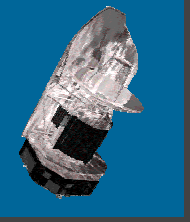
Heterodyne Instrument for the Far Infrared (HIFI)

SRON
Netherlands Institute for Space Research

Netherlands Organisation for Scientific Research

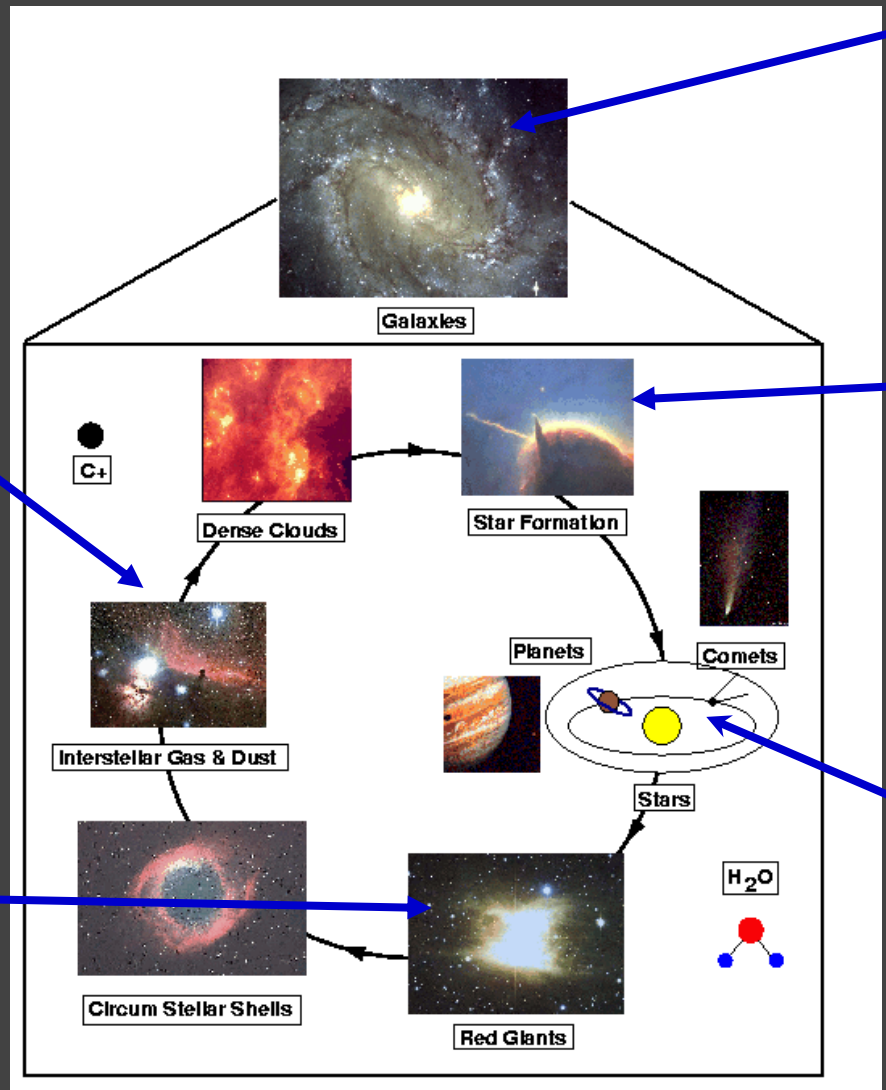
HIFI Science Targets in a nutshell: Life Cycle of Galaxies



HIFI

ISM in Galaxies
- Physical conditions
- Star formation

ISM in the Milky Way
- Physical conditions
- Chemistry
- Energetics
- Dynamics
- Isotopic gradients

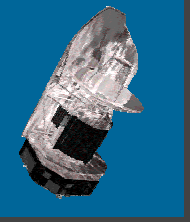


Star formation
- Physical conditions
- Chemistry
- Energetics
- Dynamics
- Role of Water

Stellar evolution
- Mass loss
- Composition

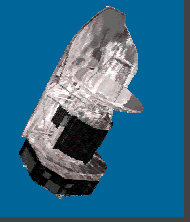
Solar System
- Water in Giant Planet
- Chemistry Martian atmosphere

SRON

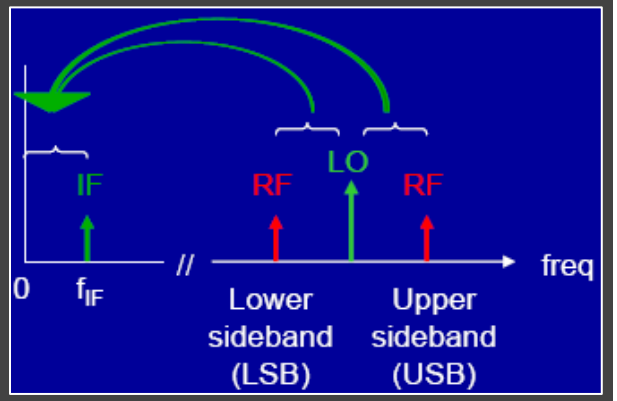


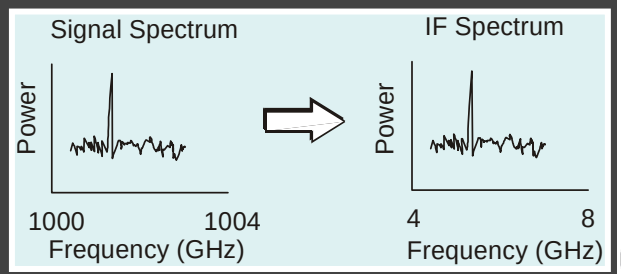
Herschel-HIFI Consortium

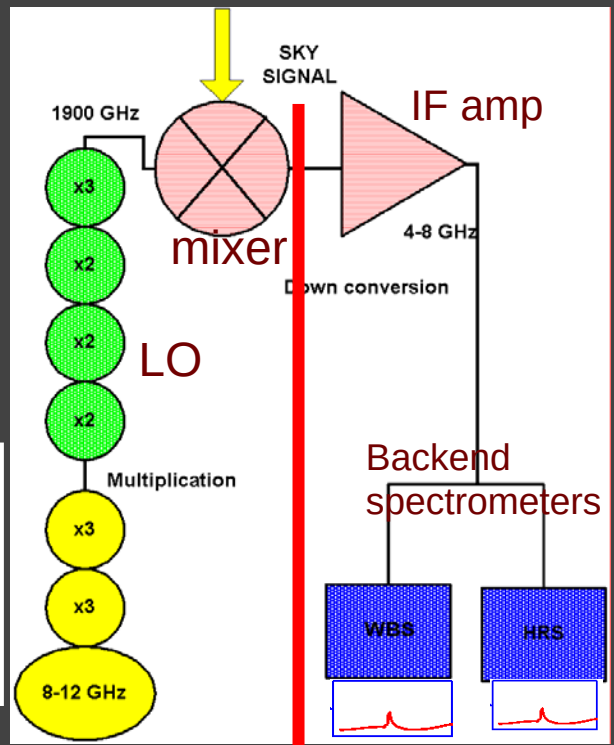
The Netherlands: SRON -Groningen - Utrecht University of Delft	**USA:** Caltech and JPL, Pasadena Univ. of Amherst
France: CESR Toulouse LRM-DEMIRM with IRAM Observatoire de Bordeaux	**Germany:** KOSMA, I. Phys Institut, Köln Max Planck Inst. , Lindau Max Planck Inst. für Radioastronomie Bonn
Italy: CAISMI-CNR, Florence IFSI, Rome	**Poland:** Space Research Center Copernicus Astr. Institute.
Spain: Centro Astron. deYebes/OAN CSIC, Madrid	**Sweden:** Onsala and GARD, Chalmers TH, Göteborg
Switzerland: ETH, Zürich	**Canada:** CSA and Waterloo Univ.
Ireland: Maynooth College NUI	With contributions from: **Taiwan** (IF-2 amp. design) **Russia** (HEB NbN layers)

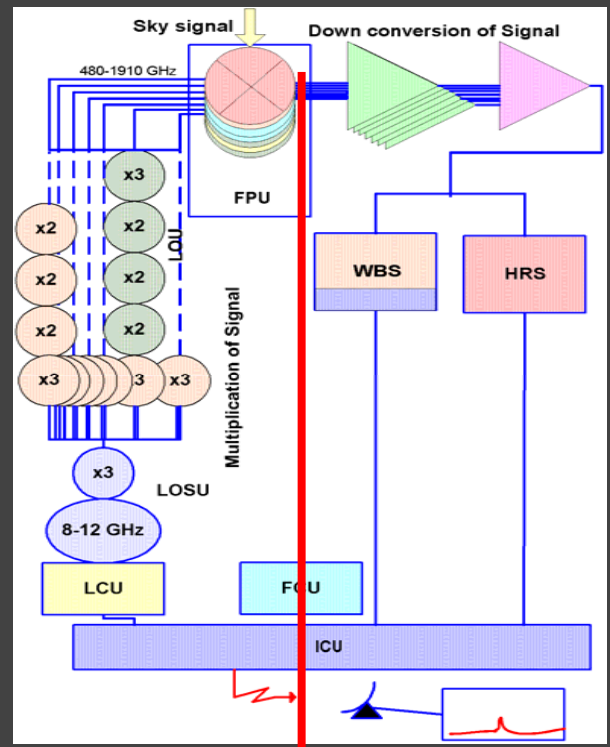


Heterodyne Technical Principle and Modular Approach in HIFI





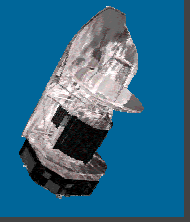




2×7 LO bands
2×7 Mixers H/V

Frequency dependency

Spectral resolution



HIFI Instrument

Requirements — Resulting Concept

Design Requirements

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

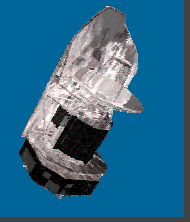
3. Calibration Accuracy: 10% baseline; 3% goal

