Observing Opportunities
with
Heterodyne Instrument for the Far Infrared
(HIFI)

An overview of the instrument
and
of the HIFI GT Programme

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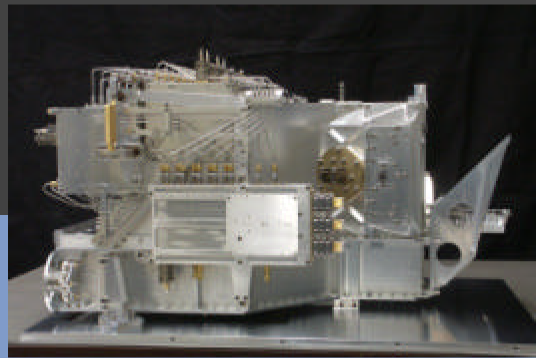
SRON
Netherlands Institute for Space Research

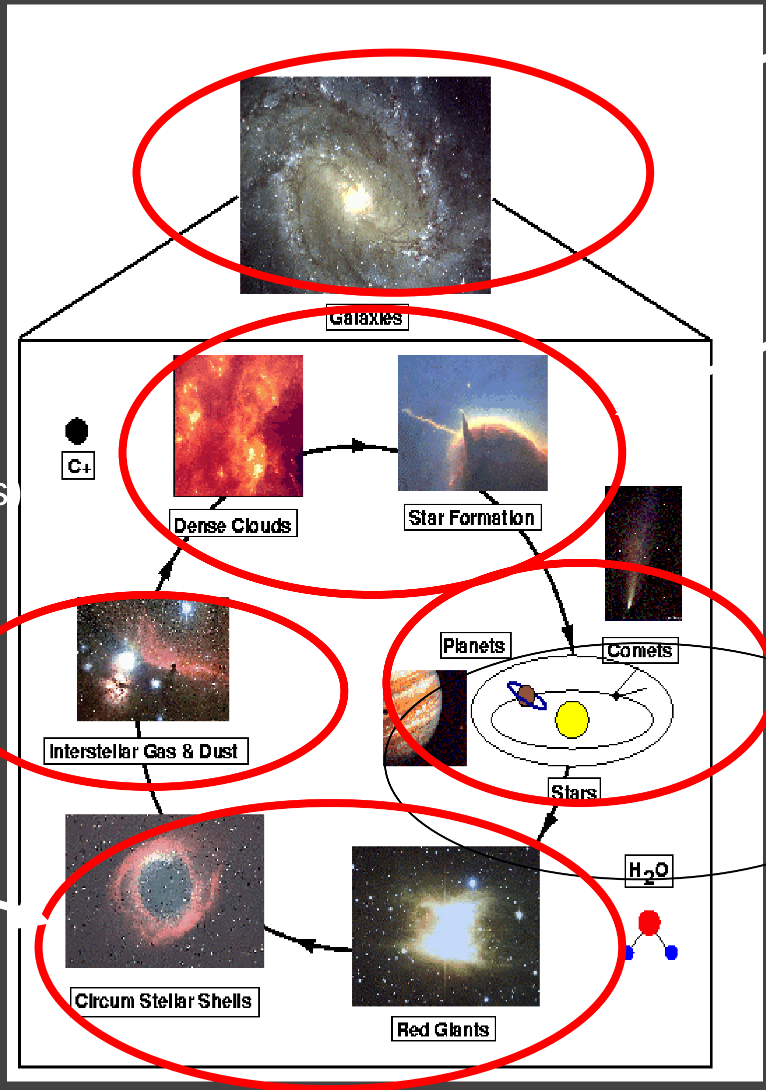


Netherlands Organisation for Scientific Research

Lay-out Talk

- HIFI Science Objectives
- Requirements on Instrument
- Heterodyne principle
- Instrument design + block diagram
- Signal chain
- Observing modes
- HIFI GT Key Programmes

HIFI Science Objectives: Life Cycle of Gas and Dust



ISM in Galaxies:
- Normal galaxies
- Physical properties of star-forming ISM

ISM in the Milky Way:
- Structure
- Dynamics (pressure)
- Composition (gradients)

Dense cores and star-formation:
- Temperature, density structure
- Dust properties
- Stellar IMF

Late stages of stellar evolution:
- Winds
- Shells
- Asymmetries
- Composition

Solar System:
- Water in Giant Planets
- Atmospheric chemistry
- Water activity and composition of comets

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HIFI Top Level Requirements

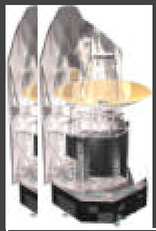
HIFI designed for:
- Spectral Scans and Spectral line surveys
- @ Very high spectral resolution
- Widest possible coverage in the unexplored FIR/Submm range

- *Frequency coverage:*
  - ***480 – 1250 GHz (625-240 mm)***
  - ***1410 – 1910 GHz (212-157 mm)***

- *Near-quantum noise limit sensitivity (goal <3hn/k)*
- *Instantaneous IF bandwidth): 4 GHz (in 2 polarisations)*
- *Spectral Resolution 140 – 280 kHz –0.5 and 1 MHz*
- *Calibration Accuracy: 10% baseline; 3% goal*
- *Angular Resolution (with Herschel): 12"- 40"*

Velocity resolved spectroscopy with radio techniques,
With the largest space telescope available to date

Compromises:
- **Single frequency/? at a time**
- **Single sky pixel**



Instrument Top Level Requirements and Resulting Concept

HIFI designed for:
- Spectral Scans and Spectral line surveys
- Very high spectral resolution
- Widest possible coverage in the unexplored FIR/Submm range

1. **Frequency coverage:**
   480 – 1250 GHz (625-240 μm)
   1410 – 1910 GHz (212-157 μm)

2. **Sensitivity**
   Near-quantum noise limit sensitivity
   - IF bandwidth/Resolution:
     - 4 GHz (in 2 polarisations)
     - 140 – 280 kHz –0.5 and 1 MHz

3. Calibration Accuracy: 10% baseline; 3% goal

- **Heterodyne spectroscopy**
  - single pixel on the sky
  - very high spectral resolution
- **7 dual-pol mixer bands**
  - 480-1250 GHz (625-240 μm) 5x2 SIS mixers,
    IF 4-8 GHz
  - 1410-1910 GHz(212-157 μm; 2x2 HEB mixers,
    IF 2.4-4.8 GHz
- **14 LO sub-bands**
  - LO source unit in common
  - LO multiplier chains
- **2 spectrometer systems;**
  - for each polarisation
    - auto-correlator spectrometer
    - acousto-optical spectrometer

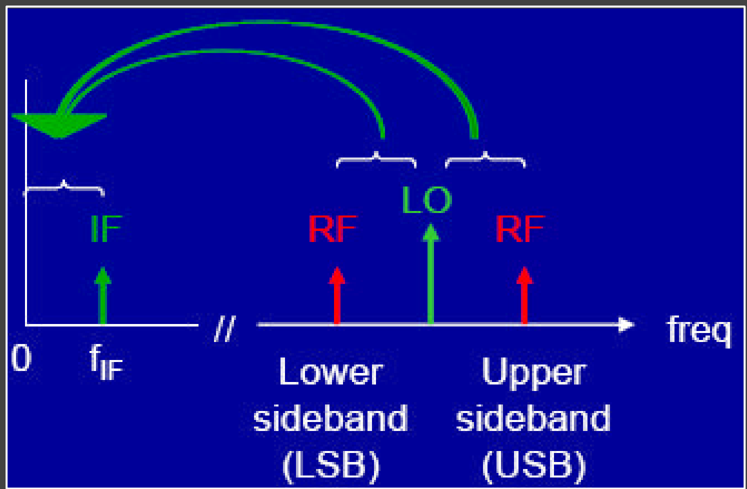
Angular Resolution (with Herschel):
12”- 40”

Herschel-HIFI Consortium

The Netherlands: SRON Groningen/SRON Utrecht DIMES, University of Delft	USA: Caltech and JPL, Pasadena Univ. of Amherst
France: CESR Toulouse LRM-DEMIRM with IRAM Observatoire de Bordeaux	Germany: KOSMA, I. Physikalisches Institut, Köln Max Planck Inst. Für Aeronomie, Lindau Max Planck Inst für Radioastronomie Bonn
Italy: CAISMI-CNR, Florence IFSI, Frascati	Poland: Space Research Center, Warsaw
Spain: Centro Astronómico de Yebes/OANbb	Sweden: Onsala and Chalmers TH, Göteborg
Switzerland: ETH, Zürich	Canada: CSA
Ireland: Maynooth College NUI	With contributions from Taiwan in the development

Heterodyne principle

- Heterodyne principle = mixing of two frequencies (signal + local oscillator) to produce (sum and) difference signal (intermediate frequency = IF)
- Mixing needs non-linear element (e.g. diode, SIS junction) = MIXER

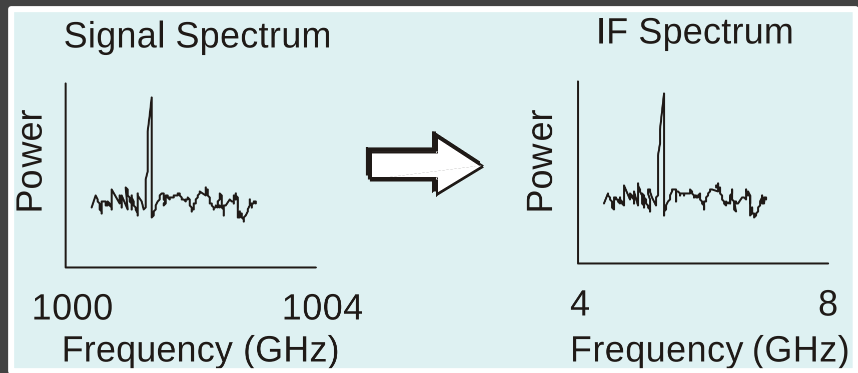


$F_{IF} = | F_{LO} - F_{RF} |$

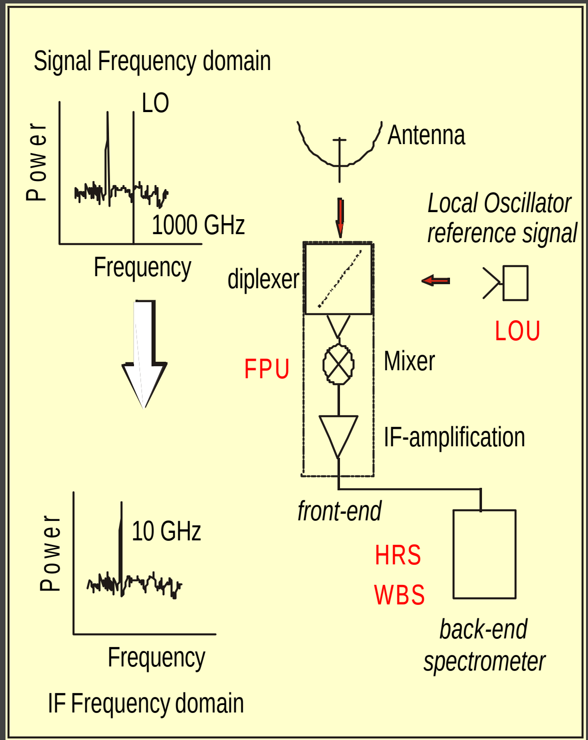
Double sideband mixer: both sidebands converted to same IF

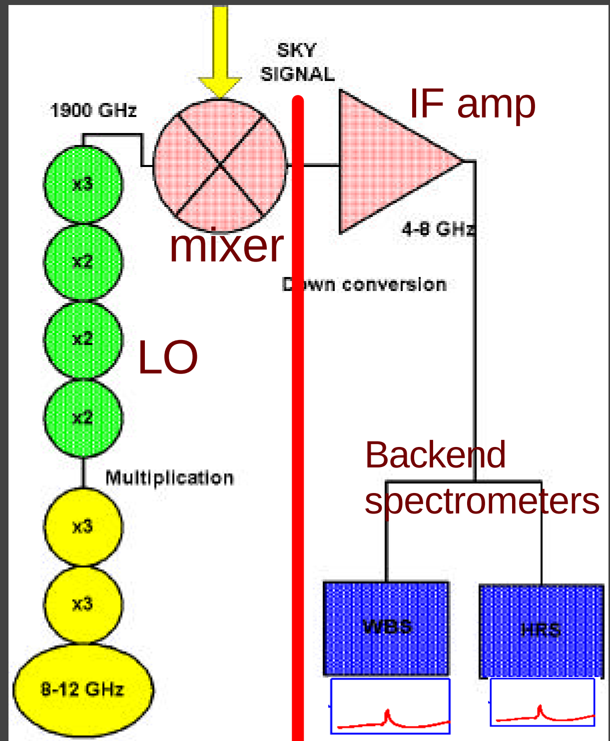
?IF= bandwidth IF amplifier= instant. bandwidth

