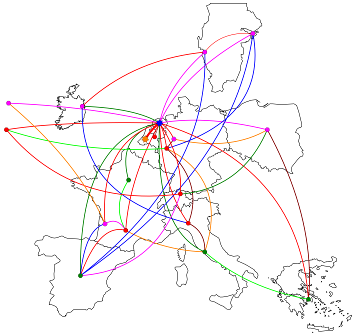
HIFI lessons for CCAT

Volker Ossenkopf, Pat Morris, Ronan Higgins



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Overview

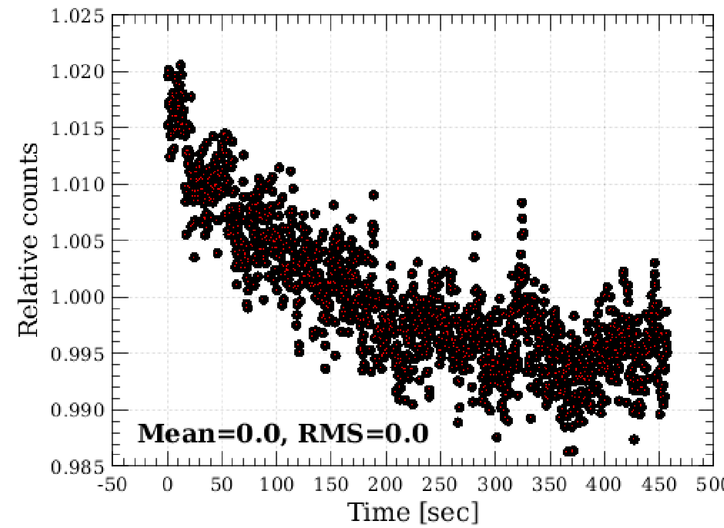
- Observing modes
  - Instrument stability as main driver
  - Sequencing for best performance
- Calibration
  - Internal calibrators
  - Celestial calibrators
  - Beam calibration
  - Standing waves
- Typical science use
- Data processing

Observing modes

Instrumental drifts require loop of reference and calibration observations

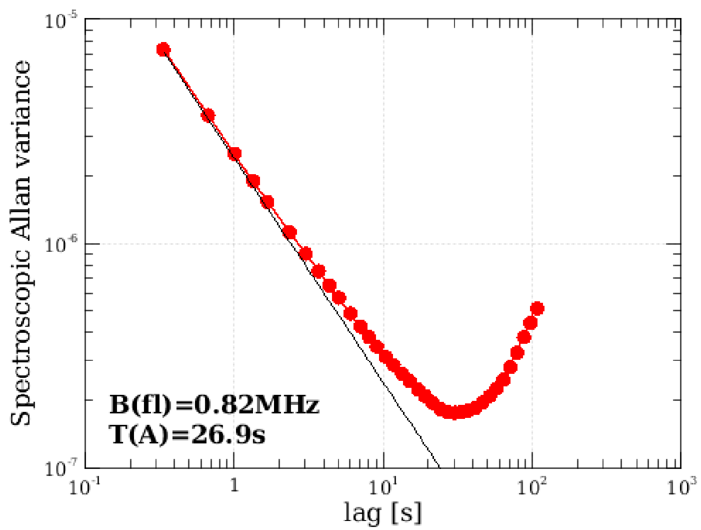
HIFI HEB gain variations as function of time:

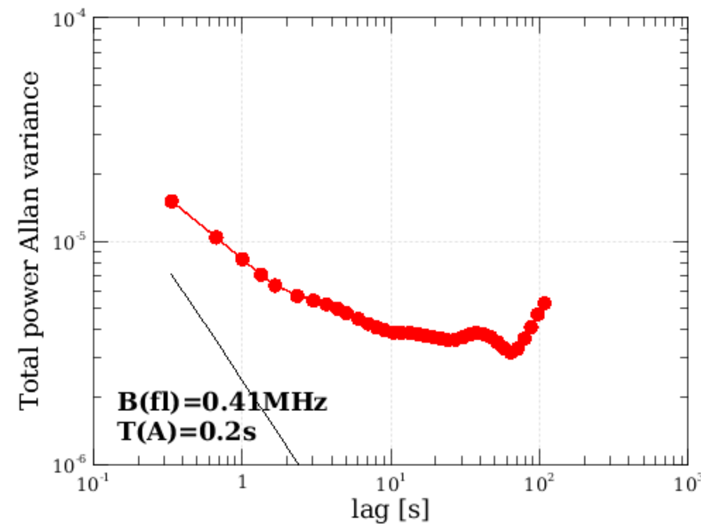
- LO-stability is absolutely essential!
- Multipliers, mechanics, standing waves
- Include atmosphere for CCAT!



