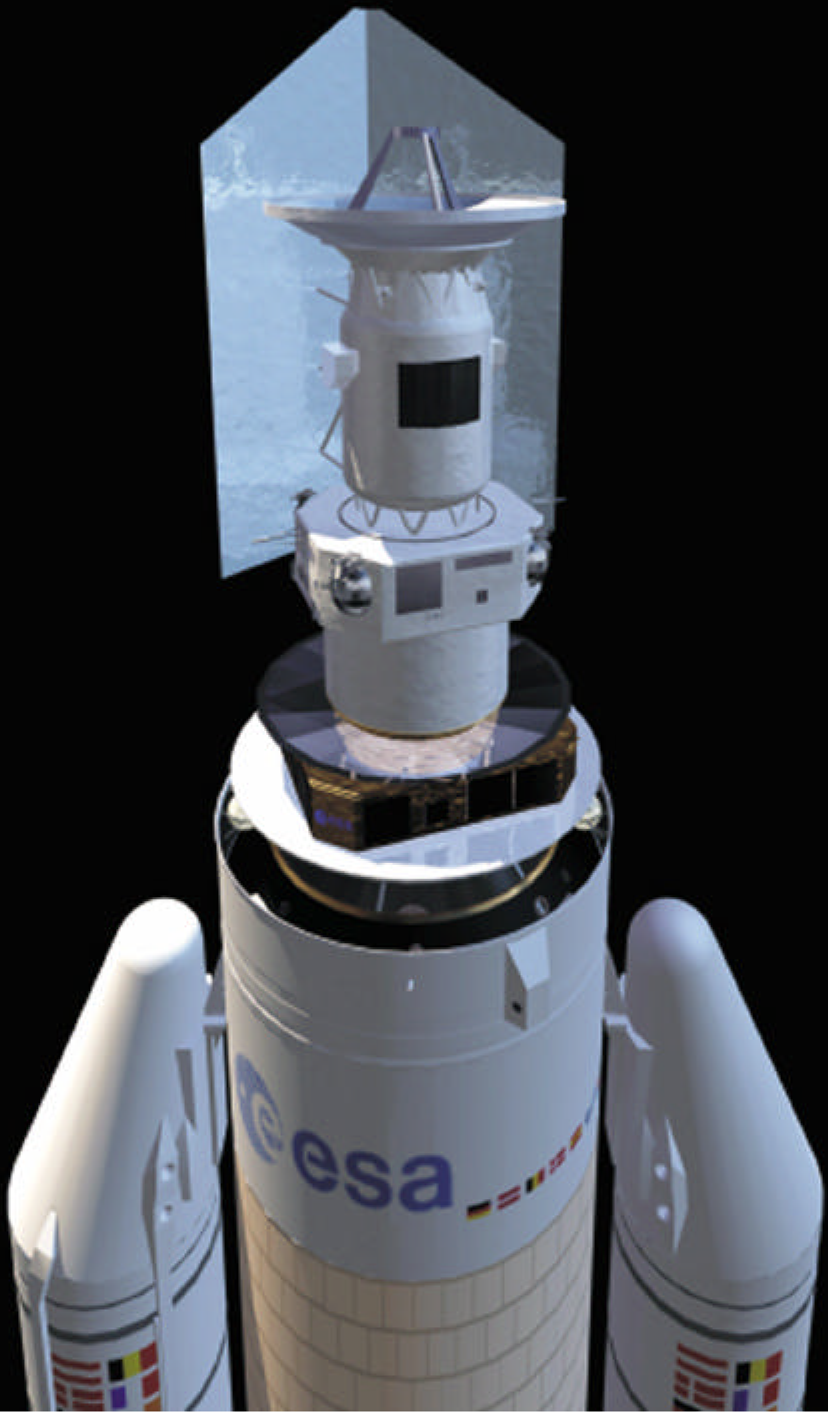
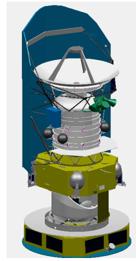
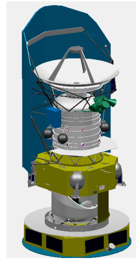
FIRST/Planck Payload Review

ESTEC
23.05.2000





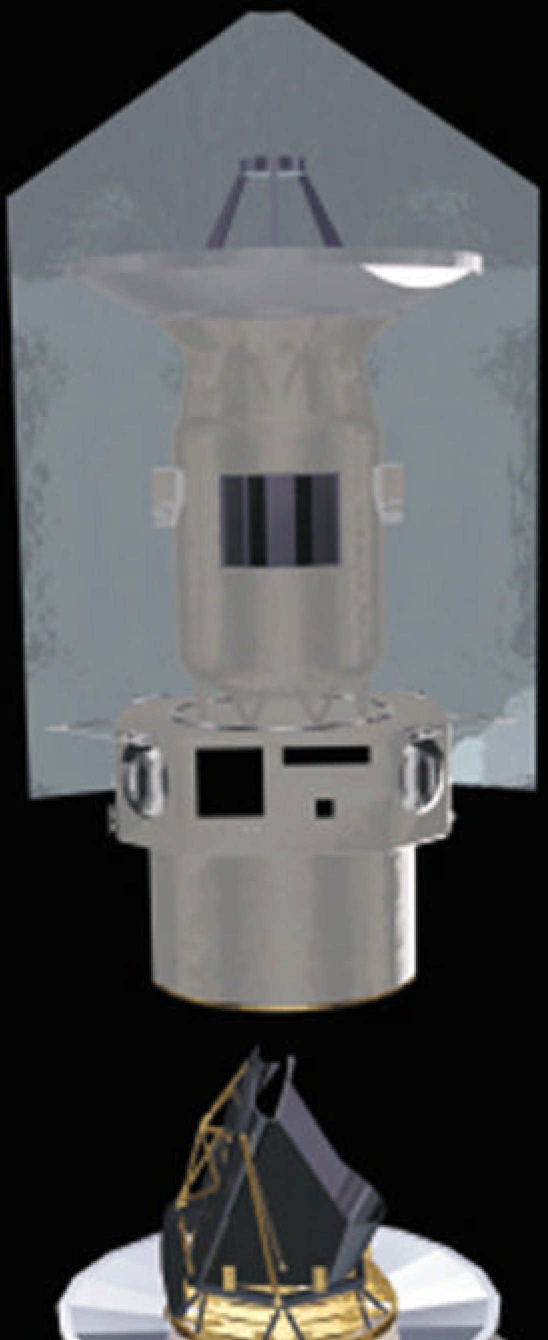
FIRST/Planck Payload Review

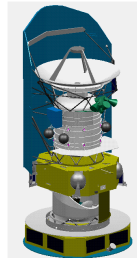


Welcome and Review Objectives

R.M. Bonnet ESA D/SCI

FIRST/Planck

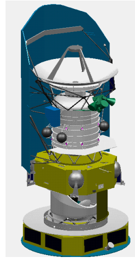




FIRST/Planck Payload Review

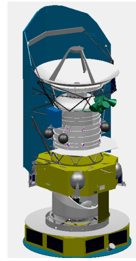
2. Agenda
3. ITT Status

F. Vandenbussche ESA/Estec



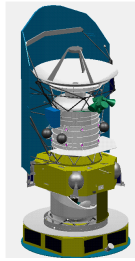
FIRST/Planck Payload Review Agenda

09:00-09:05	1. Welcome/Introduction/Review Objectives (RMB)
09:05-09:10	2. Agenda (FV)
09:10-09:30	3. ITT Status Overview (project) (FV)
09:30-09:45	4. FIRST Payload (GP)
09:45-10:00	4.1 FIRST Telescope Status (GP)
10:00-10:45	4.2 HIFI Status (TdG - HIFI PI, 45 min)
10:45-11:00	Coffee break
11:00-11:45	4.3 PACS Status (AP - PACS PI)
11:45-12:30	4.4 SPIRE Status (MG - SPIRE PI)
12:30-13:30	Lunch Break



FIRST/Planck Payload Review Agenda

12:30-13:30	Lunch Break
13:30-14:00	5. Planck Payload (JT)
14:00-14:15	5.1 Planck Straylight Status (PdM)
14:15-15:00	5.2 LFI Status (NM - LFI PI)
15:00-15:15	Coffee Break
15:15-16:00	5.3 HFI Status (JLP - HFI PI)
16:00-16:15	5.4 Planck Reflectors Status (HUNN - DSRI)
16:15-16:30	6. Review Conclusions (RMB)

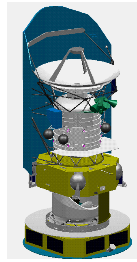


2. FIRST/Planck Invitation to Tender (ITT) status

2.1 Procurement Proposal

Following the industrial briefing which took place in December 1999, a Procurement Proposal has been prepared. The Procurement Proposal covers the definition, design, development, manufacture, integration and testing of FIRST and Planck spacecraft as well as the industrial support for their launch in early 2007.

The Industrial Policy Committee has endorsed the Procurement Proposal in the session of 7/8 March 2000.



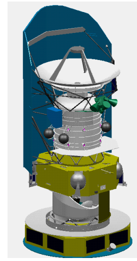
2. FIRST/Planck Invitation to Tender (ITT) Status (cont'd)

2.2 Composition/schedule

The Invitation to Tender is being prepared by ESA. The Instrument Interface Documents (A and B) will be part of the ITT with other contractual and system support documentation.

The FIRST telescope specification and Planck Telescope and reflectors/inner baffle specifications will be part of the ITT.

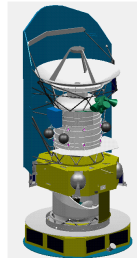
A Tender Evaluation Board (TEB) has been established and will meet for a pre-TEB on 19 June 2000.



Release of ITT is planned for 1 September 2000

Industrial Proposal(s) expected 1 December 2000

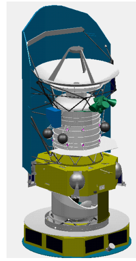
Kick-off of Phase B for 1 June 2001



2.3 HIREL Part Procurements

Prior to the selection of the Prime, the procurement of Hirel-parts has been initiated by ESA via a competitive Invitation to Tender as a result of which the FIRST/Planck Parts Procurement Agent will be selected to start immediately a coordinated Hirel-parts procurement scheme which will encompass the procurement of all Hirel-parts for the FIRST/Planck mission including the parts for the individual experiments for those Principal Investigators who may wish to participate.

The selected Prime will be requested to adopt and manage the Part Procurement Agent with the first three months of Phase B. Meanwhile, the Project Office will manage the Agent.



2.4 HIREL Parts Procurement Schedule

Proposal from Industry requested for 19 June 2000

Evaluation till mid July 2000

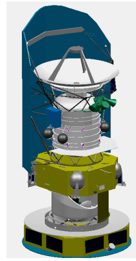
Kick-off meeting with Procurement Agent on 27 July 2000

Introductory meeting with the Principal Investigators - Procurement Agent - ESA planned on 28 July 2000 at Procurement Agent’s premises (TBC)

Mature Instruments Parts list available begin June 2000

Parts Procurement Agreement - Principal Investigators/

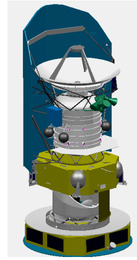
ESA to be signed in June 2000



2.5 Instruments

The selected Prime Contractor will be responsible for the management of the payload and spacecraft technical interfaces and individual experiment development schedules, delivery dates and margins.

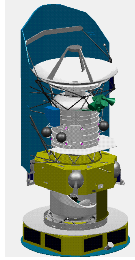
The selected Prime will be requested to prepare the agreement between the Prime Contractor and Instruments for the handling of the interfaces within the 3 months after Phase B kick-off.



2.6 Instruments Delivery Dates

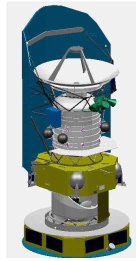
To support the proposed protoflight philosophy, the following models are expected to be delivered by the FIRST/Planck instruments:

- Cryogenic Qualification Model (CQM): April 2003
- Avionics Model (AVM): April 2003
- Flight Model (FM): July 2004
- Flight Spares (FS): July 2005



2.7 FIRST Telescope/Planck Reflectors delivery dates

FIRST Flight telescope model	October 2004
Flight spare (to be agreed)	January 2005
Planck QM reflectors and Inner baffle	January 2003
Flight Model	March 2004
Flight spare (QM refurbished)	January 2005



4. FIRST Payload

G. Pilbratt - ESA/ESTEC

FIRST science and payload

'FIRST and Planck Payload Review at D/SCI level'

ESTEC, 23 May 2000

Göran L. Pilbratt

Astrophysics Division

Space Science Department of ESA

Contents (15 min):

- FIRST science (drivers)
- Science payload (overview)
- Instrument review status

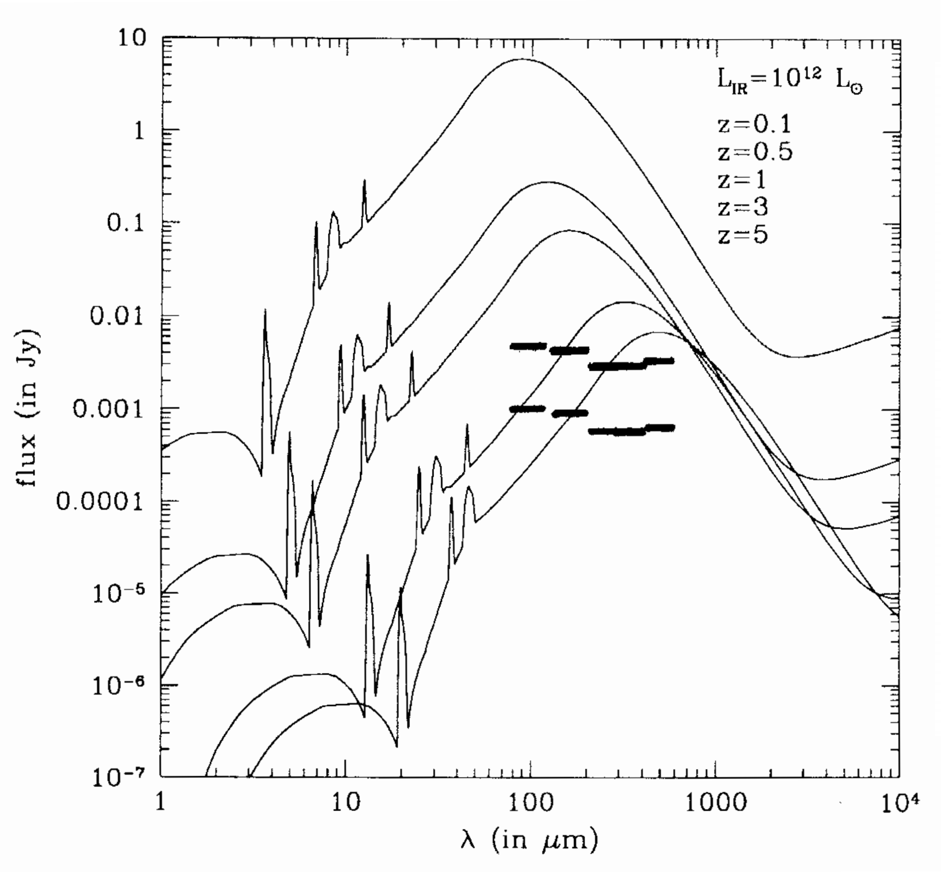
FIRST major science objectives:

- To study the formation of galaxies in the early universe, and their evolution
- To study the formation of stars and the physics of the interstellar medium
- To study cometary, planetary, and satellite atmospheres

FIRST 'targets':

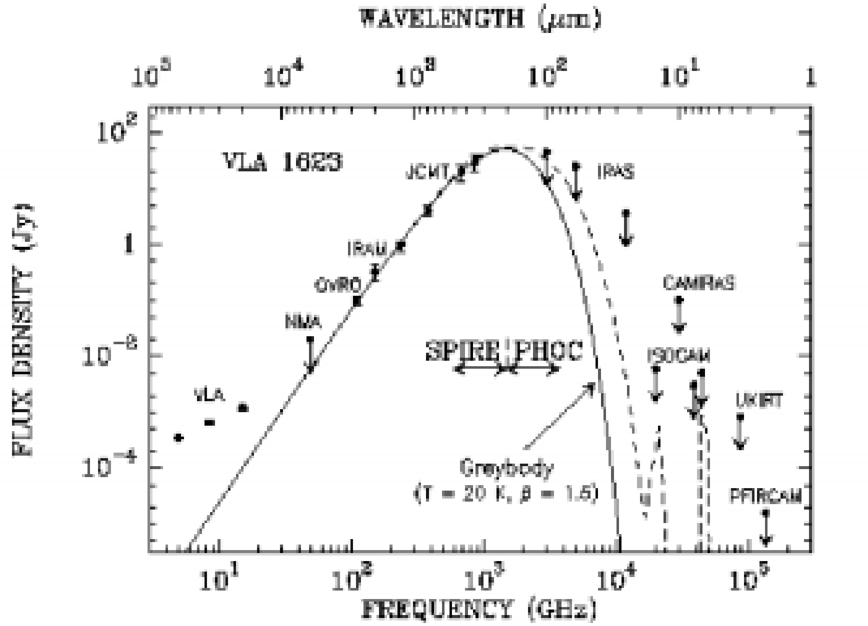
- Thermal radiation from black-bodies (dust grains) with T in range 5 - 50 K
- Spectral (molecular and atomic) lines from gases with T in range 10 - few x100 K
- => the SEDs of IR galaxies (discovered by IRAS, studied by ISO) and proto-stars (discovered by mm/submm radio observations) peak in the FIRST wavelength range!

$L_{bol} \sim 10^{12} L_{sun}$ IR galaxy at different z



Guiderdoni et al. Proc. XVIIth Moriond Astrophysics mtg, ‘Extragalactic Astronomy in the Infrared’ pp. 521, 1997

SED of ‘prototype’ Class 0 proto-star



Adapted from: André, Ward-Thompson, Barsony, ApJ 406, 122, 1993

FIRST observation examples:

- Deep broadband extragalactic surveys in the 100-600 μm range
  - How and when did galaxies form ? Unknown population of high-z IR galaxies ? Star formation rate ?
- Follow-up spectroscopy on sub-samples
  - What powers luminous galaxies and AGNs (star-bursts vs. black holes) ? How do they evolve ?
- Interstellar medium / star formation studies in the Galaxy and in other galaxies
  - How do stars form out of the ISM ? Astrochemistry as a probe ! Nearby galaxies templates !
- Solar system science
  - What is the history of the solar system ? Comets - pristine material ! Planetary / satellite atmospheres !

Unique characteristics of FIRST:

- FIRST is the first space facility to completely cover the entire far infrared and submillimetre (60 - 670 μm) range
  - Low emissivity (few %), passively cooled (70-90 K), large telescope (3.5 m)
  - Total absence of atmospheric absorption - full access to this poorly explored spectral range
  - Total absence of atmospheric emission - low and stable background across the whole range
  - Deep photometry & full spectral coverage !
- For λ < 200 μm FIRST has much larger - and admittedly much warmer - telescope than earlier cryogenic telescope missions ISO / SIRTF / Astro-F
- In the FIRST band, the SOFIA airborne facility has warmer, smaller, higher emissivity telescope, and residual atmospheric absorption and emission
- FIRST will offer a large amount of observing time: longer lifetime (specification >3 years) than ISO - roughly 1000 SOFIA flights a year !

Instrumental science requirements:

Telescope

- Size: maximize aperture size; collecting area (sensitivity) and linear (angular resolution)
- Shape and wavefront error: per design and compatible with wavelength coverage
- Background: lowest possible temperature, temperature gradients (spatially and temporally), and emissivity; straylight requirements

Instruments

- Wavelength coverage: maximise in FIRST range
- Sensitivity: should be background limited
- Field of view: maximise for imaging
- Spatial resolution: diffraction limited by telescope size
- Spectral resolution: low, moderate, and high - depending on observation

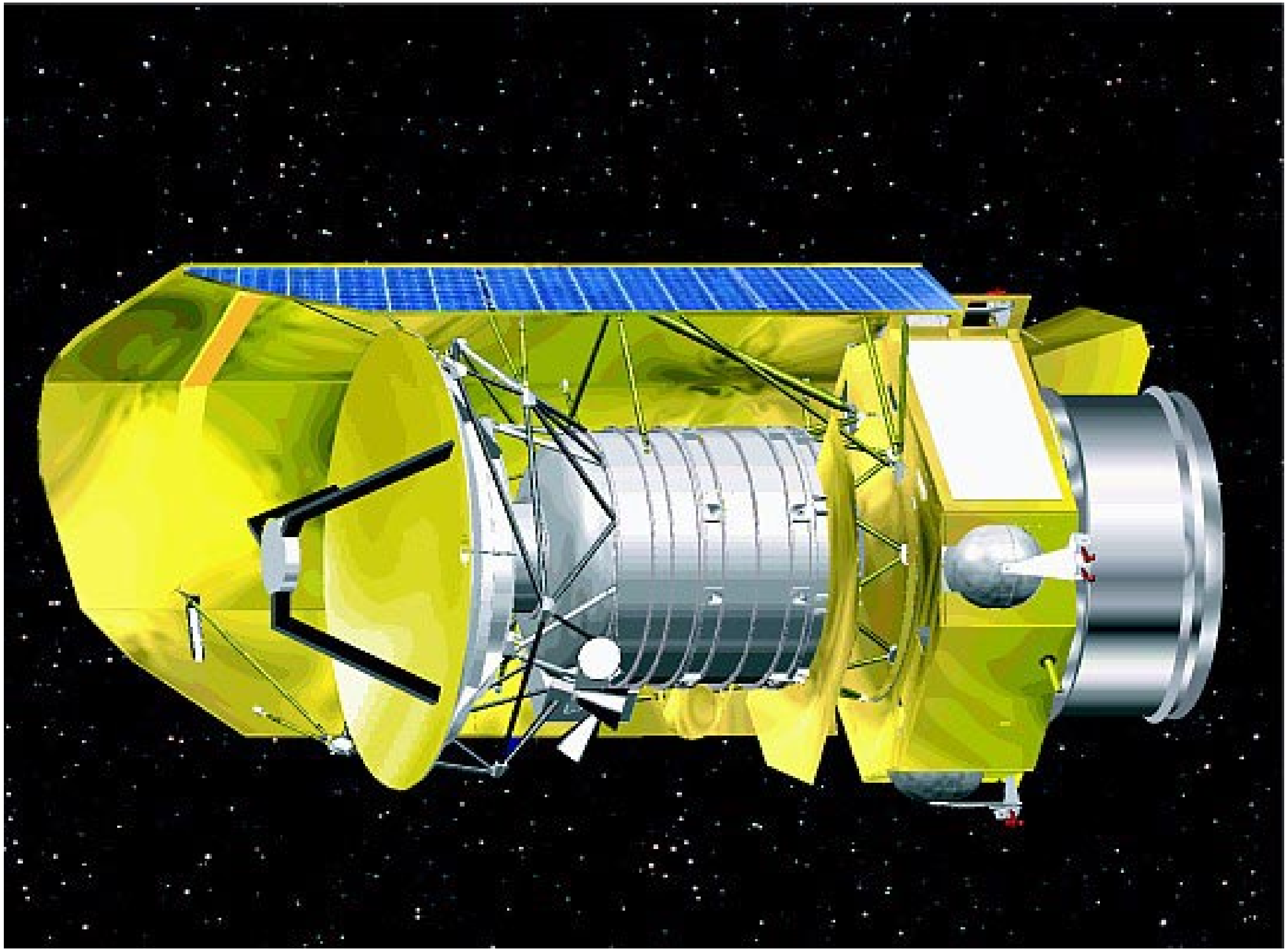
Instrumental science trade-offs:

Telescope

- Size vs. temperature: maximize size, accept passive cooling (higher temperature)

Instruments

- Sensitivity: need cryogenic cooling
- Wavelength coverage: use ‘radio’ and ‘infrared’ techniques
    - direct detection (photoconductors, bolometers) driven towards longer wavelengths
    - heterodyne techniques (mixers) driven towards shorter wavelengths
    - heterodyne detection more advantageous with increasing spectral resolution
    - => FIRST payload is a mix of techniques
- Field of view: use arrays of detectors, as large as possible
- Spatial resolution: couple to telescope beam appropriately
- Spectral resolution: all instruments provide some spectroscopic capability



Science instruments and Principal Investigators

HIFI - Heterodyne Instrument for FIRST *(Th. de Graauw, SRON, Groningen, The Netherlands)*

- very high resolution heterodyne spectroscocy covering 480 - 1250 GHz with five pairs of dual-pol. SIS, and one or two bands in the 1410 - 1910 range with dual-pol HEB mixers; LO by amplifier/multiplier chains, instantaneous bandwidth 4 GHz; backends providing a range of spectral resolutions
- SIS and HEB mixers operate at 2 K, provided by straps to the helium tank

PACS - Photoconductor Array Camera and Spectrometer *(A. Poglitsch, MPE, Garching, Germany)*

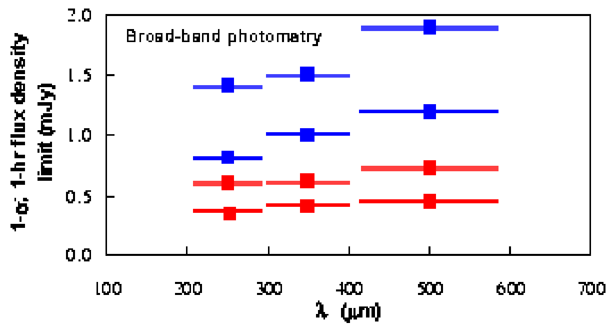
- imaging photometry simultaneously in the two 60-90/90-130 and 130 - 210 μm bands, covering the same 2'x3' FOV; or 5x5 pixels spectroscopy in the same bands; using two Ge:Ga 25x16 'bulk' photoconductor arrays
- bolometer arrays operate at 300 mK, provided by internal closed-cycle ^{3}He fridge; photoconductor arrays operate at 1.7 / 2.2 K, provided by straps to the helium tank

SPIRE - Spectral and Photometric Imaging REceiver *(M. Griffin, QMW, London, UK)*

- imaging photometry in the three 250, 350, and 500 μm bands simultaneously, covering the same 4'x8' FOV; or low- to medium-resolution spectroscopy over approximately 2'x2' FOV; using bolometer detector arrays
- all detectors operate at 300 mK, provided by internal closed-cycle ^{3}He fridge

Summary - instrumental capabilities

Red: point; Blue: map



- SPIRE
  - broadband imaging of 4x8 arcmin field in 3 colours simultaneously; 250, 350, 500 μm
  - for larger fields: scanning 'on-the-fly' or mosaicing
  - spectroscopy smaller field 2.6x2.6 arcmin; 200-670 μm; R~20-100
- PACS
  - broadband imaging of 2x3 arcmin field in 2 colours simultaneously; 75/110, 170 μm
  - for larger fields: scanning 'on-the-fly' or mosaicing
  - spectroscopy smaller field 47x47 arcsec; 60-210 μm; R~1000
- HIFI
  - single pixel instrument, complete spectral coverage over 480-1250 GHz (625-240 μm), plus 1 or 2 additional higher frequency (shorter wavelength) bands
  - map by moving the spacecraft: raster pointing or scanning 'on-the-fly'
  - very high resolution spectroscopy; R up to $\sim 10^7$

Instrument review sequence:

- Instrument Science Verification Review (ISVR, end 1999/early 2000)
- Instrument Intermediate Design Review (IIDR, end 2000/early 2001)
- Instrument Baseline Design Review (IBDR, mid/end 2001)
- Instrument Hardware Design Review (IHDR, mid/end 2002)
- Instrument Critical Design Review (ICDR, mid/end 2003)
- Instrument Flight Acceptance Review (IFAR, Q3 2006)

Status of ISVRs:

- PACS: Concluded, RIDs being addressed; but now: PACS redesign (CEA detectors)
- SPIRE: Has been performed in sections, final ‘wrap-up’ section to come
- HIFI: To be closed by Δ-ISVR on 25 May; frequent technical meetings

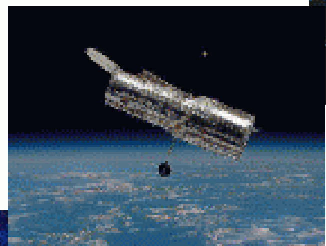
FIRST: The "Fifth Great Observatory"

The view from 'over there'!

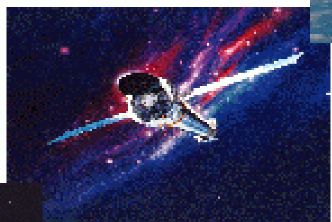
The view from 'over here'!

FIRST (Far-IR& Submm)
FIRST

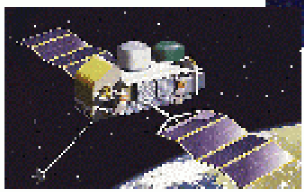
SIRTF (IR)
ISO



HST (UV/Visible)
HST

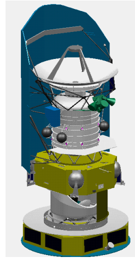


AXAF (X Rays)
XMM



CGRO (Gamma Rays) ***INTEGRAL***

Completing the Spectrum Coverage

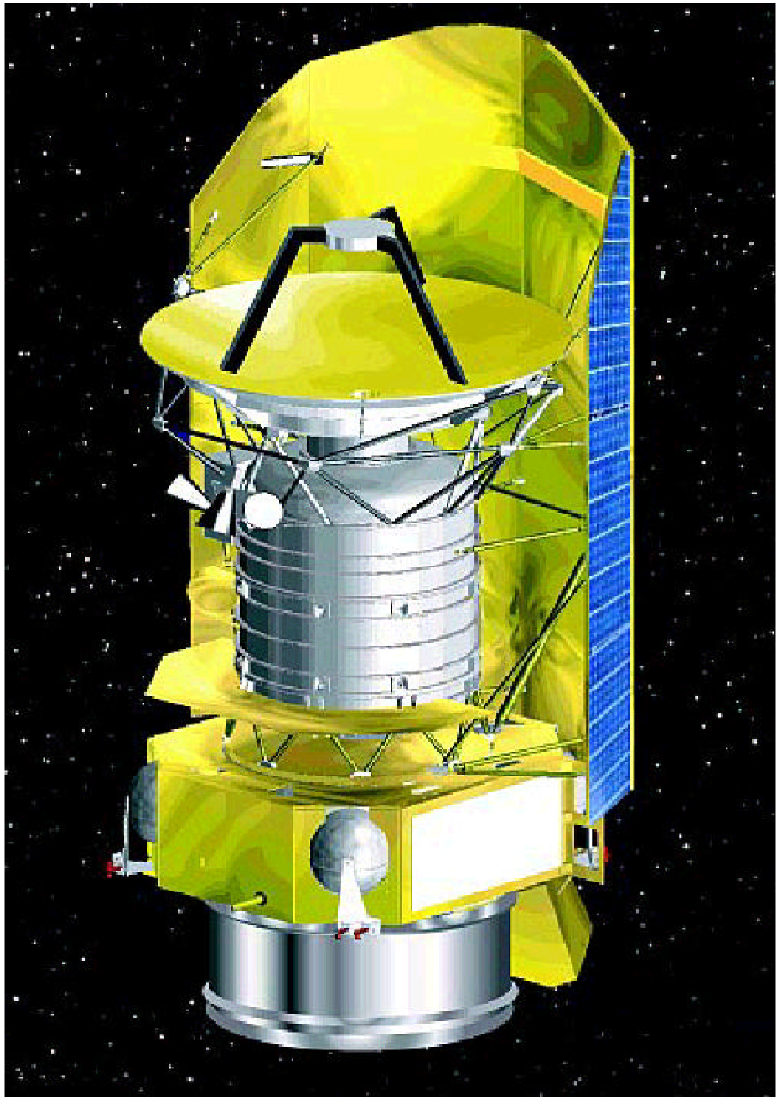


4.1 FIRST Telescope Status

G. Parks - NASA/JPL

FIRST Telescope Status

FIRST/Planck Payload Review



Gary S. Parks

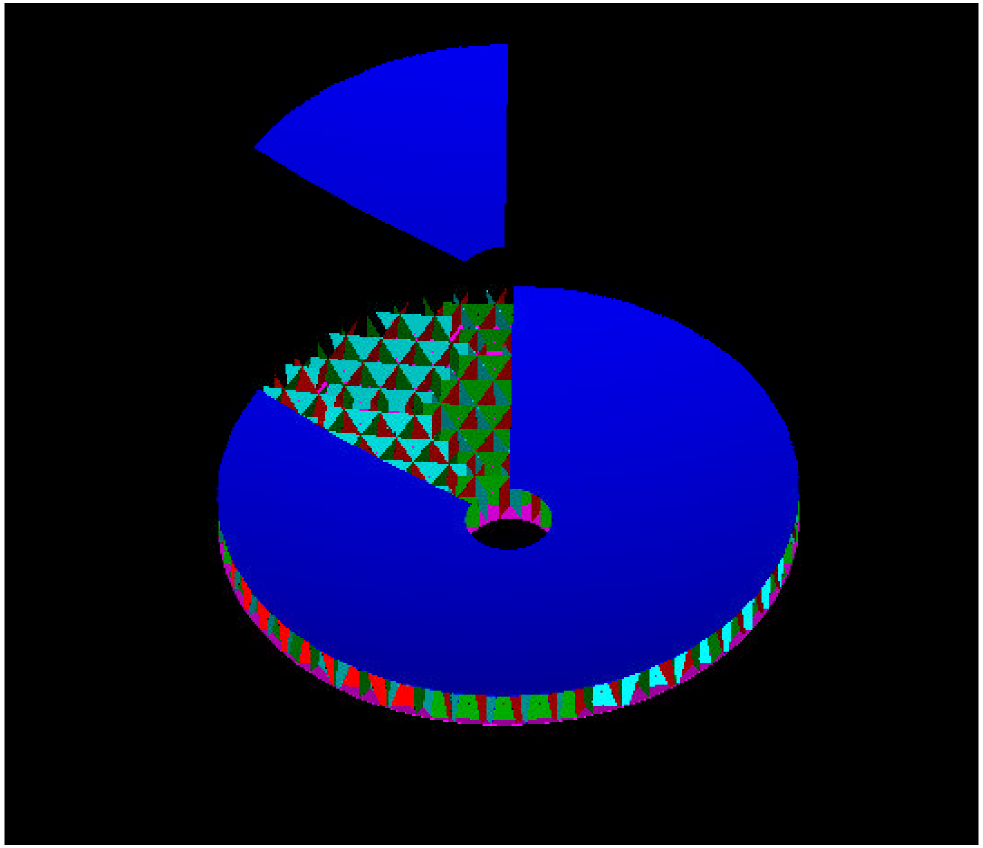
23 May, 2000

Status Overview

- Team is on track with their development plan
- Based on feedback from November '99 review, details of the development plan were improved
- Testing of the 2-meter demonstrator was initially a problem
  - Limited results to 200K full aperture, 100K subaperture
- Re-testing the demonstrator has now been completed
  - Changes included a quiet environment and new IR camera for the measurement interferometer
  - Successful tests were conducted down to 70K
- Matra SiC has been reviewed as a possible backup or alternative to CFRP
  - Technical/programmatic review held on May 3-4
- Plan is to achieve technical readiness by the PDR (July)

Primary Mirror Design Approach

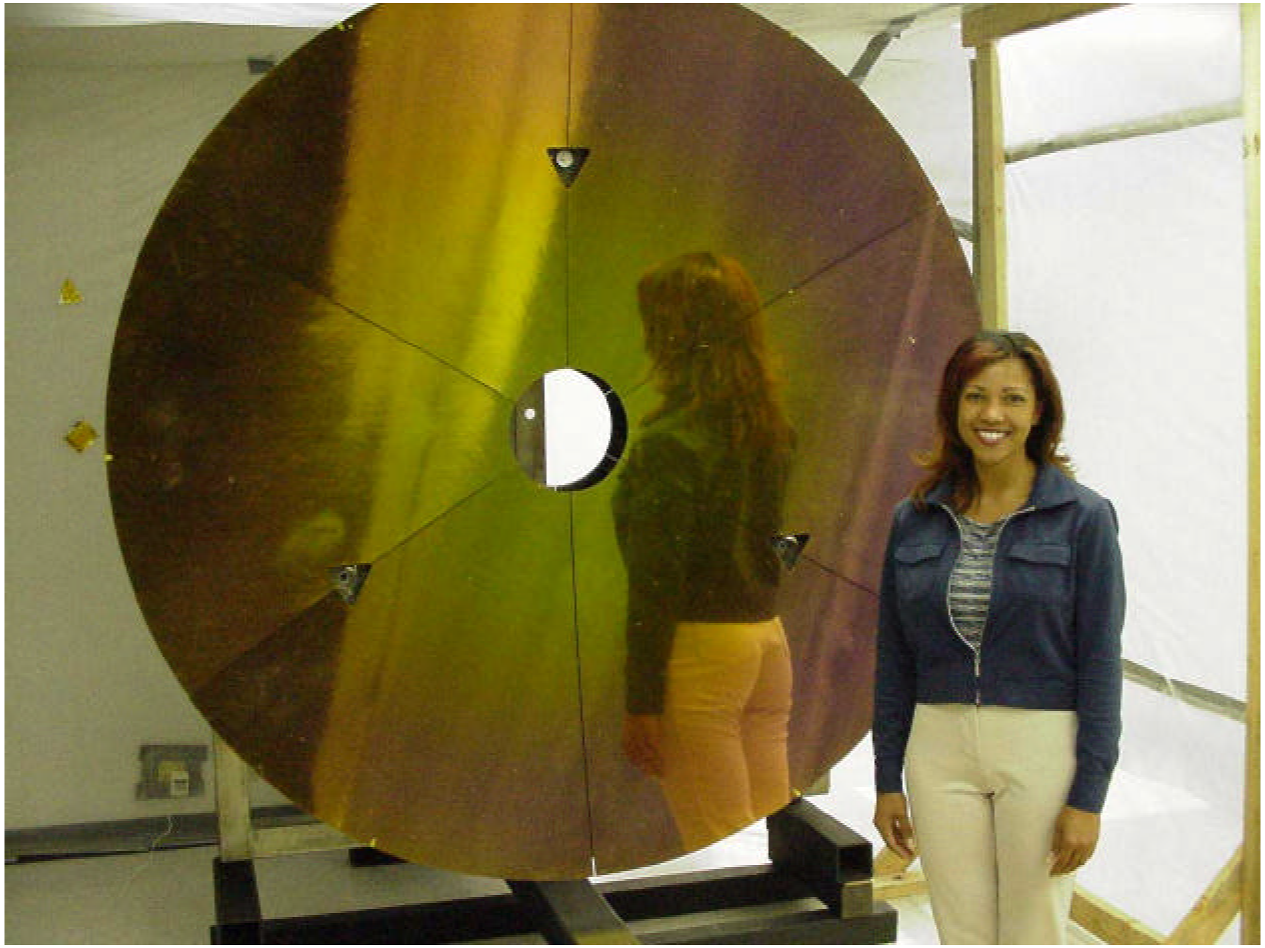
- Segmented Front and Back Faceskins
  - 60° Segments
  - Seams Coincident Front-to-back
- Modular Core
- Embedded Metallic Fittings Serve As Interface Attach Points
- Assembly Process Results in Monolithic Mirror



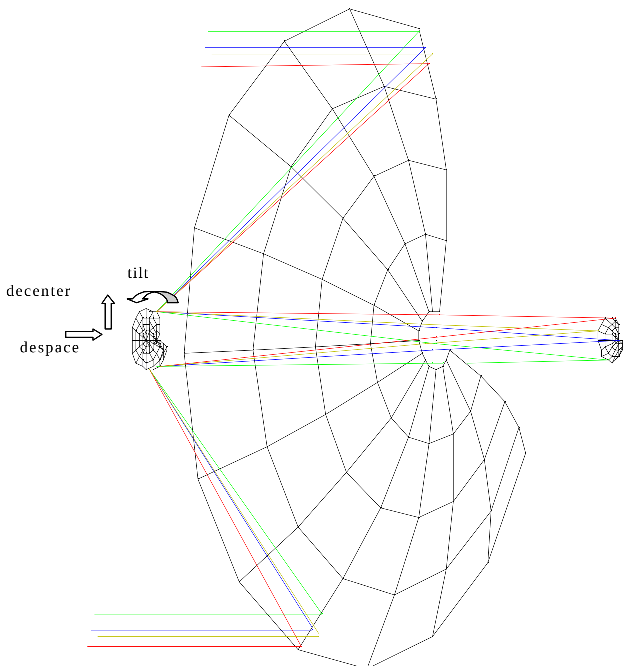
Major Accomplishments

- Telescope preliminary design completed (to be reviewed in June)
- Substantial improvements (3X) in material uniformity have been achieved
  - Improved material is the single biggest factor in achieving the telescope wavefront performance
- Fabricated test articles for evaluation and demonstration of technology readiness
  - 3 individual petals of a 2meter mirror (materials and processes evaluation)
  - 2meter mirror performance demonstrator
  - Full size petal facesheets to demonstrate ability to fabricate full size mirror
- Completed the development of accurate model to predict the performance of the full size telescope
  - Model/test correlation to be completed prior to PDR in July
- Completed the testing of the 2meter demonstrator
- Successfully demonstrated gold coating of mirror

2m Mirror Gold Coated



Passive Shape Correction (Telescope Performance Contingency)



- **Position and shape of secondary mirror (M2) can be used to correct errors at temperature**
  - **Despace, decenter and tilt of M2 can be used to compensate for errors in M1**
  - **M2 ROC and conic can also be adjusted to compensate Primary**
  - **Local adjustments in M2 figure compensate for low order errors in Primary (M1)**
  - **M1-M2 despace used as first compensator**

Results Summary From Earlier Test

- Although a limitation in the test setup did not allow testing of the 2-meter mirror down to the operating temperature (80K), tests at 200K (full aperture) and 100K (sub-aperture) provided encouraging results
  - **Test results at 200K (Note 3.5 μm requirement)**
    - **Total RMS Error at 200K (no correction) 2.81 μm**
    - **Total RMS Error at 200K (with correction) 1.56 μm**
  - **Calculated results extrapolating from measured data**

	2-Meter	3.5-Meter
Total Error at 80K (no correction)	6.42 μm	7.28 μm
Total Error at 80K (with correction)	2.45 μm	2.64 μm

- Current material capability is about twice as good as that used in the 2-meter demonstrator (suggests that numbers above can be reduced by 1/2)
- Design improvements and better material availability should have a substantial impact on improving mirror performance

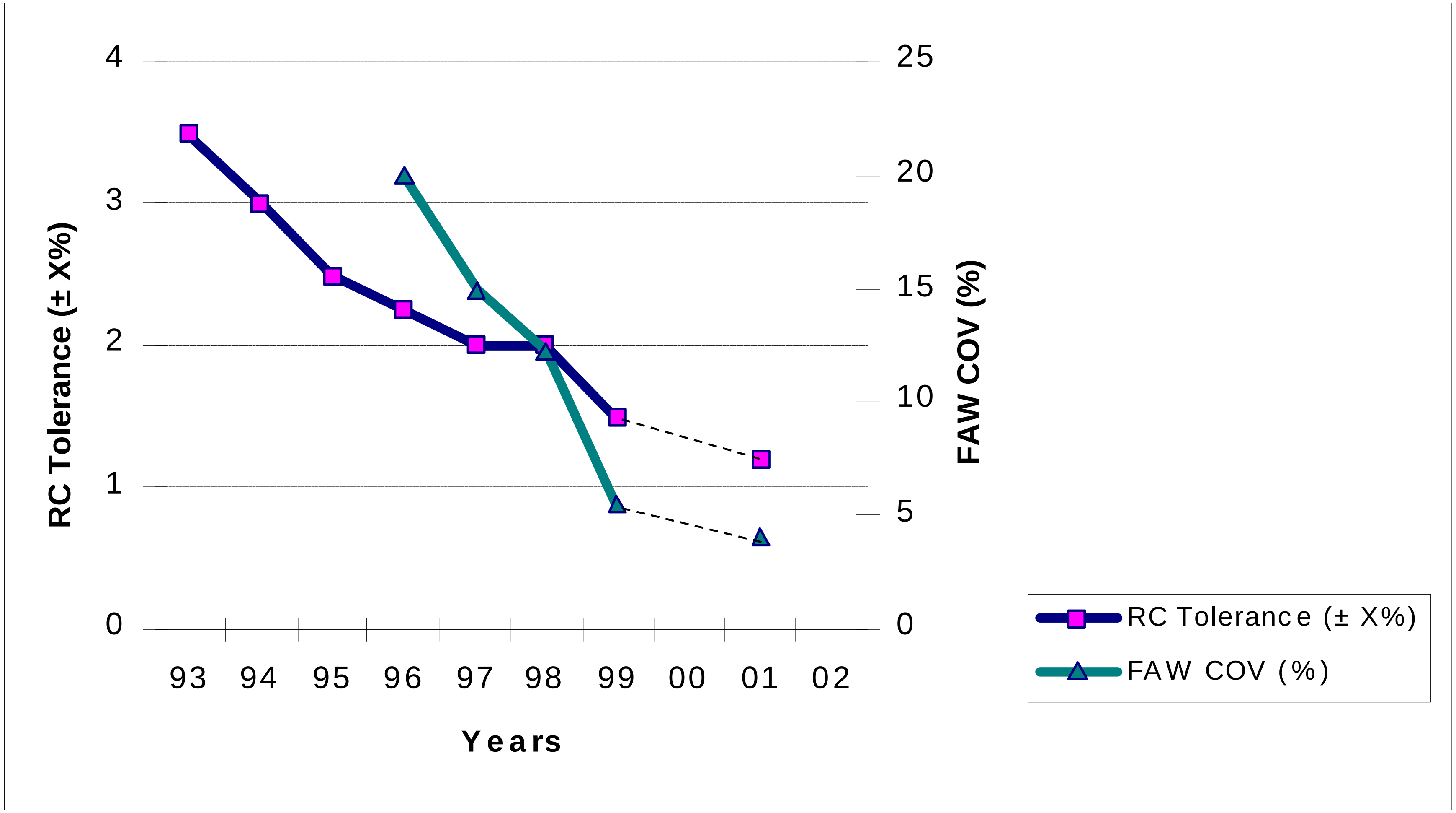
Planned Improvements

- **Several changes have been identified to reduce the low order errors**
  - Improved (fiber / resin) quality
  - Tooling
    - > Alternative petal lay-up mold design (thermal mass)
    - > Mirror assembly mold with vacuum assembly capability
- **Several changes have been identified to reduce the mid spatial errors**
  - Improved adhesive for bond-line control
  - Core cell size, skin thickness
  - Rib thickness
  - Shape of lay-up mold

Current Key Activities

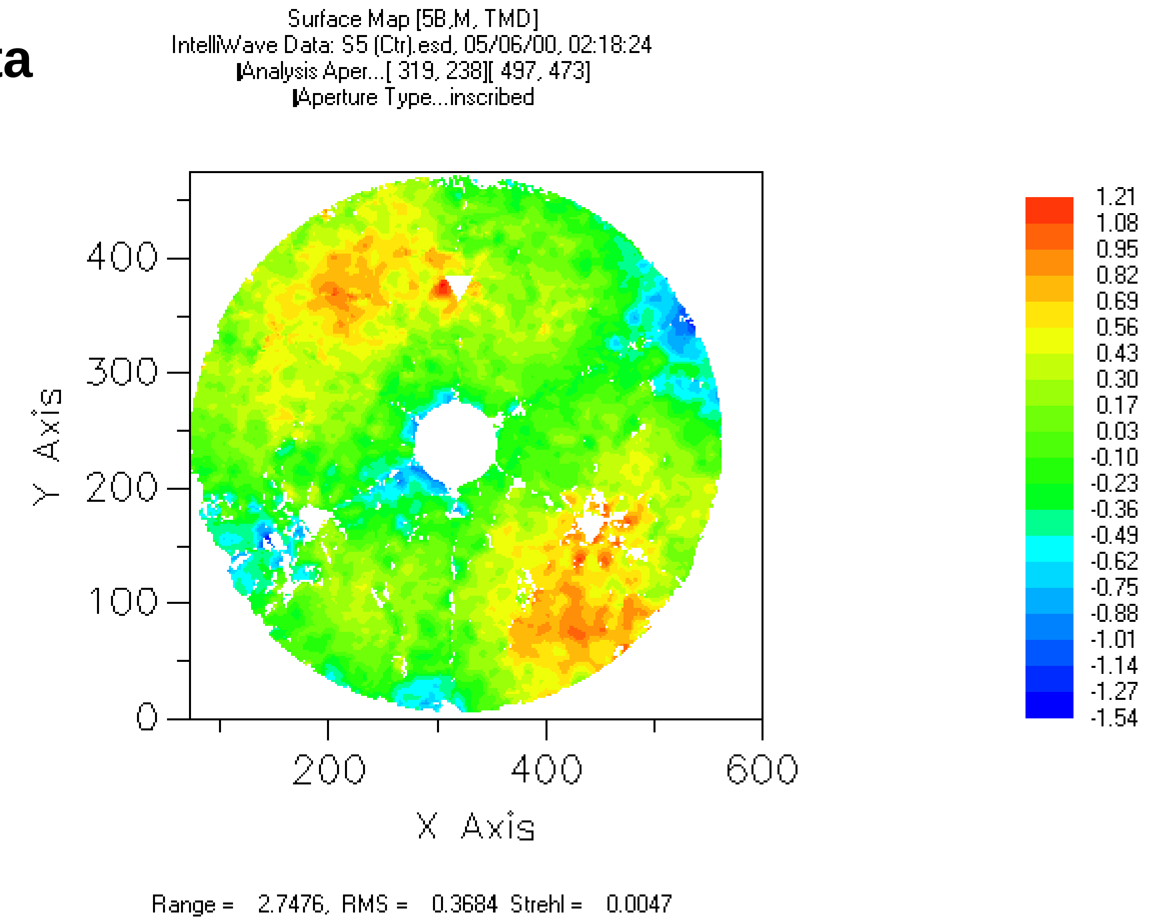
- Complete the correlation between the test results and the design/performance model
  - Report will be issued prior to PDR in July
- Preparation for upcoming reviews
  - Peer (expert technical) reviews in June
  - PDR/Confirmation readiness review in July
  - JPL director reviews in August
  - NASA confirmation review in September
- Finalize plans to begin implementation (phase C/D) in October 2000

Material Quality Trends



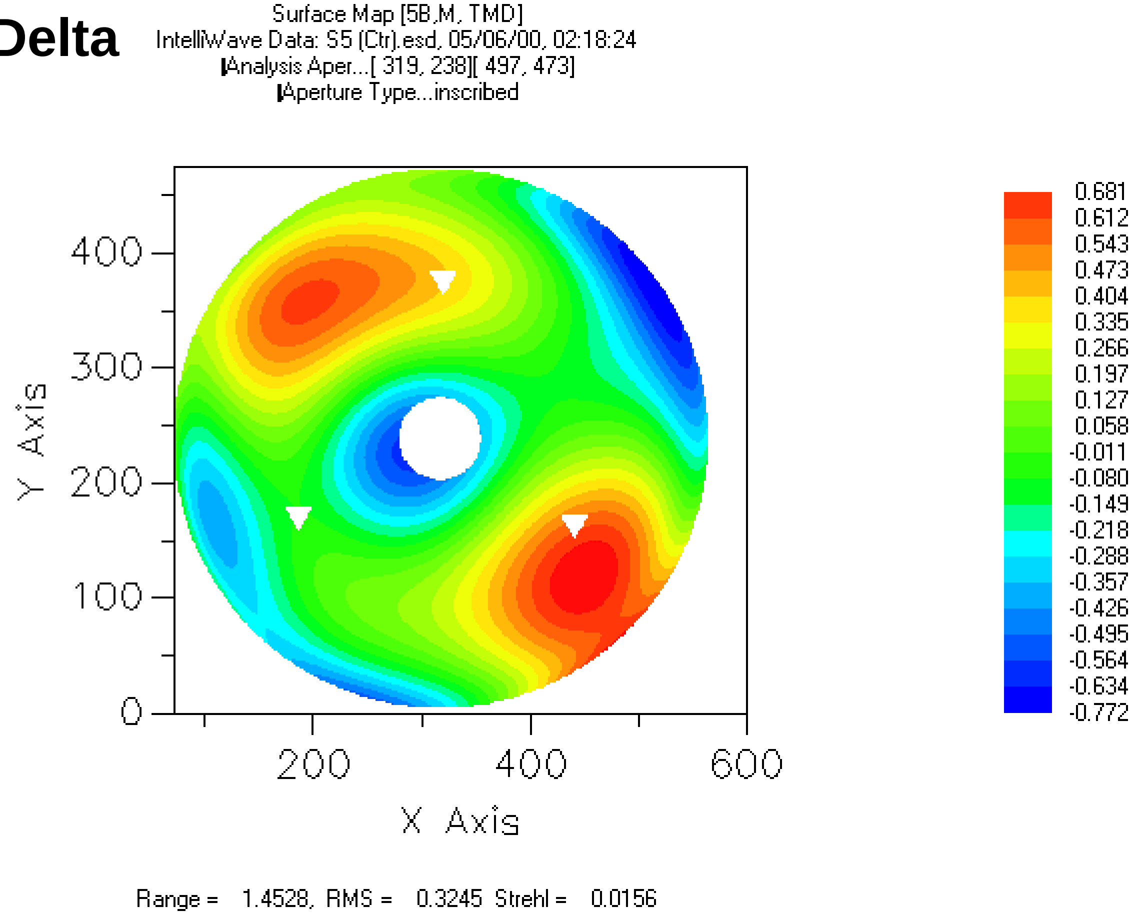
Delta Figure

- **293K to 70K Delta**
  - **Full Surface**



Delta Figure (Low Order Terms)

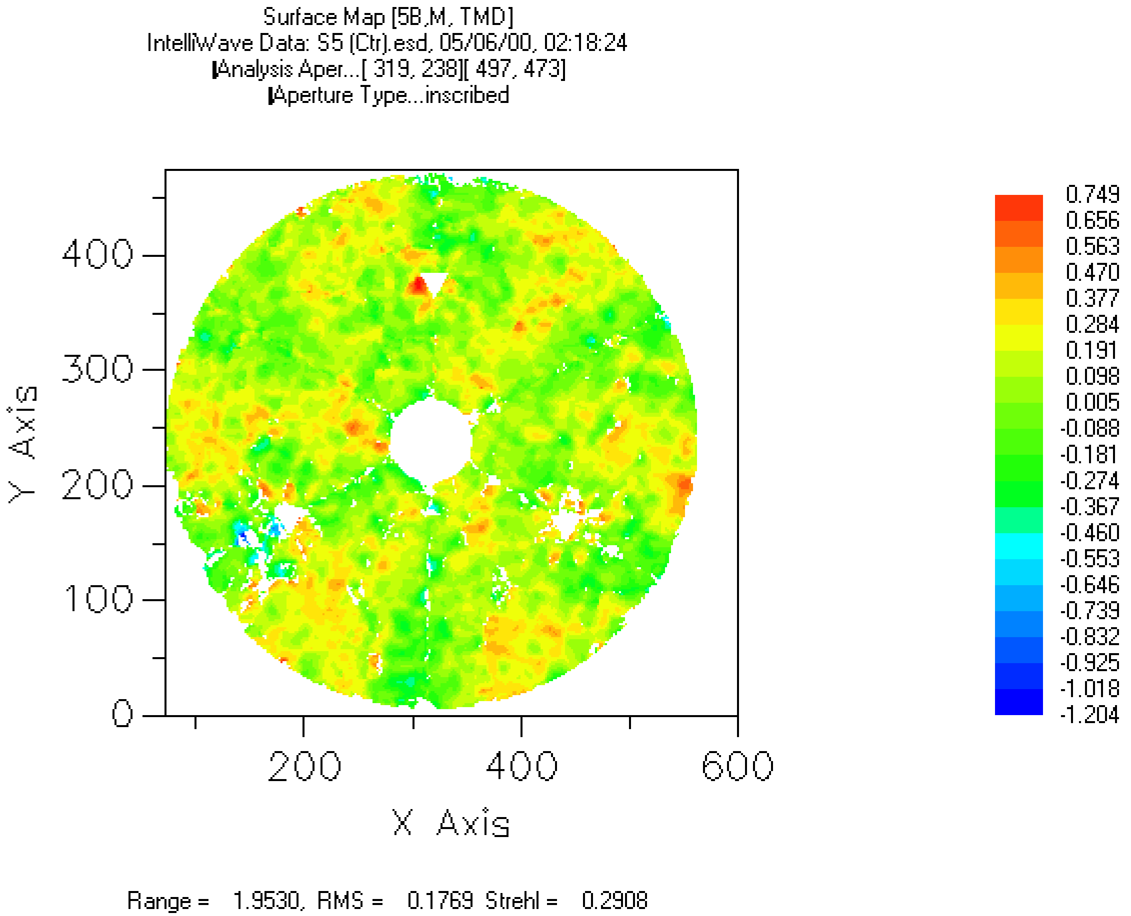
- **293K to 70K Delta**
  - **Low Order**



Piston	1.0000
Tilt	0.0000
Tilt	0.0000
Focus	0.0000
Astigmatism	-0.1476
Astigmatism	-0.6019
Coma	-0.0816
Coma	-0.0726
Spherical	-0.3565
Coma	-0.0516
Coma	-0.1534
Astigmatism	0.1245
Astigmatism	0.1671
Coma	0.0570
Coma	0.0365
Spherical	0.1997
Astigmatism	-0.1306
Astigmatism	-0.0805
Coma	-0.0341
Coma	-0.0033
Astigmatism	-0.0277
Astigmatism	-0.0137
Coma	-0.0707
Coma	-0.0107
Spherical	-0.0011
Coma	0.0376
Coma	0.0852
Astigmatism	0.0877
Astigmatism	0.0964
Coma	-0.0410
Coma	-0.0613
Astigmatism	0.0413
Astigmatism	0.0120
Coma	0.0505
Coma	0.0045
Spherical	0.0315

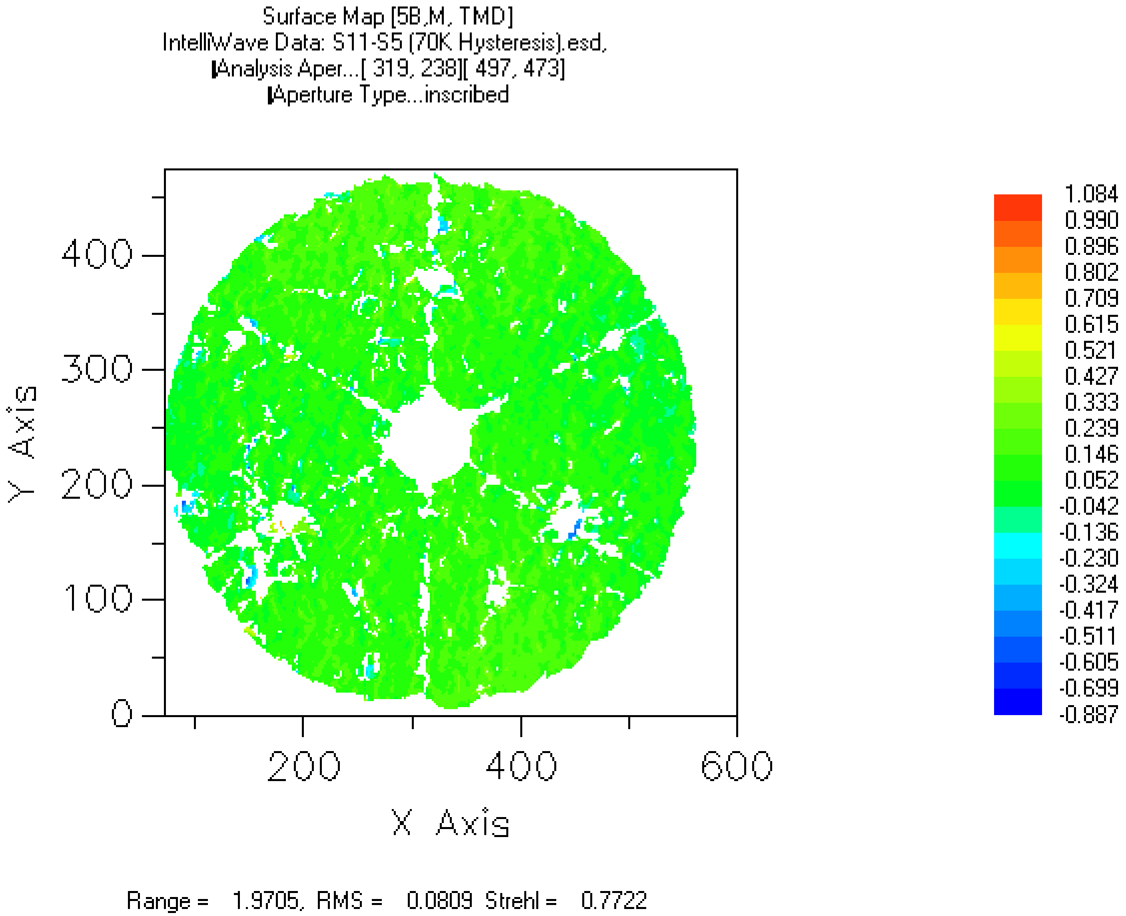
Delta Figure (Residual terms)

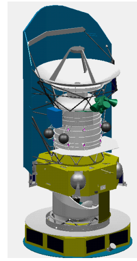
- **293K to 70K Delta**
  - **Residual**



Delta Figure (Hysteresis)

- **70 K Hysteresis**
  - **Full Surface**





4.2 HIFI Status

T. de Graauw Groningen

HIFI STATUS 23-5-2000

Thijs de Graauw
(thijsdg@sron.rug.nl)

Overview:

- Introduction
- Science Capabilities
- Consortium/Team – Management
- Instrument Design
- Instrument Development, Deliverables, Models
- Critical Areas

Introduction

Status (I)

- HIFI ready to pass Delta-ISVR: close-out meeting on 25 May
- Technical development is well underway. Most critical area (LO) funded only since January 2000!
- Detailed planning and costing almost completed
- JPL budget and HIFI schedule constraints required a de-scope:
  - Aluminum Technology for Hot Electron Bolometers in HIFI bands 6 and 7 not feasible. Too slow progress in development, although Proof of Concept.
    - ➢ Niobium Technology HEBs are now baseline (NbN as back-up)
    - ➢ Direct impact is that more LO power is required at higher frequencies
    - ➢ No HIFI-internal cooler required anymore
  - Band 7 multipliers are not possible due to cost constraints at NASA-JPL
    - ➢ Band 7 LO was technically the most challenging
    - ➢ Loss of science capabilities identified (still compliant with the FSEC)
    - ➢ Real estate of band 7 mixer and LO assembly will be used for band 6 to ensure optimum capability in this frequency range

Status (II)

- Open procurement issues to be closed soon:
  - Canadian involvement in LO Source Unit (25 May 2000)
  - WBS-IF procurement solution identified
- NASA-JPL delivery/performance uncertainties under study:
  - NASA PDR reviews in June-September period
- Outcome may require further re-scoping HIFI to maintain science capabilities
  - Back-up solutions and close-out schedule identified (July/Sept 2000)
  - Work in progress
  - No negative impact on interfaces to satellite, schedule, and design foreseen
  - Close contact with FIRST/Planck project and project scientist on these issues exists.

Science Capabilities:

- Requirements
- Instrument Capabilities
- Main Science Drivers
- SURD table

Science Capabilities

HIFI top level requirements (new)

- Frequency coverage:
  - 480 – 1250 GHz (625-240 µm)
  - 1410 – 1910 GHz (212-157 µm)
- Near-quantum noise limit sensitivity (goal $<3h\nu/k$)
- Instantaneous IF bandwidth: 4 GHz
- Frequency Resolution 140 kHz – 280 kHz – 1 MHz
- Calibration Accuracy: 10% baseline; 3% goal

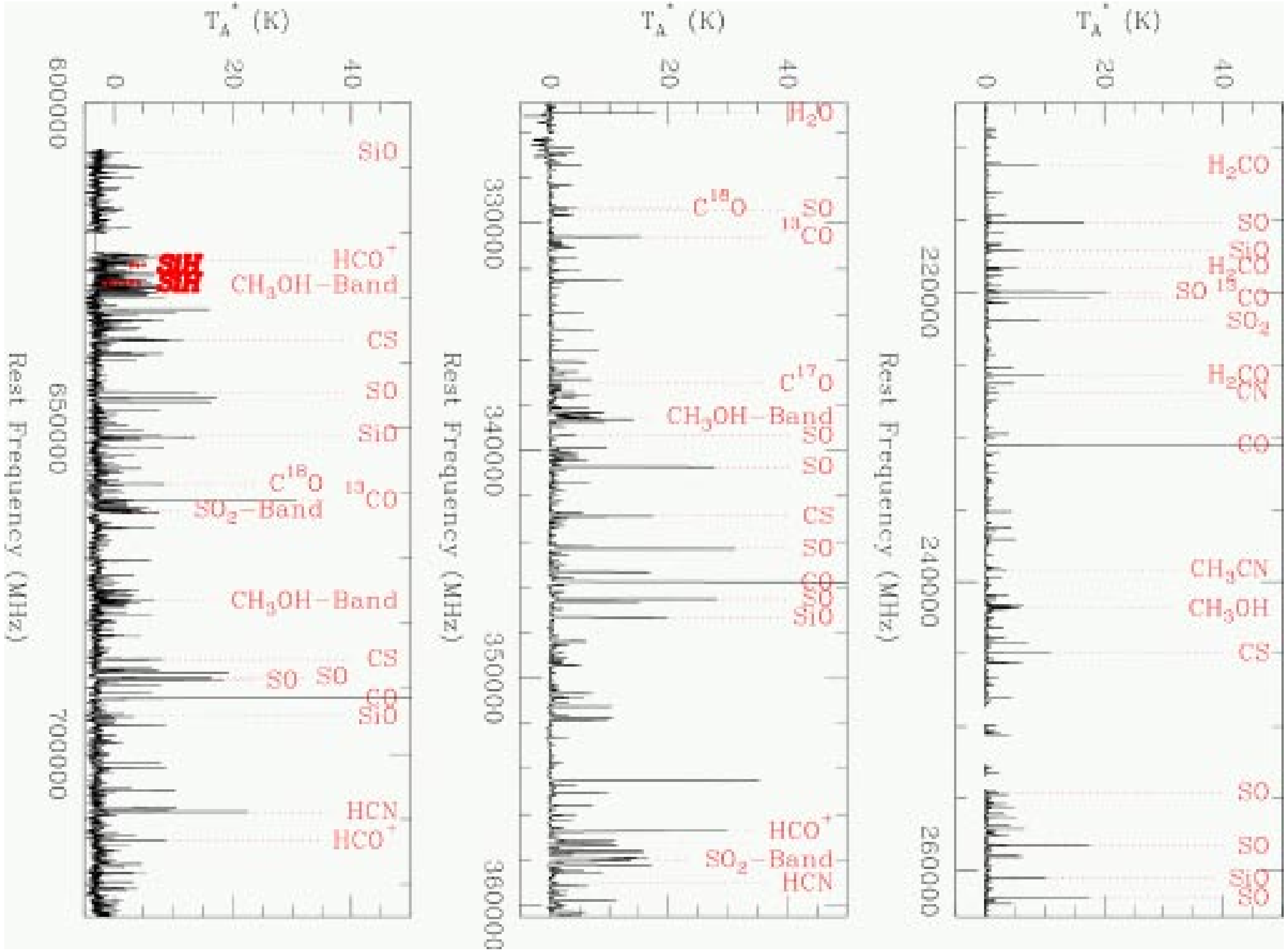
HIFI Instrument Capabilities

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

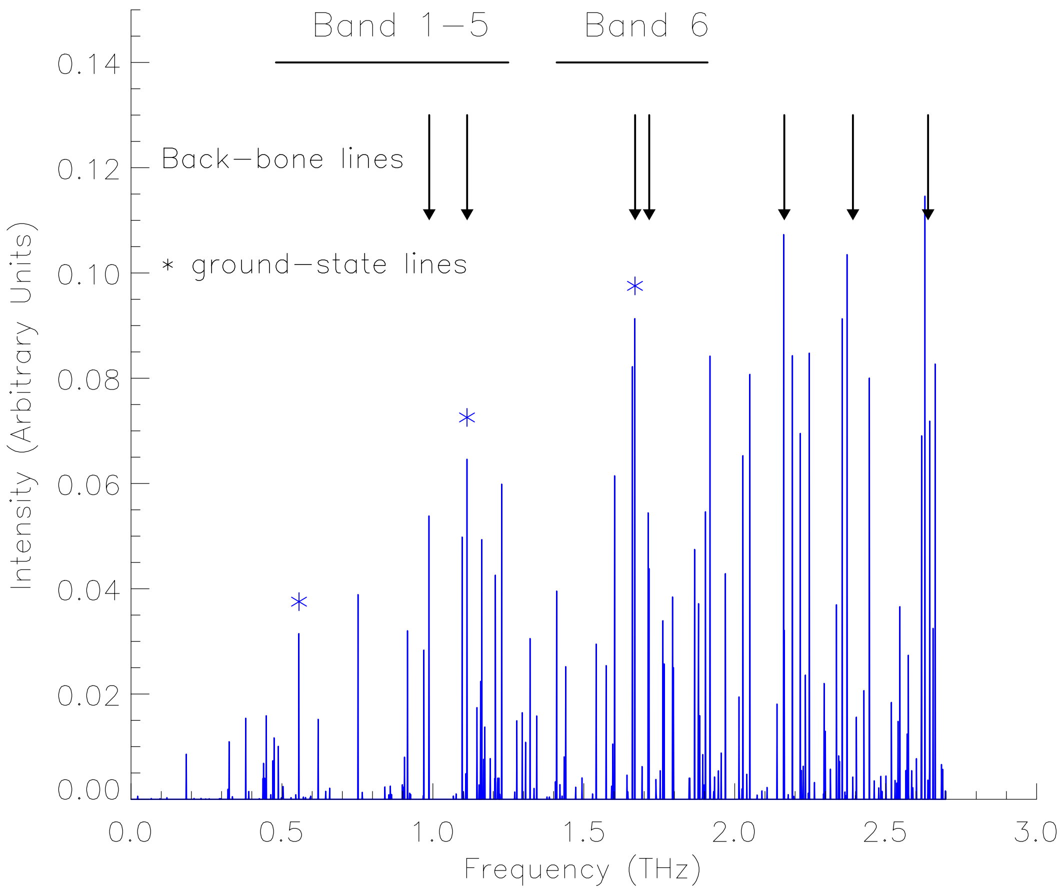
Science Capabilities

I. HIFI: Submm Spectral Survey Machine

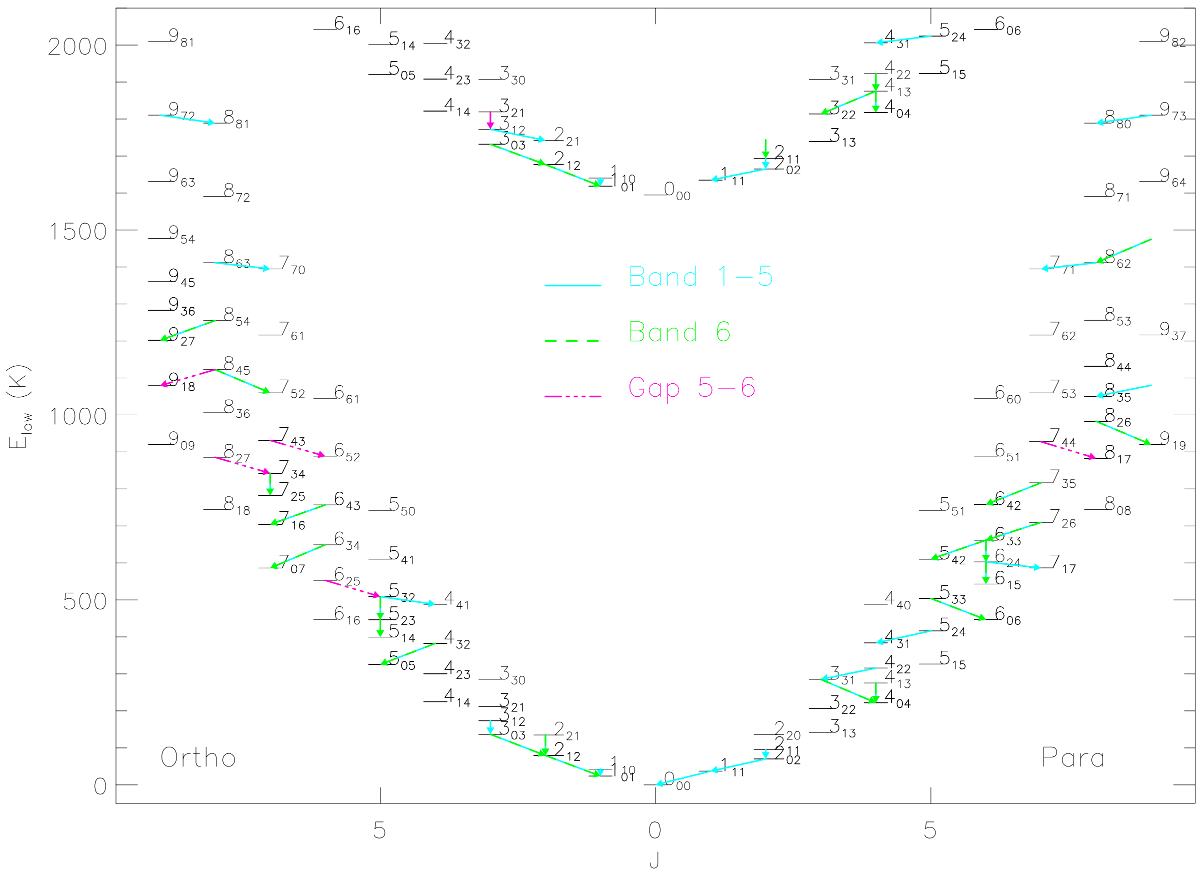
CSO Spectral survey of Orion



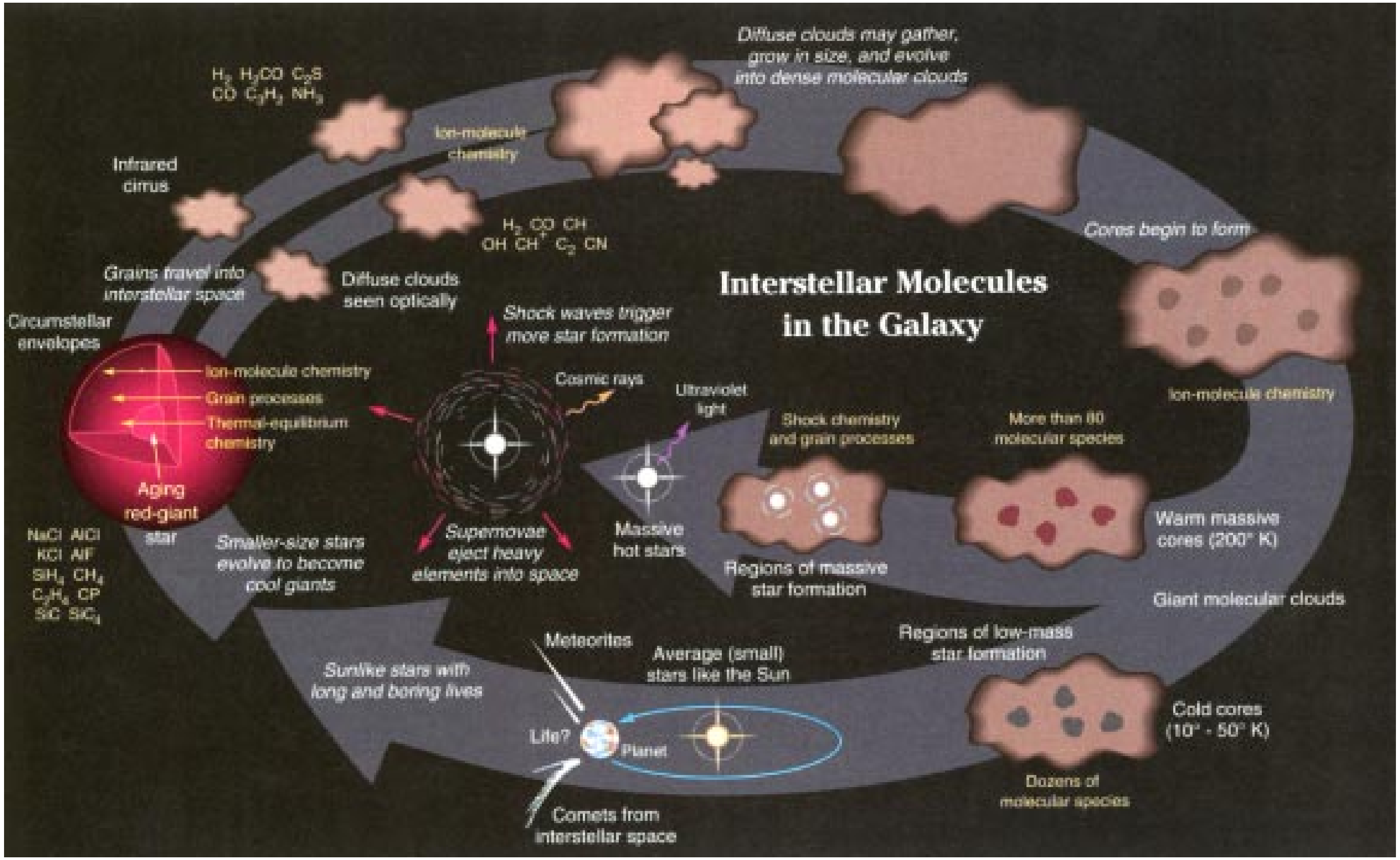
II. Thermal Water Spectrum



Energy Level Diagram of Water



III. Lifecycle of Stars, Planetary Systems and Interstellar Matter



HIFI Science Drivers (SURD)

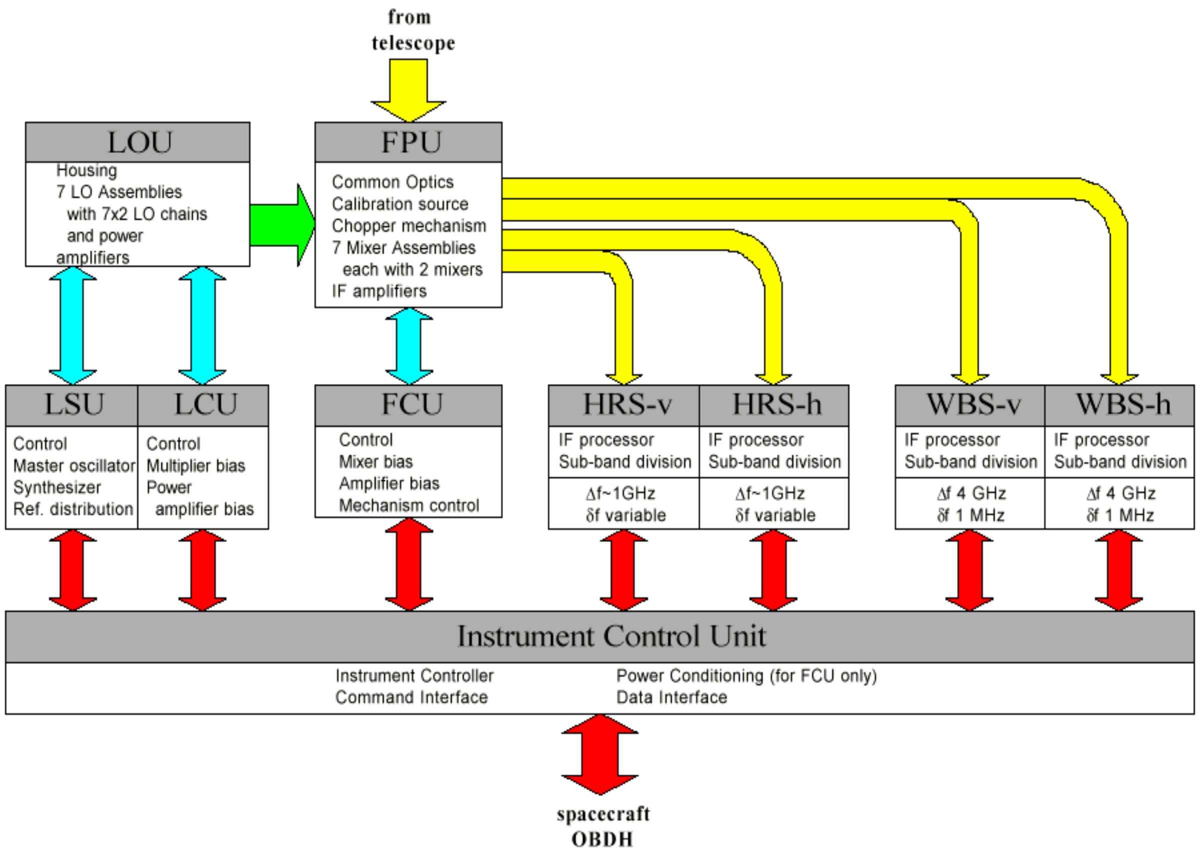
UNIQUE + CORE		HIFI Bands					
		1	2	3	4	5	6
	Science Drivers	(480-640)	(640-800)	(800-960)	(960-1120)	(1120-1250)	(1410-1910)
	(A) Water	**X-H-S**			**X-H-S**	**X-S**	**X-S**
	(B) Molec. Universe	**X**	**X**	**X**	**X**	**X**	**X**
	(C) [C II] at (high) z	**X-S**	**X-S**	**X-S**	**X-S**	**X-S**	**X-S**
	(D) ISM in Galaxies	**X**	**X**	**X**	**X**	**X**	**X**
	(E) Diffuse ISM	**X-H**		**X-H**	**X**		**X-S**
	Star Formation	**X**	**X**	**X**	**X**	**X**	**X**
	Death of Stars	**X**	**X**	**X**	**X**	**X**	**X**
	(F) SSO: Comets	**X-H**		**X-H**	**X-H**		
	SSO: Planets	**X**	**X**		**X**	**X**	**X**

