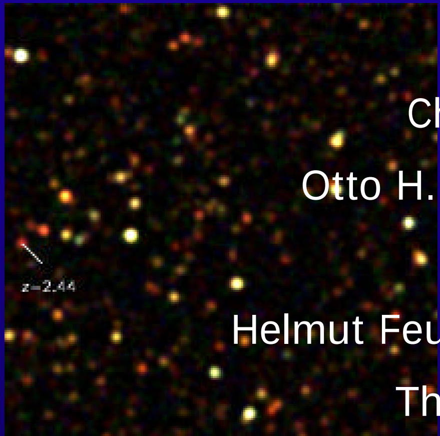
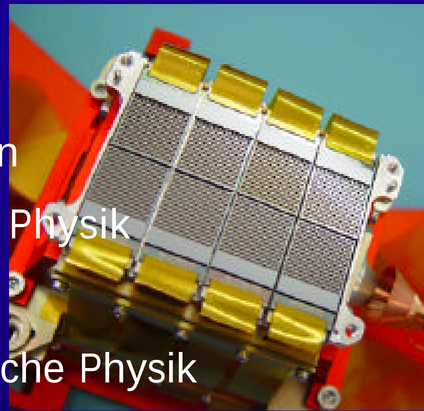
Herschel Photodetector Array Camera & Spectrometer

Eckhard Sturm, MPE Garching

Albrecht Poglitsch, MPE Garching

Christoffel Waelkens, Katholieke Universiteit Leuven

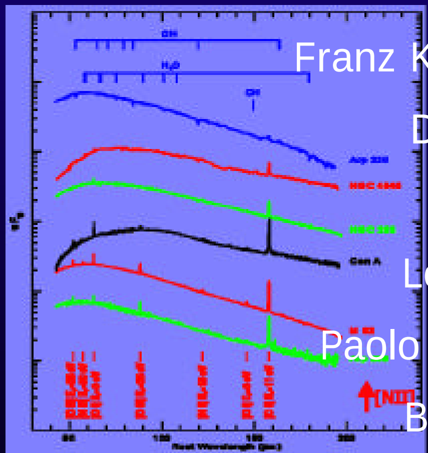
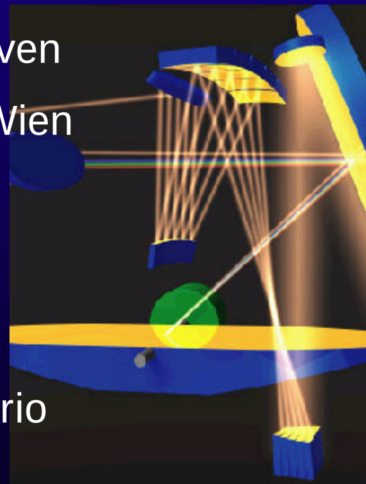
Otto H. Bauer, Max-Planck-Institut für extraterrestrische Physik

Jordi Cepa, Instituto de Astrofísica de Canarias

Helmut Feuchtgruber, Max-Planck-Institut für extraterrestrische Physik

Thomas Henning, Max-Planck-Institut für Astronomie

Chris van Hoof, Interuniversity Microelectronics Center Leuven

Franz Kerschbaum, Institut für Astronomie der Universität Wien

Dietrich Lemke, Max-Planck-Institut für Astronomie

Etienne Renotte, Centre Spatial de Liège

Louis Rodriguez, Commissariat a l'Energie Atomique

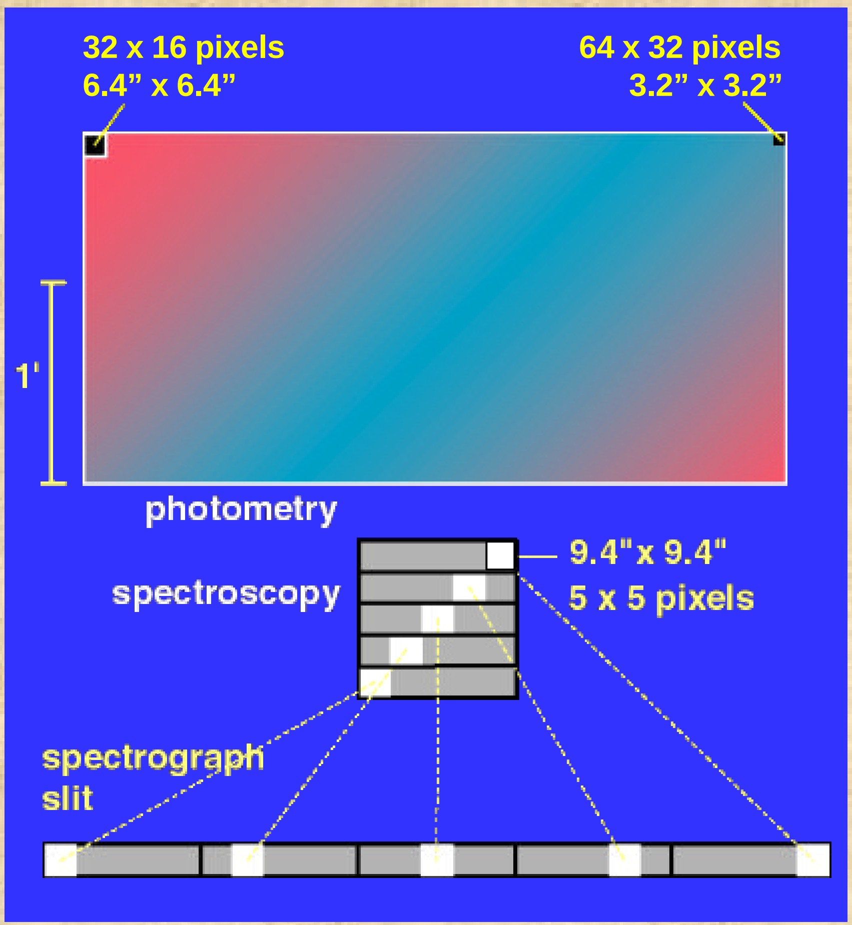
Paolo Saraceno, Istituto di Fisica dello Spazio Interplanetario

Bart Vandenbussche, Katholieke Universiteit Leuven

Instrument Concept

- **Imaging photometry**
  - two bands simultaneously (60-85 or 85-130 µm and 130-210 µm) with dichroic beam splitter
  - two filled bolometer arrays (32x16 and 64x32 pixels, ~ full beam sampling)
  - point source detection limit ~4 mJy (5s , 1h)
- **Integral field line spectroscopy**
  - range 57 - 210 µm with 5x5 pixels, image slicer, and long-slit grating spectrograph (R ~ 1500)
  - two 16x25 Ge:Ga photoconductor arrays (stressed/unstressed)
  - point source detection limit 3...20 x10^{-18} W/m^2 (5s , 1h)

