HIFI Routine Phase Calibration Plan

Version Draft 0.8 of 2010-02-06, by Michael Olberg

Abstract

This document is the top level document for HIFI calibrations carried out during the routine phase of the Herschel satellite mission. It provides the general assumptions and recalls the objectives of these activities. It gives a detailed description of regularly re-occuring activities during this phase and outlines the procedure for failure scenarios, which may require additional efforts. The consequences on the routine phase from the HIFI LCU failure have been taken into account.

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Applicable Documents

Doc. ref		Title
SRON-G/HIFI/SP/2000-01	AD01	Science User Requirements Document
LRM-ENS/HIFI/PL/2000-01	AD02	HIFI calibration plan

Reference Documents

Doc. ref		Title
FIRST/FSC/DOC/0114	RD01	FIRST Operations Scenario Document
ICC/2008-122	RD02	HIFI Commissioning Phase Plan
ICC/2008-156	RD03	HIFI Performance Verification Plan

Contents

1 Introduction

The routine phase is the main driver for the Herschel operations. This phase is when astronomical data are produced, and consequently also the phase when the "customers" of Herschel – the astronomers – will play a major role in the operations.
As part of the mission time-line it takes place after about 4–4.5 months:

- Launch and Early Orbit Phase (nominal duration: a few days)
- Spacecraft and Instrument Commissioning Phase (nominal duration: 1 month)
- Calibration and Performance Verification Phase (nominal duration: 2 months)
- Science Demonstration Phase (nominal duration: 1 month)[1]
- Routine Phase (nominal duration: minimum 3 years)

1.1 Acronyms

ACMS	Attitude Control and Measurement System
AD	Applicable Document
AOR	Astronomical Observation Request
AOT	Astronomical Observation Template
COP	Commissioning Phase
CUS	Common Uplink System
DP	Data Processing
DTCP	Daily Telecommunication Period
ESA	European Space Agency
FCU	Focal plane Control Unit
FM	Flight Model
GT	Guaranteed Time
HCalSG	Herschel Calibration Steering Group
HCSS	Herschel Common Science System
HIFI	Heterodyne Instrument for the Far-Infrared
HPBW	Half Power Beam Width
HSC	Herschel Science Centre
IA	Interactive Analysis
ICC	Instrument Control Centre
ILT	Instrument Level Test
KP	Key Programme
LCU	Local oscillator Control Unit
LOU	Local Oscillator Unit
MTL	Mission Time Line
PACS	Photo-detector Array Camera and Spectrometer
PSP	Priority Science Program (modified HIFI SDP after LCU failure)
PV	Performance Verification
RD	Reference Document
SAA	Solar Aspect Angle
SDP	Science Demonstration Phase
SFT	Short Functional Test
SPIRE	Spectral and Photometric Imaging REceiver

[1] For HIFI, after failure of the nominal LCU, this has been replaced by a Priority Science Program (PSP)

2 Background

The following information is in large parts reproduced from RD01, for the convenience of the reader.

2.1 Calibration and Engineering Observations

In operations the ICCs' main tasks are: monitoring instrument health, calibrating the instrument, and the provision of data reduction software. The task of calibrating the instruments can be divided into two parts: calibration planning and calibration analysis. For calibration planning, calibration observations are submitted to the HSC for scheduling, wherever possible using standard AOTs to observe internal or external sources. Calibration analysis uses various software tools (such as RTA and IA) to reduce the resulting HK and science data, to relate them to existing observations of the same type and to compare with models and/or data from other facilities. The results of this analysis can then flow back into the next cycle of calibra- tion planning and data reduction. Although calibration observations will normally be specifically requested, the ICCs may use any observation for the sole and explicit purpose of calibrating their instruments without this being considered as an infringement on observation proprietary rights.
Engineering observations are at the lowest level in the sense that these observations do not use the standard command sequences generated by AOTs, but are "manually" assembled through the editing of scripts that generate commands (in the same way AOTs are defined) and consisting of "blocks" validated during ILTs. These observations can be used for very specific cases of instrument calibration (which cannot be achieved through AOTs) or for instrument diagnostic purposes. All observations, including engineering observations, will be requested through templates.

