The Herschel Heterodyne Instrument for the Far-Infrared (HIFI)

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SRON Netherlands Institute for Space Research

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Acknowledgements:
• Space- and Science Funding Agencies and Institutes of all involved ESA countries; plus ESA, NASA and CSA, and Industries,
• Hundreds of engineers, scientists, managers, etc..

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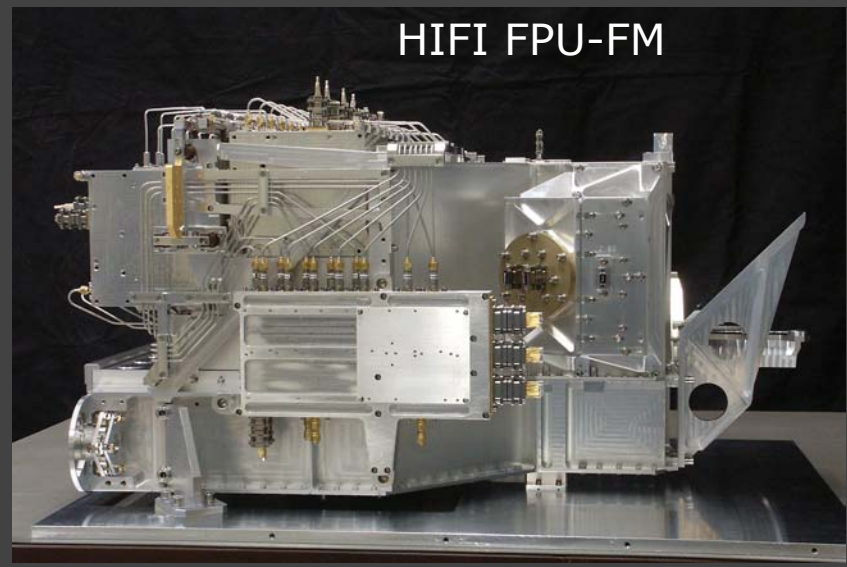
Netherlands Institute for Space Research

The Herschel Heterodyne Instrument for the Far-Infrared (HIFI)

Lay-out Presentation:

Scientific motivation

- HIFI consortium
- Instrument design
- Instrument Observing modes
- First ILT results
- Instrument Capabilities
- "HIFI" key programs



HIFI Programmatic Status:

- 2004 CQM delivered
- 2005 CQM successfully tested/
  FPU-FM integrated (1235) and start testing
- 2006 FPU-FM fully integrated and testing ongoing;
  Final Instrument Level tests, including calibration and characterisation, start mid- August till end of the year, after delivery and integration in August of last LO unit (LSU)

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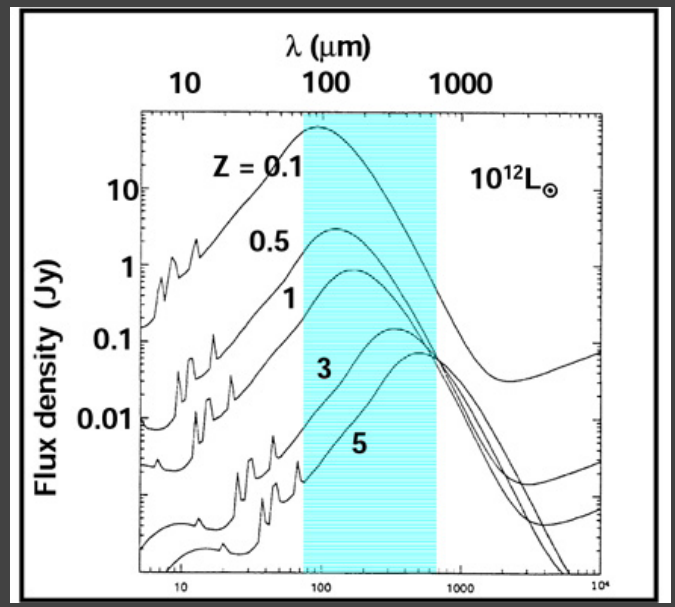
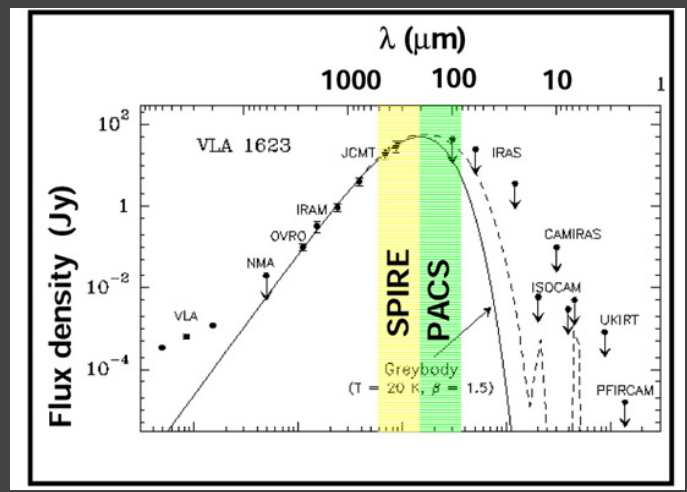
Herschel isnaddressing the last unexplored region of the EM spectrum: The Cool Universe

- **Herschel spectral coverage is the entire FIR/Submm**
  - black-bodies 5-50 K
    - continuum radiation
    - dust grains (re-)radiating
  - *gasses 10-few100 K*
    - *Zillions of atomic/ionic/molecular spectral lines*

- **HIFI unique science** is in the area of formation and evolution of galaxies & star/planet systems

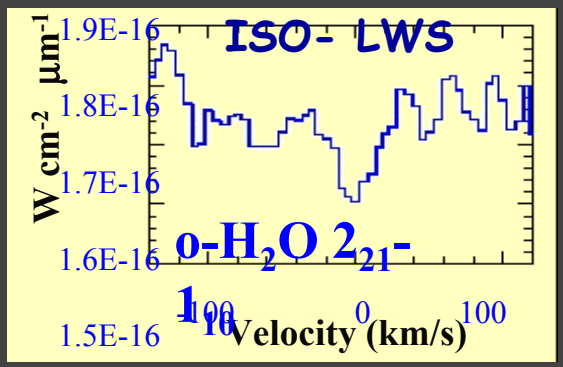


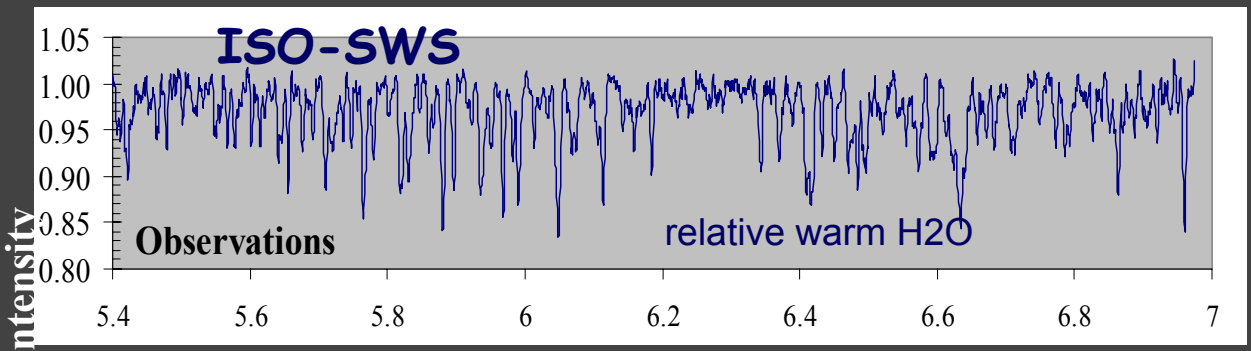


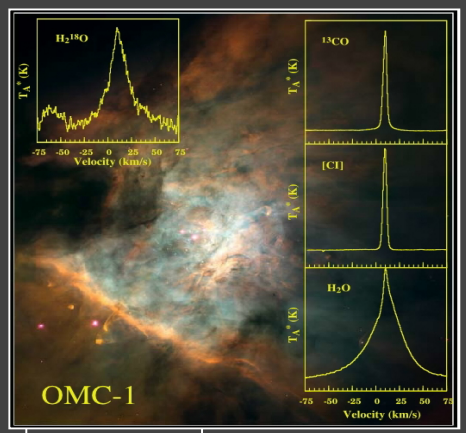
Herschel Unique Science: Observations of Water

Water abundant from SWAS, ODIN, ISO, Spitzer, etc

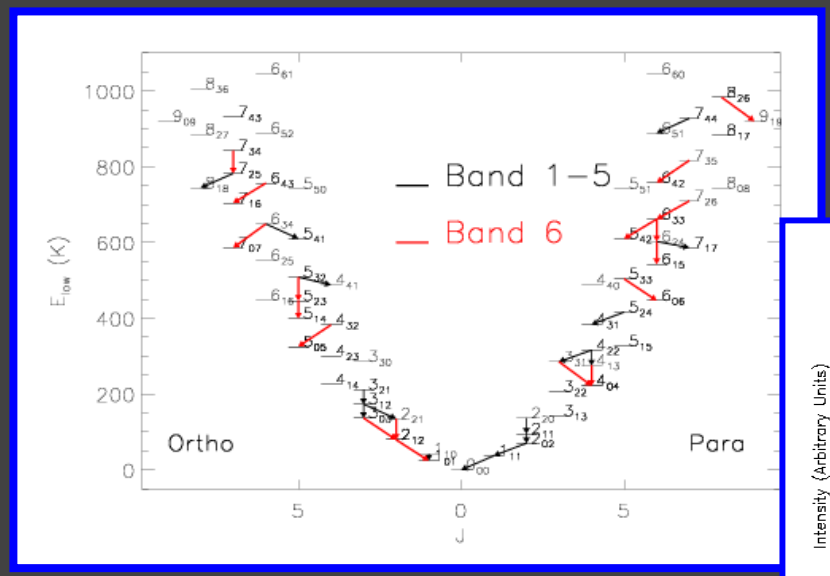
HIFI has coverage for variety of densities and excitation conditions

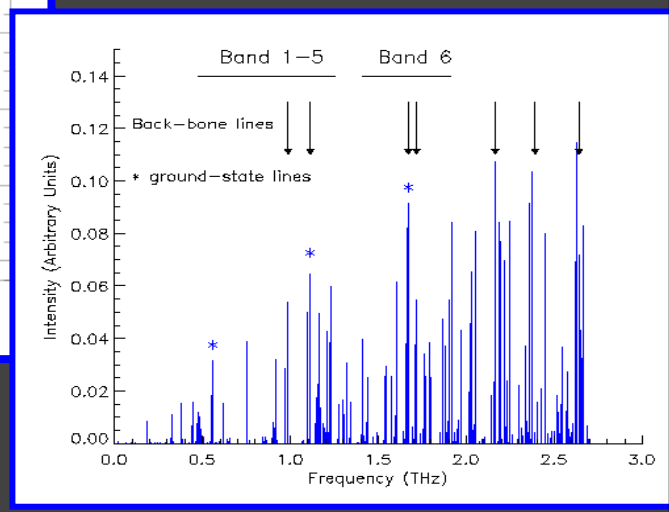






SWAS





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Role Water as chemical and physical probe

