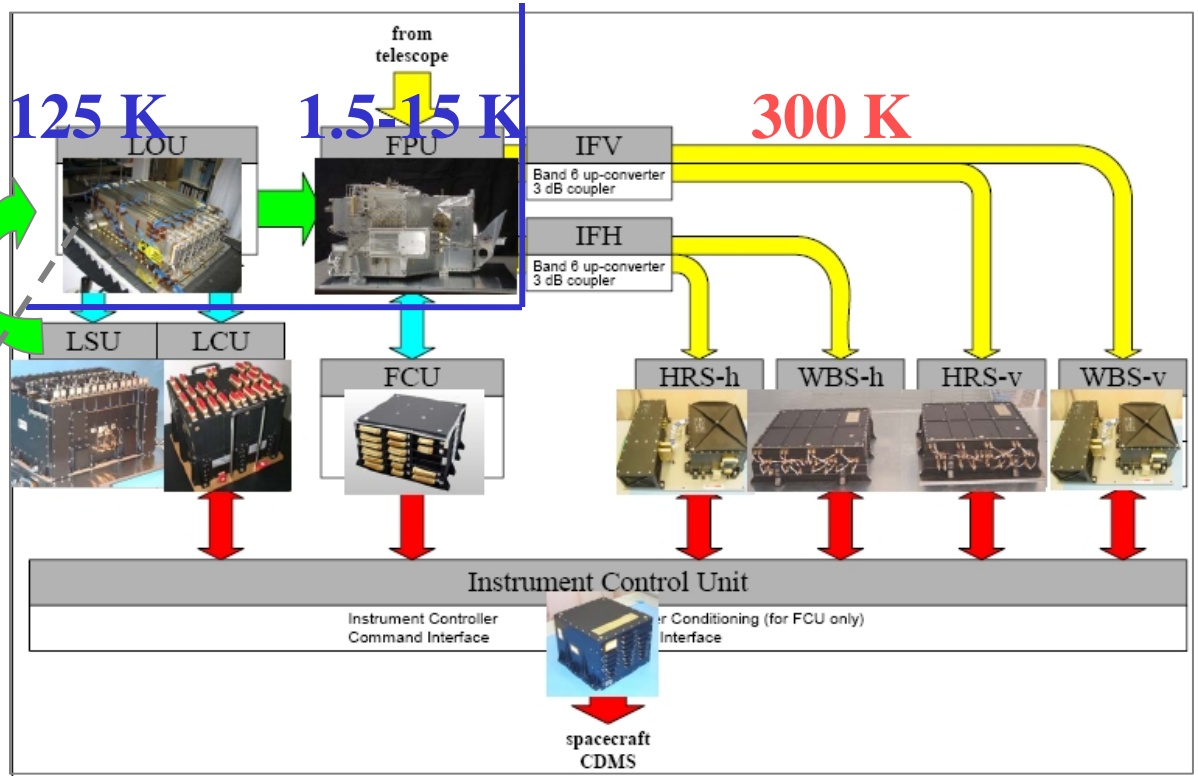
Instrument Subsystems





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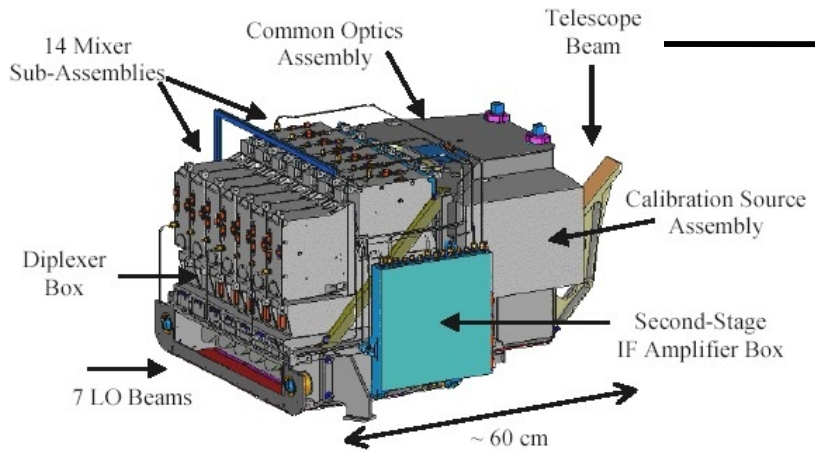
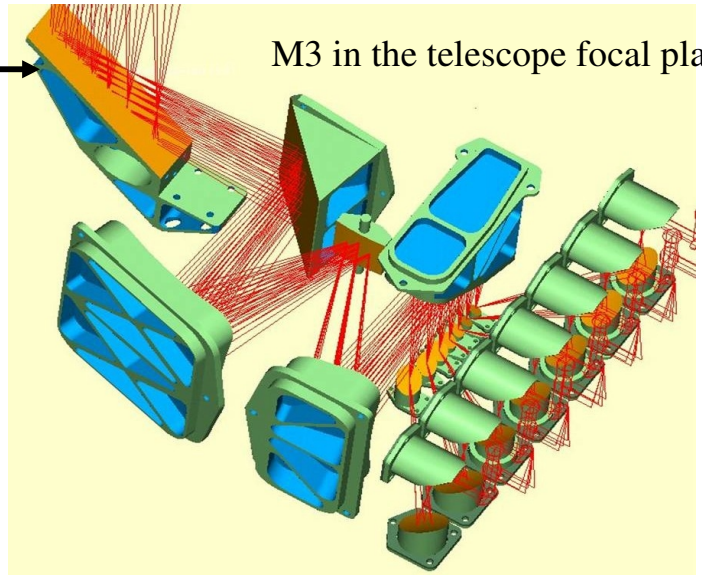
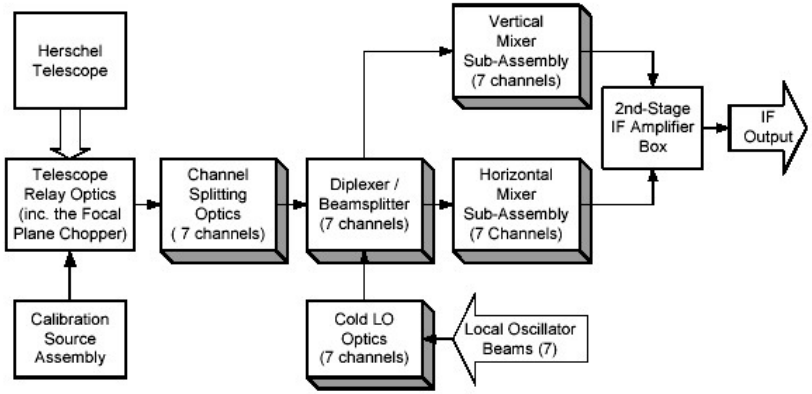
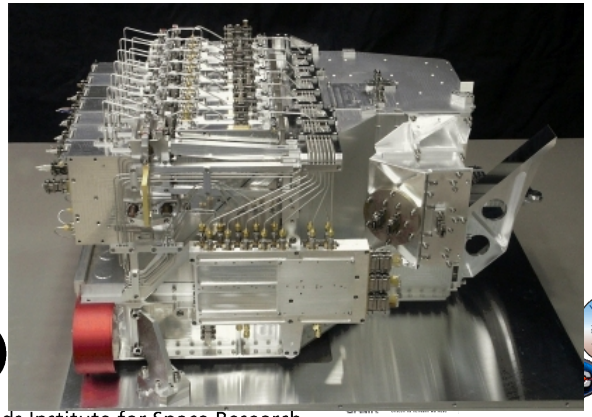
HIFI Layout and Optics

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