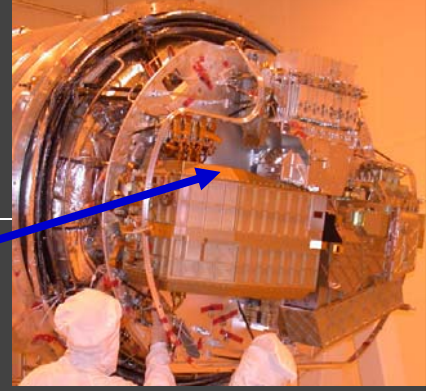
Implementation

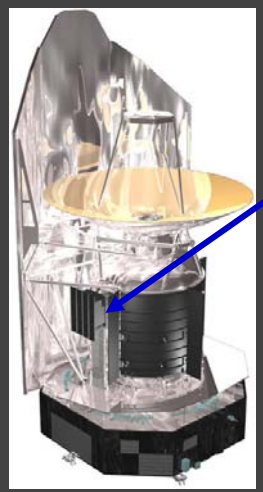
- **Heterodyne spectroscopy**
  - single pixel on the sky
  - very high spectral resolution
- **7 dual-pol mixer bands**
  - 480-1250 GHz (625-240 mm) 5x2 SIS mixers, IF 4-8 GHz
  - 1410-1910 GHz(212-157 mm; 2x2 HEB mixers, IF 2.4-4.8 GHz
- **14 LO sub-bands**
  - LO source unit in common
  - LO multiplier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

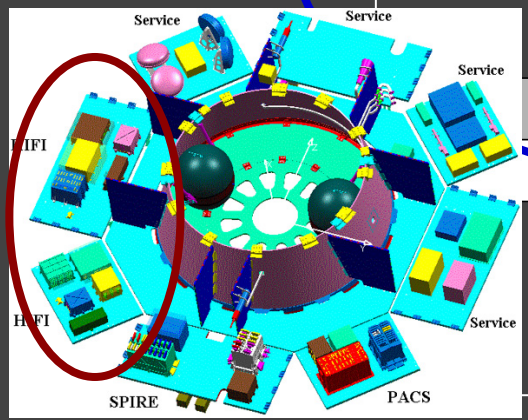
Single pixel on the sky
Angular Resolution (with Herschel): 12”- 40”

HIFI Block Diagram









From Telescope

LOU	FPU	IFV	IFH	LSU	LCU	FCU	HRS-h	WBS-h	HRS-v	WBS-v
Housing 7 LO Assemblies with 7x2 LO chains and power amplifiers	Common Optics Calibration source Chopper mechanism 7 Mixer Assemblies each with 2 mixers IF amplifiers	Band 6 up-converter 3 dB coupler	Band 6 up-converter 3 dB coupler	Master oscillator Synthesizer Ref. distribution	Control Multiplier bias Power amplifier bias Sec Power for LSU	Control Mixer bias Amplifier bias Mechanism control	IF processor Sub-band division Δf~1GHz δf variable	IF processor Sub-band division Δf 4 GHz δf 1 MHz	IF processor Sub-band division Δf~1GHz δf variable	IF processor Sub-band division Δf 4 GHz δf 1 MHz