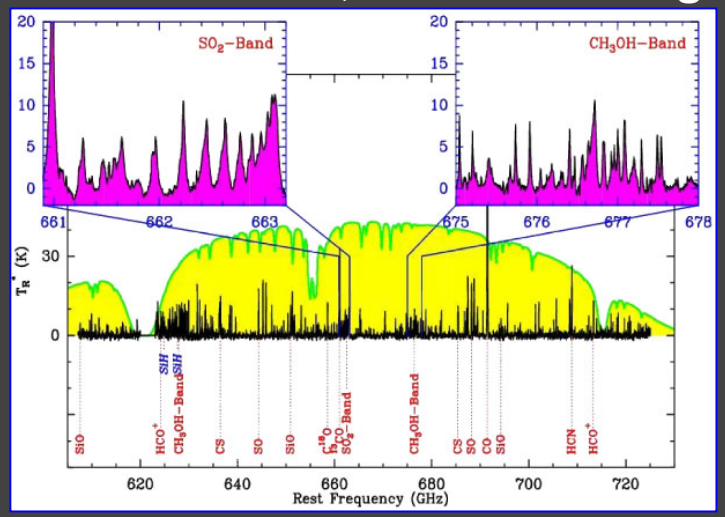
- H_2O abundance shows large variations in SF regions:
  $<10^{-8}$ – 3. 10^{-4} => unique probe of different physical regimes
- Traces basic processes of freeze-out onto grains and evaporation, which characterize different stages of evolution

  pre-stellar cores ¬> YSO's ¬> disks ¬> comets
- H_2O's role in the thermal balance: when and where does H_2O become dominant heating or cooling agent?
- H_2O as a dynamical probe of high density gas: infall (?), outflow, quiescent gas, mixing, …
- HDO/H_2O: determined by gas-phase or grain-surface processes? Relation with comets?

HIFI Unique Science: Molecular Universe Spectral Line Surveys

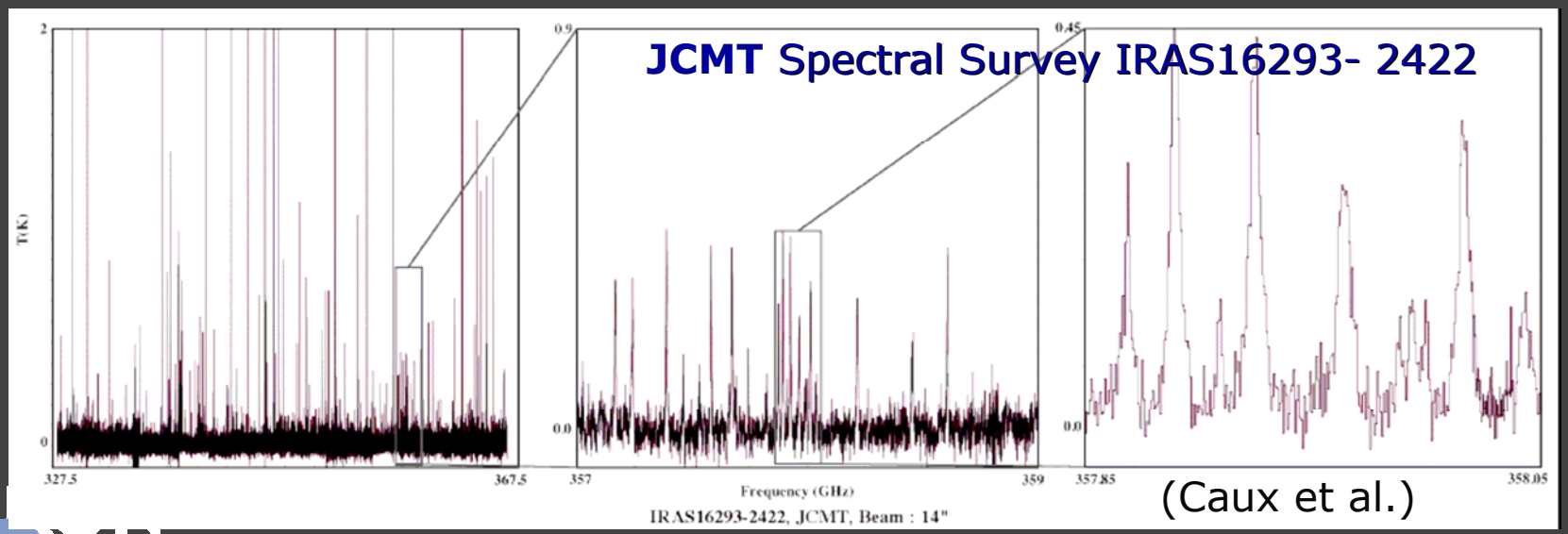
CSO Spectrum of Orion: 8 nights

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



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

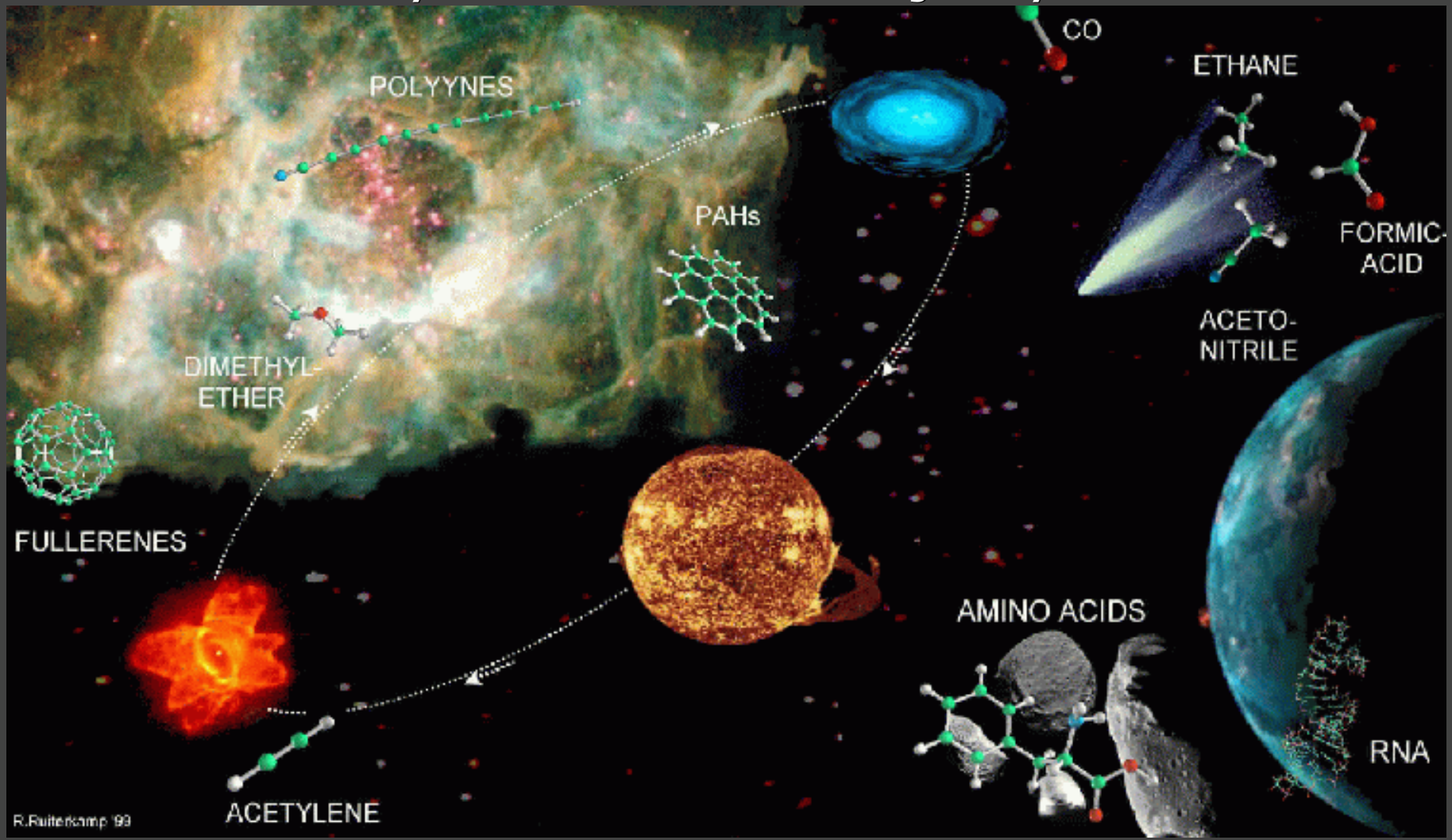
HIFI will be able to survey outside of the atmospheric windows and at frequencies never probed before, allowing for searches of new molecules.



(Caux et al.)

Cycle of Organic Molecules in the Universe:

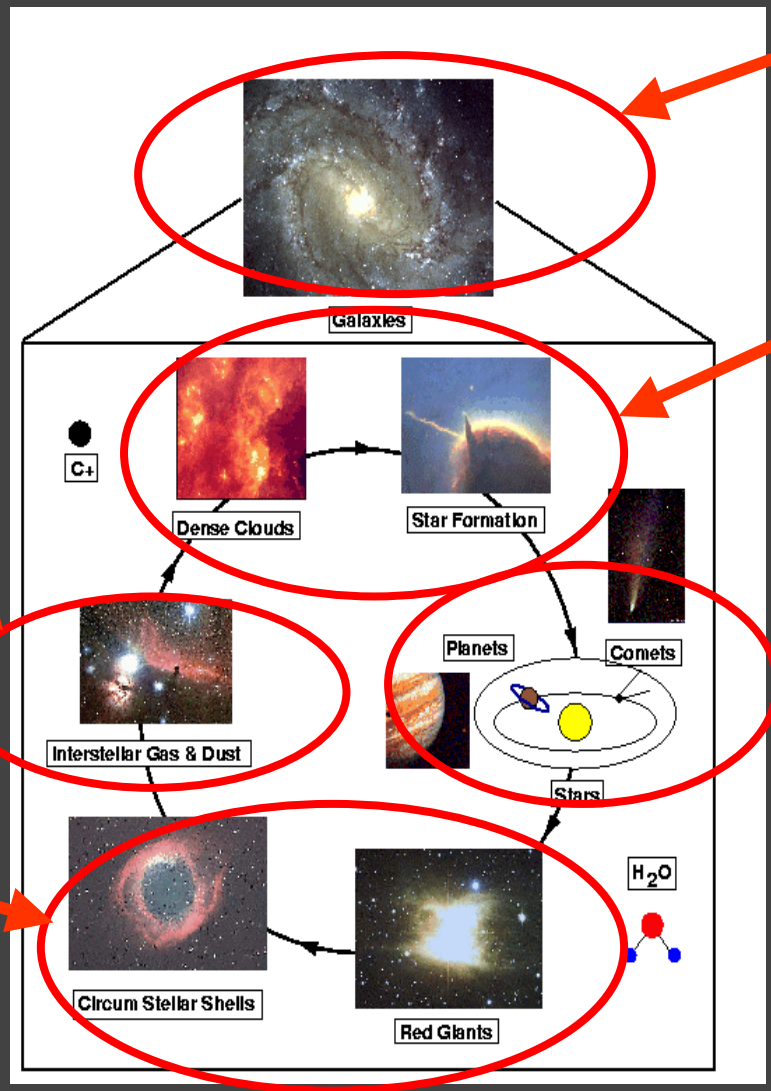
Interstellar Organics are formed in ISM Gas, Stellar Outflows and on Dust Grains; Organic material integrated in Solar System, chemically processed/destroyed; In Final Stage of Stars, dust and elements are returned to the ISM; Organic molecules may have seeded the Earth during this cycle



