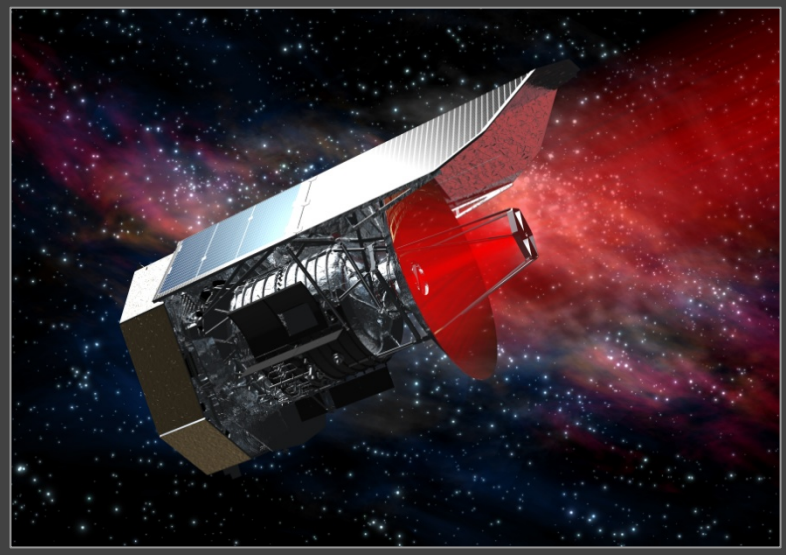

The Herschel-Heterodyne Instrument for the Far-Infrared (HIFI): Instrument and Pre-launch Testing.

Thijs de Graauw
SRON and Leiden Observatory, NL
Joint ALMA Observatory, CL

SRON
Netherlands Institute for Space Research

Acknowledgements:
Space- and Science Funding Agencies and Institutes of all involved ESA countries; plus ESA, NASA and CSA, and Industries,
Netherlands Organisation for Scientific Research

The Herschel-Heterodyne Instrument for the Far-Infrared (HIFI): Instrument and Pre-launch Testing.

Thijs de Graauw [1,2,3], Nick Whyborn[1,3], Frank Helmich[1], Pieter Dieleman[1], Peter Roelfsema[1], Emmanuel Caux[4], Tom Phillips[5], Juergen Stutzki[6], Douwe Beintema[1], Arnold Benz[7], Nicolas Biver[8], Adwin Boogert[9], Francois Boulanger[10], Sergey Cherednichenko[19], Odile Coeur-Joly[4], Claudia Comito[11], Emmanuel Dartois[10], Albrecht de Jonge[1], Gert de Lange[1], Ian Delorme[8], Anna DiGiorgio[12], Luc Dubbeldam[1], Kevin Edwards[1,13], Michael Fich[13], Rolf Güsten[11], Fabrice Herpin[13], Netty Honingh[6], Robert Huisman[1,] Herman Jacobs[1], Willem Jellema[1], Jon Kawamura[14],Do Kester[1], Teun Klapwijk[25], Thomas Klein[11], Jacob Kooi[5] , Jean-Michel Krieg[8], Carsten Kramer[6], Bob Kruizenga[24], Wouter Laauwen[1], Bengt Larsson[15], Christian Leinz[11], Rene Liseau[15], Steve Lord[8], Willem Luinge[1], Anthony Marston[1,16], Harald Merkel[19], Rafael Moreno[8], Patrick Morris[9], Anthony Murphy[23], Albert Naber[1], Pere Planesas[3,17], Jesus Martin-Pintado[18], Micheal Olberg[1,19], Piotr Orleanski[20], Volker Ossenkopf[1,6], John Pearson[14], Michel Perault[21], Sabine Phillip[11], Mirek Rataj[20], Laurent Ravera[4], Paolo Saraceno[12], Rudolf Schieder[6], Frank Schmuelling[6] , Ryszard Szczerba[23], Russell Shipman[1], David Teyssier[1,16], Charlotte Vastel[4], Huib Visser[24], Klaas Wildeman[1], Kees Wafelbakker[1], John Ward[14], Roonan Higgins[1,23], Henri Aarts[1], Xander Tielens[1,26], Peer Zaal[1] .

SRON
Netherlands Institute for Space Research

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Netherlands Organisation for Scientific Research

Herschel-HIFI Consortium

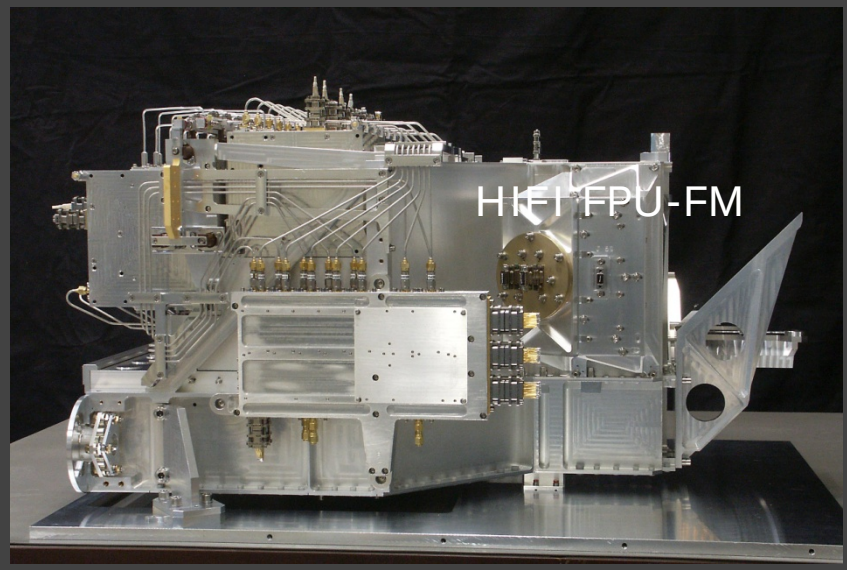
The Netherlands: SRON Groningen/SRON Utrecht DIMES, University of Delft	USA: Caltech and JPL, Pasadena Univ. of Amherst
France: CESR Toulouse LRM-DEMIRM with IRAM Observatoire de Bordeaux	Germany: KOSMA, I. Physikalisches Institut, Köln Max Planck Inst. Für Aeronomie, Lindau Max Planck Inst für Radioastronomie 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

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

Lay-out Presentation:

Scientific motivation

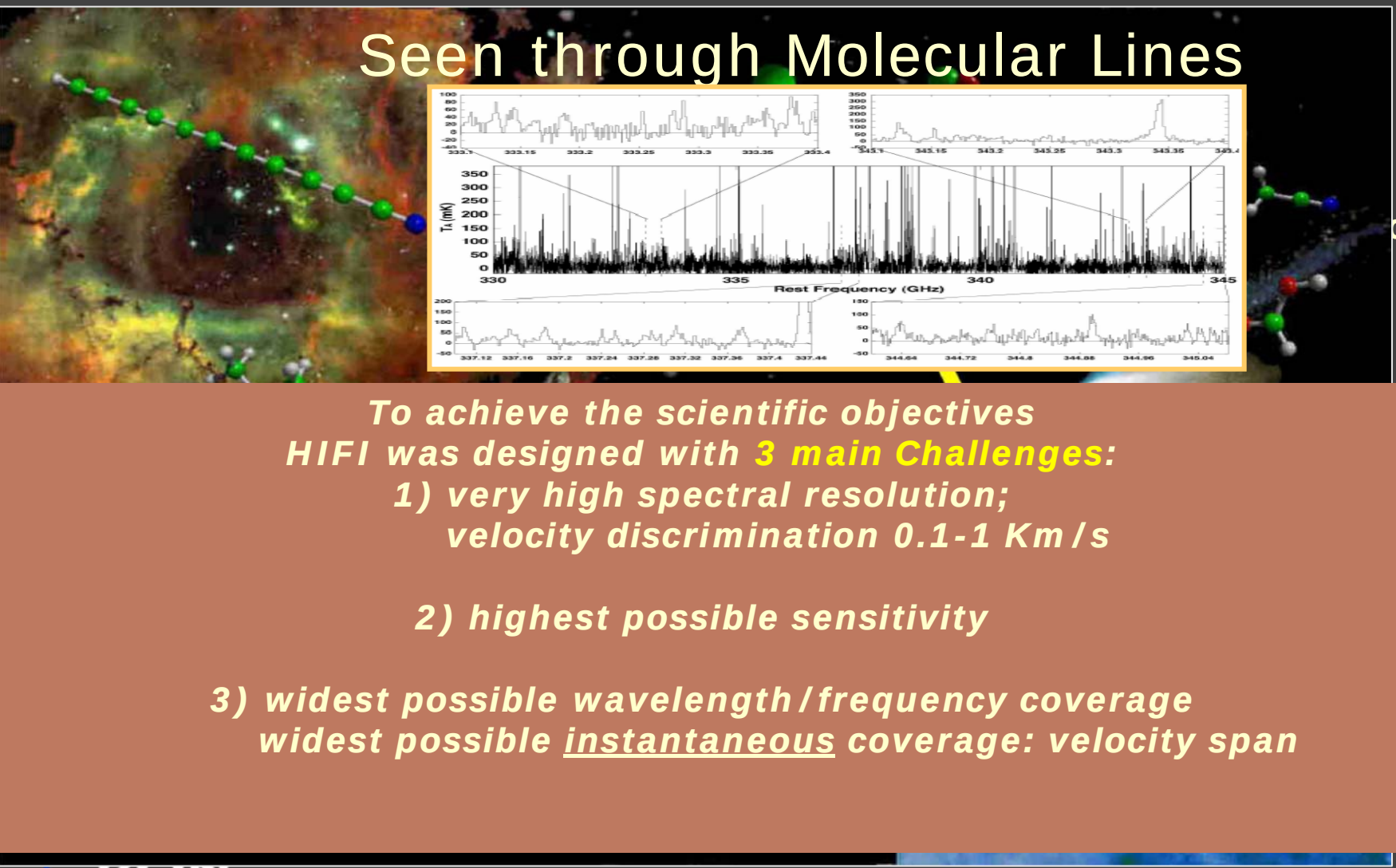
- HIFI consortium
- Instrument design
- First ILT results
- Instrument Capabilities



HIFI Programmatic Status:

- 2004 CQM delivered
- 2005 CQM successfully tested/
  FPU-FM integrated (1235) and started testing
- 2006 ++FPU-FM fully integrated and testing ongoing;
  ++ Final Instrument Level tests, including calibration and characterisation, started December till July 2007.
- 2007mid—2008 Integration in Satellite and system tests

HIFI main Science:
Life Cycle of Gas and Dust in Our- and Nearby Galaxies:



To achieve the scientific objectives
HIFI was designed with 3 main Challenges:

1) very high spectral resolution;
velocity discrimination 0.1-1 Km/s

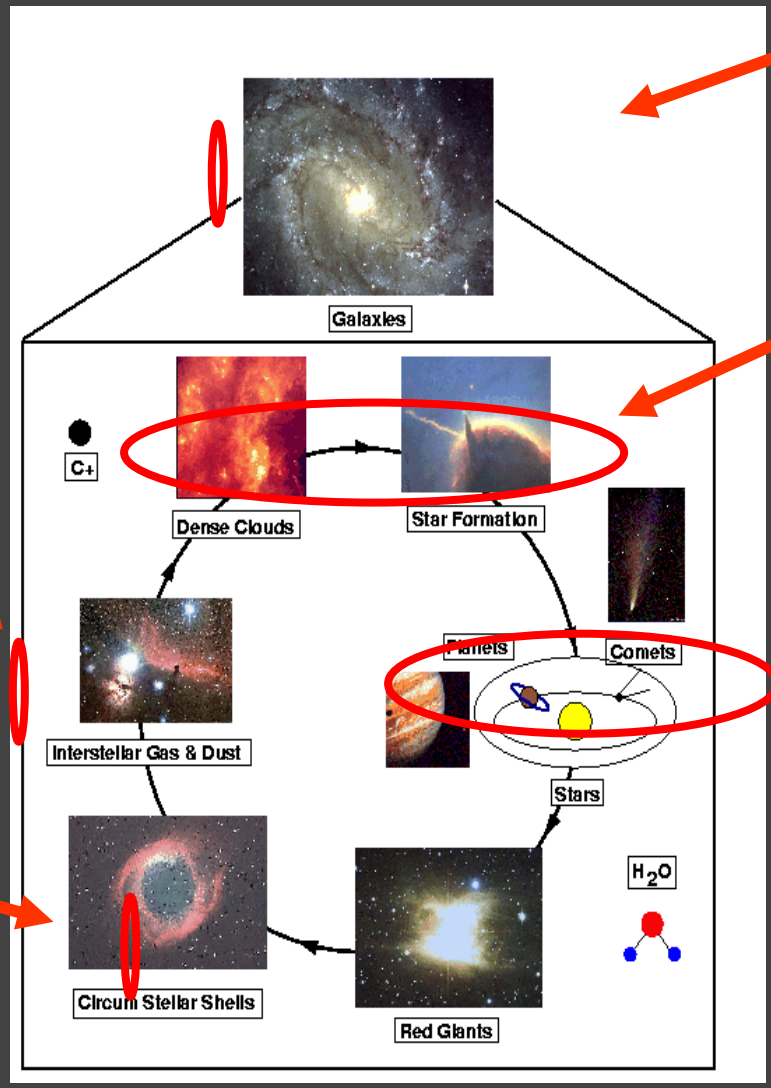
2) highest possible sensitivity

3) widest possible wavelength/frequency coverage
widest possible <u>instantaneous</u> coverage: velocity span

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

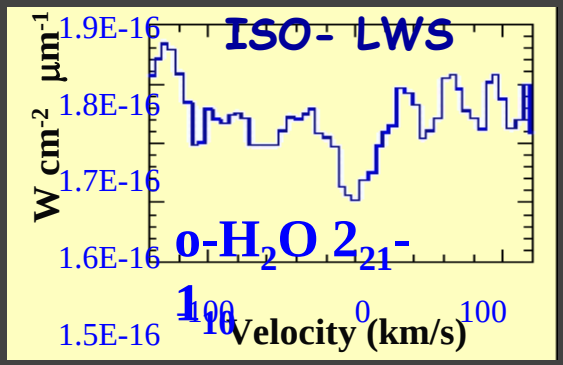
Solar System:
- Water in Giant Planets
- Atmospheric chemistry
- Water activity and composition of comets

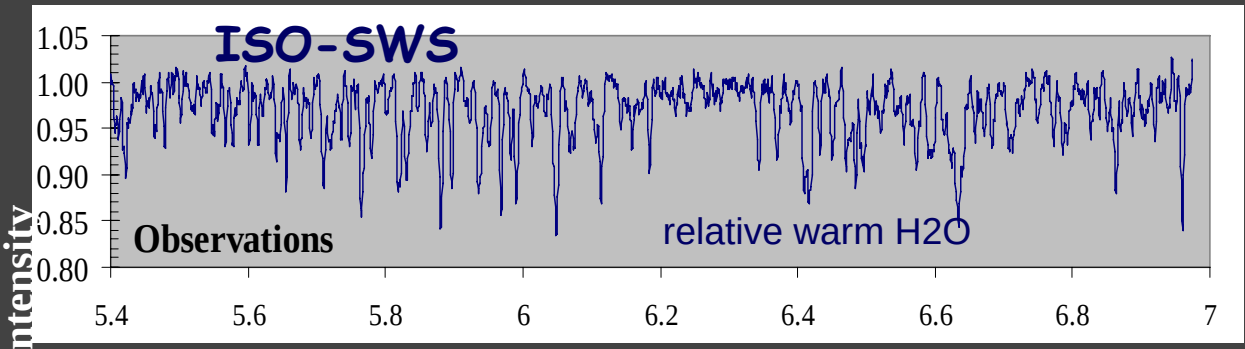
SRON

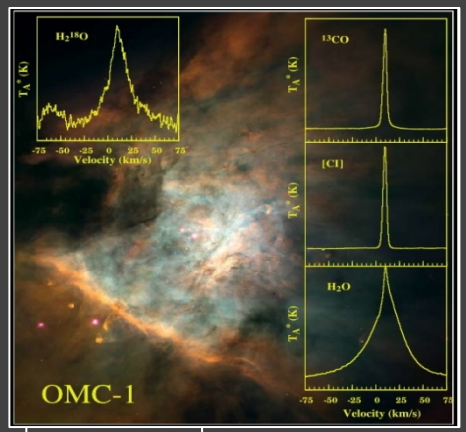
Herschel Unique Science:

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

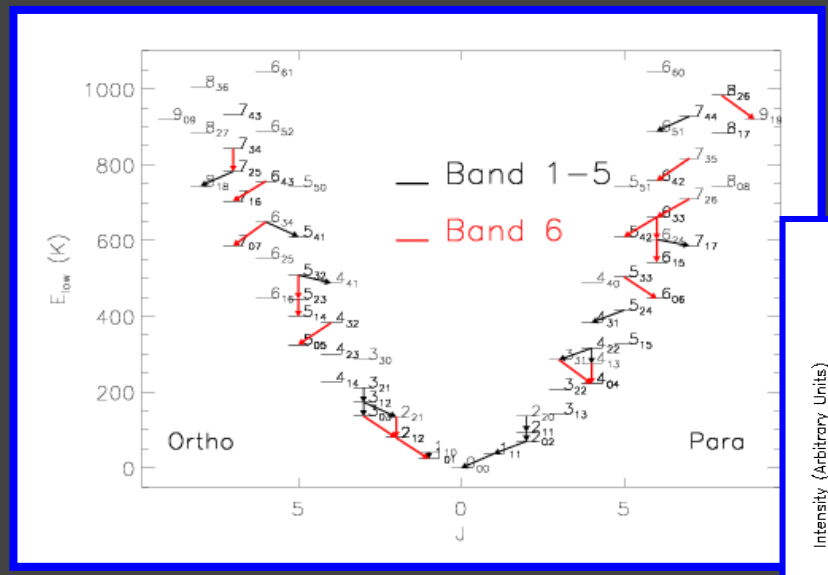
HIFI has coverage for variety of densities and excitation conditions

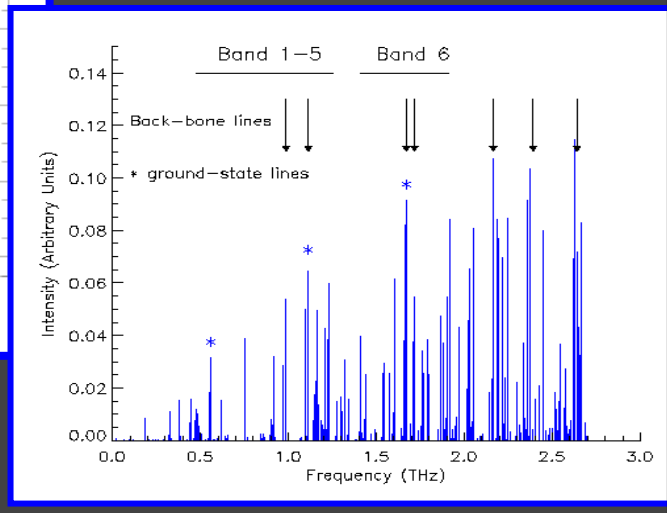






SWAS



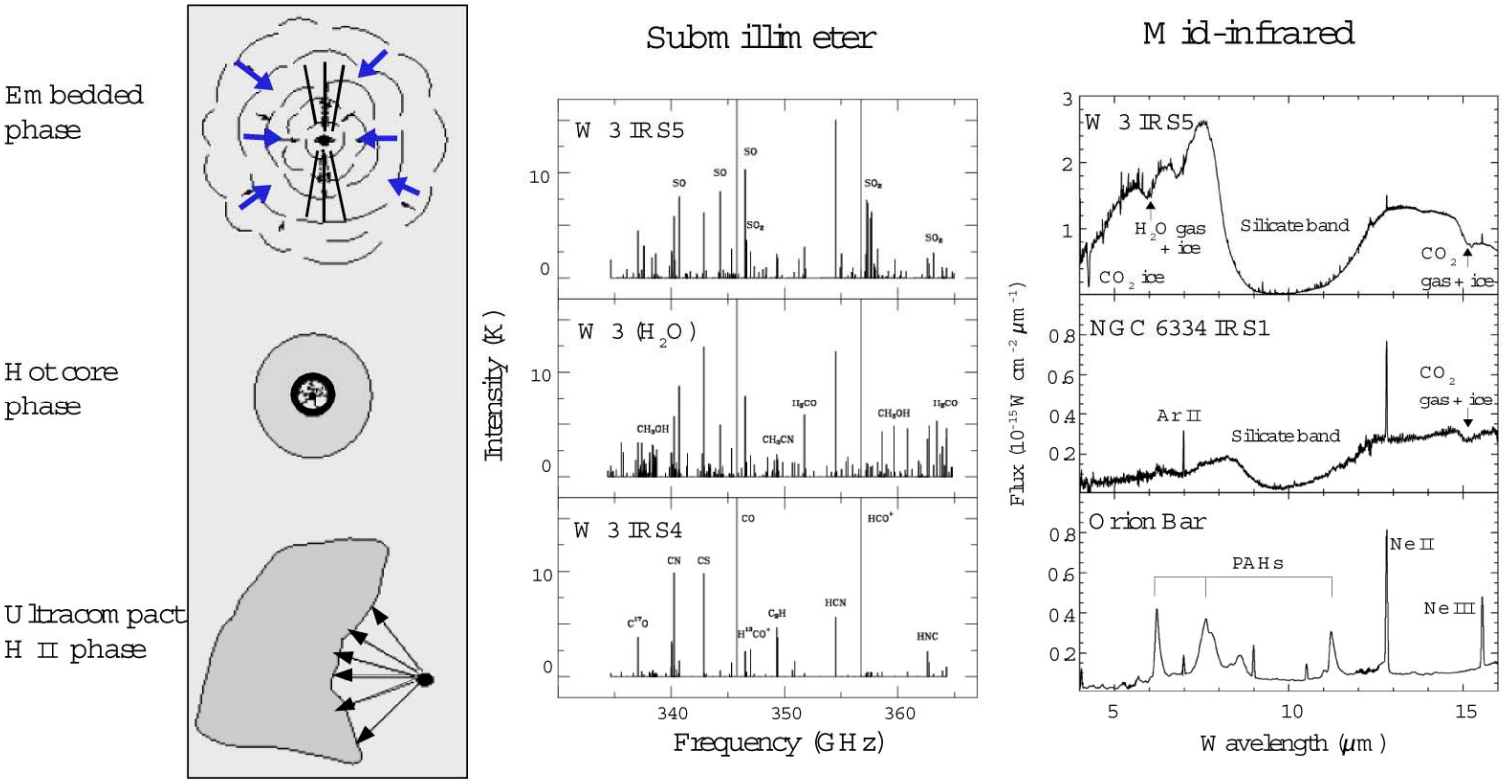


Role Water as chemical and physical probe

- 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?