Focal Plane Footprint



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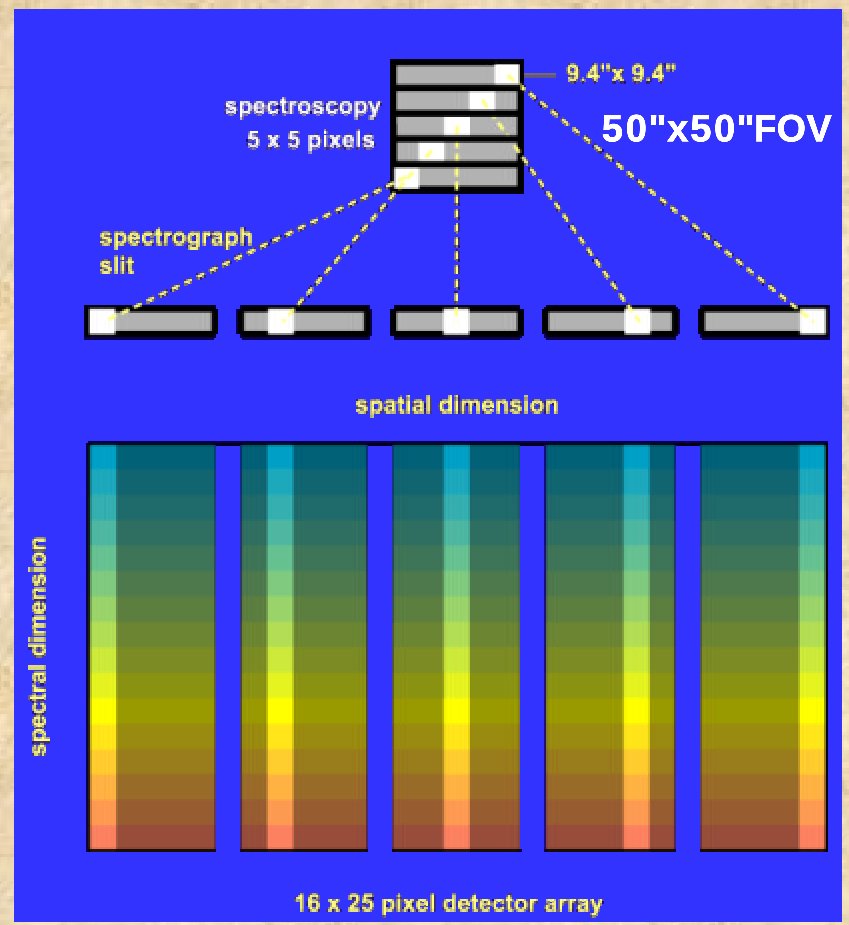
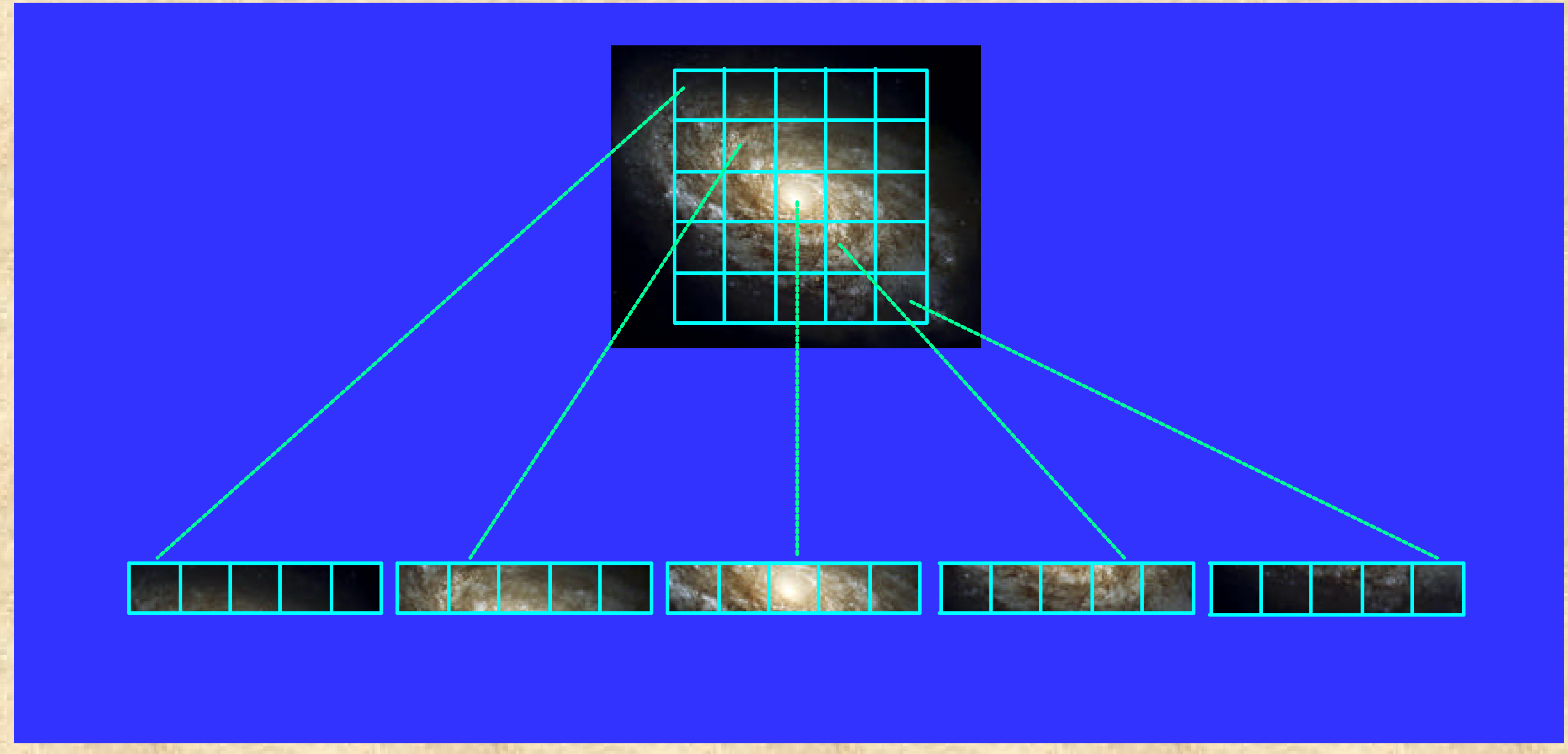
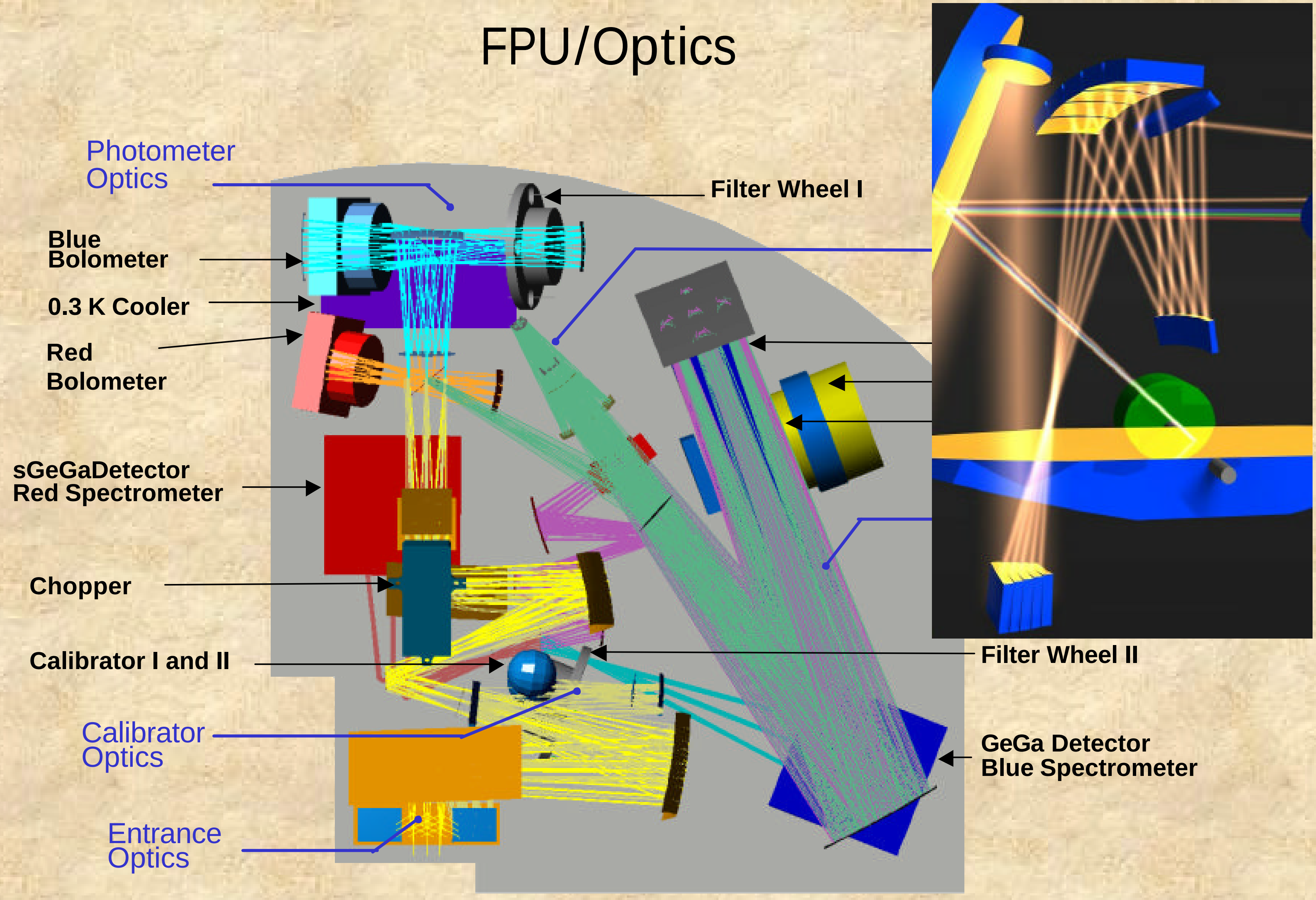
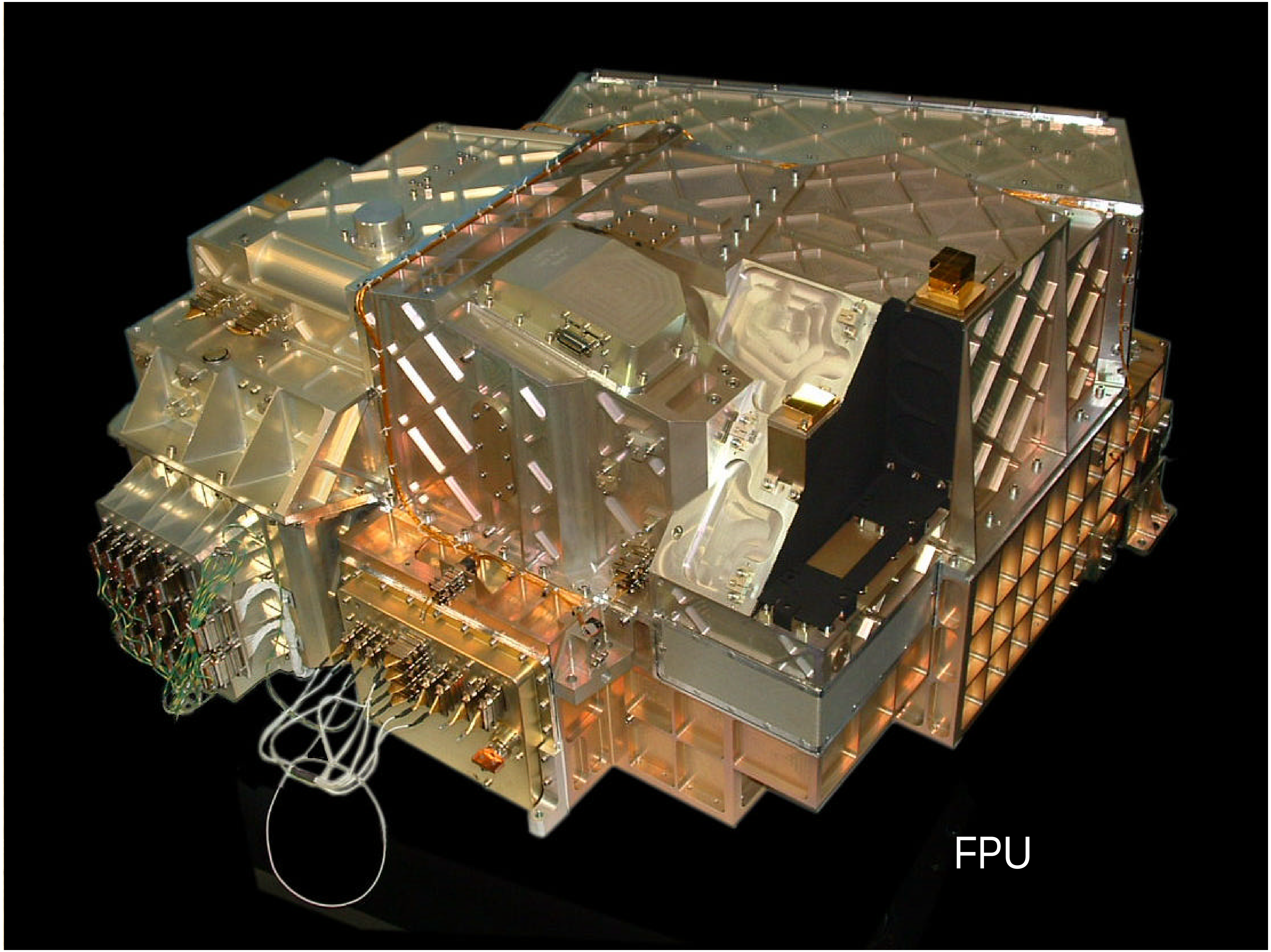


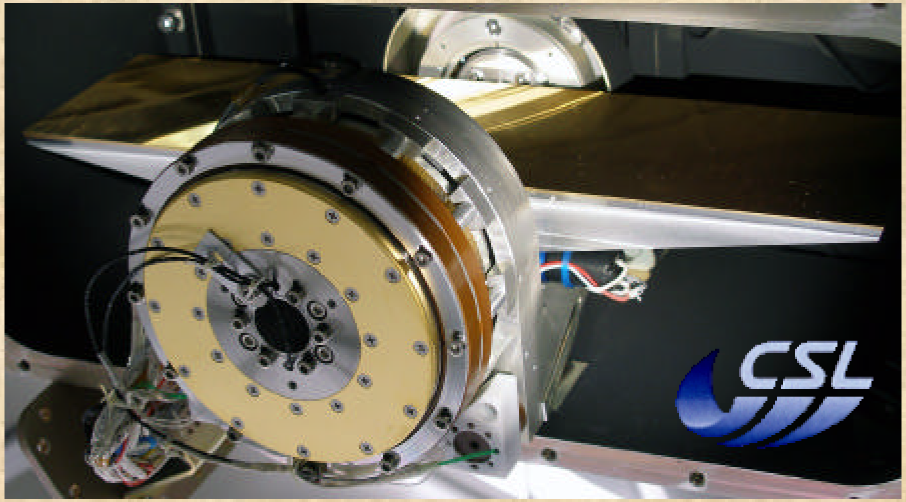


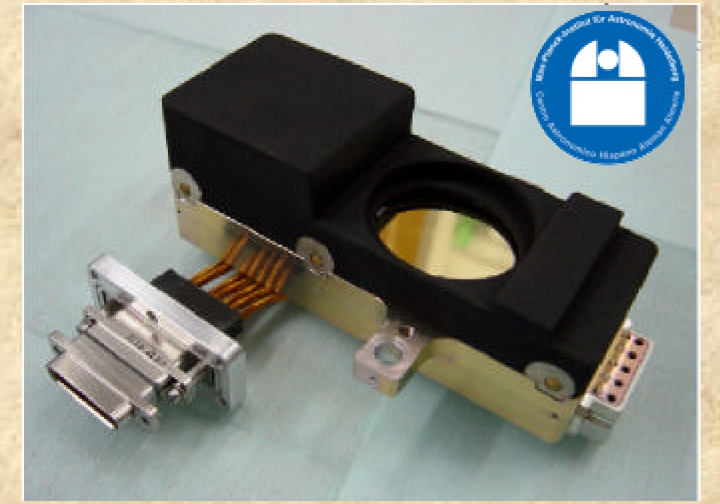
FPU/Optics

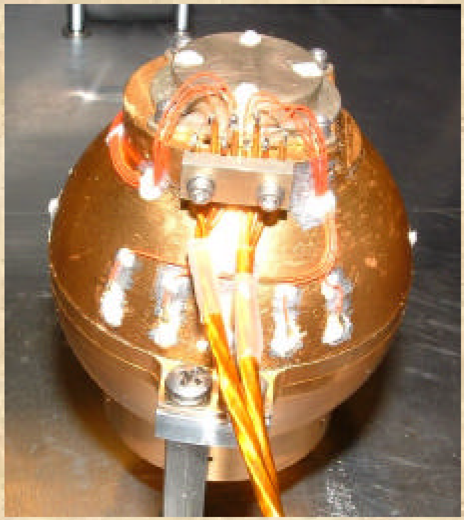

Photometer Optics
Filter Wheel I
Blue Bolometer
0.3 K Cooler
Red Bolometer
sGeGaDetector Red Spectrometer
Chopper
Calibrator I and II
Filter Wheel II
Calibrator Optics
GeGa Detector Blue Spectrometer
Entrance Optics