Herschel-HIFI Science: Life Cycle of Gas and Dust Star Formation & Evolution

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

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



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

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

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

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HIFI 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

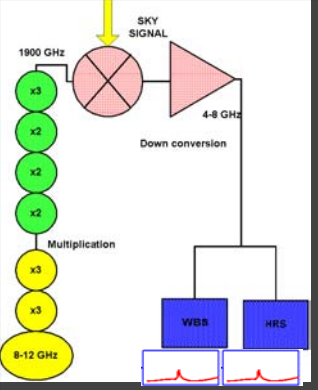
- IF bandwidth/Resolution:
  - 4 GHz (in 2 polarisations)
  - 140 – 280 kHz –0.5 and 1 MHz

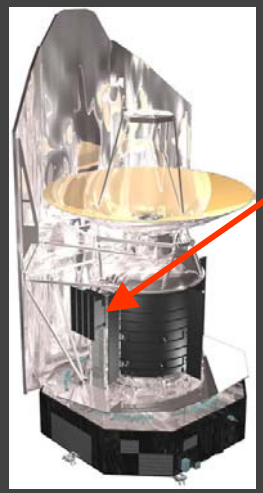
3. Calibration Accuracy: 10% baseline; 3% goal

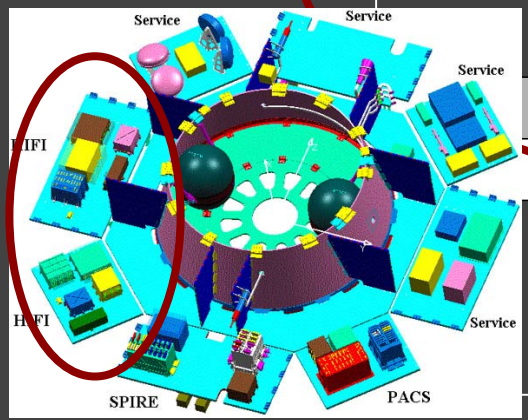
- **Heterodyne spectroscopy**
  - single pixel on the sky
  - very high spectral resolution
- **7 dual-pol mixer bands**
  - 480-1250 GHz (625-240 μm) 5x2 SIS mixers, IF 4-8 GHz
  - 1410-1910 GHz(212-157 μm; 2x2 HEB mixers, IF 2.4-4.8 GHz
- **14 LO sub-bands**
  - LO source unit in common
  - LO multiplier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

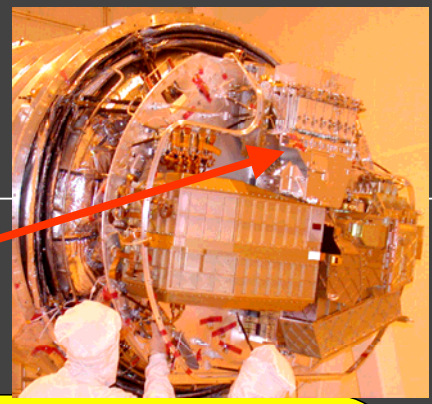
Angular Resolution (with Herschel): 12”- 40”

HIFI Block Diagram









From Telescope

LOU	FPU	IFV	IFH
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

LSU	LCU	FCU
Master oscillator Synthesizer Ref. distribution	Control Multiplier bias Power amplifier bias Sec Power for LSU	Control Mixer bias Amplifier bias Mechanism control

HRS-h	WBS-h	HRS-v	WBS-v
IF processor Sub-band division	IF processor Sub-band division	IF processor Sub-band division	IF processor Sub-band division
Δf~1GHz δf variable	Δf 4 GHz δf 1 MHz	Δf~1GHz δf variable	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

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

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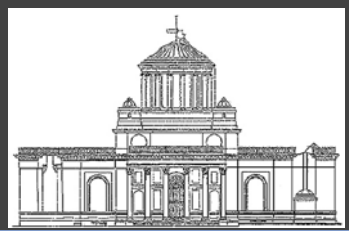
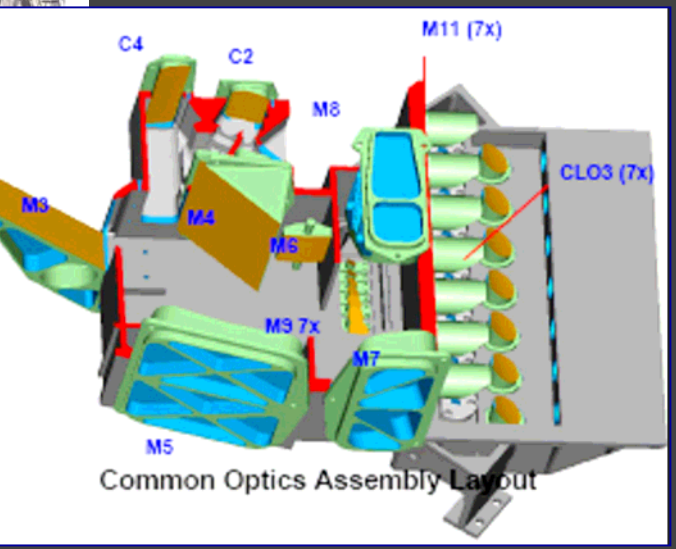
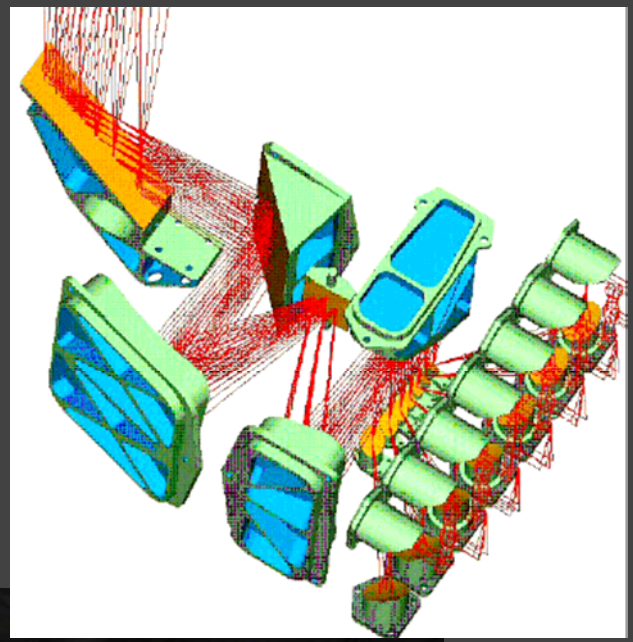
SPACE RESEARCH CENTRE

