Herschel Spectroscopy

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http://www.rssd.esa.int/herschel/community_info.shtml

Topics

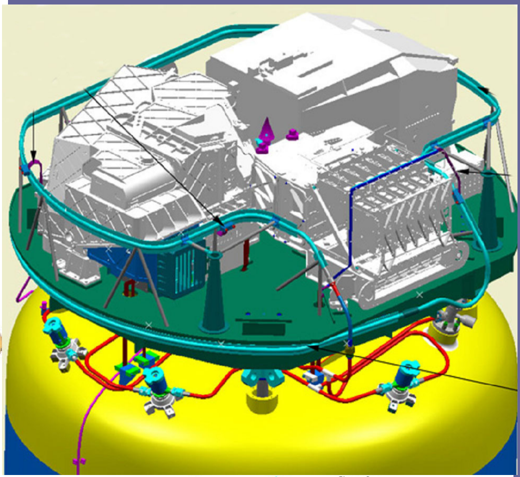
- Introduction Herschel
- Herschel AO and Key Program approach
- Instruments and their (spectroscopic) capabilities
  - PACS
  - SPIRE
  - HIFI
- Key Programs of PACS, SPIRE and HIFI
- Most Wanted Molecules and Lines

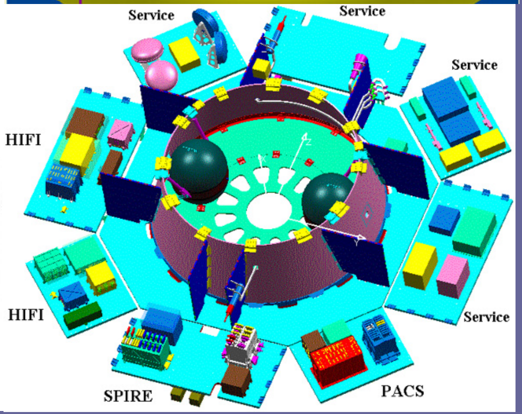
Herschel spacecraft

- telescope diameter 3.5 m
- telescope WFE < 6 μm
- telescope temp < 90 K
- telescope emissivity < 4%
- abs/rel pointg (68%) < 3.7″ / 0.3″

- **science instruments 3**

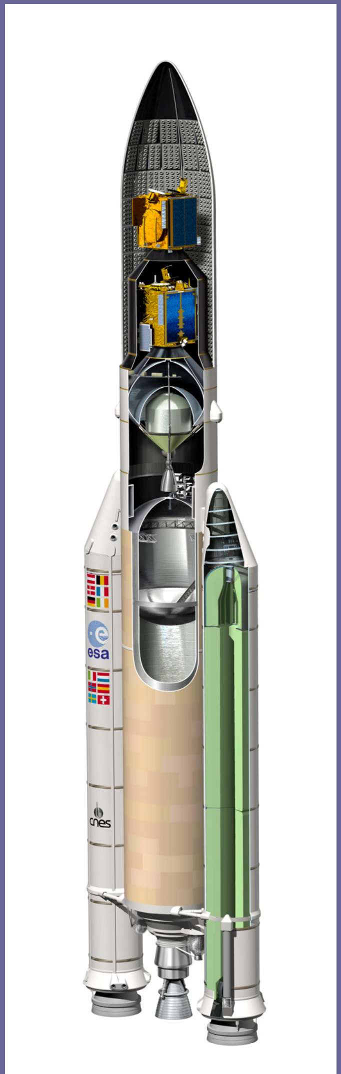
- science data rate 130 kbps
- cryostat lifetime 4.0±0.4 years
- height / width ~ 7.5 / 4 m
- launch mass ~ 3200 kg
- power ~ 1500 W
- orbit ‘large’ Lissajous around L2
- solar aspect angle 60-120 deg
- launcher (w Planck) Ariane 5 ECA





Launcher

- Launcher version:
  - Ariane 5 - ECA (cryogenic upper stage)
  - qualification flight V164
- Payload configuration:
  - Planck in lower position
  - Herschel in upper position
  - Sylda5/ACU2624
  - Long fairing
- Launch Autonomy:
  - 25 hours
- L2 Injection strategy:
  - direct injection
  - 25 minutes powered phase
- L2 Injected mass capability:
  - ≥6273 kg including adaptors



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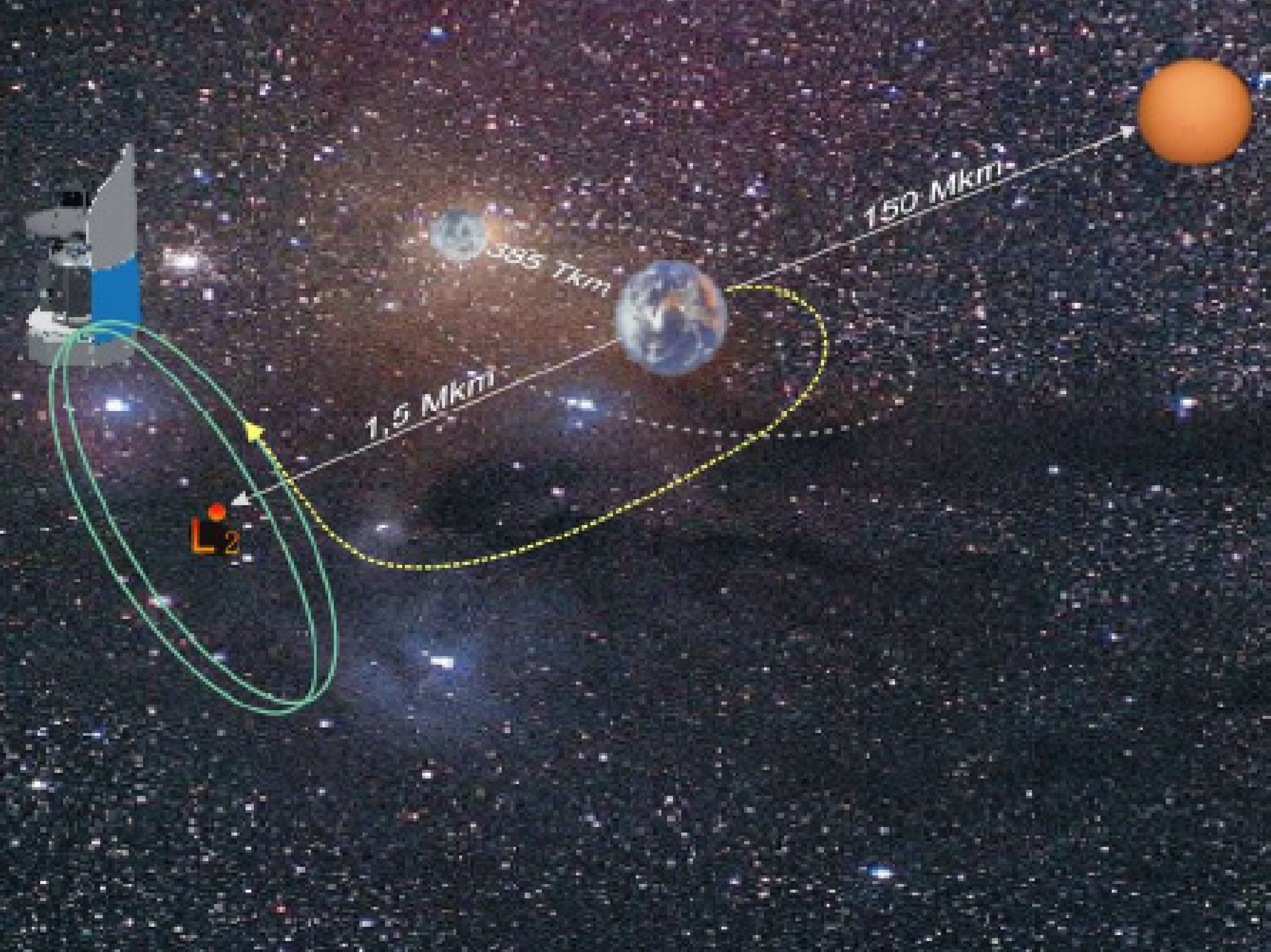
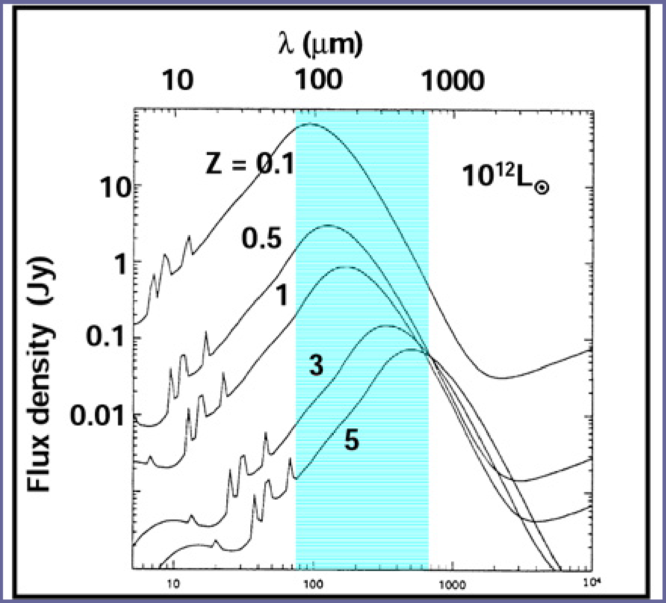
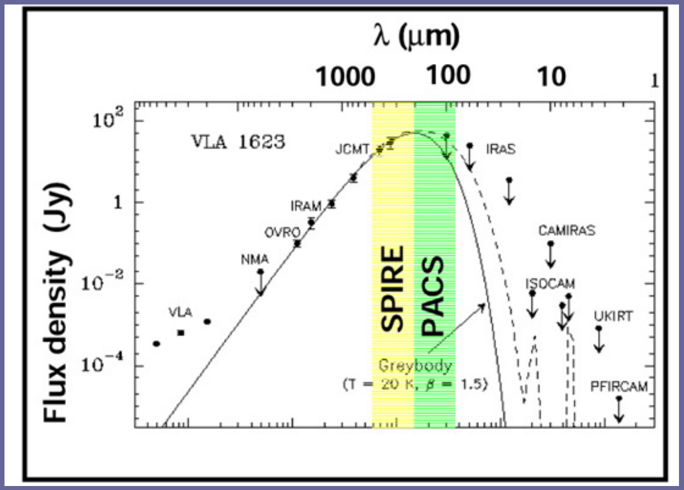

150 Mkm
385 Tkm
1,5 Mkm
L2

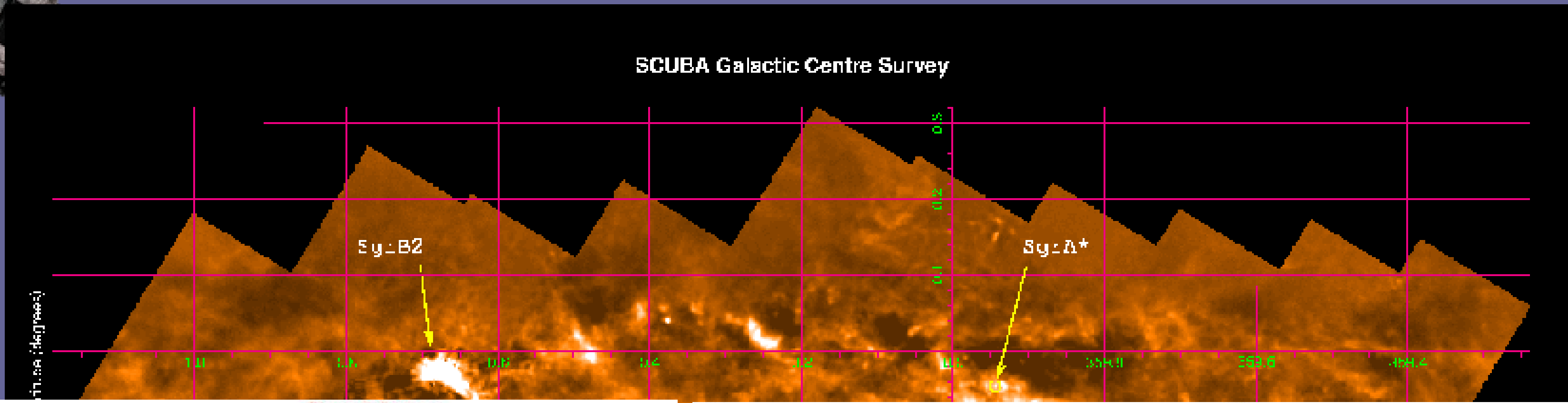
The Cool Universe

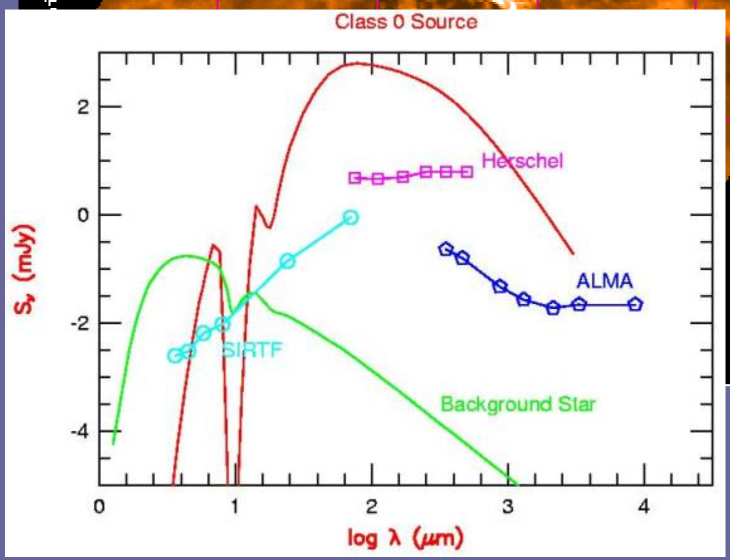
- **Herschel spectral coverage**
  - black-bodies 5-50 K
    - continuum radiation
    - dust grains (re-)radiating
  - gases 10-few100 K
    - brightest atomic/molecular lines
- **Herschel strengths**
  - covers IR-Gal & ISM SED peaks
  - wide area mapping
  - spectral scans, water lines
- **Herschel emphasis**
  - **formation and evolution of galaxies & stars**
  - **ISM physics & chemistry**
  - **solar system bodies**

