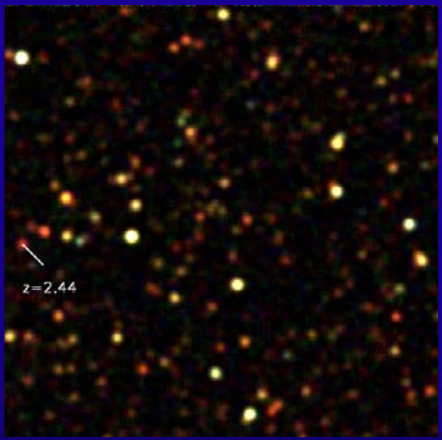
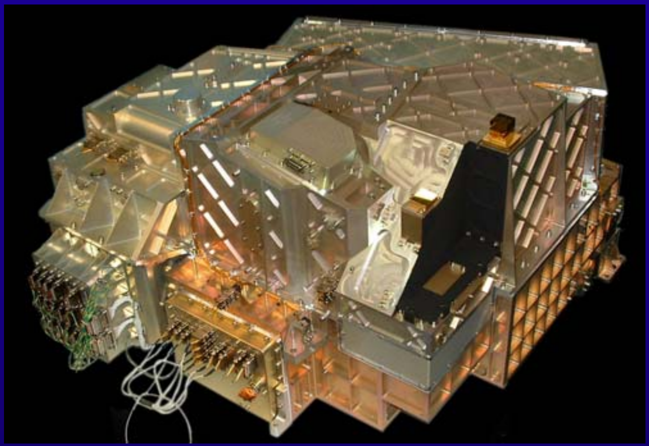
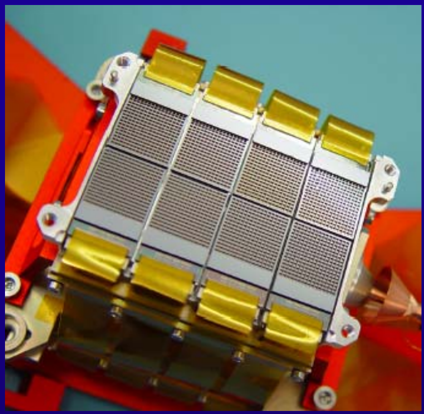
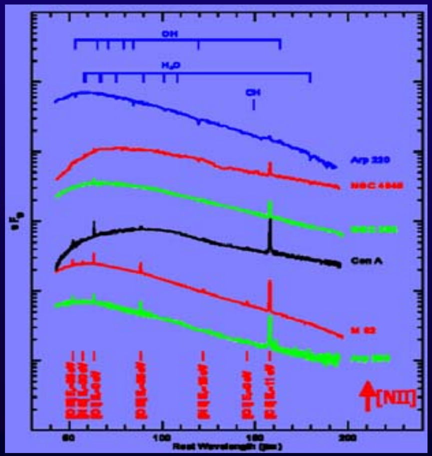
Herschel Photodetector Array Camera & Spectrometer

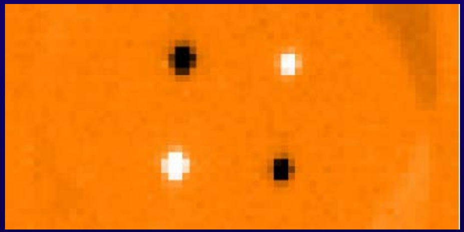
Albrecht Poglitsch (MPE) for the PACS Consortium

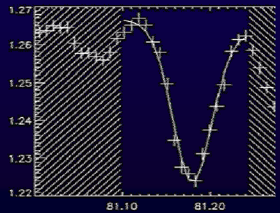


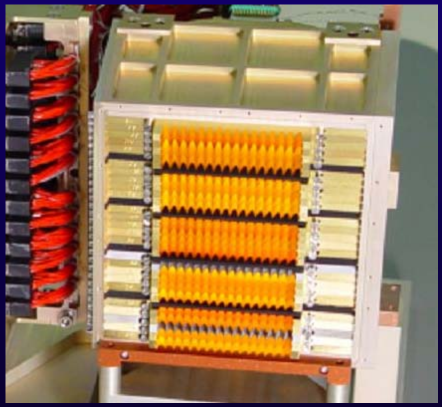


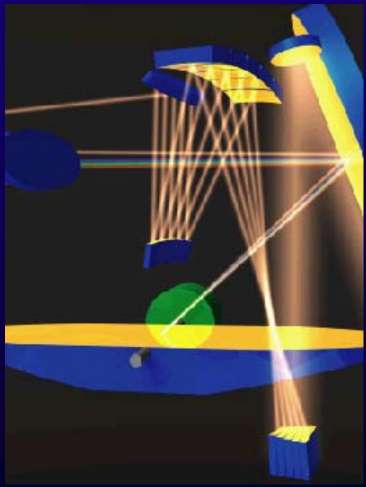








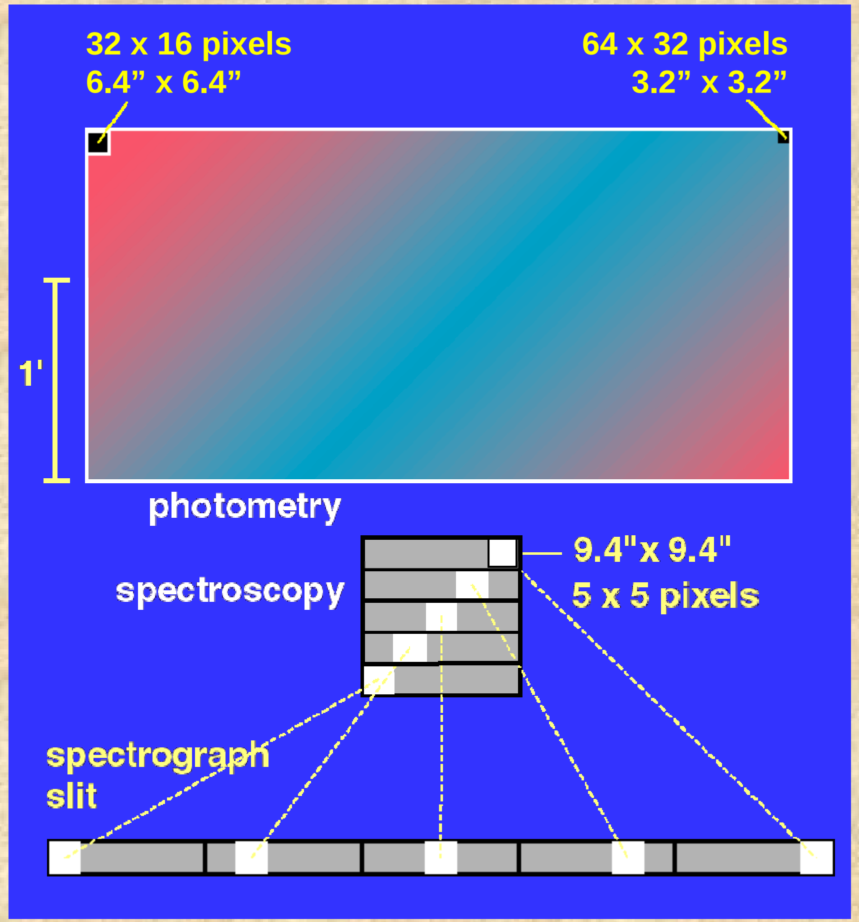




Instrument Concept

- **Imaging photometry**
  - two bands simultaneously (60-85 or 85-130 μm and 130-210 μm) with dichroic beam splitter
  - two filled bolometer arrays (32x16 and 64x32 pixels, ~ full beam sampling)
  - point source detection limit ~4 mJy (5σ, 1h)
- **Integral field line spectroscopy**
  - range 57 - 210 μm with 5x5 pixels, image slicer, and long-slit grating spectrograph (R ~ 1500)
  - two 16x25 Ge:Ga photoconductor arrays (stressed/unstressed)
  - point source detection limit 3...20 $\times 10^{-18}$ W/m^2 (5σ, 1h)

Focal Plane Footprint



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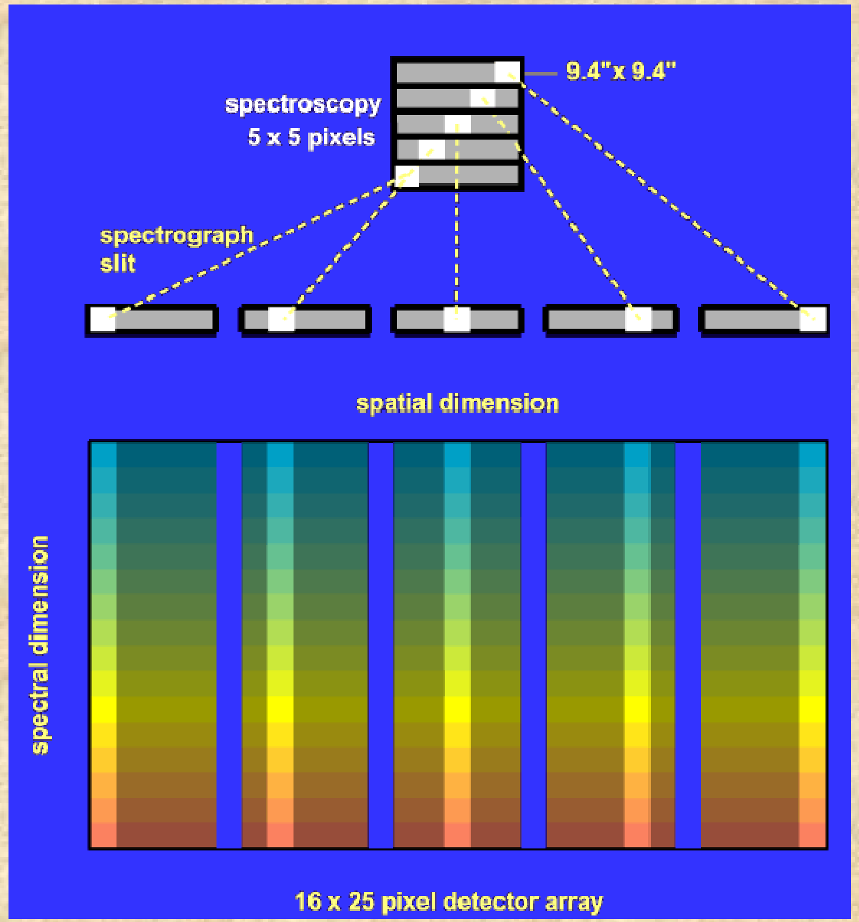
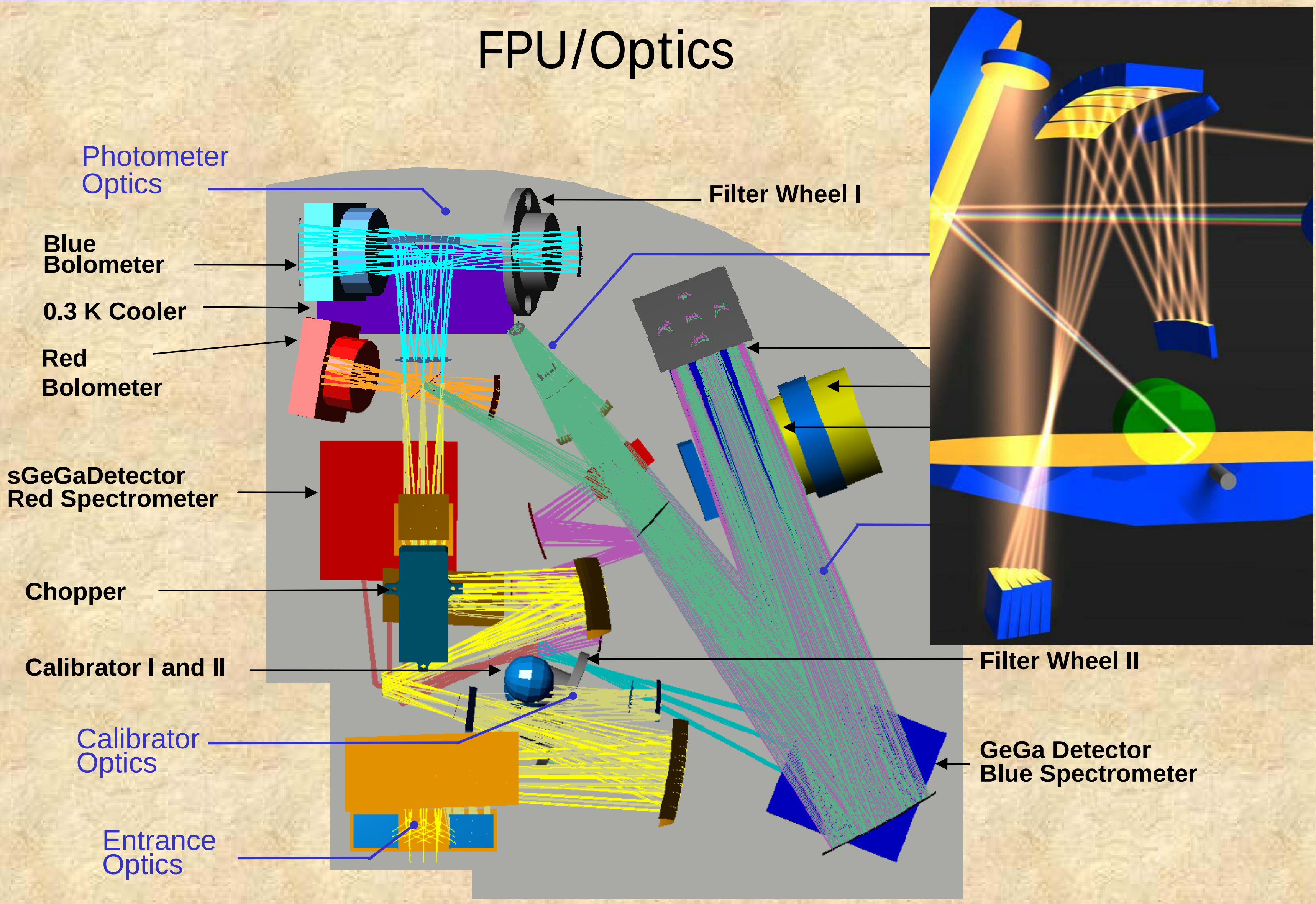
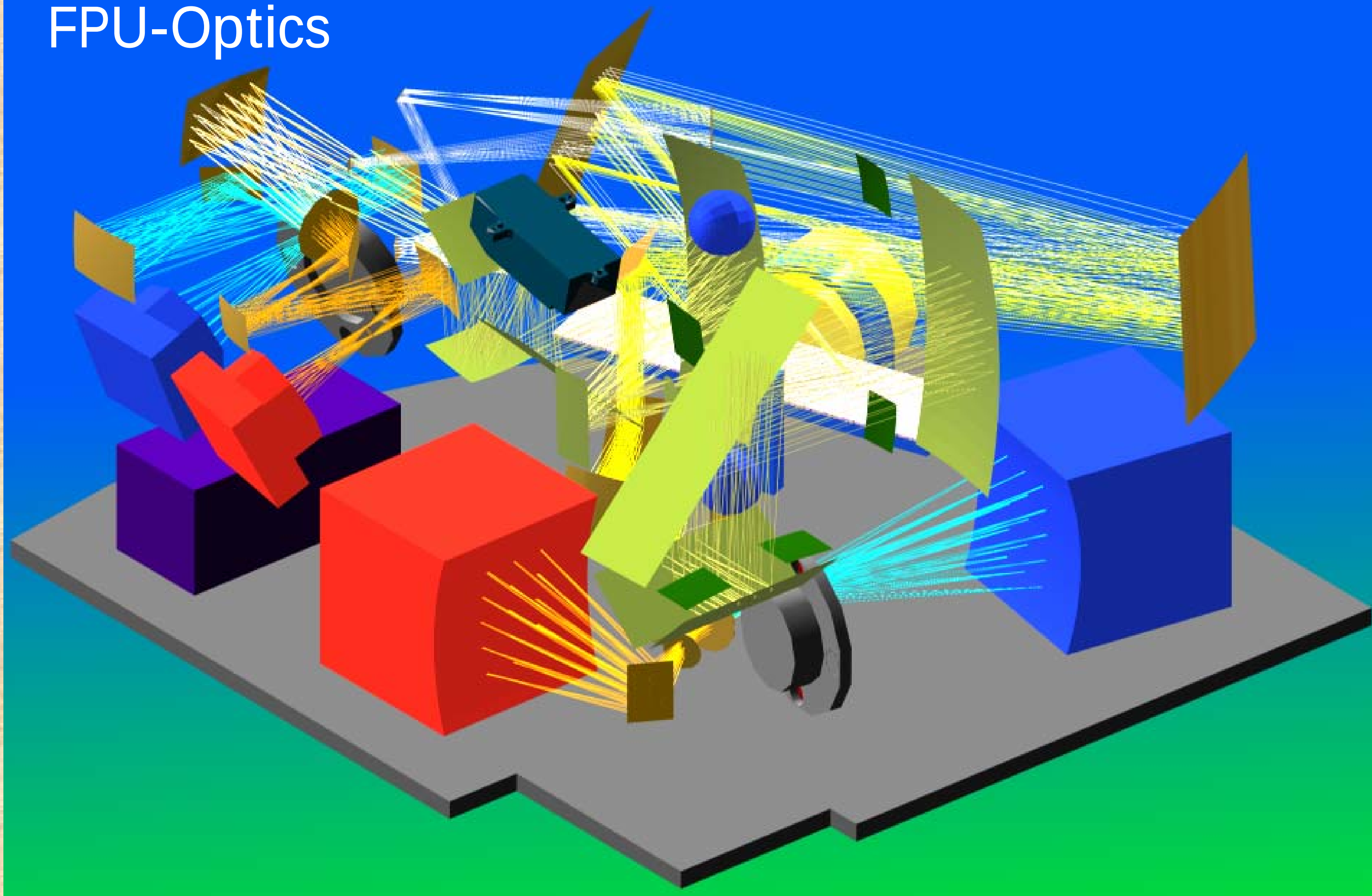
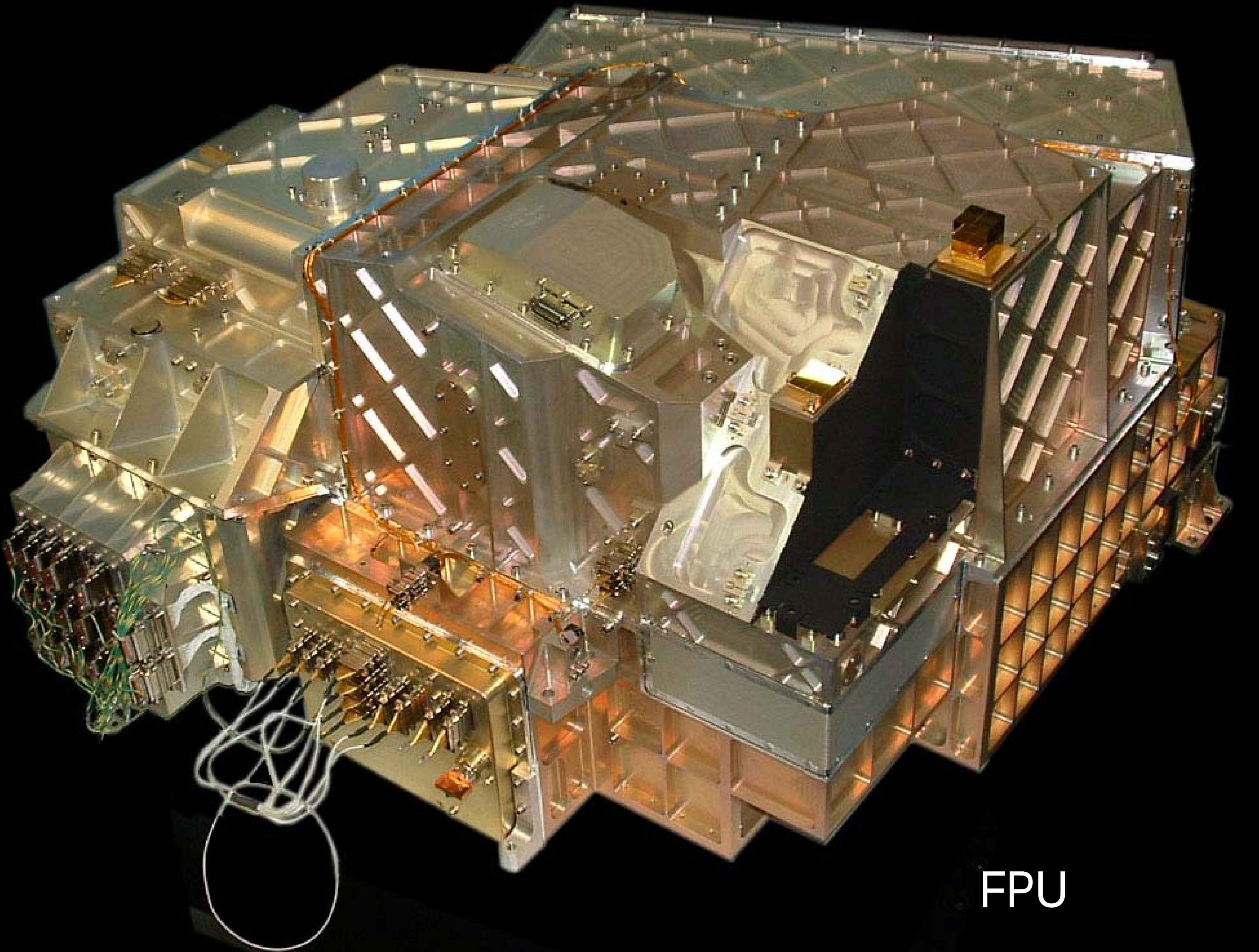