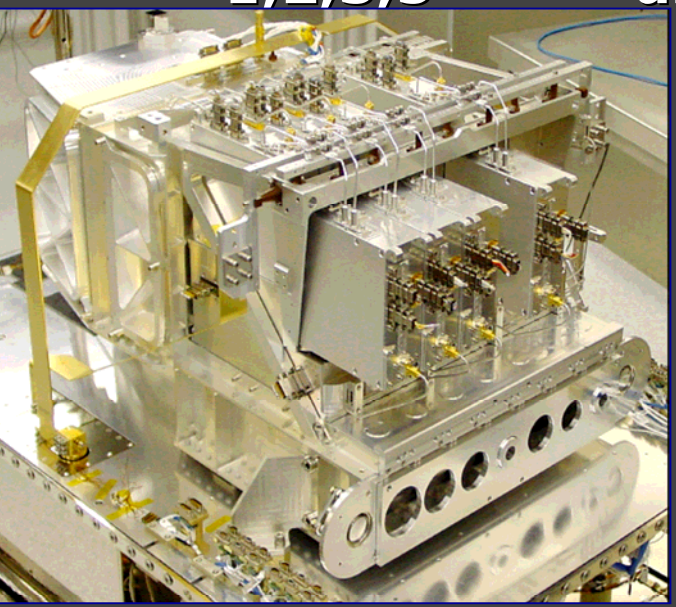


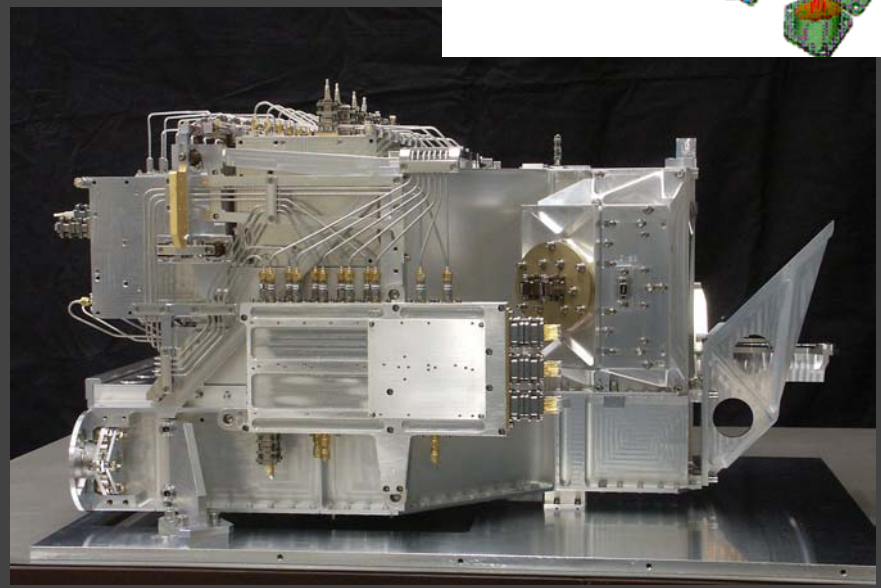
Common Optics Asembly



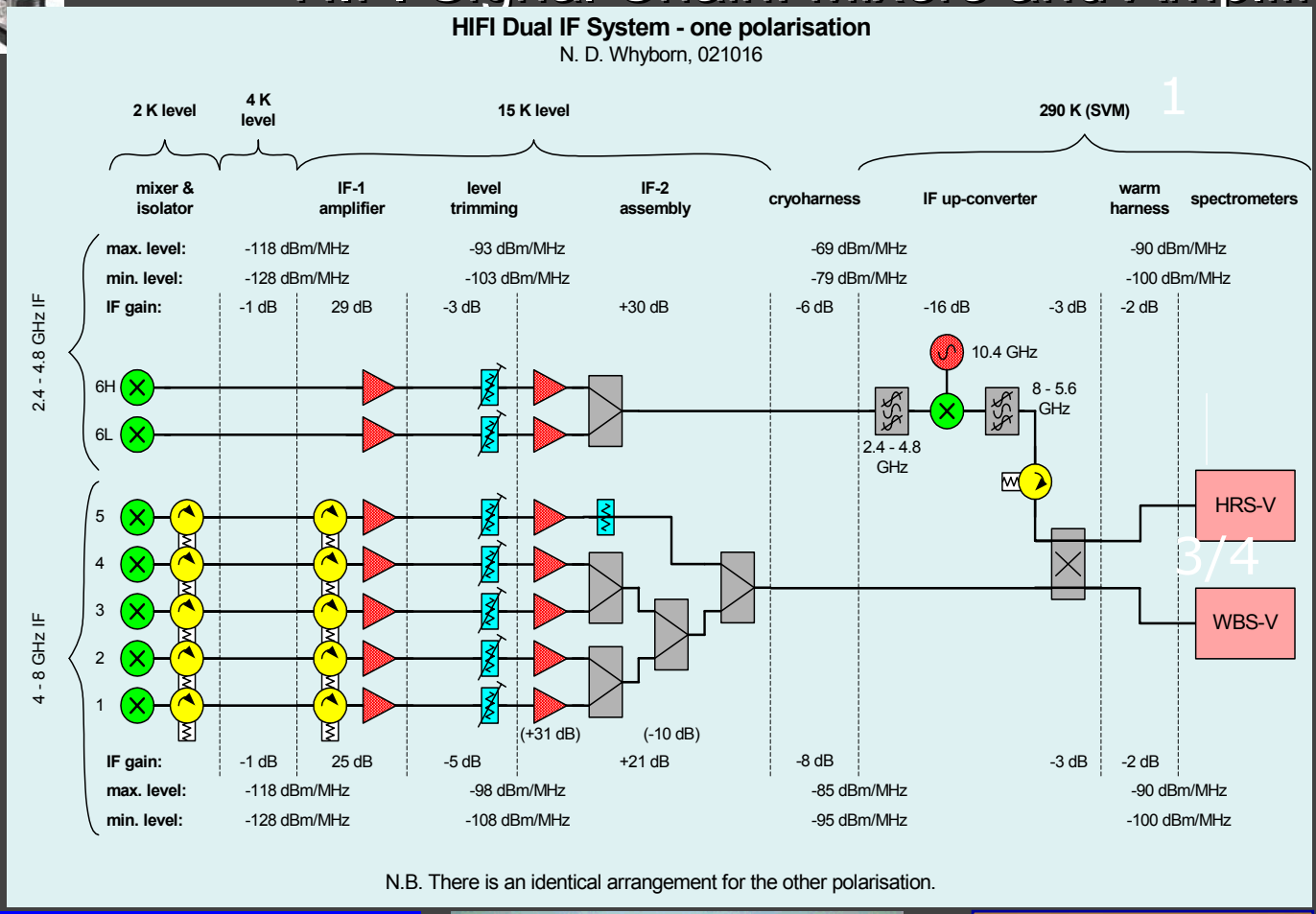


HIFI FPU FM with mixer bands 1,2,3,5 and complete

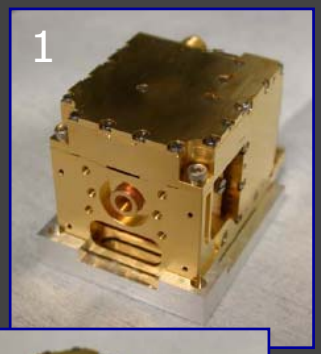


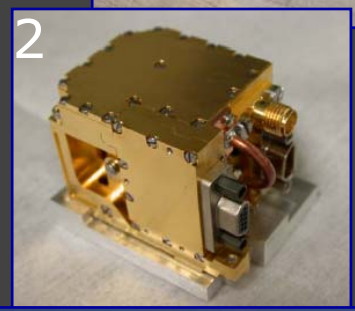


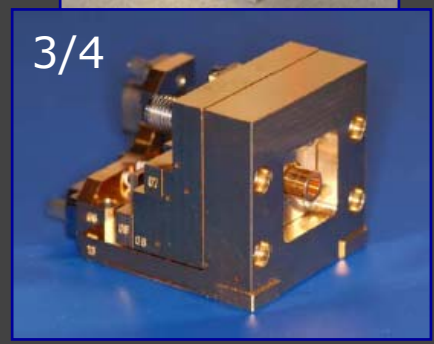
HIFI Signal Chain: Mixers and Amplifiers



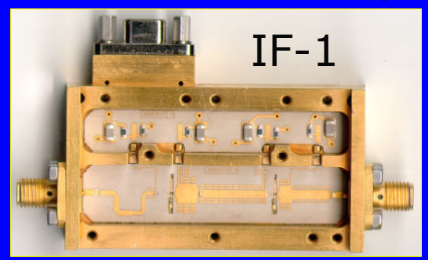
N.B. There is an identical arrangement for the other polarisation.

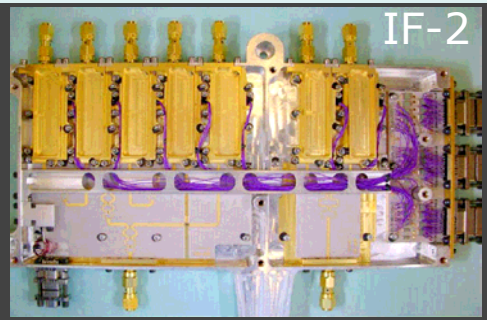


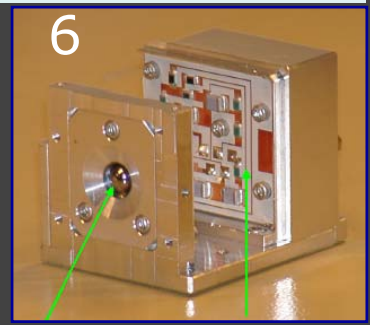




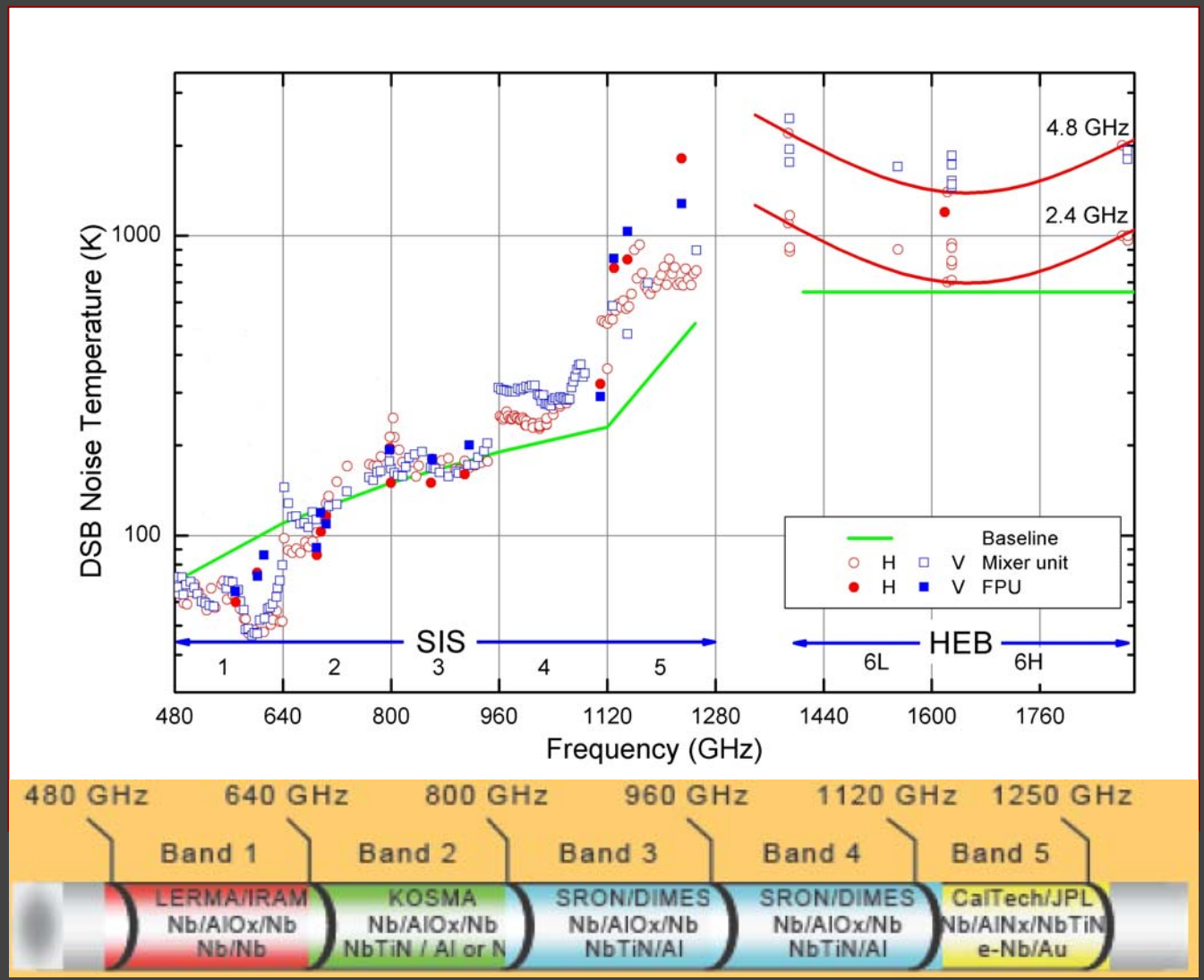
QM & FM PROGRAMS (First Prototype)