Instrument Control Unit

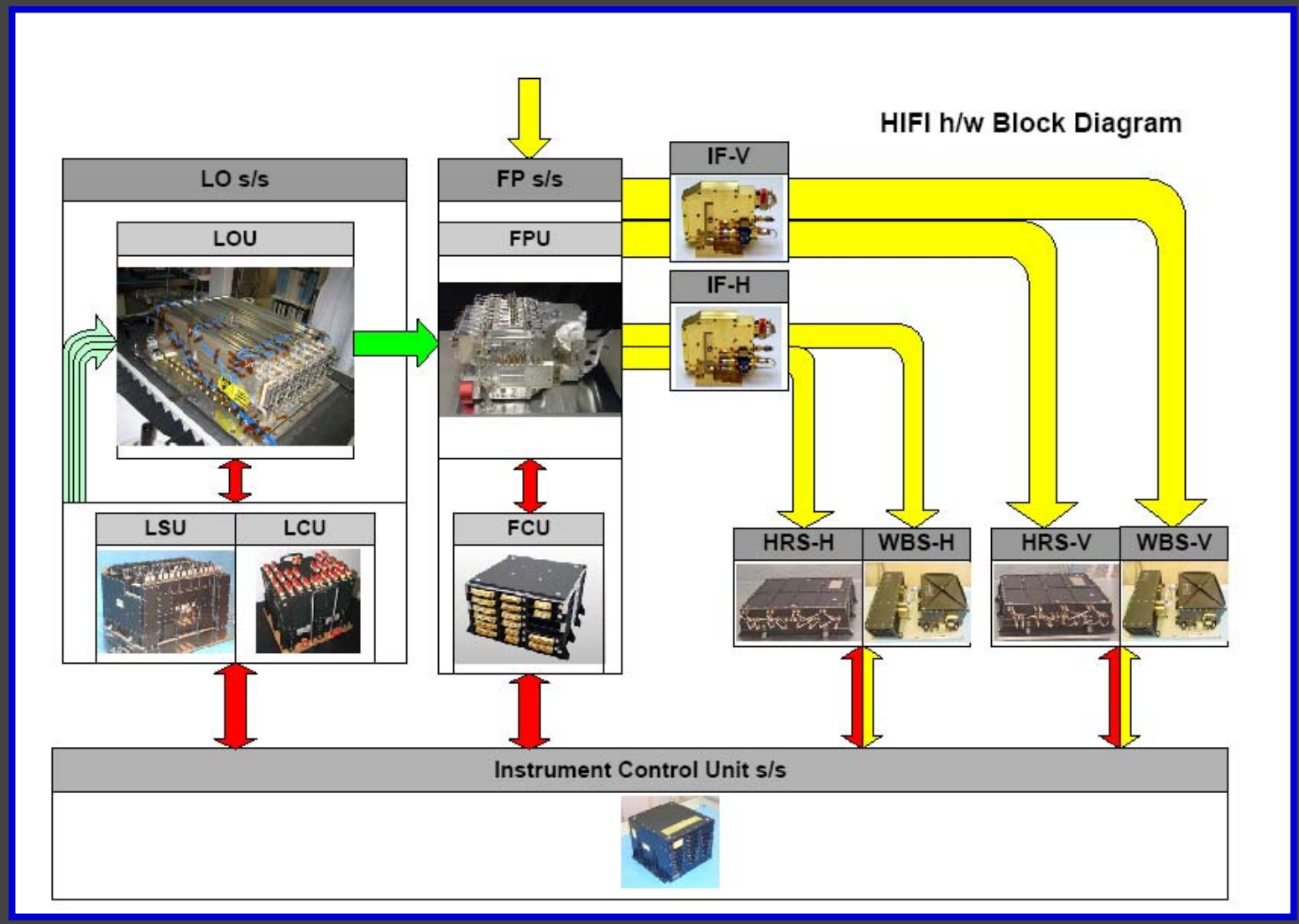
Instrument Controller
Command Interface

Power Conditioning (for FCU only)
Data Interface

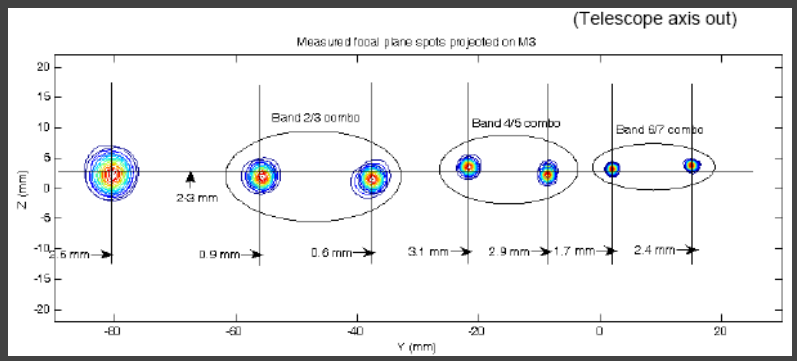
spacecraft
CDMS

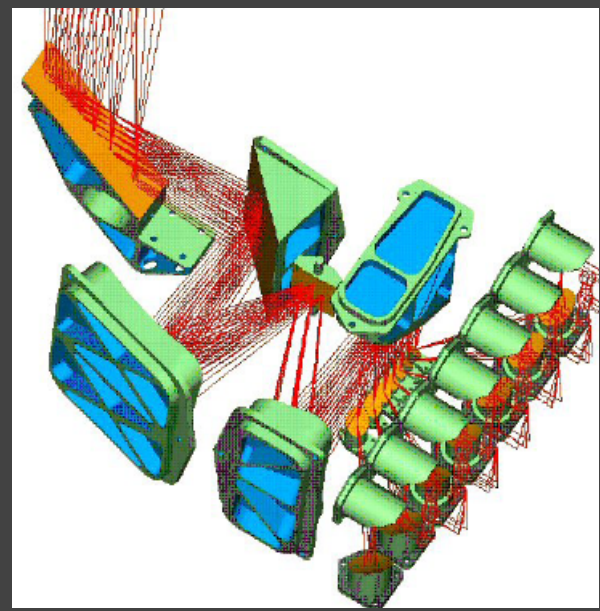
In Service Module

HIFI FM with all flight units delivered
ILT is progressing

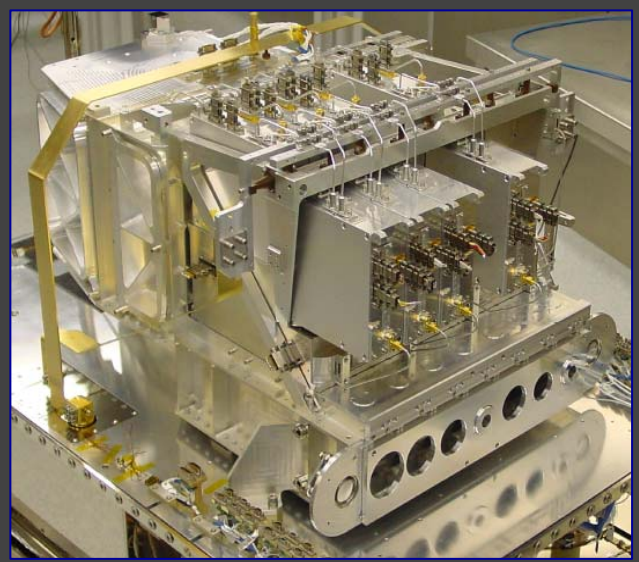


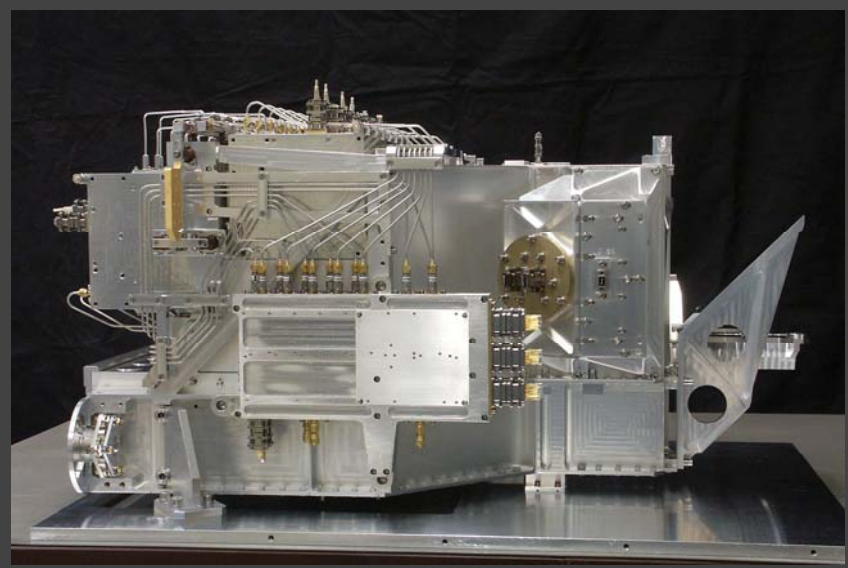
Common Optics Assembly
Other band- other pointing

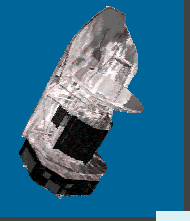




HIFI FPU FM with mixer bands 1,2,3,5 and complete

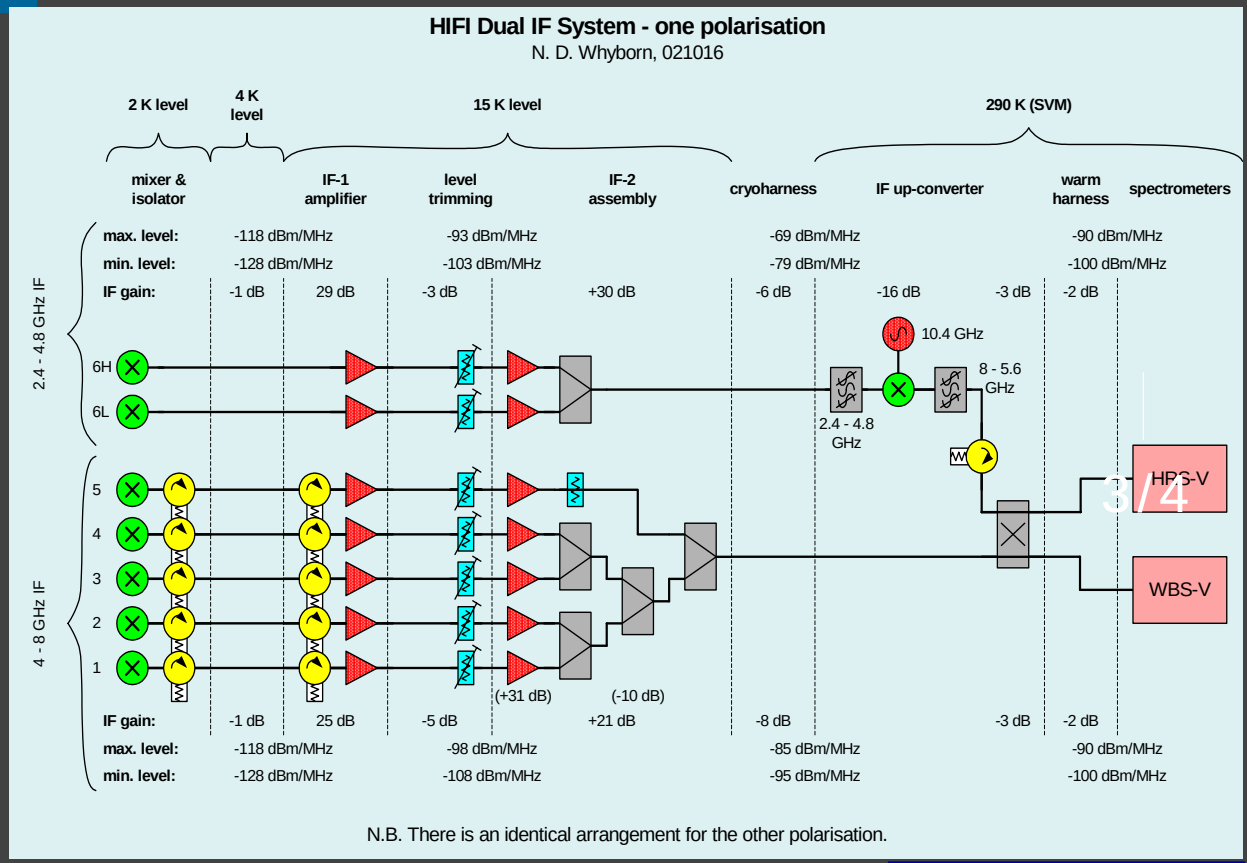




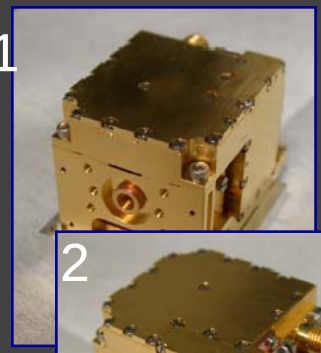


HIFI Signal Chain: Mixers and Amplifiers

HIFI



1



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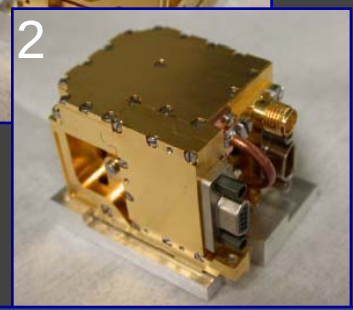
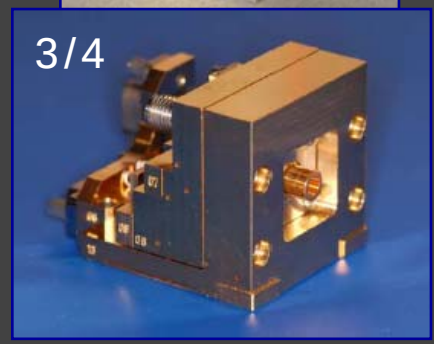
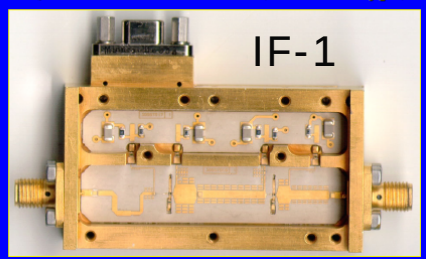


3/4



5

QM & FM PROGRAMS (First Prototype)



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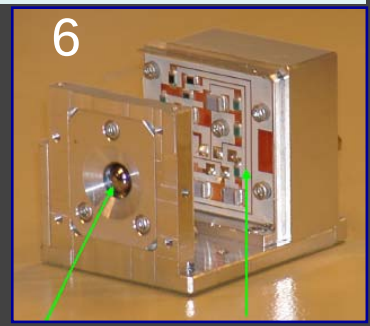
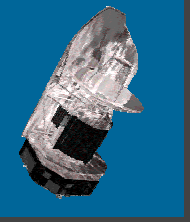
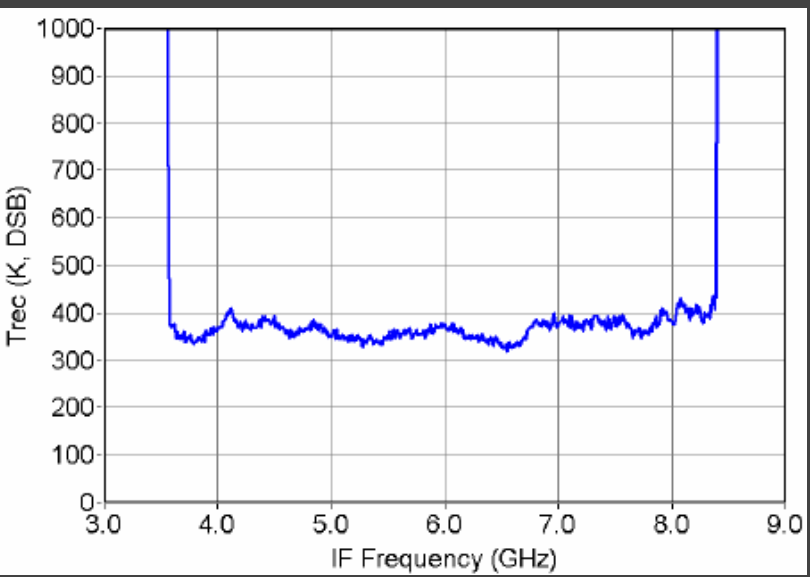