Chemistry - as diagnostic tool



Ph.D. Thesis, Boonman (2003)

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

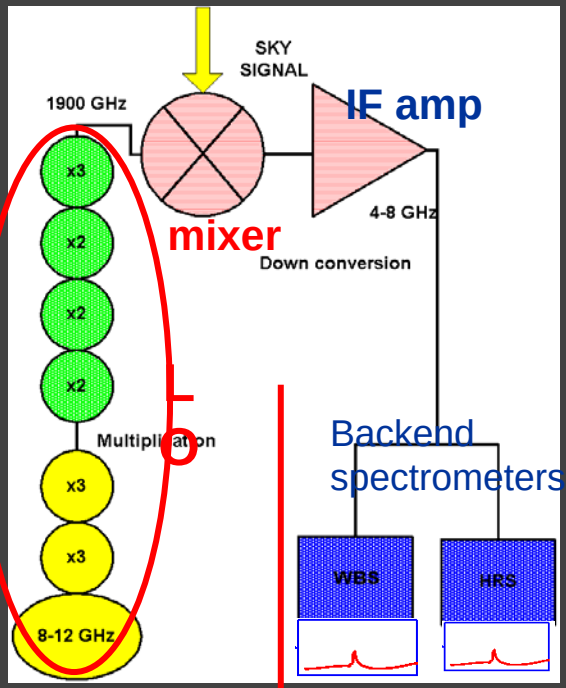
3. Calibration Accuracy: 10% baseline; 3% goal

- **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

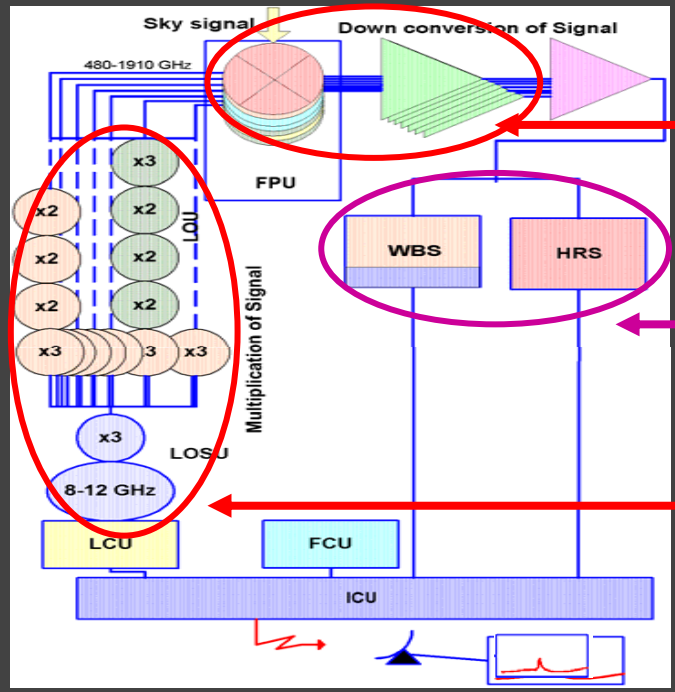
Angular Resolution (with Herschel): 12”- 40”

2) To cover wide frequency range:
HIFI consists of 7 receivers

Basic receiver elements



7 Mixer bands and 7×2 LO's



7 Mixers/amps

2×2 Spectrometers (common)

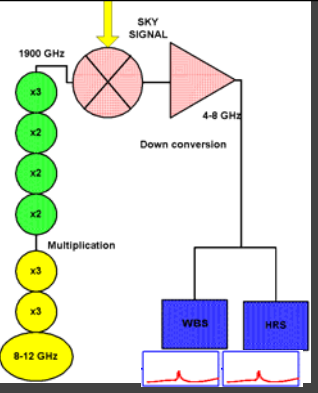
2×7 LO bands

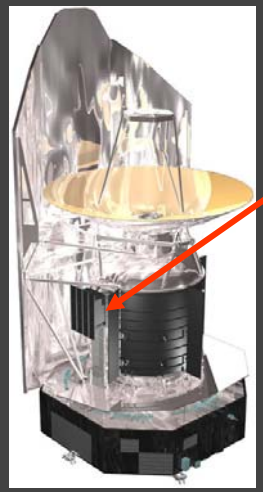
Frequency Dependency and range

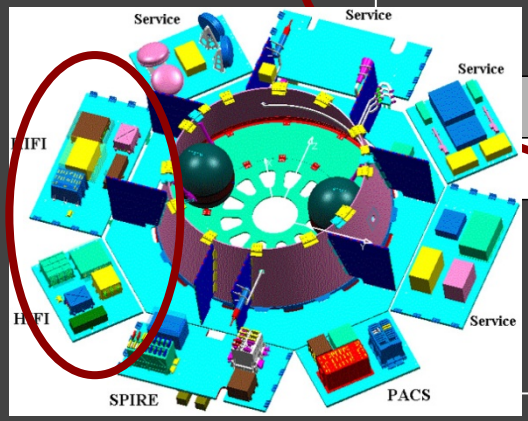
Spectral resolution

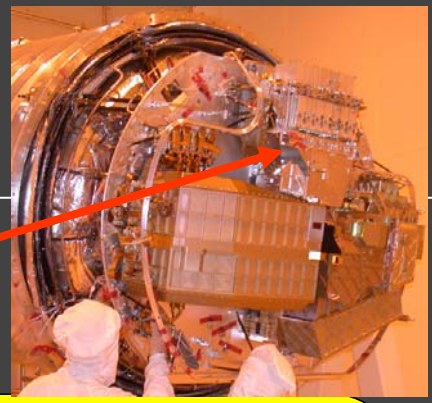
3) High Sensitivity
with superconducting mixers (SIS and HEB)