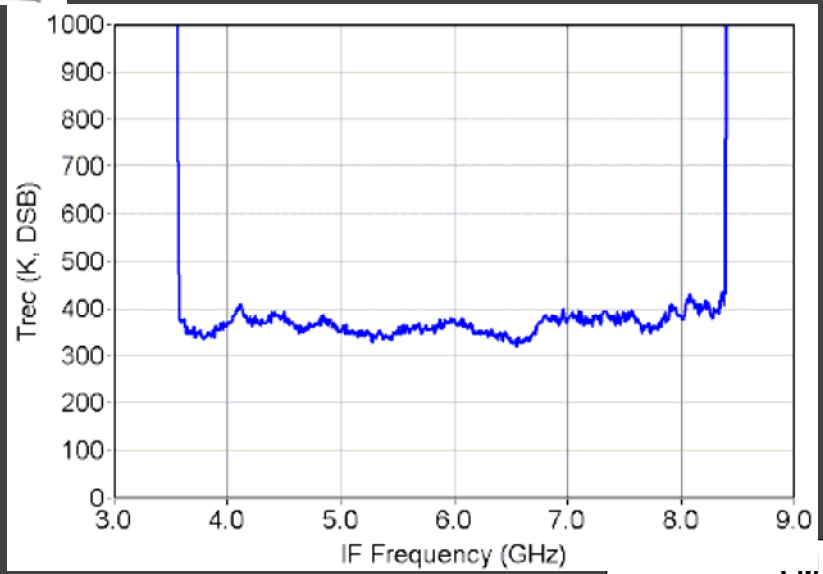




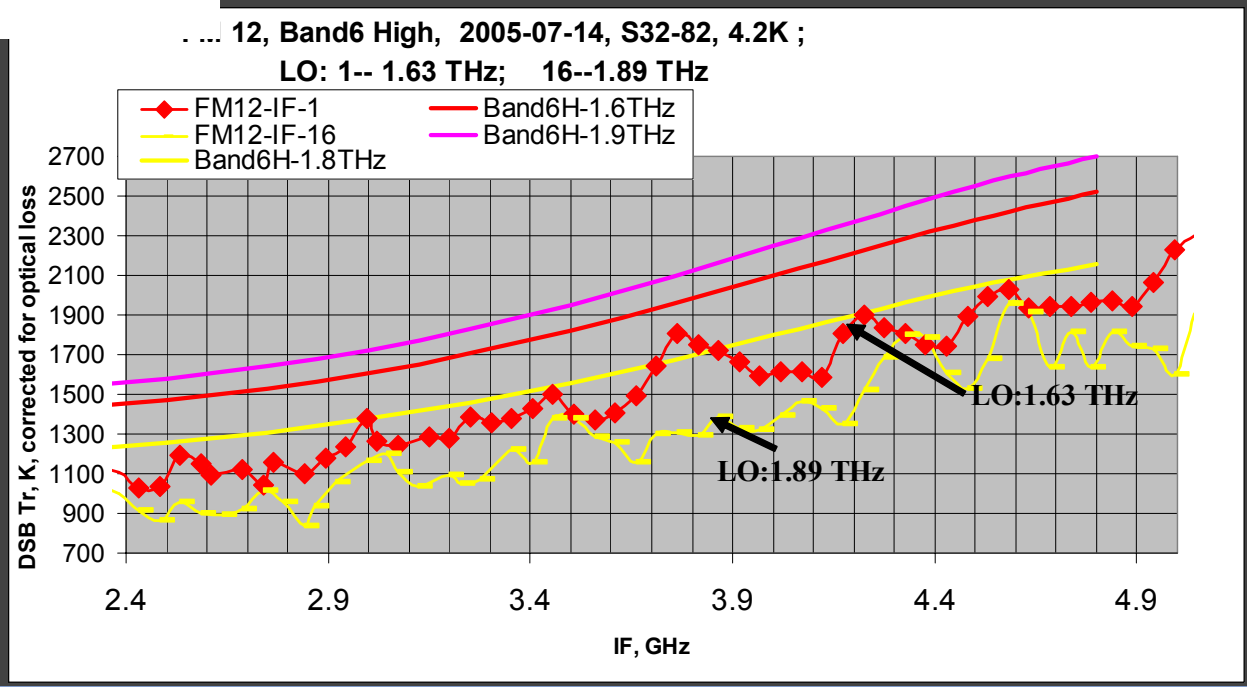
HIFI Flight Mixer Performance at Unit level (open symbols) and after integration in the FPU



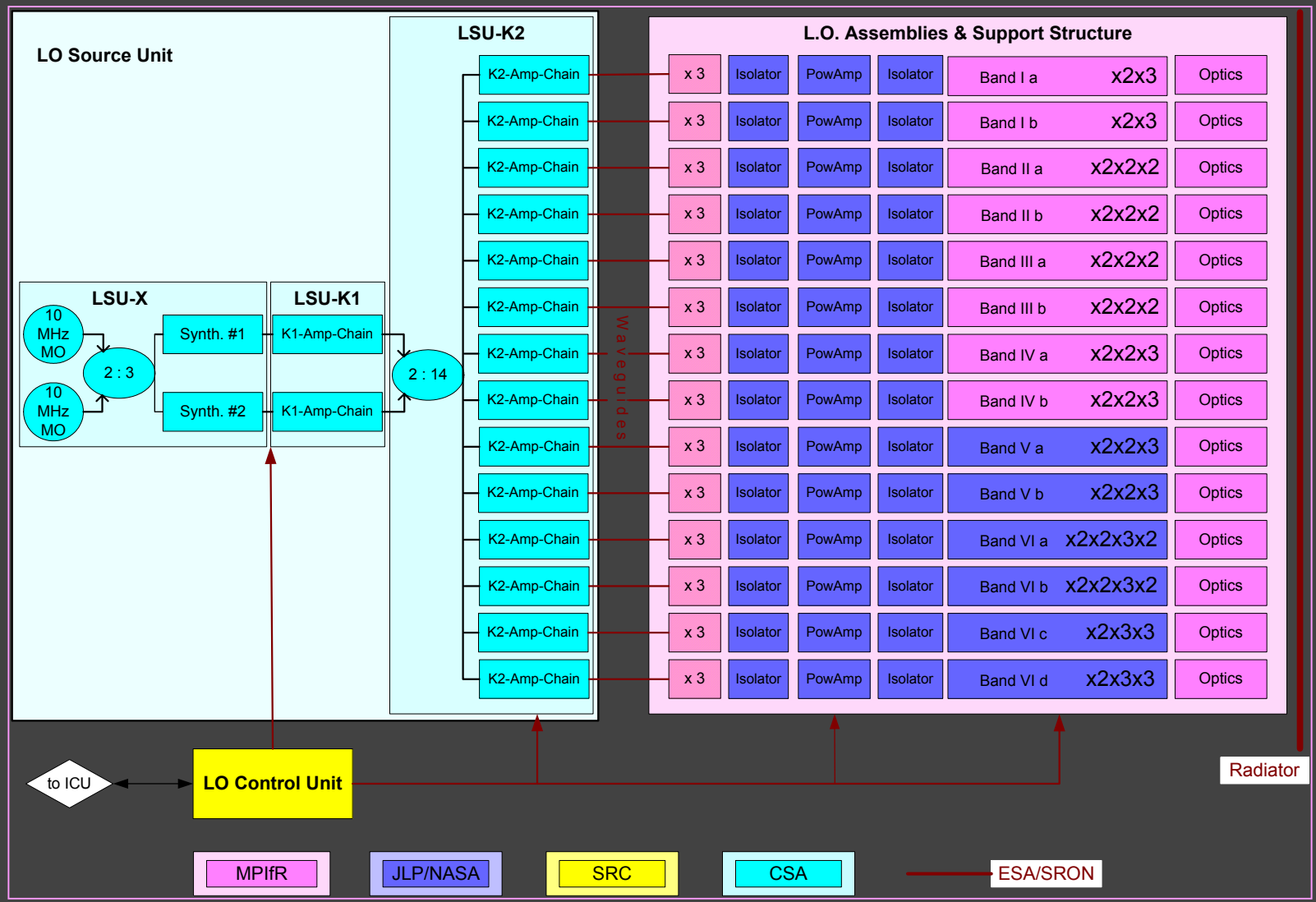
Band-3 SIS Noise Temperature as function of IF



Band-6 HEB Noise Temperature as function of IF

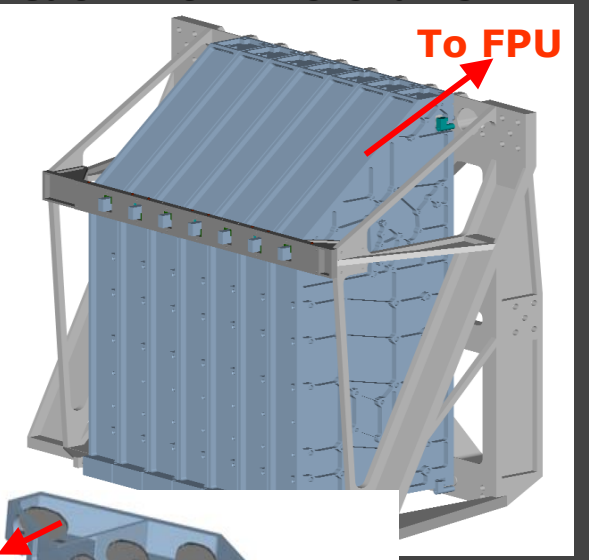


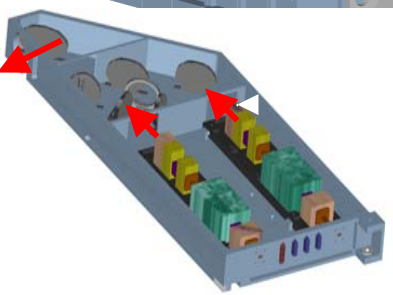
LO subsystem block diagram for LO Source Unit and LO assemblies



HIFI LO frequency multiplication scheme with all-planar devices and no mechanical tuners

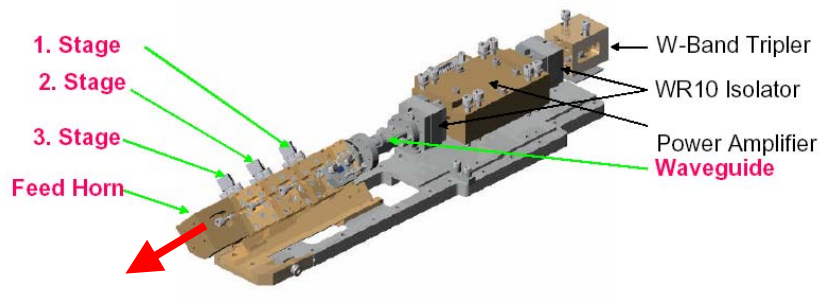
LOU with 7 LO assemblies each with 2 LO chains