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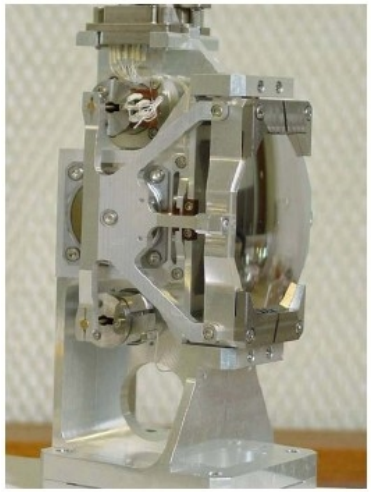
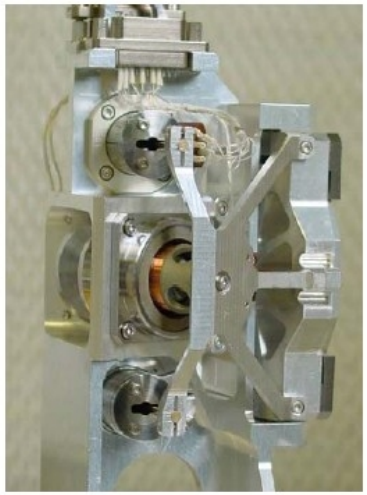
Chopper Mechanism

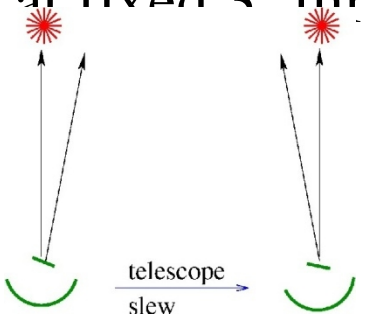
So-called M6 mirror, workhorse of Dual Beam Switching and Load Chop Observing Modes to

- 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)