Allan variance quantifies the drift:

- distinguish spectroscopic and total power Allan variance





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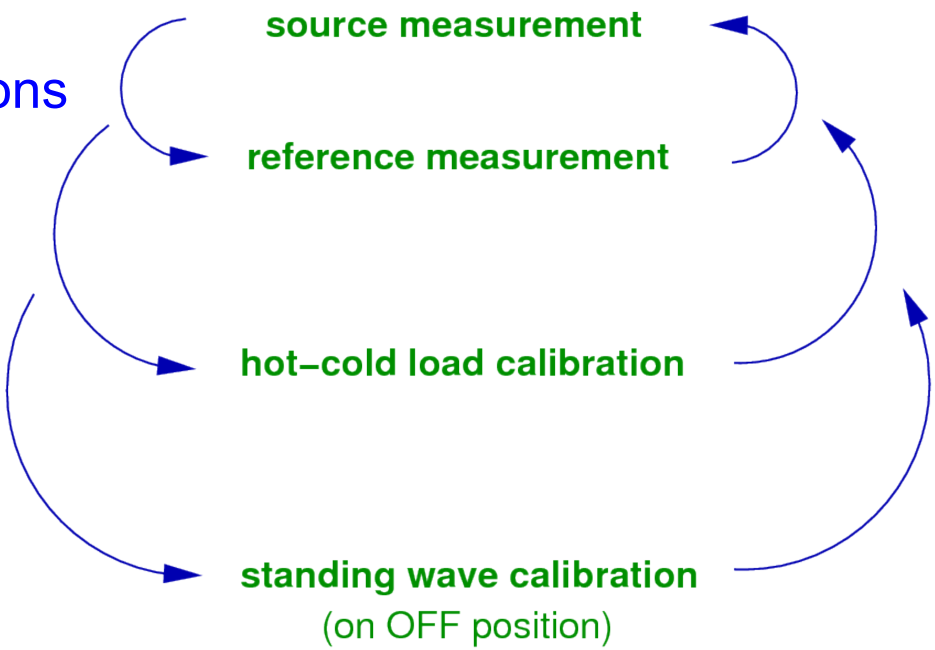
HIFI Observing modes

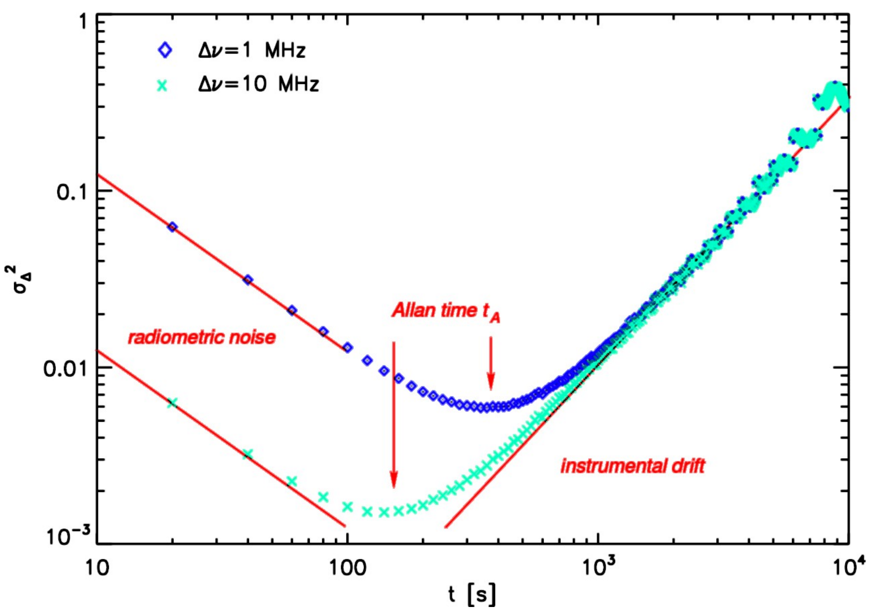
Instrumental drifts require loop of reference and calibration observations



Determined by Allan stability time t_A:

• Depends on the goal resolution of the observation!

→ Not universal number!



• *The stability of spectroscopic instruments: a unified Allan variance computation scheme,* A&A 479 (2008), 915

• *Optimization of mapping modes for heterodyne instruments,* A&A 495 (2009), 677

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HIFI Observation “Sequencing” Concept

To guarantee best integration and calibration sequence, HIFI uses a *sequencer*, which minimizes an observing cost function

$$\chi^2 = (total\ noise)^2 \times t_{obs} + penalties$$

with $(total\ noise)^2 = (radiometric\ noise)^2 + (drift\ noise)^2$

Observer

HSpot

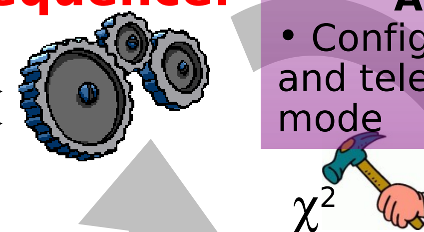
GUI

Observing setup
- target, sky setup
- LO frequencies
- spectrometers, etc.

Observing goals:
- Total observing time
- SSB Noise goal
- Min/max goal resolution

Calibration Files
- Stability parameters
- T_{sys}, beam parameters
- Slew model
- ...

Sequencer



AOT Logic
- Configure instrument and telescope pointing mode

Sequence Parameters
- backend readout period
- chop or switch cycle
- load periods, etc.

Command Sequence

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Observing Modes

HIFI's observing modes very successful overall:

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 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

- Concepts of all but load-chop modes applicable to CCAT.
- DBS has been HIFI's workhorse.
  - Good optical design and stability at most frequencies in the SIS bands would even allow for an efficient ***single* beam switch** mode → option for CCAT?