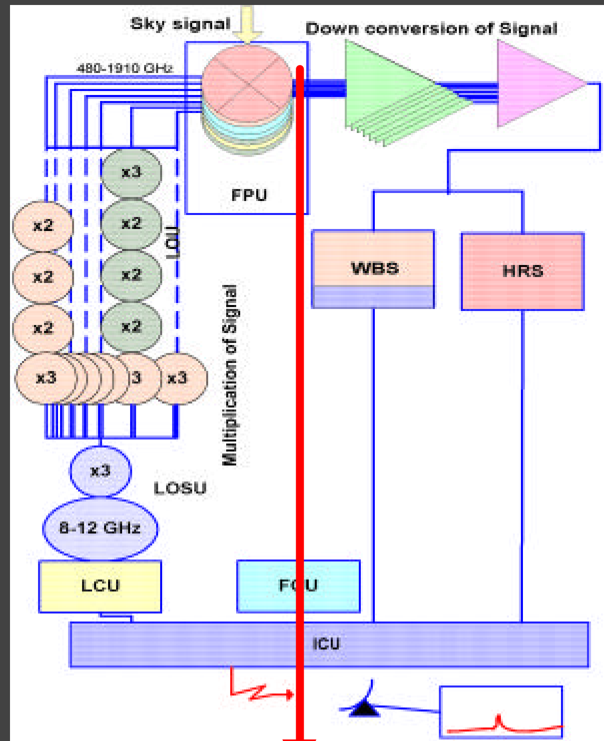
Tuning LO= Tuning Detection Frequency



Heterodyne Technical Principle and Modular Approach in HIFI



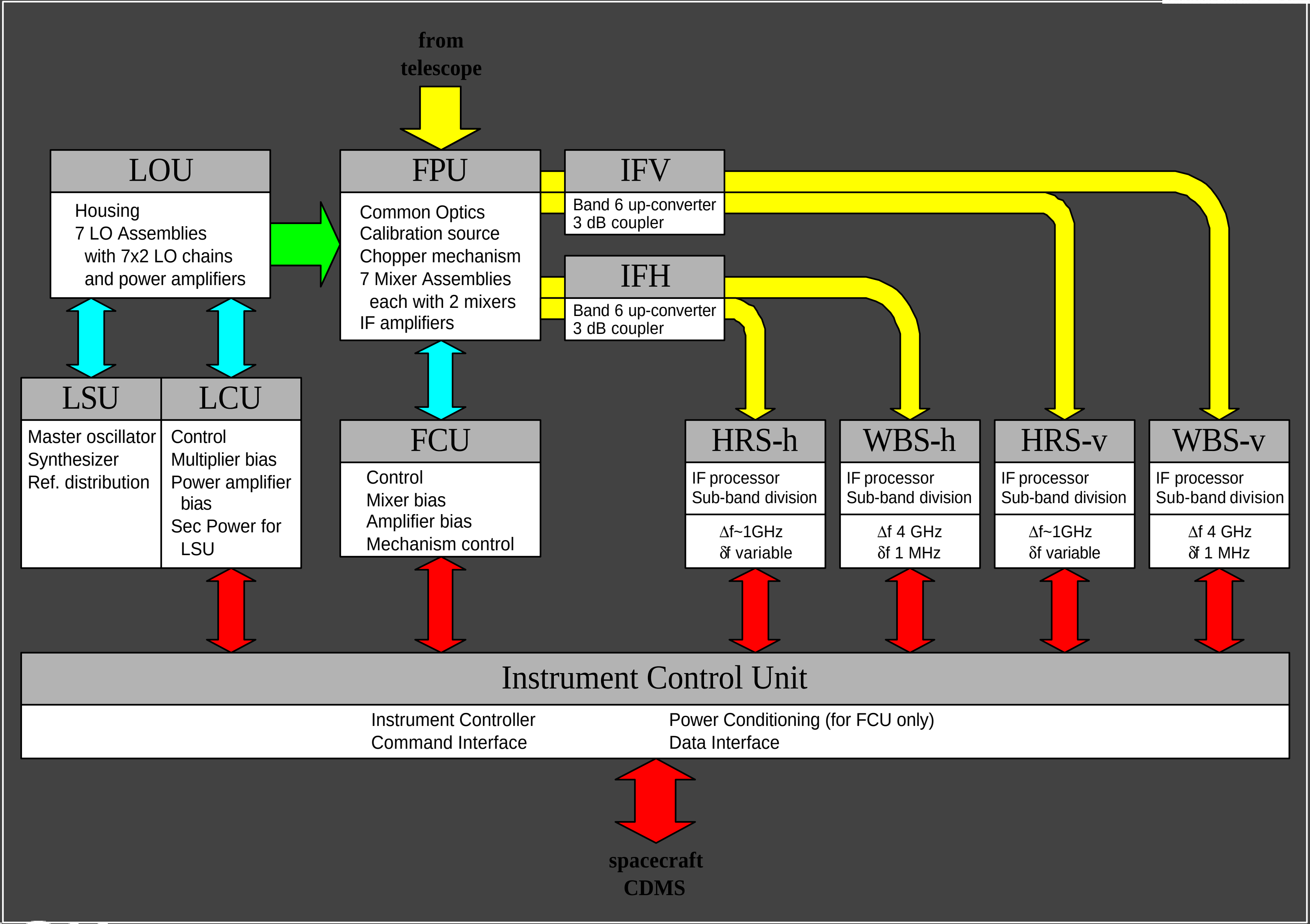




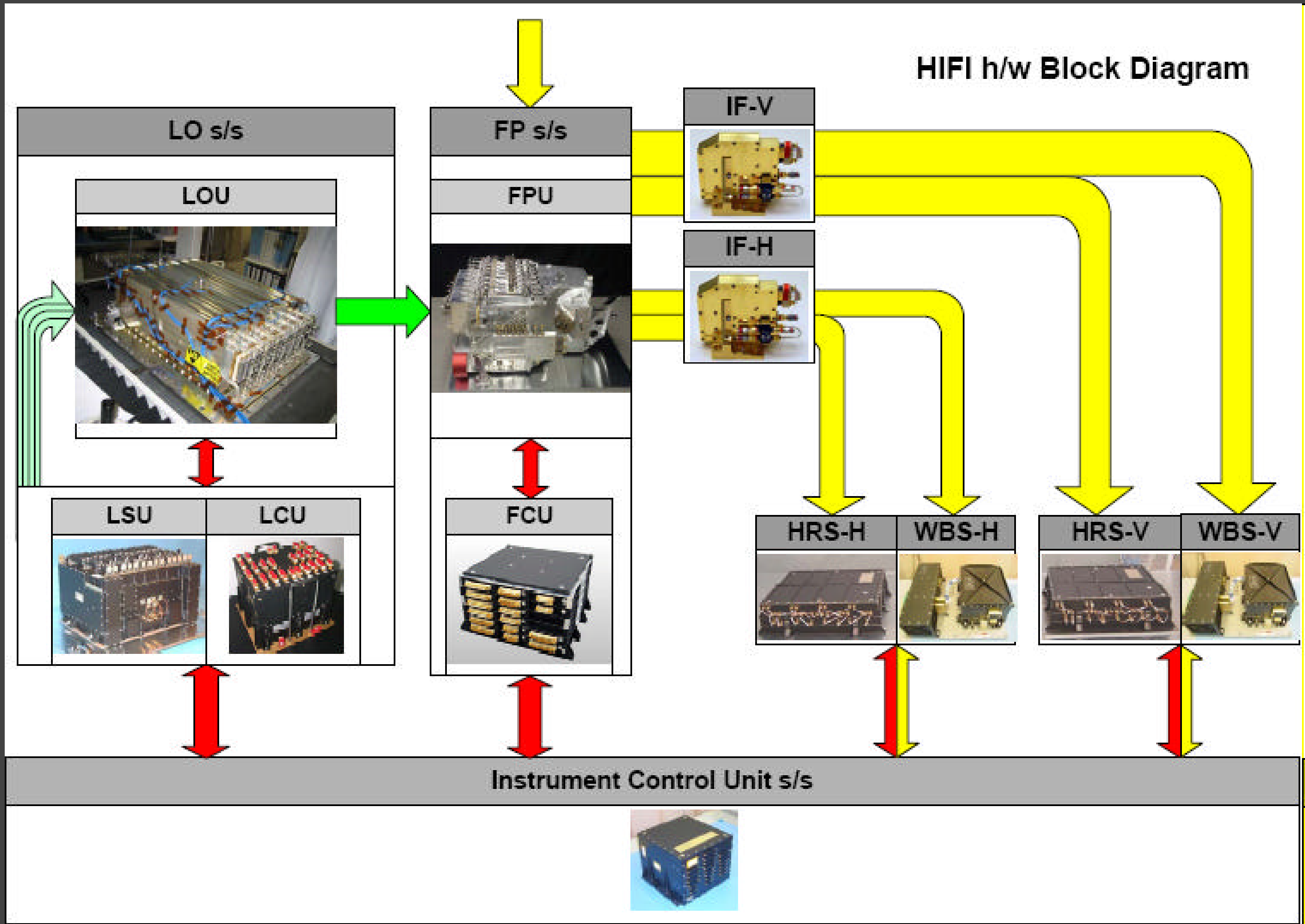
2×7 LO bands
2×7 Mixers H/V

Frequency dependency | Spectral resolution

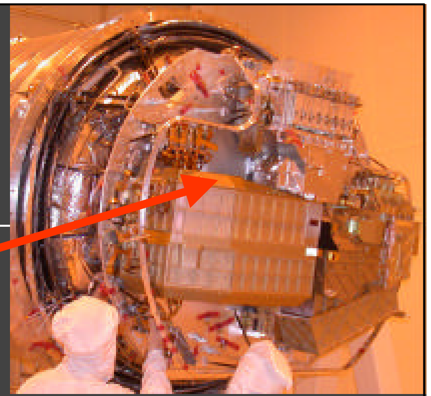
HIFI Block Diagram

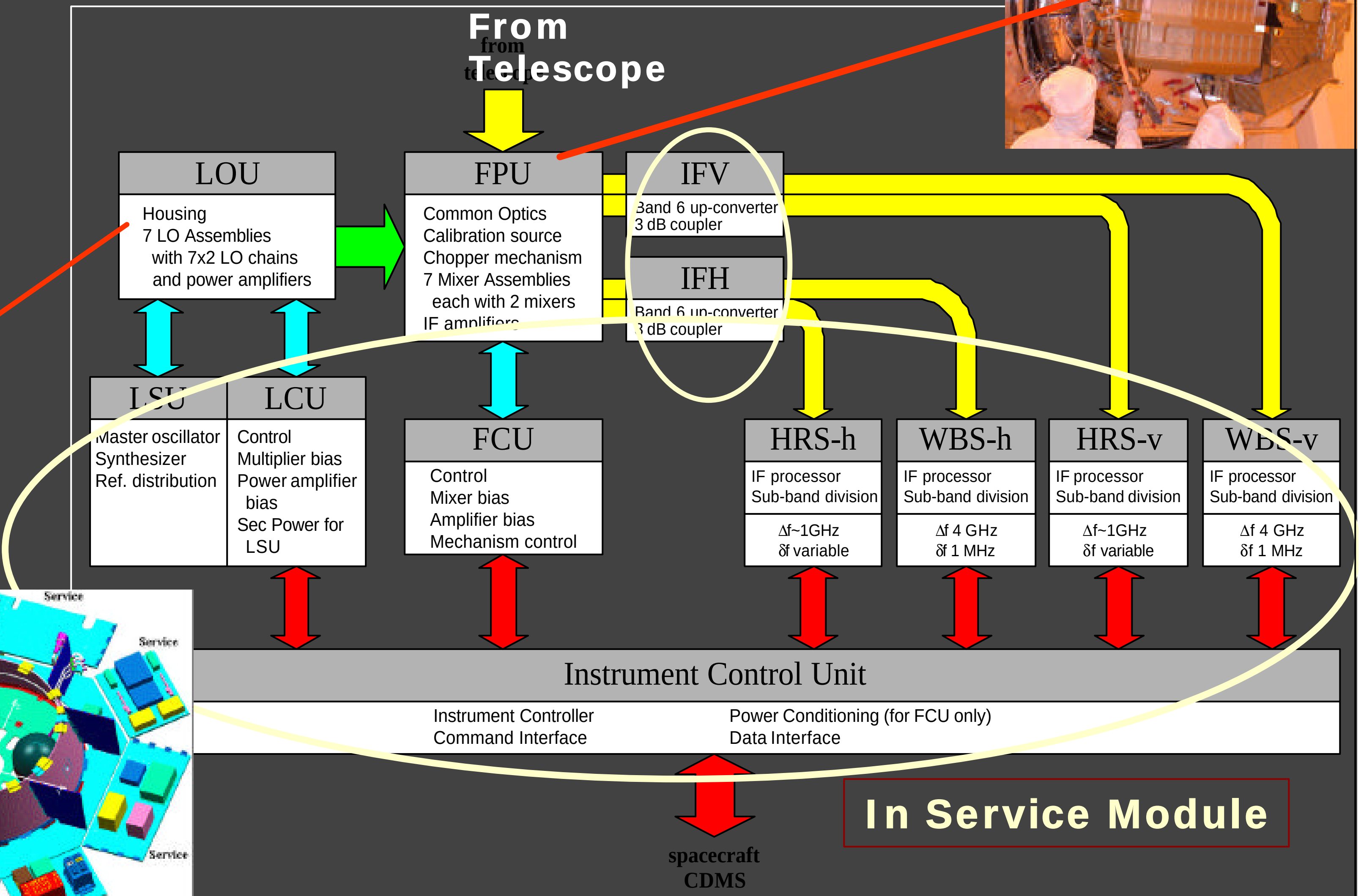


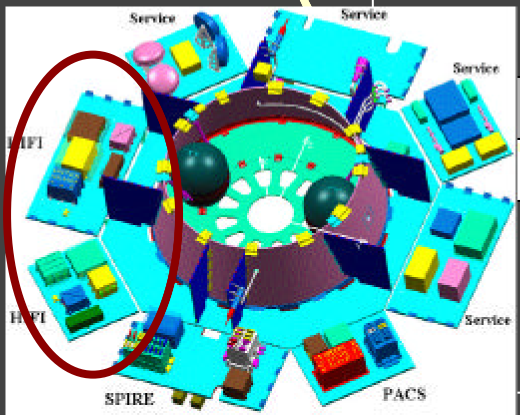
HIFI FM units in blockdiagram



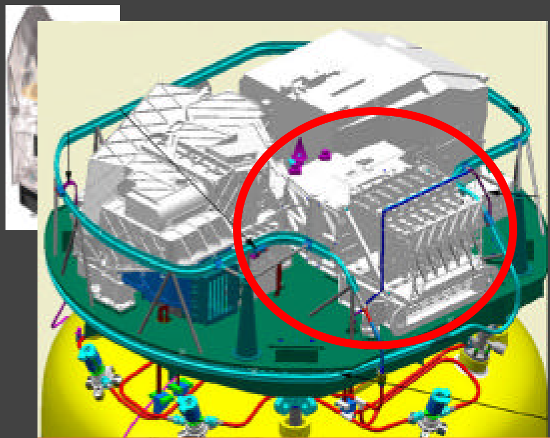
HIFI Block Diagram

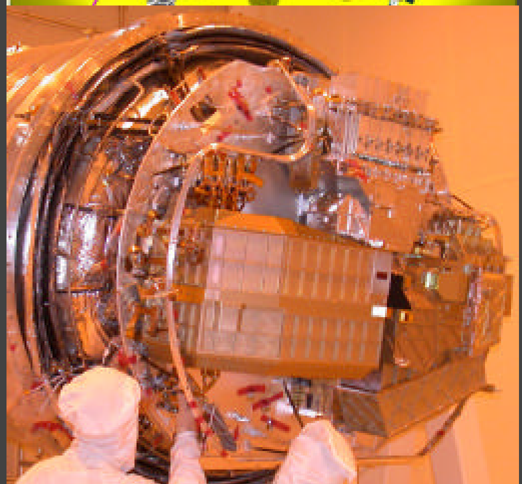


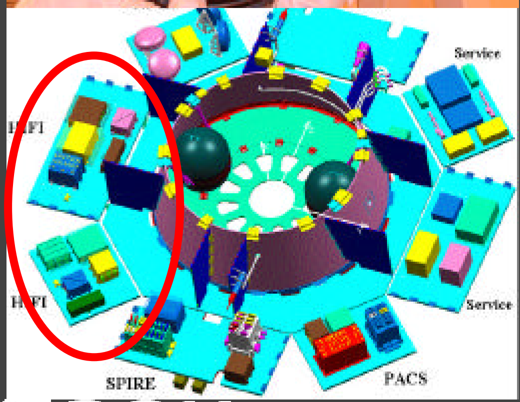


