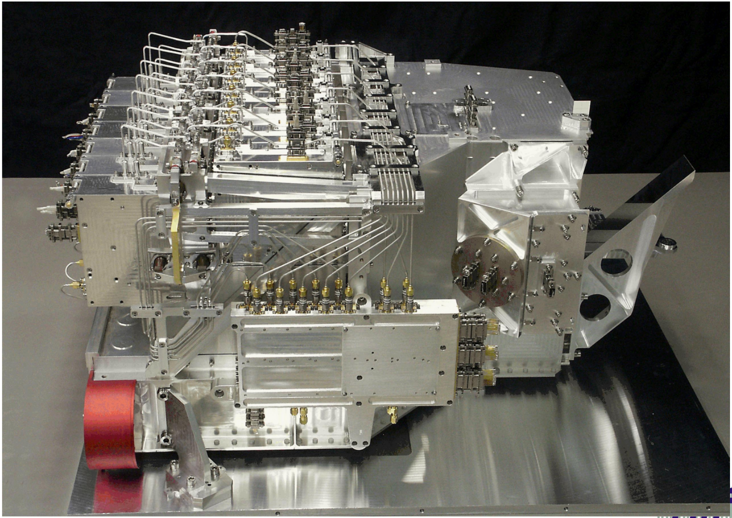
HIFI calibration status and plans

Michael Olberg – on behalf of the HIFI calibration group

SRON – Onsala Space Observatory

CSIC, 06-Feb-2008

HIFI Focal plane unit



Main features

technical

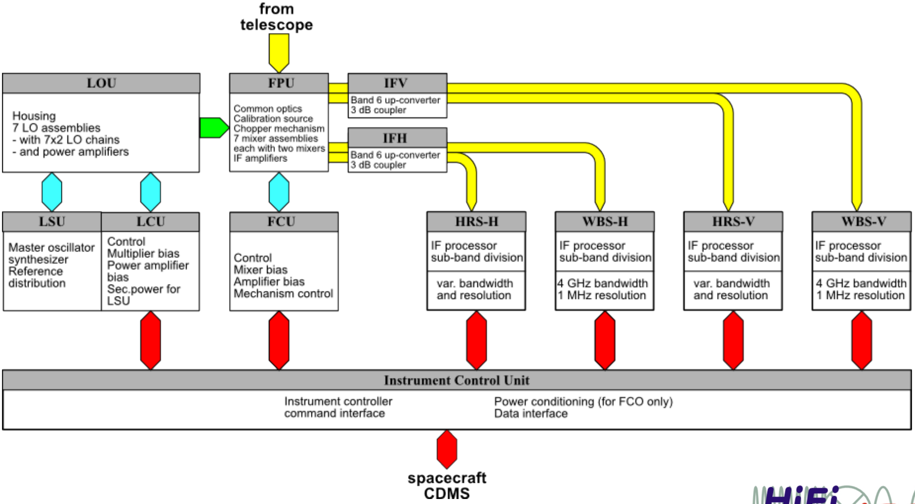
- high spectral resolution (down to 0.1 MHz), high sensitivity.
- 7 mixer assemblies $\times$ two polarisations, two LO chains per band: $\rightarrow$ slightly different apertures on sky
- bands 1–5 SIS technology (480–1250 GHz), bands 6 and 7 HEB mixers (1410–1910 GHz)
- DSB receivers: frequencies LO $\pm$ IF observed simultaneously
- LO power optimised for one polarisation
- beam widths between $\approx$ 45–12 arcsec

Main features

science

- ISM and star formation in our own and external galaxies
- diffuse interstellar medium in the Milky Way
- late stages of stellar evolution
- solar system studies
- many water lines, coverage of SWAS/Odin and ISO combined.