Calibration issues

Internal calibrators:

- 100 K and 12 K blackbodies provide reliable absolute scale
- Depend critically on exact temperature measurement
  - No easy adjustment for linearity tests
- Standing waves towards non-perfect blackbodies
- Temperature scale should cover celestial intensities
  - Exception for HIFI: Jupiter
  - Non-linearities need to be covered

Non-linear response:

- Noticeable non-linearity in FTS
- IF design
- Mixer-bias change from direct detection in HEBs → prefer SIS for CCAT ?
- Additional continuum response from LO phase noise

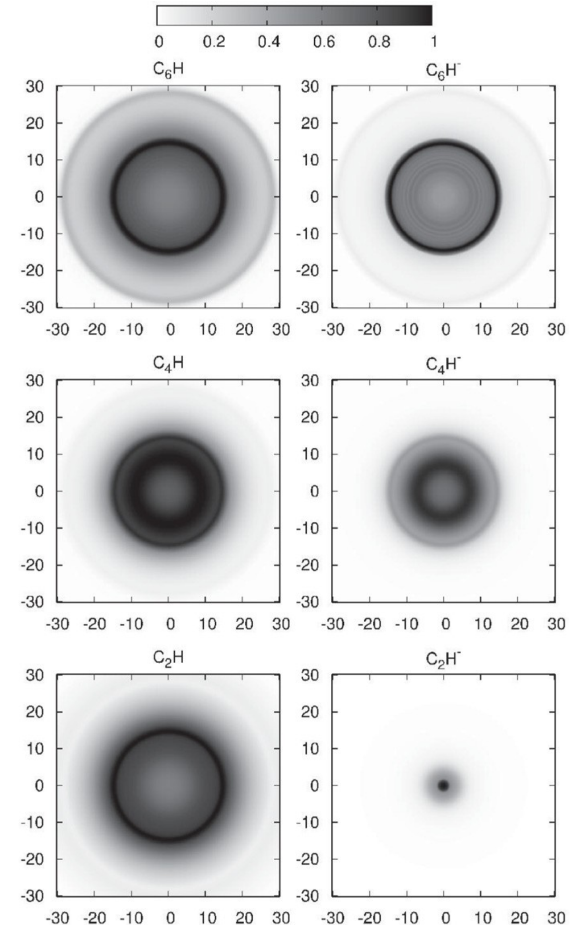
Calibration issues

Celestial calibration sources:

- Very few bright, compact targets with accurately known SED available
- The bright AGB stars are time-variable, structured or radially extended at many frequencies.

→ CCAT must rely on Herschel calibration for its point source calibrators at high frequencies!

- HIFI relies primarily on Mars for beam calibrations.
    - Uranus and Neptune used for verifications.
    - Planet models from R. Moreno.

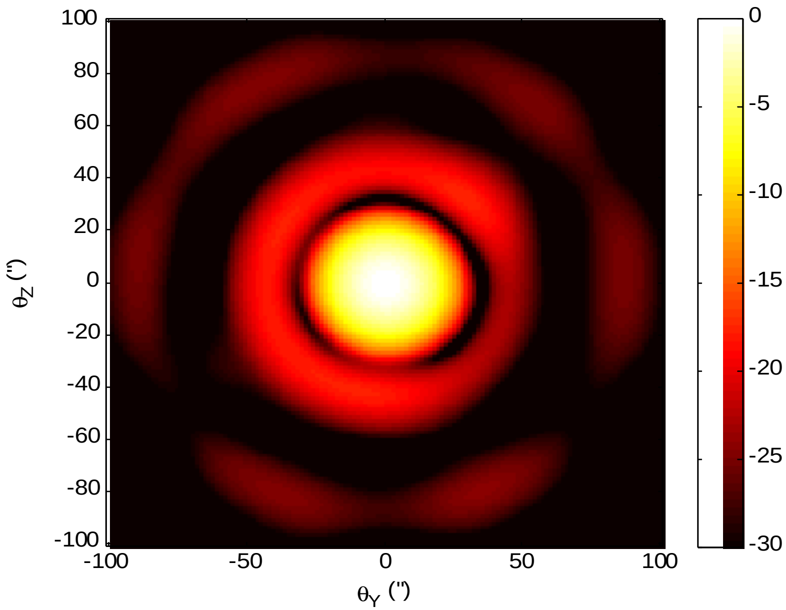


IRC+10216
(Cordiner & Miller 2009)

HIFI beam Parameters

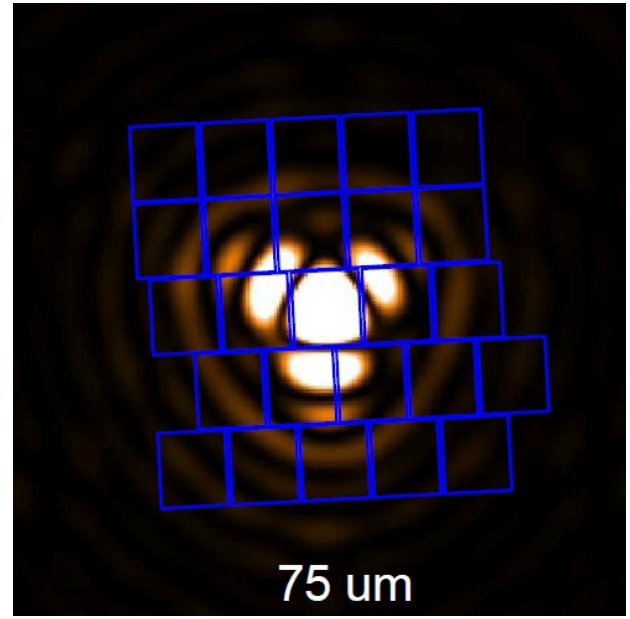
- Beam shape profile from DBS raster maps of Mars and optics simulations
  - Mapping at all frequencies is time-expensive
  - Parameters determined so far assume a Gaussian profile
- The measured beam patterns have several unexplained deviations from full optical model of HIFI + telescope.