FPU/Optics

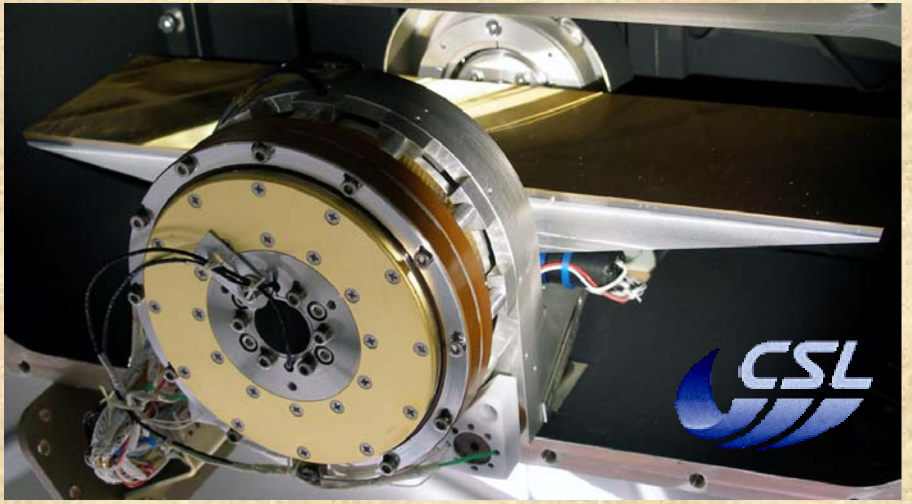

Photometer Optics
Blue Bolometer
0.3 K Cooler
Red Bolometer
sGeGaDetector Red Spectrometer
Chopper
Calibrator I and II
Calibrator Optics
Entrance Optics
Filter Wheel I
Filter Wheel II
GeGa Detector Blue Spectrometer

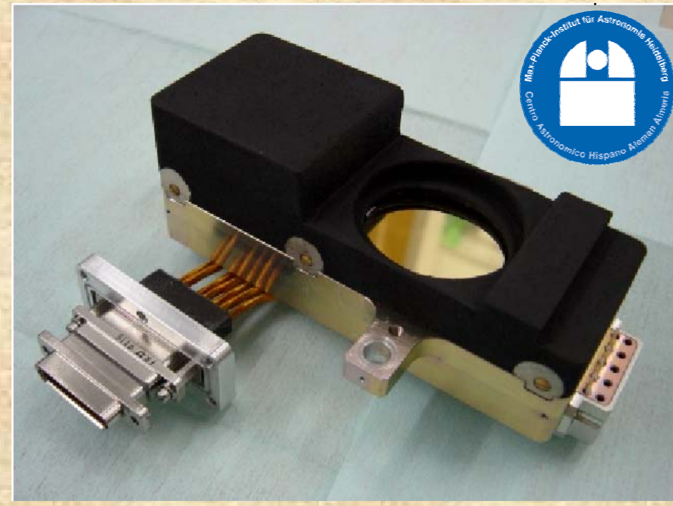
FPU-Optics

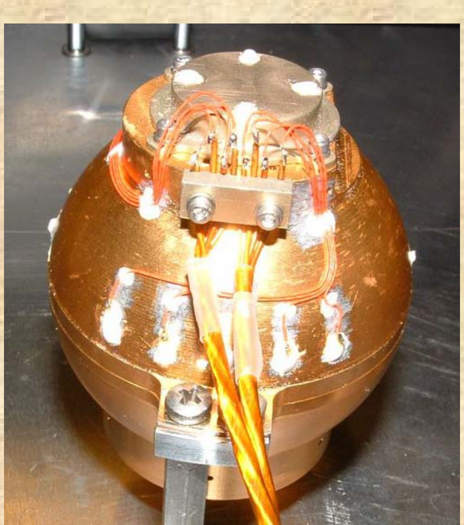


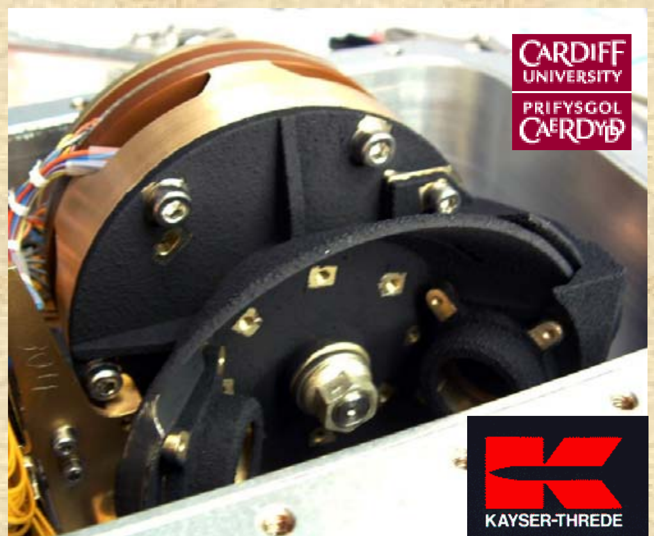

FPU

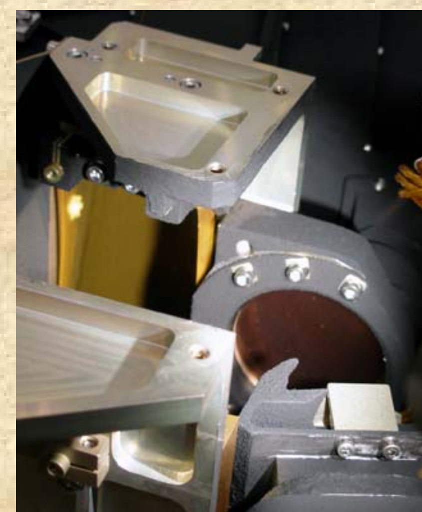
FPU Subunits Picture Gallery









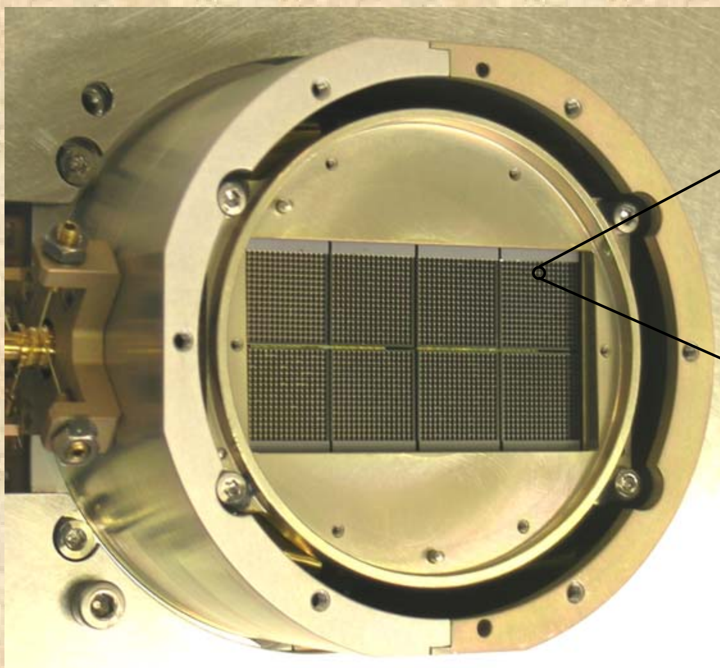


dapnia

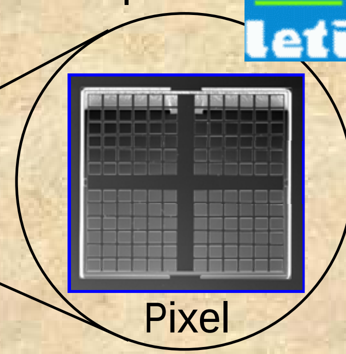
saclay

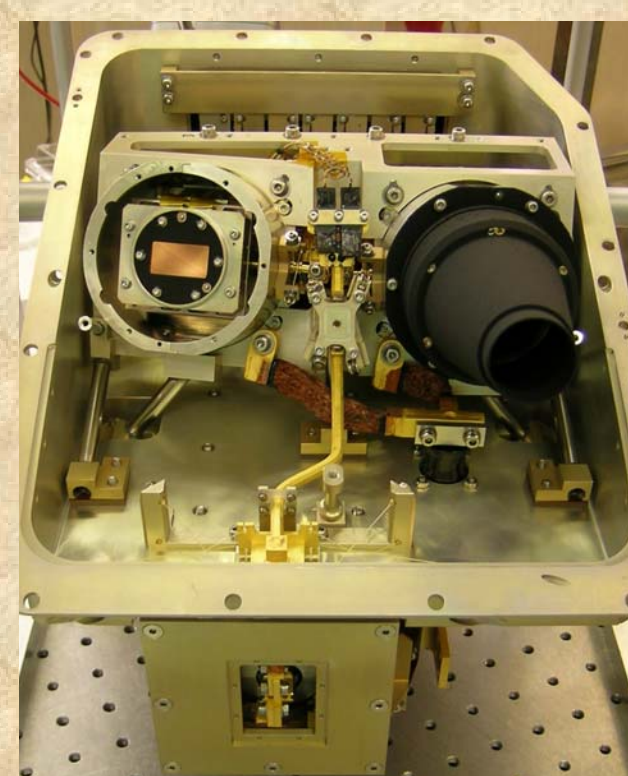
Bolometer Arrays (Photometer)

