SPIRE: Herschel's Sub-millimetre Camera and Spectrometer

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On behalf of the SPIRE Consortium
(Canada, Italy, France, Spain, Sweden, UK, USA)

The SPIRE Consortium

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- Cardiff University, UK
- CEA Service d'Astrophysique, Saclay, France
- Institut d'Astrophysique Spatiale, Orsay, France
- Imperial College, London, UK
- Instituto de Astrofisica de Canarias, Tenerife, Spain
- Istituto di Fisica dello Spazio Interplanetario, Rome, Italy
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- Mullard Space Science Laboratory, Surrey, UK
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- UK Astronomy Technology Centre, Edinburgh, UK
- Rutherford Appleton Laboratory, Oxfordshire, UK
- Stockholm Observatory, Sweden
- Università di Padova, Italy
- University of Lethbridge, Canada

Instrument Design Drivers

- **Photometer**
  - Deep mapping with highest efficiency and largest possible field of view
    - Multi-band coverage with simultaneous observation
  - Point and compact source observation with high efficiency

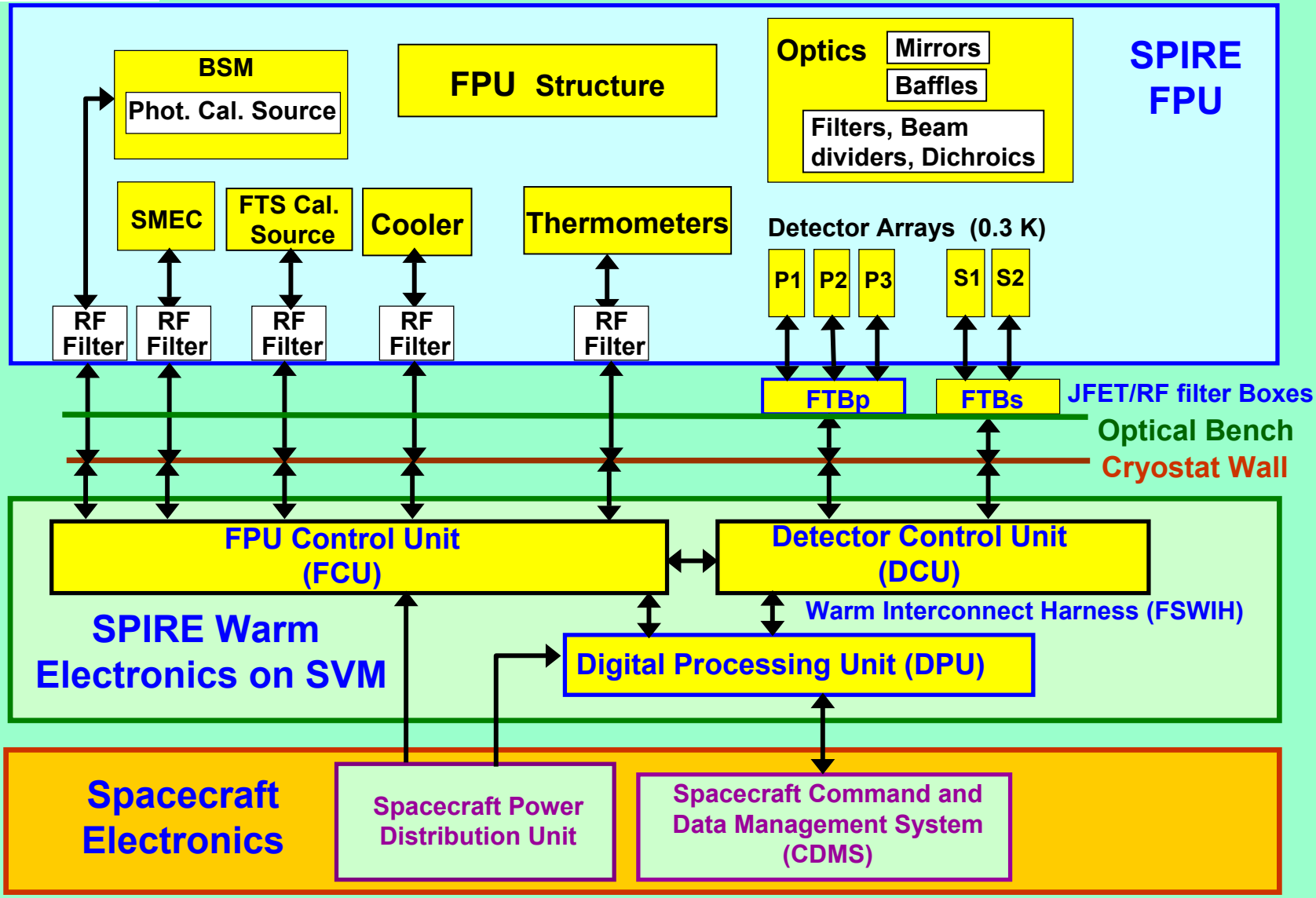
- **Spectrometer**
  - Sensitivity optimised for point/compact source spectroscopy
  - Imaging spectroscopy with maximum available field of view
  - Wide wavelength coverage
  - Variable spectral resolution (few x 10 to few x 100)

- **Both**
  - Thermal background dominated by the Herschel telescope
  - Simplicity, affordability, reliability, ease of operation
  - Complementary to other Herschel instruments and other facilities

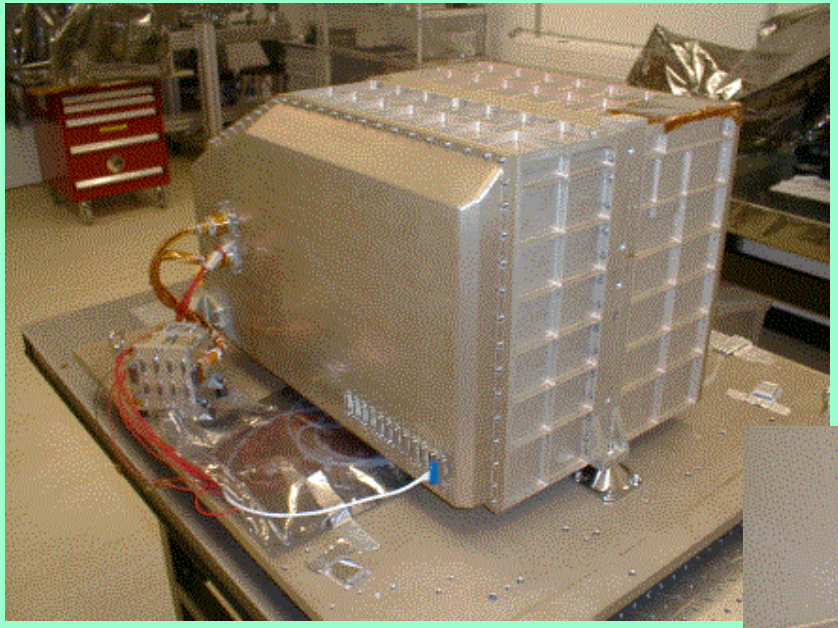
Instrument Summary

- **3-band imaging photometer**
  - 250, 360, 520 μm (simultaneous)
  - $\lambda/\Delta\lambda \sim 3$
  - 4 x 8 arcminute field of view
  - Diffraction limited beams (17, 24, 35")
- **Imaging FTS**
  - 200 - 670 μm
  - 2.6 arcminute field of view
  - $\Delta\sigma$ = 0.4 cm^{-1} (goal 0.04 cm^{-1})
    ($\lambda/\Delta\lambda \sim$ 20 - 100 (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
  - No on-board data processing