Consortium/Team – Management:

- Organigramme

- Involved Institutes

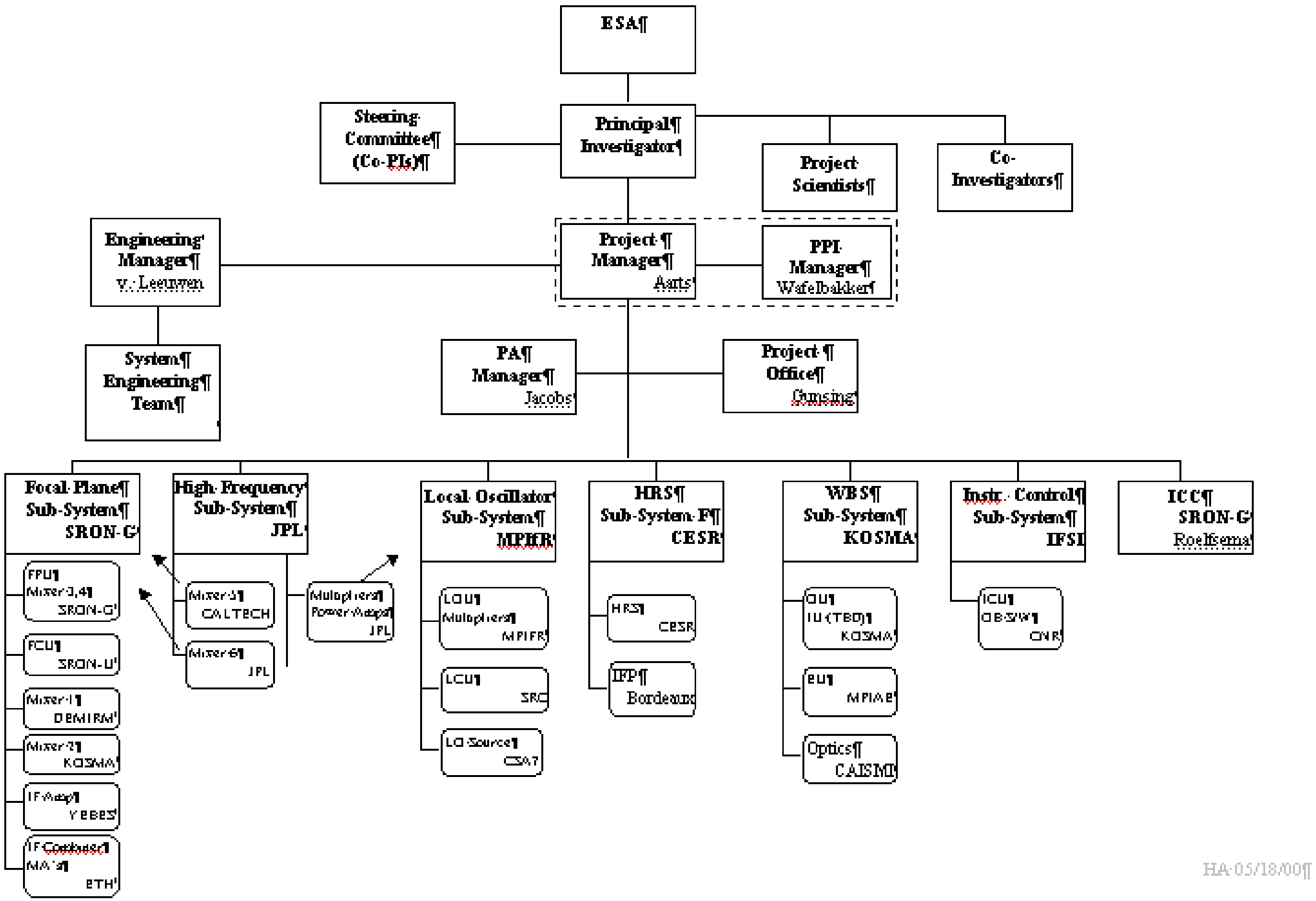
Organisation follows Main Configuration Items



Instrument Block Diagram

Consortium/Team – Management

HIFI Organigram



Consortium/Team – Management

Countries and Institutes participating in the hardware

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/OAN	**Sweden:** Onsala/Chalmers TH, Göteborg
Switzerland: ETH, Zürich	**Canada:** CSA (tbc)
With contributions from Taiwan and MRAO in the development	

Instrument Design:

- Design Status
- FPU
- LO
- HRS
- WBS

HIFI Design Completion Status

	Prototype Hardware	Conceptual Design	D/QM Design	Detailed Design
FP S/S – FPU		X	X	
FP S/S – FCU		X	X	
LO S/S – LOU		X		
LO S/S – LSU		X		
LO S/S – LCU		X		
WBS	X	X		
HRS	X	X		
ICU		X	X	

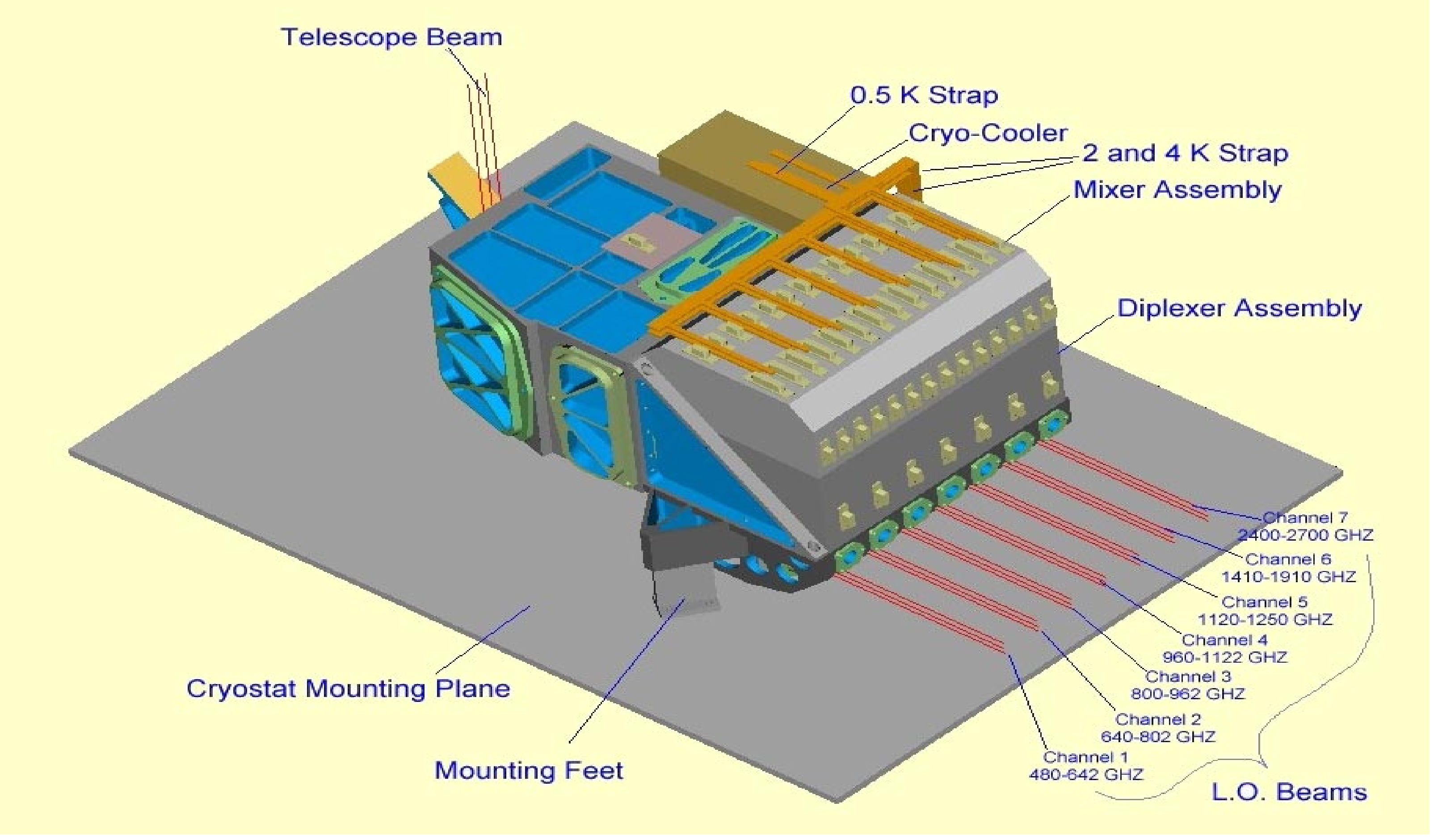
Conceptual Design: Interfaces, Budgets

D/QM Design: Detailed Configuration

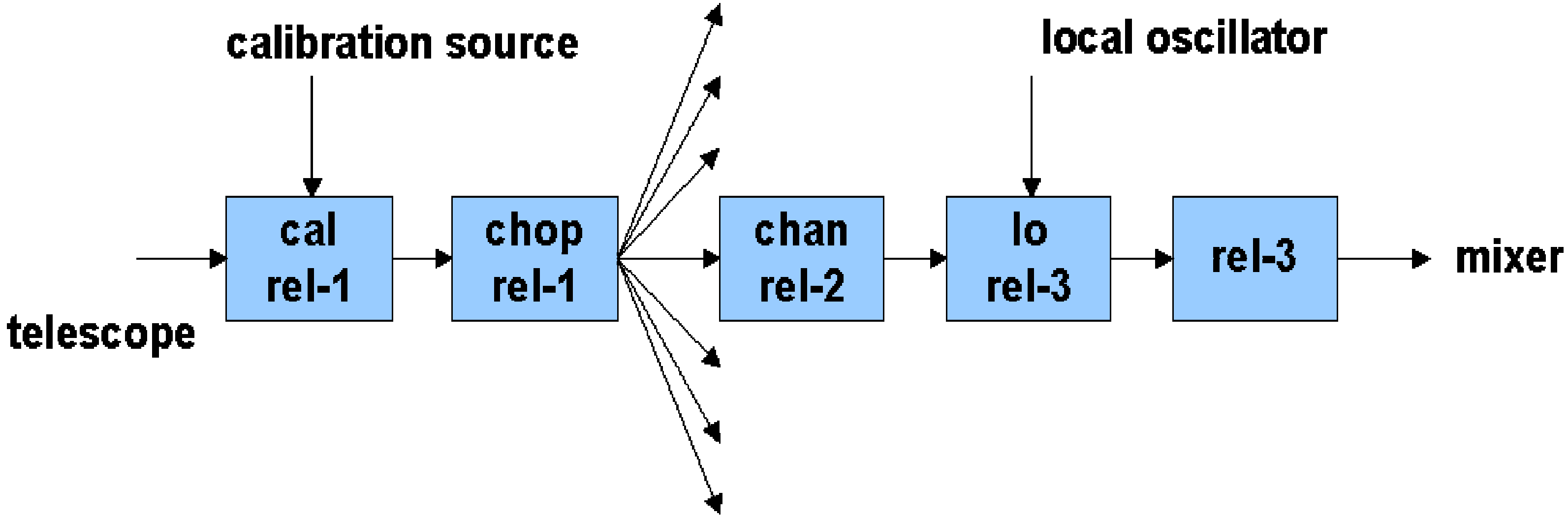
Detailed Design: Production Drawings

Instrument Design

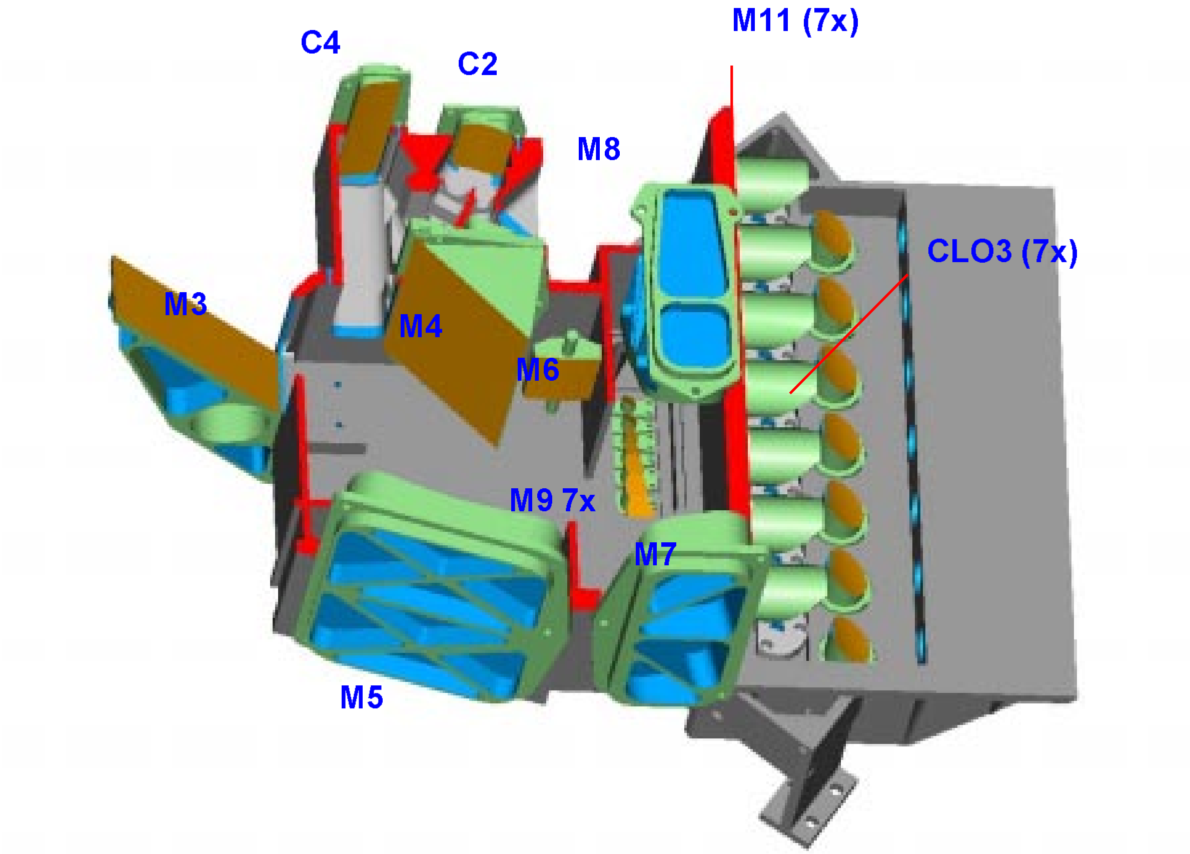
Focal Plane Unit Lay-out



HIFI Functional Block Diagram

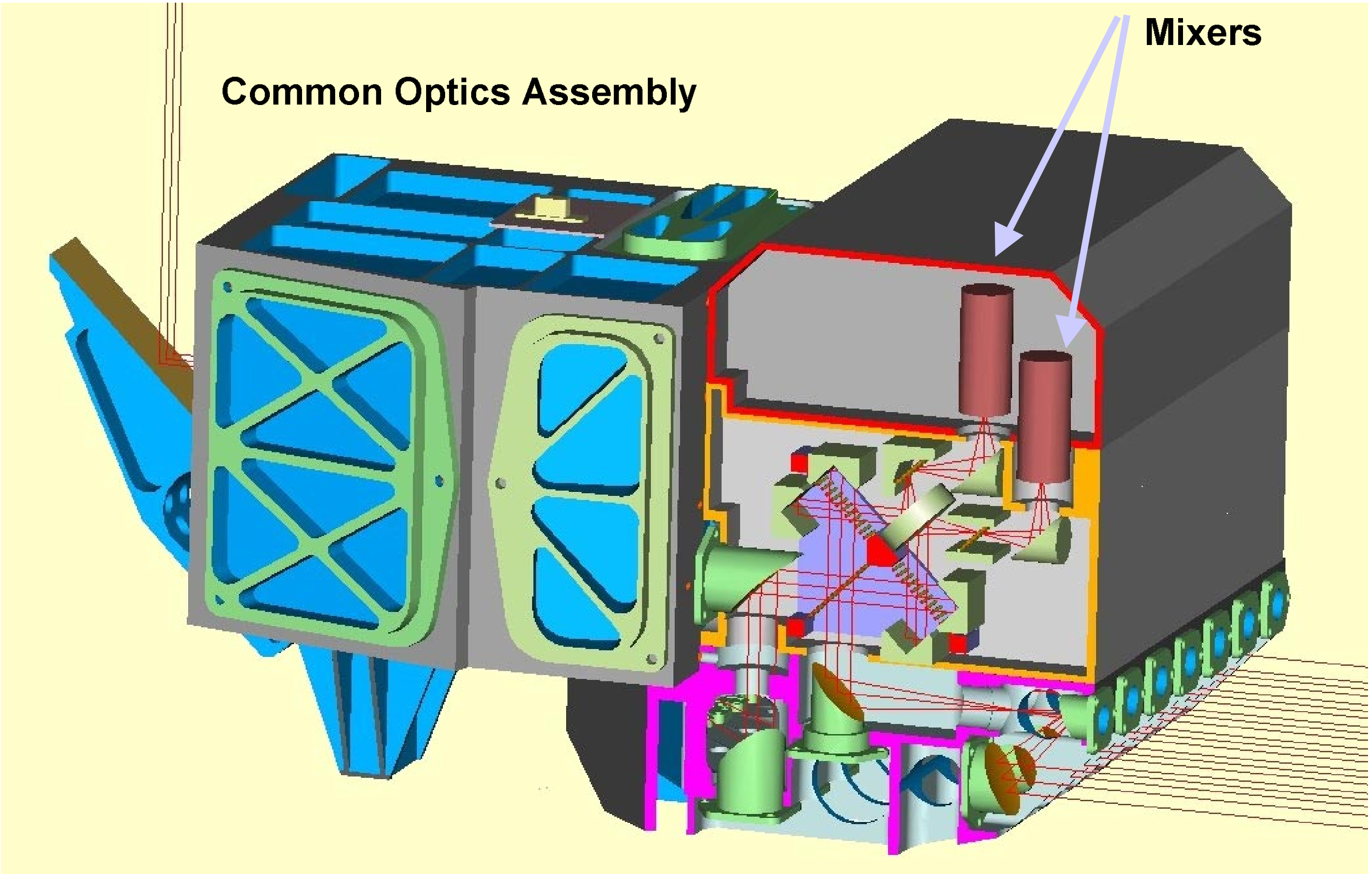


Common Optics Assembly Lay-Out

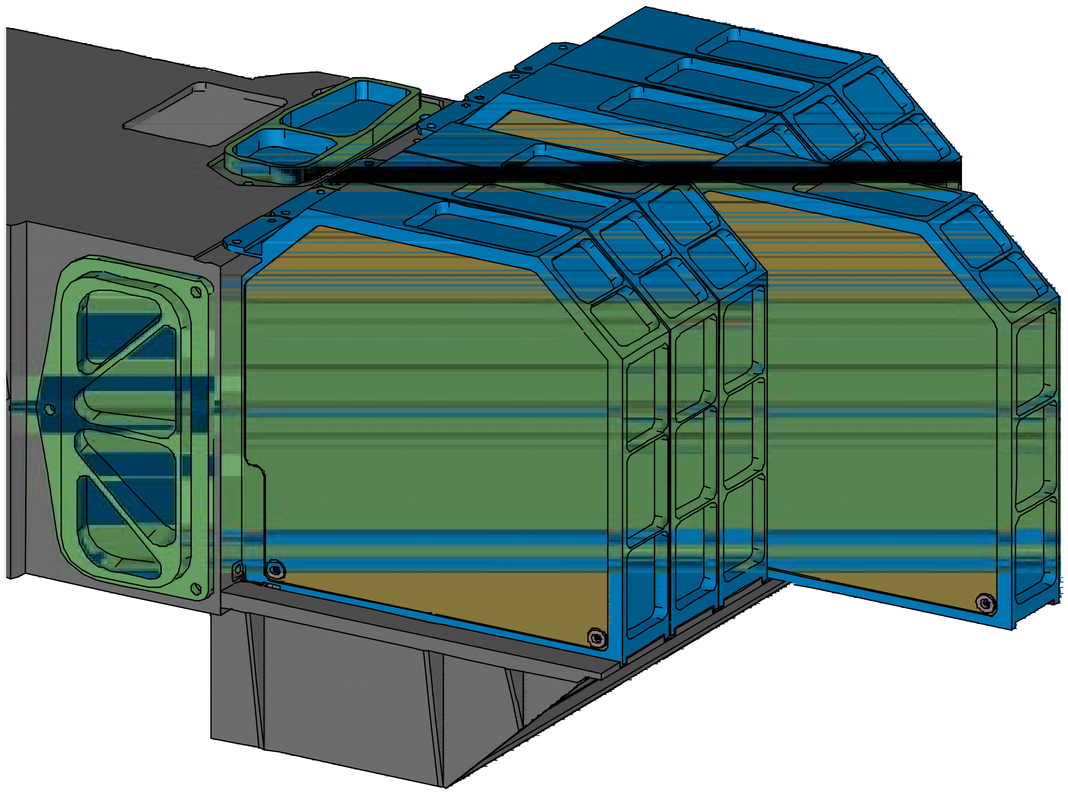


Instrument Design

Mixer Assembly Lay-out



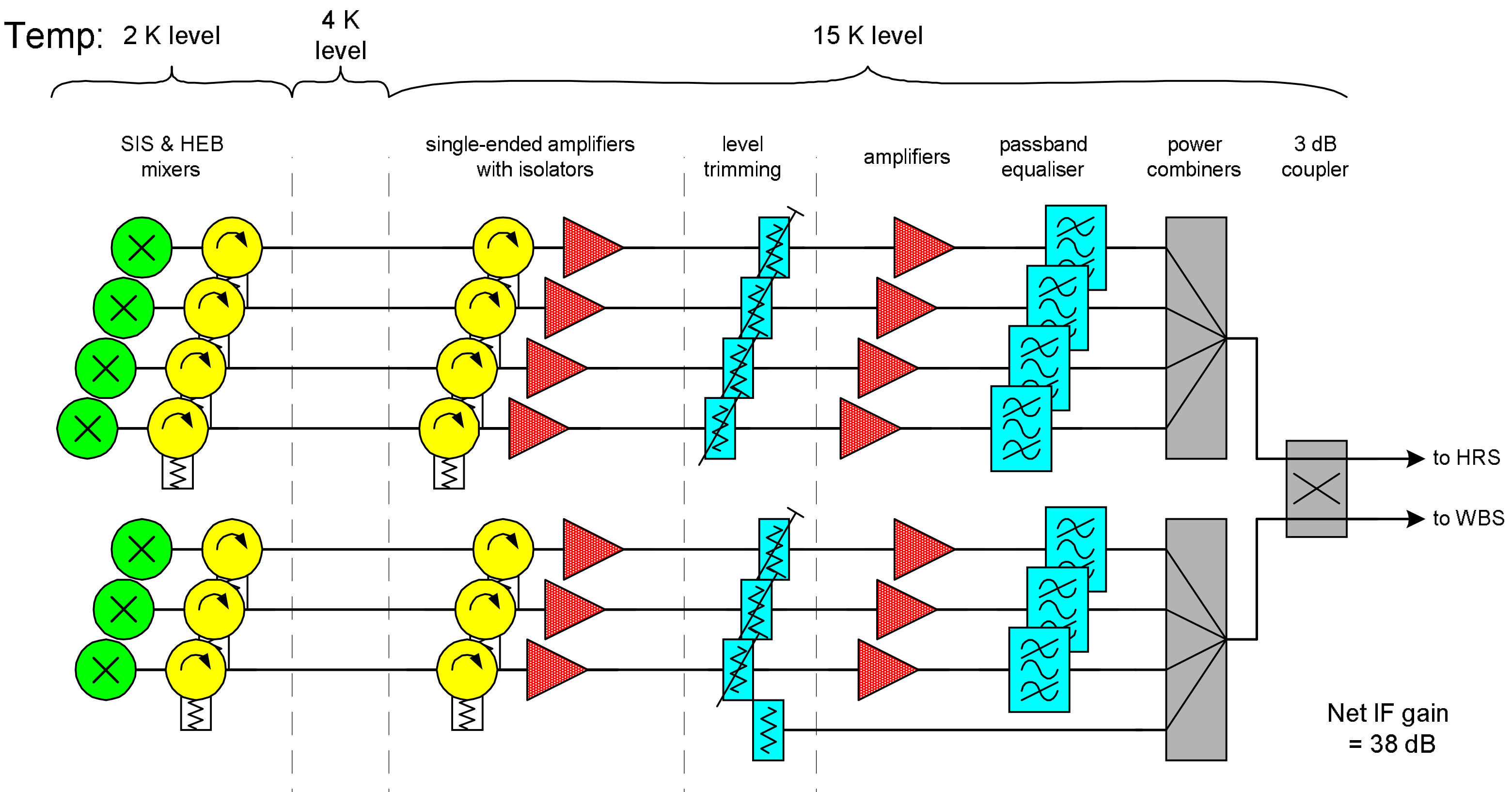
Mixer Assembly Boxes Mounting to Structure



Engineering model of the mixer console, mounted on liquid nitrogen cooled vibration test set-up

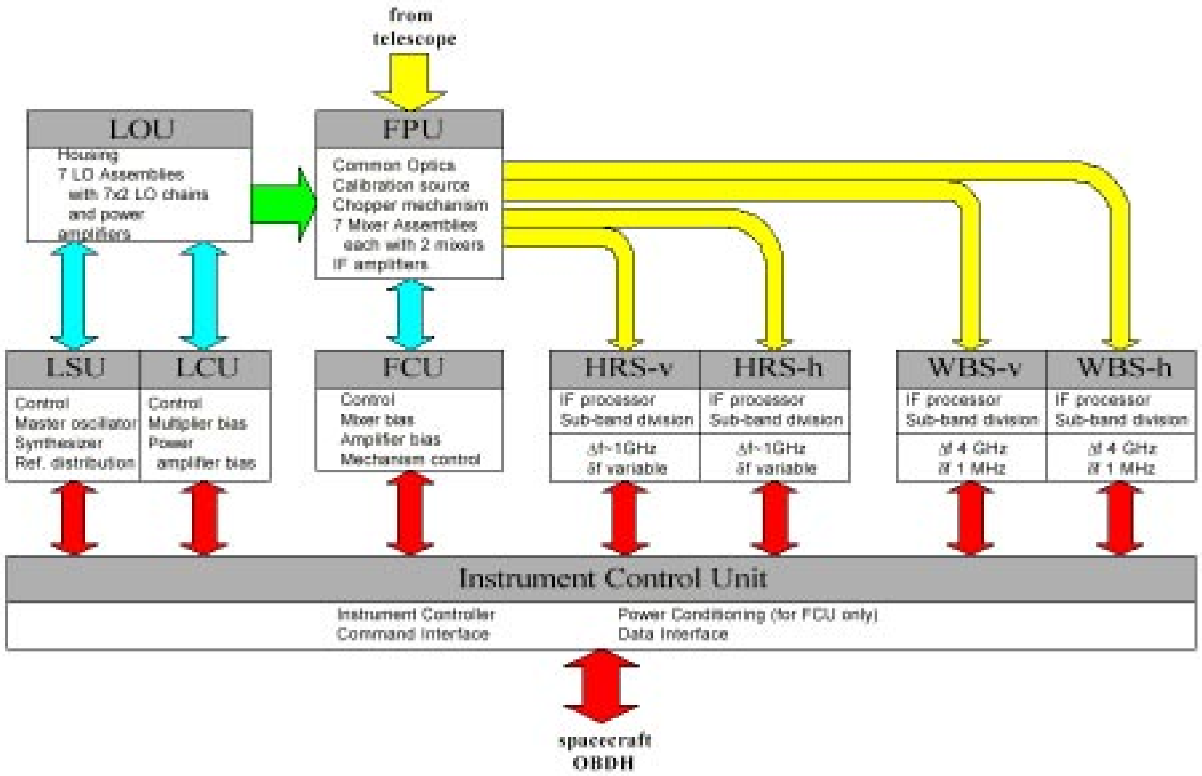
Instrument Design

IF pre-amplification scheme for one polarization

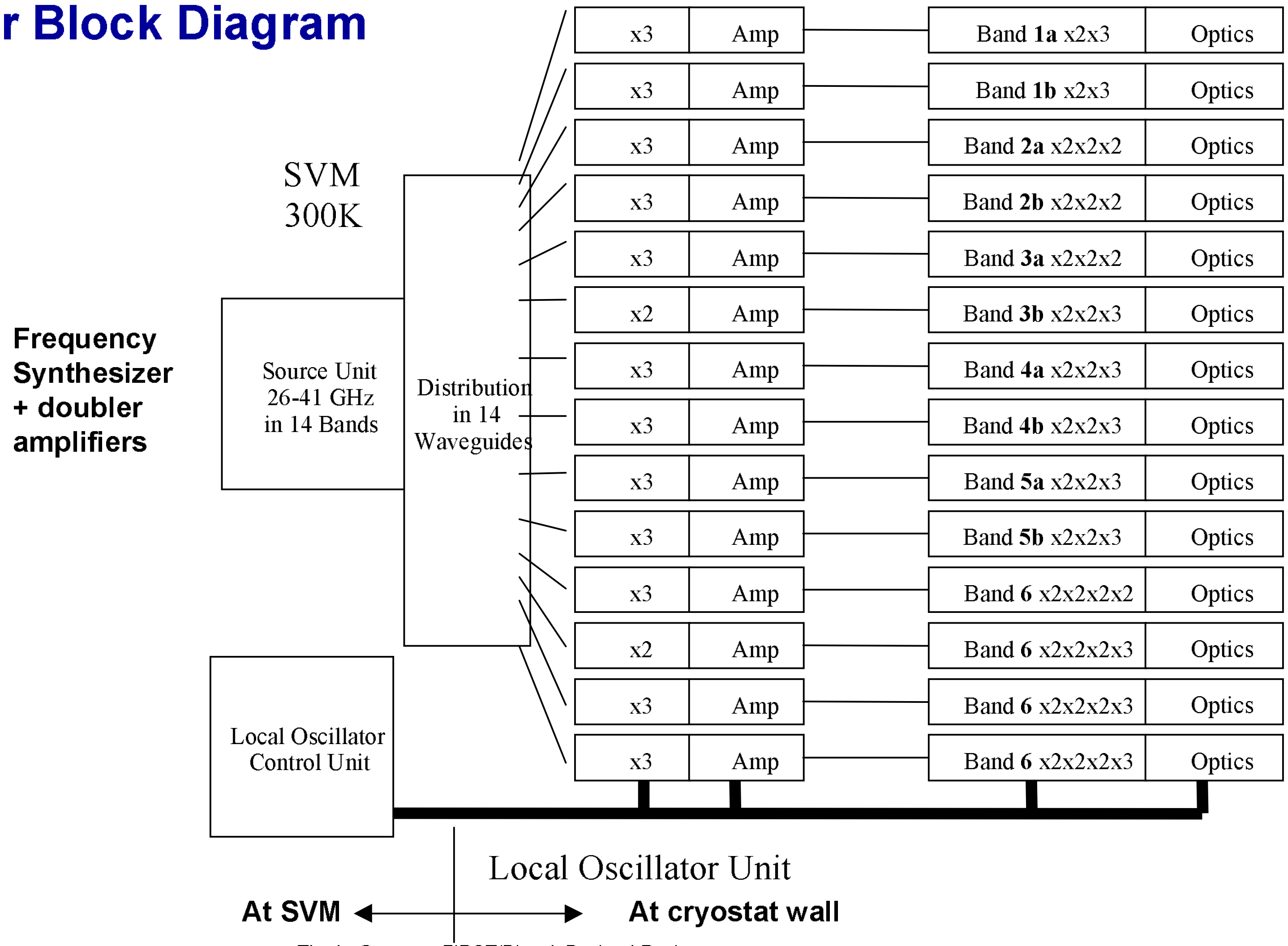


IF gain:	n/a	22 dB	-3 dB	32 dB	-3 dB	-6.5 dB	-3.5 dB
location:	MA	MA	COA		COA		
procured by:	SRON	Spain	SRON		Switzerland		

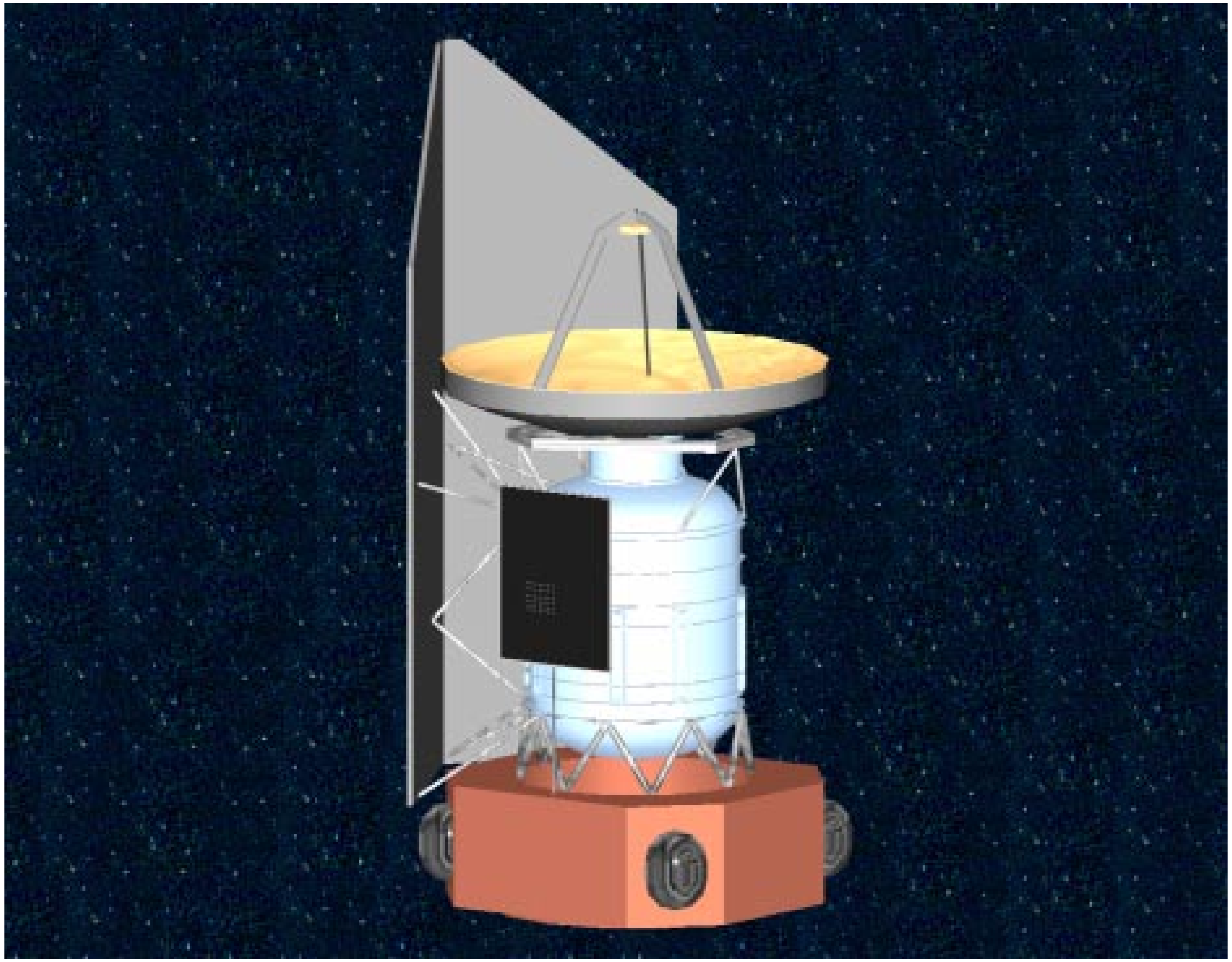
Instrument Block Diagram



Local Oscillator Block Diagram

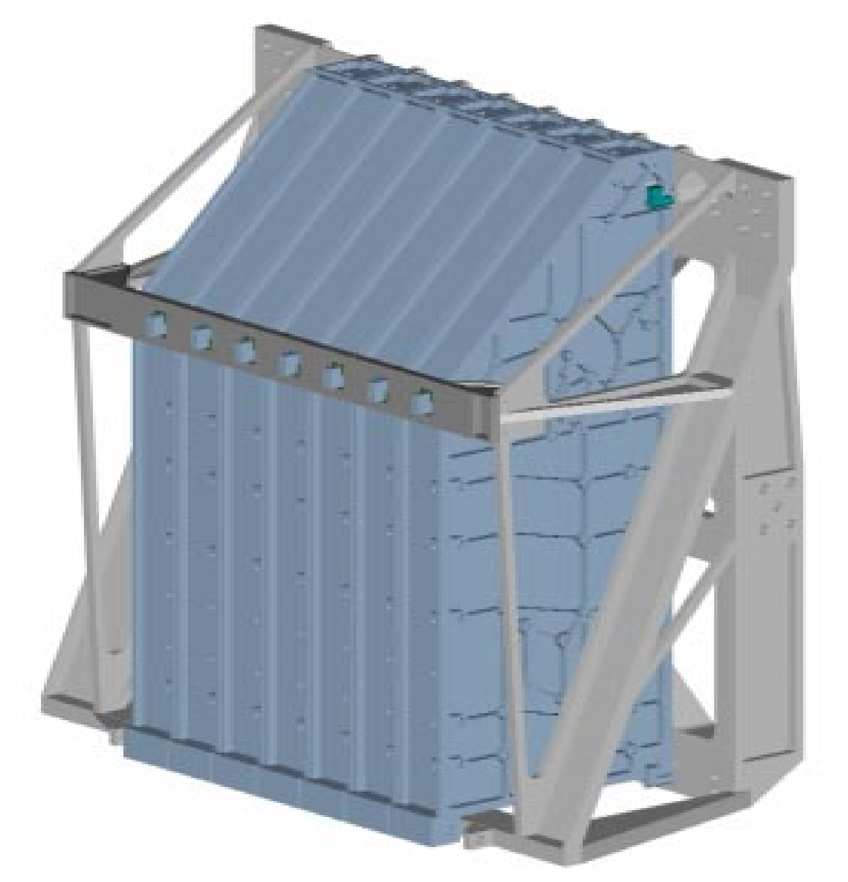


Location LOU

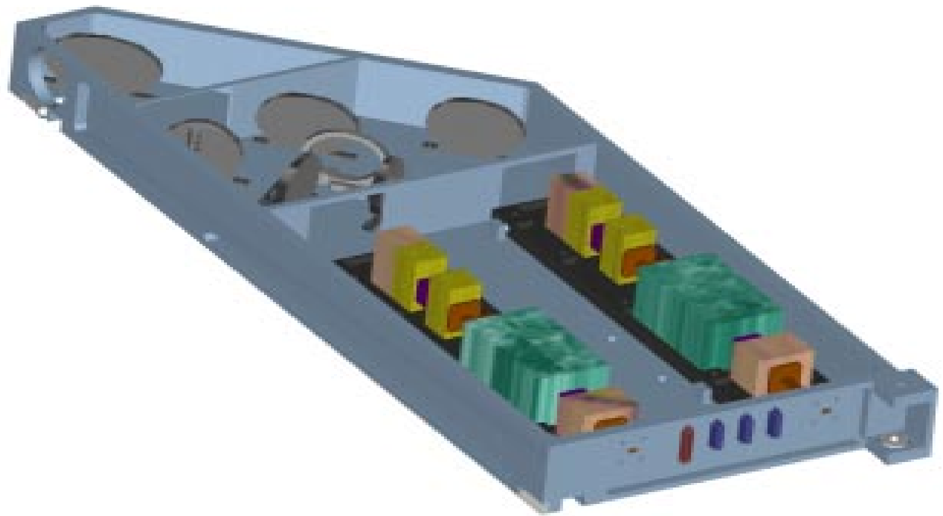


LO Design

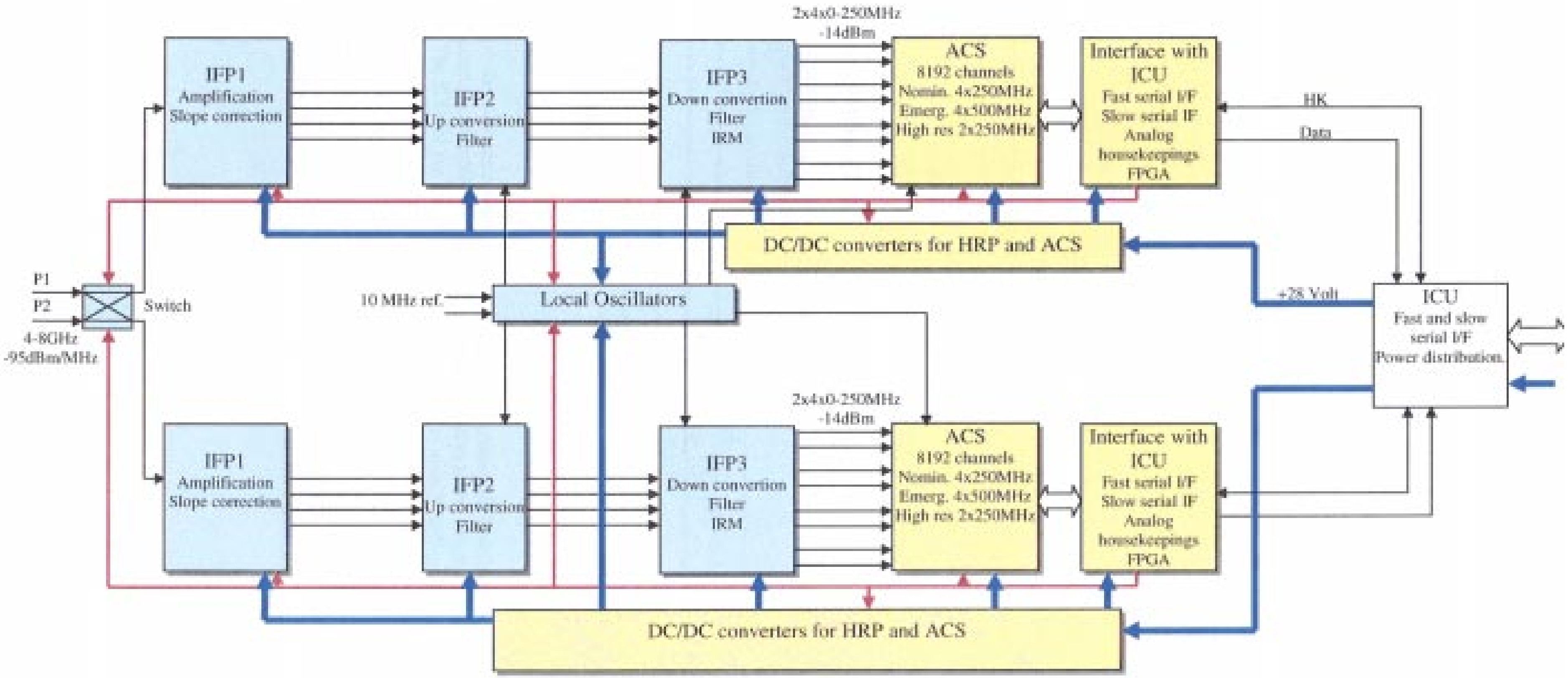
LOU with LO Assemblies



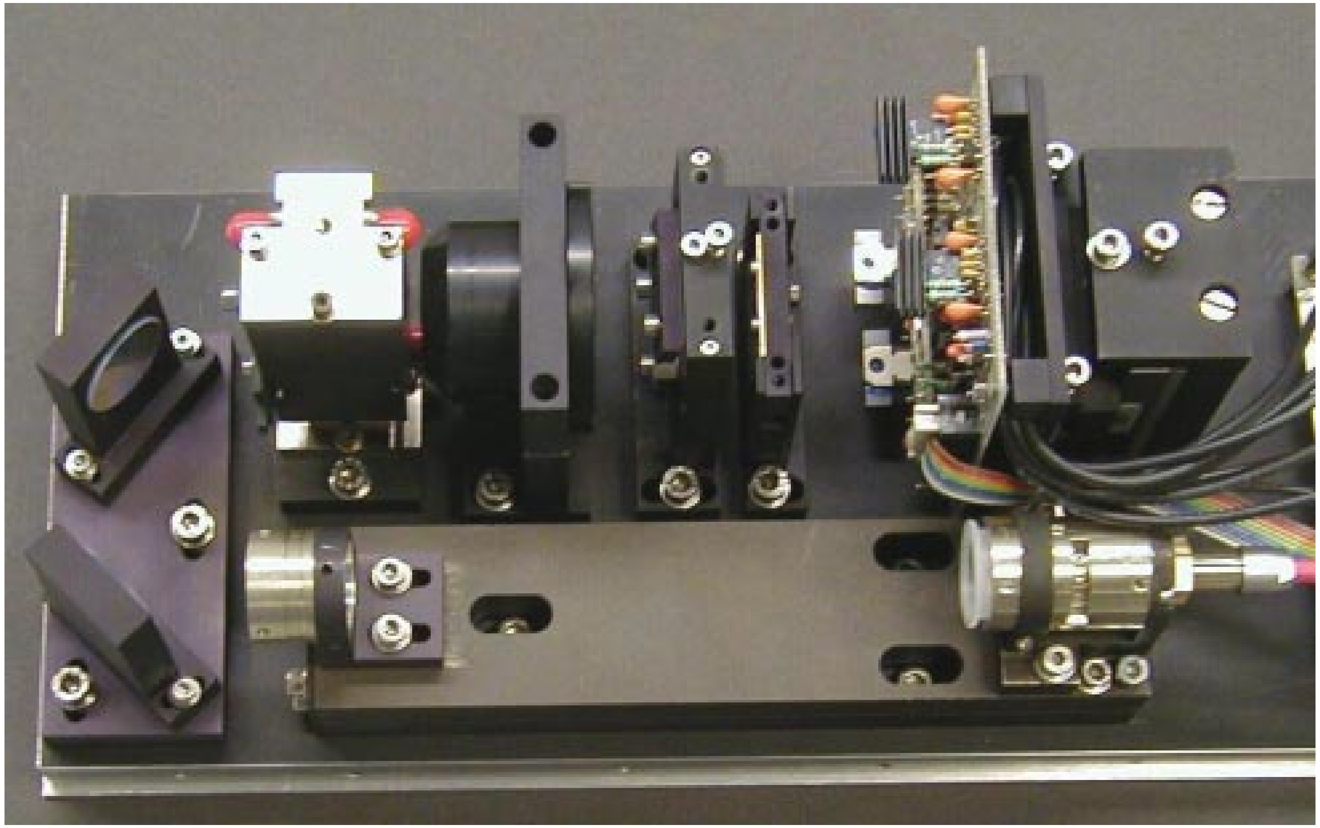
LO Assembly with two Multiplier Chains



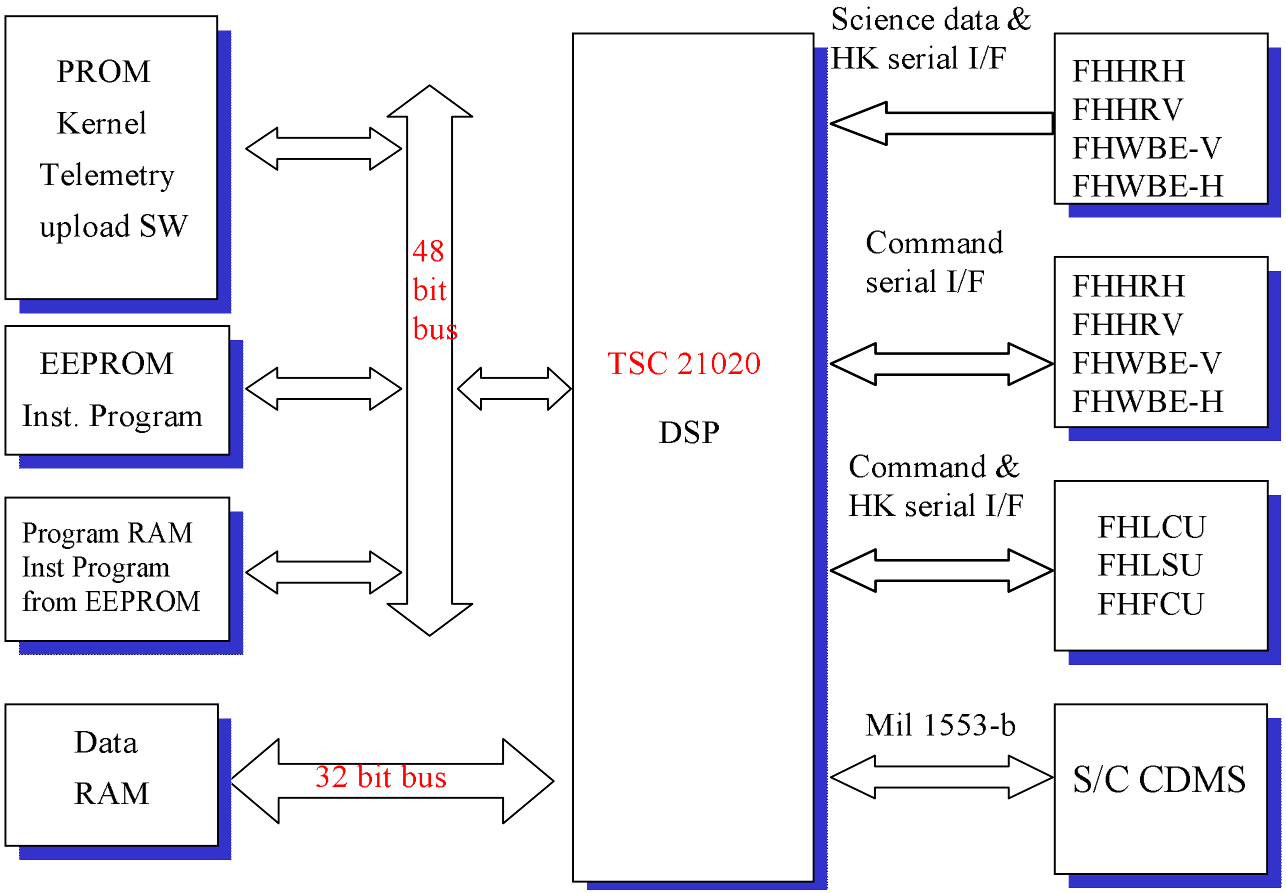
HRS diagram


2x4x0-250MHz
-14dBm
IFP1
Amplification
Slope correction
IFP2
Up conversion
Filter
IFP3
Down convertion
Filter
IRM
ACS
8192 channels
Nomin. 4x250MHz
Emerg. 4x500MHz
High res 2x250MHz
Interface with
ICU
Fast serial I/F
Slow serial IF
Analog
housekeepings
FPGA
HK
Data
DC/DC converters for HRP and ACS
P1
P2
4-8GHz
-95dBm/MHz
Switch
10 MHz ref.
Local Oscillators
+28 Volt
ICU
Fast and slow
serial I/F
Power distribution
2x4x0-250MHz
-14dBm
IFP1
Amplification
Slope correction
IFP2
Up conversion
Filter
IFP3
Down convertion
Filter
IRM
ACS
8192 channels
Nomin. 4x250MHz
Emerg. 4x500MHz
High res 2x250MHz
Interface with
ICU
Fast serial I/F
Slow serial IF
Analog
housekeepings
FPGA
DC/DC converters for HRP and ACS

DM version of the WBS optics unit



ICU is Common Development with PACS and SPIRE
(ICU Architecture shown below)



Instrument Development, Deliverables, Models

- Performance Critical Items Addressed Here:
  - Mixers
  - LO multipliers
  - Technology roadmaps

- Models

- Planning and Schedule

Mixer Technology Development Issues:

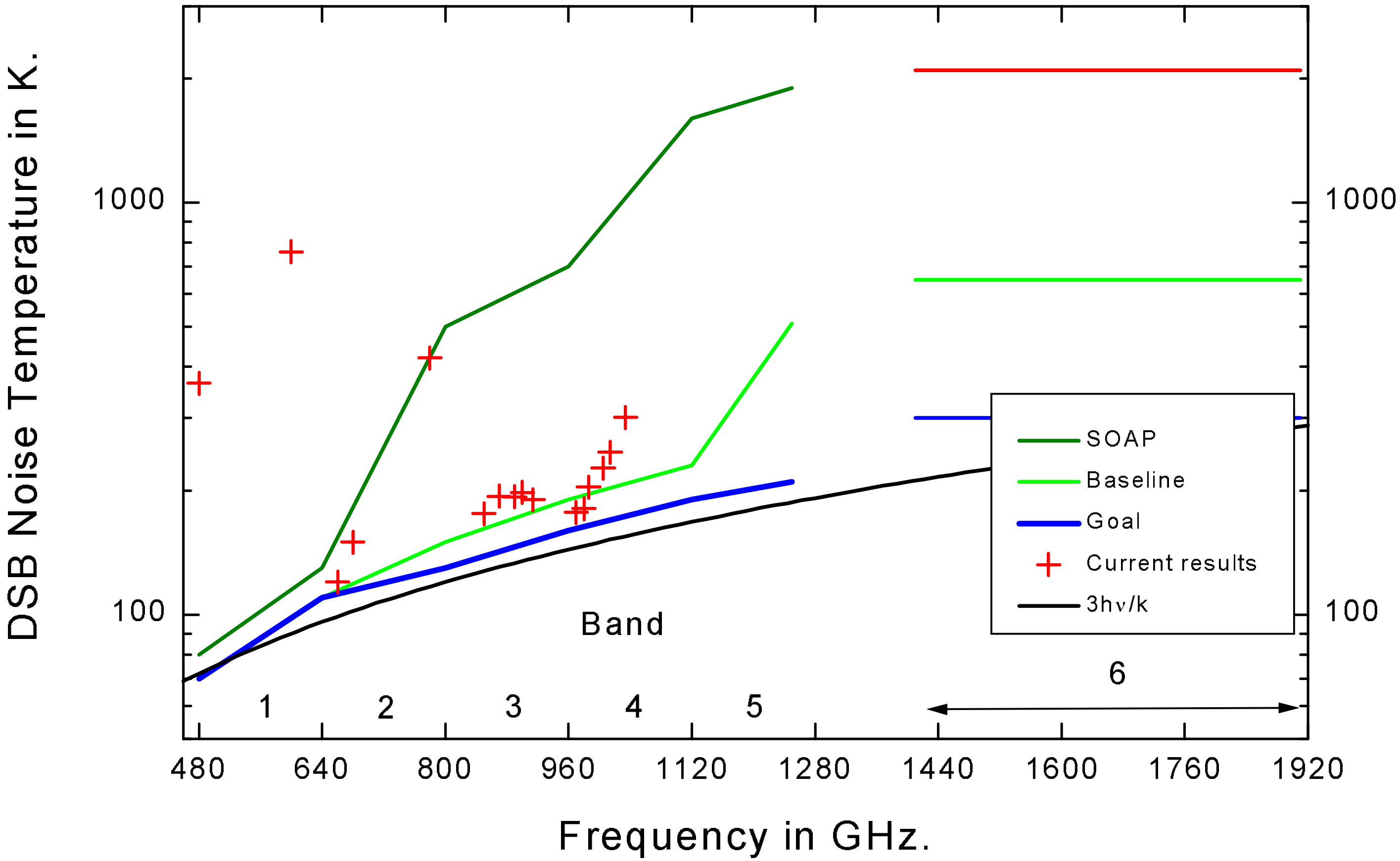
	Challenge	RF coupling,Detector	Device,Layer Technology		
Band			SOAP	Baseline	Goal
1	RF Bandwidt	WG,Horn	Nb SIS,Nb	Nb SIS,Nb	Nb/Al SIS,Nb
2	RF Bandwidth,Sensitivity	WG,Horn	Nb SIS,Nb	Nb SIS,NbTiN/Al	Nb/Al SIS,NbTiN
3	Sensitivity	WG,Horn	Nb SIS,Al	Nb SIS,NbTiN/Al	Nb/Al SIS,NbTiN/Al
4	Sensitivity,Layer Technology	WG,Horn	Nb SIS,Al	Nb SIS,NbTiN/Al	Nb/AlN/NbTiN SIS,NbTiN/Al
5	Sensitivity,Layer Technology,Device Fabrication	QO,Planar Antenna	Nb HEB	Nb HEB	
6	Sensitivity,Device Fabrication,IF Bandwidth	QO,Planar Antenna	Nb HEB	Nb HEB	

Mixer Technology Road Map Bands 3 and 4

	Demonstration Model	Qualification Model/Flight Model
Performance Requirements:		
Bandwidth	800-962 and 960-1122	800-962 and 960-1122 (flat within 1 dB)
Sensitivity	200-700 K @960 GHz	Baseline=190 K, Goal = 160 K @ 960 GHz

Fall Back	Bottom Top Wire Junction Definition	Al Al AlOx optical	Bottom Top Wire Junction Definition	Fgap>=1200 Low res Al AlOx optical
Baseline	Bottom Top Wire Junction Definition	Fgap>=1200 Low res Al AlOx optical	Bottom Top Wire Junction Definition	Fgap>=1200 Low res Al Fgap>=1200 High Jc AlNx or AlOx E-beam and e-beam
Goal	Bottom Top Wire Junction Definition	Fgap>=1200 Low res Al Fgap>=1200 High Jc AlNx or AlOx E-beam and e-beam	Bottom Top Wire Junction Definition	Fgap >=1200 Fgap >=1200 High Jc AlNx or NbTiN/AlN/NbTiN E-beam

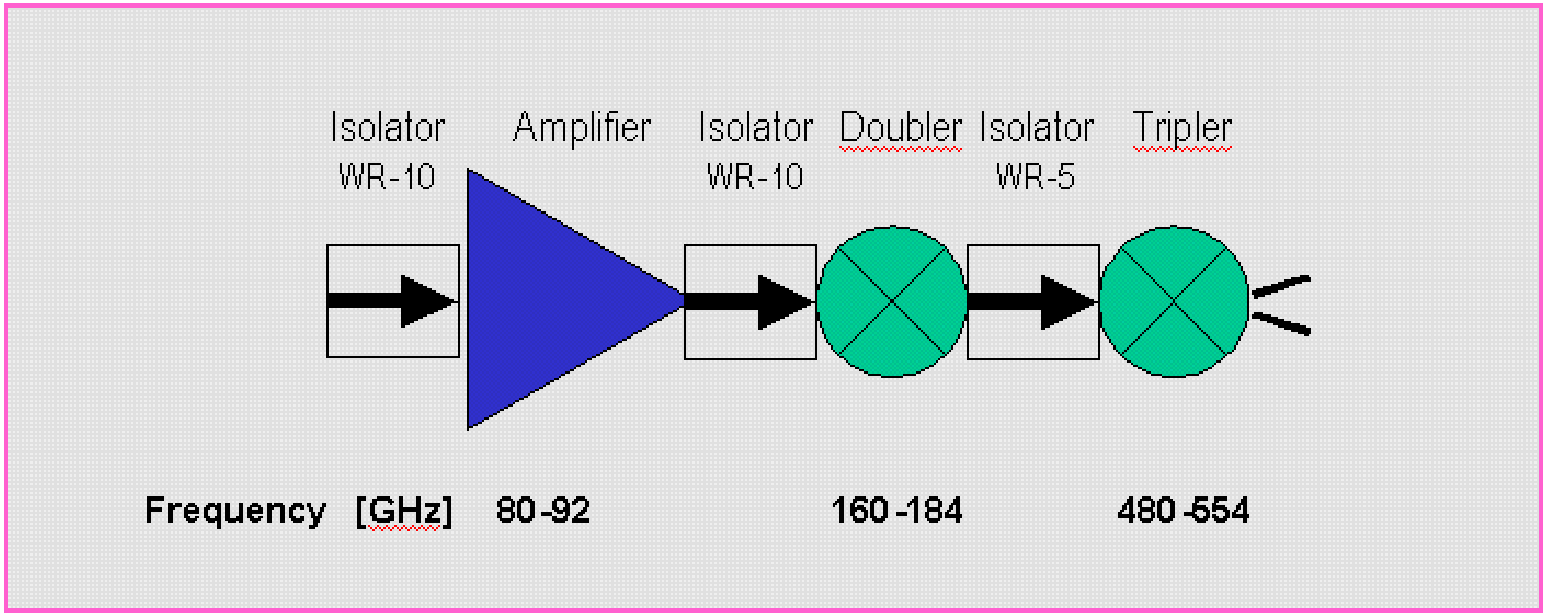
Mixer Noise Temperatures: Requirements and Recent Results



LO Multiplier Development Scheme in GHz

Power Amplifiers		A	B	C	D
Multiplication Scheme		71-79	80-92	88-99	92-106
2	**x2**	142-158	160-184	176-198	184-212
4	2**x2**	284-316	320-352	352-396	380-420
6	2**x3**		**1a:480-552**		**1b: 552-636**
8	2x2**x2**		**2a:640-704**	**2b:704-792**	**3a:800-840**
12	2x2**x3**	**3b:852-948**	**4a:960-1056**	**4b:1056-1120**	**5:1140-1260**
16	2x2x2**x2**			**6a:1408-1584**	**6c:1472-1696**
24	2x2x3**x2**	**6b:1704-1896**			

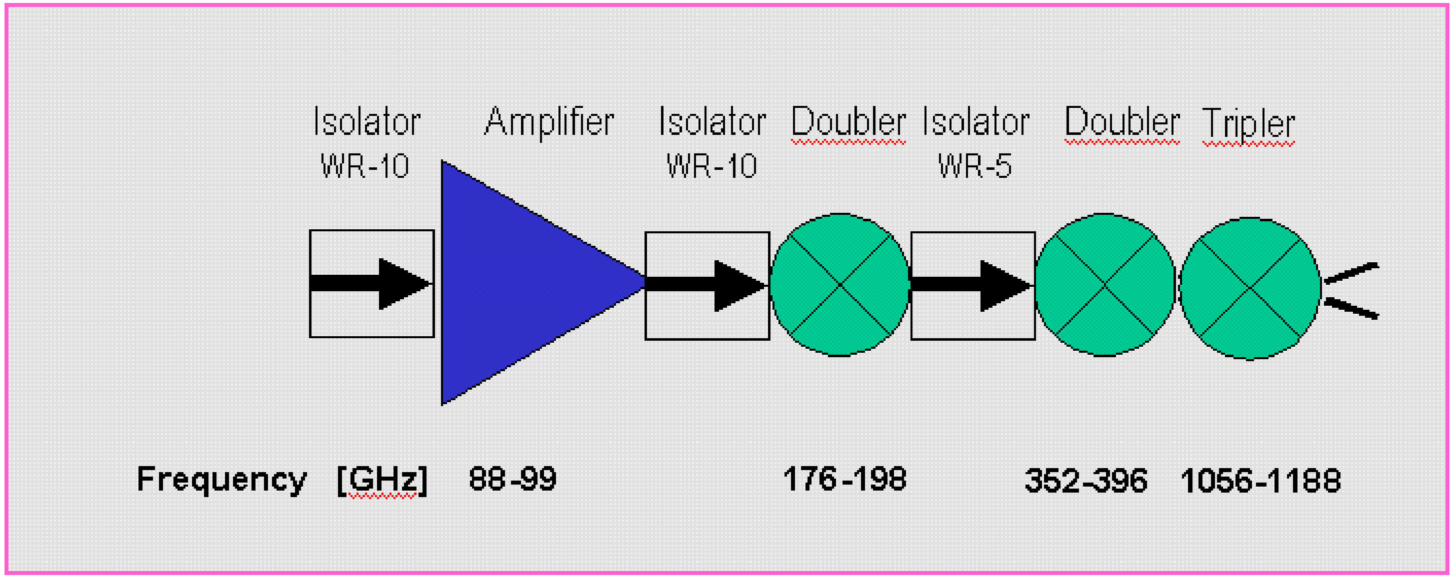
Technology Roadmap: LO Band Ia



Instrument Development,
Deliverables, Models

Power Amplifier	80-92 GHz				Need Date	
	prototype		flight qualified			
Req. Power [mW]	>200		>200		tbd	06.00
Meas. Power [mW]	..		..			
Isolator WR-10					asap	
Losses [dB]	0.6 dB					
Req. Input Power [mW]	>200		>200			
1st stage Doubler	160-184 GHz					
	discrete		substrate-less			
	E/dp/LF0		E/dp/LFx	Z/dp/LFx		
Meas. Freq. Cvg. [GHz]	..	..	..	..		
Exp. Output Power [25%]	>30		>30			
Meas. Output Power [mW]	..	..	..	..		
	Selection					
Isolator WR-5						
Losses [dB]	ca. 1 dB					
Exp. Input Power [mW]	>40					
2nd stage Tripler	480-554 GHz					
Min. Freq. Cvg.	489-546 GHz					
Exp. Output Power [3%]	1.200					
Requ. Min. Power [mW]	0.021					
	discrete		substrate-less			
	E/3-4/LF2		E/3-4/LF2	Z/3-4/LF2	LF2: 06.-10.00	
Meas. Freq. Cvg. [GHz]	..		..			
Meas. Output Power [μW]	..		..			
	Selection					

Technology Roadmap: LO Band IVb (DM)



Instrument Development,
Deliverables, Models

Power Amplifier	88-99 GHz				Need Date
	prototype		flight qualified		
Req. Power [mW]	>200		>200		tbd 08.00
Meas. Power [mW]	..		..		
Isolator WR-10					asap
Losses [dB]	0.6 dB				
Req. Input Power [mW]	>200		>200		
1st stage Doubler	176-198 GHz				
	discrete		substrate-less		
	E/dp/LF0	Z/2/LF1	E/dp/LFx	Z/dp/LFx	
Meas. Freq. Cvg. [GHz]	..	..	..	..	
Exp. Output Power [25%]	>50		>50		
Meas. Output Power [mW]	..	..	..	..	
	Selection				
Isolator WR-5					
Losses [dB]	ca. 1 dB				
Exp. Output Power [mW]	>40		>40		
2nd stage Doubler	352-396 GHz				
	discrete		substrate-less		
	E/dp/LF0		E/dp/LFx	Z/2/LF1	
Meas. Freq. Cvg. [GHz]	..	..	..	..	
Exp. Output Power [15%]	>6		>6		
Meas. Output Power [mW]	..	..	..	..	
	Selection				
3rd stage Tripler	1056-1188 GHz				
Min. Freq. Cvg.	1056-1113 GHz				
Exp. Output Power [1.5%]	0.090				
Requ. Min. Power [mW]	0.020				
	substrate-less		membrane		UF2: 09.-03.01 LF2: 06.-10.00
	E/3-4/LF2	Z/3-4/LF2		Z/S/UF1	
Meas. Freq. Cvg. [GHz]	..		..		
Meas. Output Power [µW]	..		..		
	Selection				

Schedule and Planning

- Top-down and bottom-up: Schedule became the Plan!
- Considered realistic (based on experience from previous space and non-space heterodyne projects)
- LO is on critical path:
  - Late start funding for LOU, with band 1-4 LO chains
  - LO Source Unit procurement decision
  - LO Chains development: performance impact

SRON

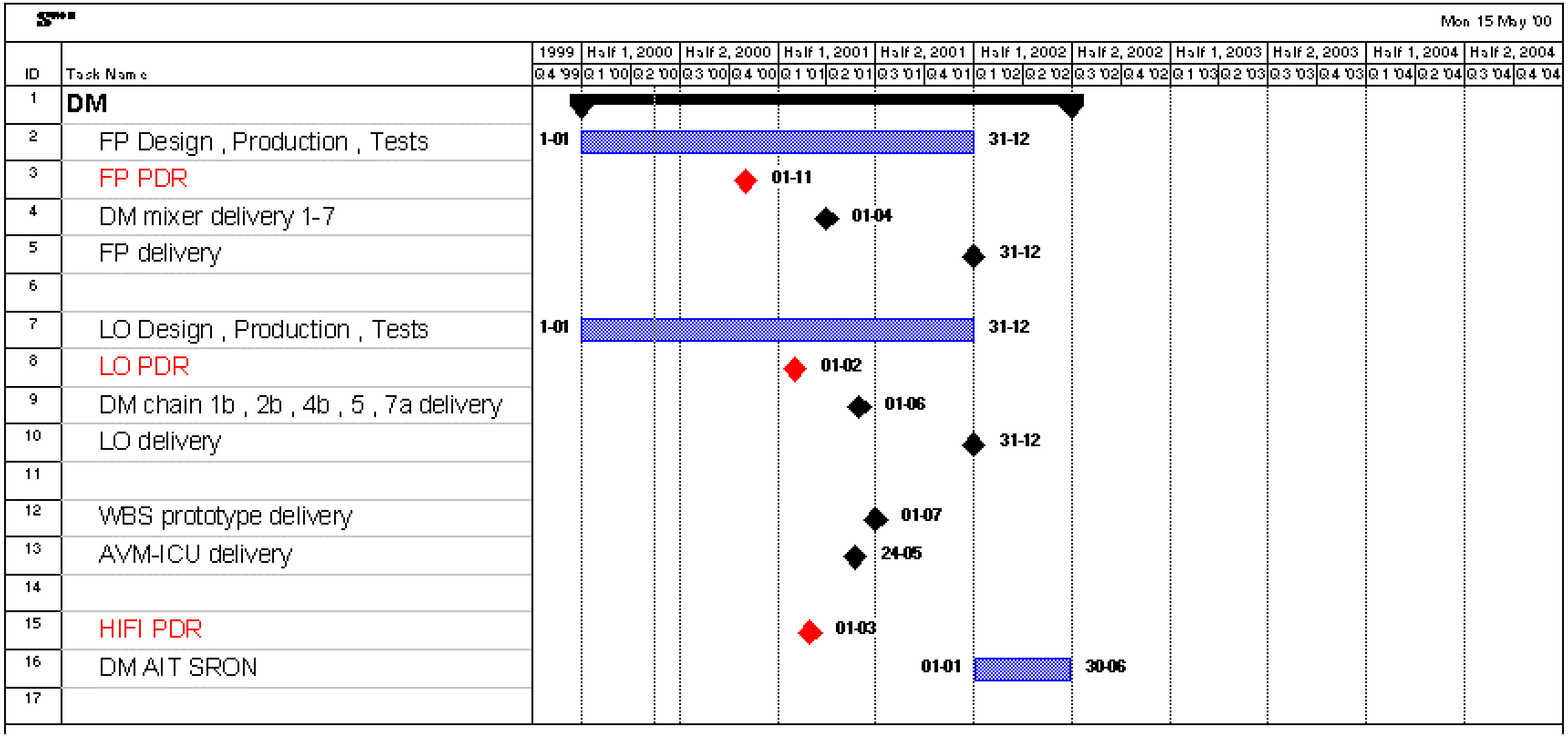
Instrument Development, Deliverables, **Models**

HIFI

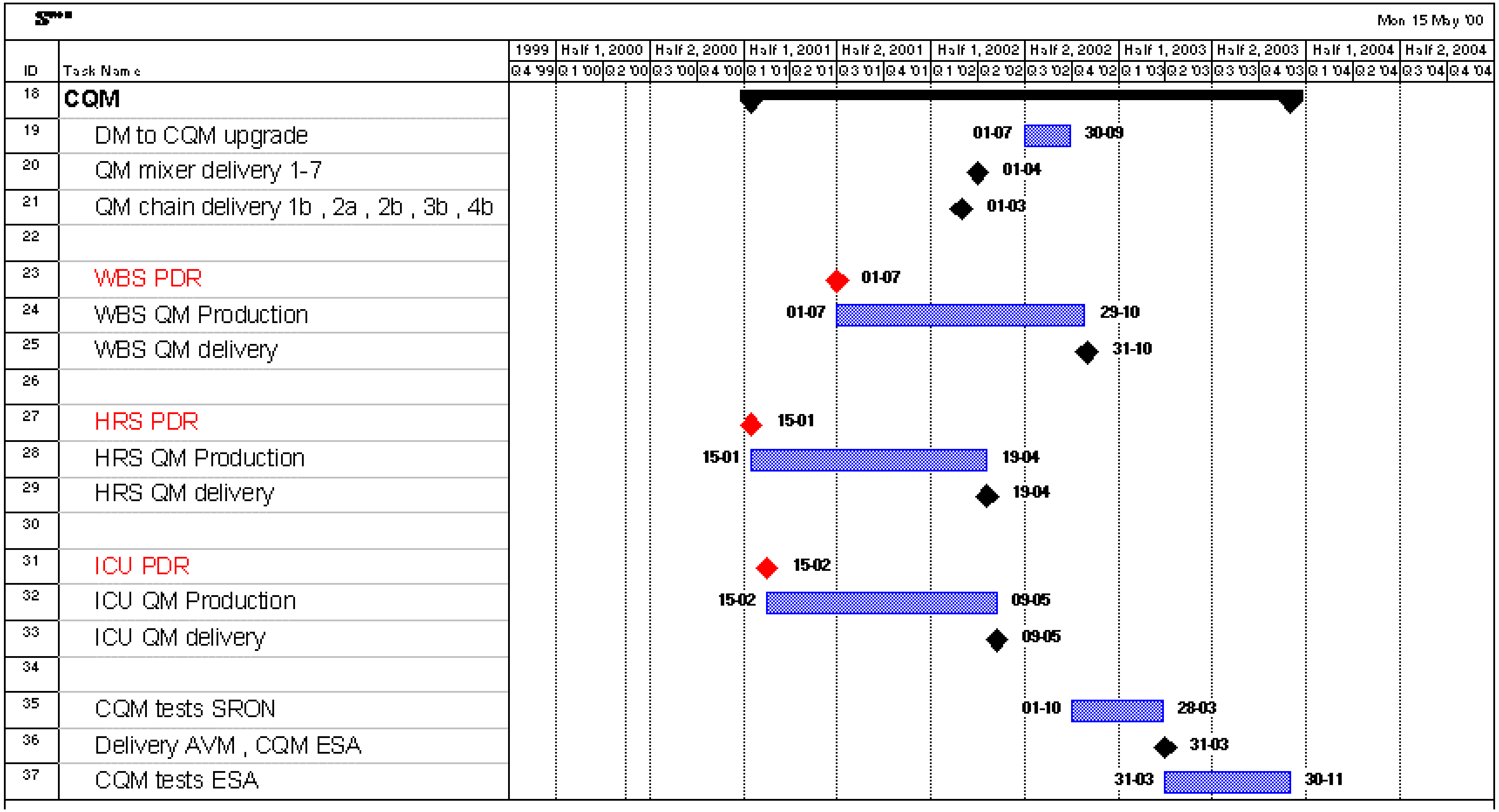
CI/Level	Build Standard				Flight Instrument Configuration				
	E/PT	D	Q	F	DM	AVM	CQM	FM	FS
Flight Instrument					Y		Y	F	
FP S/S					Y		Y	F	
FPU					Y		Y	F	Parts ,Ma's
Common Opt Assy					Y		Y	F	
◆ Structure&Optics			Y	Y	Q		Q	F	
◆ Mech.&Cal.Source	Y	Y	Y	Y	D		D	F	
Mixer Assy					Y		Y	F	
◆ Structure&Optics	Y	Y	Y	Y	D		Q	F	
◆ Special Parts	Y	Y	Y	Y	D		D	F	
◆ Mixer Ch. Comp's	Y	Y	Y	Y	D		D ,Q	F	
FCU	Y	Y		Y	E	Sim.	D	F	Kits
LO S/S					Y		Y	F	
LOU					Y		Y	F	
◆ Structure			Y	Y	Q		Q	F	
LO Assy					Y		Y	F	
◆ Structure&Optics		Y	Y	Y	Q		Q	F	
◆ Special Parts	Y	Y	Y	Y	D		D	F	
◆ LO Ch.Comp's	Y	Y	Y	Y	D		D ,Q	F	
LCU	Y	Y		Y	E	Sim.	D	F	Kits
LSU	Y	Y	TBD	Y	Ec	Sim.	TBD	F	Kits
WBS S/S	Y		Y	Y	E	Sim.	Q	F	Parts
HRS S/S			Y	Y		Sim	Q	F	Parts
ICU S/S		Y	Y	Y	D	D	Q	F	Boards

DM Master Planning

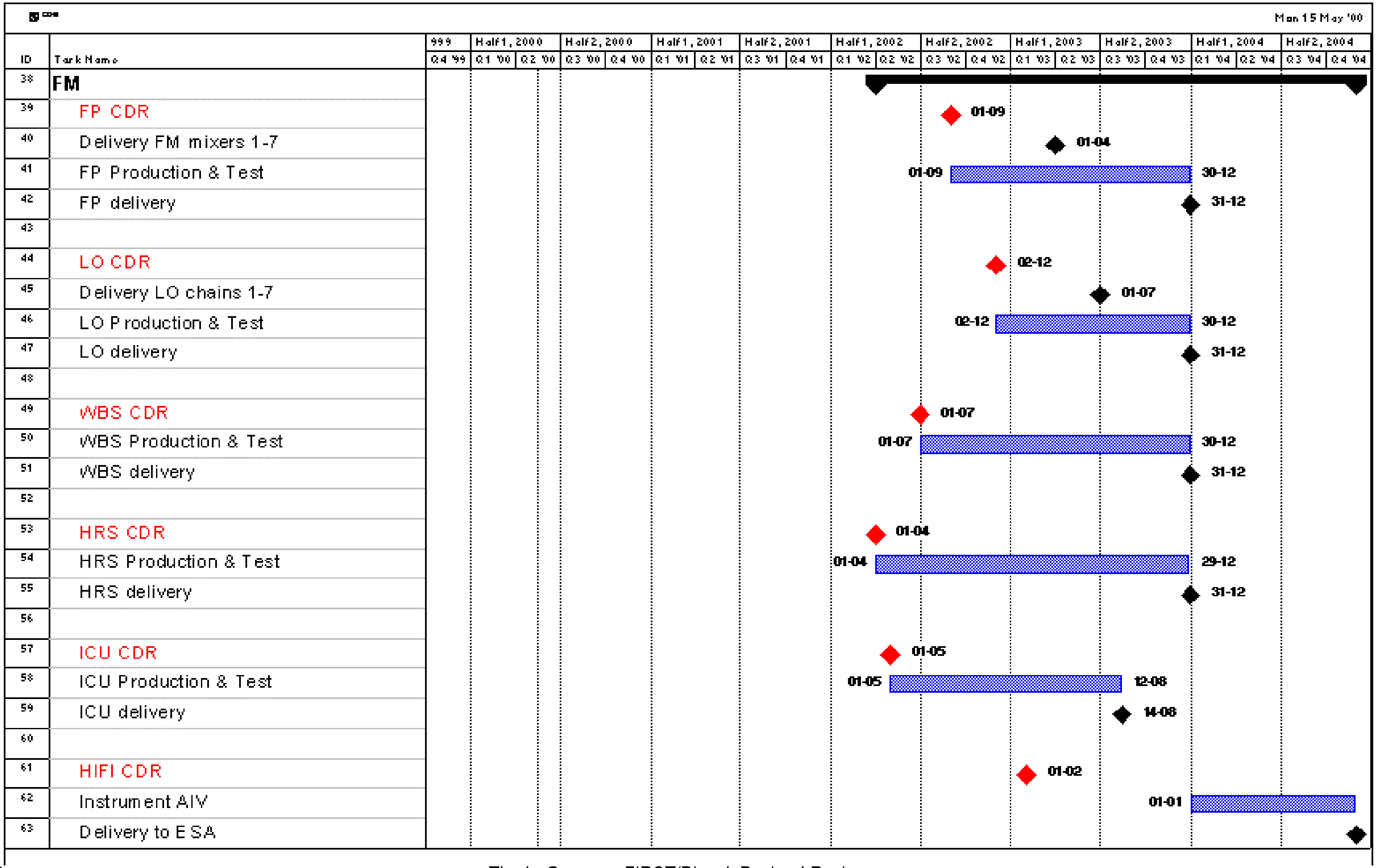
(DM Testing Completed by Mid 2002: Input for FM Design



CQM/AVM Master Planning



FM Master Planning



Important System Design Areas:

(Affecting HIFI Performance; understood between Project and HIFI)

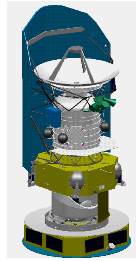
- **Pointing accuracy**
- **Temperature stability and range**
- **Standing waves**

Critical Areas for HIFI:

- **LO Technical Development**
- **FM Schedule**
- **S/C contractor on-board for interface definition: CDMS and EMC areas**

SUMMARY:

- Delta ISVR close-out 25 May
- Instrument design rapidly converging
- Band 7 loss affects science capabilities; still within FSEC criteria
- Definition of interfaces (int. and ext.) well advanced
- SIS Mixer development progressing well
- LO development criticality identified (performance and schedule)
- Planning shows CQM delivery on time; FM delivery late