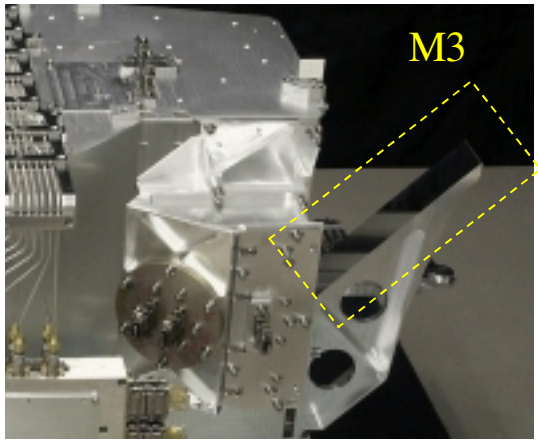


Chopping of the telescope beam at fixed 3' throw, up to 5 Hz.

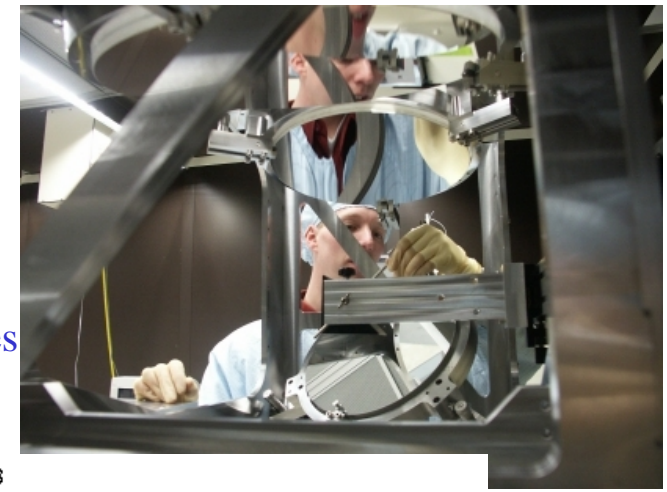


Chopping to the thermal

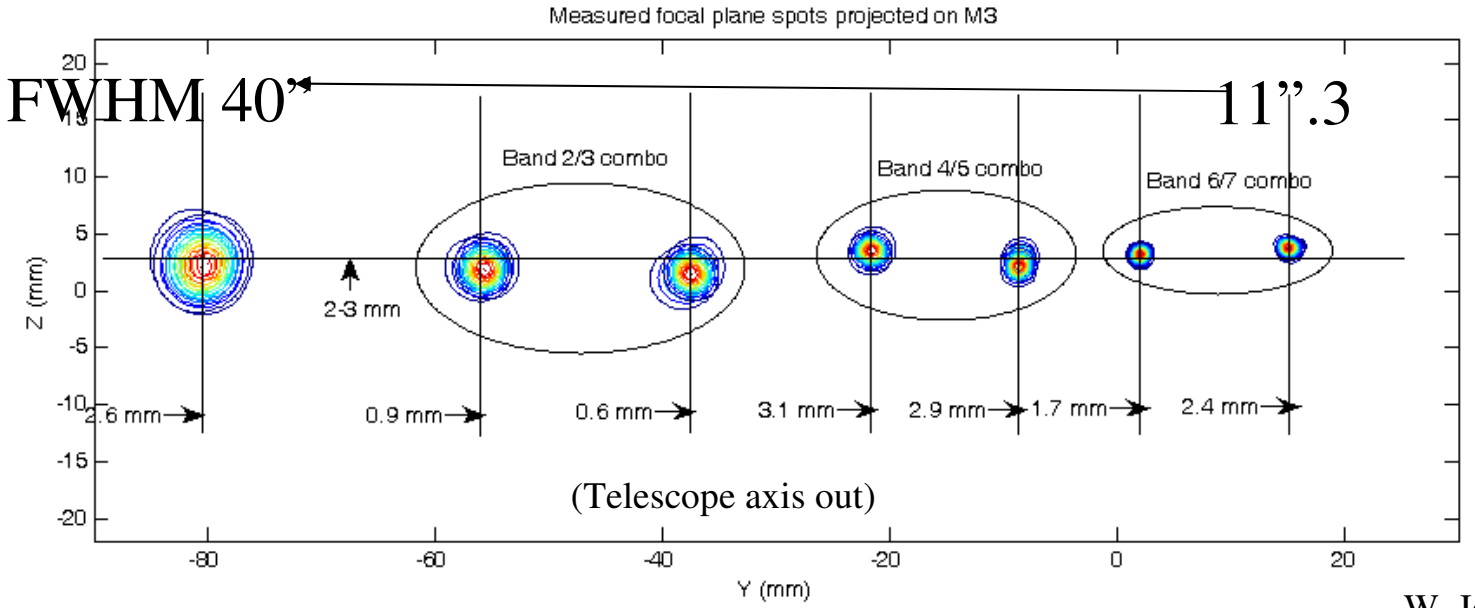
HIFI on the "sky"



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



Beams sizes / waist properties are nominal.

