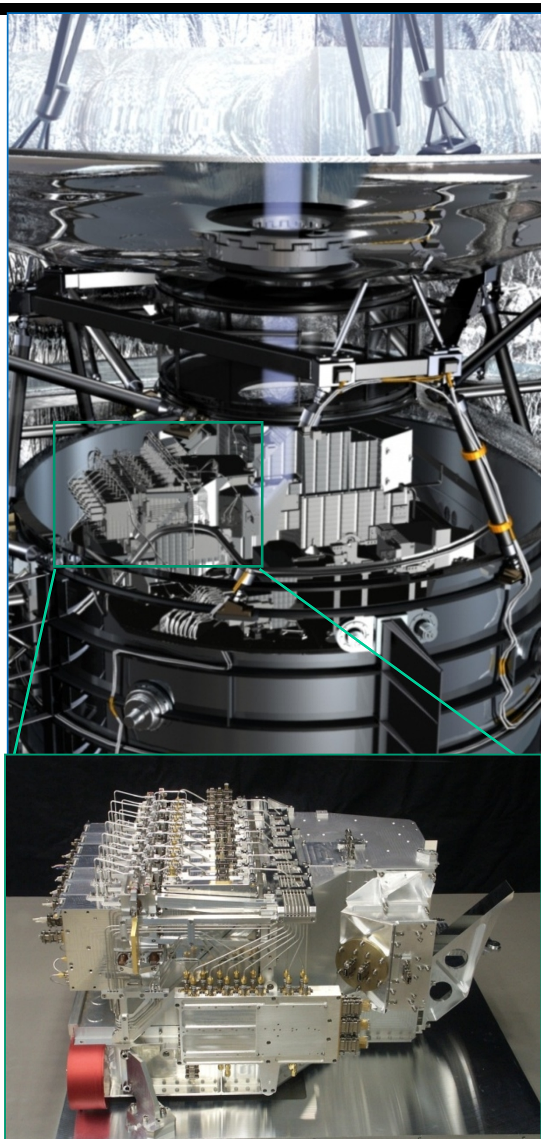


Introductory HIFI Data Processing Workshop

NASA Herschel Science Center

Pasadena, 12-14 September 2012

Goals and General Remarks

- Learn HIPE: become familiar with the GUI concepts and usage, how to execute pipelines and explore your data
- Learn where to find HIFI data reduction scripts and how to use them, and how to write simple custom scripts
- Learn how to read/ingest your data in HIPE
- Learn how to process HIFI data to Level 2+ products
- Learn about resources and support NHSC can provide
- Processing ⇨ science in HIPE with CASSIS (joint session)
- Sessions will use public data for demo and practice purposes. You can use your own data instead.
- This meeting is informal. Feel free to interrupt anytime if you have questions or we're going too fast or slow.
- This meeting is being broadcast on WebEx. All: Avoid background talking during presentations and demos! Presenters: Pace yourself! Webex users: interrupt anytime!

HIFI Workshop Team

NHSC team:

Adwin Boogert (scientist)

Herschel DP Training "Champions"

Colin Borys (scientist)

Herschel DP Mgt Group

Pat Morris (scientist)

Herschel DP User Group

NHSC HIFI manager

Joan Xie (software developer)

doDeconvolution, fitFringe

Annie Hoac (software developer)

fitBaseline, fitHifiFringe, unit converter

U. Waterloo (Canada):

Carolyn McCoey (scientist)

Herschel DP Training "Champions"

HIFI ICC deputy manager

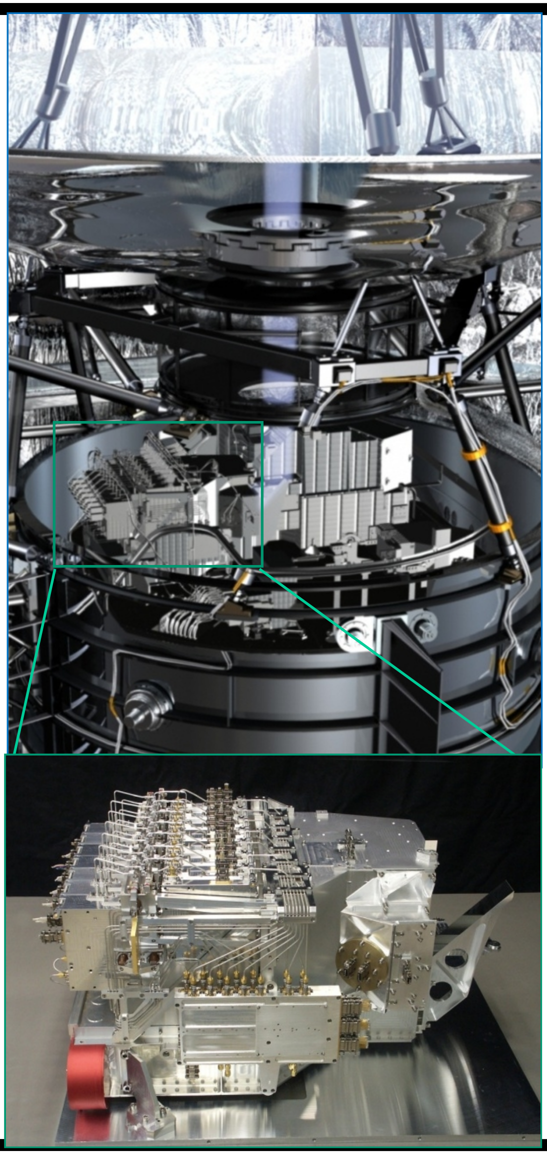
IRAP, Toulouse:

Emmanuel Caux (scientist)

HIFI Co-PI

HIFI Users Group

CASSIS plugin



The HIFI Instrument
Status, AOTs, and Calibrations

Pat Morris

Adwin Boogert, Colin Borys (NHSC)

Carolyn McCoey (Univ. of Waterloo)

Emmanuel Caux, IRAP (ex-CESR)

Thanks – Frank Helmich (HIFI PI) and the HIFI Consortium

Outline

- Part I: Instrument Status and Health
- Part II: Calibrations
- Part III: AOTs Status

Part I
Instrument
Review, Health, Status

HIFI is the most powerful and versatile heterodyne instrument operated in space for observing molecules and atomic lines in the FIR/submm regime at ultra high spectral resolutions. HIFI is an instrument for astrochemistry.

•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:

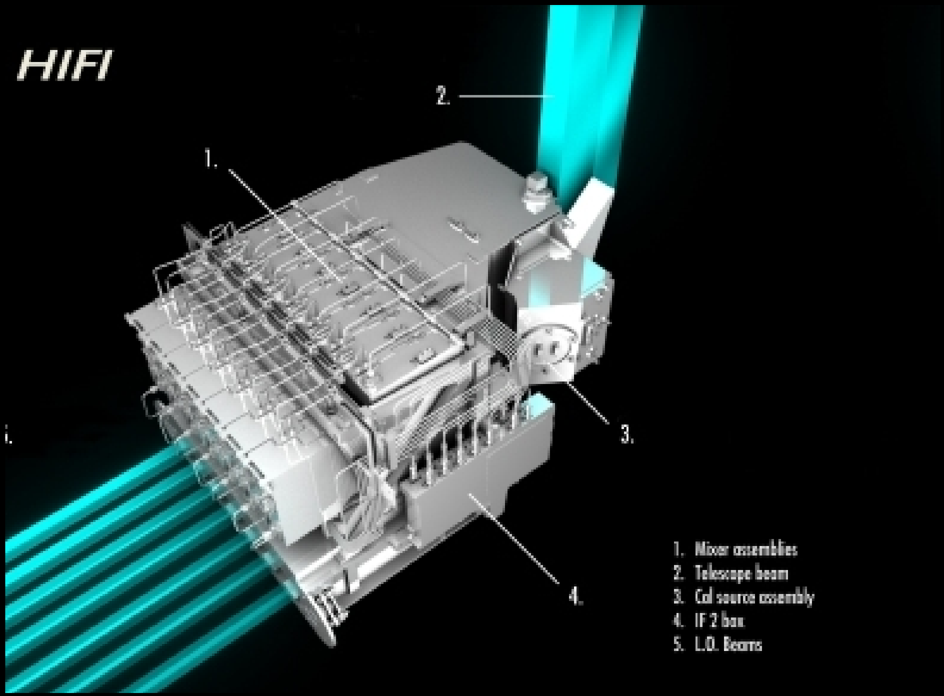
1410-1910 GHz, IF 2.4-4.8 GHz

14 LO sub-bands
LO source unit in common
LO multiplier chains

2 spectrometer systems
-Auto-correlator spectrometer (HRS)
-Acousto-optical spectrometer (WBS)