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

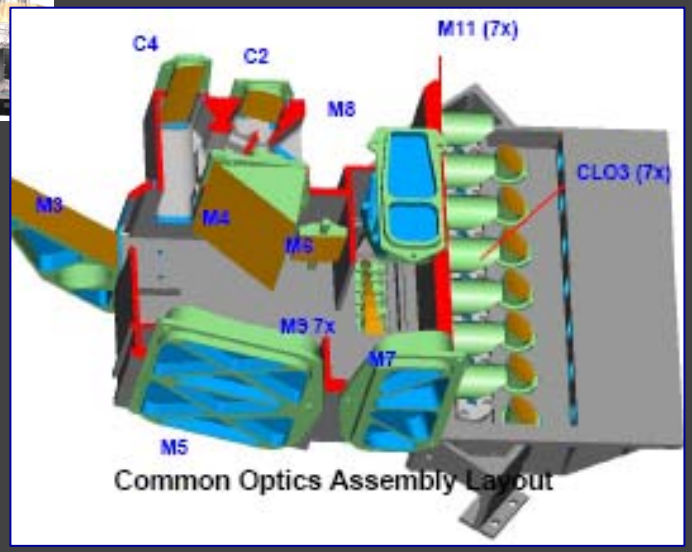
Instrument Control Unit

Instrument Controller
Command Interface

Power Conditioning (for FCU only)
Data Interface

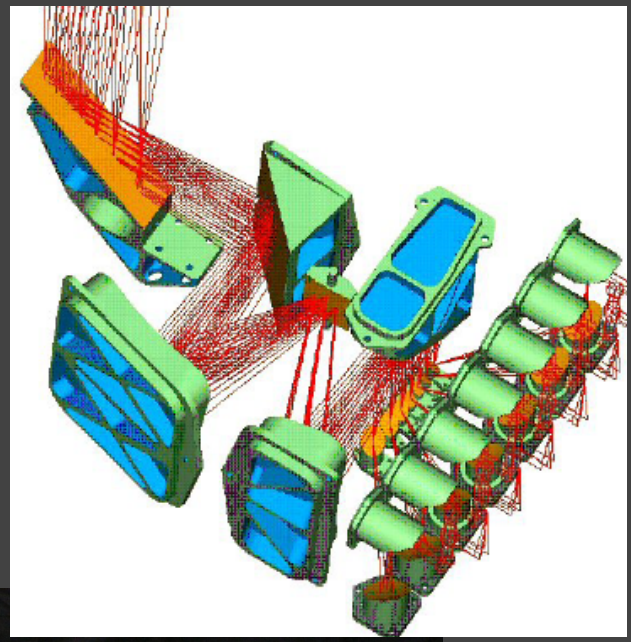
spacecraft CDMS

In Service Module

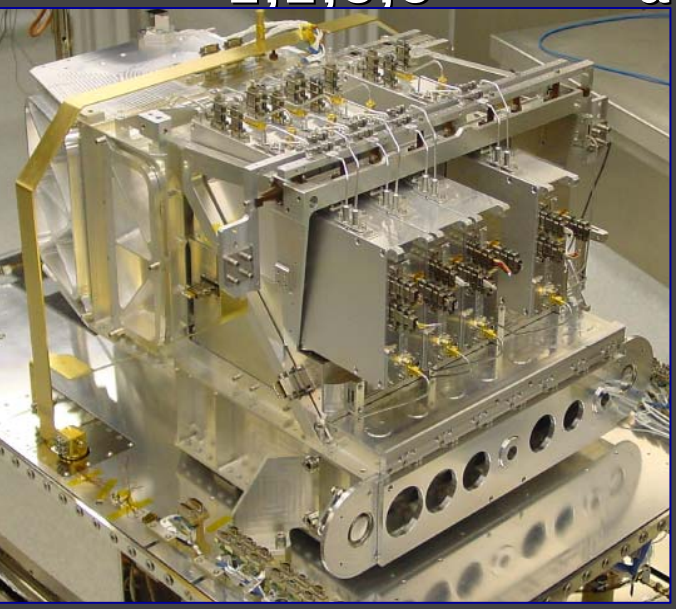


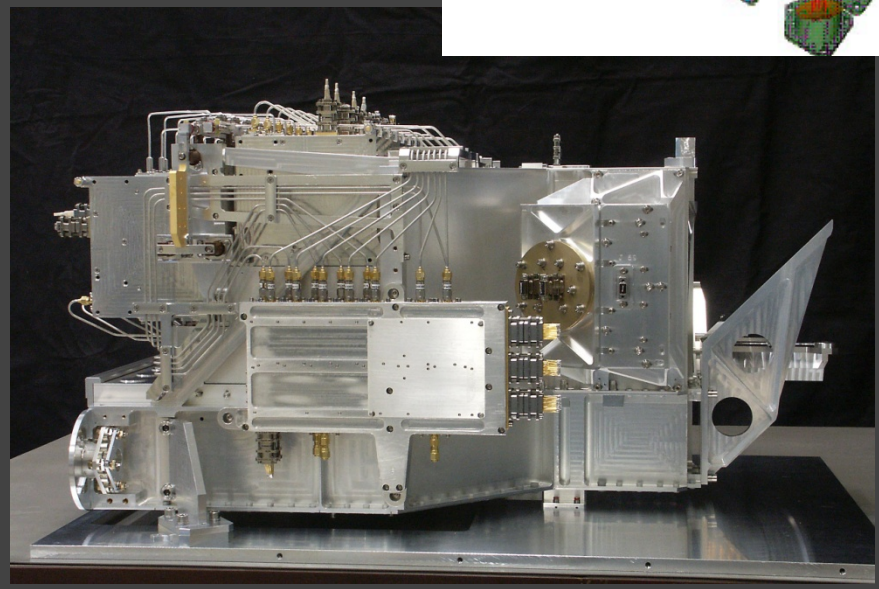
Common Optics Assembly Layout

Common Optics Asembly

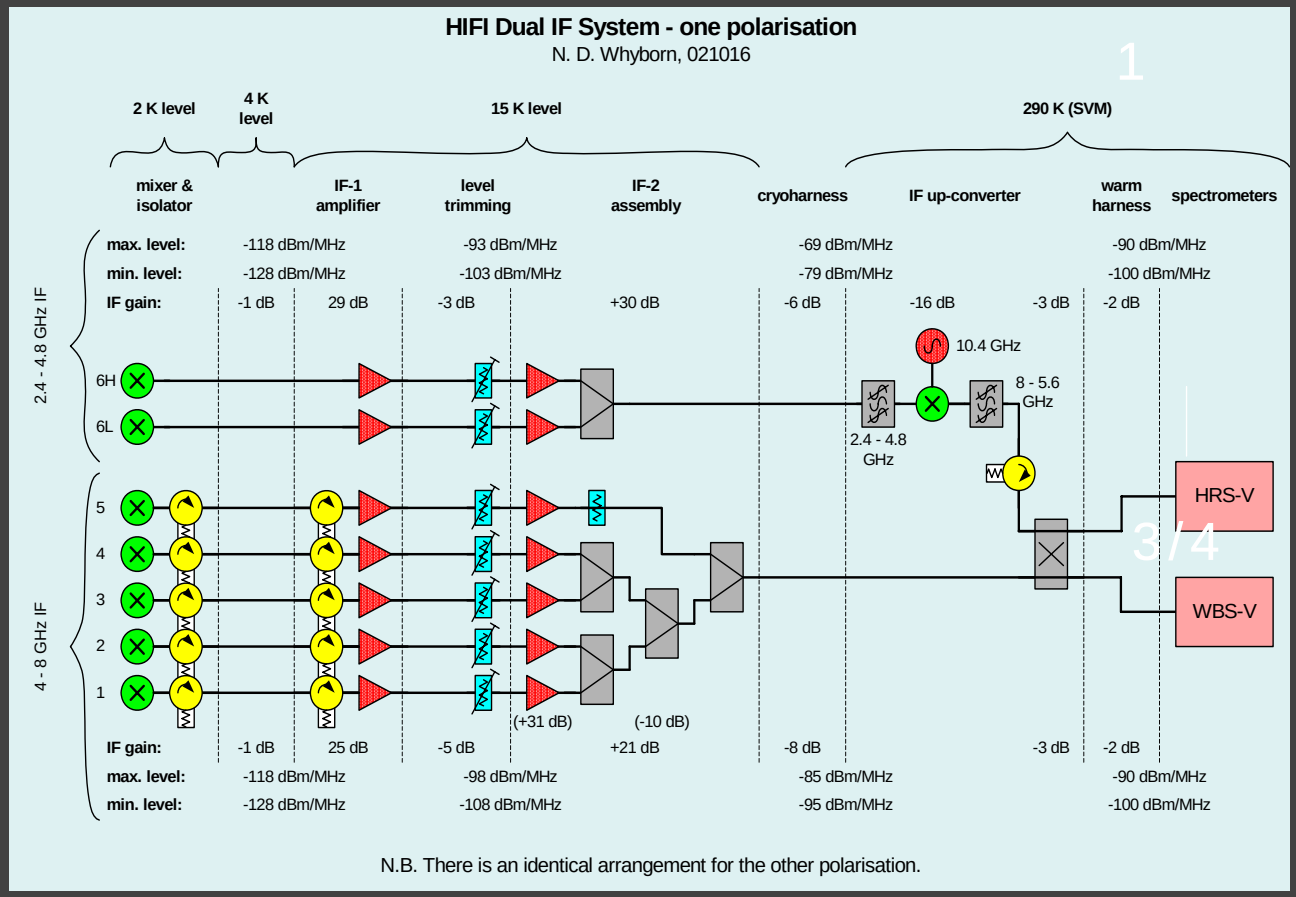


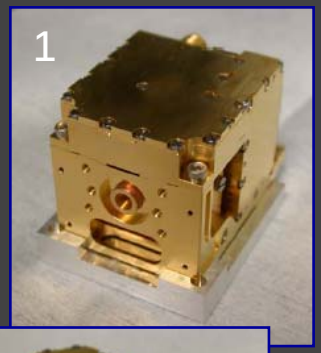
HIFI FPU FM with mixer bands 1,2,3,5 and complete

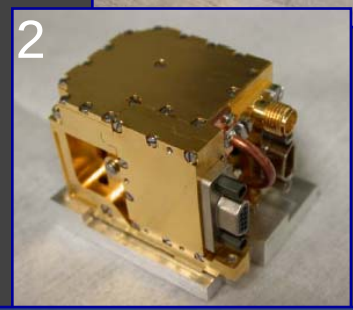


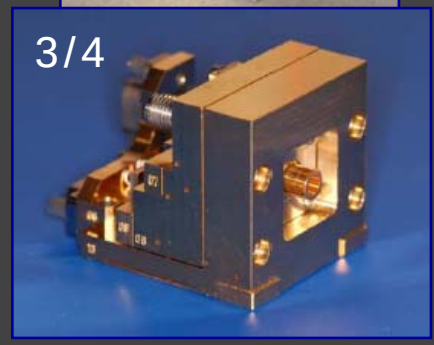


HIFI Signal Chain: Mixers and Amplifiers

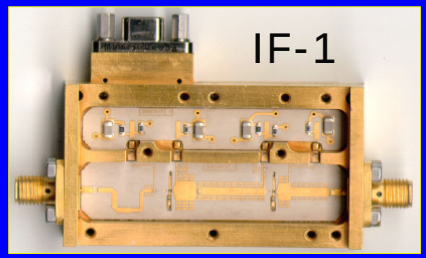


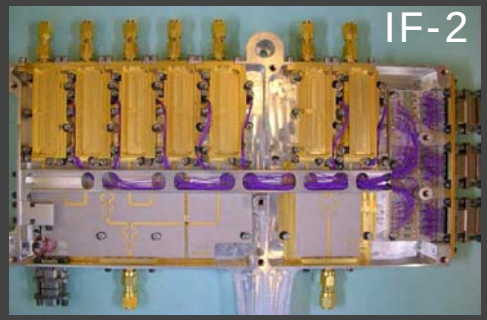


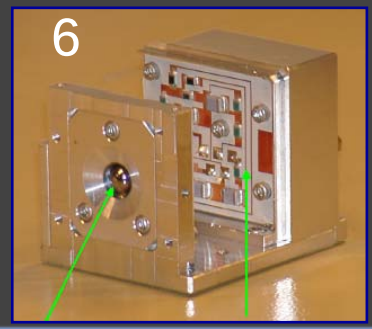


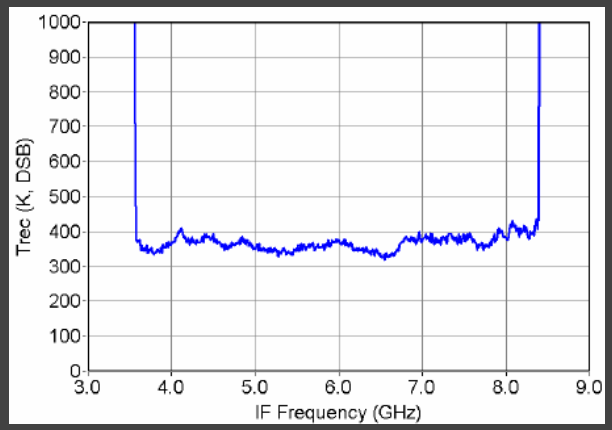


QM & FM PROGRAMS (First Prototype)