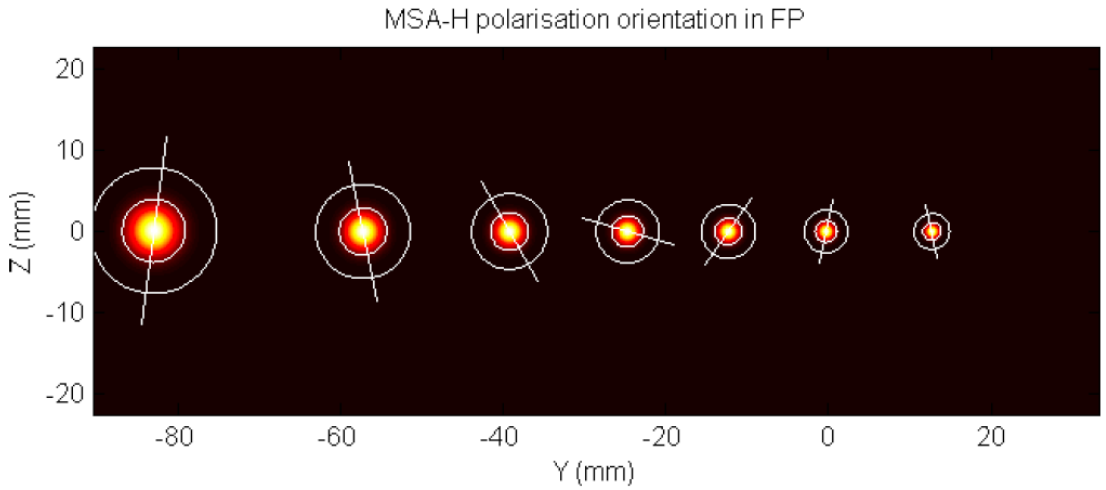


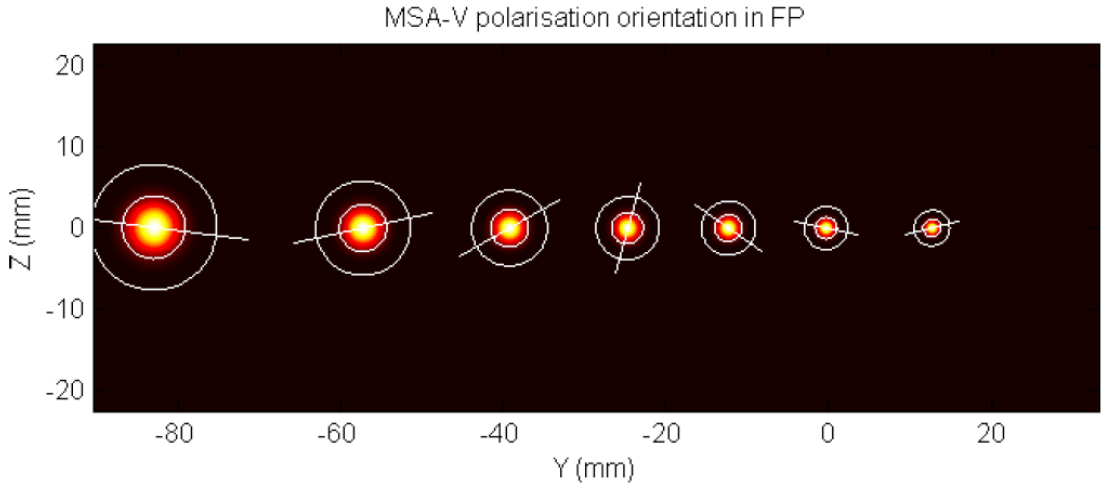
(Telescope axis out)