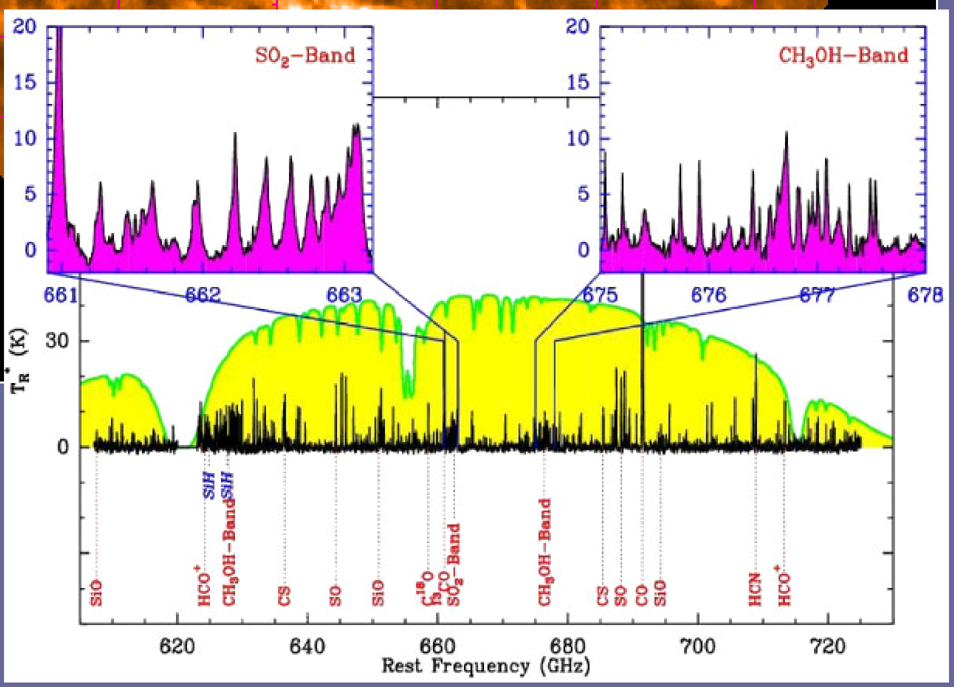




Surveys & follow-up







$0.1L_{sun}$ protostar at 300 pc

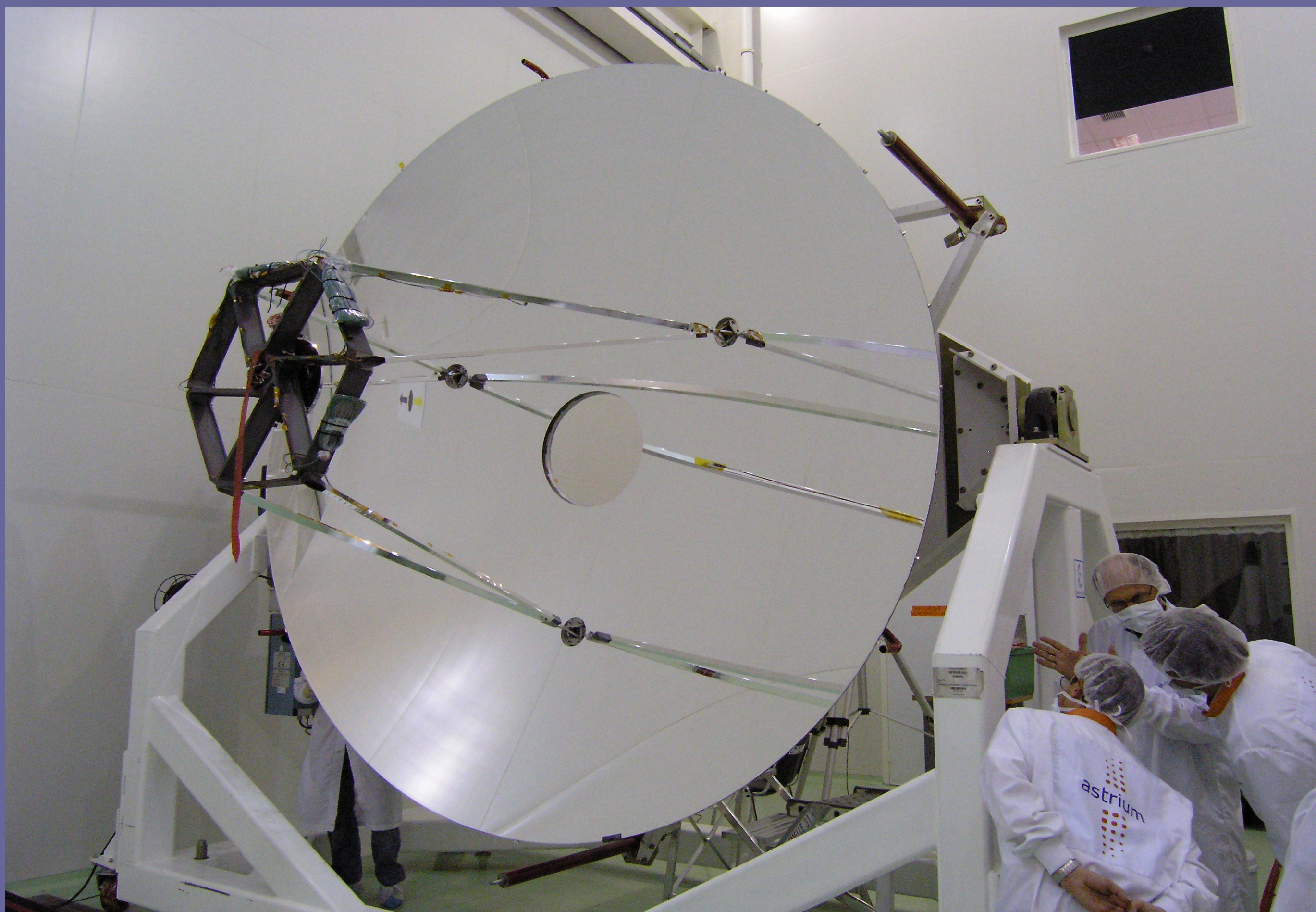
Herschel – when?

- **Herschel**
  - launch in 2008
  - science payloads and spacecraft are late
  - telescope also a bit late,

… will be launched with Planck
  - spacecraft issues
  - science payload

- **Expect Herschel & Planck launch in 2008, not before May… (August)**

- **Initial Herschel AO in early 2007**


astrium

APCO
HERSCHEL PLANCK SVM MGSE
VERTICAL INTEGRATION STAND

APCO

Herschel observatory capabilities

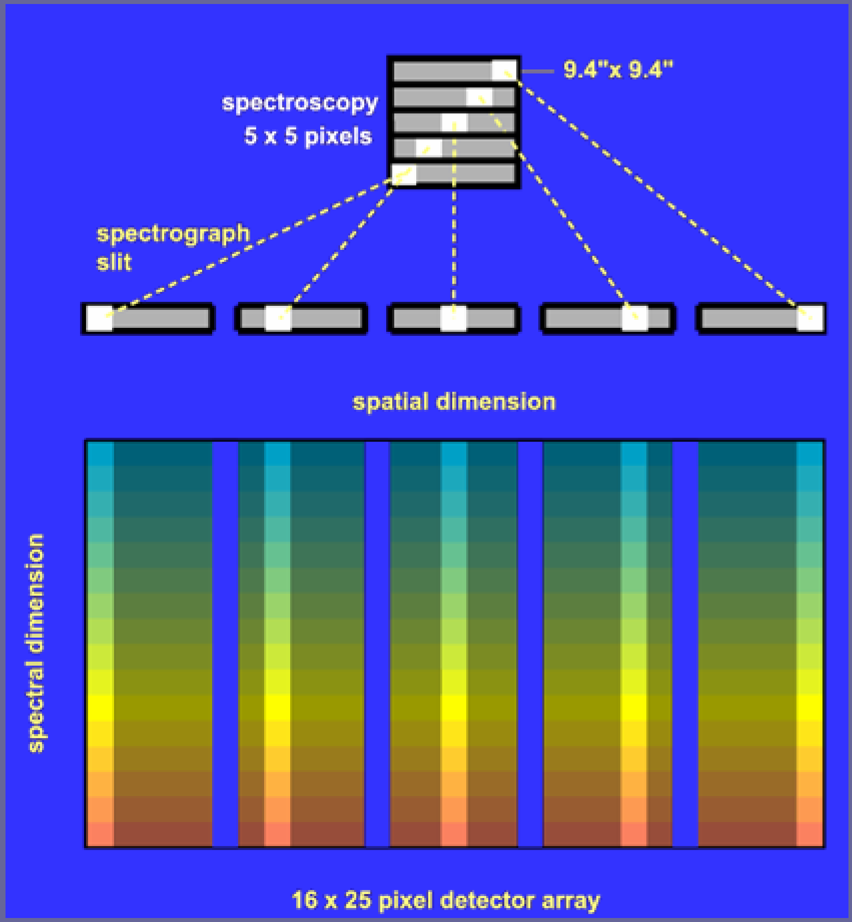
- **Photometry - imaging, 6 broad bands in 75-500 μm range**
  - **PACS** - simultaneous 2 colour fully-sampled (0.5Fλ) imaging with FOV 1.75x3.5 arcmin with R~2.5 centred at 75/110 and 170 μm
  - **SPIRE** - simultaneous 3 colour 2Fλ imaging with FOV 4x8 arcmin with R~3 centred at 250, 363, and 517 μm
  - for larger fields 'on-the-fly' mapping, mosaicing
  - sensitivity is somewhat wavelength and observing mode dependant, very roughly for point sources 1mJy - 1σ - 1 hour; for mapping confusion limit is important

- **Spectroscopy - in 57-670 μm range, R in 20-10^7 range**
  - **PACS** - 5x5 spatial x16 spectral pixels, FOV 0.8 arcmin, R~1500, λ ~57-210 μm
  - **SPIRE** - FTS spectrometer, R ~20-100+, FOV 2.6 arcmin, λ ~200-670 μm
  - **HIFI** - heterodyne spectroscopy with R up to 10^7, λ ~157-212 and 240-625 μm, 2 orthogonal polarisations, 4000 spectral channels per polarisation, single pixel on the sky, mapping by 'on-the fly' or mosaicing observations

PACS Instrument Concept

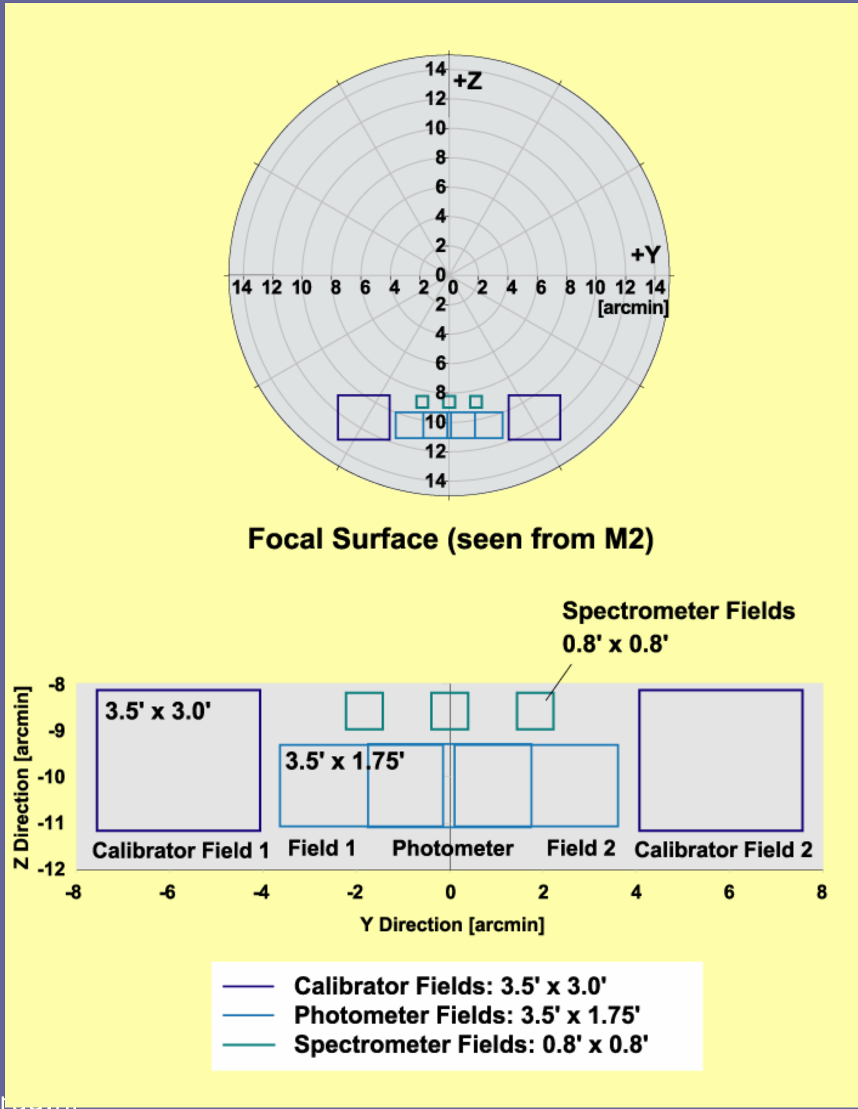
- **Imaging photometry**
  - two bands simultaneously (60-85 or 85-130 µm and 130-210 µm) with dichroic beam splitter
  - two filled bolometer arrays (32x16 and 64x32 pixels, full beam sampling)
  - point source detection limit ~4 mJy (5σ, 1h)
- **Integral field line spectroscopy**
  - range 57 - 210 µm with 5x5 pixels, image slicer, and long-slit grating spectrograph (R ~ 1500)
  - two 16x25 Ge:Ga photoconductor arrays (stressed/unstressed)
  - point source detection limit 3…20 $\times10^{-18}$ W/m^2 (5σ, 1h)

Focal Plane Footprint



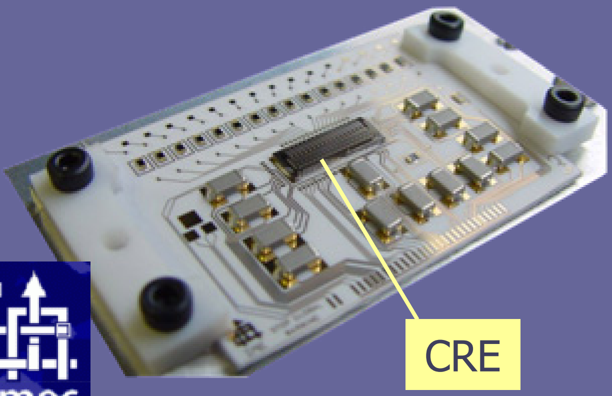
Observing Modes

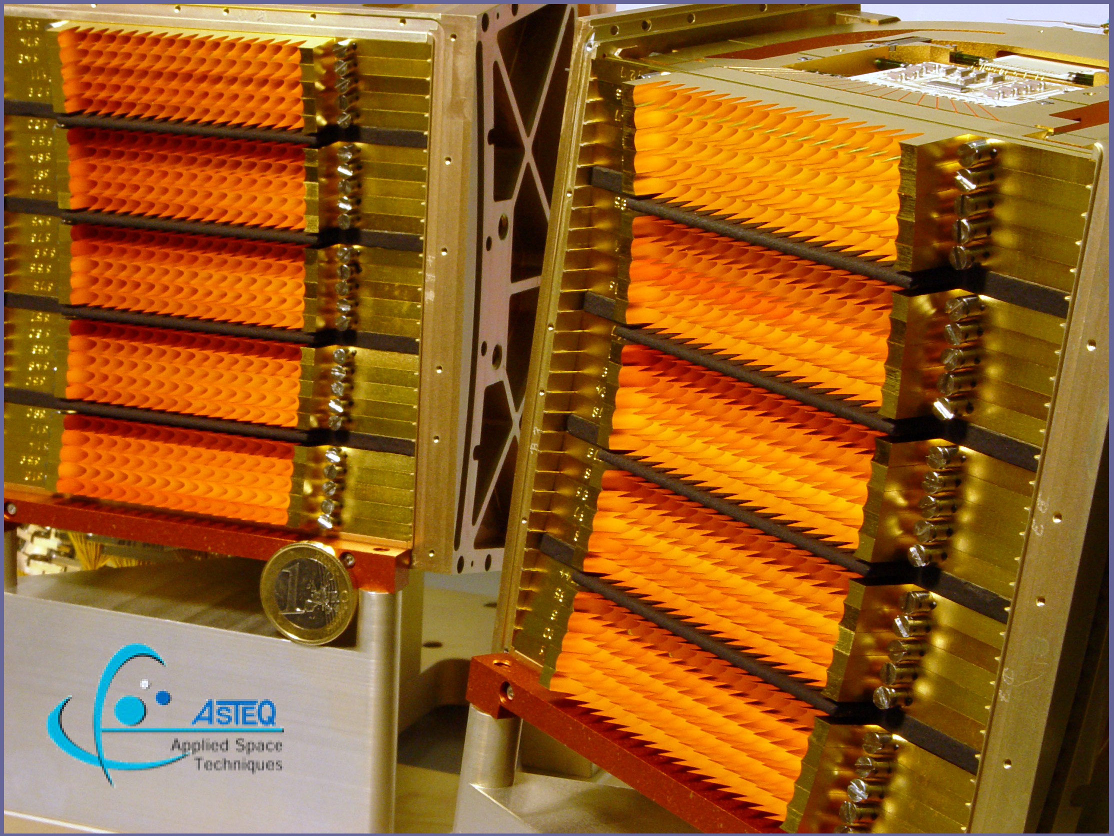
- Combinations of *instrument modes* and *satellite pointing modes*
- Instrument modes:
  - dual-band photometry
  - single-band photometry
  - line spectroscopy
    - observation of individual lines
  - range spectroscopy
    - observation of extended wavelength ranges
- Pointing modes:
  - stare/raster/line scan
  - with/without nodding
- Internal chopper
  - background subtraction
  - calibration

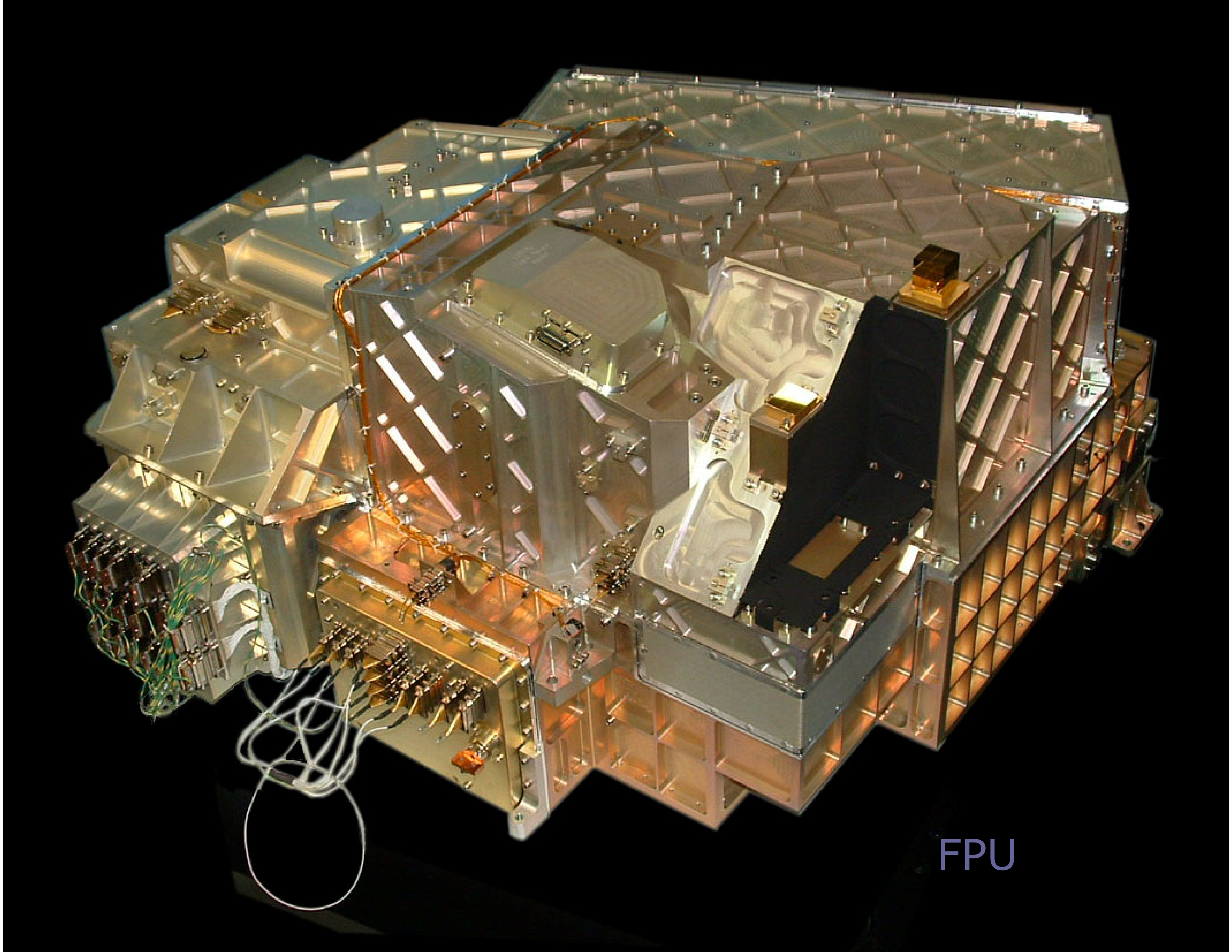


Photoconductor Arrays (Spectrometer)