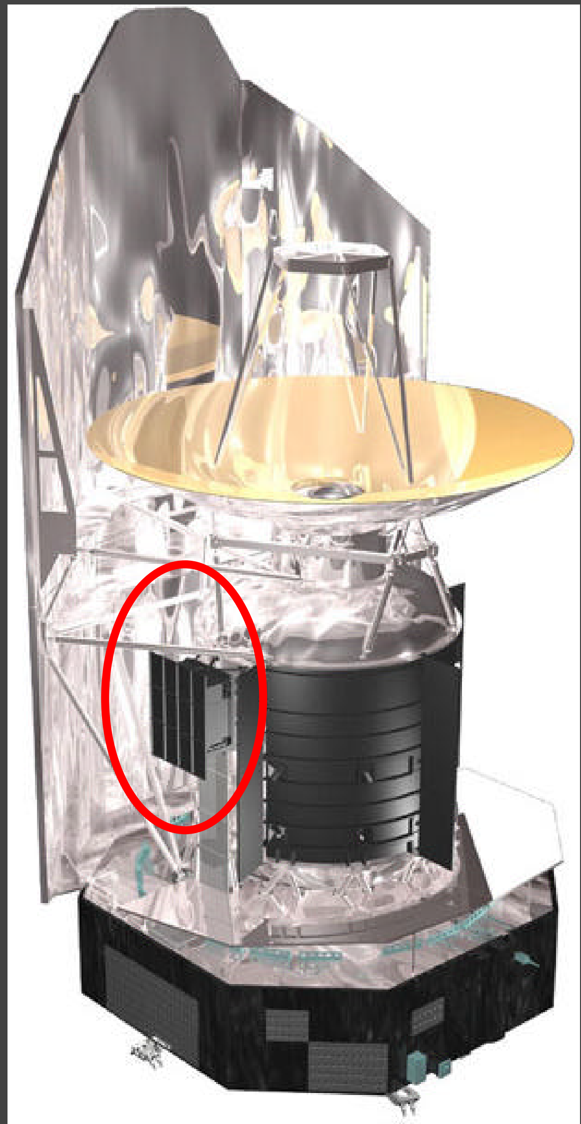


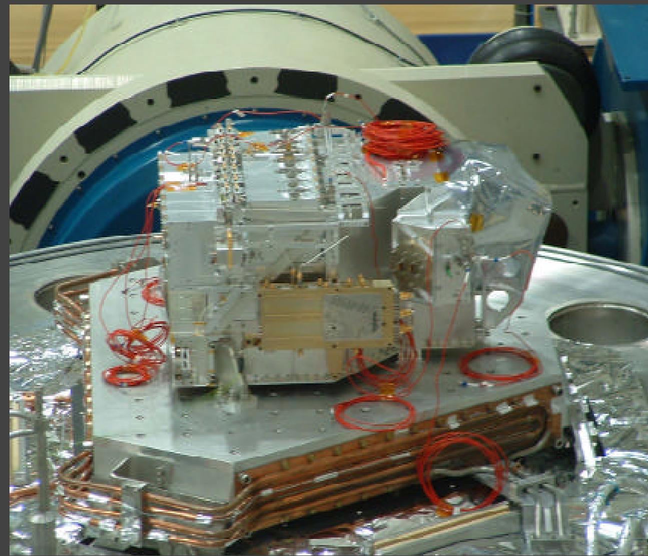
HIFI in Herschel

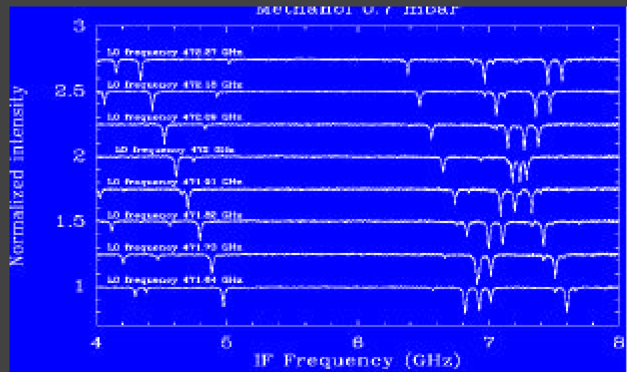




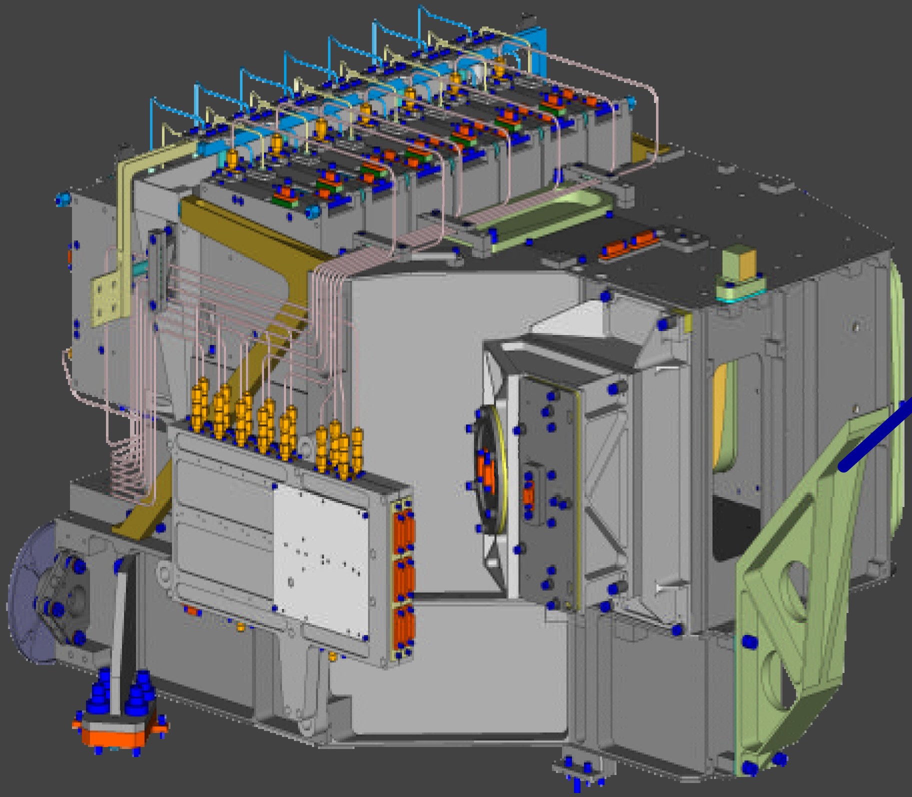


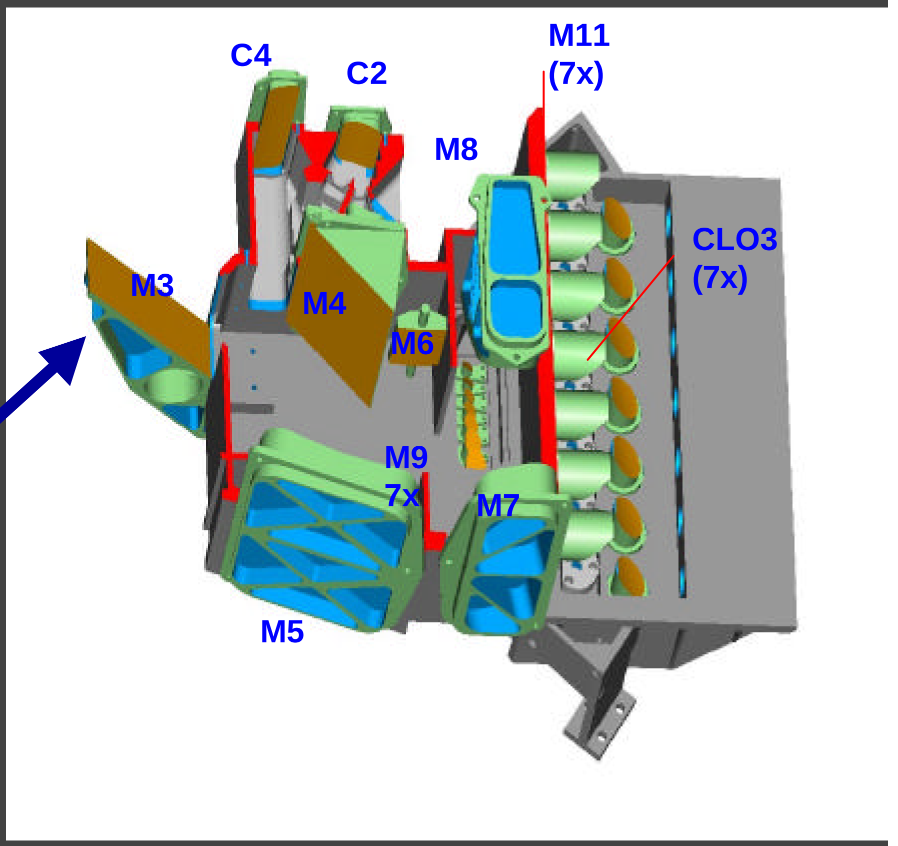


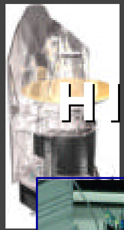




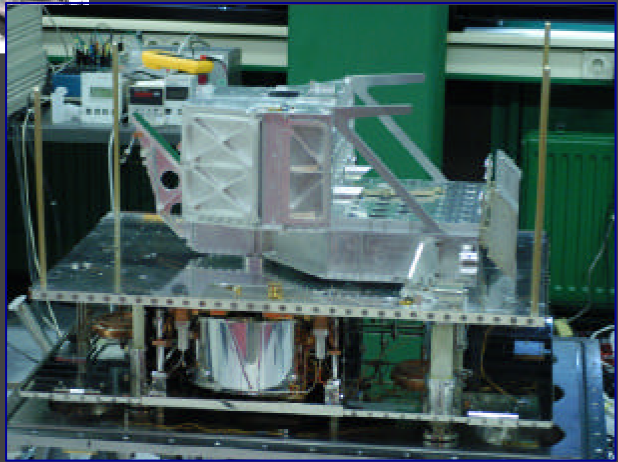
HIFI-Focal Plane Unit

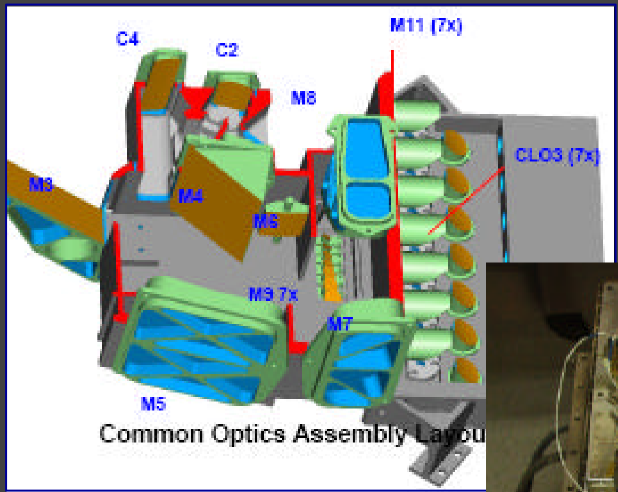


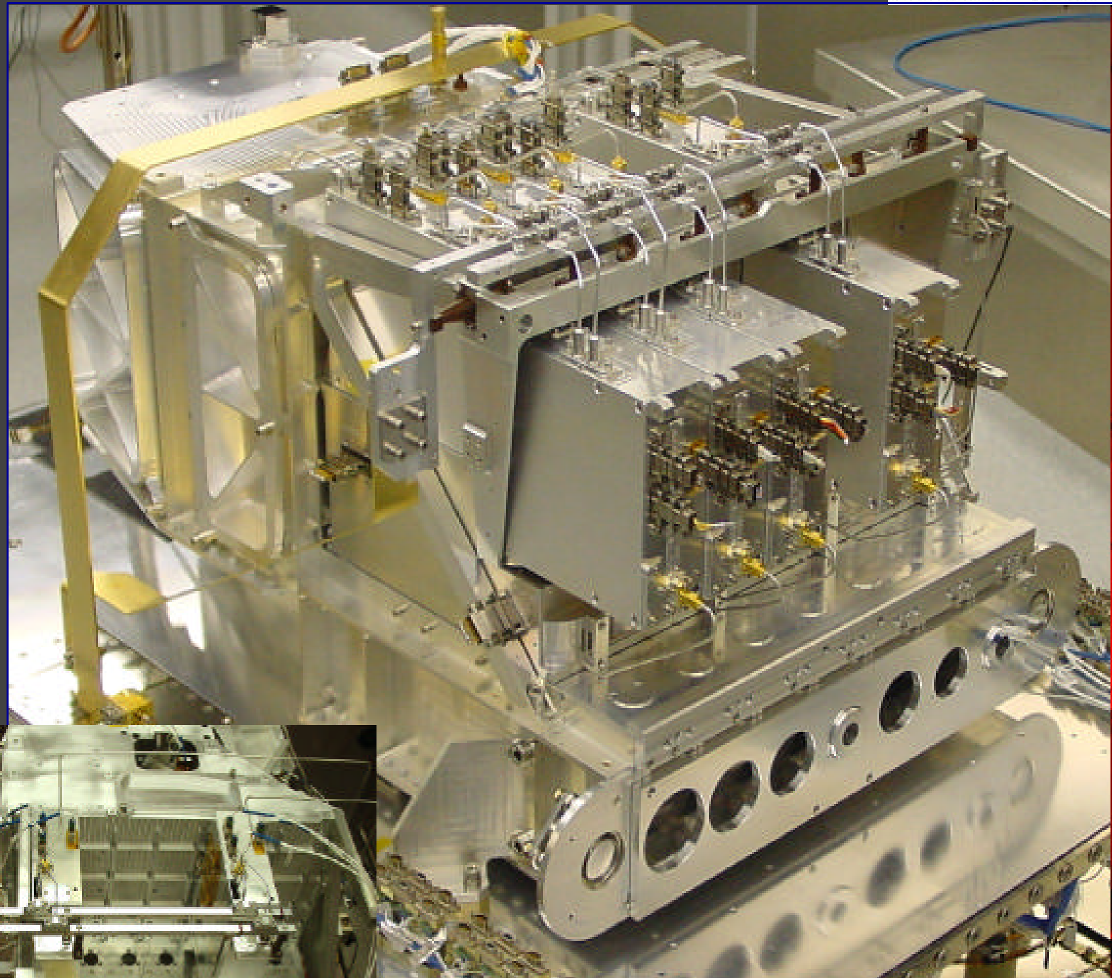


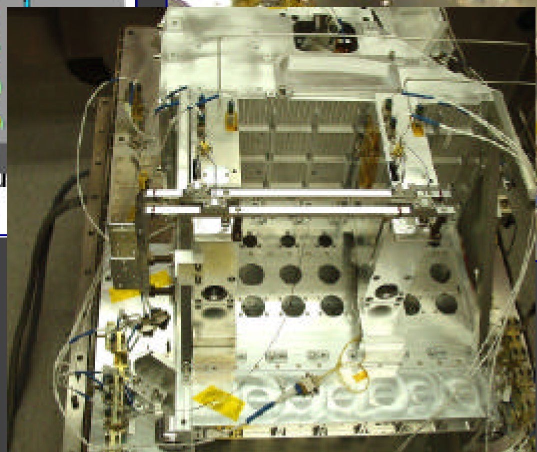


HIFI FPU Flight Model with mixer bands 1,2,3,5

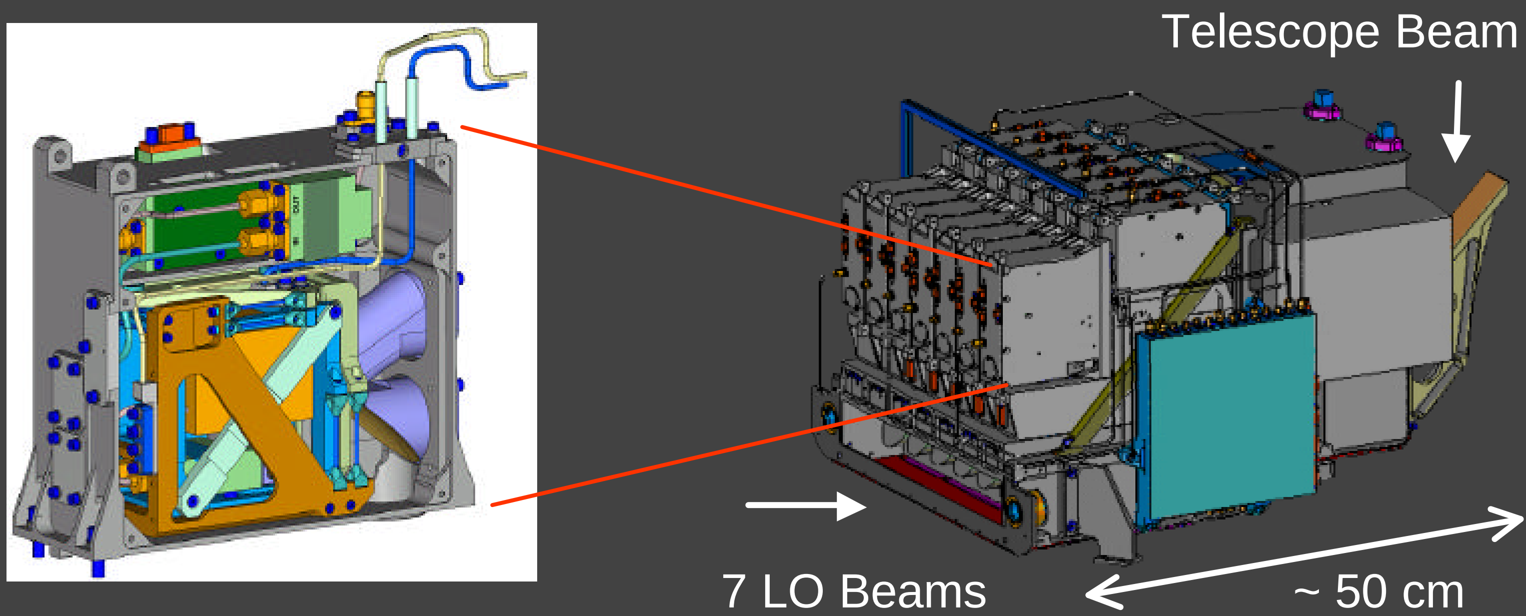








The HIFI FPU and MSA



Each Mixer Sub-Assembly with

- **Focussing optics**