IF bandwidth/resolution
- 4 GHz (in 2 polarizations)
- 0.14, 0.28, 0.5, and 1 MHz
- Velocity discrimination < 0.1 km/s (R>10^6)

Angular Resolution (w/ telescope):
11”.3 (high-ν end) to 40” (low-ν end)



Sensitivity
Near-quantum noise limit sensitivity

Calibration Accuracy
10% radiometric baseline, 3% goal

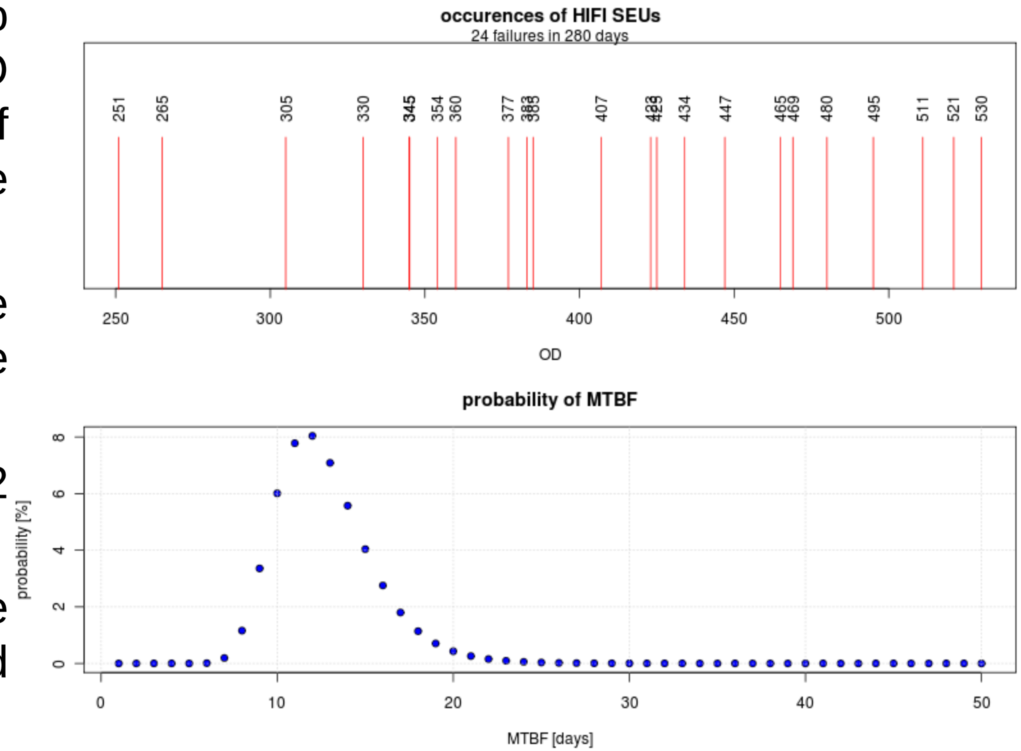
HIFI Status/Health

- HIFI continues to operate with full functionality on its redundant-side electronics.
  - Recall 8/2009 a CR-induced bit-flip on the LO Control Unit → unprotected faulty shut-down while observing, breaking a critical DC-DC converter. A similar event on the Instrument Control Unit in 3/2012, fully recovered. SEUs are a fact of HIFI “routine” operations.
  - See next slide for frequency of events.

- Sub-systems are healthy, with 2 caveats:
  - Comb generator for the WBS-V is fading; HRS cross-calibration procedures in place if/when the comb signal dies.
  - LCU OXCO (10 MHz signal for locking LO chains, LSU, WBS and HRS) crystal heater circuit is thermally spiking, in reaction to LSU temp control switching on/off. Situation is OK, loss of the heater circuit would mean some degradation to frequency calibrations.

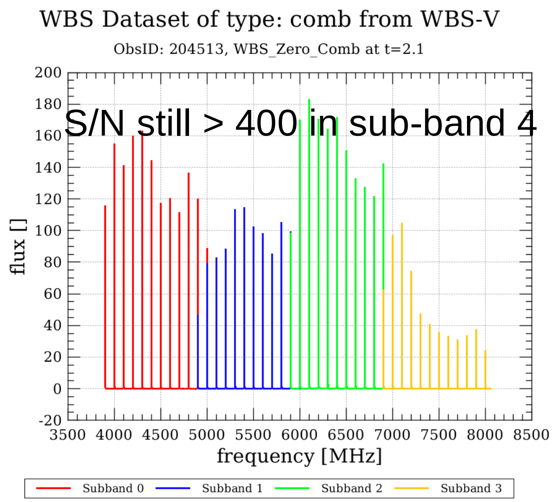
HIFI Single Event Upsets

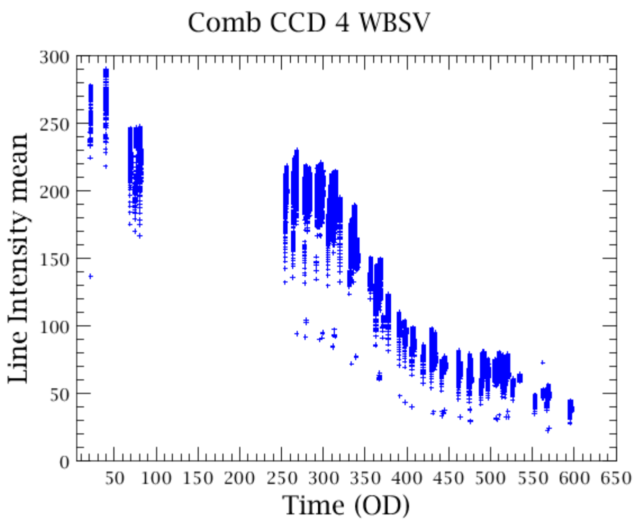
- An SEU in August 2009 attributed to CR on a sensitive memory chip in the LO control unit caused premature power-off of the LOU, killing HIFI's Prime side (DC/DC converter part failure)
- HIFI runs on its REDUNDANT side since February 2010, with new intensive fault protection S/W.
- SEU occurring statistically every 12 days
- Two full power cycles (last resort) have been required, when HIFI stopped reacting to commands.



WBS-V comb fade

- WBS-V comb has a failed component, already discovered in 2007. It could not be removed and repaired.
- Comb line intensities continue to drop, now to < 40 counts, much lower than specs.





- Possible reduction of accuracy in determining comb line positions, reduced frequency calibration accuracy expected.
- Alternative method of WBS-V frequency calibration in place, using WBS-HRS cross correlation.
- WBS-H shows no issues.

In-orbit Performance

A&A 537, A17 (2012)
DOI: 10.1051/0004-6361/201015120

Astronomy & Astrophysics

In-orbit performance of *Herschel*-HIFI*

P. R. Roelfsema[1], F. P. Helmich[1], D. Teyssier[2], V. Ossenkopf[1,3], P. Morris[4], M. Olberg[1,5], R. Shipman[1], C. Risacher[1], M. Akyilmaz[3], R. Assendorp[1], I. M. Avruch[1,27], D. Beintema[1], N. Biver[26], A. Boogert[4], C. Borys[4], J. Braine[22,23], M. Caris[6], E. Caux[7,8], J. Cernicharo[15], O. Coeur-Joly[7,8], C. Comito[6], G. de Lange[1], B. Delforge[10], P. Dieleman[1], L. Dubbeldam[1], Th. de Graauw[17], K. Edwards[16], M. Fich[16], F. Flederus[1], C. Gal[3], A. di Giorgio[12], F. Herpin[22,23], D. R. Higgins[21], A. Hoac[4], R. Huisman[1], C. Jarchow[9], W. Jellema[1], A. de Jonge[1], D. Kester[1], T. Klein[6], J. Kooi[19], C. Kramer[3], W. Laauwen[1], B. Larsson[13], C. Leinz[6], S. Lord[4], A. Lorenzani[11], W. Luinge[1], A. Marston[2], J. Martín-Pintado[15], C. McCoey[16], M. Melchior[14], M. Michalska[20], R. Moreno[26], H. Müller[3], W. Nowosielski[20], Y. Okada[3], P. Orleański[20], T. G. Phillips[19], J. Pearson[25], D. Rabois[7,8], L. Ravera[7,8], J. Rector[4], M. Rengel[9], H. Sagawa[9], W. Salomons[1], E. Sánchez-Suárez[15], R. Schieder[3], F. Schlöder[3], F. Schmülling[3], M. Soldati[14], J. Stutzki[3], B. Thomas[1], A. G. G. M. Tielens[18], C. Vastel[7,8], K. Wildeman[1], Q. Xie[4], M. Xilouris[24], C. Wafelbakker[1], N. Whyborn[17], P. Zaal[1], T. Bell[19], P. Bjerkeli[5], E. de Beck[28], T. Cavalié[9], N. R. Crockett[29], P. Hily-Blant[30], M. Kama[1,31], T. Kaminski[32], B. Leflóch[30], R. Lombaert[28], M. De Luca[26], Z. Makai[3], M. Marseille[1], Z. Nagy[1,27], S. Pacheco[30], M. H. D. van der Wiel[1,27], S. Wang[29], and U. Yıldız[18]

