Herschel Photodetector Array Camera & Spectrometer

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

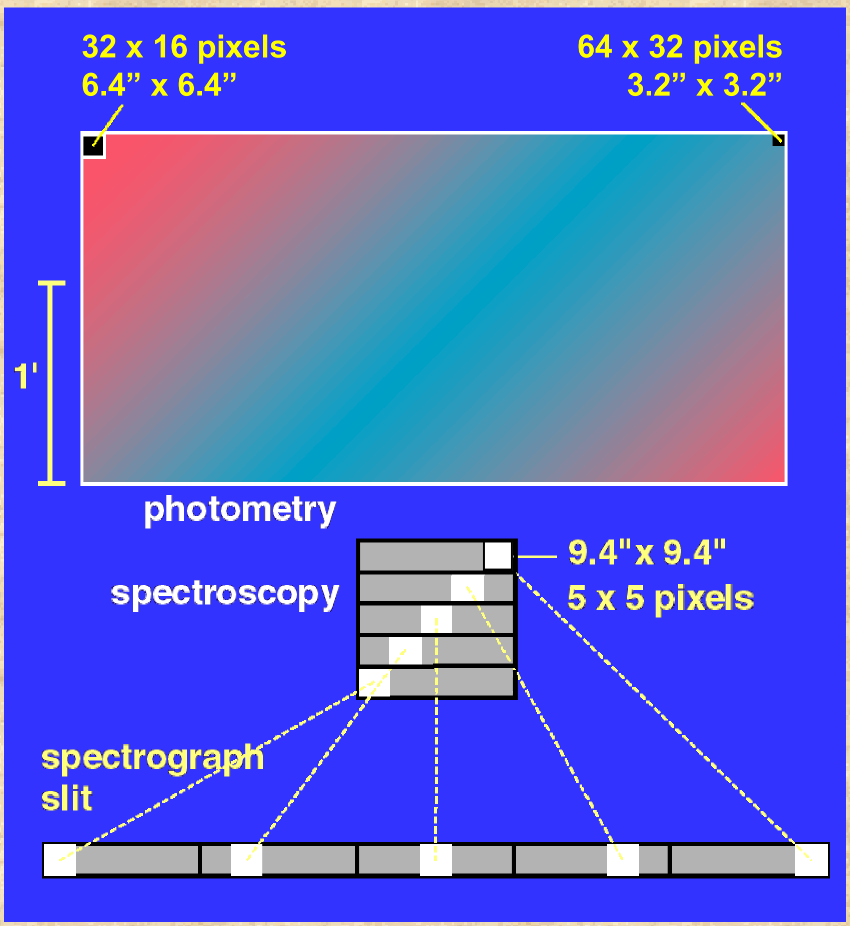
Paolo Saraceno, Istituto di Fisica dello Spazio Interplanetario

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 (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 x10^{-18} W/m^2 (5σ, 1h)

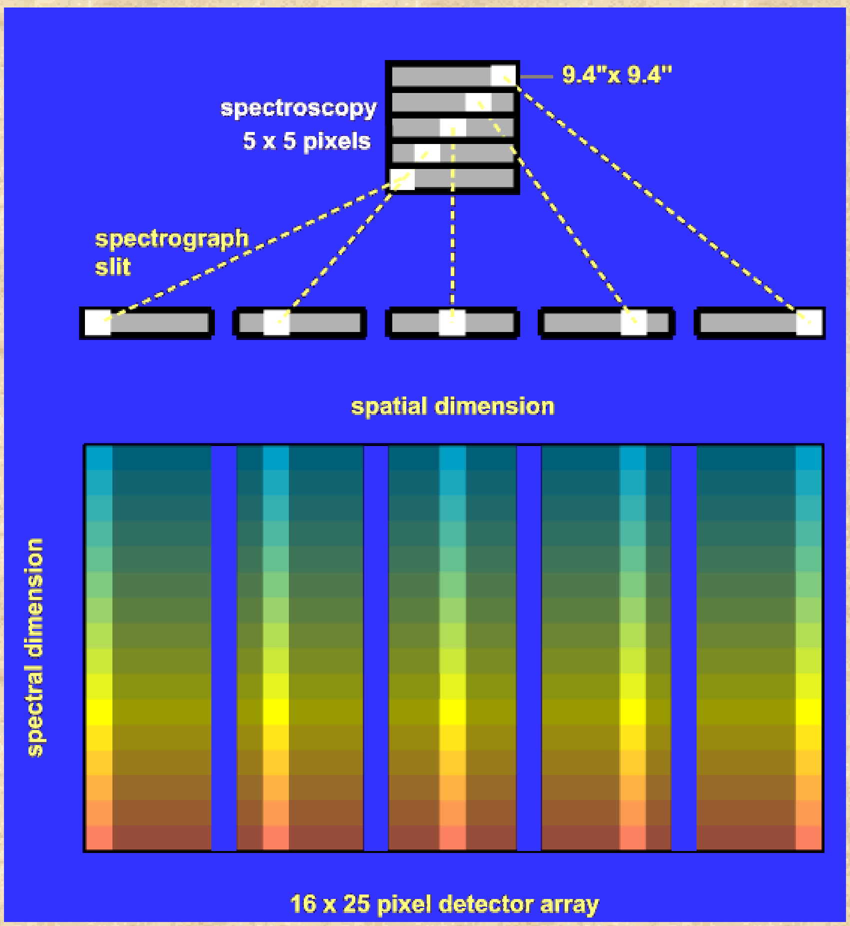
Focal Plane Footprint



Instrument Concept

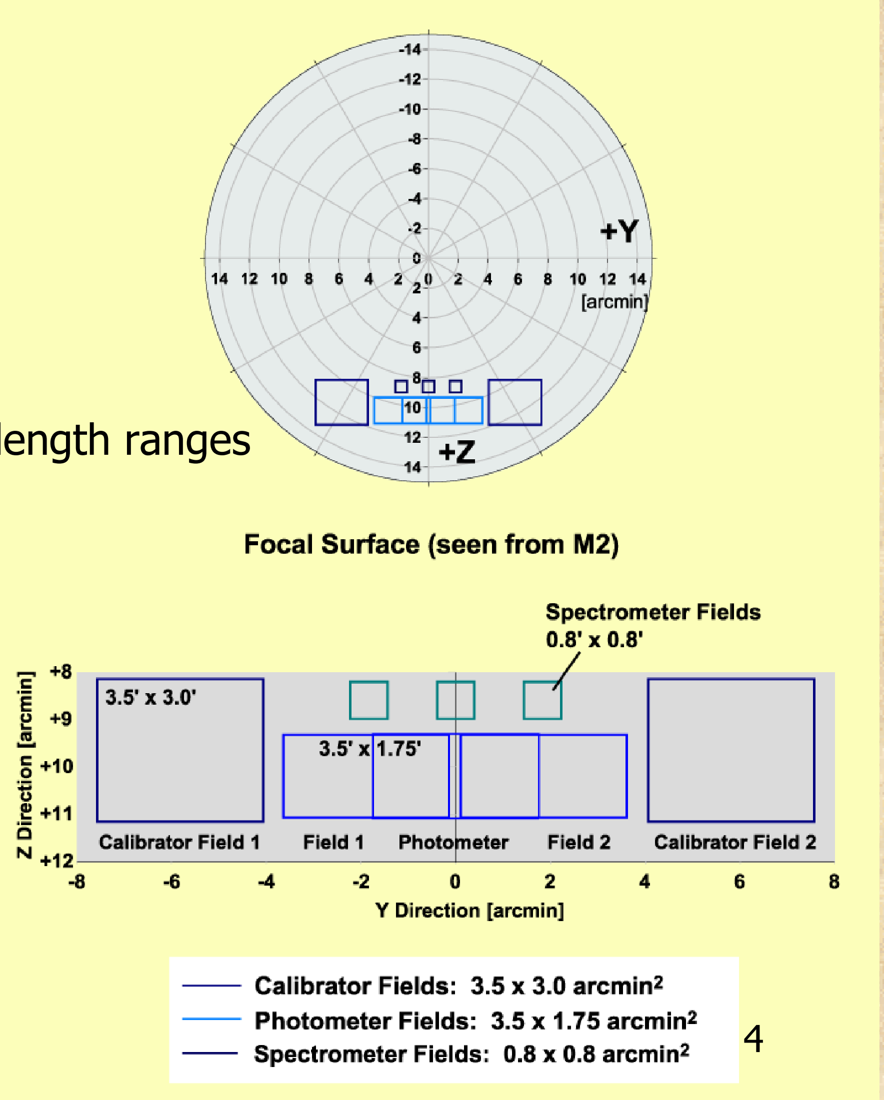
- **Imaging photometry**
  - two bands simultaneously (60-85 or 85-130 μm and 130-210 μm) with dichroic beam splitter
  - two filled bolometer arrays (32x16 and 64x32 pixels, full beam sampling)
  - point source detection limit ~4 mJy (5σ, 1h)
- **Integral field line spectroscopy**
  - range 57 - 210 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