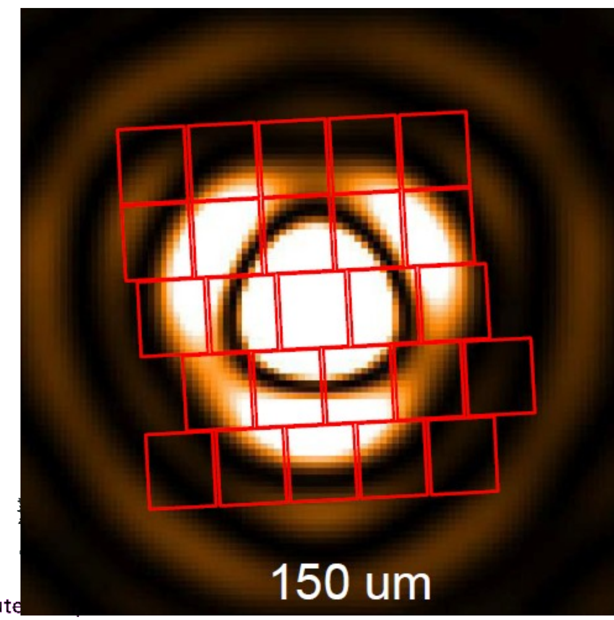
Typical example (2H) of actual beam
Peak side-lobe level: -17.51 dB



As-designed nominal beam
Peak side-lobe level: -18.85 dB

PACS beam parameters





- Fraction of PSF seen by a pixel depends on
  - Wavelength
  - Pointing jitter
  - Details of beam pattern

    → Flux calibration error: 30% !

- Jiggle mode / jittering mode essential for sub-sampled arrays
  - Stability constrained
  - Differential measurement increases noise

Theoretical illumination of the PACS array from a point source based on beam pattern

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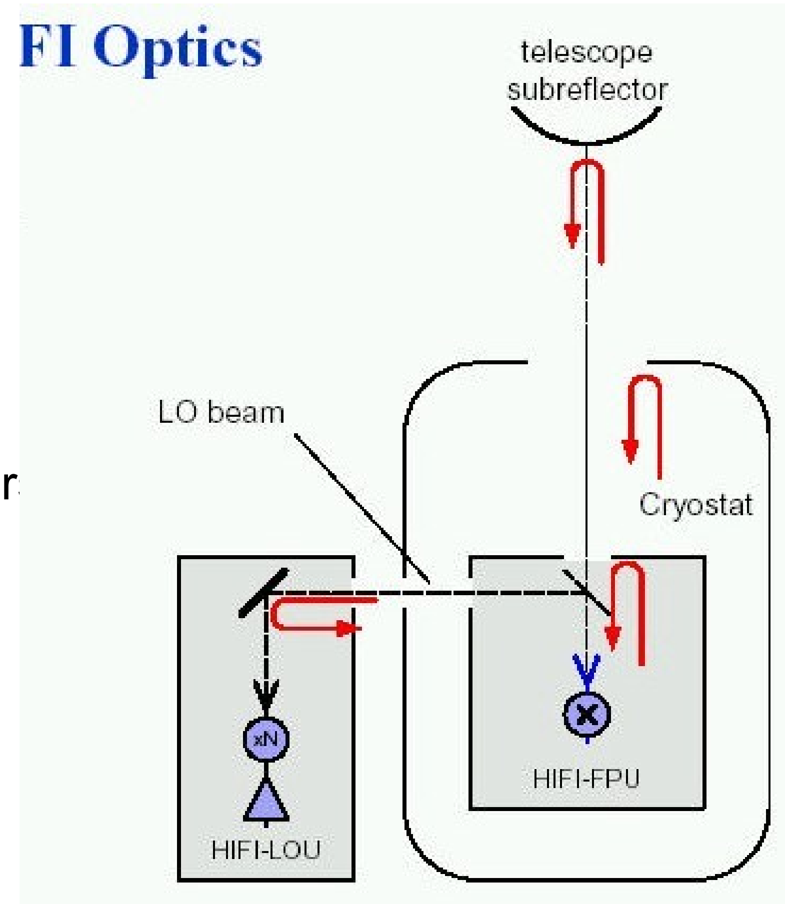
Standing waves

Common problem in sub-mm instruments since the wavelength of radiation is comparable with the optics dimensions

Standing waves present:

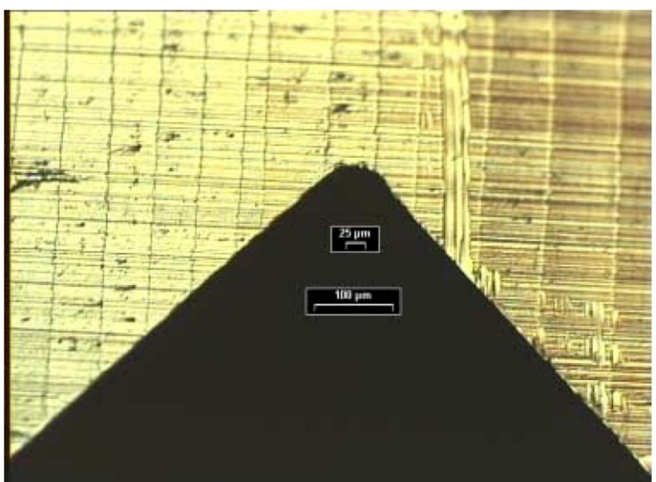
- Optical path to primary and secondary mirror
- Optical path to calibration source (hot/cold)
- Standing waves to LO
- Standing waves to diplexer roof-top
- Standing wave in the HEB electrical chain



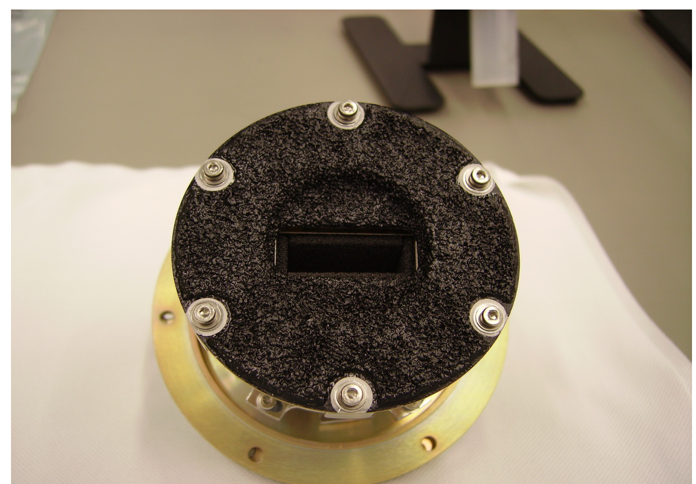
Standing waves in optics

- Avoid having surfaces perpendicular to each other in the optics:
  - Mixer and LO horns/lenses
  - Calibration loads
  - Diplexer mirrors
  - Beam truncations
- Standing waves in the optics are particularly seen towards the lower frequencies bands with bigger beams