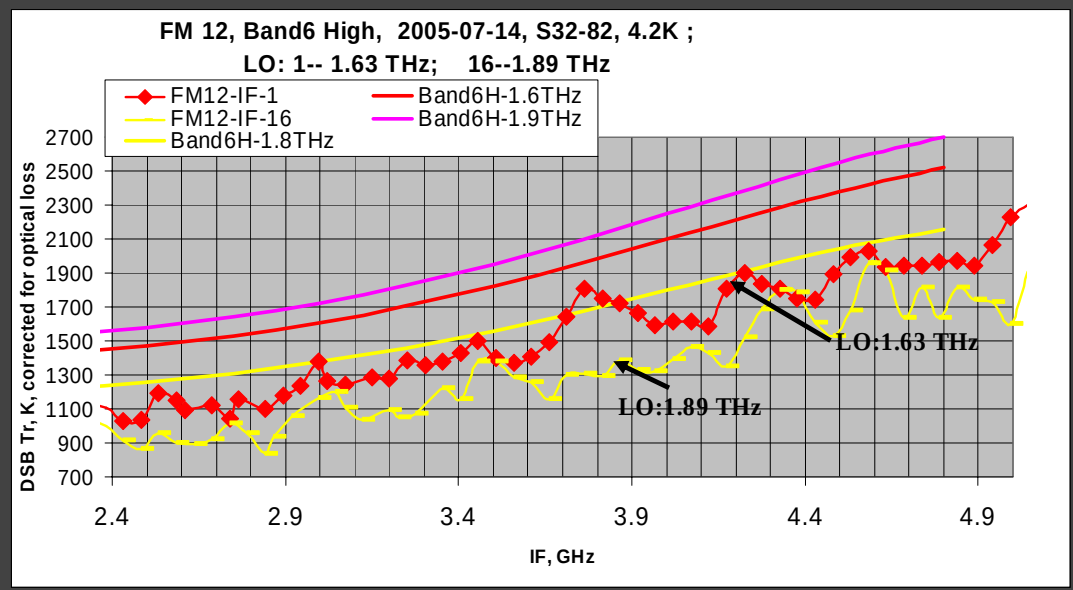
IN HIFI: ONE FREQUENCY Band is working at a time with 2 mixers;

- In orthogonal polarisation, also for redundancy.
- One LO band, with 2 sub-bands, match the corresponding mixer band

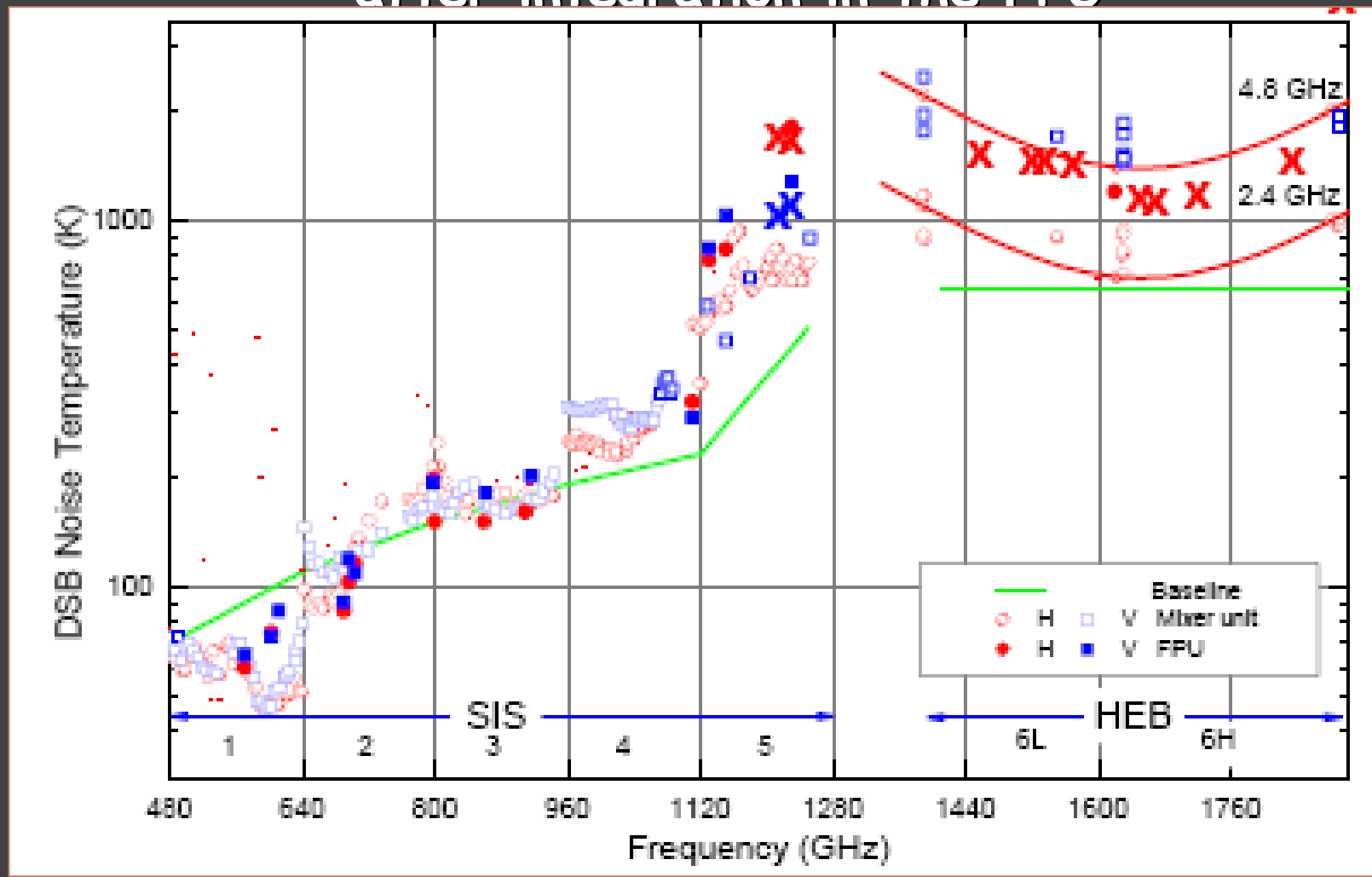
Band-3 SIS Noise Temperature as function of IF



Band-6 HEB Noise Temperature as function of IF

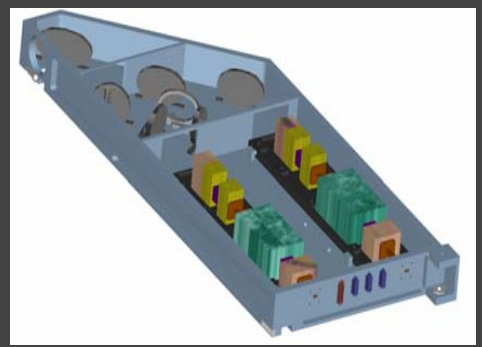


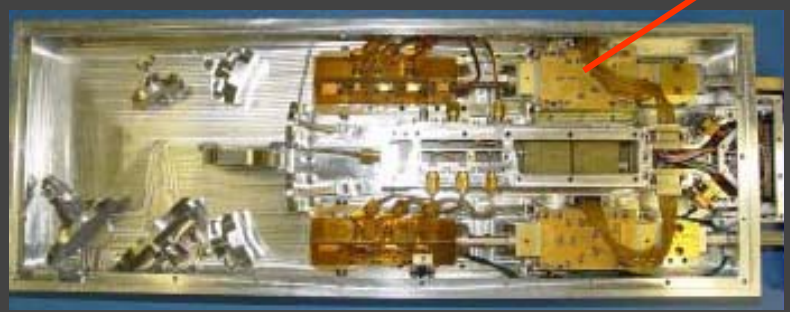
HIFI Flight Mixer Performance at Mixer Unit level (open symbols) and after integration in the FPU