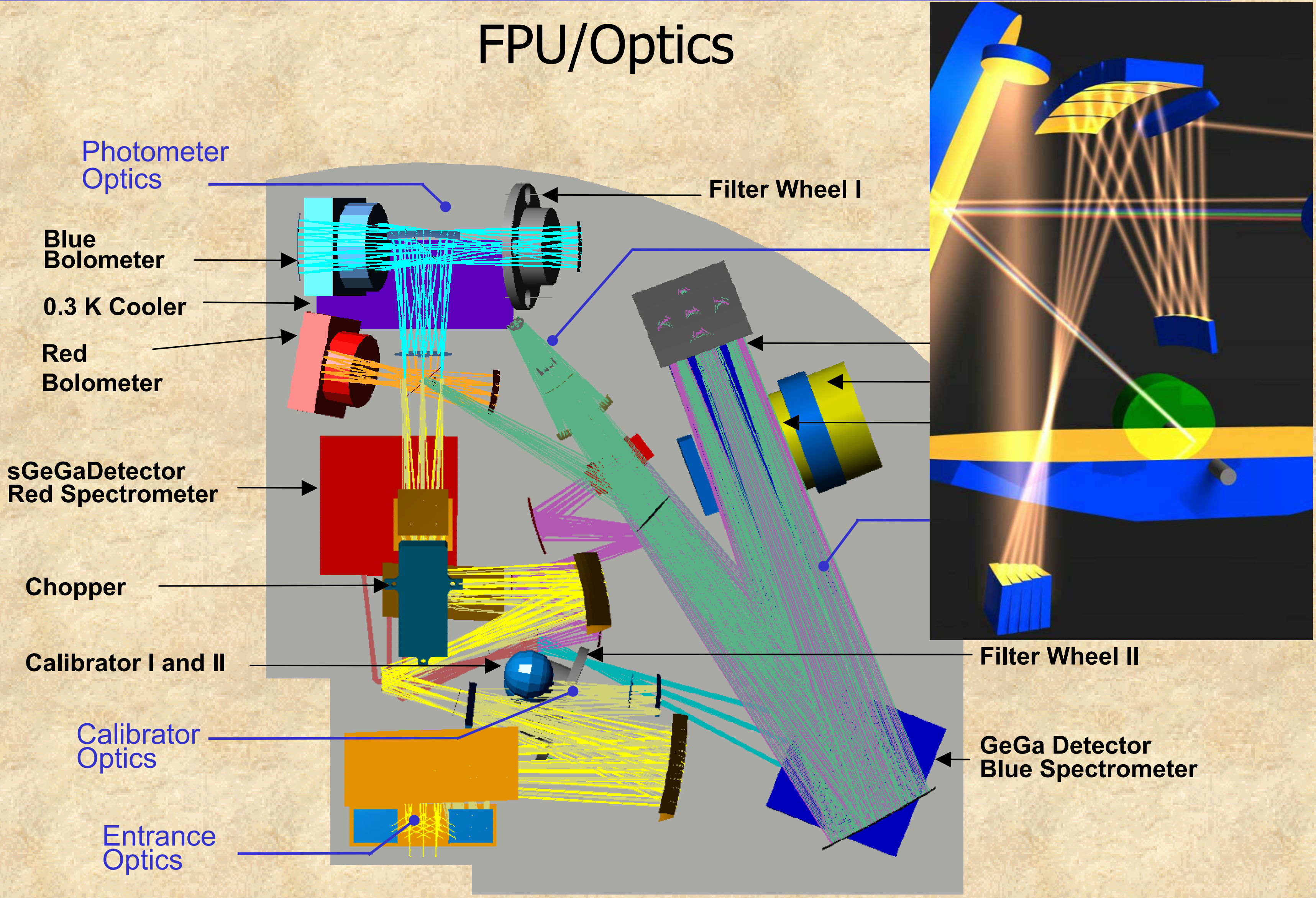


Observing Modes

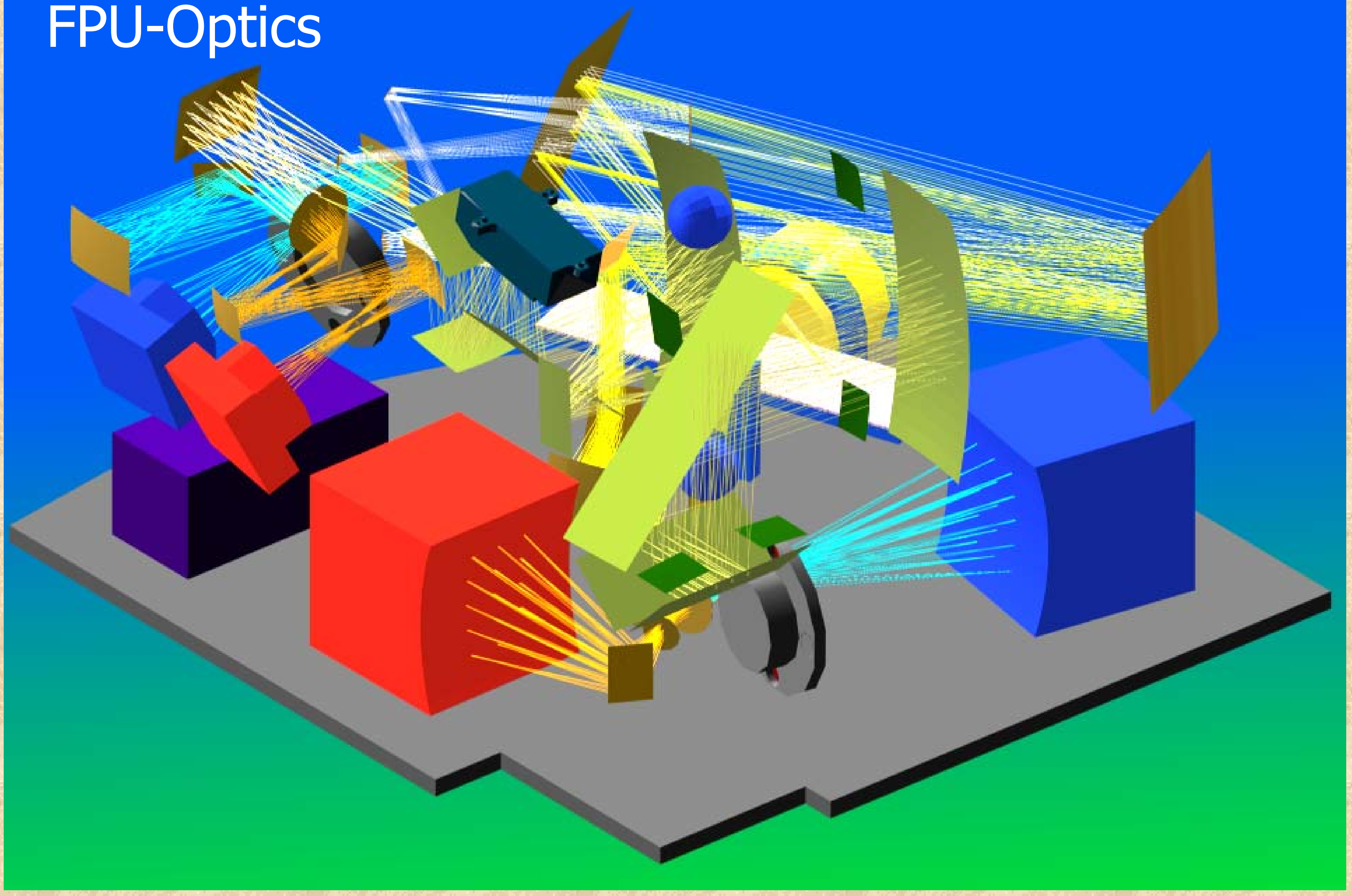
- Combinations of *instrument modes* and *satellite pointing modes*
- Instrument modes:
  - photometry (dual-band)
  - line spectroscopy
    - observation of individual lines
  - range spectroscopy
    - observation of extended wavelength ranges
- Pointing modes:
  - stare/raster/line scan
  - with/without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