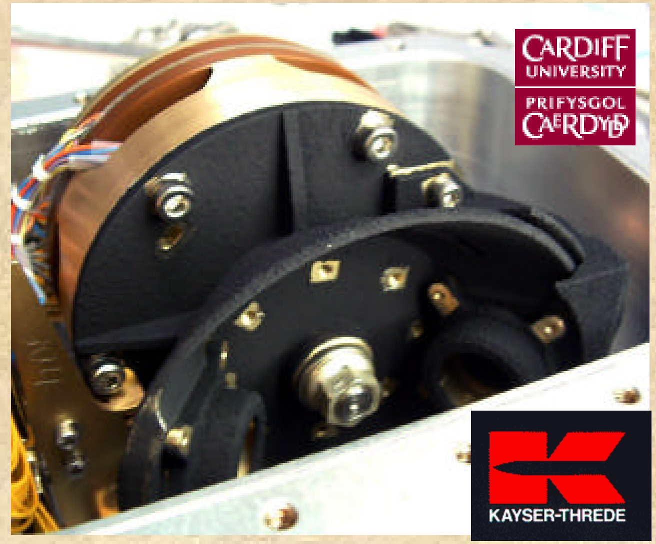

FPU

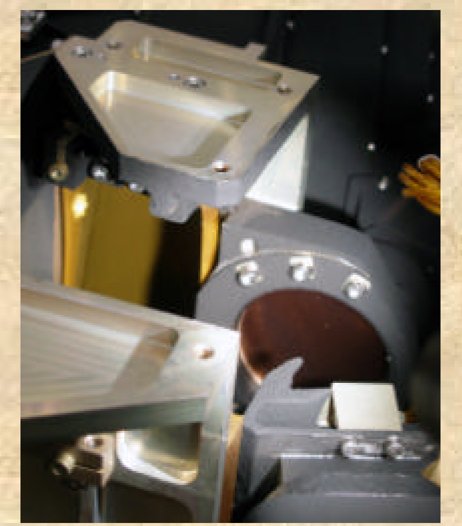
FPU Subunits Picture Gallery





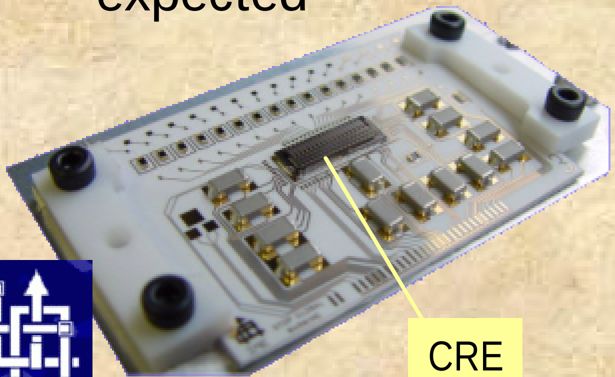


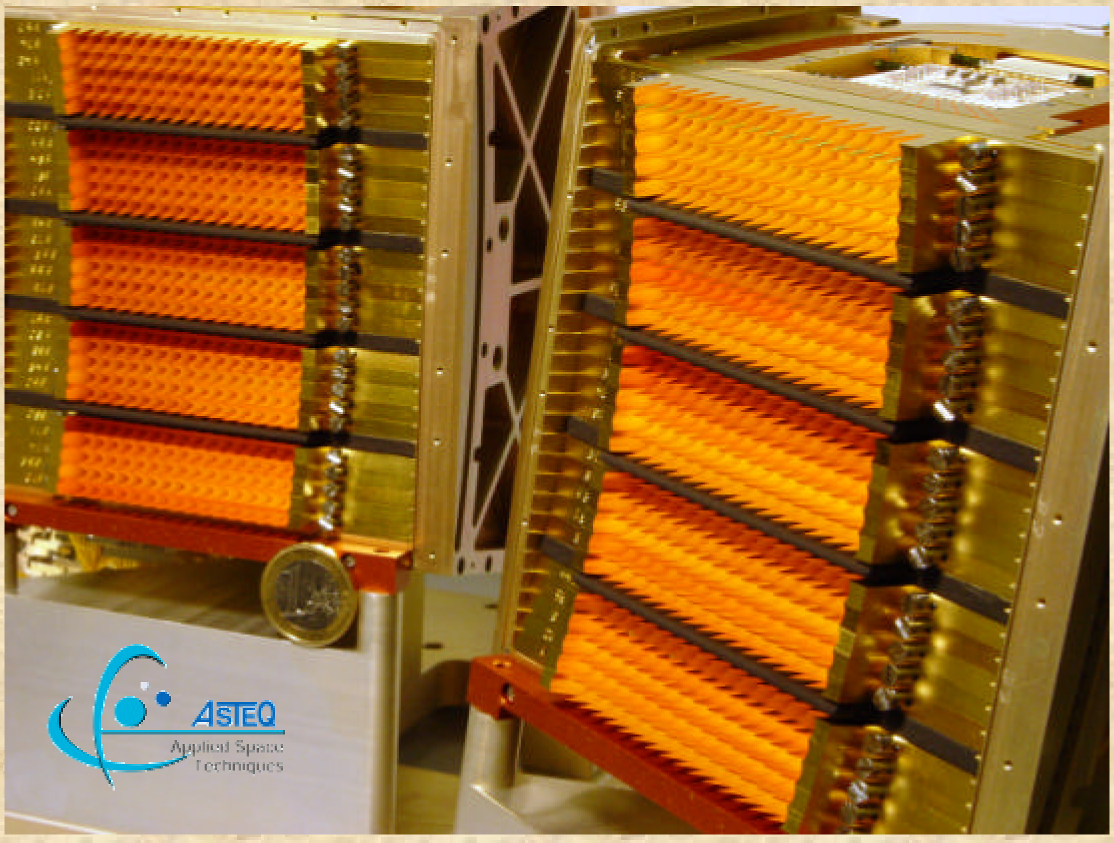




Photoconductor Arrays (Spectrometer)

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

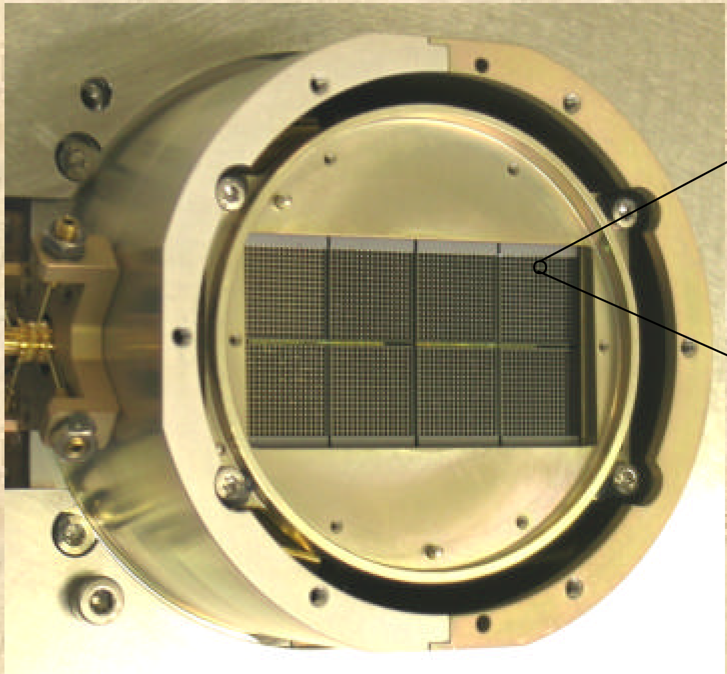




dapnia cea saclay

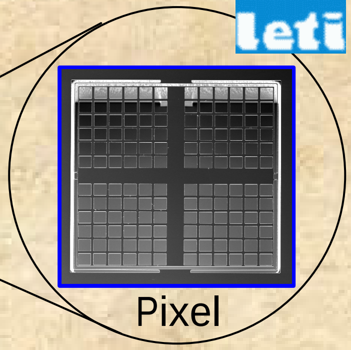
Bolometer Arrays (Photometer)

- Two filled arrays: 64x32 pixels (blue) and 32x16 pixels (red)
- Bolometers and multiplexing readout electronics operating at 0.3K
- Detector/readout noise comparable to background-noise (FM)
- Cooler hold time ~55h

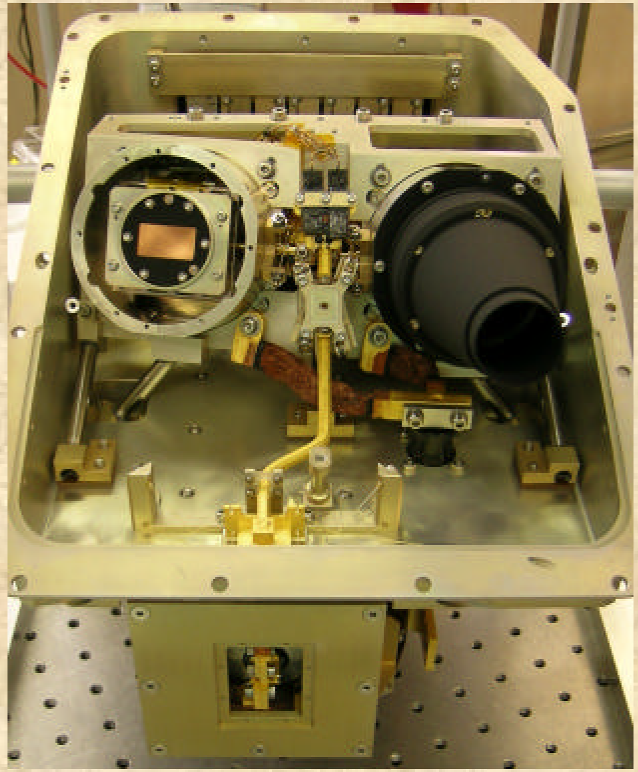


Blue focal plane

cea leti

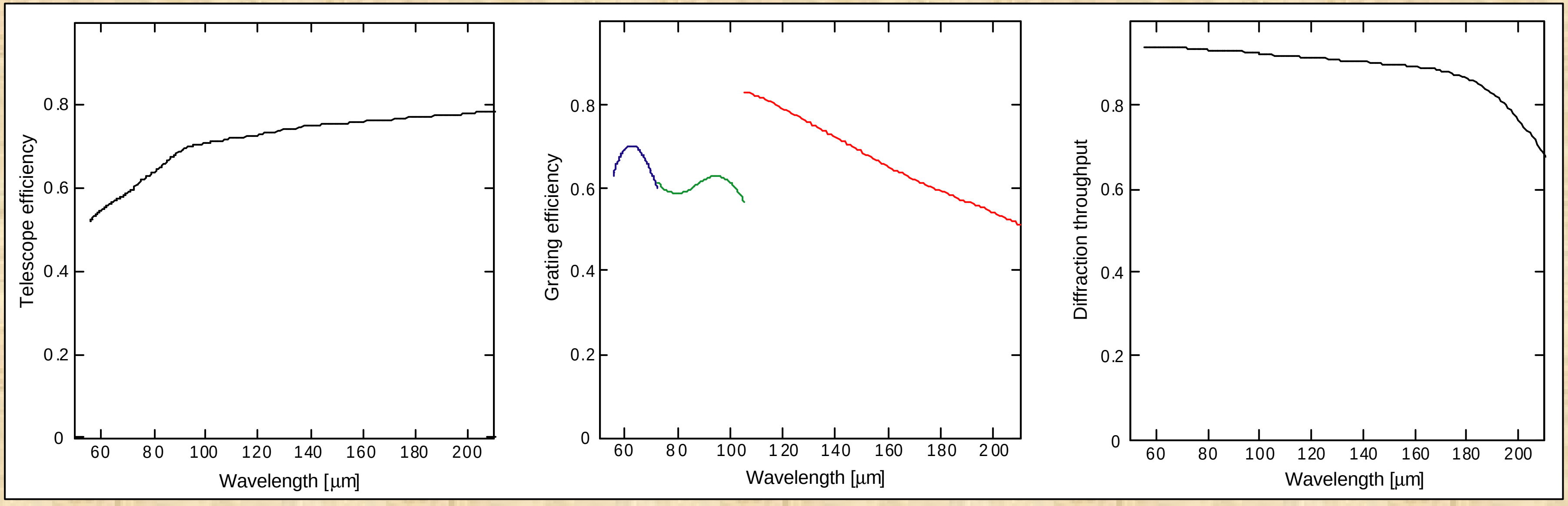


Photometer unit with blue + red focal planes and ^{3}He cooler



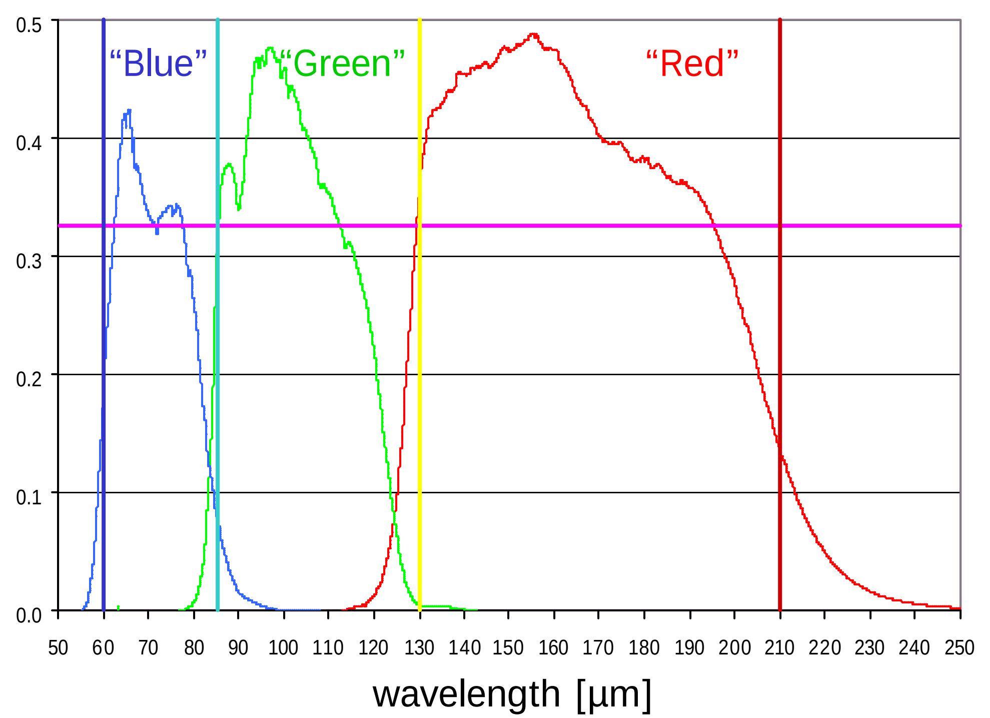
Estimated Instrument Performance

- Calculated optical efficiencies
  - telescope main beam (diffraction + WFE)
  - grating in respective diffraction orders
  - diffraction losses due to IFU (image slicer)