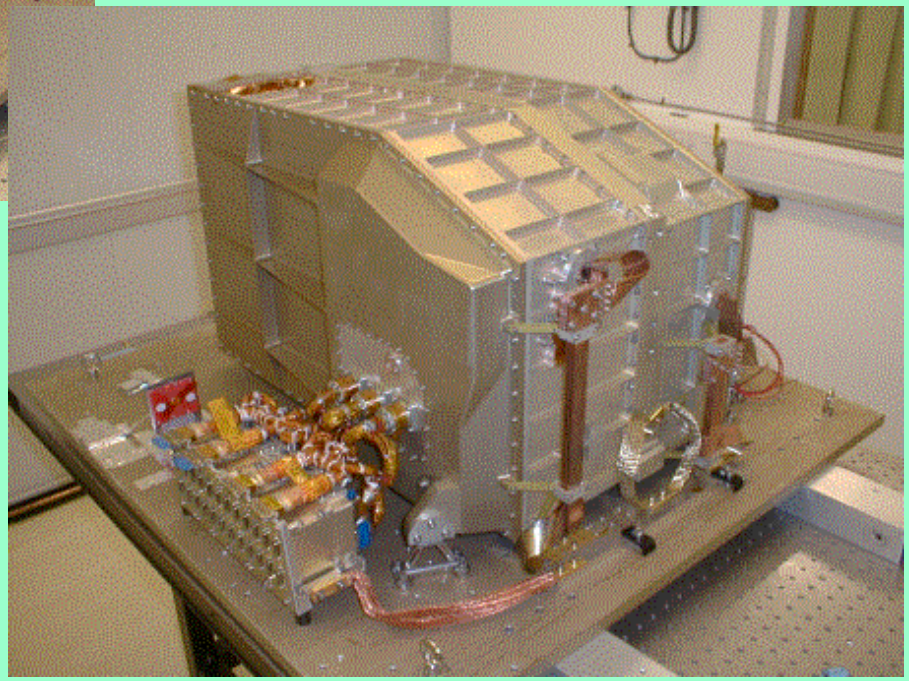
SPIRE Block Diagram



Focal Plane Unit

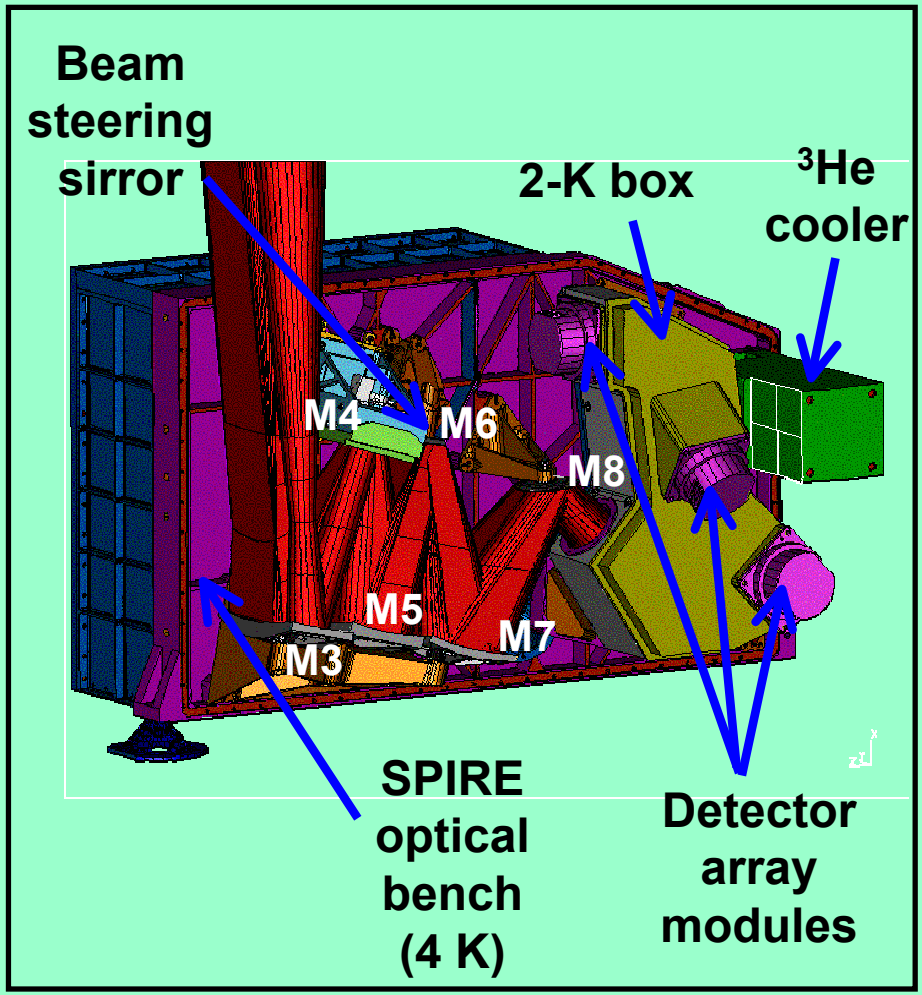


Spectrometer side

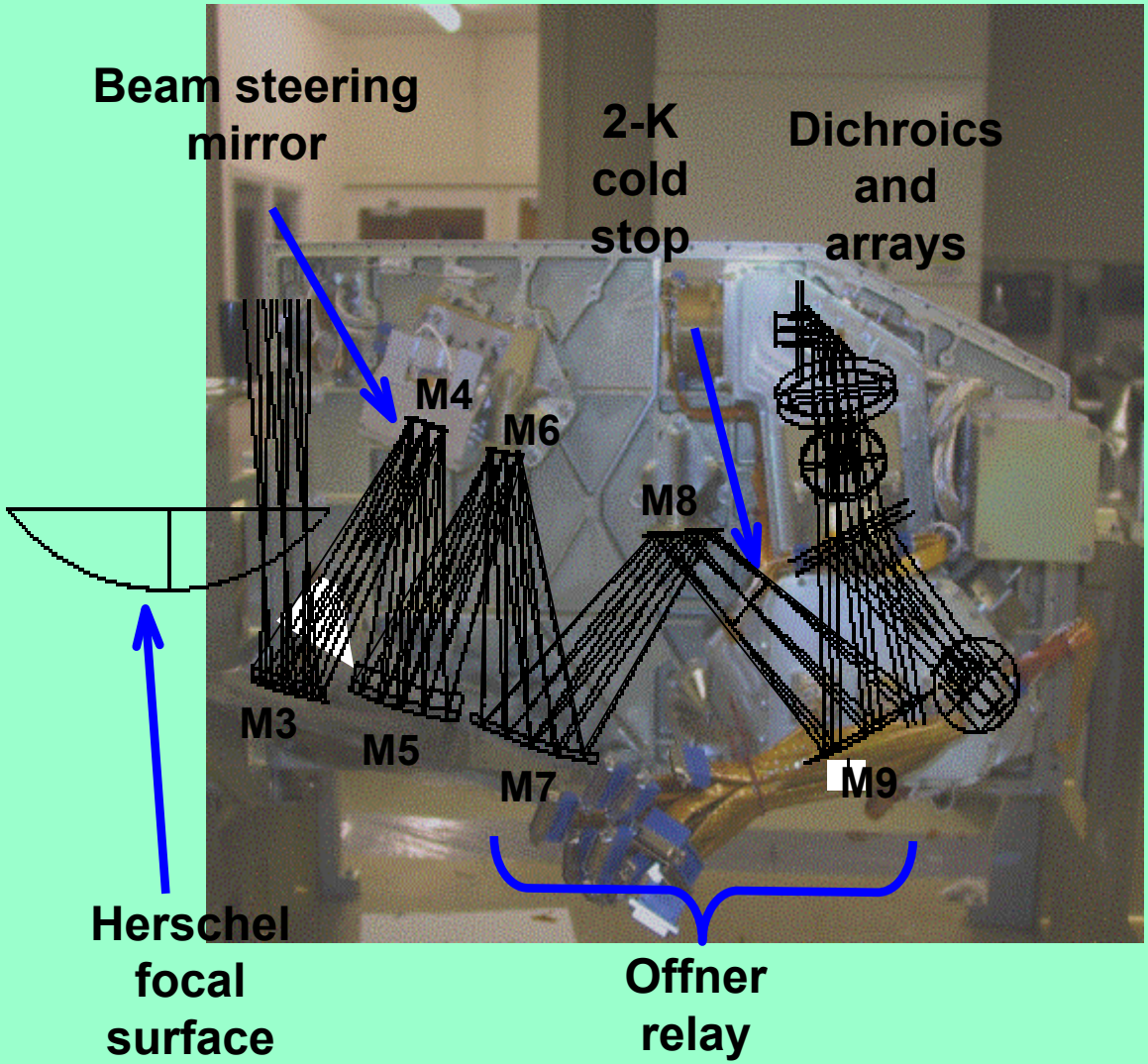


Photometer side

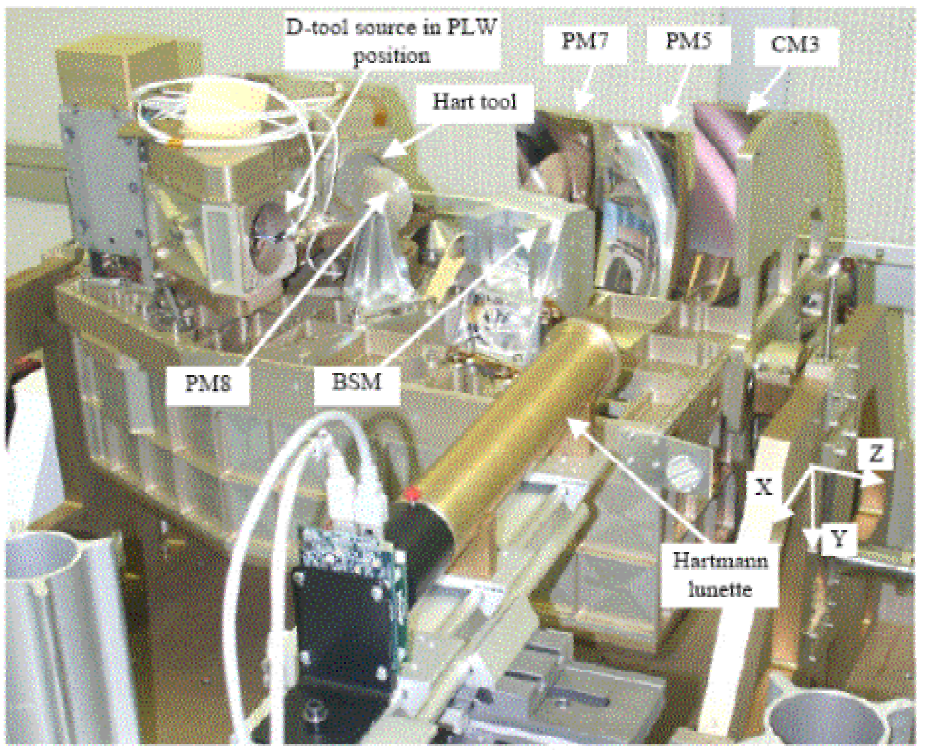
Photometer Layout and Optics

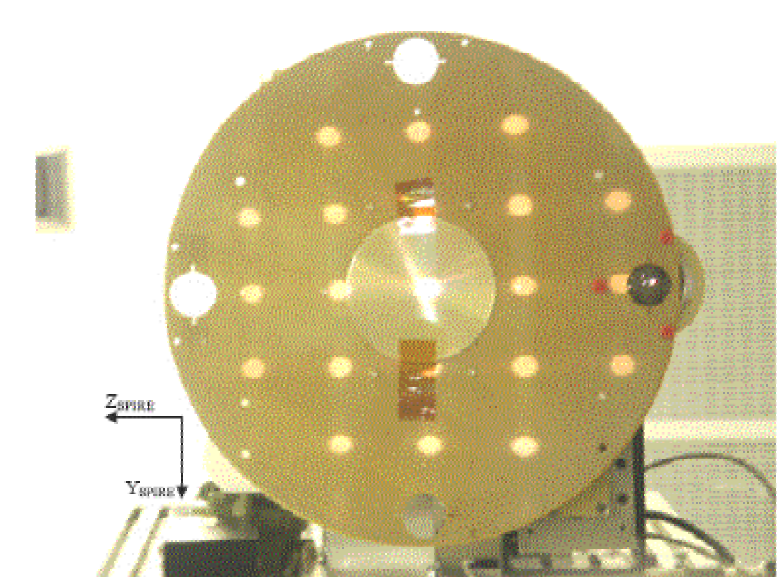


Photometer Implementation

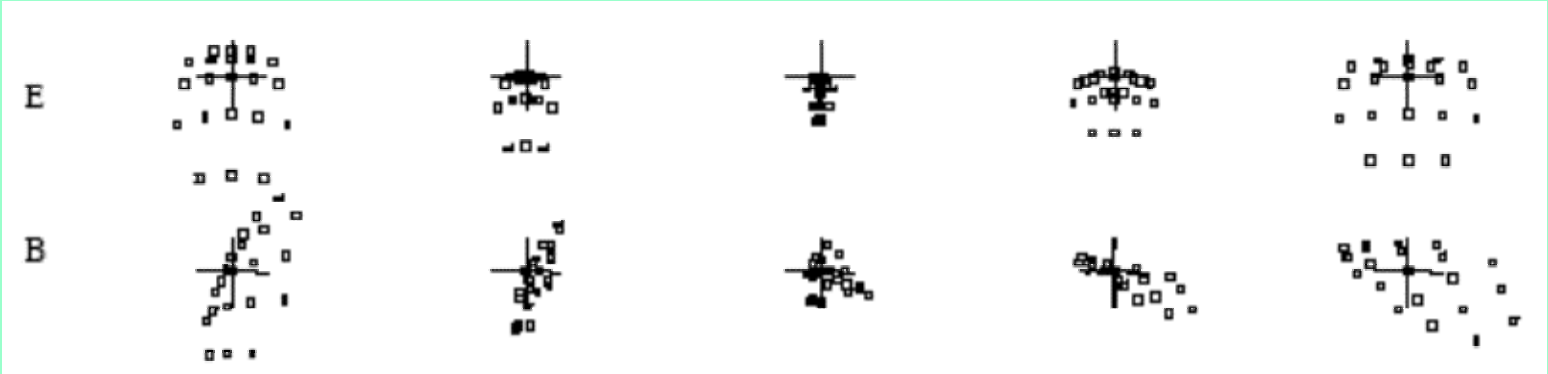


Photometer Alignment





Photometer Alignment Result



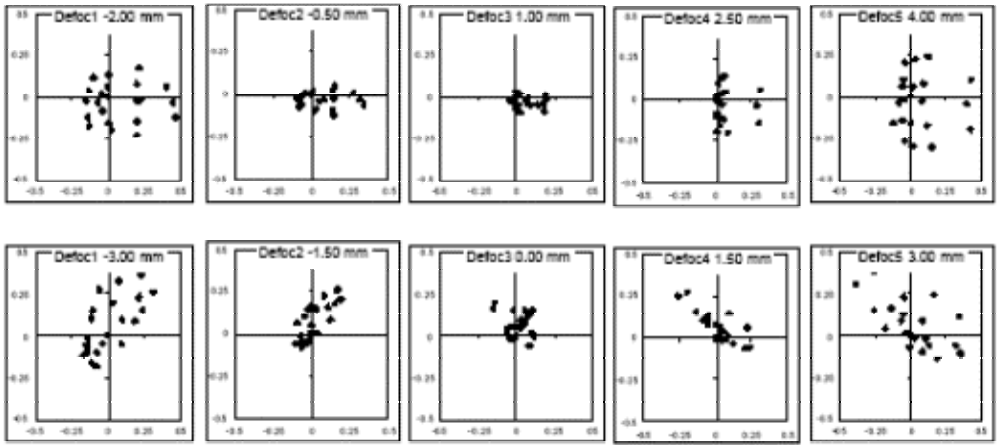
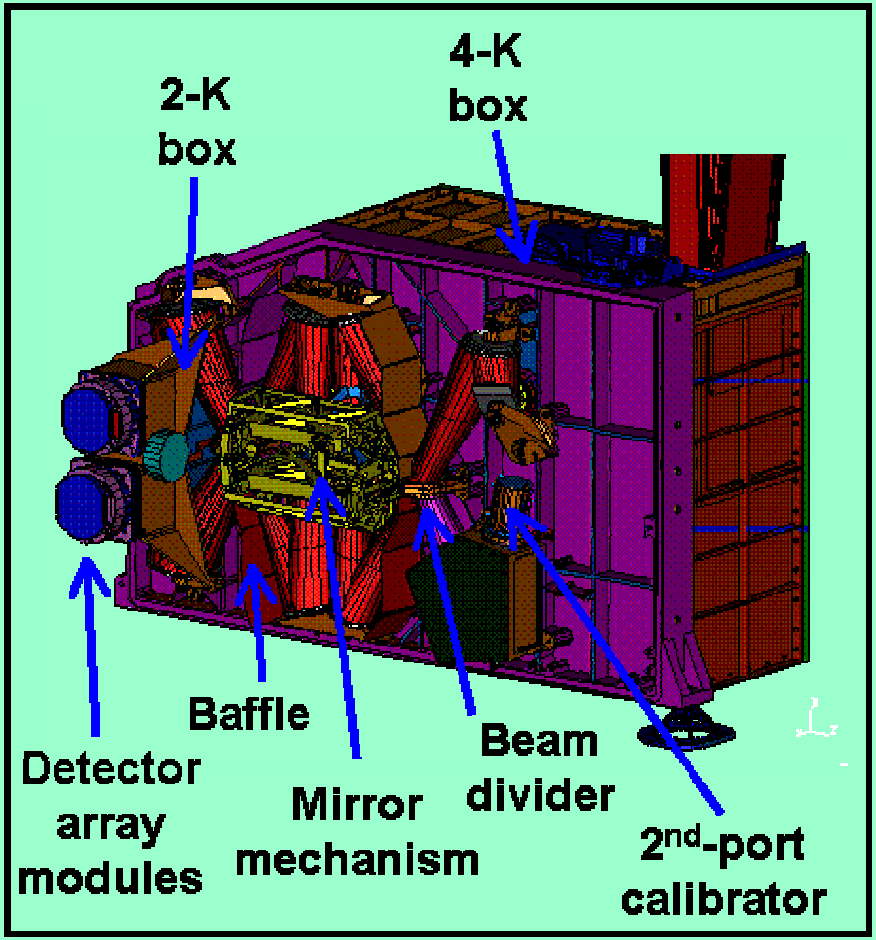
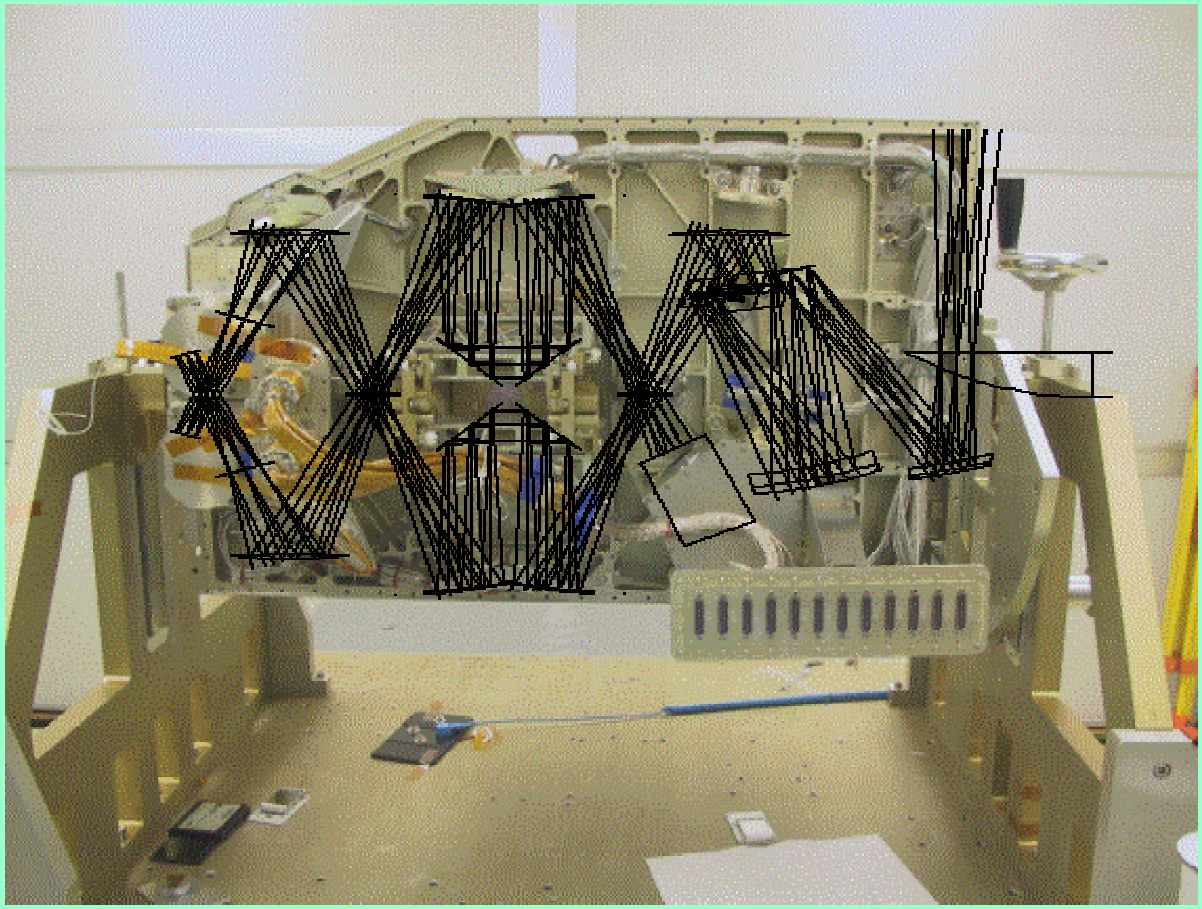