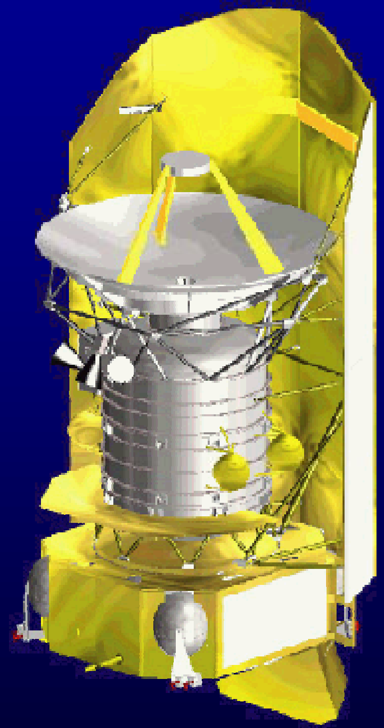


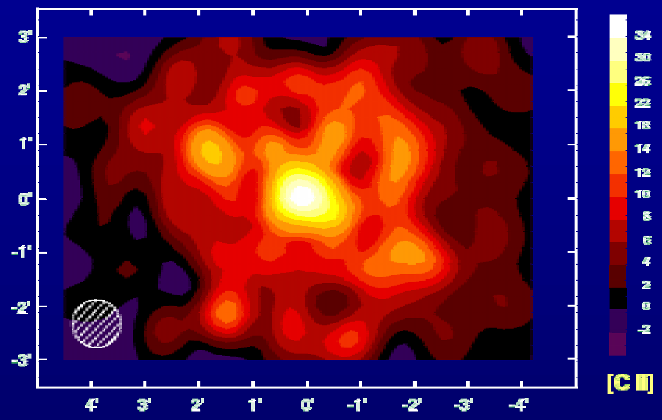
4.3 PACS Status

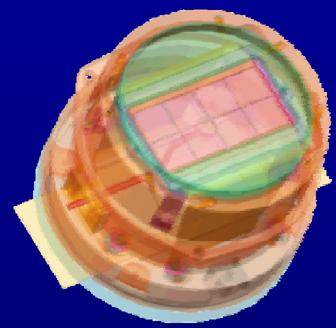
A. Poglitsch - MPE Garching

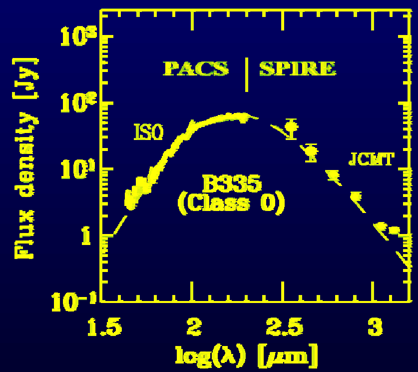
FIRST Photoconductor Array Camera & Spectrometer (PACS)

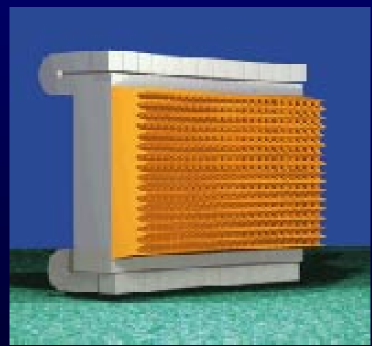
Albrecht Poglitsch, MPE Garching

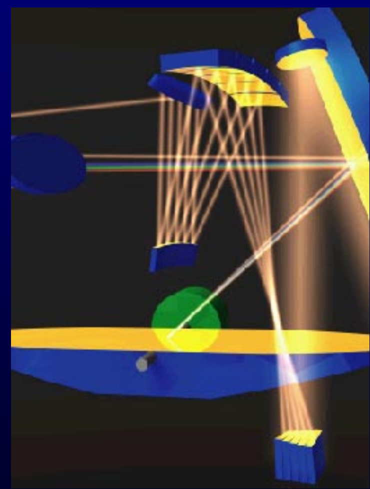








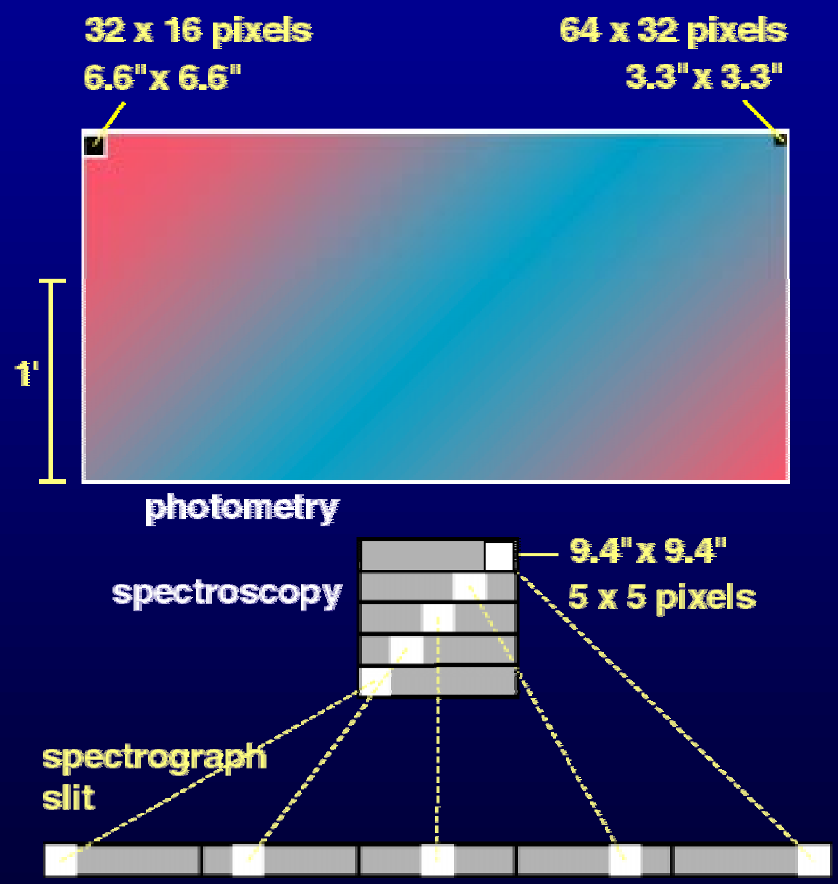




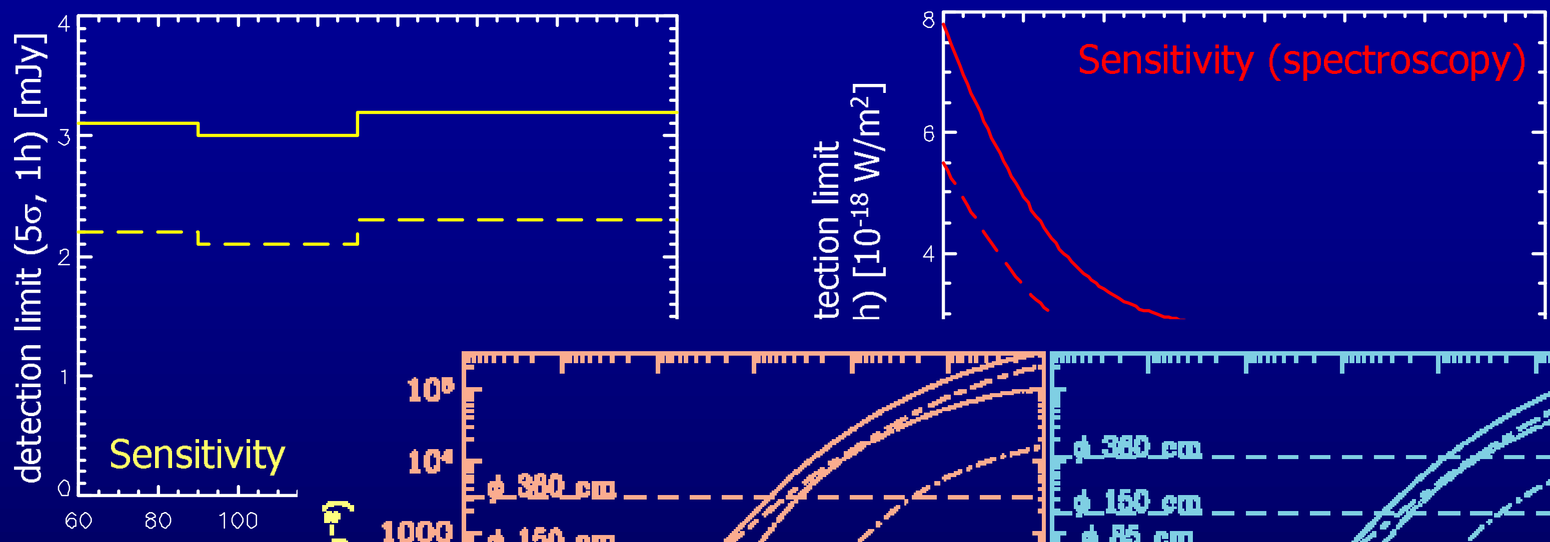
PACS In A Nutshell

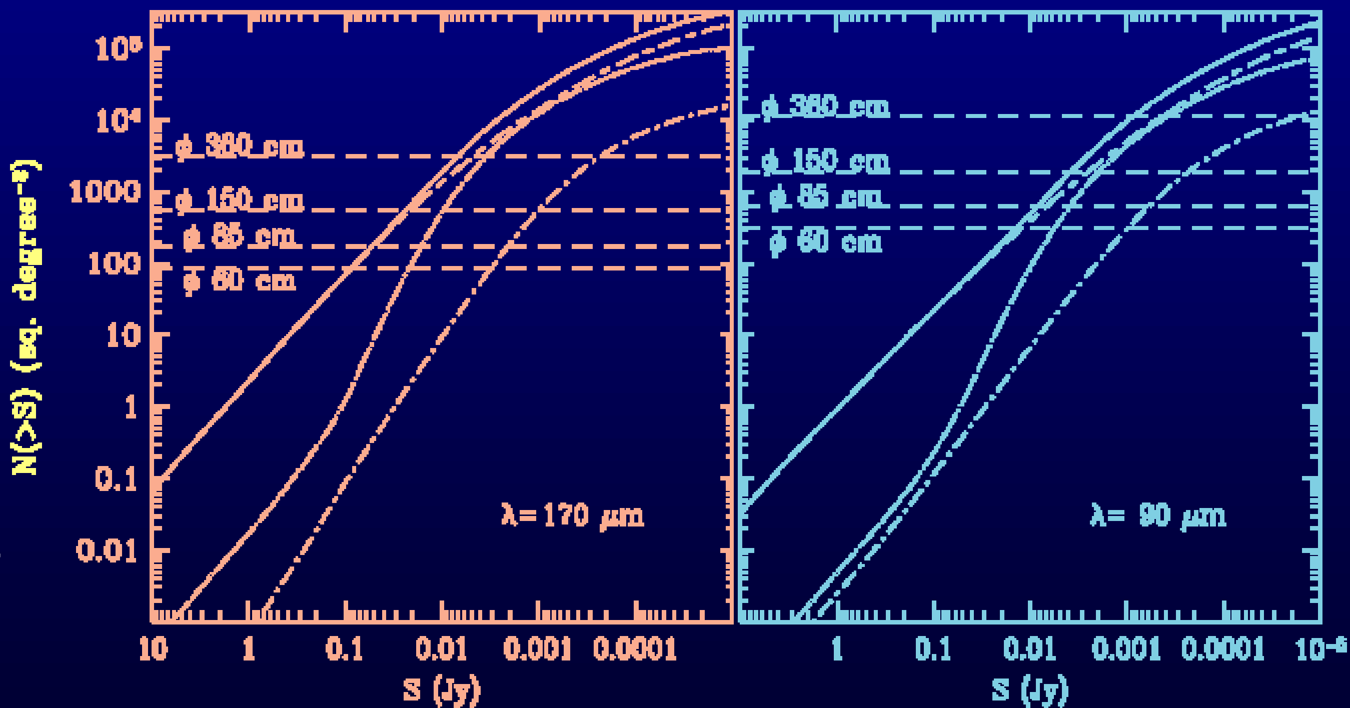
- **Imaging photometry**
  - two bands simultaneously (60-90 or 90-130 μm and 130-210 μm) with dichroic beam splitter
  - two filled bolometer arrays (32x16 and 64x32 pixels)
  - point source detection limit ~3 mJy (5σ, 1h)
- **Integral field line spectroscopy**
  - range 57 - 210 μm with 5x5 pixels, image slicer, and long-slit grating spectrograph (R ~ 1500)
  - two 16x25 Ge:Ga photoconductor arrays (stressed/unstressed)
  - point source detection limit ~3×10^{-18} W/m^2 (5σ, 1h)

Focal Plane Footprint



PACS Performance

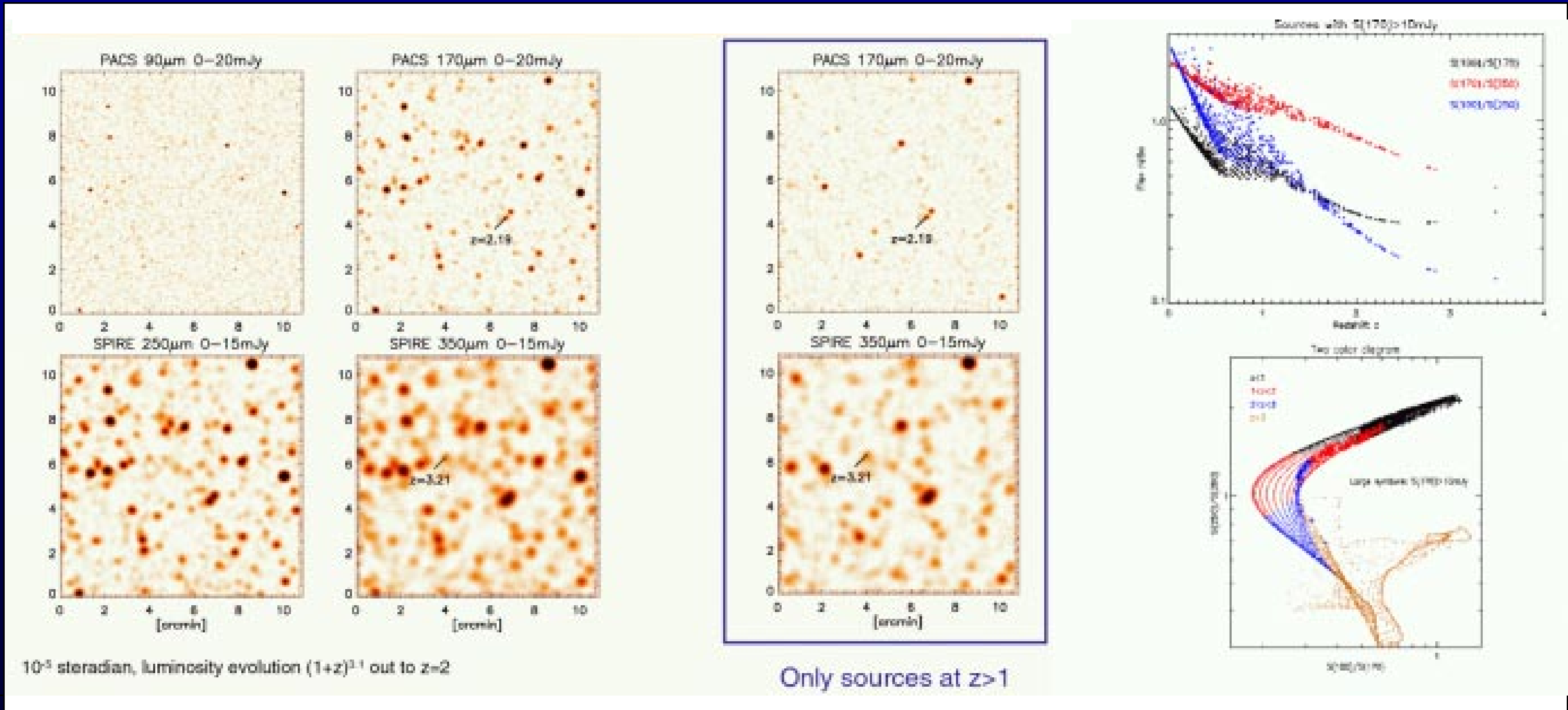




FIRST/PACS 5σ
confusion limit

PACS Scientific Objectives

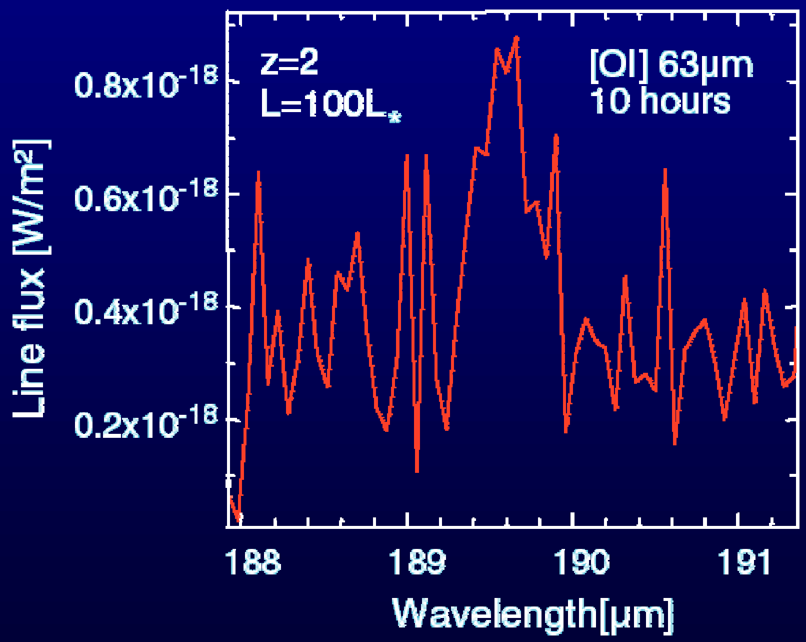
- How and when have galaxies formed in the Universe?
  - Deep multi-band photometric surveys (together with SPIRE): search for high-z FIR-luminous galaxies; photometric redshift

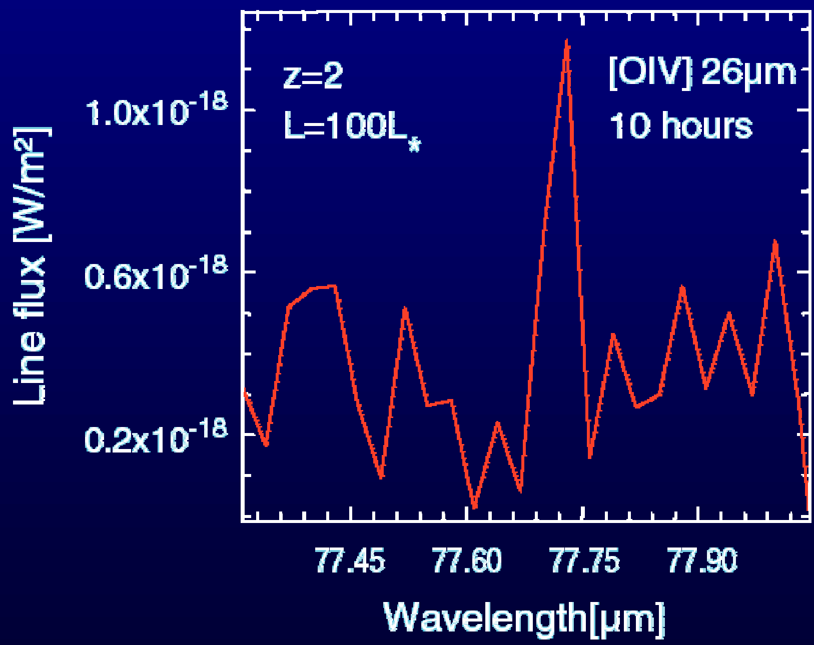


Simulated photometric surveys (PACS+SPIRE) of actively star-forming galaxies and derived color-color plots. PACS observing time: 3 h (σ = 2 mJy)

PACS Scientific Objectives (cont.)

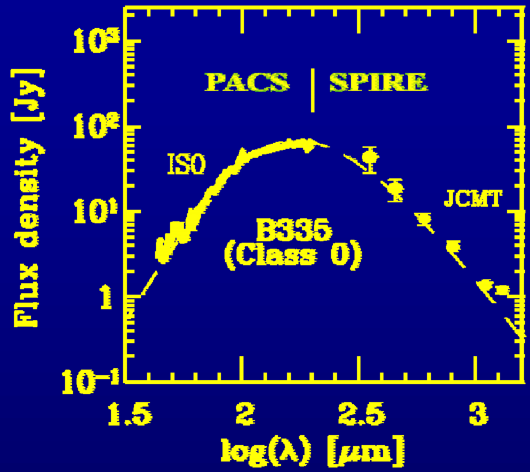
- How and when have galaxies formed in the Universe?
  - Follow-up spectroscopy:
    what powers sources (AGN / starburst), and how do they evolve

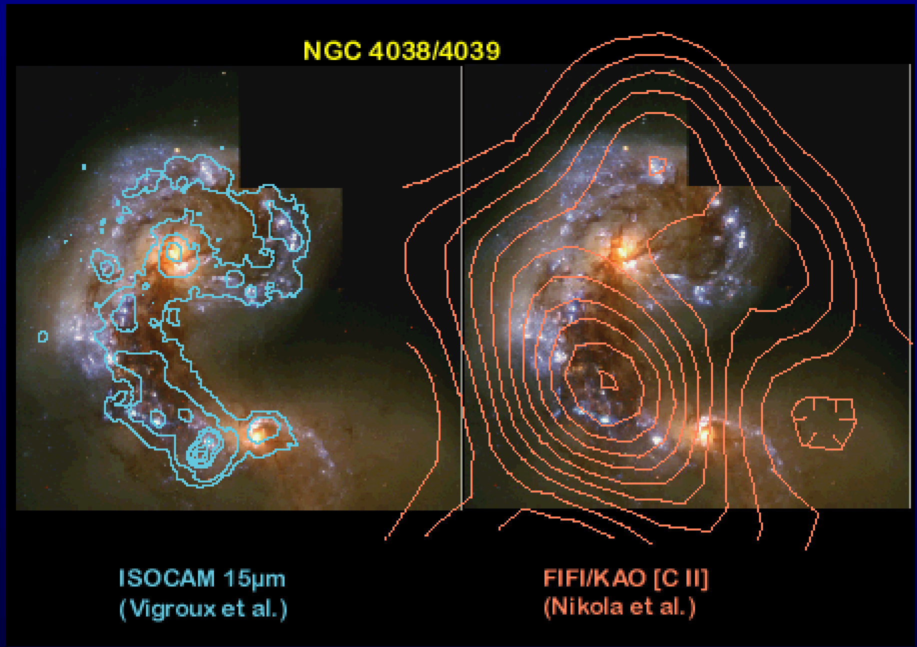




PACS Scientific Objectives (cont.)

- How do stars form out of the interstellar medium (Galactic/extragalactic)?
  - Photometric surveys of nearby molecular clouds (together with SPIRE): unbiased search for protostars down to 0.03 $M_{\odot}$





Local galaxies: star formation and ISM. Photometric and spectral line mapping for detailed studies of star formation on galactic scales (trigger mechanisms, metallicity effects)

- What has been the history of our Solar System?
  - Giant planet atmospheres: composition, profile, origin of water
  - HD line: D/H ratio in Solar System bodies probing the composition of pre-solar grains

The PACS Consortium

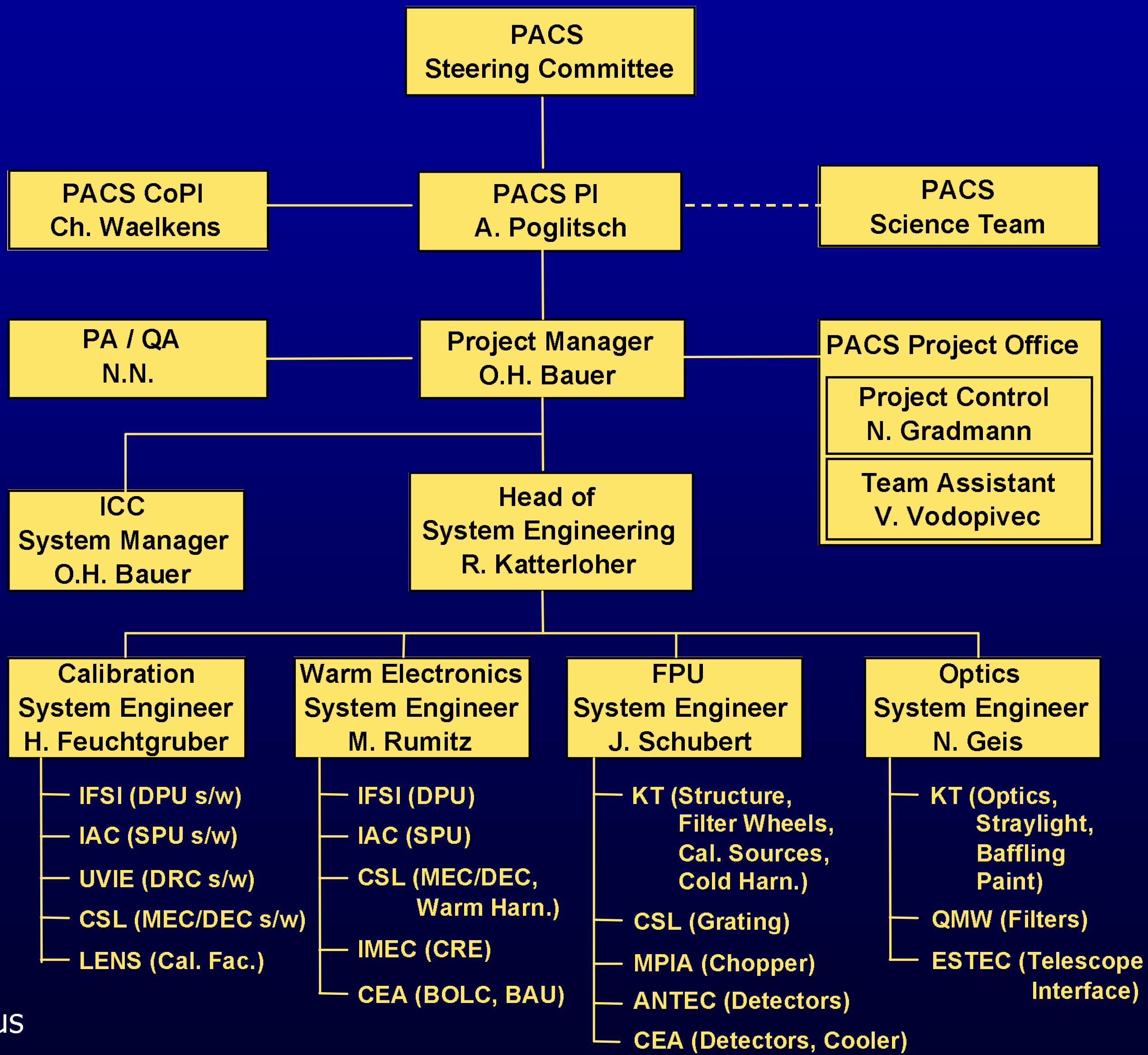
· PI	Albrecht Poglitsch	MPE Garching, Germany
· Co-PI	Christoffel Waelkens	KU Leuven, Belgium

Co-I´s :

· Austria:	Franz Kerschbaum	UVIE Wien
· Belgium:	Chris van Hoof	IMEC Leuven
	Rik Huygen	KU Leuven
	Claude Jamar	CSL Liège
· France:	Suzanne Madden Louis Rodriguez Marc Sauvage	CEA Saclay
	Hervé Wozniak	OAMP Marseille

· Germany:	Otto H. Bauer Helmut Feuchtgruber Reinhard Genzel Reinhard Katterloher Dieter Lutz Eckhard Sturm Linda Tacconi	MPE Garching
	Ulrich Klaas Dietrich Lemke	MPIA Heidelberg
	Thomas Henning	AIU Jena
· Italy:	Paola Andreani	OAP Padova
	Paolo Saraceno	IFSI Roma
	Gianni Tofani	OAA Arcetri
· Spain:	Jordi Cepa	IAC Tenerife

PACS Management Structure



PACS Steering Committee

(1) Original Composition:

Germany	Dr. M. Otterbein, Dr. H.-J. Blome	DLR
Belgium	Dr. J.W. Bernard	SSTCA
Italy	Prof. Dr. G. Tofani	OAA
Spain	Prof. Dr. J. Cepa	IAC
Austria	Prof. Dr. J. Ortner	ASA
France	-	

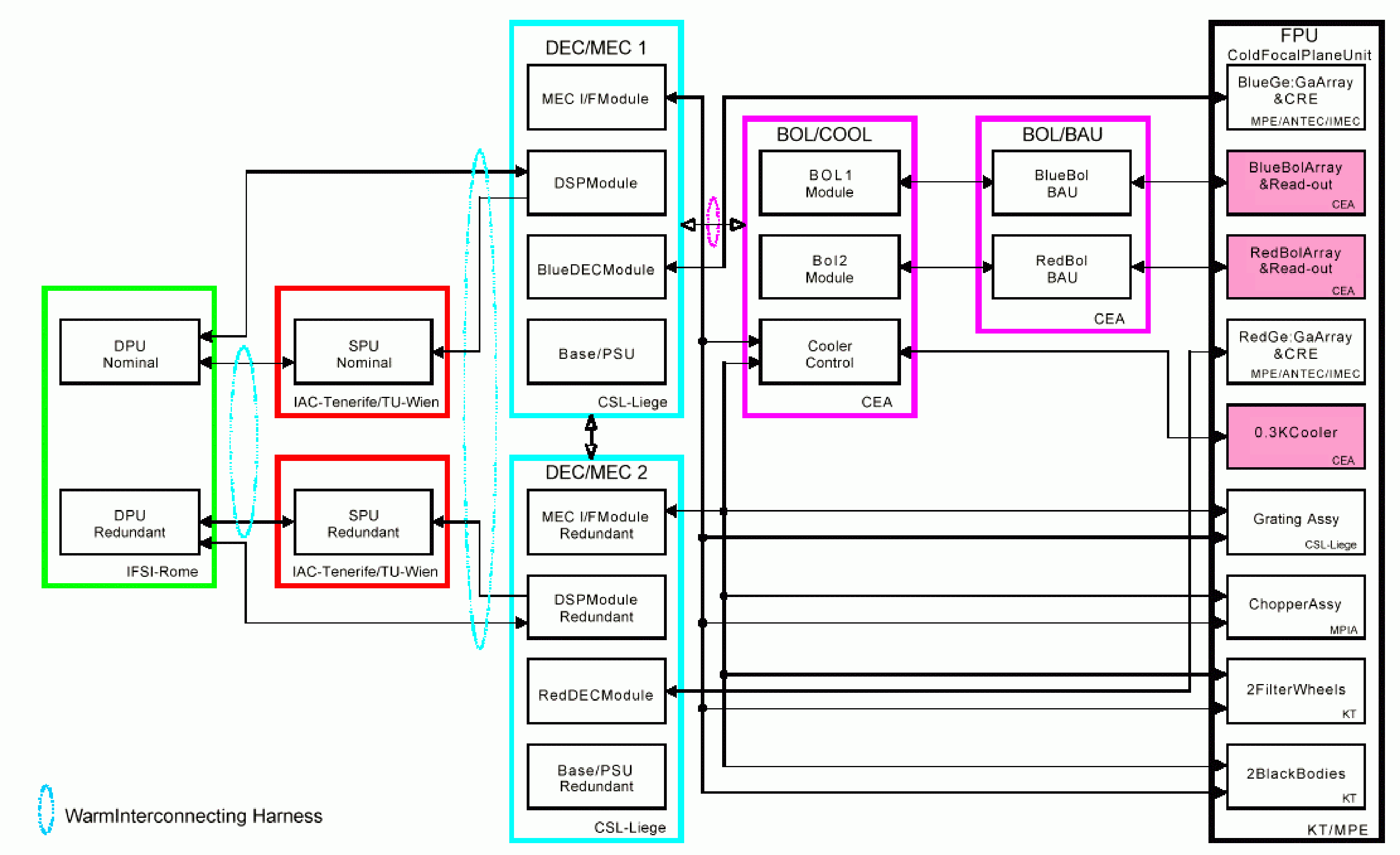
First meeting: May 20,1998: PACS funding proposal for SPC meeting

(2) New Composition:

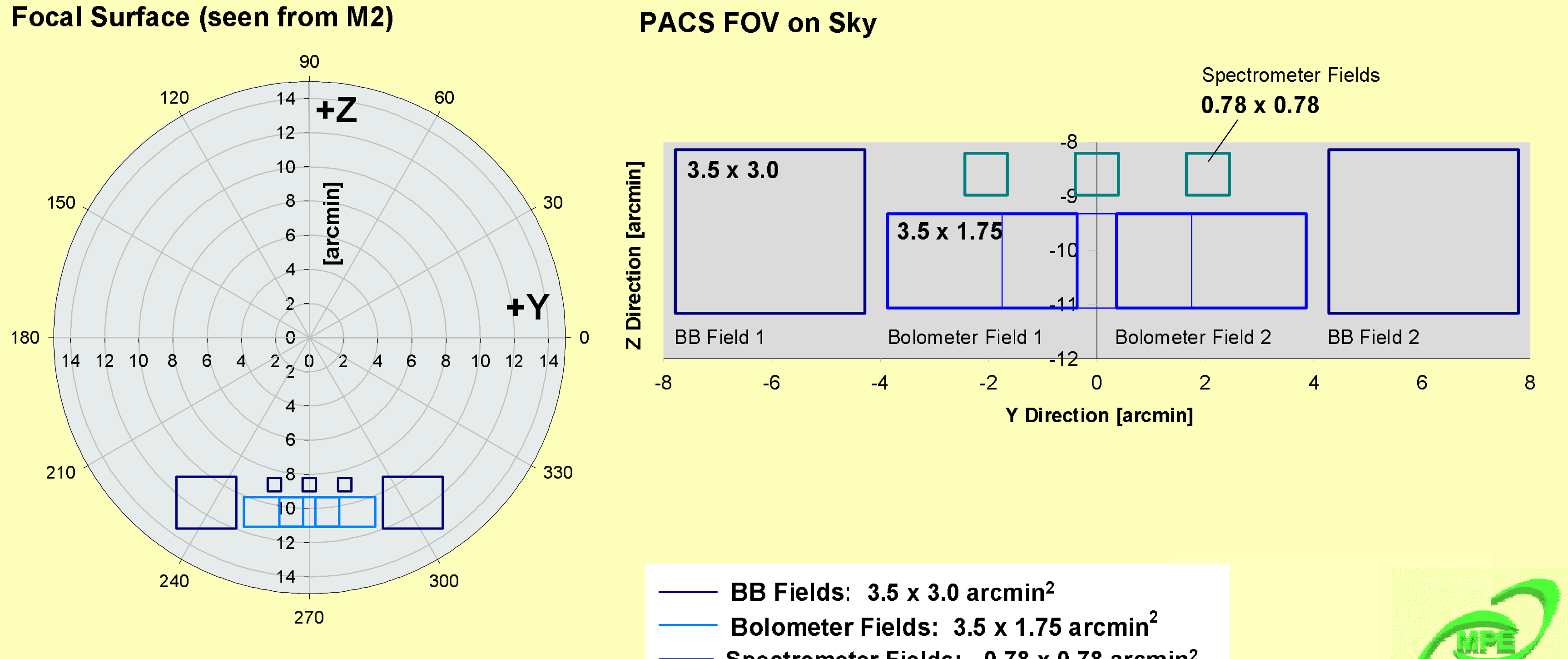
Germany	Dr. G. Hartmann	DLR
Belgium	Dr. J.W. Bernard	SSTCA
Italy	Prof. Dr. G. Tofani	OAA
Spain	Dr. M. Serrano	CDTI
Austria	Dr. K. Pseiner	ASA
France	Dr. M. Joubert	CNES

Next meeting: end June 2000

Instrument Units and Subsystem Responsibilities



PACS Design: Focal Plane Footprint



BB Fields: 3.5 x 3.0 $arcmin^2$
Bolometer Fields: 3.5 x 1.75 $arcmin^2$
Spectrometer Fields: 0.78 x 0.78 $arcmin^2$

Definition of the FOV for the Photometer

Rayleigh-Criterium:

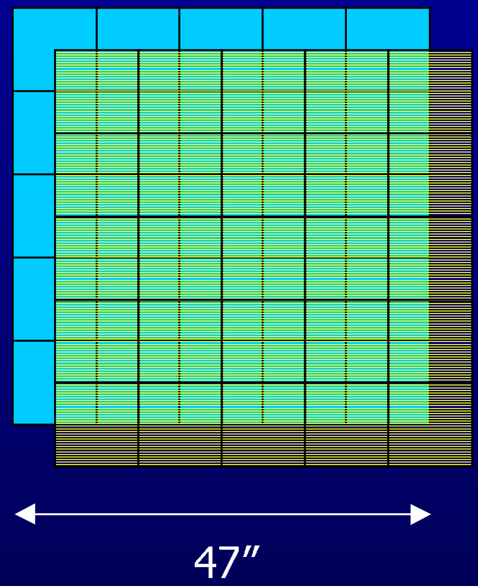
2 pixel per 1.2 λ/D at the diffraction limited wavelength

Detector	Pixel	FOV/Bolometer [arcmin]	FOV/Pixel [arcsec]	Diffraction Limited Wavelength [µm]
blue	32 x 64	**1.75 x 3.5**	3.3	77
red	16 x 32	**1.75 x 3.5**	6.6	174

Physical pixel size: 0.75 x 0.75 mm^2

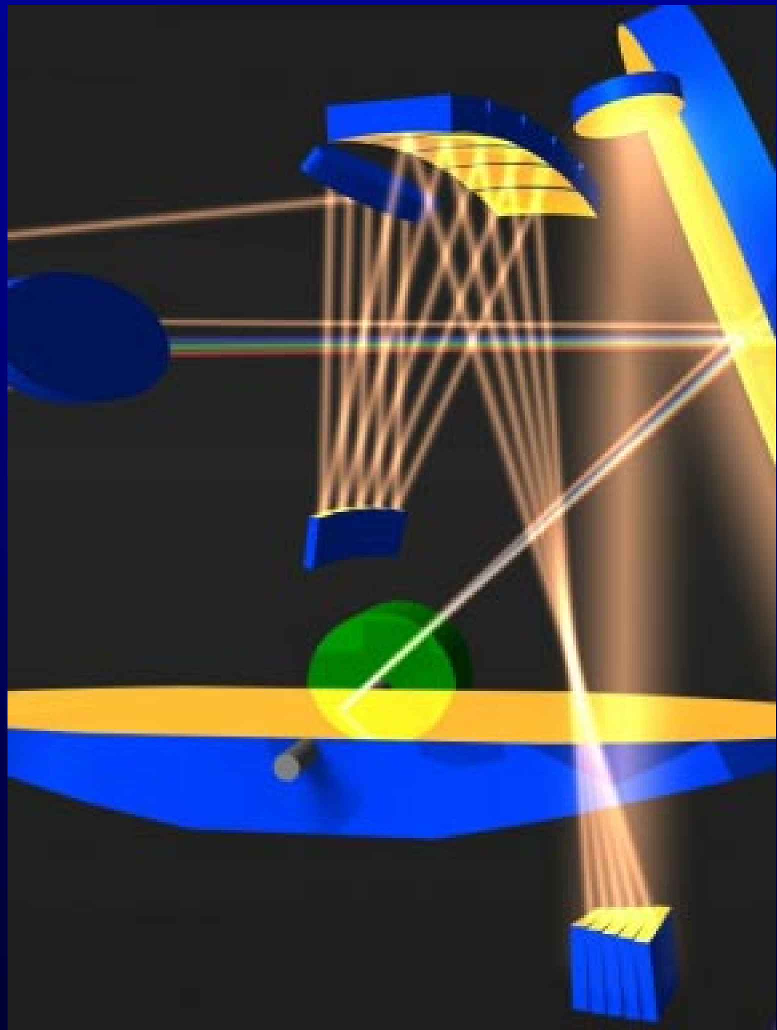
Definition of the FOV for the Spectrometer

- Pixel scale has to be a compromise
  - small number of spatial pixels limits field of view
  - diffraction introduced by image slicer does not allow full sampling
  - large wavelength range requires compromise
- Physical optics analysis shows that 9.4″/pixel gives low enough diffraction losses (15% at 175 µm) with acceptable spatial resolution/sampling
- Full spatial sampling in the long-wave band with two, slightly offset pointings

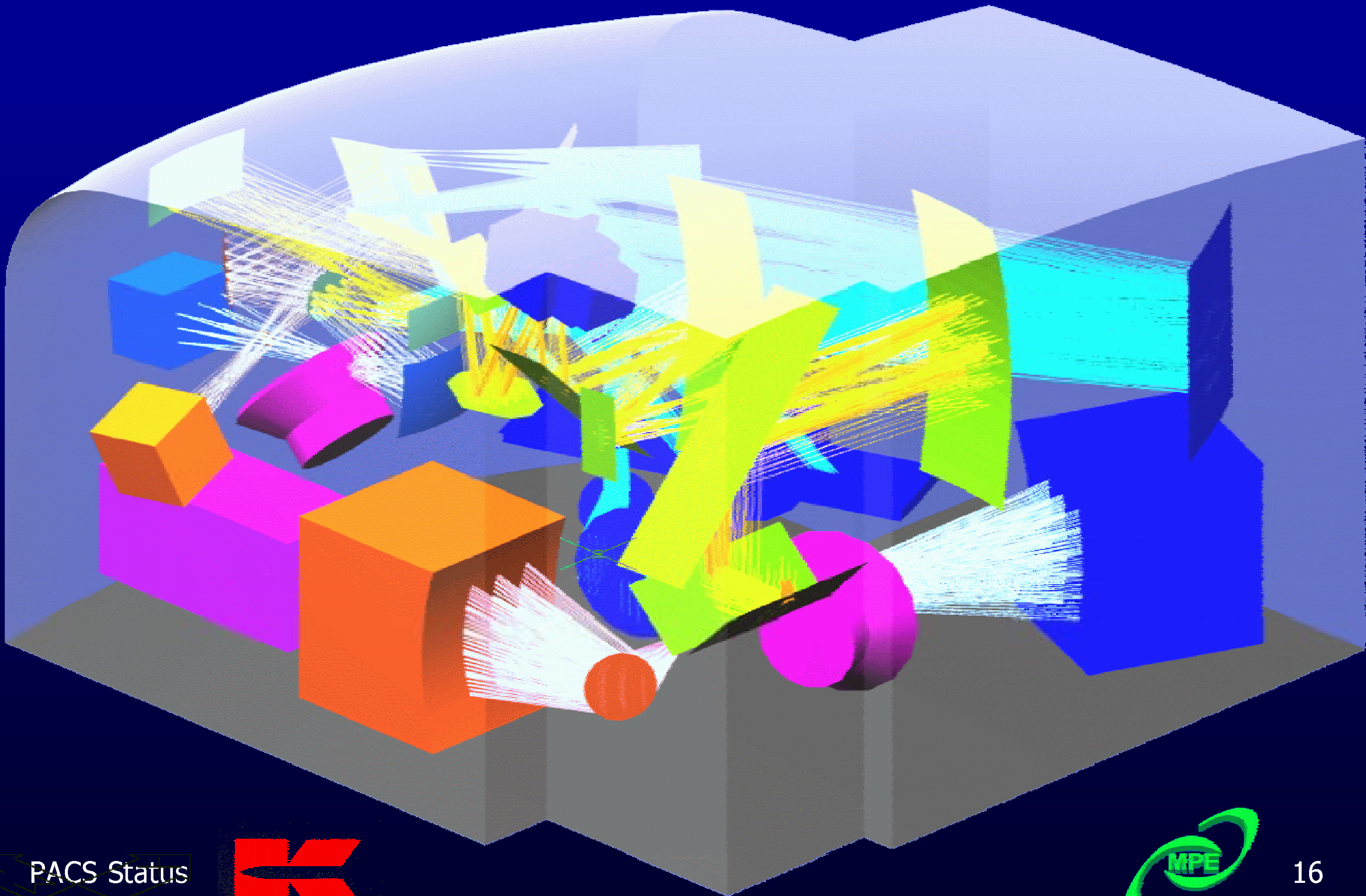


PACS Integral Field Line Spectrometer

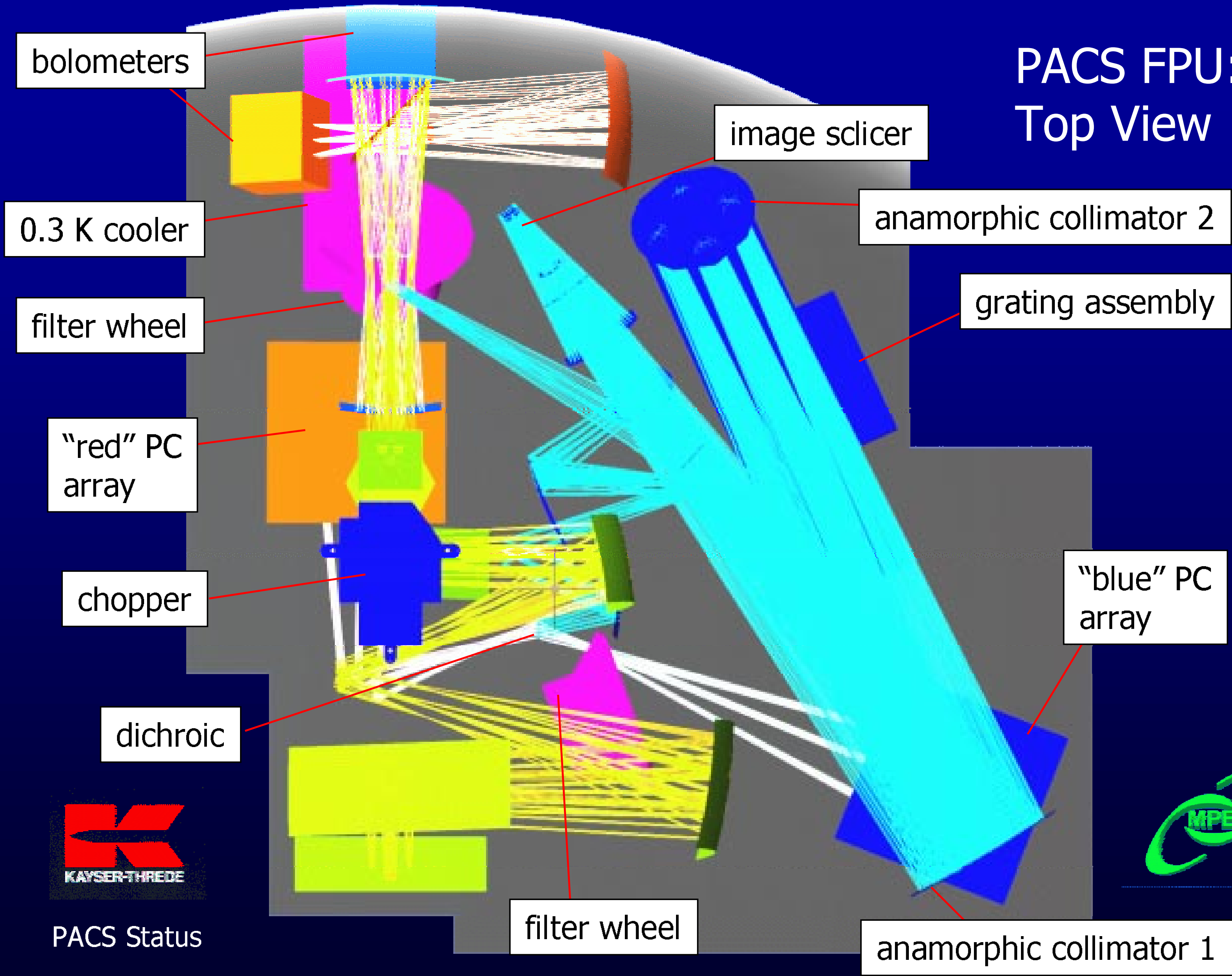
- Optical “image slicer” re-arranges 2-D field of view (5x5 pixels) along 1-D slit (1x25 pixels)
- Grating spectrograph disperses light
- Dispersed slit image is projected on 2-D detector array
- 16 spectral channels recorded simultaneously for each spatial element



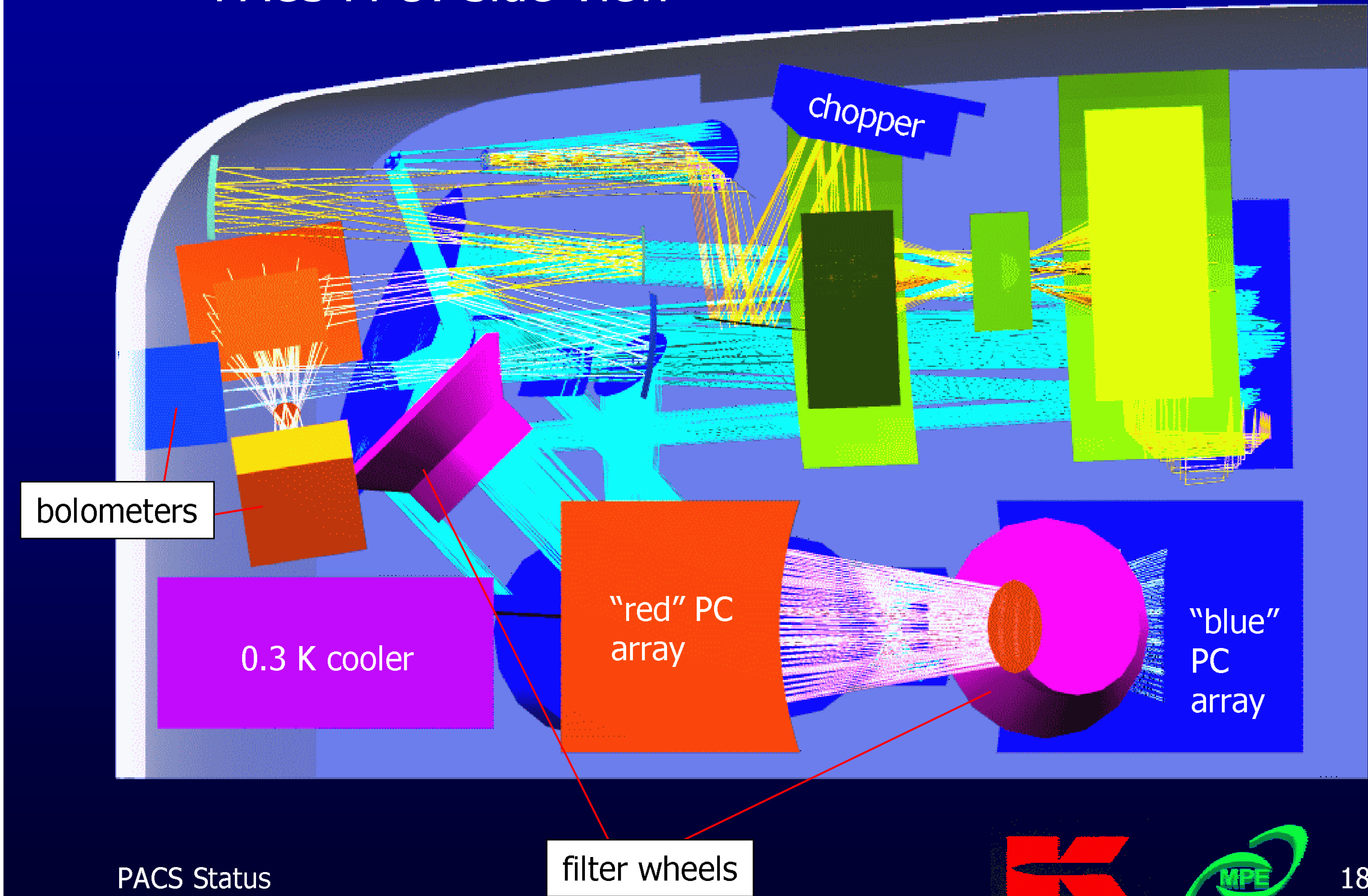
PACS FPU



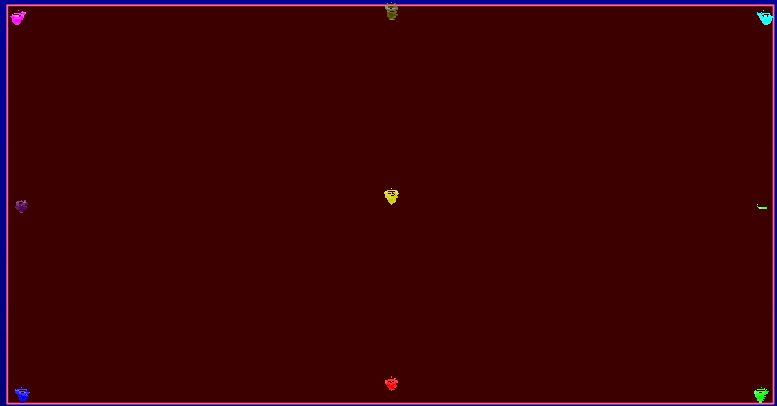
PACS FPU: Top View

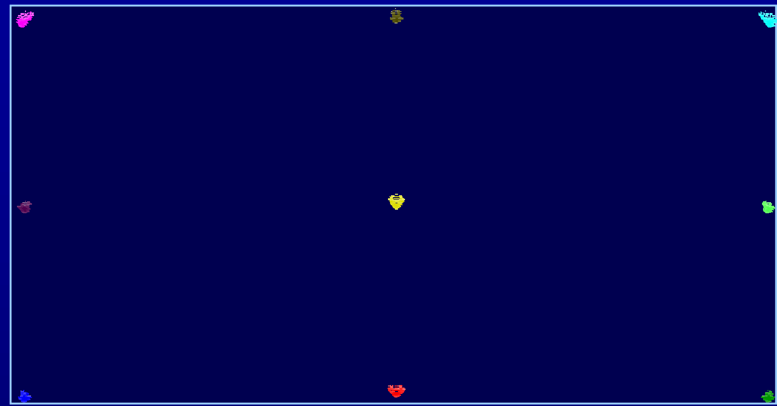


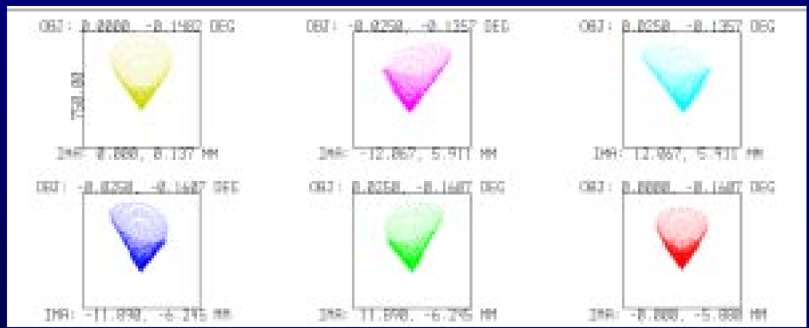
PACS FPU: Side View

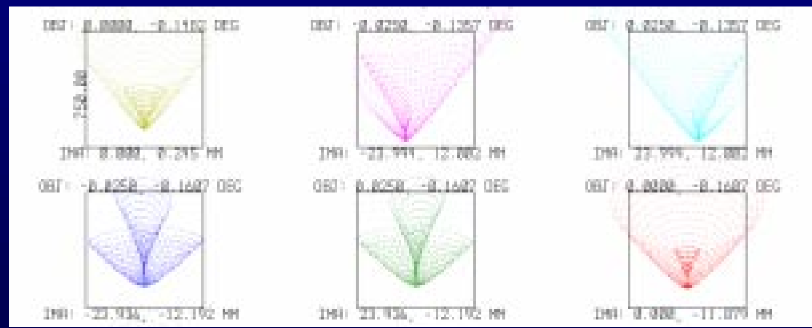


Photometer Image Quality







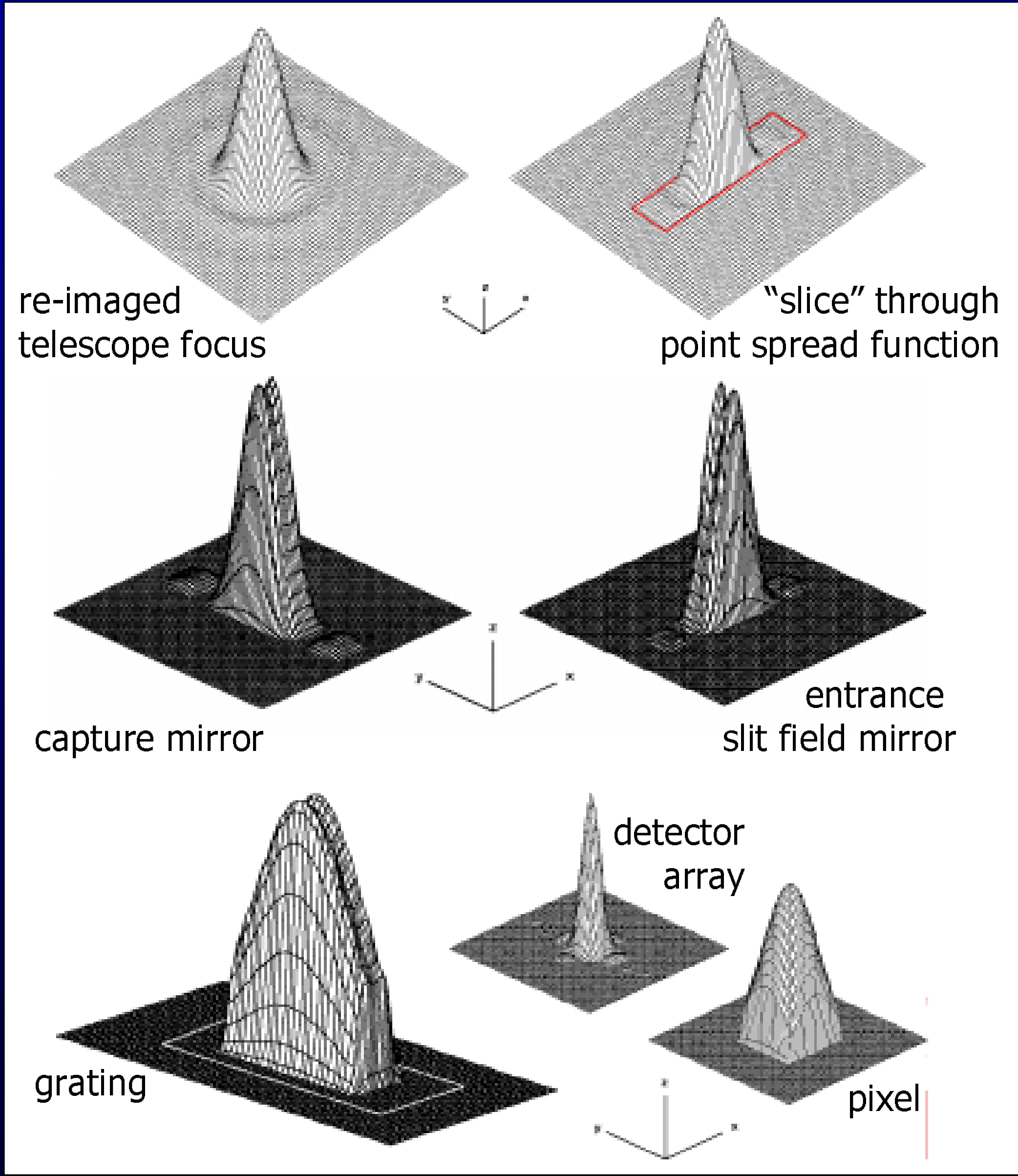


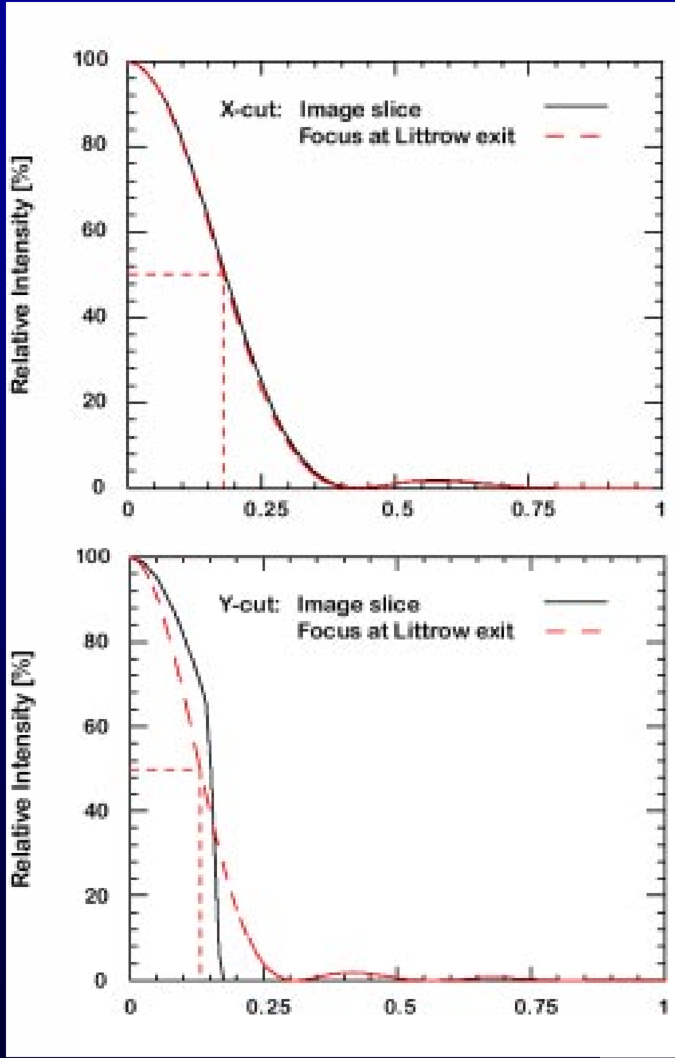
Aberrations of full optical train (telescope + PACS) included

- Strehl ratio 0.99
- Distortion < 1 pixel

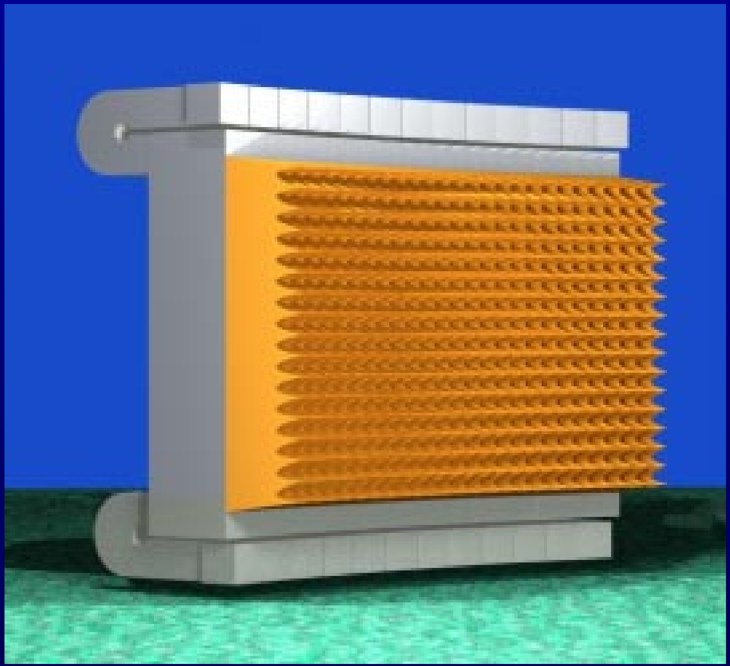
- Strehl ratio >0.95
- Distortion ~ 1 pixel

PACS Spectrometer Diffraction Analysis



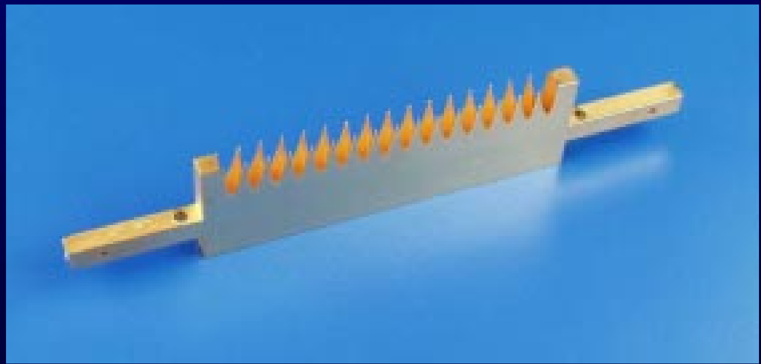


PACS Ge:Ga Photoconductor Arrays



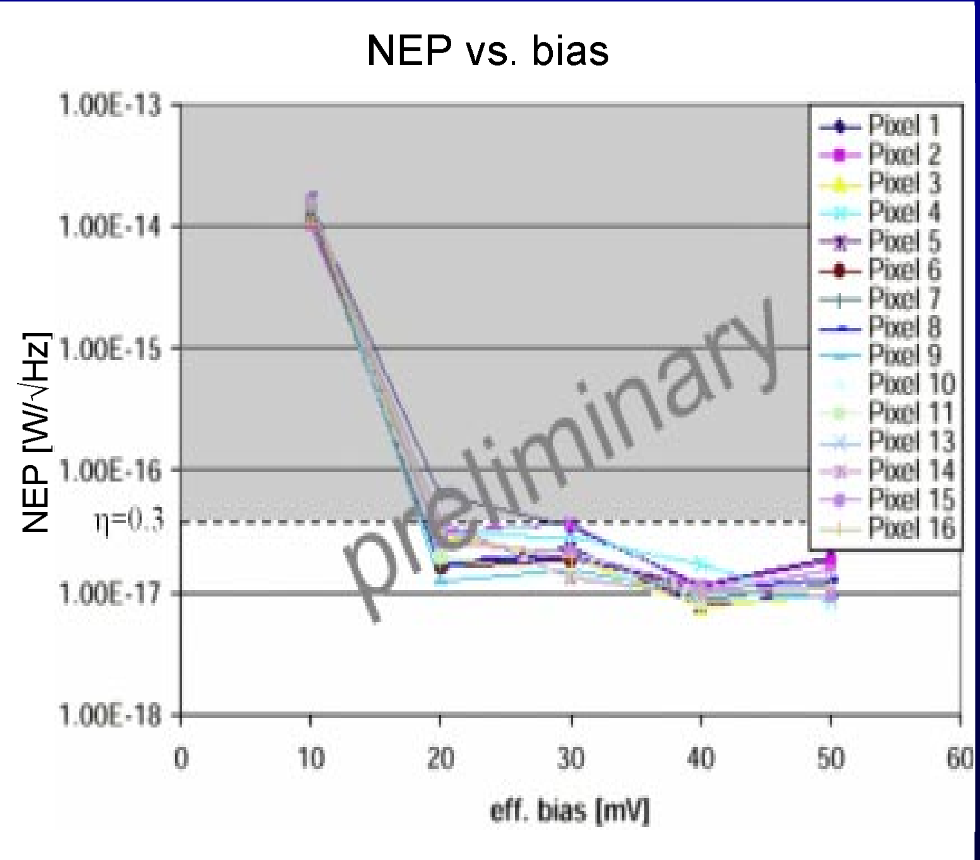
- 16x25 pixel filled arrays
  - 25 linear modules
  - integrated cryogenic readout electronics

16 pixel stressed detector module

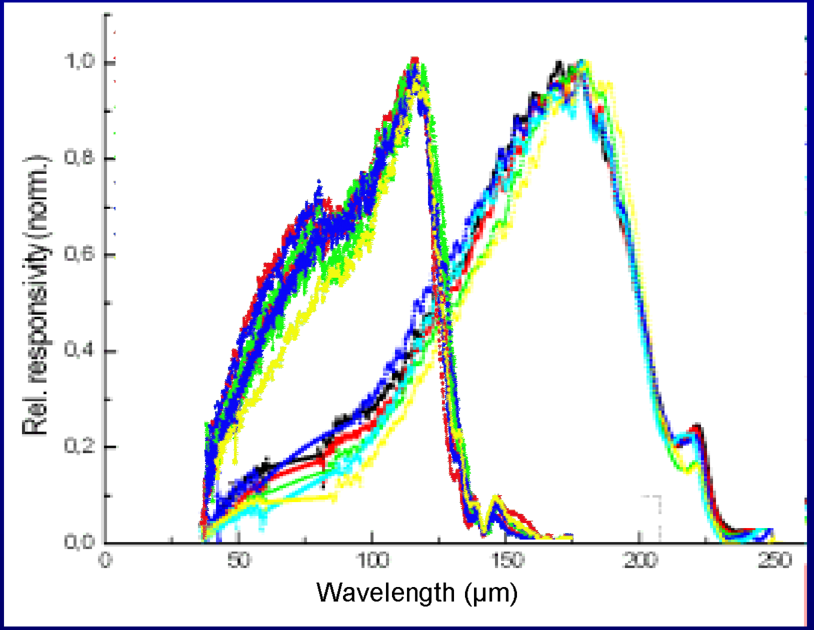


Feed optics: light cone array

PACS Photoconductor Modules



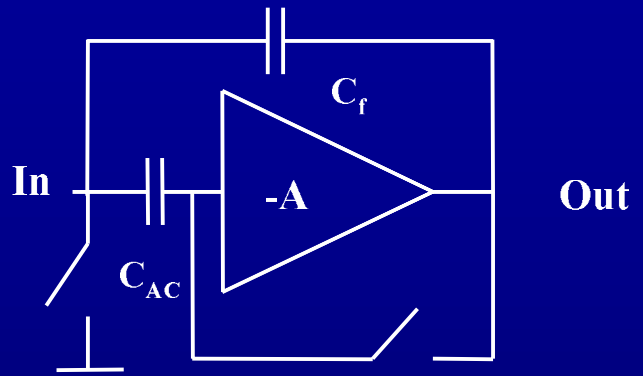
T=1.7K, P=9x10^{-14}W, t_{int}=1 s, C_{int}=10 pF



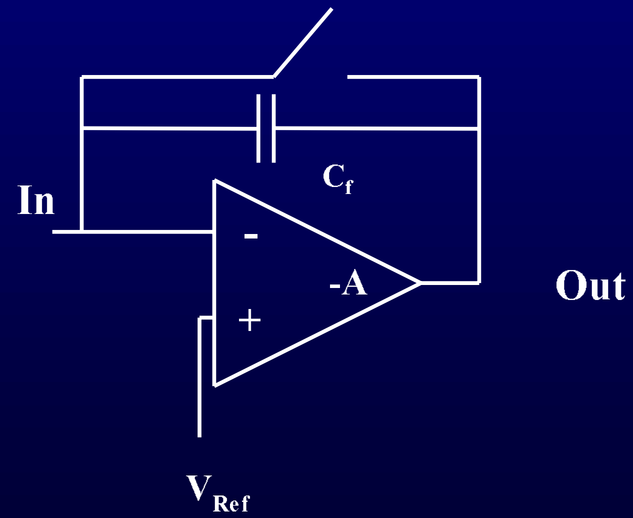
- Ge:Ga photoconductors
  - unstressed: 40 - 120µm
  - stressed: 110 - 210µm
  - background-limited in both, photometry and spectroscopy, if amplifier noise is low enough

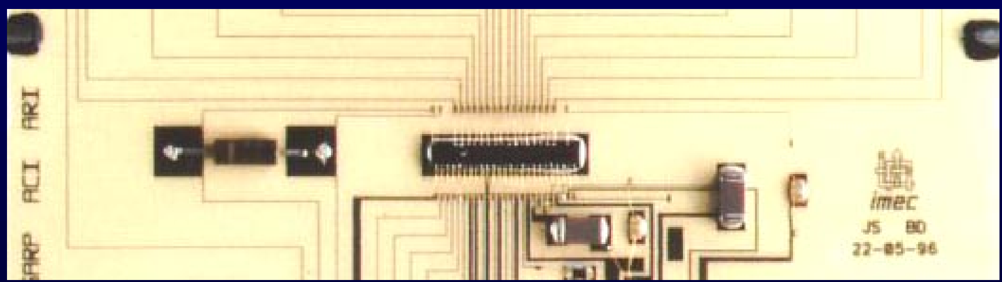
PACS Cryogenic Readout Electronics

- Capacitive feedback transimpedance amplifier (CTIA) for each pixel, based on AC-coupled inverter or DC-coupled differential amplifier stage in silicon CMOS technology
- 16 CTIAs multiplexed on each CRE chip for each linear detector module
- CRE chips integrated in detector modules
- <u>Amplifier noise compatible with background-limited performance in spectroscopy only!</u>