- Two 25x16 pixel filled arrays
- Extrinsic photoconductors (Ge:Ga, stressed/unstressed)
- Integrated cryogenic readout electronics (CRE)
- Near-background-noise limited performance expected

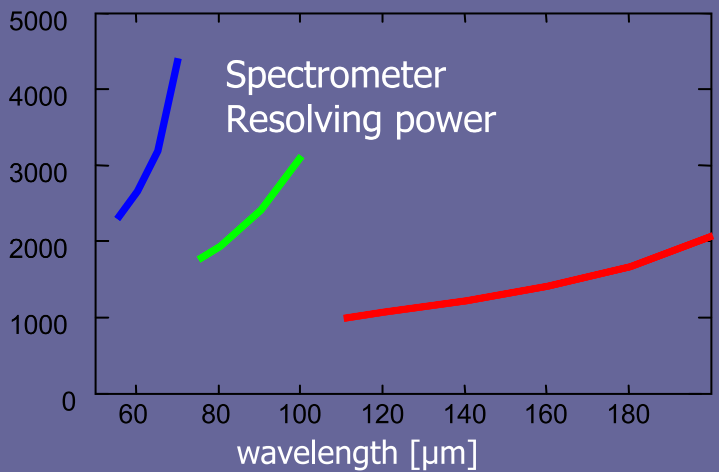


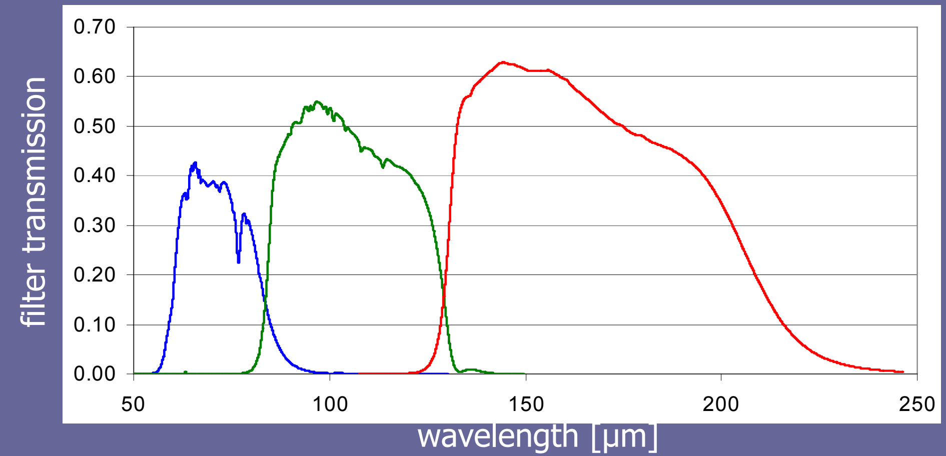


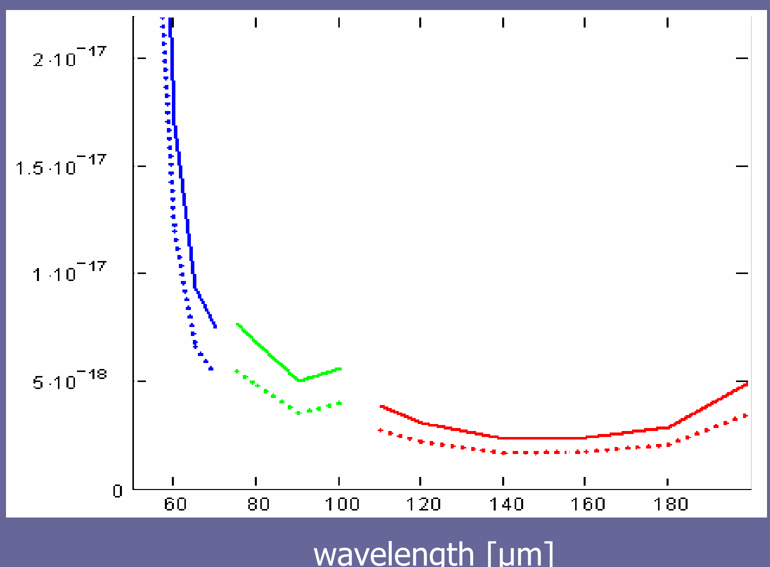


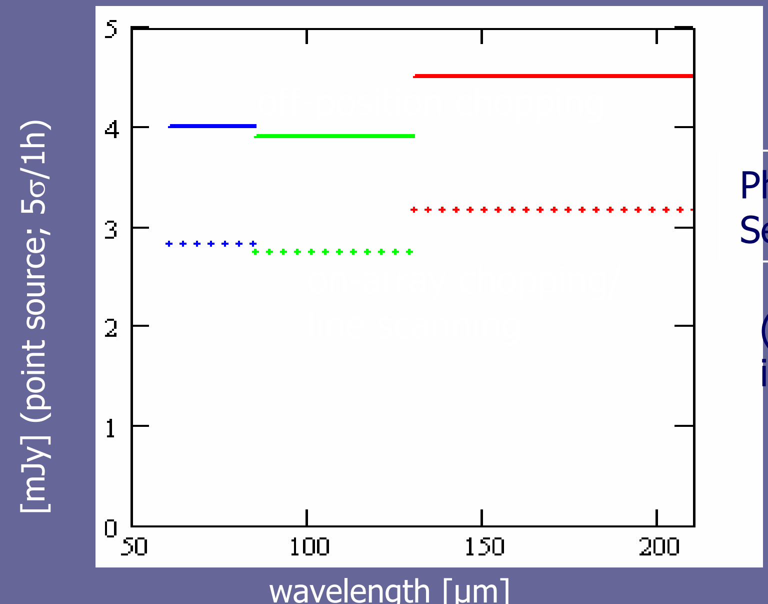
FPU

Predicted Instrument Performance









Photometer
Sensitivity

(10'x10'
in 1 day)

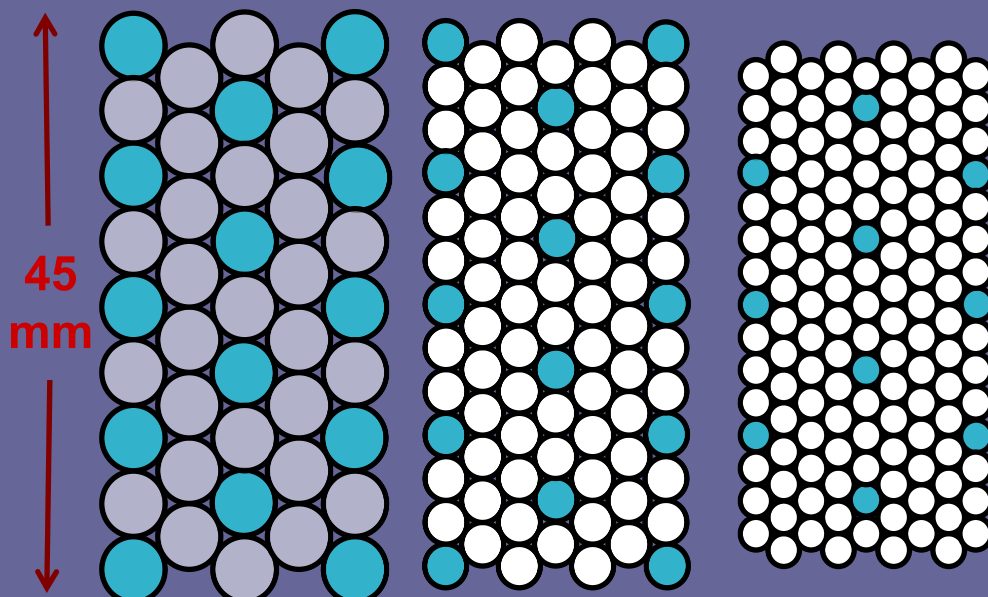
SPIRE Detector Arrays: 300 mK NTD Ge Bolometer Arrays with $2F\lambda$ Feedhorns

Photometer

520 μm
43 detectors

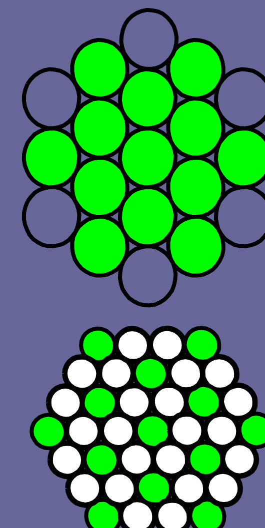
360 μm
88 detectors

250 μm
139 detectors



Spectrometer

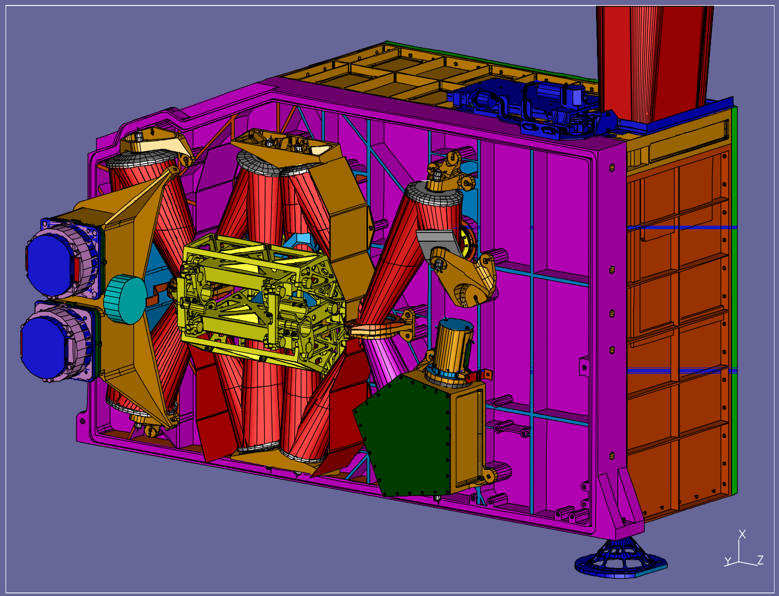
315-670 μm
19 detectors



200-325 μm
37 detectors

⇒ **Coincident beam centres**

Imaging Fourier Transform Spectrometer



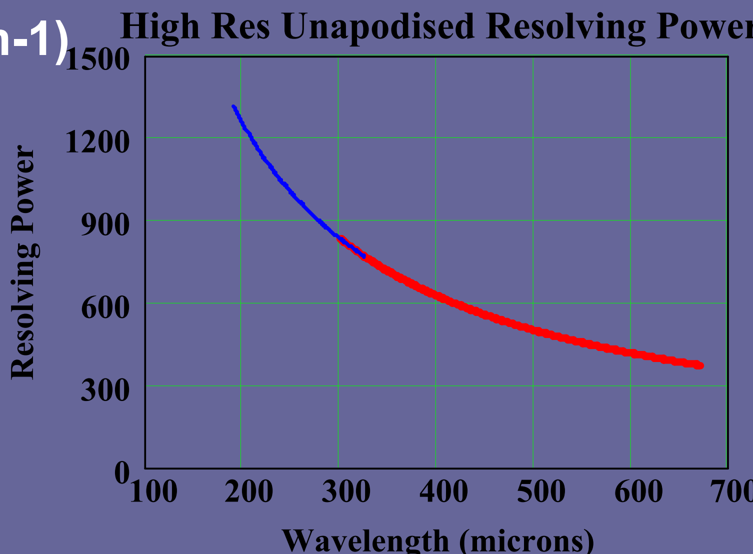
200 - 670 µm (observed simultaneously)

- **Spectral resolution adjustable:**
  - 1 cm-1 - 0.04 cm-1

- **Point source spectroscopy (with 2.6 arcmin sparse map)**
  - **Lines (Ds = 0.04 cm-1)**
    D*F* = 7 – 10 x 10-17 W m-2 ·
  - **Spectrophotometry (Ds = 1 cm-1)**
    D*S* = 250-350 mJy

- **Fully sampled mapping of 2.6 arcmin field of view**

- **Sparse or fully sampled raster mapping of larger areas**



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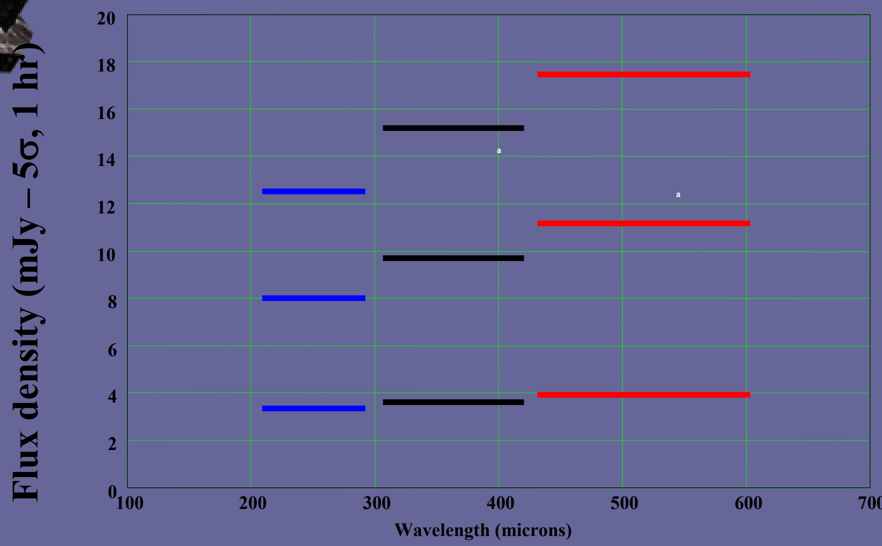
SPIRE Predicted performance

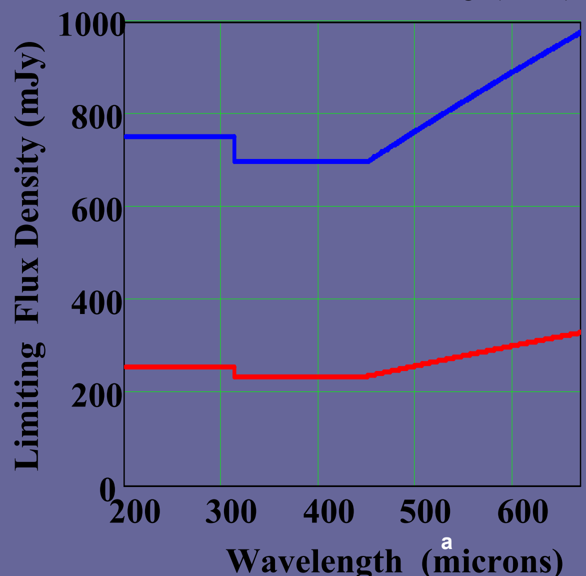


Jiggle map

Scan map

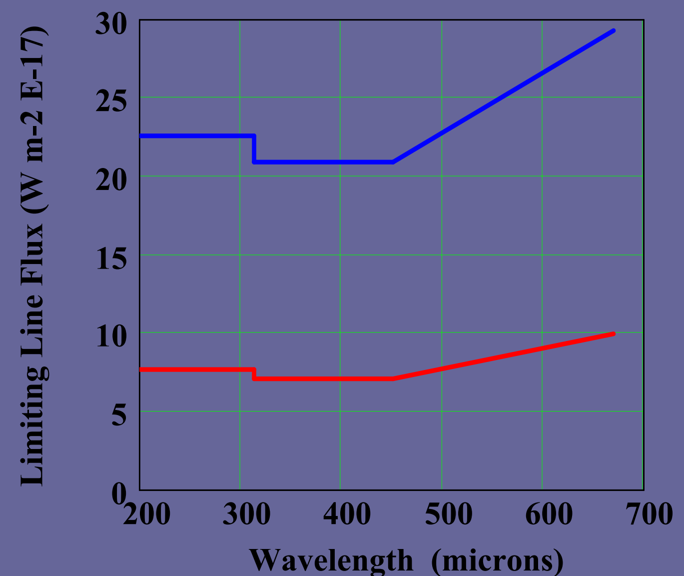
Point source (7-point)