Figure 11. Through-focus spoy diagrams obtained from the Hartmann tests for field point E (upper row) and B (lower row). See Figure 10 for explanations.

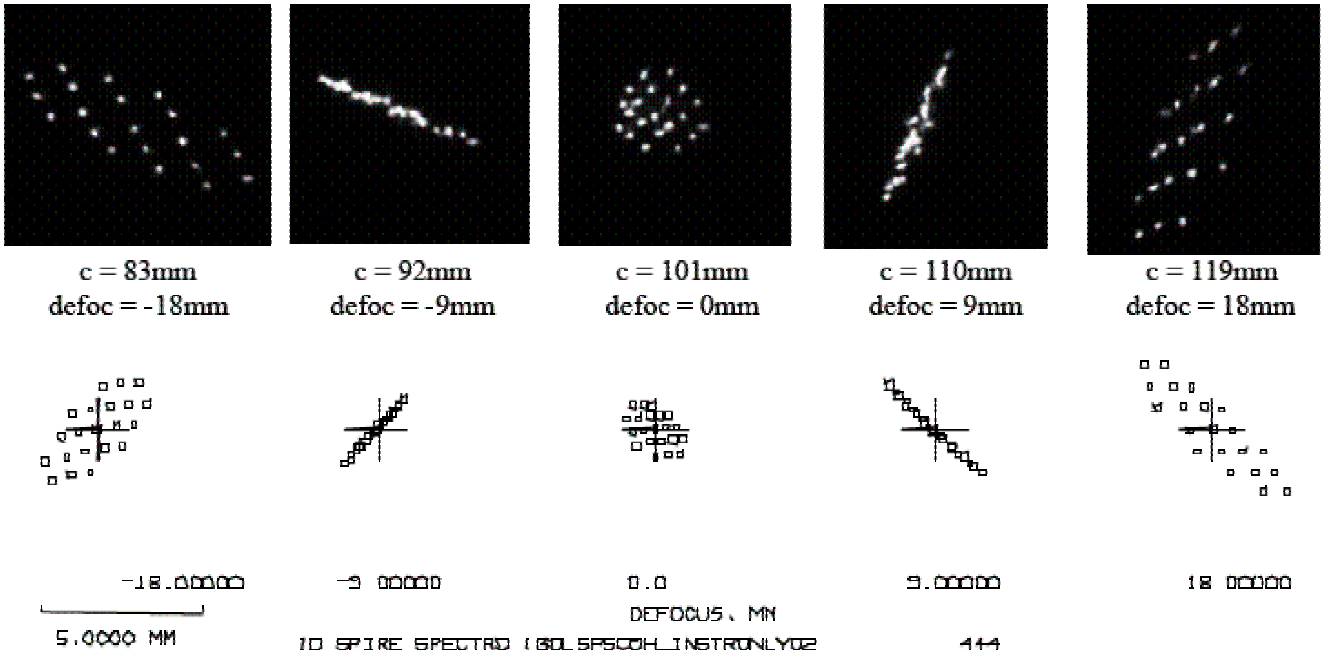
FTS Layout and Optics

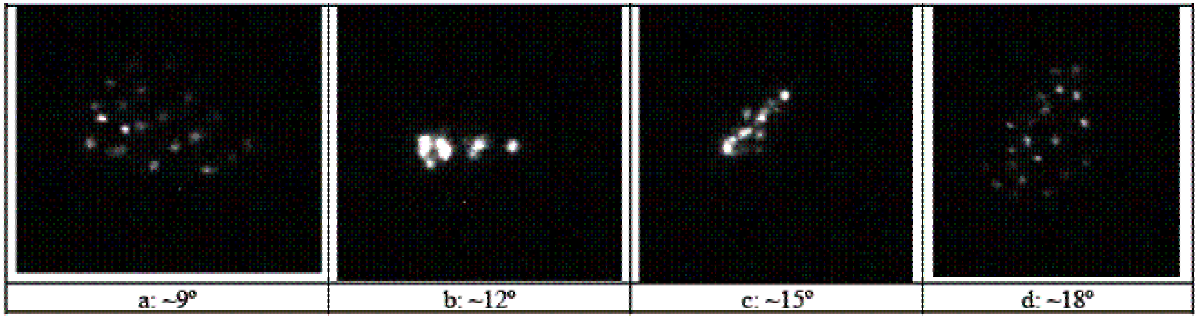


Spectrometer Implementation

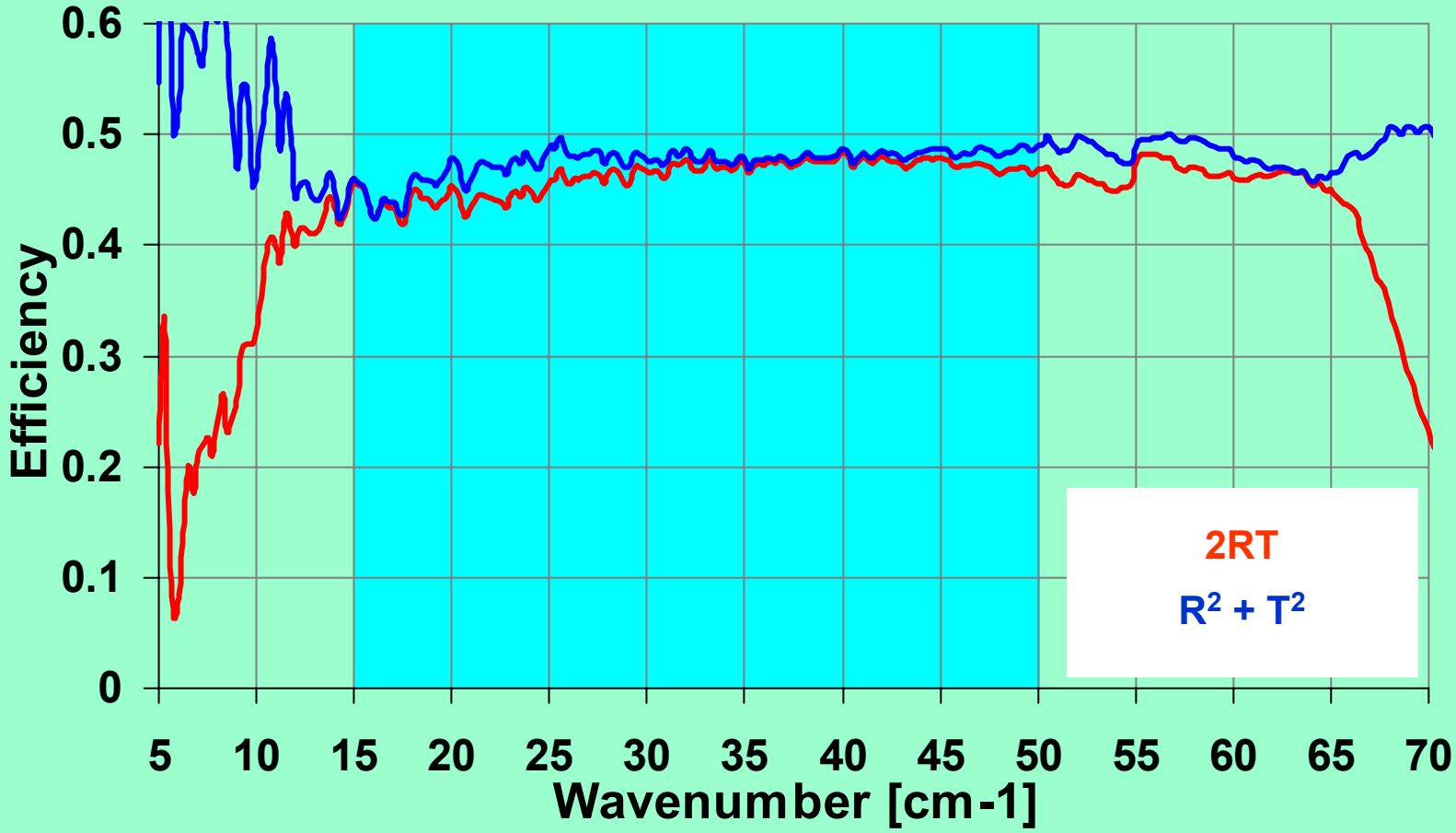


Spectrometer Alignment Results



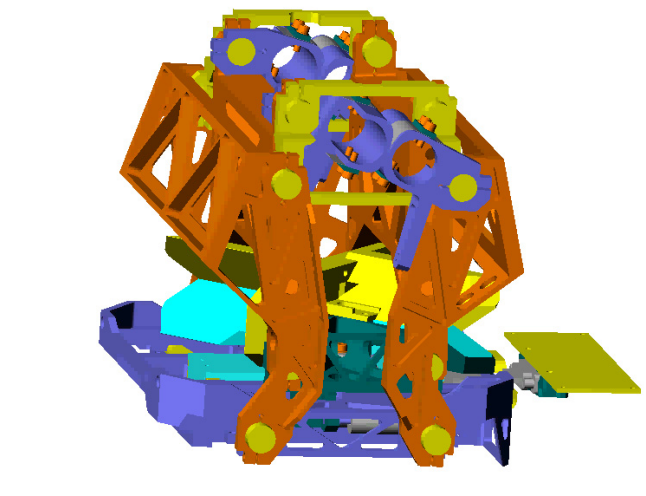


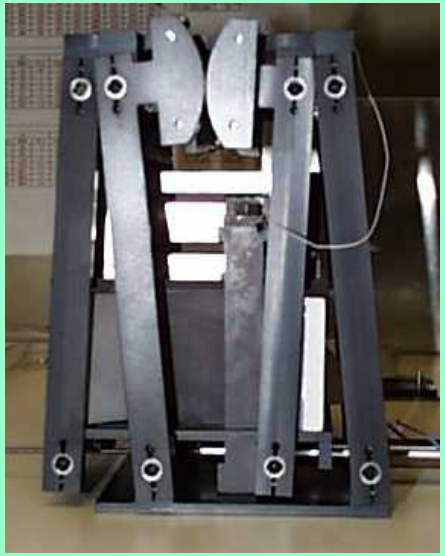
FTS Prototype Broadband Beam Divider



FTS Mechanism

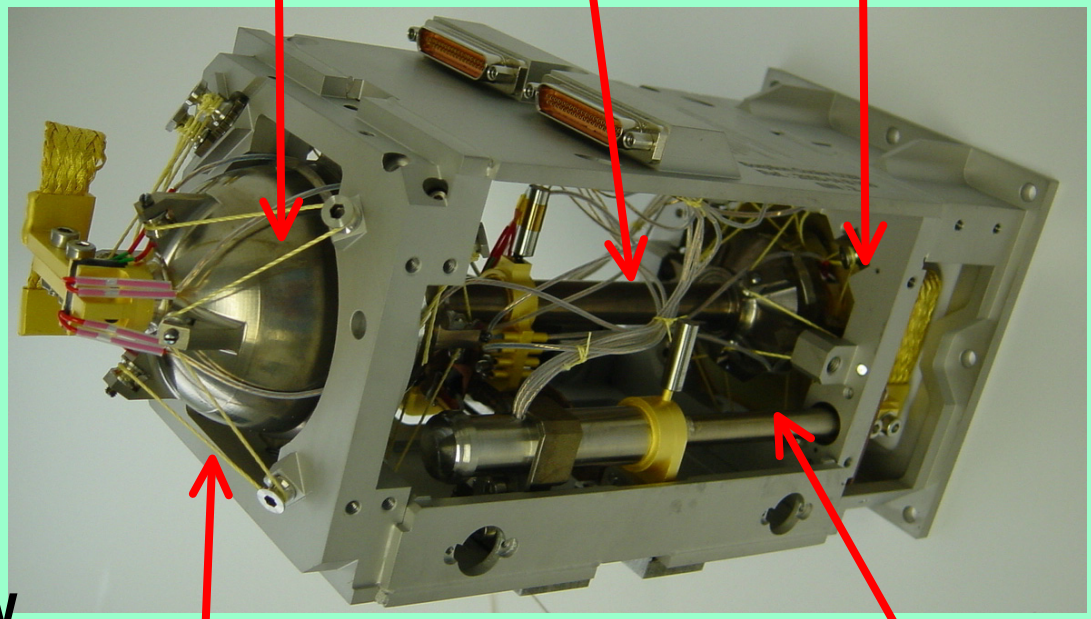
- Double parallelogram carriage with toothless gear
- Moiré fringe position measurement system (0.01 μm accuracy)
- -0.3 ⟷ +3.5 cm movement
- Continuous scan or step-and-integrate operation





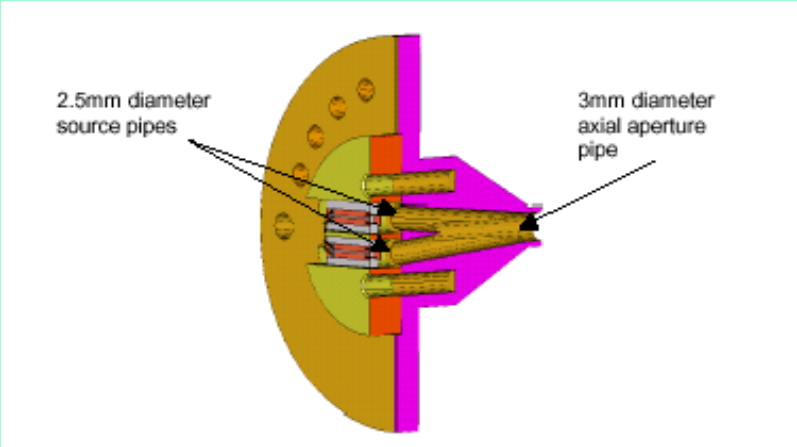
(Lionel's wonderful) ^{3}He Cooler

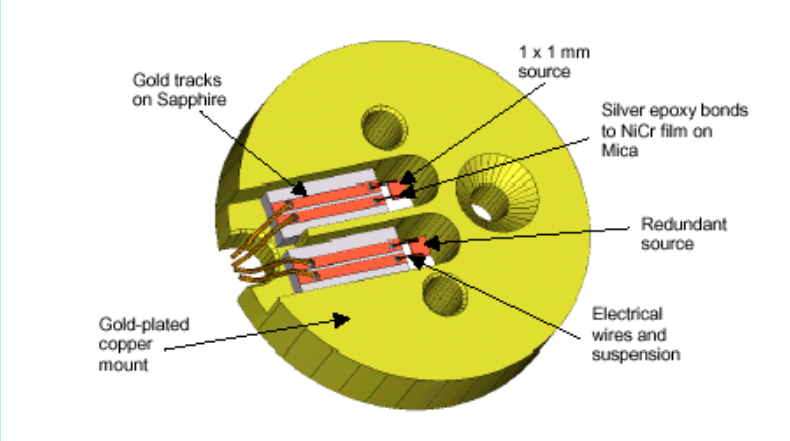
- Cold stage temp. < 280 mK
- Hold time > 46 hrs
- Cycle time < 2 hrs
- Average load on ^{4}He tank < 3 mW
- Heat lift provided to detector arrays > 10 μW
- Gas-gap heat switches (no moving parts)