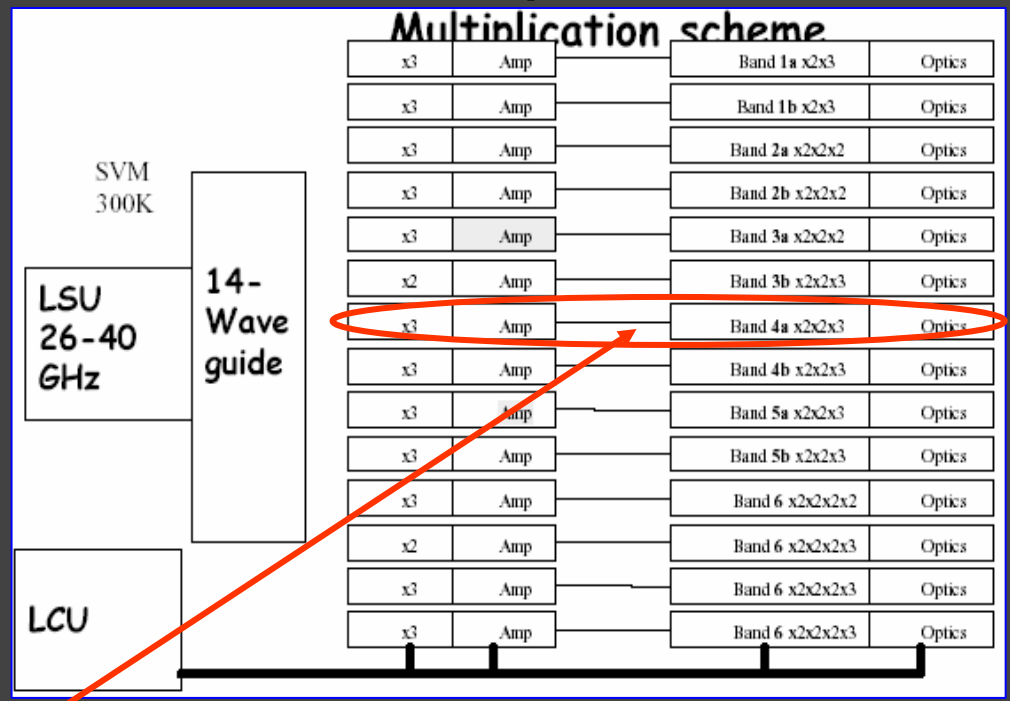


HIFI Local Oscillator Subsystem

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

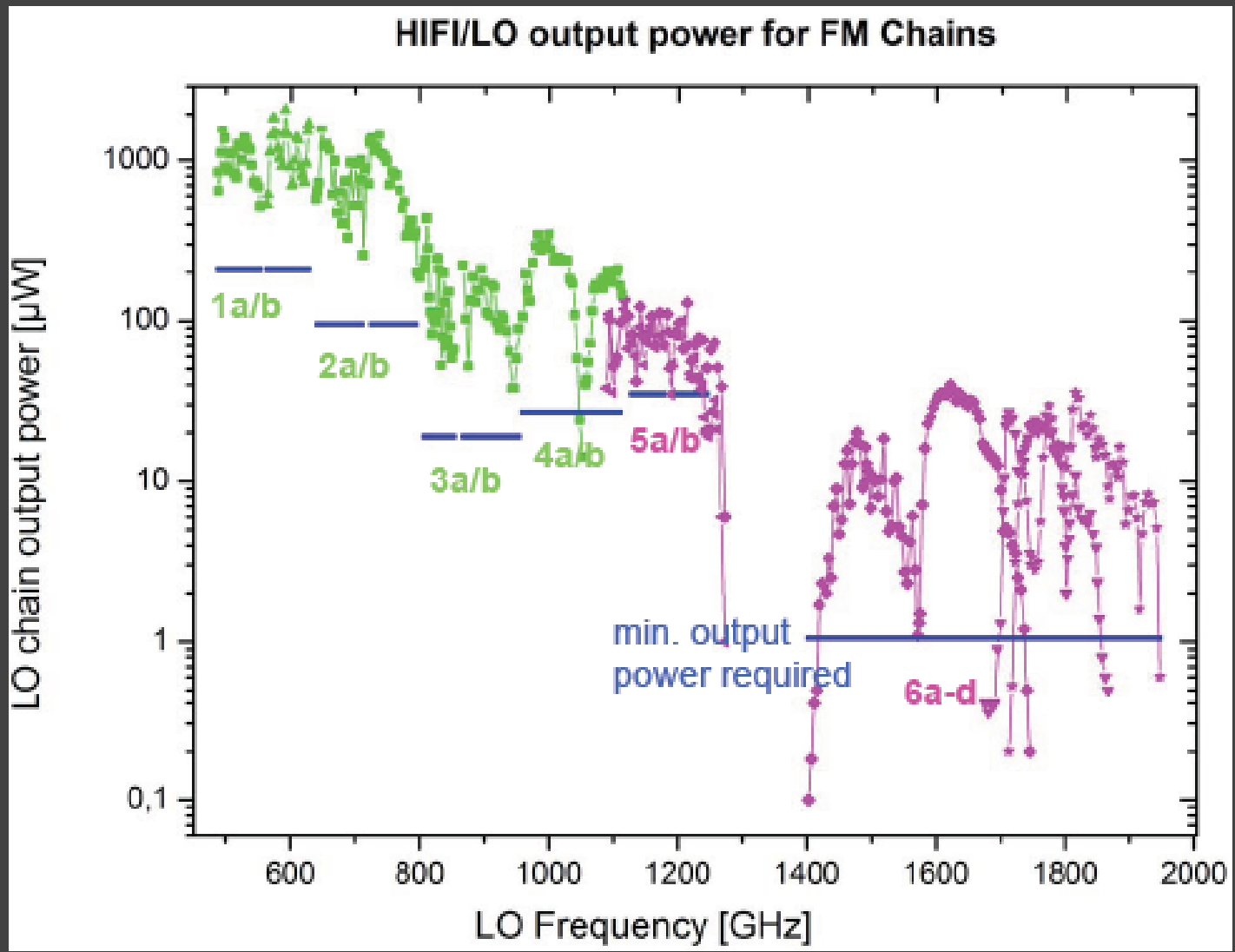




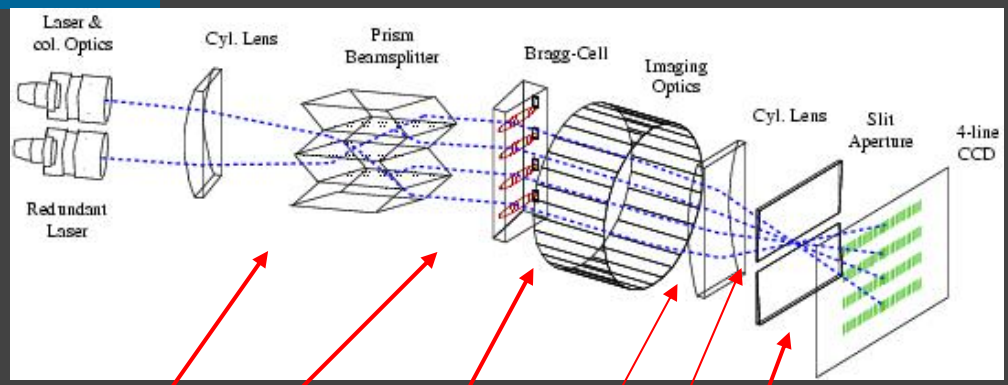


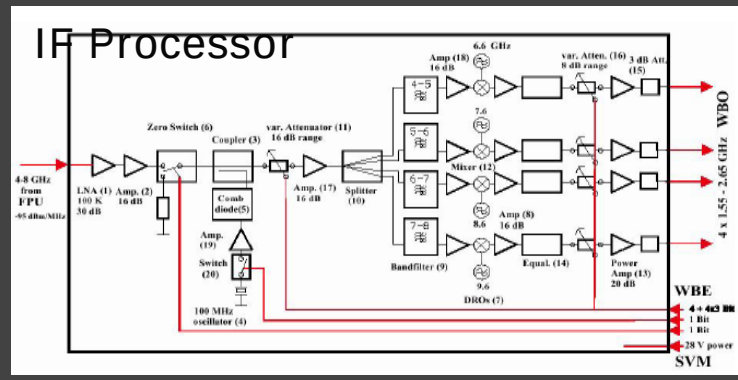
LSU

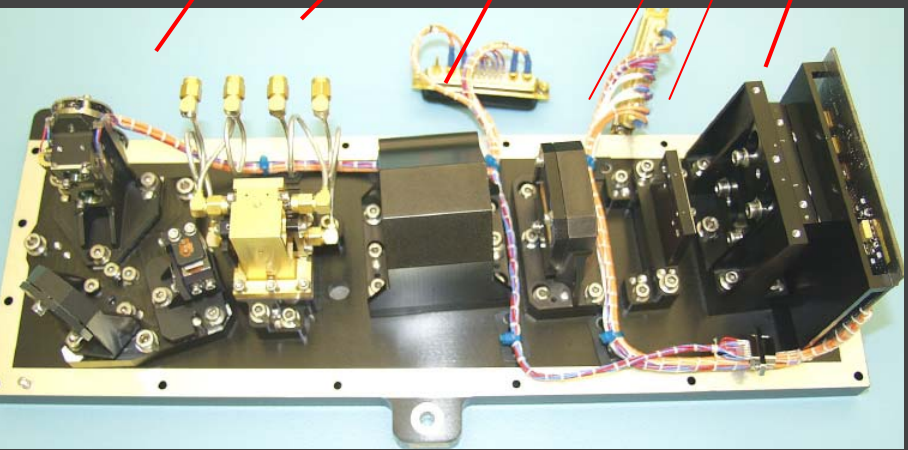
LO chain performance:
Bands 1-4 by RPG; Bands 5, 6L, 6H by JPL



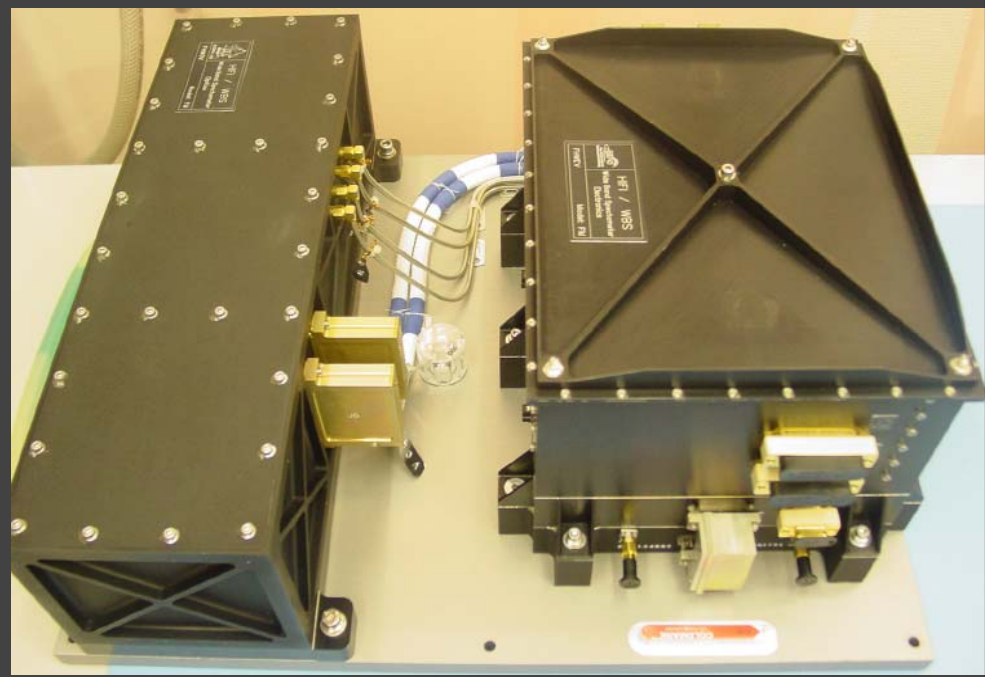
WBO FM (one Polarisation) with 1.1 MHz resolution and 4GHz bandwidth