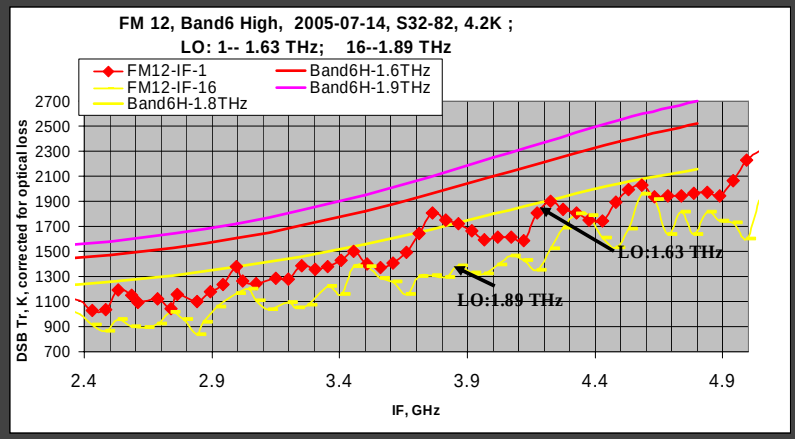




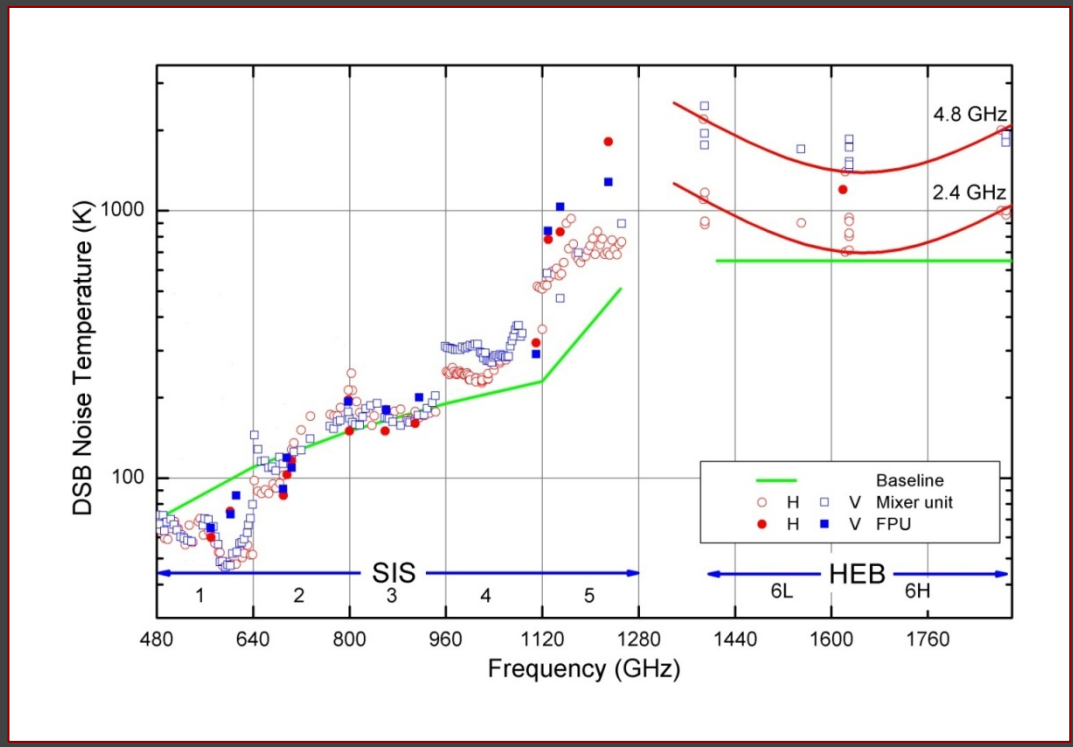




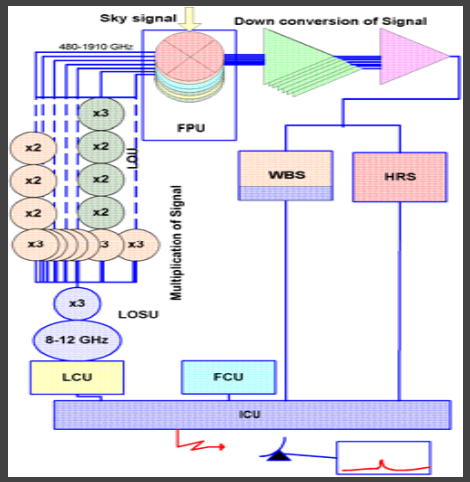
Band-3 SIS Noise Temperature as function of IF

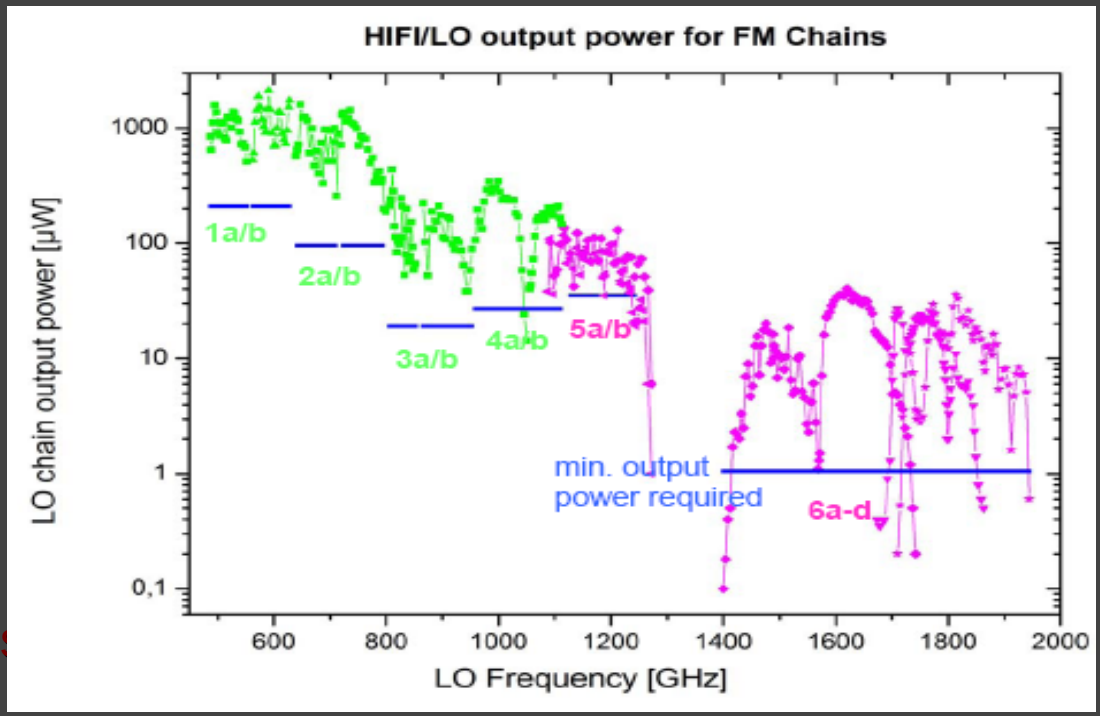


Band-6 HEB Noise Temperature as function of IF



Local Oscillator Scheme: A common source LSU; 2×7 multiplication chains in 7 assemblies, located opposite the FPU outside the cryostat

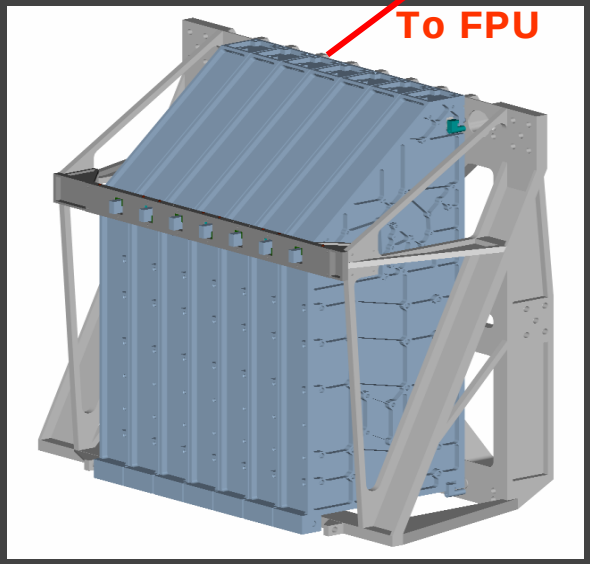


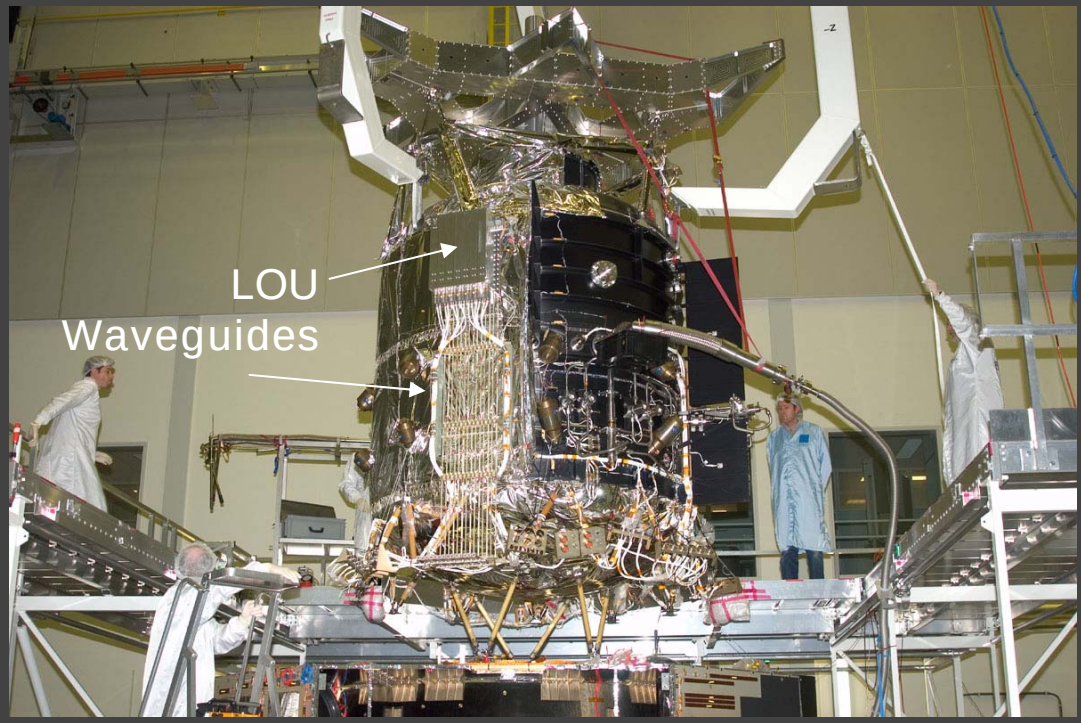


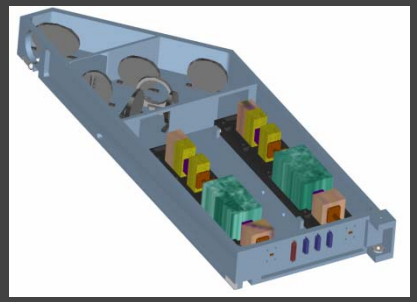
- LOU with 7 LO assemblies
- each with 2 LO chains (10%)