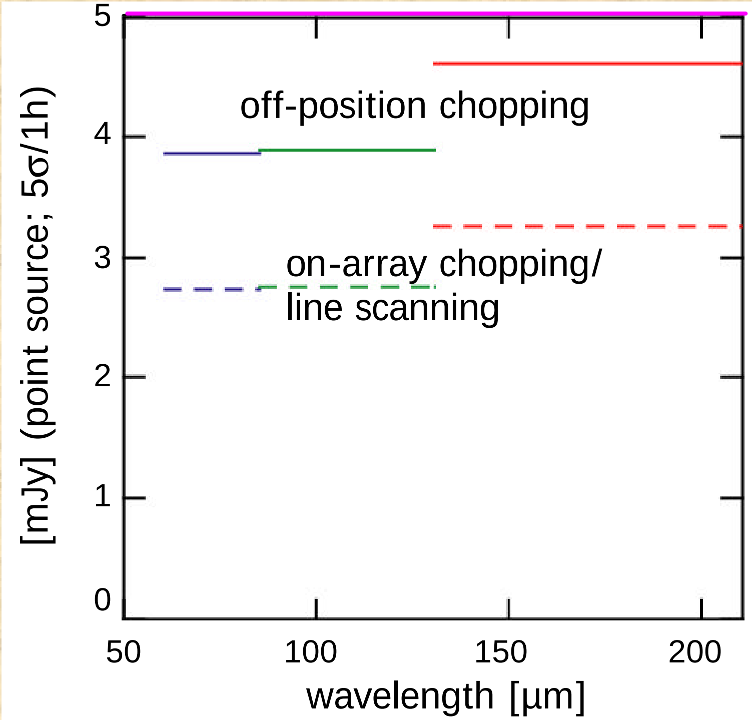


Expected Performance Photometry

Photometer bands: filter transmission x detector efficiency

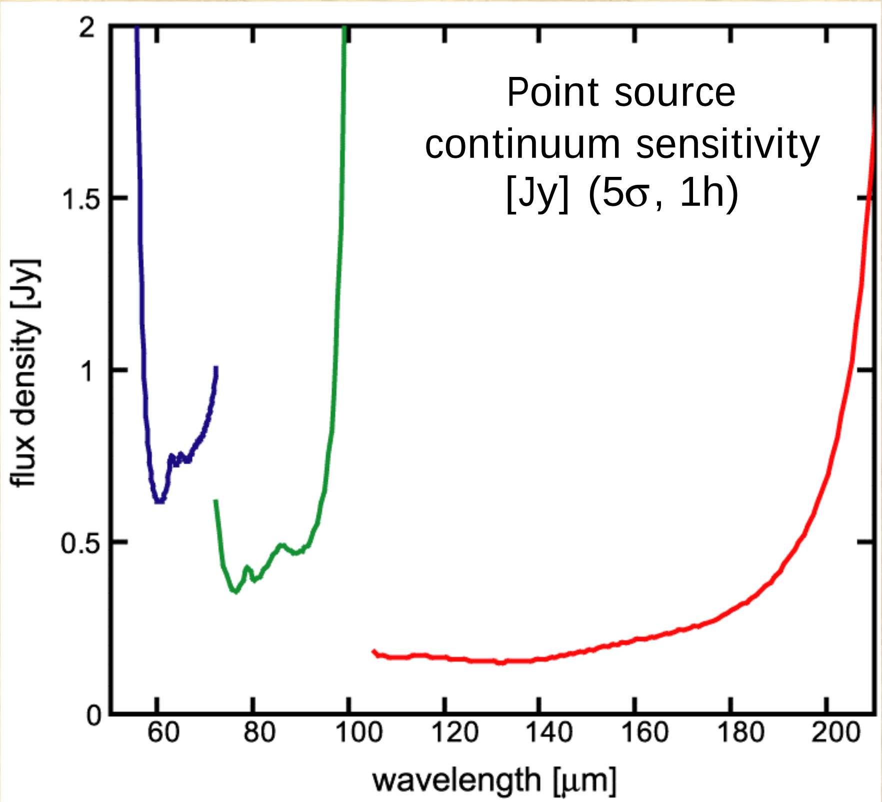


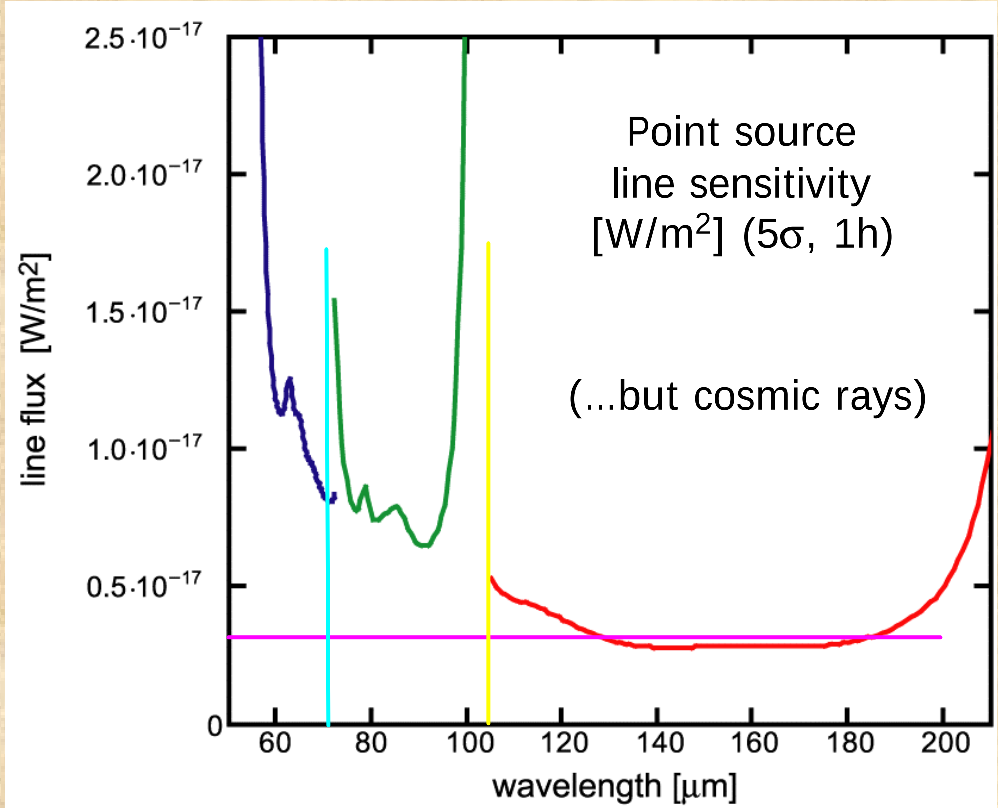
Sensitivity



- Requirements (band definition: ±5%, sensitivity: 5mJy, 5s/1h) expected to be met

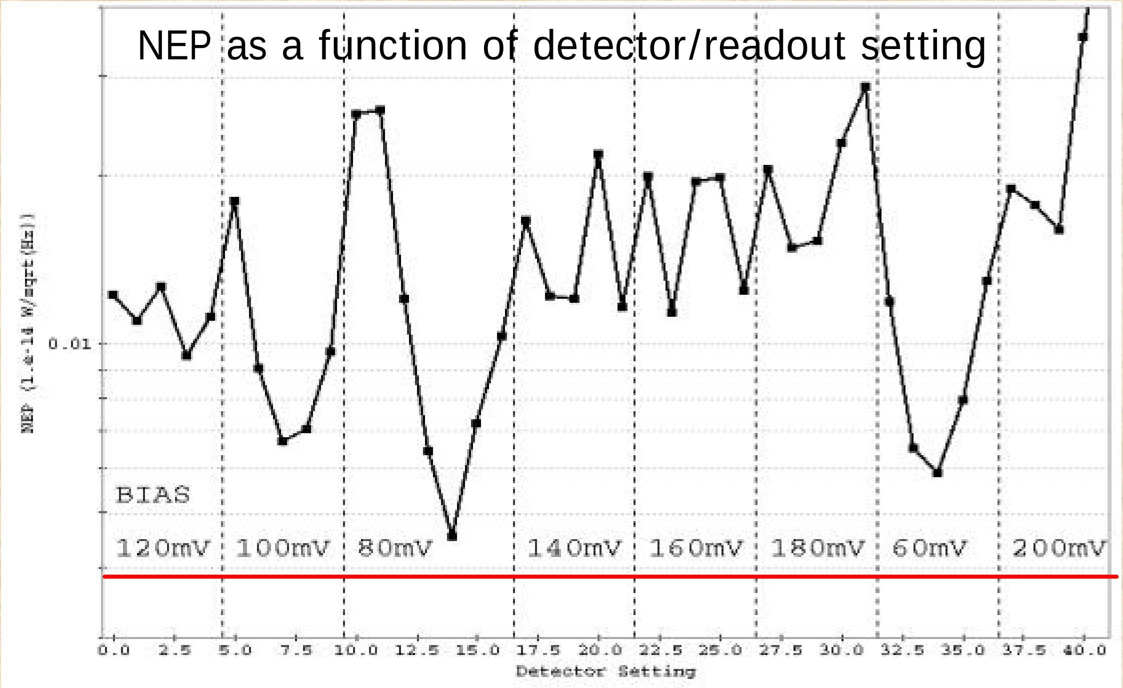
Expected Performance Spectroscopy





- Gap from ~ 95 to 105 µm
- Calculated for (off-array) chopping
- Sensitivity requirement only partly met

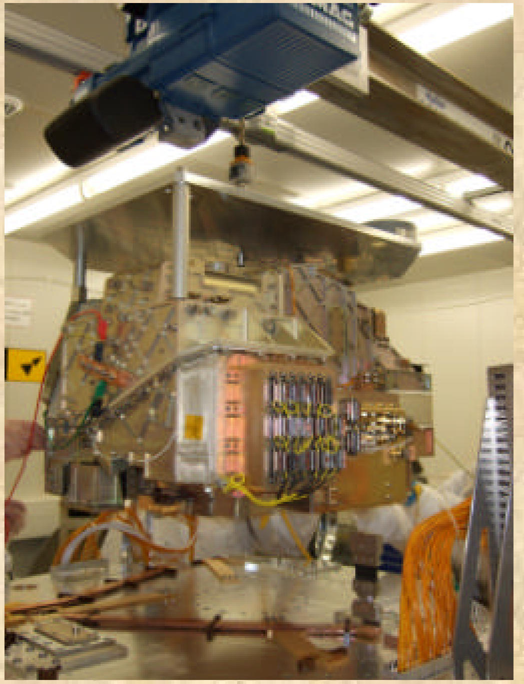
Operation/Performance under p+ Irradiation

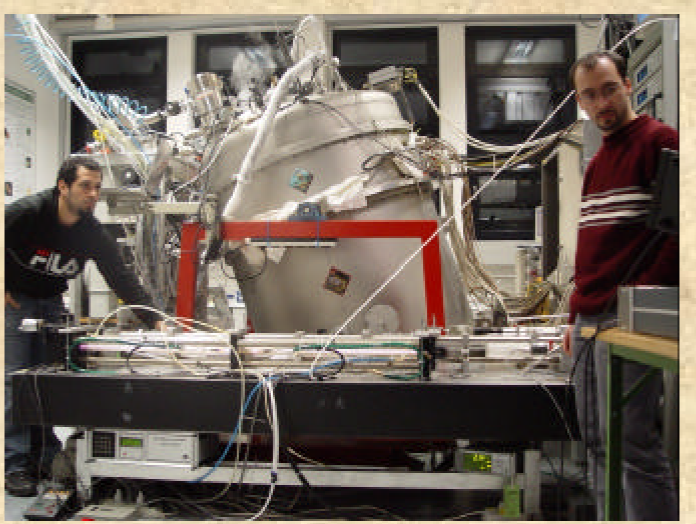


Simulated chopped observation with one ramp/chopper plateau.
For each bias value, 5 ramp lengths tested: 1s, 1/2 s, 1/4 s, 1/8s, 1/16 s.
The detector was in its high responsivity plateau, ~2 hours after the last curing.