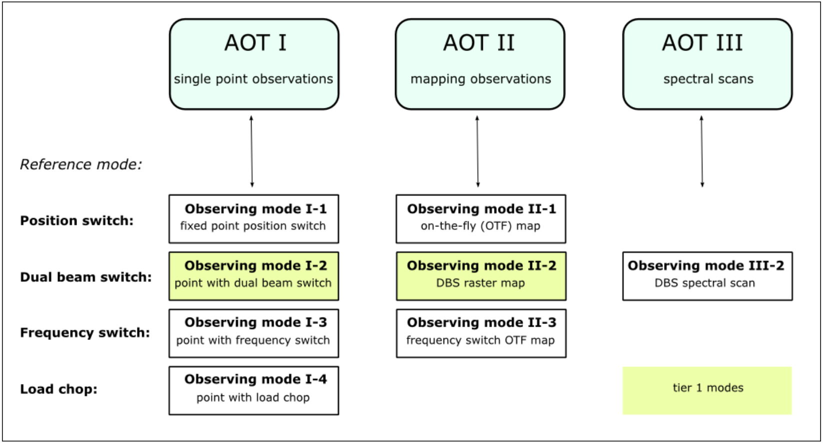
HIFI Focal plane unit



Signal path

- common IF, only one mixer sub-assembly on sky at any one time
- up-converters to map lower bandwidth HEB-bands (2.4–4.8 GHz) to standard 4–8 GHz HIFI IF band.
- one AOS (WBS) and one correlator (HRS) per polarisation
- WBS frequency calibration based on internal frequency comb generators, HRS local oscillators locked to LSU signals

HIFI observing modes



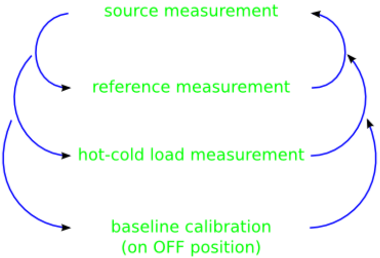
Observing modes

Hierarchical structure of reference and calibration loops:

Reference loop
length determined by system stability time

Bandpass calibration loop
length determined by bandpass stability time

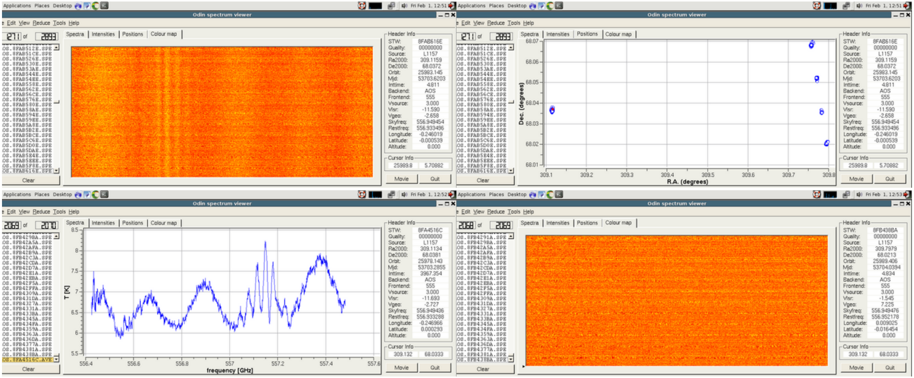
Baseline calibration loop
length determined by baseline stability time



The three different Allan times determine the period of the three loops.

Cancellation of standing waves

An example from Odin:



Note: colour map in channel order, spectrum in frequency order.

Calibration equation

$$J_S - J_R = \frac{\eta_h + \eta_c - 1}{G_{ssb}\eta_l + \omega_{ssb}} \times \frac{c_S - c_R}{c_{hot} - c_{cold}} \times \ldots$$

- η_h, η_c: coupling efficiencies for hot (100 K) and cold (15 K)
- G_{ssb}: signal sideband gain: response in signal sideband divided by total response from both sidebands, equal contribution $\rightarrow G_{ssb} = 0.5$.
- ω_{ssb}: standing wave contribution in signal sideband; line intensities are modulated by standing wave in their "native" sideband, continuum baseline is influenced by standing waves in both sidebands
- counts c_X obey radiometer equation: $\frac{\delta c}{c-z} = \frac{1}{\sqrt{\delta\nu t_{int}}}$
- requirement: intensity calibration better than 10% (3%) base-line (goal)