- **One mixer**
- **Two IF isolators**
- **One IF cryo-amplifier**
- **Cabling etc.**

Focal Plane Unit includes

- **Imaging optics**
- **LO + telescope beam combination**
- **14 (2 x 7) Mixer Sub-Assemblies (MSA)**

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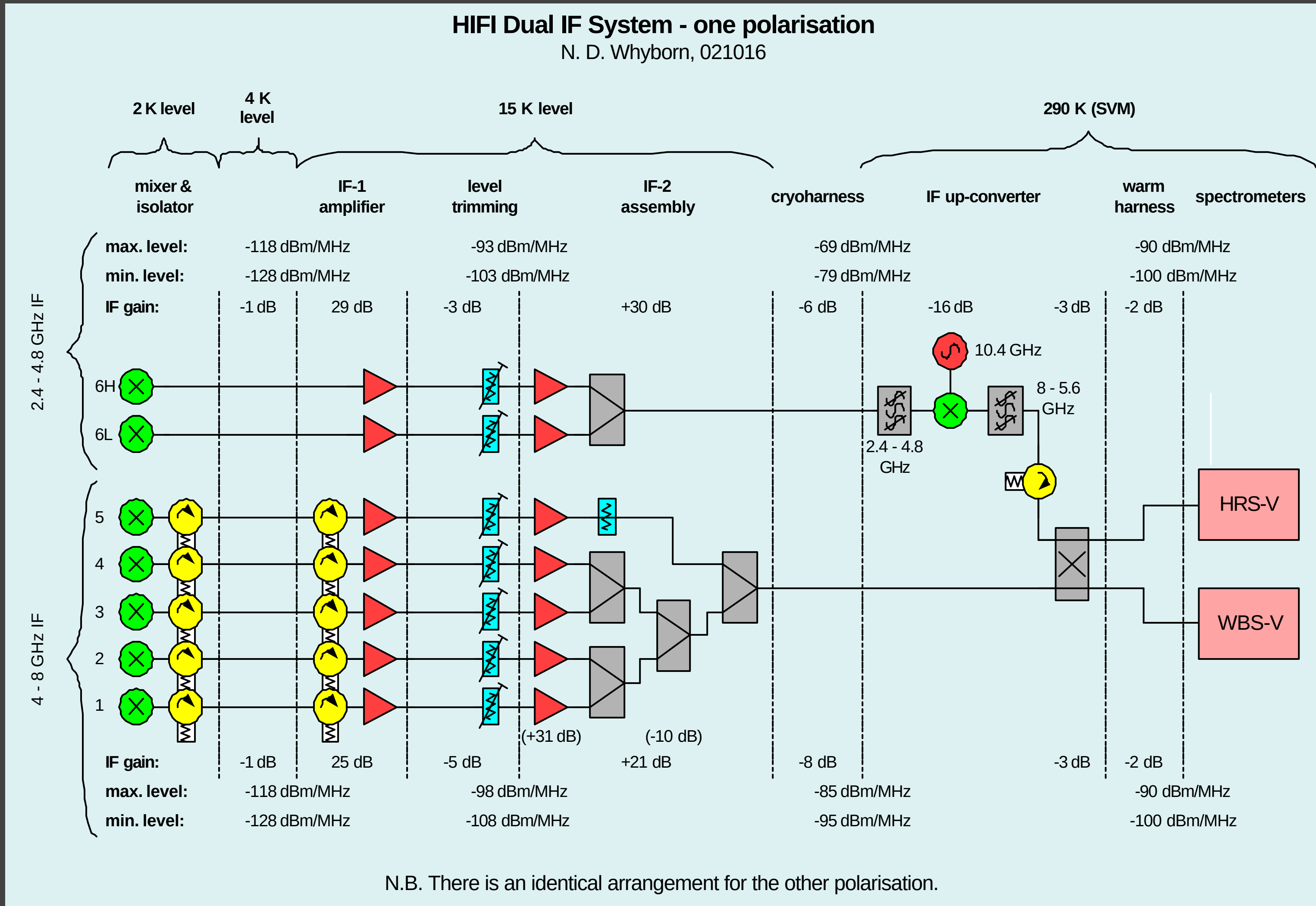
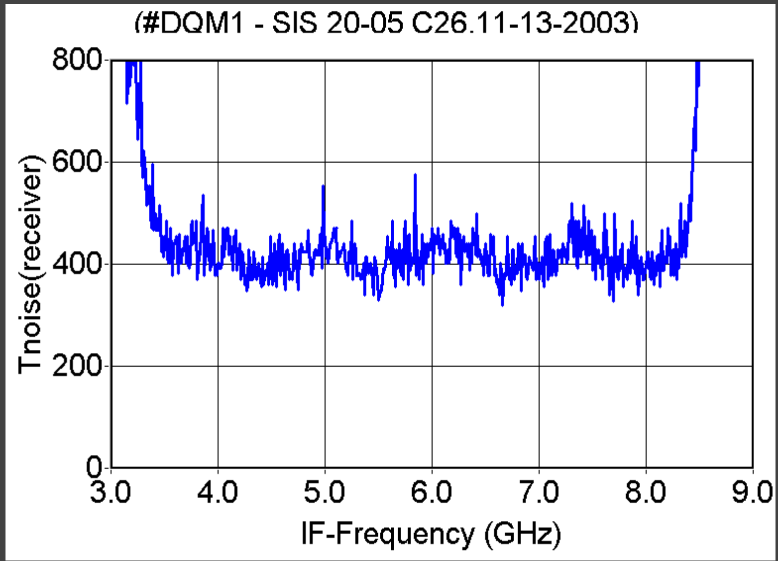
HIFI IF signal chain

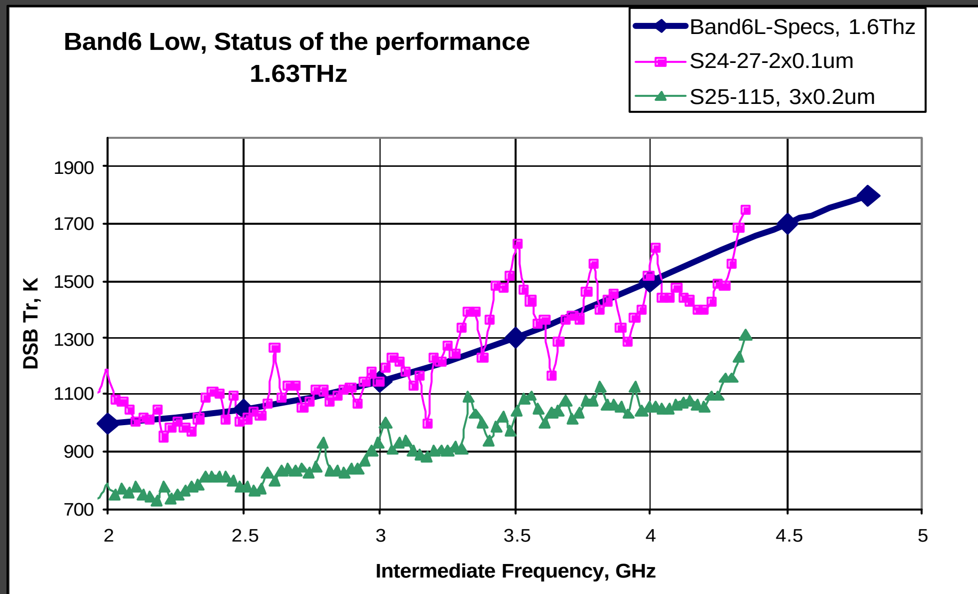


Mixer Unit IF performance



SIS Mixer IF performance
Bands 1,2,3,4,5

HEB Mixer IF Performance
Bands 6 and 7



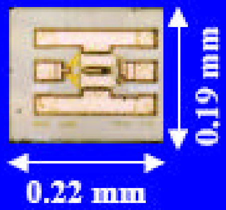
Spanish contribution to HIFI: All IF pre-amplifiers and ICC