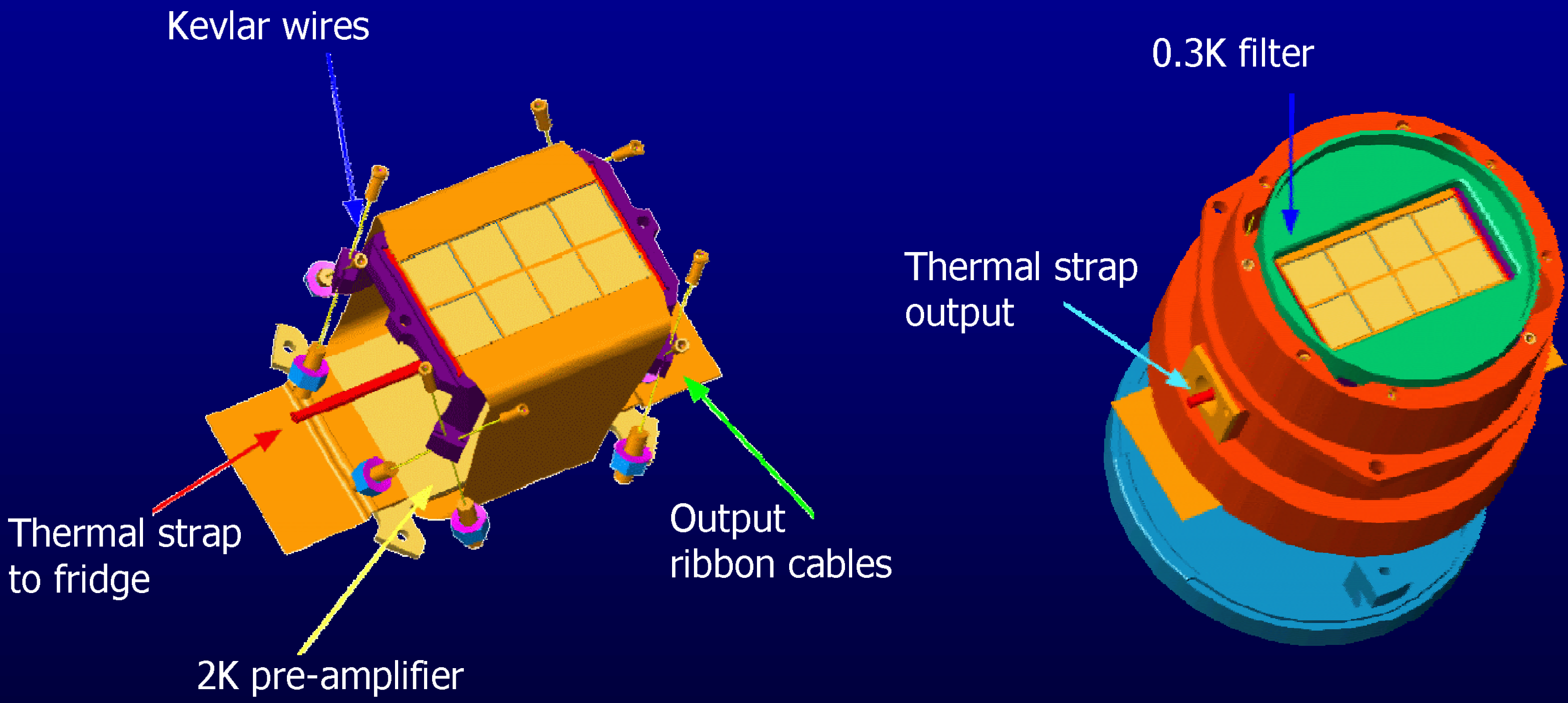


CTIA architectures

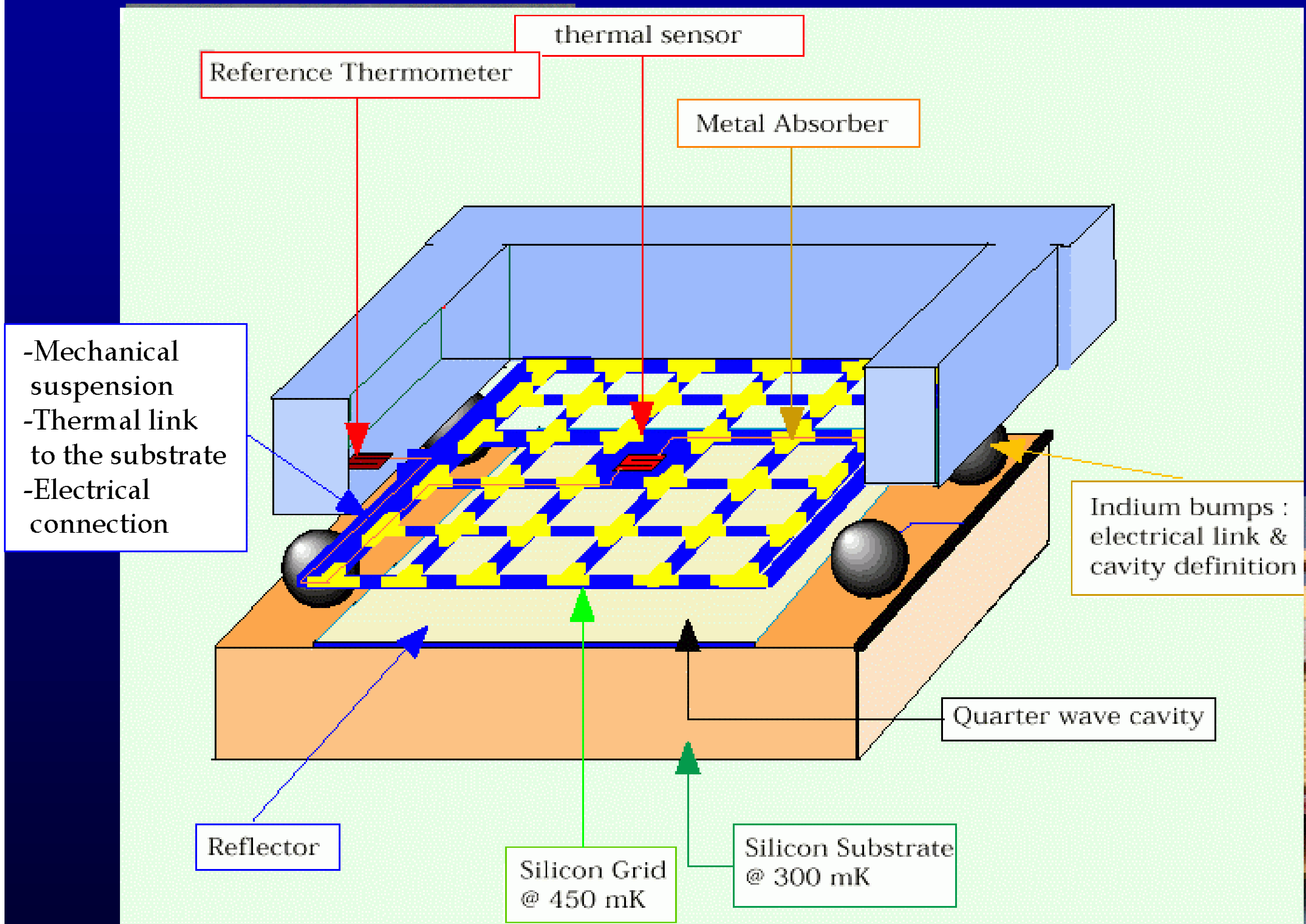


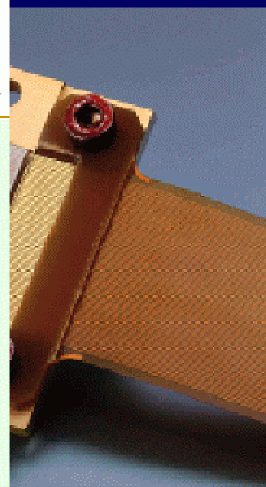


CEA Bolometer Array Assembly

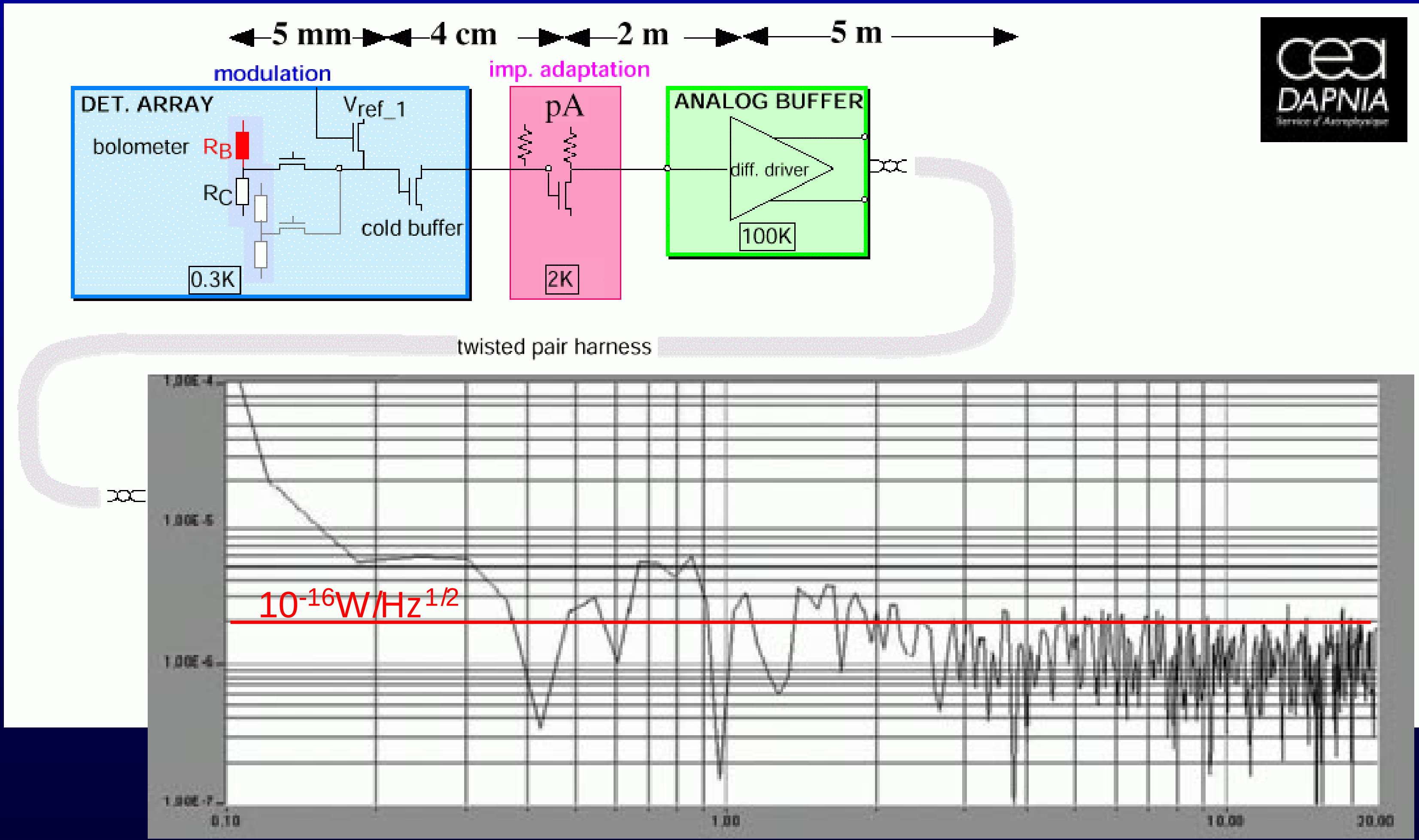


Bolometer Arrays: 16x16 Subarray

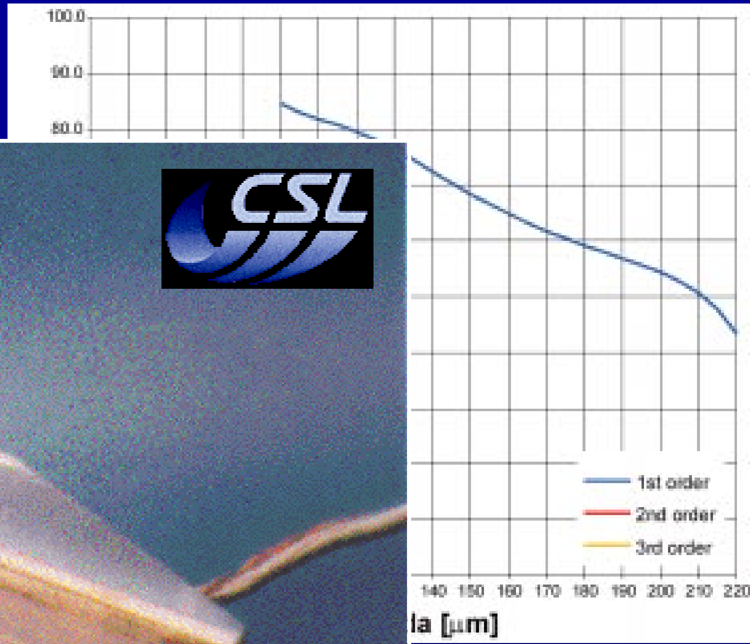




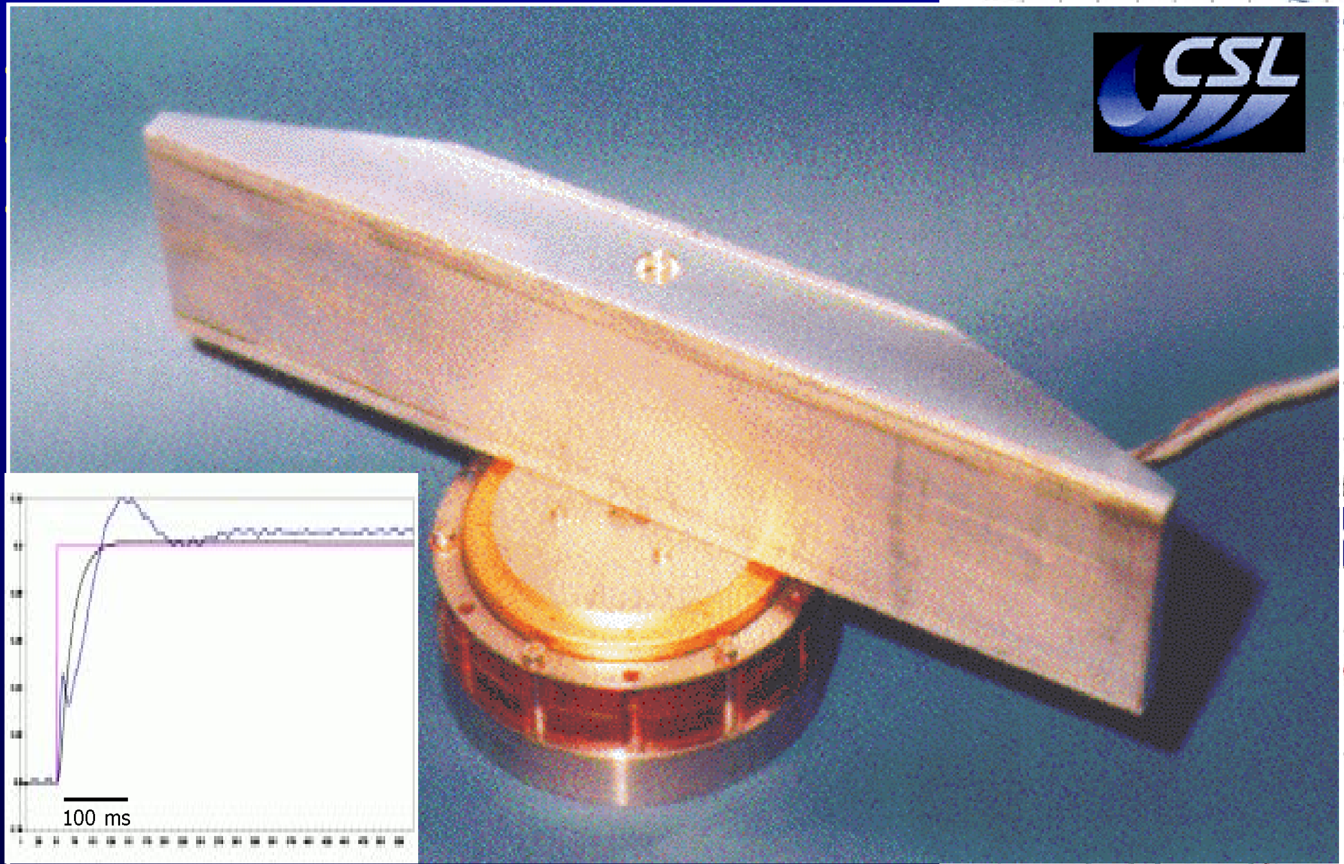
Bolometer Readout & Performance

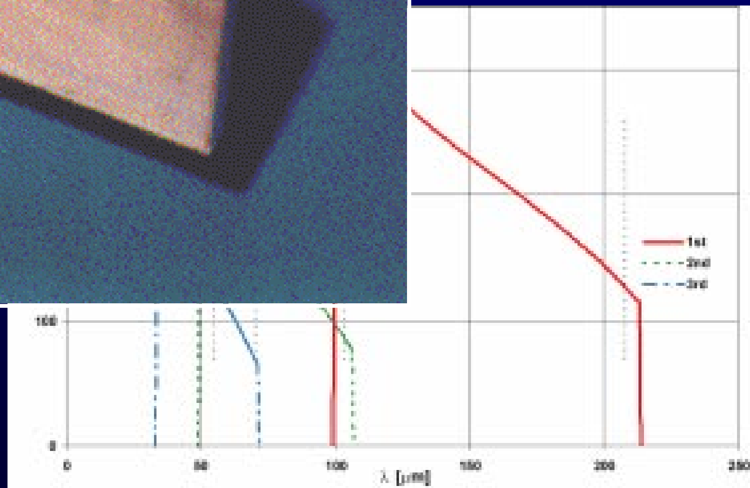


PACS Grating



d resolution (below)

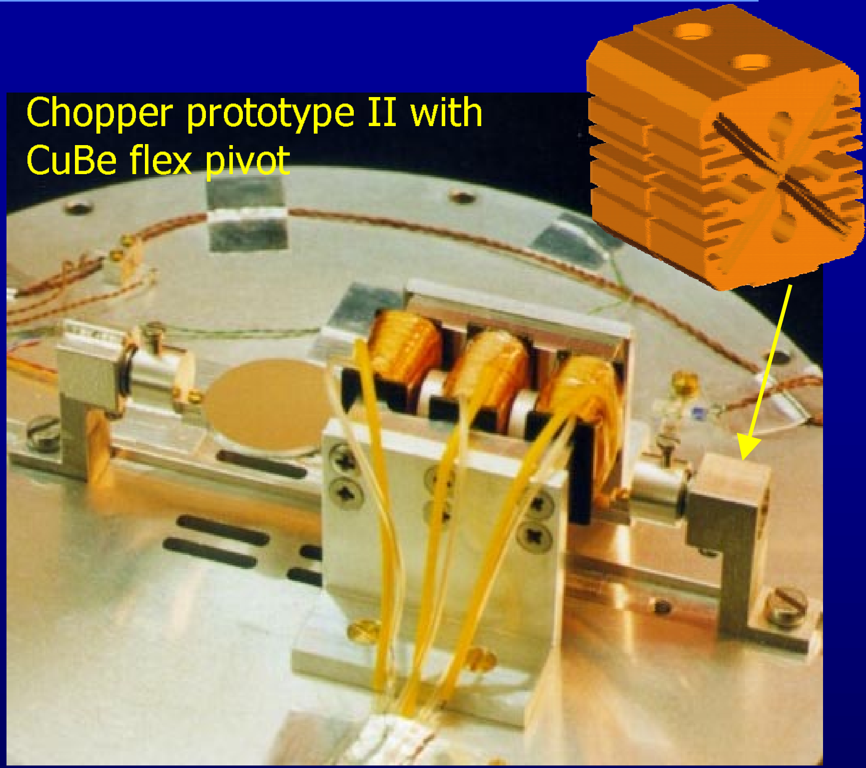


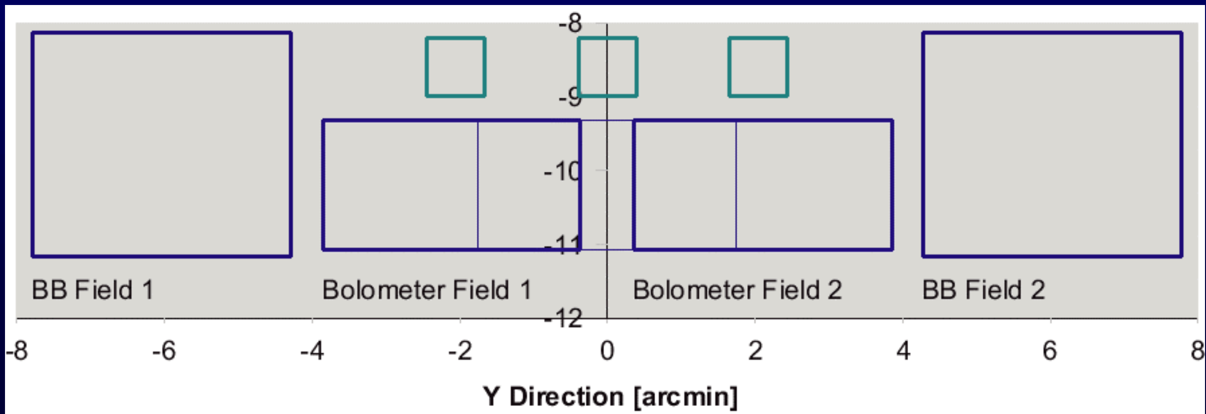


- Cryogenic torquer motor drive
- Inductosyn angular resolver

PACS Chopper

- Chopper with variable throw and arbitrary waveform used for spatial modulation and for observation of internal calibration sources
- Electromagnetic linear drive
- Monolithic CuBe flexural pivots
- Magnetoresistive position sensors
- Duty cycle > 80%





Parameters of PACS Instrument Model

optical element	efficiency	
	photometry	spectroscopy
Lyot stop	0.9	0.9
filters	0.4	0.4
mirrors	0.85	0.74
slicer diffraction	-	0.85
grating	-	0.65

level	T (K)	ε	effective transmission		relative bandwidth	
			photometry	spectroscopy	photometry	spectroscopy
telescope	80	0.04	0.31	0.15	$2.5^{-1}/2.2^{-1}$ (a)	1700^{-1}
baffle	65	0.01	0.34	0.16	$2.5^{-1}/2.2^{-1}$ (a)	1700^{-1}
"15 K" optics	15	0.05	0.34	0.16	$2.5^{-1}/2.2^{-1}$ (a)	1700^{-1}
"4 K" optics	5.5	0.15	760/190 (b)	4 (b)	1.5^{-1}	1.5^{-1}

(a) Values for the photometry modes from 60-90 / 90-130 µm and 130-210 µm, respectively.

(b) The formal transmission of >1 takes into account the acceptance solid angle of the light cones / bolometer pixels which differs from the beam solid angle.

Background, NEP, Spectroscopic and Photometric Sensitivity

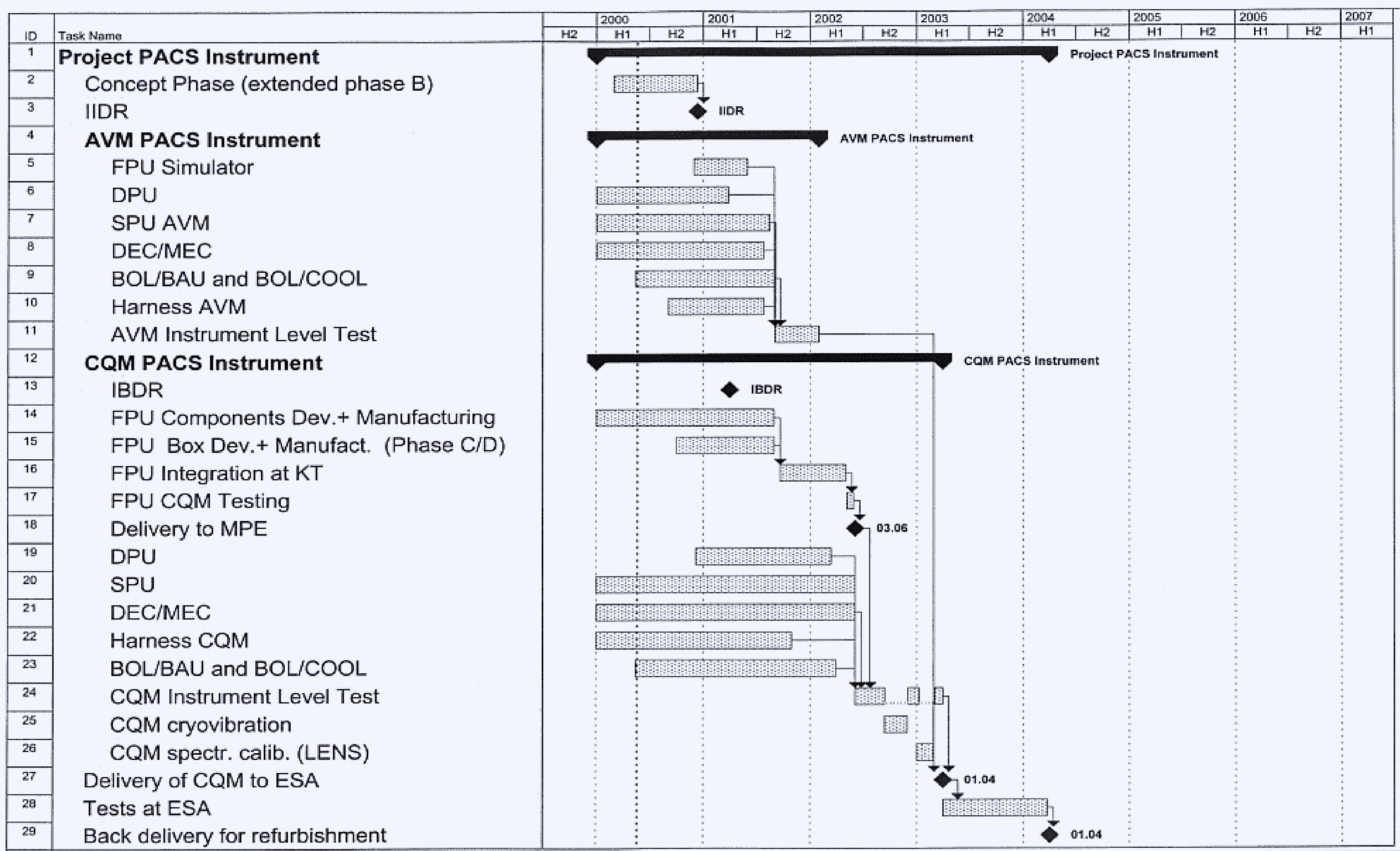
λ (μm)	R	Telescope efficiency	η_{pixel} [a]	Background (W)	BLIP NEP[b] ($W\ Hz^{-1/2}$)	Coupling[c] correction	System NEP ($W\ Hz^{-1/2}$)
60	1700	0.55	1	4.3×10^{-14}	4.4×10^{-17}	28	1.2×10^{-15}
90	1700	0.69	1	2.6×10^{-14}	2.8×10^{-17}	22	6.2×10^{-16}
130	1700	0.74	0.64	1.3×10^{-14}	1.6×10^{-17}	25	4.3×10^{-16}
180	1700	0.77	0.34	6.8×10^{-15}	1.0×10^{-17}	34	3.8×10^{-16}
60 – 90	2.5	0.64	0.13	7.8×10^{-12}	2.3×10^{-16}	31	7.7×10^{-15}
90 – 130	2.5	0.73	0.11	4.1×10^{-12}	1.4×10^{-16}	30	5.1×10^{-15}
130 – 210	2.2	0.77	0.19	7.5×10^{-12}	1.5×10^{-16}	22	3.9×10^{-15}

assumed detector NEPs: $5x10^{-18}$ $W/Hz^{1/2}$ (spectroscopy); 10^{-16} $W/Hz^{1/2}$ (photometry)

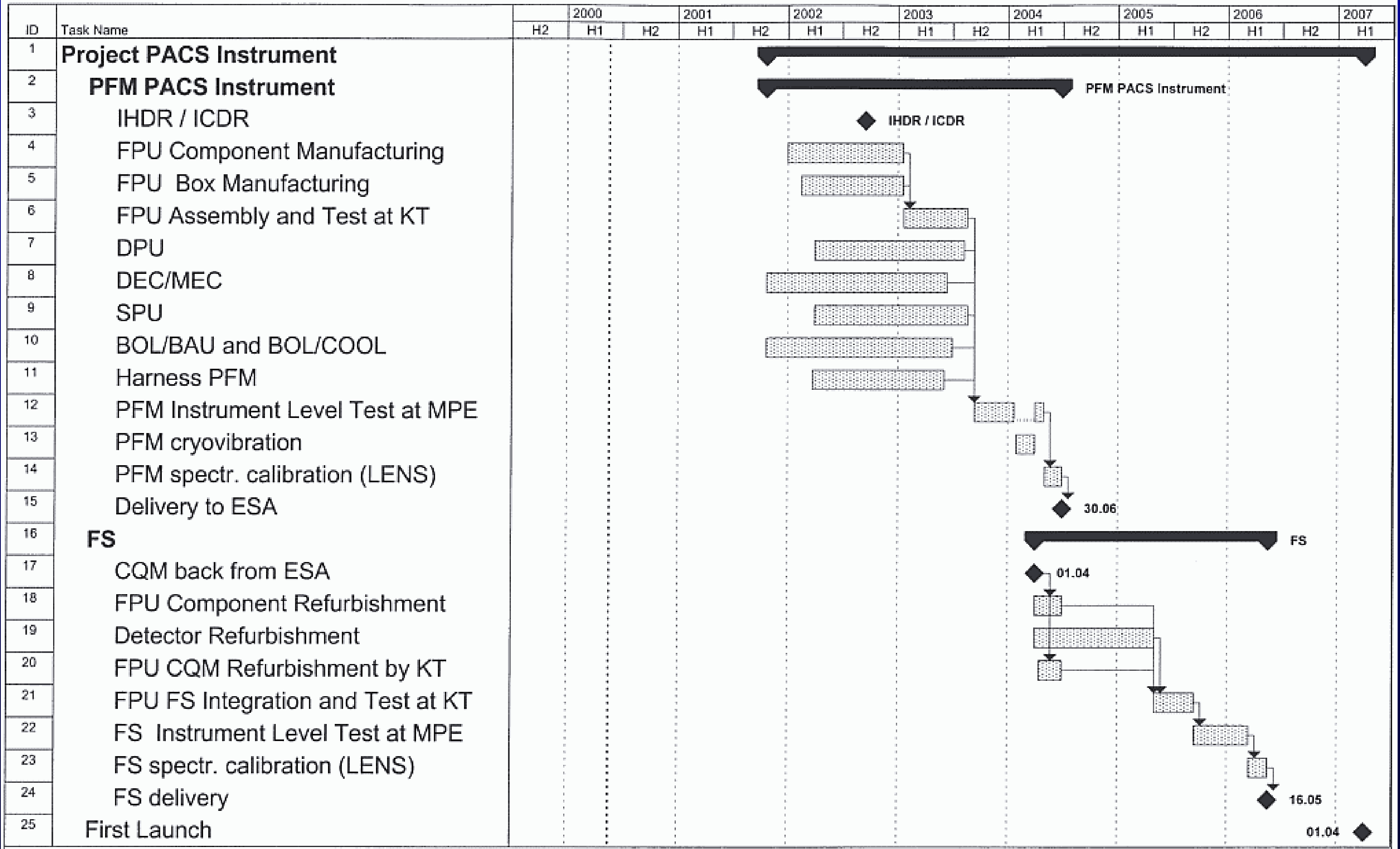
	spectroscopy				**photometry**		
λ(μm)	**60**	**90**	**130**	**180**	**60–90**	**90–130**	**130–210**
Point source detection limit (5σ, 1 hour)	7.8 (5.5)* $\times 10^{-18}$ Wm^{-2}	4.0 (2.8)* $\times 10^{-18}$ Wm^{-2}	2.8 (2.0)* $\times 10^{-18}$ Wm^{-2}	2.5 (1.8)* $\times 10^{-18}$ Wm^{-2}	3.1 (2.2)* mJy	3.0 (2.1)* mJy	3.2 (2.3)* mJy

*) with on-array chopping

PACS Development Schedule



PACS Development Schedule

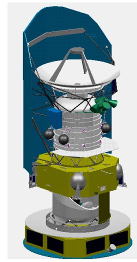


PACS Funding Status

- Austria: Received verbal confirmation that the proposal for the first phase(2000-2005) has been accepted by the funding ministries.
- Belgium: Funds for end 1999 and 2000 are not yet available. Belgian PRODEX projects are currently pending; approval expected mid-June. Major procurements are pending.
- France: CNES/CEA will fund extended involvement in PACS
- Germany: DLR agrees with overall funding proposal and supports new instrument concept. Funding started summer 1999.
- Italy: Funding for AVM started. Proposal for other phases in preparation.
- Spain: Funding for EM started. Proposal for other phases in preparation.

Critical Areas

- Late PRODEX funding in Belgium
  - start of CSL funding ~6 months late
  - delay in critical grating/drive prototype development
  - delay of QM grating assembly delivery by ~5 months; formal recovery to original schedule possible, but with great risk (no prototype)
- Decision on optical bench implementation
  - aluminium bench instead of carbon fiber would mean substantial positive impact on FPU design
  - in order to save time & cost and reduce risk, decision is needed very soon
- Missing high-level protocol for IEEE1553B interface
  - to be used for communication between DPU and CDMS
  - definition needed for WE development within 3 months



4.4 SPIRE Status

M. Griffin QMWC London

SPIRE

SPIRE PROJECT STATUS

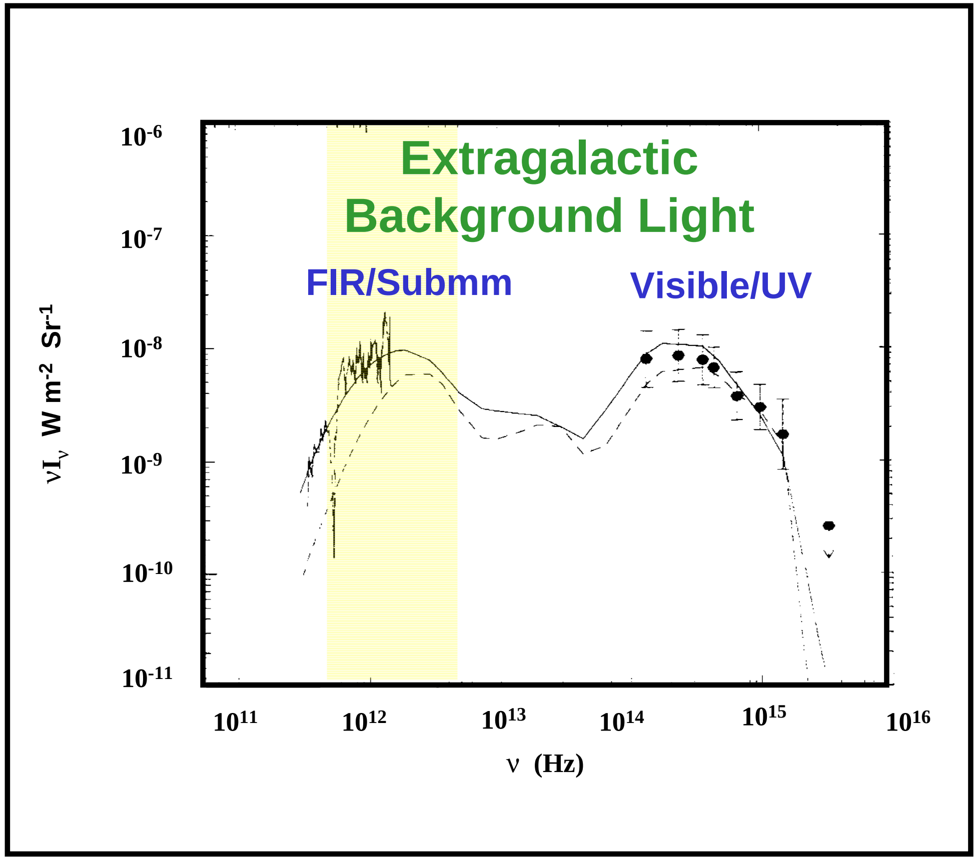
- **Scientific capabilities and goals**
- **Instrument design**
- **Consortium and management structure**
- **Instrument development plan**
- **Critical areas**

SPIRE

Main Scientific Goals

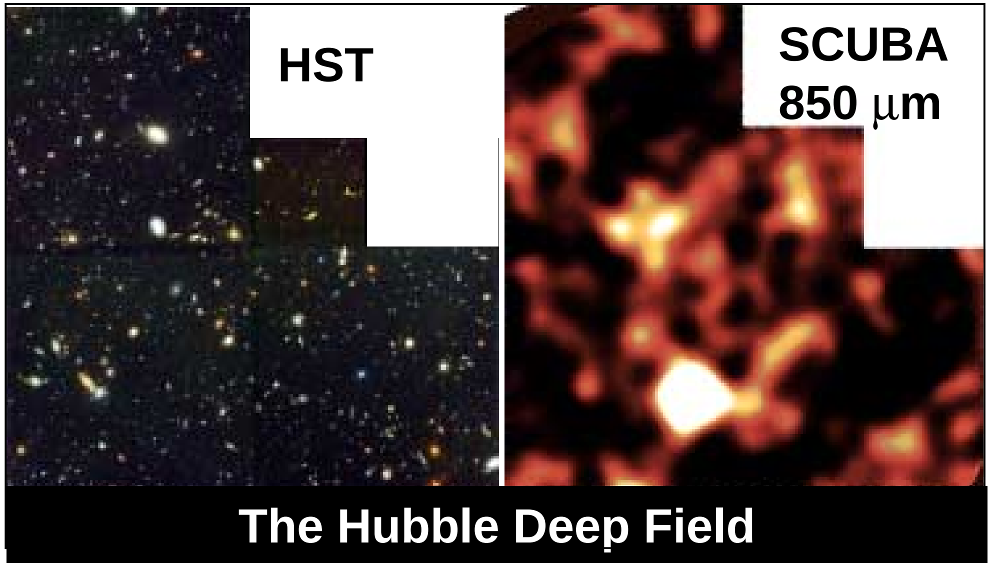
SPIRE concentrates on exploiting capabilities that are unique to FIRST

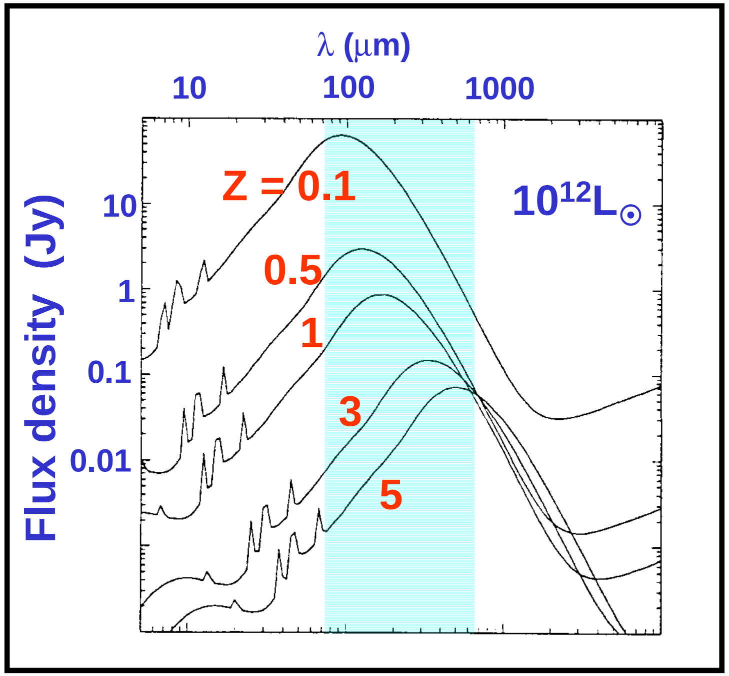
- **Deep photometric surveys of high-redshift galaxies**
- **Survey of our galaxy for protostars**
- **Imaging spectroscopy of the interstellar medium and nearby galaxies**
- **Follow-up/complementary observations with FIRST and other facilities**

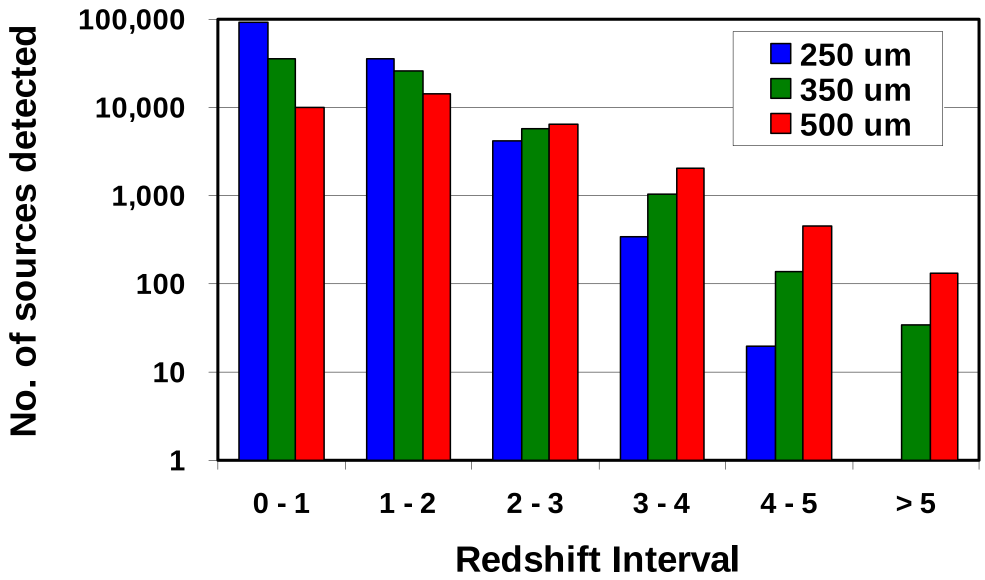


SPIRE

High-z Galaxy Survey
100 days,
100 Sq. Deg.







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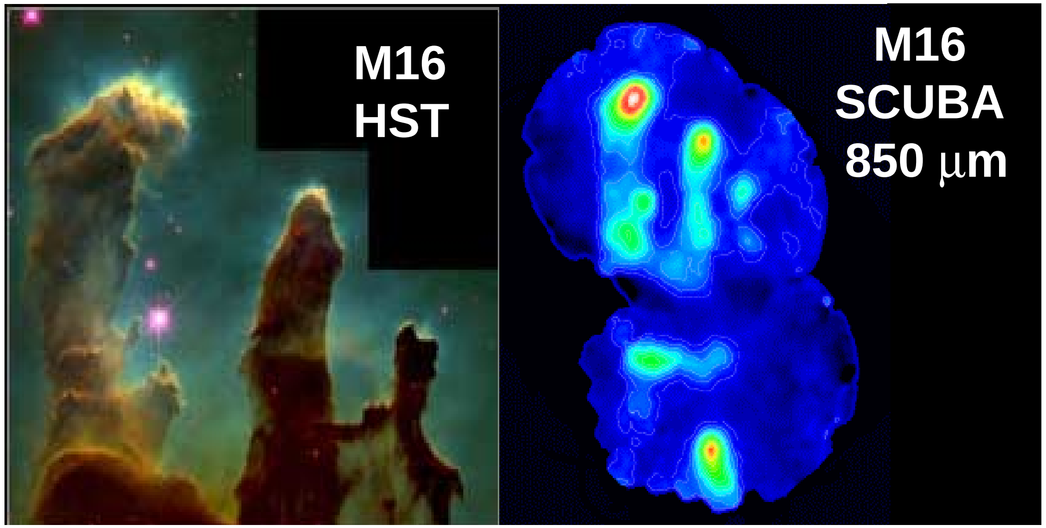
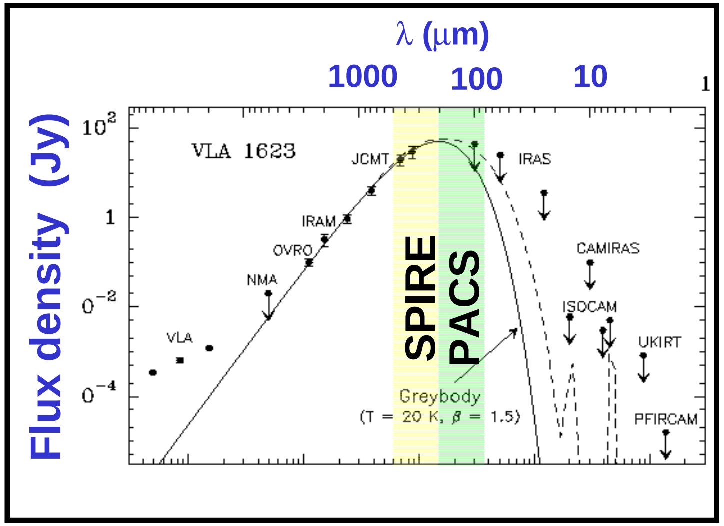
Star Formation and the Interstellar Medium

- **Complete census of protostars in local star-forming clouds**
  - **Cluster formation**
  - **Structure and fragmentation of molecular clouds**
  - **Origin of the stellar Initial Mass Function**

- **Imaging spectroscopy of the interstellar medium and nearby galaxies**





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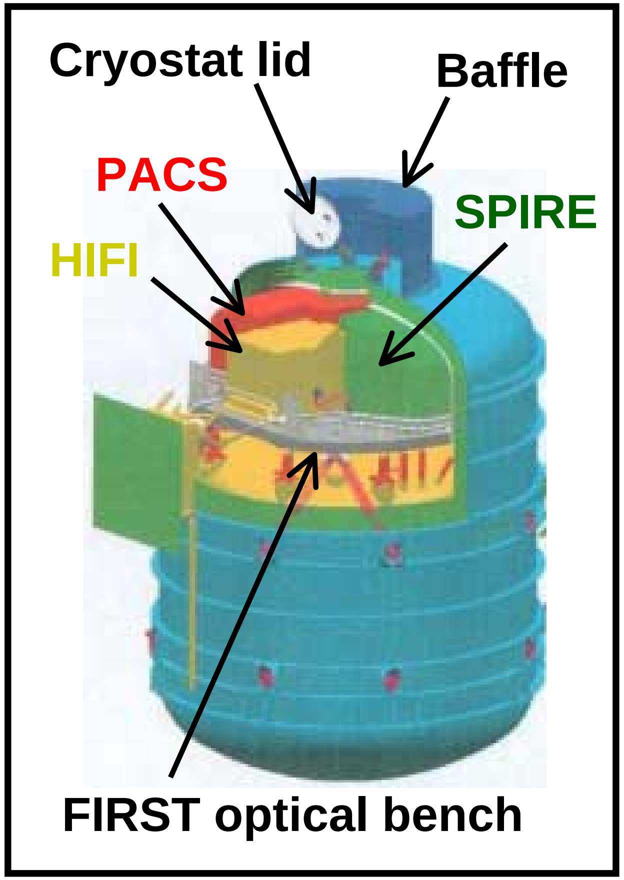
SPIRE Instrument Summary

- **3-band imaging photometer**
  - 250, 350, 500 μm (simultaneous)
  - $\lambda/\Delta\lambda \sim 3$
  - 4 x 8 arcminute field of view
  - Diffraction limited beams (18, 25, 36")
- **Imaging FTS**
  - 200 - 670 μm
  - 2.6 arcminute field of view
  - $\Delta\sigma = 0.04\ cm^{-1}$
    ($\lambda/\Delta\lambda \sim 20 - 1000$ at 250 μm)
- **Design features**
  - Sensitivity limited by thermal emission from the telescope (80 K; ε = 4%)
  - ^{3}He cooled detector arrays (0.3 K)
  - Feedhorn-coupled spider web NTD bolometers
  - Minimal use of mechanisms
    - Beam steering mirror; FTS mirror drive



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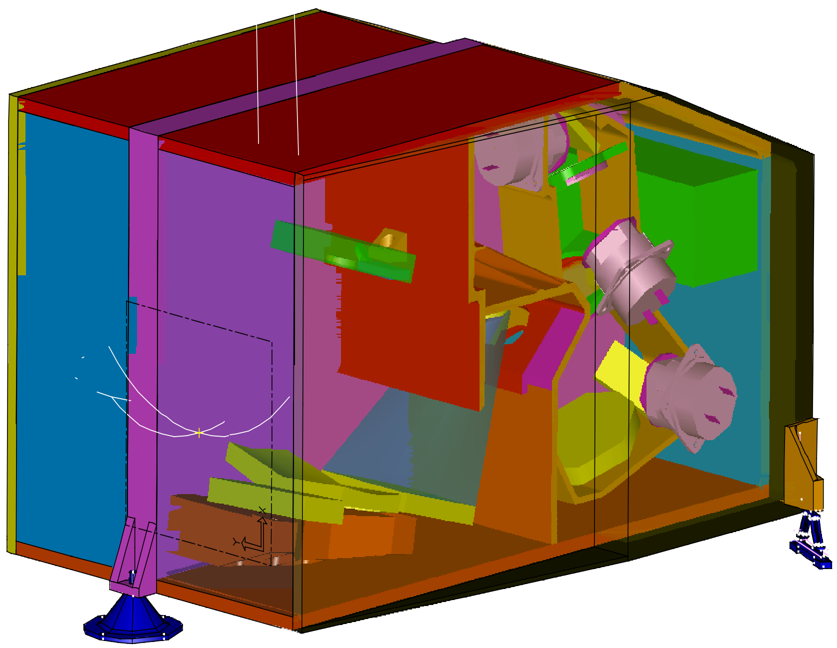
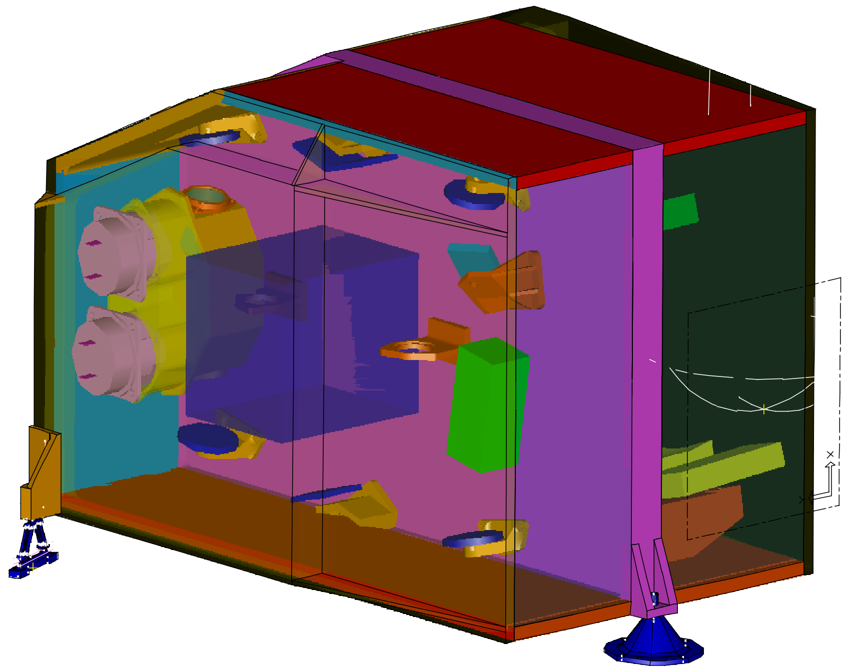
FPU Internal Layout

Photometer



Spectrometer



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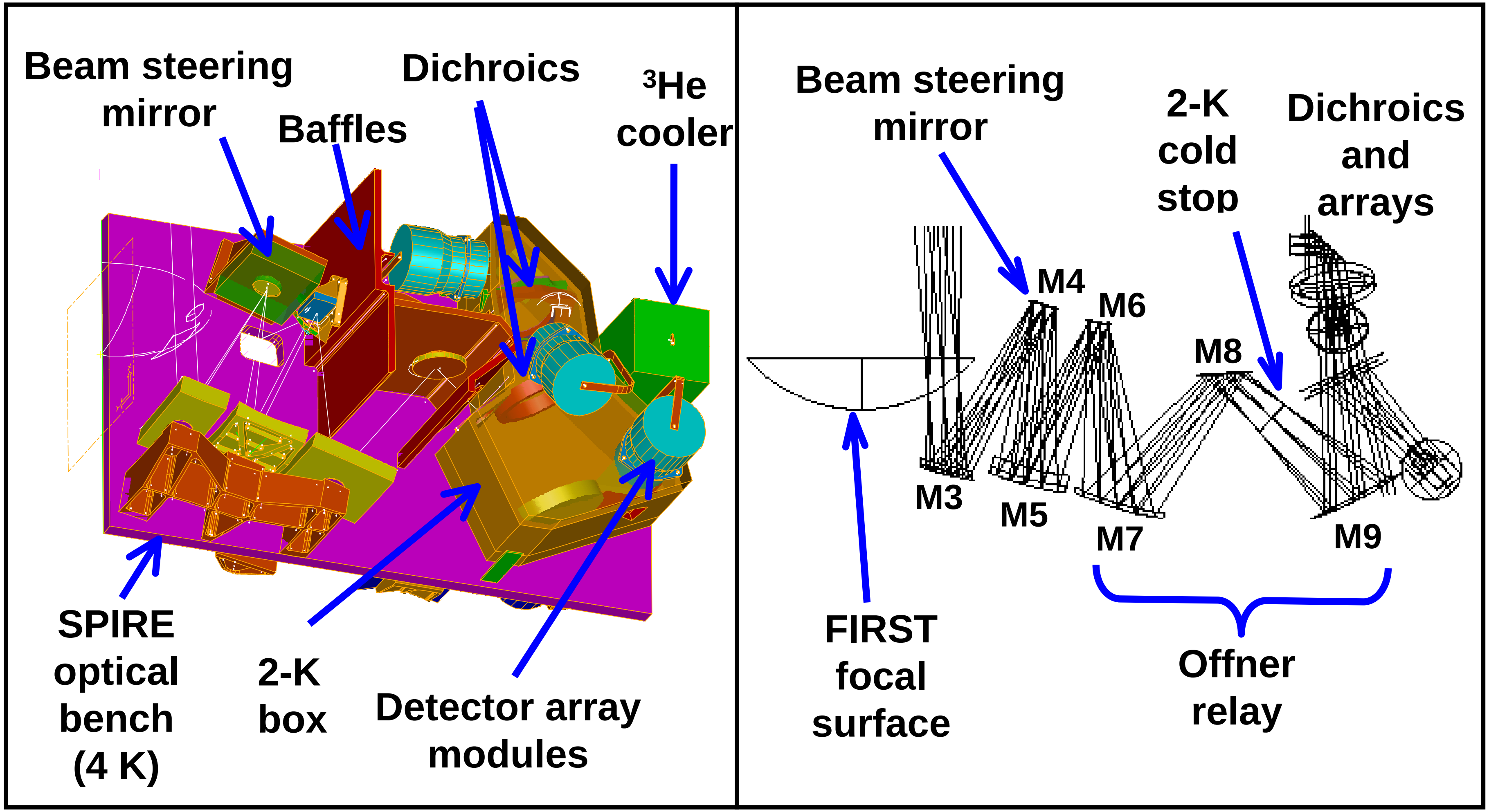
Photometer Layout and Optics



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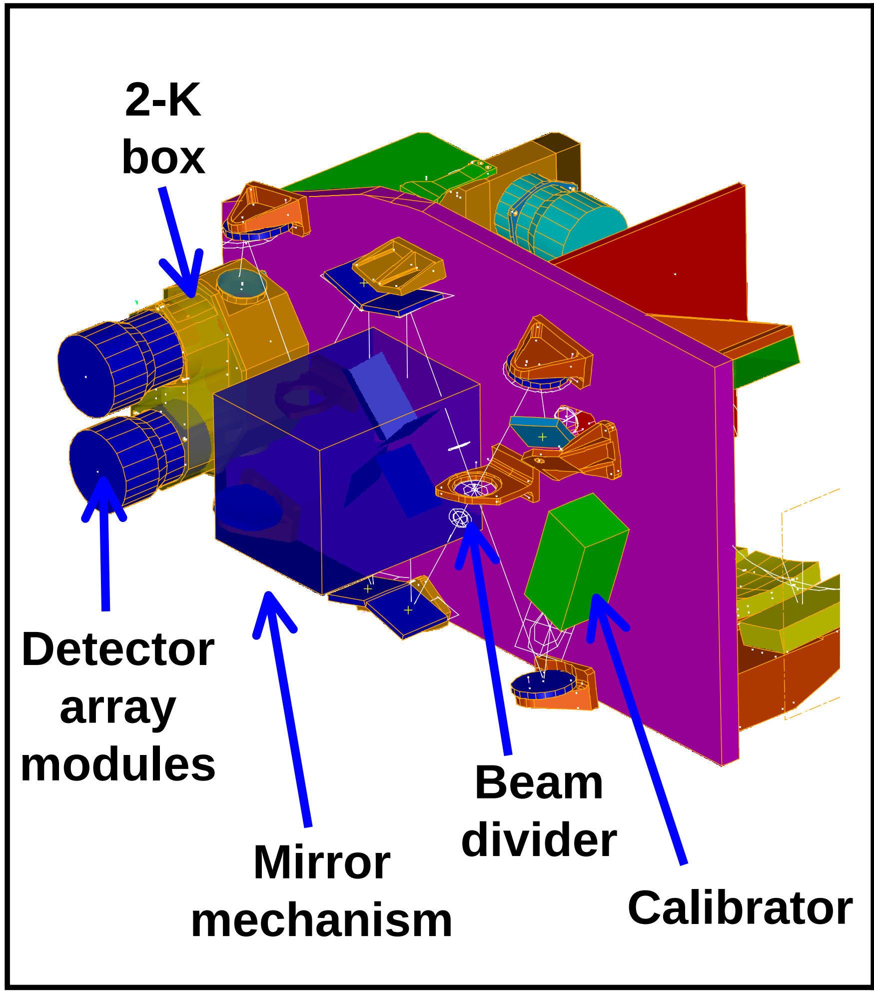
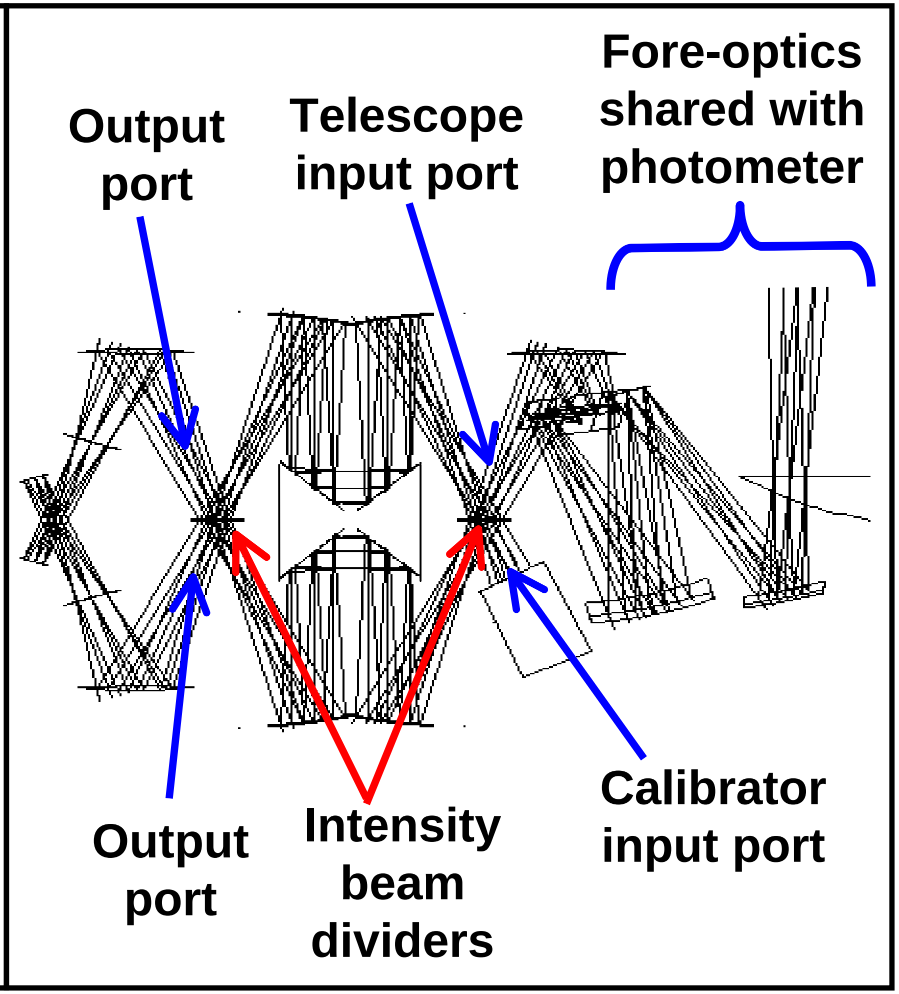
FTS Layout and Optics





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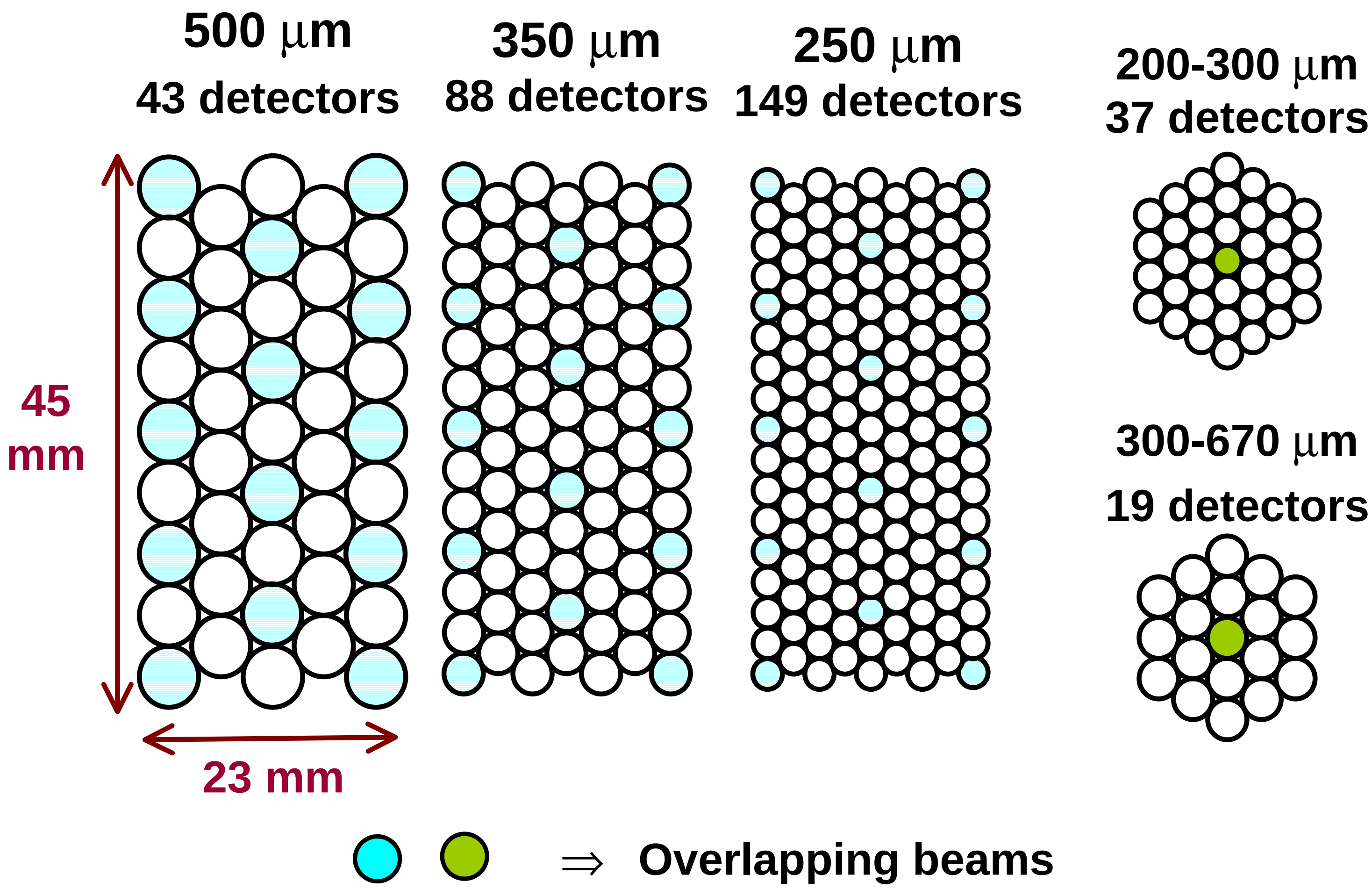
Detector Arrays (2Fλ feedhorns)

Photometer	Spectrometer



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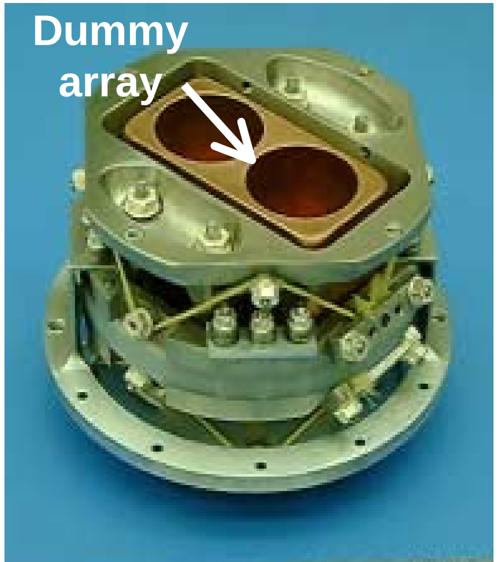
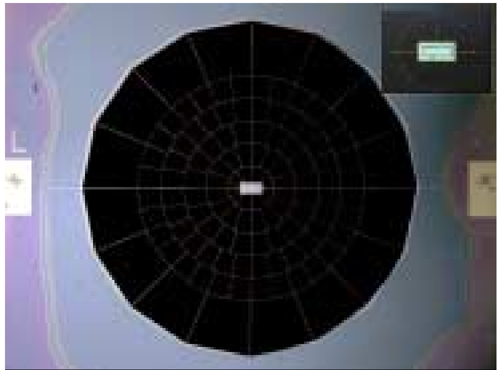
Prototype Hardware

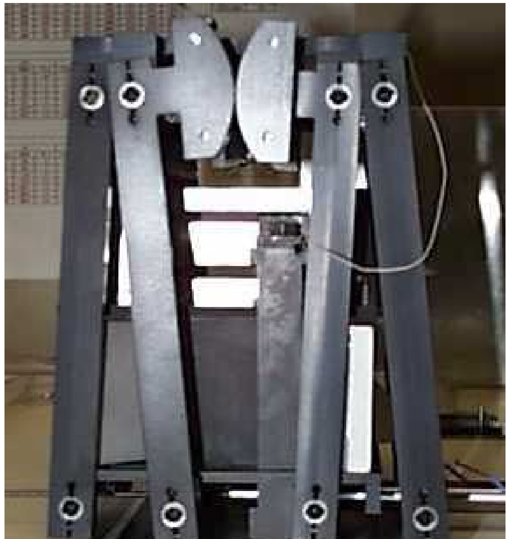
^{3}He cooler



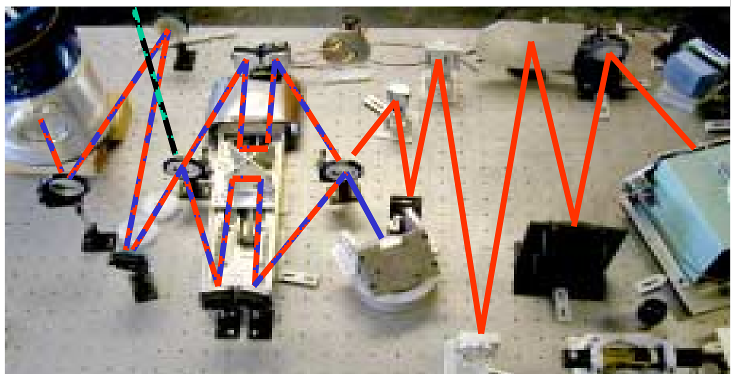
Array module



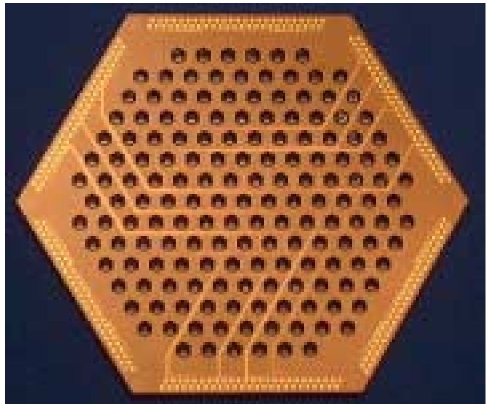
Spider-web bolometer



FTS mechanism



Mach-Zehnder FTS



Bolometer array

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Instrument Sensitivity

Photometry			
λ (μm)	250	350	500
Point source ΔS (1σ, 1hr) (mJy)	0.48	0.53	0.59
4' by 8' map ΔS (1σ, 1hr) (mJy)	1.1	1.2	1.5

Spectroscopy				
λ (μm)		200	400	670
Line Spectroscopy: Δσ = 0.04cm^{-1}				
ΔF (1σ, 1hr) (W m^{-2} x10^{-18})	Point source:	5.4	6.9	14
	2.6' map:	13	16	32
Low-resolution spectrophotometry: Δσ = 1cm^{-1}				
ΔS (1σ, 1hr) (mJy)	Point source:	18	23	46
	2.6' map:	44	53	108

Sensitivity and field of view both improved over figures in the SPIRE proposal

SPIRE

Instrument Sensitivity for Deep Surveys

λ (μm)	FWHM (arcsec.)	1-σ; 1 sec. point source limit (mJy)	Confusion noise limit (1 source per 40 beams) (mJy)	Time needed to reach confusion limit at 5σ (min.)	Field of view (sq. arcmin.)	Time to map 1 sq. deg. to the confusion limit (days)
250	18	65	23.4	3.2	32	0.27
350	25	74	24.0	4.0	32	0.34
500	36	87	17.4	10.4	32	0.89

Confusion limits are from models of M. Rowan-Robinson

Survey examples:

- **100 sq. deg. confusion-limited extragalactic survey (100 days)**
- **Follow-up survey of 400 sq. deg. Planck DECS (10 days)**

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SPIRE Hardware Responsibilities

Institute	Role
Astronomy Technology Centre, Edinburgh	Beam Steering Mechanism (BSM); FPU Systems Engineering
Obs. de Meudon, Paris	FTS expertise and design support
CEA, Grenoble	^{3}He cooler
Goddard Space Flight Center, Maryland	Internal calibrators
Instituto di Fisica dello Spazio Interplanetario, Rome	Digital Processing Unit (DPU); On-Board Software
JPL/Caltech, Pasadena	Bolometer array modules; JFET Box
Laboratoire d'Astophysique, Marseille	Optics, FTS mechanism; FTS/BSM electronics
Mullard Space Science Laboratory, Surrey	FPU structure
Queen Mary and Westfield College, London	Testing and calibration of bolometer arrays; filters, dichroics, beam dividers
Rutherford Appleton Laboratory, Oxfordshire	Project management; Project office; AIV and ground calibration
CEA, Service d'Astrophysique, Saclay	Detector Readout and Control Unit (DRCU)
University of Saskatchewan, Canada	Shutter; AIV facility hardware (TBC)
Stockholm Observatory	DRCU and instrument simulators
TBD	Instrument cold vibration

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SPIRE ICC Responsibilities

- ICC Centres (including manpower)
  - ICC Operations Centre at RAL (sole interface with ESA)
  - DAPSAS Centres at ICSTM, London and CEA, Saclay
- Additional manpower for ICC development and operations provided by:
  - IAC, Tenerife
  - IFSI, Rome
  - Padova Observatory
  - University of Saskatchewan
  - IPAC, Pasadena
  - Stockholm Observatory

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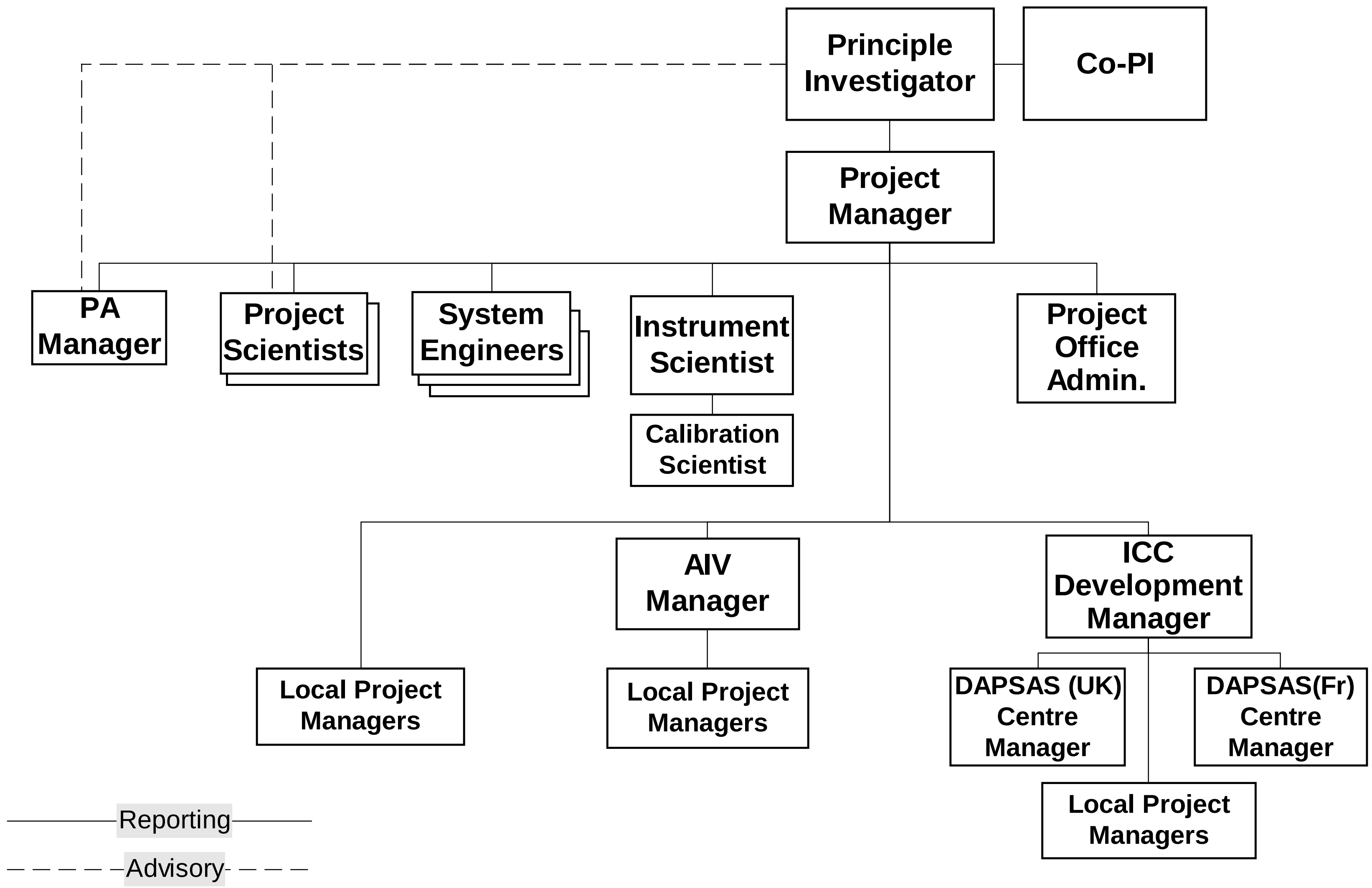
Management Structure



SPIRE

Model Philosophy 1

- **AVM**
  - Includes DPU and DRCU Simulator
  - Flight standard (DPU), no redundancy, commercial parts
  - Functionality not yet finalised - need to simulate anomalies and science data?
  - Parts not from same manufacturer (TBD) as FM

- **CQM**
  - Flight standard subsystems, but not all redundancy
  - Two full detector arrays; others partly-filled
  - SPIRE requirements more stringent than ESA's - use as QM
  - Schedule driven by Critical Design Review date and PFM programme, not QM delivery
  - Schedule includes warm vibration of Structural Model (STM) to mitigate risk

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Model Philosophy 2

- **PFM**
  - Fully flight standard

- **FS**
  - Cold Units
    - Fully flight standard
    - May be refurbished CQM units
    - Question of need for spare FPU vs. repair
  - Warm Units
    - DPU : spare cards only
    - DRCU : spare unit or spare cards, TBD
    - WIH : spare unit

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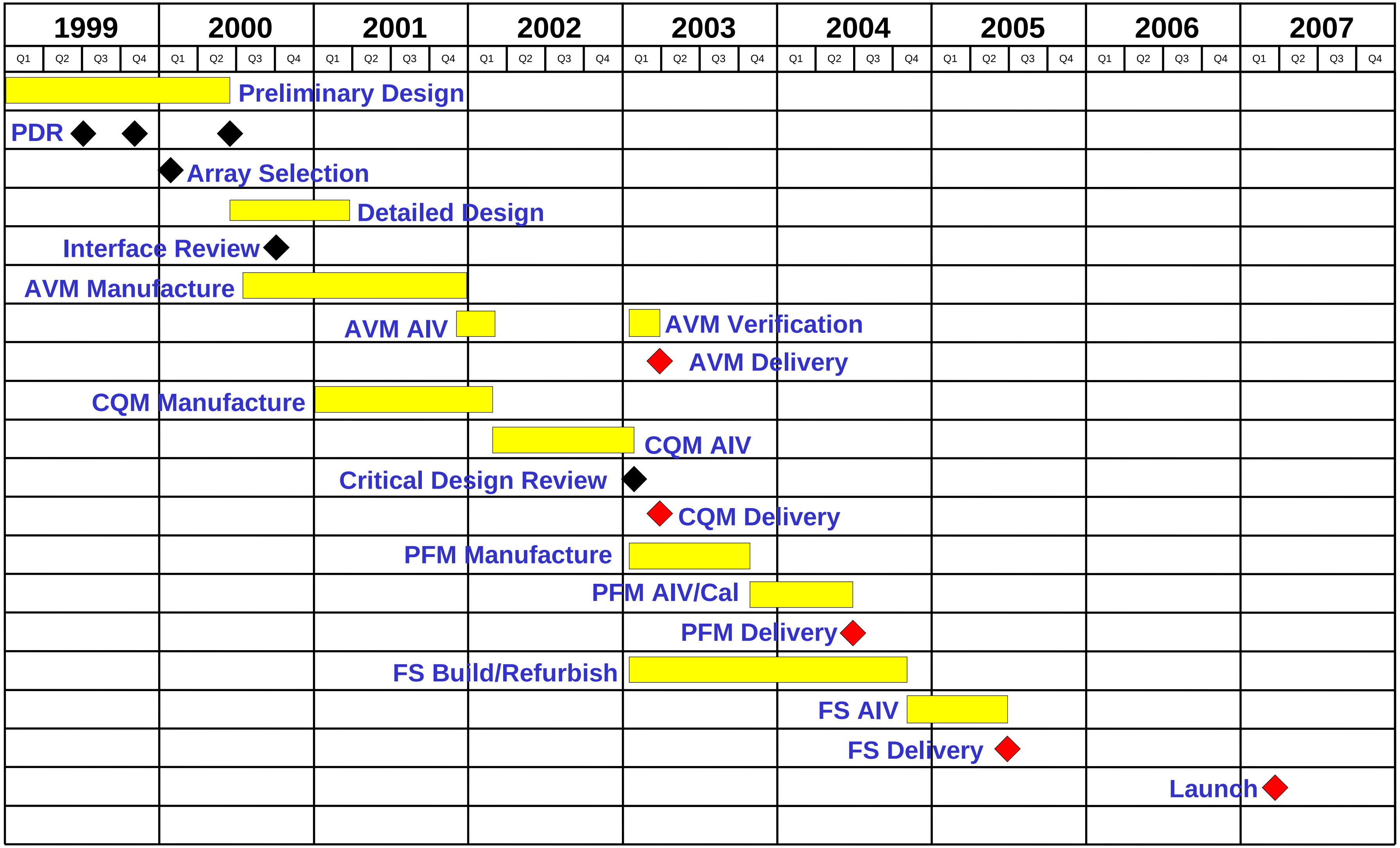
Schedule



SPIRE

Preliminary Design Review/ISVR

- **July 1999:** **Science Requirements; Instrument Requirements; Focal Plane Unit**

  December 1999: **Warm Electronics**

  Jan/Feb 2000: **Detector Array Selection**

- **All have had ESA and independent oversight**

- **Review programme agreed with ESA to cover the *Instrument Science Verification Review***

- **Last Phase: June 26/27 2000**
  - **Design updates**
  - **Clarifications following detector selection**
  - **Detailed assessment of schedule and development plan**

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Detailed Design Review/IIDR

- **October 2000:**
  - **Formal review and freezing of:**
    - **All interfaces**
    - **Qualification status and plans**
    - **Subsystem Development Plans**
  - **Identification of long lead-time items**

- **October 2000 - February 2001:**
  - **Series of specific subsystem technical reviews**
  - **Each of these to release the subsystems for manufacture**

SPIRE

AVM Development Plan

- Feb 02: Deliveries of AVM warm electronics units
  - AVM Verification
- Aug 02: Use for CQM verification and testing
- Feb 03: AVM acceptance testing
- Apr 03: AVM delivery to ESA

SPIRE

CQM Development Plan

- Mar 02: Deliveries of CQM focal plane subsystems
  - STM integration and alignment tests
  - STM vibration tests (warm)
  - Instrument integration and alignment check
- Aug 02: Test readiness review
  - Functional and performance tests
- Nov 02: Cold vibration tests
  - Functional and performance tests
  - Performance verification
- Jan 03: FPU Critical Design Review
- Mar 03: Delivery of QM WE units
  - QM Warm Electronics Qualification
- Apr 03: CQM delivery to ESA

CQM testing is carried out using the AVM warm electronics

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PFM Development Plan

- **Sep 03: Deliveries of PFM focal plane subsystems**
  - **Instrument integration and alignment check**
- **Jan 04: Test readiness review**
  - **Functional and performance tests**
- **Mar 04: Cold vibration tests**
  - **Functional and performance tests**
- **Apr 04: Delivery of PFM WE units**
  - **PFM warm electronics qualification**
  - **Calibration (6 weeks)**
- **Jul 04: PFM delivery to ESA**

PFM testing is carried out using the QM warm electronics

SPIRE

FS Development Plan

- **Sep 04: Deliveries of PFM focal plane subsystems**
  - **Instrument integration and alignment check**
- **Jan 05: Test readiness review**
  - **Functional and performance tests**
- **Mar 05: Cold vibration tests**
  - **Functional and performance tests**
- **Apr 05: Delivery of PFM WE cards**
  - **FS warm electronics verification**
  - **Calibration (6 weeks)**
- **Jul 05: FS Delivery to ESA**

Some manufacturing starts with the CDR (Jan 03), some with return of the CQM (Apr 04)

FS testing is carried out using the FS cards in the QM warm electronics boxes

Funding Status

- **UK:**
  - **Fixed funding envelope: any delay has to be accommodated within the limit**
  - **Some additional work taken on after array selection**
  - **Funding shortfall for ICC still to be addressed**
- **France:**
  - **CNES have committed to providing DRCU, FTS, ^{3}He cooler**
  - **ICC funding to be clarified**
- **USA:**
  - **Funding for detector arrays secure**
  - **Possible contributions to FTS mechanism, internal calibrators**
- **Canada:**
  - **Support for shutter and ICC staff effort confirmed**
  - **Contribution to AIV facility under discussion**
- **Italy, Sweden, Spain: Funding is secure**

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Critical Areas: Spacecraft Interfaces

- Optical bench: CFRP or Aluminium
  - Designing for *either* option is problematic
  - Significant cost/complexity implications
  - SPIRE has strong preference for Aluminium
- DPU-CDMS packet transfer protocol
  - Impact on DPU design and EGSE, which have to be frozen soon
- Use of SCOS2000 for system level tests
  - Choice of any other system by contractor will lead to extra work for SPIRE
- Qualification programme schedule
  - CQM must be build and qualified very shortly after contractor is appointed
- EMC/EMI
  - Difficult area for bolometer instruments, requiring attention to the whole system

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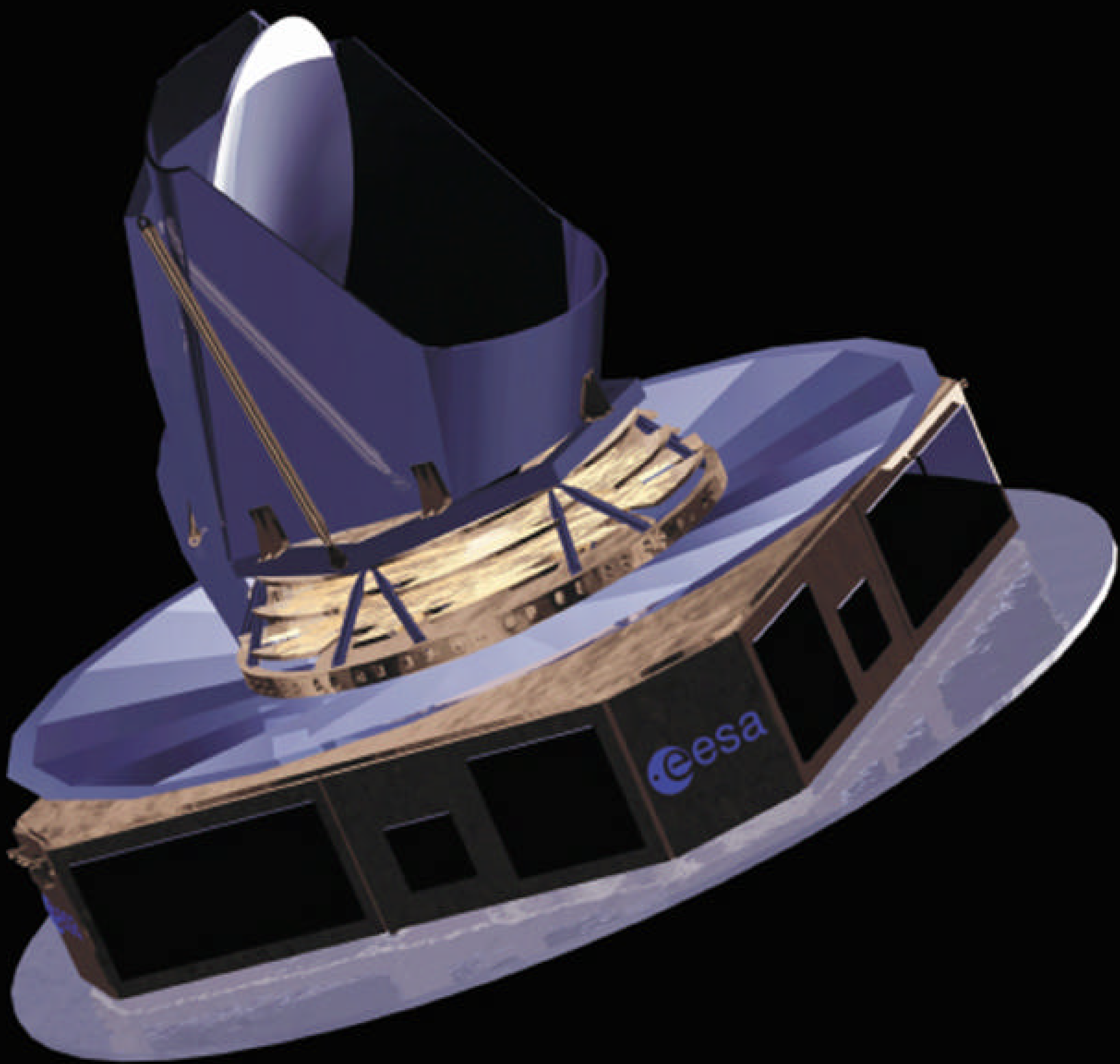
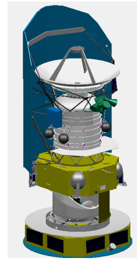
Critical Areas: SPIRE

- **Stray light**
  - **Potential problem with any low background bolometer instrument**
- **FPU mechanical/thermal engineering**
  - **STM programme highly desirable to verify performance and mitigate risk**
- **FTS mechanism**
  - **Challenging mechanism with stringent specifications**
- **Cold vibration facility**
  - **Assumption that ESA will arrange for its provision**
- **Lack of margin in schedule**
  - **Need to complete CQM programme before starting PFM programme**

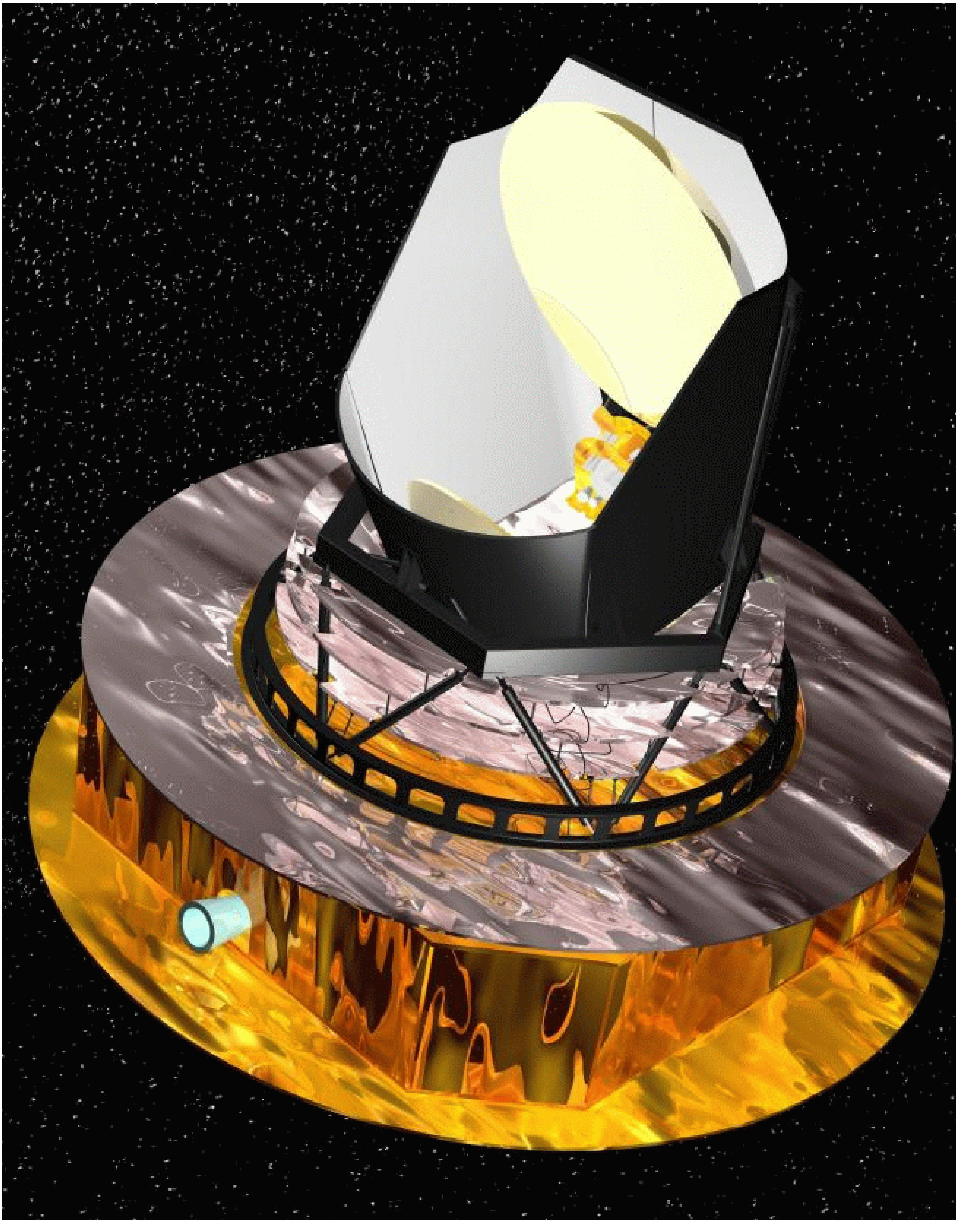
Planck Satellite





5. Planck Payload

J. Tauber ESA/ESTEC



Payload review - 23/5/2000

1. Scientific objectives
2. Extracting science from Planck
3. Planck in a wider context
4. Payload overview
5. Review cycle and status

1. Scientific objectives

Key Scientific Objectives

- CMB anisotropy maps to an accuracy $\Delta T/T \sim 1 \times 10^{-6}$, on angular scales <10' → 180°
- Cosmological parameters, H_o, Ω_o, Ω_b, ... to a precision of a few percent
- Tests of inflationary models of the early Universe
- Search for non-gaussianity/topological defects
- Initial conditions for formation of large-scale structure
- Nature of dark matter
- Detection of Sunyaev-Zeldovich effect in thousands of rich clusters of galaxies
- Extragalactic sources and backgrounds
- Maps of Galaxy at frequencies 30 → 1000 GHz

Main Observational Objective:

To image the whole sky at wavelengths near the peak of the spectrum of the Cosmic Microwave Background Radiation Field (CMB), with a sensitivity $\Delta T/T \sim 10^{-6}$, and angular resolution ~5 arcminutes.