Diplexer rooftop mirror angle



Hot calibration load



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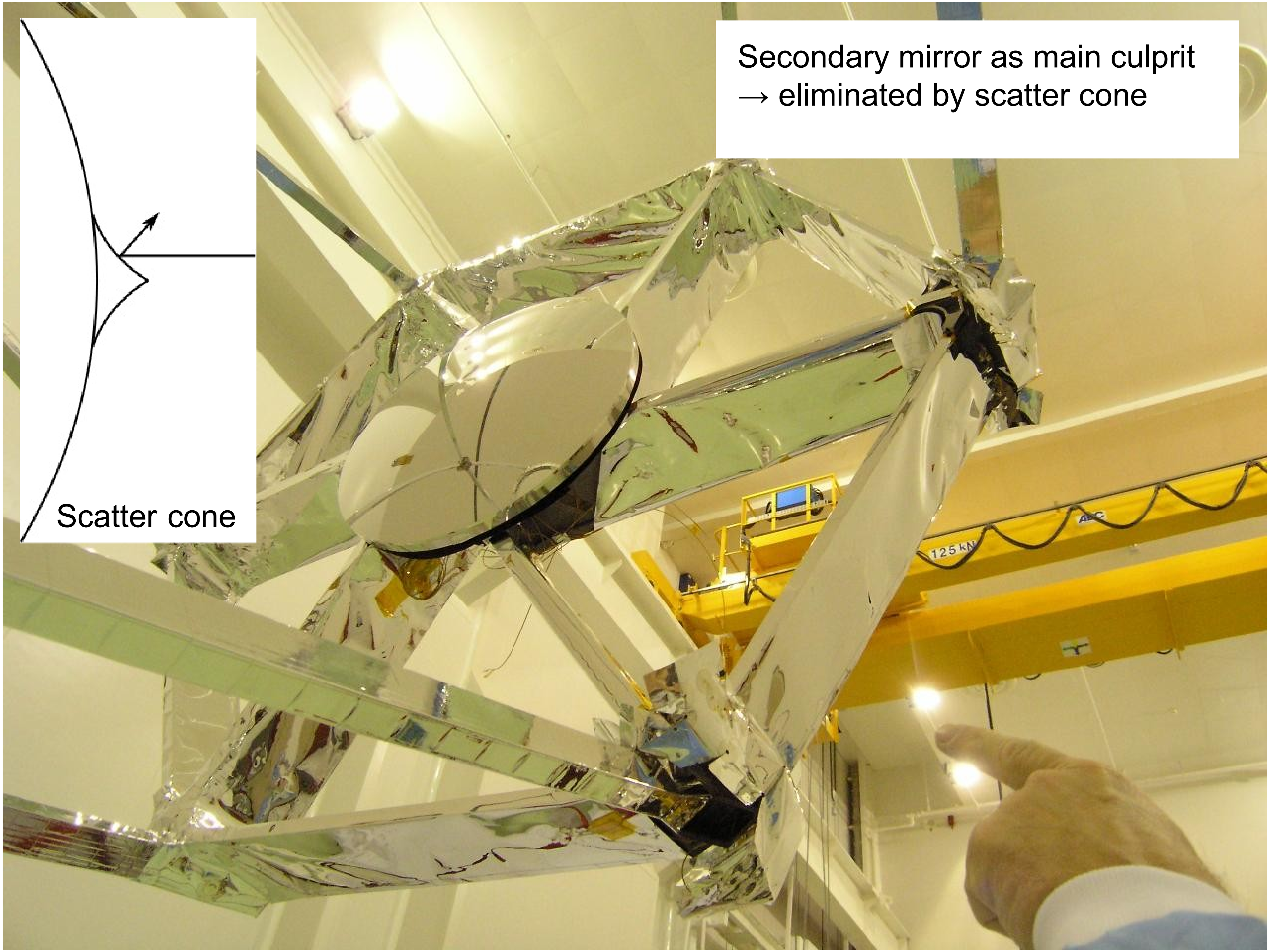
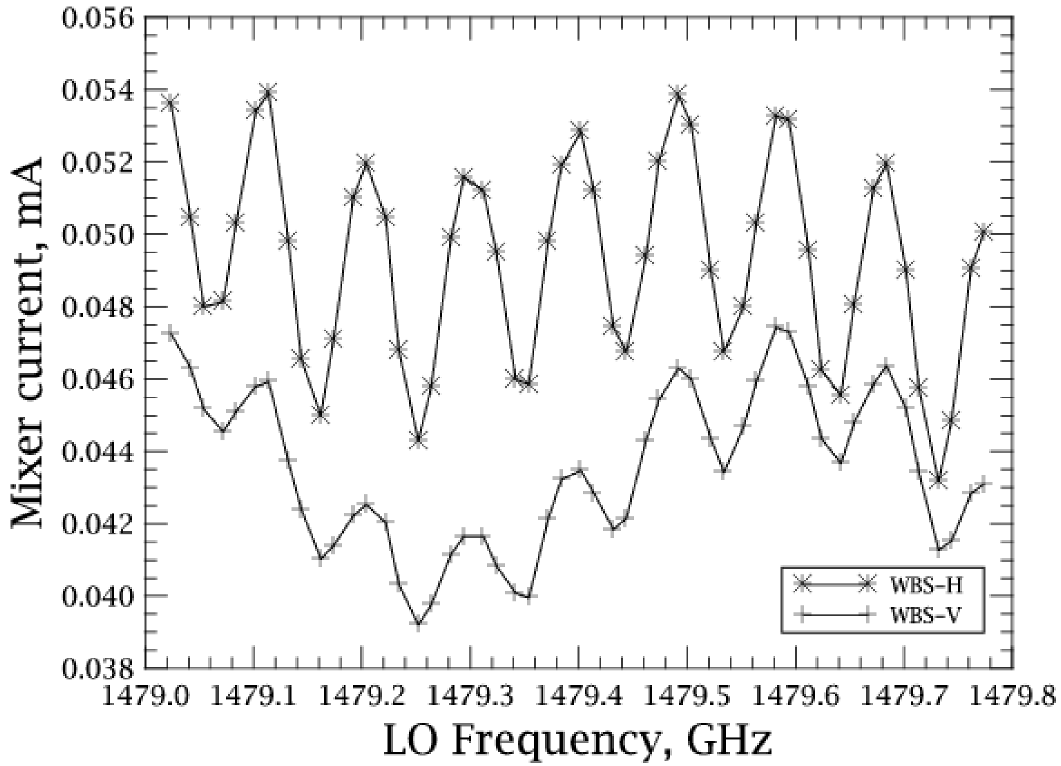

Secondary mirror as main culprit
→ eliminated by scatter cone
Scatter cone
125 kN