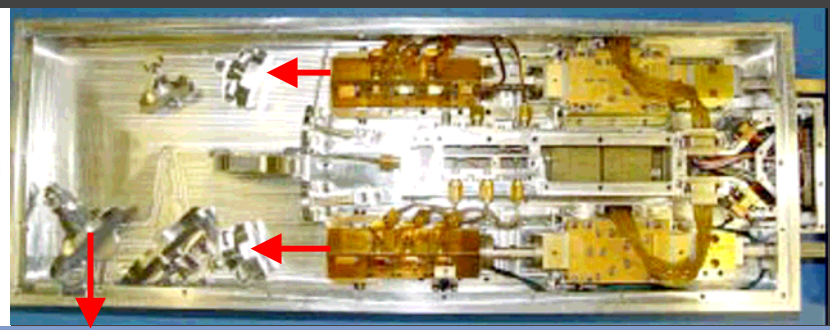




PA bands	71-79 GHz	80-92 GHz	88-99 GHz	92-106 GHz
x2	142-158	160-184	176-198	184-212
x2 x2	284-316	320-368	352-396	368-424
x2 x3	426-474	480-552 Band Ia: 488-546	528-594	552-636 Band Ib: 560-633
x2 x2 x2	568-632	640-736 Band IIa: 647-710	704-792 Band IIb: 724-793	736-848 Band IIIa: 807-848
x2 x2 x3	852-948 Band IIIb: 862-953	960-1104 Band IVa: 967-1042	1056-1188 Band IVb: 1056-1113	1104-1272 Band Va+b: 1127-1242
x2 x2 x2x2	1136-1264	1280-1472	1414-1584 Band VI-Lowa 1418-1596	1472-1696 Band VI-Lowb 1472-1696
x2 x3x3			1472-1696 Band VI-Lowb 1584-1782	1704-1908 Band VI-high a/b 1704-1906

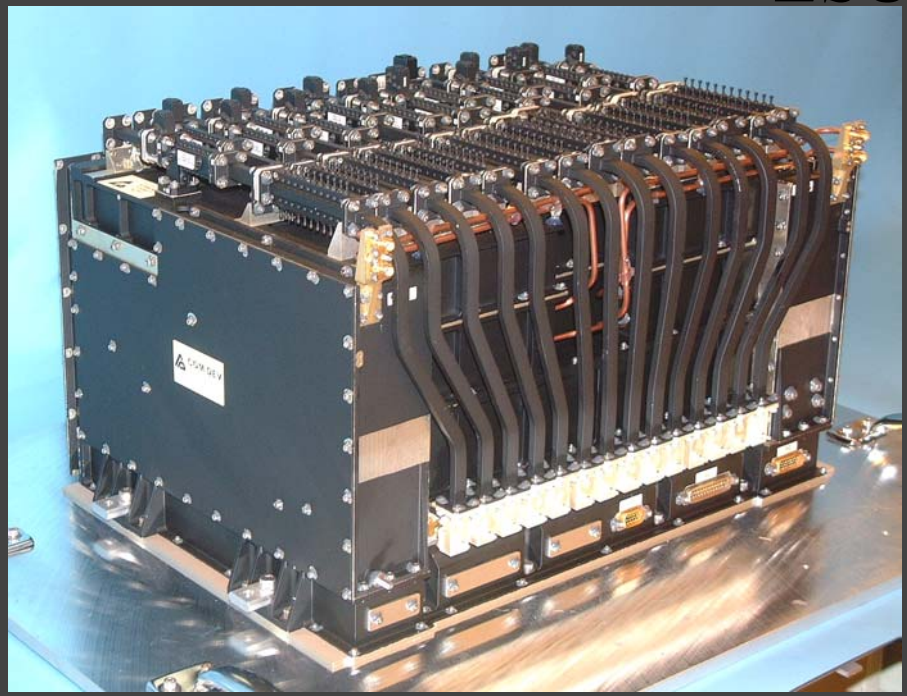
(from J.Pearson et al.)