Observational Strategy:

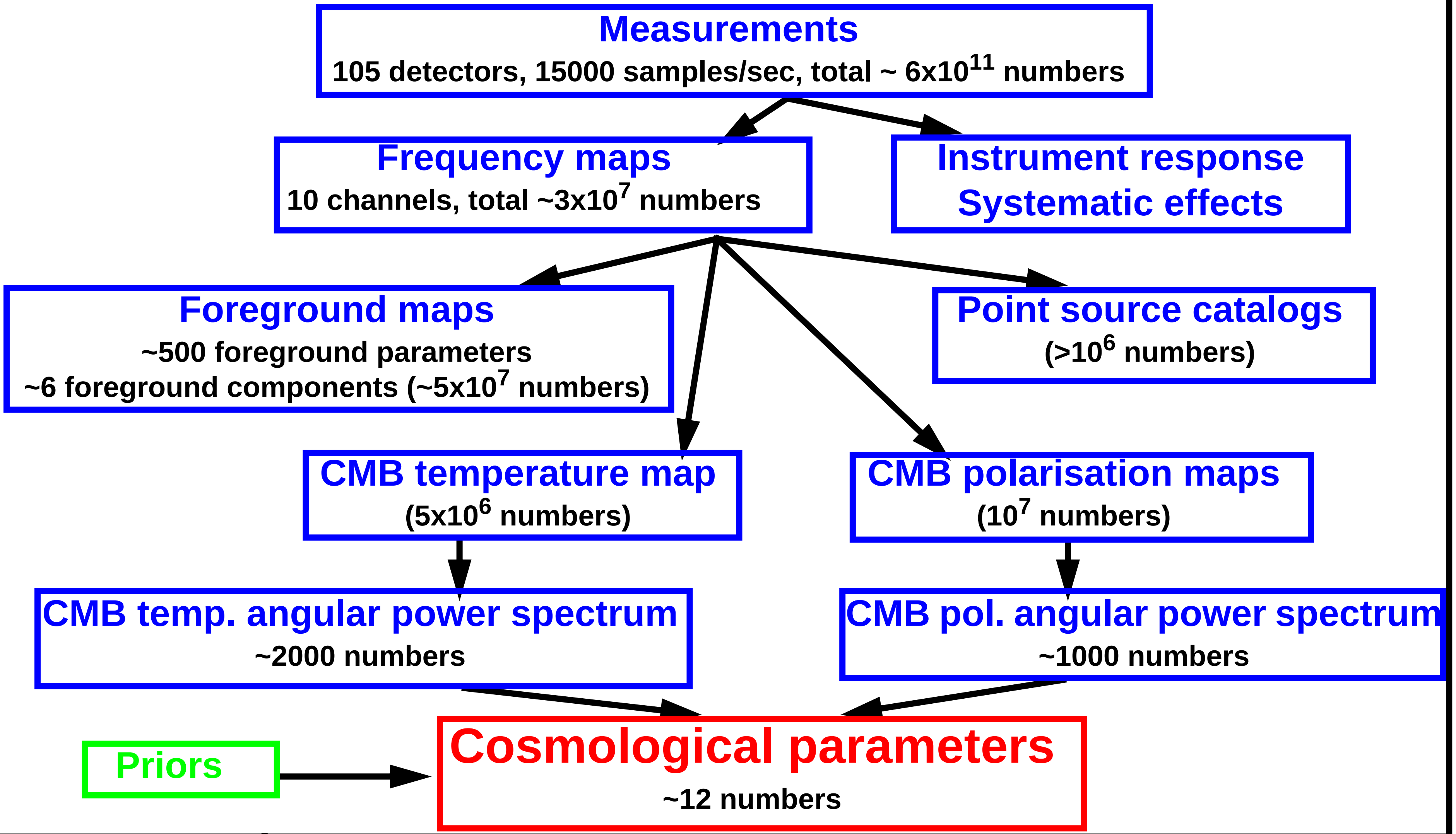
- **Two successive all-sky surveys**
- **1.5 metre aperture telescope**
- **wide frequency coverage (30 Ghz - 900 GHz)**
- **State-of-the-art detectors**
- **extreme attention to systematic effects**

esa

PLANCK

2. Extracting science from Planck

Extracting the science



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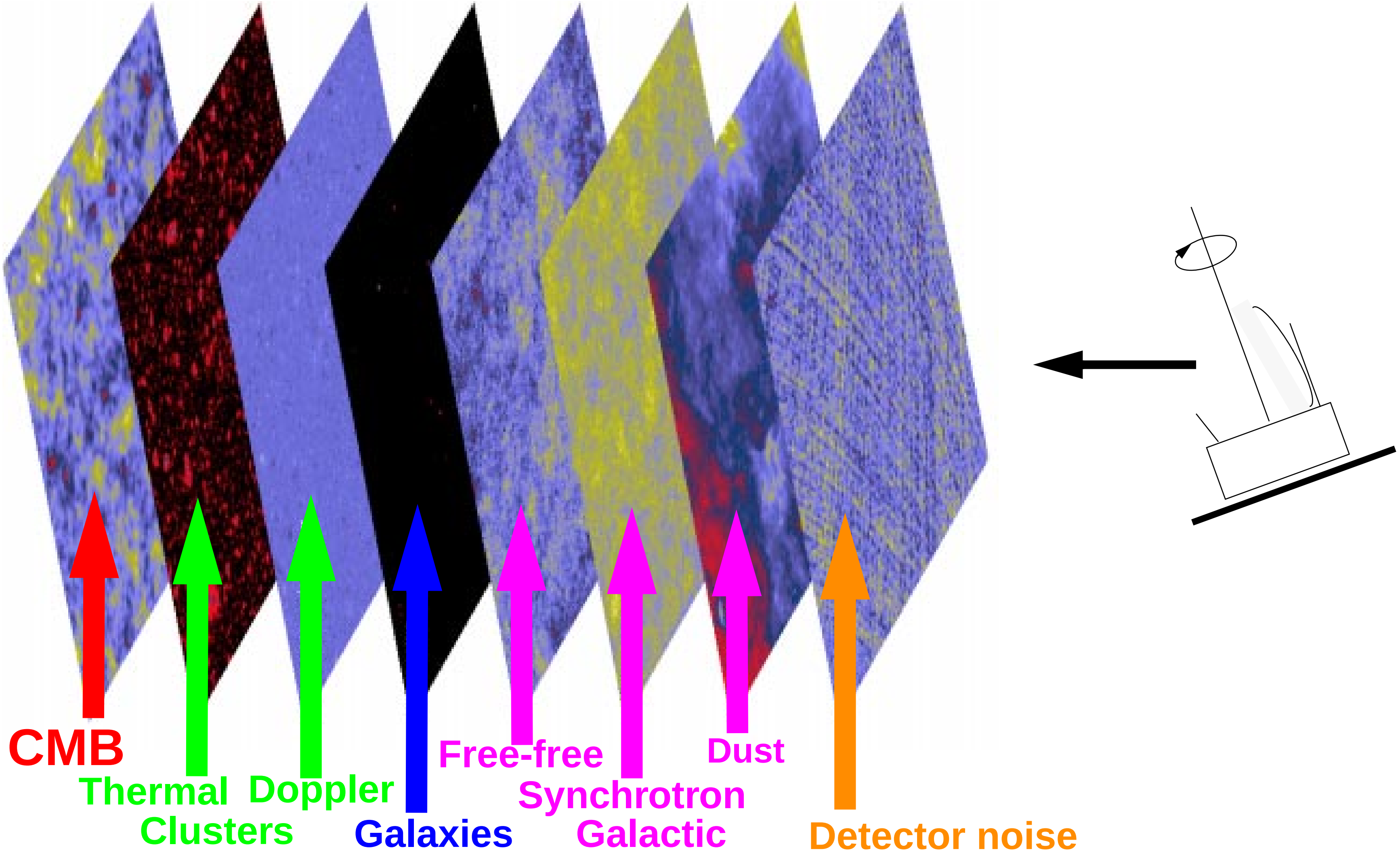
Foreground separation



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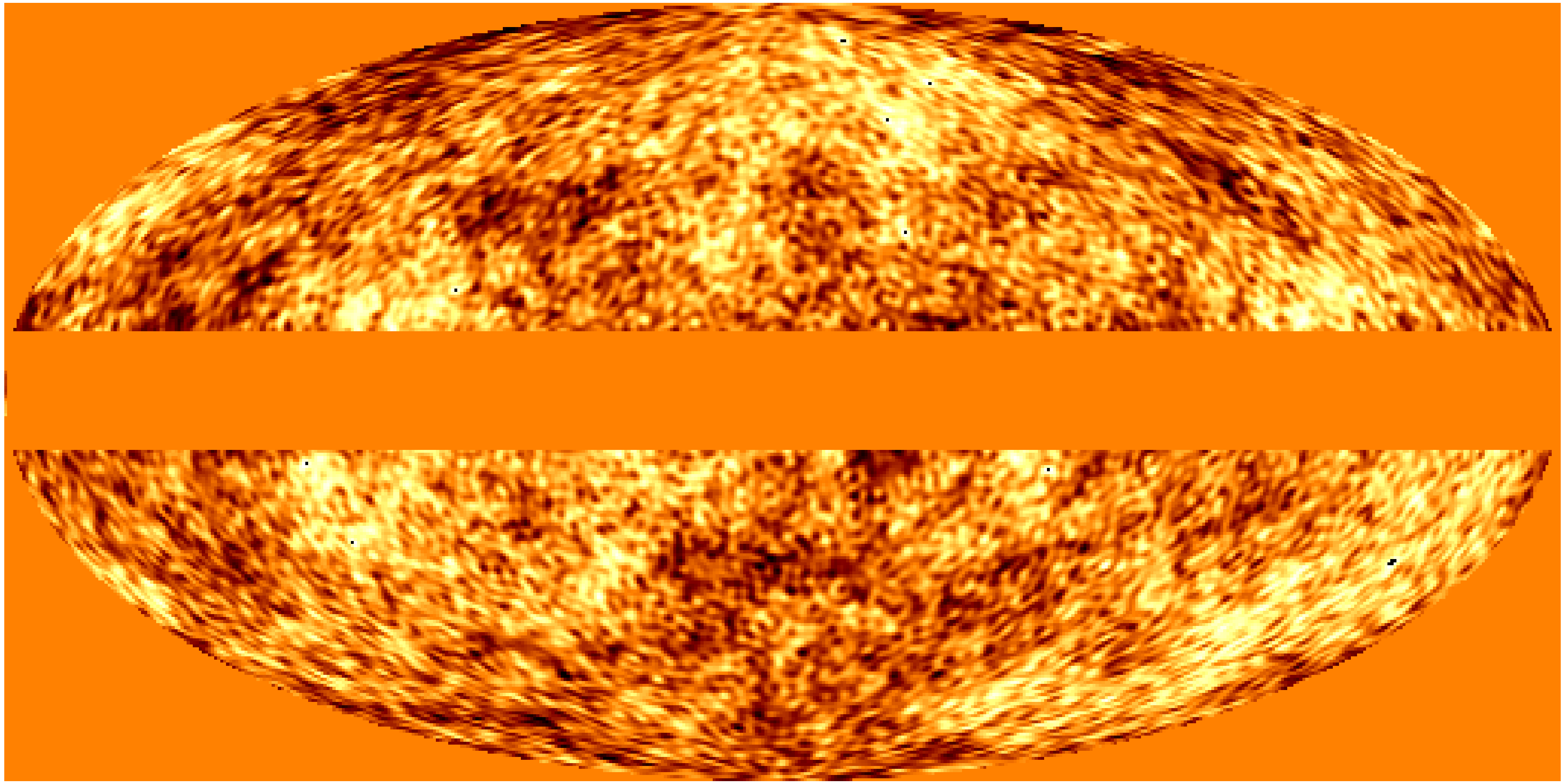
PLANCK

The CMB according to Planck



Simulated CDM Ω=1 model,$\Delta\Theta$=10', $\Delta T/T=2\times10^{-6}$

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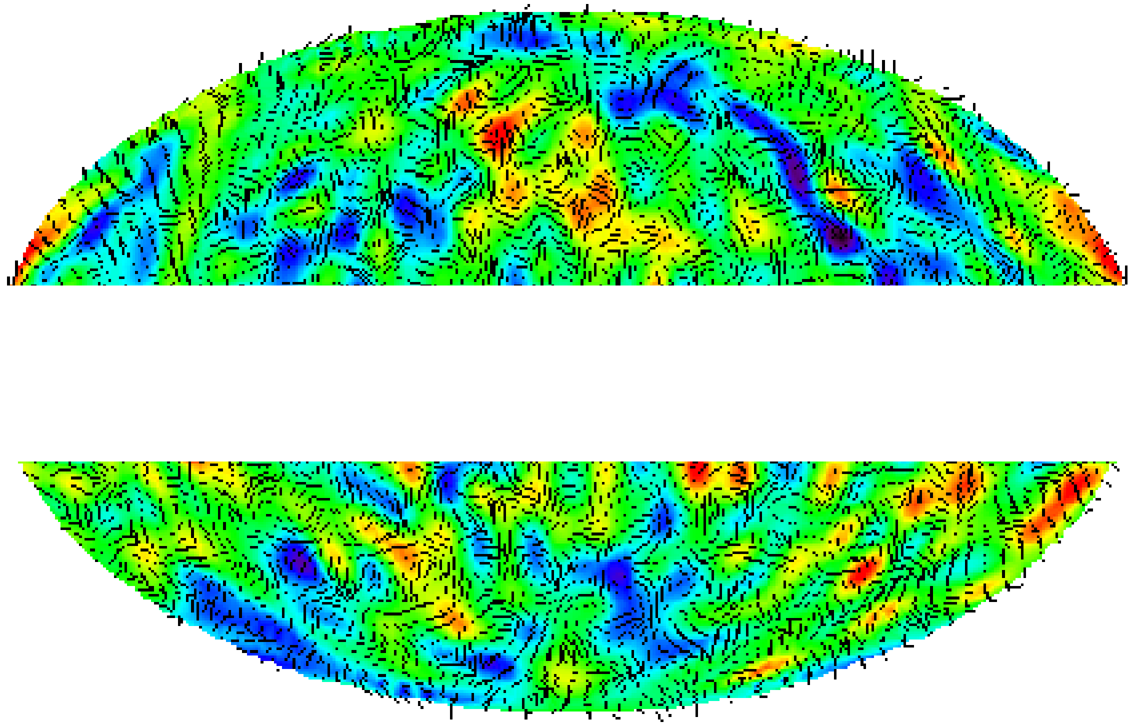
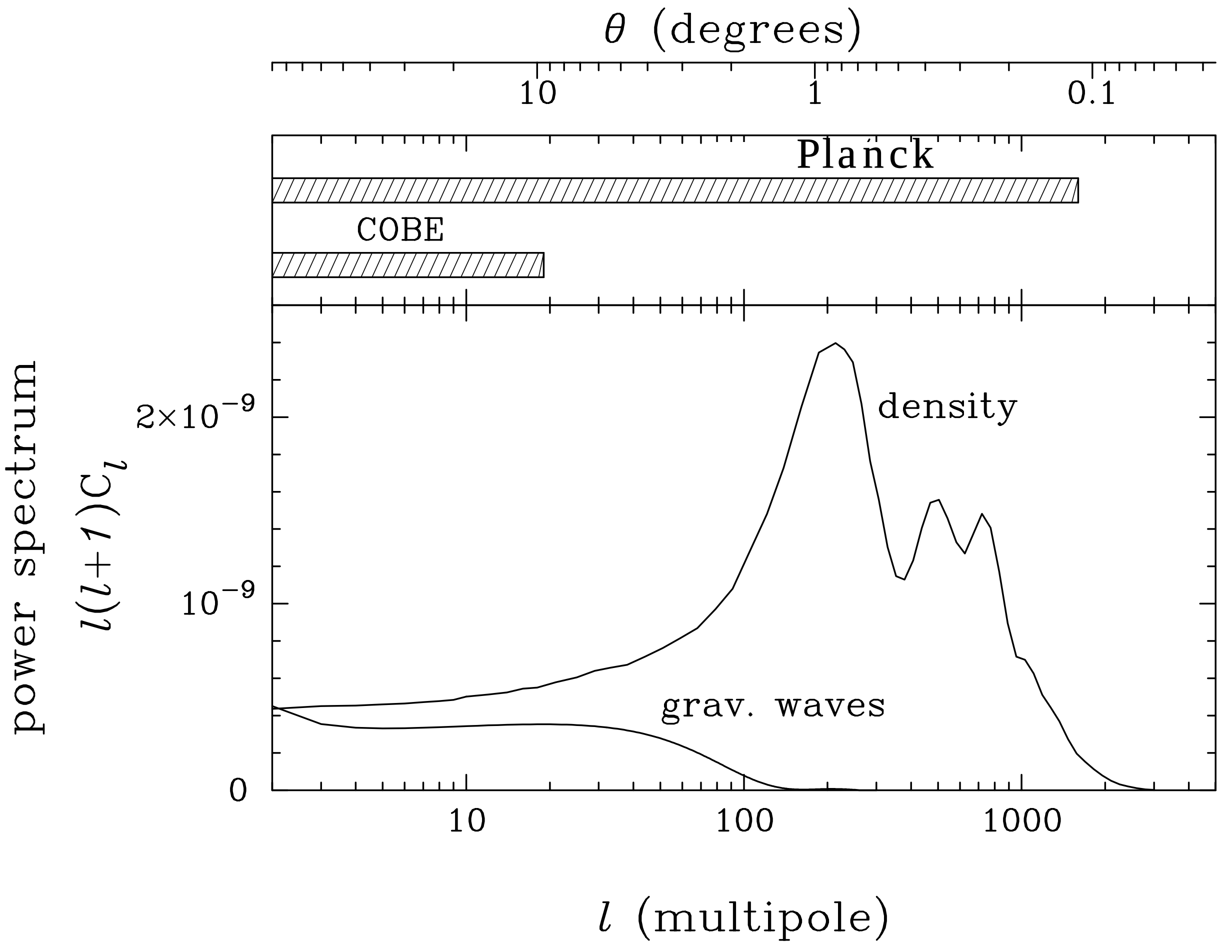
CMB map with polarisation



Caldwell et al 1998

Theoretical angular power spectrum of CMB anisotropies



$$\frac{\Delta T}{T} = \sum_{l,m} a_l^m Y_l^m(\theta,\varphi)$$

$$C_l = \langle |a_l^m|^2 \rangle$$

(Inflationary CDM scenario)

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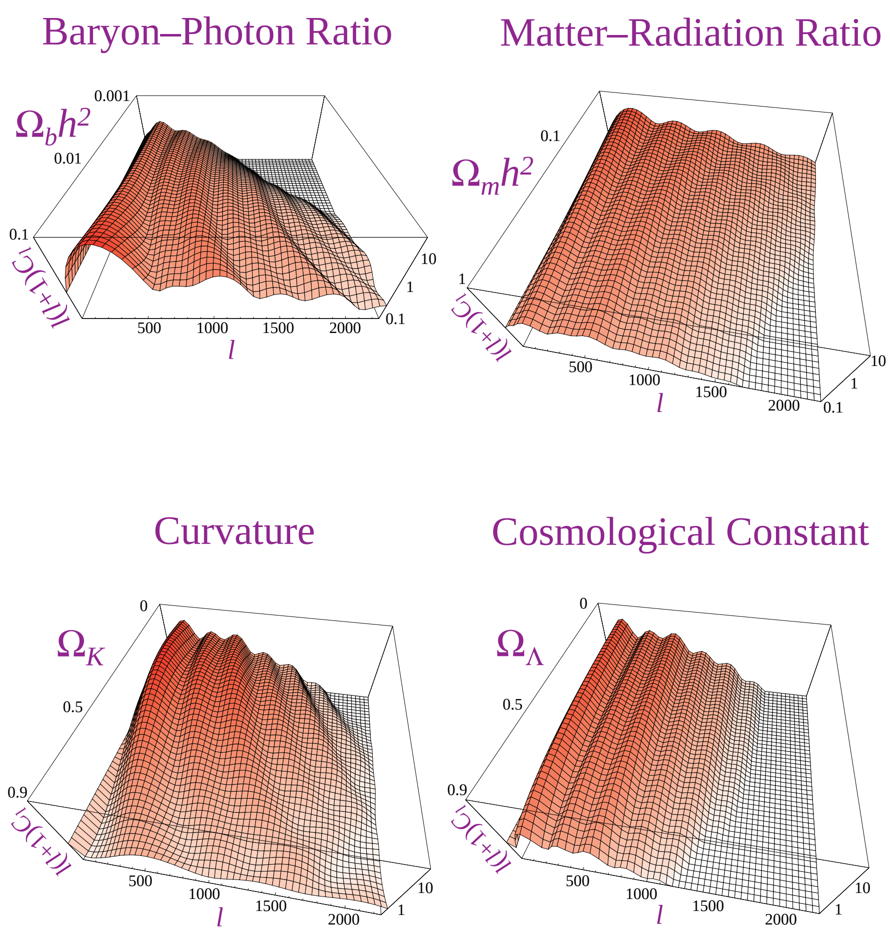
Main Cosmological Parameters

- Ω_o Cosmological total density parameter
- H_o Hubble constant
- Ω_b Baryon density
- Ω_c Cold dark matter density
- Λ Cosmological constant
- N_s Spectral index of scalar perturbations
- Q Amplitude of fluctuation spectrum
- r Ratio of Gravitational wave to density perturbations
- τ_r Residual optical depth due to reionisation

Cosmological Parameters in the CMB

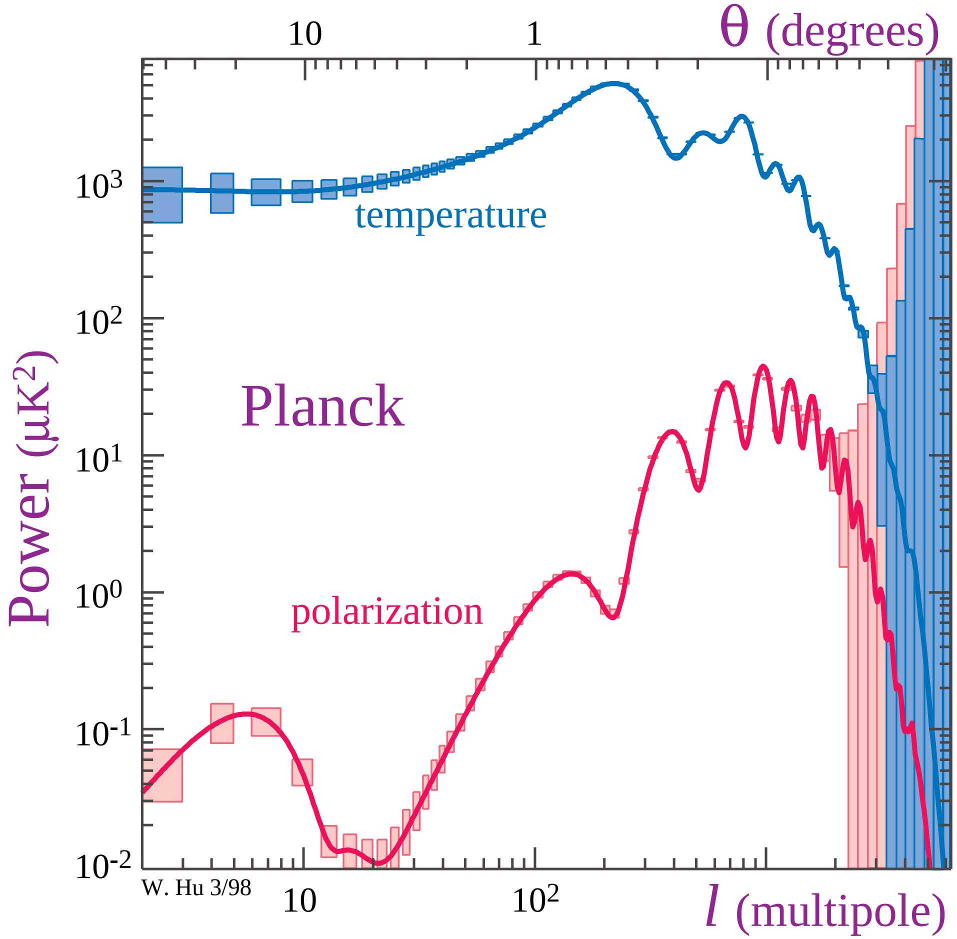
The shape of the power spectrum depends very sensitively on the value of the cosmological parameters



W.Hu 2/98

Predicted power spectrum recovery by Planck

Both the temperature and the polarisation angular power spectra are accurately recovered



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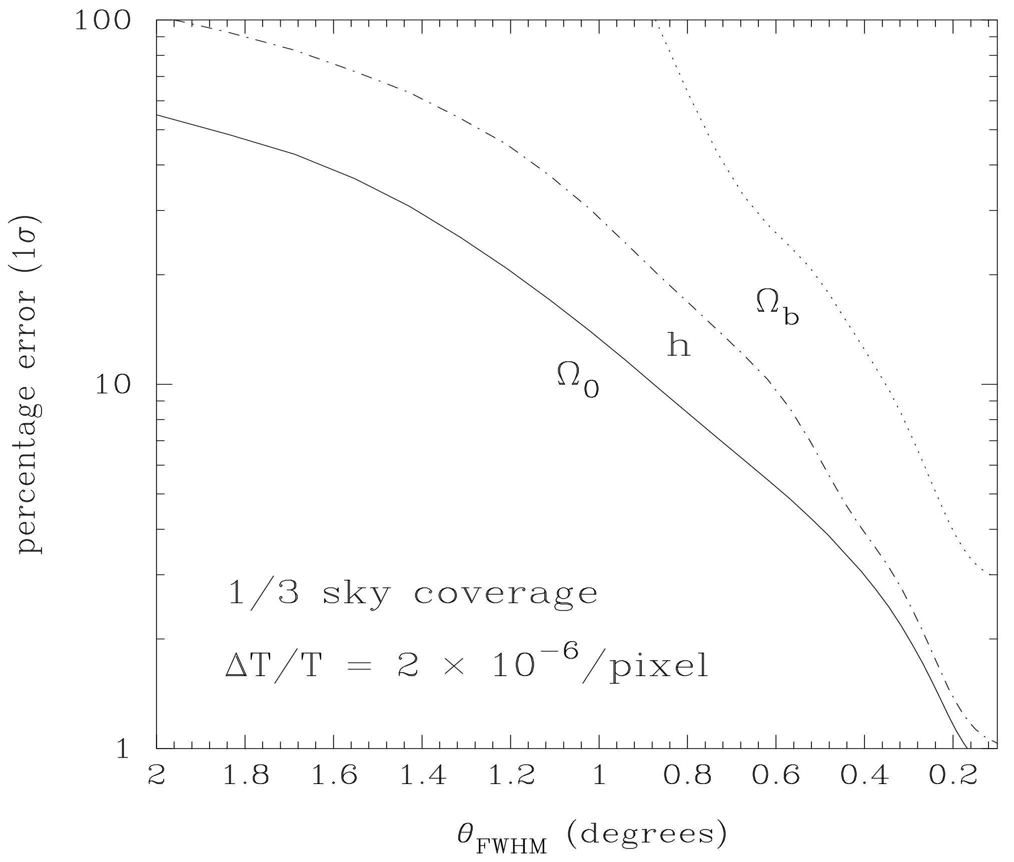
Accuracy of recovery of fundamental parameters



Maximum likelihood estimates in an eight dimensional parameter space

(Ω_0, h, Ω_b, n_s^3, Q_{rms}, n_s/n_t, Λ, τ_{reion})

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Priors

- 1st and 2nd generation CMB experiments
  - balloon-borne, e.g. BOOMERanG and a dozen others
  - ground-based, e.g. VSA, and two dozen others
  - MAP
- Large scale structure (2dF, SDSS, etc)
- SN searches
- Nucleosynthesis
- Hubble constant
- Stellar ages
- Lensing surveys
- Particle physics

3. Planck in a wider context

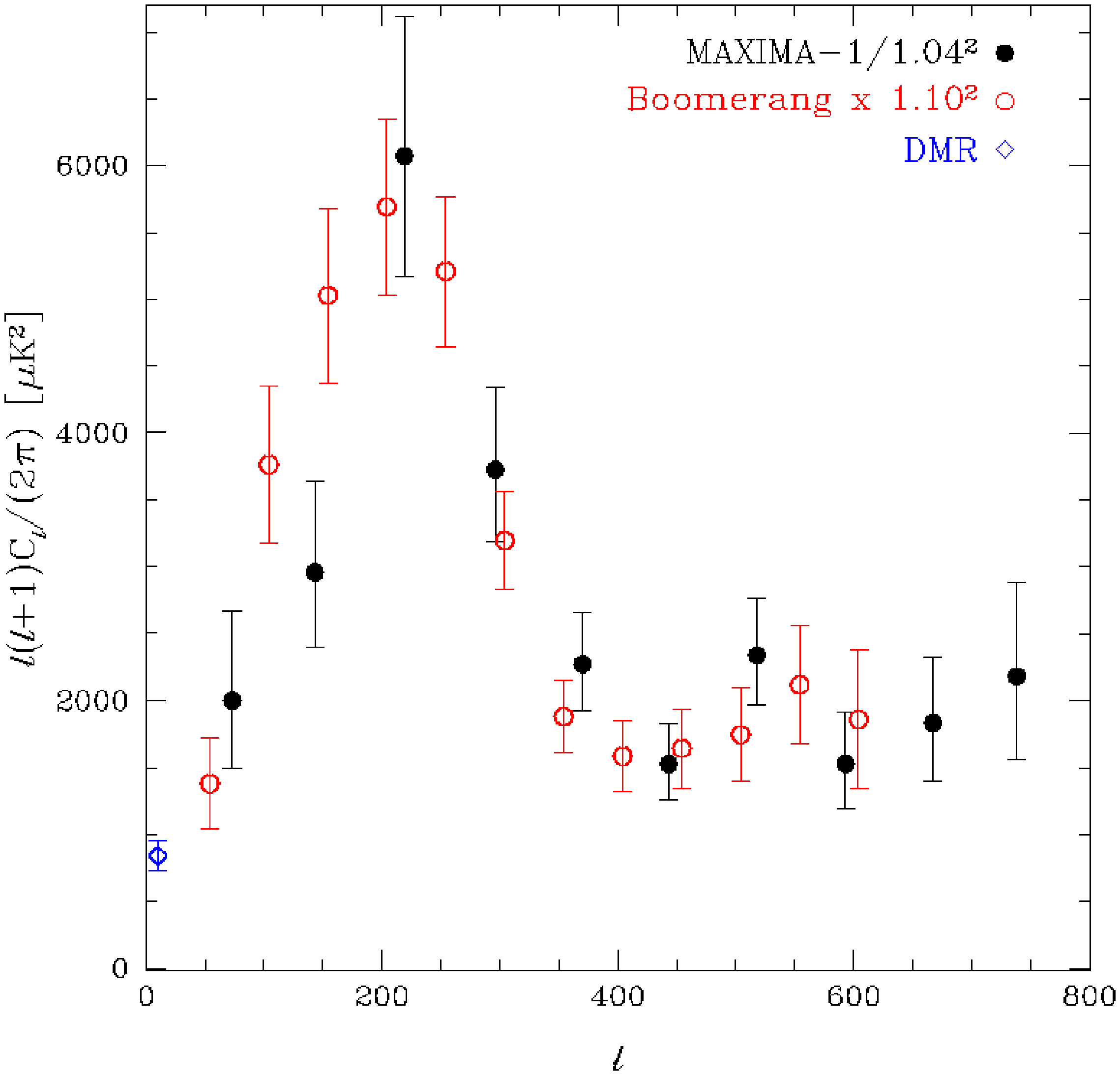
The coming decade

- Progress in 2nd generation CMB experiments:
  - balloon-based experiments are already reaching their natural limits (instrument-related, backgrounds, sky coverage,...)
  - MAP will confirm and extend their results
  - interferometers are coming on line
- Progress in other areas:
  - large scale structure
  - lensing surveys
  - supernovae
  - ...
- Progress in data analysis techniques
- Narrowing down the range of cosmological models

MAXIMA

&

Boomerang



Hanany et al 2000

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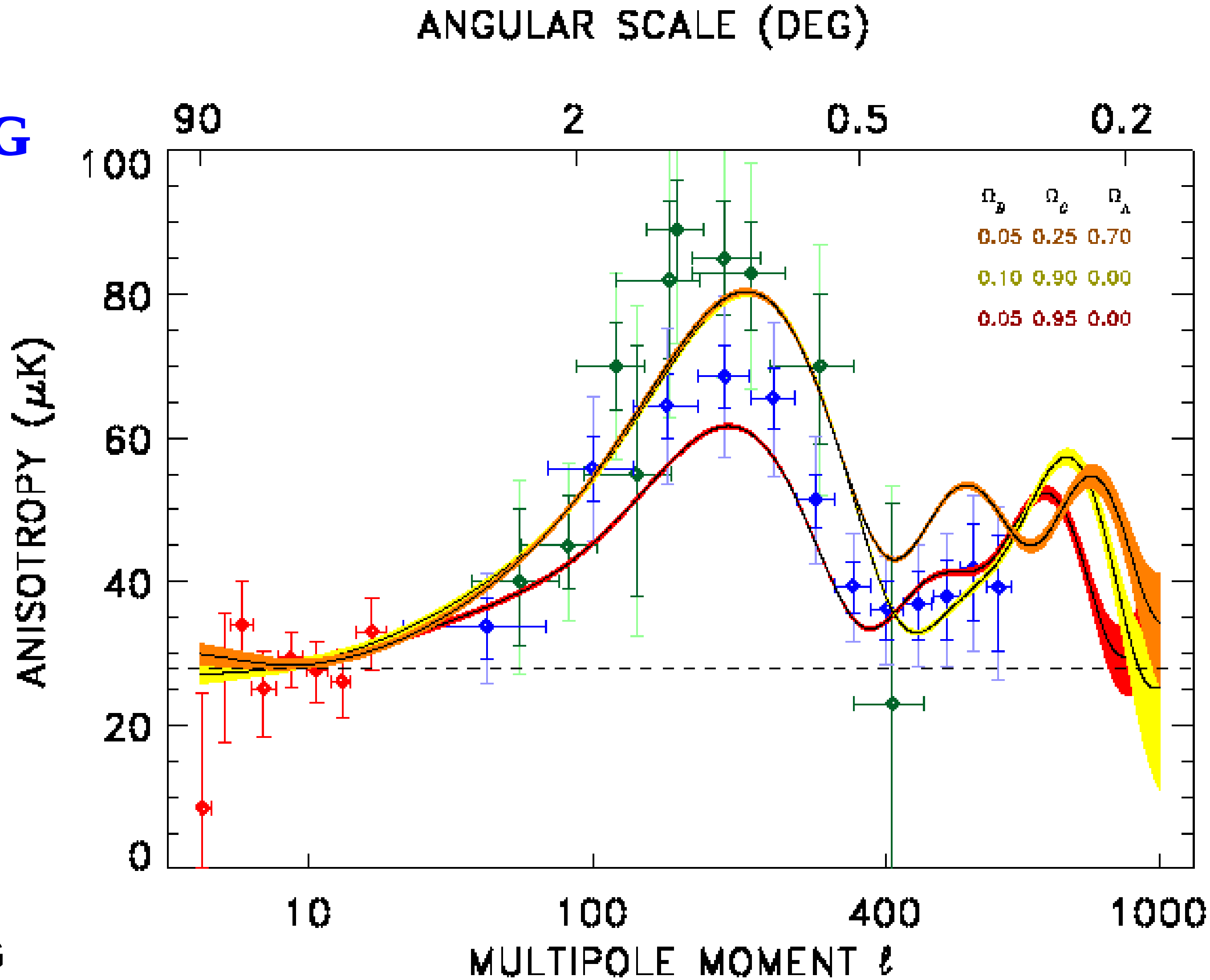
MAP vs BOOMERanG



◆ COBE

◆ TOCO

◆ BOOMERanG

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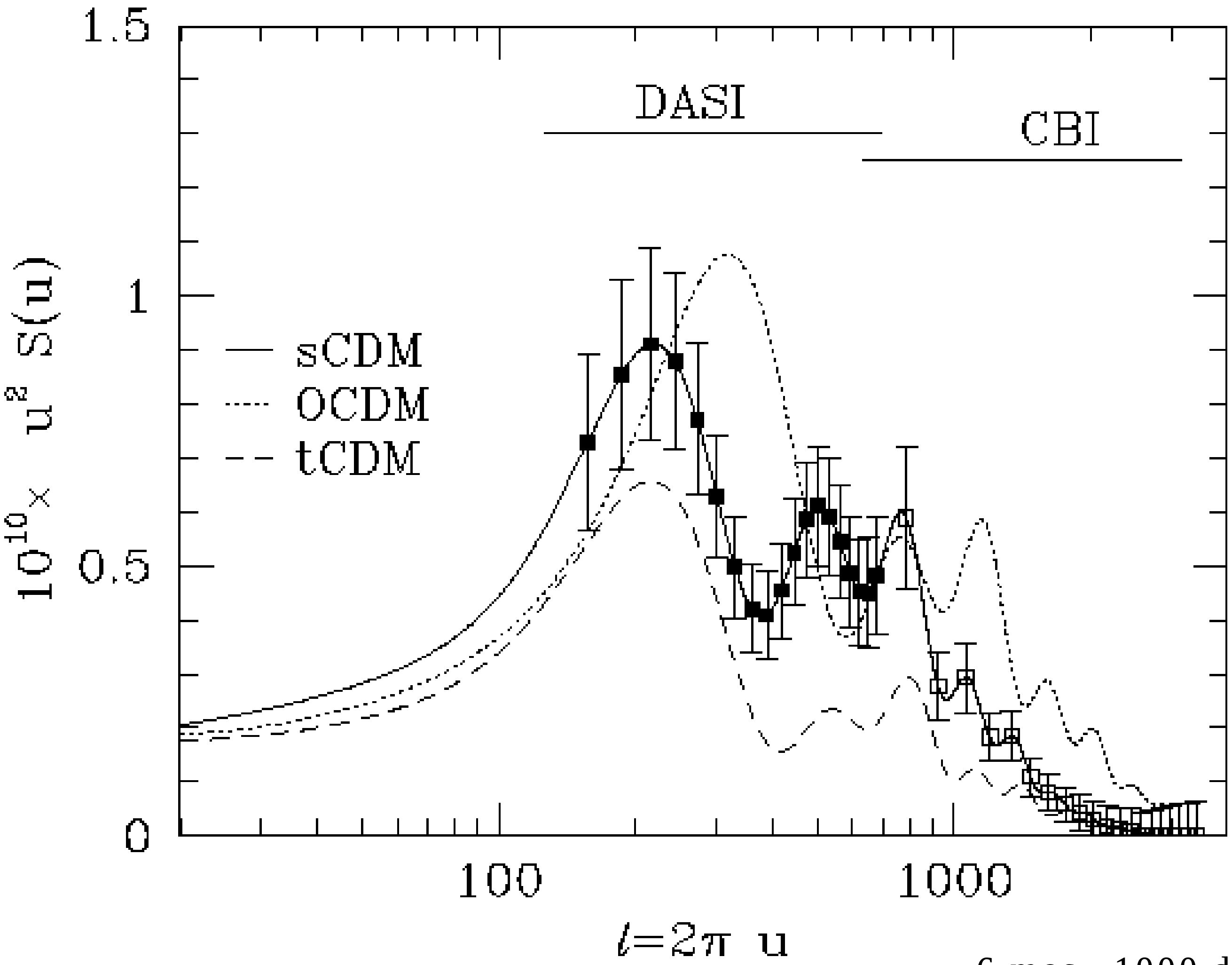
Predicted performance of typical interferometers: DASI, CBI

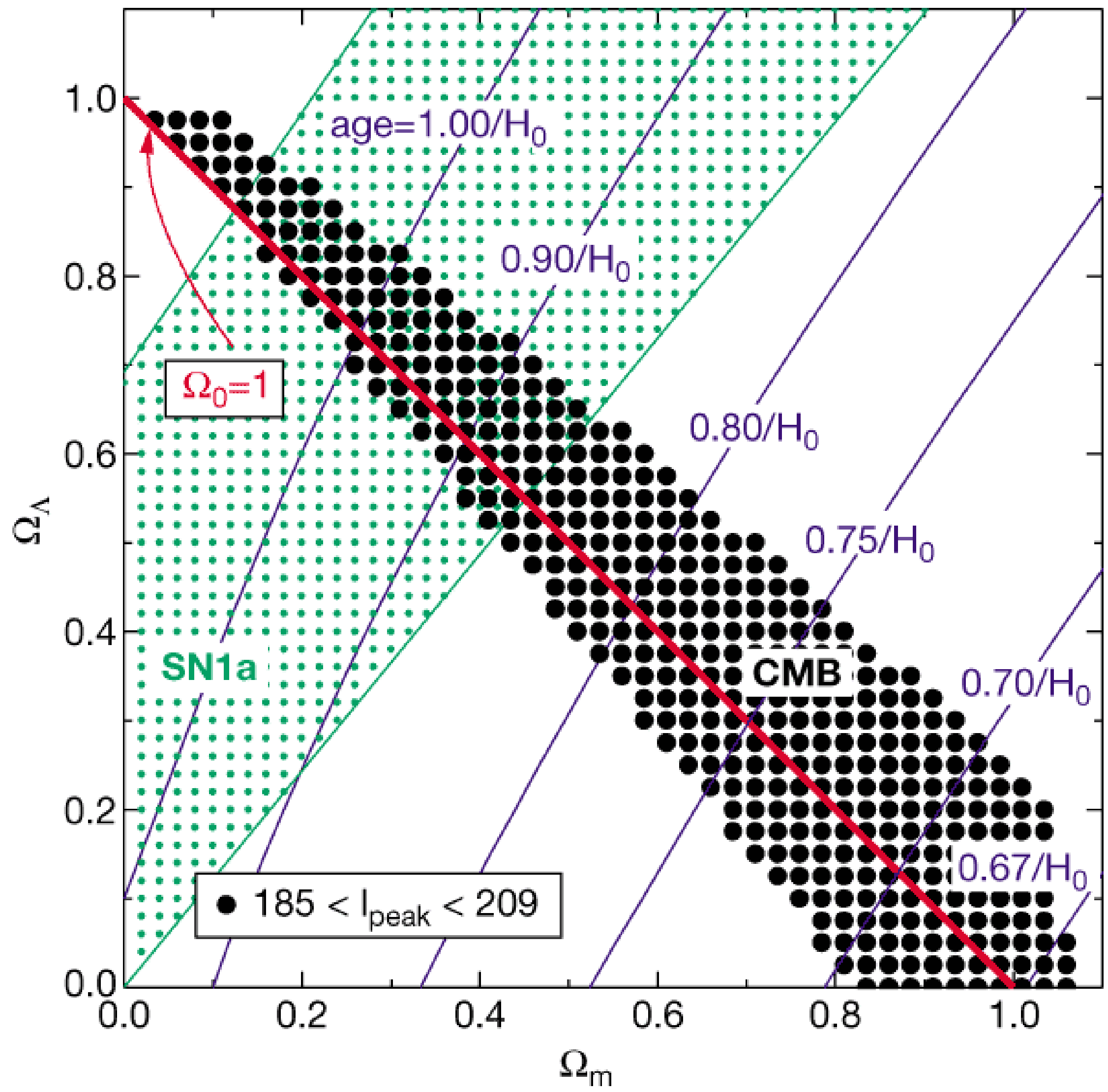


Halverson et al 1999

6 mos., 1000 deg^2

Boomerang

De Bernardis et al 2000



PLANCK

Planck - the 3rd generation

- A leap forward for CMB experiments:
  - broad frequency range (x10 improvement)
  - angular resolution (x2 improvement)
  - sensitivity (x10 improvement)
  - immunity to systematics (orbit, design)
  - polarisation
- Precise and reliable cosmological parameters
  - with no other priors
  - together with other information
- An IRAS-like database to be exploited for:
  - galaxy clusters (e.g. S-Z effect)
  - galactic astrophysics

CMB experiments

	COBE/DMR	BOOMERanG	CBI	MAP	Planck
Freq. range	30-90	90-400 GHz	26-36 GHz	22-90 GHz	30-857 GHz
No. of frequency channels	3	4	10	5	9
Angular resolution	7^o	10.5’-13’	4’.5-8’	12’.6-66’	5’-33’
Sky coverage	100%	3%	3%	100%	100%
10^{-6} Δ *T* Sensitivity (10’x10’)	20 (in 10^ox10^o)	~40	~15	~50	~5
Polarisation	no	Future	yes	yes	YES
Raw data size	1 Gbyte	10 Gbyte		1 Tbyte	5 Tbyte
No of pixels	6144	10^5		10^6	5×10^6
Time to reduce data	2 yrs	2 yrs		1 yr	1 yr
Generation	**1st**	**2nd**			**3rd**

esa

PLANCK

MAP vs Planck

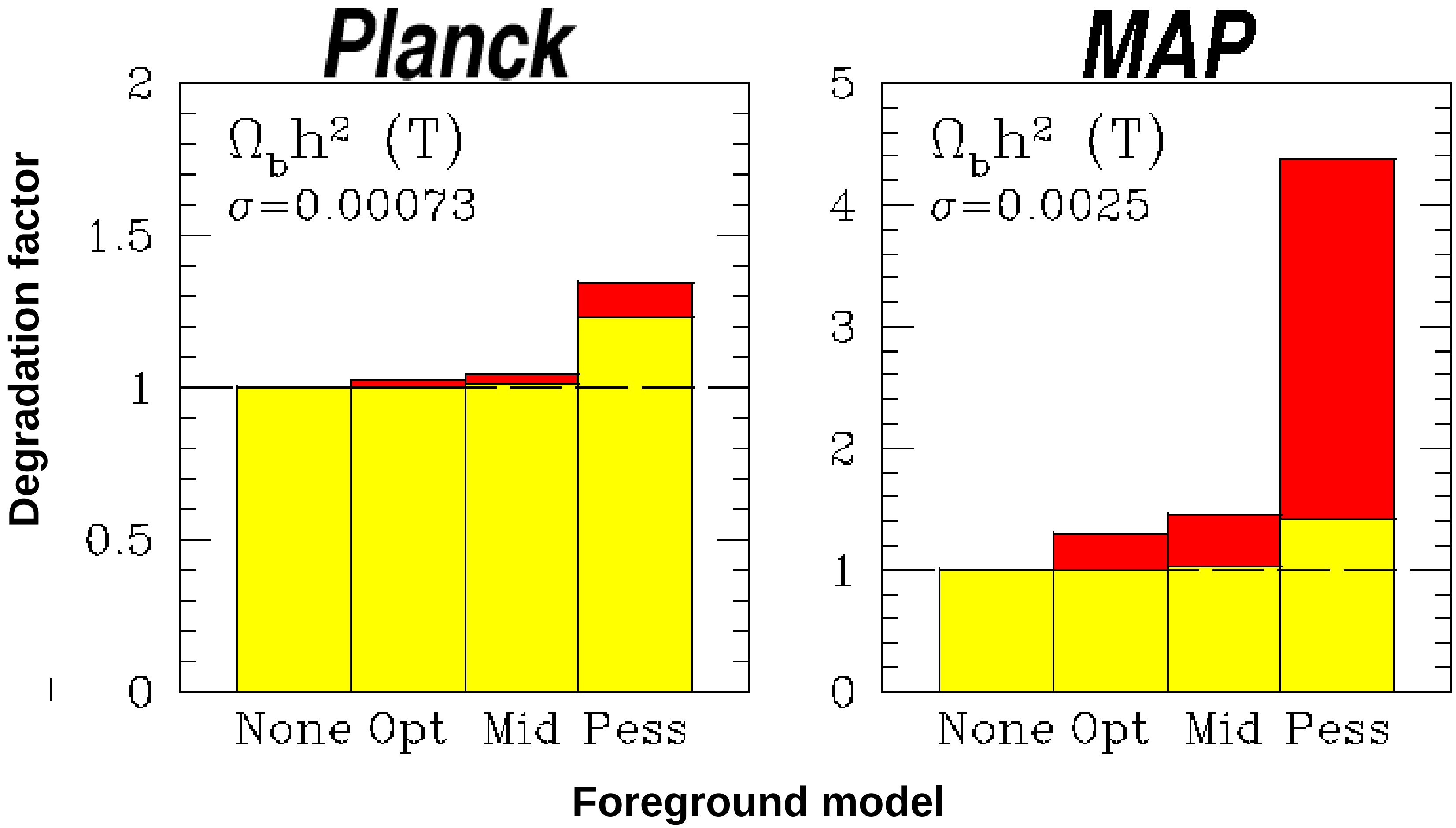
MAP					
Center Frequency (GHz)	22	30	40	60	90
Number of Detectors	4	4	8	8	16
Angular Resolution (‘)	66	38	32	18	12.6
Δ *T* Sensitivity (μK, 18’x18’)	35	35	35	35	35
Polarisation	yes	yes	yes	yes	no

Planck										
Center Frequency (GHz)	30	44	70	100	100	143	217	353	545	857
Number of Detectors	4	6	12	34	4	12	12	6	8	6
Angular Resolution (‘)	33	23	14	10	10.7	8.0	5.5	5.0	5.0	5.0
Δ *T* Sensitivity (μK)	4.3	6.5	9.7	11.6	4.6	5.4	11.6	39	400	18mK
Δ *T* Sensitivity (μK, 18’x18’)				~3.8	~1.5					
Polarisation	yes	yes	yes	yes	no	yes	yes	no	yes	no

esa

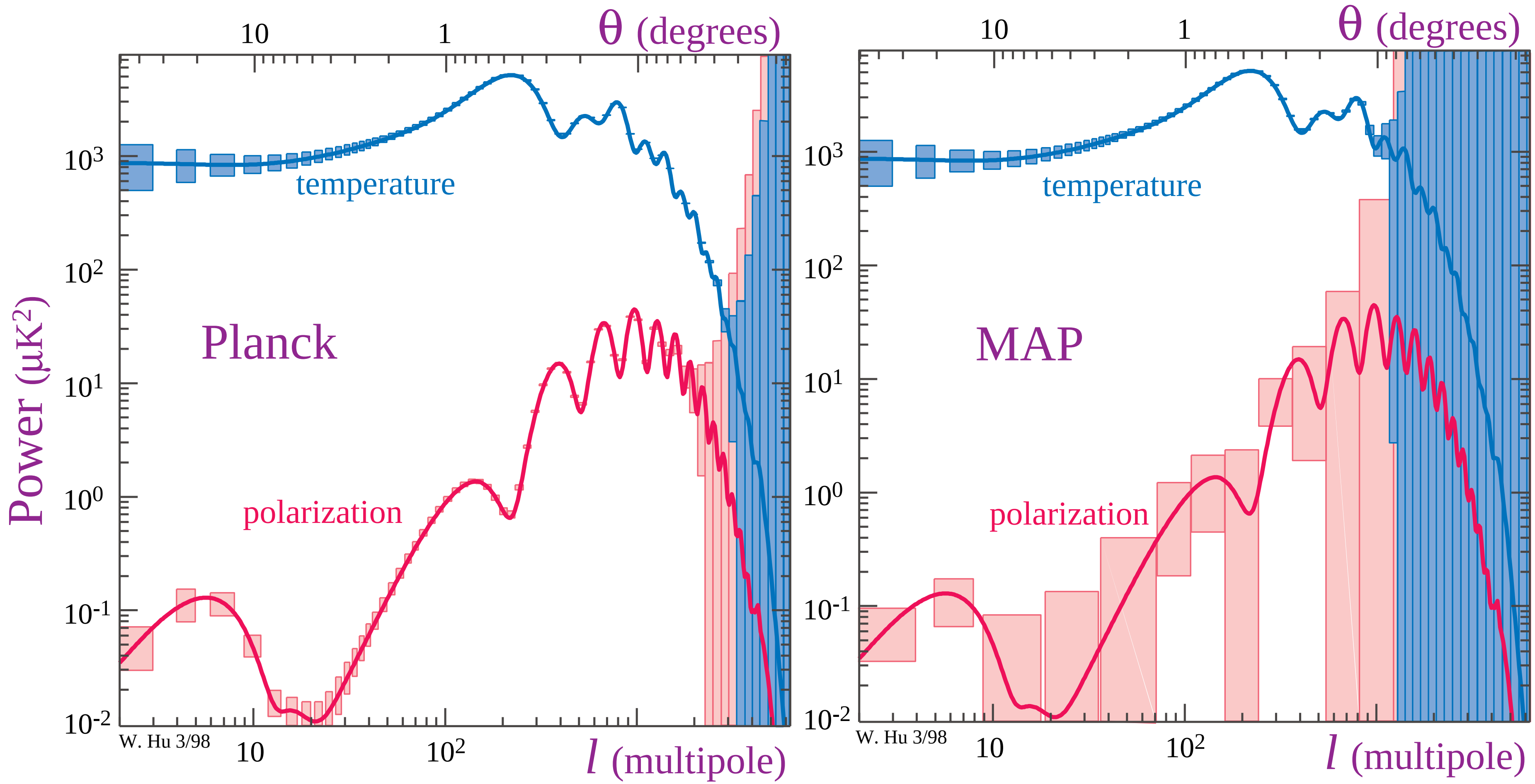
PLANCK

MAP vs Planck and foregrounds



Tegmark et al 2000

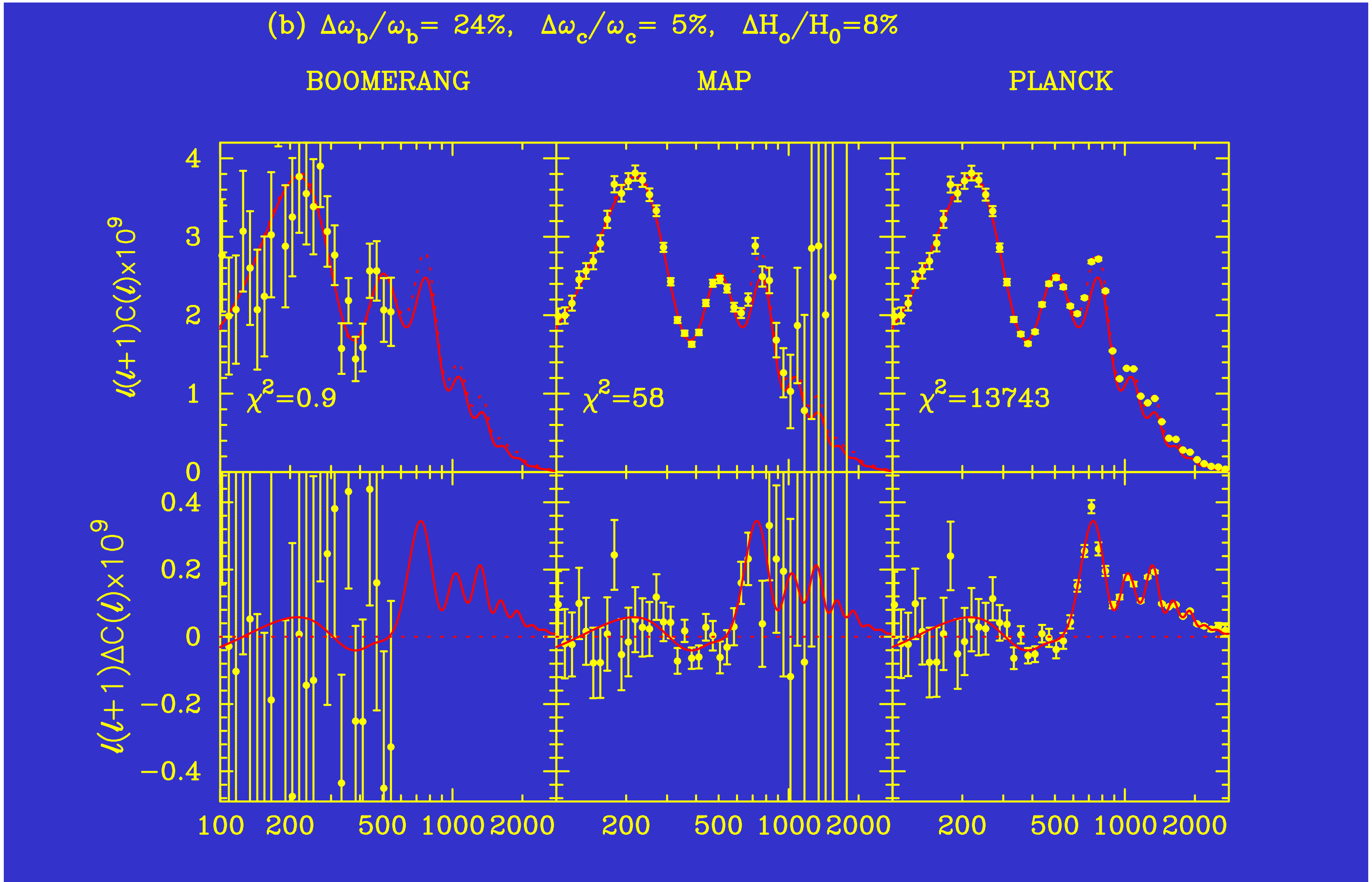
Comparison of Planck and MAP



esa

PLANCK

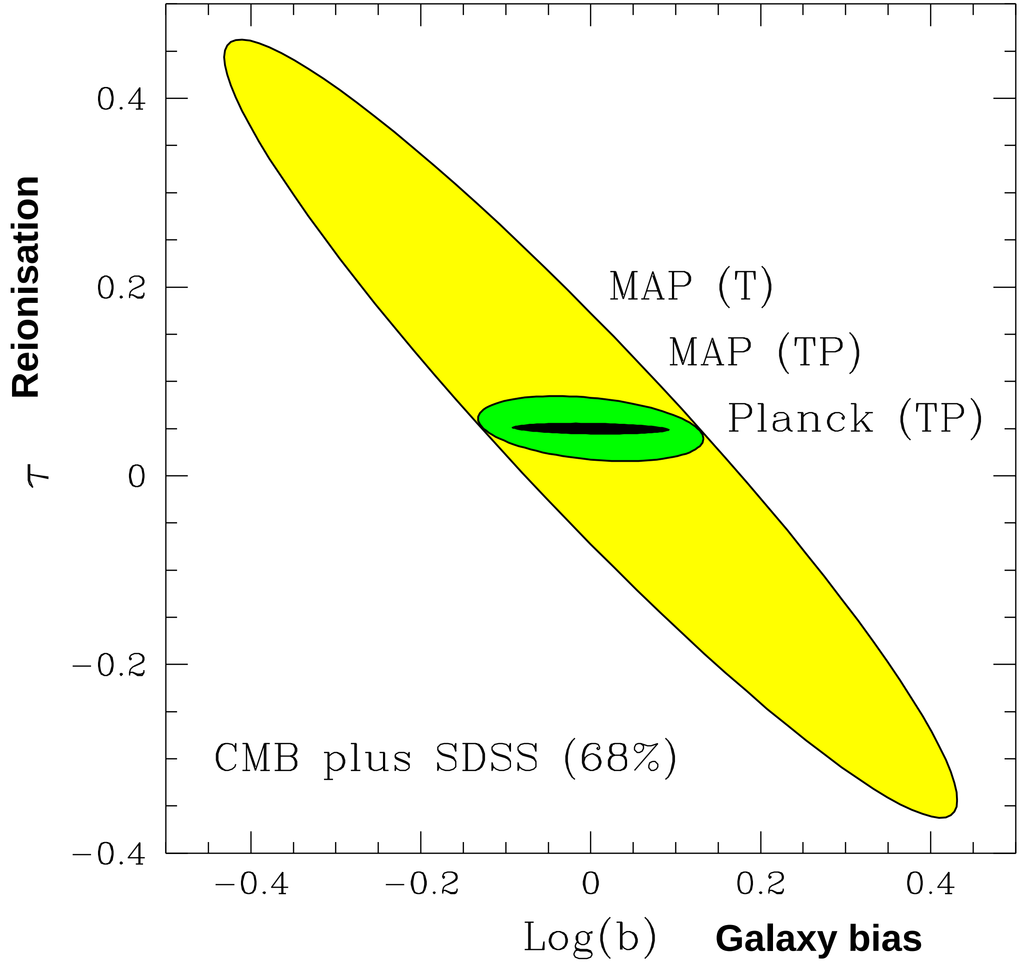
Discriminating between cosmological models



Efstathiou 1999

PLANCK

Planck and SDSS



Eisenstein, Hu, and Tegmark 1999

Non-CMB Science highlights

Sunyaev-Zeldovich effect

- Measurement of y in > 10^4 clusters
- Cosmological evolution of clusters to z > 1
- H_o and X-ray measurements, gas properties
- Bulk velocities on scales > 300 Mpc

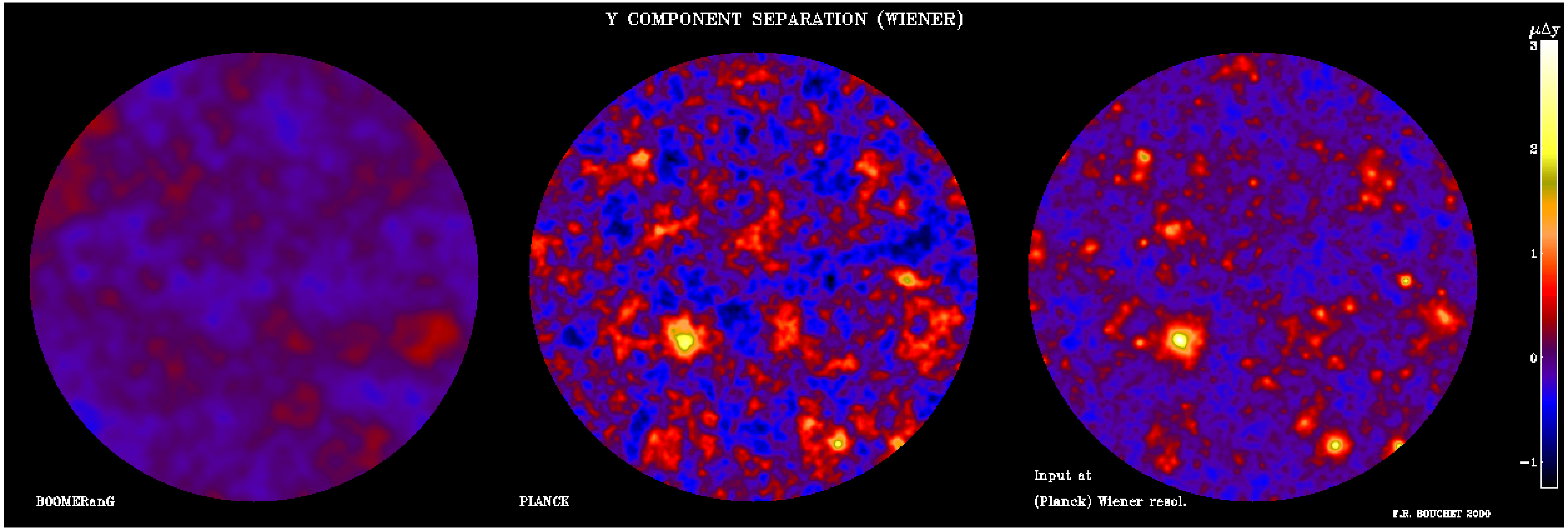
Extragalactic sources

- IR and radio galaxies
- AGN's, QSO's, blazars
- Evolution of galaxy counts to z > 1
- Far-IR background fluctuations

Galactic studies

- Dust properties
- Cloud and cirrus morphology
- Star forming regions
- Cold molecular clouds
- Maps of free-free and synchrotron emission
- Cosmic ray distribution
- Galactic magnetic field

Recovery of cluster S-Z profile

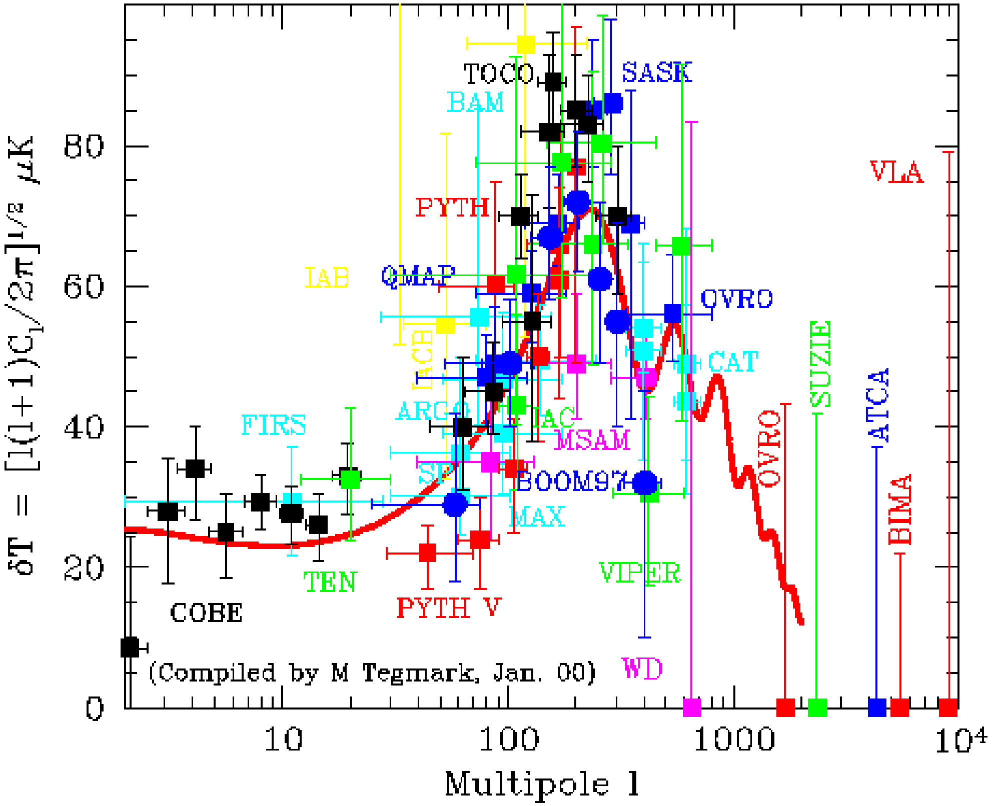


Boomerang Planck Input model

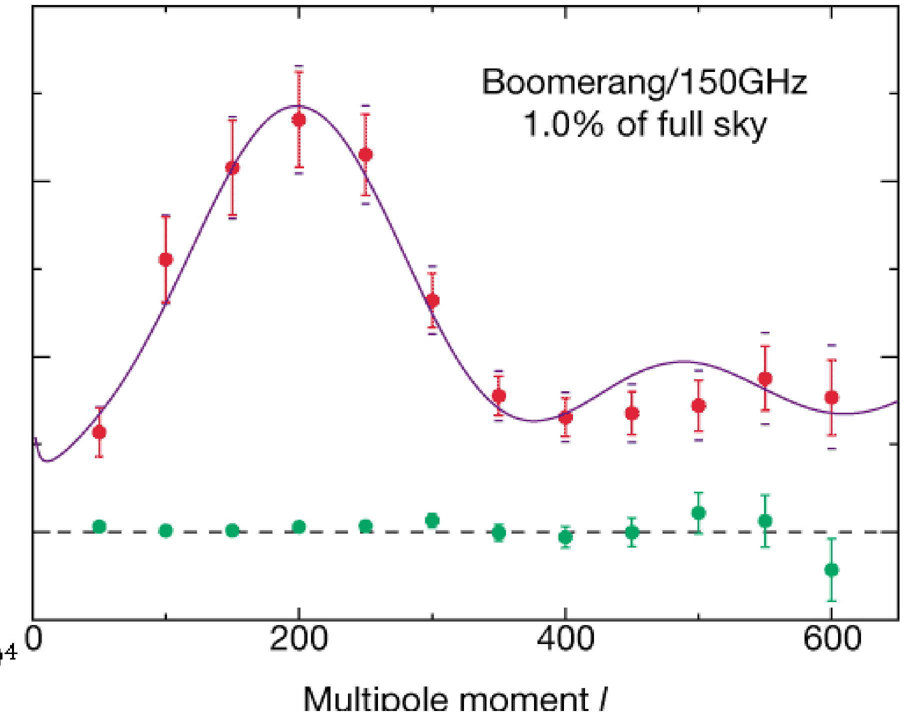
Summary

• 2nd generation CMB missions are starting to fulfill their promise - as expected
• Together with other priors, they will constrain a few cosmological parameters - as expected
• They have natural limits which can only be overcome with a 3rd generation experiment
• They are extremely useful as a stepping stone towards Planck:
    • technical experience
    • priors
    • knowledge of foregrounds
    • data handling and analysis techniques

The power of a single, well-targeted experiment



Before BOOMERanG



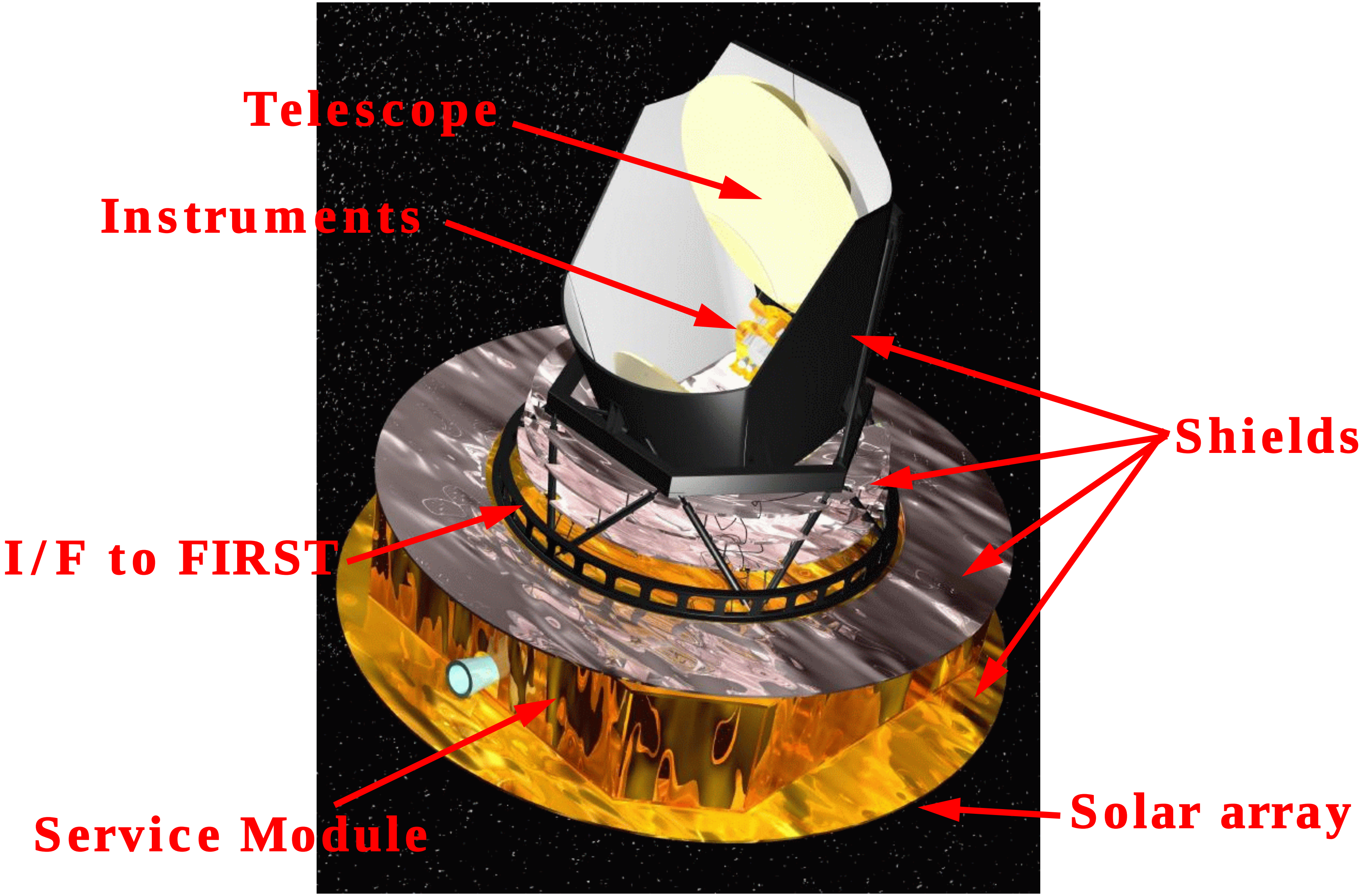
After BOOMERang

The scientific promise of Planck

The 3rd generation CMB experiment that will uniquely provide:

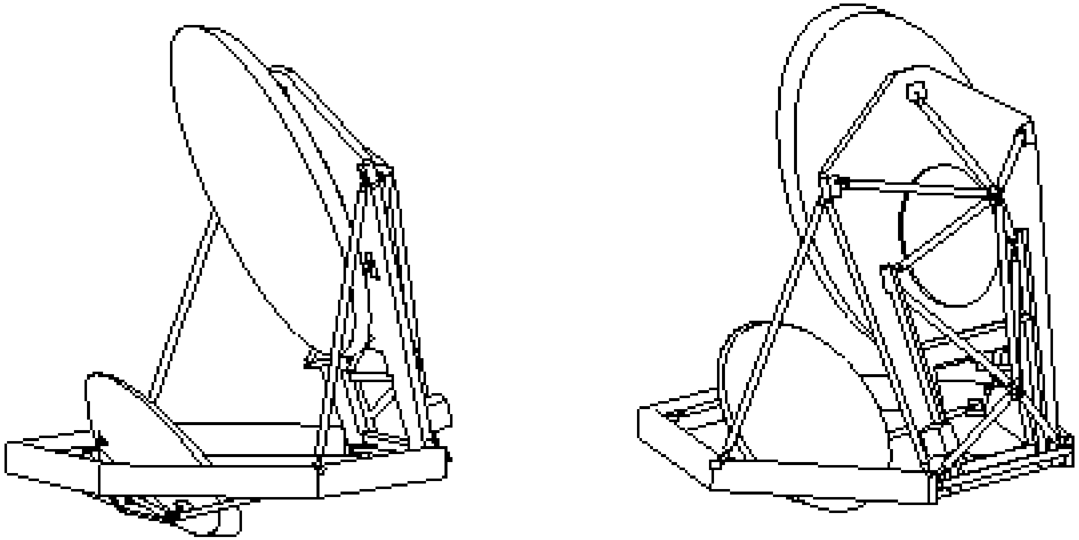
- reliable and precise values of the most fundamental cosmological parameters of our Universe
- a database of scientific information that will be used in cosmology and astro-physics for decades to come

4. Payload overview


Telescope
Instruments
Shields
I/F to FIRST
Service Module
Solar array

Planck Telescope

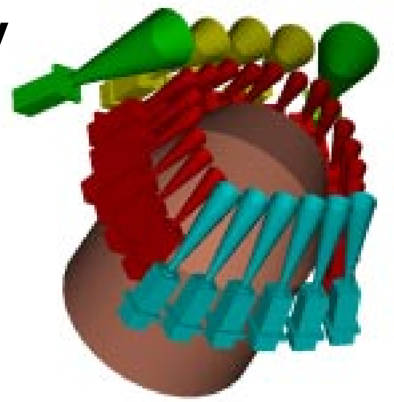
- Primary: 1.50 x 1.89 m ellipsoid (CFRP)
- Secondary: 1.02 x 1.04 m ellipsoid (CFRP)
- System:
  - 1.5 m circular projected aperture
  - Total MWFE<40 μm rms
  - Total ε <0.01
- Reflectors will be developed by a Consortium of danish institutes led by the Danish Space Research Institute (PI: Dr. H.U. Norgaard-Nielsen)



Planck Instruments

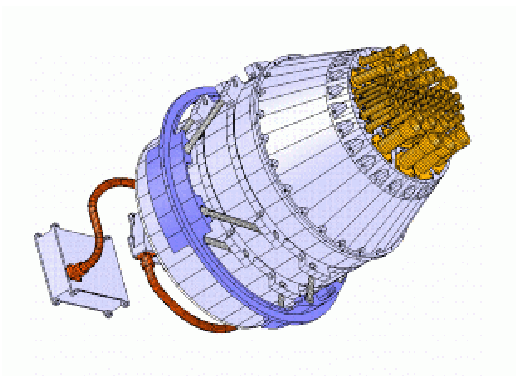
Low Frequency Instrument:

- PI: Dr. N. Mandolesi, TeSRE-CNR, Bologna, Italy
- Ring array of 56 radio receivers
- Frequency coverage 30 - 100 GHz (10 - 3 mm)
- Operating temperature 20 K
- Best angular resolution ~10 arcmin
- Best per pixel sensitivity ~12 μK



High Frequency Instrument:

- PI: Dr. J.L. Puget, IAS, Paris, France
- Circular array of 48 bolometers
- Frequency coverage 100 - 857 GHz (3 - 0.3 mm)
- Operating temperature 0.1 K
- Best angular resolution ~5 arcmin
- Best per pixel sensitivity ~ 5 μK



Goal Planck instrument characteristics

Telescope	1.5 m. (projected aperture) offset; shared focal plane; system emissivity 1%									
	Viewing direction offset 80-85^{o} from spin axis.									
Center Frequency (GHz)	30	44	70	100	100	143	217	353	545	857
Detector Technology	HEMT radio receiver arrays				Bolometer arrays					
Detector Temperature	~20 K				0.1 K					
Cooling Requirements	H_2 sorption cooler				H_2 sorption cooler + 4K J-T stage + Dilution system					
Number of Detectors	4	6	12	34	4	12	12	6	8	6
Angular Resolution (‘)	33	23	14	10	10.7	8.0	5.5	5.0	5.0	5.0
Bandwidth ($\Delta\nu/\nu$)	0.2	0.2	0.2	0.2	0.25	0.25	0.25	0.25	0.25	0.25
$\Delta T/T$ Sensitivity per res. element (12 months, 1σ, 10^{-6} units)	1.6 (P)	2.4 (P)	3.6 (P)	4.3 (P)	1.7	2.0 (P3.7)	4.3 (P8.9)	14.4	147.0 (P208)	6670.
Flux sensitivity (12 months, 1σ, mJy)	9	17	23	24	8	9	11	19	38	43
NEB (10^{-3} MJy $\sqrt{s}$sr)	2	5	11	16	5	7	14	26	50	58

5. Review cycle and status

Instrument reviews

- Science Verification Review (end 1999)
- Intermediate Design Review (mid/end 2000)
- Baseline Design Review (mid/end 2001)
- Hardware Design Review (mid/end 2002)
- Critical Design Review (mid/end 2003)
- Flight Acceptance Review (end 2006)

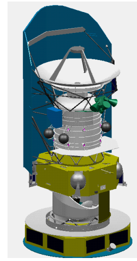
Instrument Science Verification Review

- Sorption cooler: 12/10/99
- HFI: 13-14/10/99
- LFI: 10-11/11/99
- Data Processing Centres: 1-2/12/99
- Status: satisfactory once Board recommendations are implemented

Planned Telescope Reflector Reviews

- Demonstration Programme Review (end 2000)
- Requirements Review (end 2000)
- Preliminary Design Review (beg 2001)
- Hardware Design Review (end 2001)
- Qualification Review (beg 2002)
- Acceptance Review (beg 2004)

Status: review cycle has not started



5.1 Planck Straylight Status

P. de Maagt ESA/ESTEC

STRAYLIGHT EVALUATION FOR PLANCK

Objective

To evaluate compliance with the straylight requirement of Planck and to issue recommendations.