W. Jellema

SRON Netherlands Institute for Space Research

H and V Polarized Mixer Beams





W. Jellema

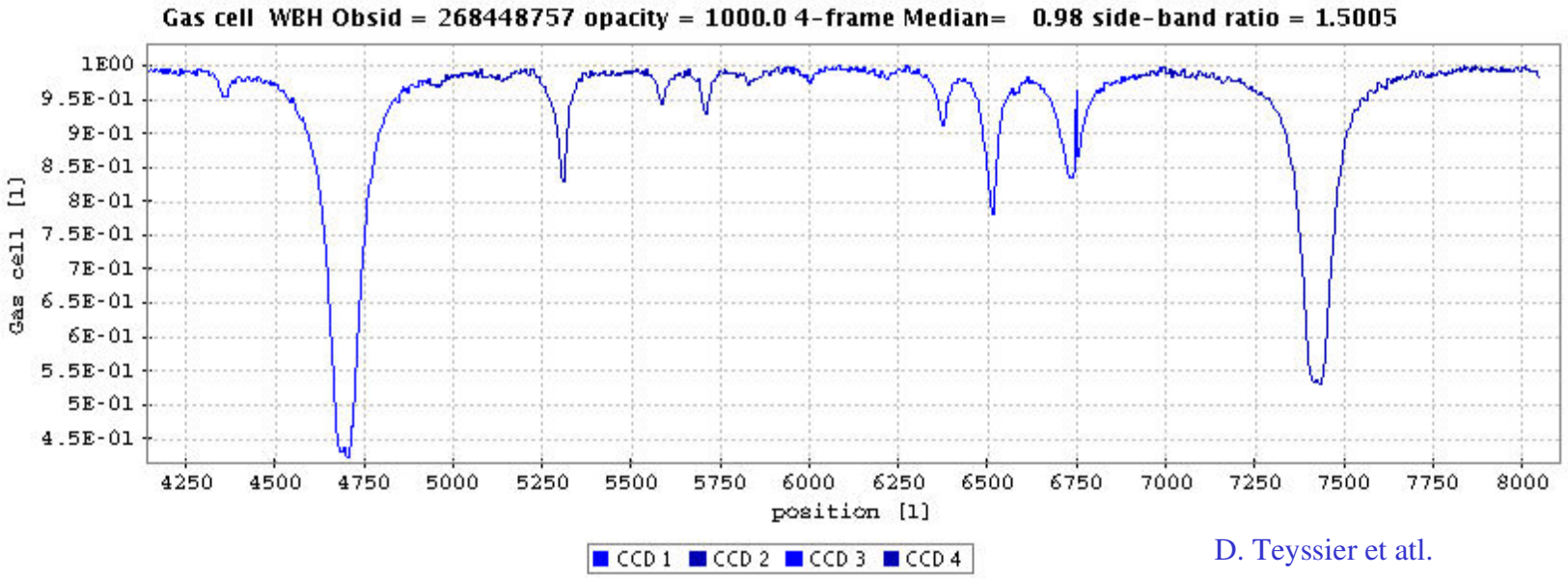
Band	θ_X(°) MSA–H	θ_X(°) MSA–V
1	82.5	-7.5
2	-78.2	11.8
3	-59.8	30.2
4	-15.3	74.7
5	54.8	-35.2
6L	77.5	-12.5
6H	-77.0	13.0

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.

Netherlands Institute for Space Research

FM Spectral Performance Tests with the gas cell



D. Teyssier et atl.

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 closer to 1.1 or less.

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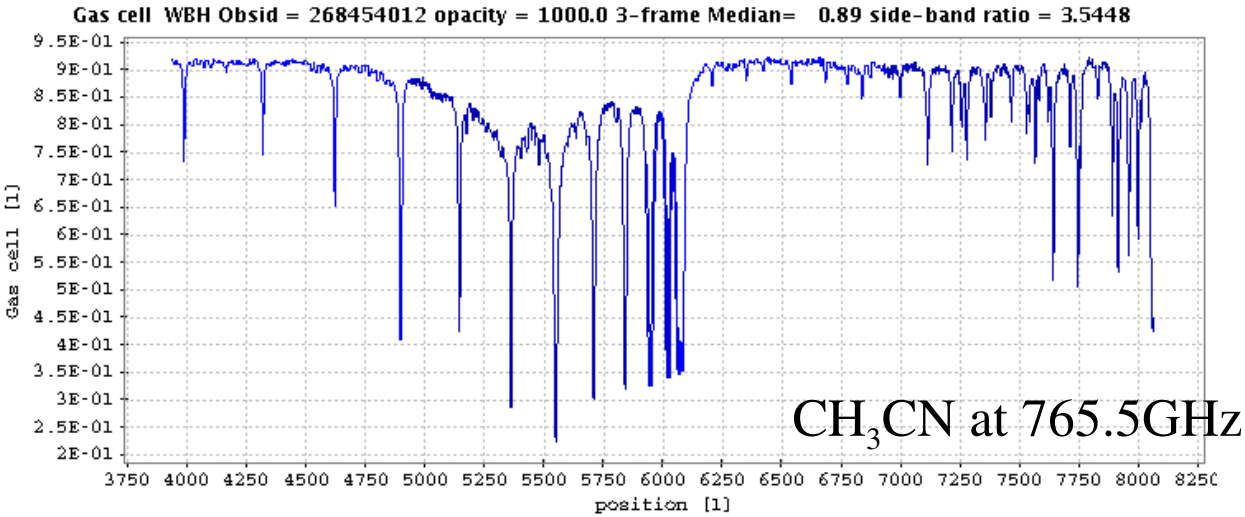
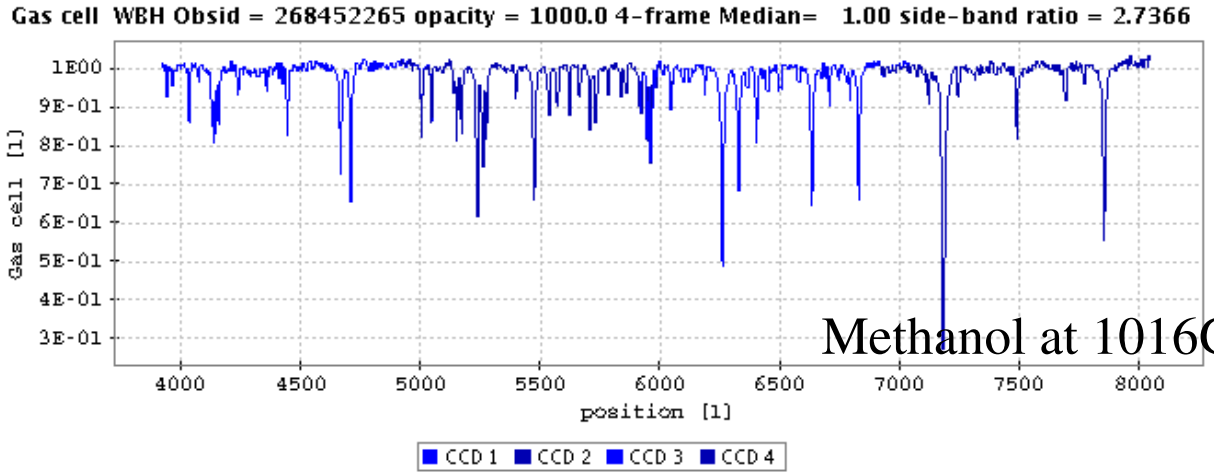
Acetonitrile, Methanol