CAY

Centro Astronómico de Yebes
Observatorio Astronómico Nacional

HIFI

Transistors

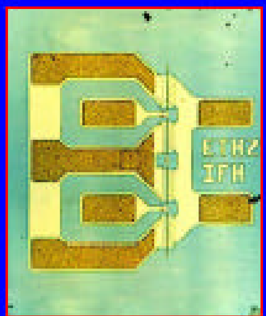


TRW T-42 CRYO3

- 200×0.1 μm gate
- Best performance

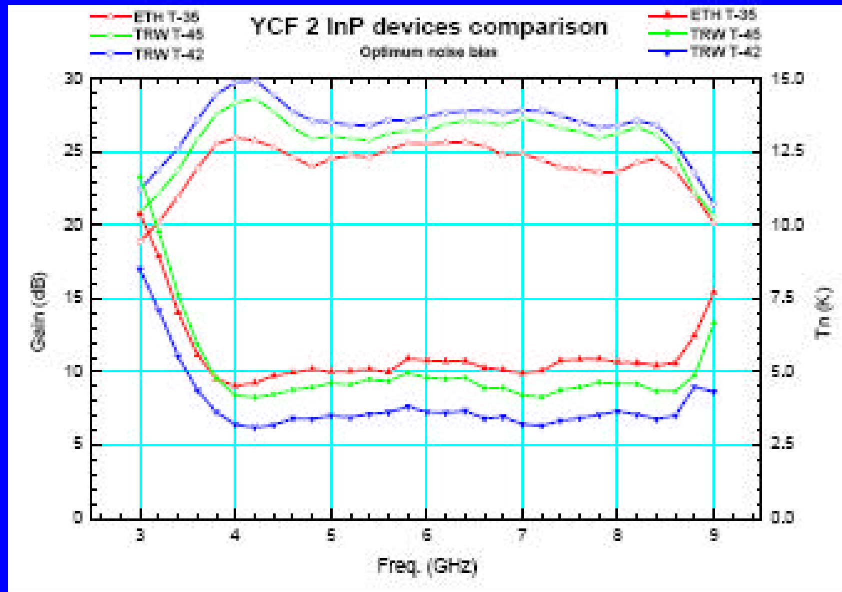
TRW T-45 CRYO4

- 200×0.1 μm gate
- Used in DMs
- Space qualifiable, to be used in FMs
- CHOP developed



ETH T-35

- 200×0.2 μm gate
- Experimental transistor
- Design by request
- Used in MPAs



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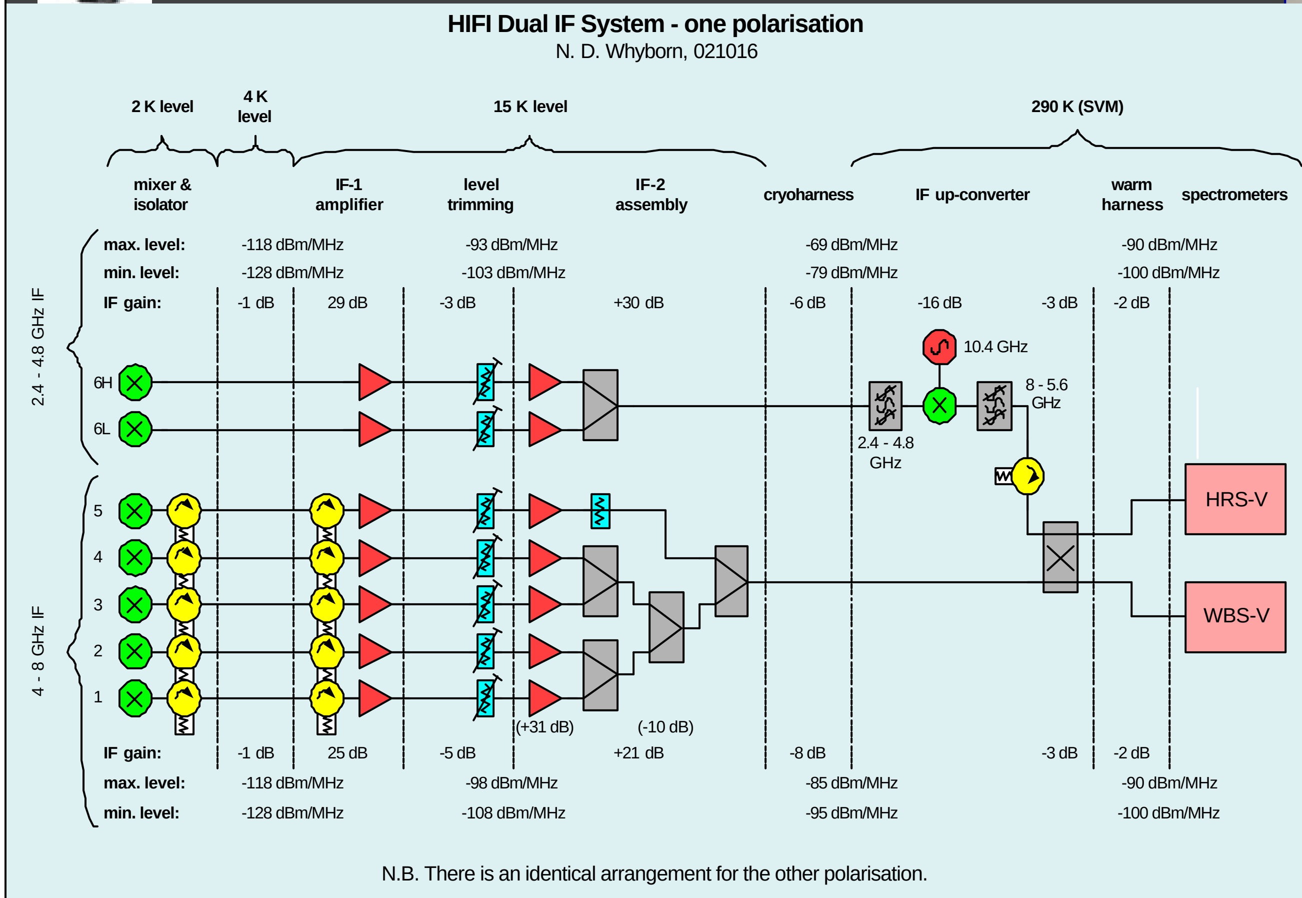
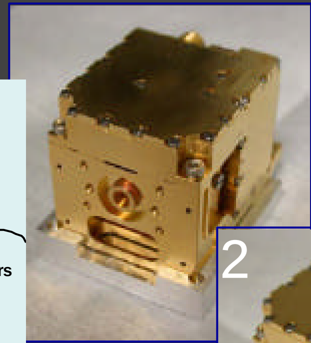
HIFI Signal Chain: Mixers and Amplifiers



1



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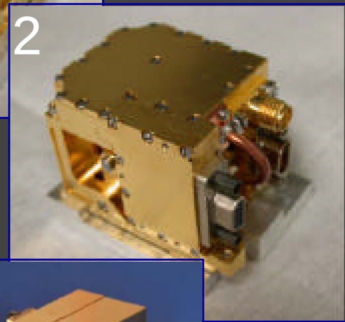
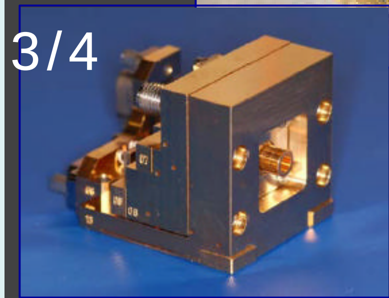
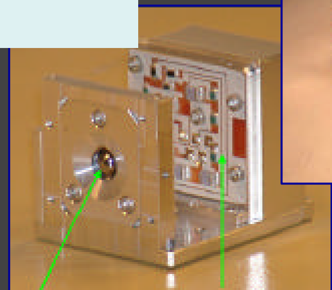


3/4



5

6



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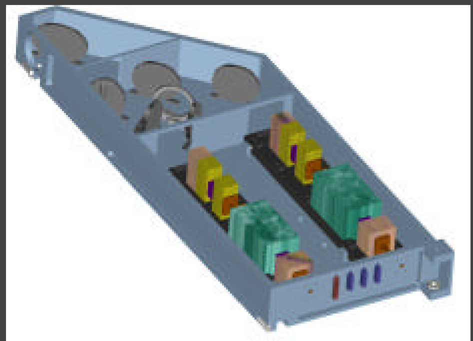
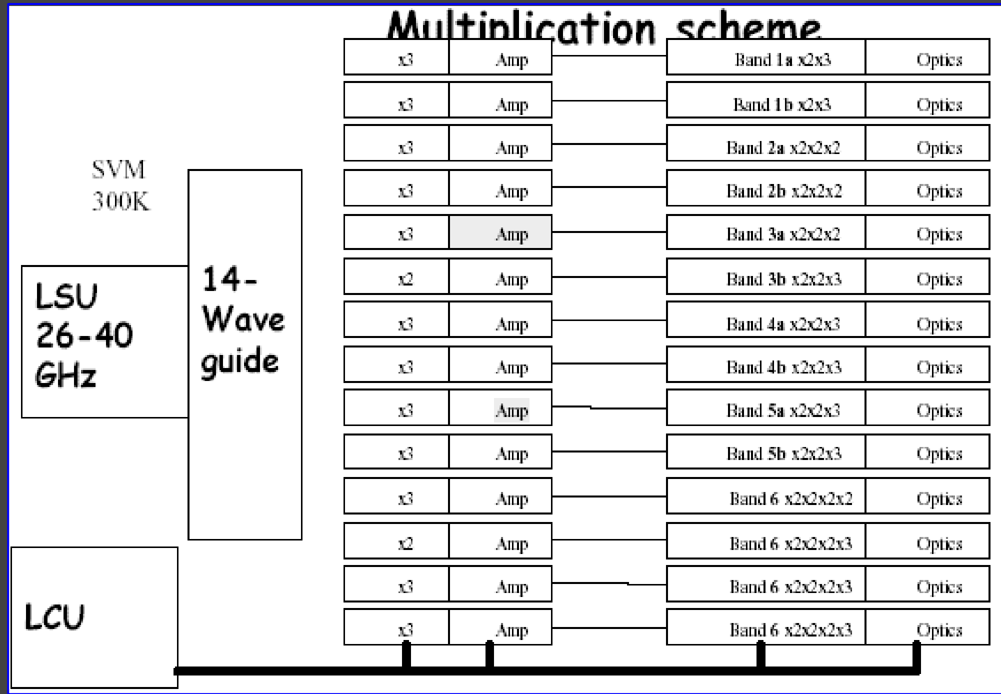
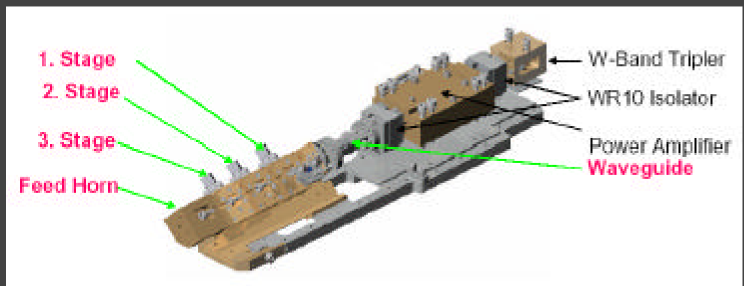
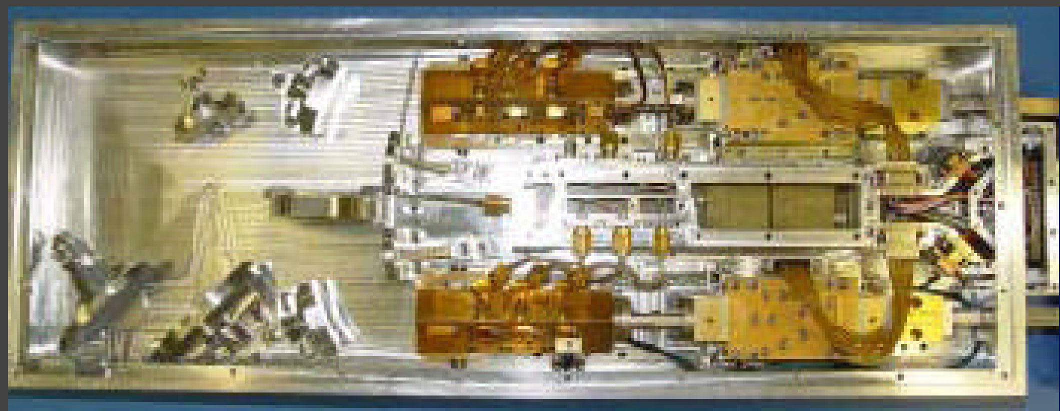
HIFI Local Oscillator Subsystem