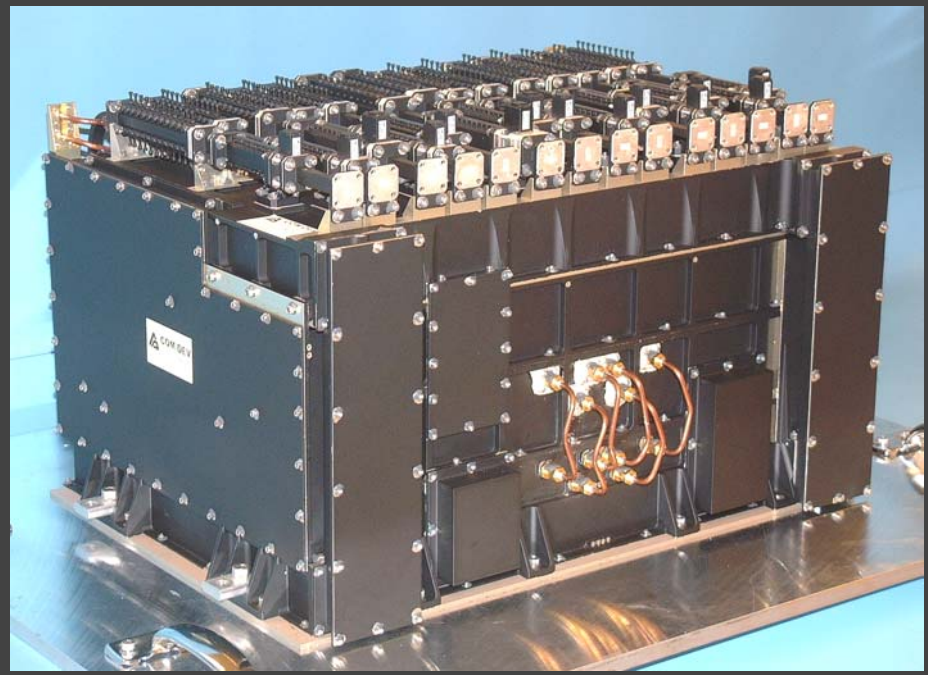




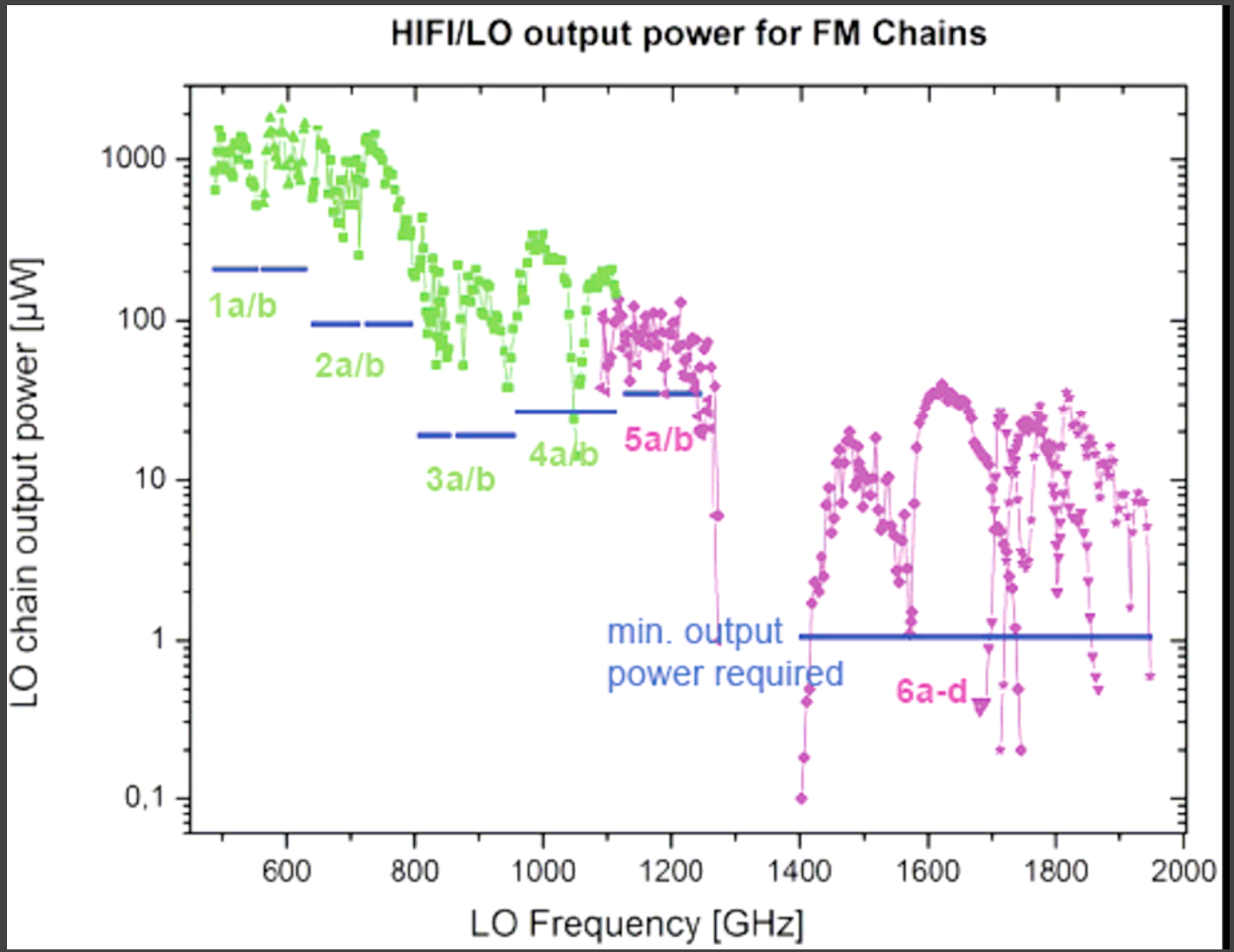
LO Assembly with two chains

LSU - DM

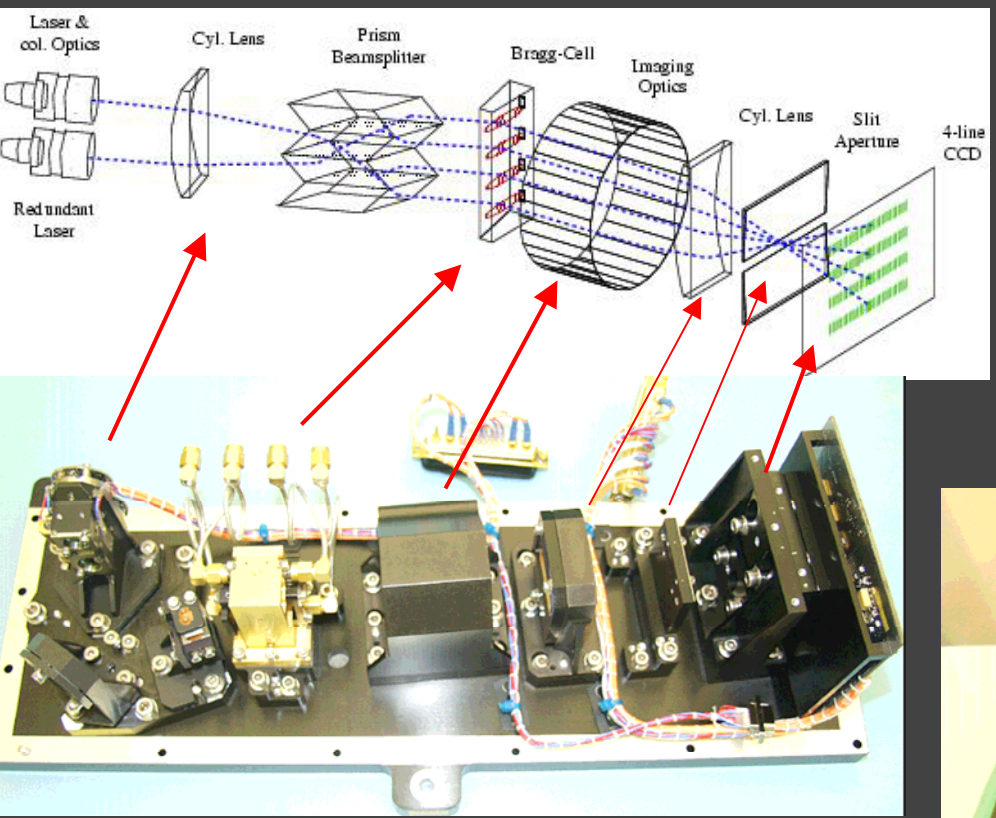




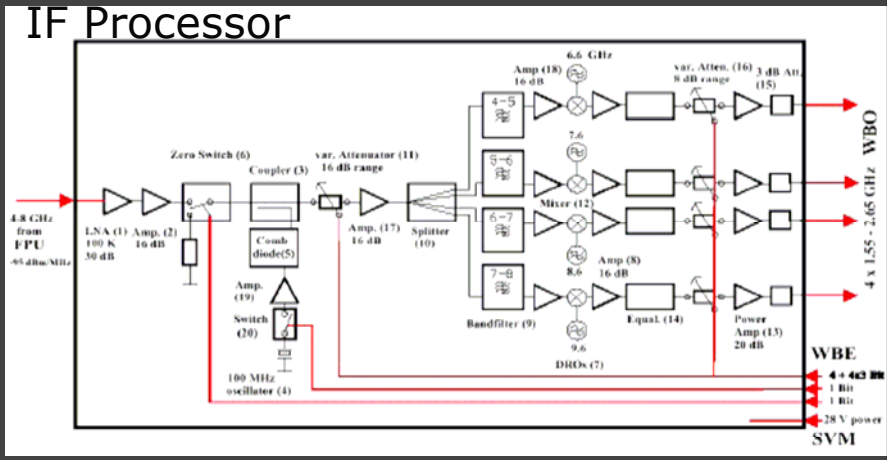
Latest update LO chain performance:
Bands 1-4 by RPG; Bands 5, 6L, 6H by JPL



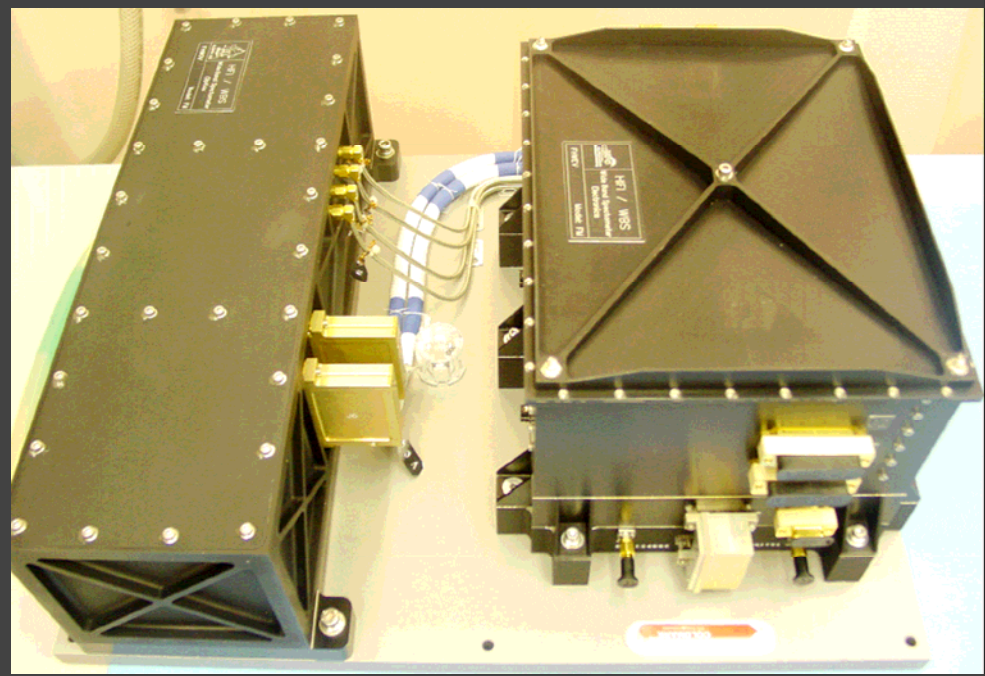
WBO FM (one Polarisation) with 1.1 MHz resolution and 4GHz bandwidth



IF Processor



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

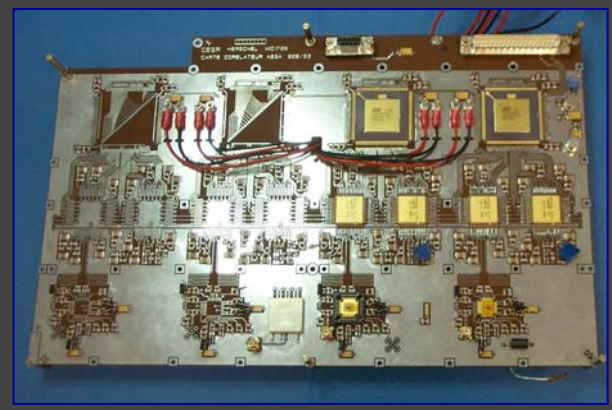


HIFI-HRS (auto-correlator) FM Capabilities

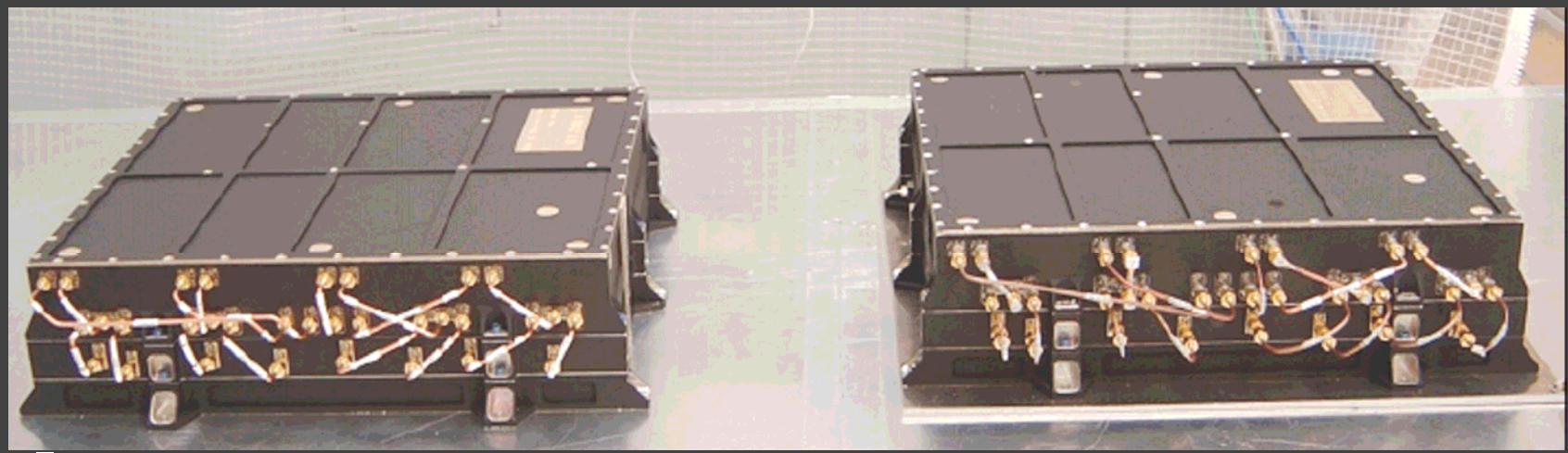
	Requirements		FM capabilities	
Mode	high Resolution	Normal Resolution	Low Resolution	Wide Band
Number of Bands	1 1	2 2	4 4	8 8
Bandwidth	250 235	250 235	250 235	500 470
FWHM (MHz)	0.14 0.125	0.27 0.25	0.54 0.5	1.1 1.0

Efficiency : better than 80% over the whole band

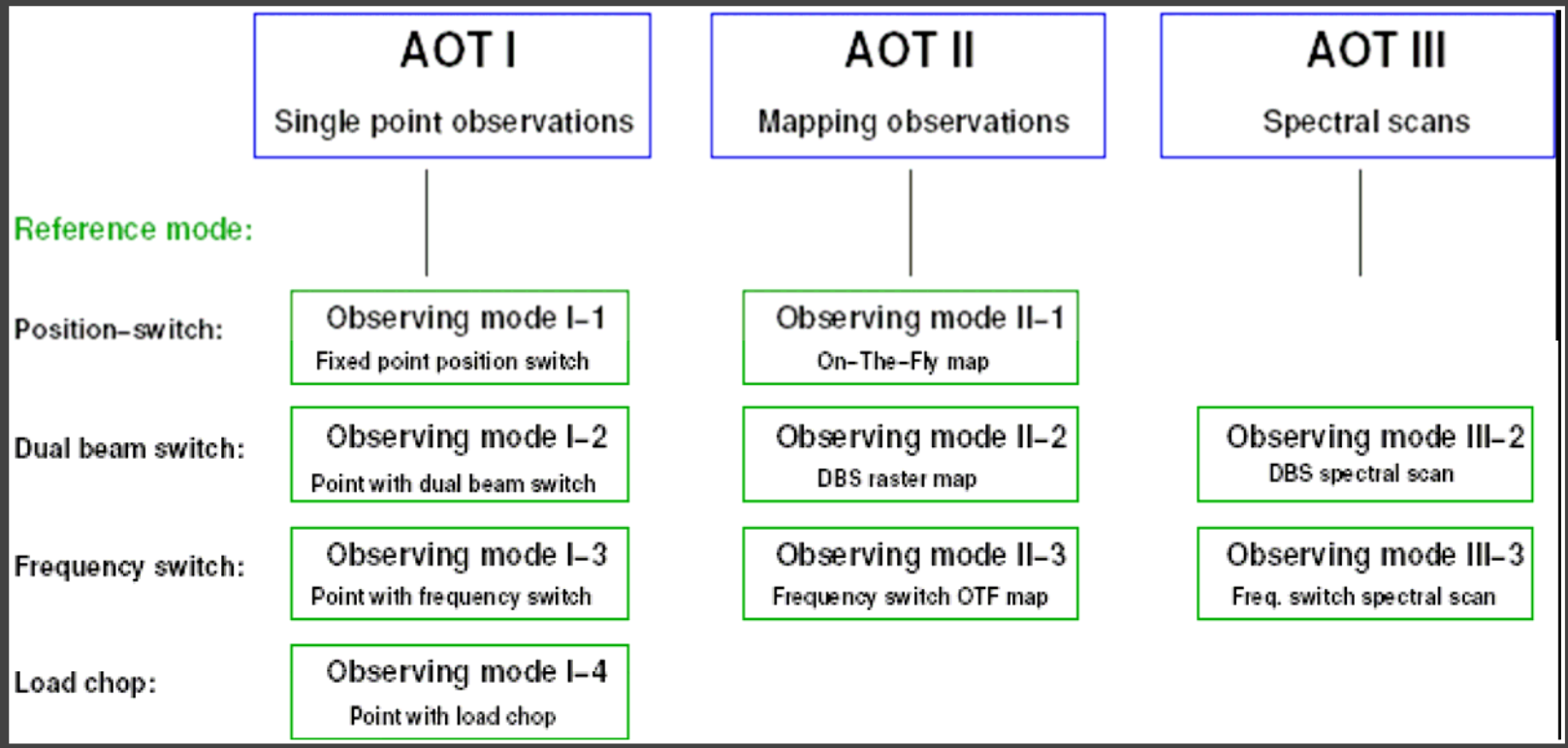
Linearity with software correction : better than 1%