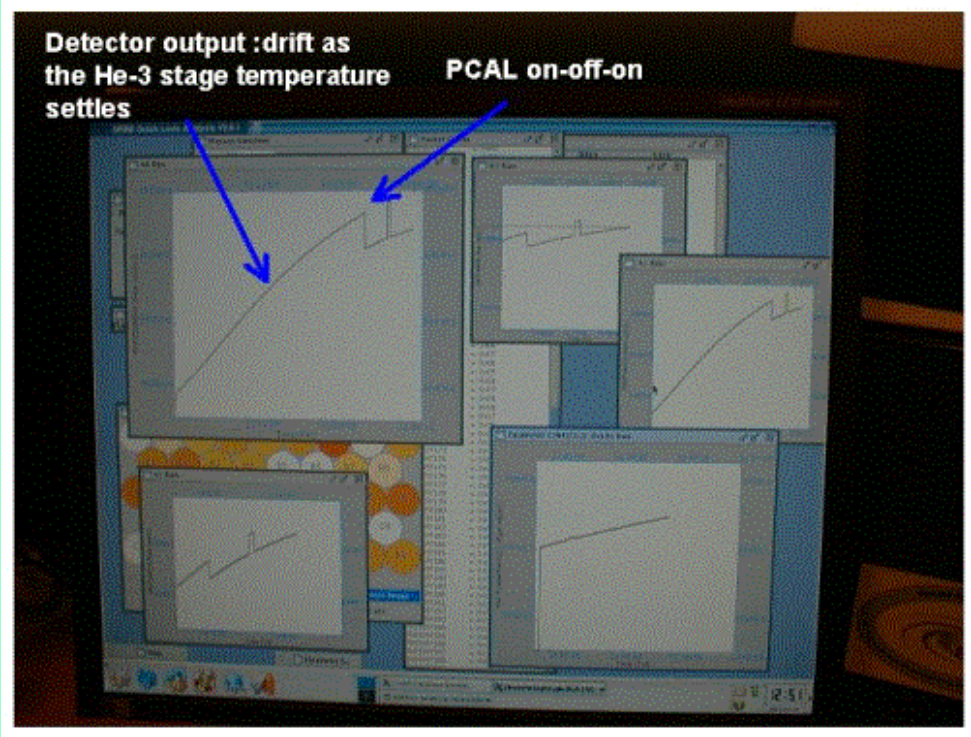


CQM cooler

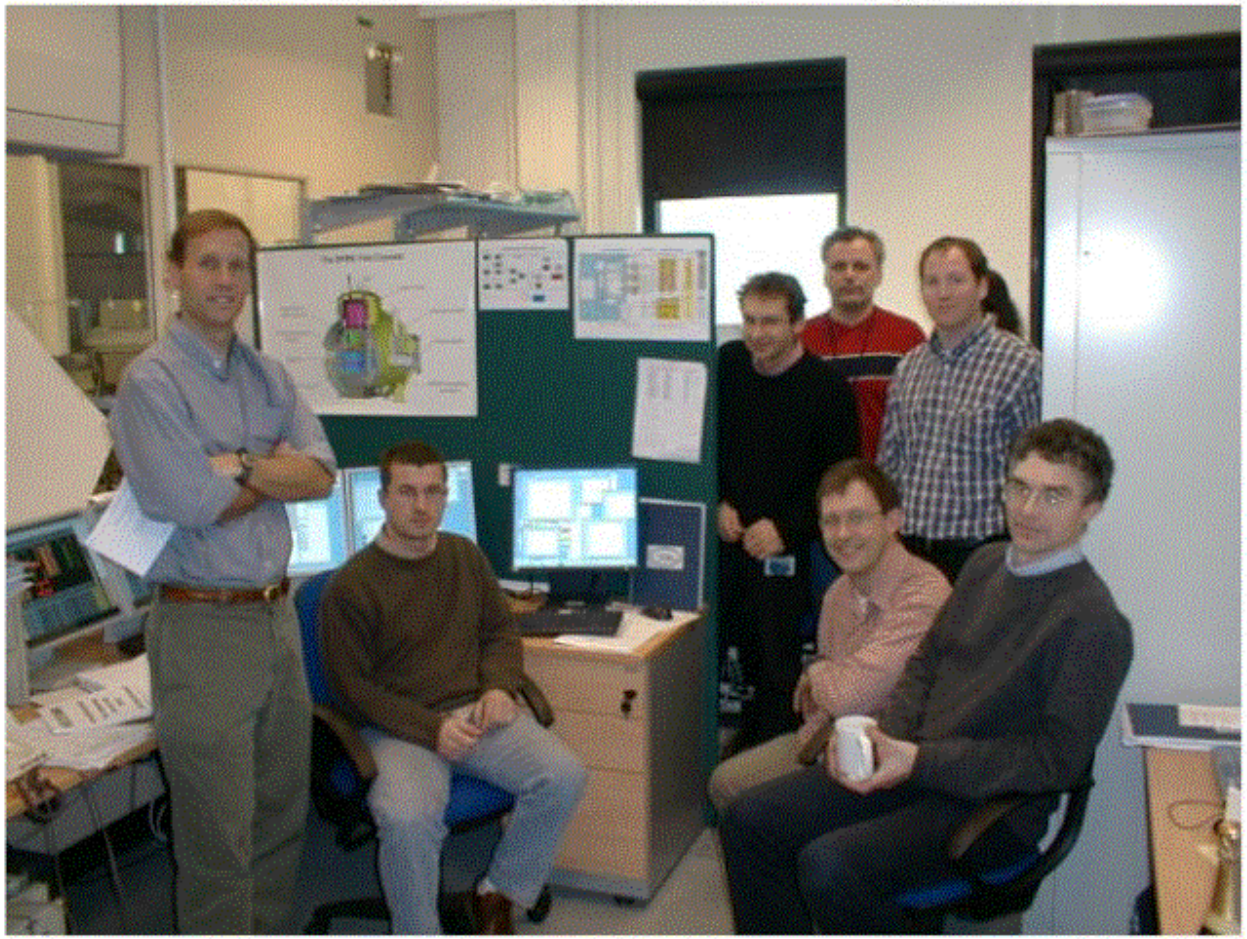
Photometer Thermal Source





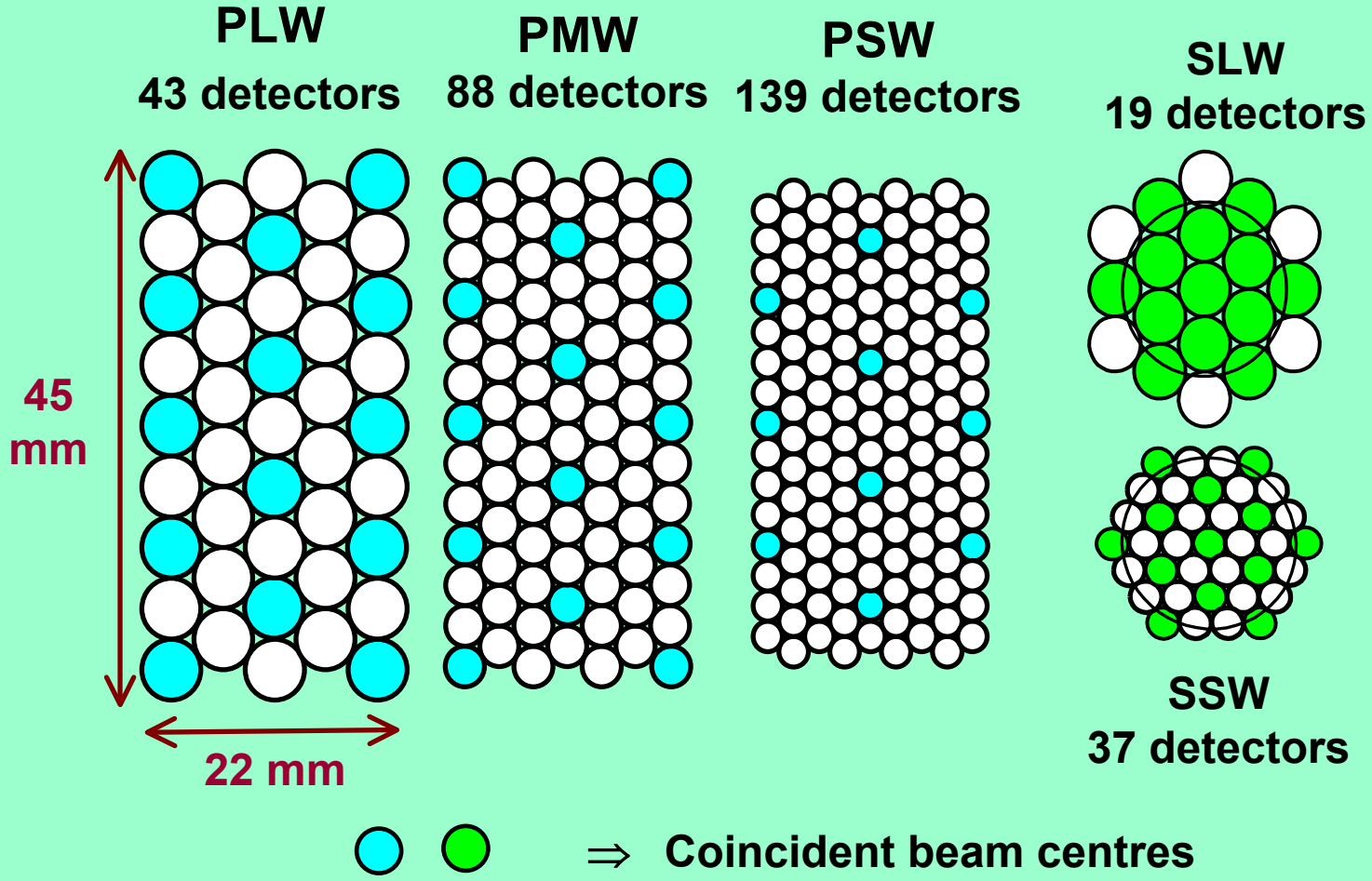


SPIRE CQM first light, 4 February 2004



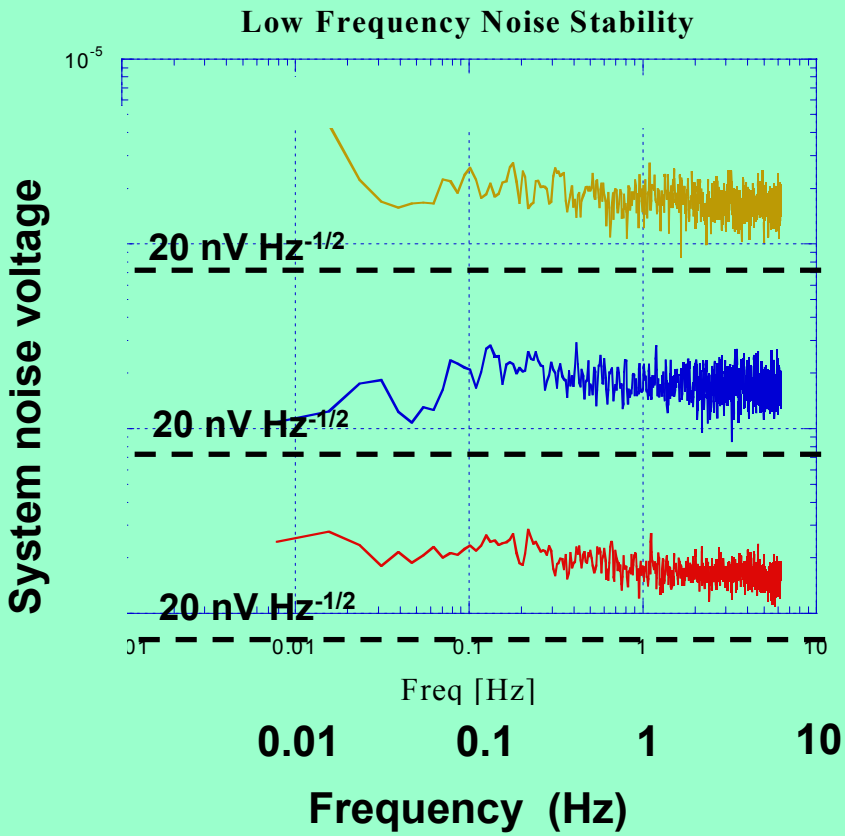
Detector Arrays (2Fλ Feedhorns)

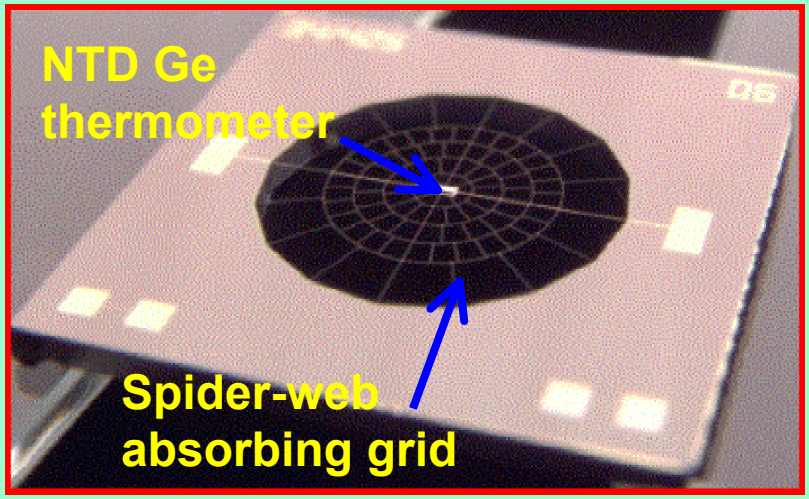
Photometer	Spectrometer

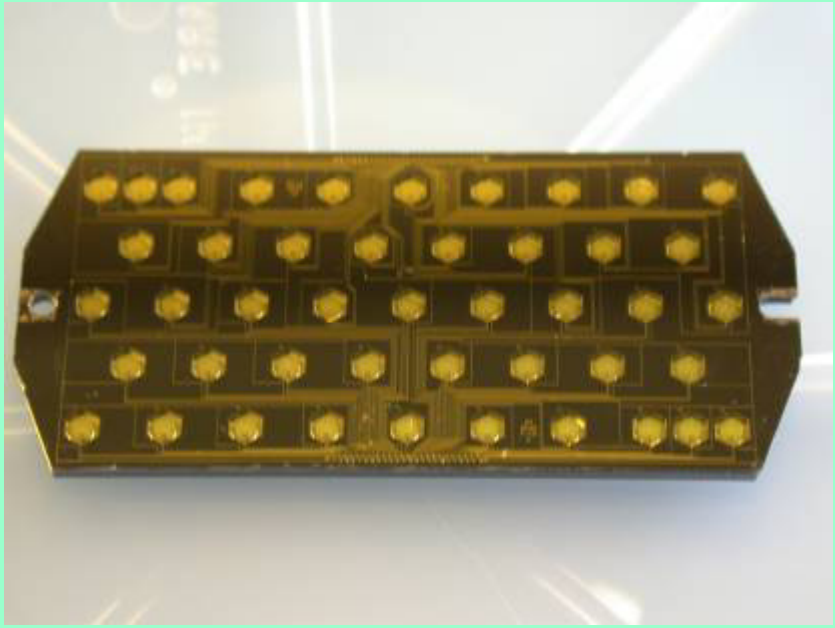


NTD Ge Bolometer Arrays

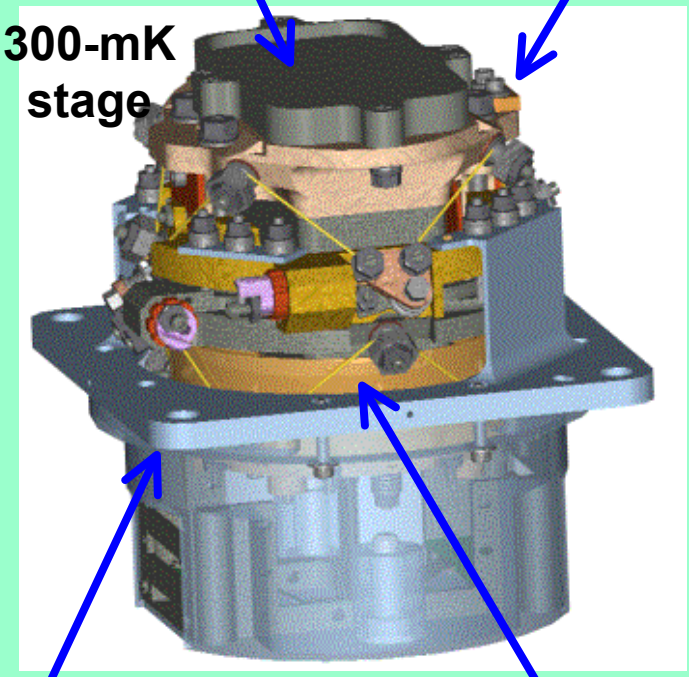
- NEP ~ 3 x 10^{-17} W $Hz^{-1/2}$
- 120-K Si JFET readout
- 1/f noise knee < 100 mHz