<= LOU with 7 LO assemblies LO assembly each with 2 LO chains









HIFI Spectrometers
Each Polarisation has one WBS and HRS

WBS: Acousto-Optical Spectrometer

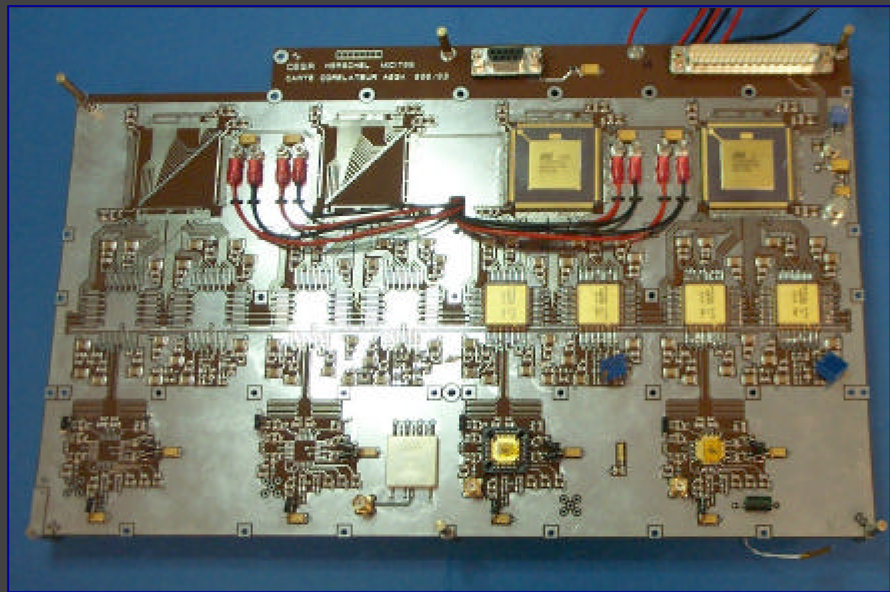
- bandwidth 4 GHz, resolution 1.1 MHz
- 0.6 / 0.15 km/s @ 480 / 1900 GHz
- SWAS heritage

Requirements **HRS** FM capabilities

Mode	high Resolution	Normal Resolution	Low Resolution	Wide Band
Number of Bands	1 1	2 2	4 4	8 8
Bandwidth	250 235	250 235	250 235	500 470
FWHM (MHz)	0.14 0.125	0.27 0.25	0.54 0.5	1.1 1.0

Efficiency : better than 80% over the whole band

Linearity with software correction : better than 1%



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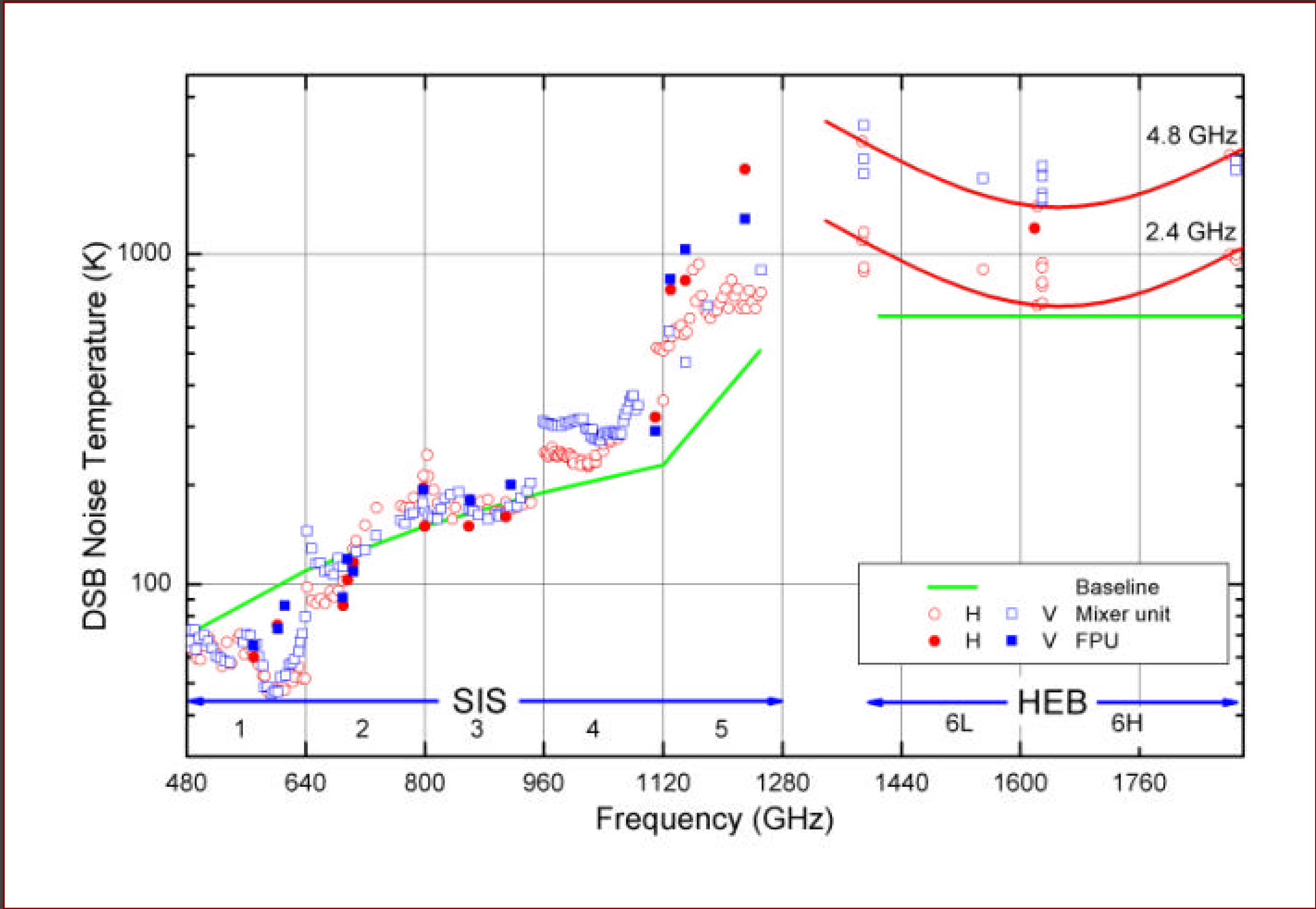
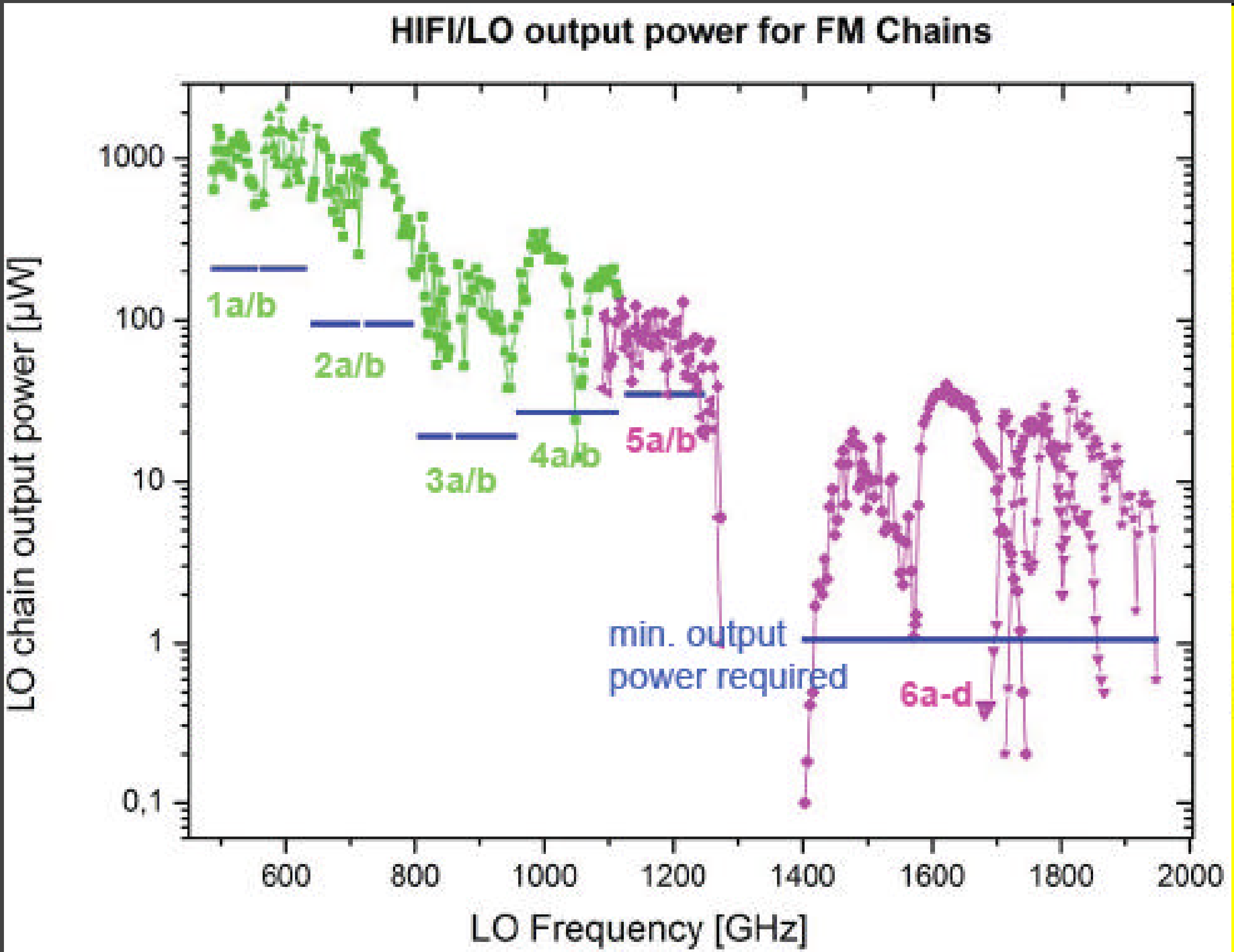
HIFI Flight Mixer Performance at Mixer Unit level (open symbols) and after integration in the FPU



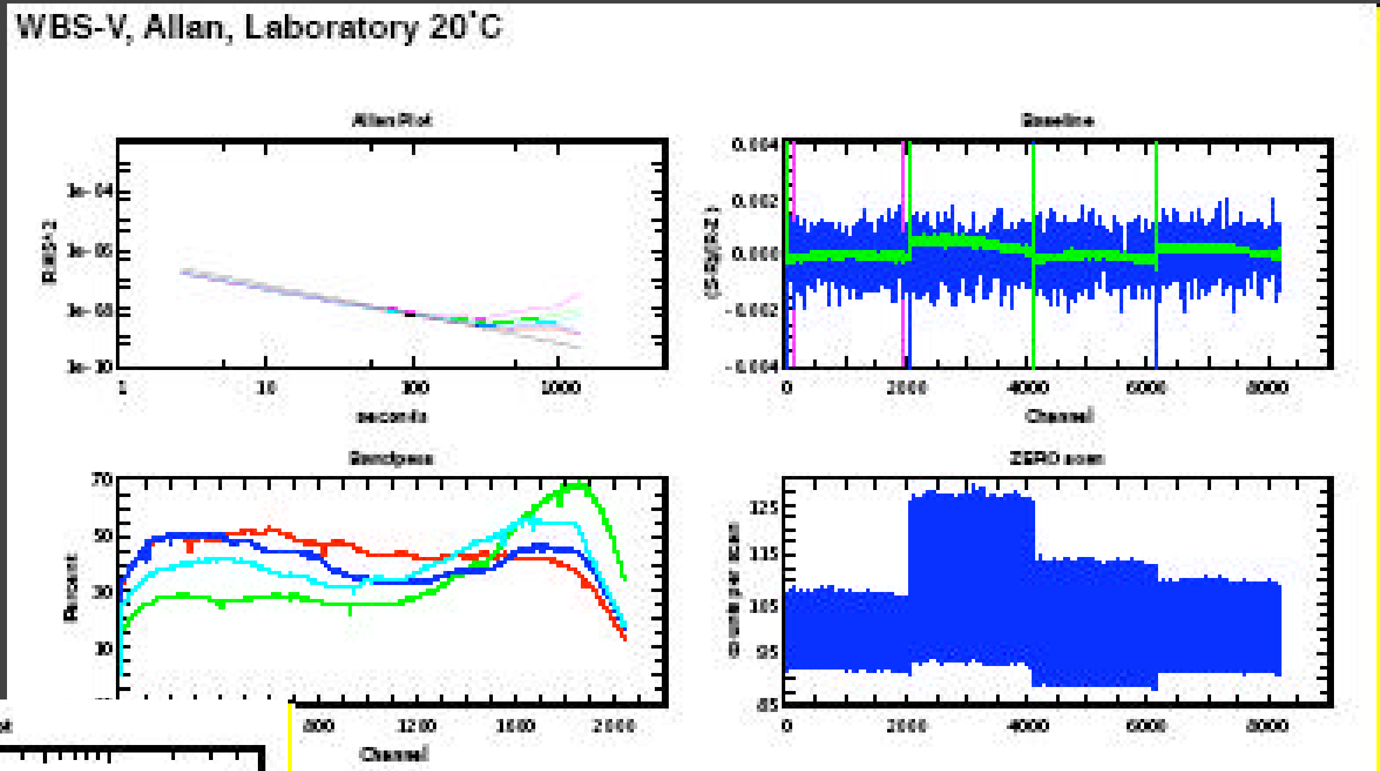
LO chain performance:
Bands 1-4 by RPG; Bands 5, 6L, 6H by JPL