(Affiliations can be found after the references)

Received 31 May 2010 / Accepted 7 September 2011

ABSTRACT

Aims. In this paper the calibration and in-orbit performance of the Heterodyne Instrument for the Far-Infrared (HIFI) is described.
Methods. The calibration of HIFI is based on a combination of ground and in-flight tests. Dedicated ground tests to determine those instrument parameters that can only be measured accurately using controlled laboratory stimuli were carried out in the instrument level test (ILT) campaign. Special in-flight tests during the commissioning phase (CoP) and performance verification (PV) allowed the determination of the remaining instrument parameters. The various instrument observing modes, as specified in astronomical observation templates (AOTs), were validated in parallel during PV by observing selected celestial sources.
Results. The initial calibration and in-orbit performance of HIFI has been established. A first estimate of the calibration budget is given. The overall in-flight instrument performance agrees with the original specification. Issues remain at only a few frequencies.

Key words. methods: observational – space vehicles: instruments – instrumentation: spectrographs

1. Introduction

The Heterodyne Instrument for the Far-Infrared (HIFI, De Graauw et al. 2010) is designed to be a very high spectral resolution receiver ($R \gtrsim 10^6$), with near-quantum limited performance for frequencies between 480 and 1910 GHz onboard the *Herschel* Space Observatory (Pilbratt et al. 2010). The high spectral resolution is mandatory for interpreting line emission as observed in a wide range of astrophysical environments with local velocity variations of only a few km s^{-1} or less. The near quantum-limited performance with an absolute calibration accuracy of 10% is needed for a detailed study of absorption lines and intercomparison of water lines in the same or different mixer bands. With the level of detail in the line profiles that HIFI provides, the physical and dynamical conditions for all gaseous material along the line-of-sight can be unraveled. The accessibility of numerous molecular lines, as well as important atomic and ionic lines, with vastly different excitation conditions allow for constraining these conditions in great detail. The wealth of molecules also allows physical conditions and evolutionary stages to be inferred by examining the chemical conditions seen with HIFI.

In this paper the calibration and in-orbit performance of the HIFI instrument are discussed and compared with the resolution, sensitivity, and calibration needs. A short introduction to the instrument is given in Sect. 2 with an overview of the standard HIFI observing modes. Sections 3 and 4 describe the various parameters derived from the instrument level testing (ILT), CoP, and PV phases. Section 5 gives the overview of the HIFI observing modes and the corresponding astronomical observation template (AOT) validation. Finally in Sect. 6, the processing tools and processing steps for HIFI data is described.

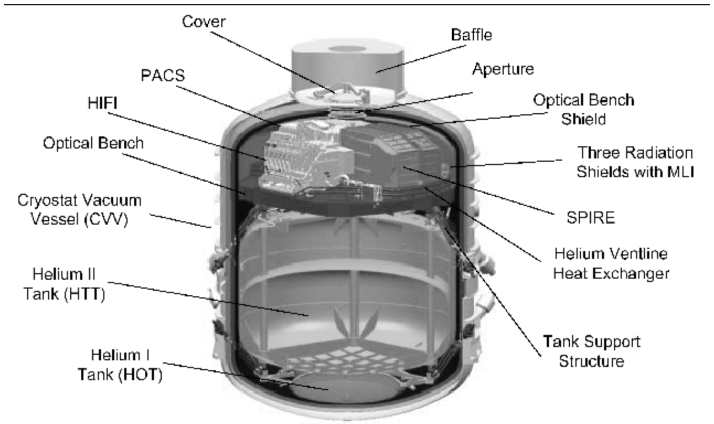
2. The HIFI instrument

The HIFI instrument is based on the heterodyne technique, where the sky signal at a frequency ν_{sky} is mixed with an ultrastable internally generated local oscillator (LO) signal at frequency ν_{LO}. These two signals are mixed in the focal plane unit (FPU) using a nonlinear mixing element. The output electrical signals contain the sum and the difference frequencies, at $\nu_{LO} + \nu_{sky}$ and at $\nu_{LO} - \nu_{sky}$. The high-frequency component is filtered away, while the difference frequency component

* *Herschel* is an ESA space observatory with science instruments provided by European-led Principal Investigator consortia and with important participation from NASA.

Observatory News

- Cryogen expected to run out late-Feb/early-Mar 2013 (~6 months > requirement).



- No post-He science.
- Industry and MOC may experiment with pointing, various subsystems, sensors.
- Telescope has a radiation monitor (CCD) maybe useful to continue data collection at L2.

- Some “degradation” of the mirror surface has been noticed; could be some micro-roughening by zody particles (~60 µm size to be consistent with increase in emissivity at shorter wavelengths), and/or cosmic ray aging effects.

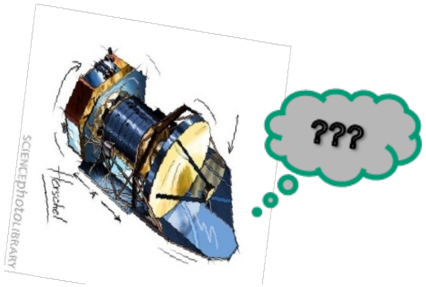
Update Telescope Pointing

Telescope pointing accuracy has evolved and improved from changes mainly to how the star tracker is operated over the mission.

- Absolute Pointing Error is the uncertainty after slewing to target
  - **Currently APE = 0”.8**
  - The APE is mission phase dependent, and has ranged up to ~3”.0
- Spatial Relative Pointing Error applies to offsets within an observation, e.g. the telescope nod in DBS point modes or offsets in raster maps.
  - **Currently the SRPE = 1”.0 – 1”.5**, depending on the number of guide stars used (9 or 18).
- Relative Pointing Error describes the telescope drift over specified time intervals. Applies to all observations, and becomes visible for example as deviations from a linear path in OTF map legs.
  - **Currently the RPE ~0”.3/minute**.

Caveat about pointing performances

- Remember that quoted performances in terms of APE, SRPE, etc are statistically-derived. The distributions tend to be Gaussian, but observations may have their own issues which are sometimes noticeable, sometimes not.
- Some systematics are present in HIFI data, for reasons which may not be understood at this time. E.g.,



  - the OTF map "zig-zag",
  - the possibility of errors in the SIAM by LO sub-band such that one beam may be more accurately placed than the other,
  - possible long settling effects following offsets.
- Users should always check that the reconstructed pointing of their data makes sense. Use HSpot to compare with the planned AOR.

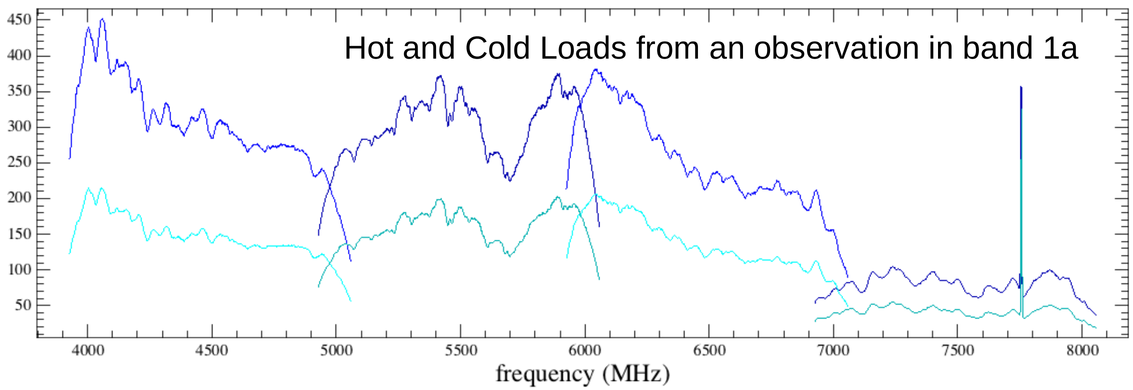
Pointing Product

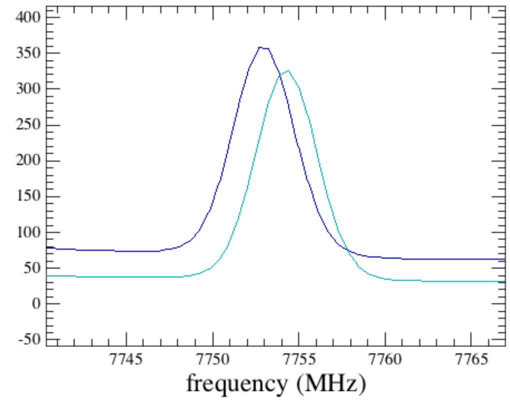
- The Pointing Product accompanying each observation contains the planned and reconstructed pointing history, along with various quality flags. It is resampled to the spectral dataset timeline, and sky coordinates are assigned to each spectrum after rotations associated with the H and V beams are applied using the SIAM.
- The contents of the pointing product receive some correction factors in STA operation that can be taken into account on the ground.
  - The most recent correction involves compensation for focal length of STA1 when CCD operating temperature was lowered to reduce effects of warm pixels, applying over the period of OD 320-762.
  - The new Pointing Product will be applied during bulk reprocessing of observations with SPG 9.1.
- See: **herschel.esac.esa.int/twiki/bin/view/Public/SummaryPointing**