Source module | Bragg-cell | Imaging optics | Cyl. lens | CCD

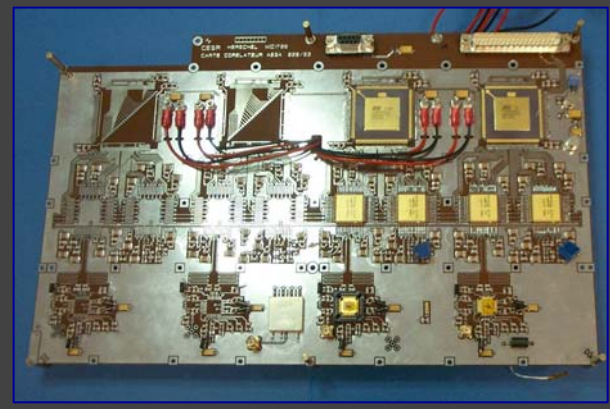


HIFI-HRS (auto-correlator) FM Capabilities

Requirements			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

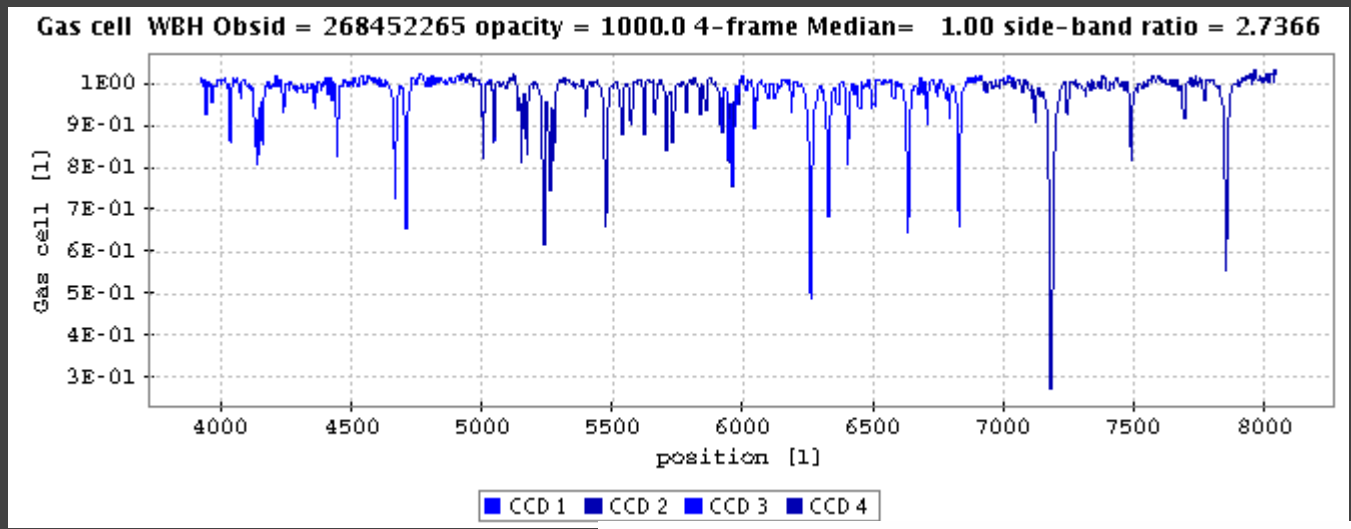
Linearity with software correction : better than 1%



2 HRS FM modules

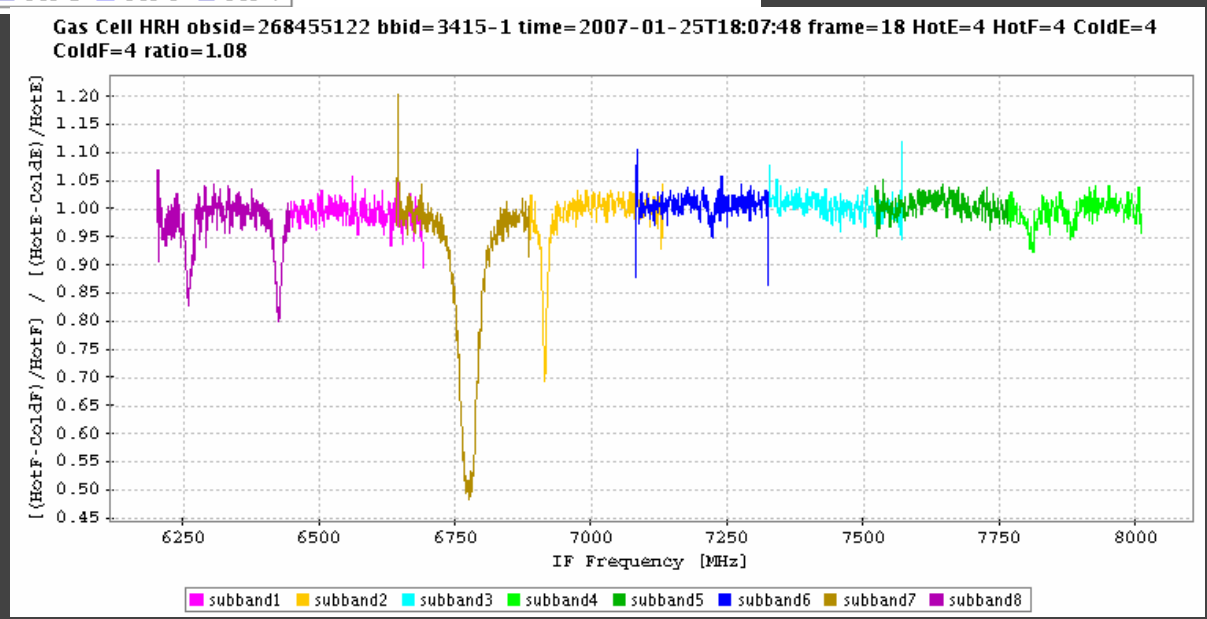
HIFI FM Test set-up

HIFI FM ILT spectra



Methanol
1016 GHz
With WBS

SO_2
1696 GHz
With HRS



HIFI Observing Modes and AOT summary

	AOT I Single point observations	AOT II Mapping observations	AOT III Spectral scans
Reference mode:			
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		

- Dual Beam Switch with internal copper and telescope nod
- Position Switch efficiency depending on off-position slew
- Frequency Switch with switching LSU
- Optimum AOT depending on stability Telescope-Instrument System

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

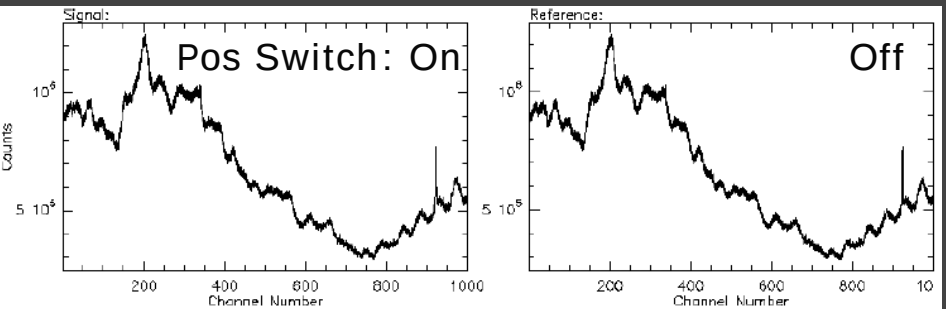


Figure 3 Typical level 0 raw data for single dish sub-millimetre signal and reference source scans.

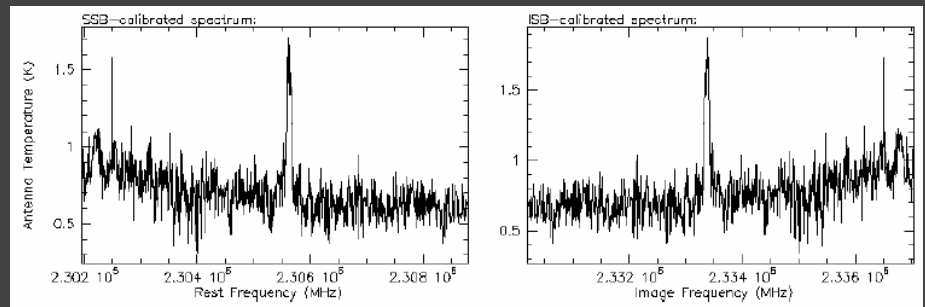
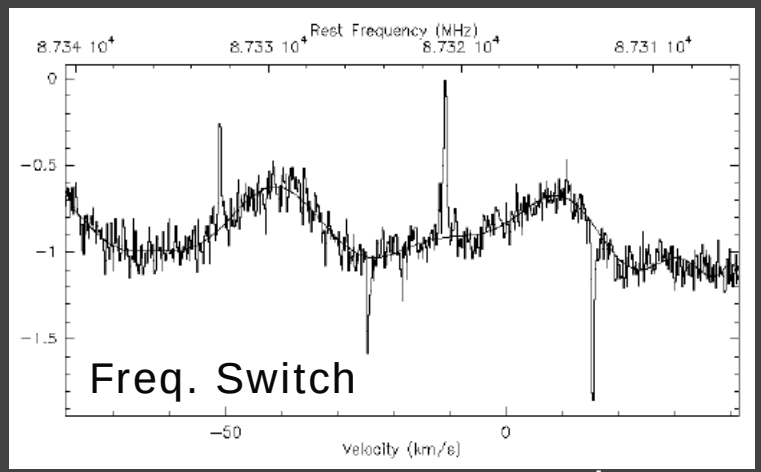


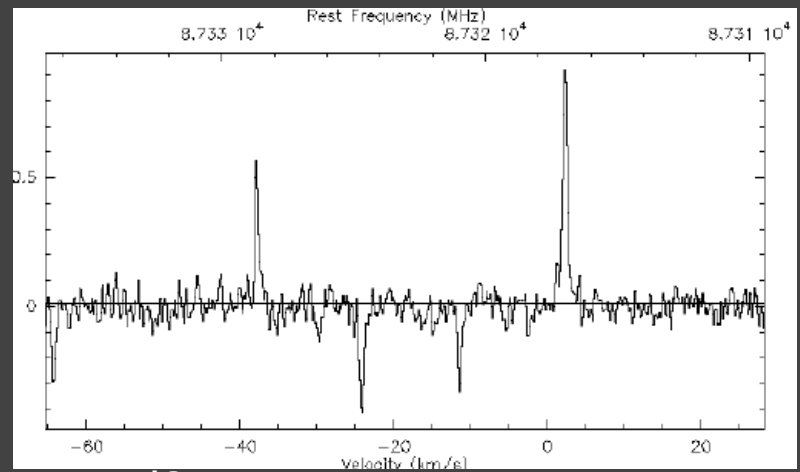
Figure 4 Typical narrow band single dish sub-millimetre level 1 calibrated scans.