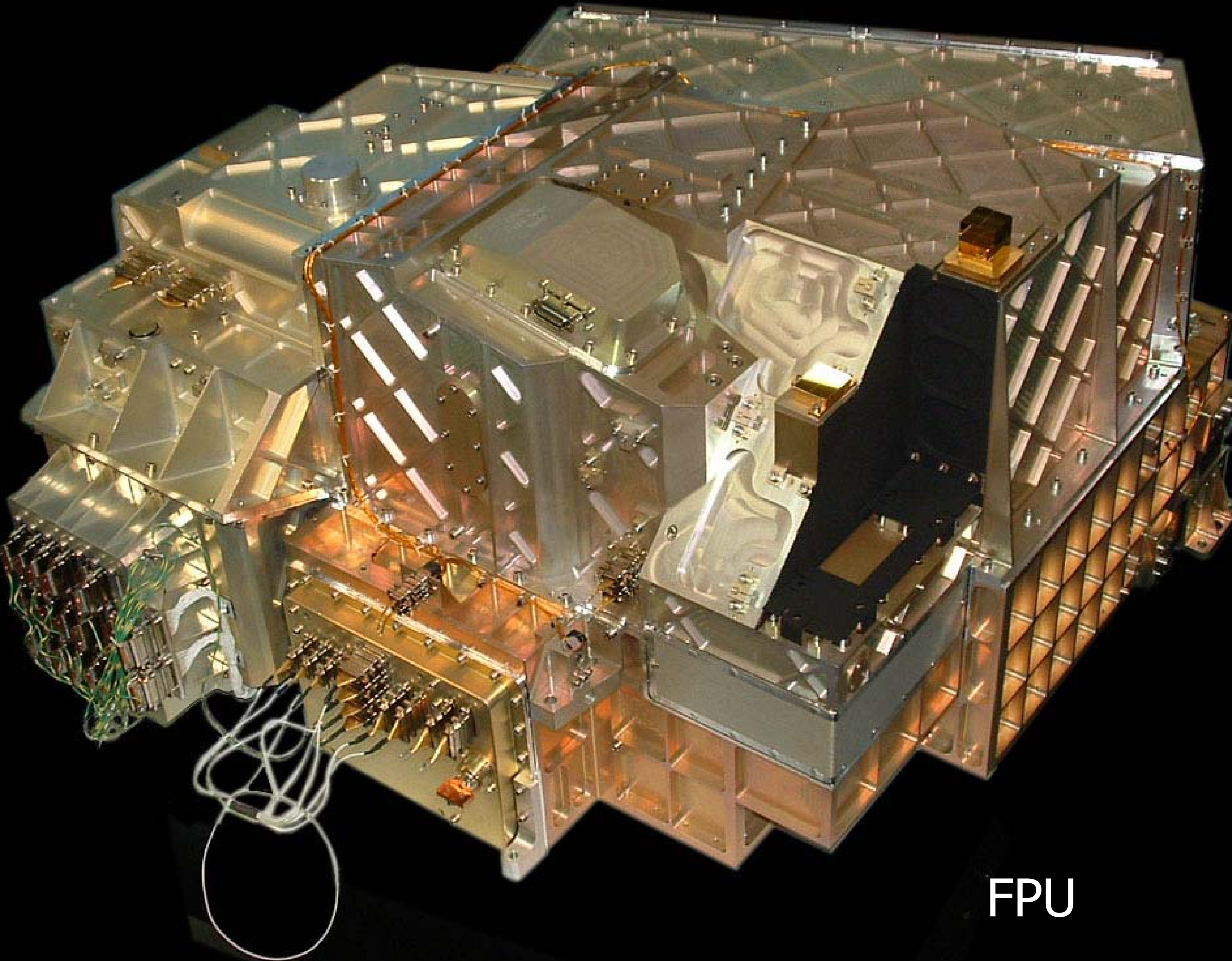


FPU/Optics


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

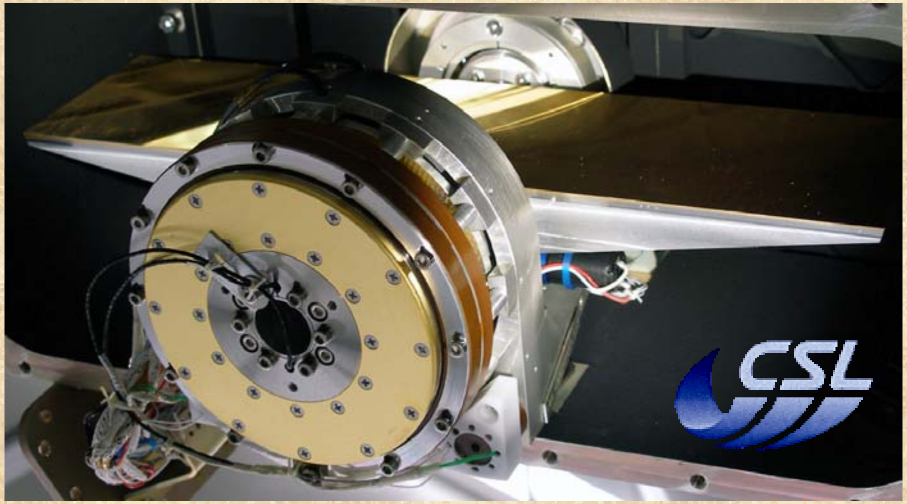
FPU-Optics

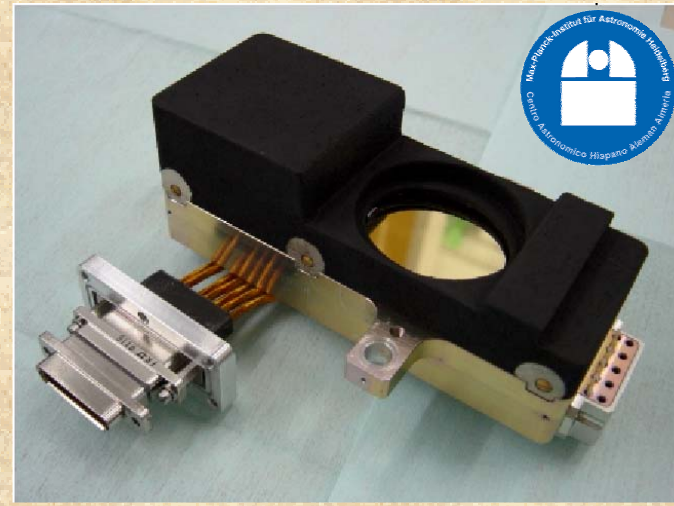


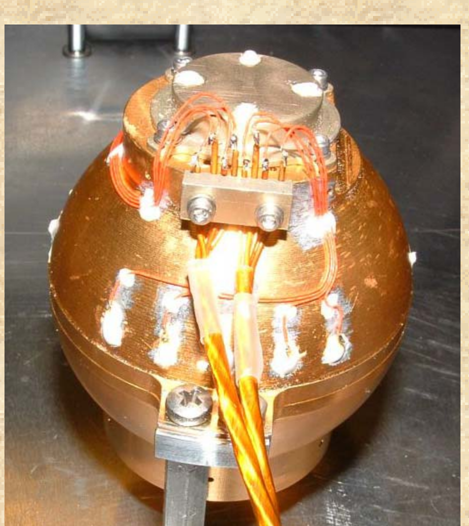


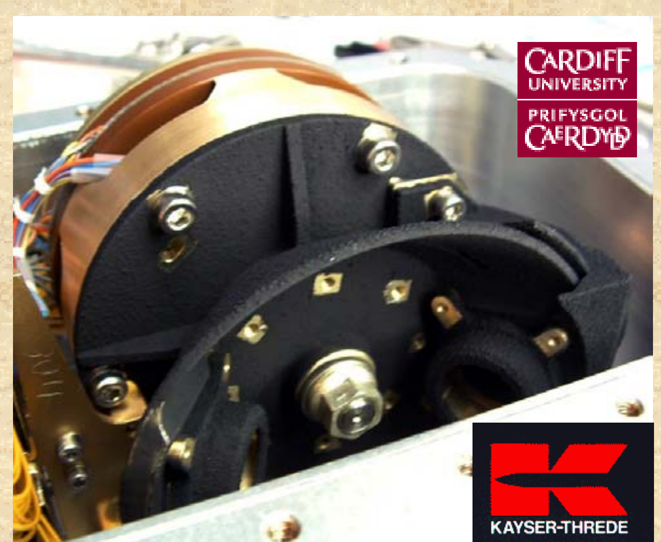
FPU

FPU Subunits Picture Gallery



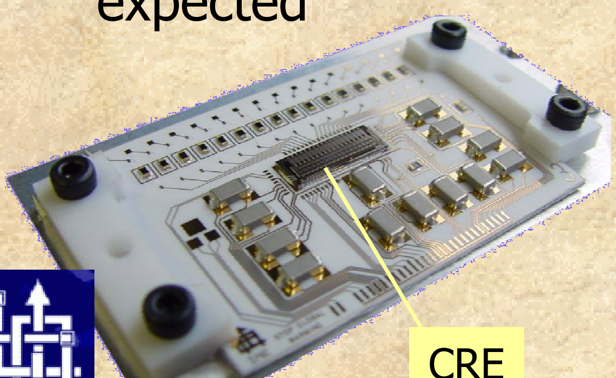






Photoconductor Arrays (Spectrometer)

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

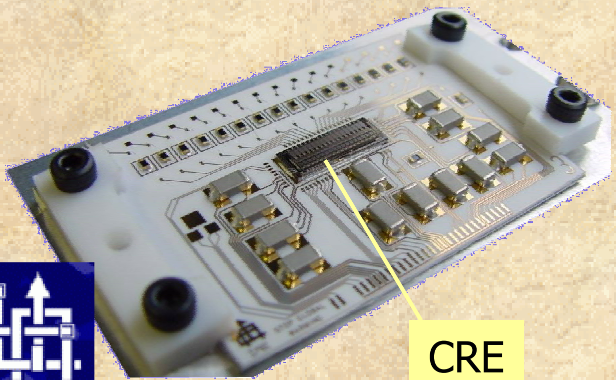


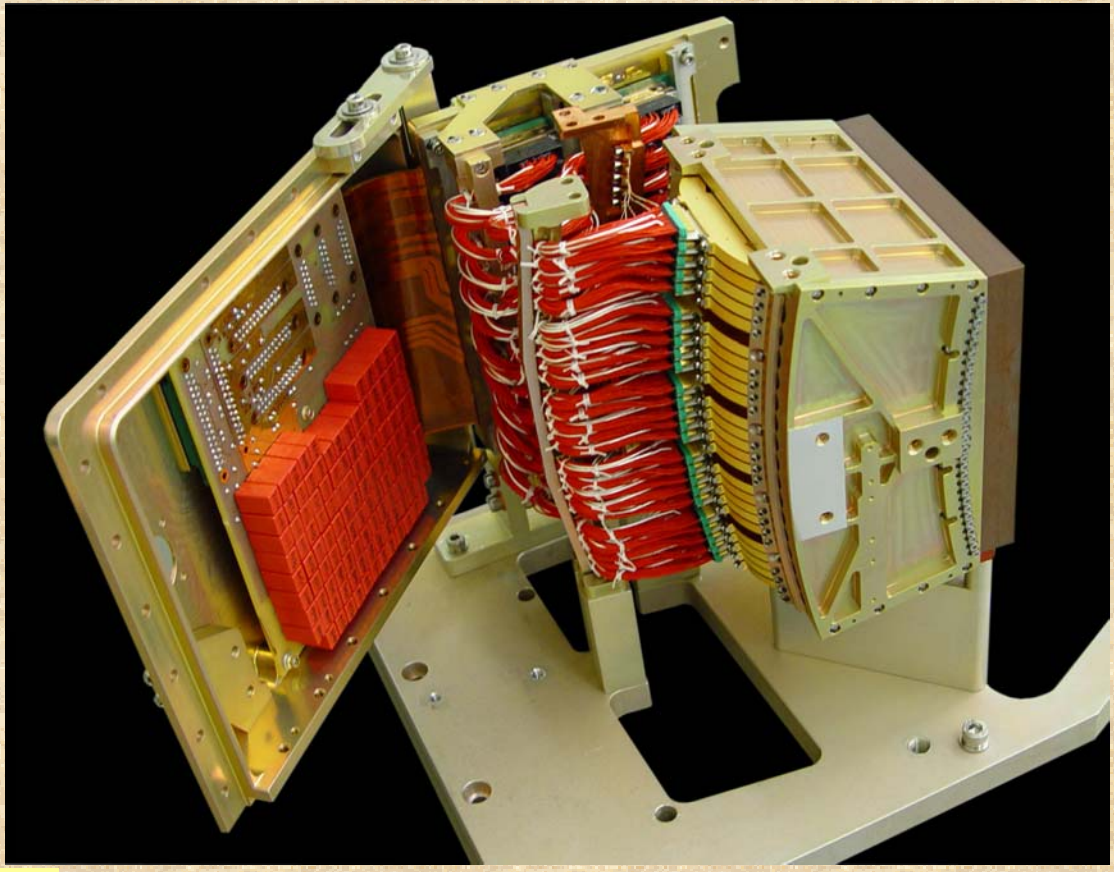
imec

CRE details: Merken et al. [6275-43]

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

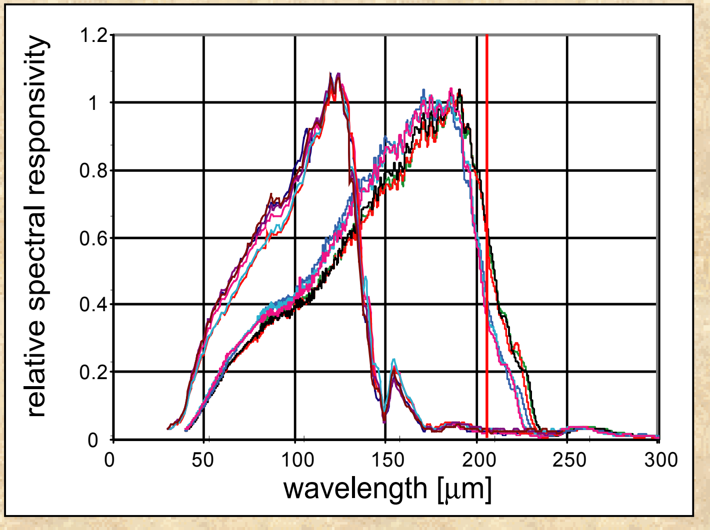


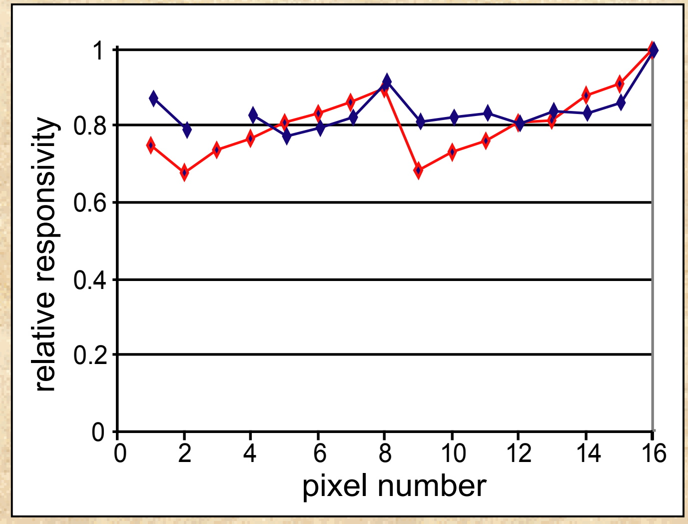


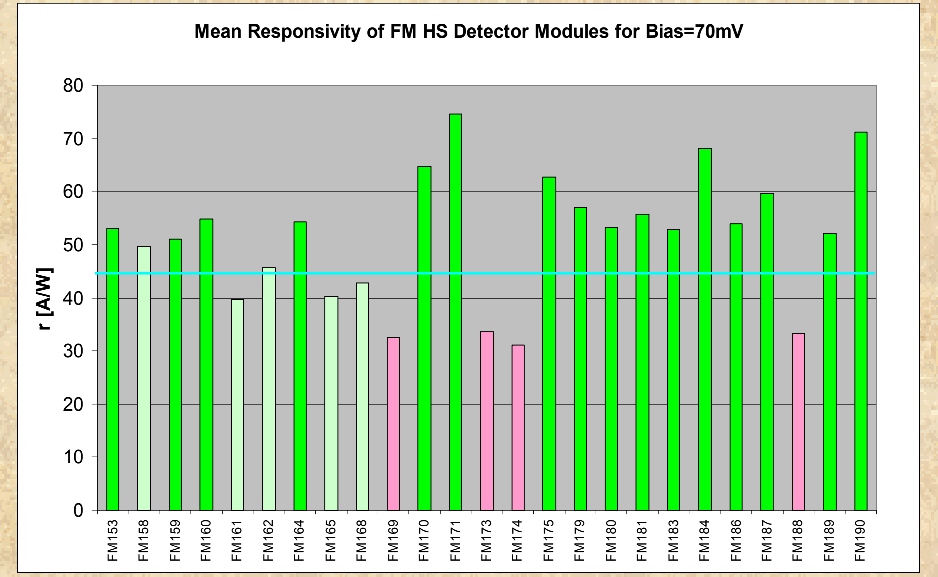
CRE details: Merken et al. [6275-43]