Part II
Calibrations

LO Spurs and Spurious Response

•Impurity features in HIFI are manifest as ~25MHz, Gaussian-shaped features in hot, cold, on, and off data.





- Both WBS and HRS are affected.
- **Because they look a lot like astronomical lines, they can fool users**.

•Repeatable ones tabulated in PHS (HSpot) and pipeline tables.

- In the pipeline, the hot/cold loads are searched in all science observations, and spurs are flagged.

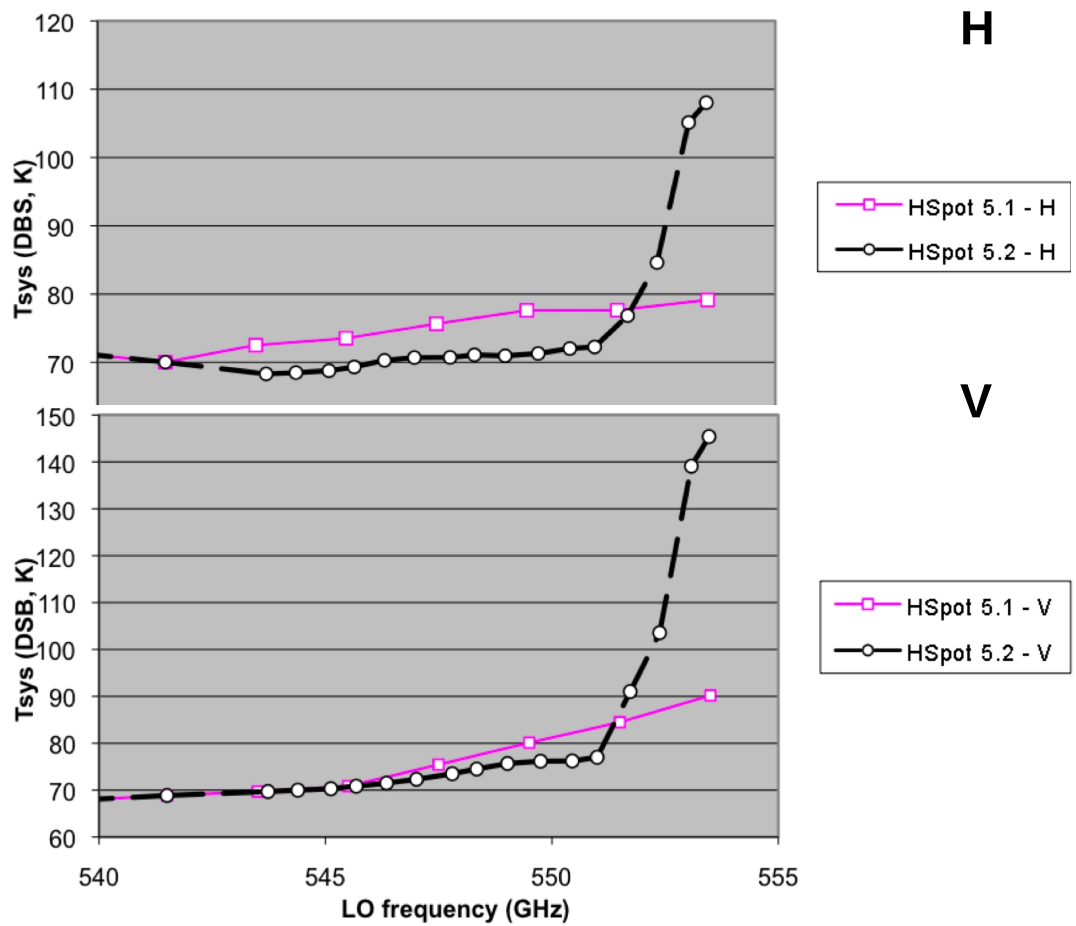
Spur clean-up at instrument level, Band 1a example

Many of the most troublesome impurities (e.g. near key lines) have been cleaned up, by (time/labor intensive) tests and changes to multiplier sett

Band 1a spur eliminated (557 GHz H2O line region)

System temperature increased at upper 1.5 GHz of band

Sensitivity in band 1a is better than that in band 1b for LO frequencies up to 551.9 GHz.



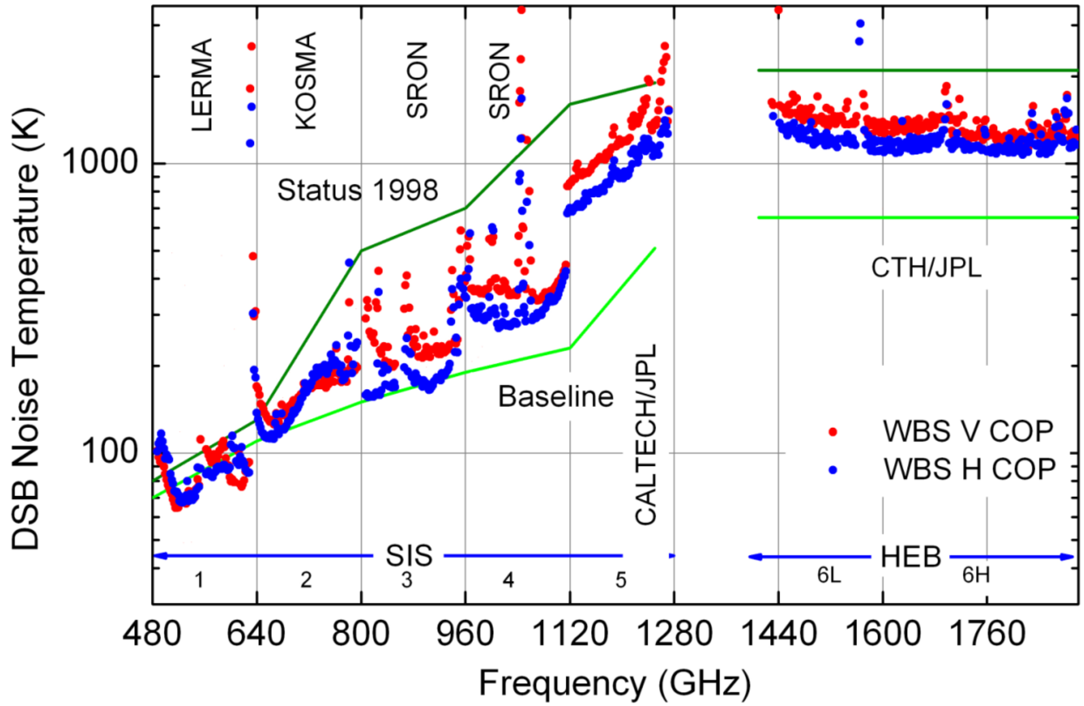
Band 5b purification

- LO-band 5B had several LO spikes at the same time
  - Result is that the IF consists of several frequency bands superposed on each other.
    - Calibration of all frequencies within the IF was unknown
  - Purification efforts took many weeks.
  - AORs in 5b were released in December 2010.

- Band 5B was not alone in impurities but in the diplexer bands the diplexer can moved and the signal evaluated at each setting to give purest signal more efficiently (in observing terms).
  - Purification in bands 3b/7b done this way (Band 5 has no diplexing).

- Purification is major triumph for modeling of the LO chains!