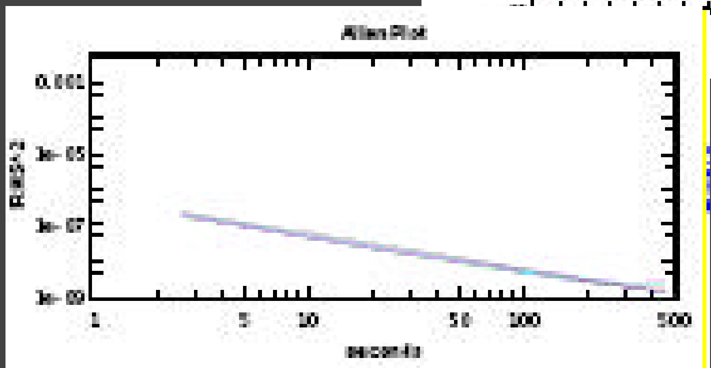


Expected HIFI sensitivities needs correction for latest sensitivity data

	Band					
	1	2	3	4	5	6
Frequency Range (GHz)	480-640	640-800	800-960	960-1120	1120-1250	1410-1910
Receiver Noise (DSB, Baseline) (K)	90	130	170	210	370	650
Receiver Noise (DSB, Goal) (K)	84	120	160	190	210	650
Flux Limit (5σ, 1hr, R=10^4) (Jy)	1.5	2.0	2.3	2.5	2.7	4.6
Flux Limit (5σ, 1hr, R=10^4) (mK)	3.4	4.4	5.1	5.6	6.0	10
Line Flux limit (5σ, 1hr, 10^4) (10^{-18} Wm^{-2})	0.9	1.4	2.0	2.6	3.2	7
Line scan (1σ, 24hrs, f=1MHz) (mK)	16	16	16	16	16	34
Spectral Resolution (MHz)	0.14 – 0.28 – 1.00					

WBS Performance
Allan variance measurements:
Stability >200 sec





For temperature stability < 0.01 C/hr
At 10 C

Observing with Herschel-HIFI

HIFI Observing Modes:

- **dual beam switching (fast)**
- **position switching (slow)**
- **frequency switching**

- **on-the-fly mapping (with FS or LS)**
- **frequency survey (scan)**

- **chopper (wheel) type calibration**
- **asteroids as primary calibrators?**

HIFI AOTs(3) and Observing Modes (4)

Reference mode:	AOT I Single point observations	AOT II Mapping observations	AOT III Spectral scans
Position-switch:	Observing mode I-1 Fixed point position switch	Observing mode II-1 On-The-Fly map	
Dual beam switch:	Observing mode I-2 Point with dual beam switch	Observing mode II-2 DBS raster map	Observing mode III-2 DBS spectral scan
Frequency switch:	Observing mode I-3 Point with frequency switch	Observing mode II-3 Frequency switch OTF map	Observing mode III-3 Freq. switch spectral scan
Load chop:	Observing mode I-4 Point with load chop		

HIFI Data Products and Processing Levels (ground-based heritage)

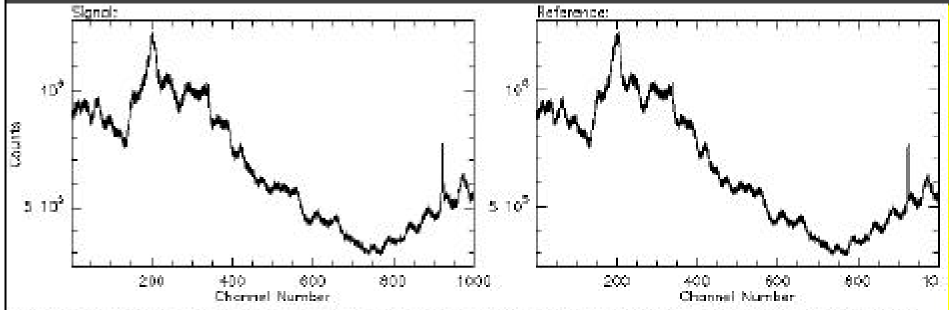


Figure 3 Typical level 0 raw data for single dish sub-millimetre signal and reference source scans.

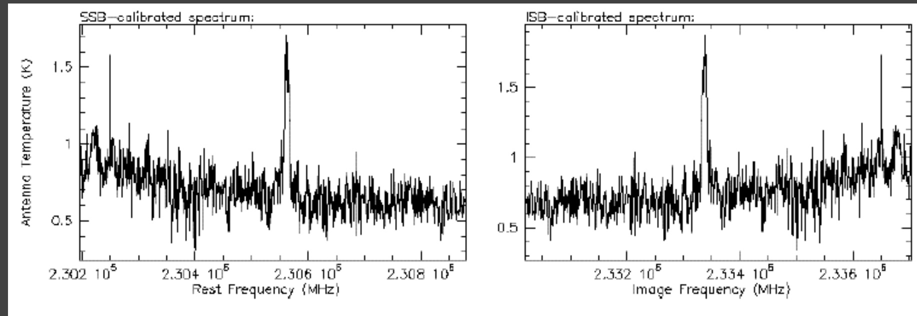
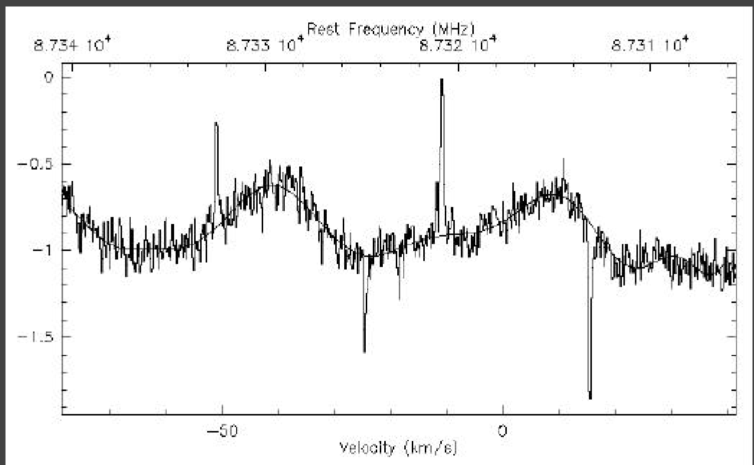
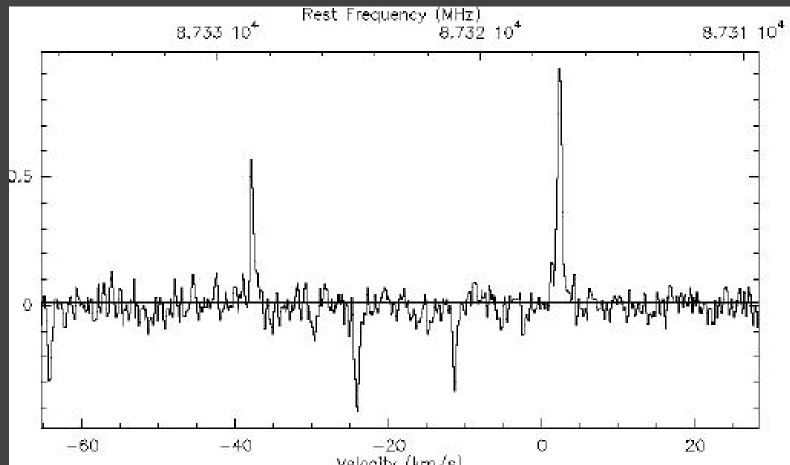


Figure 4 Typical narrow band single dish sub-millimetre level 1 calibrated scans.

Level0

Level1





Level1

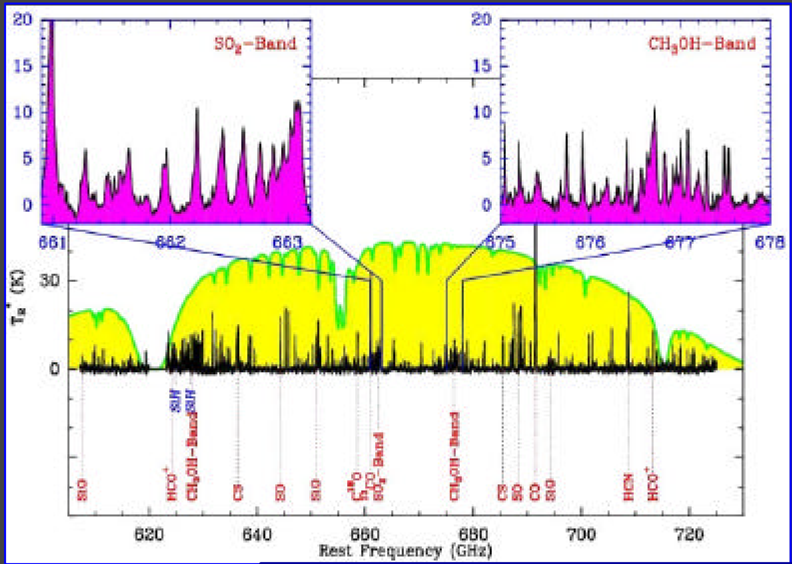
Level2

HIFI Guaranteed Time Key Programs

HIFI Spectral Line Surveys

CSO Spectrum of Orion: 8 nights

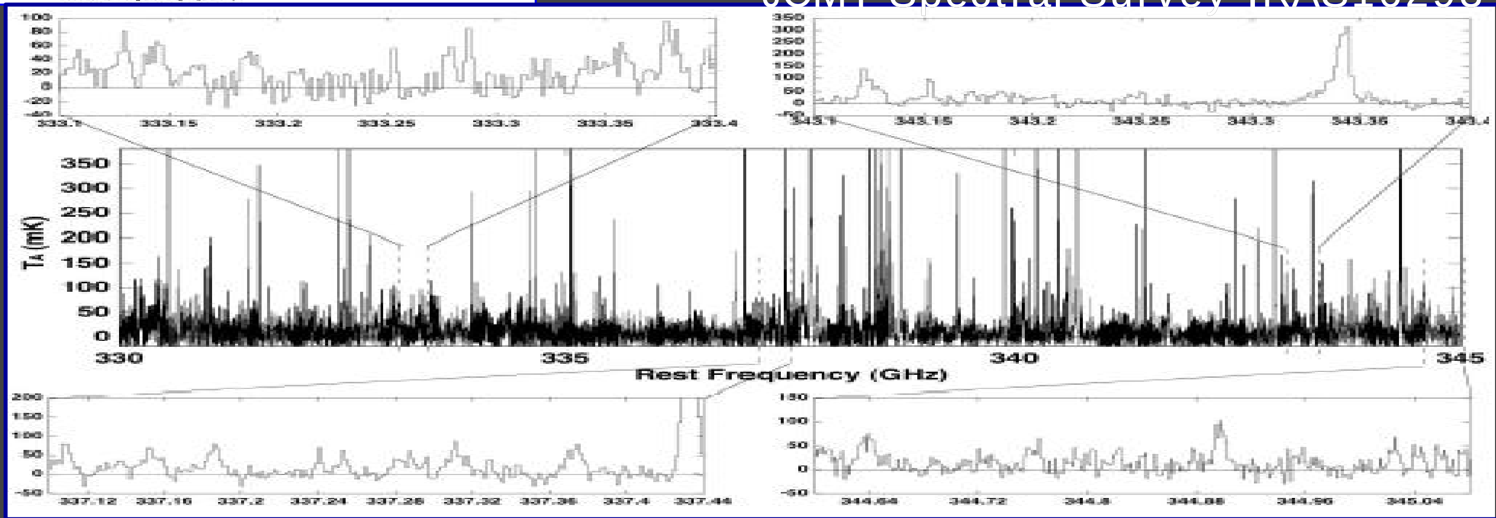
For HIFI: < 1 hr; Total HIFI range in 12 hours

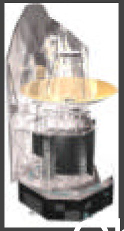


Spectral survey of Orion-KL showing hundreds of molecular lines with atmospheric transmission overlaid.

HIFI will be able to survey outside of the atmospheric windows and at frequencies never probed before, allowing for searches of new molecules.