Detector Performance

- Distribution of spectral response within modules
- Distribution of photometric response within modules
- Distribution of absolute photometric responsivity between modules

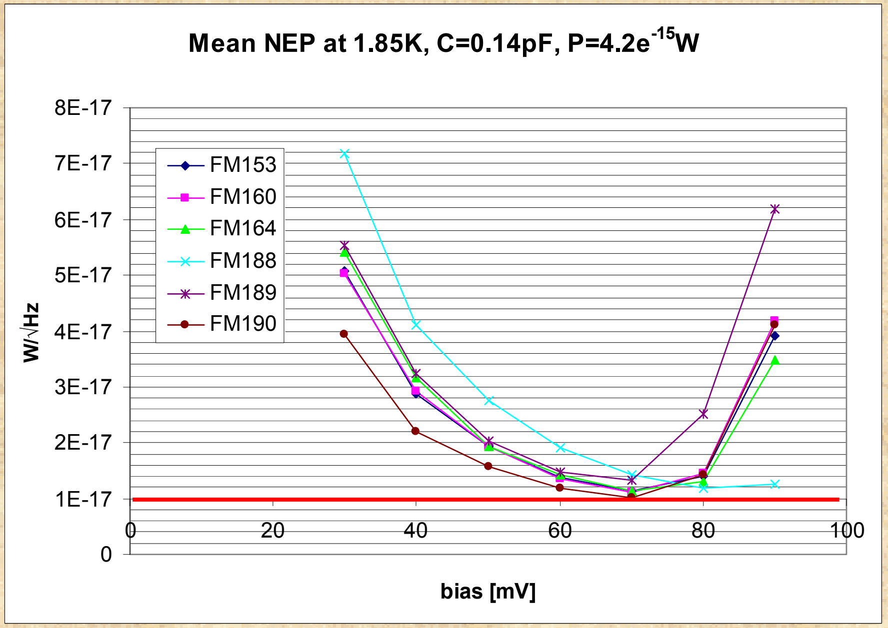


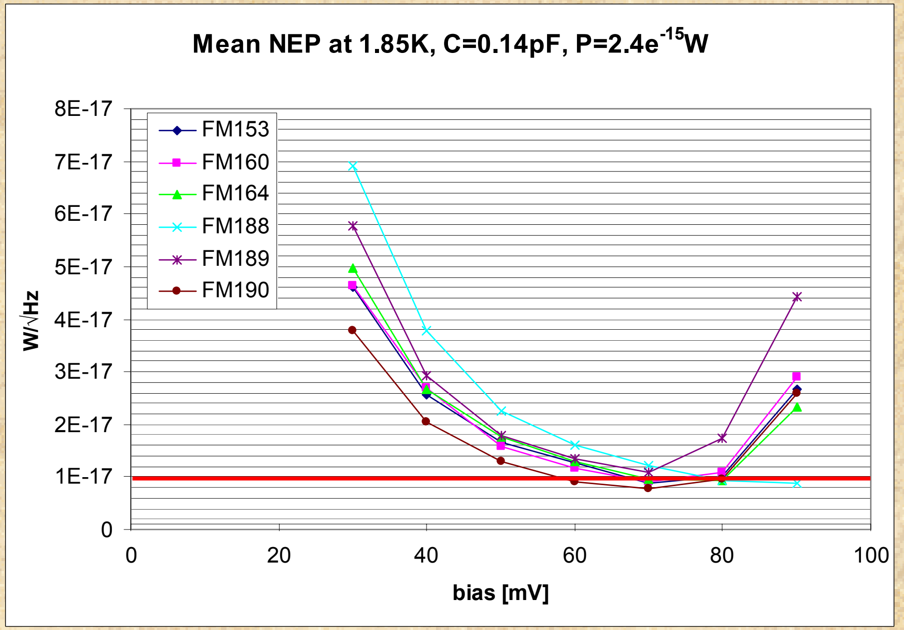




Detector/CRE Performance

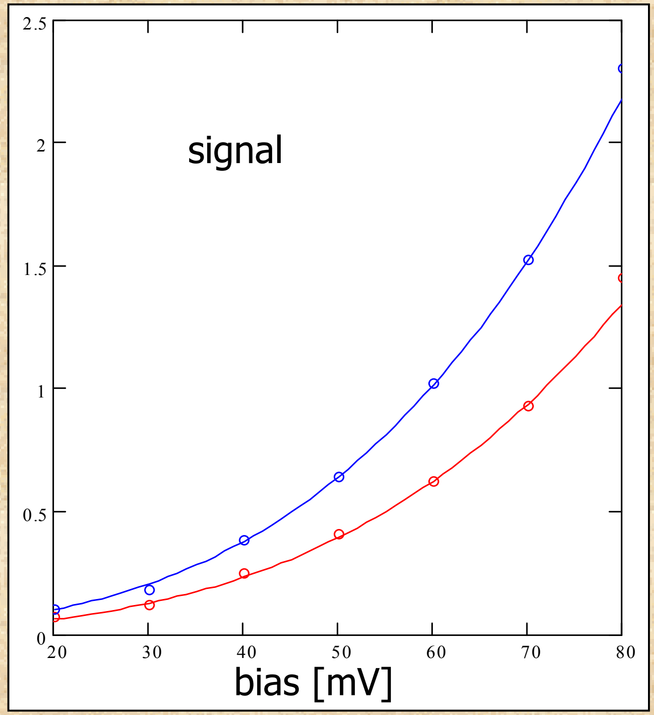
- Near background-noise limited performance with peak DQE=0.26 achievable for high-stress detectors with FM CREs
- Analysis of proton tests on HS module indicates no significant excess noise with optimized modulation scheme, IR curing works as well as thermal curing





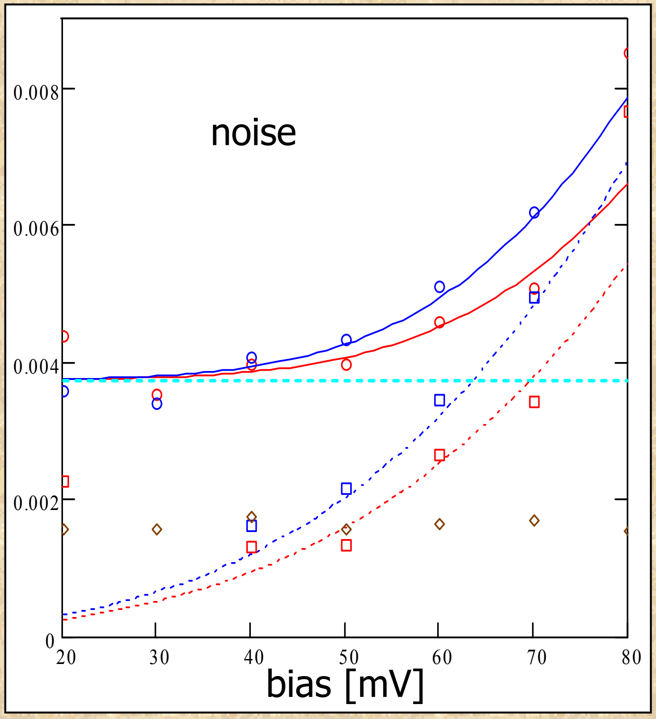
Measurement with lab equipment (not optimized for noise)

Background- vs. Readout Noise



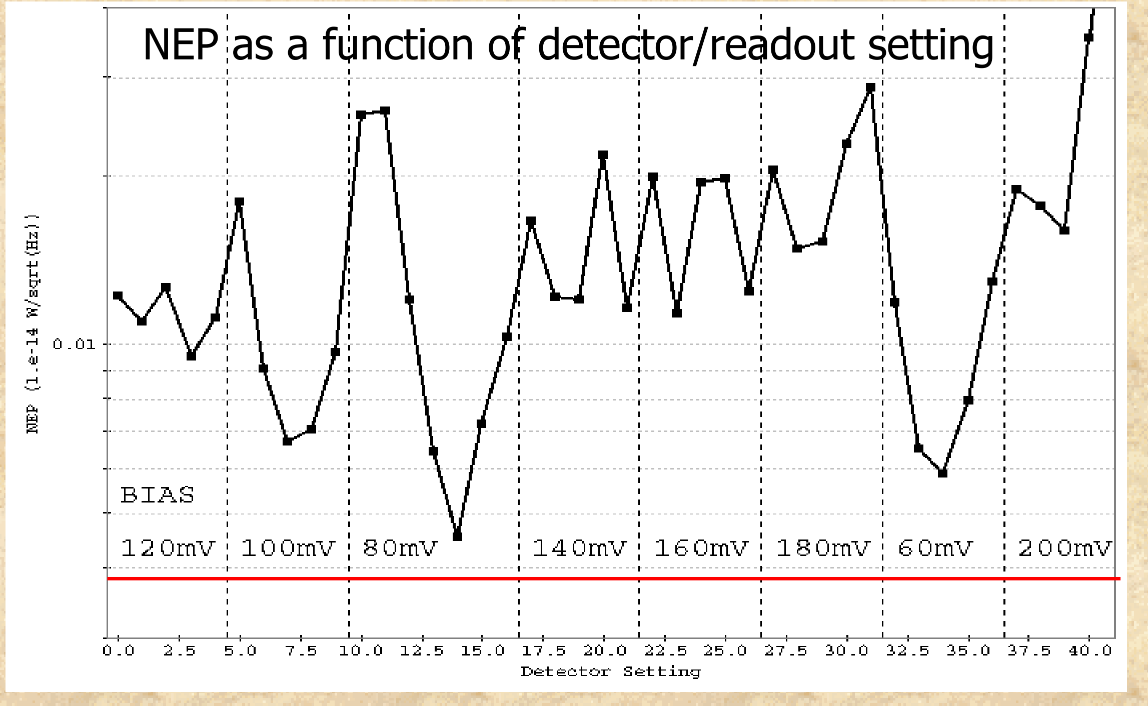
4.7×10^{-15} W
2.9×10^{-15} W

Circles:
measured noise
Dashed line:
CRE noise
Squares:
CRE noise subtr.
Solid lines:
combined model
Dotted lines:
background noise



- Observed noise explained as photon noise + CRE noise
- S/N (of photon noise) requires QE=0.26
- With observed noise of readout (integrated with detector), near-BLIP for HS (red) array expected, but (most likely) not for LS (blue) array

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.