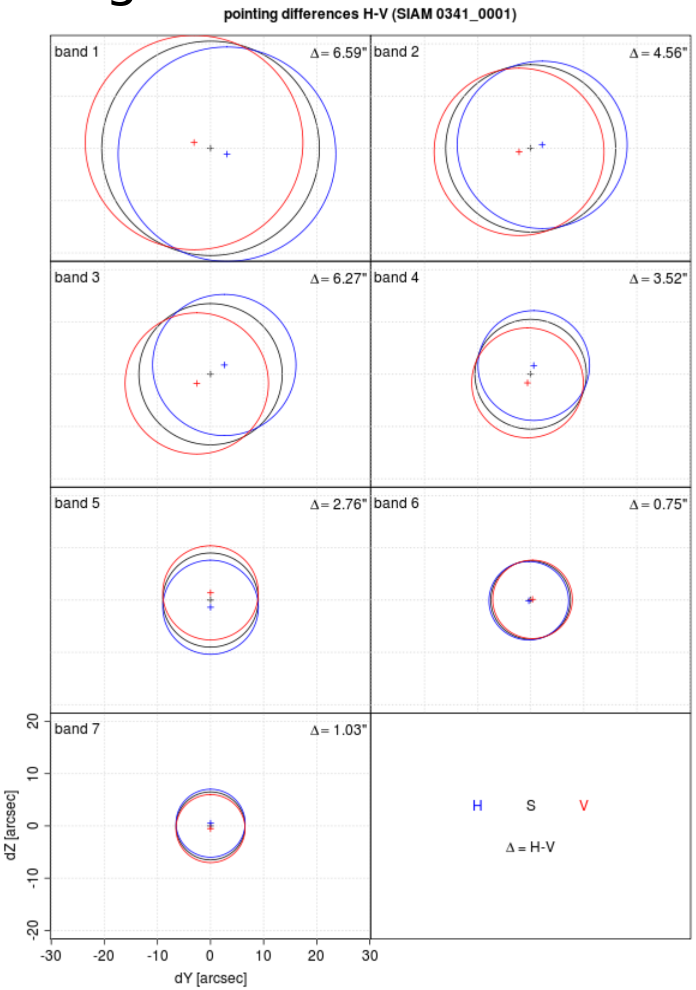
Sensitivities

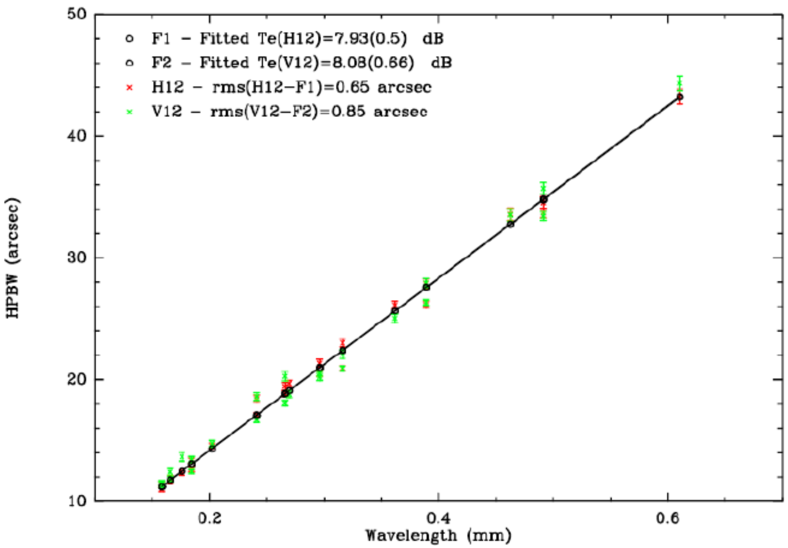


- Sensitivities are driven mainly by System Temperatures and Aperture (or beam) Efficiencies.
- **Tsys as** before launch; small changes at specific frequencies to mitigate impurities and unstable tunings (also: adjustments to band limits).
- To check if observations achieve HSPOT prediction: compare at same goal resolution (apply box car smooth)!

Beam Calibrations

- H/V beam sizes and co-alignment





- Measured mainly from Saturn, Uranus, Mars

- Beam offsets are taken into account in the HIFI pipeline since HIPE 5.0

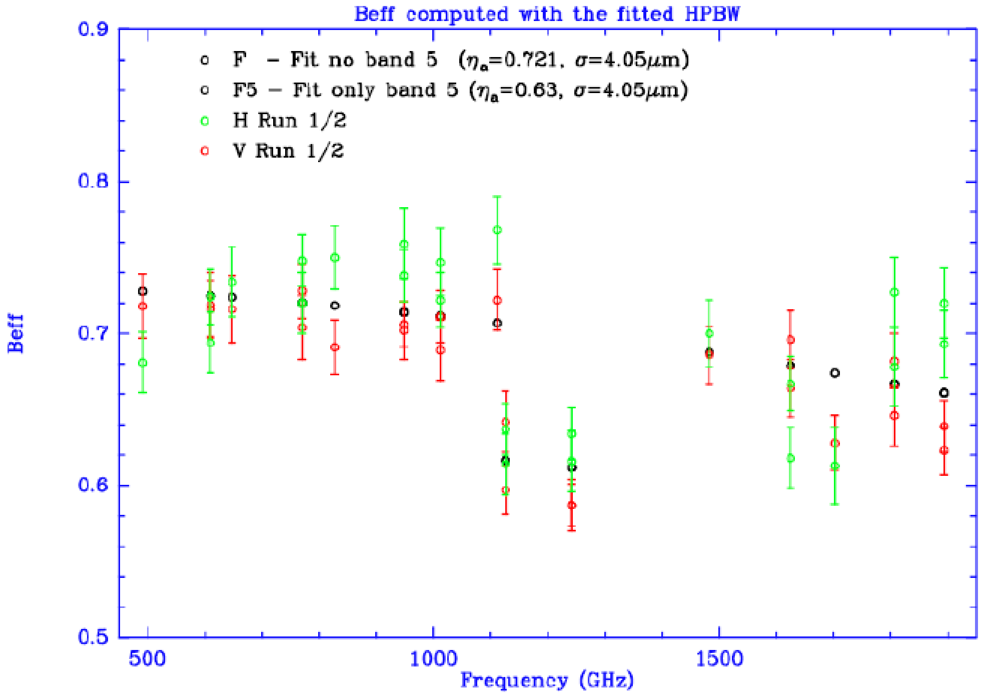
Efficiencies

- Beam efficiencies measured on Mars

  + Overall ~10% better than pre-launch estimates

  o Data taken before Nov 2010 should have somewhat better noise performance (HSpot 5.2 uses updated effciencies).

  – Band 5a/b are an exception, ~10% lower.



Beff accuracy ± 4 %

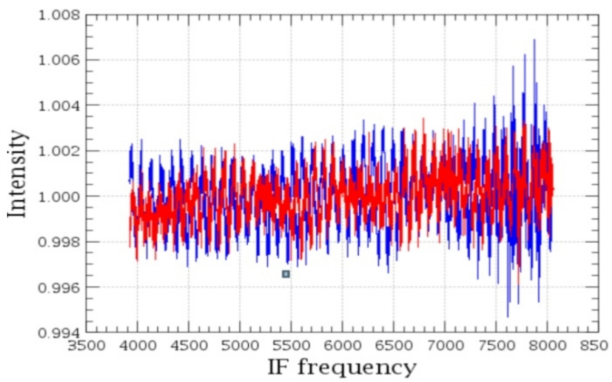
Standing Waves

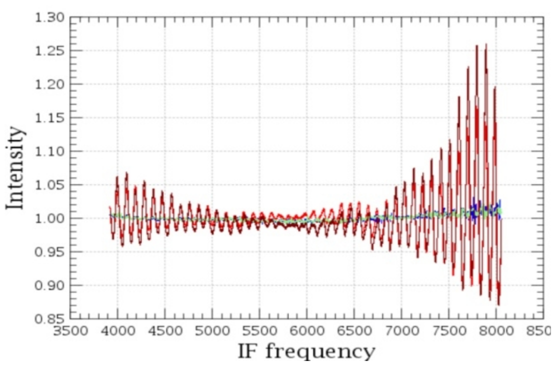
Standing waves from optical and electronic components seen in HIFI spectra. Pipeline removes those by using appropriate chopping against sky or load, nodding, or frequency switch. Residual waves might still be seen in Level 2 data, and this has been taken into account in HSPOT sensitivity calculations. Much can be taken out in post-pipeline processing. Wave-type is HIFI-band dependent:

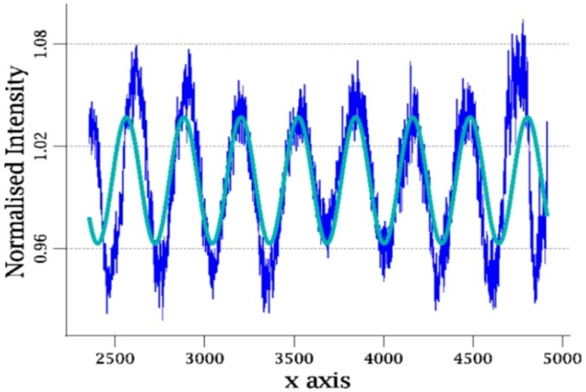
Beamsplitter bands 1, 2, and 5 exhibit sine waves

Diplexer bands 3 and 4 show sine waves with amplitude increasing to IF band edges

HEB bands 6 and 7 waves are electrical, not optical sine waves. Best treatment requires special “matching” method.