Instrument model value, based on lab measurements without irradiation

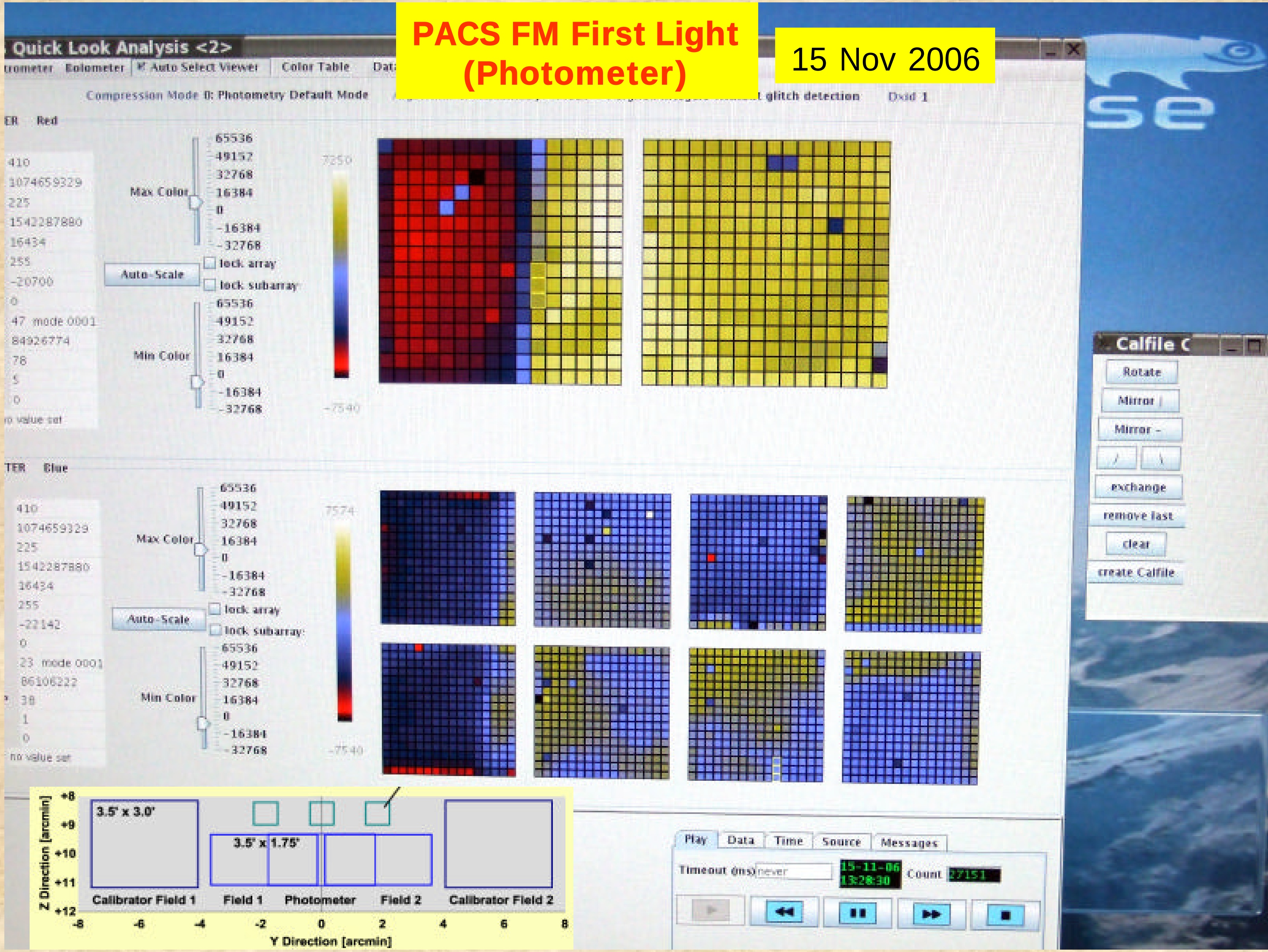
- With optimum bias setting (lower than in lab!) and ramp length/ chopping parameters, NEP close to lab values possible in space
- Curing may be necessary only after solar flare, or once per day (self-curing under telescope IR background sufficient)



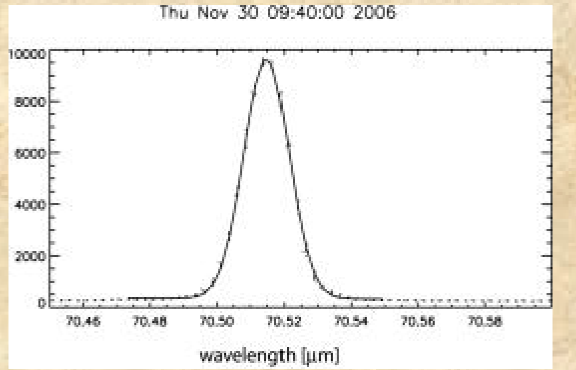


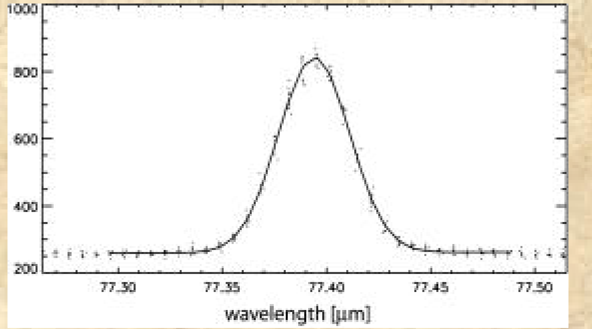
PACS FM First Light (Photometer)

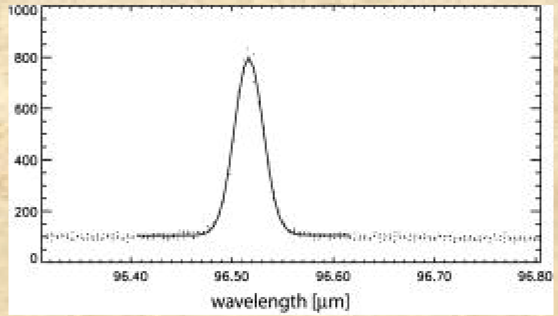
15 Nov 2006

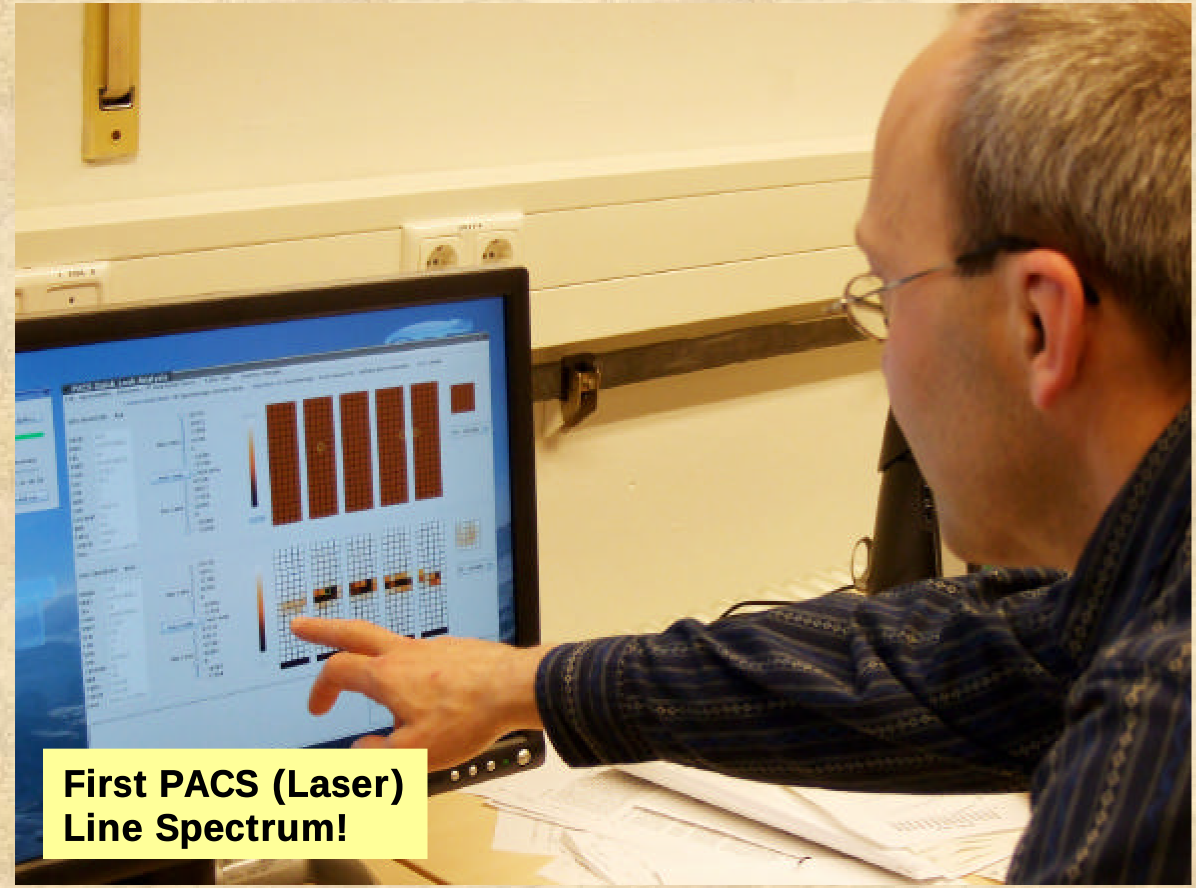



PACS Quick Look Analysis
Stripchart <2>
Blue detector: Pixel (7, 7)
Frame No.
First Light in the Blue Spectrometer!
... and all 25 modules are alive ...


Thu Nov 30 09:40:00 2006
10000
8000
6000
4000
2000
0
70.46
70.48
70.50
70.52
70.54
70.56
70.58
wavelength [µm]


1000
800
600
400
200
77.30
77.35
77.40
77.45
77.50
wavelength [µm]

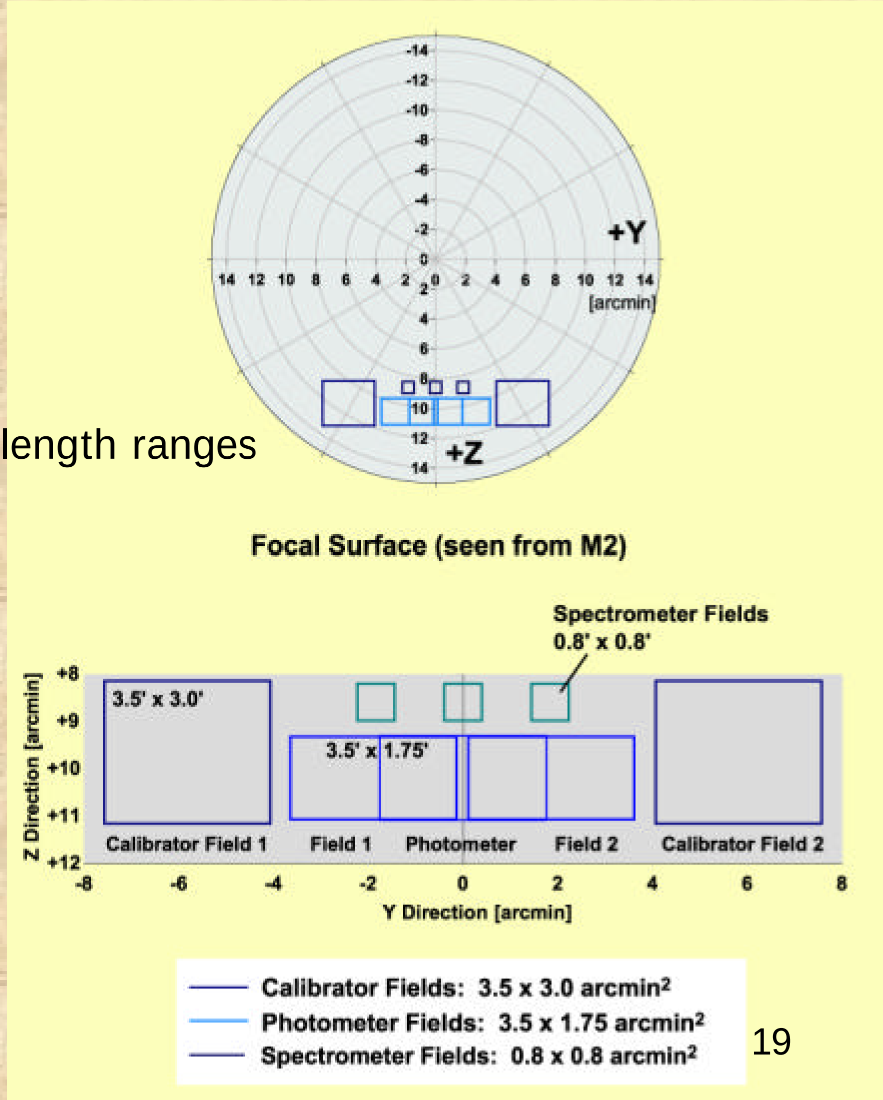

1000
800
600
400
200
0
96.40
96.50
96.60
96.70
96.80
wavelength [µm]

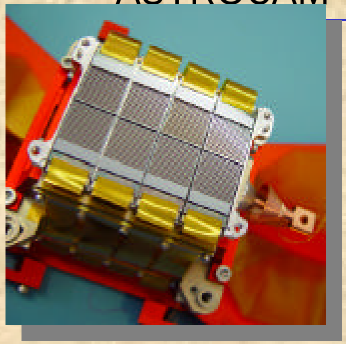

First PACS (Laser)
Line Spectrum!