Standing waves in LO path



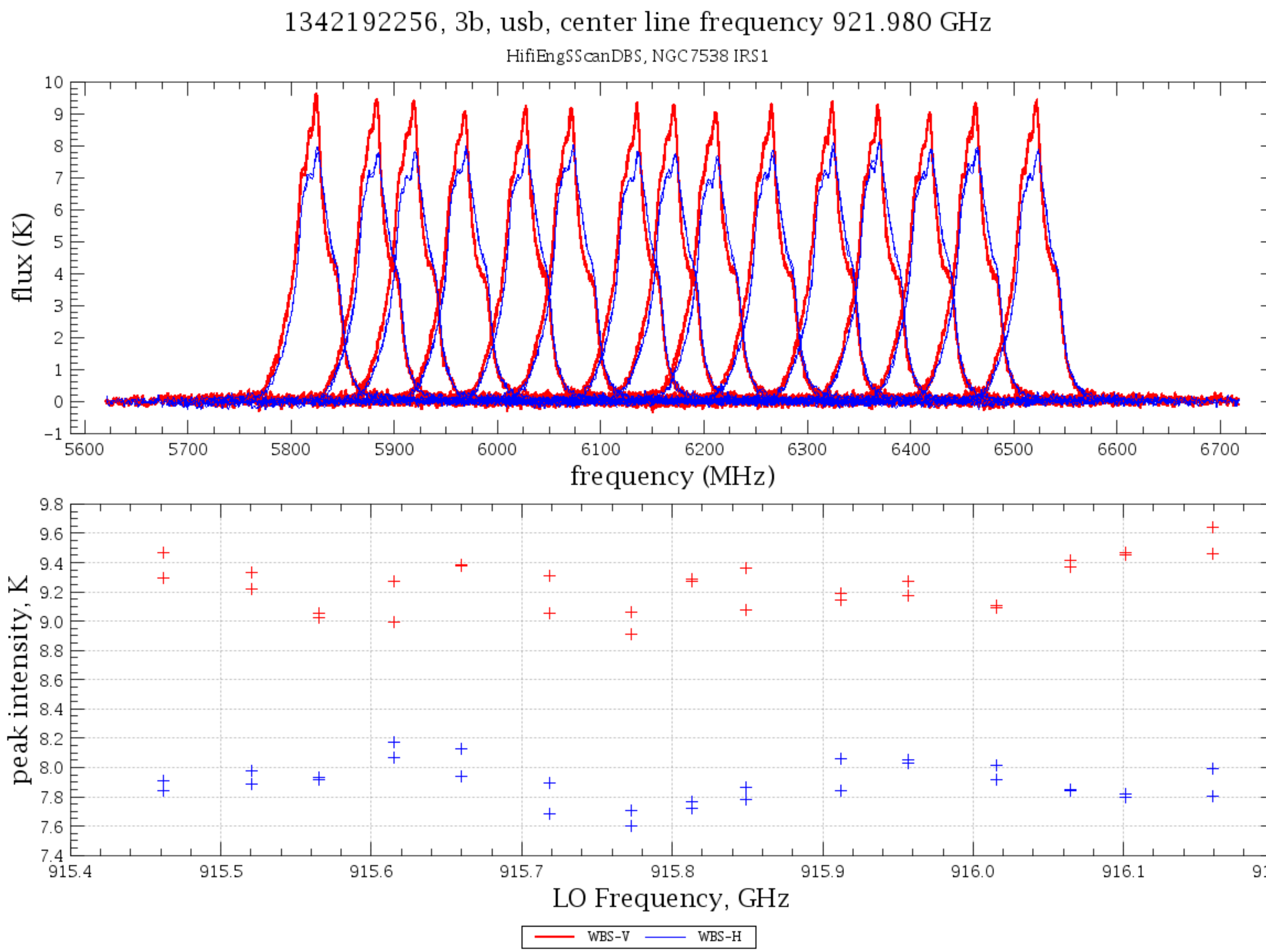
Mixer current for H and V mixers when changing LO frequency with fixed LO power.

- 92MHz modulation corresponding to distance between the LO and mixer focus
- 680MHz standing wave corresponding to a reflection between diplexer rooftop mirror and the mixer focus

- Standing waves lead to baselines ripples
- Problematic for frequency switch observations, leading to a gain difference between the 2 phases.

Effect on line intensity

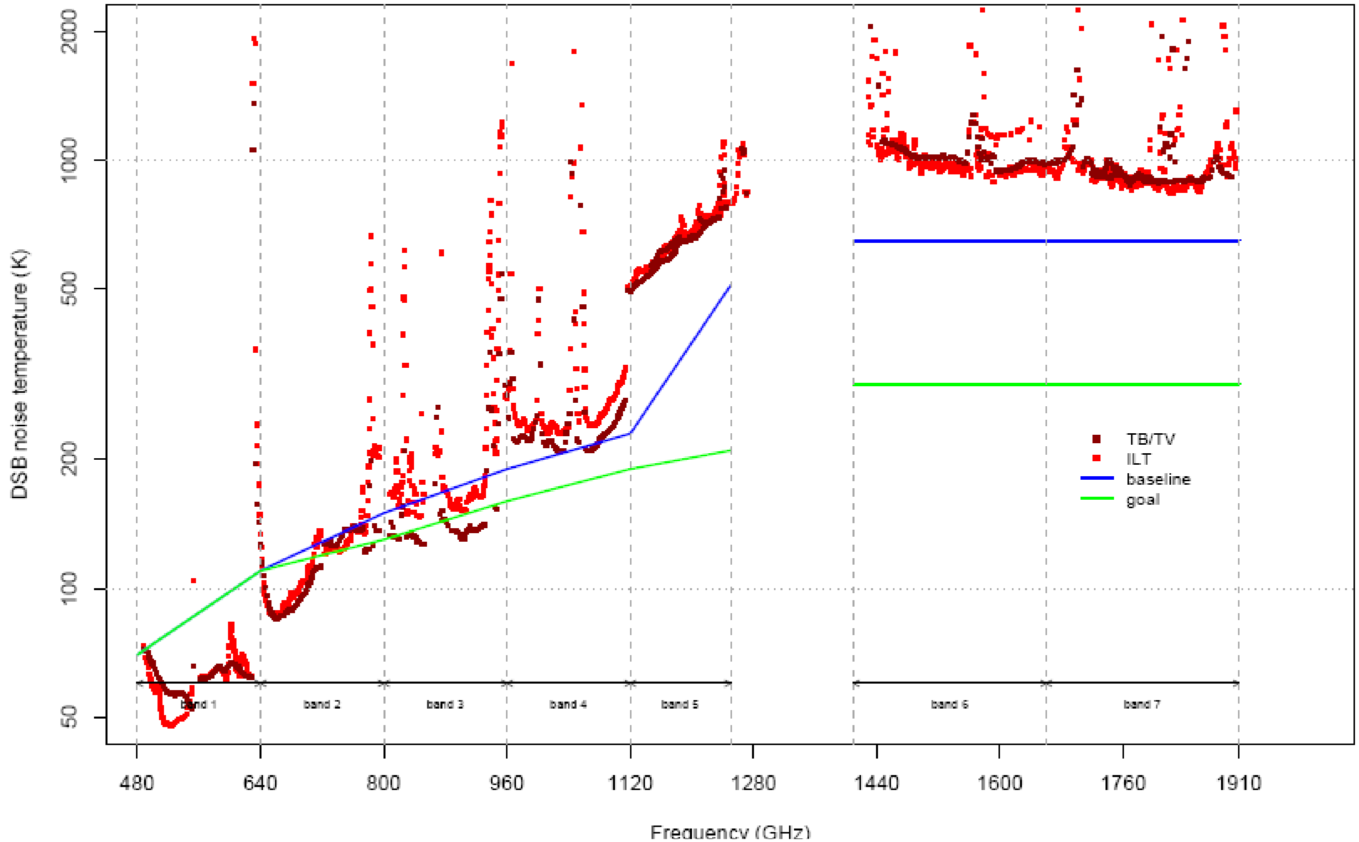
Standing wave introduce a 5-10% uncertainty in line intensity for the diplexer bands