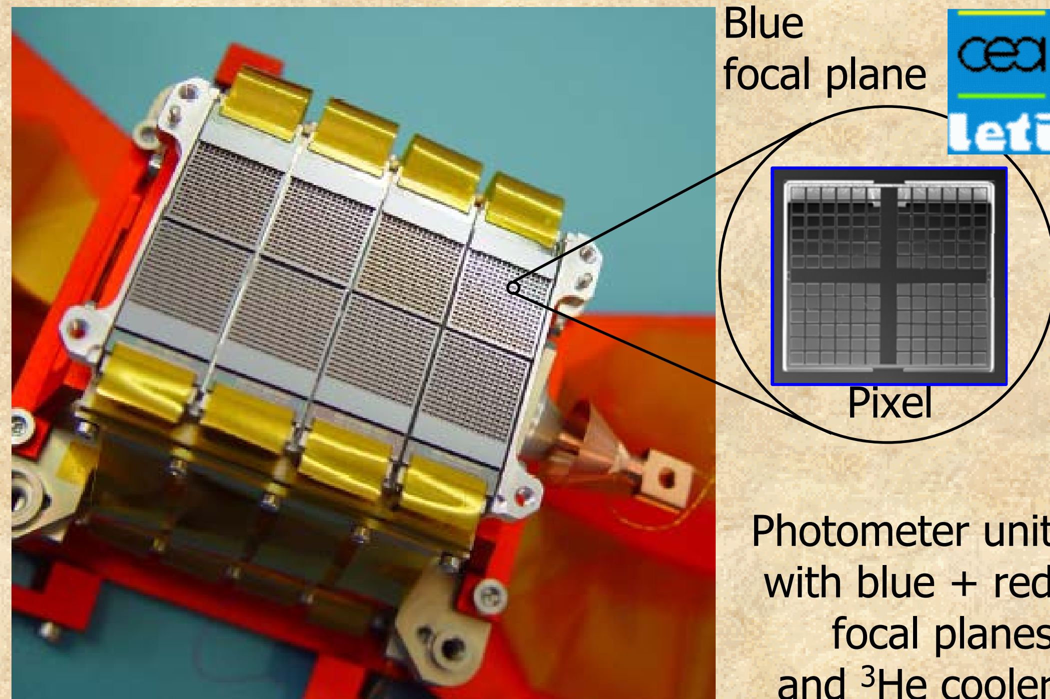
Instrument model value, based on lab measurements without irradiation

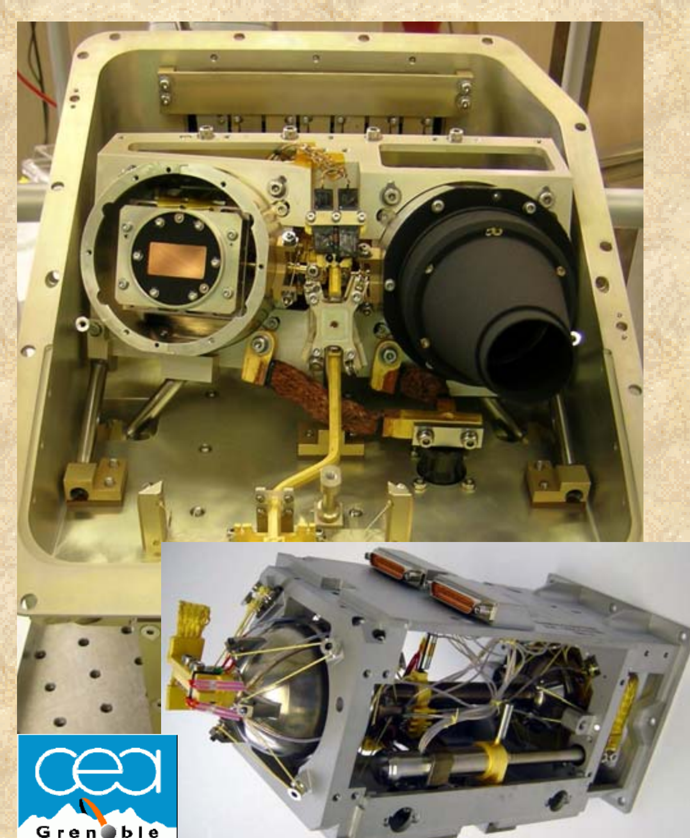
- With optimum bias setting (lower than in lab!) and ramp length / chopping parameters, NEP close to lab values possible in space
- Curing may be necessary only after solar flare, or once per day (self-curing under telescope IR background sufficient)

Further details: Katterloher et al. [6275-42]
Stegmaier et al. [6265-89]

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 ~59h

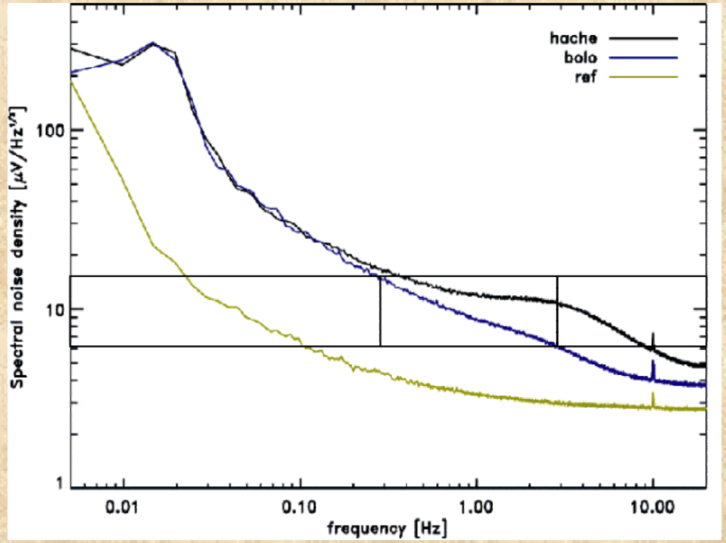


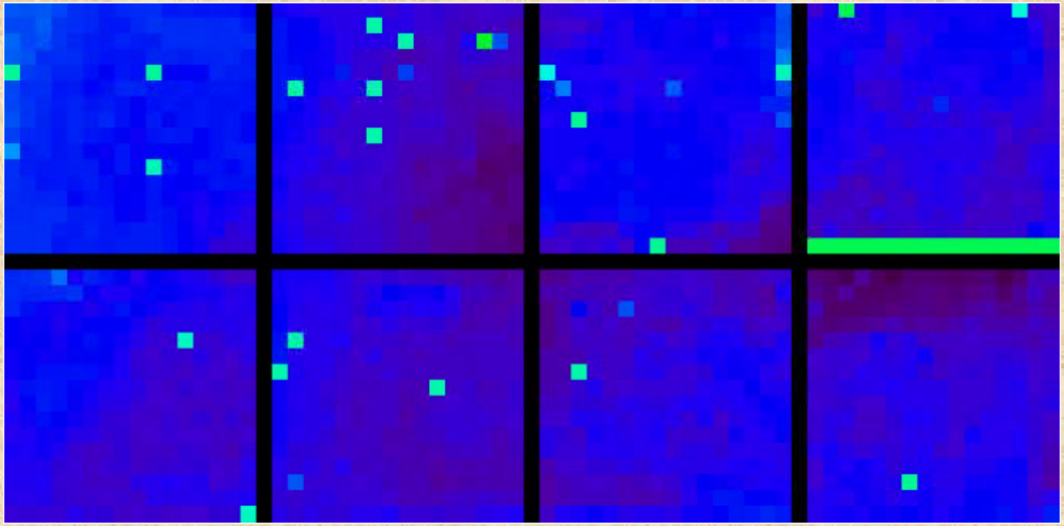


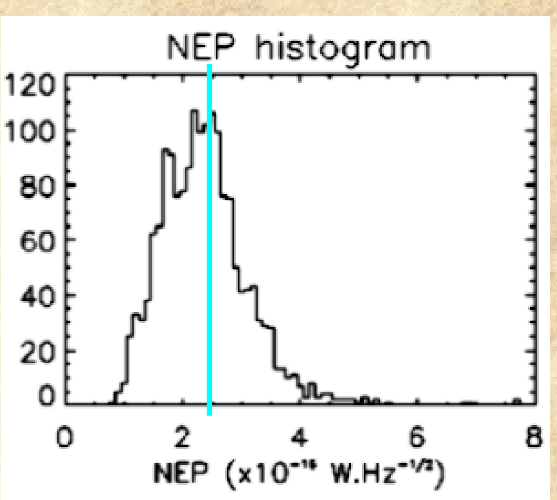
Photometer unit with blue + red focal planes and ^{3}He cooler

FM Blue BFP Performance

- Pixel yield ~98%
- NEP ~1.7 x BLIP
  - But 1/f noise
  - Best NEP only for fast modulation (chopping/ scanning)



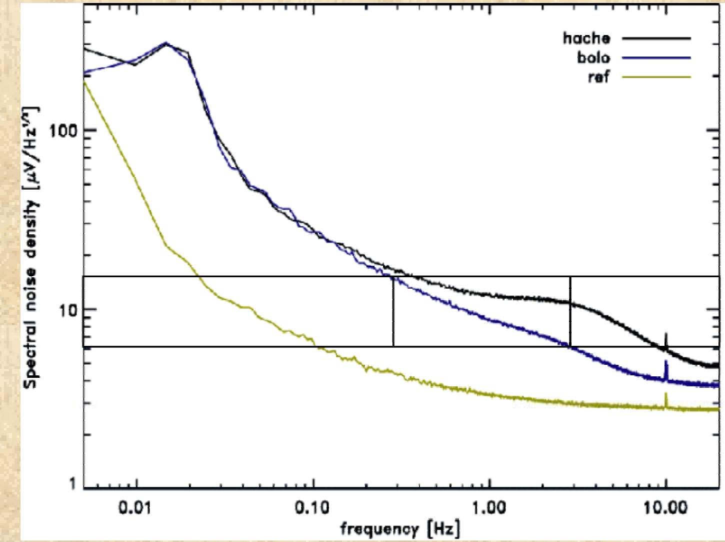


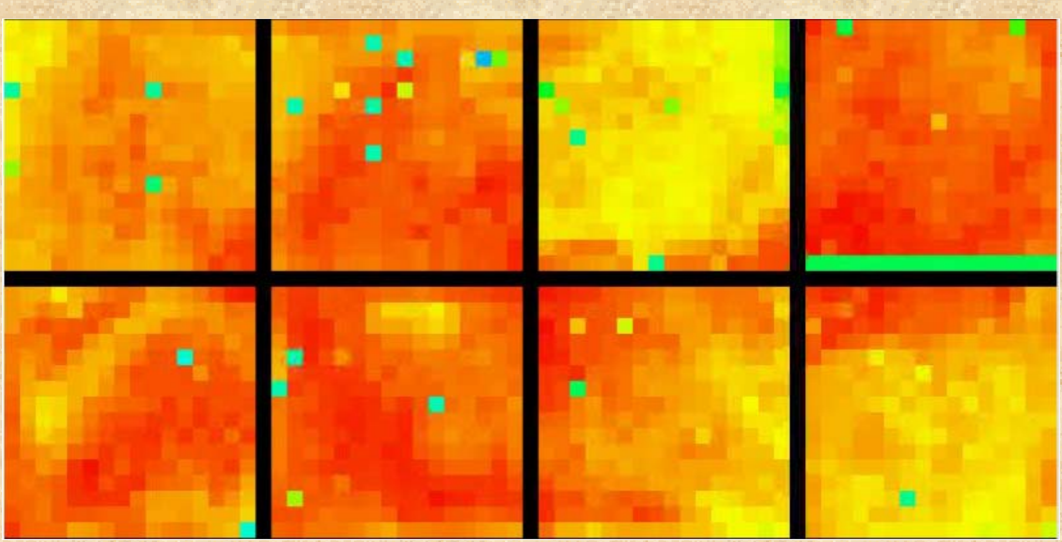


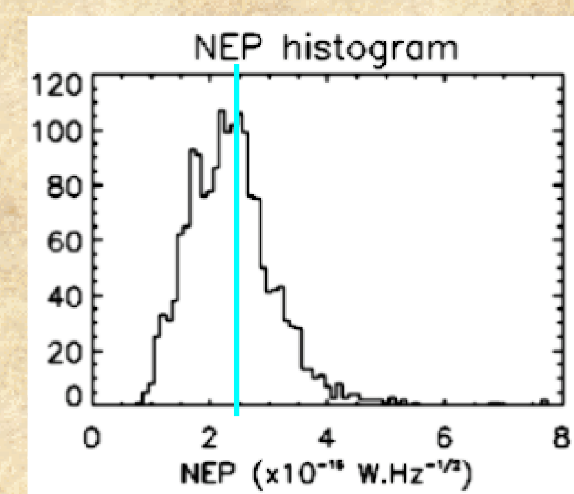
Further details: Billot et al. [6265-11]
Simoens et al. [6275-01]