JCMT Spectral Survey IRAS16293

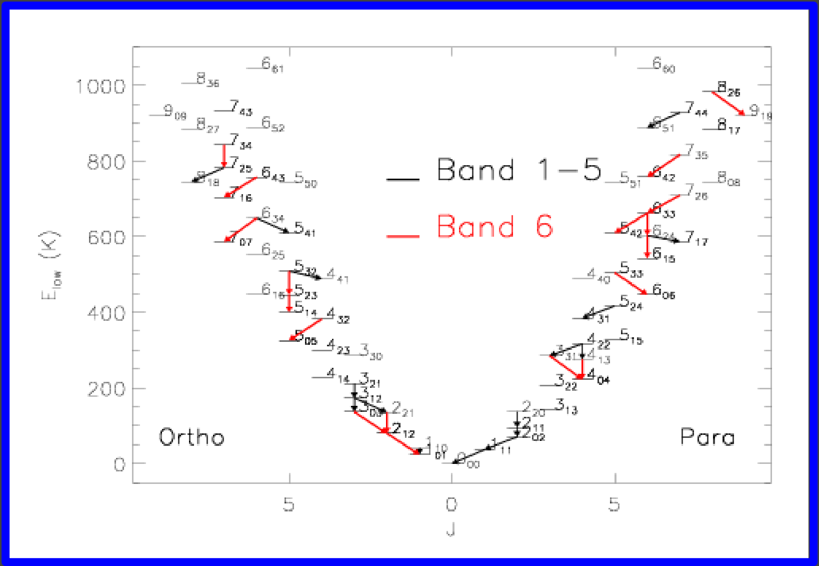


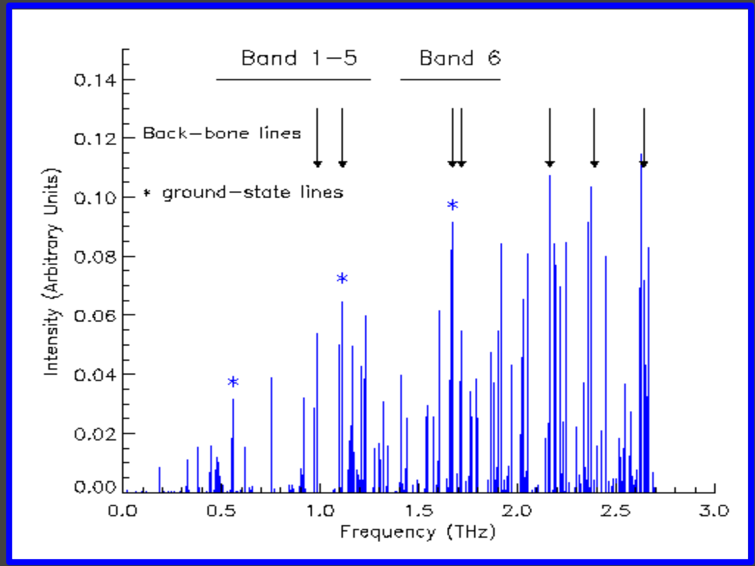


HIFI water line observations

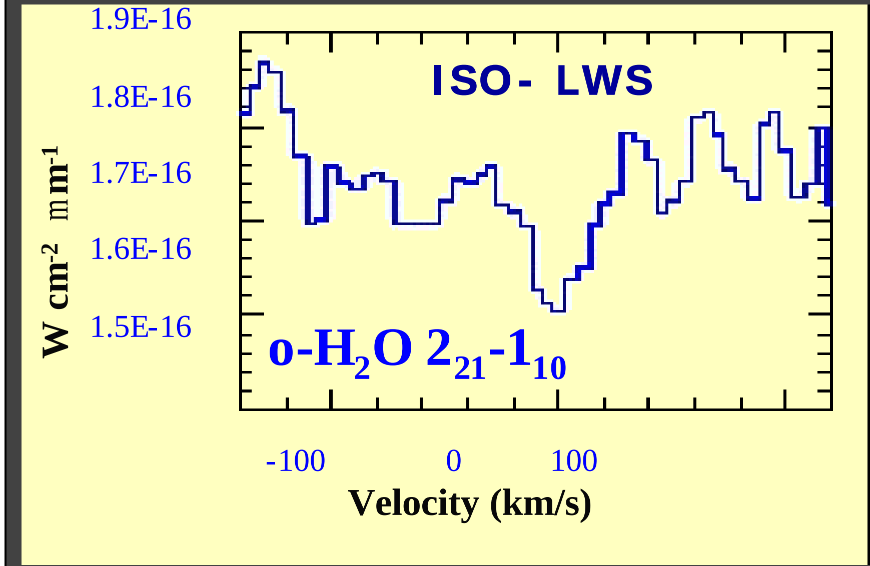
Observations by ISO and SWAS/Odin have shown: **Water is present in a variety of objects all over the Galaxy.**

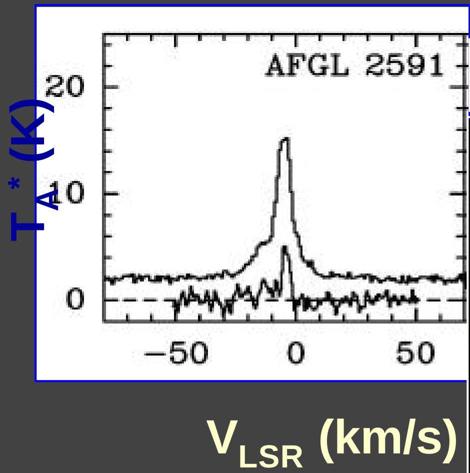
The high resolving power, high sensitivity and large frequency coverage of HIFI, combined with Herschel’s smaller beam ‘will extend our knowledge by orders of magnitude’

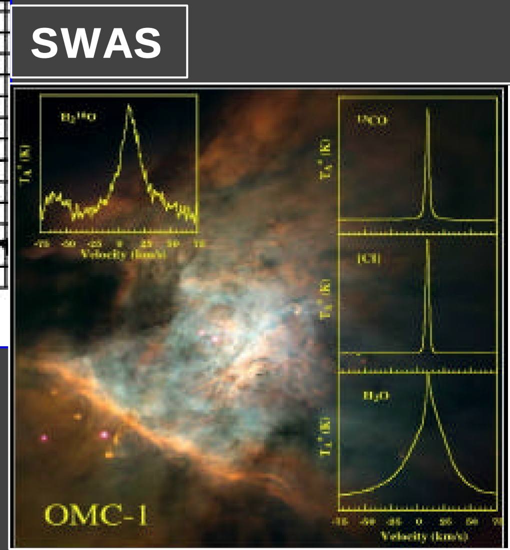


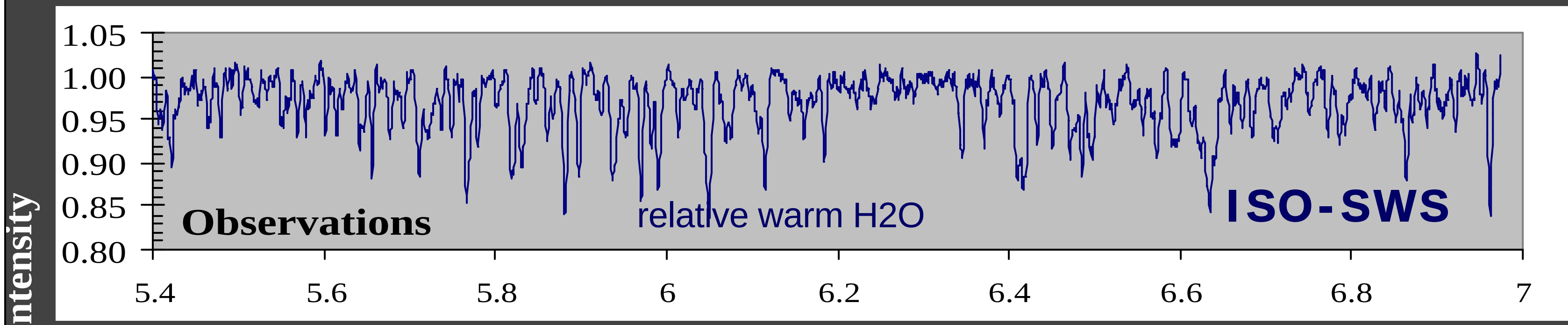


HIFI Unique Science: Water abundant from SWAS, ODIN, ISO, Spitzer, etc



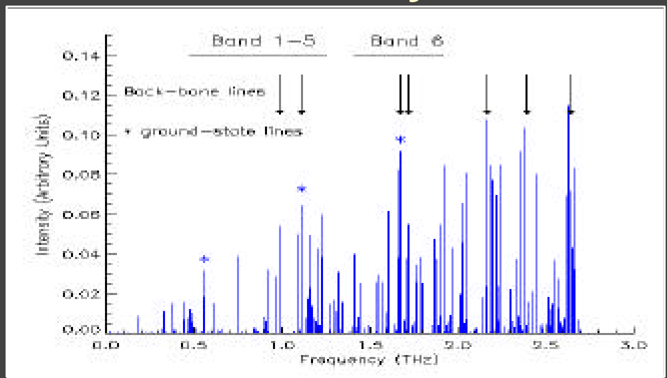


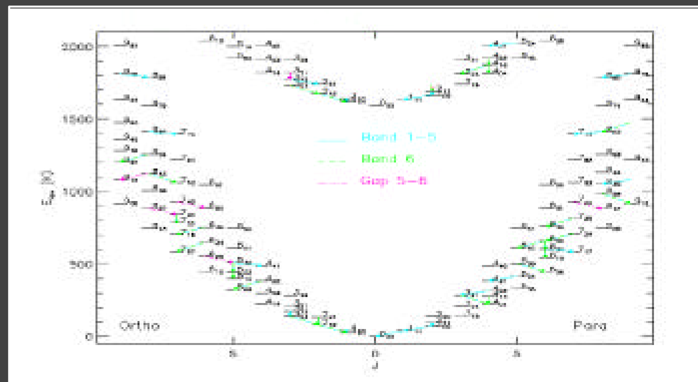




General questions when considering WATER Observations

- How many H2O lines are needed to answer scientific goals?
- Which lines are most diagnostic?
- Do we observe mostly strong H2O lines or do we go primarily for weak/isotopic lines? How deep do we need to integrate (e.g., 10 times deeper than LWS, 10 times weaker than Orion scaled for distance?)
- Which additional lines/molecules? OH, CH, CH+, CO,OH, etc..
- How to cope with frequency dependent beam size? (10”—40”)?
- How to cope with pointing inaccuracies? Small Maps?
- Importance of mapping?
- Absorption line studies feasibility?
- Which and how many PACS lines





General questions when considering SPECTRAL SCAN Observations

- How many sources per category? Has each category at least one strong enough source?
- Full scans (=all 7 HIFI bands) versus partial scans (< 1-5 band)
- How deep do we need to integrate?
- Line confusion limits? (Frequency range dependent?)

- How to cope with frequency dependent beam size? (10”—40”)
- How do we cope with pointing errors?
- Extension with PACS and SPIRE spectral surveys?

HIFI Key Programs with possible Open time Key projects OVERVIEW: (with coordinator's name)

1. The Star Formation Program

1.1 WATER (E. van Dishoeck)

1.2 Spectral Scans (C. Ceccarelli)

1.3 The Orion and Sgr B2 regions (T. Bergin)

2. ISM

2.1 The Warm ISM (V. Ossenkopf)

2.2 Hydrides and Molecular Carriers (M. Gerin)

3. Late stages of Stellar Evolution (coordinator V. Bujarrabal)

3.1 WATER and CO observations of AGB envelopes, PPNe and PNe

4. Extragalactic Science (R. Guesten)

4.1 Physical and Chemical Conditions of the ISM in Galactic Nuclei

4.2 The Physics of the ISM in Low-Metallicity Environments**

5. Water and Chemistry Studies in the Solar System (P. Hartogh and E. Lellouch)

1.1 Star Formation: WATER

(E. van Dishoeck)

A comprehensive set of water observations towards a large sample of proto stars, covering a wide range of masses and luminosities

Category	Prep. obs	Herschel data	Chem. models	Rad. transfer
LM pre-stellar cores				
LM Class 0				
LM Class I				
LM outflows				
Intermediate. Mass POs				
High Mass PO				
Hot Cores / UC HII				
Disks-Young				
Disks-Debris				

Preliminary Approach:

Observe 5--15+ objects in each category in TBD number of H_2O lines

- Number of H_2O lines varies from few (cold clouds, disks) to >10 (hot cores) per category (incl. $H_2{}^{18}O$ and HDO)
- Observe complementary lines of CO, ^{13}CO, OH, O, H_3O^+,
- Complementary PACS + SPIRE TBD (continuum, lines)

1.2 the HIFI Star/Planet Formation: The Orion and Sgr B2 regions (T. Bergin)

- Comprehensive and complete survey of these two objects by Herschel/HIFIand with PACS. These observations fall into two categories:
  - spectral surveys (KL/IRC2, Orion-S, Orion Bar; Sgr B2 (N), Sgr B2(M)

1.3 Star/Planet Formation: "Unbiased" spectral surveys (C. Ceccarelli)

- Complete and partial spectral surveys of some (~7?) sources, covering various stages of evolution with a wide range of physical and chemical conditions.

2.1 The Warm ISM
(V. Ossenkopf)

- FIR spectroscopy of molecular clouds heated by UV radiation and shocks covering a broad range of parameters so that we can test models of photo-dissociation regions (PDRs) and models of shock fronts and study the combined effect of both on the chemical and physical structure of the warm and dense ISM.

- Using HIFI and PACS:
- About 18 sources: like S140, S106, ? Oph, IC 443, etc..
- Lines: Water, OH, CH, CH+, NH, NH+, CO, ...

SRON

2.2 ISM: Hydrides and Molecular Carriers (M. Gerin)

- Observations of Hydrides and C- Clusters and complex molecules with HIFI and PACS
- A.o. H_2O, CH, CH^+, NH, NH^+, NH_2, NH_3, HF, HDO, etc..

3. Late stages of Stellar Evolution: Water and CO observations of AGB envelopes, PPNe and PNe (V. Bujarrabal)

- Observations of WATER and CO, as a function of evolutionary stage, nebula mass, element abundances, initial stellar masses etc. towards a selected number of sources

4. Physical and Chemical Conditions of the ISM in Galactic Nuclei (R. Guesten)

Observe a representative set of important cooling lines in nearby galaxies, AGN and starburst nuclei

The bright fine-structure lines of neutral and ionized atomic carbon, nitrogen and oxygen, a unique set of water lines, and the high-excitation CO transitions. (HIFI and PACS observations)

Subjects that will be addressed:

- 4.1.1 The Physical Conditions of the ISM in the Galactic Center
- 4.1.2 Excitation studies of starbursts, ultra-luminous galaxies, AGNs, and Interacting Galaxies and Mergers
- 4.1.3 The chemical complexity in extragalactic nuclei: line surveys and absorption line studies toward x-galactic nuclei
- 4.2 The Physics of the ISM in Low-Metallicity Environments.

Water in the Solar System
(P. Hartogh and E. Lellouch)

A - Water in the outer solar system

1- Planets

Observations:

a) Observe 2 to 4 water lines, of different intensities, on each of the five Outer Planets
b) Map a high-frequency water line (1717 GHz) on Jupiter
c) Monitor these lines typically once a year

2- Comets

Observations:

a) Search for H2O emission in weak/distant comets
b) Observe H2O lines on comets with production rate >2e28 sec-1
c) Observe HDO on the same comets

B- Water and chemistry in the Martian atmosphere

Observations:

a) Mars in H2O lines, and lines of O2, O3, H2O2, CO and 13CO
b) Isotopes of H2O and deep dedicated search for OH and HO2
c) A spectral survey