- 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
- Cooler hold time ~50h



Blue
focal plane

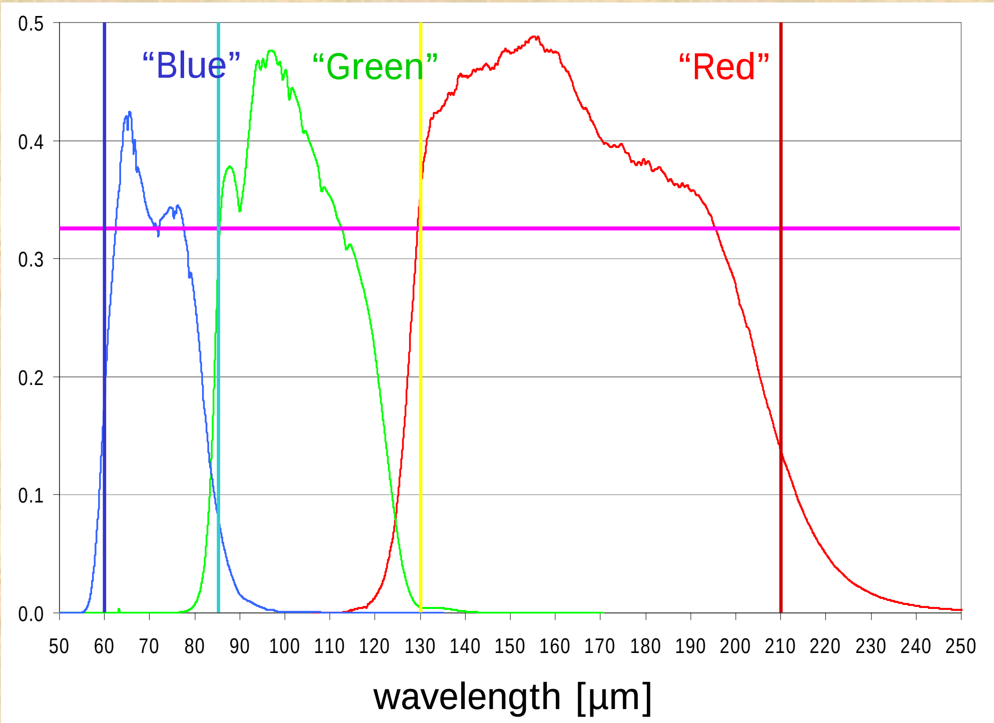




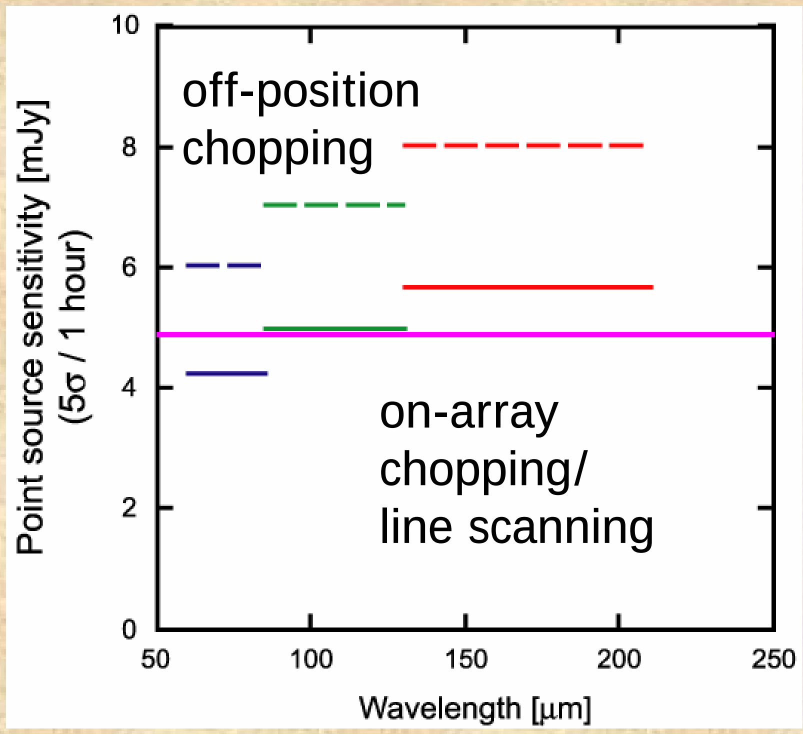
Photometer unit
with blue + red
focal planes
and ^{3}He cooler

Expected Performance Photometry (DDCS)

Photometer bands: filter transmission x detector efficiency



Sensitivity

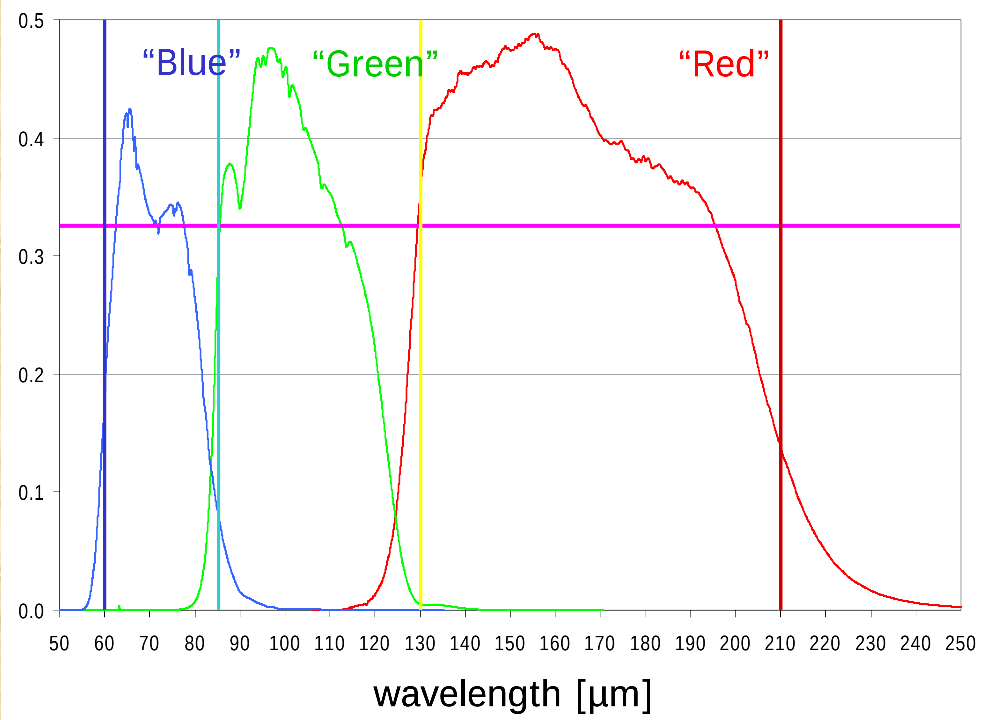


Used by HSPOT (+ "conservatism factor")

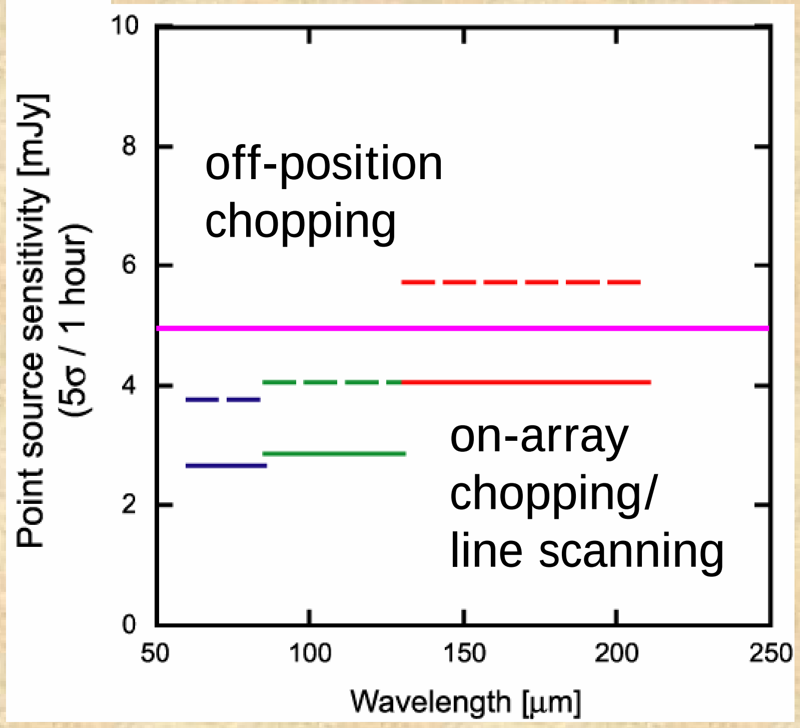
- Requirements:
  band definition: ±5%, sensitivity: 5mJy, 5σ/1h

Expected Performance Photometry (Direct)

Photometer bands: filter transmission x detector efficiency



Sensitivity

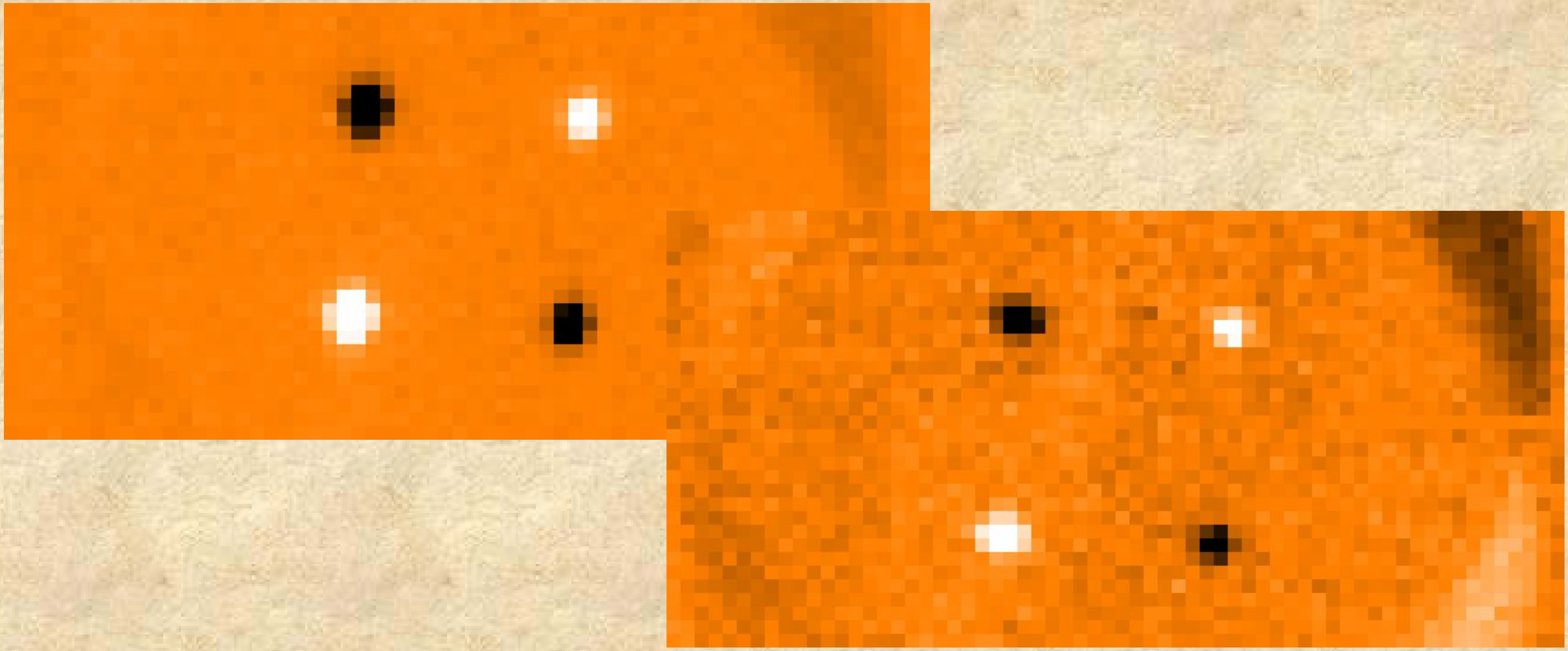


Used by PACS

- Requirements:
  band definition: ±5%, sensitivity: 5mJy, 5σ/1h

Final decision after EMC test at system level!

Blue Photometer PSF

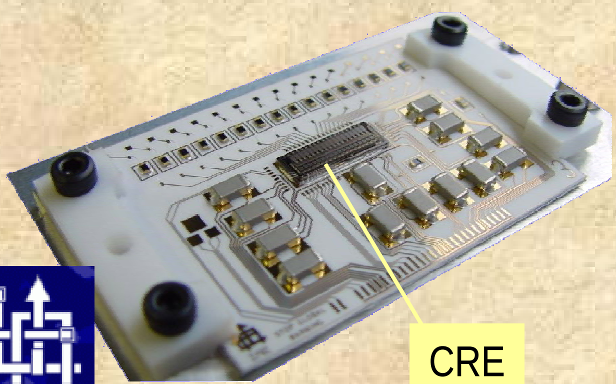


Chopped/nodded observations similar to “Point Source Photometry” mode

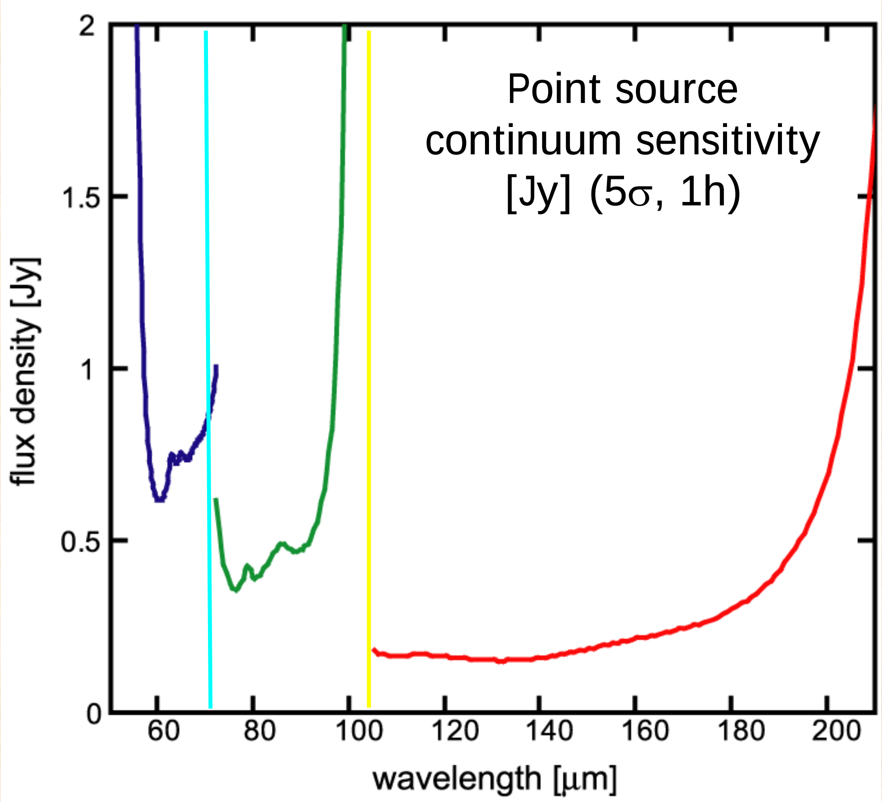
Point spread function from 2-d Gaussian fit: ok

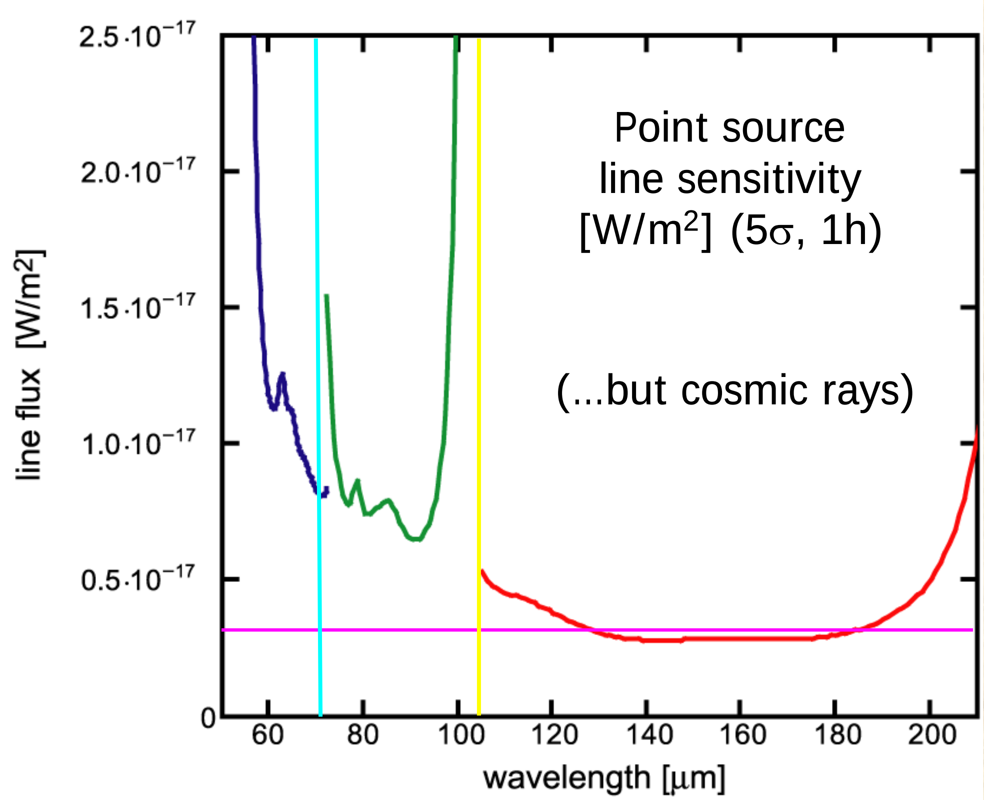
Photoconductor Arrays (Spectrometer)