- Photometry
- Spectrophotometry
- Line spectroscopy
- at 5σ, 1 hr



Fully-sampled map

Point source/ sparse map



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 with high sensitivity

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

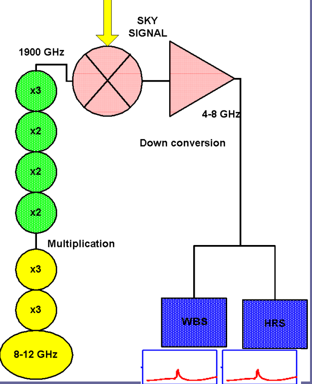
2. Sensitivity
Near-quantum noise limit sensitivity
- IF bandwidth/Resolution:
  - 4 GHz (in 2 polarisations)
  - 140 – 280 kHz –0.5 and 1 MHz

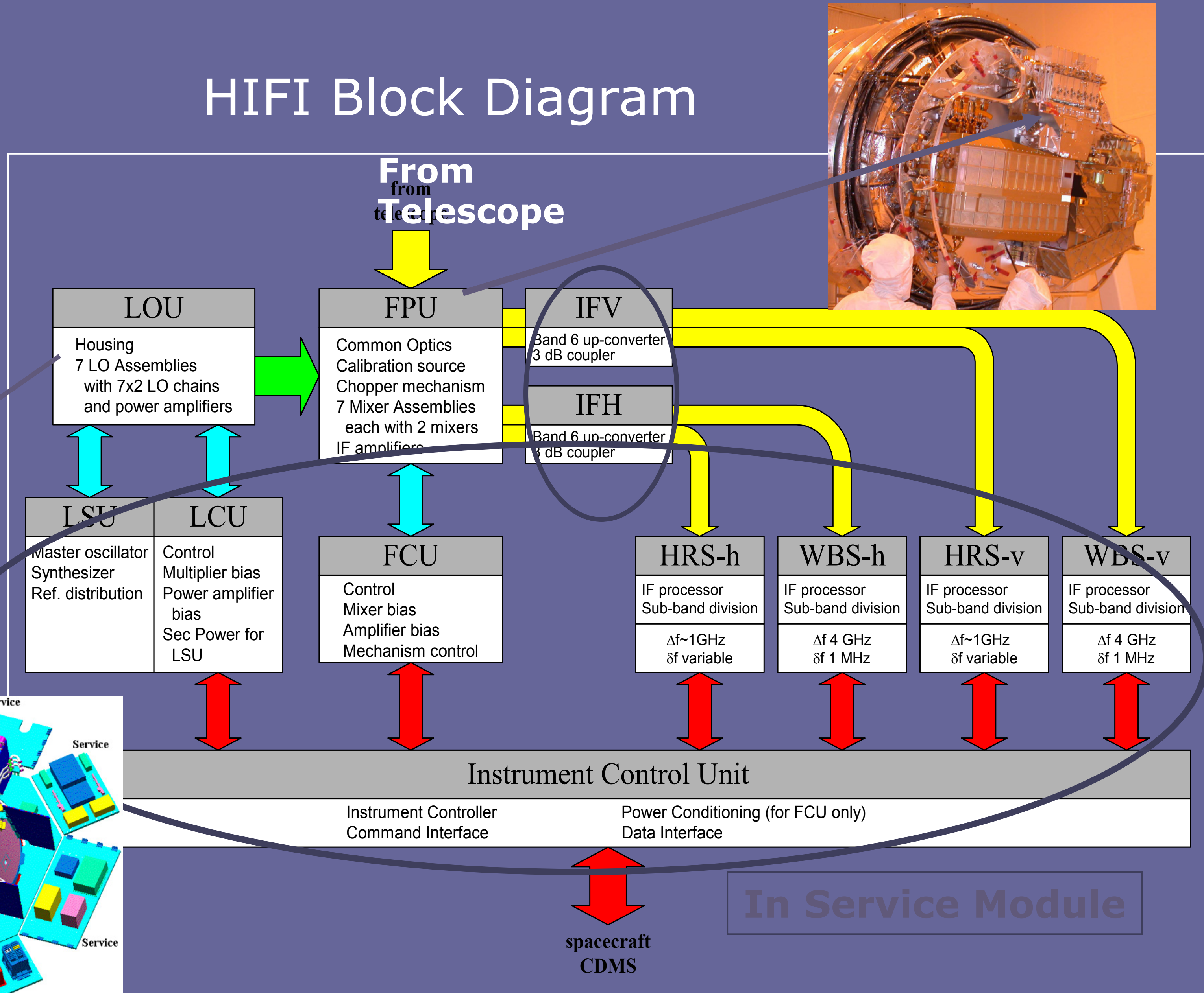
3. **Calibration Accuracy**: 10% baseline; 3% goal

- **Heterodyne spectroscopy**
  – single pixel on the sky
  – very high spectral resolution
- **7 dual-pol mixer bands (DSB)**
  – 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
- **7 LO bands with 14 LO sub-bands**
  – LO source unit in common
  – 14 LO multiplier chains
- **2 spectrometer systems;**
  – for each polarisation
    - auto-correlator spectrometer
    - acousto-optical spectrometer

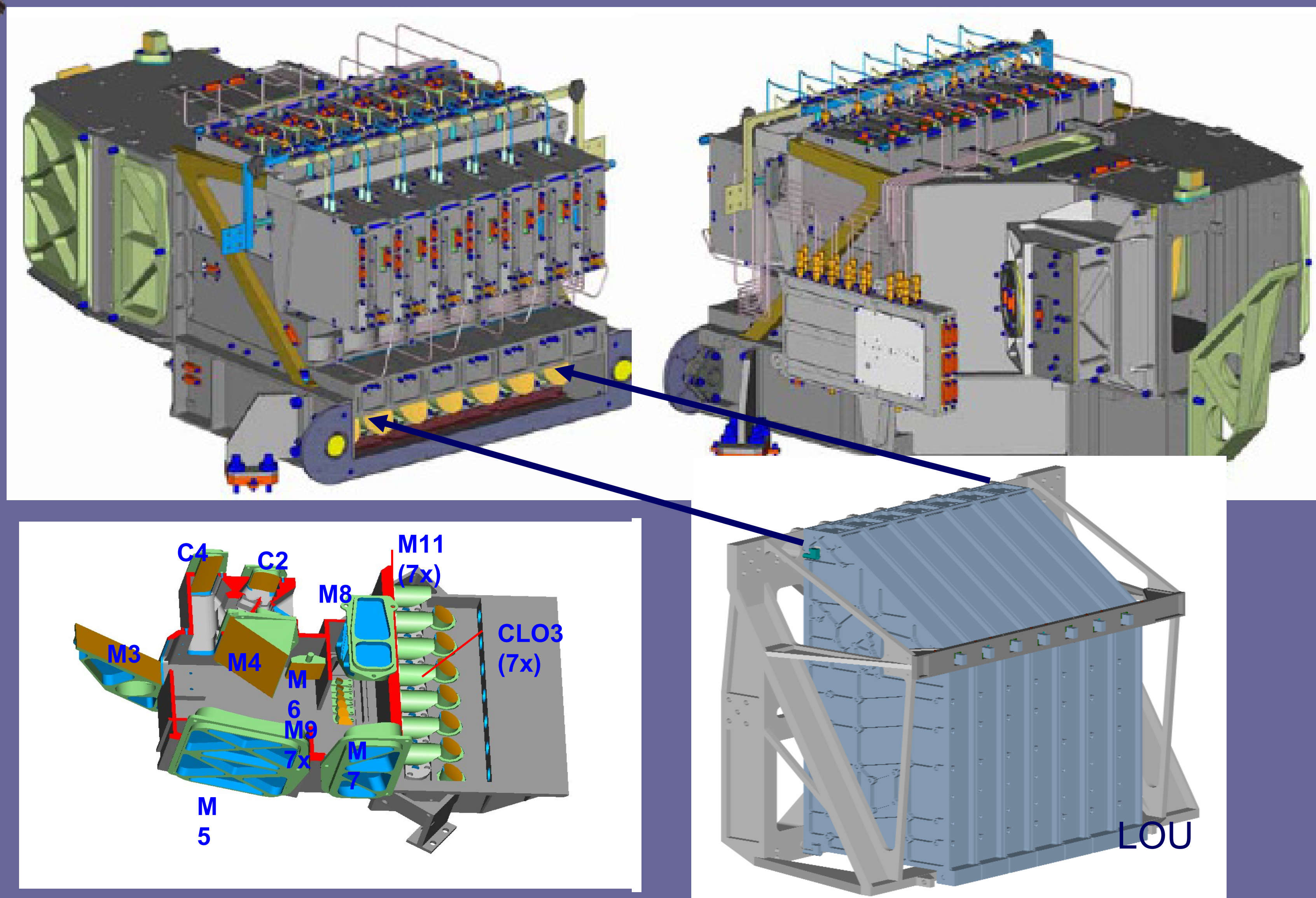
NB: Angular Resolution (with Herschel): 12”- 40”

HIFI Block Diagram

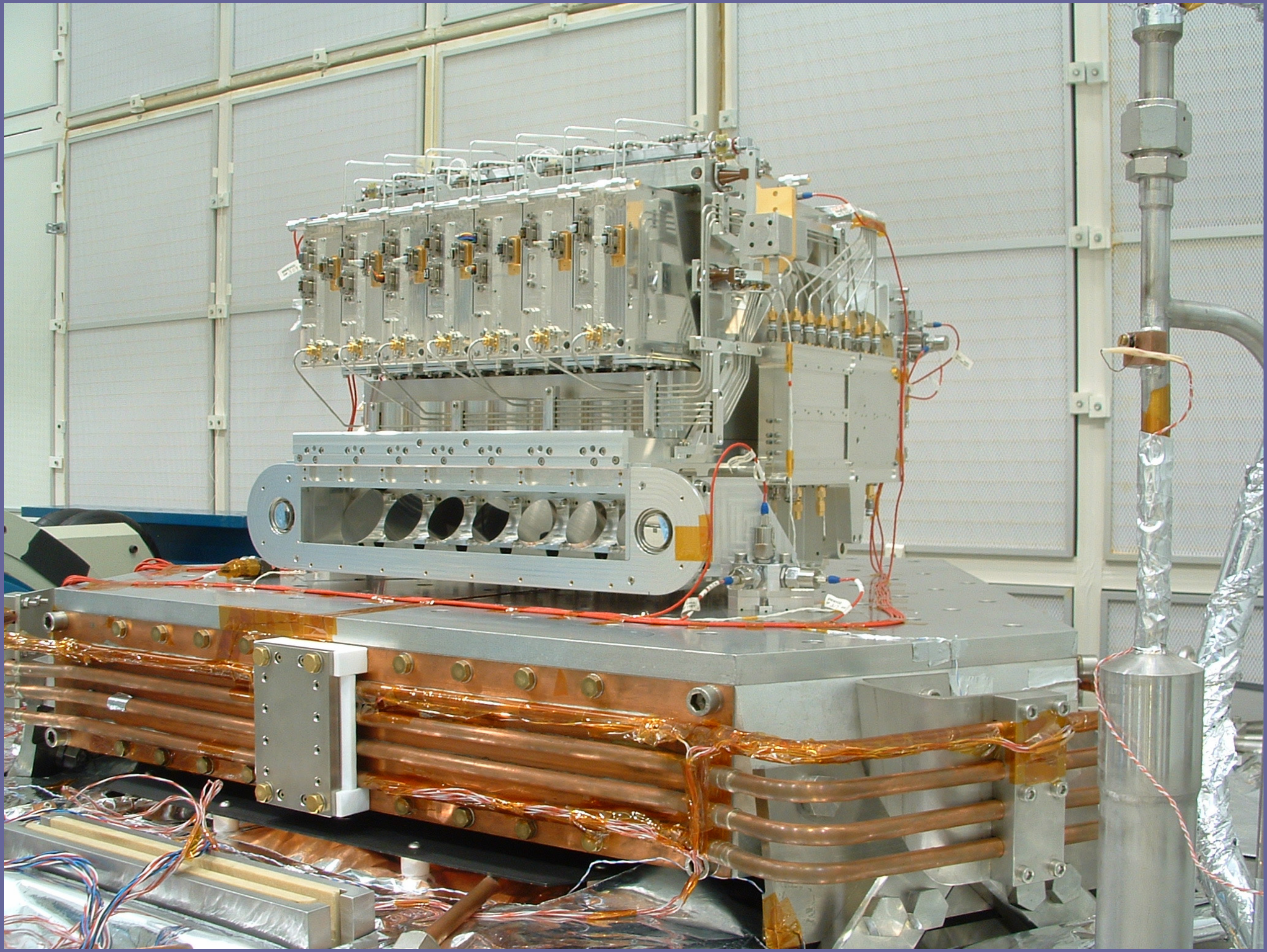




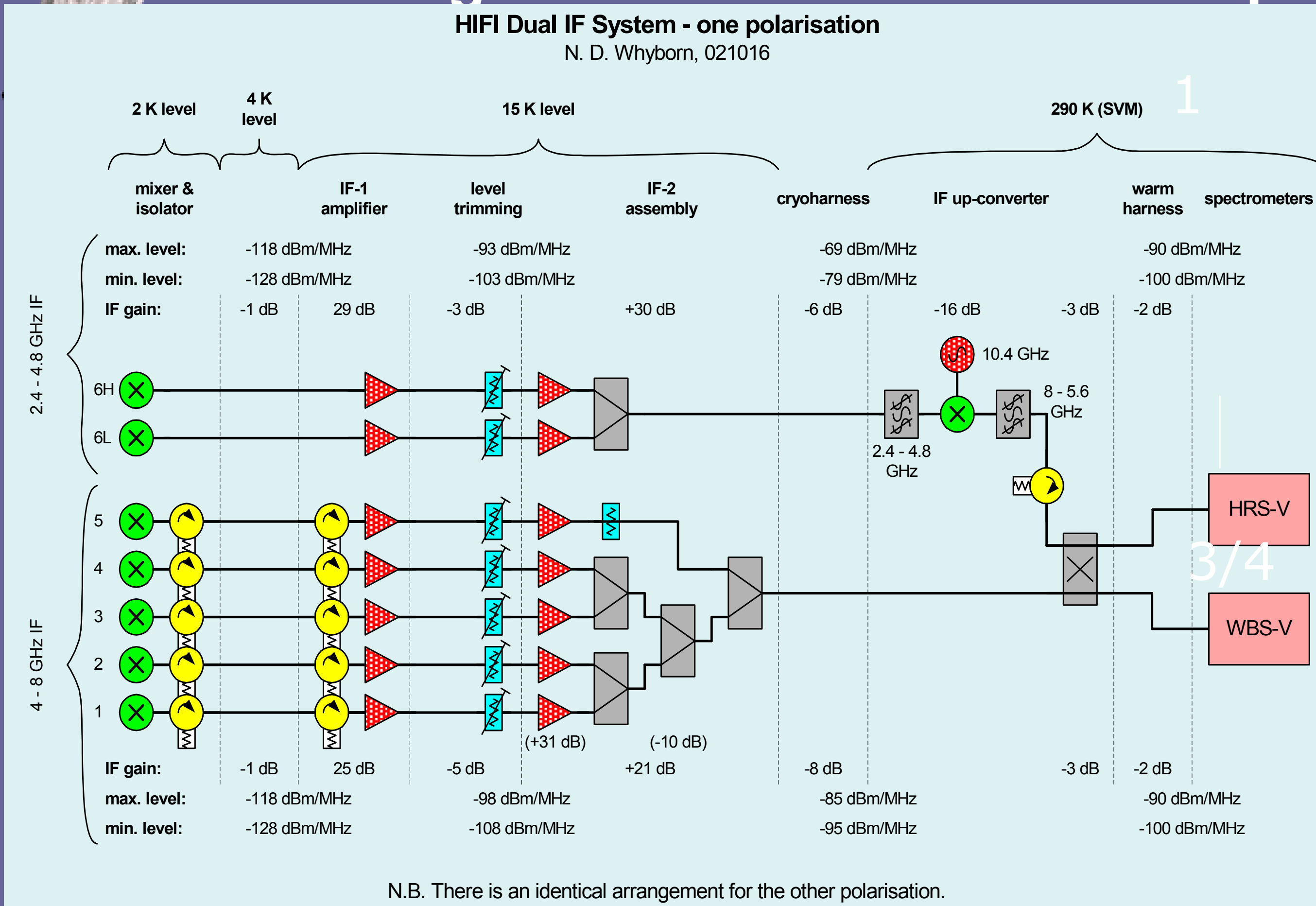
HIFI Focal Plane Unit

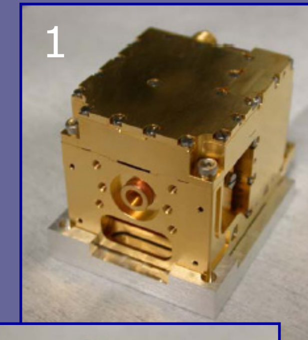


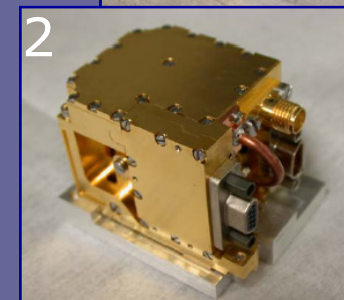
FPU at the vibration facility

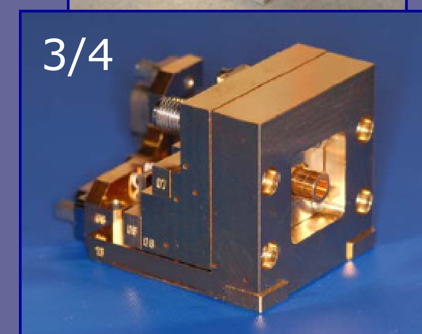


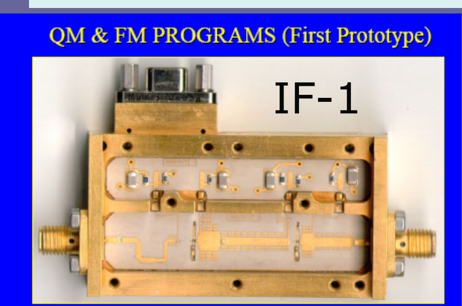
HIFI Signal Chain: Mixers and Amplifiers