2.2 Planning and Execution of Calibration and Engineering Observations

For every nominal scheduling period the ICCs select and prioritise a set of observations based on their agreed long-term calibration plan. The observations contained in such a set are verified (by the ICCs) to be consistent and schedulable (using time estimators, visibility tools and e.g. the HSC mission planning tools) and handed over to the HSC for scheduling. As part of a calibration or engineering observation, specific scheduling constraints can be provided, such as "schedule at the start of an operational day", "schedule observation A 20 minutes after observation B", "schedule at a specific absolute time", or "use a specific S/C configuration". Repetitive calibrations (e.g. to be carried out every n^{th} day/week) enter the system as a series of independent observations submitted to the HSC for scheduling. The ICCs and the HSC have a joint responsibility to collaborate to ensure that cross-calibration requirements are fulfilled by the planned instrument specific calibration observations.
Normally, calibration and engineering observations are submitted at fixed times within the agreed nominal scheduling cycle. When warranted, e.g. by non-nominal instrument behaviour, a much shorter time scale (3 days, TBC) for the submission and planning of a calibration or engineering observation can be accommodated.
HSC personnel select the proposed calibration and engineering observations and insert them into the observation schedule in agreement with the specified scheduling constraints. The resulting schedule may or may not be a mix of calibration, engineering and normal observations. After submission of the observation schedule to the MOC, the calibration and engineering observations are carried out as normal observations and the resulting data are ingested into HCSS by the HSC according to normal operating procedures. Contrary to failed "normal" observations, however, the HSC will not undertake to reschedule failed calibration or engineering observation without a specific request from the relevant ICC.

2.3 Analysis of Calibration and Engineering Data

Calibration and engineering observations are analysed using standard reduction steps (IA tools) to the maximum extent possible. This analysis, which is mostly carried out by calibration scientists from the ICCs or HSC, leads to an assessment of the status and behaviour of the instrument by performing trend analysis, and to the derivation of detailed instrument calibration parameters. Multiple values (e.g. "nominal"

and "test") for such parameters are supported by the processing software. Once "test" values for such parameters are accepted as new "nominal" values after ICC/HSC review, they are approved by a CCB, and made available as such through HCSS for general use, e.g. by the standard product generation software or, when relevant, by the scientific mission planning system.
Relevant conclusions with respect to overall instrument calibration and health are added to the calibration status report, which is periodically produced by each ICC. When warranted by the results of the ongoing calibration, the long term instrument calibration plan and strategy are adjusted. If necessary, additional calibration sources are selected or more information on available calibration sources is sought (e.g. using additional observations of calibration sources using other Herschel instruments or ground-based facilities). At regular intervals the larger astronomical community is informed about the status of the instrument calibration and the calibration strategy. Note: For critical observations, e.g. investigations following an instrument failure, it may be necessary for parts of the ground segment, and in particular for the ICCs to revert to the setup for the commissioning phase, during which ICC personnel is physically present at the MOC, which is not normally the case during routine phase.

2.4 Serving the user

Herschel offers guaranteed and open observation time. The guaranteed time (approximately 1/3 of the total time) is owned by contributors to the Herschel mission, mainly by the PI consortia, but there is also some time belonging to the HSC and the mission scientists; the remainder (thus about 2/3) is open time. Throughout the entire operational lifetime of the Herschel mission, the observation time will be shared between guaranteed and open time. The guaranteed time observing programmes will be defined by the guaranteed time holders through the submission of observing proposals. The open time will be allocated to the general community (including the guaranteed time holders) on the basis of calls for observing proposals.
A small amount of open time will be reserved (discretionary time) for targets that could not have been foreseen at the time of the deadline for a call. The formation of large observer collaborations collectively addressing key scientific topics will be actively encouraged, there will be a special call for "key" projects. There are a number of issues where the proposing/observing astronomer and the ICC planning and carrying out the routine phase calibration observations interact, albeit indirectly:

- An on-line environment is provided for the users to plan - and fill in - the observation details of their accepted proposals in proposal submission stage 2. The user is able to use the latest measured performance of spacecraft and instruments determined during the calibration and performance verification period or, should performance values change with time, the routine phase.
- Observation Time Estimators are available on-line to allow instrument operations to be optimized, using knowledge of background fluxes, stabilisation times, etc. These time estimators will be refined throughout the mission as additional experience is gained.
- On reducing the retrieved observational data the user may note an instrument anomaly or question the calibration procedures which are in place in the data reduction pipeline of a given user release. User feed-back from the user to the ICC, via the HSC, will trigger calibration procedure reviews via an SxR mechanism.[2]

3 Objectives

Based on the preceeding section, the objectives of a calibration program as part of routine phase operations are as follows:

- check the integrity of the HIFI instrument at regular intervals, the periodicty of which will be controlled by instrument requirements and instrument scheduling constraints.
- provide a sufficient amount of data of uniform quality to be used for necessary trend analysis.

[2] Observers are not expected to contact ICCs directly.

- re-evaluate observing mode parameters and and allow re-optimisation when necessary.
- react to problem reports, warnings and failures which can be solved by new, updated calibration procedures.

4 Assumptions

We make the following assumtions:

- Commissioning, performance verification and science demonstration phases have been successfully carried out.[3]
- Retrieval of science and HK data via telemetry works nominally.
- The framework for dealing with calibration parameters, i.e. the software infrastructure needed for version control and updates, is in place.

4.1 Assumed time-line

At present it is assumed that HIFI is scheduled as prime instrument every 21 (TBC) days for a period of 5 (TBD) days.

5 The HIFI LCU failure

On August 2, 2009, the LCU on the nominal side of the HIFI instrument failed. A switch on of the redundant side is currently foreseen to happen in January 2010, when the remaining PV activities will be carried out, to be followed by a priority science program of 400 hours.
The analysis of the occured failure has led to a modified approach of the HIFI instrument, in the sense that an effort is made to reduce the number of HIFI band switches as much as possible.
For the routine phase this means that routine phase calibrations are now expected to be much more coordinated with routine phase astronomical observations and will carry out calibration AORs only in bands already in use by the astronomy program. Whereas the original routine phase plan would have scheduled a series of consecutive calibration observations in several bands, the new plan tries to synchronize these observations with the band usage of the routine phase MTL scheduled by the HSC.

6 Routine phase activities

6.1 Quarterly functional tests

The objective of these 3-monthly tests is to monitor the health of the instrument sub-system key components, such as the diodes in the focal plane control unit (FCU) and the local oscillator unit (LOU), as well as the mechanical units such as the chopper and the diplexers. In practice, they correspond to down-scaled versions (where applicable) of the initial SFT conducted after the instrument switch-on(s). The main difference is that here they are run on the MTL.

6.1.1 Chopper health check

Objective: The test monitors all calibration parameters related to the chopper (end stop voltages, close-loop parameters, etc) and if necessary may lead to the revision of some of the settings. In essence it serves to check that the chopper integrity is maintained all over the mission and that no degradation on the mid-to-long term are affecting the unit.

[3] However, any actual failure or anomaly discovered during these phases which can be dealt with through altered/improved calibration procedures should lead to corresponding updates on this document.

Pre-conditions: The instrument can be in normal or dissipative mode. This test does not require pointing, therefore it can be run during DTCP.

Test duration: The test consists of 4 AORs, of total duration 4 min.

6.1.2 WBS functional tests

Objective: The test monitors the health of the WBS main components, such as the lasers, the zero and COMB switches, as well as the IF-power level attenuators. It is a full repeat of the original SFT.

Pre-conditions: The instrument can be in normal or dissipative mode. This test does not require pointing, therefore it can be run during DTCP.

Post-conditions: The laser switching creates an instable behaviour of the WBS during the period following the test. In the 2 hours following the FT, the backend stability is insufficient to perform tests like IF-feedback, stability, or normal (non-robust) AOTs. That needs to be taken into account.

Test duration: The test consists of 1 AOR, of total duration 20 min.

6.1.3 HRS functional tests

Objective: The test monitors the health of the HRS main components, such as the internal LOs and the IF-power level attenuators. It is a full repeat of the original SFT.

Pre-conditions: The instrument can be in normal or dissipative mode. This test does not require pointing, therefore it can be run during DTCP.

Test duration: The test consists of 1 AOR, of total duration 23 min.