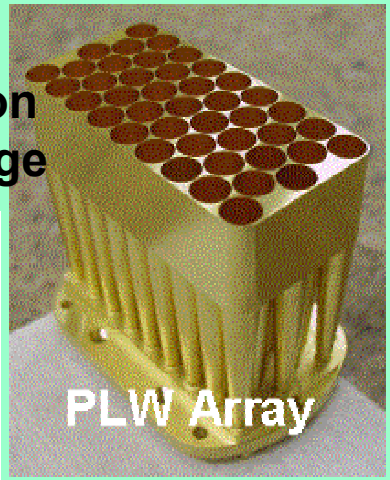


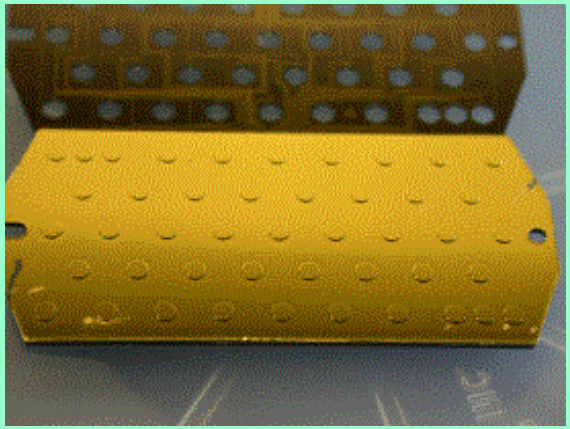


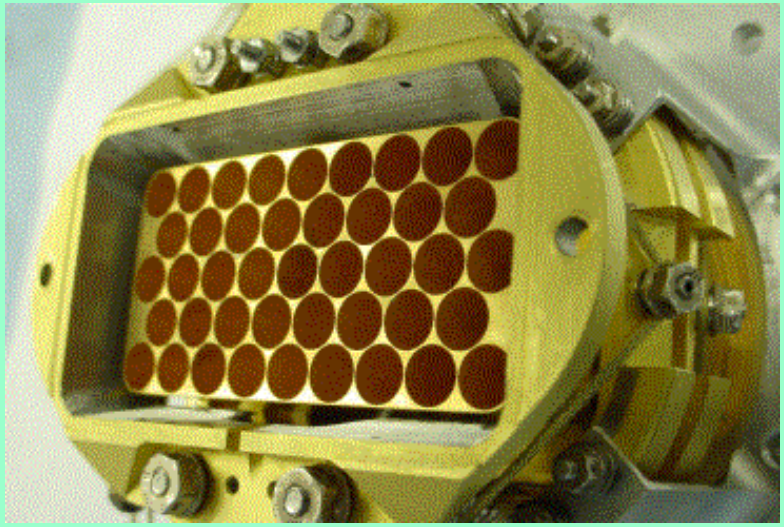


CQM Bolometer Array Module

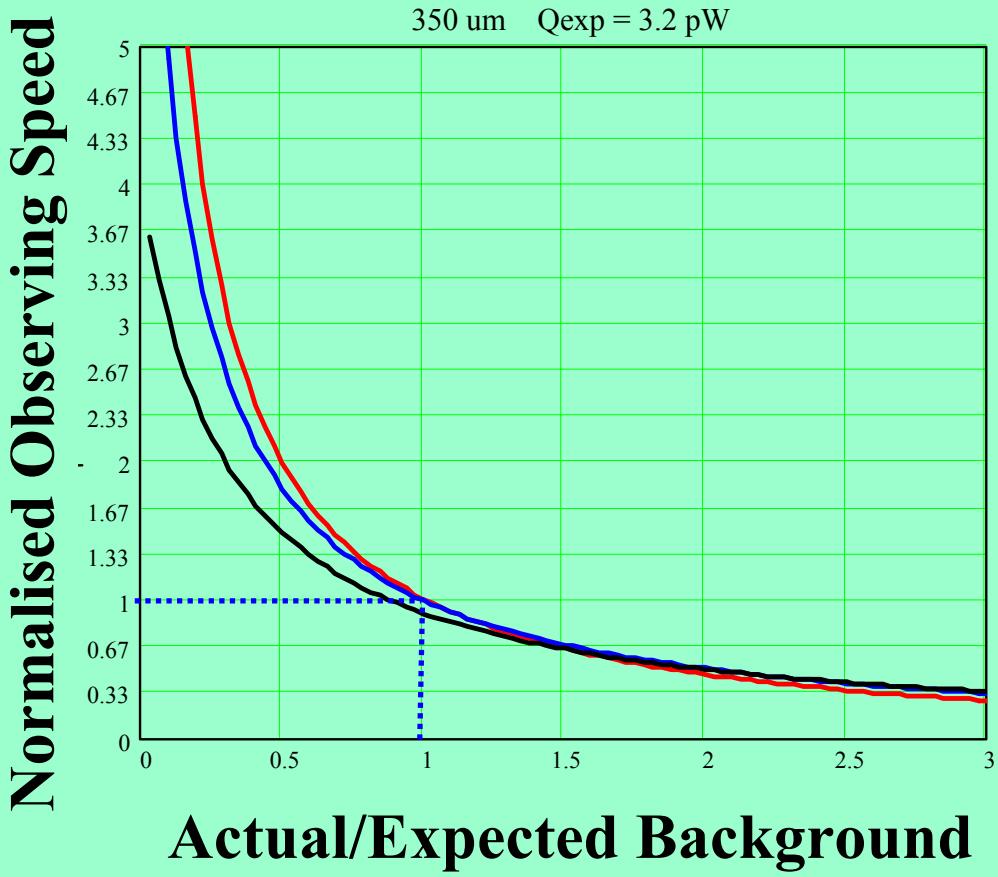








Observing Speed vs. Telescope Background Power (350 μm)