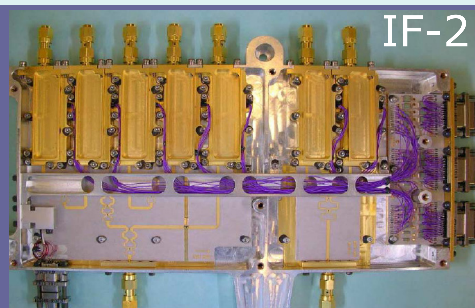


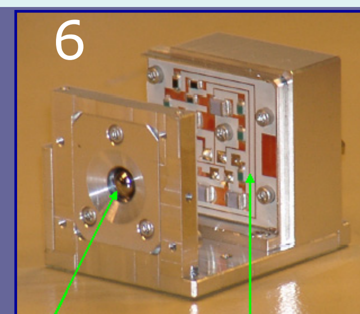




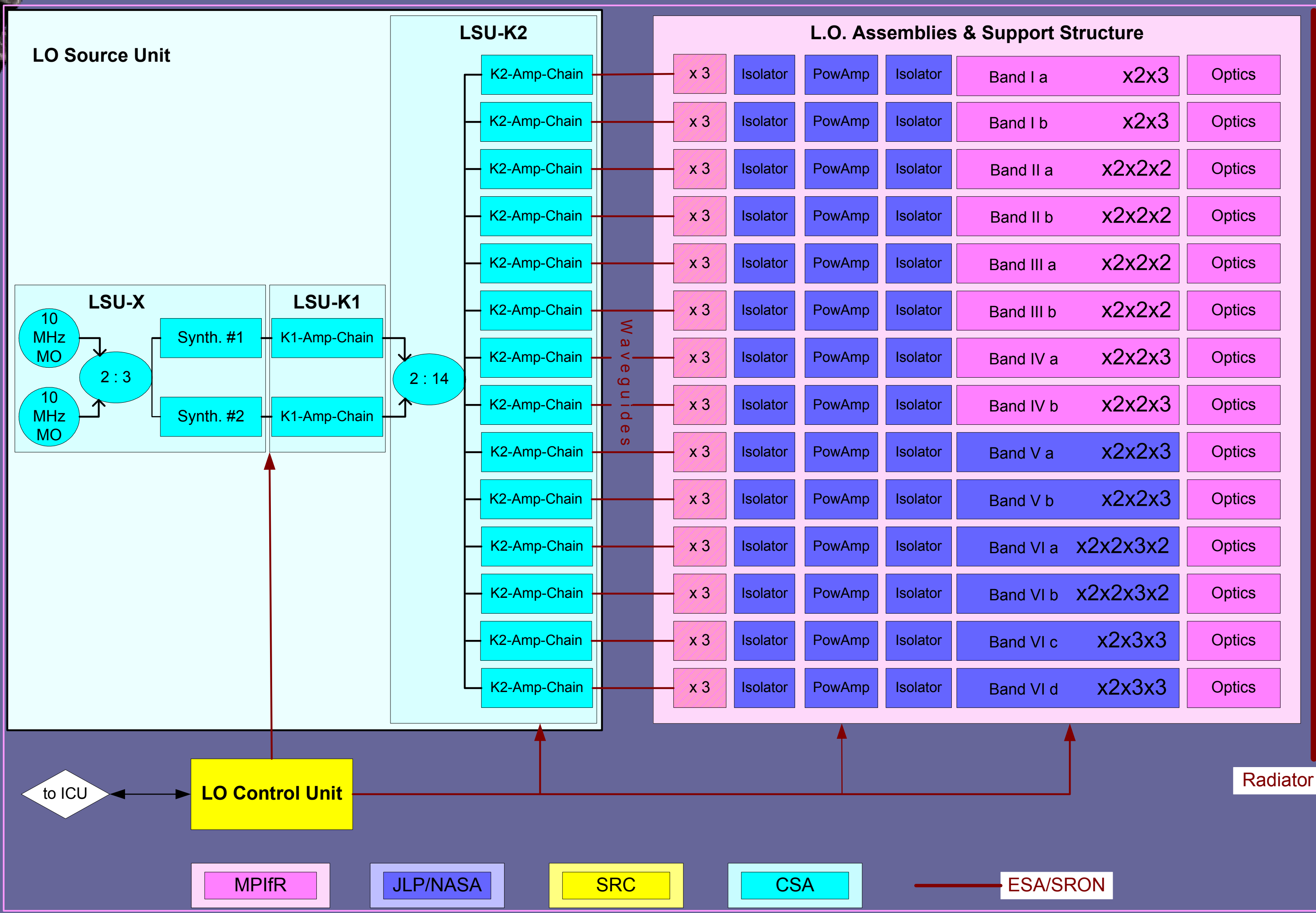






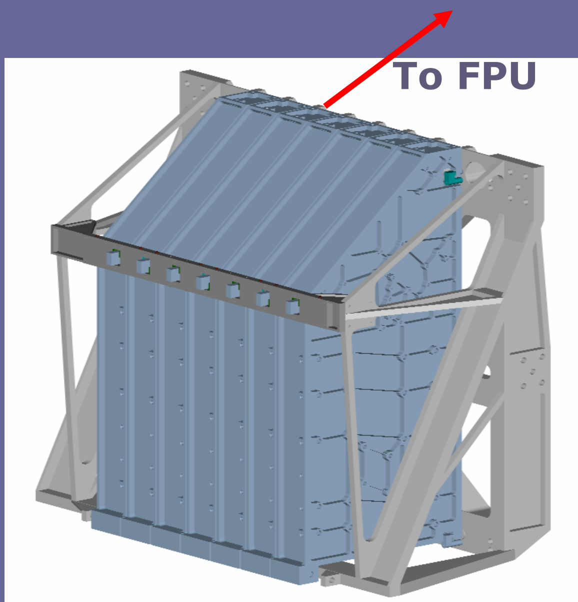


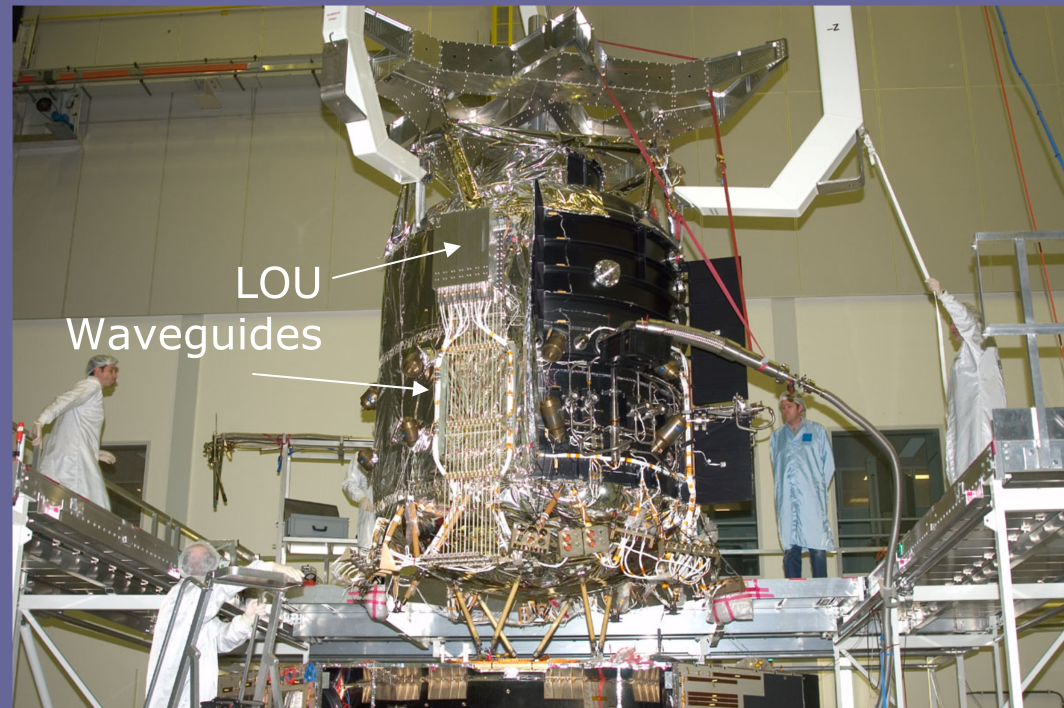
LO subsystem block diagram for LO Source Unit and LO assemblies

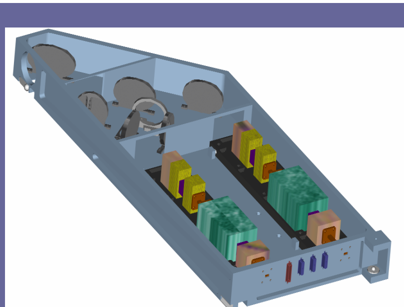


HIFI LO frequency multiplication scheme with all-planar devices and no mechanical tuners

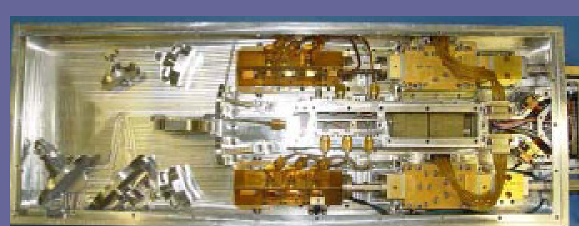
LOU with 7 LO assemblies each with 2 LO chains

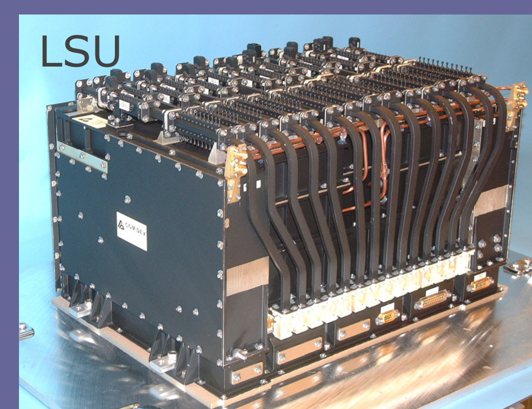






LO Assembly with two chains





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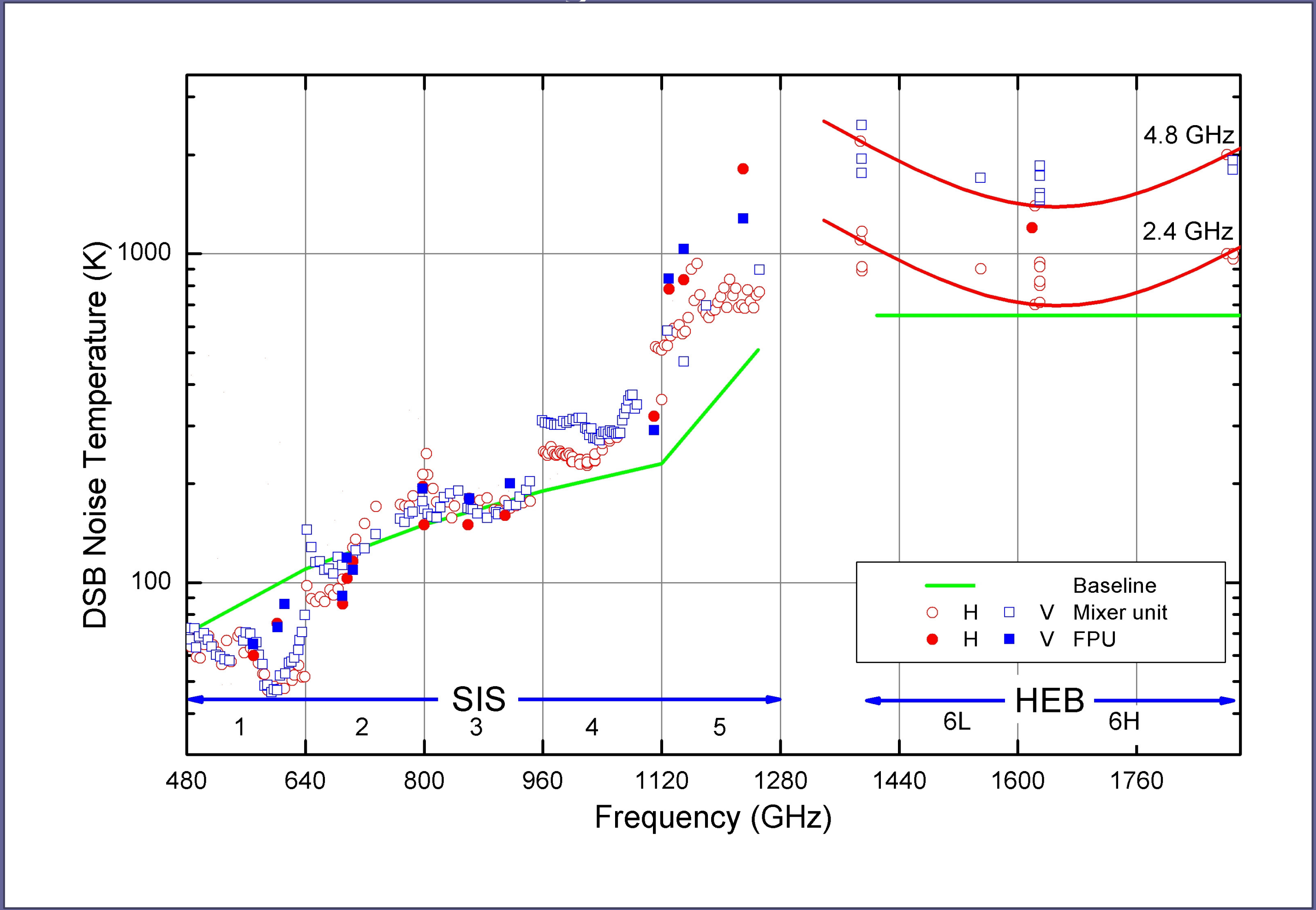
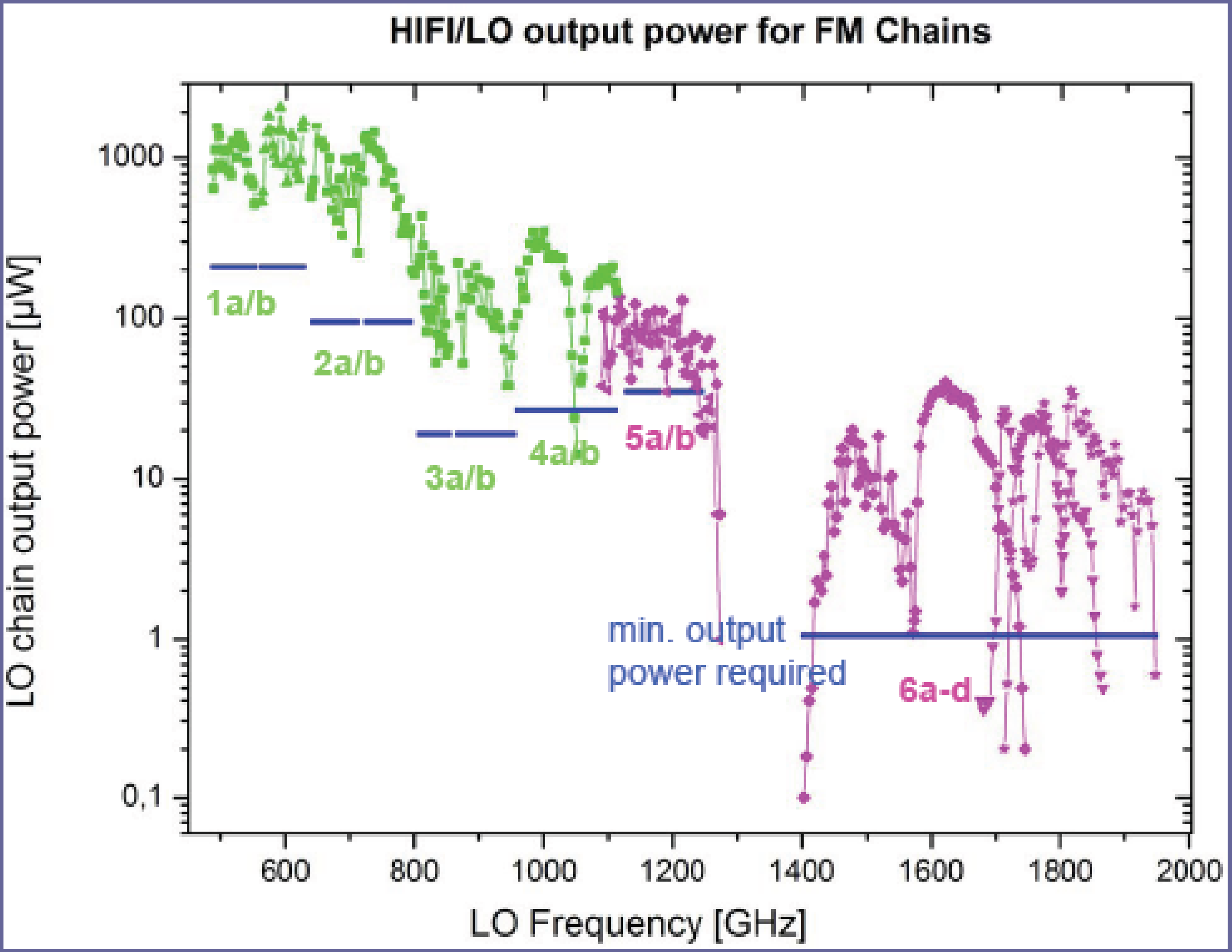
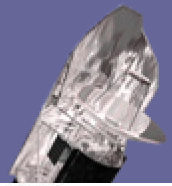
HIFI Flight Mixer Performance at Mixer Unit level (open symbols) and after integration in the FPU