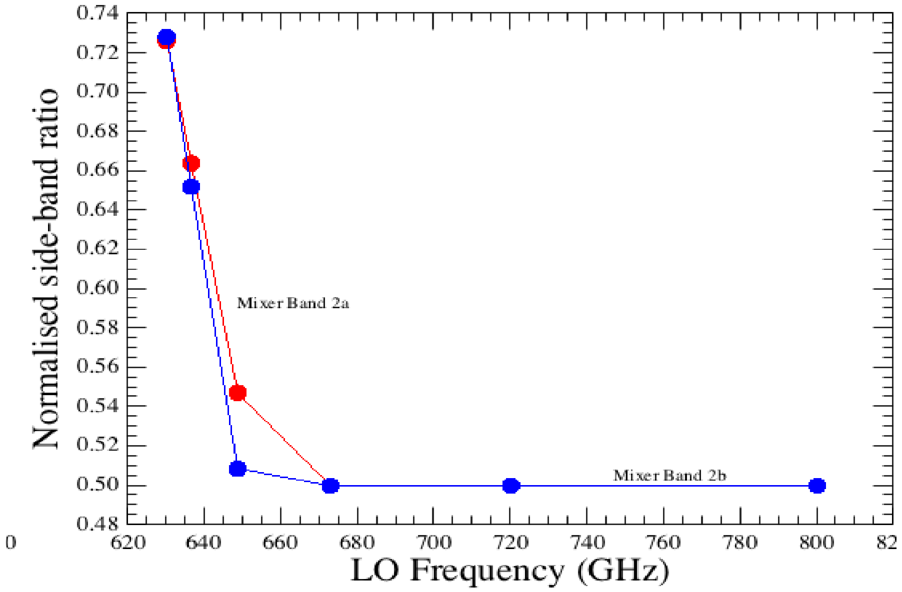






Side Band Ratios

- Sideband gain corrections are applied to band 2A and 5 in the 9.0 pipeline. They are significant near 2A IF band edge. Applied values can be found in the calibration tree (see demos later today). Values for other bands may change in future pipeline versions!
- The level 2 LSB and USB products have these corrections applied. Depending on the sideband the line is located in, one or the other product needs to be used for science.



Calibration Information Resources

- HIFI Instrument by deGraauw, T. et al. 2010 A&A 518 6 and **HIFI In-Orbit Performance by P. Roelfsema, et al. 2012, A&A, 537, 17** are the citations for publications.

- Further documentation on calibration topics and specialized data analysis scripts are located on the HIFI Calibration Web:

herschel.esac.esa.int/twiki/bin/view/Public/HifiCalibrationWeb

  - Can be easily followed from HSC's main page.
  - Regularly updated.

Part III

HIFI Observing Modes highlights

Tips about HSpot in DP

- HIFI pipeline has modules and product data tree which depend on the AOT and calibration (reference) mode which was selected in HSpot.
- Helpful to have HSpot running during data reduction, with corresponding AOR(s) loaded, and time estimation output on predicted performances (e.g. rms noise) handy.
  - The use of the line lists and Frequency Editor for visualizing where **lines of interest and spur/spurious response ranges** fall in the two sidebands,
  - AOR overlays can be valuable references, especially if you are accessing observations planned by others from the public HSA.
- Remember that you can download the KP/OT1-2 AORs from HSC's database using HSpot
  - File → View Accepted Proposal
  - The proposal name can be found in HSA query output and in the observation context header.

AOT Schemes with HSPOT v6.0 and later

Reference scheme	AOT I Single Point Observations	AOT II Mapping Observations	AOT III Spectral Scans
1 - Position Switch	Mode I – 1 Point PositionSwitch	Mode II – 1 OTF Nyquist or lower sampling option	
2 – Dual Beam Switch	Mode I – 2 DBS or FastDBS Continuum stabilization option	Mode II – 2 DBS or FastDBS Raster DBS or Fast DBS Cross Continuum stabilization option Nyquist or lower sampling option	Mode III – 2 DBS or FastDBS Continuum stabilization option
3 – Frequency Switch	Mode I – 3 FSwitch Sky reference option	Mode II – 3 OTF FSwitch Sky reference option Nyquist or lower sampling option	Mode III – 3 FSwitch Sky reference option
4 – Load Chop	Mode I – 4 Load Chop Sky reference option	Mode II – 4 OTF Load Chop Sky reference option Nyquist or lower sampling option	Mode III – 4 Load Chop Sky reference option

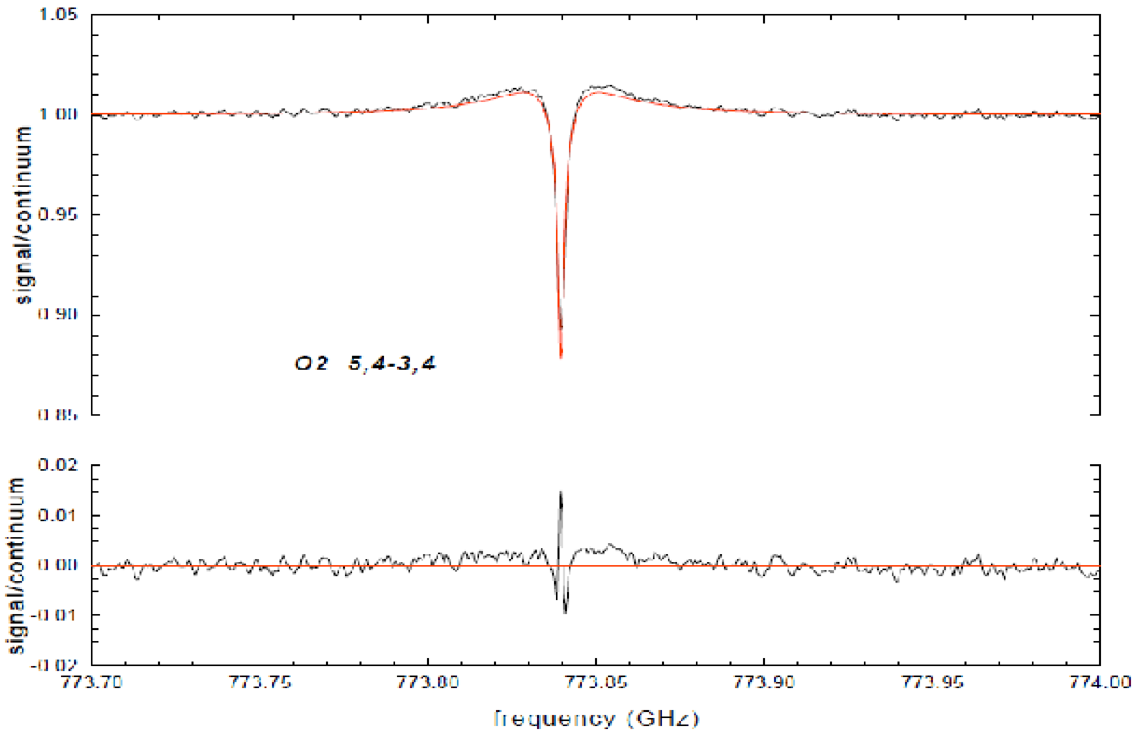
Point Mode AOT

- The point mode AOT is the most basic observation one can do.
  - Operates at a single target position.
  - Operates at a single LO tuning.
  - All reference schemes are allowed.

First submm detection of O2.

Mars fixed frequency, Point Mode AOT, Dual Beam Switching (tracking mode).