FM Blue BFP Performance

- Pixel yield ~98%
- NEP ~1.7 x BLIP
  - But 1/f noise
  - Best NEP only for fast modulation (chopping/ scanning)

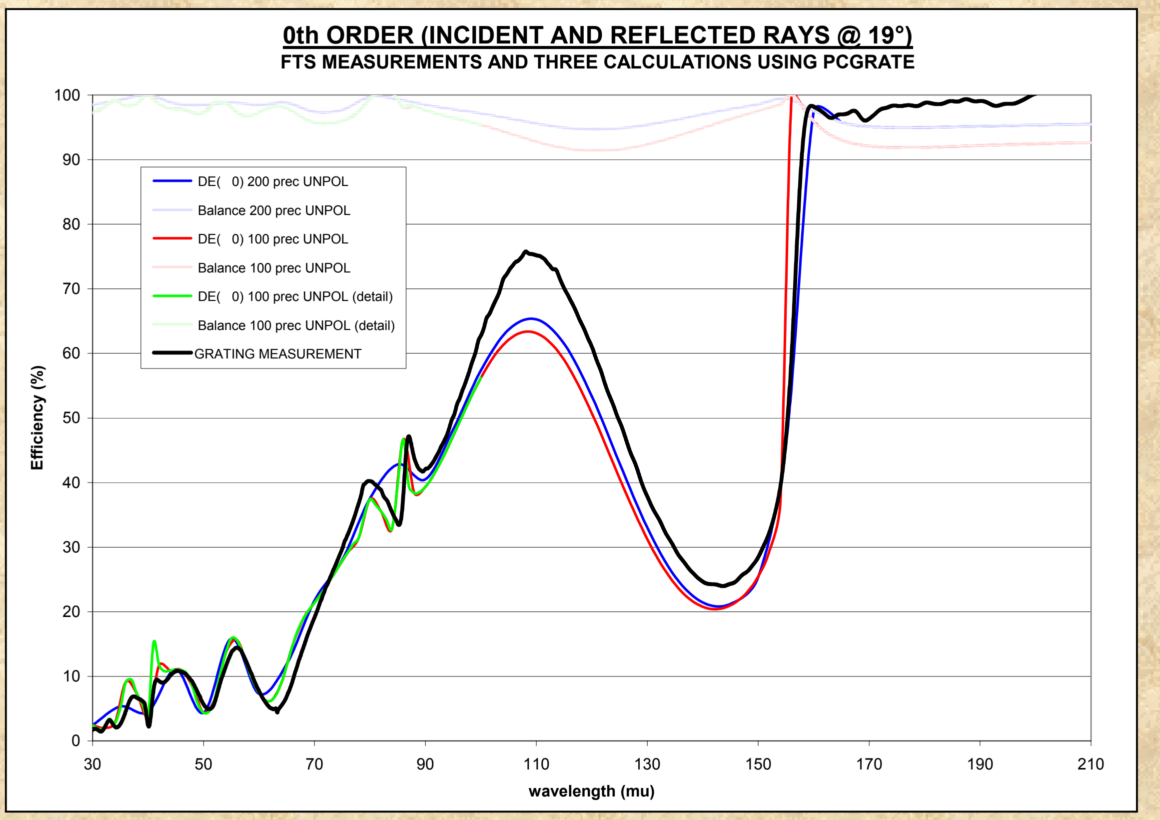






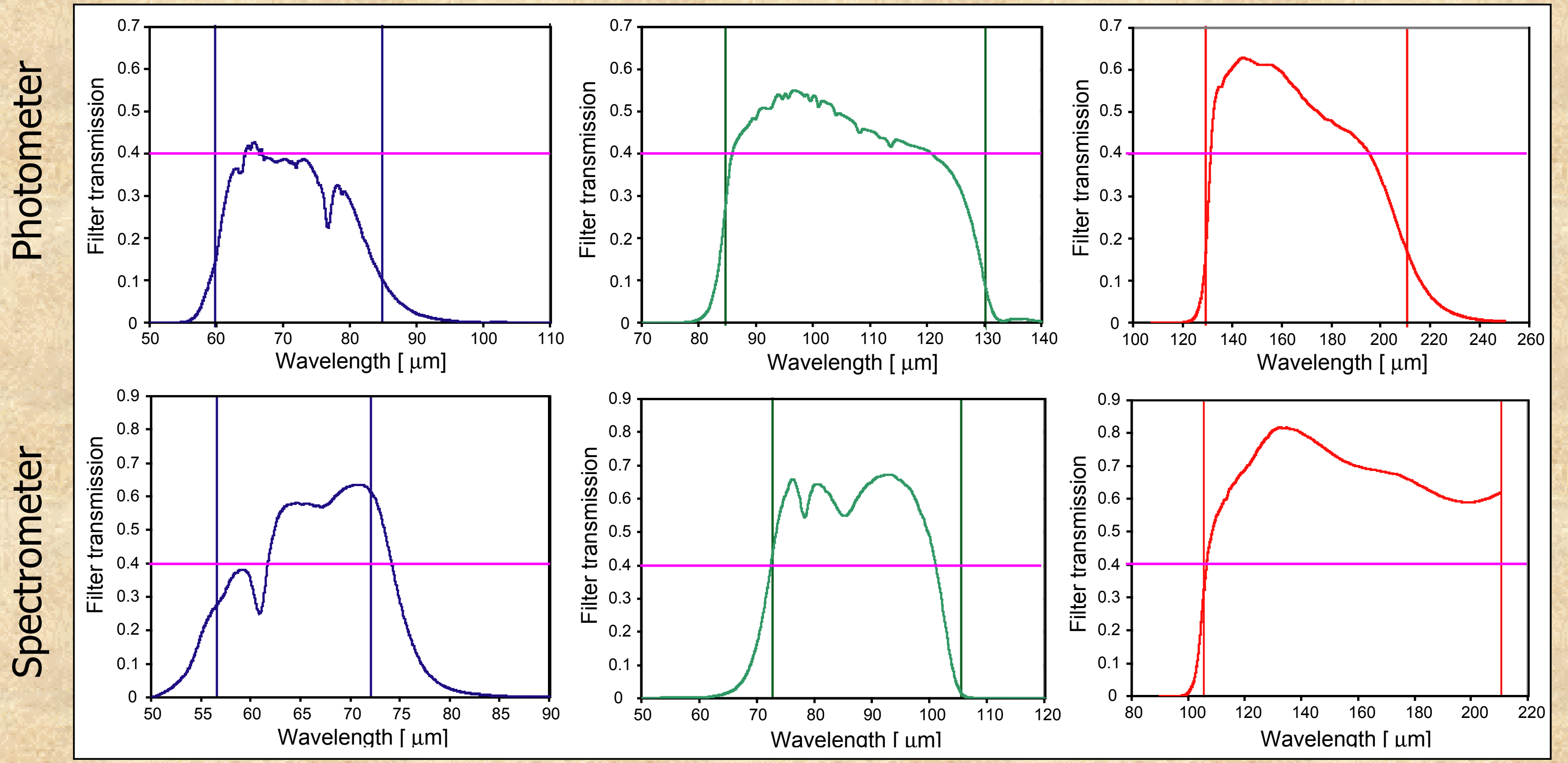
Further details: Billot et al. [6265-11]
Simoens et al. [6275-01]

Grating Efficiency Verification



- Measurement done on production sample in different optical configuration than PACS; however, it gives strong indication that
  - Grating groove profile is correct
  - Numeric E&M model prediction is correct

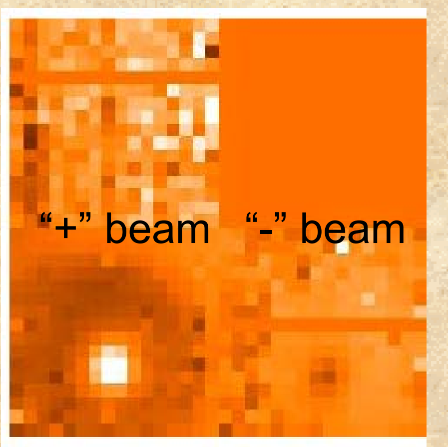
Filter Performance



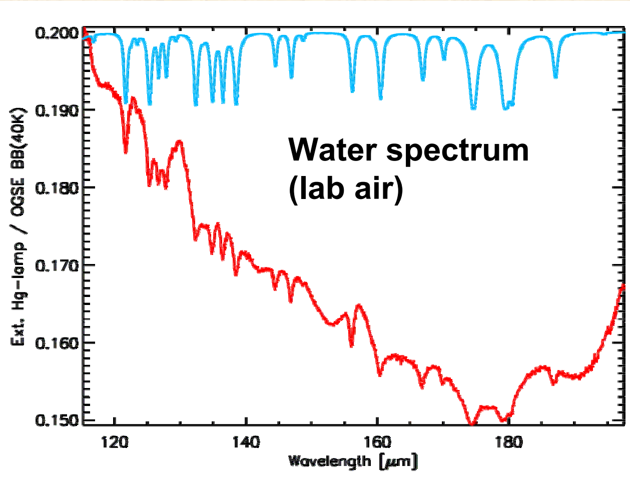
- Requirement of 40% in-band transmission fulfilled or exceeded in most bands

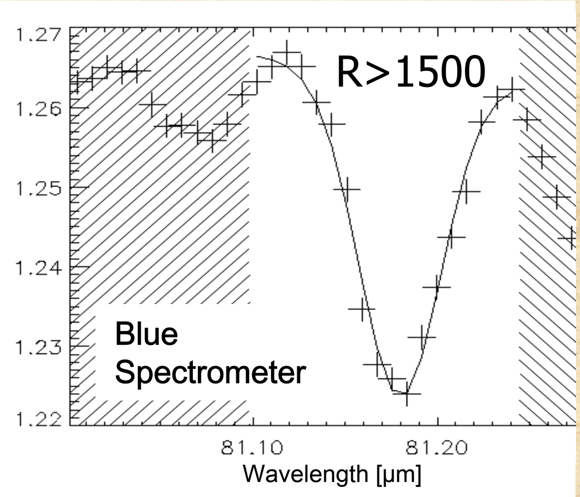
QM Instrument Test: Optical Performance

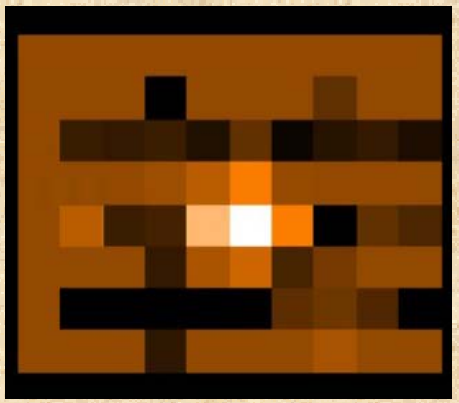
- Source: ~ diffraction PSF size hole mask in front of external blackbody, contrast ~1% of background
- PSF wider than expected (25-45%); attributed to defocus of test optics
- Lower limit to spectral resolving power from measurement of saturated water lines → ok