PACS Observing Modes and AOTs

Observing Modes

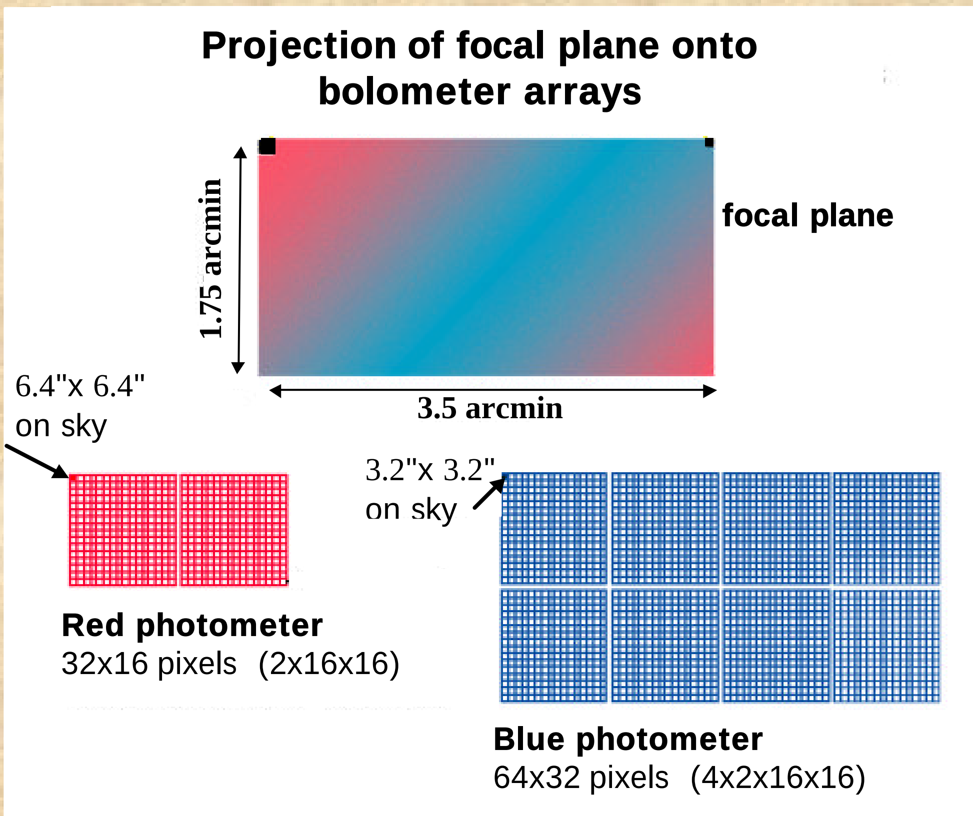
- Combinations of *instrument modes* and *satellite pointing modes*
- Instrument modes:
  - photometry (dual-band)
  - line spectroscopy
    - observation of individual lines
  - range spectroscopy
    - observation of extended wavelength ranges
- Pointing modes:
  - stare/raster/line scan
  - with/without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





Photometer Observing Modes

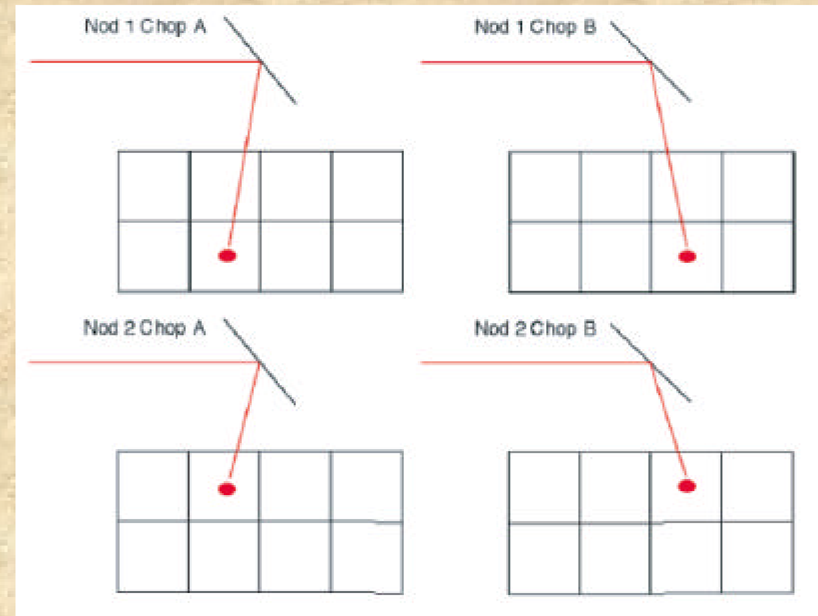
- **Point source photometry** (chopped/nodded)
- **Small extended source photometry** (chopped/nodded)
- **Raster mapping** (chopped/nodded)
- **Scan mapping** (unchopped)
- **Freeze frame** fast scan map ?



Dual Band: 75+170 µm *or* 110+170 µm

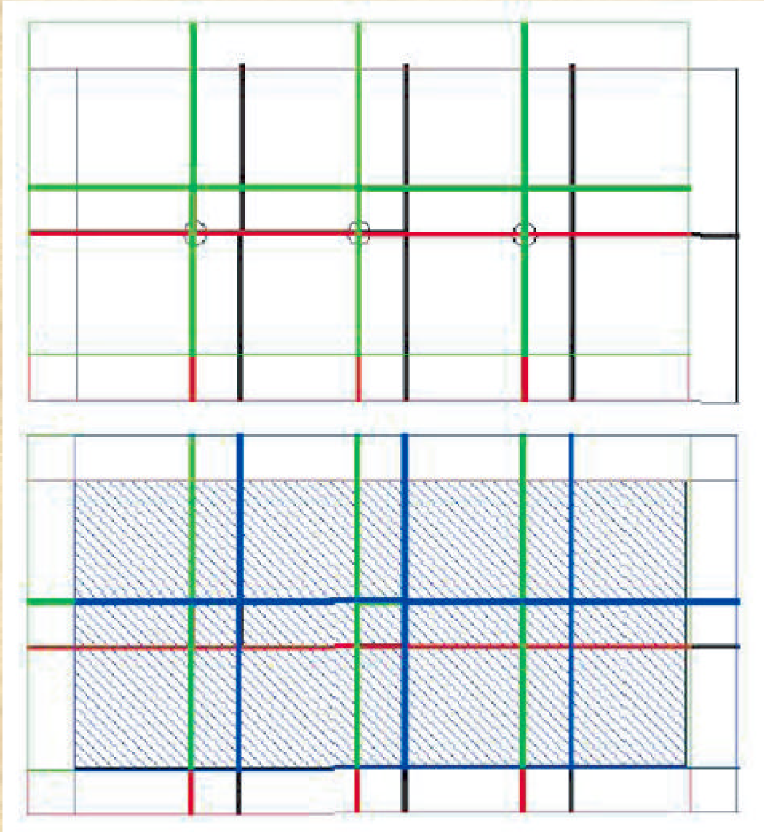
Photometer Observing Modes

- Point source photometry
  - Targeted at observations of sources which are completely isolated and point-like or smaller than one blue matrix. This AOT uses chopping and nodding, both with amplitude of 1 blue matrix, and dithering with a 1 pixel amplitude, keeping the source on the array at all times. **Minimum execution time: 5.5min** (incl. 3min for slew)



Photometer Observing Modes

- "Small source" photometry
  - Targeted at observations of sources that are smaller than the array size, yet larger than a single matrix. To be orientation independent, this means sources that fit in 2' × 2'. This AOT uses chopping and nodding, but the source cannot be kept on the array at all times. **Minimum execution time: 15min** (incl. all slew overheads).

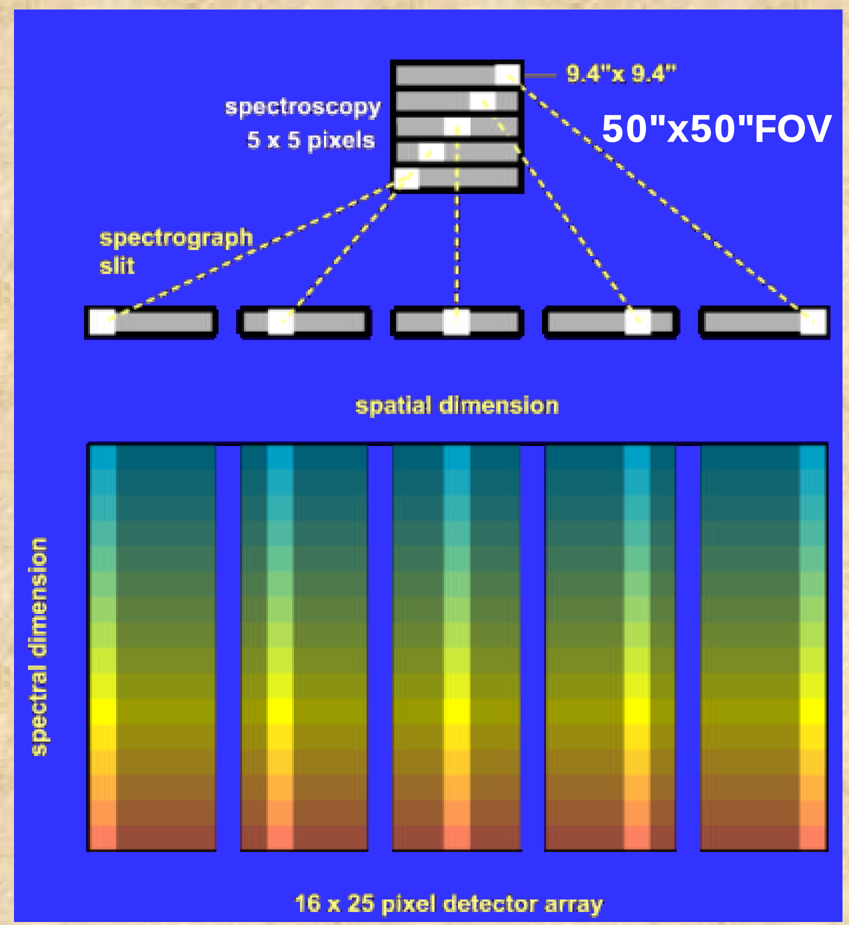


Photometer Observing Modes

- Large area photometric mapping
  - This mode is necessary to map sources larger than the array size, or to cover large contiguous areas of the sky (photometric surveys). There are two ways to perform this kind of observations:
    - Scanning (without chopping): the satellite slews continuously along parallel lines at a user-specified speed (10, 20 or 60 arcsec/s)
      - Filled arrays allow arbitrary scanning orientation
      - 1 square degree in 3 hours (at 10”/s)
    - Rastering: the satellite goes through a rectangular grid pattern of points (that can be repeated)
      - Note: Rastering without chopping probably precluded by 1/f noise

Spectrometer Observing Modes

- **Line Spectroscopy: observation of individual line(s)**
  - Chop/nod or wavelength switching
  - Staring or mapping
- **Range Spectroscopy: observation of extended range(s)**
  - Chop/nod or off position
  - Staring or mapping
  - SED mode



Spectrometer Observing Modes

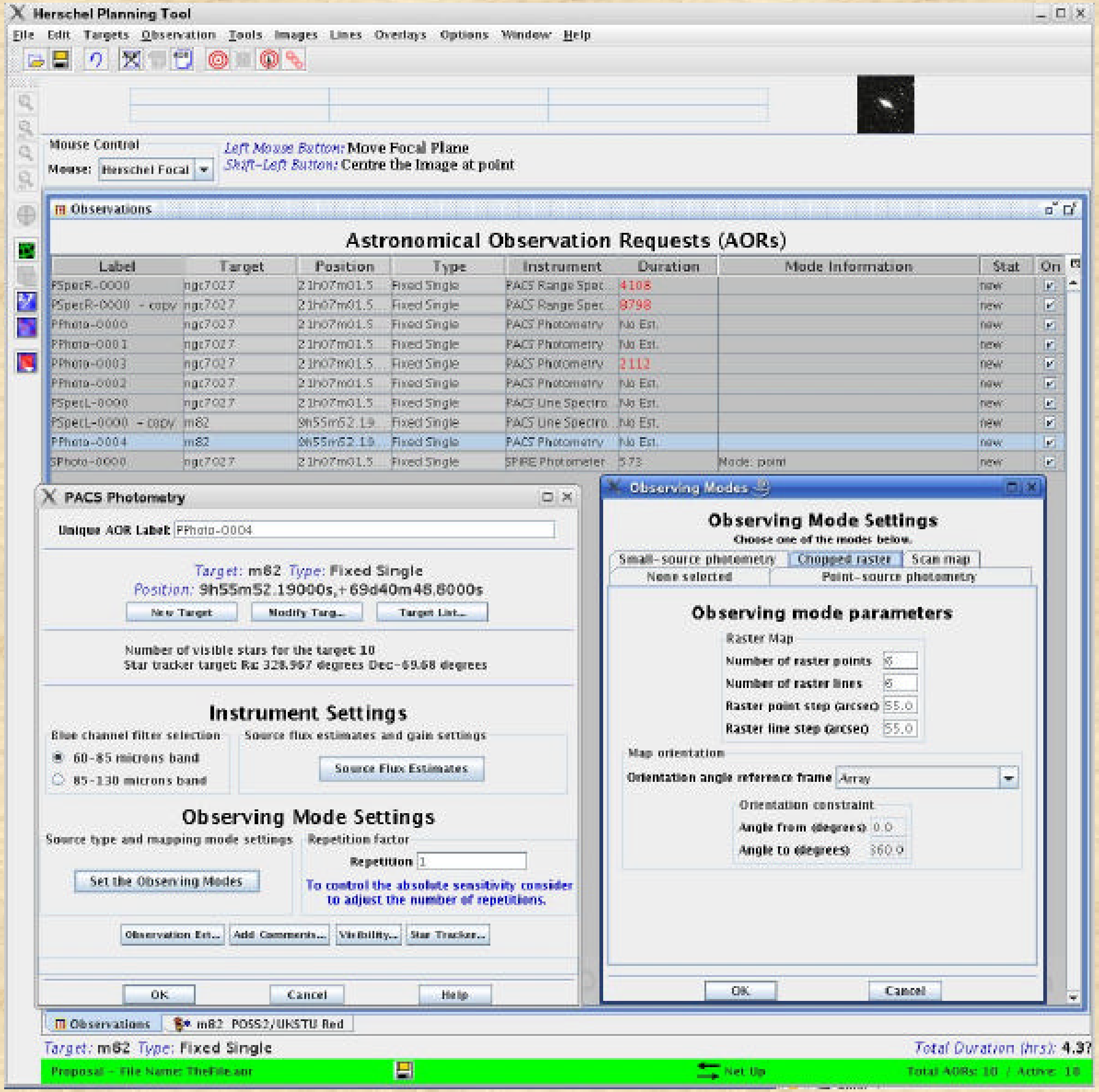
- **Line Spectroscopy: observation of individual line(s)**
  - Chop/nod or wavelength switching
  - POINTED: single satellite pointing
  - POINTED WITH DITHER: small spacecraft movements perpendicular to the chopper direction to compensate for slicer effects in case of slightly mispointed targets
  - MAPPING: limited to rectangular small regions with a maximum extension of 2.8 arcmin to allow for clean chopper off-positions for each raster point; fixed large chopper throw; map parameters in spacecraft coordinates
  - Wavelength switching: For one spectral line, the grating will be frequently switched between on-line and off-line. The same pattern will be repeated a few times at slightly shifted wavelength
  - Spectral sampling >3 samples/FWHM (by small up/down scan)
  - **Minimum execution time: 192 s**