Typical science use

• 90% of engineering and calibration effort goes into 5% of frequencies

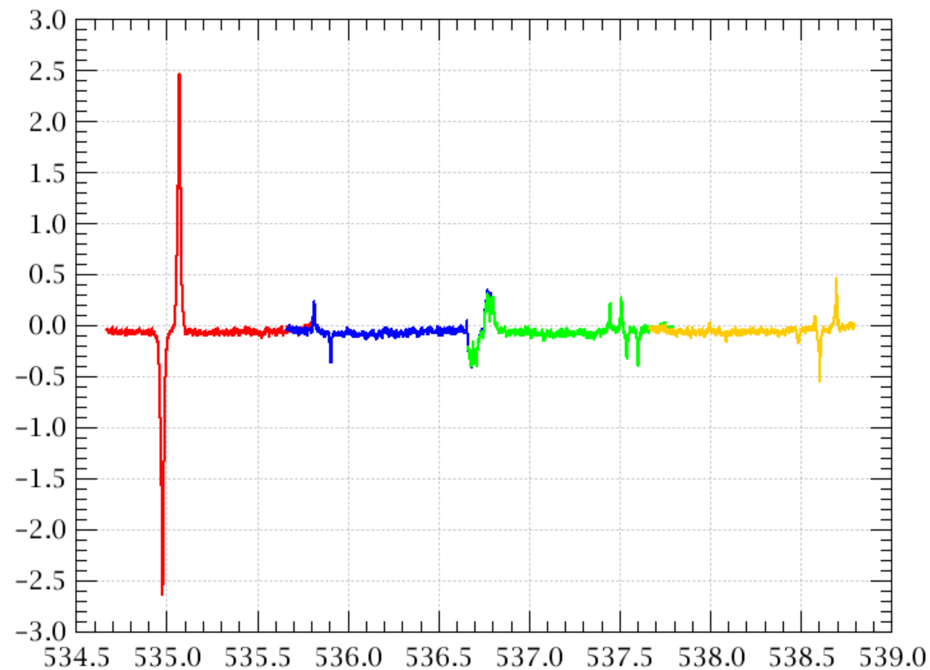
HIFI T_{sys} plot in ground-based tests: Most effort went into all the “spikes” with insufficient LO power, impurities and spurious signals



• 80% of all science is done at 10% of frequencies

Typical science use

- Broad IF always always encourages multi-line usage
  - Double-sideband taken as advantage, not as burden → requires good transmission to be applicable to CCAT
- Most observations go for >0.5km/s resolution
  - Very little HRS usage
- Resolution-dependent stability counts. In most cases
  - even the slow Herschel pointing is fast enough for narrow lines,
  - even 4Hz chopping is not fast enough for very broad lines and continuum.



Simultaneous observation of 10 lines in 4GHz. In frequency-switch, lines from the two sidebands can be easily identified.

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Data Processing

- Astronomers stick to what they know, particularly at the point that basic data processing/calibration can be separated from data refinements and science tools.
  - Herschel offers many analysis tools following 100's of man years of effort. These may or may not be exploited.
  - GILDAS or CASA provide a sound base that CCAT should be able to build on.
- The key is flexible I/O data formats which are robust in commonly used environments.
  - Do not force astronomers to think about data management.
    - searchable database of science and calibration data essential
    - common infrastructure from instrument-level-tests to science
- Housekeeping at high rate (1s) important
  - temperatures, mixer currents, LO settings, mirror settings, telescope settings