Level 0

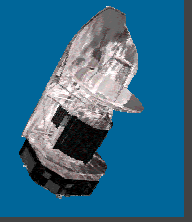
Level1



Level1

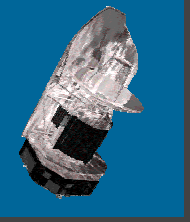


Level2



HIFI EXPECTED SENSITVITY ESTMATED JANUARY 2007 (+ large effects from overheads)

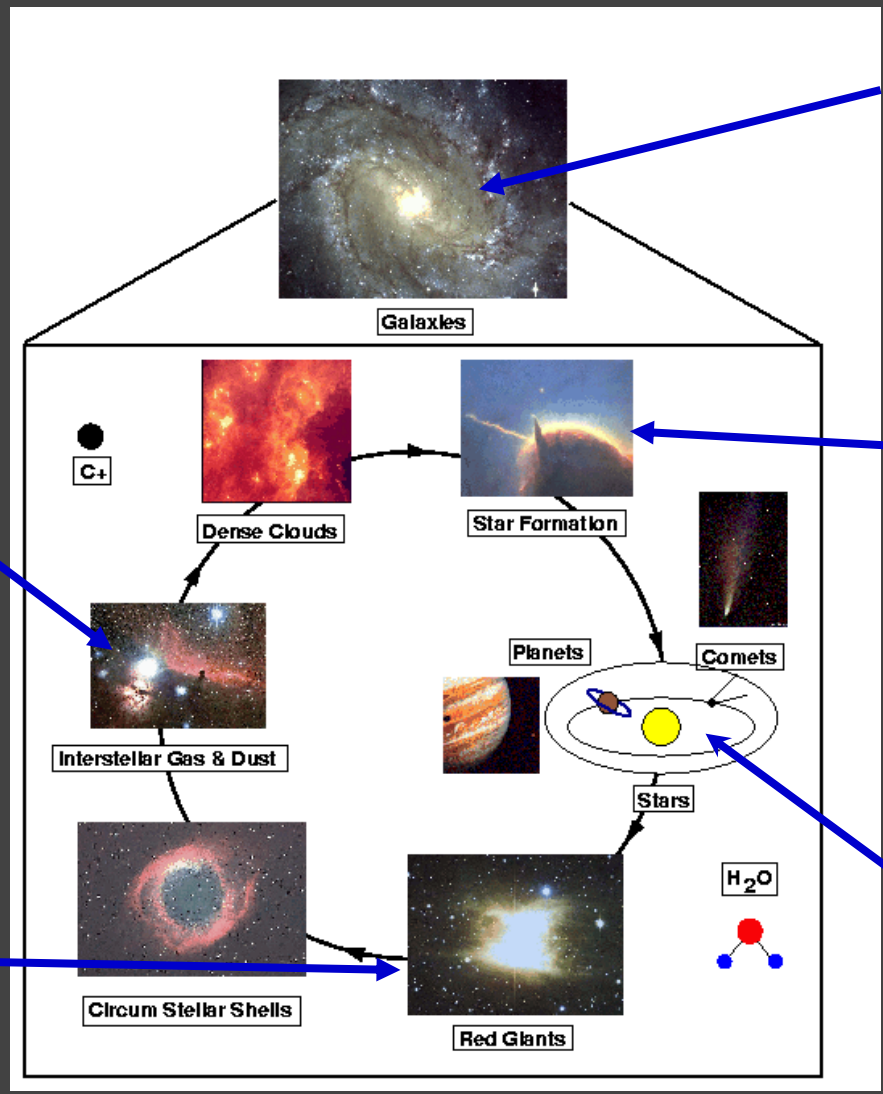
	Mixer Band						
	1	2	3	4	5	6	7
Frequency range	480-640	640-800	800-960	960-1120	1120-1250	1410-1660	1660-1920
Receiver Noise (SSB) (K)	180	400	480	900	2000	3000	3200
Flux limit (1σ, 1hr, 1km/s) (mK)	5.8	11	13	22	46	60	60
Flux limit (1σ, 1hr, 1km/s) (Jy)	2.6	5.2	5.7	9.9	21	36	36
Flux limit (1σ, 1hr, 1km/s) (10^{-18} Wm^{-2})	0.06	0.14	0.18	0.36	0.87	2.0	2.2
Line scan (50 GHz in 10 hr, 1σ) (mK)	8	14	25	35	100	150	150



Life Cycle of Galaxies

HIFI

ISM in the Milky Way
- Physical conditions
- Chemistry
- Energetics
- Dynamics
- Isotopic gradients



ISM in Galaxies
- Physical conditions
- Star formation

Star formation
- Physical conditions
- Chemistry
- Energetics
- Dynamics
- Role of Water

Stellar evolution
- Mass loss
- Composition

Solar System
- Water in Giant Planet
- Chemistry Martian atmosphere

SRON

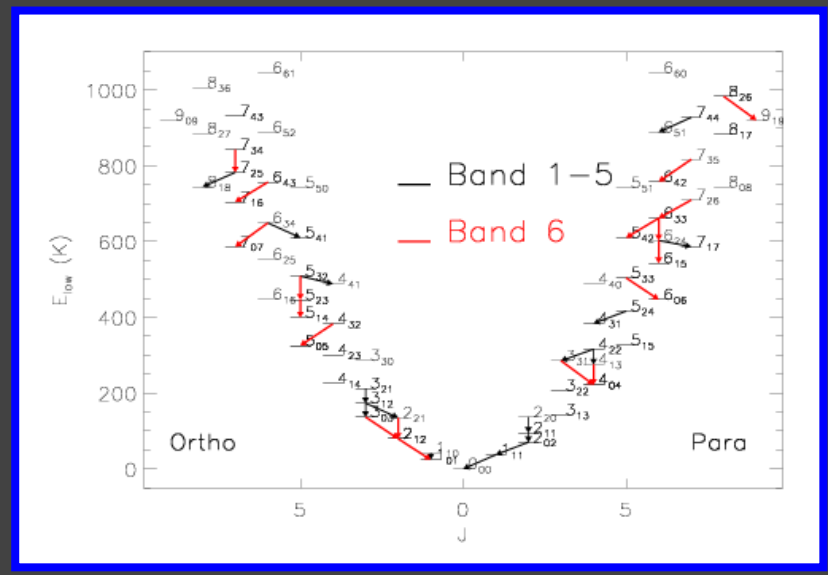
HIFI UNIQUE SCIENCE I: WATER

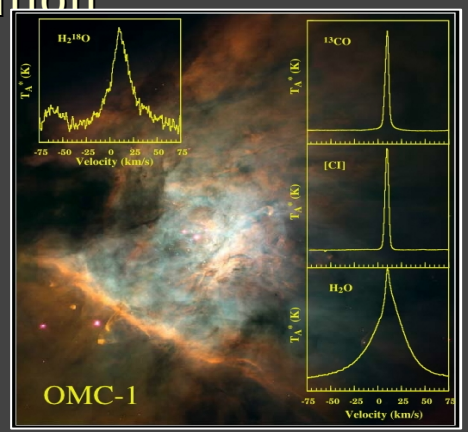
Water plays a key role in the chemistry and energy balance of a wide variety of regions

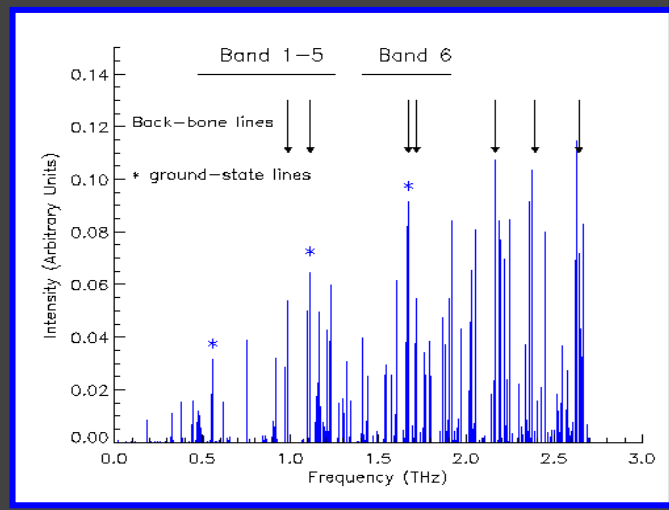
HIFI is designed to measure ~40 lines of H_2O and isotopes plus H_3O^+, OH and O_2 lines

Key questions:

- What is the distribution of water ?
- How does this evolve ?
- How does this affect the evolution of interstellar and circum-stellar media ?