Straylight is the radiative power that reaches a detector within its RF bandwidth, and that does not originate from sources in the far-field of the antenna main beam.

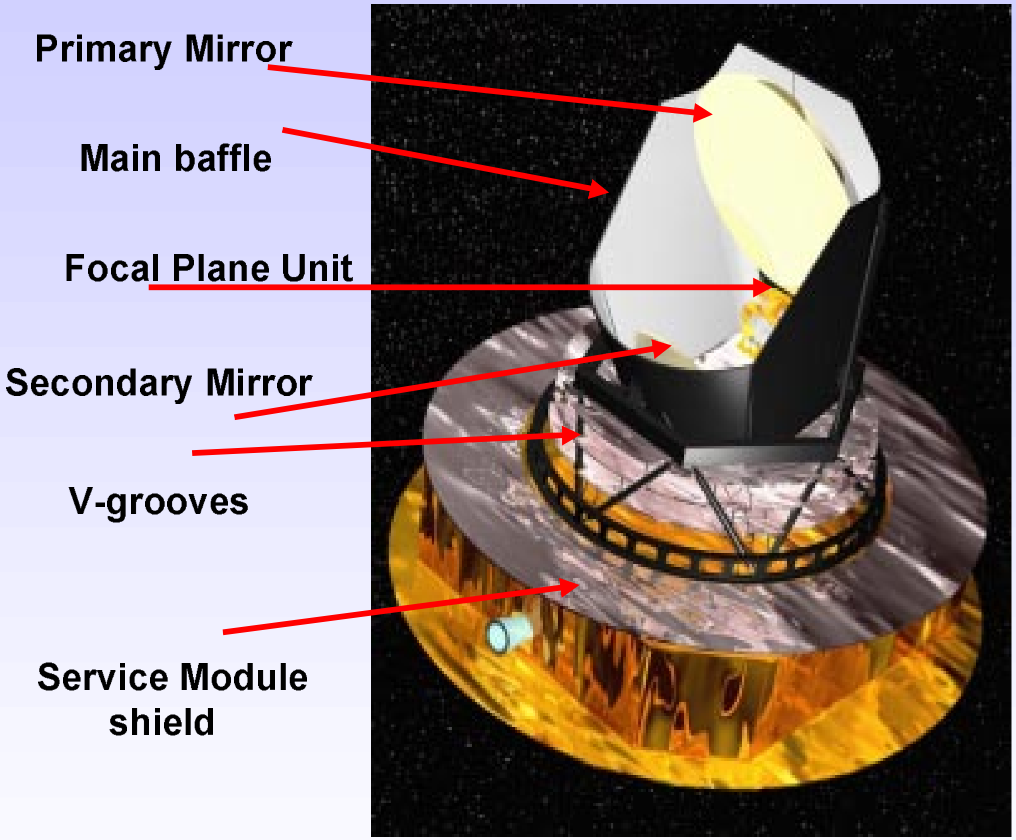
Variations in the straylight are a source of noise in the detector that cannot easily be separated from intrinsic noise or variations in the sources of interest.

This leads to the concept of:

SIN (Straylight Induced Noise)

Planck Straylight Analysis

Planck Payload Module



Main Challenges

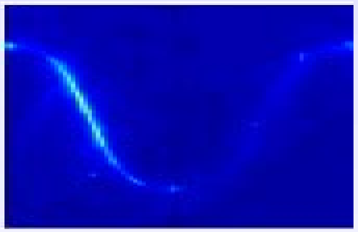
- Accuracy required
- Frequency range
- Complex structure
- new straylight approach

needs very specific tools that are pushed to the limits

Sources of Straylight

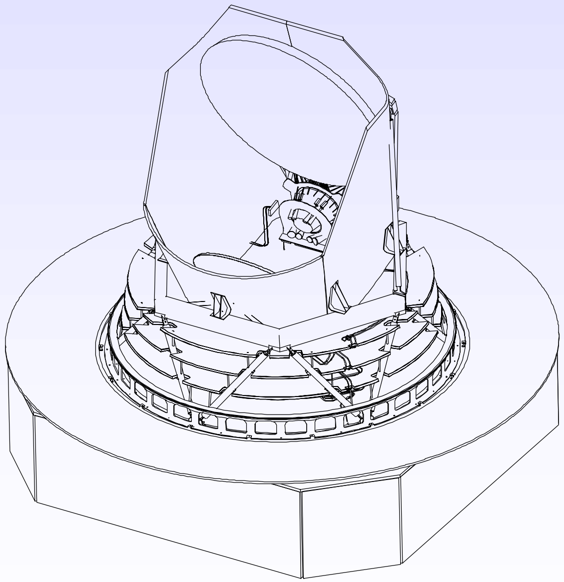
Assessment of effect of straylight signals due to

Sources “external” to the S/C + “internal” S/C self-emission

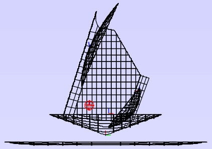


Milky Way emission

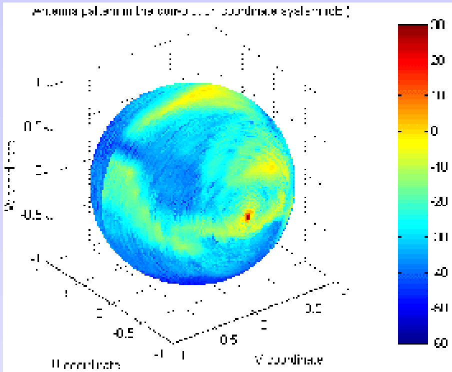
Sun *Earth* *Moon*



Generation of EXTERNAL SIN

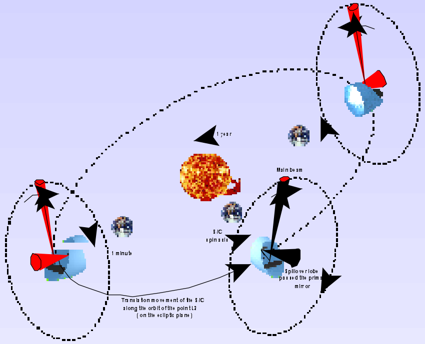


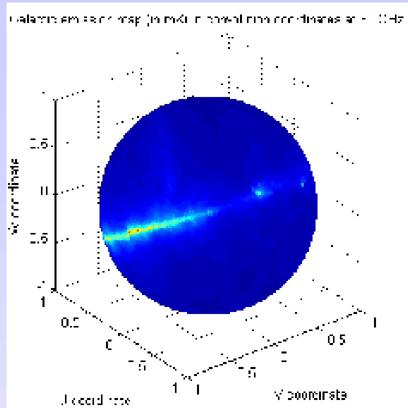
Payload model



4π radiation pattern

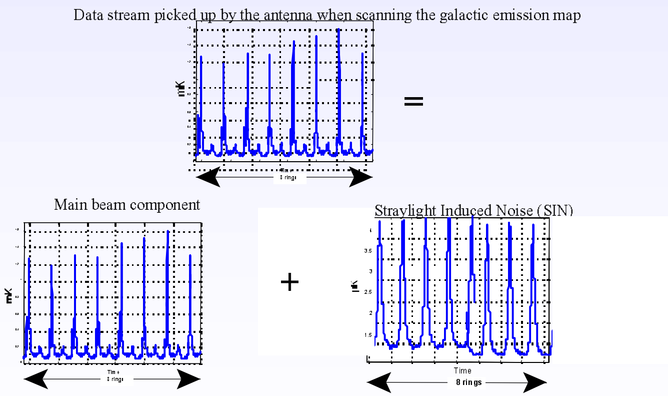
Observation strategy



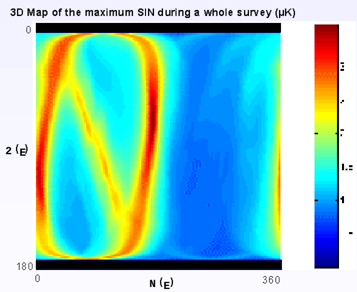


4π sky model

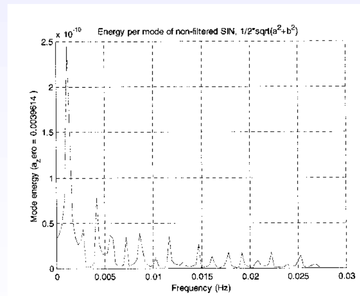
Payload configuration



Straylight signal (time)



Straylight signal (sky)

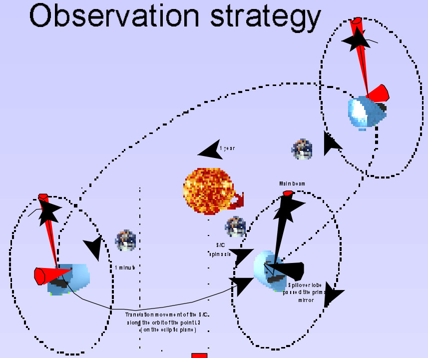


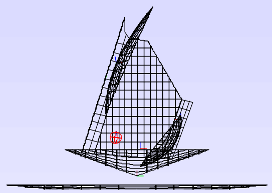
Straylight signal (harmonics)

Generation of INTERNAL SIN

TOS-EEA

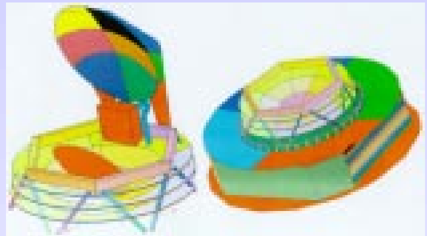
Observation strategy



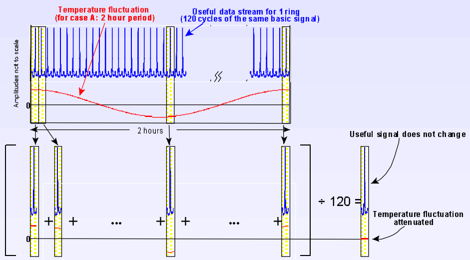


Payload model

RF coupling

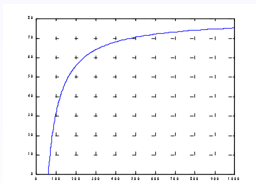


Temperature model

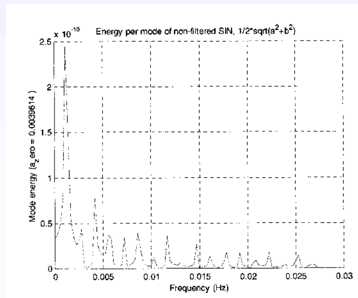


Averaging process

Payload configuration



Temporal attenuation



Straylight signal (harmonics)

Antenna alone

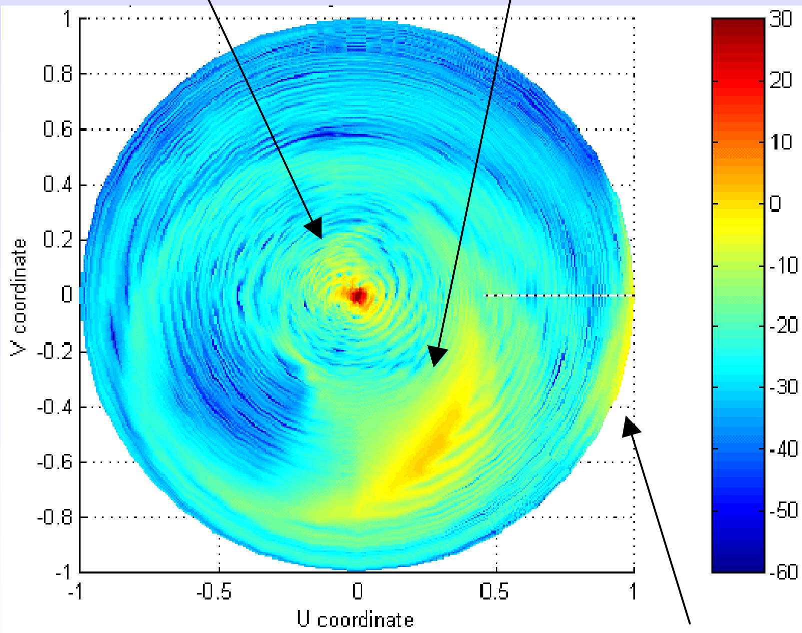
TOS-EEA

Plot of the 3-D radiation pattern at 30 GHz

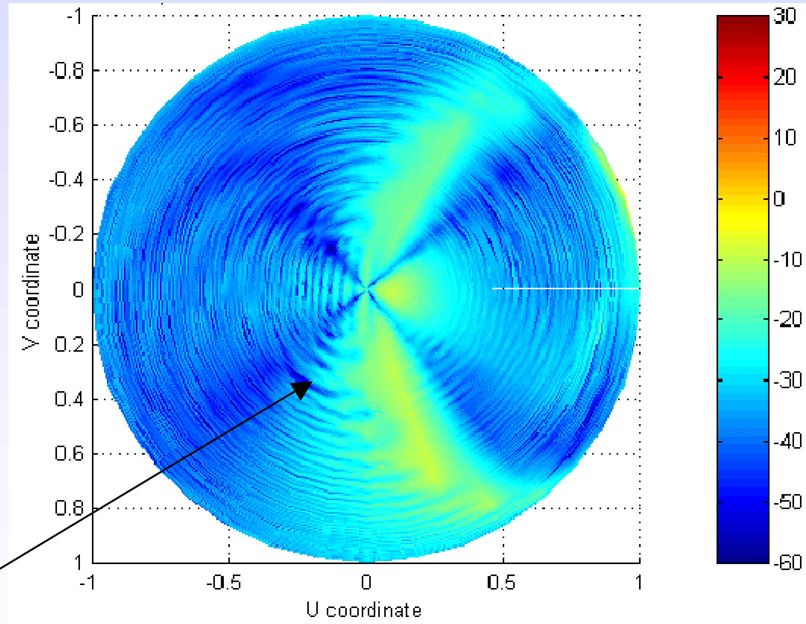
Seen from the boresight direction

Main lobe

Direct feed spillover



Seen from the anti-boresight direction



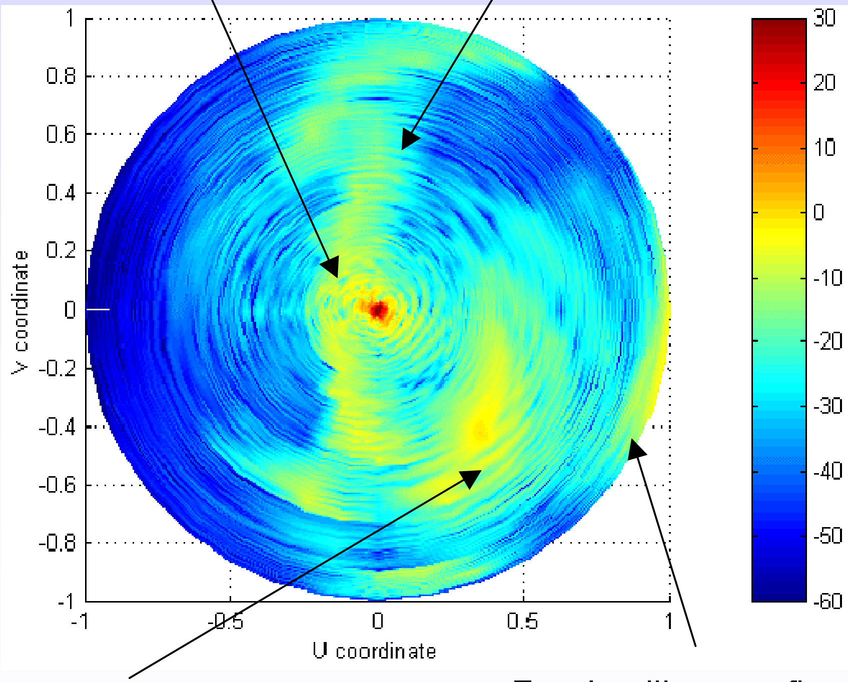
Feed spillover reflected on secondary mirror

Plot of the 3-D radiation pattern at 30 GHz

Seen from the boresight direction

Main lobe

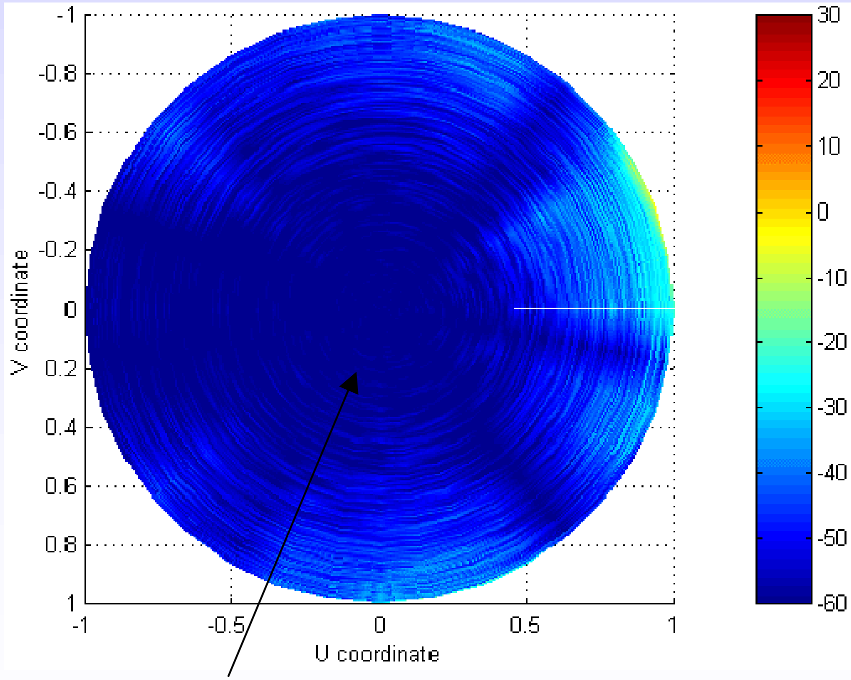
Reflected power on lateral walls



Direct spillover from feed

Feed spillover reflected on secondary mirror

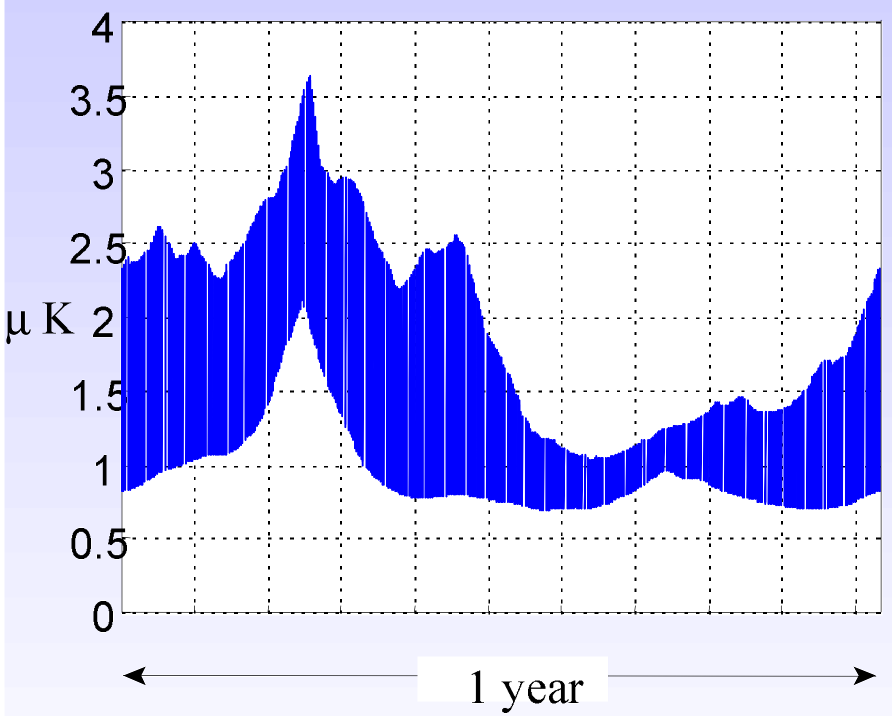
Seen from the anti-boresight direction



Cleaner pattern in the anti-boresight region

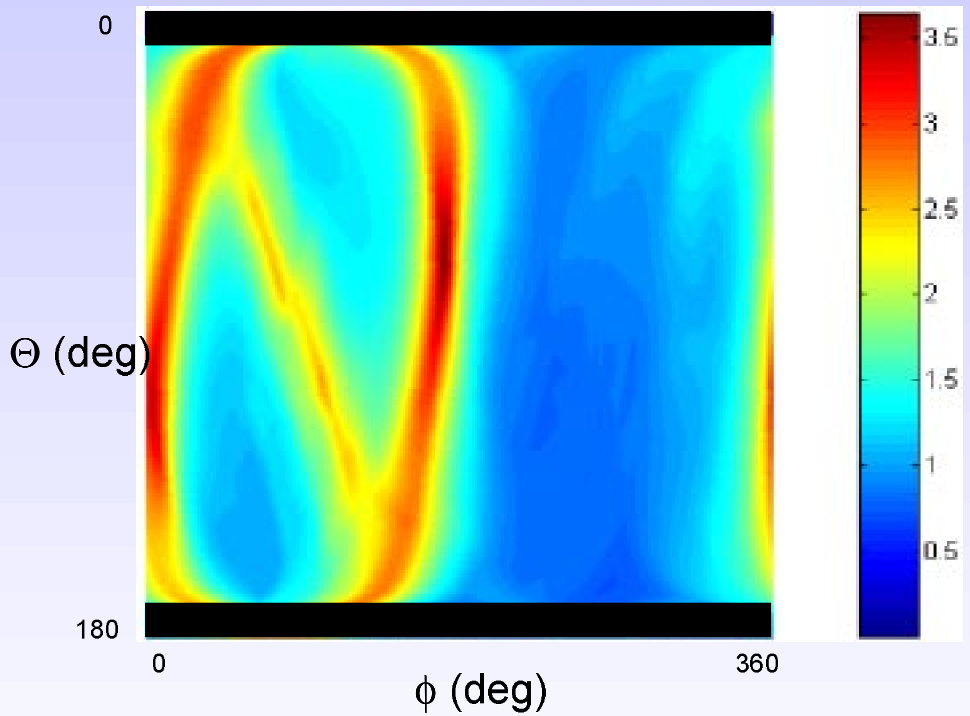
Straylight results at 30 GHz

Maximum and minimum straylight signal for each S/C spin axis orientation



S/C spin axis tilt angle = 0

3D Map of the maximum straylight Signal during a whole survey



Straylight safely within specs

Straylight approach for Planck

An external panel of eminent European and US straylight experts was convened in early 1999 to review the approach. The panel “endorsed the professionalism of the approach and results” and made further valuable recommendations.

Tasks Performed:

✓ Radiation pattern of antenna, alone and with baffle, analysed with GRASP8 using Physical optics and Geometrical Theory of Diffraction at 30,100 and 353 GHz.

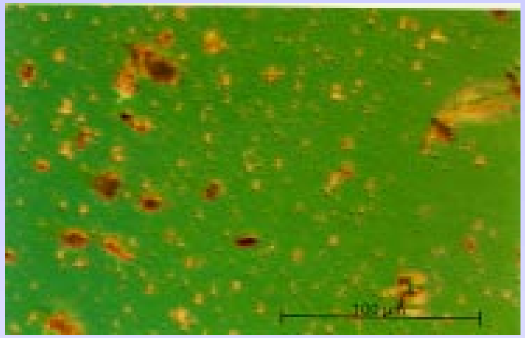
✓ Straylight effect has been estimated using a ‘flight simulator’ at 30 and 100 GHz.

✓ Several detailed supporting studies performed (e.g. cracks, polarization, mutual interaction, abberations,..)

Straylight issues under investigation

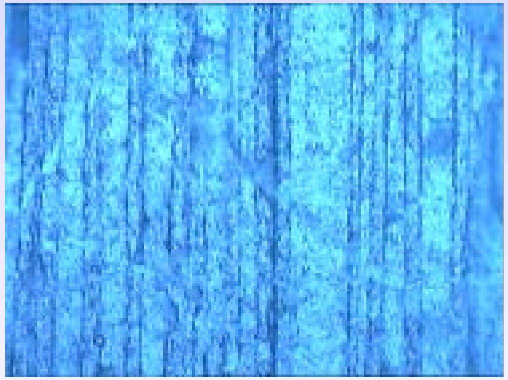
dust contamination, also has an impact

on integration

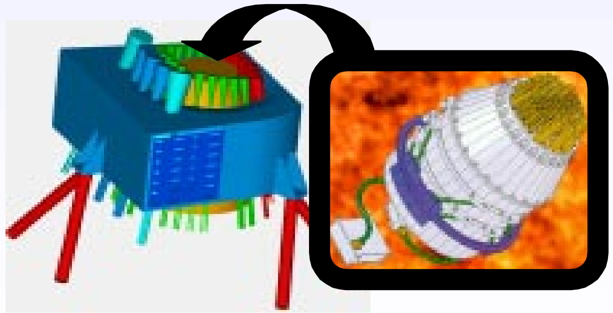


microcracks and edges, also have an impact

on fabrication (technology).

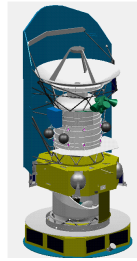


Mutual interaction and mutual coupling
at instrument level



Main conclusions

- ✓ External straylight can be controlled by simplified working requirements.
- ✓ Internal straylight needs tight control of temperature fluctuations.
  Detailed thermal analysis shows that it can be controlled.
- ✓ Experimental validation required.
  Dedicated Radio Frequency model planned
  Related TRP/GSTP activities on-going.
- ✓ Straylight analysis for PLANCK is a complicated task (needs specific expertise + state of the art tools) that has to be continued throughout the project.



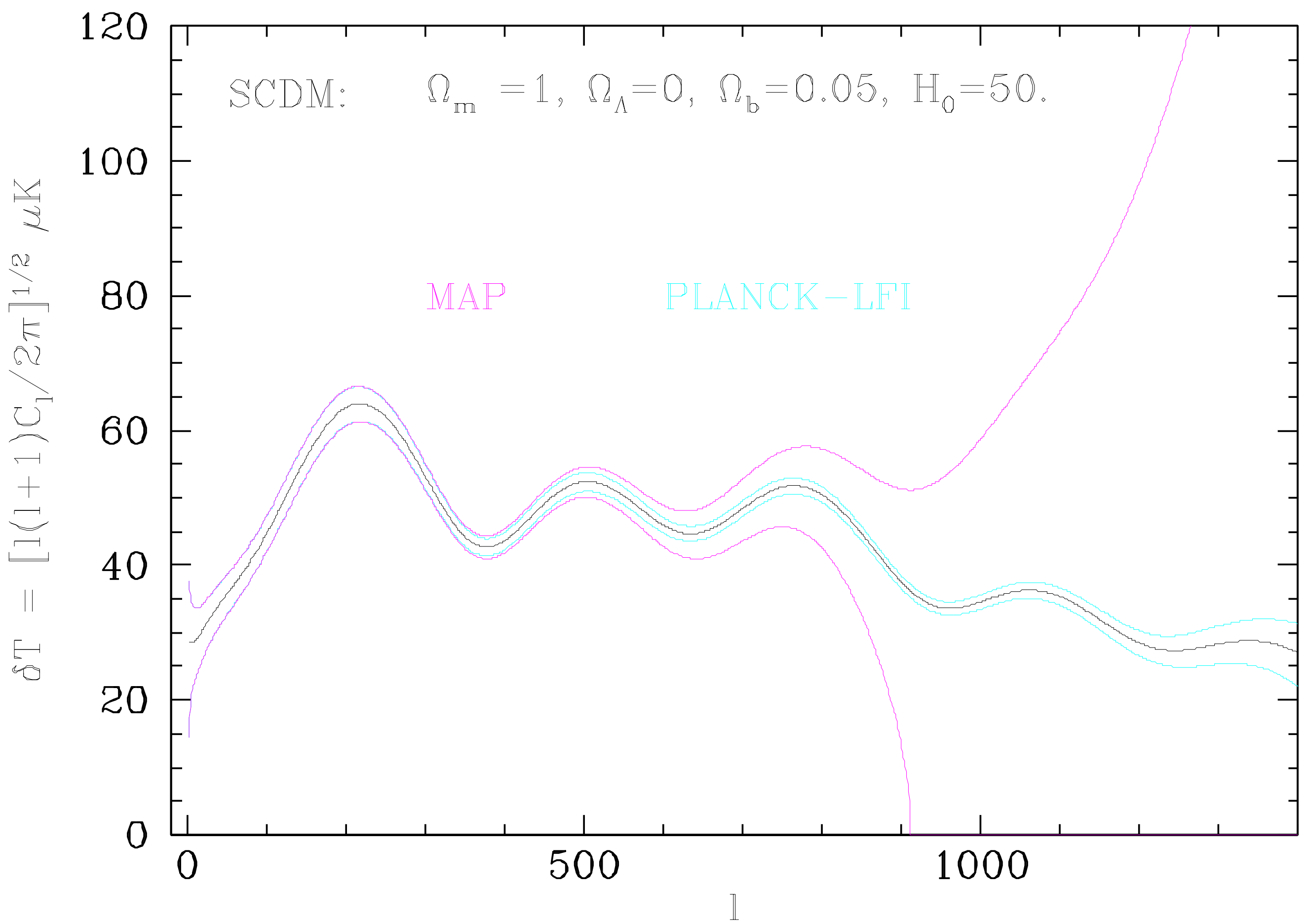
5.2 LFI Status

N. Mandolesi TeSRE Bologna

Summary

- Science Capabilities
- Instrument Design & Status
- LFI Consortium Team

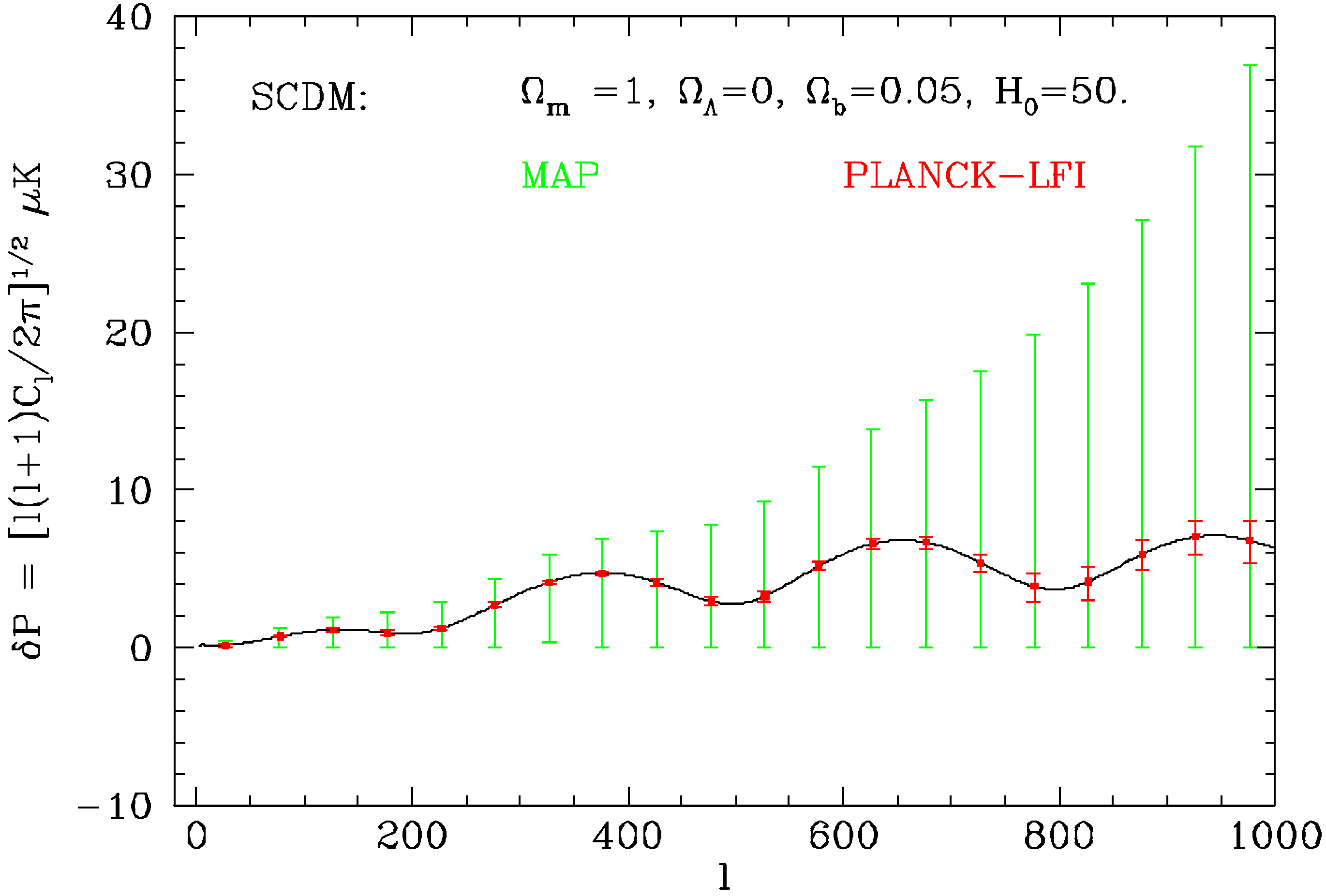
Planck/LFI Power Spectrum (vs. MAP)



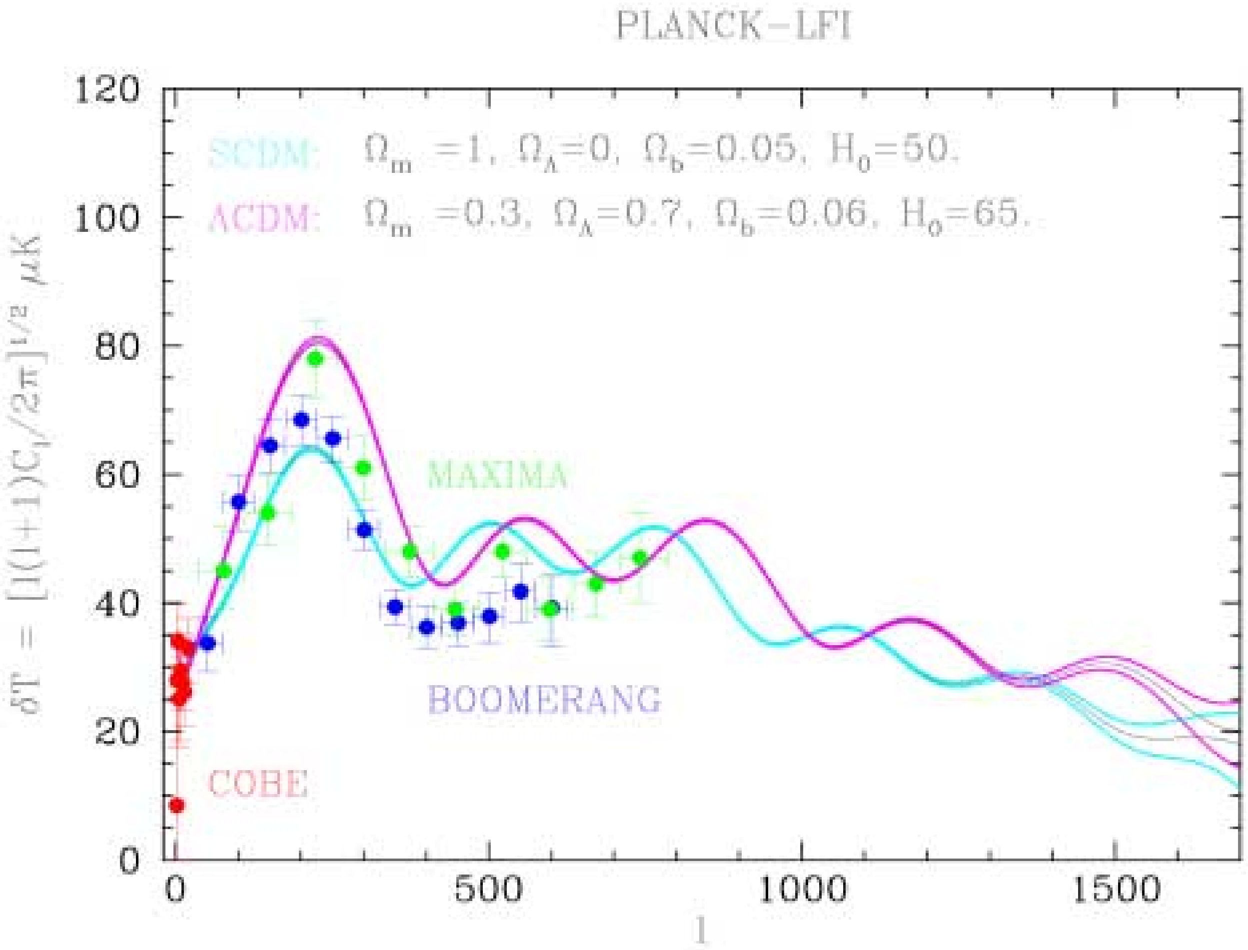
Goal Performances

Center Frequency (GHz)	30	44	70	100
Detector Technology	HEMT radio receiver arrays			
Detector Temperature	~20 K			
Cooling Requirements	H_2 sorption cooler			
Number of Detectors	4	6	12	34
Angular Resolution (Ô)	33	23	14	10
Bandwidth ($\Delta \nu / \nu$)	0.2	0.2	0.2	0.2
$\Delta T/T$ Sensitivity per res. element (12 months, 1σ, 10^{-6} units)	1.6 (P)	2.4 (P)	3.6 (P)	4.3 (P)
Flux sensitivity (12 months, 1σ, mJy)	9	17	23	24
NEB (10^{-3} MJy $\sqrt{sr}$)	2	5	11	16

LFI Polarisation Power Spectrum (vs. MAP)



Comparison with Boomerang and Maxima



Some Interpretations of the Boomerang Data

Boomerang returns expeditely, by M. White et al., astro-ph/0004385, proposes a marginally closed universe…

New CMB constraints on the cosmic matter budget: trouble for Nucleosynthesis?
by M. Tegmark et al., astro-ph/0004393, indicates high baryon content…

Remarks on the Boomerang results, the cosmological constant and the leptonic asymmetry,
by J. Lesgourgues et al., astro-ph/0004412, suggests lepton asymmetry, no cosmological constant…

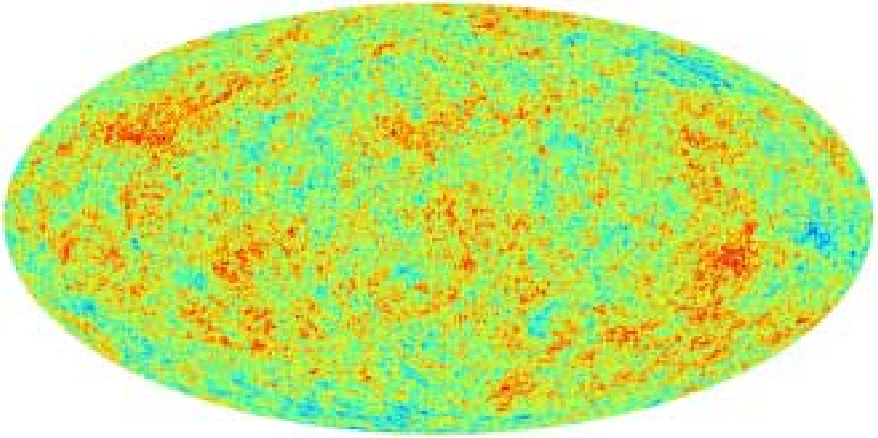
Is there evidence for topological defects in the Boomerang data?, by F.R. Bouchet et al.,
astro-ph/0005022, hybrid models containing both topological defects and inflationary perturbations…

Decaying neutrino and a high cosmological baryon density, by S.H. Hansen et al., astro-ph/0005114 thinks at
τ–nutrino decaying into e-neutrino plus scalars…

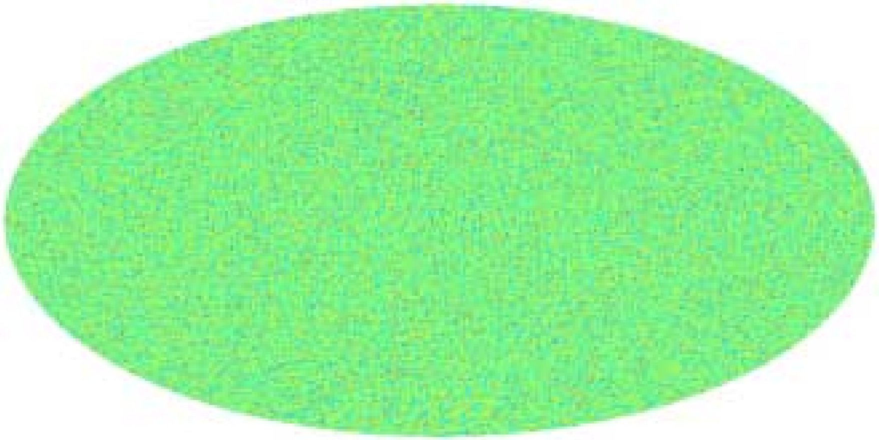
Cosmic strings in the age of Boomerang, by C.R. Contaldi, astro-ph/0005115,
cosmic strings and/or inflationary perturbations and/or cosmological constant…

Decaying Cold Dark Matter model and Small-Scale Power, by R. Cen, astro-ph/0005206,
decaying CDM plus cosmological constant…

Temperature and Q-Polarisation



Temperature Map



Polarisation Map

Planck Cosmological Parameter Recovery

Target model: ΛCDM with $\Omega_m = 0.35$, $\Omega_\Lambda = 0.65$, $\Omega_B = 0.05$, $h = 0.65$, $T/S = 0$, $n_S = 1$, $n_T = 0$, $\tau = 0.05$.

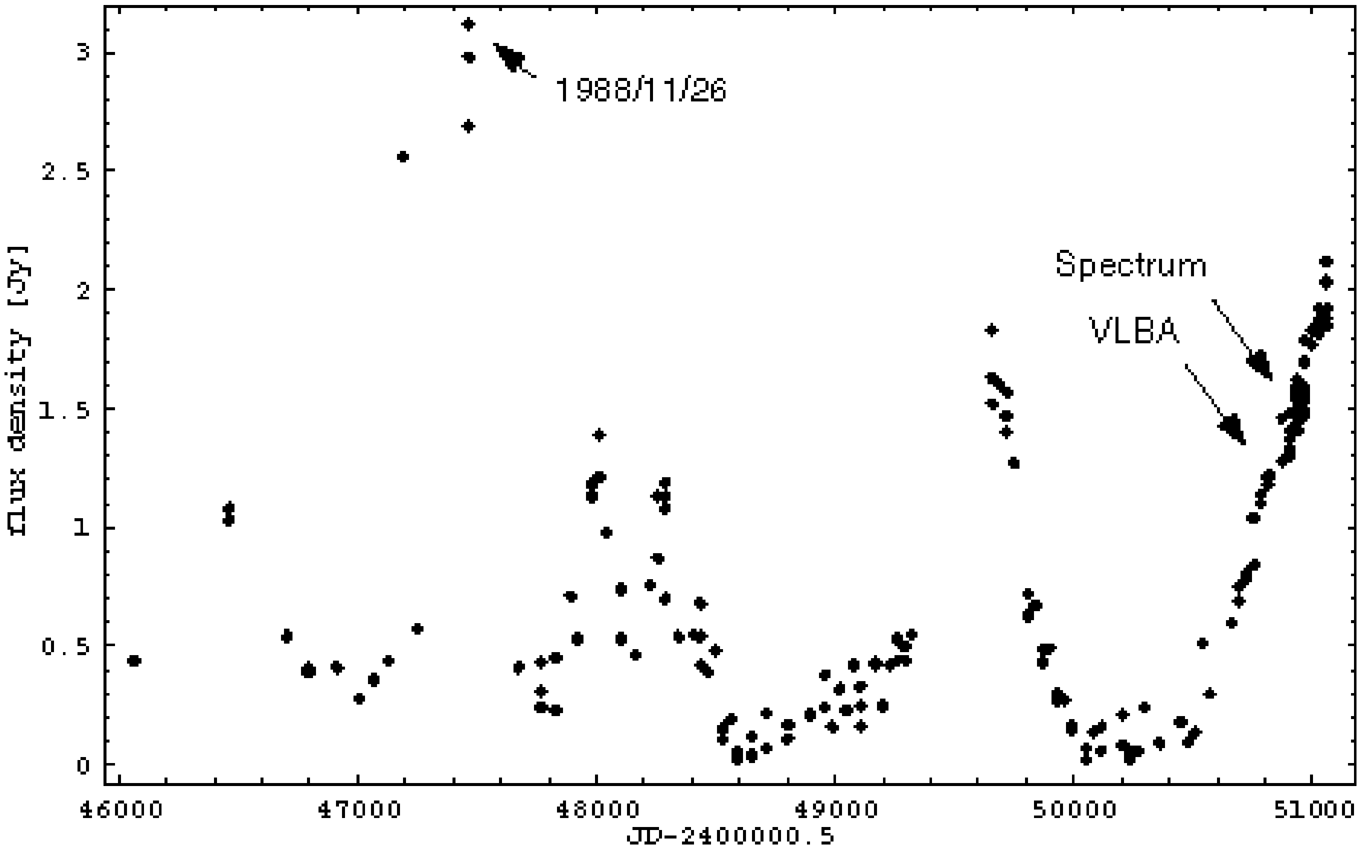
From Eisenstein, Hu & Tegmark, 1998

Quantity	T	T & P
h	1.1	0.13
Ω_m	1.2	0.14
$\Omega_m h$	0.40	0.046
Ω_Λ	0.96	0.11
Ω_K	0.26	0.030
$\ln(\Omega_m h^2)$	0.064	0.018
$\ln(\Omega_B h^2)$	0.035	0.010
$m_\nu(\mathrm{eV}) \propto \Omega_\nu h^2)$	0.58	0.26
Y_P	0.018	0.013
$n_S(k_{\mathrm{fid}})$	0.041	0.0008
$n_S(H_0)$	0.18	0.039
α	0.015	0.0004
$\ln P_\Phi(k_{\mathrm{fid}}) \equiv \ln A_S^2$	1.1	0.073
$\ln P_\Phi(H_0)$	1.3	0.16
T/S	0.35	0.012
τ	0.59	0.004
$\ln\sigma_8$	0.42	0.057
$\ln\sigma_{50}/sigma_8$	0.75	0.093

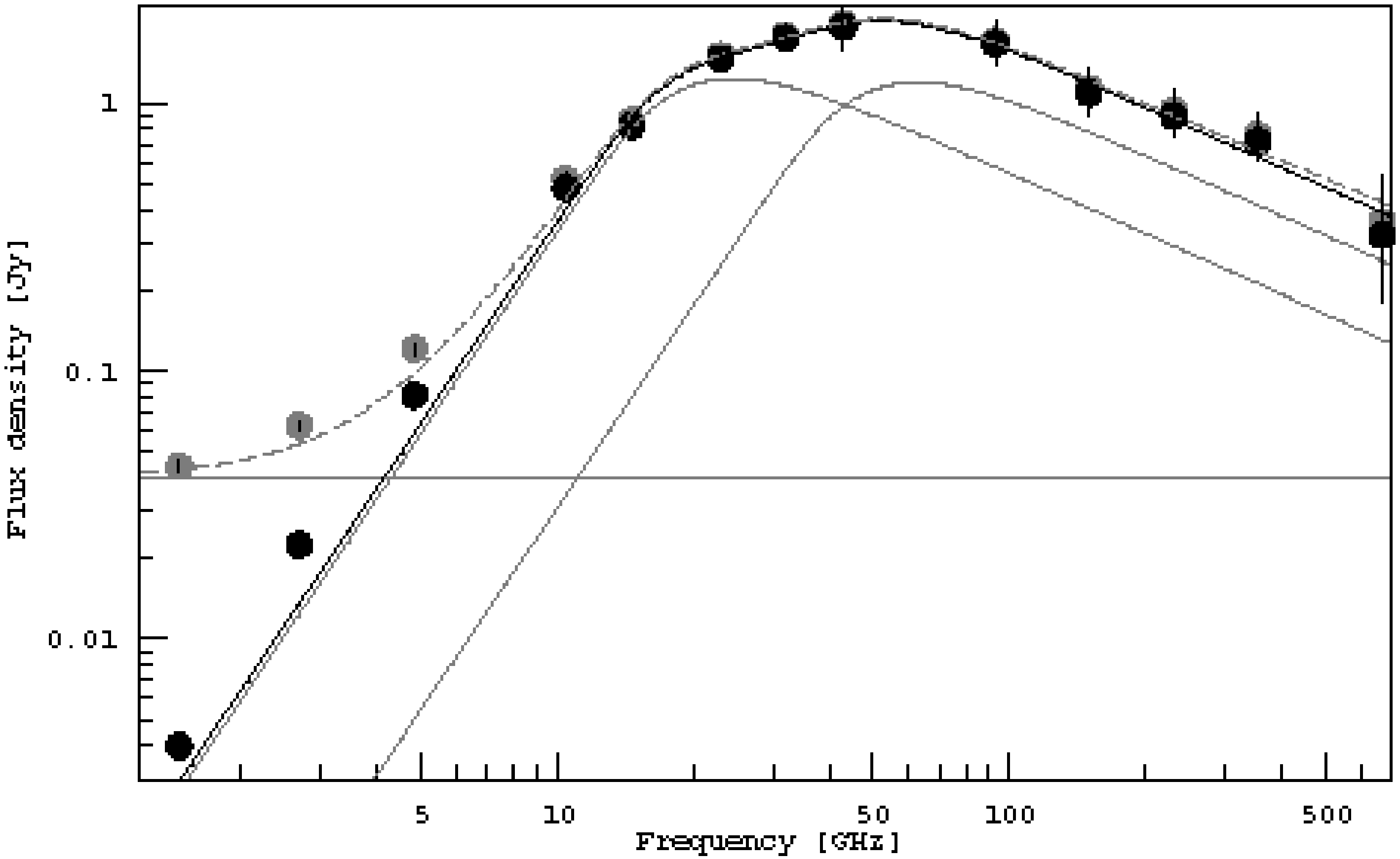
Astrophysics with LFI

- LFI Surveys unique in detecting populations of rare objects with hard spectra
- LFI Surveys emphasize bright radio sources with flat or inverted spectra
- BLAZARS
  - Spectral Energy distribution
  - Variability
- GPS Sources
- Other classes of source: ADS, AGN, Galactic stars, SN remnants, etc.
- S-Z
- Galaxy

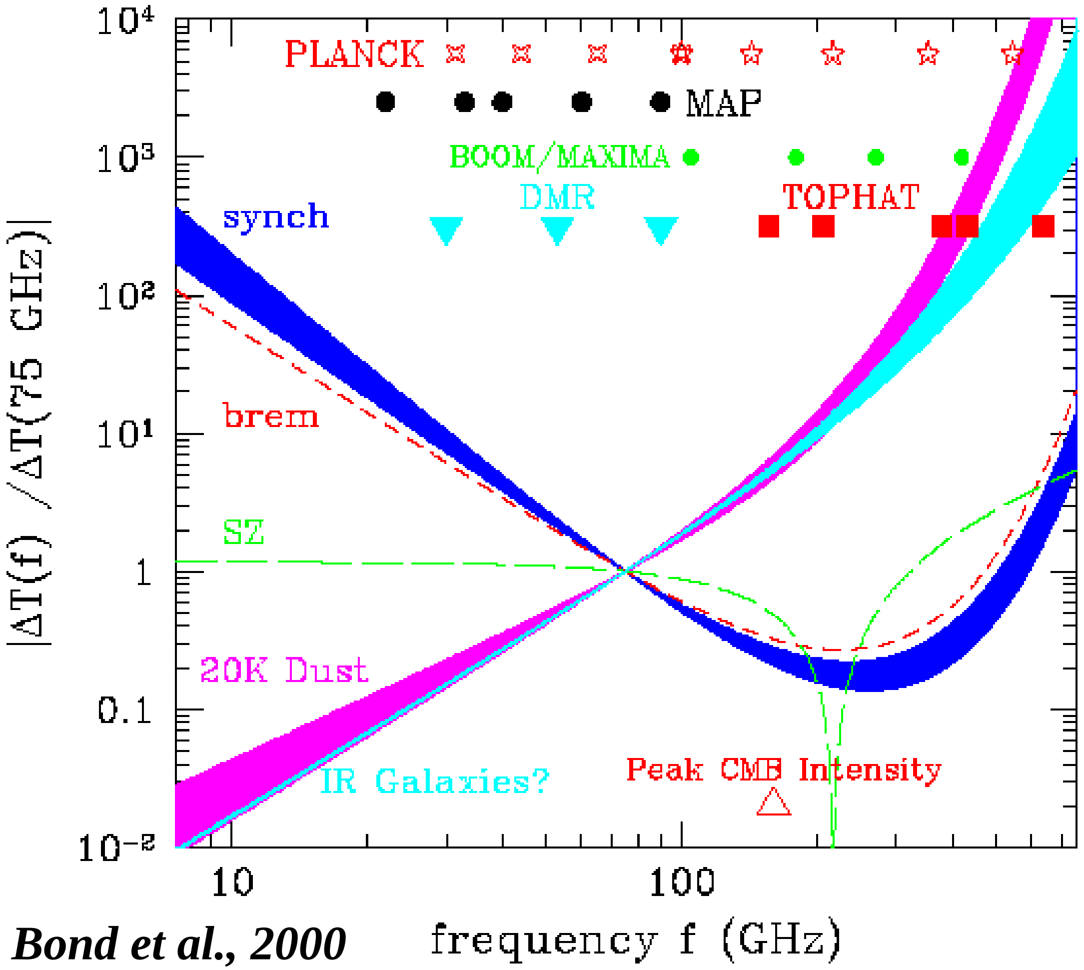
III Zw 2 Flare



GigaHertz Peaked Spectrum Sources (GPS)



Foregrounds vs. Frequency

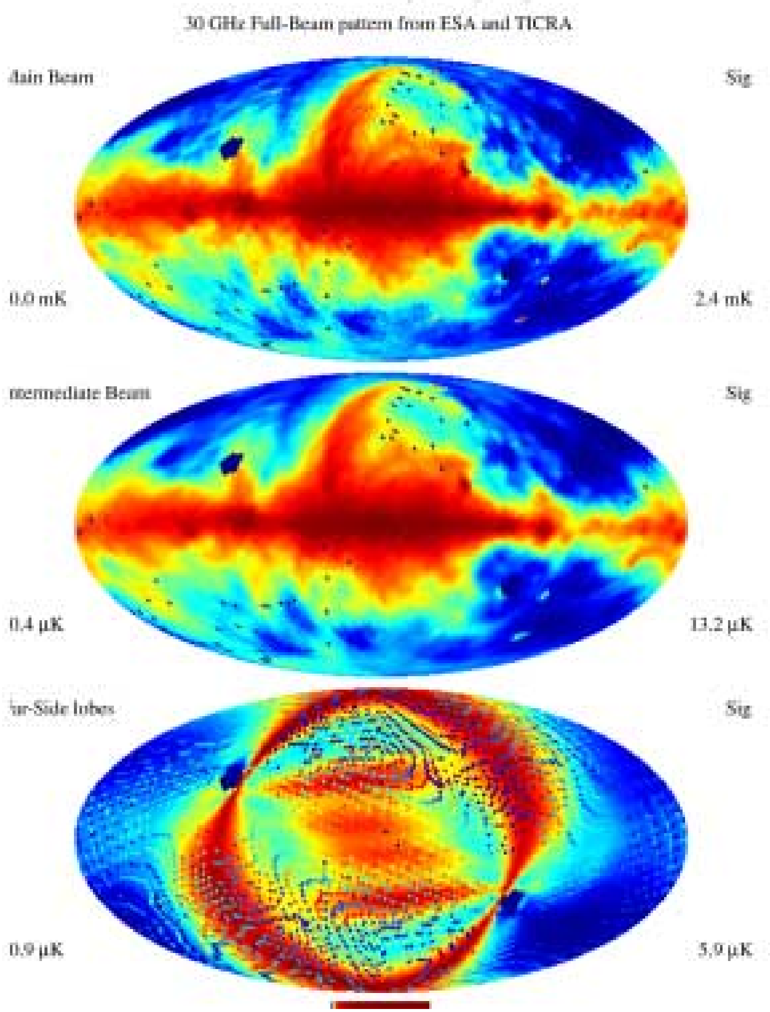


Bond et al., 2000

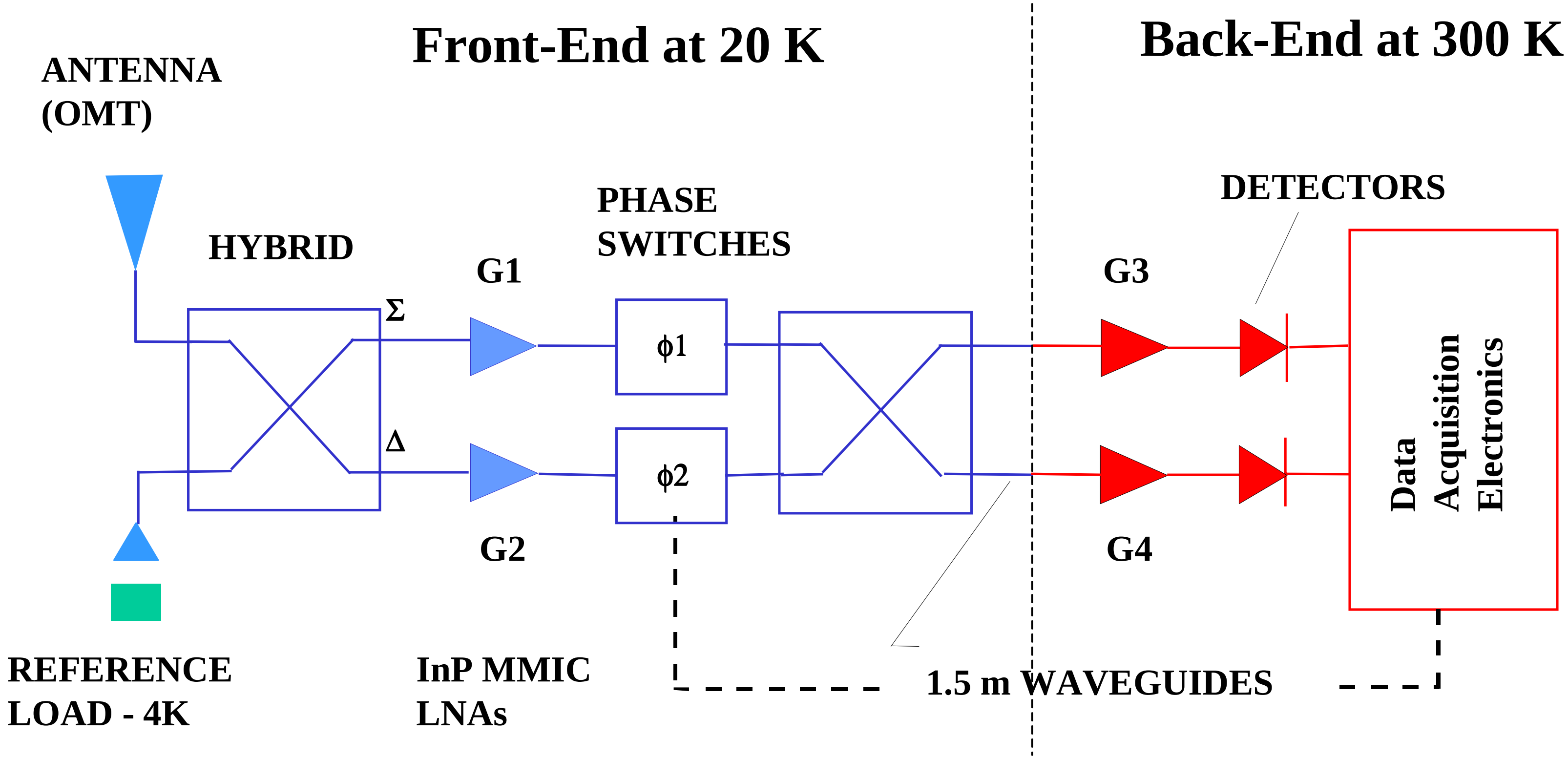
LFI Main Design Driver

- **Sensitivity**
- **Suppression of Systematics**
  - **1/f Noise**
  - **Thermal Effects**
  - **Straylight**
  - **Main Beam Gaussianity**
- **Control of Residual Systematics**

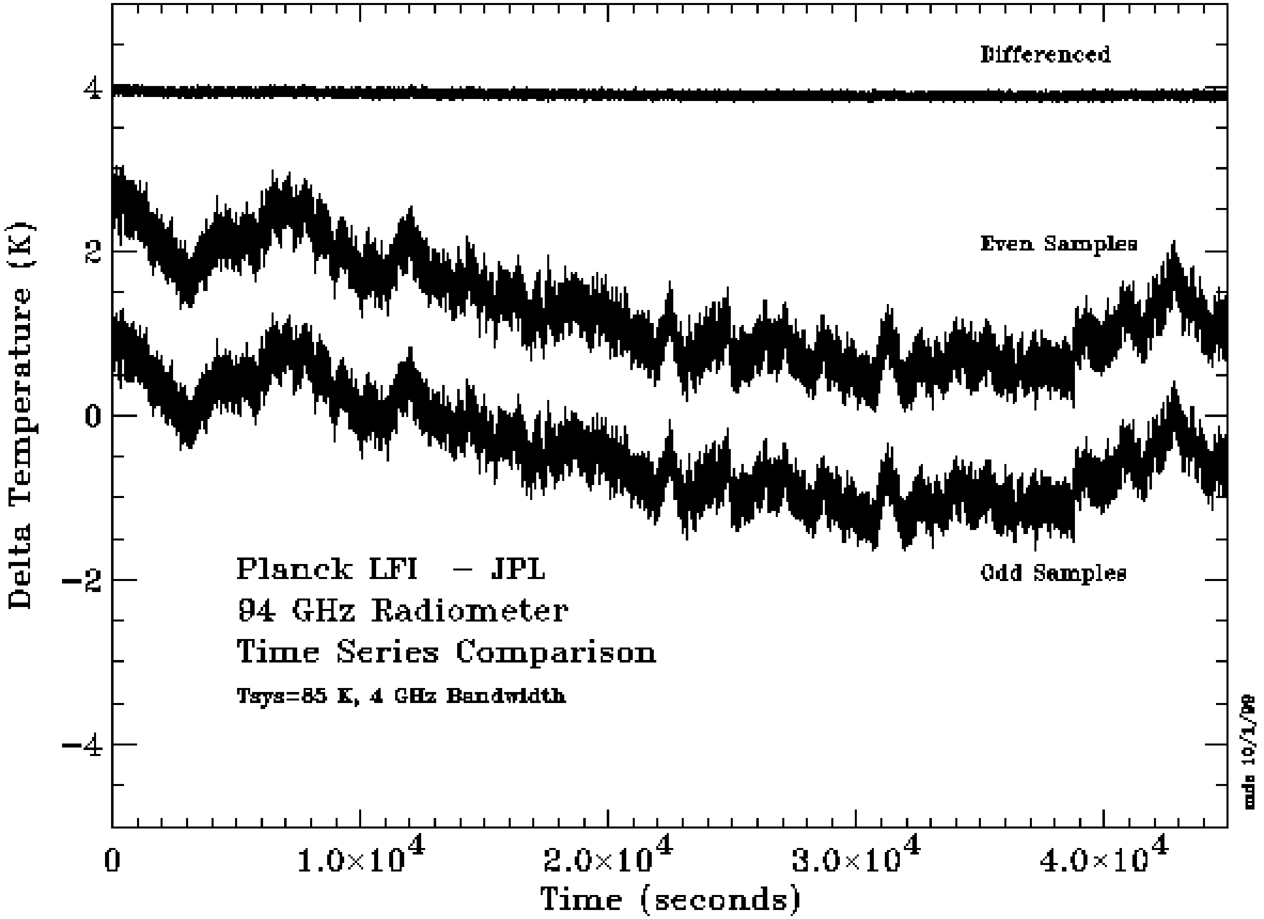
Straylight Simulation (30 GHz Carrier Telescope)



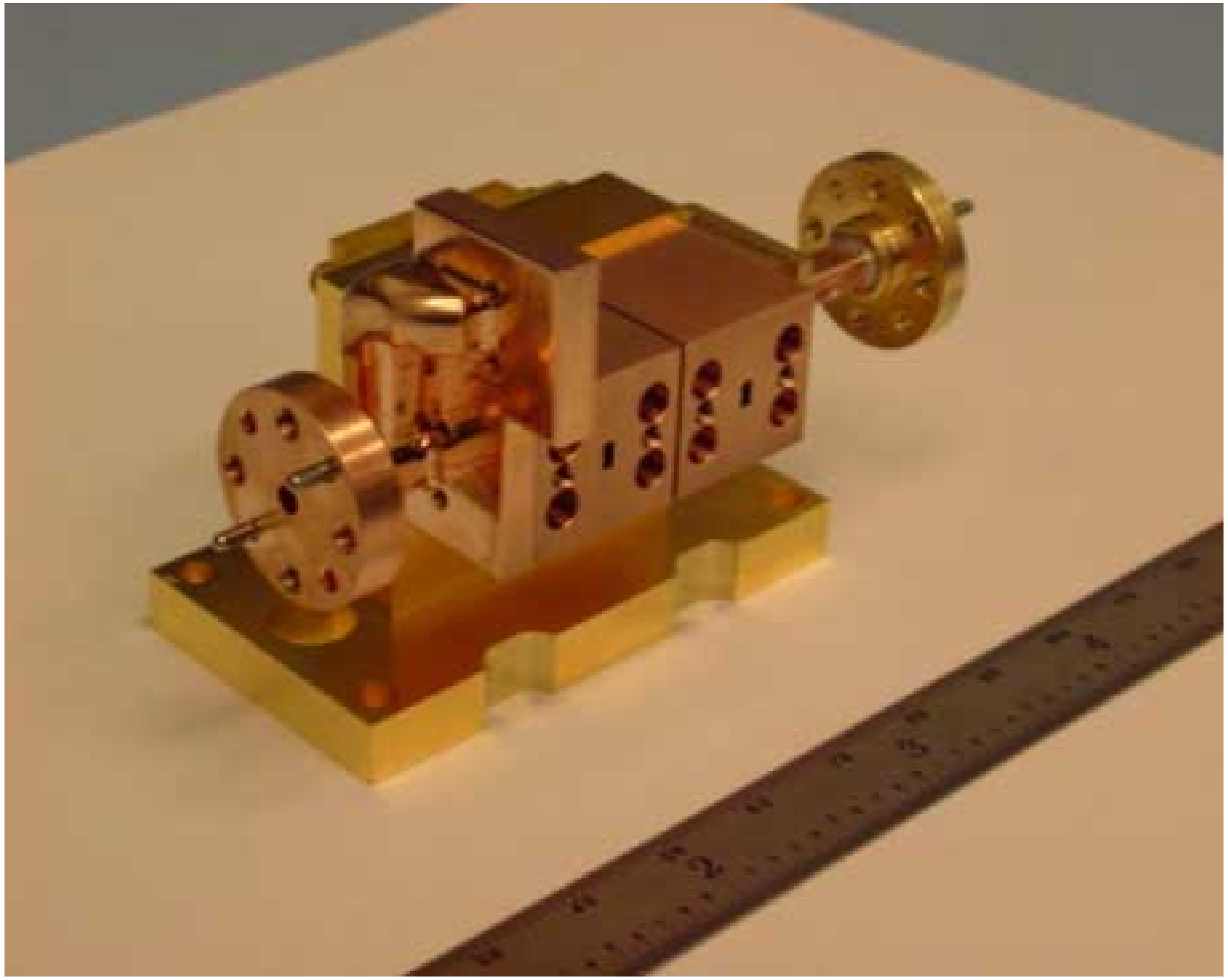
Radiometer Block Diagram



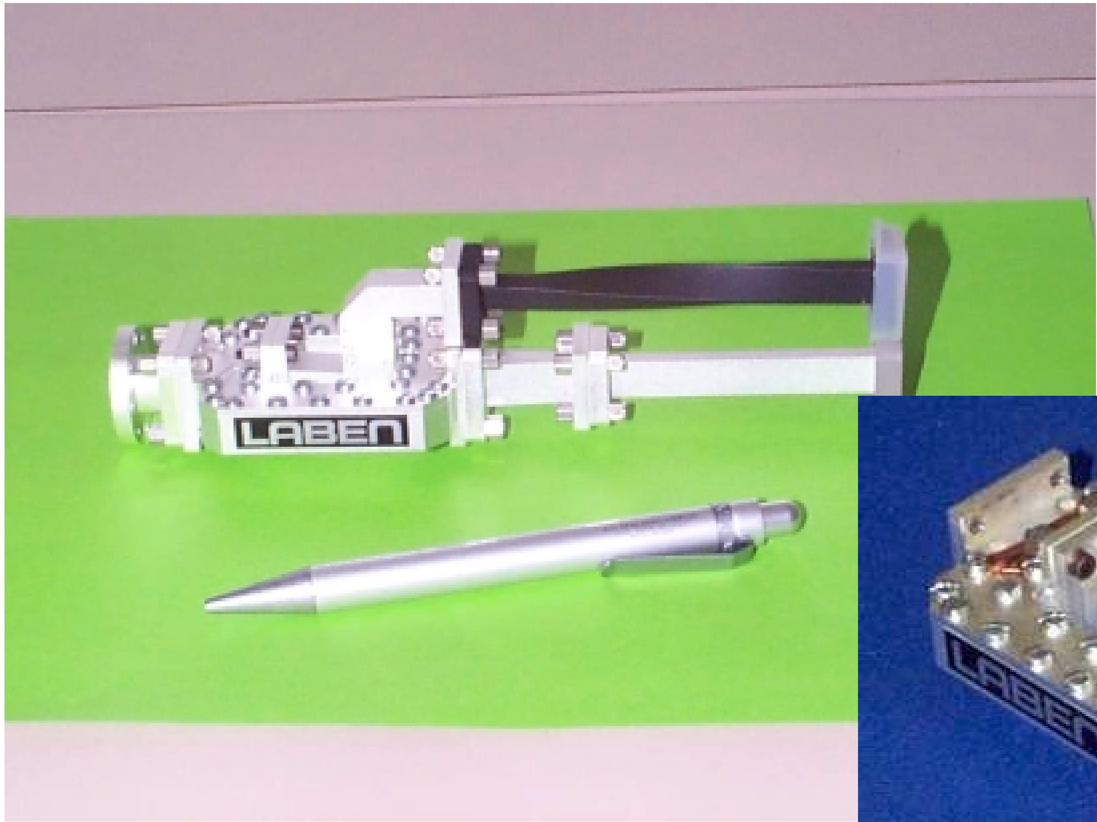
Differential Design Output

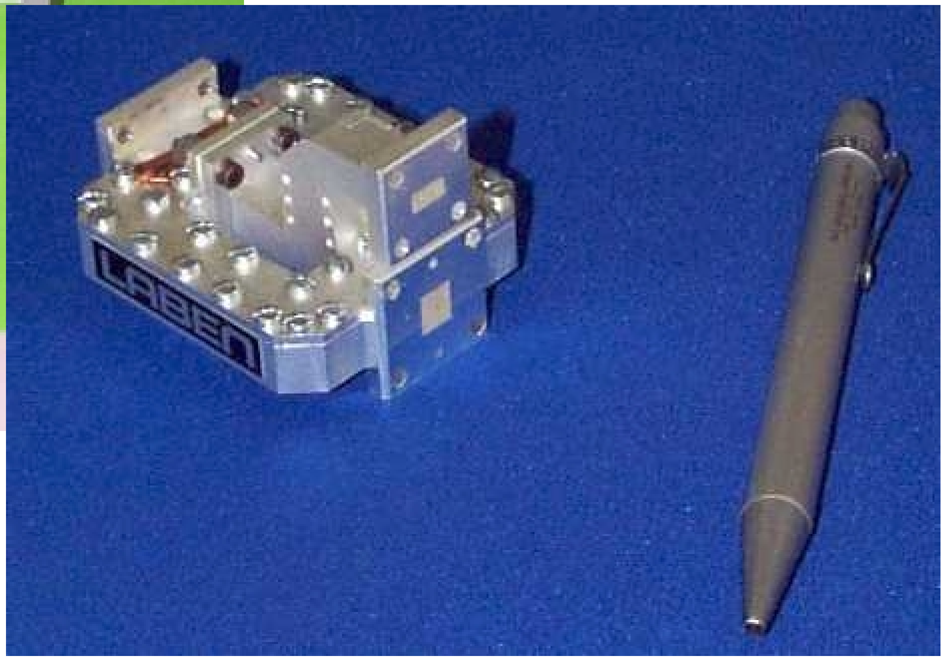


100 GHz EBB Radiometer FEM

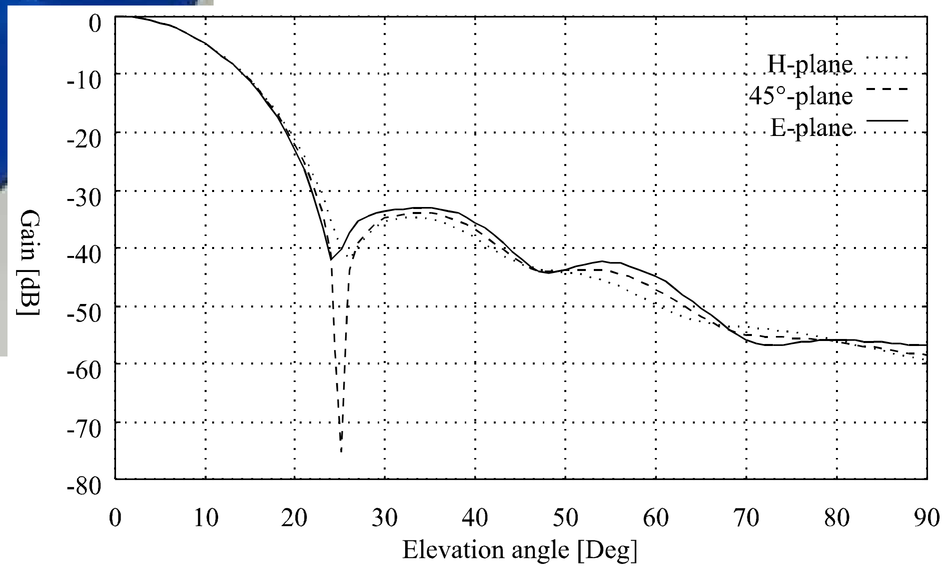


30 GHz EBB OMT



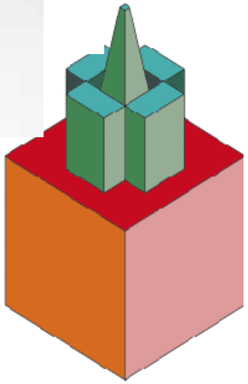


30 GHz EBB Feed Horn



4K Reference Load

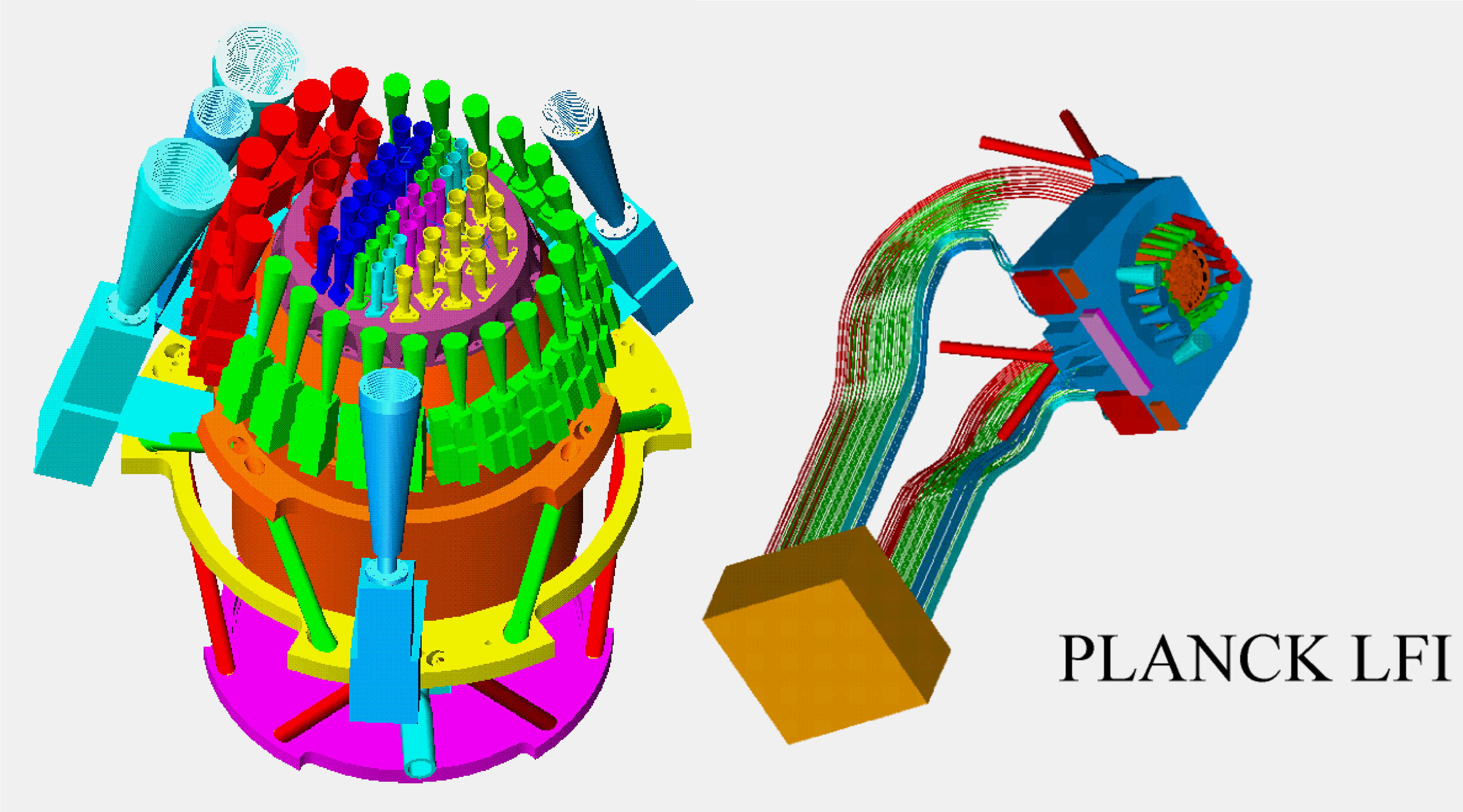
Material preparation



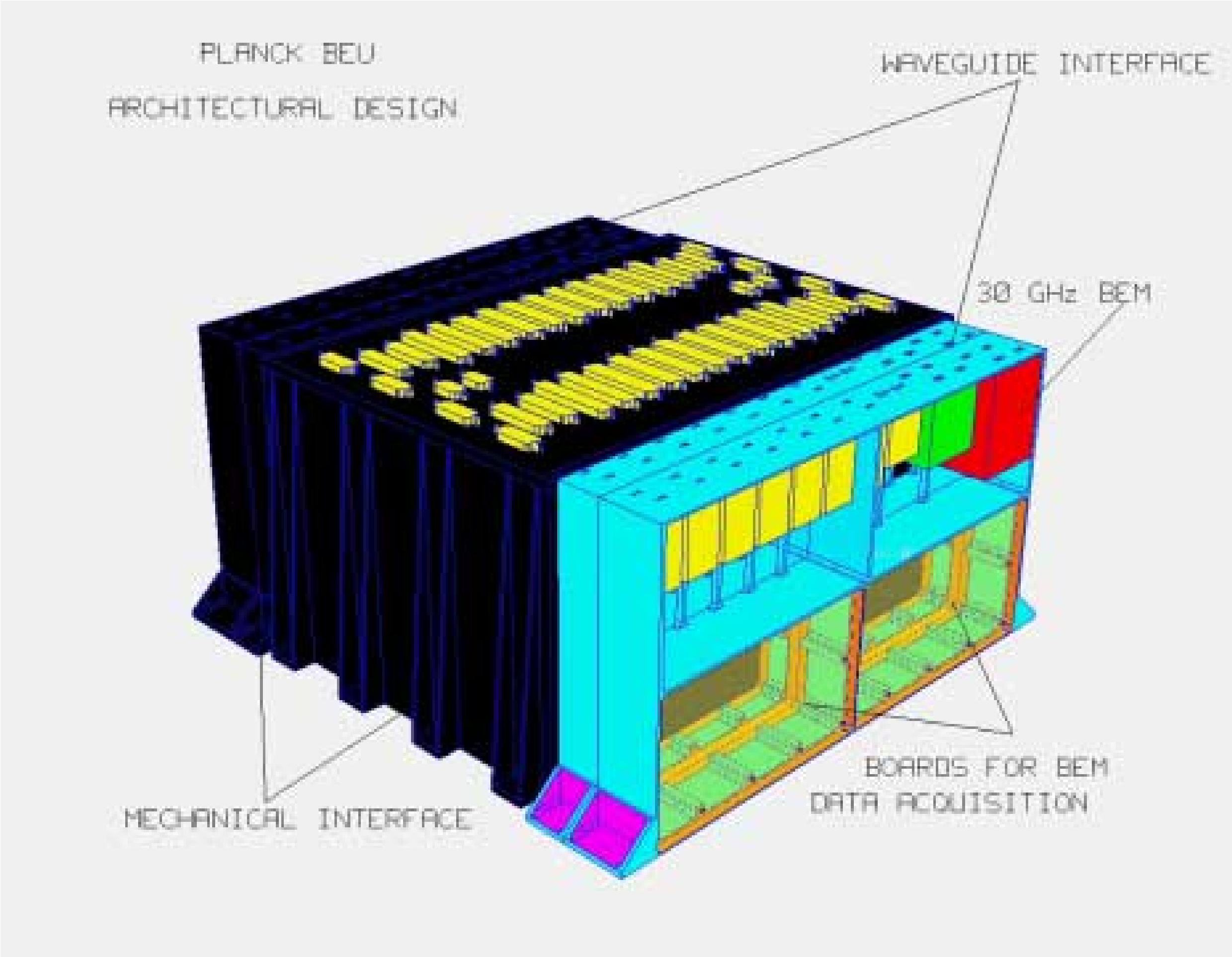
Radiometric Design and Test

Cryogenic Tests

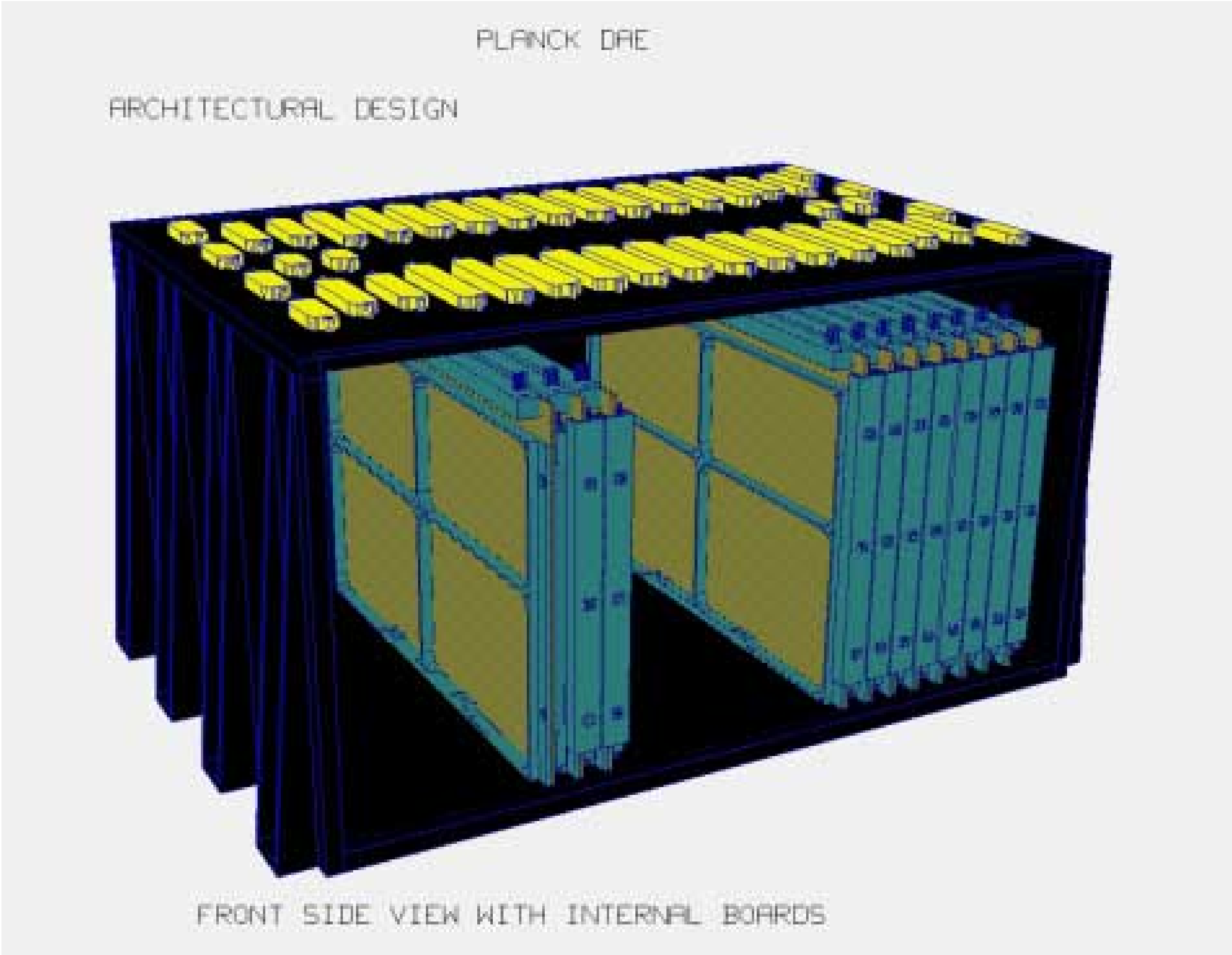
Focal Plane Unit and FEU/BEU



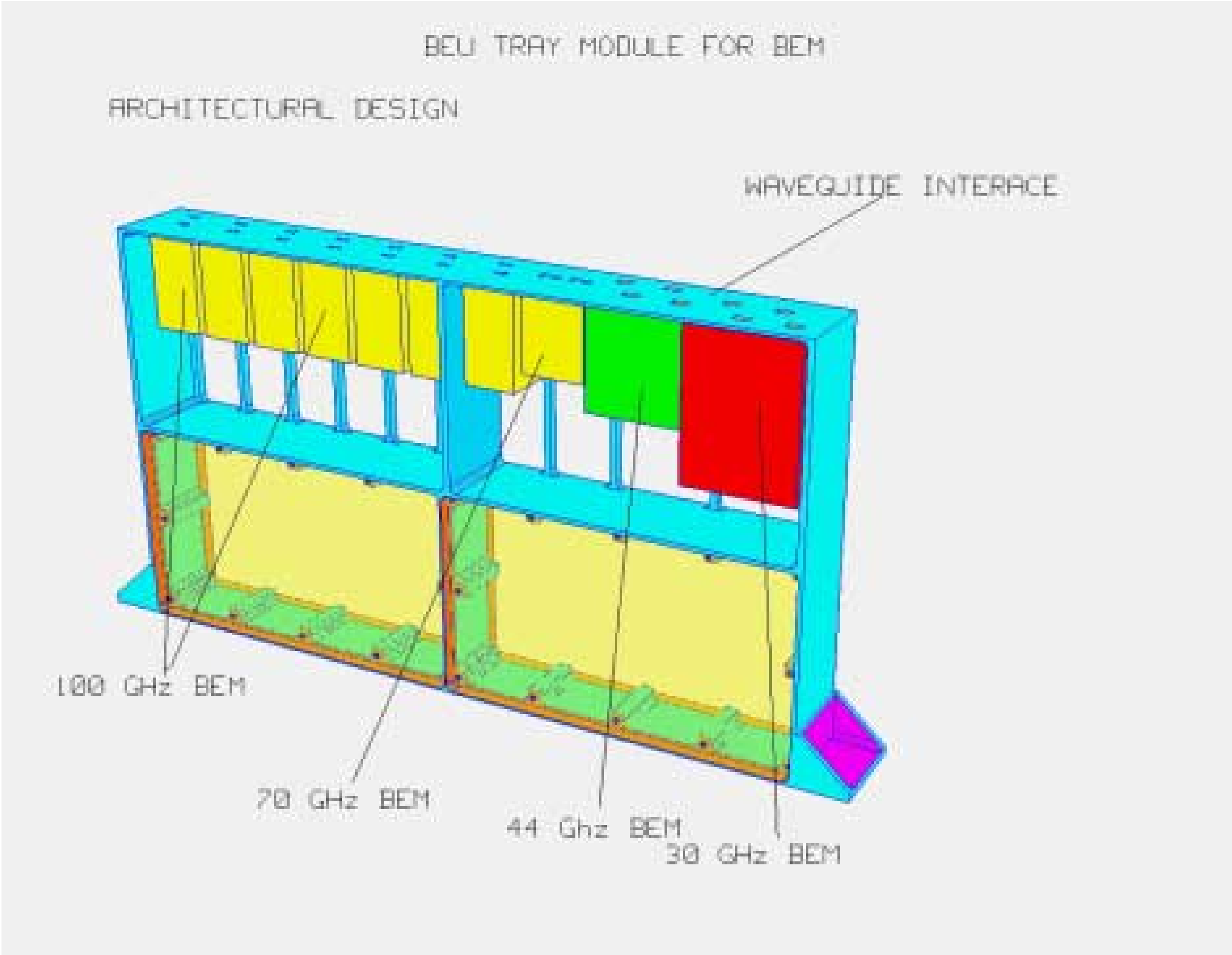
Planck/LFI BEU



Planck / LFI DAE



Planck/LFI BEM



Currently Achieved LNA Noise Performances

	30 GHz	44 GHz	70 GHz	100 GHz
Goal T_Amp (K)	6.0	10.6	17.3	29.2
Achieved T_Amp (K)	9 (§)		<25 (*)	45
T_Amp in reduced power (K)	9.9		28	50
Ratio	1.7		1.6	1.6

(§) Measured noise through the 20% band is 8.5K at 13K operating temperature, which yields about 9 K extrapolating to 20K operation.