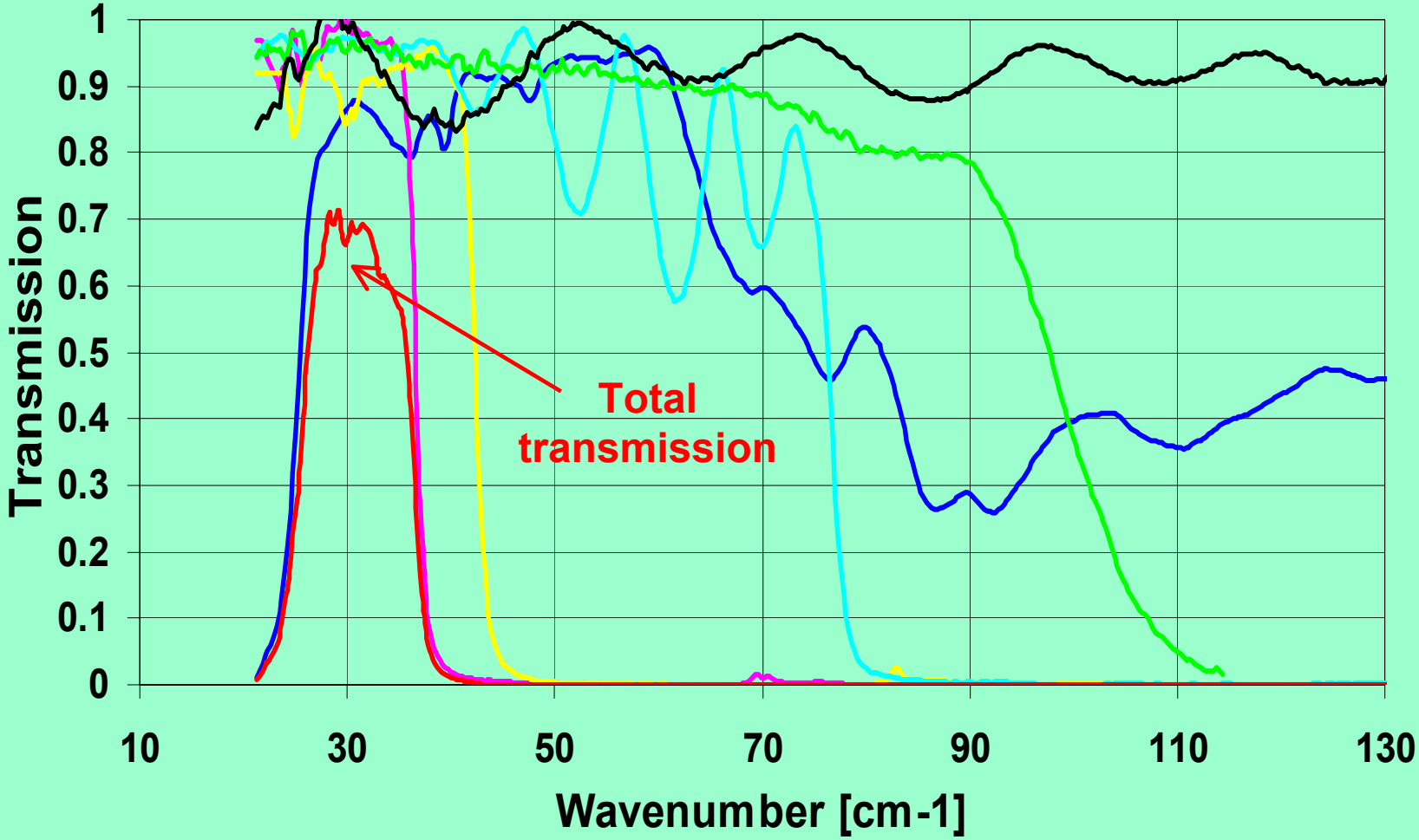


$Q_{des} = Q_{exp}/2$

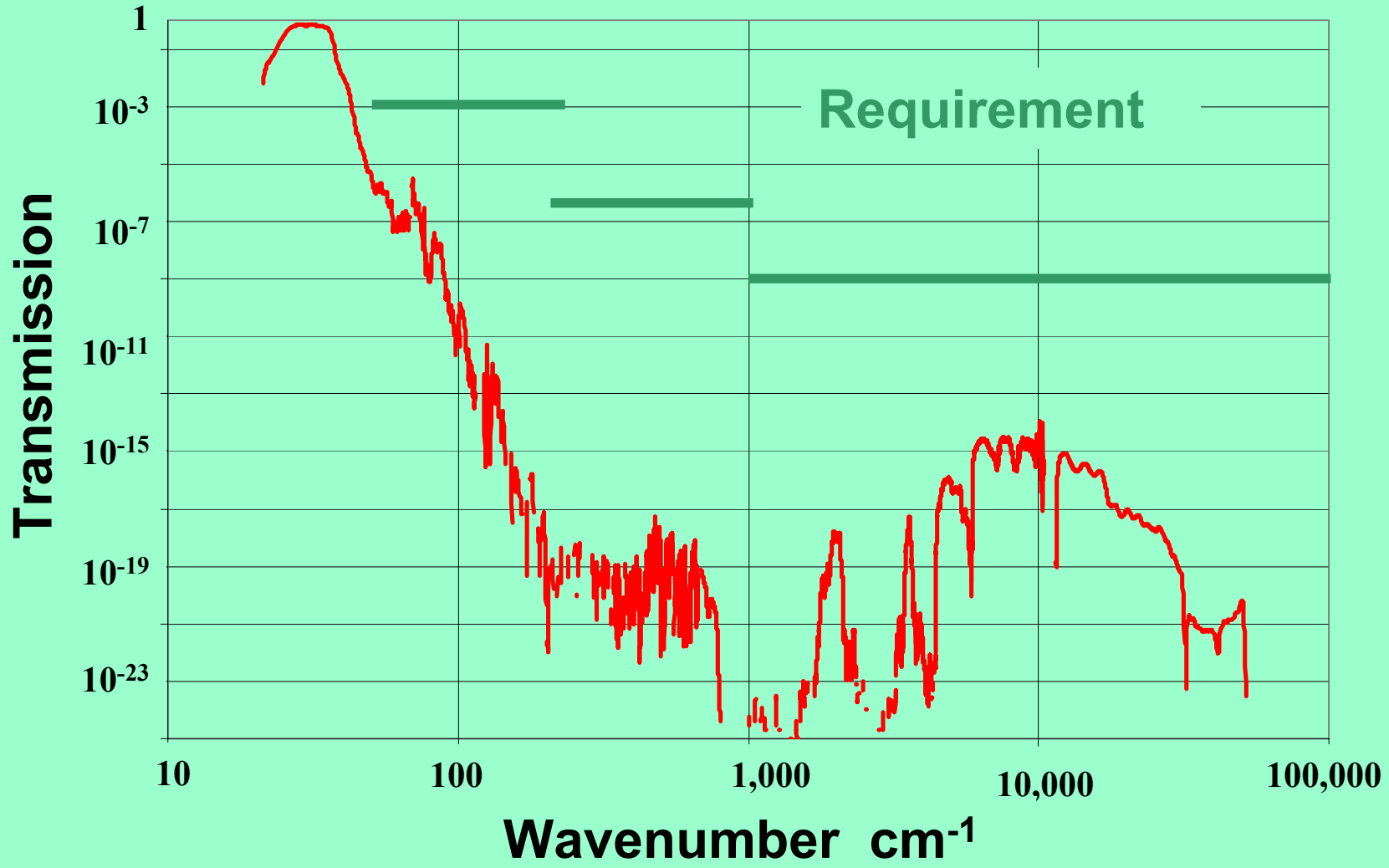
$Q_{des} = Q_{exp}$

$Q_{des} = 2Q_{exp}$

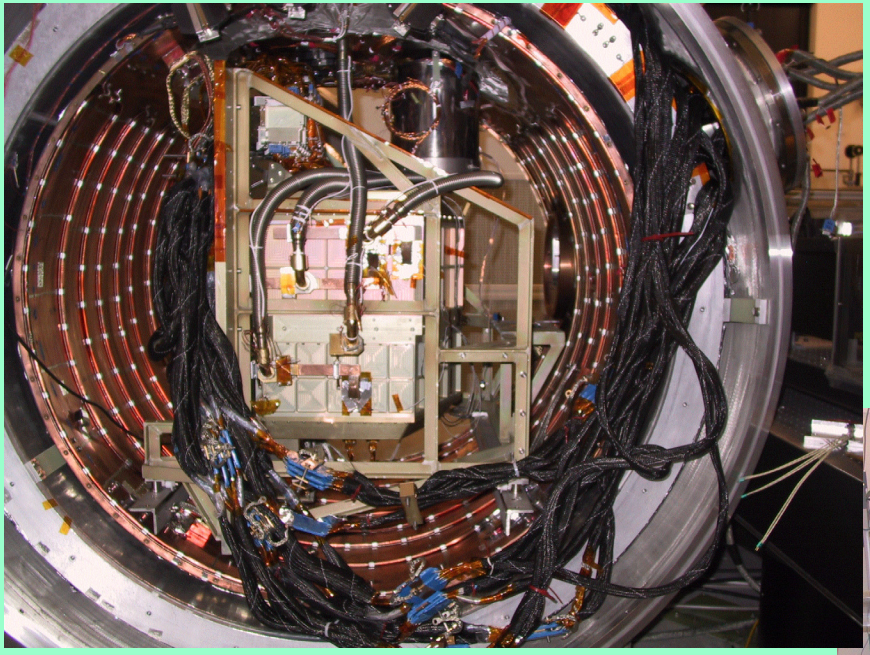
Example Prototype Filtering Scheme

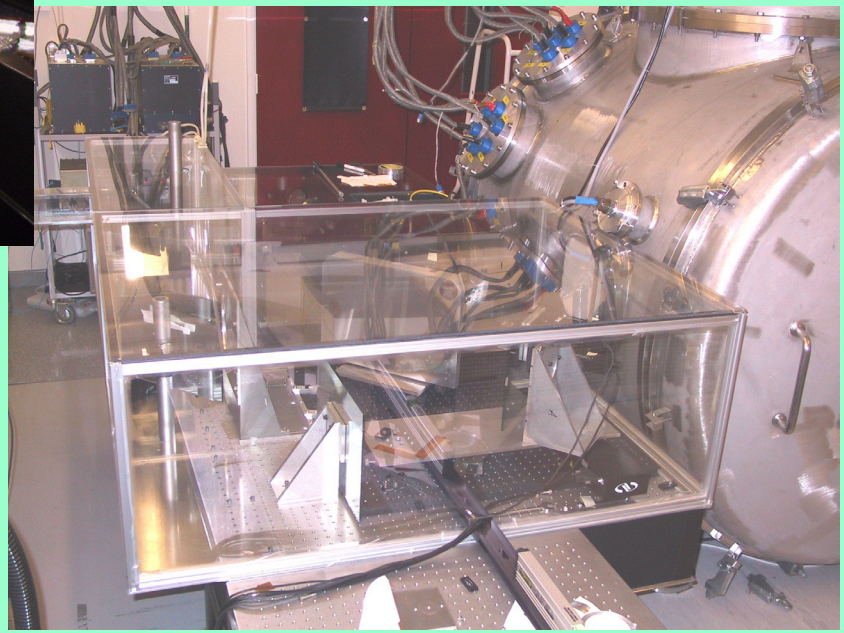


Filter Out-of-Band Rejection

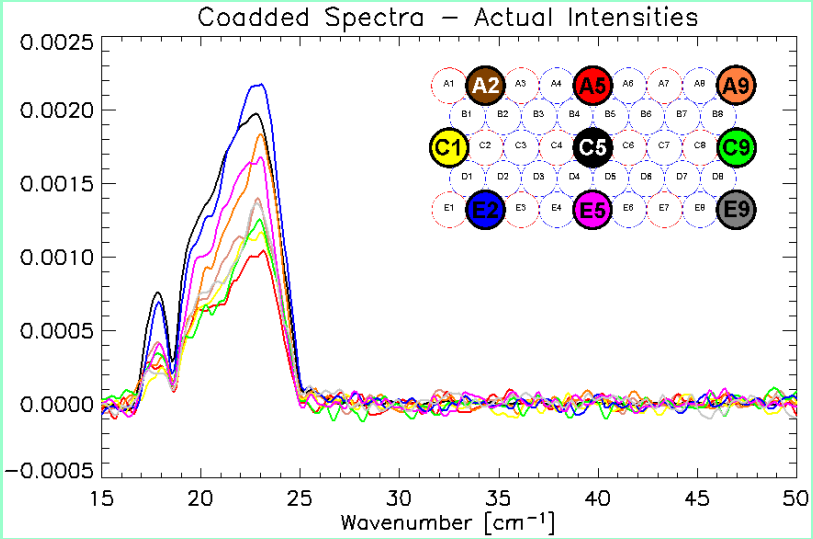


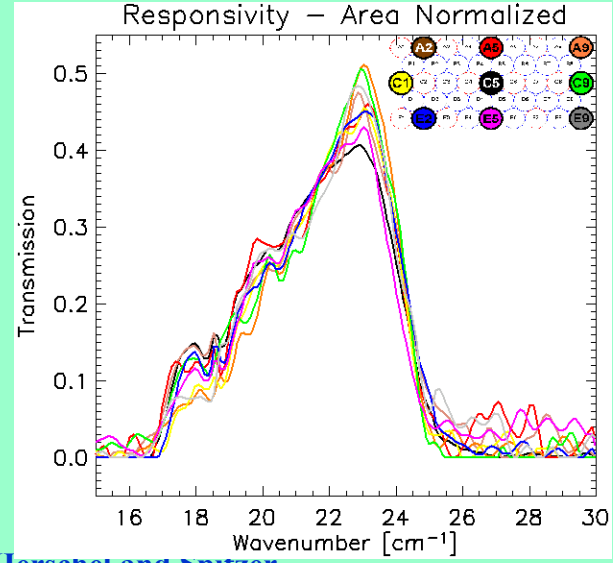
Test facility has an external spectrometer

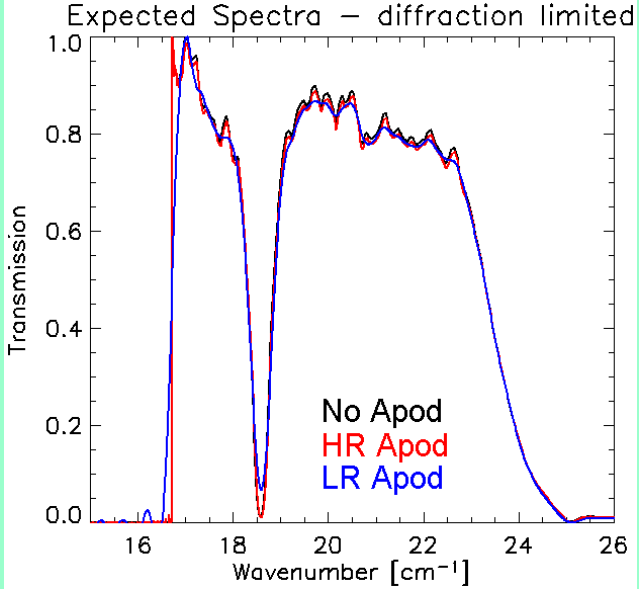




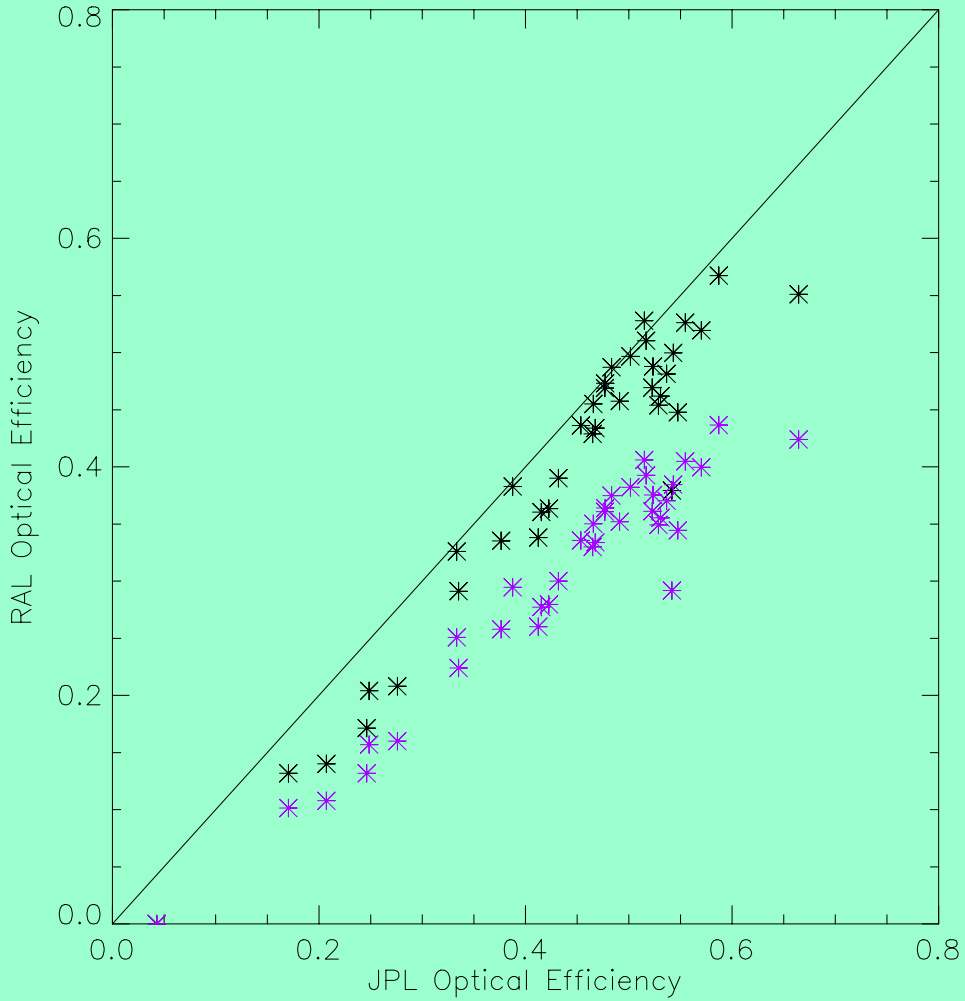