CH_3CN at 765.5GHz WBS-H



Methanol at 1016GHz WBS-H

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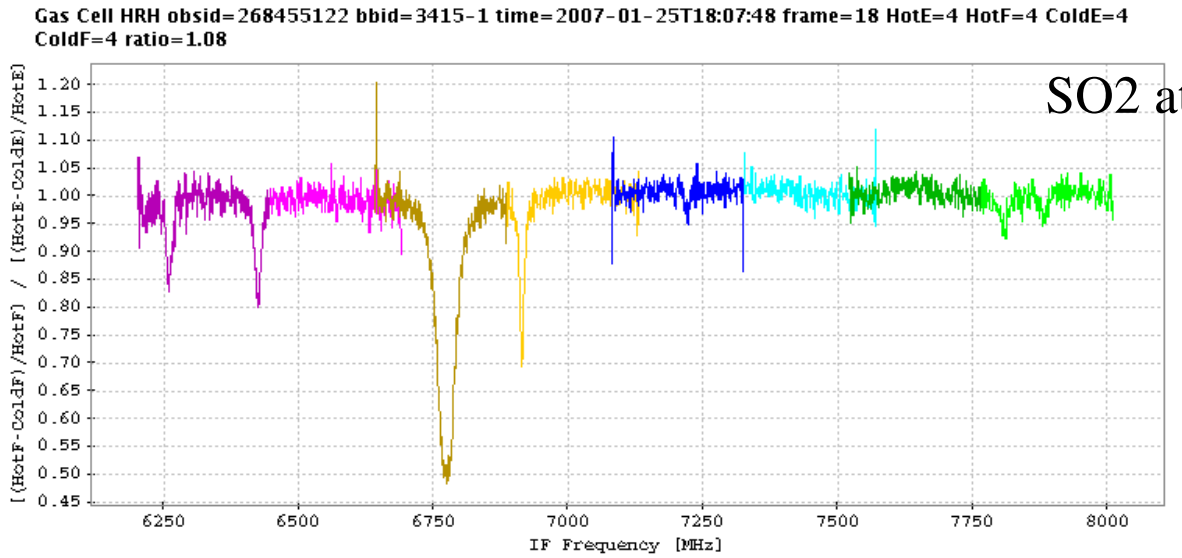
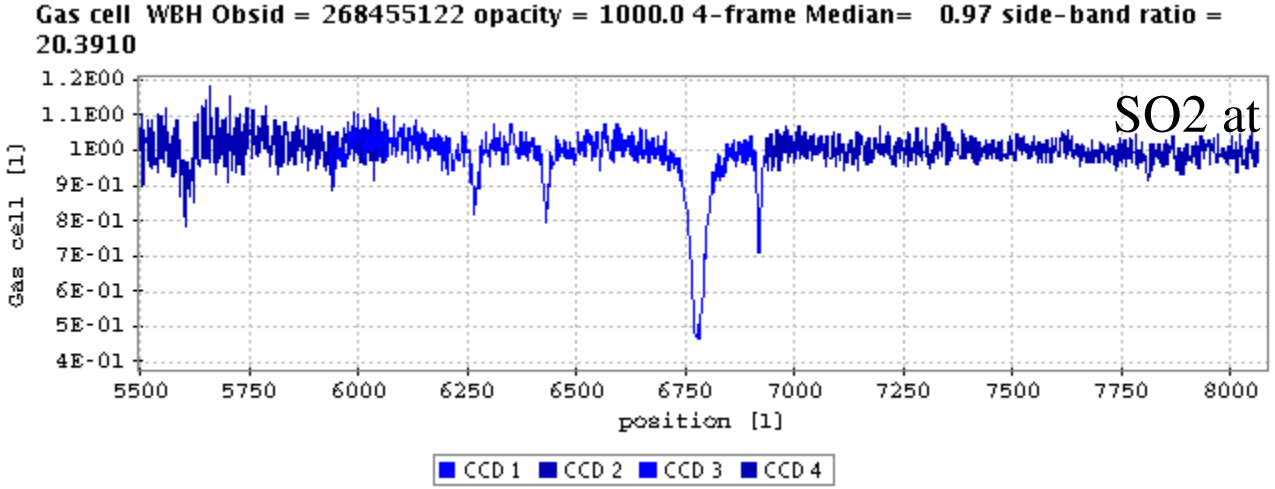
SO with HRS and WBS