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

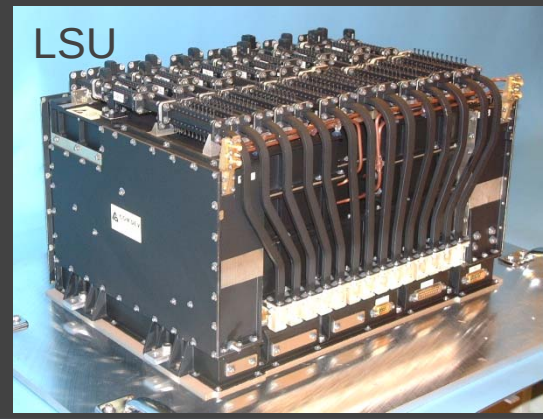
LOU with 7 LO assemblies each with 2 LO chains



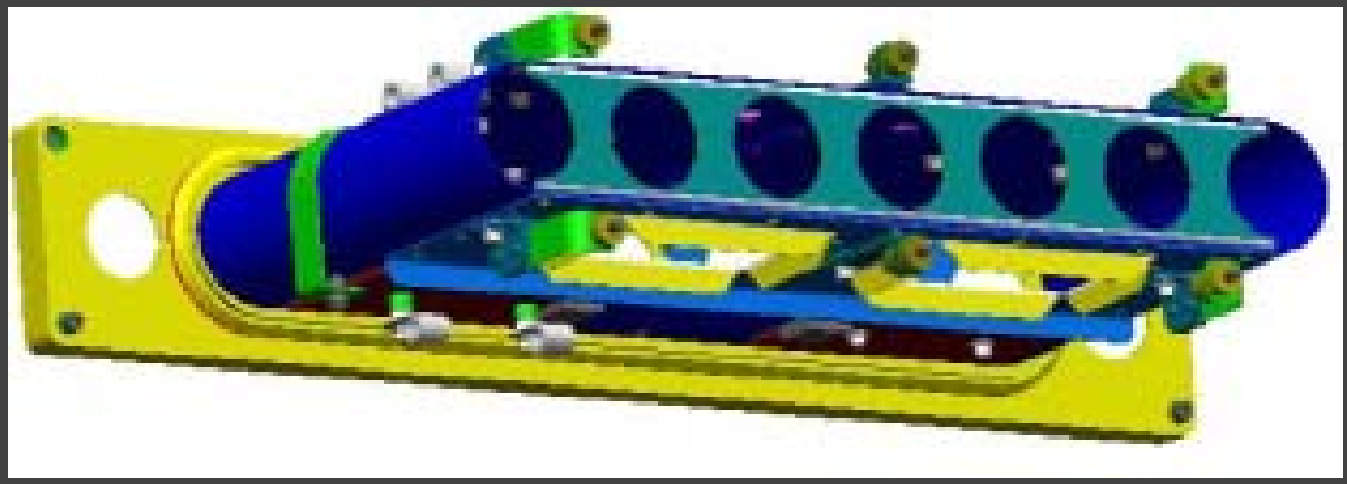


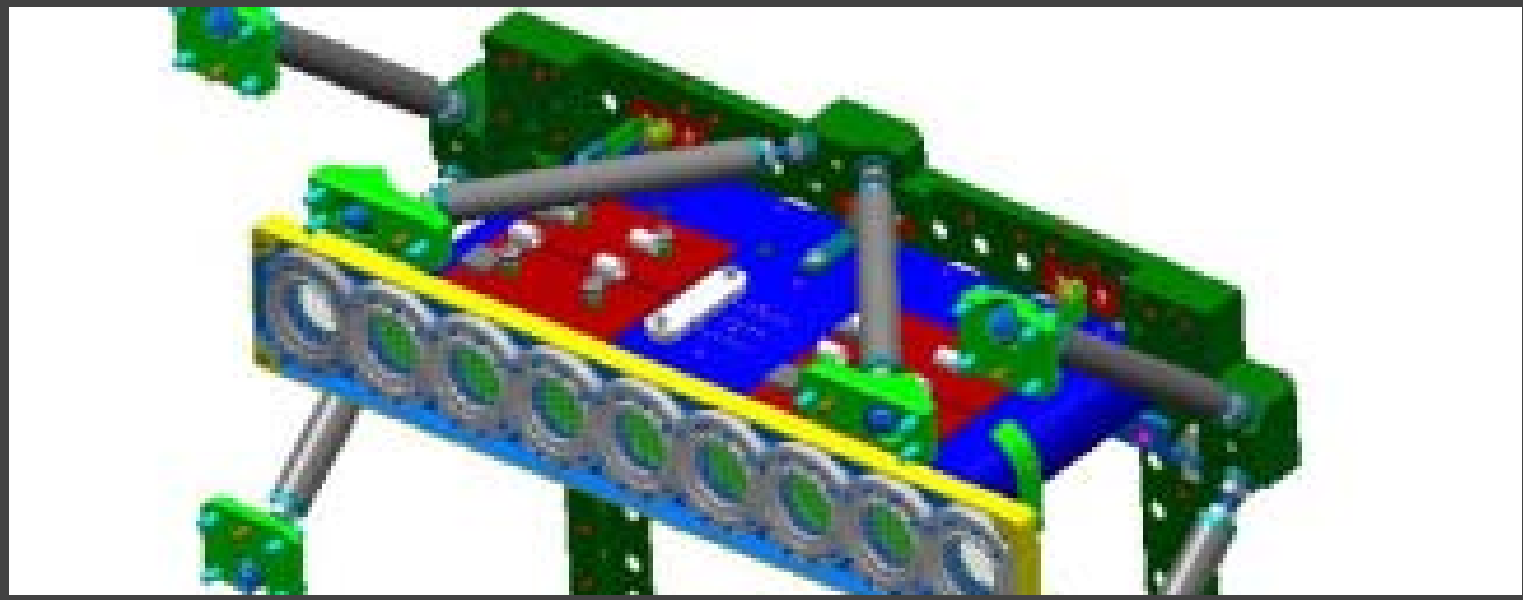


LO Assembly with two chains

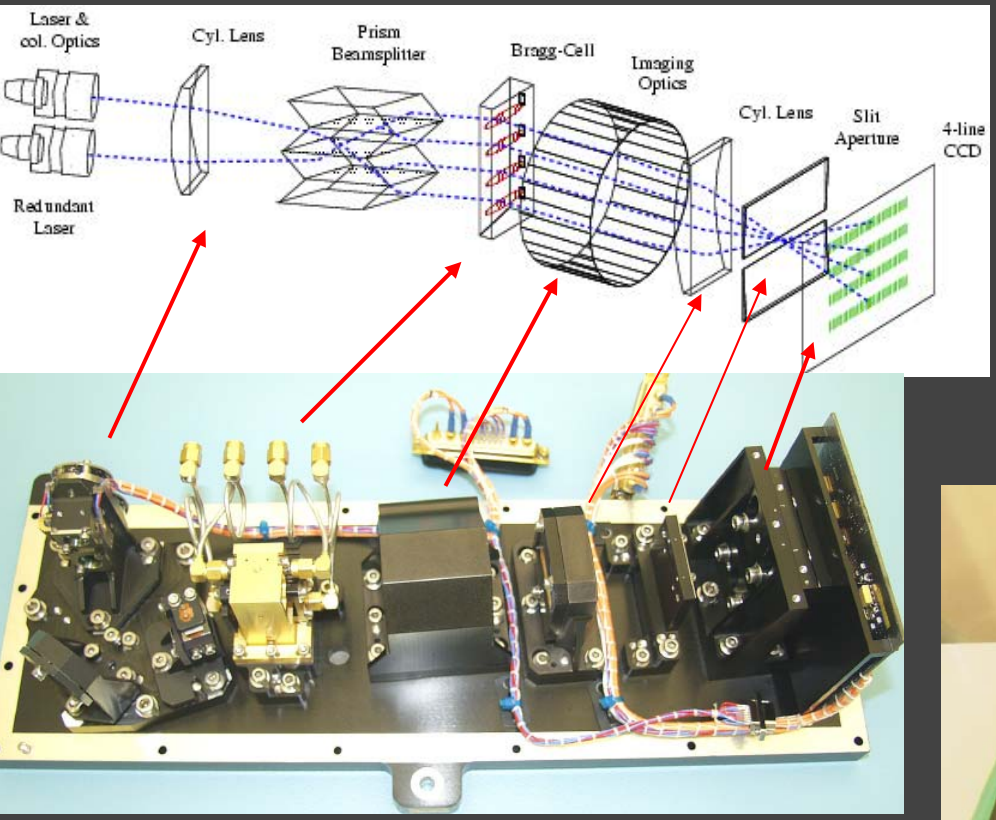


External De-icing baffle to be used for attenuator

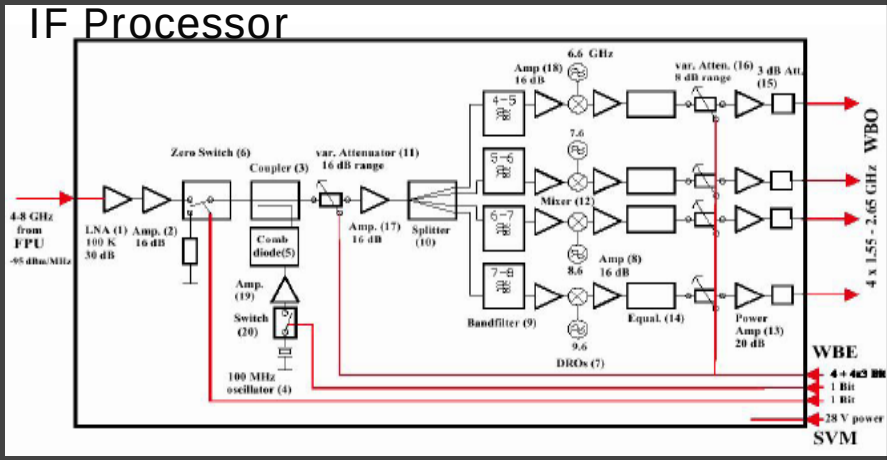




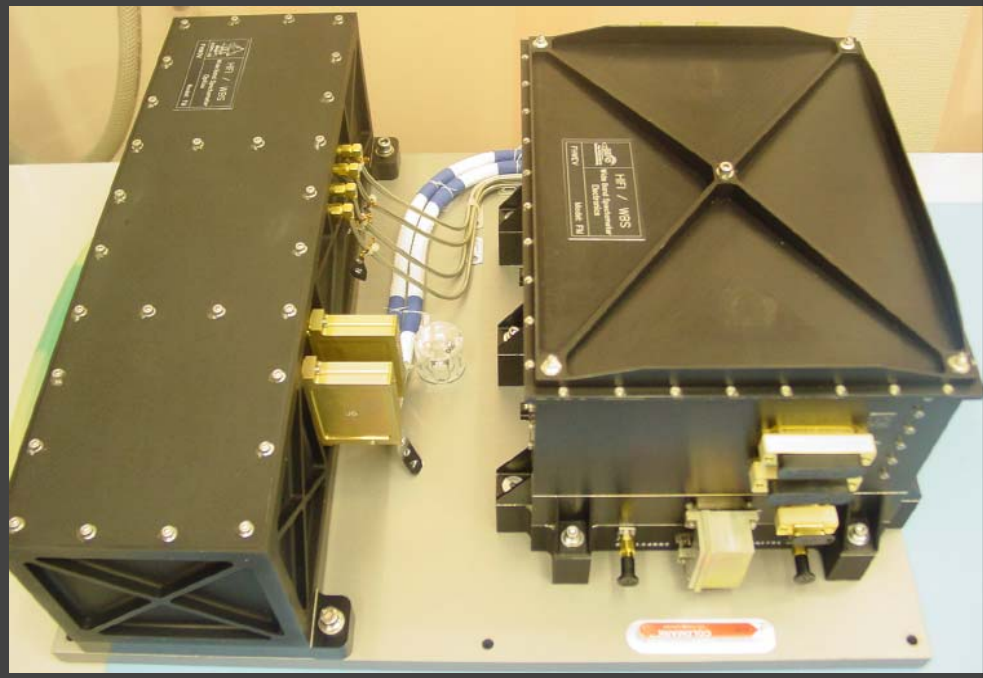
WBO FM (one Polarisation) with 1.1 MHz resolution and 4GHz bandwidth