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

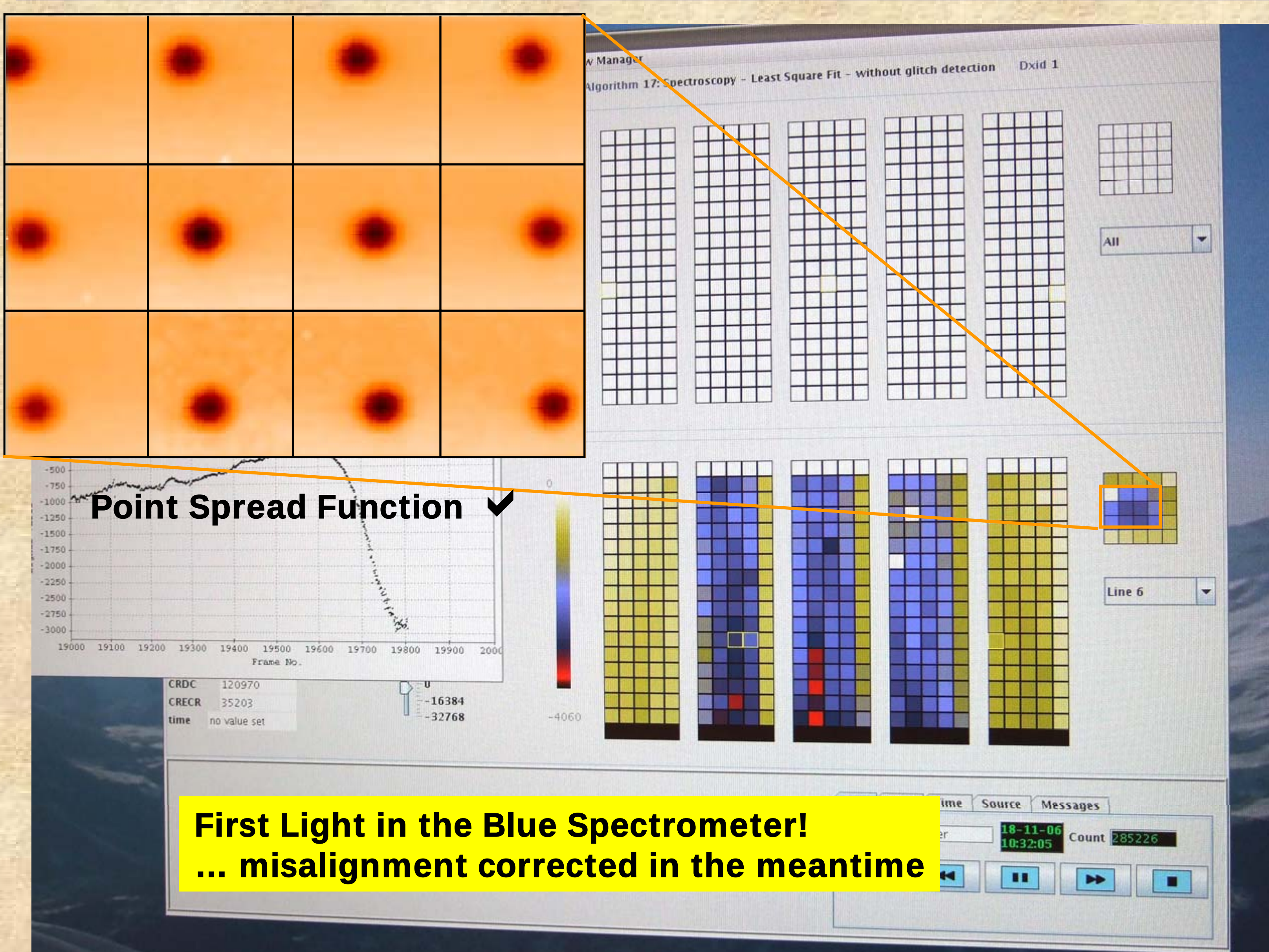


Expected Performance Spectroscopy





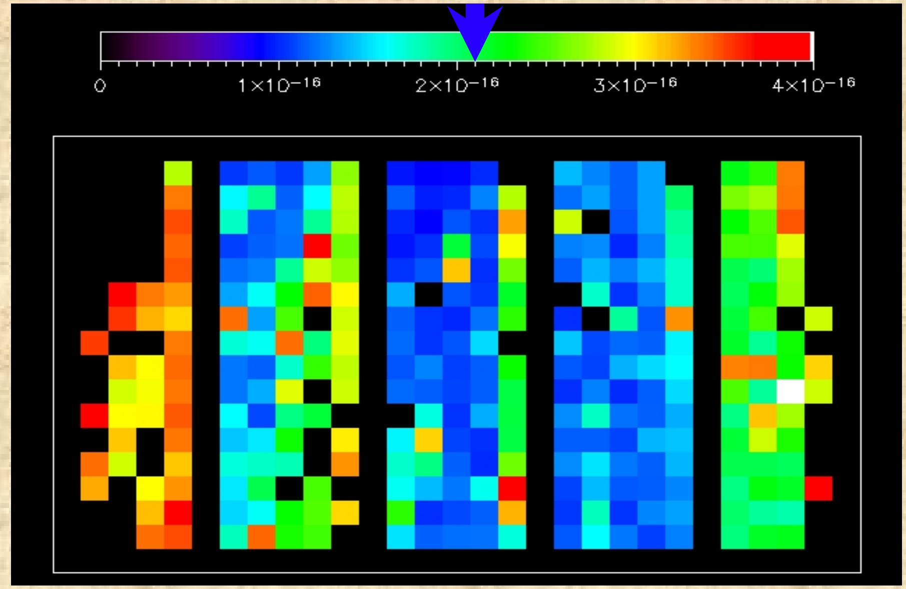
- Sensitivity gap from ~ 95 to 105 µm
- Calculated for (off-array) chopping
- Sensitivity requirement partly met

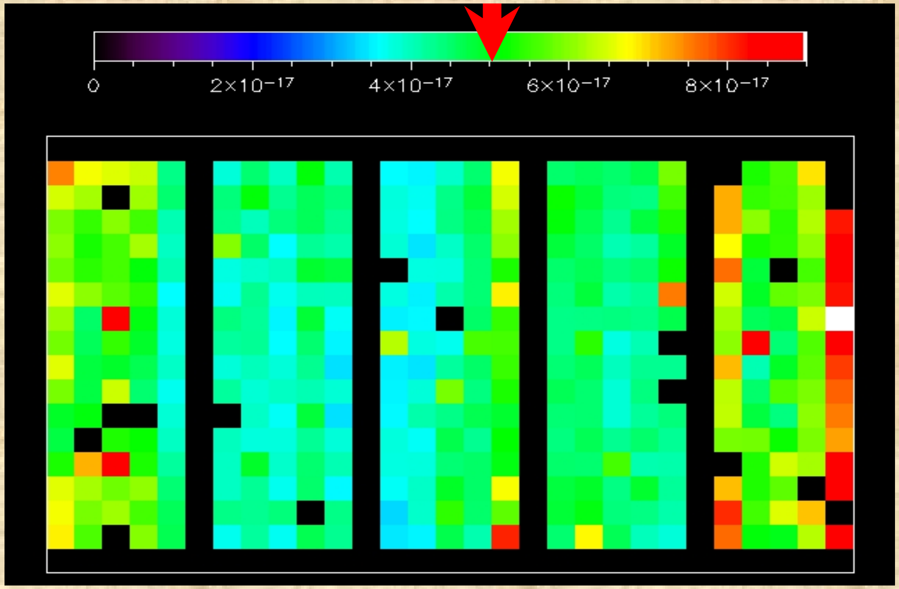


Point Spread Function ✓

First Light in the Blue Spectrometer!
… misalignment corrected in the meantime

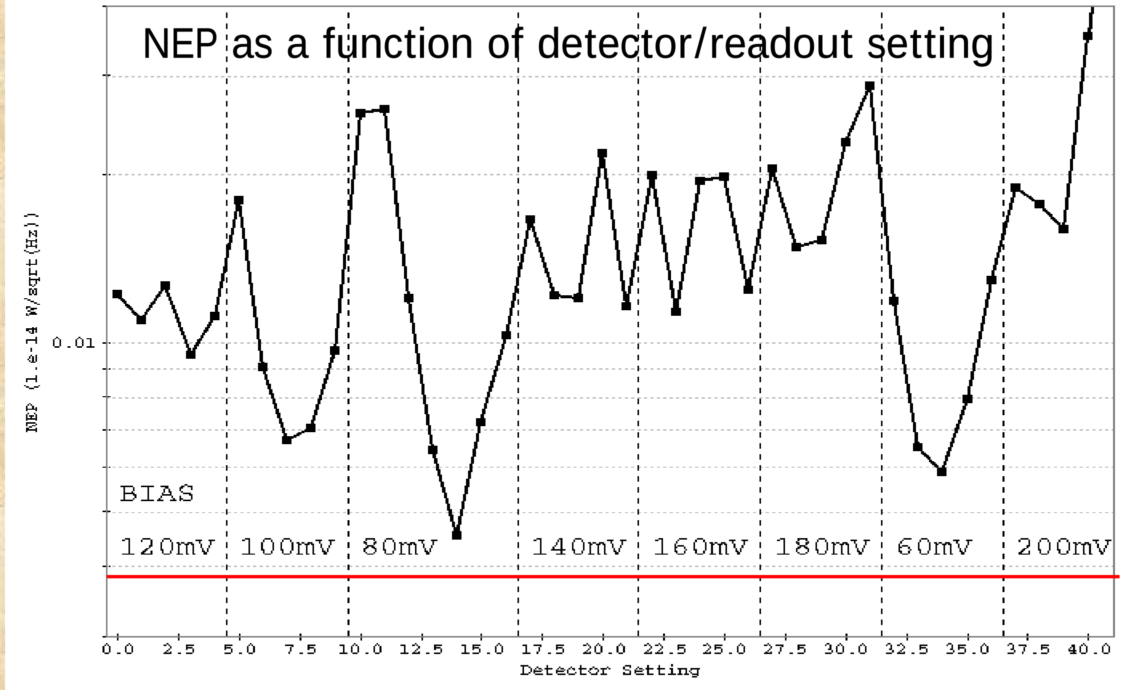
Check: ILT System NEP Maps





- Measurements @ 88 µm (blue; left) and 194µm (red; right)
- For central 3 blocks (with nominal illumination) NEPs referred to entrance of instrument agree quite well with model predictions - marked by arrows - based on detector/CRE measurements and measured/calculated optical transmissions/efficiencies

Operation/Performance under p+ Irradiation

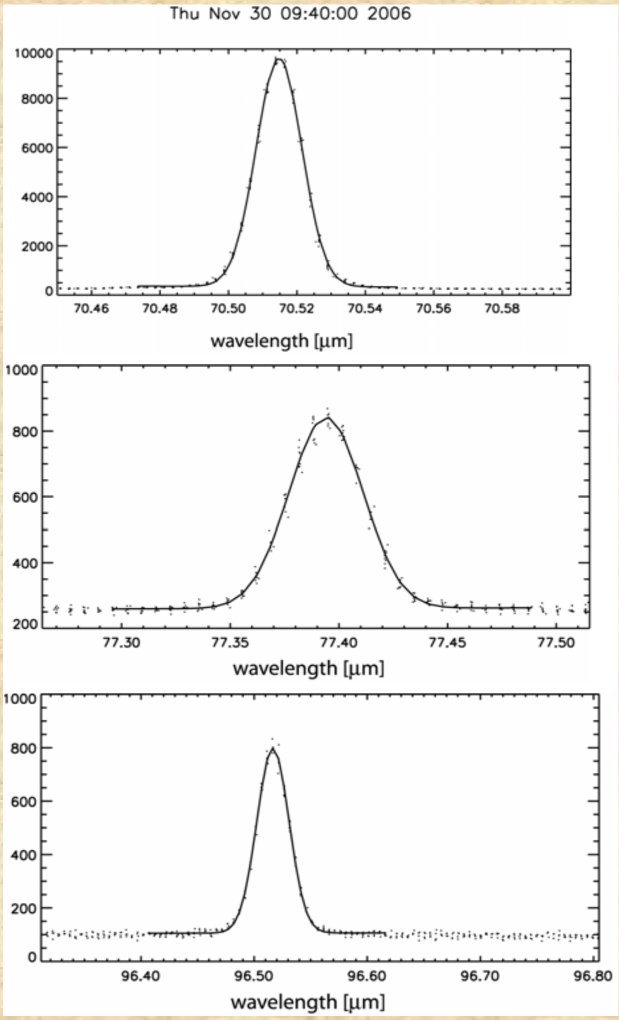


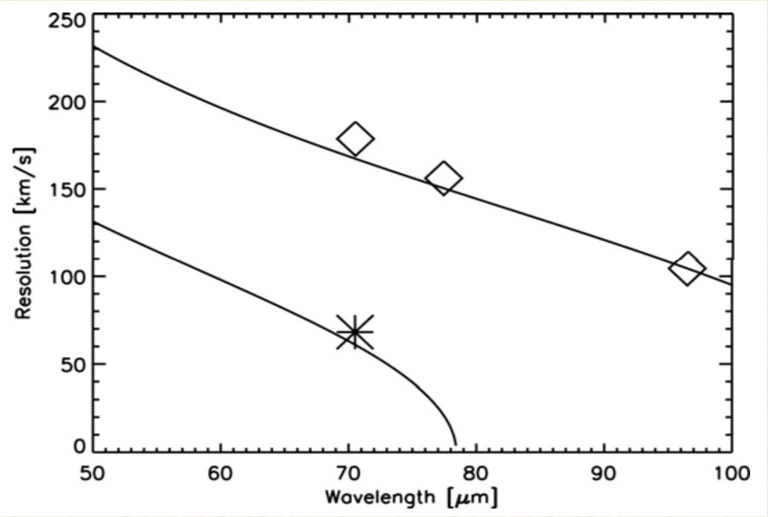
Simulated chopped observation with one ramp/chopper plateau.
For each bias value, 5 ramp lengths tested: 1s, 1/2 s, 1/4 s, 1/8s, 1/16 s.
The detector was in its high responsivity plateau, ~2 hours after the last curing.