Measured CQM Response







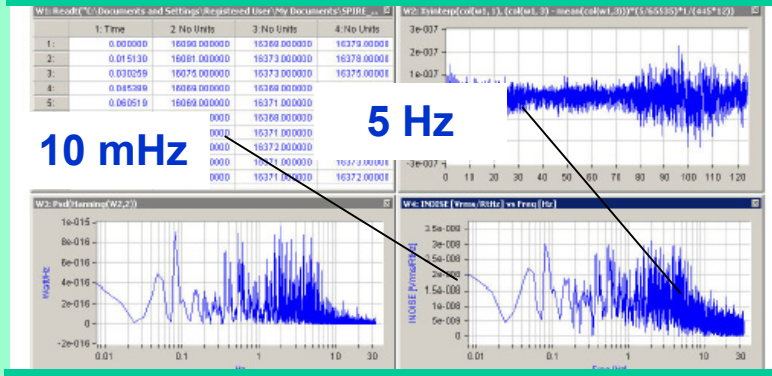
Measured Optical Efficiency of CQM Array



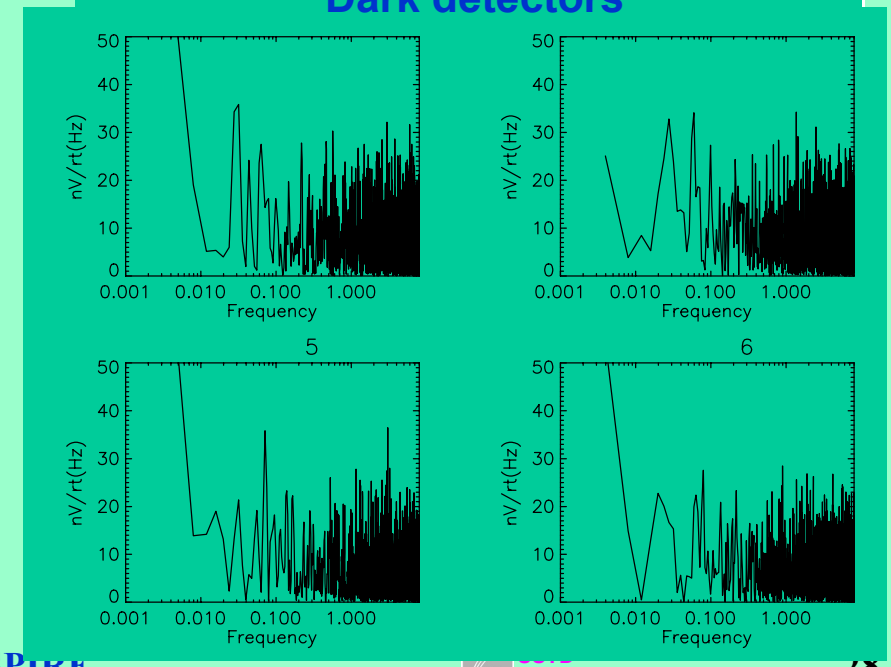
Electronics

- We need low noise amplifiers to exploit inherent stability of detectors

Shorted inputs



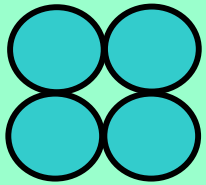
Dark detectors



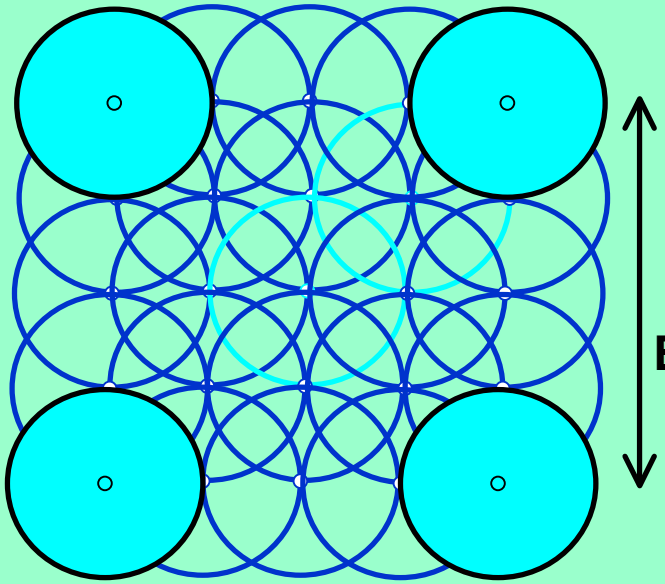
Sky Sampling with Feedhorn Arrays

Full sampling of the image require scanning or "jiggling" of the telescope pointing