Blue *photometer*, chopped/nodded

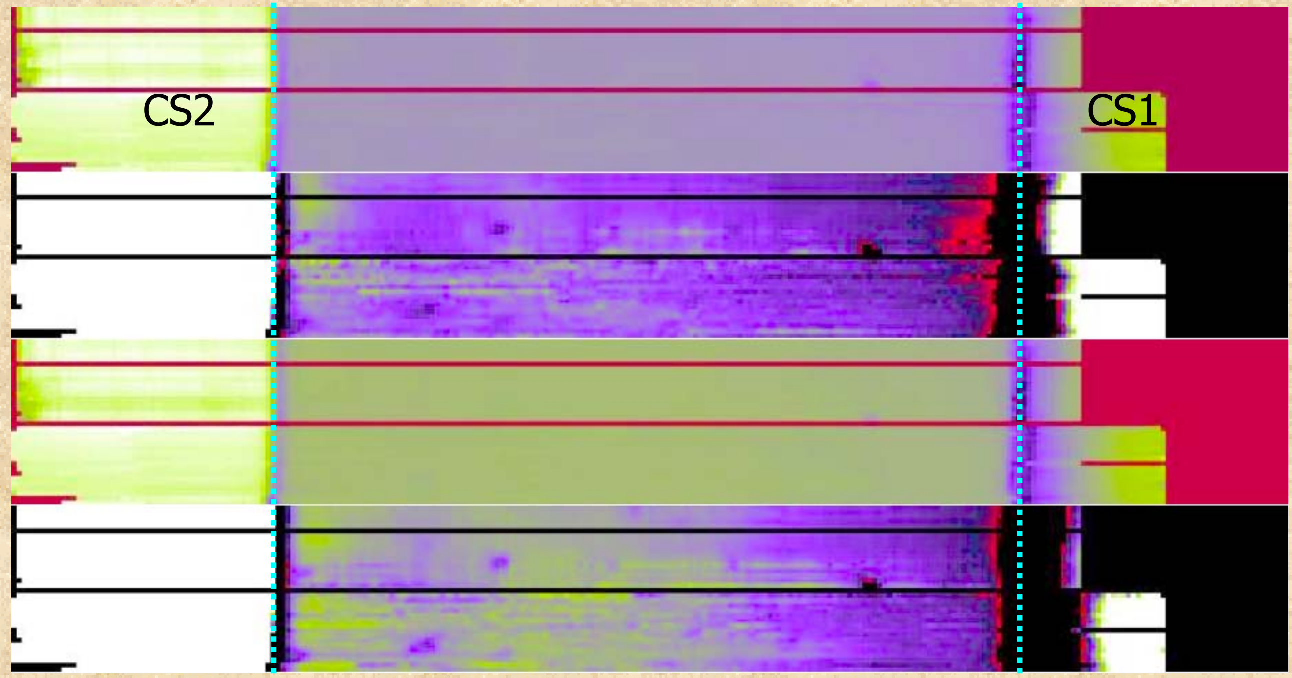






Blue *spectrometer*, partial x-y raster of focal plane

QM Instrument Test: Photometer Flatfield



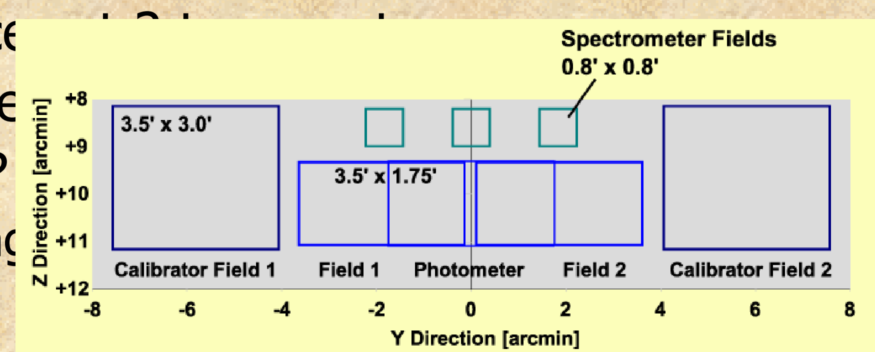
BB1

BB1 (contrast up)

BB2

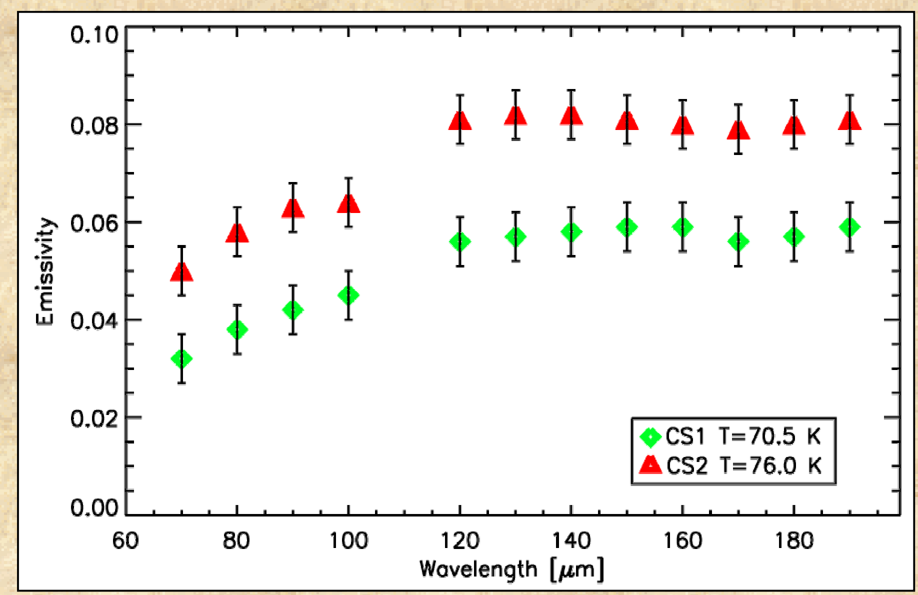
BB2 (contrast up)

- Chopper scan over full FoV, including internal calibration sources
- Illumination: cryogenic BB source
- Flatfielding algorithm (through re
- Structure/spots in optics (filters?
  - elimination by dithering/scanning

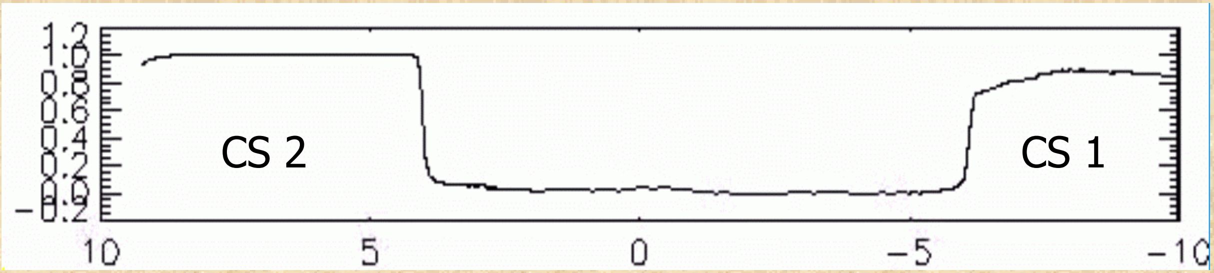


QM ILT: Calibration Sources Performance

- Emissivity
  - Measured against cryogenic OGSE blackbody
  - Values are within specified range.
  - But CS 1 value is likely off due to inhomogeneity