SO2 at 1696.5GHz HRS-H

(2.4 GHz IF)



SO2 at 1696.5GHz WBS-H

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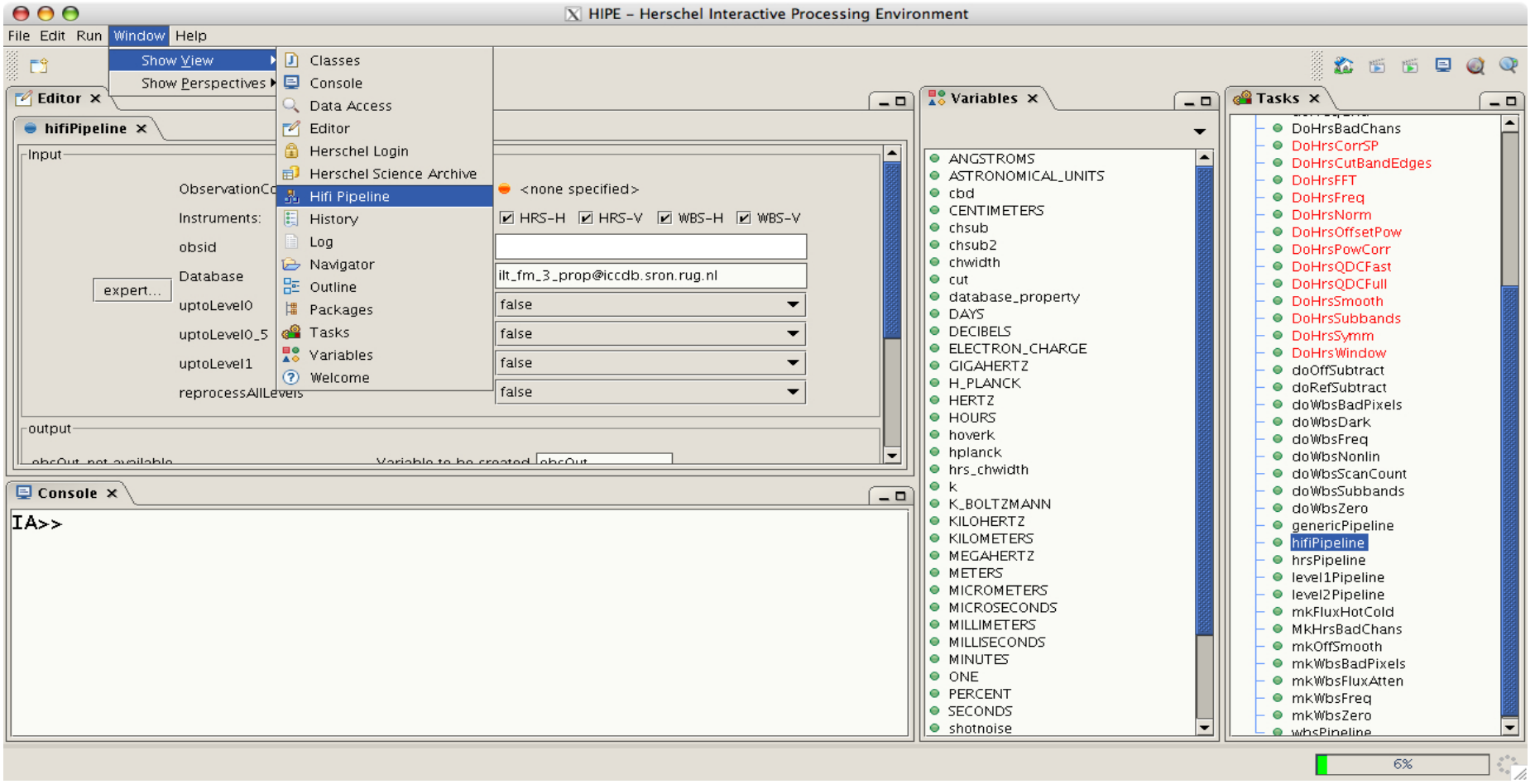
HIPE: Running Pipeline 'Lights Off'