Instrument model value, based on lab measurements without irradiation

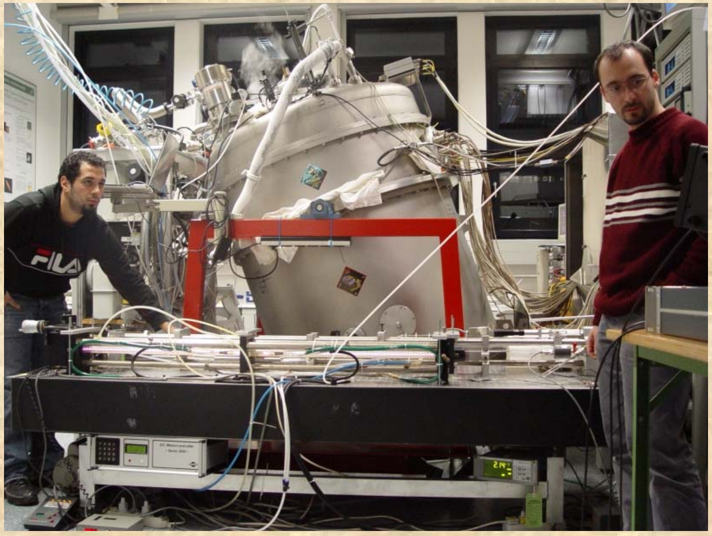
- With optimum bias setting (lower than in lab!) and ramp length/ chopping parameters, NEP close to lab values possible in space
- Curing may be necessary only after solar flare, or once per day (self-curing under telescope IR background sufficient)

Spectral Resolution





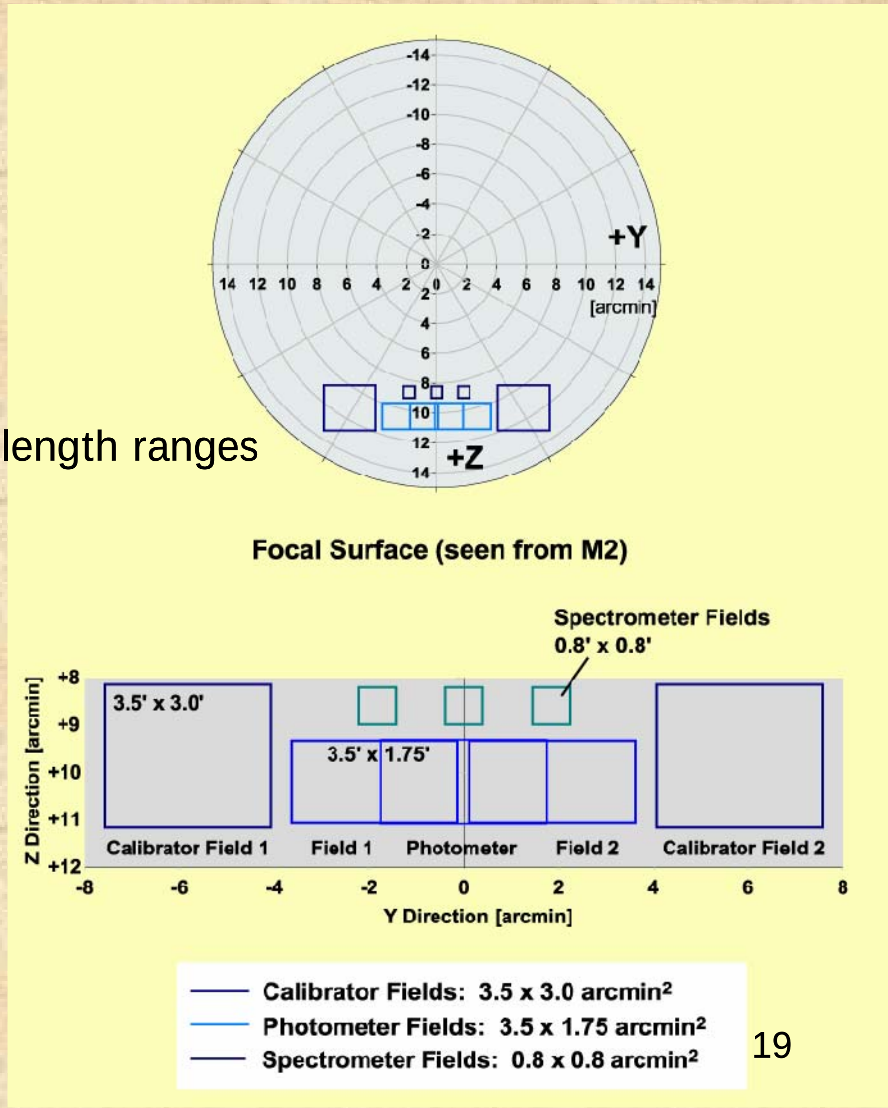
...As expected,
no ghosts seen

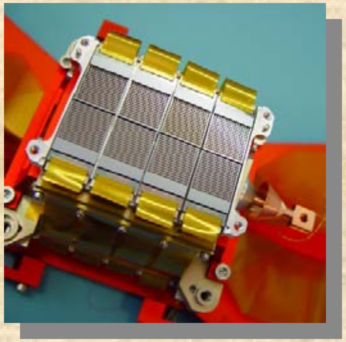


Observing Modes and AOTs

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



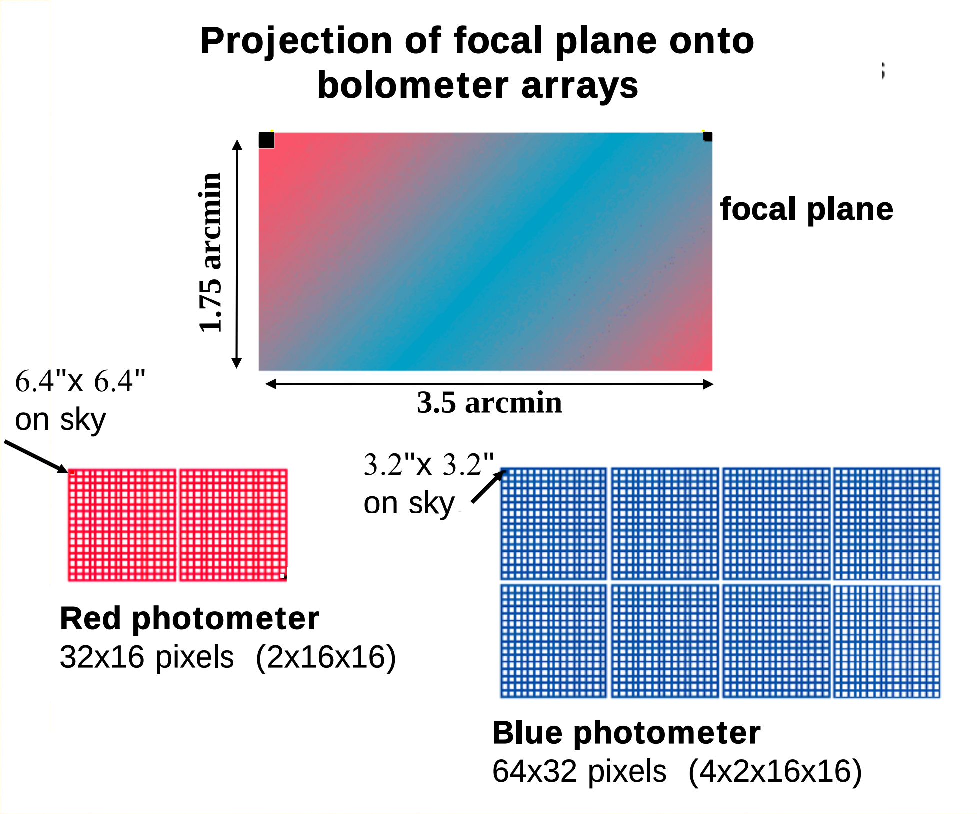


Photometer Observing Modes

→ B. Altieri, tomorrow

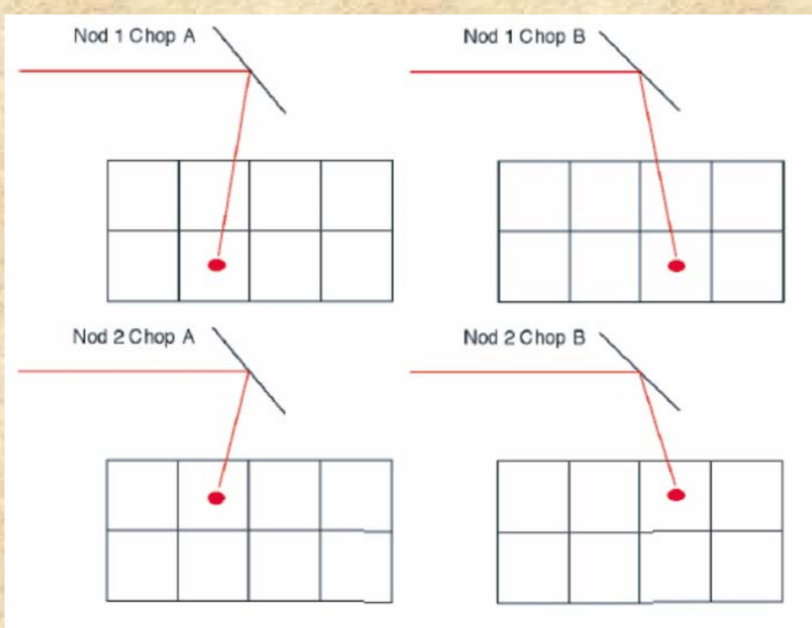
- **Point source photometry** (chopped/nodded)
- **Small extended source photometry** (chopped/nodded)
- **Raster mapping** (chopped)
- **Scan mapping** (unchopped)

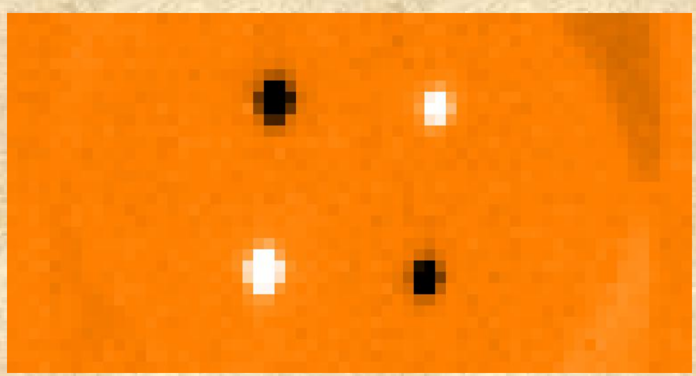
Dual Band: 75+170 µm
or 110+170 µm



Point Source Photometry

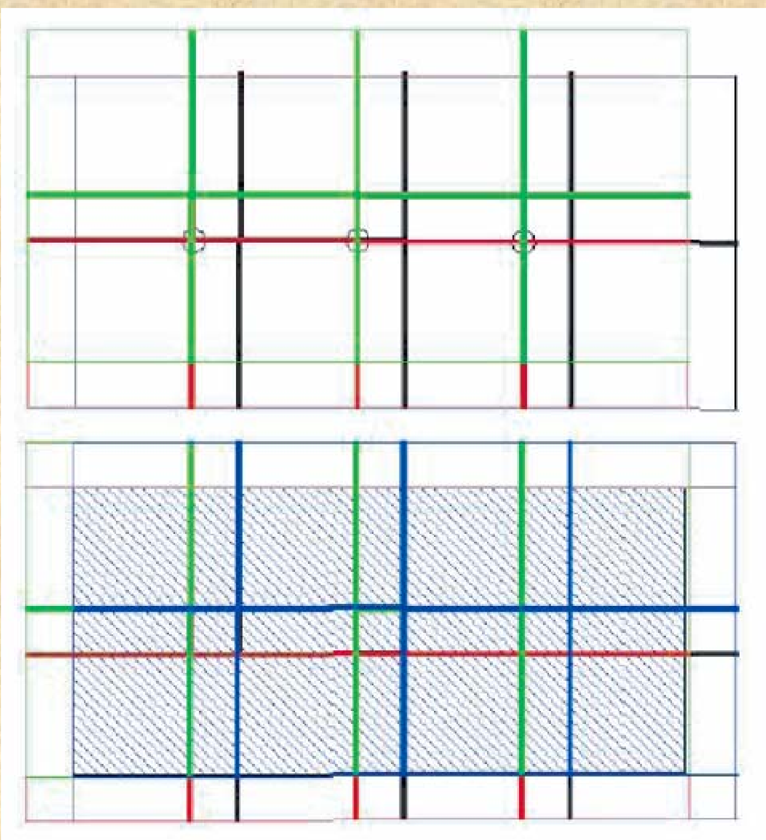
- Targeted at observations of sources which are completely isolated and point-like or smaller than one blue matrix.
- Uses chopping and nodding, both with amplitude of 1 blue matrix, and dithering with a 1 pixel amplitude, keeping the source on the array at all times. **Minimum execution time: 5.5min**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





Small Source Photometry

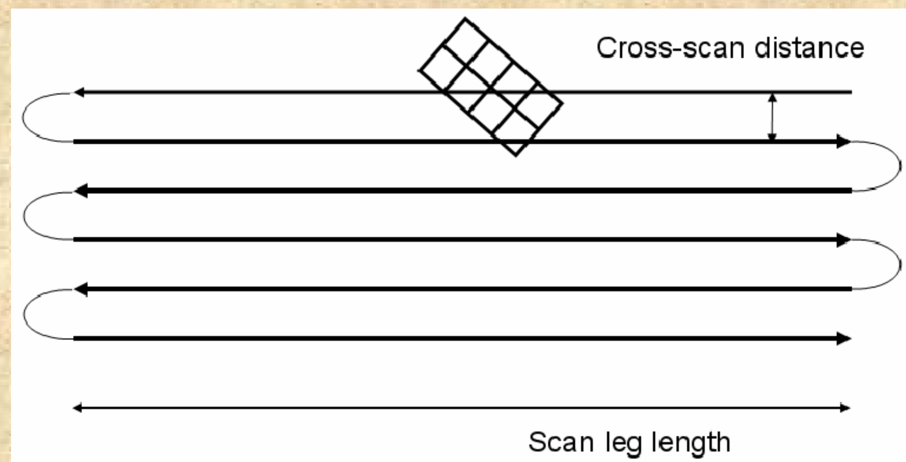
- Observations of sources that are smaller than the array size, yet larger than a single matrix. To be orientation independent, this means **sources that fit in ~1.5’ × 1.5’**.
- Off-array chopping, nodding, dithering to fill gaps. **Minimum execution time: 15min** (incl. all slew overheads).