Hartogh et al., A&A 521, L49 (2010)



Point Mode AOT

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First subr
detection

Mars fixed
frequency
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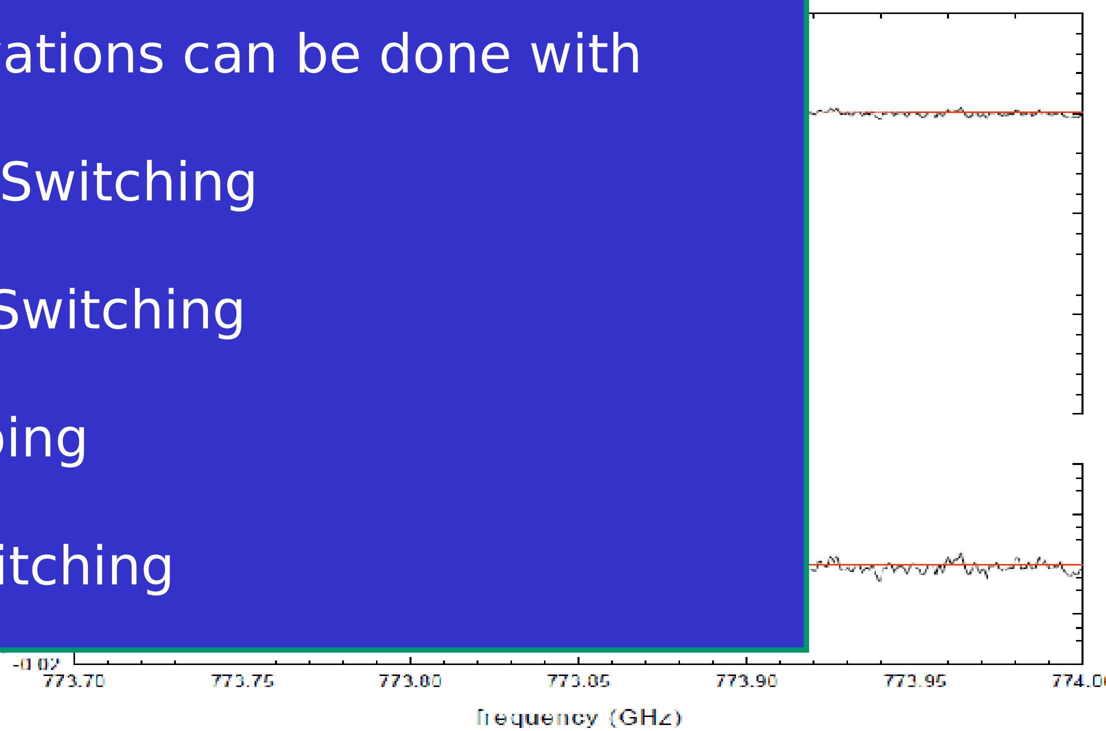
Point observations can be done with

•Dual Beam Switching

•Frequency Switching

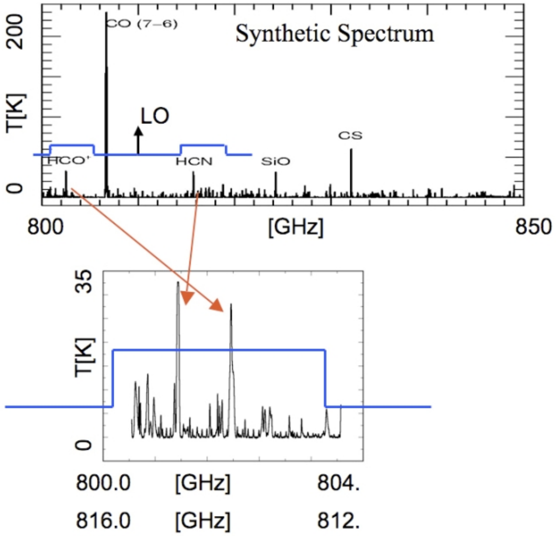
•Load Chopping

•Position Switching



Spectral Scan AOT

- A spectral scan is used when one wants to cover a frequency range greater than the bandwidth of the receiver.
  - Operates at a single target position.
  - Operates at a multiple LO tunings, but limited to just a single band.
  - All reference schemes EXCEPT position switch are allowed.
  - Unlike Point mode, HRS is NOT collected, except in very specific circumstances.
  - Spectral scans are tied to the deconvolution too
- Deconvolution tries to unwrap DSB data.
  - S(IF)=S(LO+IF) + S(LO-IF)
  - With enough coverage and redundancy, one can iteratively solve for S(nu) using the algorithm of Comito&Schilke (2002).



Double sideband spectrum

Spectral Scan AOT

- The user has to choose a redundancy, which is another way of defining the difference in spacing between consecutive LO tunings.
  - Low redundancy (large step size) may hamper the deconvolution algorithm.
  - High redundancy may be too inefficient.
  - Choice should be made based on expected line richness of source
- The user has to choose a spectral range to cover
  - Full bands
  - 'mini-scans' covering < 12 GHz do not tie the LSB from higher LO tunings to the USB at lower LO tunings, but are still popular.
- Caveat for high redundancy.
  - Normally, at each LO tuning, the instrument would collect a spectrum from the loads and the reference. At high redundancy this is very time consuming and instead calibration information is grouped such that observations at one frequency can be used to calibrate observations at nearby frequencies. This may result in standing waves not being fully removed.

Spectral Scan AOT

- The user has to choose a redundancy, which is another way of d unings.
  - ution
  - ource
- T
  - ings to
- C
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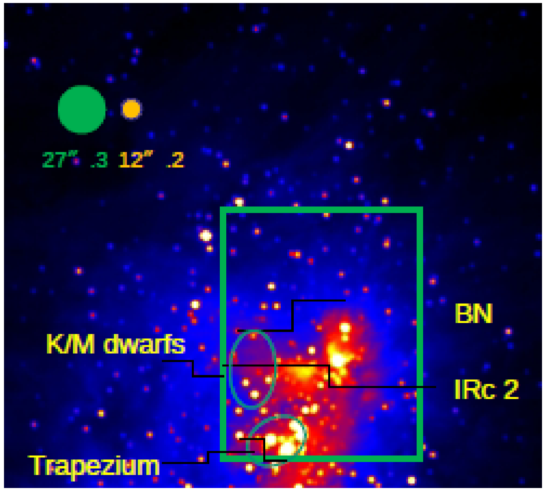
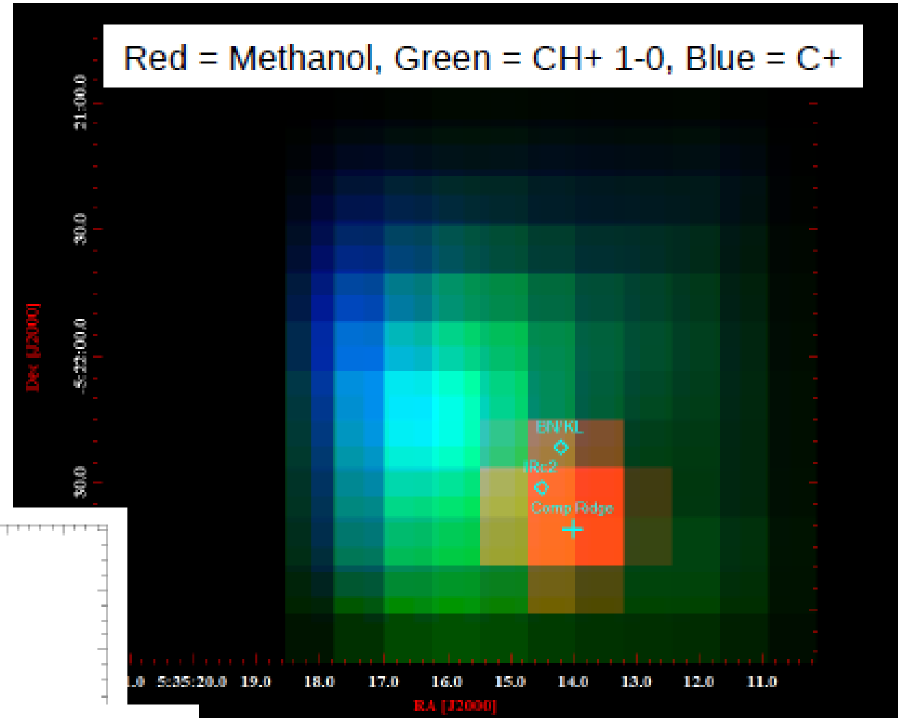
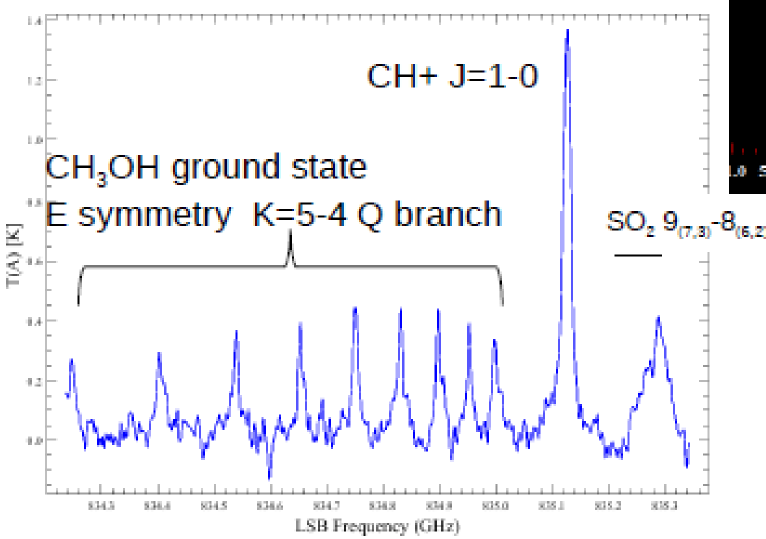
Spectral scans can be done with