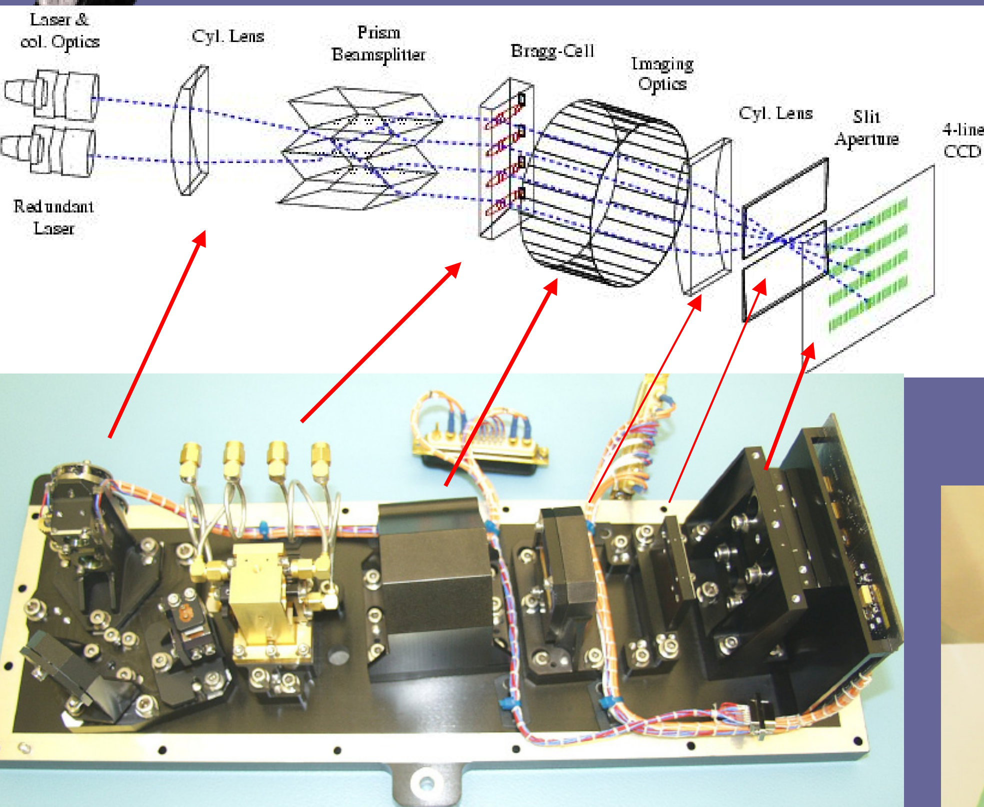


Latest update LO chain performance: Bands 1-4 by RPG; Bands 5, 6L, 6H by JPL

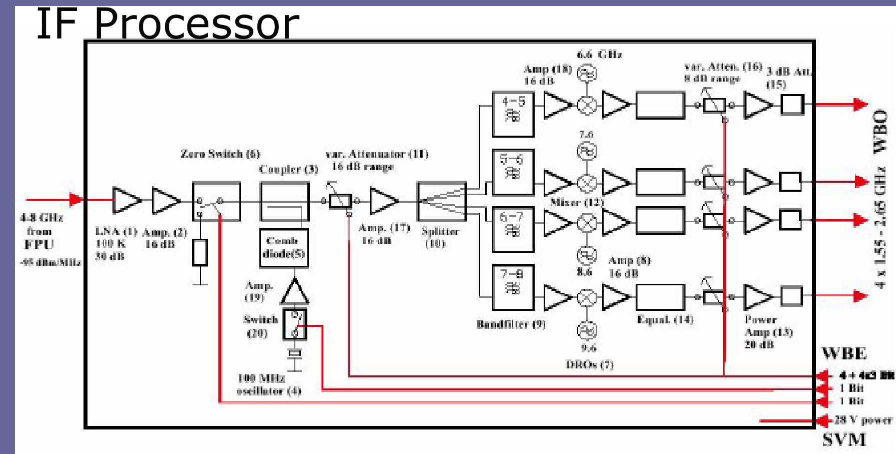


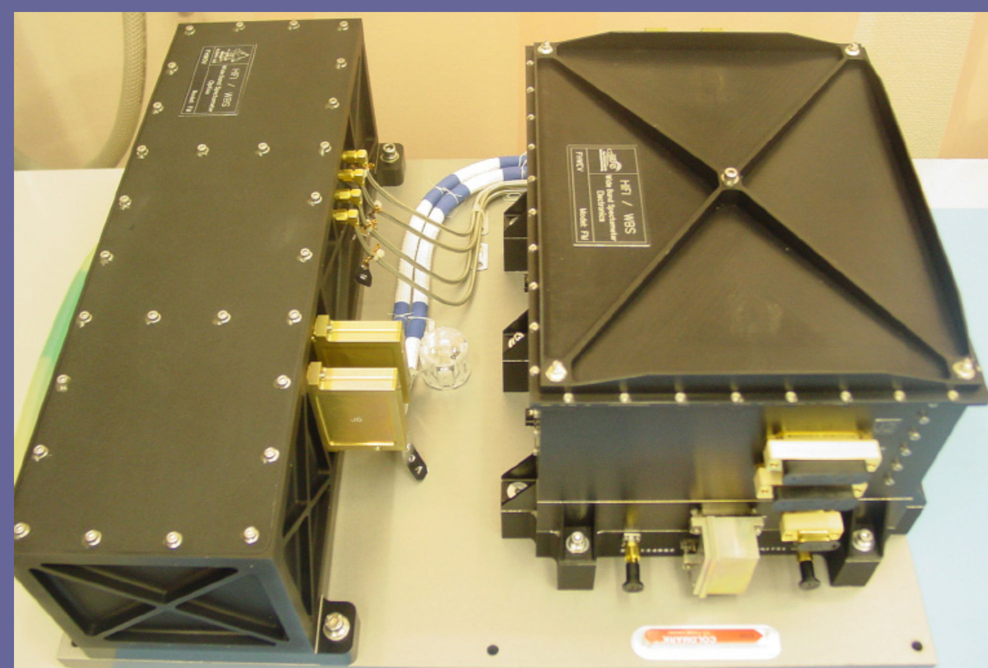


WBO FM (one Polarisation) with 1.1 MHz resolution and 4GHz bandwidth



Source module Bragg-cell Imaging optics Cyl. lens CCD



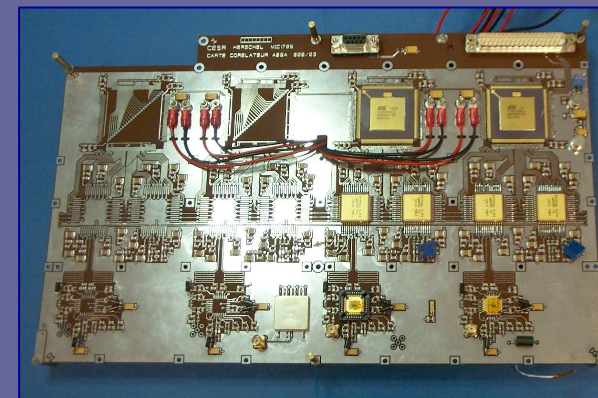


HIFI-HRS (auto-correlator) FM Capabilities

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

Expected HIFI sensitivities some adjustments needed

	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,FM) (K)	70	120	160	250	650	1200
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

Herschel ‘Key Projects’

- **Foreseen to be important upfront (SMP/instrument AO)**
  - introduced to ensure that ‘unusually large’ observing programmes can be proposed, selected, and observed
- **Definition of a ‘Key Project’ programme - it must**
  - exploit unique Herschel capabilities address (an) important scientific issue(s) in a comprehensive manner
  - require a large amount of observing time to be used in a uniform and coherent fashion
  - produce a resulting well characterised dataset of high archival value
- **Data reduction**
  - it is recognised that there is a legitimate science return interest that
    - the data generated by the observations are timely reduced, and
    - the data products and tools are made public
  - therefore ‘Key Project’ consortia must demonstrate commitment and ability to perform data reduction, and must make data products and tools publicly available at the end of the proprietary time period

Herschel AO Schedule

- AO KP (GT and OT) issue Thu 1/02/2007
  KP GT proposal deadline Thu 5/04/2007
  KP GT result official Thu 5/07/2007

  KP OT proposal deadline Thu 1/11/2007
  KP OT result official Thu 28/02/2008
  AO ‘regular’ GT cycle 1 issue Thu 28/02/2008
  AO ‘regular’ GT cycle 1 deadline Thu 3/04/2008
  GT result official Thu 5/06/2008

PACS/SPIRE GT Key Programs

- **Extragalactic Surveys** (Photometric Cameras)
- **Nearby Galaxies**
  - Physics of the ISM in low metallicity galaxies

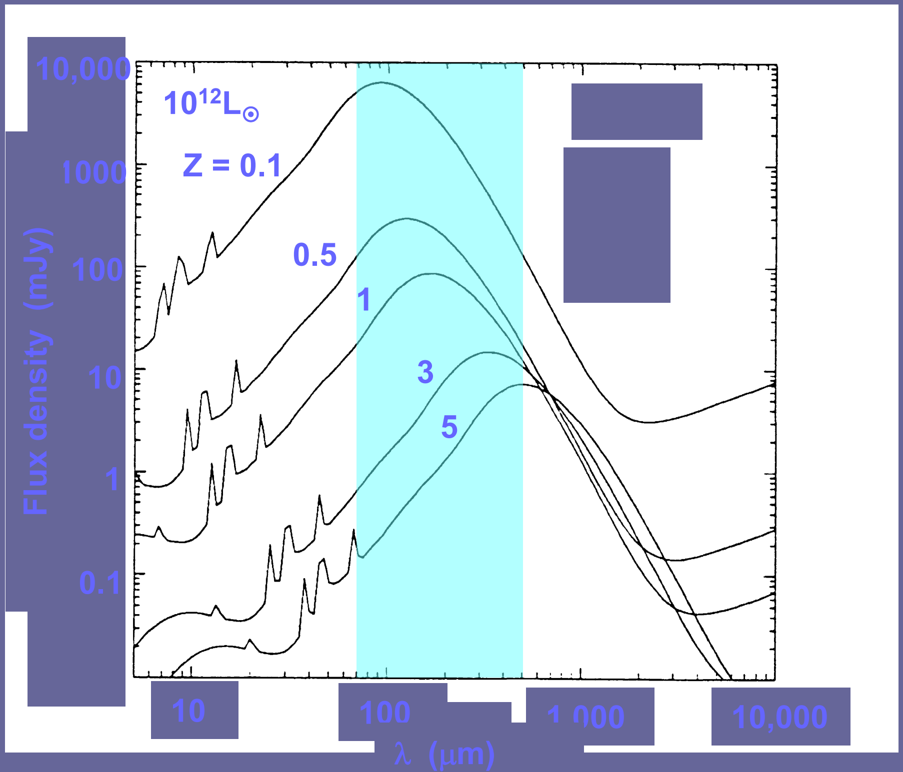
    Cohesive programme of SPIRE/PACS/HIFI photometry and spectroscopy (CII , OI, OIII, NII) + other complementary data
  - Star formation and activity in infrared bright galaxies at z<1
- **Star Formation Surveys**; High-mass Star Formation; 40 sq. deg. covering a galactic volume a few kpc in radius; imaging and spectroscopy
- **ISM**: Physics and Evolution of Interstellar Dust; Multi-band Survey of Nearby Molecular Clouds
- **Debris Disk Evolution** (mapping and spectroscopy)
- **Late Stages of Stellar Evolution**: AGB, Post-AGB, PN, Supernovae; Phys. Chem. Conditions and Dust Production by Stars and Supernovae (imaging and spectroscopy

SPIRE + PACS Extragalactic Surveys (GT + OT)

- **Unbiased surveys**
- **Small areas (below confusion limit) - several 100 sq. deg.**
- **~ 1,500 hrs of SPIRE and PACS GT + more in Open Time**

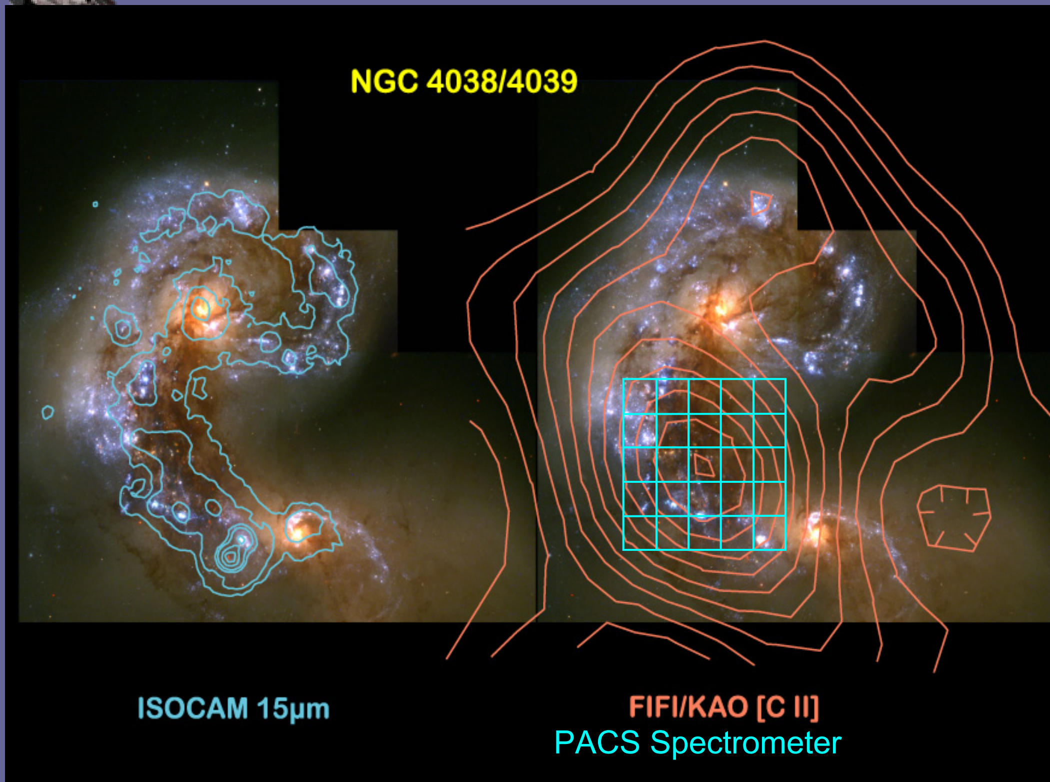
- **History of energy production**
- **Structure formation**
- **Cluster evolution**
- **Lensing**
- **CIRB fluctuations**
- **AGN-starburst connection**
- **Planck DECS fields**