(*) Measured room temperature Tamp of 170K (2 dB), which scaled to operation at a physical temperature of 20K yields a noise temperature in the range 20-25 K.

W –Band performances: LFI vs. MAP

	Number of Feeds	Physical Temp (K)	Amp Noise Temp (K)	Nominal lifetime (months)	Sens. per 0.3° pixel (μK)(^)
MAP	4 + 4	95	100-130	24	35
Planck-LFI "Achieved"	17	20	50	14	11
Planck-LFI "Goal"	17	20	29.3	14	7

(^) Antenna Temperature

Power Dissipation Budget (mW)

	Requirement	Measured(*)
30 and 44 GHz	155	154-175
70 GHz	132	
100 GHz	262	245

(*) Including InP Front-end phase switches as measured by Millilab (May 2000)

Phase Switches Status (18 May 2000)

Baseline:
InP PIN diode phase shifters (FEM)

-Tested on 70 GHz prototype (Millilab, FIN)
- Power dissipation now acceptable (< 0.5mW)
- 20% band (as required)
- 1/f very promising (measurements running now)
- *Poor insertion loss (9-12 dB)*

Back-up solutions:

Fox-Trot scheme (FEM)

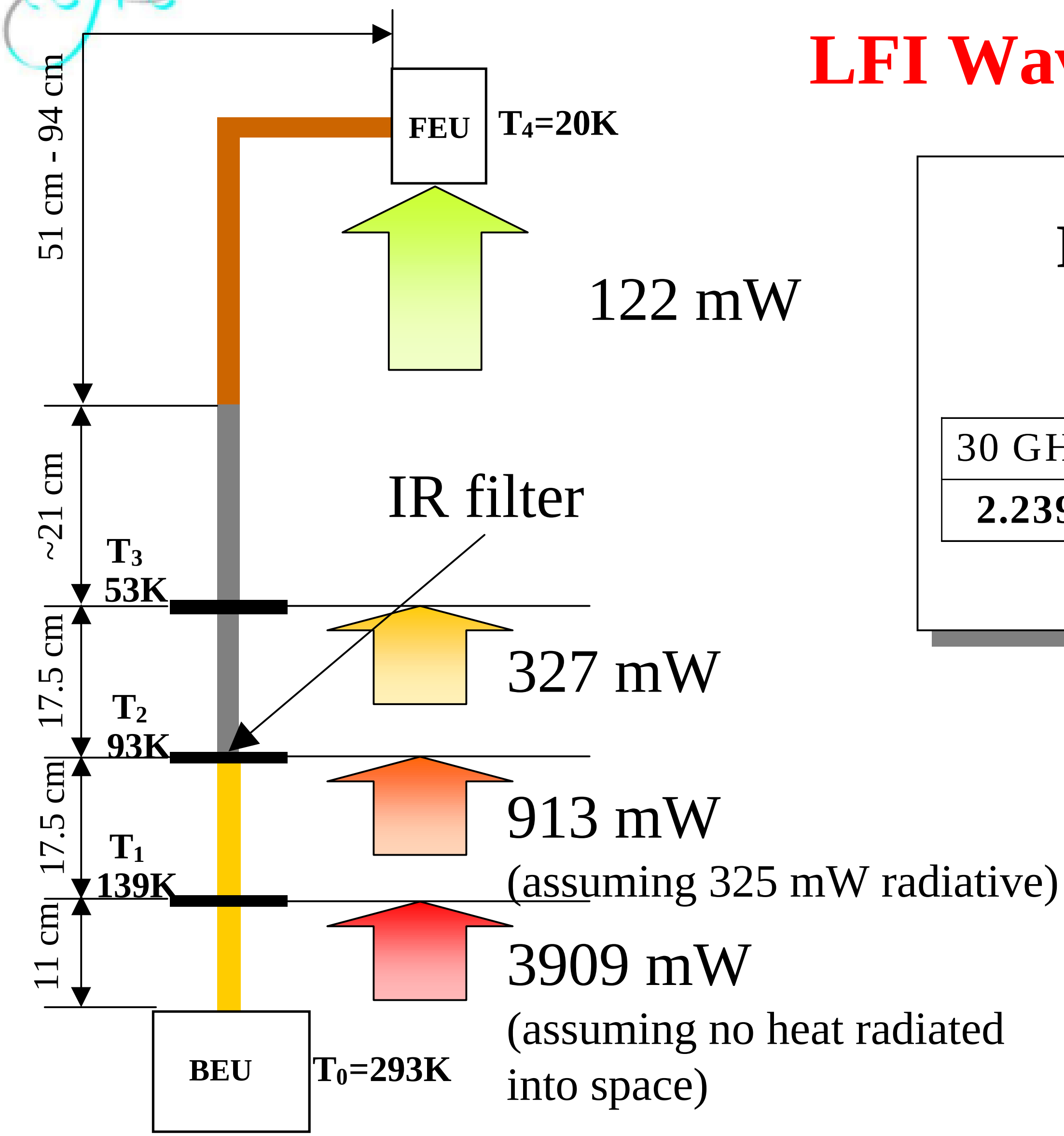
- Tested on 30 GHz prototype (Joderll, UK)
- FE at 20K, switches warm, 1.8 GHz bandwidth, 0.73K unbalanced system
- 1/f knee at 47 mHz, factor 8 improvement over baseline switching scheme
- Good isolation and return loss
- *To be tested with HEMT switches at 20K, full bandwidth*

DPDT switch (BEM)

- Tested on 100 GHz PD (JPL)
- Run in SPDT mode, Tsys =50K
- 1/f knee 50 mHz
- Easier implementation!
- *Bandwidth 7% (expected 13%): to be understood*
- *Go to DPDT scheme*

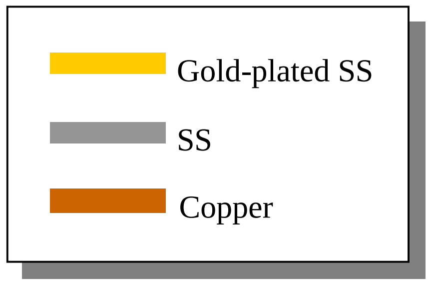
Deadline: LFI Mid-Term Review (End of June)

LFI Waveguides

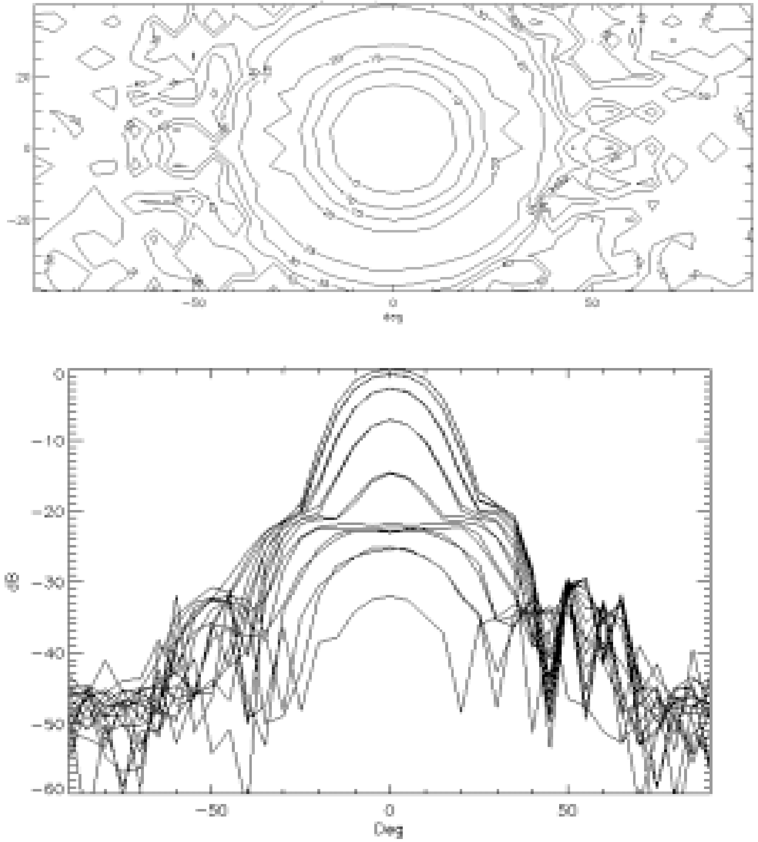


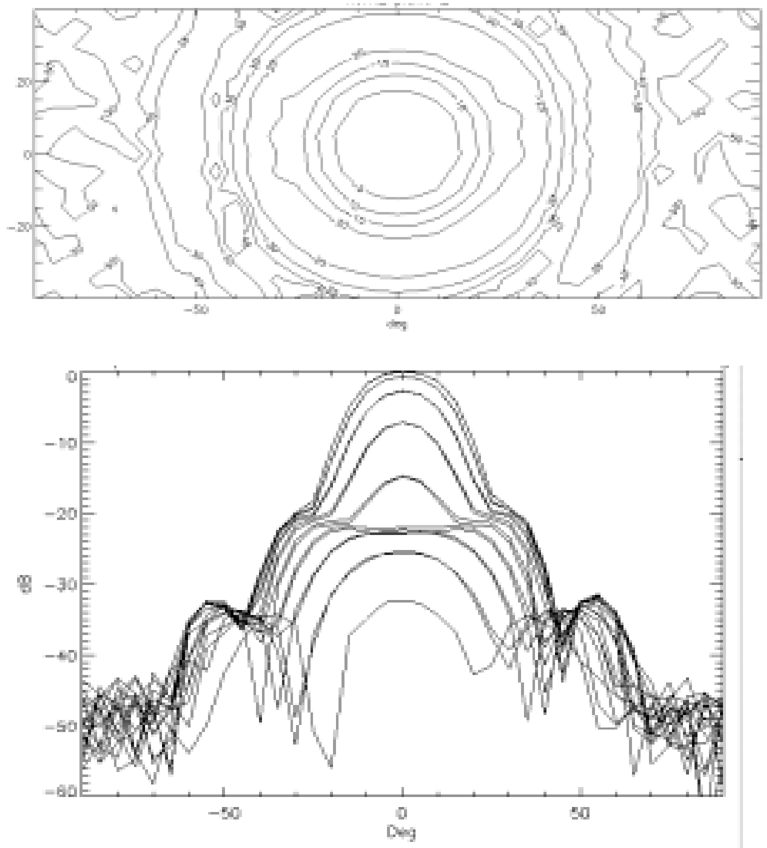
Radiometric losses (dB)

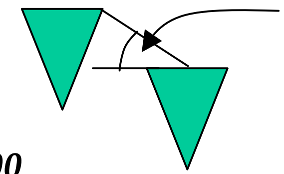
30 GHz	44 GHz	70 GHz	100 GHz
2.239	**2.745**	**4.971**	**9.115**



Mutual Coupling between Horns 1 / 2

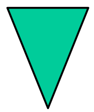




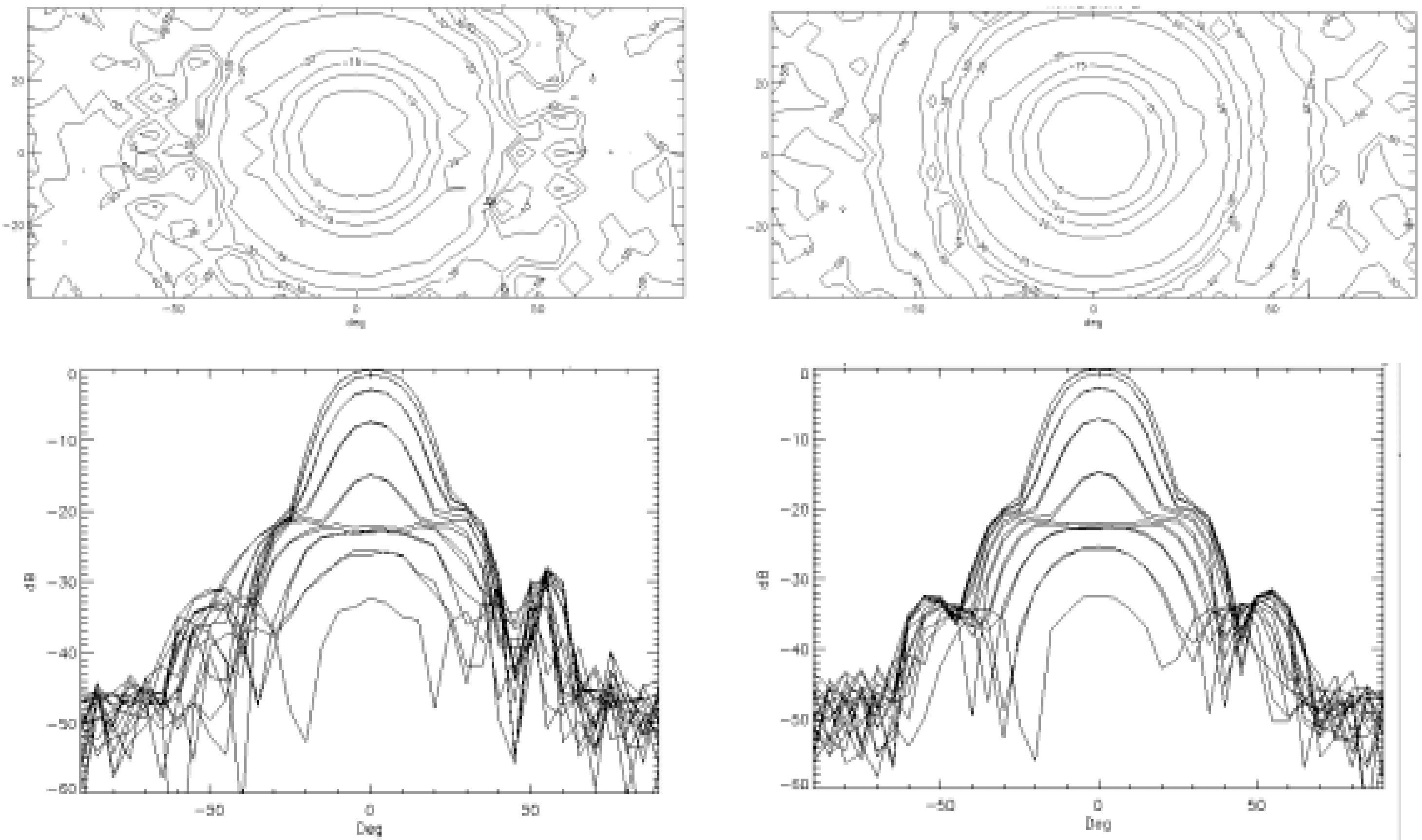


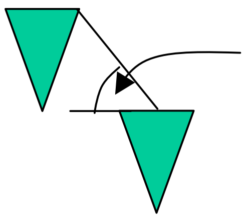
α = 41 deg

Single horn

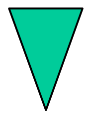


Mutual Coupling between Horns 2 / 2



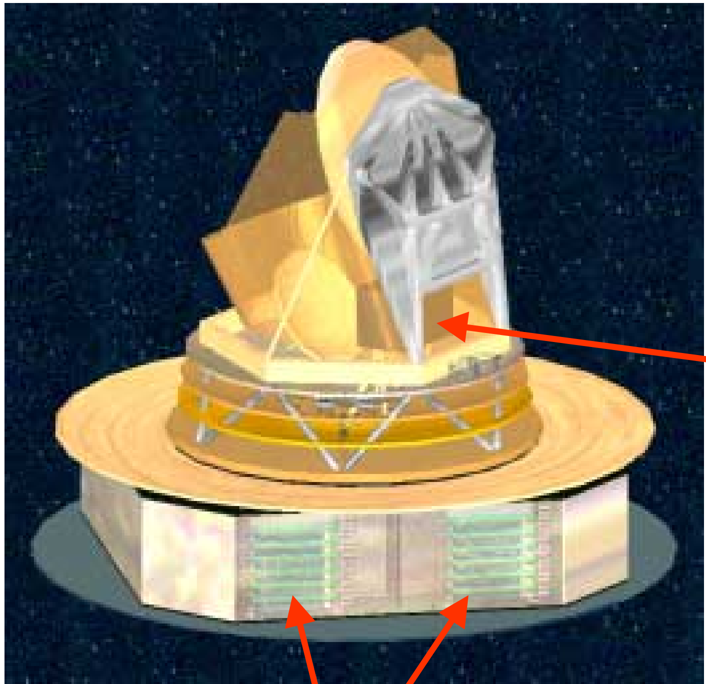


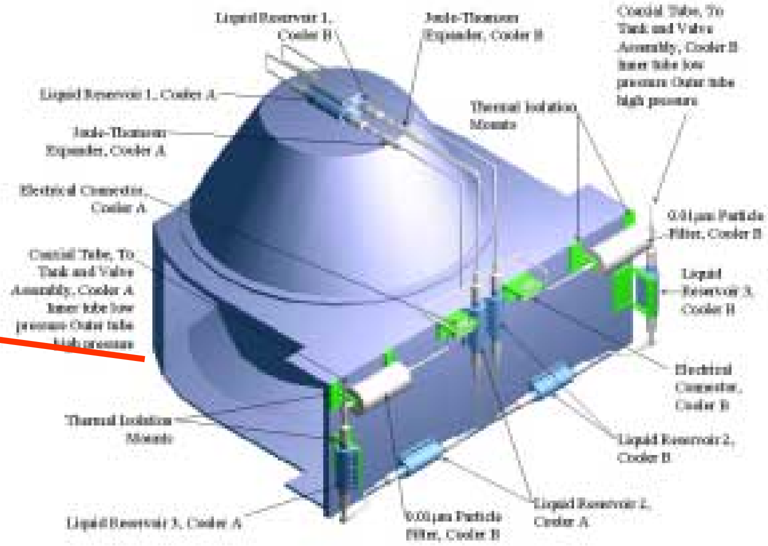
α = 50 deg

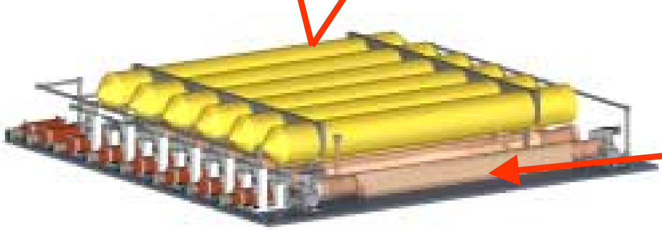


Single horn

Planck 18K/20K Sorption Cryocoolers







LFI Data Rate

	30 GHz	44 GHz	70 GHz	100 GHz	Total
Raw data produced (kb/s)	**13.3**	**19.9**	**39.9**	**113.0**	**186.1**
Reduction factors:					
Different sampling	3.3	2.3	1.4	1	1.21
Radiometer averaging	2	2	2	2	2
Rate before compression (kb/s)	**2.01**	**4.33**	**14.24**	**56.50**	**77.09**
Lossless compression	3.8	3.8	3.8	3.8	3.8
Science Telemetry Data Rate (kb/s)	**0.53**	**1.14**	**3.75**	**14.87**	**20.29**
Housekeeping					4
Packeting overhead (percent)					7
Total Data Rate (kb/s)					**25.99**
Contingency					20%
Total with contingency (kb/s)					**31.2**

LFI Data Rate – Breakdown

Assumptions

Scan Angle (degrees)	80
Spin Rate (rpm)	1.0
DAE Sampling rate (Hz)	8192
Oversampling per beam	3.0
Bits per word	16
Signal quantization (σ/q)	2

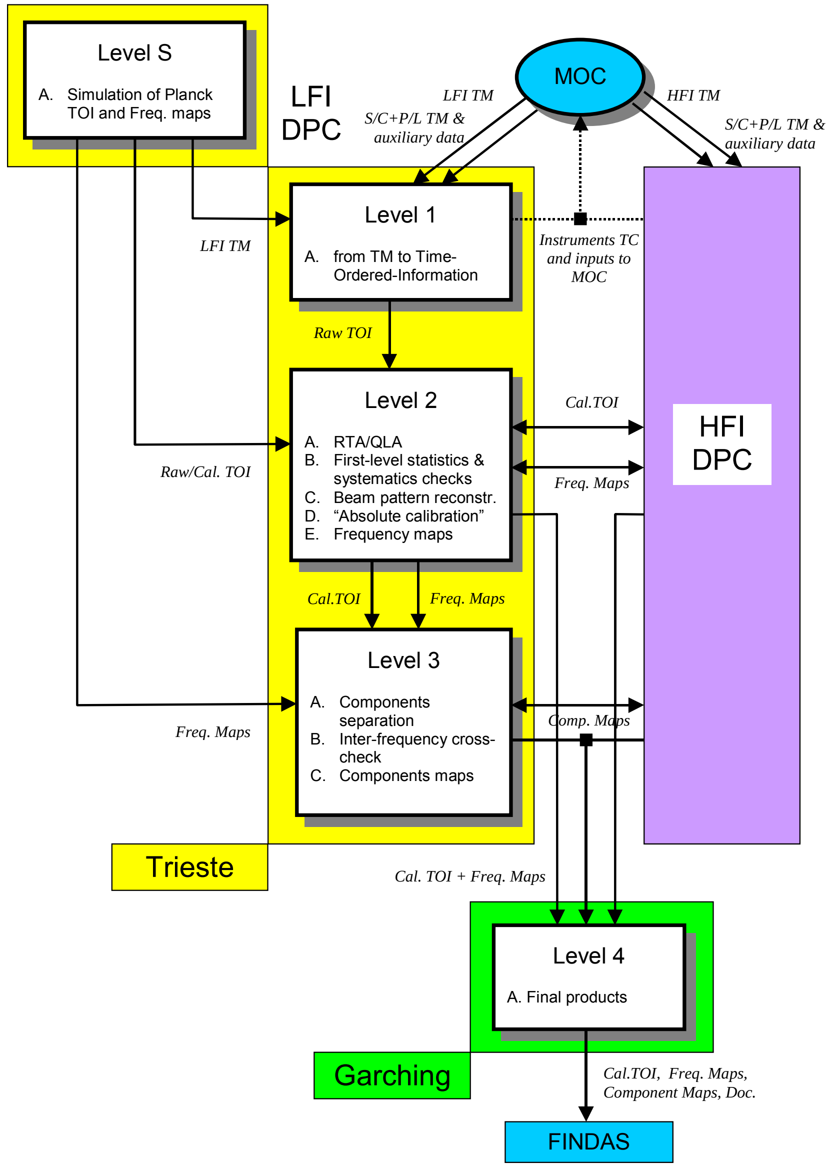
Budget

	2d Ave	No Ave
Raw data produced (kb/s)	**186.1**	**186.1**
Reduction factors:		
Different sampling	1.21	1.21
Radiometer averaging	2	
Rate before compression (kb/s)	**77.1**	**154.2**
Lossless compression	3.8	3.8
Science Telemetry Data Rate (kb/s)	**20.29**	**40.6**
Housekeeping	4	4
Packeting overhead (percent)	7	7
Total Data Rate (kb/s)	**25.99**	**45.6**
Contingency	20%	20%
Total with contingency (kb/s)	**31.2**	**54.7**

To reach telemetry rate of 31.2 kb/sec
increased HW and SW complexity is required

Planck/LFI Low Frequency Instrument

LFI DPC Data Flow



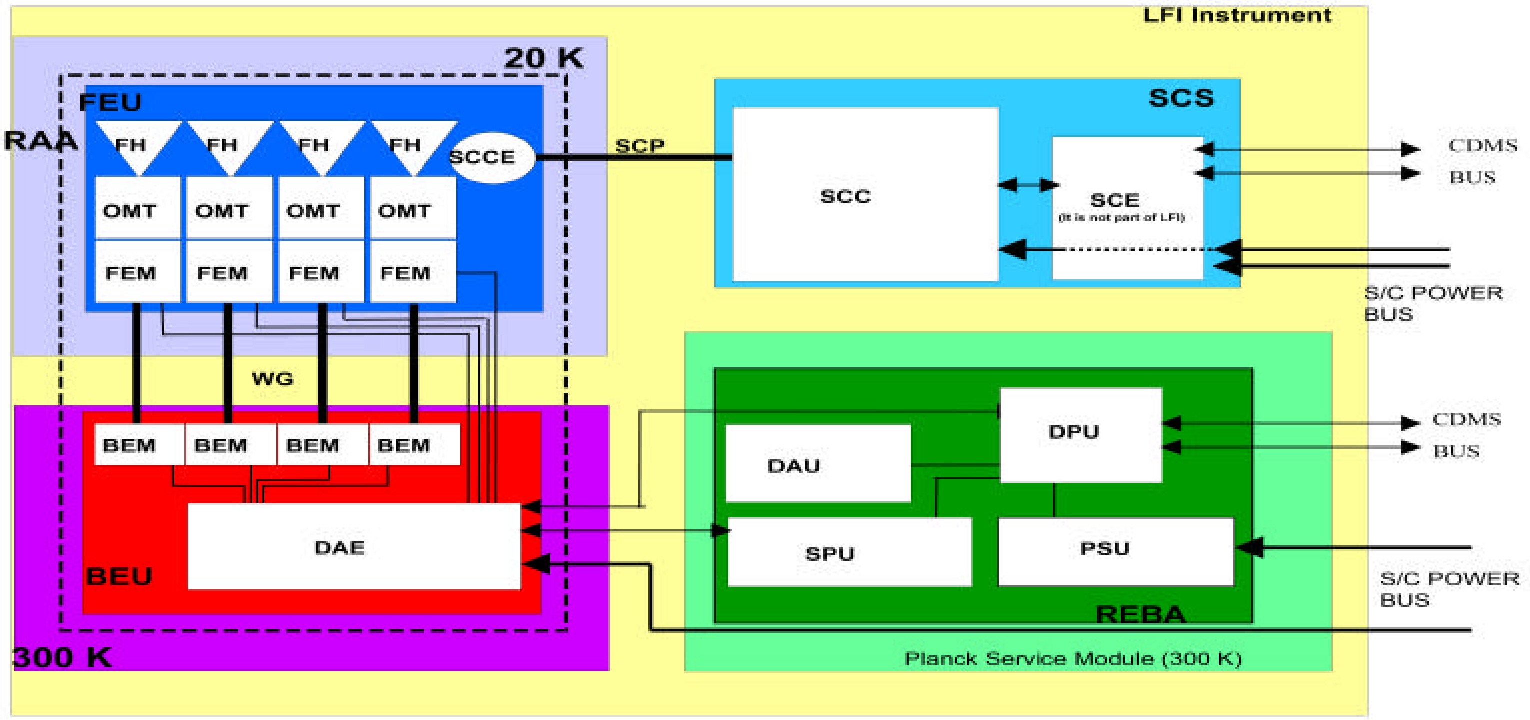
LFI Consortium Team

Country	Name	Institute
Italy (I)	N. MANDOLESI L. DANESE G. DE ZOTTI G. TOFANI N. VITTORIO R. C. BUTLER M. BERSANELLI F. PASIAN	TESRE-CNR SISSA OAP CAISMI ROMA "TOR VERGATA" UN. TESRE-CNR IFCTR-CNR OAT
Switzerland (CH)	T.J.L. COURVOISIER	INTEGRAL SCIENCE DATA CENTRE
United Kingdom (UK)	R. D. DAVIES R. DAVIS	JODRELL BANK JODRELL BANK
USA	C. R. LAWRENCE T. GAIER P.M. LUBIN G. SMOOT L. A. WADE	JPL JPL UCSB LBL JPL
Germany (D)	S. WHITE	MPA
Denmark (DK)	H.U. NOORGAARD-NIELSEN	DSRI
Sweden (S)	E. KOLLBERG	CHALMERS UNIVERSITY of TECHNOLOGY
Spain (E)	E. MARTINEZ-GONZALES R. REBOLO	UNI. DE CANTABRIA IAC
Norway (N)	PER B. LILJE	ITA, OSLO UNIVERSITY
Finland (FL)	J. TUOVINEN K. ENKVIST	MILLILAB UNIVERSITY of HELSINKI
	K. BENNET	ESA-ESTEC/SSD
	K.M. GORSKI	ESO
Poland (PL) - tbc	M. DEMIANSKI - tbc	UNIVERSITY of WARSAW

Proposed Topics for Planck's Core Program

Planck/LFI Maps	K. Gorski
Statistical Analysis of CMB Maps	G. Smoot, E. Martinez-Gonzalez
Spectral Analysis of CMB Maps	N. Vittorio
CMB Polarization Fluctuations	C. Lawrence
Solar System	
Diffuse Galactic Emission: synchrotron	R. Davies
Diffuse Galactic Emission: free-free	G. Smoot
Diffuse Galactic Emission: dust	P. Lubin, R. Rebolo
Resolved and Unresolved Galactic Sources	G. Tofani
Radio Sources	G. De Zotti, R.B. Partridge
Dusty Galaxies	L. Danese
Secondary Effects on the Fluctuation Pattern	R. Sunyaev, S. White
Search for Variable Sources	

- ***MANAGEMENT***
- ***INSTRUMENT DEVELOPMENT***
- ***DELIVERABLES & MODELS***
- ***CRITICAL AREAS***



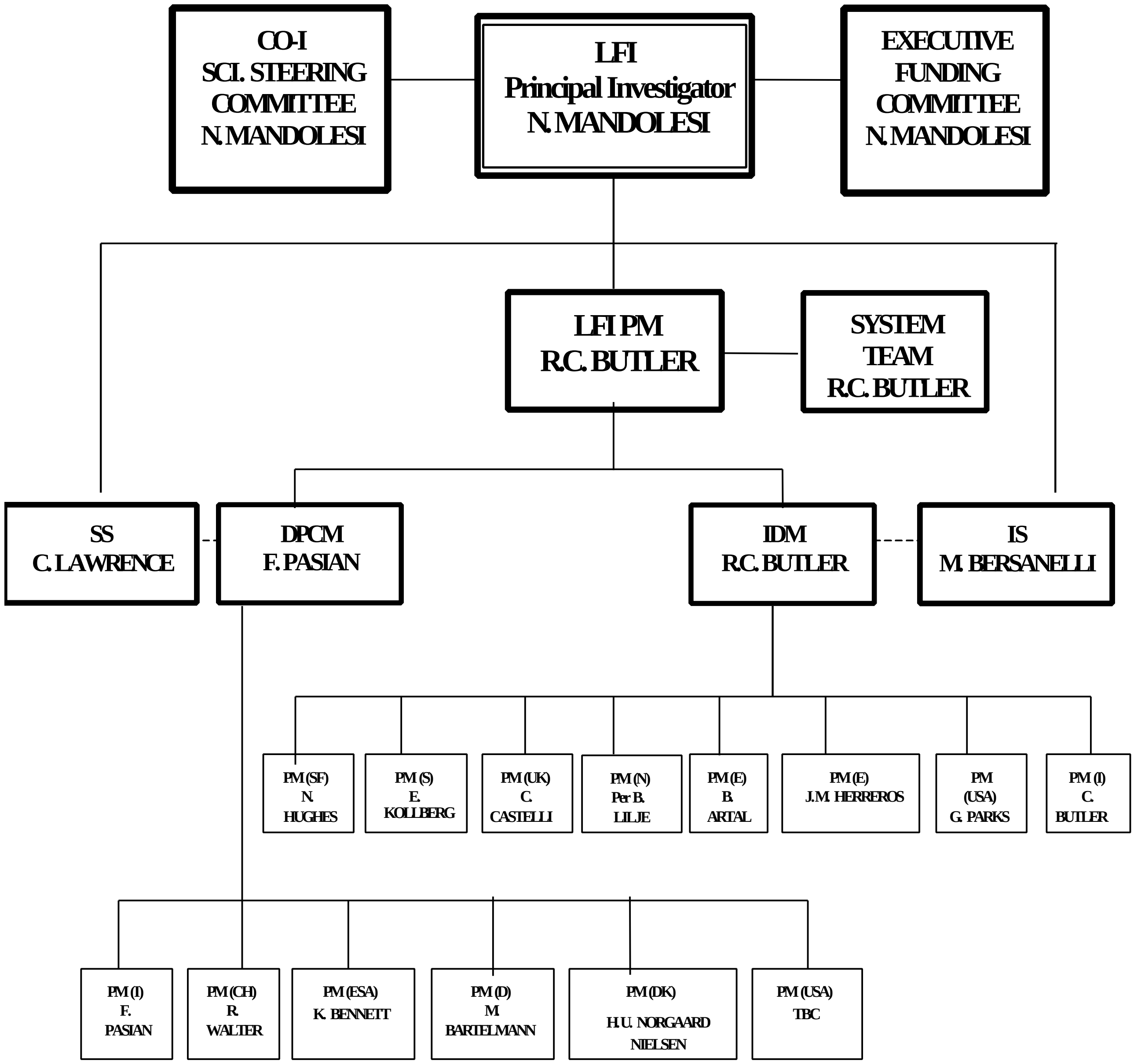
LFI Configuration Drawing (Redundant units not shown) and note that SCS is shared with HFI

Planck/LFI Low Frequency Instrument

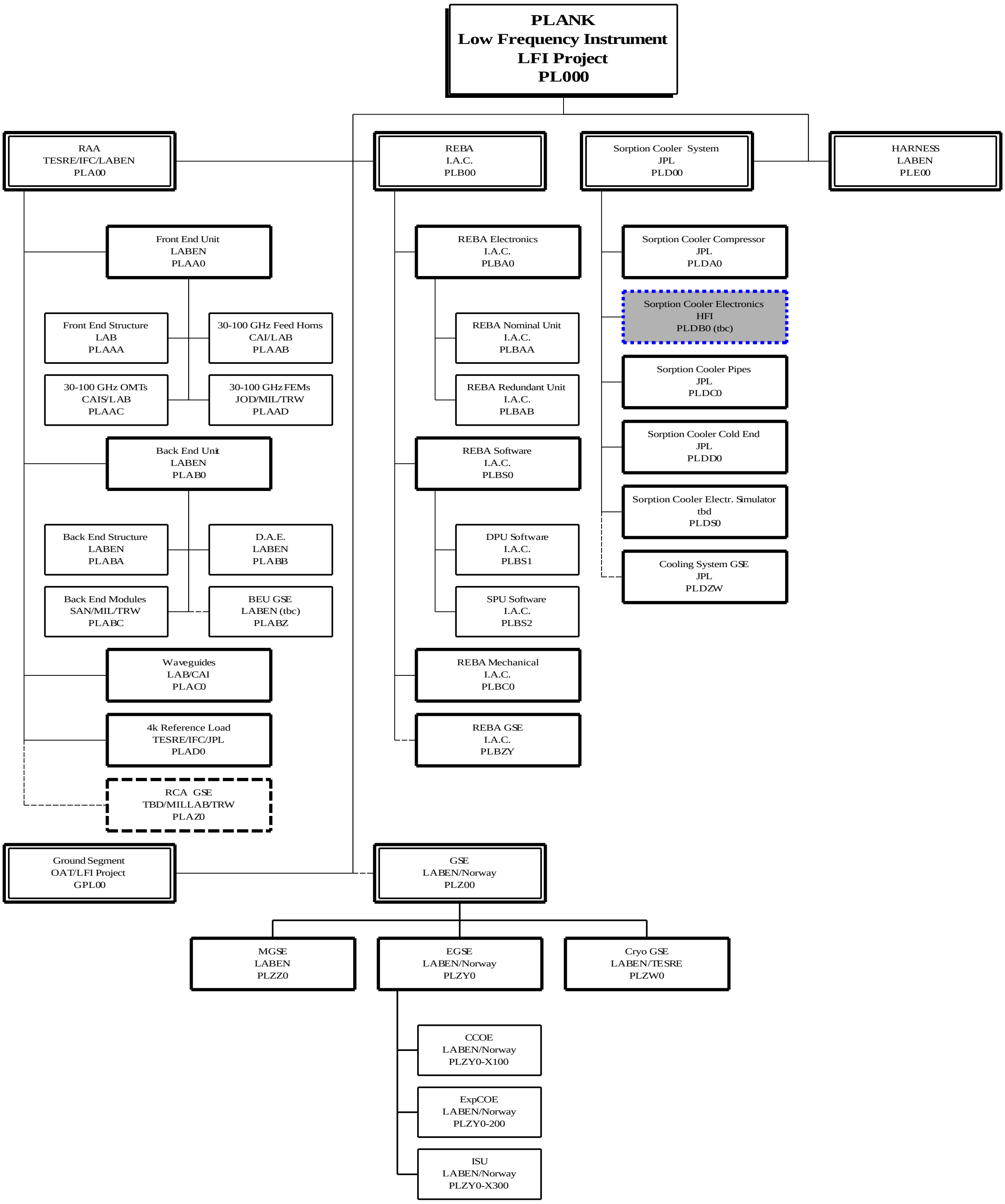
Planck LFI
TOP LEVEL TASKS

Tasks	Institute	Nation	Comment
Management System Activities (Instrument) Radiometer Array Assembly 30/44 GHz Radiometer Chain Assembly 100 GHz Front End Modules (FEM) 100 GHz Back End Modules (BEM) Data Acquisition Electronics (DAE) FPU Mechanical Structure BEU & WG Mechanical Structure 4 K Reference Load 30/44 GHz FEM + BEM Integration MGSE Cryo-GSE Harness	TESRE/CNR, Bologna	Italy	+IFC-Milan +IFC-Milan TBC +JPL +Poland (TBC)
30/44/70/100 GHz Feed Horns, OMTs, Waveguides (WG)	CAISMI/CNR, Firenze	Italy	
30/44 GHz FEMs	Univ. Of Manchester, Jodrell Bank	UK	
30/44 GHz BEMs	University of Cantabria, Santander	Spain	
70 GHz FEMs + BEMs	Millilab, Helsinki	Finland	+Chalmers Univ.-Sweden
Radiometer Electronics Box Ass.y (REBA) Data Processing Unit (DPU) SPU	IAC, La Laguna	Spain	
Sorption Cooler	JPL	USA	
Sorption Cooler Electronics	IAS	France	
SCS Harness	IAS + JPL	France/USA	
EGSE	University of Oslo	Norway	+TESRE
DPC Develop. & Operations System Activities (DPC) DPC Level 2 DPC Level 1	OAT, Trieste	Italy	+SISSA +TESRE
Simulations & Prototyping	ESO, Univ. Roma 2		
DPC Level 3	SISSA, Trieste	Italy	+OAT
DPC Level 4	MPA, Garching	Germany	

LFI MANAGEMENT STRUCTURE



High Level Product Tree



Models of LFI

The following models of LFI are foreseen:

- Prototype Demonstrators (PD's)
- Elegant Breadboard (EBB)
- Avionic Model (AVM)
- Qualification Model (QM)
- Flight Model (FM)
- Spares (FS)

LFI Development Phases

The activity has been split into 5 phases:

- Pre LFI Phase B and Breadboarding
  - Covering all activities prior to start of LFI Phase B and the Breadboard running in parallel with the LFI Phase B up to end 2000.
- LFI Phase B (Jan 2000 - Sep 2000)
- LFI Phase C/D (Oct 2000 - IFAR July 2006)
- LFI Phase E (IFAR - Start inflight operations)
- LFI Phase F Operations (18 months)

Dates of LFI Reviews

• **Pre LFI Phase B Readiness Review (PBRR)**	**4-5/10/99**
• **LFI Phase B Mid Term Review (MTR)**	**21/06/00 (*)**
• **LFI Baseline Design Review (BDR)**	**30/09/00**
• **LFI Intermediate Design Review (IDR)**	**29/06/01**
• **LFI Unit Critical Design Review (UCDR)**	**30/09/02**
• **LFI Critical Design Review**	**30/06/03**

(*) MTR start with RAA review

LFI Key Dates

• AVM Test Readiness Review	30/04/02
• QM Test Readiness Review	30/09/02
• AVM/QM Delivery	31/03/03
• EGSE Delivery	31/03/03
• FM Test Readiness Review	03/11/03
• FM Delivery	30/06/04
• FS Delivery	30/06/05

LFI Development Status

- LFI Prototyping and EBB activity is proceeding and is expected to be completed by the end of 2000 as foreseen
- LFI Phase B is proceeding in parallel and is still expected to be completed in September 2000. However the LFI MTR has been delayed (from late April - now starting in June) partly due to System level input delay, and partly due to prototype development difficulties both of which are being overcome by LFI.

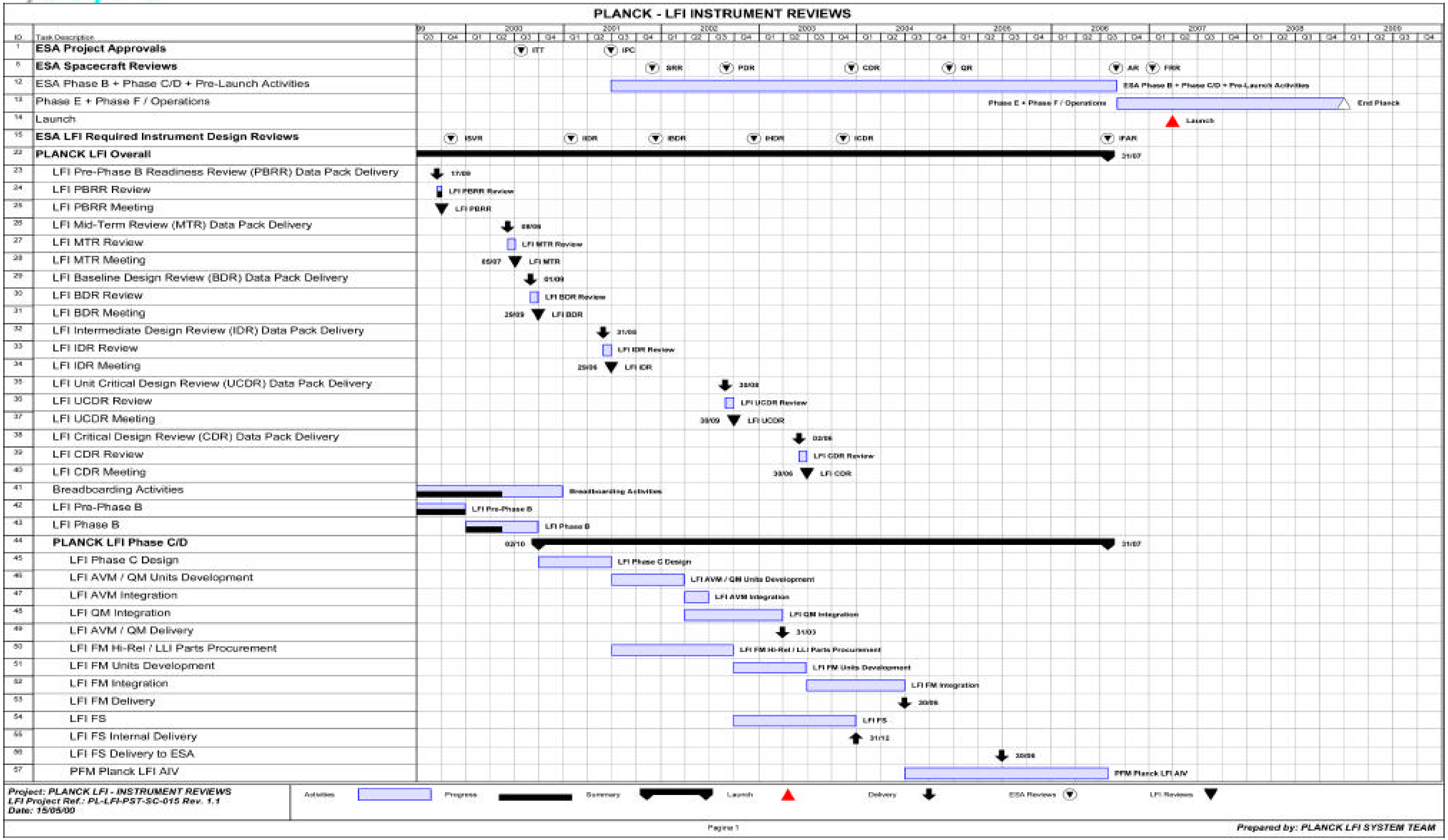
SCS Key Dates

- **Cooler Definition Review** — **15/06/00**
- **Preliminary Design Review (PDR)** — **18/12/00**
- **EBB Testing** — **01/02/01 - 31/01/02**
- **QM Test Readiness Review** — **01/05/02**
- **QM Delivery** — **31/01/02**
- **FM Test Readiness Review** — **26/12/02**
- **FM Delivery** — **26/09/03 (*)**
  - (*) Needed by LFI at 31/01/04

Sorption Cryocooler Status Report

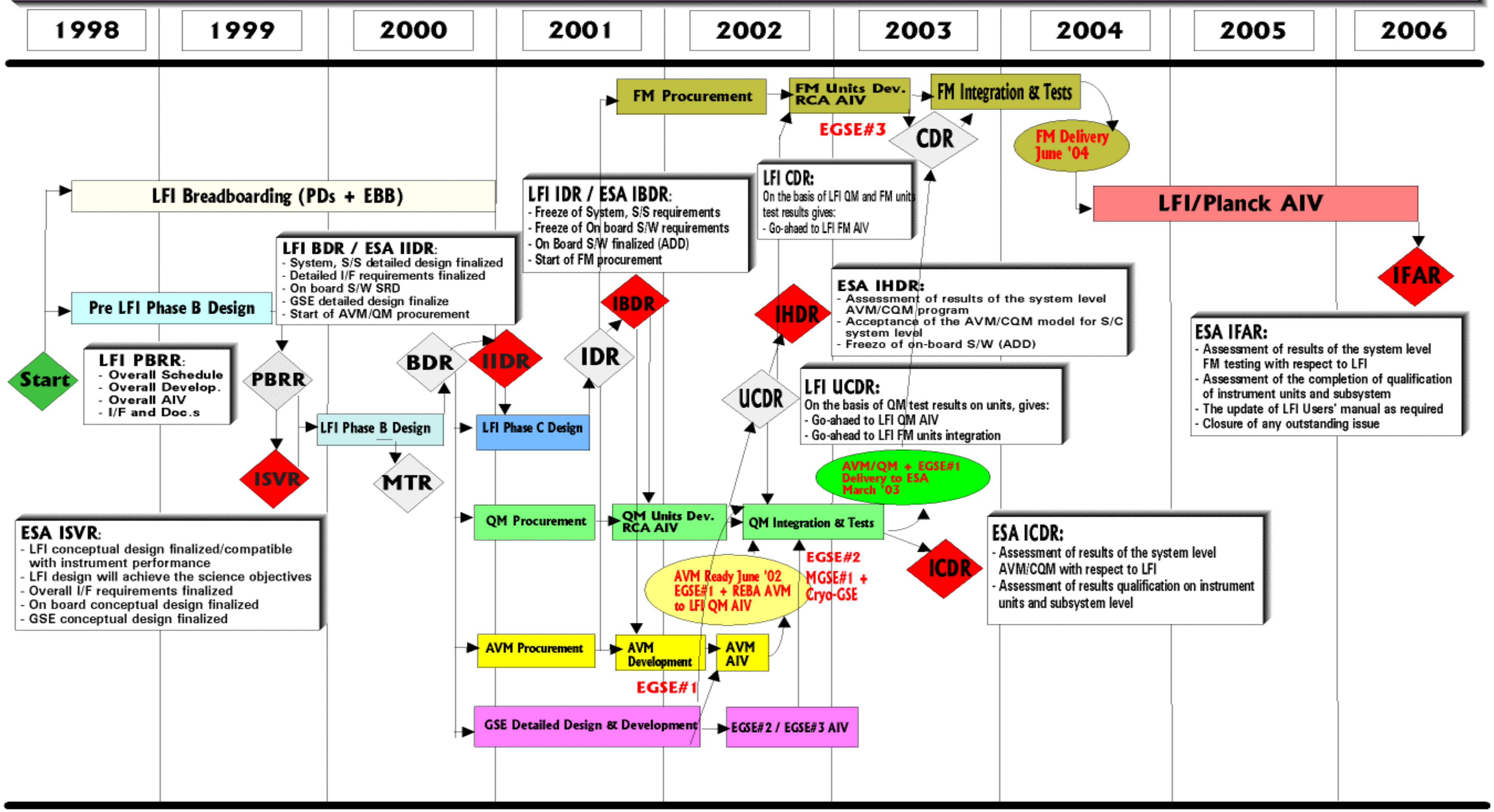
- **Performance measurements on Planck sorption-cooler compressors made with LaNiSn hydride alloy are very encouraging**
  - **Compressor performance and power efficiency has been verified**
  - **Accelerated life testing suggests major improvement in state-of-the-art lifetime (meets Planck requirement); Non-accelerated testing begun**
  - **Confirmed real breakthrough in the ability to predict cooler performance from small samples of hydride material (major reduction in schedule risk)**

Planck/LFI Low Frequency Instrument

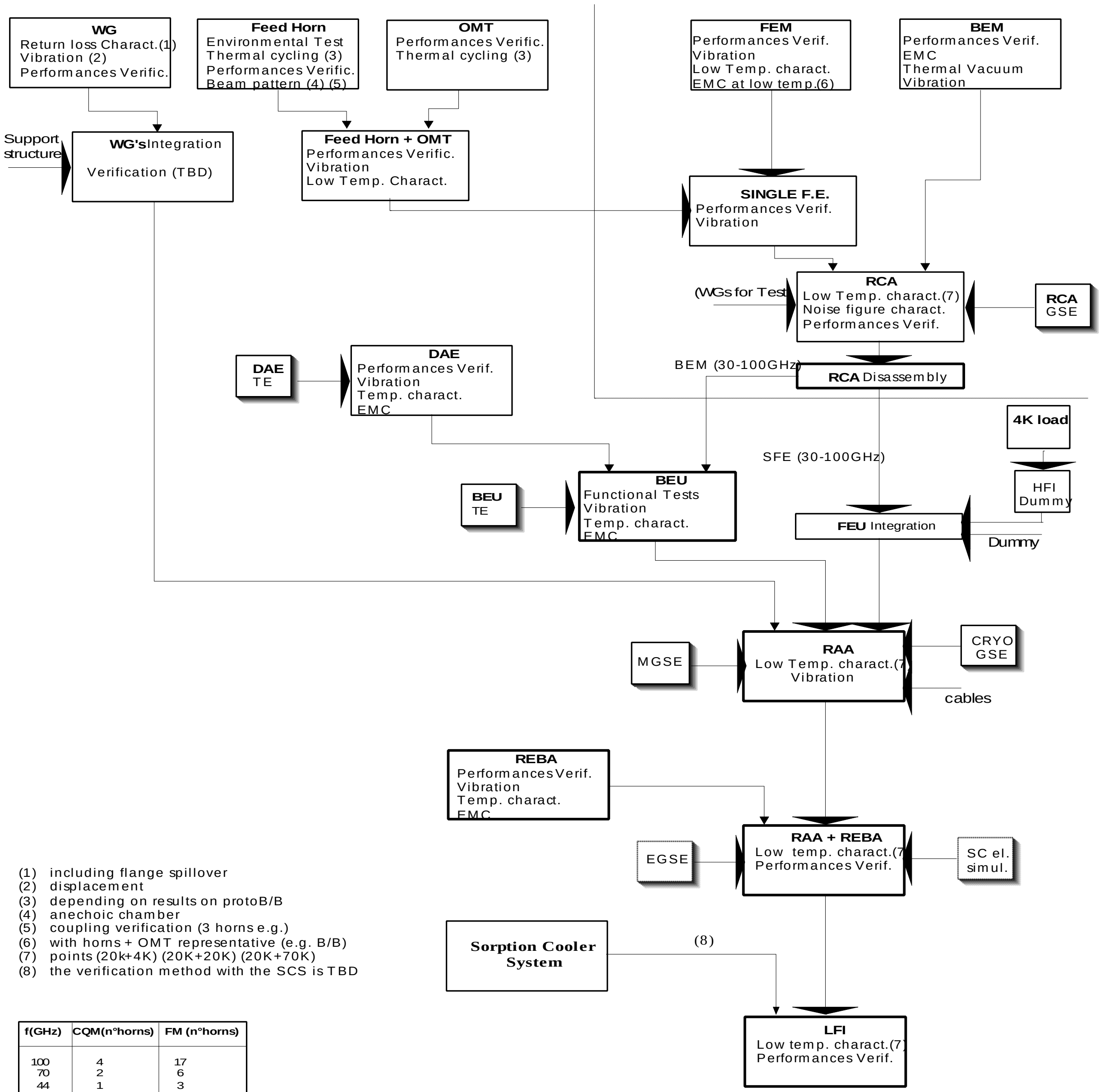


Planck/LFI Low Frequency Instrument

Planck LFI Overall Logic Diagram



Planck LFI AIV Flow Diagram



(1) including flange spillover
(2) displacement
(3) depending on results on protoB/B
(4) anechoic chamber
(5) coupling verification (3 horns e.g.)
(6) with horns + OMT representative (e.g. B/B)
(7) points (20k+4K) (20K+20K) (20K+70K)
(8) the verification method with the SCS is TBD

f(GHz)	CQM(n°horns)	FM (n°horns)
100	4	17
70	2	6
44	1	3
30	1	2

AVM DELIVERABLES

LFI AVM Deliverables	
LFI Front-end Unit	No
LFI Back-end Unit	BEU + FEU Simulator
REBA	REBA AVM main unit only (including flight S/W)
Harness	REBA to BEU+FEU Simulator
MGSE	Transport containers only
EGSE	Not deliverable
All agreed doc. including user manual	Yes

SCS AVM Deliverables	
Sorption Cooler Electronics (SCE)	SCE AVM main unit only (including flight S/W)
Sorption Cooler Compressor assembly (SCC)	Simulator main unit only
Sorption Cooler Cold End (SCCE)	No
Sorption Cooler Piping (SCP)	No
Harness	SCE to SCC only
MGSE	Transport containers only
EGSE	Not deliverable
All agreed doc. including user manual	Yes

Notes:

EGSE will be made available for incoming tests, but will not remain resident with AVM.

QM DELIVERABLES

LFI QM Deliverables	
RAA	QM-RAA: • 4 off 100 GHz radiometers out of 17 + dummies • 2 off 70 GHz radiometers out of 6 + dummies • 1 off 44 GHz radiometers out of 3 + dummies • 1 off 30 GHz radiometer out of 2 + dummies • Full 4 K Load • Full Structure • Full set of Waveguides • BEU at single redundancy level
REBA	AVM REBA main unit
Harness **EGSE** **MGSE** All agreed Doc. including the user manual	Yes Yes MGSE Yes

SCS QM Deliverables	
SCC **SCP** **SCCE** **SCE** **SCC** **SCP** **SCCE**	QM-SCC QM-SCP QM-SCCE QM One unit only No dummy Dummy to simulate FM Dummy to simulate FM
Harness **EGSE** **MGSE** All agreed Doc. including the user manual	Yes Yes (From HFI) MGSE Yes

FM DELIVERABLES

LFI FM Deliverables	
RAA	FM-RAA
REBA	FM REBA main and redundant units
Harness **EGSE** **MGSE** All agreed Doc. including the user manual	Yes Yes MGSE Yes

SCS FM Deliverables	
SCC **SCP** **SCCE** **SCE**	FM SCC + QM-SCC (as redundant unit) FM SCC + QM-SCP (as redundant unit) FM SCCE + QM-SCCE (as redundant unit) FM SCE including both main and redundant units
Harness **EGSE** **MGSE** All agreed Doc. including the user manual	Yes Yes (From HFI) MGSE Yes

FLIGHT SPARES

- **For RAA**
  - Philosophy is based on no de-integration possible once on the satellite.
  - Thus fully tested spare parts of radiometers and spare cards for BEU available for substitution.
- **For REBA**
  - Fully tested spare cards available.
- **For Sorption Cooler S/S**
  - No complete flight spare foreseen of a Sorption Cooler.
  - Spare parts will exist (including all critical delivery parts) at JPL.
  - For the Sorption Cooler electronics fully tested spare cards will be available.

LFI - MASS BUDGET

					Mass			Allocation (IID-B)
				#	*Est. [Kg]*	*Cont. [%]*	*Total [Kg]*	*Total [Kg]*
RAA					**57.21**	**23%**	**70.43**	
	FEU				21.60	25%	26.96	**27.0**
		FE Struct.(1)			13.10	20%	15.72	
		Feeds (2)			3.88	30%	5.04	
			30 GHz (*) 44GHz(**) 70 GHz (***) 100 GHz (****)	2 3 6 17	0.210 0.240 1.152 2.278	30% 30% 30% 30%	0.273 0.312 1.498 2.961	
		OMT(3)			1.80	30%	2.34	
			30 GHz (*) 44GHz(**) 70 GHz (***) 100 GHz (****)	2 3 6 17	0.460 0.480 0.300 0.561	30% 30% 30% 30%	0.598 0.624 0.390 0.729	
		FEMs(5)			2.81	37%	3.86	
			30 GHz (*) 44GHz(**) 70 GHz (***) 100 GHz (****)	2 3 6 17	0.700 0.840 0.900 0.374	43% 43% 30% 30%	1.000 1.200 1.170 0.486	
	BEU				29.81	22%	36.26	**36.3**
		BE Struct.			5.00	20%	6.00	
		DAE			22.00	20%	26.40	
		BEMs(6)			2.81	37%	3.86	
			30 GHz (*) 44GHz(**) 70 GHz (***) 100 GHz (****)	2 3 6 17	0.700 0.840 0.900 0.374	43% 43% 30% 30%	1.000 1.200 1.170 0.486	
	WG				5.00	25%	6.25	**6.3**
	4K Load				0.80	20%	0.96	
REBA					**13.50**	**10%**	**14.85**	**15.0**
Harness					**3.00**	**20%**	**3.60**	**3.6**
TOTAL					**73.71**	**20.6%**	**88..9**	**88.2**

LFI POWER BUDGET

					Power			Allocation (IIDB)
				#	*Est. [W]*	*Cont. [%]*	*Total [W]*	*Total [W]*
RAA					**28.73**	**44%**	**41.40**	
	FEU				0.55	25%	0.69	
		FE Struct.(1)			N/A	N/A	N/A	
		Feeds (2)			N/A	N/A	N/A	
			30 GHz (*) 44GHz(**) 70 GHz (***) 100 GHz (****)	2 3 6 17	N/A N/A N/A N/A	N/A N/A N/A N/A	N/A N/A N/A N/A	
		OMT(3)			N/A	N/A	N/A	
			30 GHz (*) 44GHz(**) 70 GHz (***) 100 GHz (****)	2 3 6 17	N/A N/A N/A N/A	N/A N/A N/A N/A	N/A N/A N/A N/A	
		FEMs(5)			0.55	25%	0.69	
			30 GHz (*) 44GHz(**) 70 GHz (***) 100 GHz (****)	2 3 6 17	0.077 0.078 0.132 0.262	25% 25% 25% 25%	0.096 0.098 0.165 0.327	
	BEU				28.18	44%	40.72	
		BE Struct.			N/A	N/A	N/A	
		DAE			23.00	50%	34.50	
		BEMs(6)			5.18	20%	6.22	
			30 GHz (*) 44GHz(**) 70 GHz (***) 100 GHz (****)	2 3 6 17	0.600 0.900 0.960 2.720	20% 20% 20% 20%	0.720 1.080 1.152 3.264	
	WG				N/A	N/A	N/A	
	4K Load				N/A	N/A	N/A	
REBA					**29.40**	**10%**	**32.34**	**32.3**
TOTAL					**58.13**	**26%**	**73.74**	**74.0**

SCS MASS & POWER BUDGETS

SCS MASS BUDGET

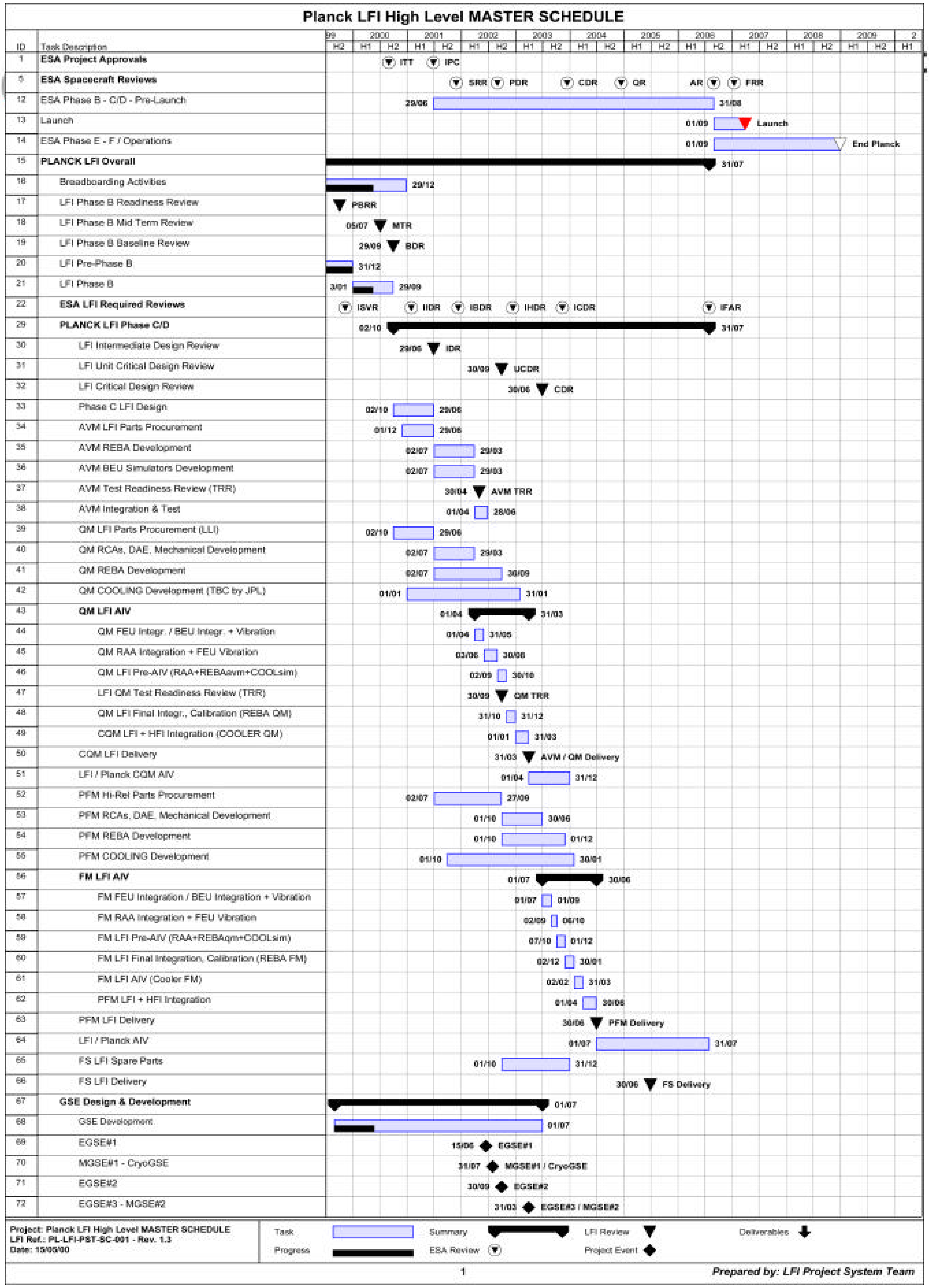
S/S	UNIT	#	Mass Est. [Kg]	Mass Cont. [%]	Mass Total [Kg]	Allocation Total [Kg]
SCS						
	SCC	1	34.80	15%	40.00	**40.00**
	SCP	1	3.10	29%	4.00	**4.00**
	SCCE	1	2.00	25%	2.50	**2.50**
	Harness SCE to SCC	1	TBD	TBD	TBD	**TBD**
	Harness SCE to SCCE	1	TBD	TBD	TBD	**TBD**
	Harness SCC to SCCE	1	TBD	TBD	TBD	**TBD**
	SCE	1	5.00		5.00	**5.00**
TOTAL	**(Harness not included)**	**1**	**44.90**	**15%**	**51.50**	**51.50**
TOTAL	**(Harness not included)**	**2**	**89.80**	**15%**	**103.0**	**103.00**

SCS POWER BUDGET

S/S	UNIT	#	Power Est. [W]	Power Cont. [%]	Power Total [W]	Allocation Total [W]
SCS						
	SCC	1	457.1 TBC	13.8%	520.0	**520.0**
	SCE	1	55.0		55.0	**55.0**
	Harness SCE to SCC	1	TBD		TBD	**TBD**
TOTAL	**(Harness not included)**	**1**	**512.1**	**12.3%**	**575.0**	**575.0**

CRITICAL AREAS

- Capability to perform Cryo testing with SCS and HFI prior to delivery of LFI for CQM and PFM campaigns.
  - We do not have a Cryo test facility capable of taking the Sorption Cooler.
  - We believe we can work around this by separate testing for sensitivity and performance plus ambient integrated tests
- Sorption Cooler Schedule is considered critical for QM, but is compliant with agreed delivery dates.
  - QM 31 Jan 2003 (No margin)
  - FM OK available 29 Sept 2003 (no margin) against required date of 31 Jan 2004
- Stray light reduction and control
  - It is necessary to continue in all areas of the satellite to use this as a design driver


Planck LFI High Level MASTER SCHEDULE
ID Task Description
1 ESA Project Approvals — ITT, IPC
5 ESA Spacecraft Reviews — SRR, PDR, CDR, QR, AR, FRR
12 ESA Phase B - C/D - Pre-Launch — 29/06, 31/08
13 Launch — 01/09 Launch
14 ESA Phase E - F / Operations — 01/09 End Planck
15 PLANCK LFI Overall — 31/07
16 Breadboarding Activities — 29/12
17 LFI Phase B Readiness Review — PBRR
18 LFI Phase B Mid Term Review — 05/07 MTR
19 LFI Phase B Baseline Review — 29/09 BDR
20 LFI Pre-Phase B — 31/12
21 LFI Phase B — 3/01, 29/09
22 ESA LFI Required Reviews — ISVR, IIDR, IBDR, IHDR, ICDR, IFAR
29 PLANCK LFI Phase C/D — 02/10, 31/07
30 LFI Intermediate Design Review — 29/06 IDR
31 LFI Unit Critical Design Review — 30/09 UCDR
32 LFI Critical Design Review — 30/06 CDR
33 Phase C LFI Design — 02/10, 29/06
34 AVM LFI Parts Procurement — 01/12, 29/06
35 AVM REBA Development — 02/07, 29/03
36 AVM BEU Simulators Development — 02/07, 29/03
37 AVM Test Readiness Review (TRR) — 30/04 AVM TRR
38 AVM Integration & Test — 01/04, 28/06
39 QM LFI Parts Procurement (LLI) — 02/10, 29/06
40 QM RCAs, DAE, Mechanical Development — 02/07, 29/03
41 QM REBA Development — 02/07, 30/09
42 QM COOLING Development (TBC by JPL) — 01/01, 31/01
43 QM LFI AIV — 01/04, 31/03
44 QM FEU Integr. / BEU Integr. + Vibration — 01/04, 31/05
45 QM RAA Integration + FEU Vibration — 03/06, 30/08
46 QM LFI Pre-AIV (RAA+REBAavm+COOLsim) — 02/09, 30/10
47 LFI QM Test Readiness Review (TRR) — 30/09 QM TRR
48 QM LFI Final Integr., Calibration (REBA QM) — 31/10, 31/12
49 CQM LFI + HFI Integration (COOLER QM) — 01/01, 31/03
50 CQM LFI Delivery — 31/03 AVM / QM Delivery
51 LFI / Planck CQM AIV — 01/04, 31/12
52 PFM Hi-Rel Parts Procurement — 02/07, 27/09
53 PFM RCAs, DAE, Mechanical Development — 01/10, 30/06
54 PFM REBA Development — 01/10, 01/12
55 PFM COOLING Development — 01/10, 30/01
56 FM LFI AIV — 01/07, 30/06
57 FM FEU Integration / BEU Integration + Vibration — 01/07, 01/09
58 FM RAA Integration + FEU Vibration — 02/09, 06/10
59 FM LFI Pre-AIV (RAA+REBAqm+COOLsim) — 07/10, 01/12
60 FM LFI Final Integration, Calibration (REBA FM) — 02/12, 30/01
61 FM LFI AIV (Cooler FM) — 02/02, 31/03
62 PFM LFI + HFI Integration — 01/04, 30/06
63 PFM LFI Delivery — 30/06 PFM Delivery
64 LFI / Planck AIV — 01/07, 31/07
65 FS LFI Spare Parts — 01/10, 31/12
66 FS LFI Delivery — 30/06 FS Delivery
67 GSE Design & Development — 01/07
68 GSE Development — 01/07
69 EGSE#1 — 15/06 EGSE#1
70 MGSE#1 - CryoGSE — 31/07 MGSE#1 / CryoGSE
71 EGSE#2 — 30/09 EGSE#2
72 EGSE#3 - MGSE#2 — 31/03 EGSE#3 / MGSE#2
Project: Planck LFI High Level MASTER SCHEDULE
LFI Ref.: PL-LFI-PST-SC-001 - Rev. 1.3
Date: 15/05/00
Task
Progress
Summary
ESA Review
LFI Review
Project Event
Deliverables
1
Prepared by: LFI Project System Team