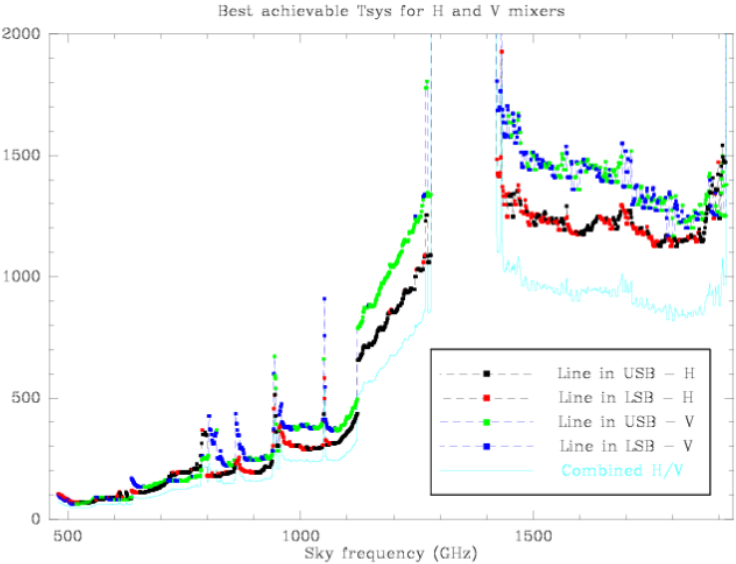
Results from ILT

- Radiometry → system performance and load coupling
- Stability → total power and spectroscopic, loop times
- Frequency → response, spectral resolution, calibration
- Gas cell → sideband gains, standing wave analysis

Radiometry

- measurement of coupling efficiencies towards hot and cold calibration loads
- calibrated against absolute photometric calibrators ("absolute hot and cold black body")
- early measurements affected by poor stability, which was later remedied by LO attenuators
- yields measurements of T_{sys} at regular intervals over all bands.
- new definition of band limits based on receiver performance, derive performance figures for "H+V" observations with proper T_{sys} weighting
- results fed back into HSPOT for proper observation planning

Instrument performance



Instrument performance

Band	LO freq.	
1a	487.5	553.0
1b	562.5	628.5
2a	634.0	718.0
2b	722.0	794.0
3a	807.0	852.0
3b	866.0	949.0
4a	957.0	1053.0
4b	1058.0	1114.0
5a	1116.0	1242.0
5b	1242.0	1272.0
6a	1429.0	1575.0
6b	1581.0	1699.0
7a	1701.0	1793.0
7b	1793.0	1906.0

- new band boundaries in HSPOT
- at a few frequencies only one mixer available
- EXPERT HSPOT will still allow operation outside of these ranges

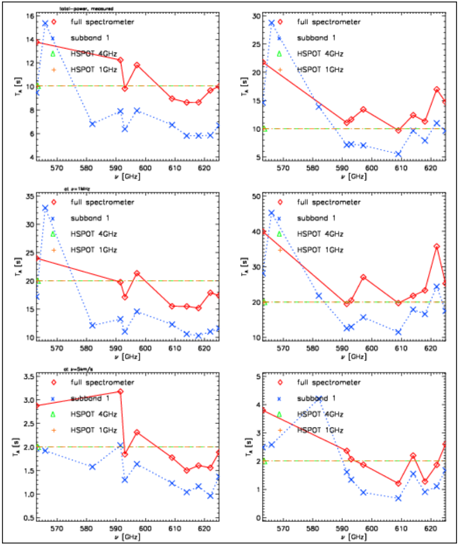
Stability

- Drives the switching times in the various observing modes.
- Total power vs. spectroscopic stability
- Difference between total band and individual sub-bands.