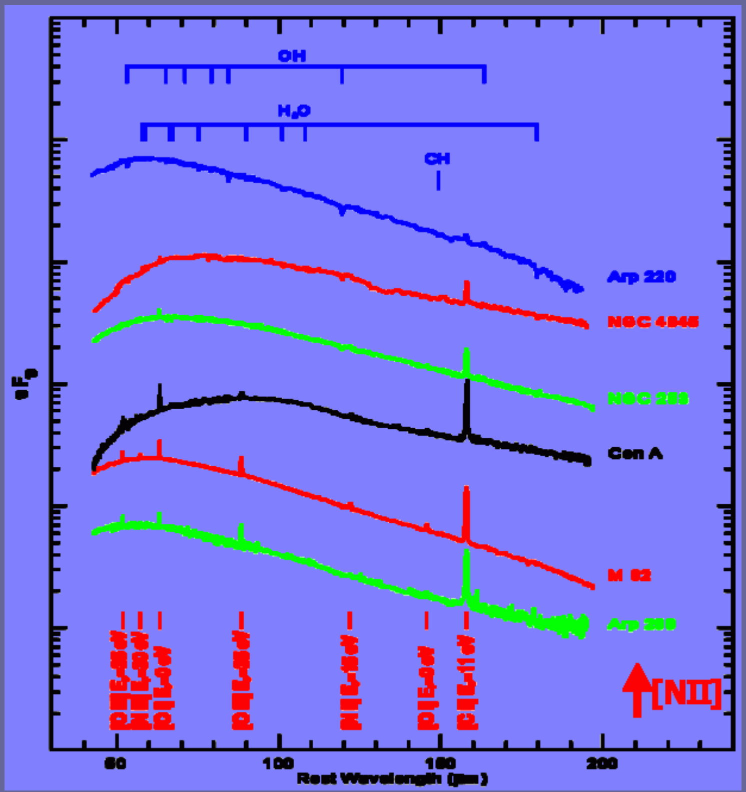
- **Follow up spectroscopy:**
  - **Redshifts**
  - **Physics and chemical evolution**



After Guiderdoni et al. MNRAS 295, 877, 1998

FIR Spectroscopy of Nearby Galaxies



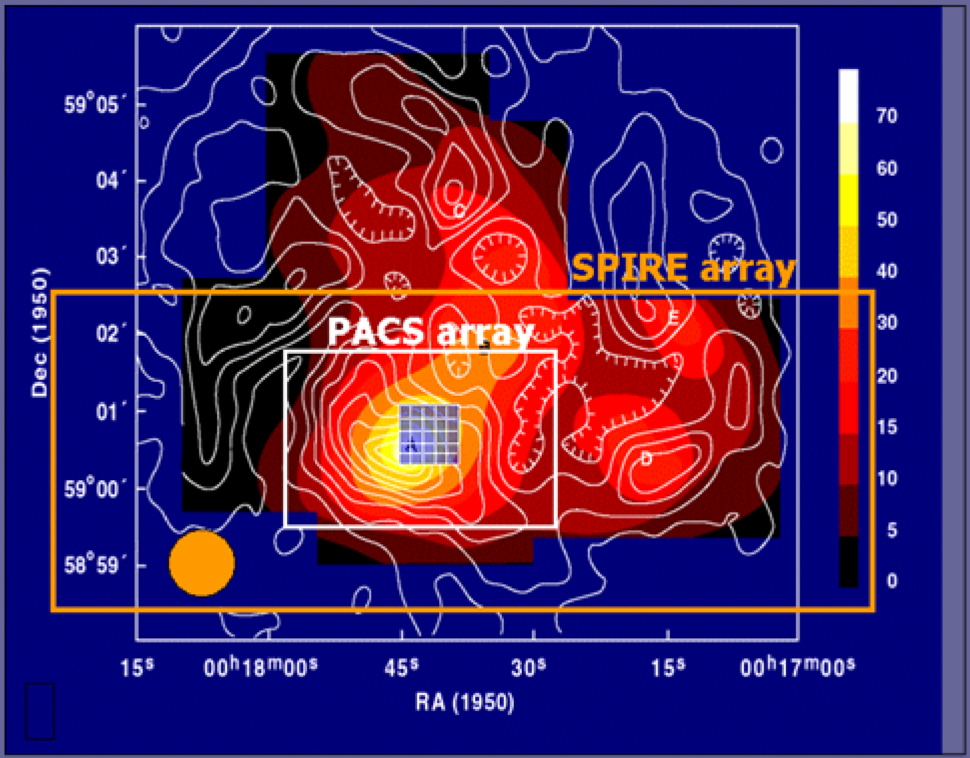


- Complement, for the first time, MIR observations with FIR spectroscopy at ~same angular resolution

- Only a handful of (nearby) ULIRGS have been observed to date at FIR wavelengths

ISM in Local Galaxies

- **Sample of 15 nearby galaxies well-studied from X-ray-radio**
  - **Early & late type spirals**
  - **Low mass spiral**
  - **Edge-on spiral**
  - **Starburst spiral**
  - **Starburst galaxy**
  - **Quiescent dwarf**
  - **Starburst dwarf**
  - **Seyferts**
  - **Ellipticals**



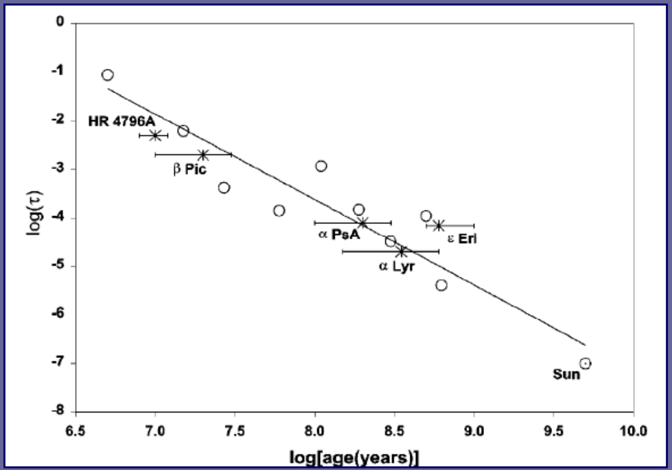
Contours: HI; Color 158 mu CII Madden et al 1997

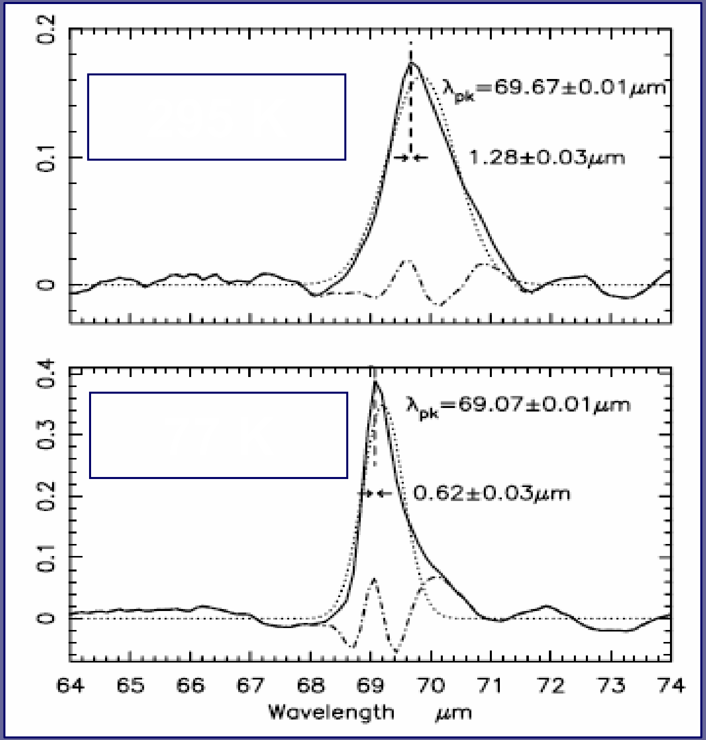
- **Spatially resolved photometry, spectroscopy with PACS, SPIRE, HIFI**
- **Detailed SEDs and dust properties**
- **Chemistry/metallicity variation and evolution**
- **Variations inside a galaxy as well as global properties**

Debris Disk Evolution

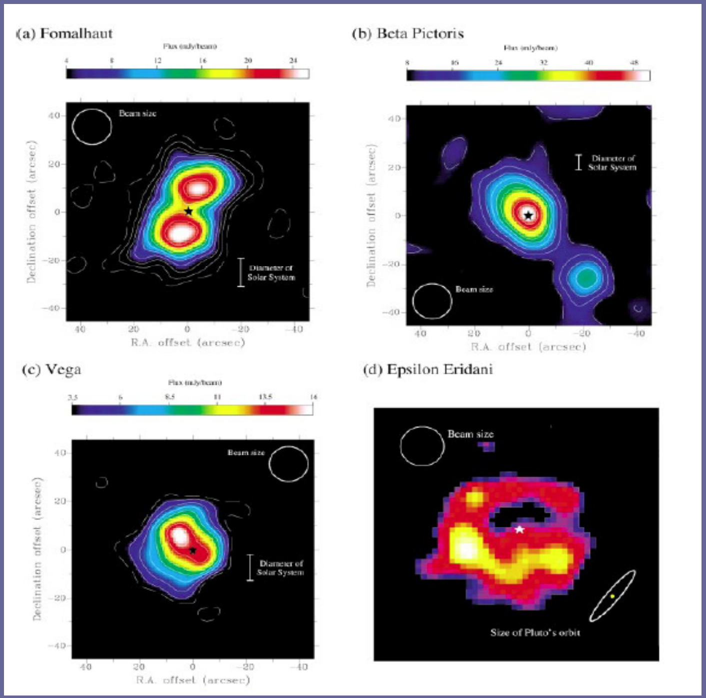
- **PACS + SPIRE mapping**
  - Dust mass vs. time/evolutionary state
  - Dust morphology and properties

- **PACS + SPIRE spectroscopy**
  - Dust features, e.g., Fosterite 69 μm

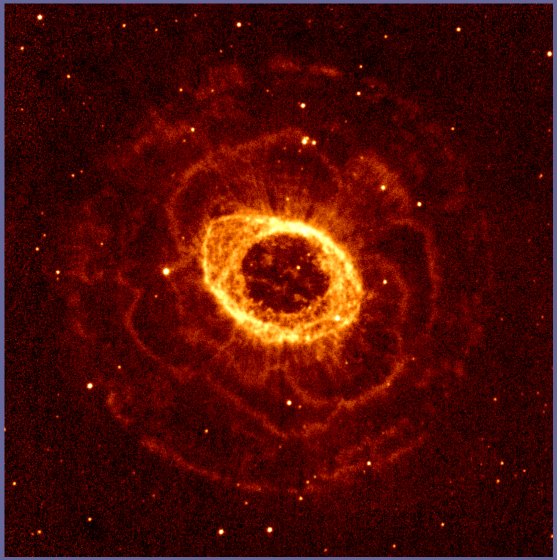




75 μm
110 μm
170 μm
250 μm
360 μm
520 μm



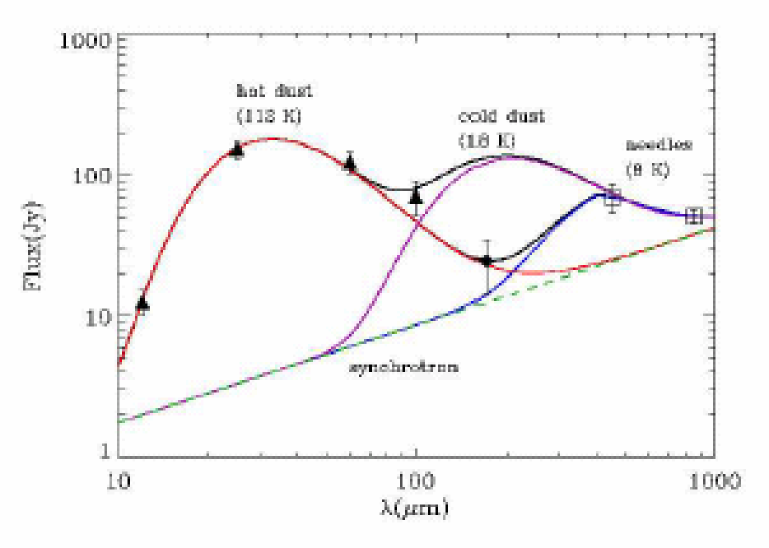
Dust Production by Stars and Supernovae



- **Post-AGB stars extended dust shells**
  - **Mass, temperature, morphology via multi-wavelength photometric imaging**

- **Evolved star chemistry**
  - **Spectroscopy of evolved objects with specific dust chemistries:** CO, HCN, and H_2O
  - **O- and C-rich stars, post-AGB objects, planetary nebulae**
  - **1 - 8 $M_\odot$ objects most important for contributing dust to the Galaxy**

- **Dust production by supernovae**
  - **Nearby SNRs (Cas A, Kepler, Tycho, Crab, etc.)**
  - **Detection of emission from dust produced and/or swept up**



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 OT KP Maps of the ORION region (J. Cernicharo))*

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)

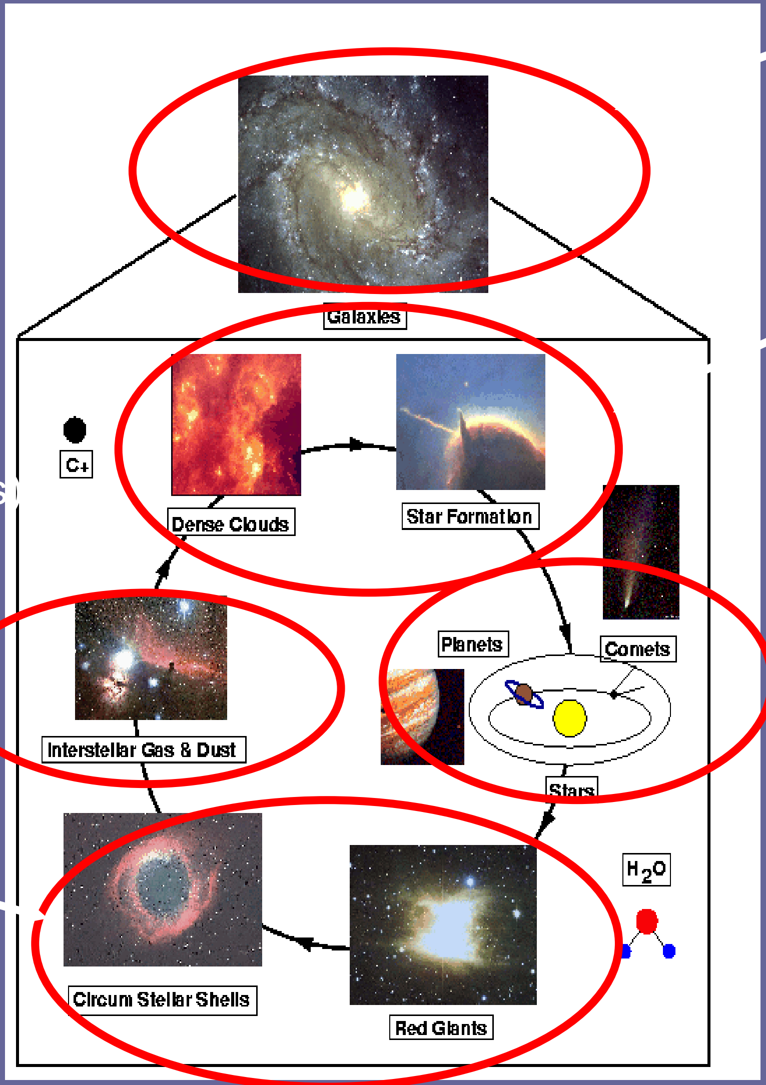
4.1 Physical and Chemical Conditions of the ISM in Galactic Nuclei

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) with PACS and SPIRE

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

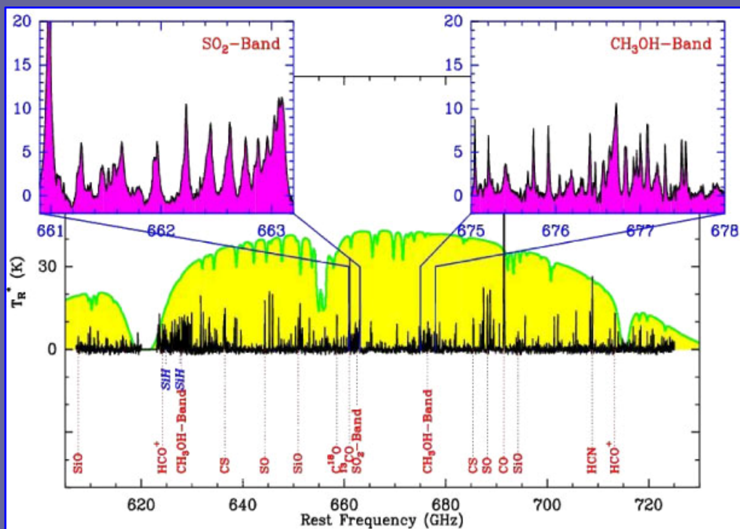
Late stages of stellar evolution:
- Winds
- Shells
- Asymmetries
- Composition