- Dual Beam Switching
- Frequency Switching (not bands 6&7)
- Load Chopping

Mapping AOT
OTF example







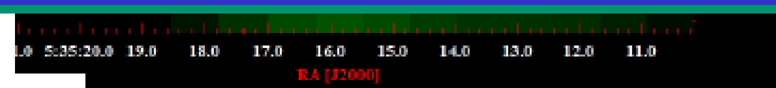
Single LO setting for CH+ and methanol

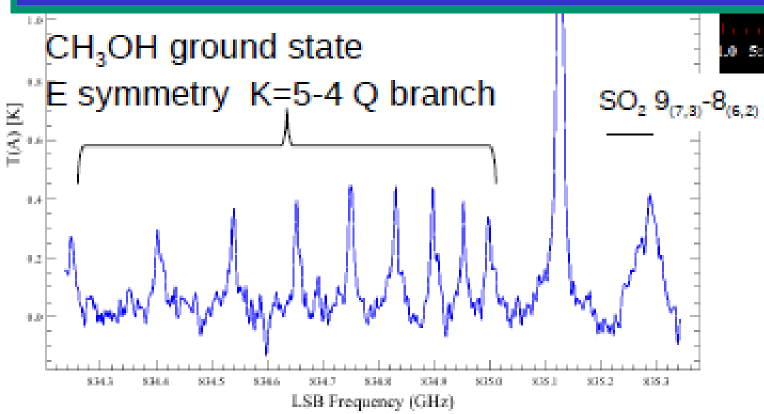
Morris et al. 2012

Mapping AOT
OTF example

Spectral mapping can be done

- **"On the Fly"** (continuous telescope motion and readouts)
  - Frequency and load chop calibration modes available
- **As a Raster**, using Dual Beam Switching
  - Normal or fast chop
  - Calibration timing available for optimum baseline stability.





Single LO setting for CH+ and methanol

Morris et al. 2012

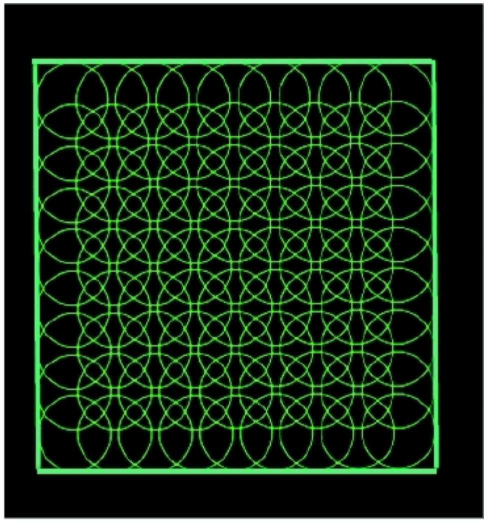
Spectral Mapping AOT

General Issues

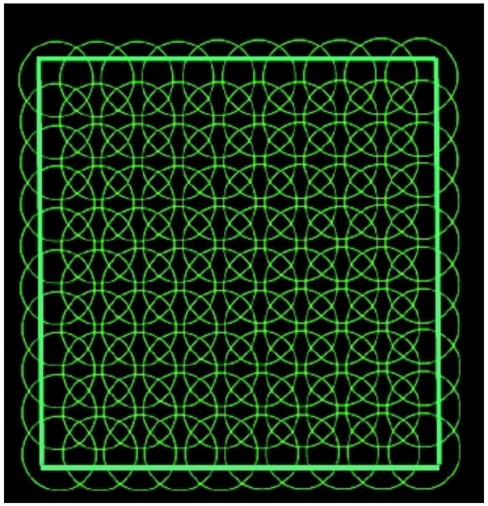
Map coverage:

- HIFI fills requested map area (plot A) different than one may be used to from ground-based telescopes (plot B).
- In OTF mode, HIFI coverage may be in between cases A and B, because mapping is very sensitive to timing correlations between instrument and telescope, and to avoid undersampling, sometimes extra readouts are added.
- HSPOT advice: always plot AOR on image to check actually mapped area

[A]



[B]



Sky sampling definitions:

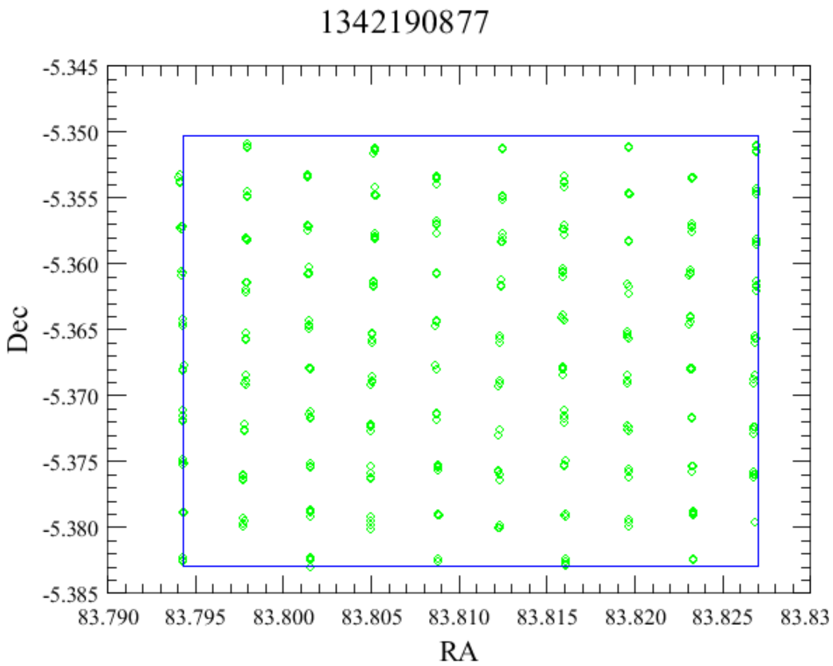
- Nyquist sampling is not the same as "half-beam" (HPBW/2) sampling.
- Nyquist has ~20% finer grid, requiring ~40% more time for fixed noise goal.

Some OTF Systematic Issues

- OTF maps may exhibit a 'zig-zag' effect.

The "zig-zag" effect:

- Slight timing mis-correlations due to command timing in the uplink system, scan speed granularity. Overall not a major problem in most maps, but it can be significant, and affect line measurements over several pixels. OTF only.



- There are currently no mitigations by the HIFI pipeline, has to be treated manually.

More details on Observing Mode performances…

- Are in the HIFI AOT Release Notes at HSC:
  - herschel.esac.esa.int/twiki/bin/view/Public/HifiCalibrationWeb

- The site also contains informational notes about
  - Beam efficiency calibrations, and effects in HSpot and the pipeline.
  - H/V beam pointing in the pipeline.

- More info on the data by mode will be covered by Carolyn (Level 1 and 2 pipeline overview), and in the mode-specific presentations and demos.

- Further resources (pages, online and video tutorials, science tools) will be explained during the workshop, and summarized at the end to take all inputs into account.

More HIFI Resources

- HSC and NHSC pages, see especially

nhscsci.ipac.caltech.edu/sc/index.php/DataReduction/HomePage

herschel.esac.esa.int/twiki/bin/view/Public/HifiCalibrationWeb

- HIFI Observers Manual
  - herschel.esac.esa.int/Docs/HIFI/html/hifi.html
- HSPOT Users Guide
  - herschel.esac.esa.int/Docs/HSPOT/html/hspot-help.html
- AOT Performance Notes
  - herschel.esac.esa.int/twiki/bin/view/Public/HifiCalibrationWeb
- NHSC and HSC DP workshops and webinars
  - Beginner and advanced levels...presentations and scripts online. Advanced level workshops planned by HSC on various topics (Nov 08—contact HSC helpdesk for more info) and NHSC on HEB pattern matching technique (TBD)
- Unit conversion tool, for the radio unit impaired and cross-instrument data comparisons:
  - nhscdmz4.ipac.caltech.edu:8081/conversions/

Questions?