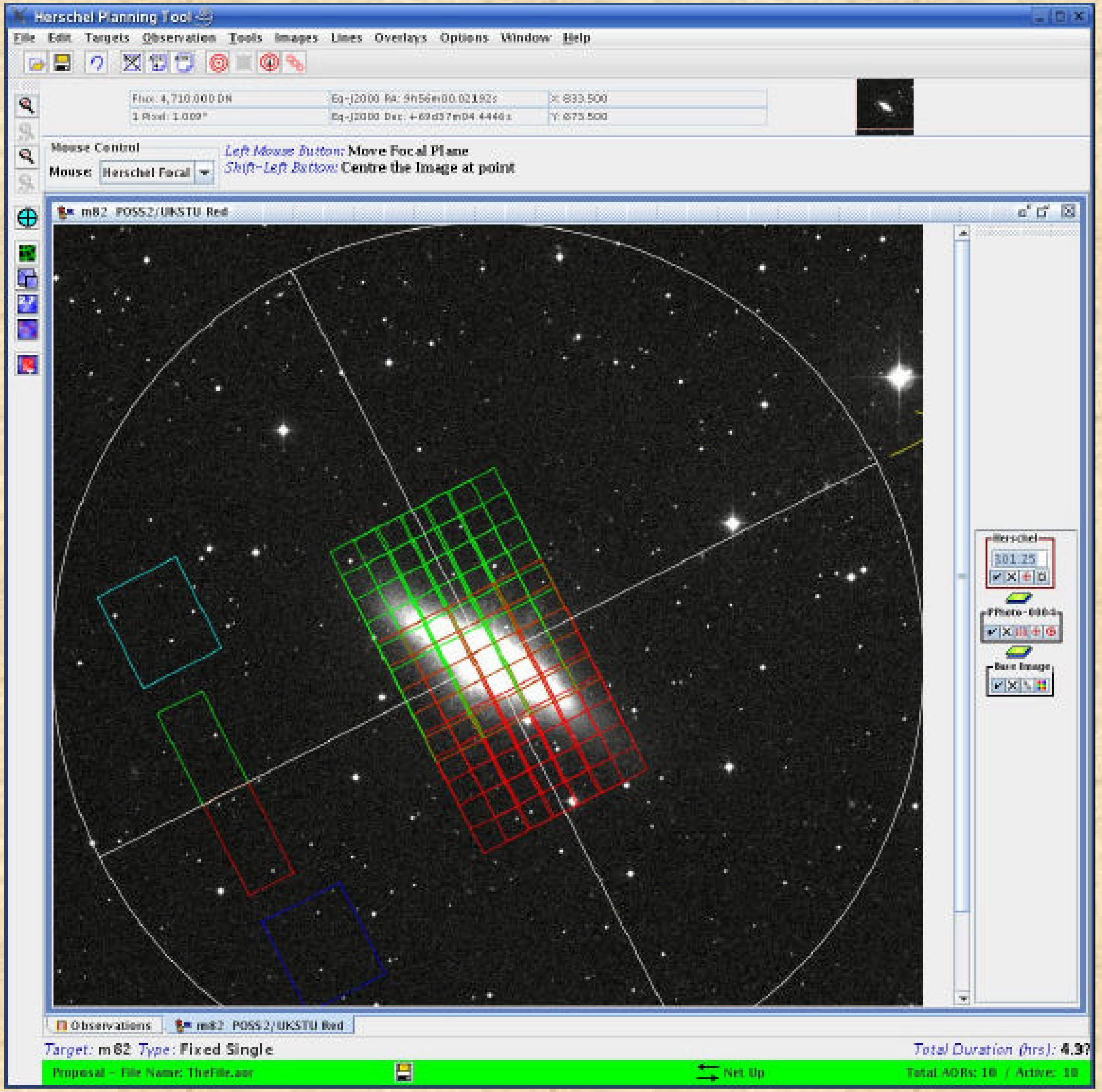
Spectrometer Observing Modes

- **Range Spectroscopy: observation of extended range(s)**
  - POINTED: single satellite pointing + chop/nod
  - POINTED WITH DITHER: small spacecraft movements perpendicular to the chopper direction + chop/nod
  - MAPPING with chop/nod: limited to rectangular small regions with a maximum extension of 2.8 arcmin to allow for clean chopper off-positions for each raster point; map parameters in spacecraft coordinates
  - MAPPING with off-position: crowed fields and extended spectral structures; chopping between sky and internal CS; map parameters in sky coordinates.
  - Spectral sampling: high (>3 samples/FWHM)
    Nyquist (optimized for speed)

Spectrometer Observing Modes

- SED Mode: full PACS wavelength range with Nyquist sampling
  - Full grating scan in first order, which covers also the complete second order in Nyquist sampling. Then, a filter switch is required, followed by a full scan of the third order (+ part of first order)
  - POINTED: single satellite pointing + chop/nod
  - POINTED WITH DITHER: small spacecraft movements perpendicular to the chopper direction + chop/nod
  - MAPPING with chop/nod: limited to rectangular small regions with a maximum extension of 2.8 arcmin to allow for clean chopper off-positions for each raster point; map parameters in spacecraft coordinates
  - MAPPING with off-position: crowded fields and extended spectral structures; chopping between sky and internal CS; map parameters in sky coordinates
  - **Minimum execution time: 2280 s**

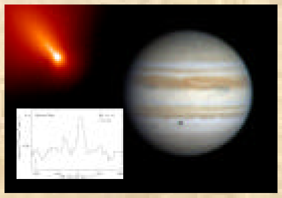
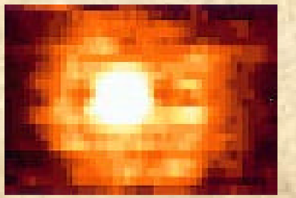
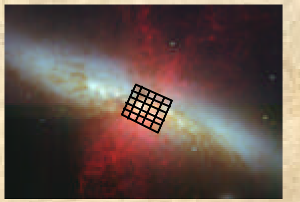
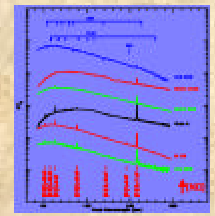
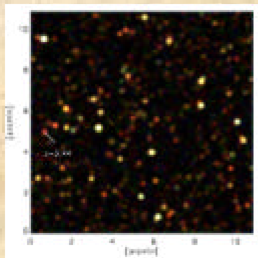
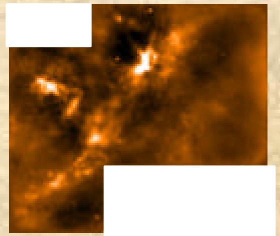

Herschel Planning Tool
File Edit Targets Observation Tools Images Lines Overlays Options Window Help
Mouse Control
Left Mouse Button: Move Focal Plane
Shift-Left Button: Centre the Image at point
Observations
Astronomical Observation Requests (AORs)
Label Target Position Type Instrument Duration Mode Information Stat On
PACS Photometry
Unique AOR Label: PPhoto-0004
Target: m82 Type: Fixed Single
Position: 9h55m52.19000s,+69d40m46.8000s
Instrument Settings
Observing Mode Settings
Set the Observing Modes
OK Cancel Help
Observing Modes
Observing Mode Settings
Small-source photometry
Chopped raster
Scan map
Point-source photometry
Observing mode parameters
Raster Map
Number of raster points
Number of raster lines
Map orientation
Orientation constraint
OK Cancel
Target: m82 Type: Fixed Single
Total Duration (hrs): 4.37


Herschel Planning Tool
File Edit Targets Observation Tools Images Lines Overlays Options Window Help
Mouse Control
Mouse: Herschel Focal
Left Mouse Button: Move Focal Plane
Shift-Left Button: Centre the Image at point
m82 POSS2/UKSTU Red
Observations
Target: m82 Type: Fixed Single
Total Duration (hrs): 4.3?
Proposal - File Name: TheFile.aor
Net Up
Total AORs: 10 / Active: 10

Science with PACS

- The opening of the 60-210 µm window by PACS to sensitive photometry and spectroscopy at high spatial resolution will address a wide range of key questions of current astrophysics concerning the origins of stars, planetary systems, galaxies, and the evolution of the Universe
- Most of the energy released e.g. in starbursts or AGNs is absorbed by interstellar dust (which prevents observation at shorter wavelengths) and re-emitted in the far infrared and sub-mm domain
- Besides dusty objects also cool and/or distant objects have their emission peak in the far-IR

- The far-IR also contains many spectral lines from atoms, ions and molecules. Largely unaffected by extinction they provide detailed information on UV radiation, density, temperature, velocities and abundances of ionized and neutral components of interstellar and circumstellar gas
- PACS is also intended to be an important driver for other projects which will explore adjacent spectral regions, such as JWST in the near/mid IR and ALMA in the mm domain

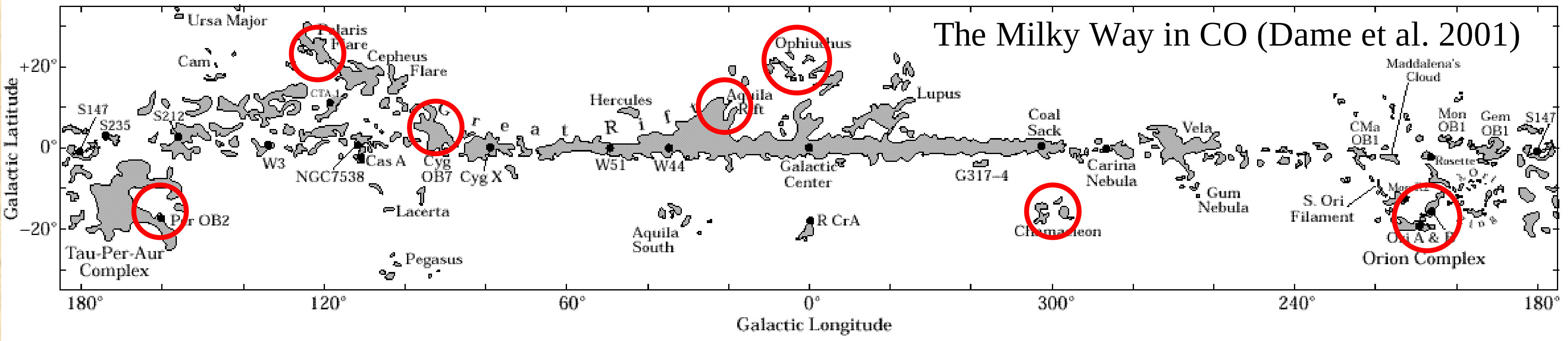







PACS GT Key Programmes

Star Formation Surveys

- Complete census of prestellar condensations and Class 0 protostars, down to the proto-brown dwarf regime
  - Luminosities, mass functions
  - Lifetimes of the various stages
  - Temperature and density structure of the nearest condensations
- Probe the link between diffuse structures and compact self-gravitating condensations
- Evolution of dust properties
- **Origin of the IMF**

(Andre, Saraceno et al.: Mapping of Gould Belt regions (140deg^2 SPIRE, 16deg^2 PACS, pointed PACS follow up)



Late Stages of Stellar Evolution

- Study the mass loss history and asymmetries in circumstellar dust shells through high resolution far-infrared imaging.

- Determine physical and chemical conditions in the inner circumstellar envelopes, through PACS spectroscopy of the important coolants CO, HCN, and H_2O, and of various dust species participating in the initial chemistry of the escaping gas.