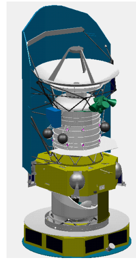
Planck LFI - DPC MASTER SCHEDULE

ID	Task Description	Start	End
1	*S/C Phase B, C/D and Pre-Launch*	02/07	31/08
2	*Launch*	01/09	30/03
3	*LAUNCH*		31/03
4	*S/C Phase E, F and Operations*	01/09	End Planck
5	**GS Reviews with ESA**	ISVR, GSRR, GSDR, GSIR, GSTRR	
11	*DPC Levels Requirements Review*		29/06
12	*DPC GS Requirements Review*		31/12
13	*DPC Levels Design Review*		30/04
14	*DPC GS Design Review*		31/12
15	*DPC Levels Implementation Review*		29/04
16	*DPC GS Implementation Review*		30/12
17	*DPC Delivery of Final Products*		31/12
18	DPC Project Office	/12	31/12
19	DPC System & Technical Coordination	/12	31/12
20	Procurement	/12	29/12
21	IDIS Design, Development & S/W Maintenance	/12	31/12
22	**DPC DEVELOPMENT PHASE**		
23	**Pipeline Breadboard Model**		
24	LFI BDR Datapack (TM inputs)		01/08
25	Level 1 URD & Coding update	/12	29/12
26	Level 1 Testing	01/01	29/06
27	LFI MTR Datapack (Instrument char.)		08/06
28	Level 2 URD & Coding update	/12	29/09
29	Level 2 Testing	02/10	13/07
30	Level 3 URD & Coding update	/12	28/02
31	Level 3 Testing	01/03	31/08
32	Level 1+2+3 Integrated Tests	16/07	31/12
33	Inputs to LFI EGSE #1 integration		31/12
34	**Pipeline Development Model**		
35	Level 1 SRD / ADD, S/W Coding & Test	01/01	30/06
36	Level 2 SRD / ADD, S/W Coding & Test	01/01	15/07
37	Level 3 SRD / ADD, S/W Coding & Test	01/01	01/09
38	Level 1+2+3 Integrated Tests	16/07	31/12
39	**Pipeline Operations Model**		
40	Level 1 DDD, S/W Coding & Test	01/01	29/06
41	Level 2 DDD, S/W Coding & Test	01/01	14/07
42	Level 3 DDD, S/W Coding & Test	01/01	31/08
43	Level 1+2+3 Integrated Tests	15/07	30/12
44	Level 4 ADD, S/W Coding & Test	01/01	01/12
45	Level (1+2+3) + 4 Integrated Tests	02/01	31/03
46	Pipeline OM Testing	03/04	30/03
47	DPC OPERATIONS PHASE	03/04	30/06
48	DPC POST-OPERATIONS PHASE	01/07	31/12
49	**DPC SIMULATION & MODELLING**		
50	Level S BB Model	/12	25/10
51	Level S Development Model	26/10	21/11
52	Level S Intermediate Model	22/11	18/12
53	Level S Operations Model	19/12	13/01
54	Level S Final Model	14/01	09/02
55	Level S maintenance	10/02	29/12
56	**SUPPORT to GROUND TESTS**		
57	Support to QM AIV	02/09	31/03
58	Support to FM AIV	07/10	30/06

Timescale: 2000 – 2011 (H1, H2)

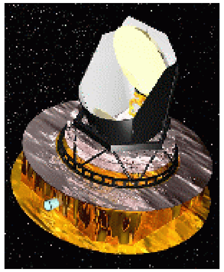
Project: Planck LFI - DPC MASTER SCHEDULE
Prepared by: LFI Project System Team
Project Ref.: PL-LFI-OAT-SC-002 Rev. 0.3

Legend: Task; Critical Task; Progress; Summary; DPC Review; Project Events; Deliverables; ESA Reviews



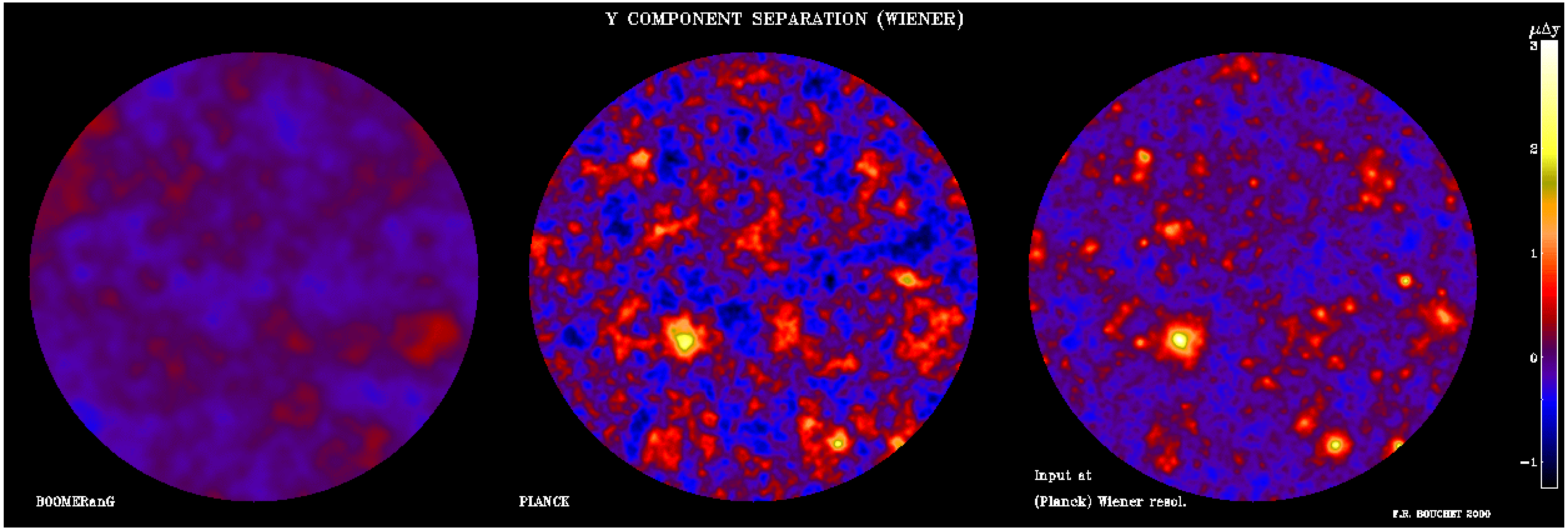
5.3 HFI Status

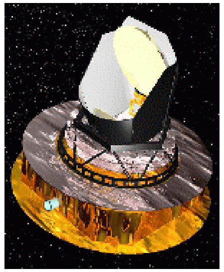
J.-L. Puget IAS-Orsay



PLANCK HFI

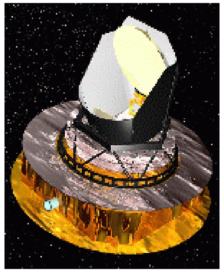
BOOMERANG PLANCK detection of clusters by their SZ effect



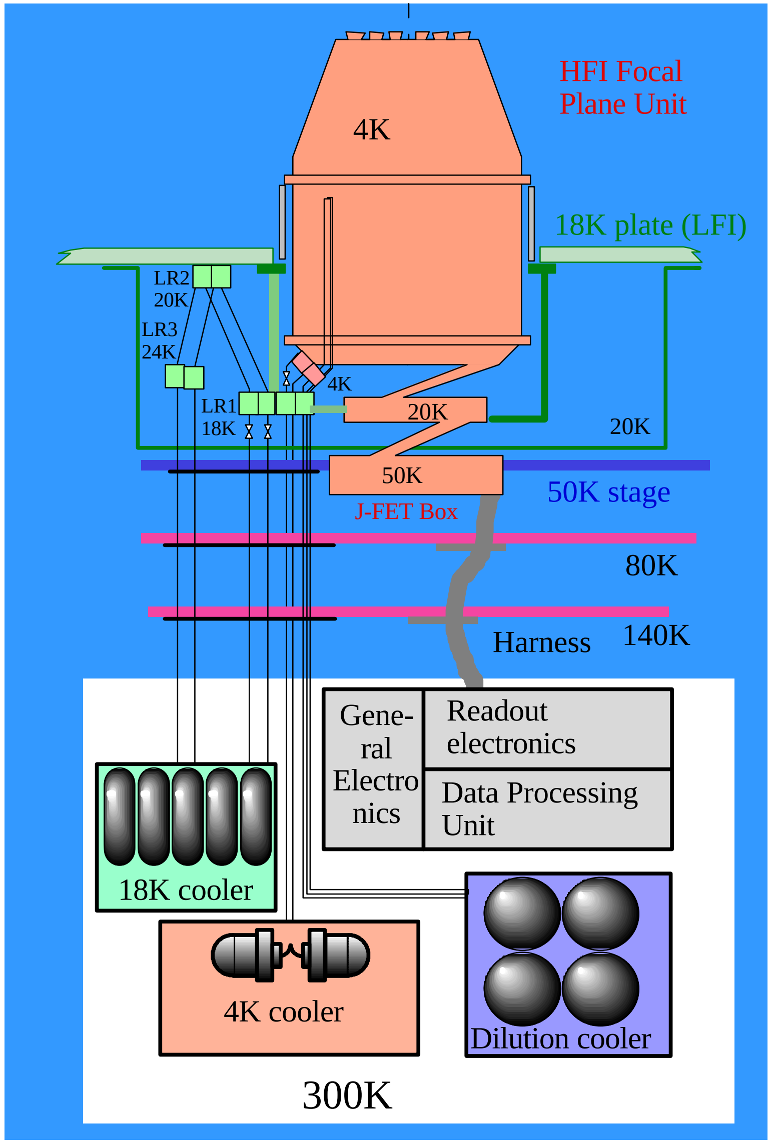


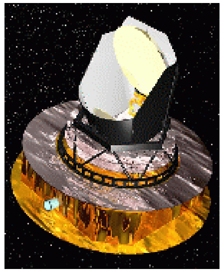
HFI requirements

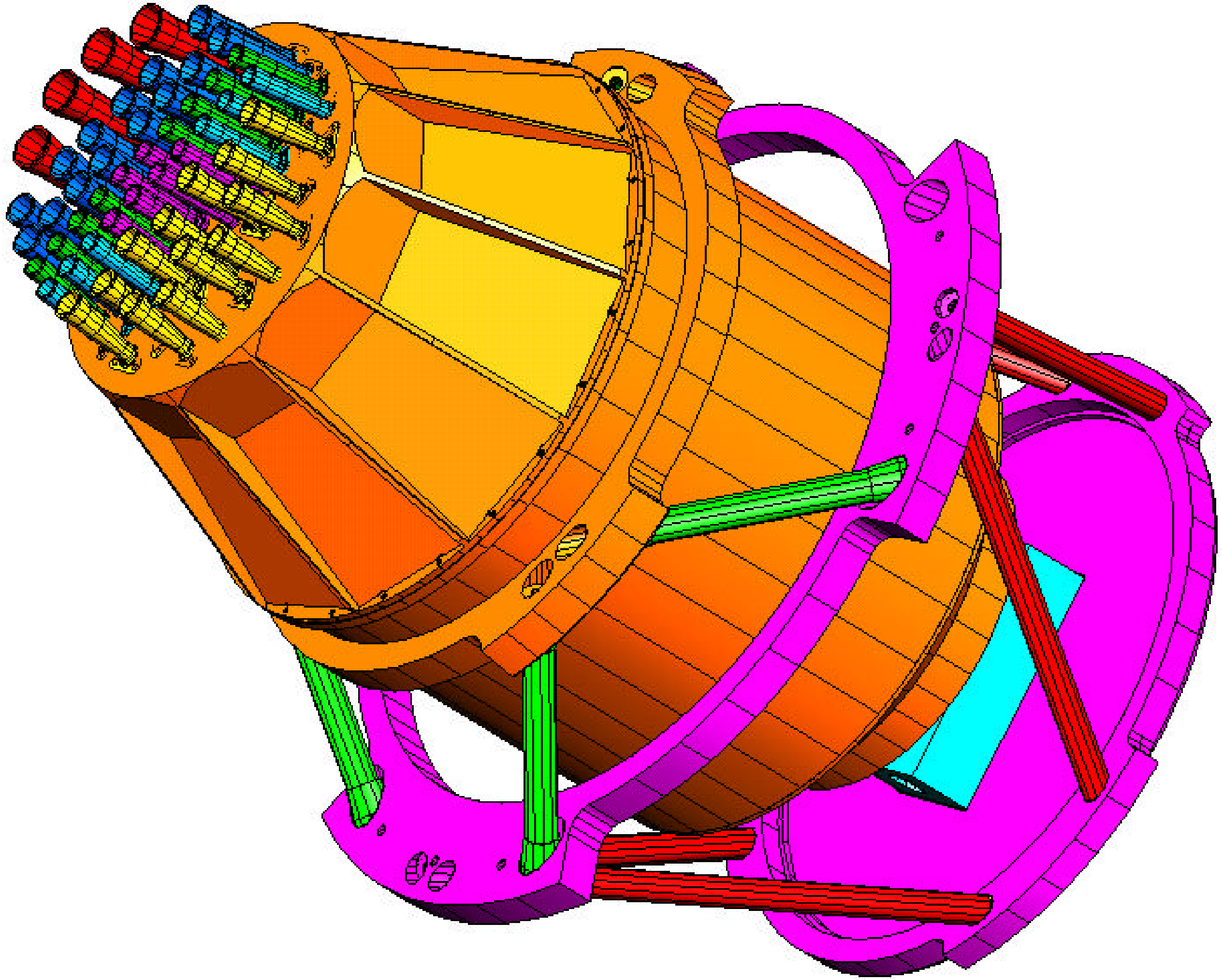
- Angular resolution of 5 arc minutes for CMB anisotropies
- For CMB channels (100-357 GHz) sensitivity limited by fundamental limits (photon noise)
- Three frequencies optimized for Sunyaev-Zeldovich effect (150-217-357 GHz)
- Two frequencies for the mapping of Galactic dust emission and of backgound due to infrared galaxies
- polarization measurements at 143 and 217 GHz (CMB optimal channel with no S-Z contribution) and 545 GHz for galactic dust polarised emission monitoring
- rejection of far side lobes optimised for 357 GHz (as far side lobes contribution minimum at 100 GHz and this channel is the highest frequency CMB one)

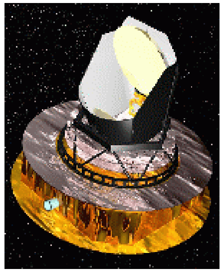


Technical requirements HFI architecture

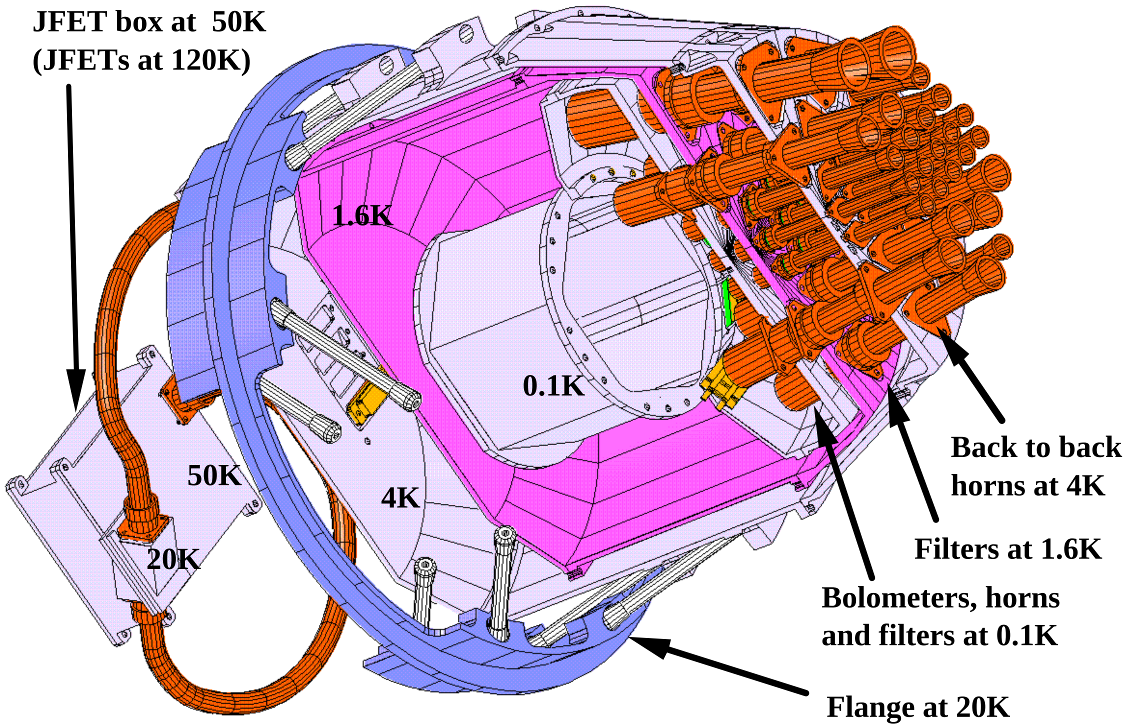








PLANCK
HFI


JFET box at 50K
(JFETs at 120K)
1.6K
0.1K
50K
4K
20K
Back to back
horns at 4K
Filters at 1.6K
Bolometers, horns
and filters at 0.1K
Flange at 20K

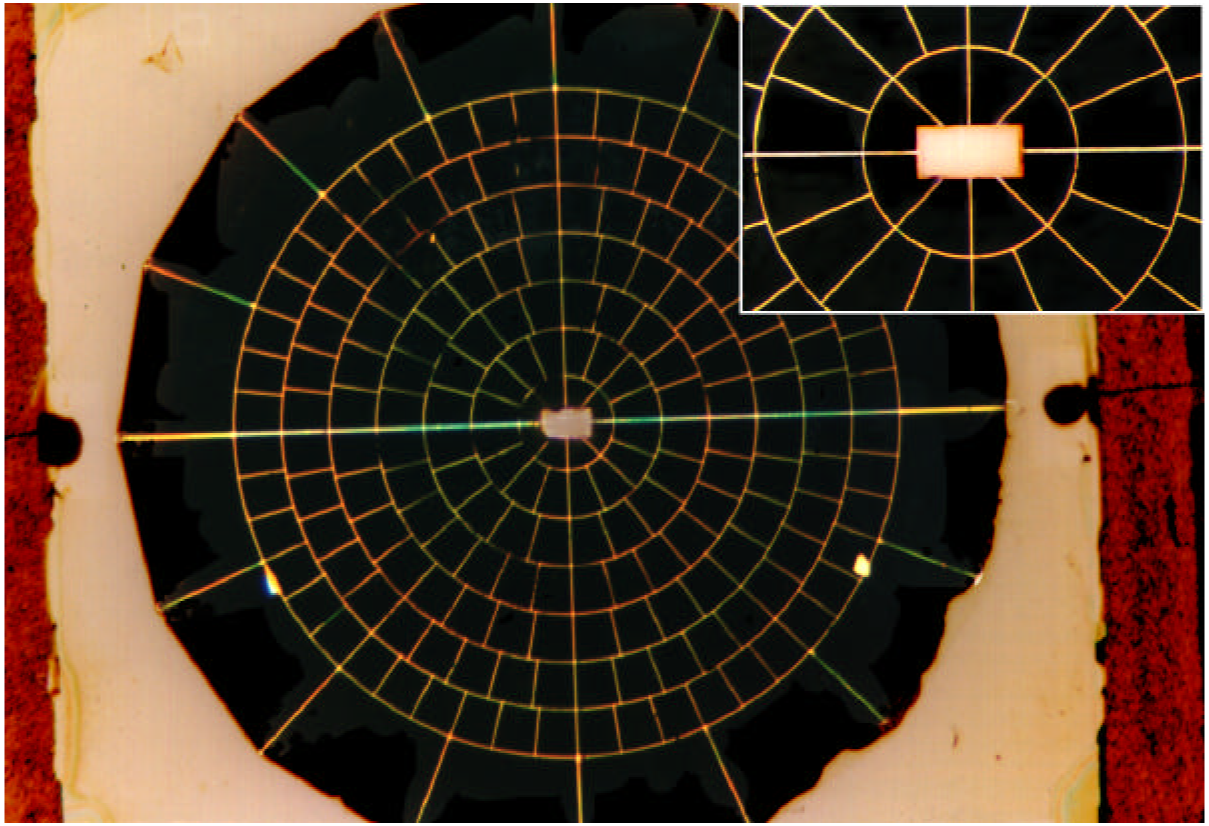
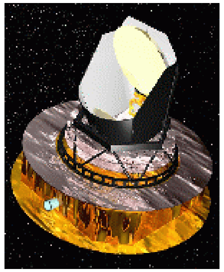


Figure 2.5.1 Prototype spider bolometer CSK18. Active absorber diameter, outer spider circle, is 5.675 mm. Inset shows NTD Ge sensor at the centre with the two thicker current carrying and thermal conductance control lines running out horizontally to electrical contacts on the silicon substrate.



PLANCK
HFI

Dilution cooler (0.1 K)

- Demonstrator has now shown that dilution and 4 K coolers work together
- Satisfactory temperature reached (<100 mK) in a configuration more difficult than Planck
- High sensitivity to vibration identified
- Cooling power of the gases measured to be

>300 nW (for 50 nW of heat input from detectors)
Autonomy with the baseline gas tanks around 20 months (two surveys + PV phase + 30 % margin)

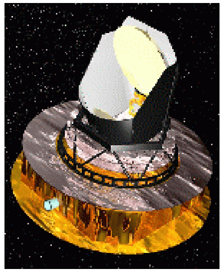
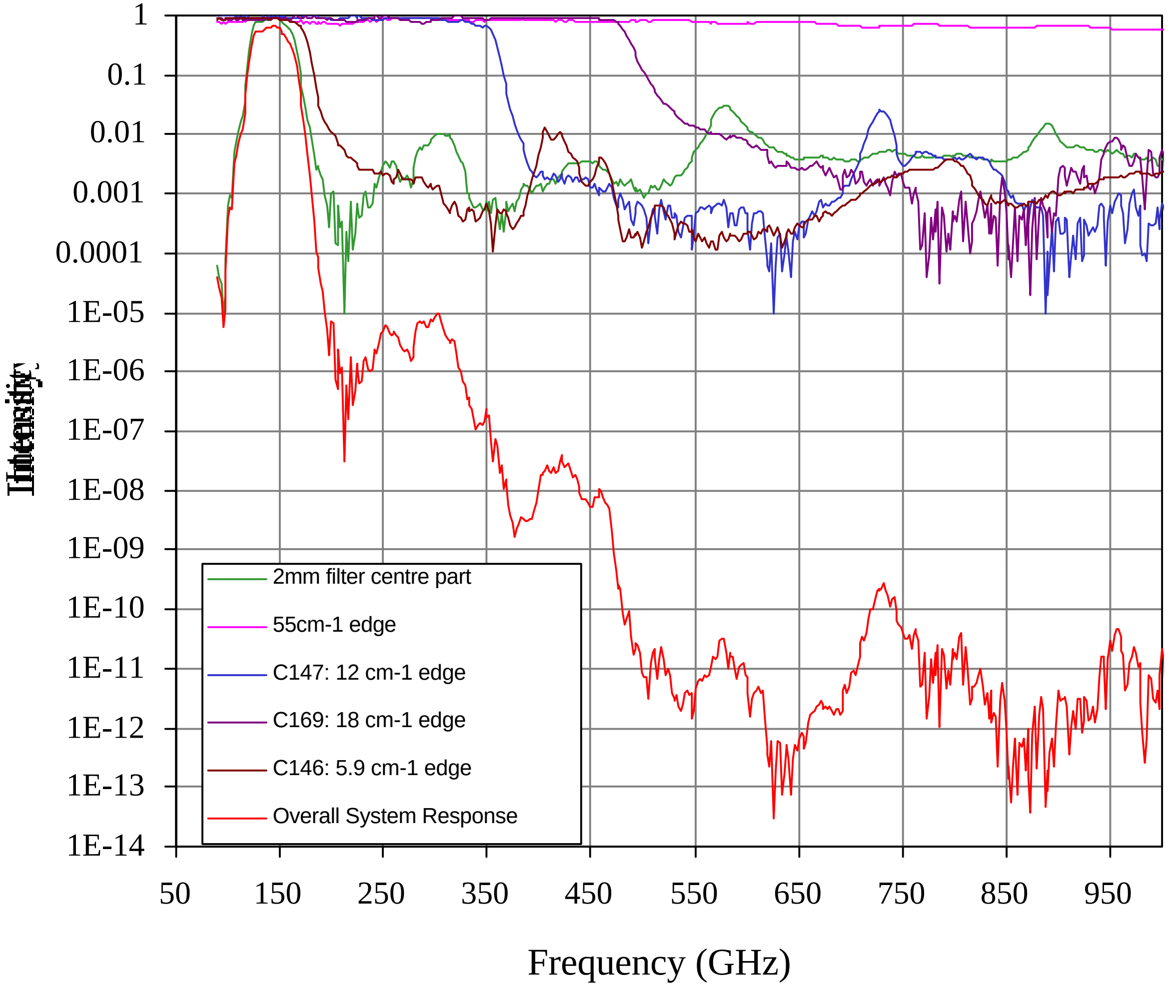
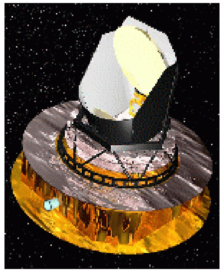


Figure 2.4.1

Plot of Prototype 143 GHz Channel Spectral Response



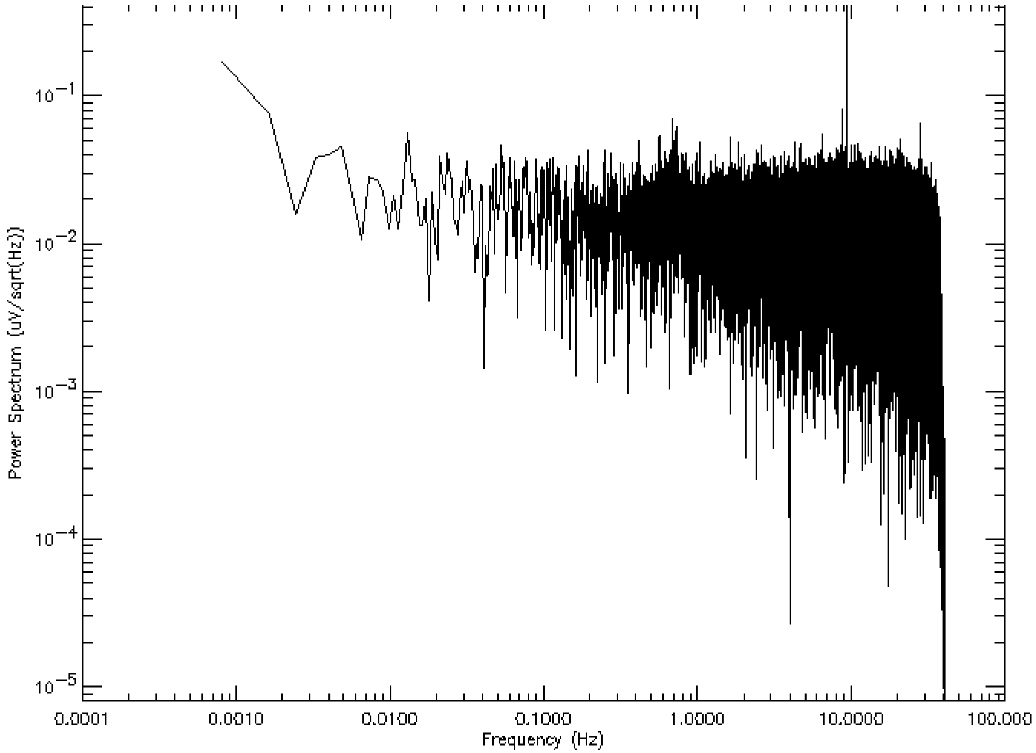


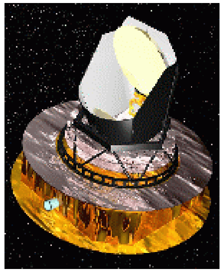
PLANCK HFI

Readout Electronics

- Low noise (30% of fundamental noise):
  - Voltage noise about $5nVHz^{-1/2}$
  - Current noise less than $5.10^{-16}AHz^{-1/2}$
- Flat noise and good transmission in the frequency range 0.016Hz-100Hz
- High dynamics (18bits)

Performances are OK.
Flight design nearly
Completed.





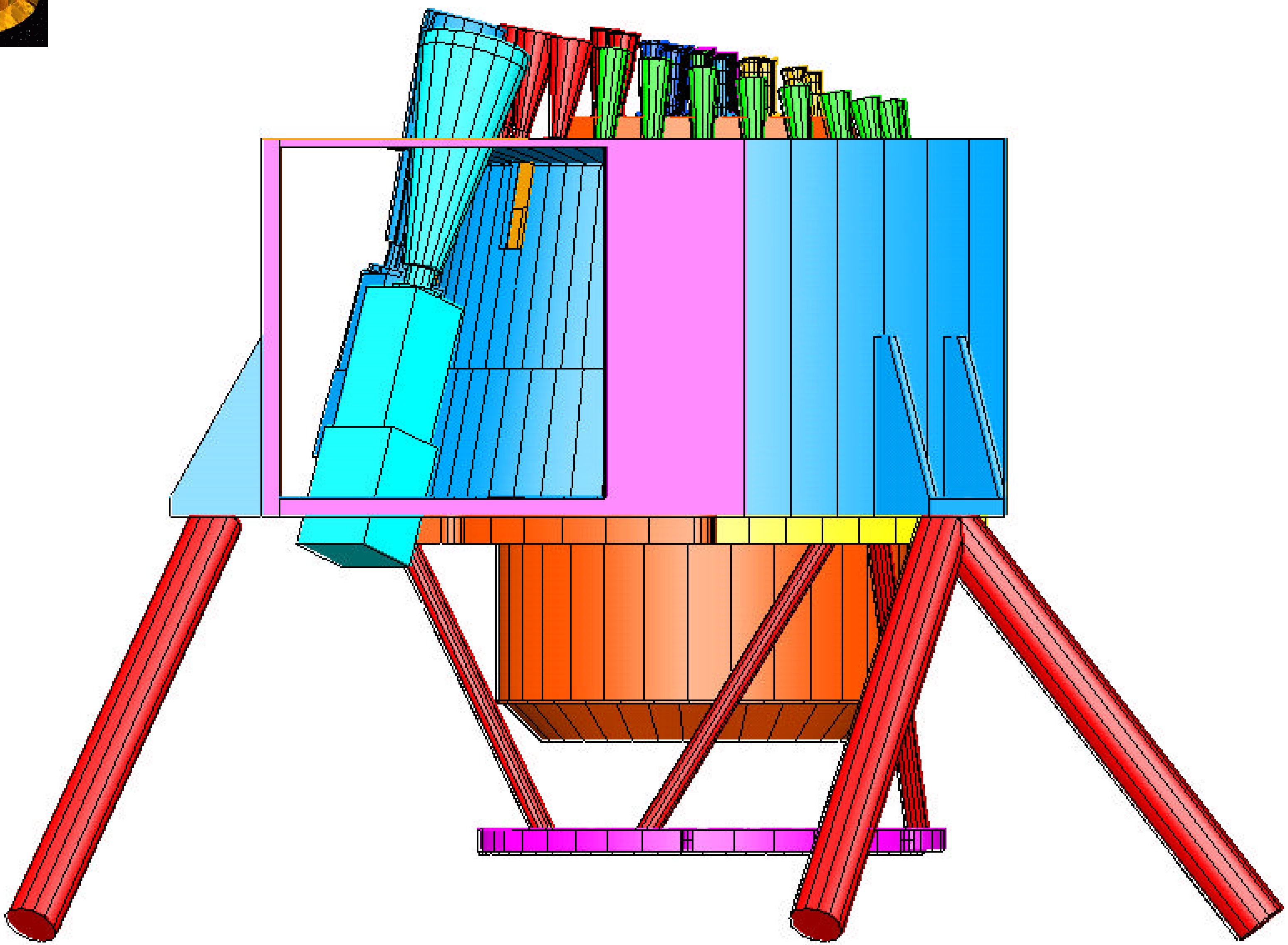
PLANCK HFI

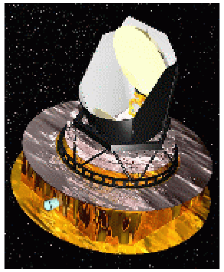
Reaching the photon noise

- Once the photon noise limit is reached, the only way to increase the sensitivity is the number of detectors or the mission duration.
- For 14 months of observation, the number of detectors needed to reach the sensitivity requirement is:

Channel central frequency (ν)	**Ghz**	**100**	**143**	**217**	**353**	**545**	**857**
Beam FWHM	**(arcmin)**	**9.2**	**7.1**	**5**	**5**	**5**	**5**
Number of Unpolarised detectors		**4**	**5**	**6**	**6**	**/**	**6**
Number of polarised detectors		**/**	**7**	**8**	**/**	**8**	**0**
ΔT/T Channel NEDT (Intensity)	**(μK/K)Hz$^{-1/2}$**	**13.1**	**11.2**	**12.7**	**50.8**	**/**	**24000**
ΔT/T Channel NEDT (U and Q)	**(μK/K)Hz$^{-1/2}$**	**/**	**21.3**	**29.4**	**/**	**508**	**/**
ΔT/T Sensitivity (Intensity)	**(μK/K)**	**2.0**	**2.2**	**3.5**	**14**	**/**	**6600**
ΔT/T Sensitivity (U and Q) Polarised	**(μK/K)**	**/**	**4.2**	**8.1**	**/**	**140**	**/**

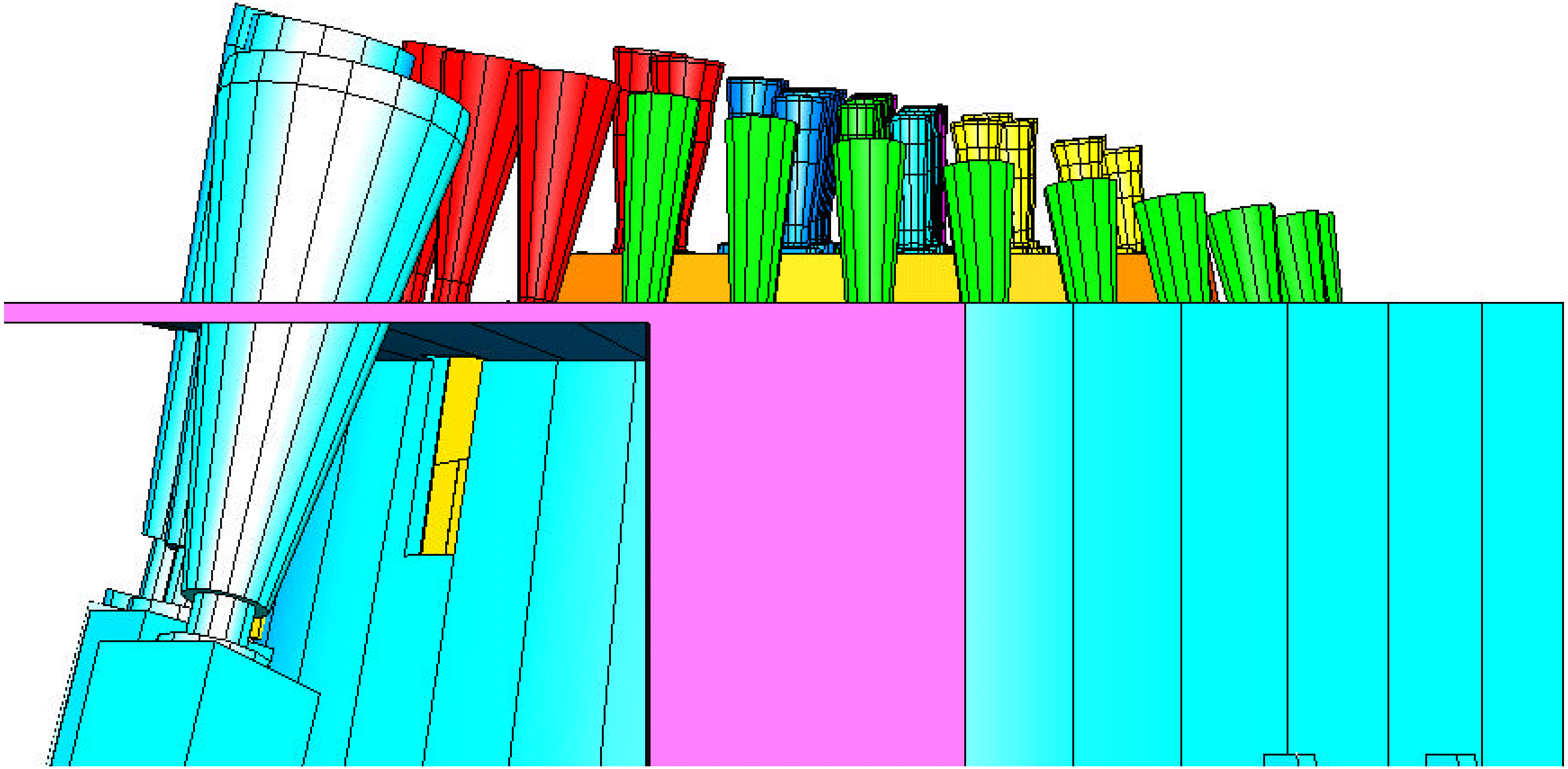
PLANCK HFI



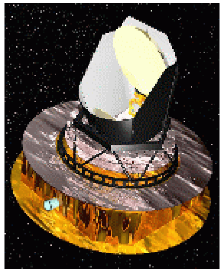


First / Planck Payload Review
23 May, 2000

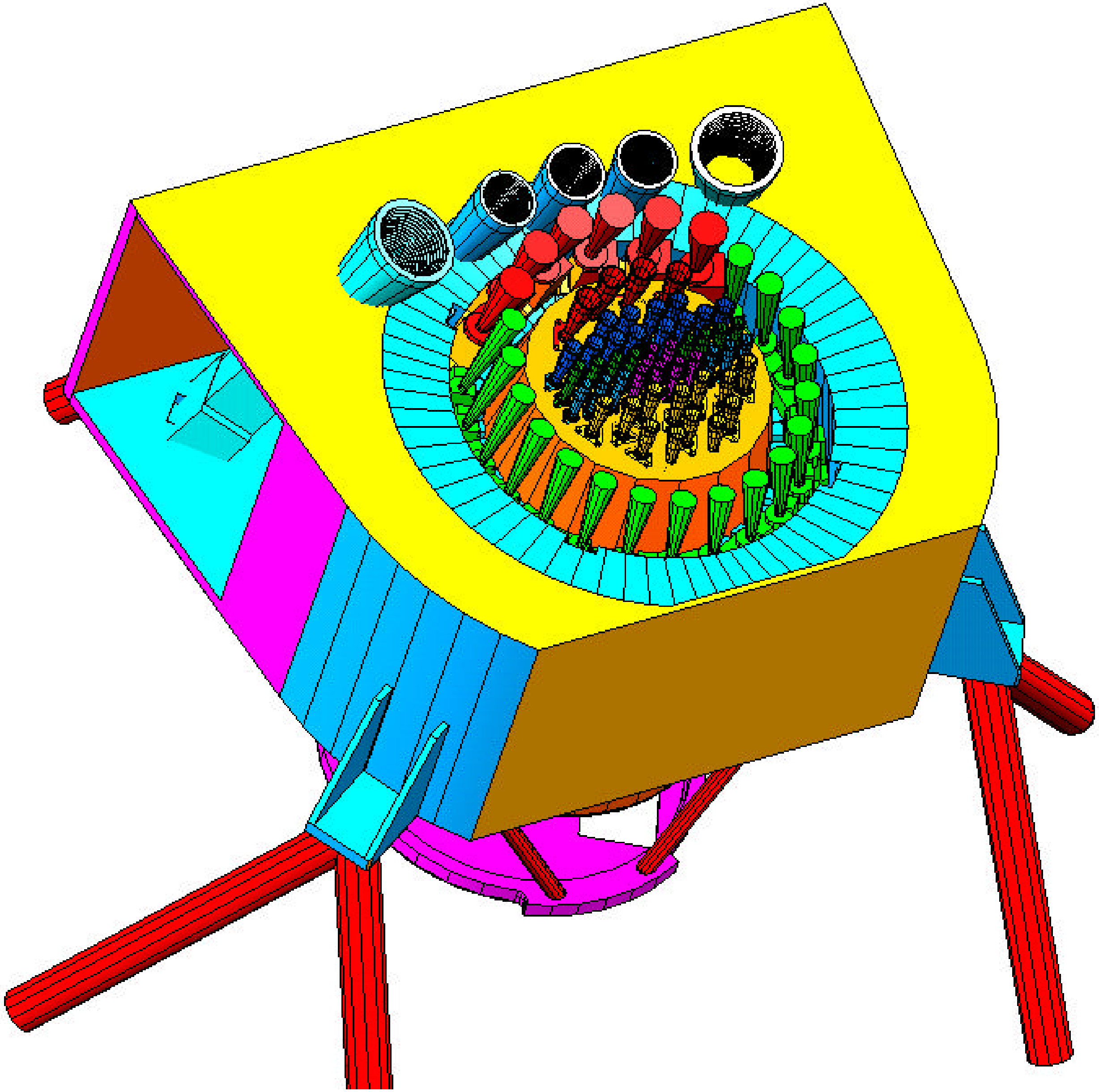
PLANCK HFI



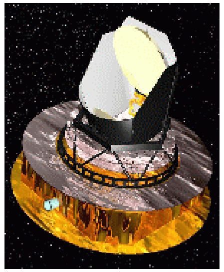
I.A.S. / J-L. Puget



First / Planck Payload Review
23 May, 2000



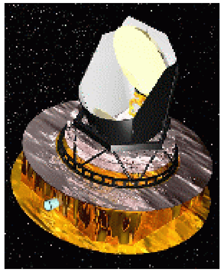
I.A.S. / J-L. Puget

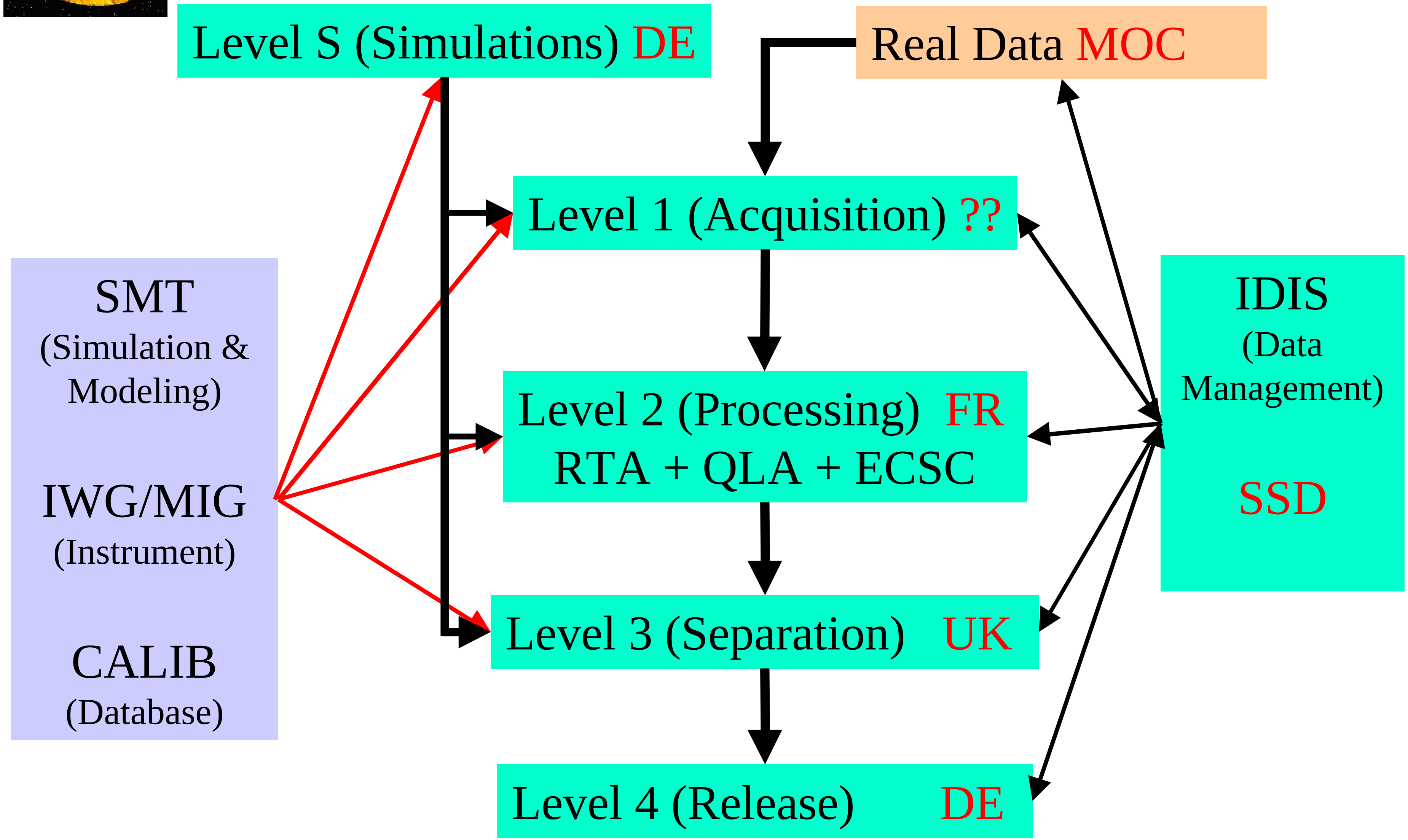


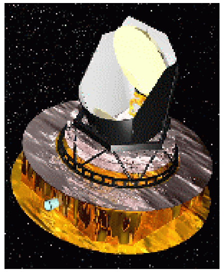
- Possibility/Need for high-accuracy results to achieve best scientific exploitation
    - Tricky systematic effects (far side lobes, …)
    - Must be well simulated before launch
    - High level of redundancy needed, iterative solutions

- Quite large data sample
    - Size = (2 To) * (Number_of_versions)
    - Computing time & memory problems
    - Development/Operations phases differences & overlap

- Multi-sites/Multi-national development
    - Management
    - Interfaces




Level S (Simulations) DE
Real Data MOC
Level 1 (Acquisition) ??
SMT
(Simulation &
Modeling)
IWG/MIG
(Instrument)
CALIB
(Database)
Level 2 (Processing) FR
RTA + QLA + ECSC
Level 3 (Separation) UK
Level 4 (Release) DE
IDIS
(Data
Management)
SSD

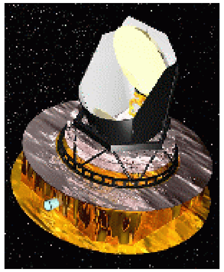


HFI DPC RESOURCES 2000-2007 in Man-Years FTE

(Permanents+PostDocs+Etc...)

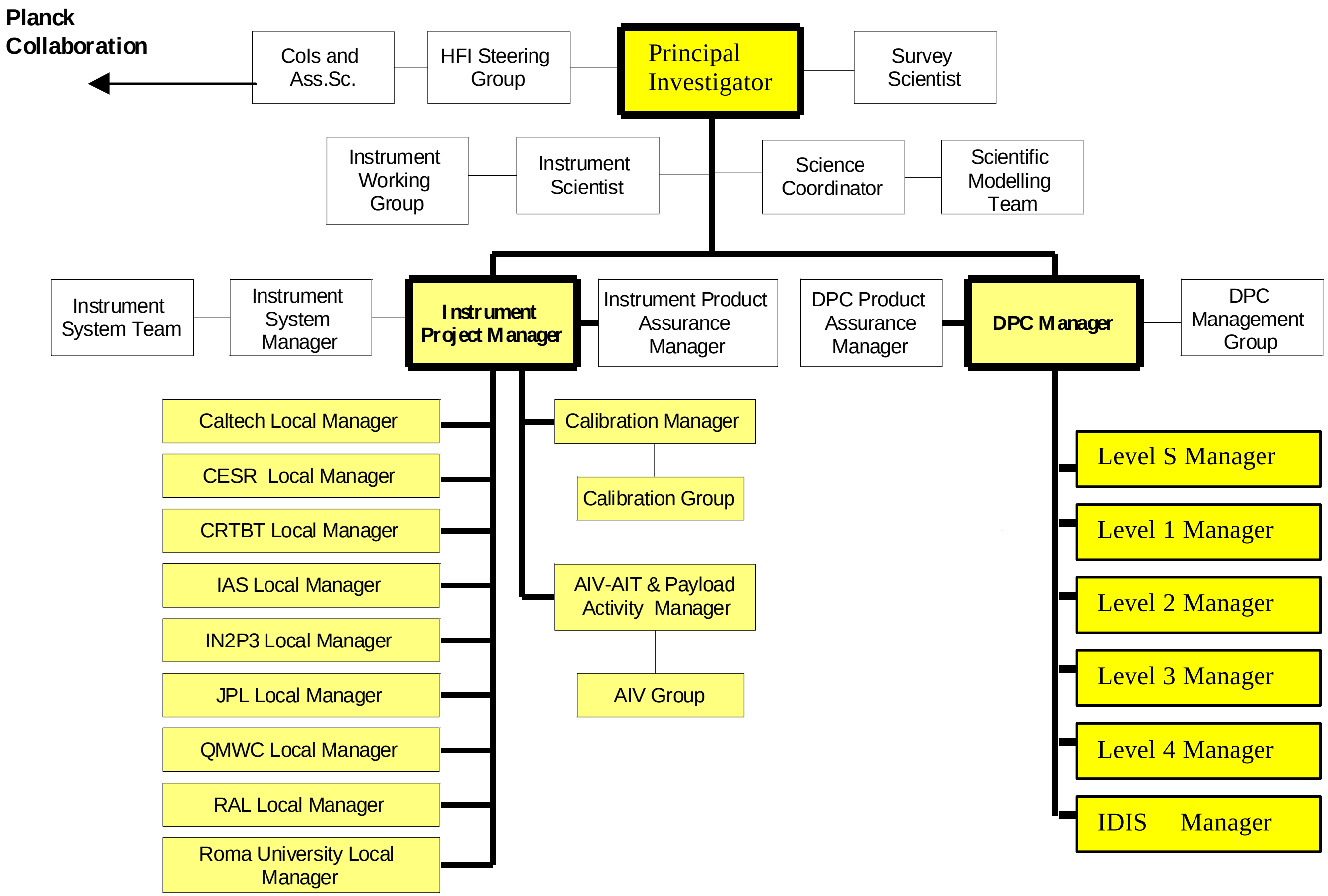
AVAILABLE	ALL TASKS	(1/2) IDIS	(1/2) LS	(1/2) L1	L2	L3	(1/2) L4	OTH.
FR	75	*0*	*5*	*0*	*62*	*8*	*0*	*0*
UK	101	*0*	*8*	*0*	*22*	*68*	*0*	*3*
US	20	*0*	*0*	*0*	*20*	*0*	*0*	*0*
(1/2) DE	33	*8*	*7*	*0*	*3*	*0*	*6*	*9*
(1/2) SSD	11	*6*	*3*	*0*	*0*	*0*	*0*	*2*
(1/2) CH	0	*0*	*0*	*0*	*0*	*0*	*0*	*0*
HFI AVAILABLE	**240**	**14**	**23**	**0**	**107**	**76**	**6**	**14**
HFI NEEDED	**255**	**13**	**21**	**10**	**110**	**76**	**10**	**15**
HFI DISCREPANCY	**-15**	**1**	**2**	**-10**	**-3**	**0**	**-4**	**-1**

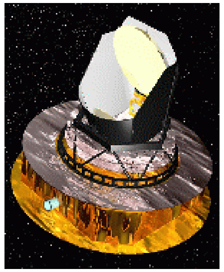
JFS 15/05/2000



PLANCK HFI

Consortium Team

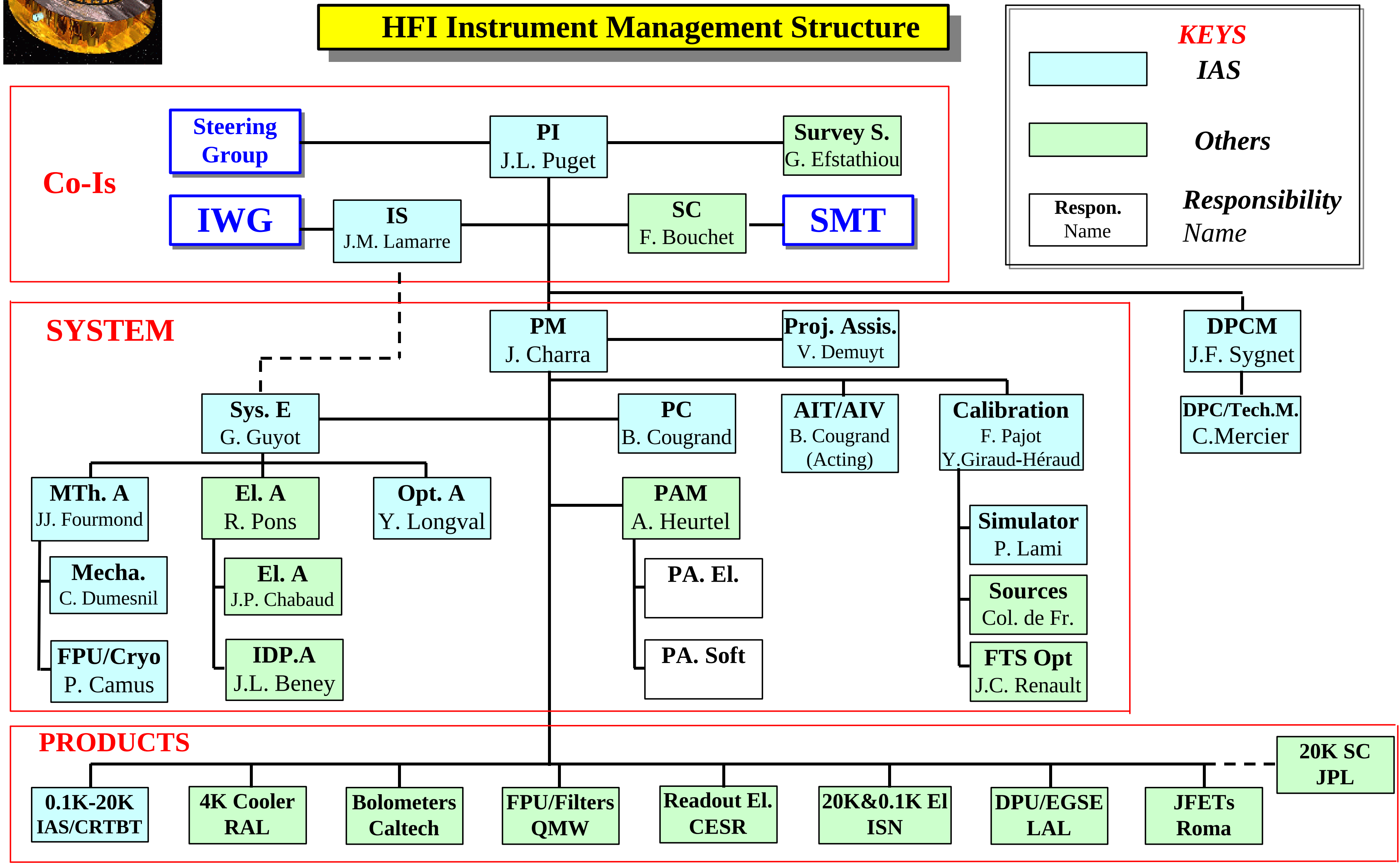




First / Planck Payload Review
23 May, 2000

PLANCK HFI

HFI Instrument Management Structure



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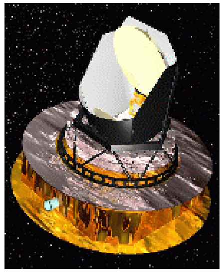

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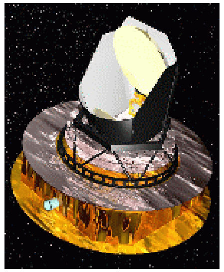
HFI

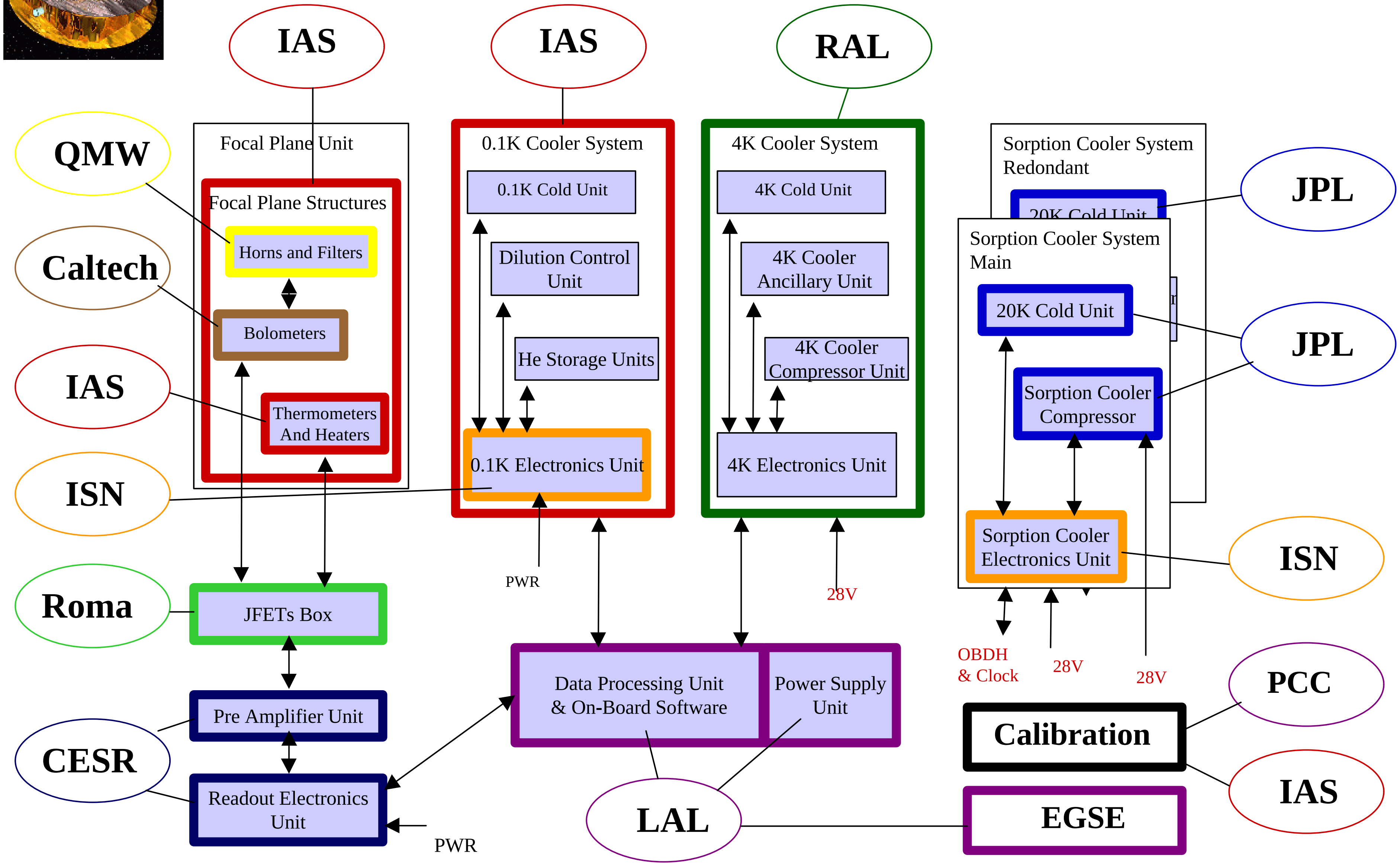
HFI Instrument Development Milestones

End of Phase B	End 2000
Hirel Parts Ordering	Early 2001
Cooling Chain End-to-end test	End 2001 / Early 2002
Calibration Facility Testing	4th Quarter 2001
CQM Focal Plane Testing	Early 2002
Qualified CQM Calibration start	Mid 2002
AVM-CQM Ready to deliver	End 2002
AVM-CQM Delivery	March 2003
CQM Return to PI	Early 2004
Flight Model Ready to deliver	March 2004
Flight Model Delivery	Mid 2004
Spares Delivery	Mid 2005

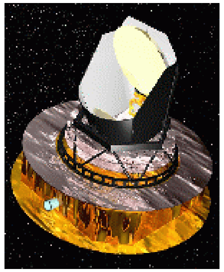


First / Planck Payload Review
23 May, 2000

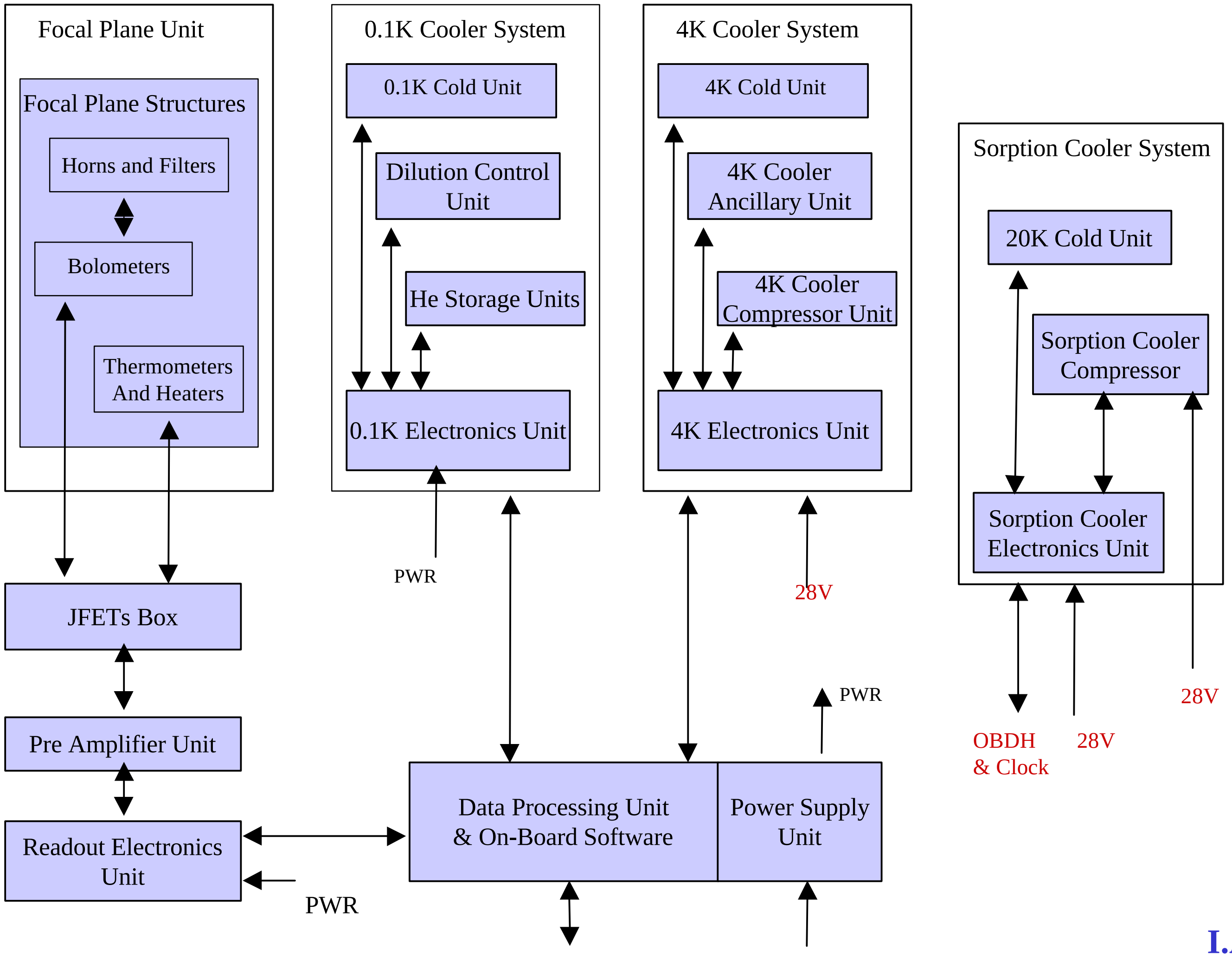
PLANCK HFI

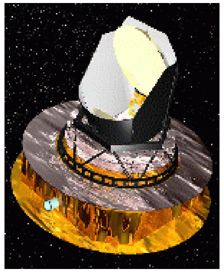


High level Memoranda of Understanding are being circulated for agreement between different procuring Institutions and the PI.



HFI Instrument Development Models





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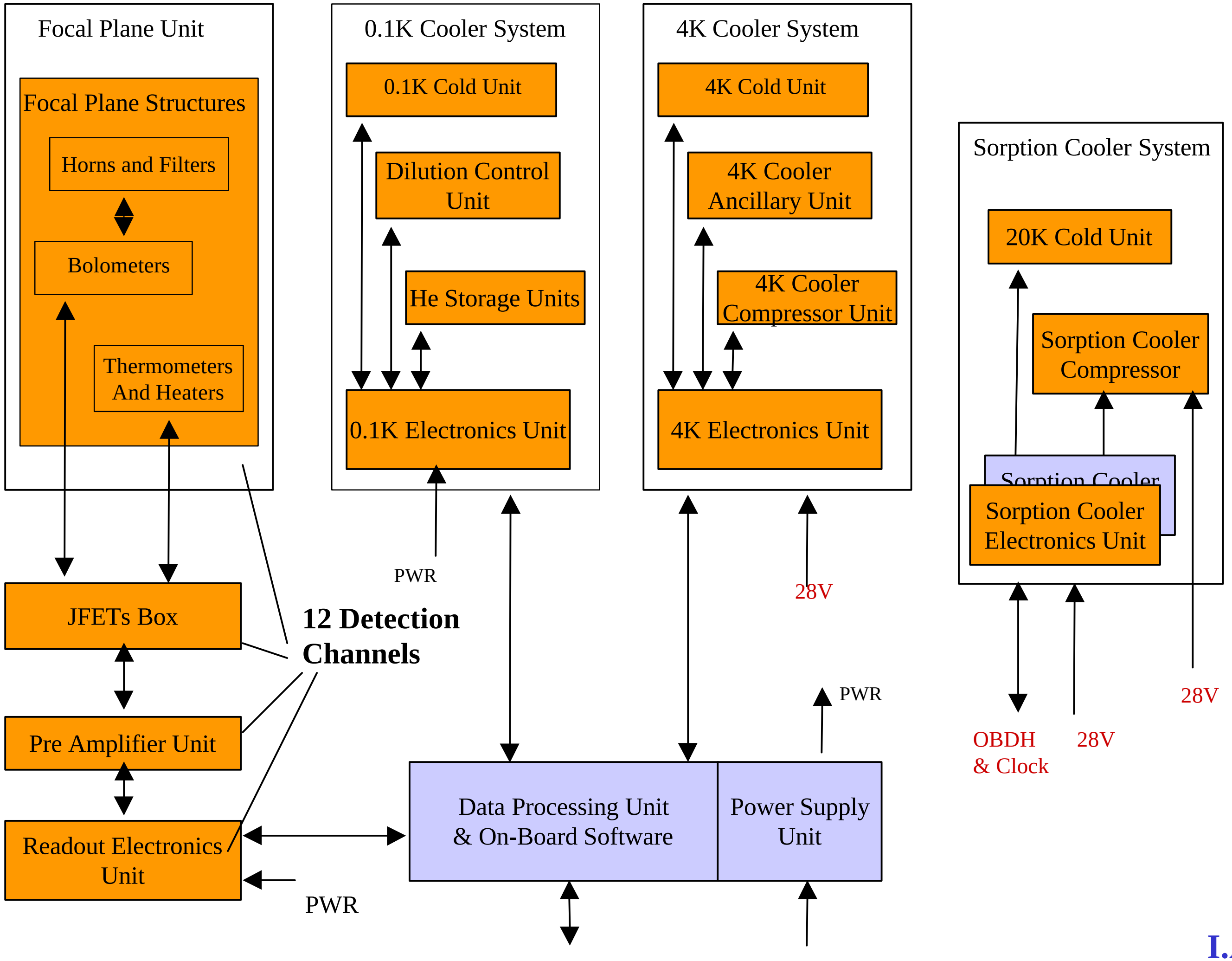
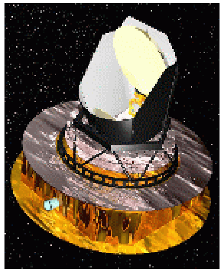
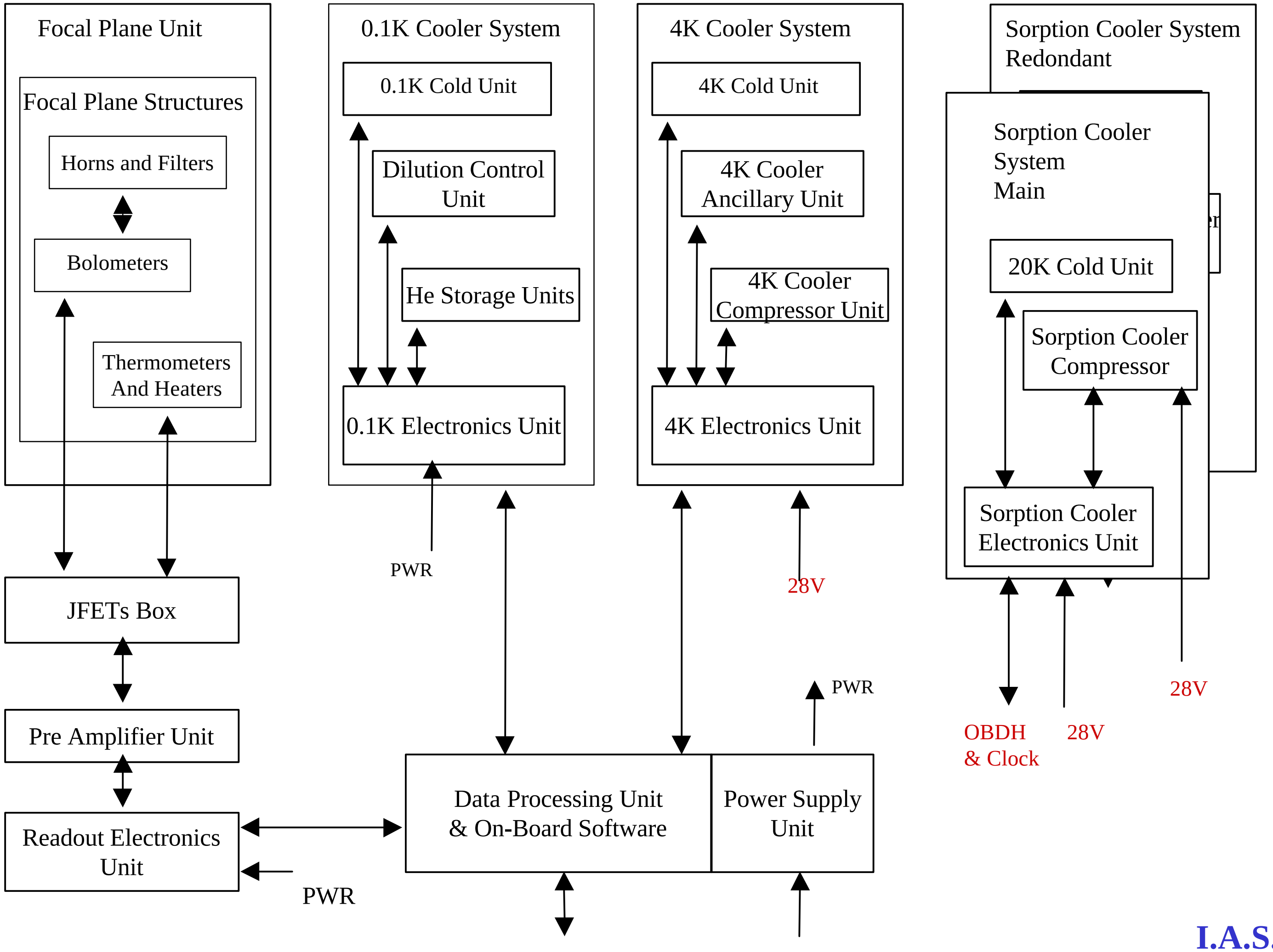
HFI Instrument AVM / CQM

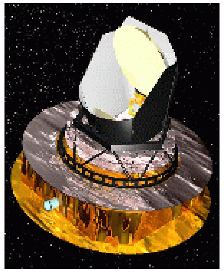




HFI Instrument Flight Model



I.A.S. / J-L. Puget



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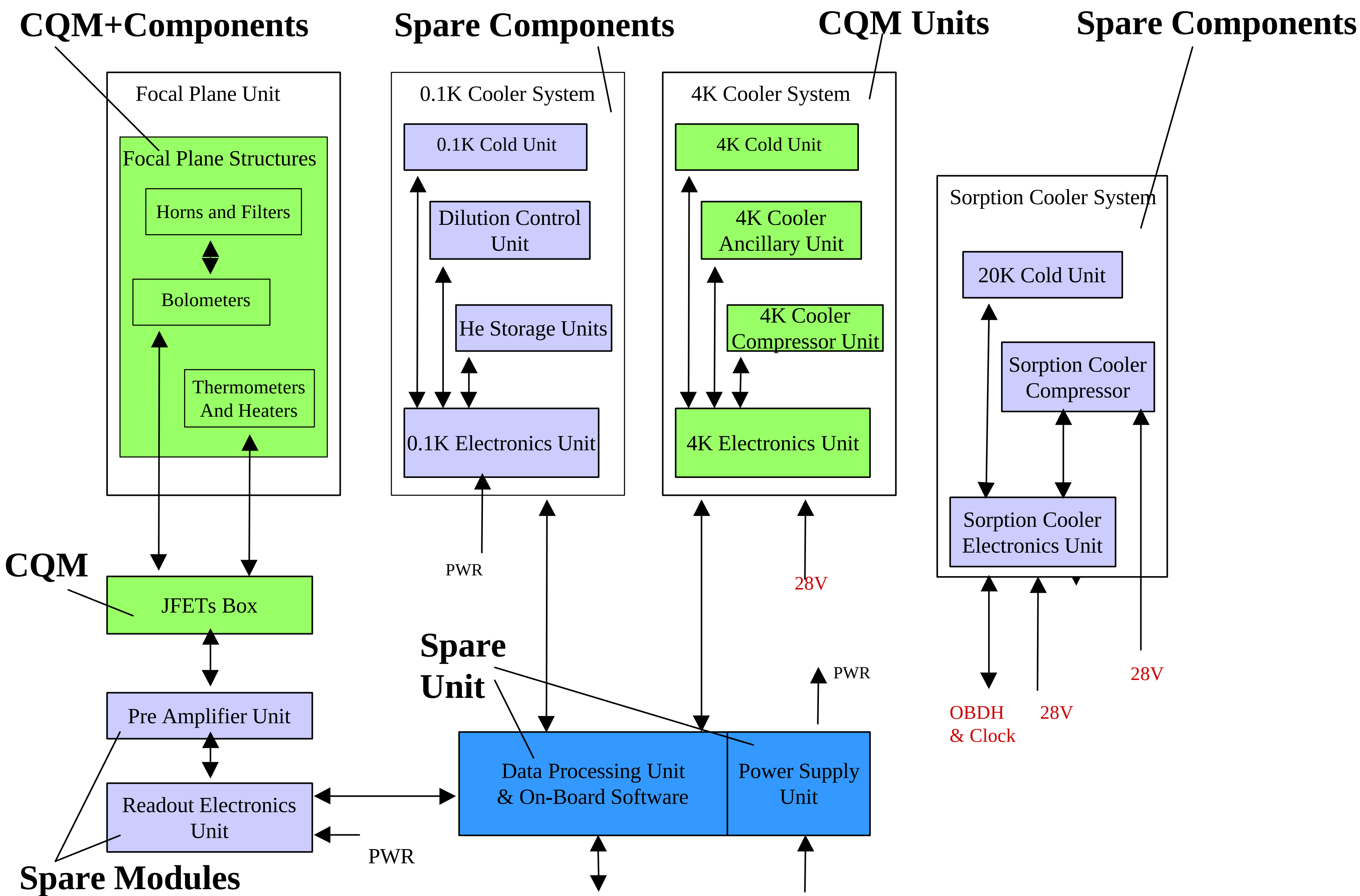
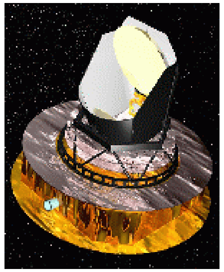
HFI Instrument Spares





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Critical areas (1)

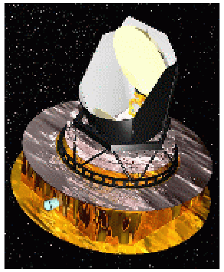
Telemetry

- Science data rate in proposal 34 kbits/sec (accepted by ESA)
- Present estimate 38 kbits/sec (data compression was a bit optimistic) 11.7% increase *(not exactly outrageous)*
- Need to add HK and overheads and margins leads to 53 kbits/sec

Present situation

60 kbits total, 2/3 for HFI gives 40 kbits for HFI, total short by 24 %

- will imply some science loss
- Project to evaluate in Phase B margins in telemetry budget, at least proposal numbers need to be traded off with other costs
  Important problem but not dramatic



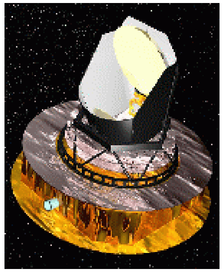
PLANCK HFI

Critical areas (2)

RAL compressors

- Doubts about MMS capability to be able to provide new ones (+ funding problems)
- Planck requirements different from FIRST / TRP program requirements: allowed leak rate of compressor setup for life time in space but does not allow ground test with compressors in the vacuum tank containing also dilution cooler
- Refurbishment by RAL satisfy news requirements
- Best (and probably only solution) need to be implemented :

    - transfer from ESA of coolers developped under TRP agreed
    - Implementation of transfer in progress



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HFI

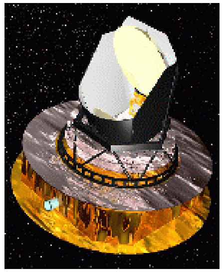
Critical areas (3)

0.1 K Cooler Vibration Susceptibility

- Microvibration/noise add to thermal load : known problem already solved on many ground/balloon experiments
- Sensitivity/problems experimented in TRP « demonstrator » solved by proper mechanical isolation of vibration sources (not fully representative of Planck design

Futures activities

- Further quantification of sensitivity of cooler to microvibration/noise by tests
- Design approach to minimise transfer of microvibration/noise to focal plane unit



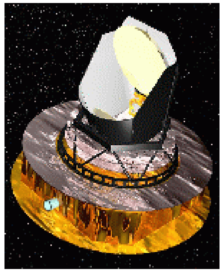
Hard Point

Contracts

- Contract with Air Liquide not signed yet because of administrative difficulties

Activities with FIRST/Planck Project

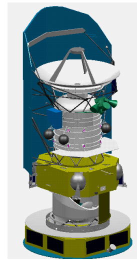
- CNES and IAS work with CNRS to obtain authorization not to go through an open Annoucement of Opportunity in view of developments done with Air Liquide



PLANCK HFI

Budget

Total development (up to 2007)	94.5 MEURO
Estimate included operations and post-operations	111 MEURO



5.4 Planck Reflectors Status

Planck Reflectors Status

DK - Planck FIRST / Planck Reflectors

- ESA/DSRI agreement to be signed by the parties at the next SPC meeting

- DK-PLANCK Consortium:

  DSRI, Theoretical Astrophysics Center, Niels Bohr Institute for Astrophysics, Physics and Geophysics

- Steering committee: 2 members from each institute

- Financial support:

  Proposal to the Danish Natural Science Research Council and Danish Committee for ESA - related Research , Autumn 1996

  Proposal approved Spring 1997

  (negotiating new financing plan)

DK - Planck **FIRST / Planck Reflectors**

- **During Phase A support from Danish Ministry of Research for the production of a test mirror (~ secondary mirror)**

Main concern:

a. Surface shape error within specification

(< 1 μm rms, for scales ≤ 0.8 mm

< 10 μm rms, for scales > 0.8 mm)

b. thermal stability of surface shape

DK - Planck

F I R S T / P l a n c k R e f l e c t o r s

- **Picture - Test Mirror**

Test of Demonstrator Model

- Mechanical measurements
- Optical measurements
- CTE measurements
- Tests of sample at ESTEC
  Main purpose: microcracks

- Cryogenic tests at CSL
  agreement on test method and setup
  preparation 6 - 9 months
  1. large scale deformations of mirror shapes
  2. small scale deformations of mirror shapes (core printthrough)

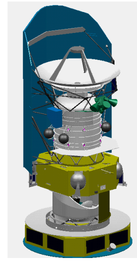
FIRST / Planck Reflectors

- **Picture**

Development Milestones

• Planck Reflector Technology Demonstration	End 2000
• Planck Telescope System Programme Plan	Mar. 2000
• Planck Telescope Reflectors ICD freeze:	Aug. 2000
• Planck Telescope Reflectors QM Delivery:	Jan. 2003
• Planck Telescope Reflectors FM Delivery:	Mar. 2004
• Planck Telescope Reflectors QM return to DSRI:	July 2004
• Planck Telescope Reflectors FS Delivery:	Jan. 2005

• Planck Telescope Reflectors Requirements Review:	Sept 2000
• Planck Telescope Reflectors Preliminary Design Review:	March 2001
• Planck Telescope Reflectors Hardware Design Review:	Sept 2001
• Planck Telescope Reflectors Critical Design Review:	March 2002
• Planck Telescope Reflectors Qualification Review:	Jan 2003
• Planck Telescope Reflectors Acceptance Review (FM):	March 2004
• Planck Telescope Reflectors Acceptance Review (FS):	Jan 2005



6. Conclusions

FIRST / Planck Project		ESA-ESTEC 23 May 2000	

FIRST / Planck Payload Review

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FIRST / Planck Project		ESA-ESTEC 23 May 2000	
FIRST / Planck Payload Review			
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