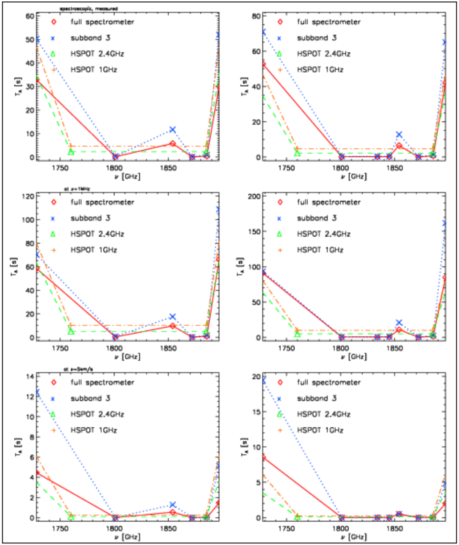
Conclusions from stability report

- use of optical attenuators has proven critical
- in general, system stability acceptable for SIS bands, marginal for HEB bands.
- stability dominated by LO sub-bands: HIFI needs to be treated as 14 receiver units.
- important to re-measure stability in TV/PV

Stability – band 1b



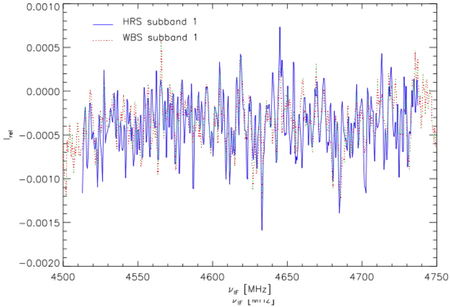
Stability – band 7b

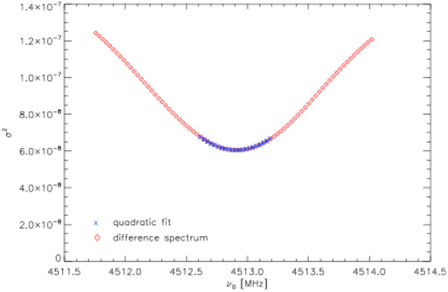


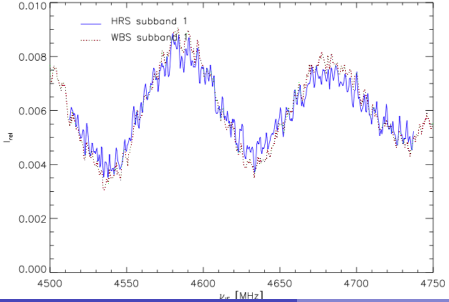
Frequency

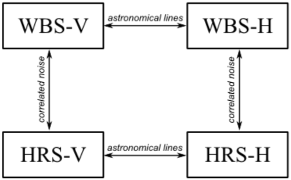
- WBS: frequency comb generator, HRS frequencies depend on LSU
- frequency response function of WBS so far measured in air only: broadened and asymmetric profile
- frequency resolution of HRS below spec in selected bands
- problem with dying comb generator on WBS-V, sent for repair
- scheme devised to frequency calibrate backends against each other
- WBS and HRS for same polarisation will see correlated noise
- different polarisations will see similar astronomical signal in same type of backend