(Groenewegen, Kerschbaum et al.: 80 AGB, post-AGB and PN down to 2 mJy/beam [1σ] in all 3 bands. Full spectra of 30 AGB, post-AGB, PN)

“Nearby” Galaxies

- Star formation and activity in infrared bright galaxies at z<1 (Sturm, Klaas, Madden et al.)
- Physics of the ISM in low metallicity galaxies (Madden et al.)
  - SEDs of 55 dwarfs, FIR spectroscopy of subset

Star Formation and Activity in Infrared Bright Galaxies at z<1

- FIR spectroscopy, to study energetics, obscuration and physical conditions of dusty, infrared bright galaxies (starbursts, AGN, (U)LIRGs)
  - using tools like HII region/photoionization diagnostics (e.g. spatially resolved [N III]/[N II], [N III]/[O III]) and PDR modeling (e.g. spatially resolved [C II]/[O I])
- Photometric mapping in three bands, to study triggering mechanisms and evolution of a large sample of interacting galaxies, and in six bands to study key templates of SBs, AGN, and ULIRGs

Star Formation and Activity in Infrared Bright Galaxies at z<1

Star formation tracers in the FIR (atomic, ionic)

[CII]	158 µm	Most important cooling lines of the atomic gas.
[OI]	63 µm	Probe the conditions in PDRs, i.e. the warm neutral
[OI]	145 µm	gas cloud surfaces which constitute a large fraction
		of the neutral medium in a galaxy.
[NII]	122 µm	Conditions in the ionized medium. Important diagnostics
[NII]	205 µm	of absolute level and excitation of star forming (and AGN)
[NIII]	57 µm	activity and of n_e @ low density (< 10^3 cm^{-3})
[OIII]	52 µm (z>0.1)	
[OIII]	88 µm	

Extinction ~ 1/10 of mid-IR (ISO-SWS, Spitzer-IRS)

Photoionization models (e.g. Cloudy, Ferland et al.), PDR models (e.g. Hollenbach & Tielens; Kaufman; Sternberg & Dalgarno)

Star Formation and Activity in Infrared Bright Galaxies at z<1

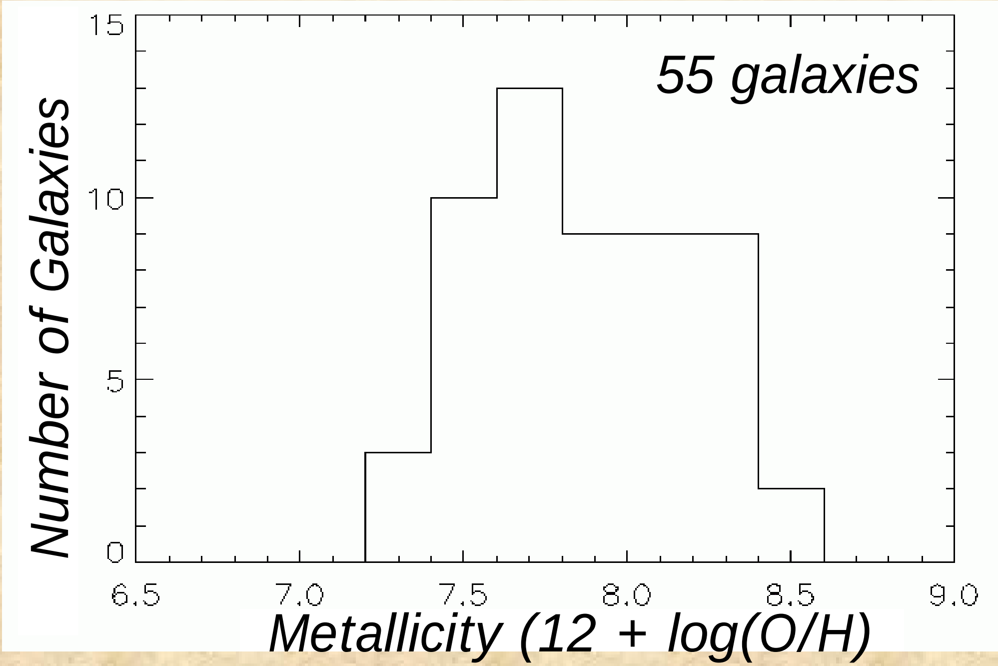
1) **Complete Nuclear Spectra of Starbursts and AGN (5 objects)**
2) **Fine-Structure Line Survey**
   ~10 SBs +~25 AGNs+ ~30 ULIRGs
   in [N III] 57µm, [O I] 63µm, [O III] 88µm, [N II] 122µm, [O I] 145µm, [C II] 157µm, [N II] 205µm.
3) **Diagnostic lines of (few) z~1 IBGs**
   ([O I] 63µm/[O III] 52µm/[O III] 88µm)
4) **Highly excited molecular emission in (few) AGN**

5) **Photometric mapping** of activity regions in 60 nearby interacting galaxies, at 70, 110 and 170 µm

   and of 16 key template objects (SBs, AGN, ULIRGs) in all PACS and SPIRE bands

Low Metallicity Dwarf Galaxies

- **PACS/SPIRE photometry and spectroscopy**
  ([C II], [O I], [O III], [N II]) + other complementary data
- **Closest analogues of high-z building blocks**
  - **ISM and SF in primordial galaxies**
- **Evolution of metals in the ISM of galaxies**
- **Dust components and properties in metal-poor galaxies**
- **Influence of metallicity on ISM structure, radiation field, star formation activity**
- **Impact of super star clusters prevalent in dwarf galaxies on surrounding gas and dust**



- **0.5 – 1/50 solar metallicity**

The PACS Evolutionary Probe (PEP): Extragalactic Photometric Surveys

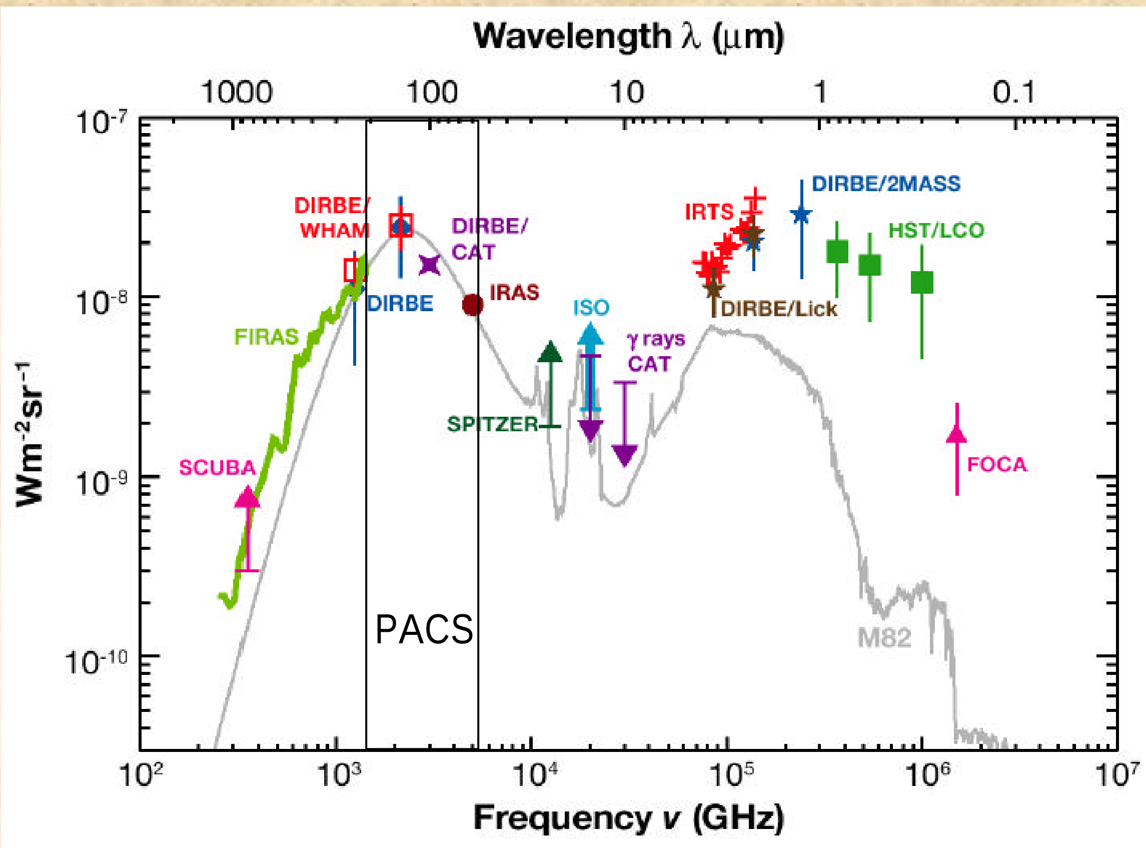
- Blank field surveys at 170, 110, 75 µm, focusing on popular multi-wavelength fields, coordinated with SPIRE surveys
- Targeted observations of massive z~1 clusters/ lensing clusters
- 650h of PACS GT (SPIRE complement: 850h)

(Lutz, Elbaz, Andreani, Cepa et al.)

Extragalactic Photometric Surveys: Science Goals

- Resolve the Cosmic Infrared Background and determine the nature of its constituents
- Determine the cosmic evolution of dusty star formation and of the infrared luminosity function
- Elucidate the relation of far-infrared emission and environment, and determine clustering properties
- Determine the contribution of AGN
- Determine the infrared emission and energetics of known galaxy populations

Resolving the CIB



Lagache et al. 2005 ARAA

Resolution into **5**s **individually detected** sources for current blank field PACS survey plans:

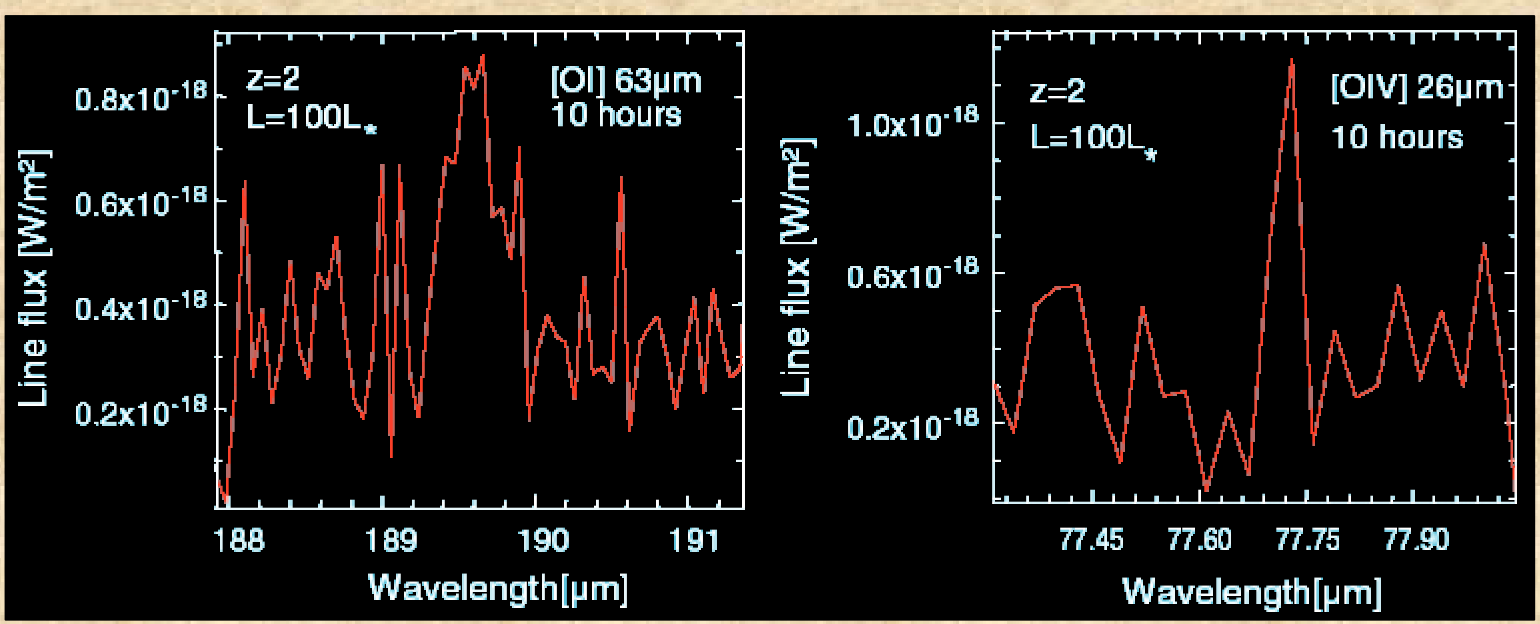
~80% @75μm
~85% @110μm
~55% @170μm

... and more from lensing clusters, stacking, fluctuation analysis,...

Individual high-z Objects

- SEDs and environment of high-z quasars
- SEDs of BAL QSOs
- Physical properties of high-z galaxies from rest-frame mid-infrared spectroscopy (few bright/lensed objects)

(Stickel, Hutsemekers, Tacconi et al.)



WE WANT MORE!

- FIR spectroscopic follow-up on sources detected in photometric surveys!
- We need a cold telescope!
- We have a (Cosmic) Vision...

PACS GT Key Programmes (summary):

Extragalactic surveys (PEP):	Lutz, Elbaz, Andreani, Cepa et al.	→ **talk** B. Altieri
Dusty young universe:	Stickel et al.	
IR bright galaxies at 0<z<1:	Sturm, Klaas, Madden et al.	→ **talk** S. Madden
Low Metallicity Dwarf Galaxies:	Madden et al.	→ **talk** S. Madden
Gould belt SF survey:	Andre, Saraceno et al.	→ **talk** P. Saraceno
Earliest phases of star formation:	Henning et al.	
Debris Disks:	Waelkens et al.	→ **talk** Ch. Waelkens
Birth of high-mass stars:	Zavagno et al.	→ **talk** A. Zavagno
Post-main-sequence stars:	Groenewegen et al.	→ **talk** Ch. Waelkens
Solar system:	HIFI-led	→ **talk** Th. Müller, **talk** R. Moreno