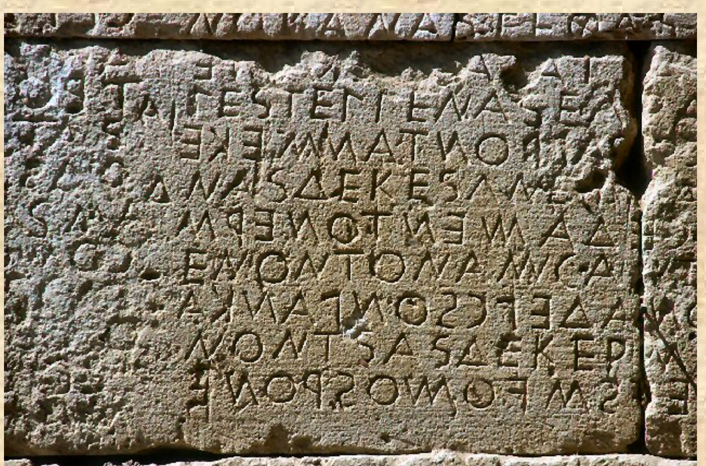


Large Area Photometric Mapping

- Map sources larger than the array size, or cover large contiguous areas of the sky (photometric surveys). Two modes:
  - Scanning (without chopping): the satellite slews continuously along parallel lines at a user-specified speed (10, 20 or 60 arcsec/s)
    - Filled arrays allow (almost) arbitrary scanning orientation
    - 1 square degree in a few hours (at 10"/s)
  - Rastering: the satellite goes through a rectangular grid pattern of points (that can be repeated).
    - Note: Rastering only with chopping (1/f noise)

Remarks on Scan Map





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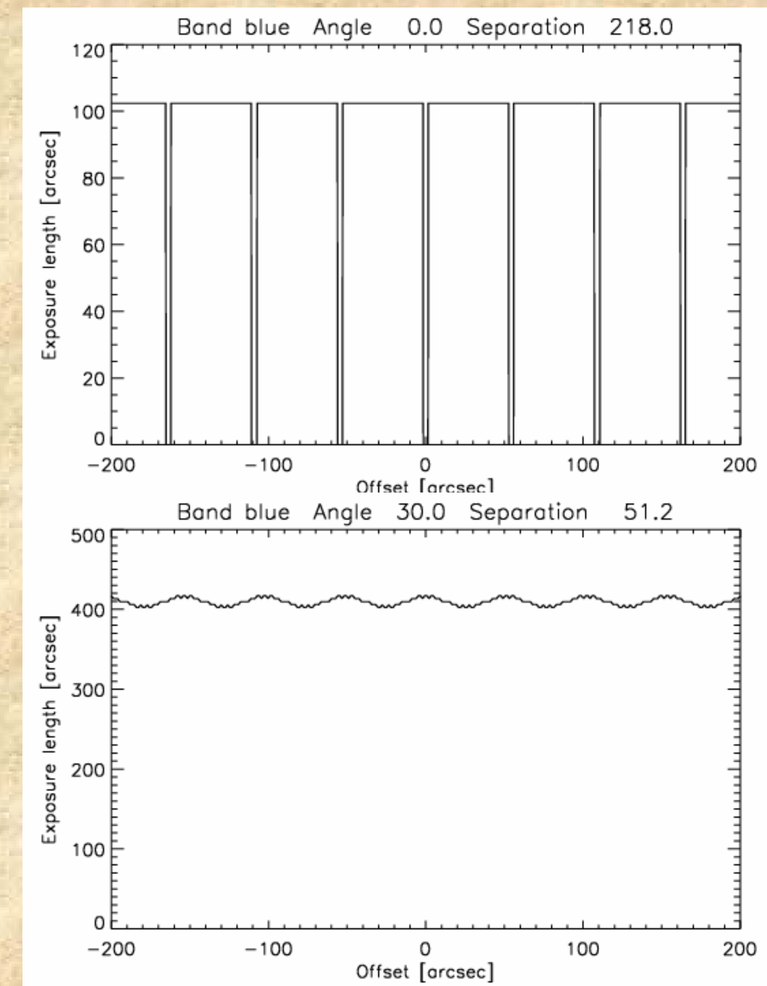
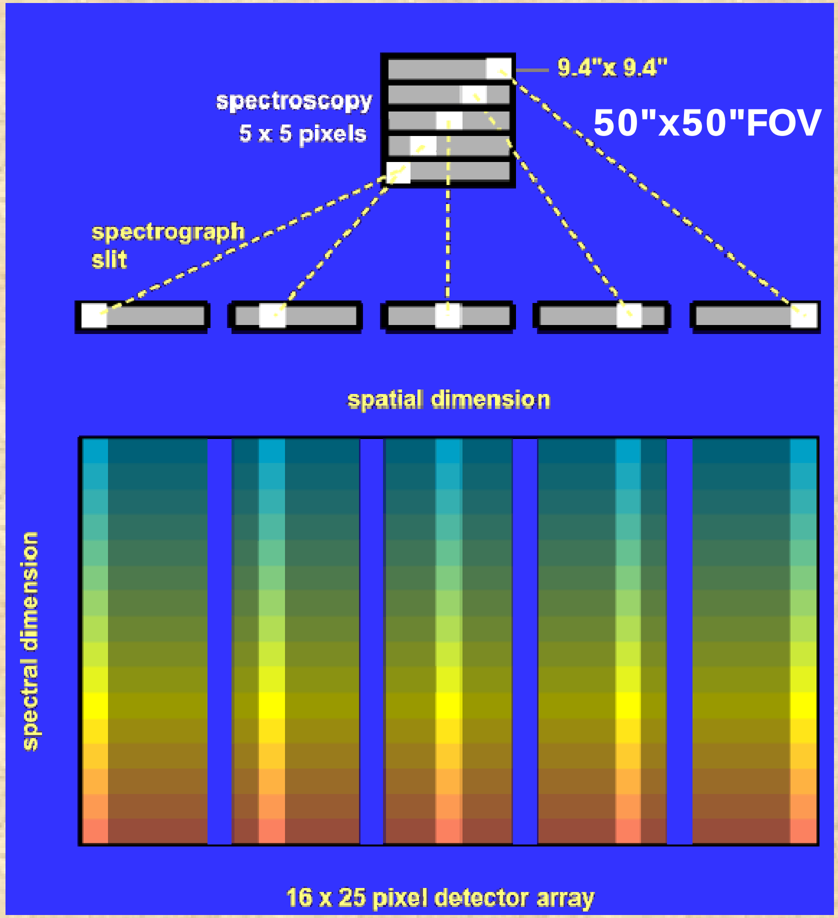


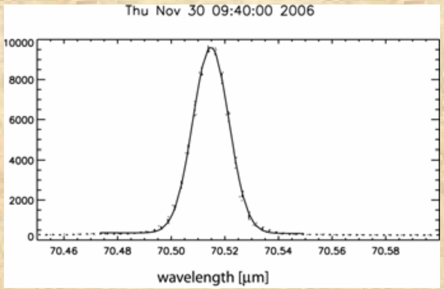
Spectrometer Observing Modes

→ E. Sturm & J. Blomaert, tomorrow



- **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

Line Spectroscopy



- Two basic modes:
  - Chop/nod
  - Wavelength switching with grating – suited for line mapping

- 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
- RASTER MAPPING: For chopped mode limited to rectangular small regions to allow for clean chopper off-positions for each raster point. Large rasters with wavelength switch

- Small O(1000km/s) wavelength range centered on line
- Spectral sampling >3 samples/FWHM for each pixel (by small up/down scan)

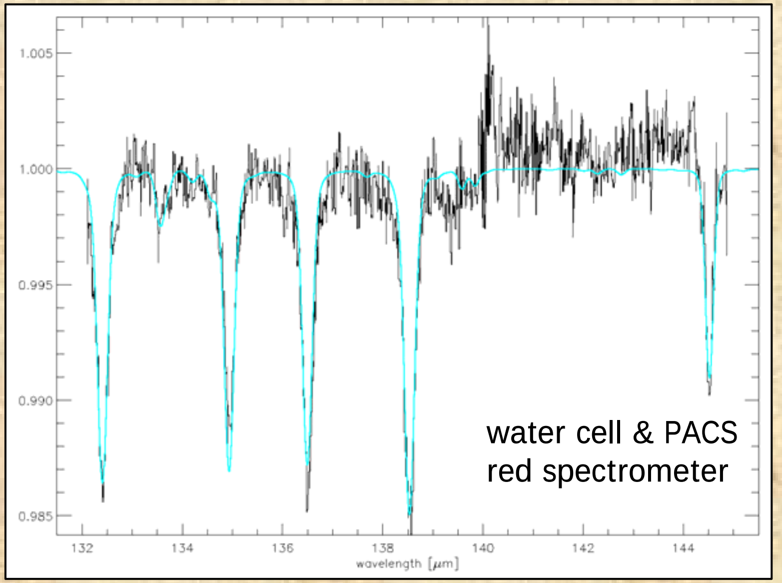
- **Minimum execution time: 6min** (under construction)

Range Spectroscopy

- 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 to allow for clean chopper off-positions for each raster point
- MAPPING with off-position: crowded fields and extended spectral structures; chopping between sky and internal CS

- Wavelength range(s) user defined

- Spectral sampling:
  - high (>3 samples/FWHM each pixel)
  - Nyquist (optimized for speed)



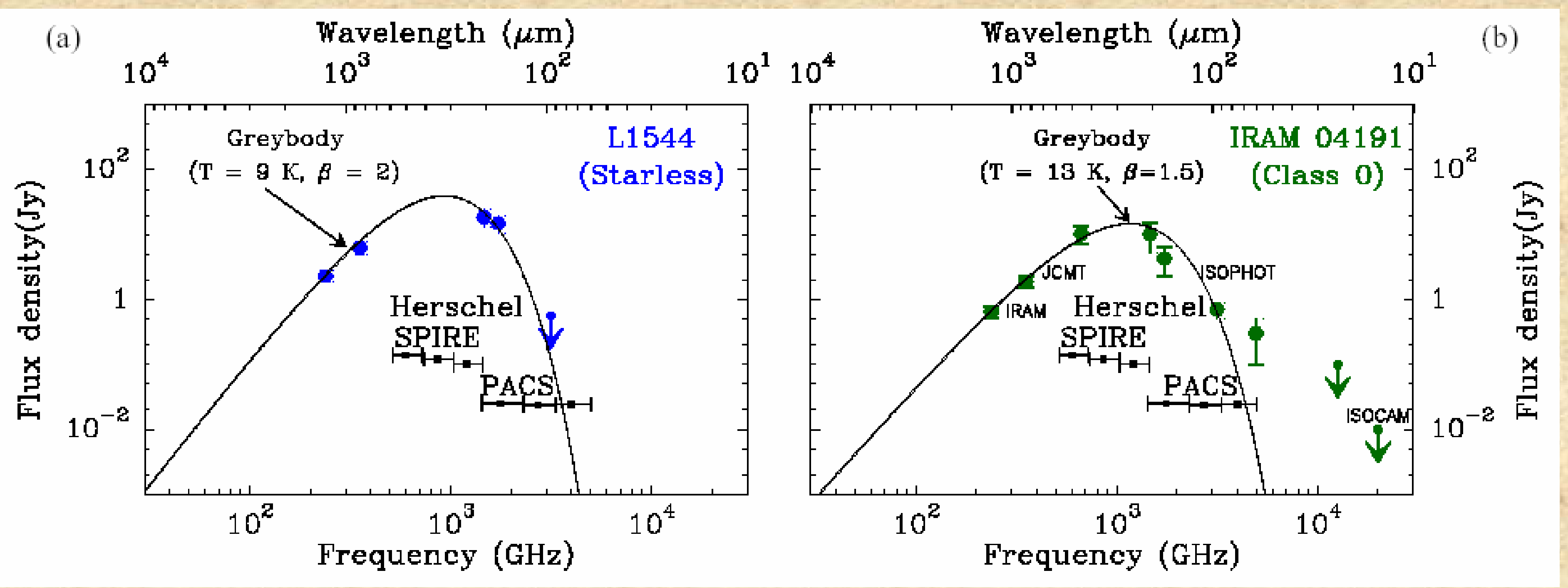
SED Mode

- Full PACS wavelength range: Order 1+2, Order 3
  - 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 to allow for clean chopper off-positions for each raster point
  - MAPPING with off-position: crowded fields and extended spectral structures; chopping between sky and internal CS; map parameters in sky coordinates
  - Spectral sampling: Nyquist
  - **Minimum execution time: 30+15min**

PACS GT Key Programmes (Summary):

Extragalactic surveys (PEP):	Lutz, Elbaz, Andreani, Cepa et al.
Dusty young universe:	Meisenheimer et al.
IR bright galaxies at 0<z<1:	Sturm, Klaas, Madden et al.
Low Metallicity Dwarf Galaxies:	Madden et al.
Gould belt SF survey:	Andre, Saraceno et al.
Earliest phases of star formation:	Henning et al.
Debris Disks:	Waelkens et al.
Birth of high-mass stars:	Zavagno et al. (SPIRE-led)
Post-main-sequence stars:	Groenewegen, Kerschbaum et al.
Solar system:	Waelkens et al. (HIFI-led)

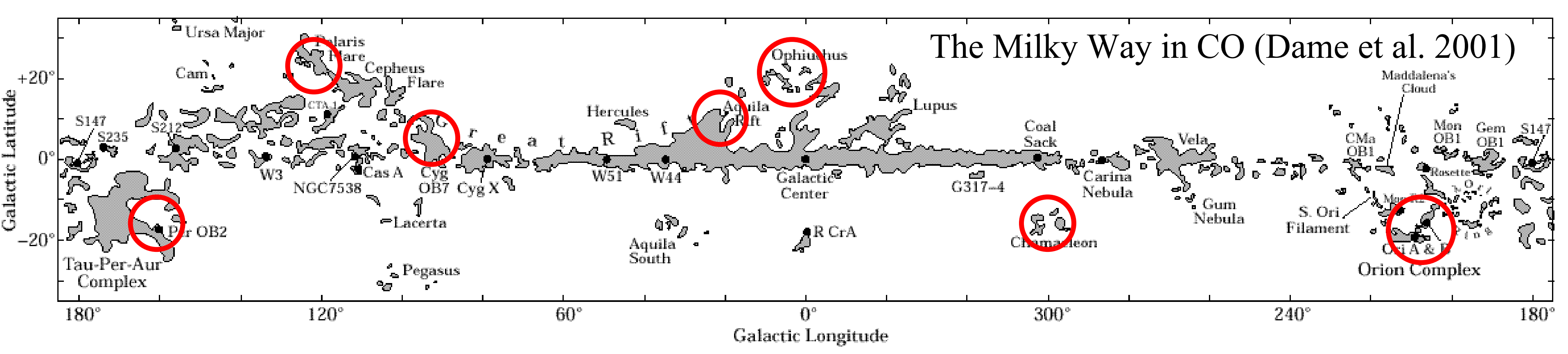
Star Formation Surveys



Star Formation Surveys

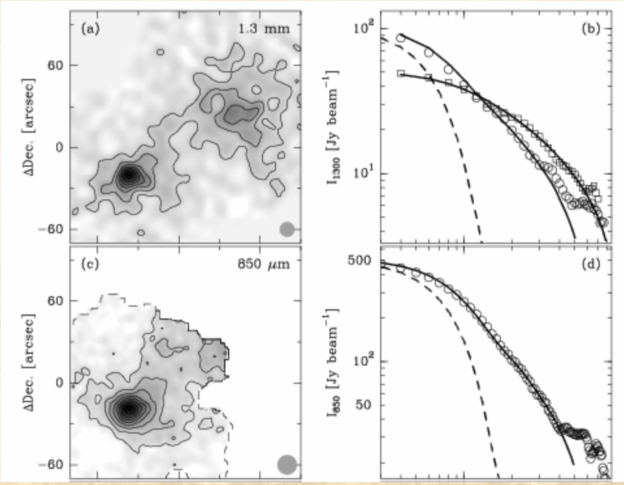
- Complete census of prestellar condensations and Class 0 protostars, down to the proto-brown dwarf regime
  - Luminosities, mass functions
  - Lifetimes of the various stages
  - Temperature and density structure of the nearest condensations
- Probe the link between diffuse structures and compact self-gravitating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



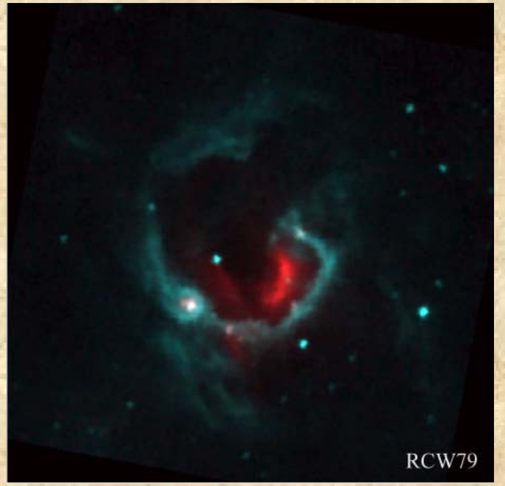
Earliest Phases of Star Formation

- Deep multiwavelength mapping of individual objects and confined regions (low & high mass)
  - Physics of collapse and fragmentation
  - Formation of high mass stars



Henning et al.

- Triggered star formation

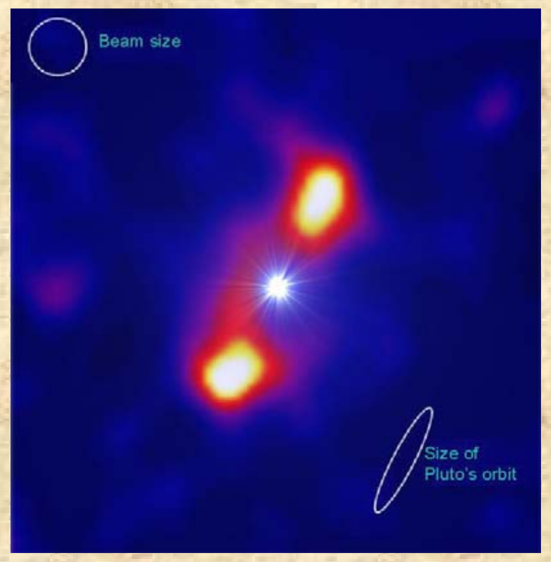


Zavagno et al.