IF Processor



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

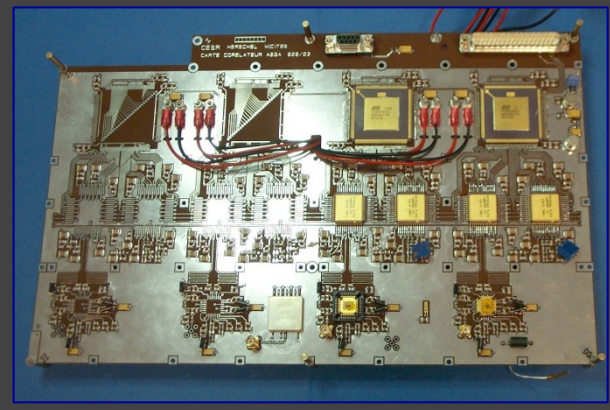


HIFI-HRS (auto-correlator) FM Capabilities

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

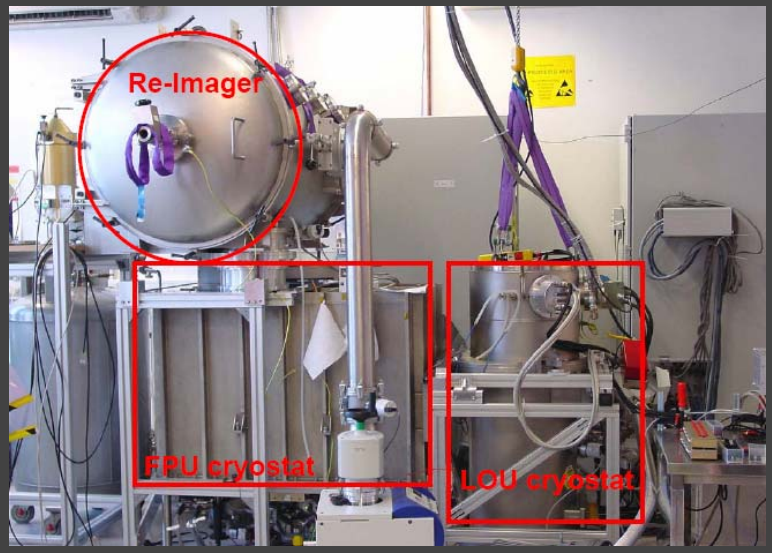
Linearity with software correction : better than 1%

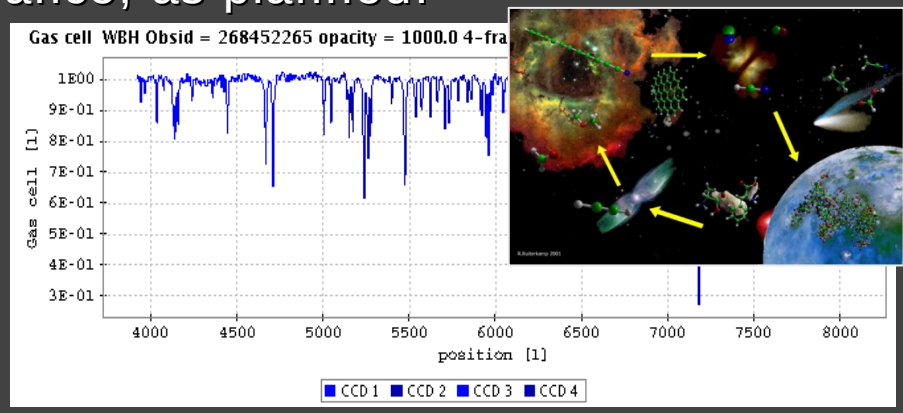


2 HRS FM modules

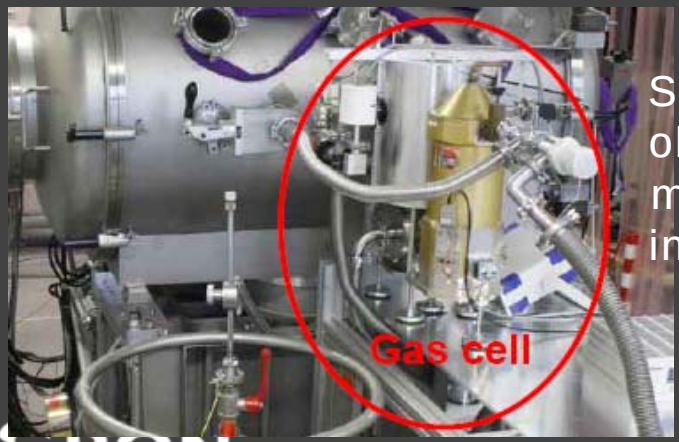
HIFI 7 months of testing: demonstrated readiness for flight

with good performance, as planned.