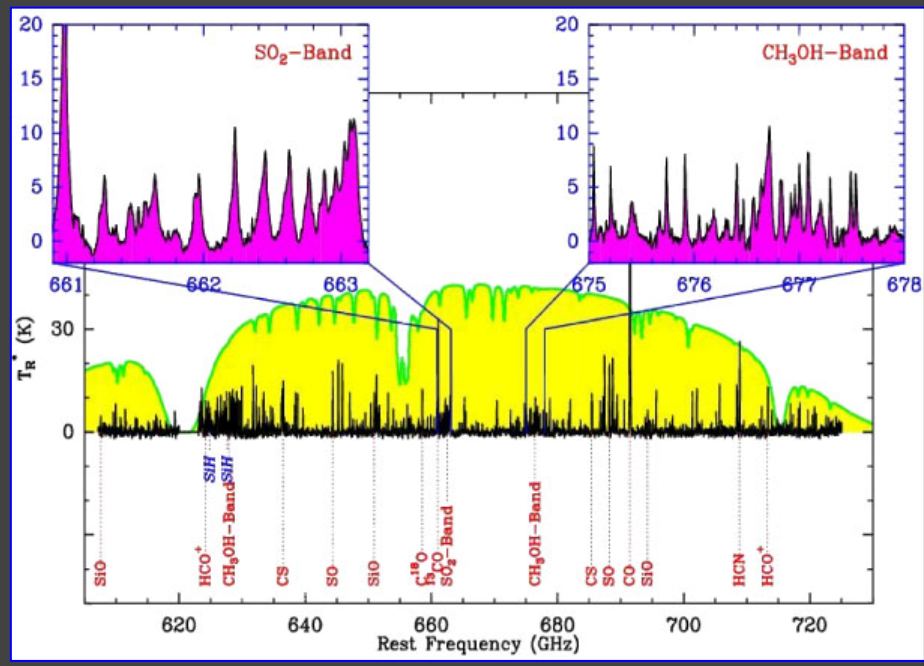




HIFI UNIQUE SCIENCE II: SPECTRAL SURVEYS

HIFI will make unbiased spectral scans of many different regions discovering a host of new species and determine reliable abundances !

- **What is the molecular inventory of space ?**
- What processes dominate interstellar chemistry ?
- How complex can the molecular universe be ?
- What is the role of interstellar molecules in the inventory of newly formed planetary systems ?
- What is the role of interstellar molecules in the origin of life ?
- What role do these molecules play in the physical evolution of these regions ?



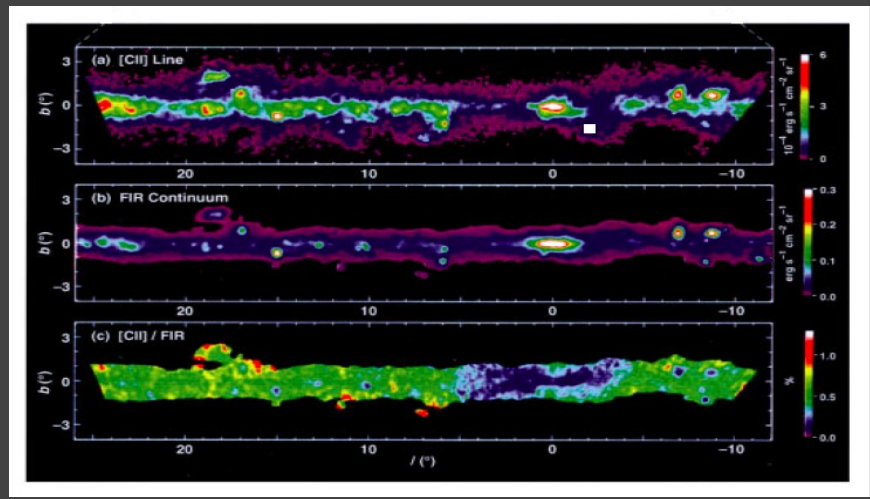
Spectral Survey of Orion in the ground-based windows

HIFI UNIQUE SCIENCE III: Interstellar medium of galaxies

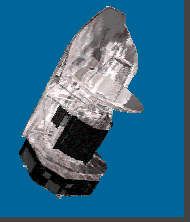
HIFI will measure the key atomic fine-structure lines of CI and CII and molecular rotational lines of hydrides

Key questions:

- How does interstellar gas couple energetically to stellar photons ?
- How does material cycle between the diffuse and molecular phases of the ISM ?
- How does interstellar chemistry get started ?



BICE map of the CII emission of the inner galaxy

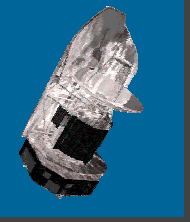


HIFI KEY PROGRAMS (8)

- Water in star forming regions: WISH — Ewine van Dishoeck
- Spectral surveys of star forming regions HS3F — Cecilia Ceccarelli
- Herschel Observations of Extra0ordinary Sources (Orion/Sgr B2) HEXOS — Ted Bergin
- Molecular Carriers in the ISM: MOLIS — Maryvonne Gerin
- H2O and Co2 obs. Of AGB, PPNe and PNe:HIFISTARSA — Valentin Bujarabal
- Warm and dense ISM: WADI — Volker Ossenkopf
- Physical and Chemical Conditions of ISM in Gal. Nuclei HEXGAL — Rolf Guesten
- Water and Chemistry in the Solar System — Paul Hartogh

For details see posters

Status: Just finished a HIFI referee program



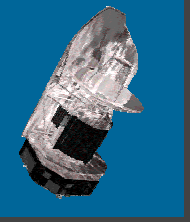
SOLAR SYSTEM

Water is key in the formation and evolution of solar system bodies

- Separates the giant planets from the terrestrial planets and the dwarfs-planets
- Dominant compound
- Driving the evolution of terrestrial atmospheres

- **Proposed observations:**
- The Martian water cycle and atmospheric chemistry
- Origin of water in the upper atmospheres of the outer planets and Titan
- Comets:
  - Water excitation and coma thermodynamics
  - The D/H ratio
  - Cometary dust

SRON



WISH: WATER IN STAR FORMING REGIONS

Water plays a key role in regions of star formation

- Central to the chemistry
- Freeze out and evaporation/sputtering
- Regulates the energy balance
- Provides a key diagnostic for the physical conditions

Observations:

- Wide range of water lines
- Broad sample with a range of YSO mass/luminosity and a range of evolutionary stages

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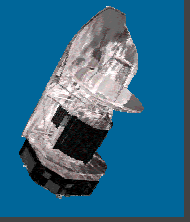


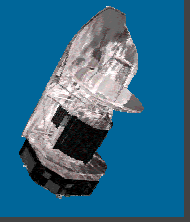
HS3F: HIFI SPECTRAL SURVEY OF STAR FORMING REGIONS

Understand the molecular inventory and chemical evolution of regions of star and planet formation

Observations:

- Unbiased spectral surveys of a sample of protostars with a range in mass/luminosity

SRON

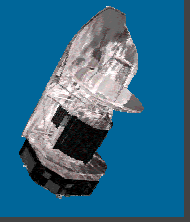


HEXOS

- Understand the physical and chemical processes relevant to star formation in the unique star forming regions: Orion and Sgr B2
  - CLASSIC EXAMPLES of phenomena found throughout the ISM
    - Hot Cores: Orion KL, Sgr B2 (N)
    - PDR's: Orion Bar
    - Shocks: Orion
    - Diffuse clouds: long line of sight – Sgr B2 (M)
  - Most interstellar molecules were first detected in these sources
  - Templates for more distant star forming regions such as those observed in other galaxies

- Observations:
  - Unbiased complete spectral surveys using HIFI and PACS of 5 key sources in Orion and Sgr B2

SRON



HIFISTARS: H_2O and CO observations of AGB envelopes, PPNe, and PNe

HIFI

- The life cyle of stars and the interstellar medium
  - Understand the death of Solar-type stars
  - Understand the mass balance of the ISM
  - Origin and evolution of water in circumstellar environments

  Observations:

- Use a wide range of H_2O and CO lines to probe the evolution of the mass loss rate and physical conditions in a wide range of stellar ejecta before they merge with the ISM

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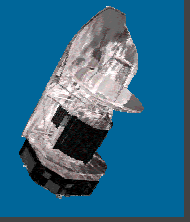
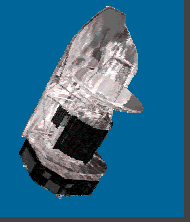


MOLIS: Molecular line carriers in the ISM

- Understand the origin and evolution of the molecular universe by probing the “first chemical steps” in the diffuse ISM
  - What is the role of shocks and turbulence dissipation ?
  - What is the role of surface chemistry ?
  - How do molecules participate in grain growth in the ISM ?
- Observations: Absorption line studies against bright background sources targeting lines of simple hydrides
  - Oxygen chemistry (H_2O)
  - HF
  - Carbon chemistry (CH, CH^+)
  - Carbon chains and rings
  - Nitrogen chemistry
  - Deuterium chemistry

SRON



WADI: The Warm and Dense ISM

- Understand the interaction of massive stars with their environment
  - What processes drive the disruption, evaporation, and dissociation of molecular clouds ?
  - How do stellar photons from massive stars affect the chemistry of the ISM ?
  - How shocks driven by massive stars drive the chemistry of their environment
- Observations:
  - Main cooling lines (OI, CII, H_2O) and simple hydrides of a sample of well-known PDRs and shocked gas regions

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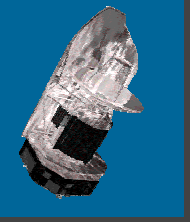

HEXGAL: PHYSICAL AND CHEMICAL CONDITIONS OF THE ISM IN GALACTIC NUCLEI

HIFI

- Physics of large scale star formation in the nearby universe
  - The ISM in the galactic center as a template for galactic nuclei
  - The physics of the gas fueling obscured nuclei of starburst, ultra-luminous galaxies and active galactic nuclei
  - The interplay of activity and chemical complexity in galactic nuclei
  - The physics of the ISM of low metallicity dwarf galaxies

- Observations:
  - Atomic fine-structure lines (OI, OIII, NII, CI, CII)
  - Molecular rotational lines (H2O, CO)
  - Spectral surveys

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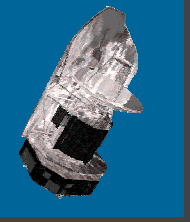

SUMMARY

- HIFI is uniquely suited to study the physics and chemistry of interstellar and circum stellar gas

- HIFI is the ultimate
  - Mean lean water machine !
  - Mean lean molecular machine !
  - Mean lean ISM machine !