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

HIFI Spectral Line Surveys; High Spectral Resolution

CSO Spectrum of Orion: 8 nights

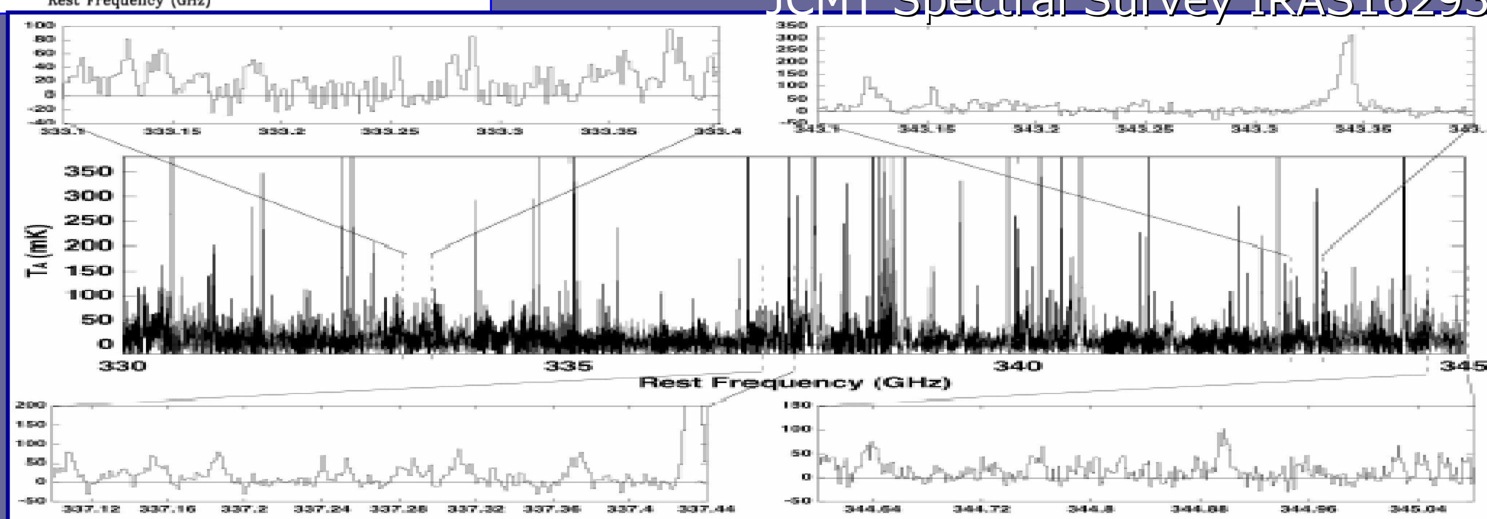
For HIFI: < 1 hr; Total HIFI range in 12 hours



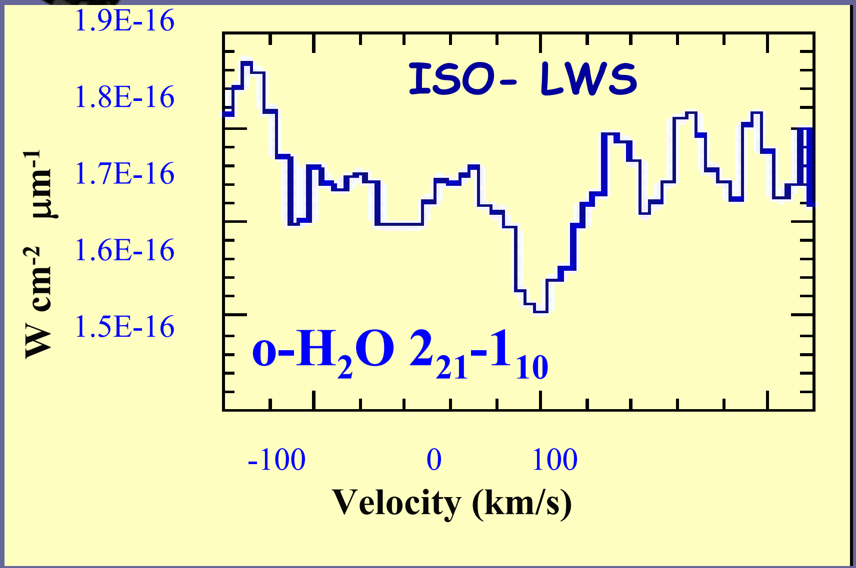
Spectral survey of Orion-KL showing hundreds of molecular lines with atmospheric transmission overlaid.

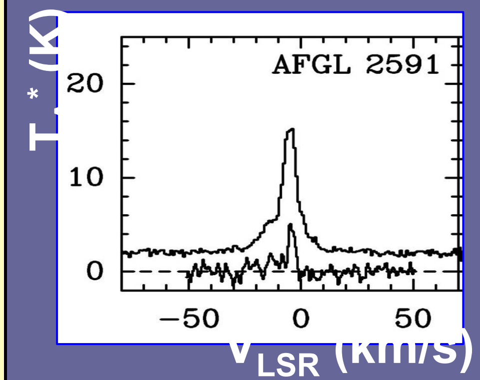
HIFI will be able to survey outside of the atmospheric windows and at frequencies never probed before, allowing for searches of new molecules.

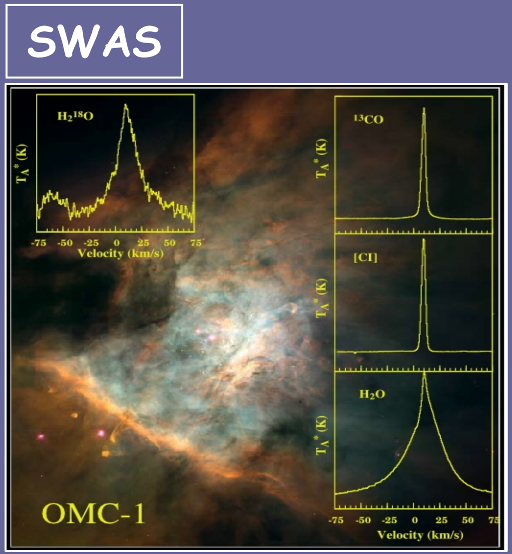
JCMT Spectral Survey IRAS16293

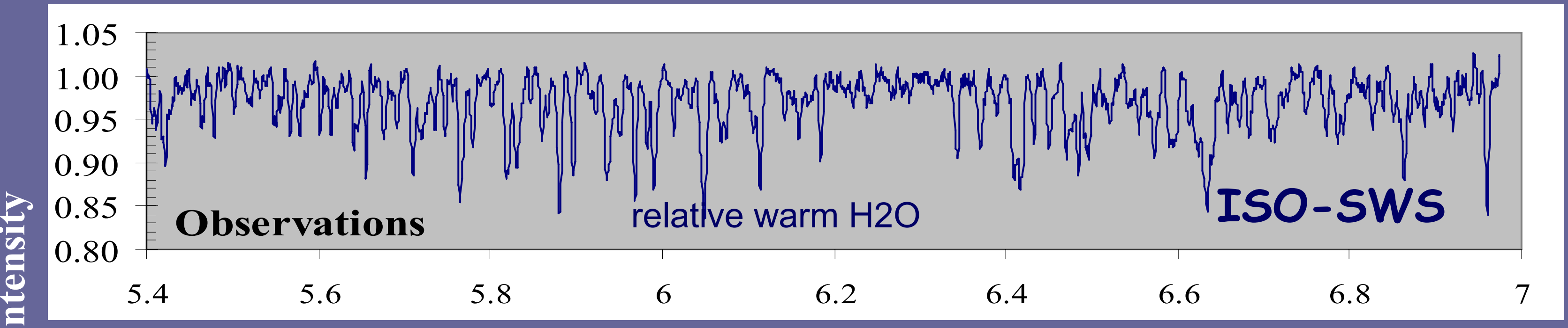


HIFI Unique Science: Water abundant from SWAS, ODIN, ISO, Spitzer, etc





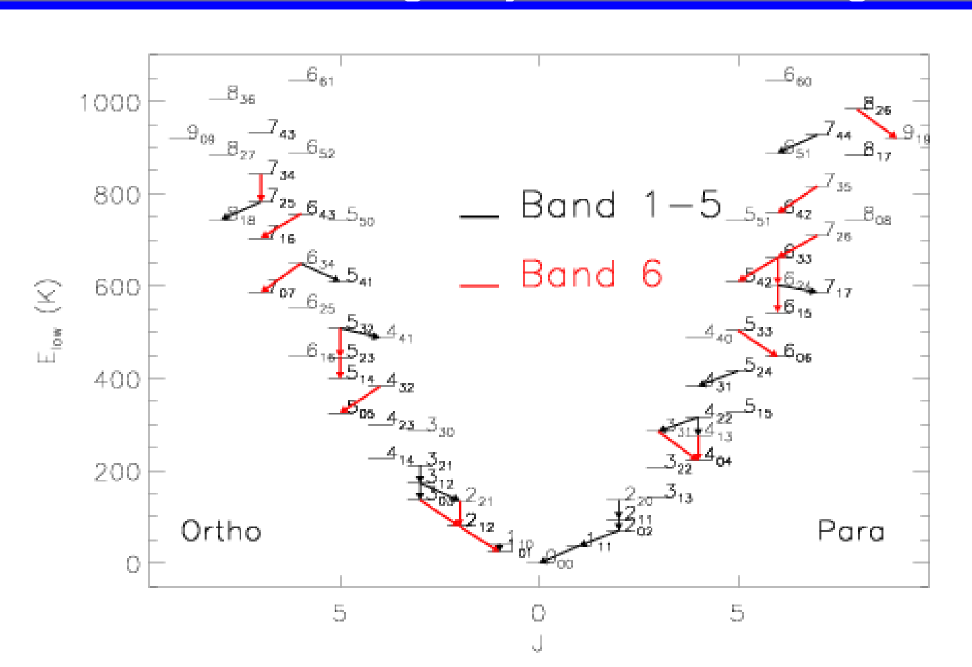


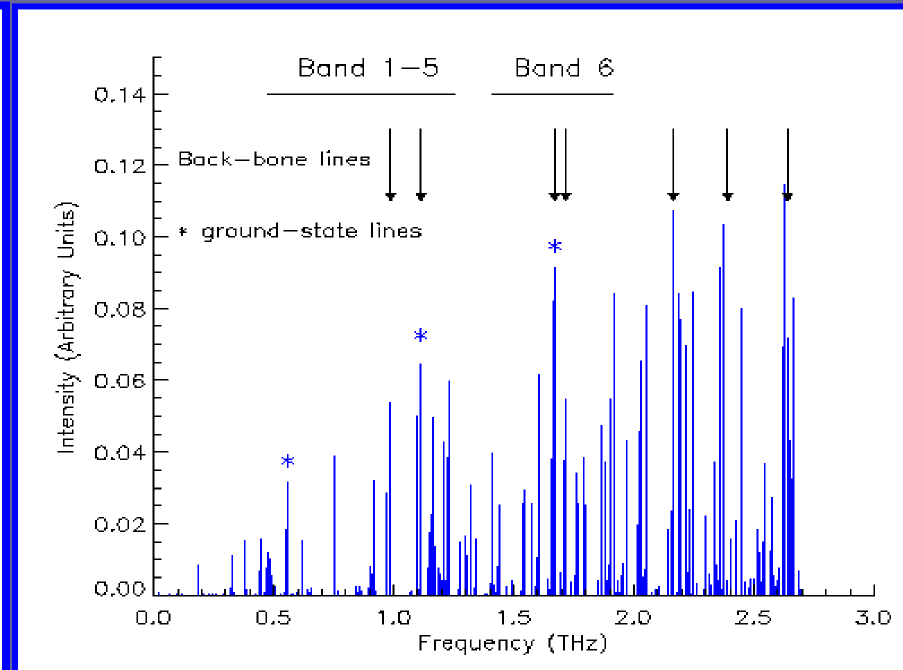


HIFI water line observations

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

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





Most Wanted Molecular Line Frequencies Under construction (1 December 1006)

Band-1

CS	489.751	1
C	492.161	2
NH2D	494.454	1
NH2D	494.455	1
NH2D	494.457	1
HDO	509.329	2
H2O	520.878	1
CH	532.721	1
CH	536.761	1
H2O-*para*	546.621	1
H2 18O-*ortho*	547.676	3
C18O	548.831	1
13CO	550.926	2
H217O-*ortho*	552.021	2
H2O-*ortho*	556.936	3
NH3	572.498	2
15NH3	572.113	2
CO	576.268	2
HDO	599.927	2
D2O	607.350	2
HCN	620.304	1
H2O-*ortho*	620.701	2
H37Cl	624.964	1
H37Cl	624.978	1
H37Cl	624.988	1
H35Cl	625.901	1
H35Cl	625.919	1
H35Cl	625.932	1

Band-4

H2O-*para*	970.315	2
NH	974.462	1
H3O+	984.697	2
OH+	984.532	1
H2O-*para*	987.927	3
13CO	991.329	1
H218O-*para*	994.675	2
NH	999.973	1
H2O-*ortho*	1000.092	2
H2S	1002.779	1
NH+	1012.524	1
CO	1036.912	3
H2O2	1047.377	1
HCN	1062.983	2
C18O	1097.163	1
H2O-*ortho*	1097.364	3
H2O-*para*	1100.088	2
C13O	1101.350	1
H218O-*para*	1101.698	3
H217O-*para*	1107.167	2
H2O-*para*	1109.586	2
H2D+	1111.741	1
H2O-*para*	1113.343	3

Most Wanted Molecular Line Frequencies
Under construction (1 December 1006)

Band-1			Band-4		
CS	489.751	1	H2O-*para*	970.315	2
C	492.161	2	NH	974.462	1
NH2D	494.454	1	H3O+	984.697	2
NH2D	494.455	1	OH+	984.532	1
NH2D	494.457	1	H2O-*para*	987.927	3
HDO	509.329	2	13CO	991.329	1
H2O	520.878	1	H218O-*para*	994.675	2
CH	532.721	1	NH	999.973	1
CH	536.761	1	H2O-*ortho*	1000.092	2
H2O-*para*	546.621	1	H2S	1002.779	1
H2 18O-*ortho*	547.676	3	NH+	1012.524	1
C18O	548.831	1	CO	1036.912	3
13CO	550.926	2	H2O2	1047.377	1
H217O-*ortho*	552.021	2	HCN	1062.983	2
H2O-*ortho*	556.936	3			
NH3	572.498	2			
15NH3	572.113	2			

Most Wanted Molecular Line Frequencies
Under construction (1 December 1006)

Band-1 (cont.)			Band-4 (cont)		
CO	576.268	2	C18O	1097.163	1
HDO	599.927	2	H2O-*ortho*	1097.364	3
D2O	607.350	2	H2O-*para*	1100.088	2
HCN	620.304	1	C13O	1101.350	1
H2O-*ortho*	620.701	2	H218O-*para*	1101.698	3
H37Cl	624.964	1	H217O-*para*	1107.167	2
H37Cl	624.978	1	H2O-*para*	1109.586	2
H37Cl	624.988	1	H2D+	1111.741	1
H35Cl	625.901	1	H2O-*para*	1113.343	3
H35Cl	625.919	1			
H35Cl	625.932	1			

Division of PACS GT

- **Nominal PACS GT = 2000 hrs**

-The birth of high mass stars 105Hrs (20 PACS, 85 Spire)

- Gould Belt survey: Probing the origin of the IMF 462Hrs (170 PACS, 252 Spire, 40 HSC TBC)

- ACS Evolutionary Probe 660Hrs (570 PACS, 80 HSC, 10 MS)

-- The Circumstellar Environment in Post-Main-Sequence Objects 225 Hrs (190 PACS, 20 MS, 12-15 HSC)

- The earliest phases of star formation 125Hrs

- Stellar Disk Evolution 230 Hrs (70h PACS + 70 SPIRE, 60 HSC, ~30 MS)

- The Dusty Young Universe 170Hrs

- Physical processes in the ISM of Very Nearby Galaxies (70 h PACS + TBD h SPIRE)

- Star formation and activity in infrared bright galaxies at $0<z<1$ (260h PACS + TBD MS)

Division of SPIRE GT

- **Nominal SPIRE GT = 2000 hrs**

High-redshift galaxies	**850 hrs**
Local galaxies	**300 hrs**
Star formation	**320 hrs**
Interstellar medium	**180 hrs**
Solar system	**50 hrs**
Stellar & circumstellar	**150 hrs**
Reserved for small programmes	**150 hrs**

- **Many programmes will involve collaboration/coordination with the PACS team**

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) 470

1.2 Spectral Scans (C. Ceccarelli) 270

1.3 The Orion and Sgr B2 regions (T. Bergin) 380

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

2. ISM

2.1 The Warm ISM (V. Ossenkopf) 170

2.2 Hydrides and Molecular Carriers (M. Gerin) 100

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

3.1 WATER and CO observations of AGB envelopes, PPNe and PNe 180

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

4. Extragalactic Science (R. Guesten) 340

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) 190 plus PACS (25) and SPIRE (50) 265