Frequency cross-correlation





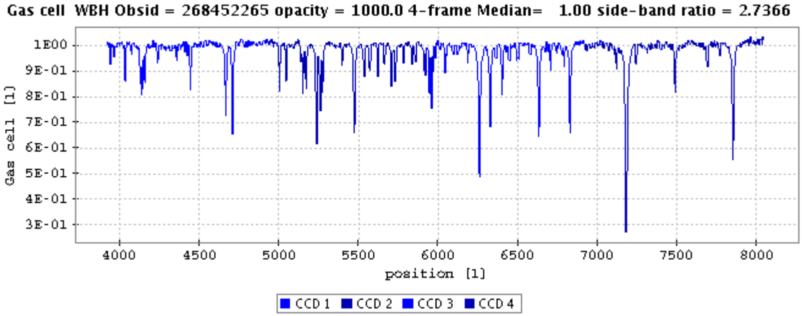




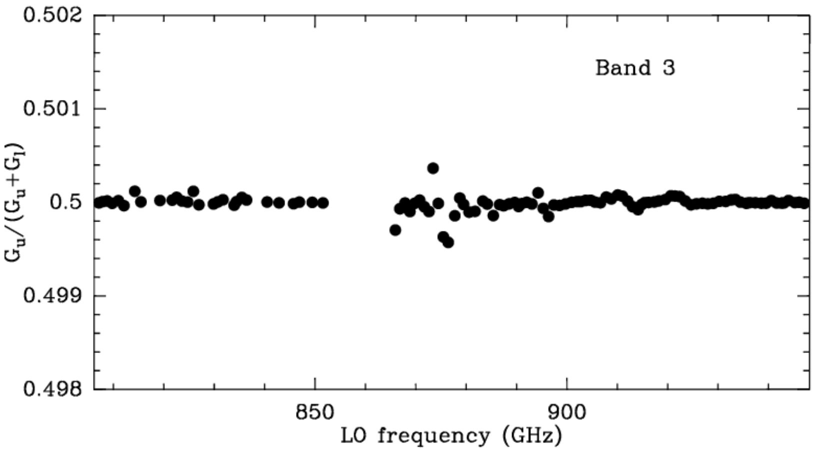
Gas cell

- Purpose: derive side band gains as function of frequency.
- baseline corrected spectra are used to fit absorption line profiles according to LTE model (uses pressure as measured in cell + HITRAN coefficients): potentially allows to use non-saturated lines
- side-band ratio adjusted for best fit to line profile
- CO lines treated first; methanol underway, requires new molecular spectroscopy data
- strong baseline ripple (standing waves) observed particularly in bands 6 & 7 (no isolators between mixers and IF).
- common working group formed for gas cell and standing waves
- analyse standing waves in terms of modelling their origin
- develop powerful fitting routines, e.g. sine wave with slowly varying frequency

Gas cell – methanol at 1016 GHz



Gas cell – derived sideband gain band 3



Performance verification

- Stability
- Aperture efficiencies
- Beam patterns
- Spectral tests
- AOT verification

Long integrations on cold sky

- test stability at selected frequencies by doing long DBS observations of cold sky
- measure and characterize LO stabilisation
- check for asymmetries of two beams
- monitor possible T_{sys} drifts
- check that integrated intensities follow white noise statistics
- repeat for different polarisations/backends
- check for serendipitous real spectral lines in final average

Aperture efficiencies

- use Uranus as calibration source
- small maps in DBS raster mode and OTF load chop (new mode)
- repeat for 2–3 frequencies per band
- data from WBS-V, WBS-H, HRS-V, HRS-H are collected simultaneously
- work towards successively higher frequencies where pointing errors, timing jitters etc. become more critical
- derive aperture efficiency as function of frequency, compare with expectations from simple Ruze model.

Beam patterns

- use Uranus or stronger source as calibration source
- larger maps to potentially detect error beams at -20 dB level
- fit 2-dim Gaussians → pointing offsets, HPBW (two orthogonal axes)
- compare results from raster maps and OTF maps
- derive relative pointing (and error) between bands
- HPBW as function of frequency: fits theory? outliers?

Spectral tests

- use spectral features in Uranus' atmosphere to check frequency calibration
- check frequencies and profiles of lines detected during AOT commissioning
- measure standing wave patterns towards strong external source (e.g. Jupiter, Saturn) in frequency region free of H_2O, CO, HCN lines (including main isotopes).

AOT performance verification

3 tier approach

- tier 1: observing modes required for early PV phase such as stability measurements and beam characterisation
- tier 2: bulk of test programme, composed of observing modes used in KPs but cover broader parameter space and more robustly test calibration schemes
- tier 3: observing modes not used in KPs

AOT PV – objectives

1. all available observing modes must be tested on celestial targets
2. modes must be tested in every mixer (sub)band
3. use representative settings
4. use combinations of the WBS and HRS in all resolution modes
5. sample most efficient sequence parameter space
6. exercise modes on fixed and moving targets
7. observe a range of target types
8. evaluate differential performances of modes