6.1.4 Mixer diode functional tests

Objective: The test monitors the health of the diodes in each of the HIFI mixers. This is in essence an IV-curve measurement, and as such is a subset of the original FPU SFT.

Pre-conditions: The instrument can be in normal or dissipative mode. This test does not require pointing, therefore it can be run during DTCP.

Test duration: The test consists of 7 AOR, of total duration 4 min.

6.1.5 LOU diode functional tests

Objective: The test monitors the health of the multiplier diodes present in each of the 14 LOU chains. This is in essence an IV-curve measurement, and as such is a subset of the original FPU SFT.

Pre-conditions: The instrument can be in normal or dissipative mode. This test does not require pointing, therefore it can be run during DTCP.

Test duration: The test consists of 14 AOR, of total duration 53 min.

6.1.6 Diplexer calibration tests

Objective: The test monitors the validity of the diplexer model used to optimally couple the LO and sky signals to the mixers. This model enters as a calibration product in the HIFI pipeline in that it affects the side-band ratio dependency over the IF. Any change to the model needs to be reflected both on up-link and down-link.

Pre-conditions: The instrument can be in normal or dissipative mode. This test does not require pointing, therefore it can be run during DTCP.

Test duration: The test consists of 4 AOR, of total duration 6 h.

6.2 Diplexer response time tests

Objective: Although the regular diplexer model measurements are the most sensitive to minute changes to either control electronics or diplexer mechanics, the measurement of the diplexer step response is a good diagnostic tool to distinguish between an electrical or mechanical cause. We therefore consider it is needed to build a history of step-responses, which are achieved by a very short test block.

Pre-conditions: The instrument can be in normal or dissipative mode. This test does not need pointing, therefore can be run during DTCP.

Test duration: The test consists of 8 AOR, of total duration 3 min.

7 IF feed-back reference dataset

It has been shown that HIFI is affected by so-called IF-feedback effects which show up when measurements performed with different chopper angles are combined. At each of those chopper positions, different interferences are created in the cavity formed by the FPU, which do not cancel out in calibrated spectra. Those features appear for deep integrations (typically above 500–1000 s), especially in the highest WBS sub-band, and most significantly in bands 3 and 4.
It has been observed that the structure of those interferences is very stable, and does not change with frequency (it is created in the IF). It is also very similar for a pumped and an un-pumped mixer. Current investigation have shown promising correction results based on the removal of a so-called reference spectrum acting as a sort of flat-field, but on a spectral scale.

Objective: This routine calibration activity consists in building the set of reference spectra needed for this correction, to be eventually applied in the pipeline.

Spectra need to be collected for each chopper voltage involved in the HIFI AOTs, and each mixer band. Integrations need to be long enough in order to not add noise to the scientific data when the reference spectrum is removed from the on-source data.

Pre-conditions: The instrument can be in normal or dissipative mode. This test does not require pointing, therefore it can be run during DTCP.

Test duration: The exact duration of this test is still under investigation, but it could be as high as several hundreds of hours. We are also still debating whether the problem could be worked around by clever settings of the LO frequencies in order to move the lines targetted for deep integration away from the WBS sub-band mostly affected by the feed-back.

8 LOU purification and spur mitigation

8.1 LOU frequency purification

The pre-launch TVTB and IOCP measurements have shown that the HIFI LOU is still impure in some frequency areas. In those regions, the LOU offers more than one single tone to the mixer and therefore picks up emission from other frequency areas (which could be as far as 40 GHz away). This will lead to wrong calibration of the targeted lines, and could bring erroneous spurious lines from the other tones.
The same problem was detected before HIFI was delivered in the 7b band around the C^+ line. A dedicated measurement plan, first in the lab, then on the instrument, proved that purity can be recovered with a new set of multiplier biases. It was later successfully applied to the band 3b as well, allowing to recover both purity and good noise figures in the bulk of this band.
The same approach is possible for almost each of the frequency areas still impure.

Objective: this activity aims at identifying new multiplier settings allowing to recover the LOU purity in well identified regions. Typically, parametric scans are performed, which measure simultaneously the purity, the noise performances, and the stability. Often a trade-off between those three has to be made, with priority to the purity.