Debris Disks

- Characterize disk masses and properties by PACS & SPIRE Photometry of ~solar mass IR excess star over a wide range of ages
- Mapping of several resolved disks/rings
- Mineralogy from full spectra

Waelkens, Henning, SPIRE, HSC, Harvey…

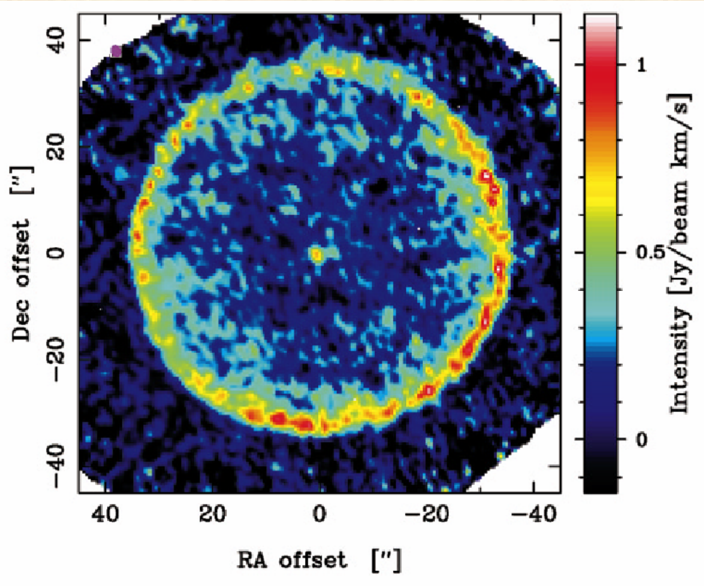


Fomalhaut, SCUBA 450μm
(Holland et al.)

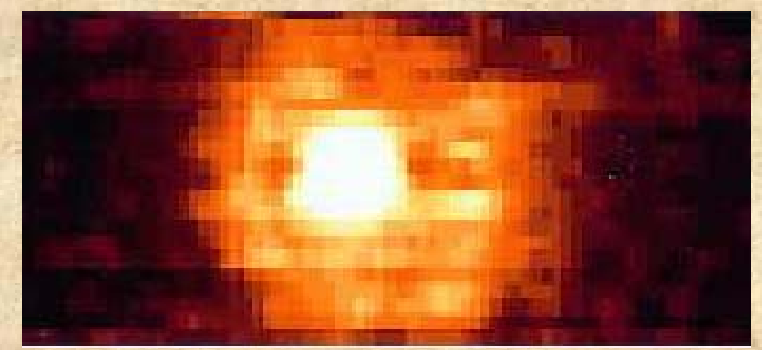
Late Stages of Stellar Evolution (1)

- Mass loss is the dominant factor in the post main sequence evolution of almost all stars...
- Study the mass loss history and structure of the circumstellar envelope through high resolution far-infrared imaging.
- Photometry/maps of ~100 AGB, RSG, post-AGB, PN, WR, LGB... down to 2 mJy/beam [1σ] in all 3 bands.

Groenewegen, Kerschbaum et al.



Olofsson et al. 2000

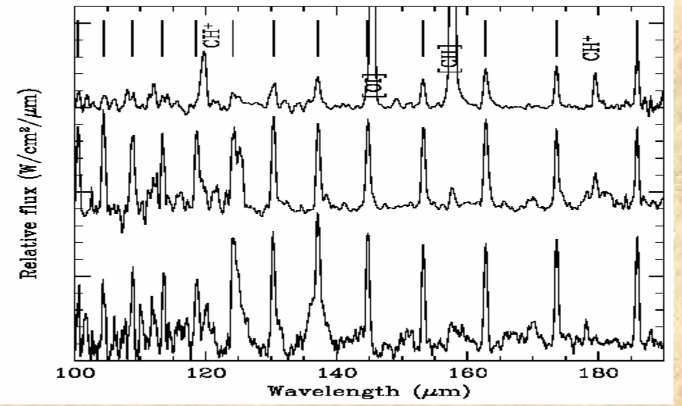


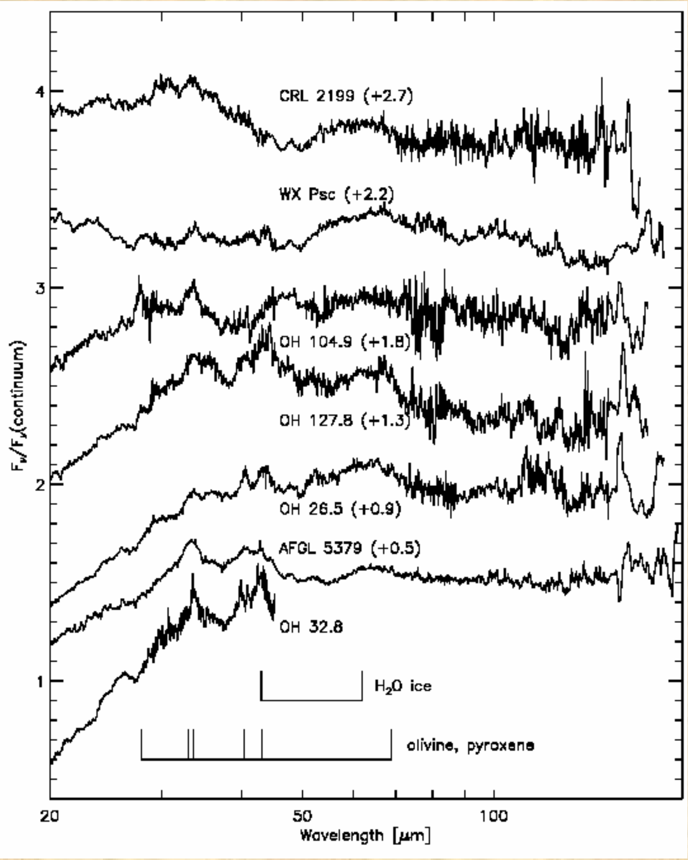
Izumiura et al. 1996

Late Stages of Stellar Evolution (2)

- 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.

Full spectra of ~50 AGB, post-AGB, PN...

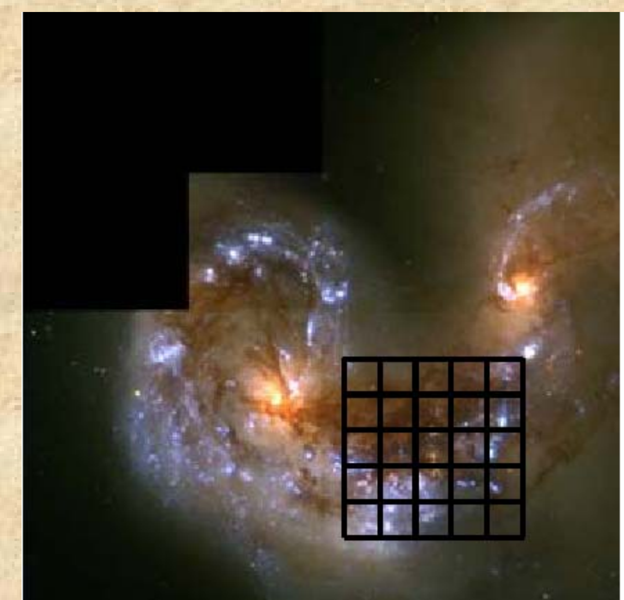




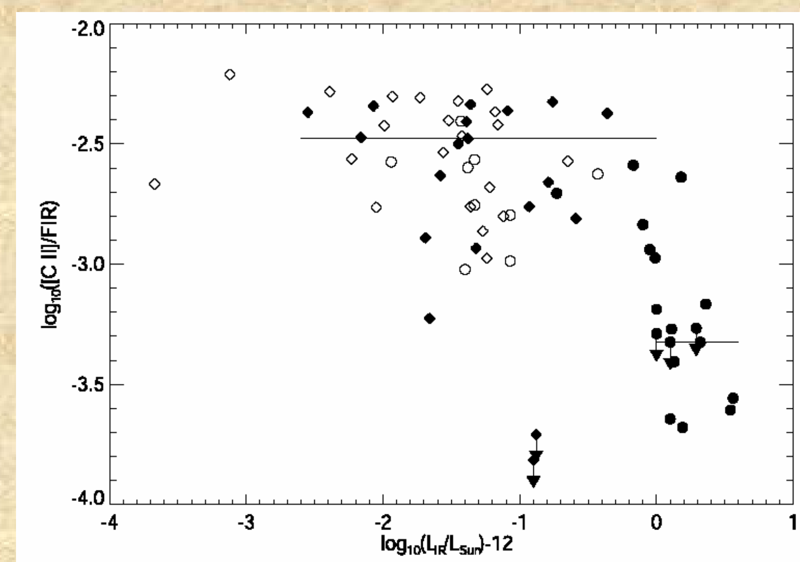
Sylvester et al. 1999
Justtanont et al. 2000

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

- FIR spectroscopy, to study energetics, obscuration and physical conditions of dusty, infrared bright galaxies (starbursts, AGN, (U)LIRGs)
  - using tools like HII region/PDR diagnostics



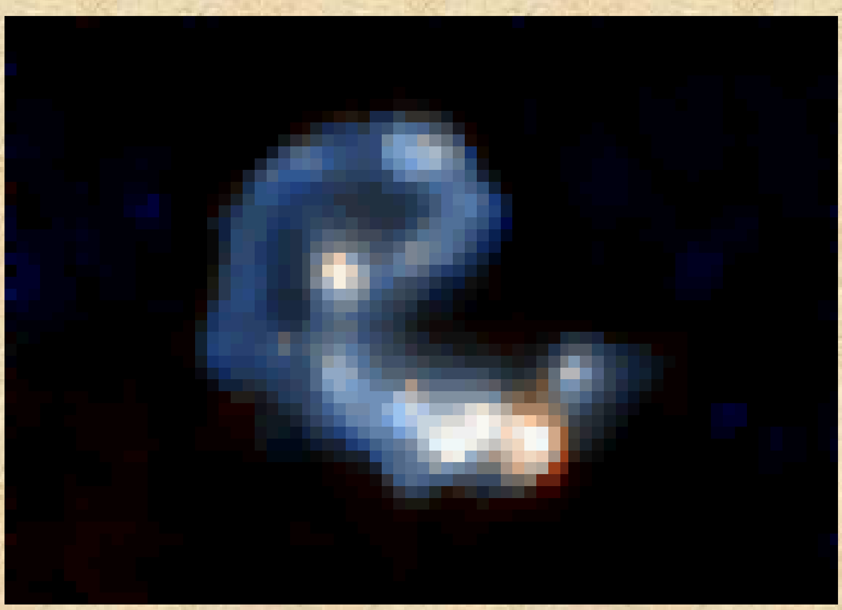
PACS Instrument & GT Programme



CII Deficit, e.g. Luhman et al. 2003

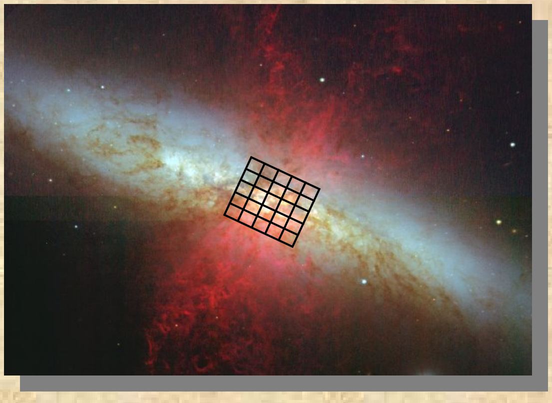
Star Formation and Activity in Infrared Bright Galaxies at z<1 (2)

- 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 (3)

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**

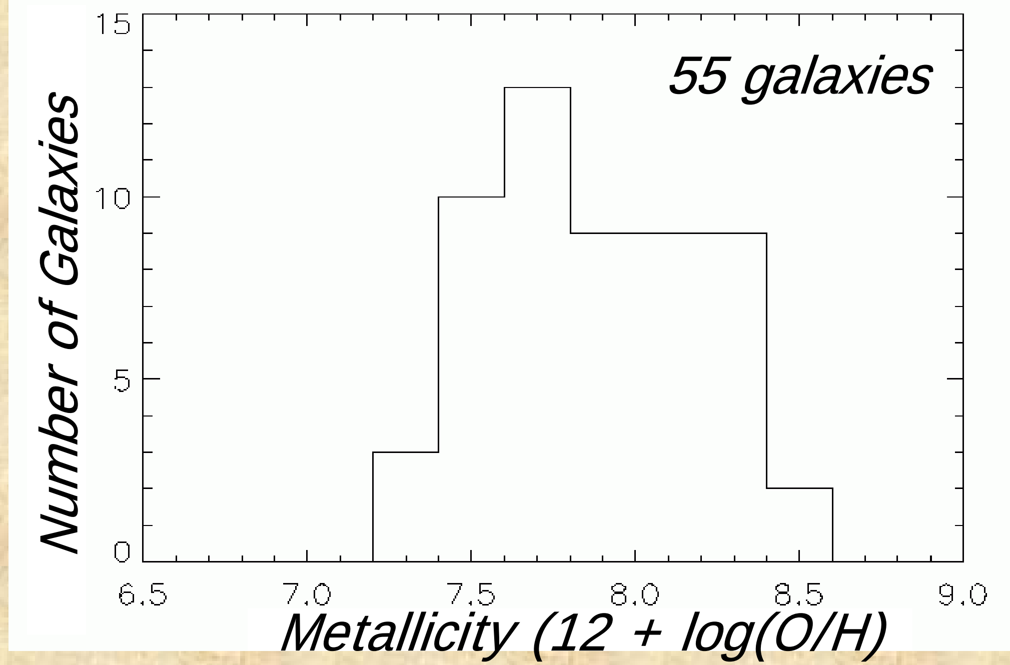


5) **Photometric mapping** of 60 nearby interacting galaxies, and of 16 template objects

Sturm, Klaas, Madden et al.