Start automated HIFI pipeline task ('SPG'): window->Show View->HifiPipeline and click on hifiPipeline in Tasks on right pane

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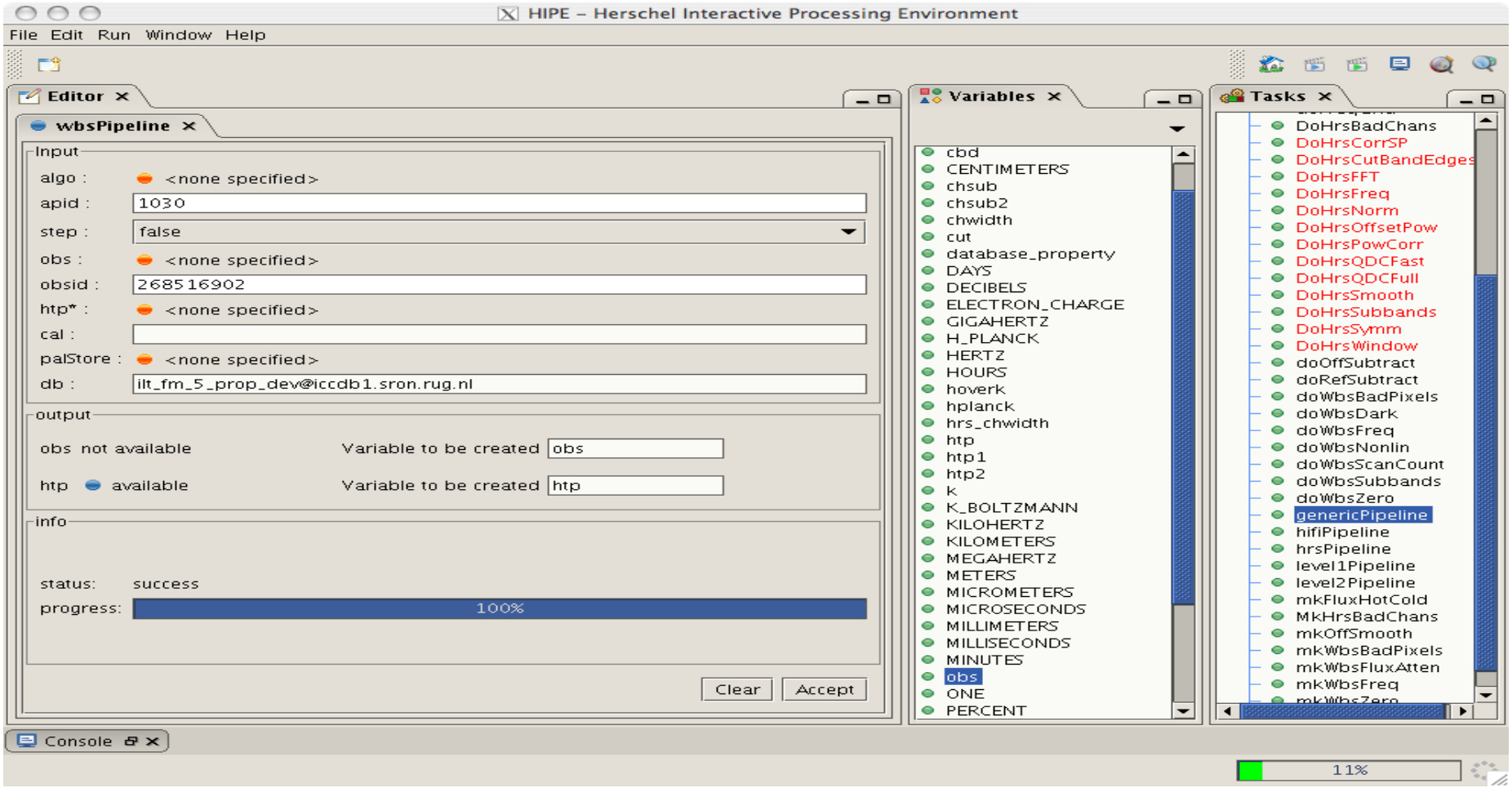
HIPE: Interactive Pipeline



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)