Pre-conditions: The instrument can be in normal or dissipative mode. This test does not need pointing, therefore can be run during DTCP.

Test duration: The following bands are concerned by this investigation:

5a: 4 h in two blocks
5b: 4 h in two blocks
7a: region around 1710–1719 GHz. 2.4 h
7b: remaining region around 1870 GHz: 2 h

8.2 LOU spur mitigation

It has been observed that the LOU can create spurious signals showing up directly in the scientific spectra. Those spurs have been catalogued and categorized according to their nature and strength. Altough most of them cannot be avoided, and are currently treated in HSpot via a warning message, we have identified two particular spurs which could affect a significant portion of the HIFI main science given their vicinity to some of the most-wanted lines in the HIFI KP. These are respectively the water line in band 1a (557 GHz) and the water line in band 4b (1107 GHz), see Fig 1.

It has been shown that the spur intensity can be mitigated, or in the best cases, removed, with optimised LOU settings.

Objectives: this activity aims at identifying optimised LOU settings in order to mitigate or ideally remove the spurs present in the vicinity of the water lines in the 1a and 4b bands respectively. Typically parametric scans are performed together with noise measurements, to see how the spur characteristics vary with those settings.

Pre-conditions: The instrument can be in normal or dissipative mode. This test does not need pointing, therefore can be run during DTCP.

Test duration: The following bands are concerned by this investigation:

1a: 2 h + possible follow-up depending on findings
4b: 2 h + possible follow-up depending on findings

9 Standing wave investigations

Objectives: Standing waves can considerably limit the final quality of an observed spectrum. Consequently a lot of effort and observing time is spent during PV on the characterisation of the various standing wave patterns that result from either specific observing modes (e.g. FSW or load-chopped observations), or specific band usage (e.g. diplexer bands or HEB bands). Although sophisticated algorithms in the HIFI data reduction pipeline my correct for artefacts introduced by standing waves, the goal must clearly be to avoid them a priori by clever design of the AOT. The careful choice of the amount of frequency throw during FSW observations is one mitigation strategy which is being tried, the significance of equal mixer currents for the individual phases of an observing mode is another issue which is being investigated.

Pre-conditions: Additional observations would be designed as a continuation of the AOT check-out program which is being carried out during PV. The instrument is being used in normal mode, pointing to a suitable astronomical source.

Test duration: TBD, this will only be clear after HIFI PV has been finished.