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…
- Evolution of metals in the ISM and dust 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



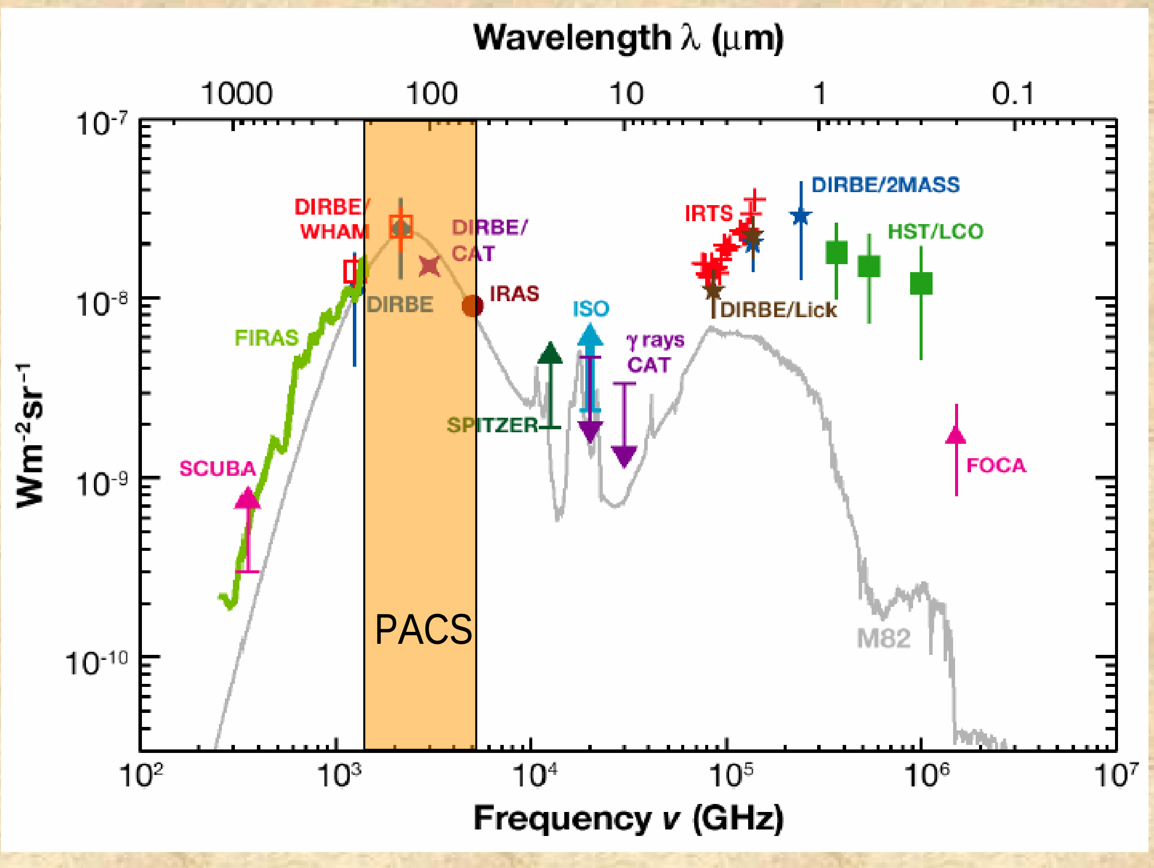
- **0.5 – 1/50 solar metallicity**

Madden 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



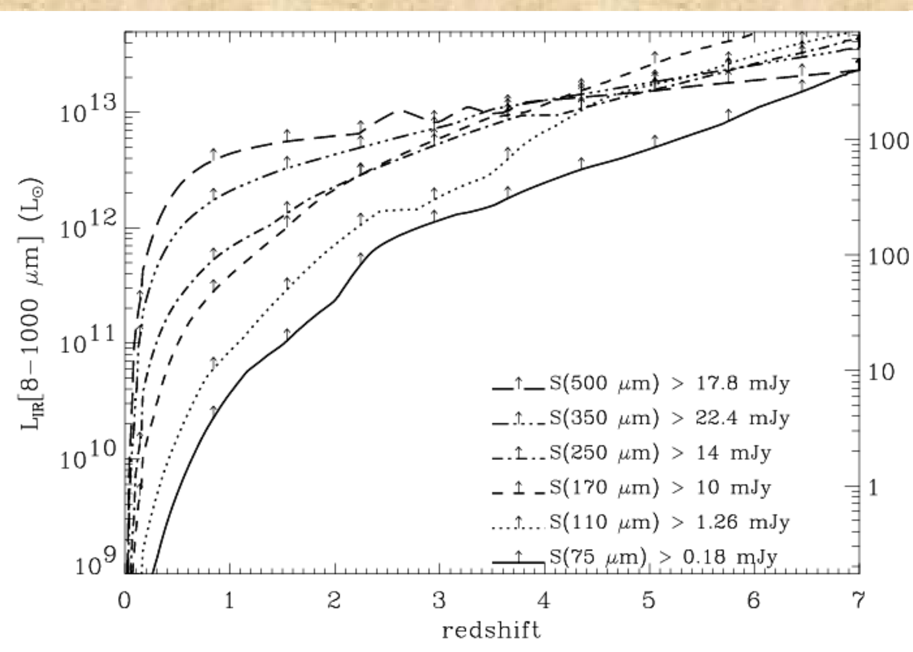
Lagache et al. 2005 ARAA

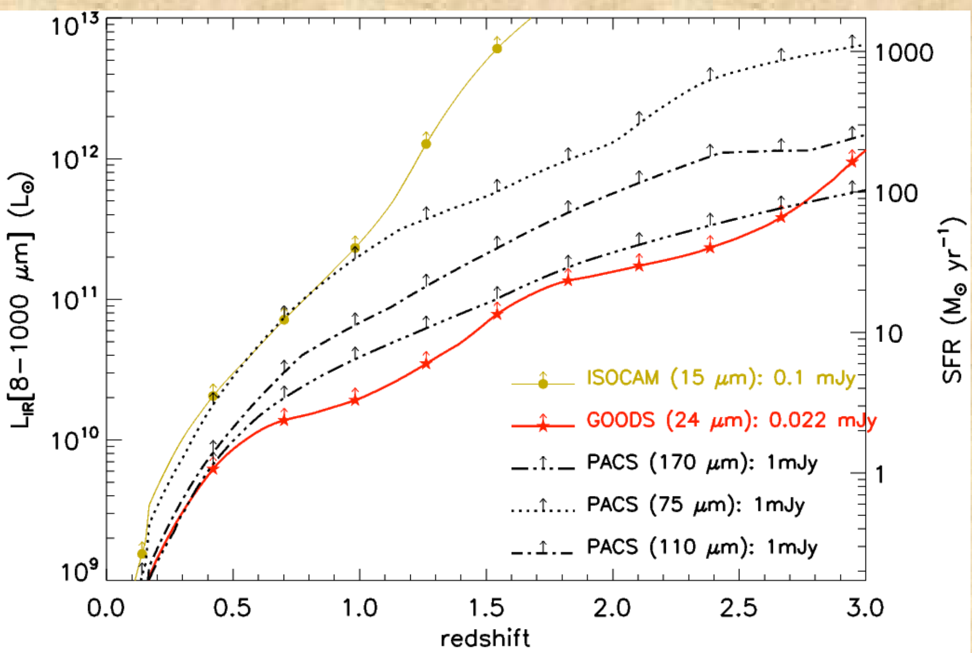
Resolution into **5σ individually detected** sources for current blank field PACS survey plans:

~80% @75μm
~85% @110μm
~55% @170μm

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

Relation to other infrared wavelengths





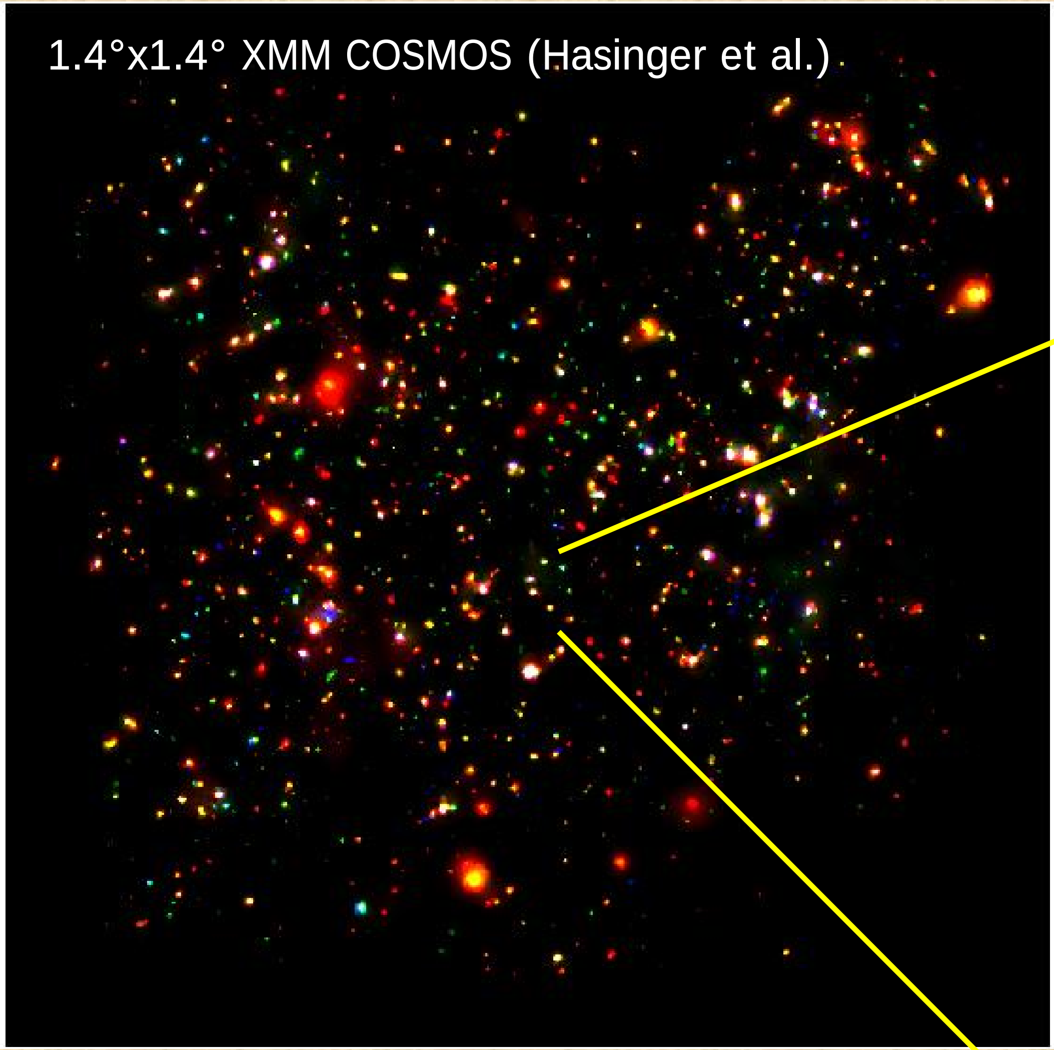
Reachable L(z) for surveys of varying depth for a *single star-forming SED family* (D. Elbaz)

PACS needed to go deep at z~1-2 **and** probe rest frame far-infrared in a way that is robust to SED variations, AGN content...

Probing a wide range of environments...

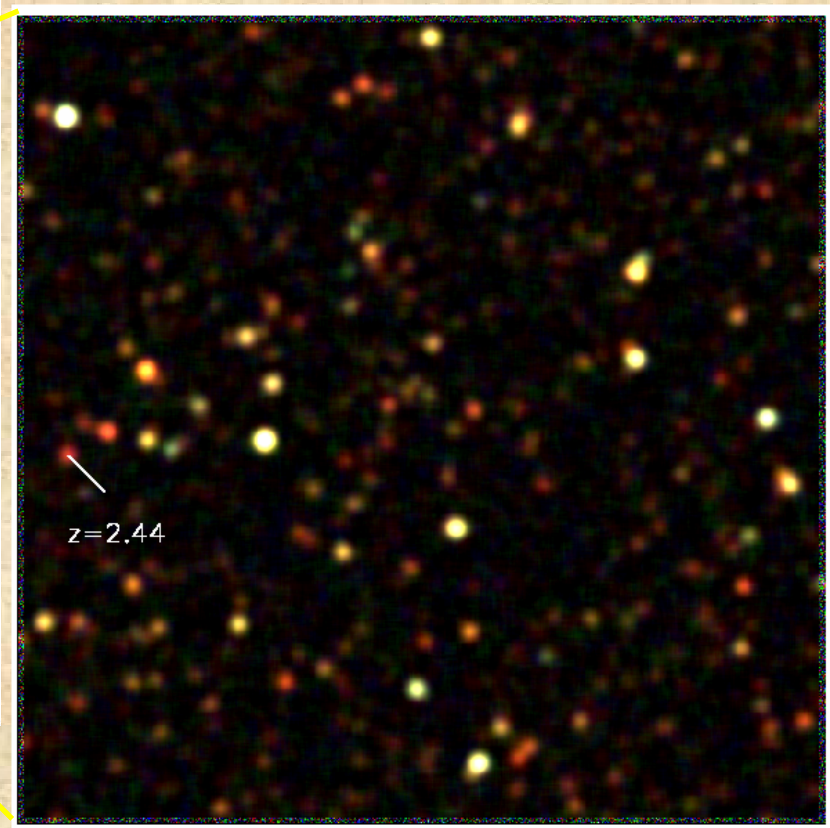
~100 Mpc spatial scale
~10^{14} M_{sun} mass scale

~200h for full 2sq.deg field to 11mJy



PACS Instrument & GT Programme

Simulated deep PACS sub-field survey



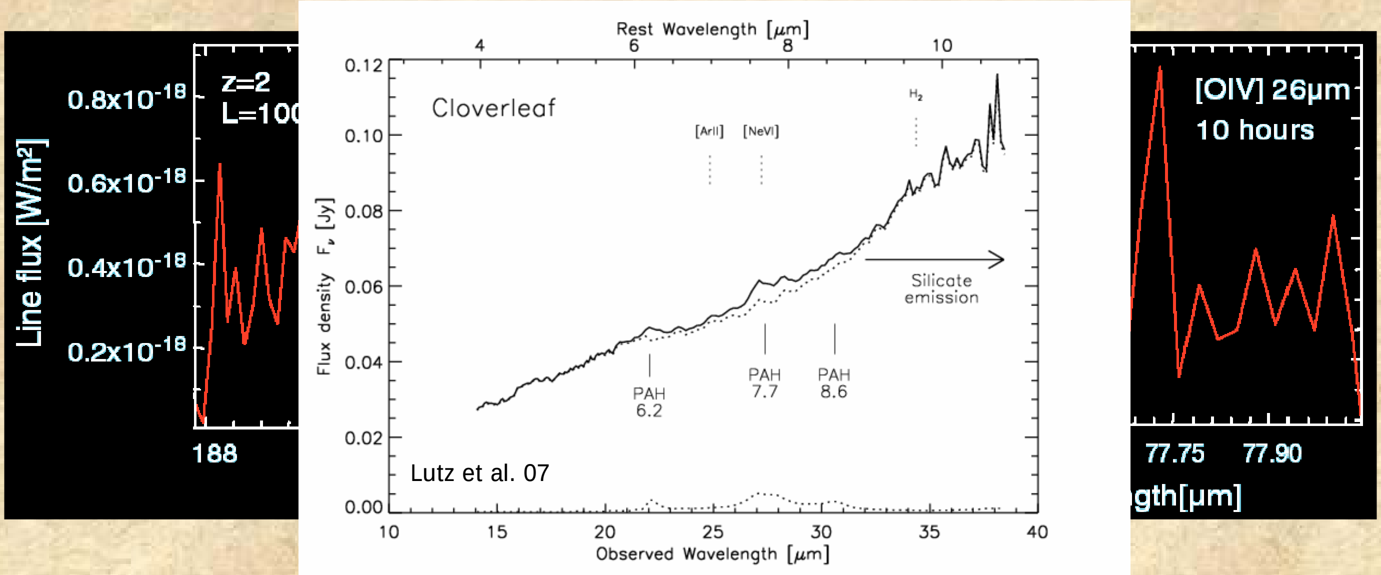
Preliminary Plans `PACS Evolutionary Probe'

GT survey ~650hours of PACS+HSC GT, coordinated with SPIRE
Lutz, Elbaz, Andreani, Cepa, Altieri, Harwit,....

Fields(s)	Size	Wavelength, 5σ depth	Time
COSMOS	2 sq.deg	110+170, 11mJy	220h
Lockman, Groth, ECDFS	3 x 0.25 sq.deg	110+170, 7mJy	3 x 34h
GOODS-N	150 sq.arcmin	110+170, 3mJy	27h
GOODS-S	150 sq.arcmin	75,110,170, 1.5mJy	2 x 115h
5 z~1 clusters	5' x 10'	110+170, 7mJy	5 x 2h
10 lensing clusters	4' x 4'	110+170, 1.5-3mJy	70h

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)



(Meisenheimer, Hutsemekers, Tacconi et al.)

PACS GT Key Programmes (Summary):

Extragalactic surveys (PEP):	Lutz, Elbaz, Andreani, Cepa et al.
Dusty young universe:	Meisenheimer et al.
IR bright galaxies at $0<z<1$:	Sturm, Klaas, Madden et al.
Low Metallicity Dwarf Galaxies:	Madden et al.
Gould belt SF survey:	Andre, Saraceno et al.
Earliest phases of star formation:	Henning et al.
Debris Disks:	Waelkens et al.
Birth of high-mass stars:	Zavagno et al. (SPIRE-led)
Post-main-sequence stars:	Groenewegen, Kerschbaum et al.
Solar system:	Waelkens et al. (HIFI-led)

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