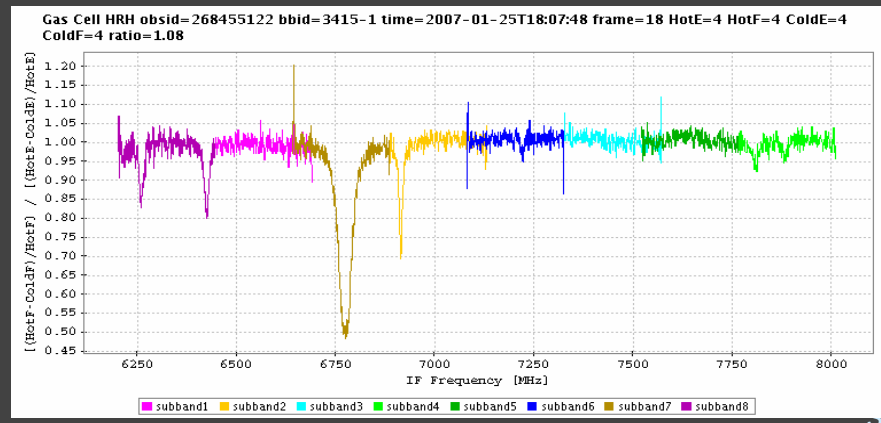




With WBS: Methanol at 1016 GHz

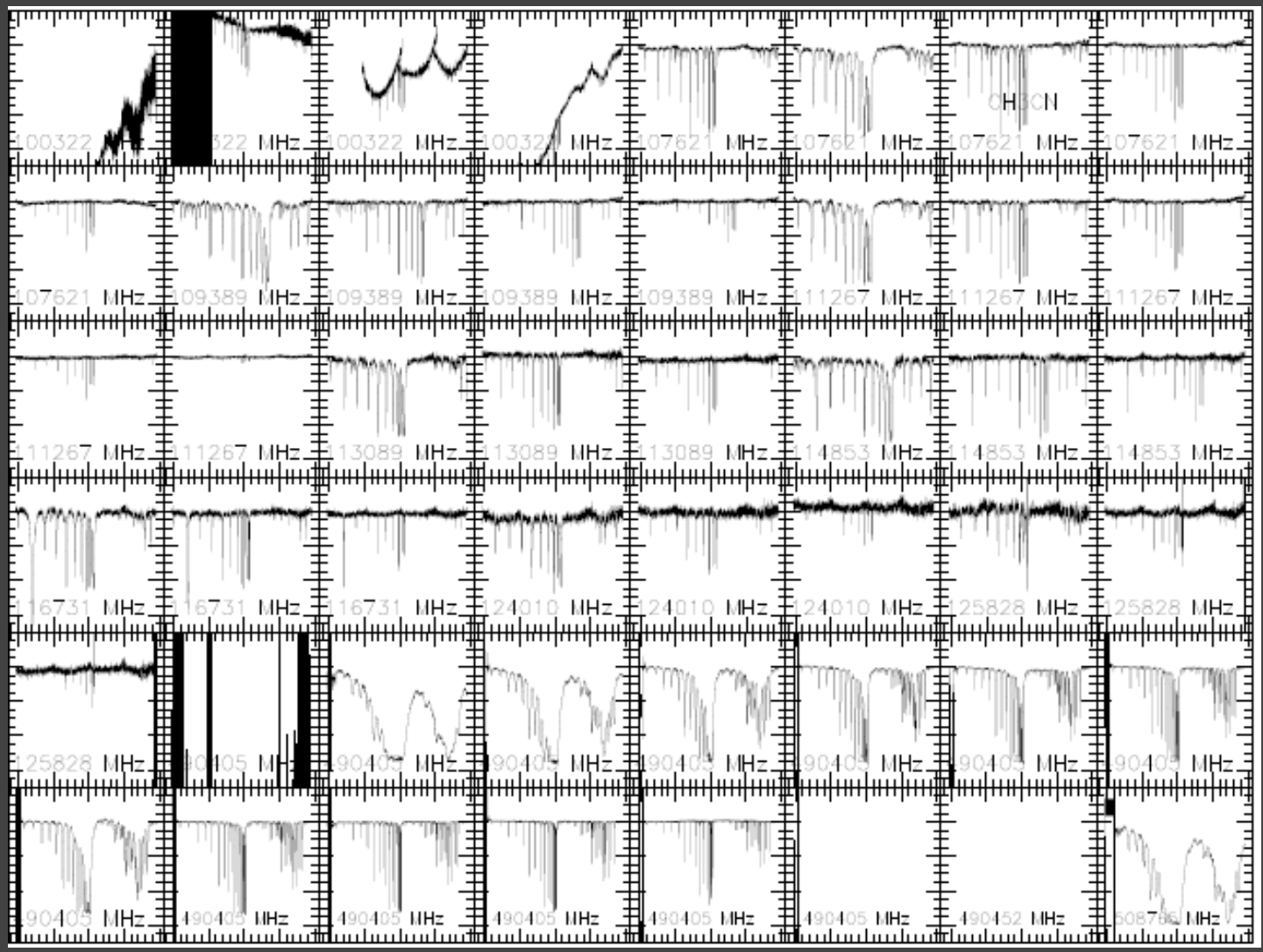


Simulating observing molecules in space



With HRS: SO2 at 1696 GHz

Gas cell tests Band 1



HIFI Stability: Allan Variance numbers

HRS-V

		Continuum [1,4] Stability (mean/std)		Spectroscopic [1,4] Stability (mean/std)		Diff. Load-Chop [1,4] Spectroscopic		Diff. Internal-Load [1,4] Spectroscopic		Diff. Load-Switch (DBS) [1,4] Spectroscopic		Tsys SSB (K)	RMS (mK) in 600s
band	Freq. (GHz)	spec >7s		spec >100s		spec >850s		spec >850s		spec >850s			
		Full	Best SubB and	Full	Best SubB and	Full	Best SubB and	Full	Best SubB and	Full	Best SubB and	Mean	Mod o-Diff
B1a	488-522	34.1/12.0	49.1/17.0	144.6/30.0	598.4/332.0	> 1800	> 1800	407.3	>=860	>> 2250	>> 2250	144.2	10.7
B1b	566-628	31.5/13.8	43.8/12.6	127.0/47.7	709.9/575.4	> 1800	> 1800	455.2	>=860	>> 2250	>> 2250	166.8	12.4
B2a	642-710	22.1/10.9	35.3/21.6	133.5/41.6	473.6/221.8	> 1800	> 1800	>=850	>=860	>> 2250	>> 2250	276.8	20.6
B2b	724-793	15.9/7.4	22.2/10.3	92.8/36.6	459.3/191.7	> 1800	> 1800	>= 700	>= 700	>> 2250	>> 2250	325.2	24.2
B3a	807-852	7.6/4.0	8.4/4.8	47.7/20.4	404.3/189.4	>> 900	>> 900	215.3	>= 700	> 1800	> 1800	631.6	47.1
B3b	866-953	13.1/7.5	13.9/8.0	56.1/27.4	192.6/85.0	>> 900	>> 900	>=850	>=860	> 1800	> 1800	536.6	40.1
B4a	980-1040	10.3/5.7	61.4/231.2	71.6/42.7	435.4/234.9	>> 900	>> 900	713.4	>=860	>> 2250	>> 2250	805.4	60.0
B4b	1065-1115	19.9/6.7	34.7/12.8	97.7/40.7	527.3/199.4	>> 900	>> 900	>= 700	>=860	>> 2250	>> 2250	807	60.2
B5a	1127-1178	26.7/10.1	47.0/24.5	123.7/33.9	448.6/209.0	>> 900	>> 900	>=850	>=860	> 1800	> 1800	1918.8	143.0
B5b	1192-1242	23.1/8.3	46.4/16.8	130.4/63.5	420.8/188.8	>> 900	>> 900	>=850	>=860	> 1800	> 1800	2658.8	198.2
B6a	1430-1570					>> 900	>> 900	800	>=860	> 1800	> 1800	3317.8	247.3
B6b	1580-1690					>> 900	>> 900	800	>=860	> 1800	> 1800	3133.2	233.5
B7a	1692-1845											3394.8	253.0
B7b	1719-1908											3705.8	276.2

Frequency Switching Tabulated (all bands as measured).

		Frequency Switching [1,2,3]					
		145MHz		154MHz		164MHz	
band	Freq. (GHz)	spec > 300s		spec > 300s		spec > 300s	
Polarization		H	V	H	V	H	V
B1a	488-522						
B1b	566-628	>>200	>>200	>>200	>>200	>>200	>>200
B2a	642-710	>>200	>>200	>>200	>>200	>>200	>>200
B2b	724-793	>200	>200	>200	>200	100	200
B3a	807-852	>>200	>>200	>>200	>>200	>>200	>>200
B3b	866-953	>200	>200	>200	>200	>200	>200
B4a	980-1040	111	111	>200	>200	>200	>200
B4b	1065-1115						
B5a	1127-1178	>>200	>>200	>>200	>>200	>>200	>>200
B5b	1192-1242	>>200	>>200	>>200	>>200	>>200	>>200
B6a	1430-1570	< 16	32	32	32	80	80
B6b	1580-1690	>>200	100	>200	200	>>200	>200
B7a	1692-1845	170	40	>200	60	>200	>200
B7b	1719-1908	>200	>200	>=130	>200	>=130	>200

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From Table to Observing Modes I

- Continuum stability = Continuum observations with OTF/Mapping
- Spectroscopic stability= Spectroscopy with OTF/Mapping
- Diff. Load Chop Spectroscopy = Double Beam Switch spectroscopy
- Diff. Internal Load Continuum = Double Beam Switch Continuum

Note: Not all Observations with same Obs Mode have same requirements (X-Gal Obs)

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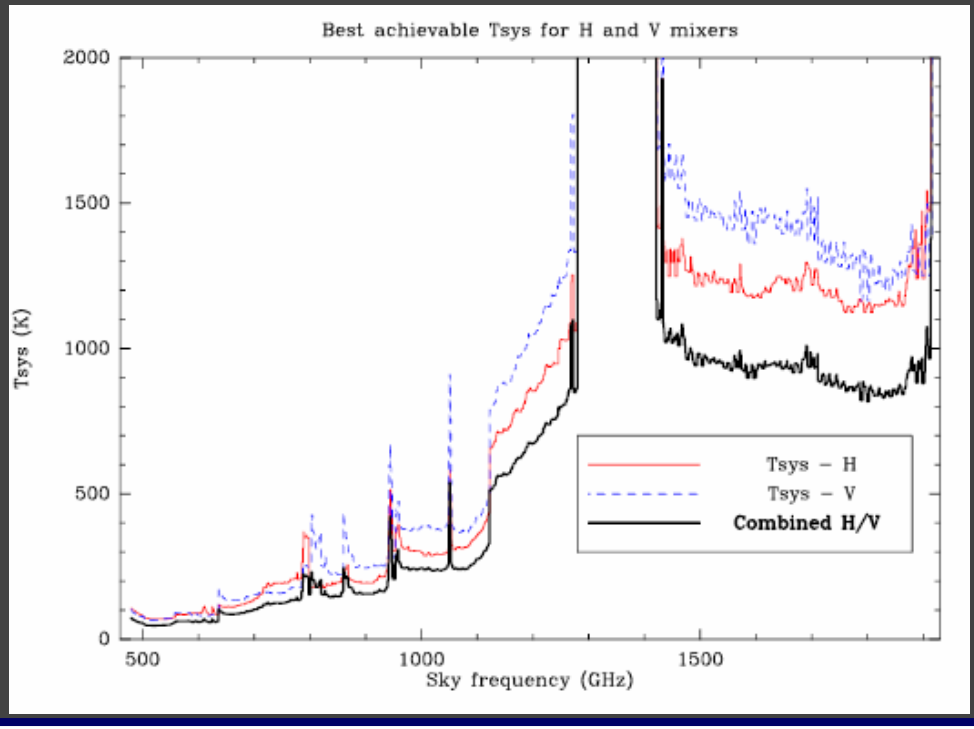
Expected HIFI sensitivities derived from ILT tests



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

HIFI Instrument Summary:

Heterodyne spectroscopy;

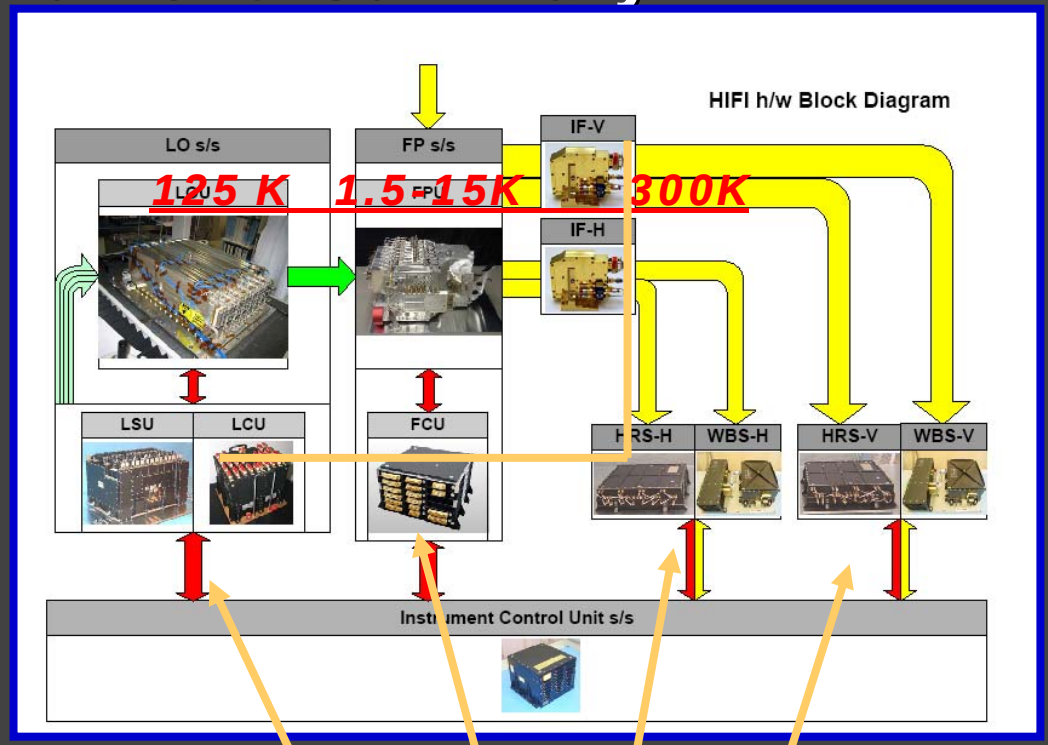
at the time in operation:

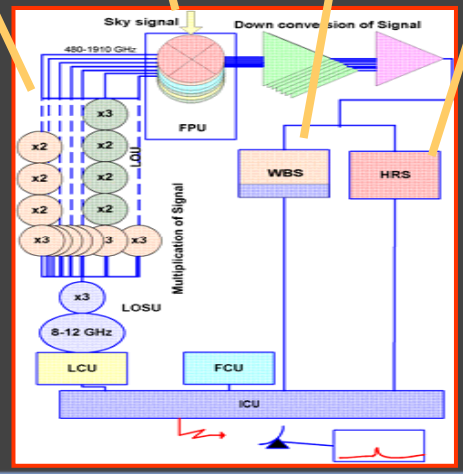
- One single pixel on the sky
- One frequency band;

- 7 dual-pol mixer bands

- 14 LO sub-bands

- 2 spectrometer systems in common;





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 Key Programs

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

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

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25 Years FIRST / Herschel
Proposal Preparatory Workshop
Noordwijkerhout, NL
May 1983

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