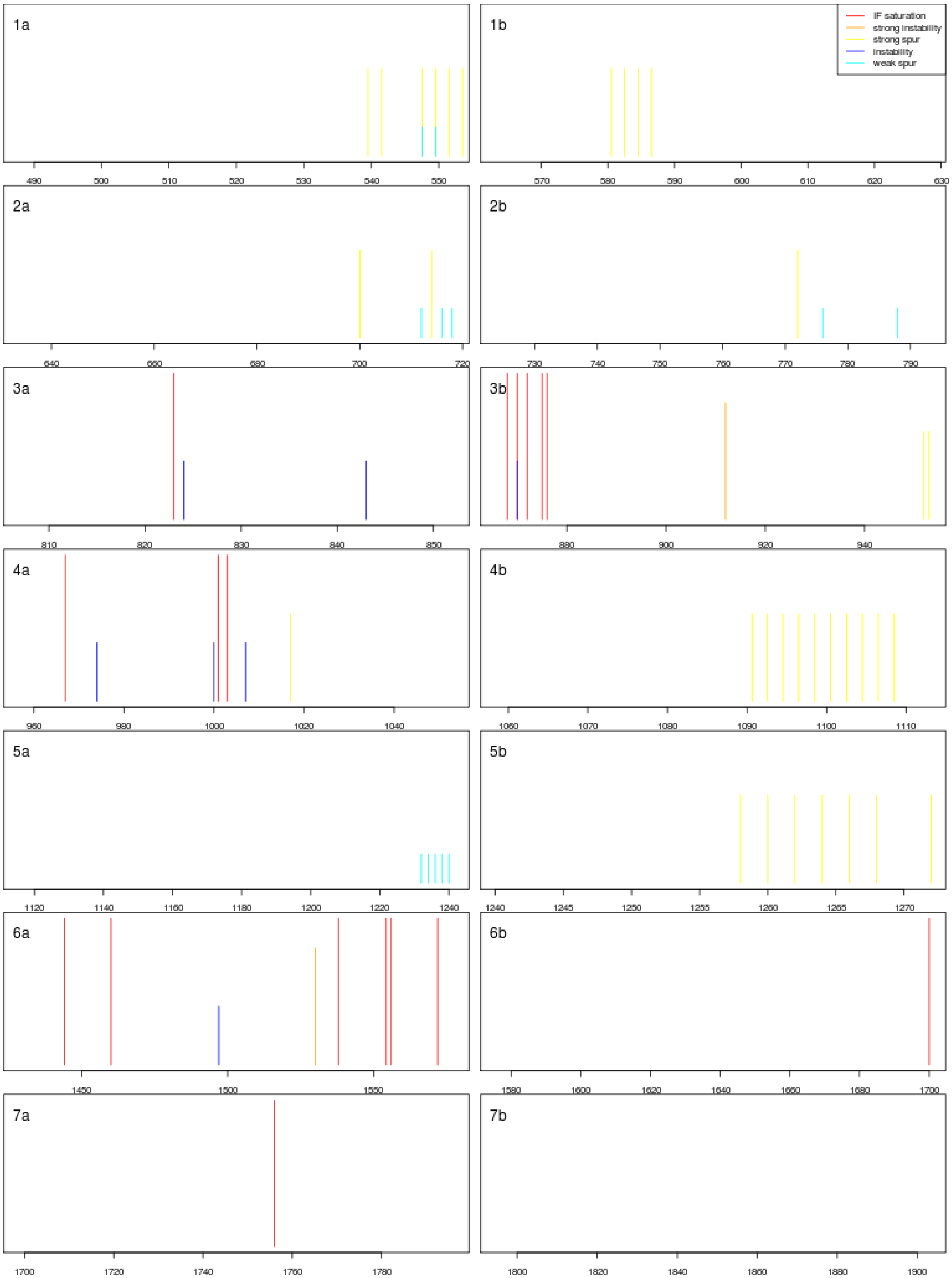

Figure 1: Shown per band are the various instabilities and spurs which are known to HSpot.

10 Side-band ratio investigations

Objectives: HIFI is using double side-band mixers. The side-band ratio is known to vary over the tuning range of one mixer band due to the overall gain variation of the mixer as a function of frequency. The transmission curves of the 8 diplexers (bands 3, 4, 6 and 7, with two polarizations each) add an extra contribution in those bands. The intrinsic side-band ratio of the individual mixer bands were studied during ILT through gas cell mesaurements. During PV the focus is on consistency checks and specific observations aimed at the diplexer contribution.

Pre-conditions: Additional observations would again be designed as a follow-up of the AOT check-out program which is being carried out during PV. The instrument is being used in normal mode, pointing to a suitable astronomical source.

Test duration: TBD, this will only be clear after HIFI PV has been finished.

11 Pointing and monitoring of beam coupling

The planets (in particular Mars) offer simultaneous checks of HIFI pointing and beam properties. These checks should be carried out at suitable intervals. A minimum time delay between two successive measurements is given by HIFI scheduling and source availability. Fig 2 shows the pattern of HIFI prime instrument time slots and availability of planets. Due to the rather scarce availability of the planets throughout the mission, we plan to use all opportunities to monitor the pointing offsets in the running SIAM, as well as the beam coupling, which are linked to the telescope properties and general alignement. During PV beam properties are measured at a number of selected frequencies per band, during routine one of these frequencies would be chosen depending on the band which is in use by the MTL of the routine astronomy program.