2 HRS FM modules



HIFI Observing Modes and AOT summary



- **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)

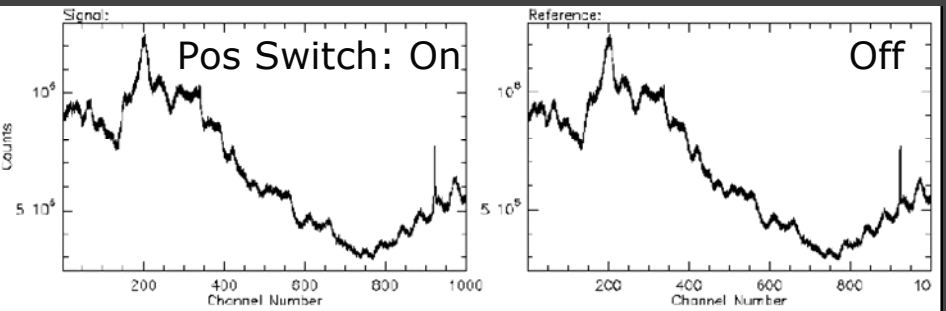


Figure 3 Typical level 0 raw data for single dish sub-millimetre signal and reference source scans.

Level 0

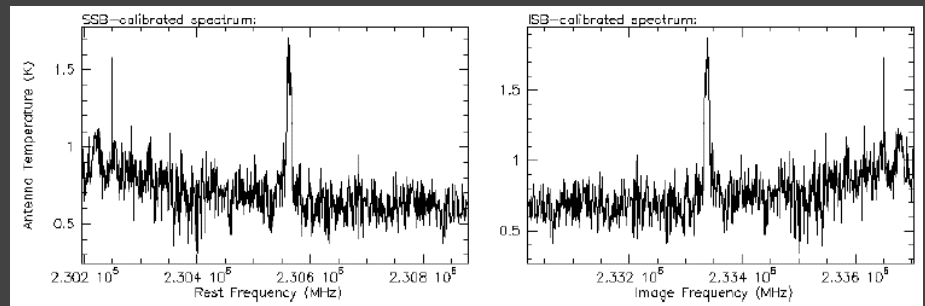
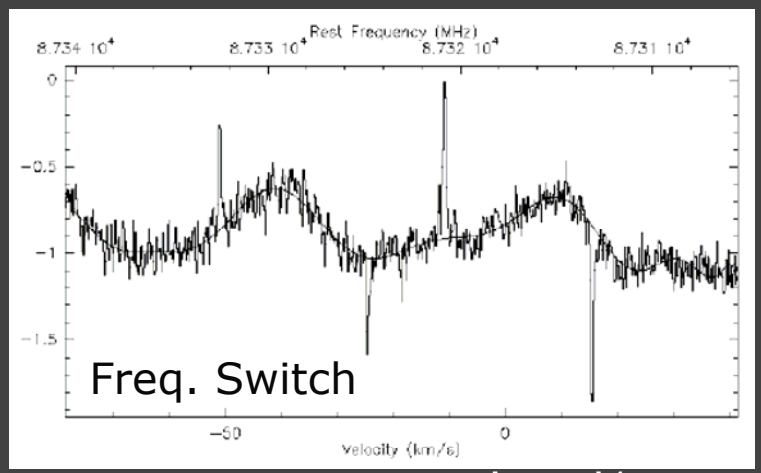
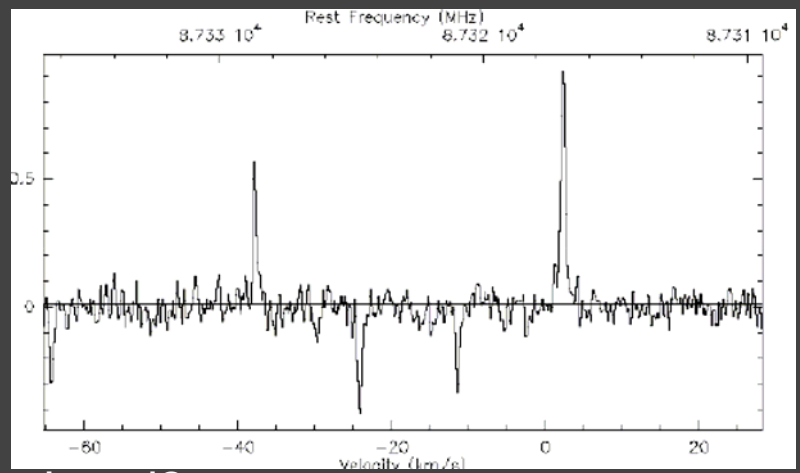


Figure 4 Typical narrow band single dish sub-millimetre level 1 calibrated scans.

Level1



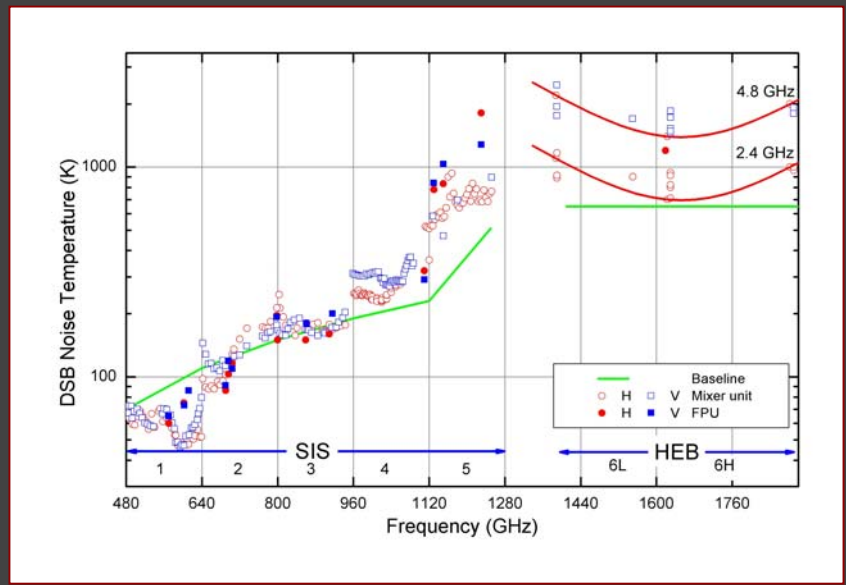
Level1



Level2

Expected HIFI sensitivities derived from FPU tests

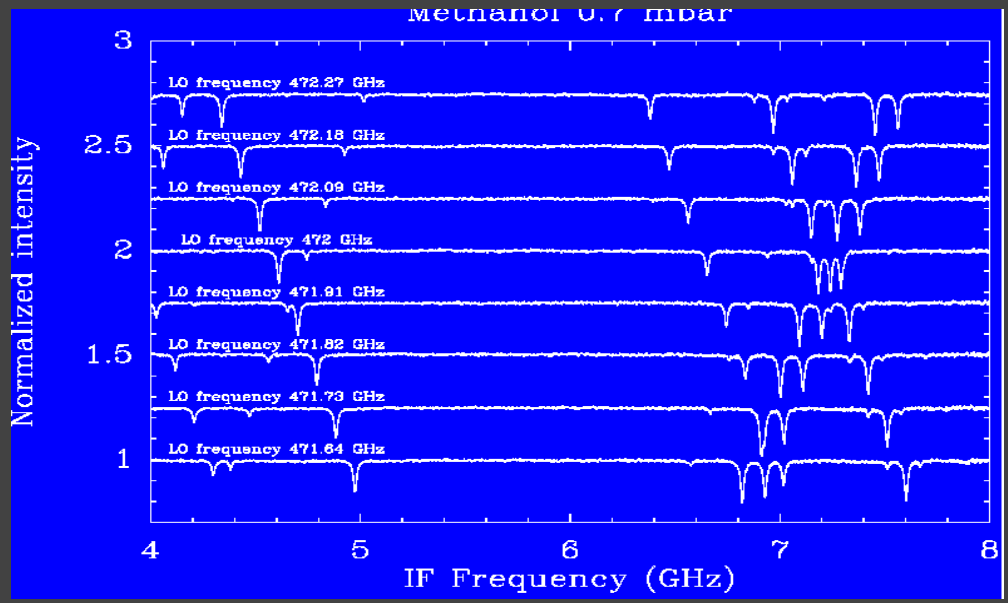
Mixer Band		1	2	3	4	5	6
Frequency Range	(GHz)	480-640	640-800	800-960	960-1120	1120-1250	1410-1910
T_sys (SSB)	(K)	160	320	480	730	2000	2500
Flux Limit (5σ, 1hr;R=10e4)	(mK)	5,0	9	12	17	43	46
Flux Limit (5σ 1hr;R=10e4)	(Jy)	2,3	4	5,5	8	20	22
Line Flux Limit (5 σ;1hr;R=1e4)	($10e^{-18}$ W/m^2)	1,3	3	5	8	24	34
Line Scan (Δv=1 km/s DBS) 1σ, 4 hrs/band(1-5),10 hrs for6L/H	(mK)	12	23	30	42	95	290



Summary for HIFI

- **Integration and Testing progressing well**
- **Delivery expected before the end of this year**
- **Preparations for operations well on track**

- **Frequency coverage as designed**
- **Sensitivity at State-of-the-art level;**
  - **Close to expected baseline;**
  - **Sensitivity lower at high frequency end where technology development progress was somewhat less**



Methanol spectrum with HIFI Development model near 500 GHz.

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)

(1.4 Maps of the ORION region (J. Cernicharo))*

(1.5 Molecular Oxygen (P. Goldsmith))*

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

(3.2 HIFI frequency surveys of AGB, PPNe and PNe; coord. Pardo)*

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)

SRON