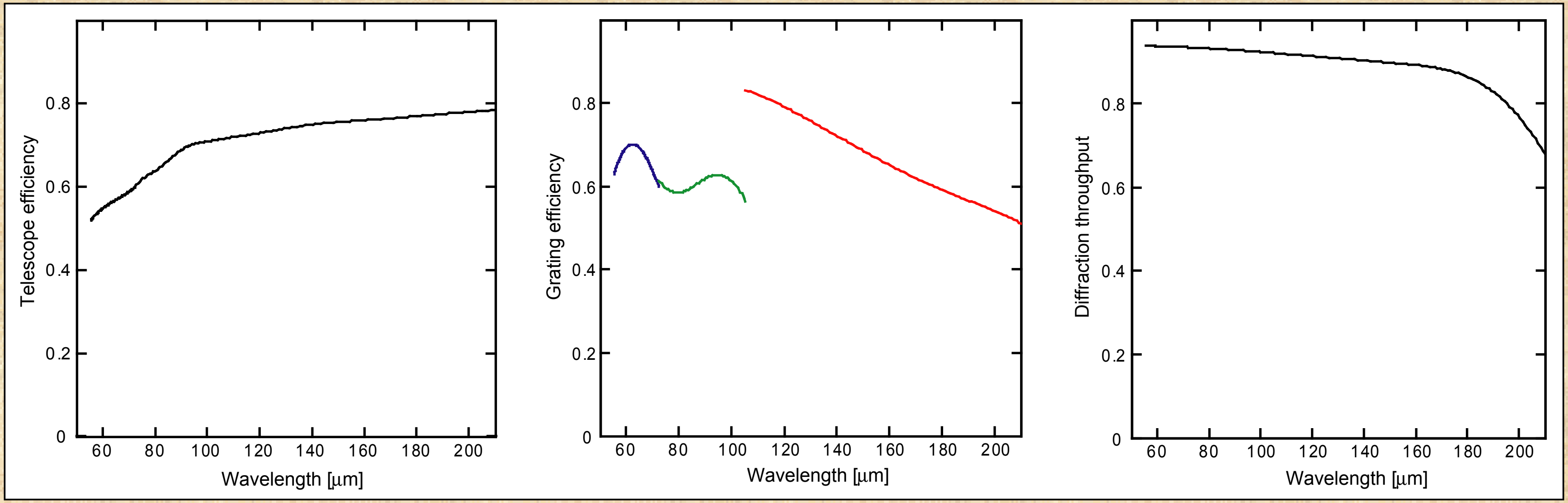
- Homogeneity
  - Ok for CS 2



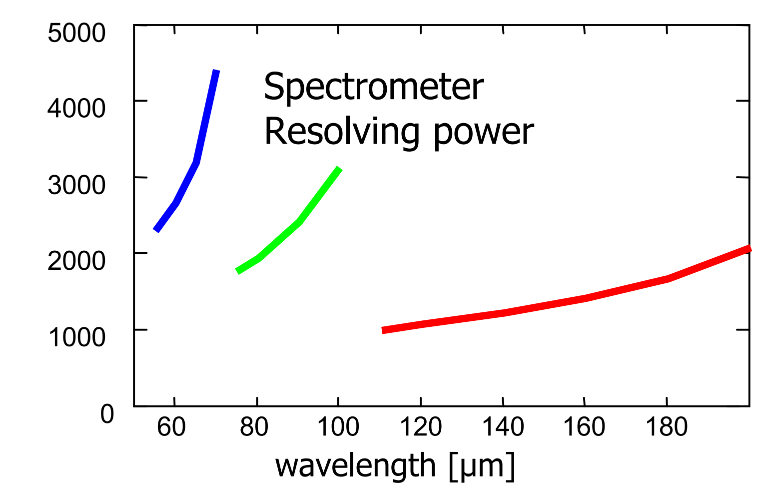
Chopper deflection angle

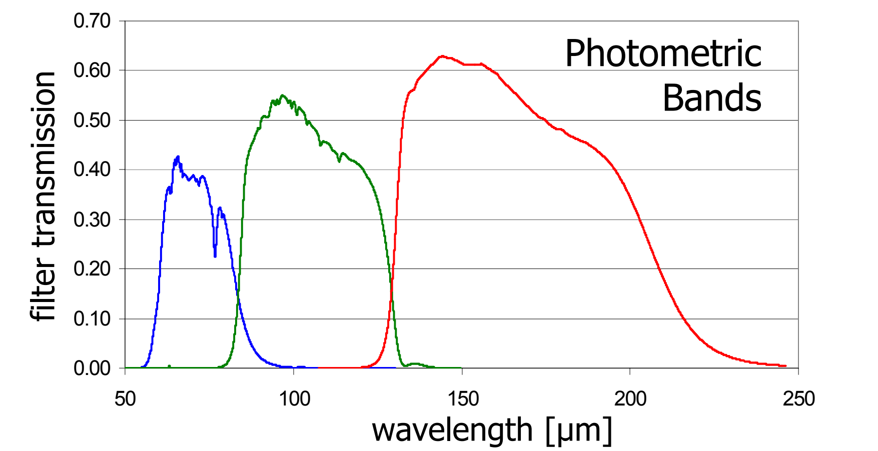
Predicted Instrument Performance

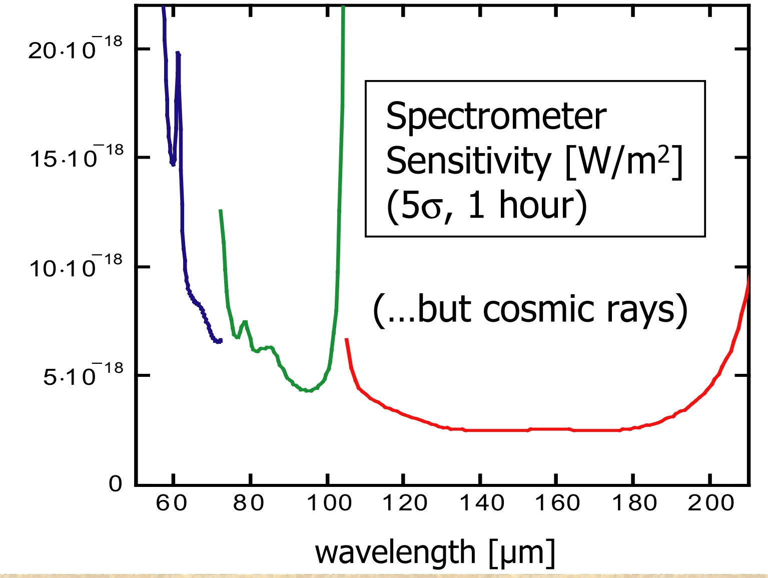
- Calculated optical efficiencies
  - telescope main beam (diffraction + WFE)
  - grating in respective diffraction orders
  - diffraction losses due to IFU (image slicer)

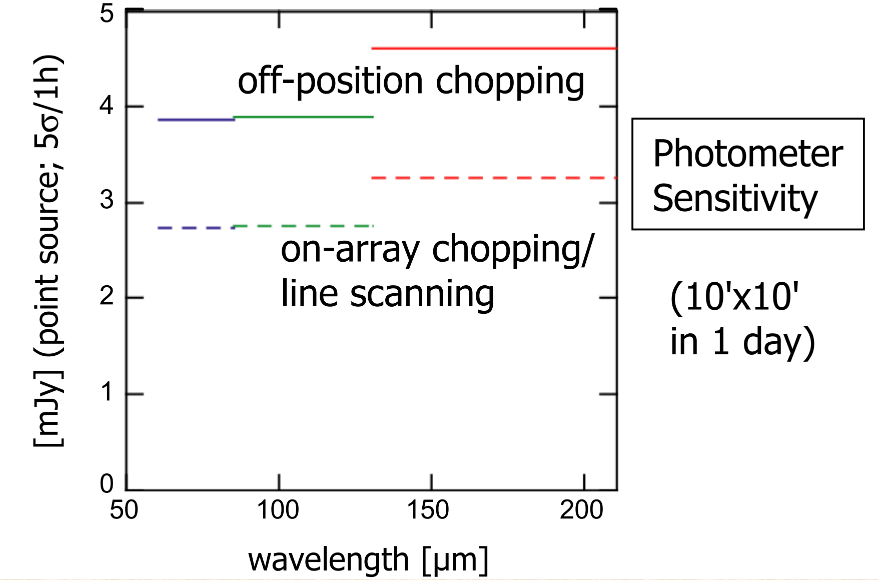


Predicted Instrument Performance



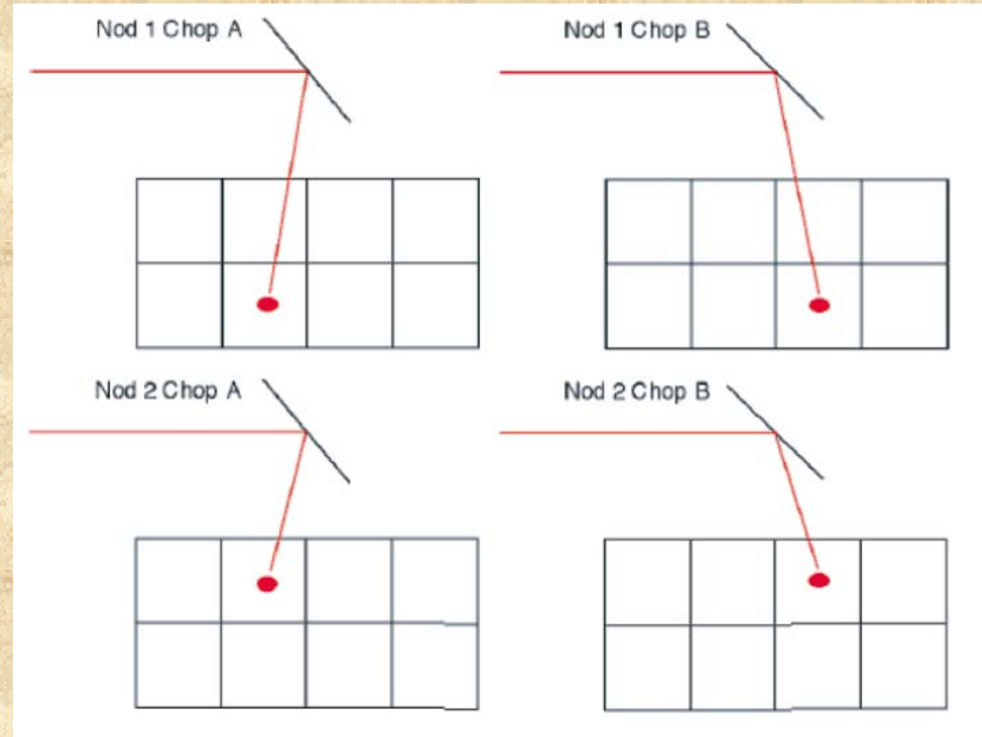






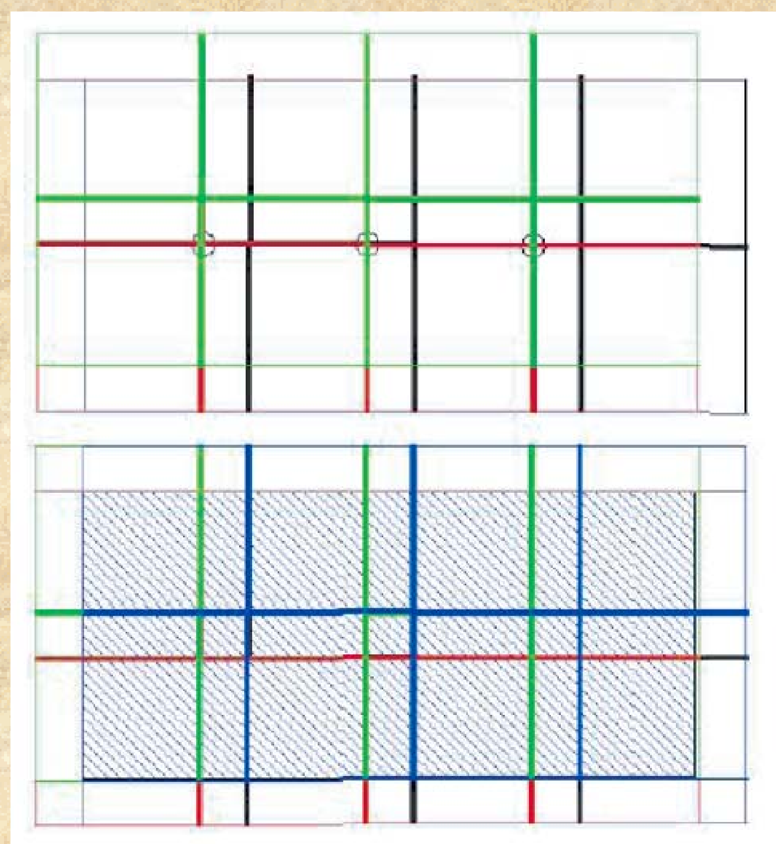
Observing Modes and AOTs

- 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.



Observing Modes and AOTs

- "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.



Observing Modes and AOTs

- 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)
      - Filled arrays allow arbitrary scanning orientation
    - Rastering
      - Note: Rastering without chopping probably precluded by 1/f noise

Observing Modes and AOTs

- 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
  - Up to 10 lines can be specified in one observation, but all lines have to be reachable without a filter change
  - Spectral sampling >3 samples/FWHM (by small up/down scan)
  - **Minimum execution time: 192 s**

Observing Modes and AOTs

- 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.
  - Up to 10 (freely defined) ranges can be specified in one observation, but all lines have to be reachable without a filter change
  - Spectral sampling: high (>3 samples/FWHM)
Nyquist (optimized for speed; **minimum time for full first+second order scan: 1440 s**)

Observing Modes and AOTs

- 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: crowed fields and extended spectral structures; chopping between sky and internal CS; map parameters in sky coordinates
  - **Minimum execution time: 2280 s**

How to Estimate Observing Times?

- Under preparation: HSPOT (developed from Spitzer SPOT) will give accurate time budgets
- Now: A simple 'Time Guesstimator' is available for feasibility checks and rough estimates, follow the link 'Time Guesstimator' at http://pacs.ster.kuleuven.ac.be/
- Be aware of confusion limits! (0.6, 3, 11mJy)