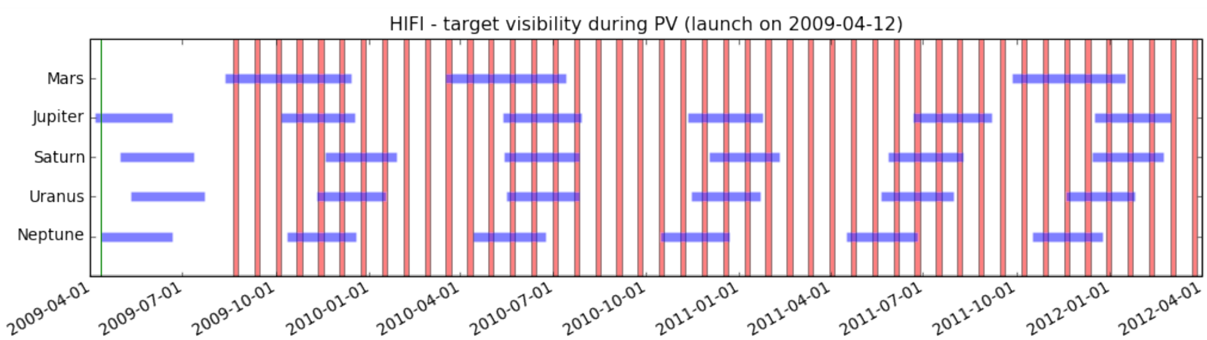

Figure 2: Availability of planets over a three year period. The vertical red bars correspond to the expected scheduling of HIFI as prime instrument every 21 days for a period of 5 days.

11.0.1 Pointing check

Objectives: Check that the pointing performance is in agreement with expectation. Check for the necessity of a SIAM update.

Pre-conditions: The HIFI instrument has been put into primary mode. Observation needs to be scheduled with proper setting of constraint properties, which otherwise prevent observations of strong SSO. Frequency selection needs to be synchronized with band usage of regular, astronomical routine observations.

Test duration: Given the considerable variation in signal strengths between the plantes, but also over the various bands for each individual planet, a typical observation addressing both pointing and beam efficiency can last between a few minutes up to one hour.

11.0.2 Beam pattern, efficiency check

Objectives: Monitor the beam efficiency, possibly re-check beam pattern.

Pre-conditions: Same as for 11.0.1.

Test duration: Preferably combined with a pointing check, for a time estimate see 11.0.1.

12 AOT optimization

It is conceivable that released AOTs can be further optimised during the routine phase. One typical aspect is that of regular tuning done on-board which might be substituted by direct use of a look-up table (LUT), saving significant time in e.g. spectral scans. A revision of the HIFI sequencer code could be another aspect. It is expected that most of the AOT calibration work is to be done based on (trend) analysis of normal observations where some certain patterns or ways for optimization are found and it is required to check whether the same holds for other frequencies/timings.
This work may well need experimental CUS updates, and consequently may involve a significant configuration management effort.
To be re-assessed at end of PV.

12.1 Monitoring of standard sources

12.1.1 CO emmission profiles from AGB stars

Objectives: Overall health check of observing system. End-to-end check of intensity and frequency calibration. Long-term monitoring of reproducibility of spectra obtained towards well-known calibrators. *Clear instructions still need to be prepared for source and band/frequency selection.*

Pre-conditions: The HIFI instrument has been put into primary mode and is operating in a band where a suitable emission line, i.e. CO transition, for monitoring is available.

Test duration: TBD, pending on design of template AOR.

A Summary table

Table 1: Summary table of requested time for HIFI routine phase calibration observations. The column "science" is used to indicate if the measurements potentially will produce scientifically valuable data.

Activity	**science**	**time requested** [hours]
functional tests every three months		
Chopper health check: 4 AORs of 4 min each	N	0.3
WBS functional tests: 1 AOR of 20 min	N	0.35
HRS functional tests: 1 AOR of 23 min	N	0.4
Mixer diode functional tests: 7 AORs of 4 min each	N	0.5
LOU diode functional tests: 14 AORs of 53 min total	N	12.4
Diplexer calibration tests: 4 AORs of 6 h total	N	24.0
Diplexer response time tests: 8 AORs of 3 min total	N	0.4
periodicity tbd		
IF feed-back reference dataset	N	$>$ 100(?)
LOU purification and spur mitigation, 2–4 h $\times$ 4 bands	Y	8–16
Standing wave investigations, duration to be clear after PV	Y	tbd
Side-band ratio investigations, duration to be clear after PV	Y	tbd
Pointing and monitoring of beam coupling	Y	0.2–1 (per source)
Beam pattern, efficiency check	Y	20–30 (all bands)
AOT optimization	Y	tbd
Monitoring of standard sources	Y	tbd