Feedhorns adjacent in the focal plane



FWHM beams on the sky don't overlap



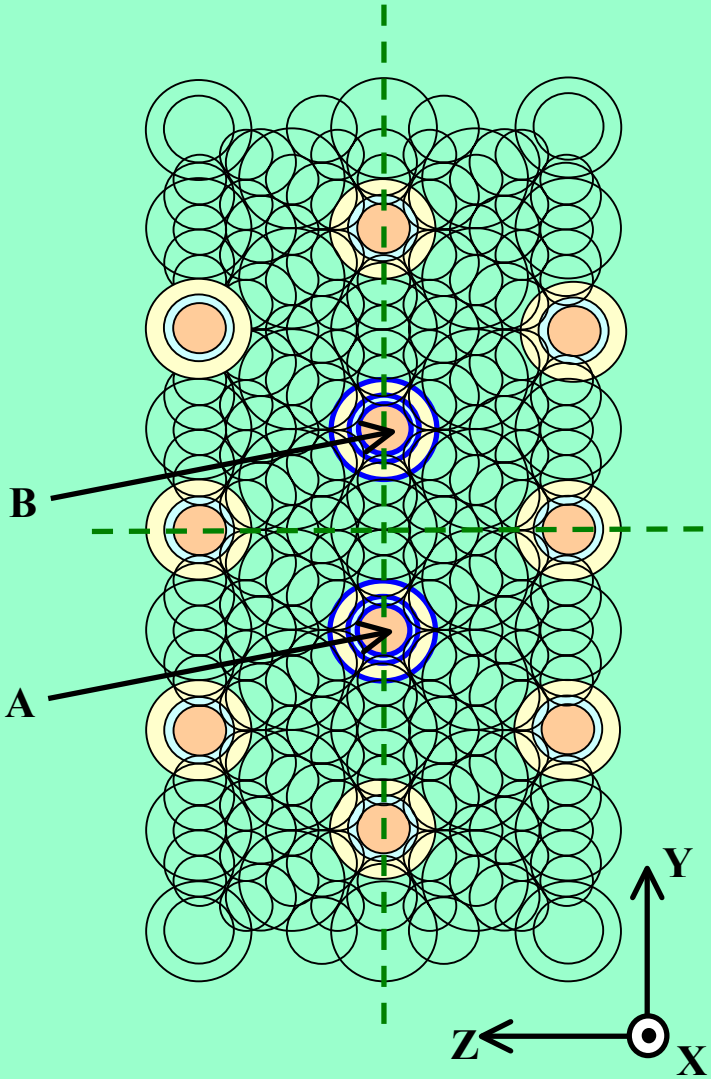
Beam FWHM ≈ λ/D

Beam separation ≈ $2\lambda/D$

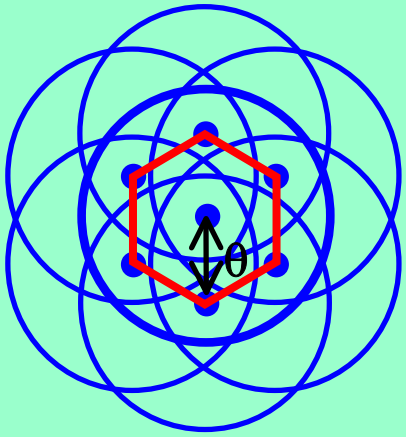
16 pointings needed for fully-sampled image

Point Source Photometry

- Telescope pointing fixed
- Chopping in Y-direction between A and B (126”)
- Simultaneous observation in the three bands with two sets of co-aligned detectors
- This is OK if the pointing is accurate enough (~ 1.5”)

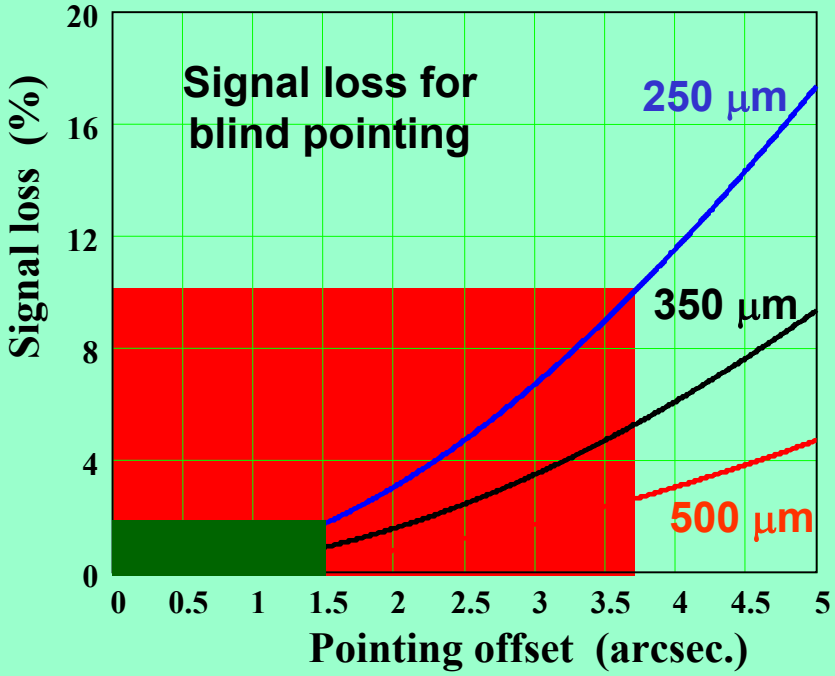


7-point Jiggle Map



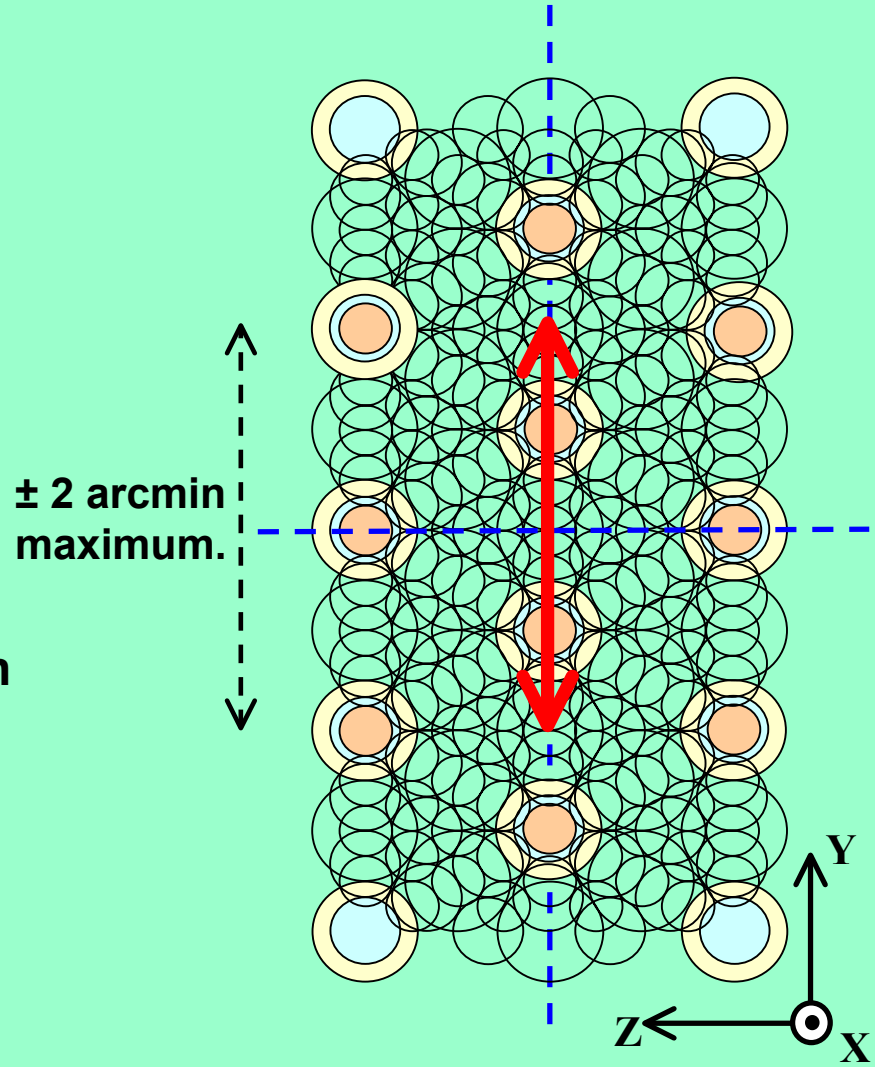
- Chopping 126”
- 7-point jiggle pattern
- Angular step θ ~ 4 - 6 arcseconds (> pointing or positional error)
- Total flux and position can be fitted
- Compared to single accurately pointed observation, S/N for same total integration time is only degraded by

  ~ 20% at 250 μm
  ~ 13% at 350 μm
  ~ 6% at 500 μm



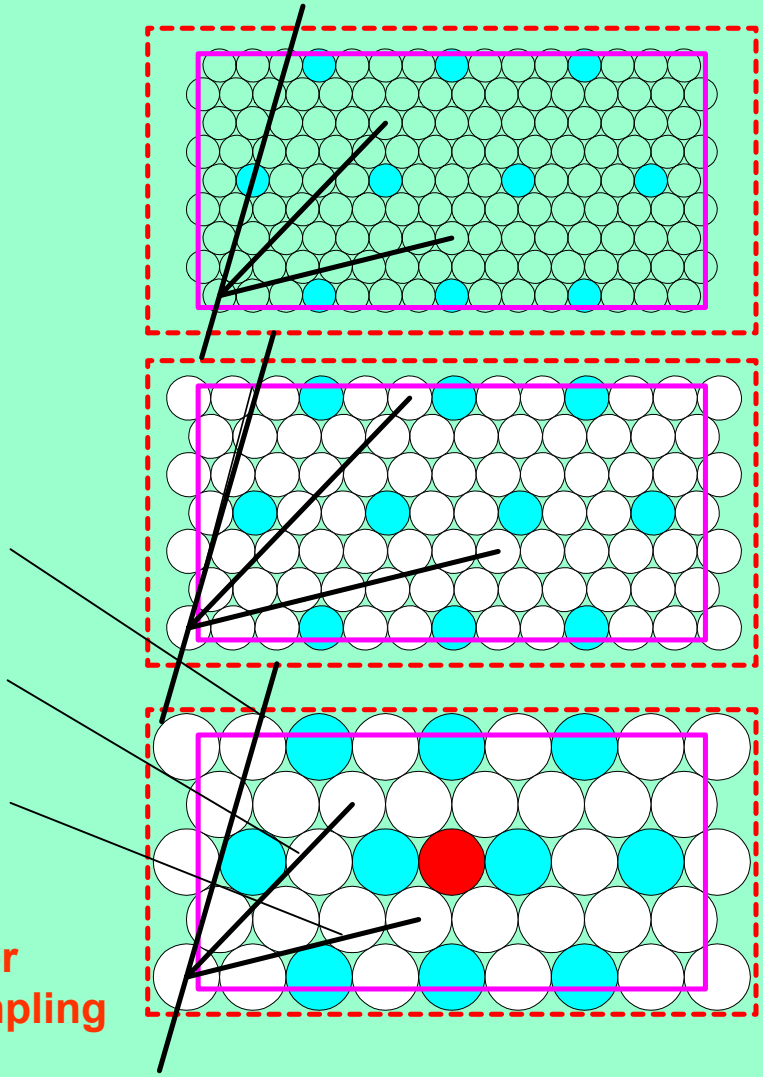
Field (Jiggle) Mapping

- Telescope pointing fixed or in raster mode
- Chopping up to 4 arcmin amplitude in Y direction
- 64-point "jiggle" pattern for full spatial sampling
- Available fov = 4 x 4 arcmin



Scan Mapping

- Telescope in line scanning mode
- Scan rate ~ 20-30”/sec – max 60”/sec
- Map of large area is built up from overlapping parallel scans
- Most efficient mode for large-area surveys



Scan directions for instantaneous full sampling

FTS Observing Modes

- $\Delta\sigma$ = 0.04 - 2 cm^{-1} by adjusting scan length

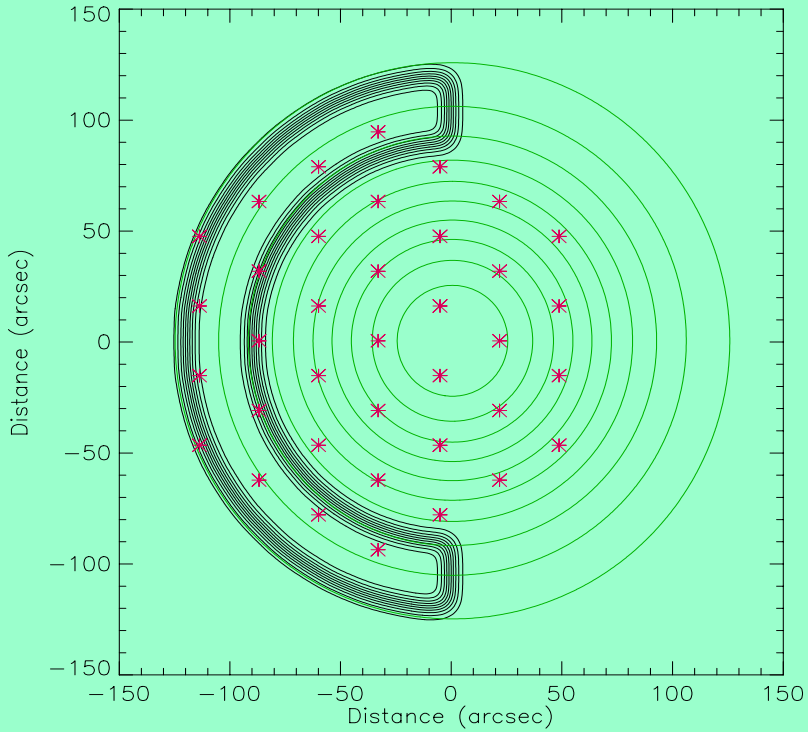
- Continuous scan:
  - Mirror scan rate = 0.5 mm s^{-1}
  - Signal frequency range = 3 - 10 Hz
  - Calibrator in 2nd port nulls telescope background

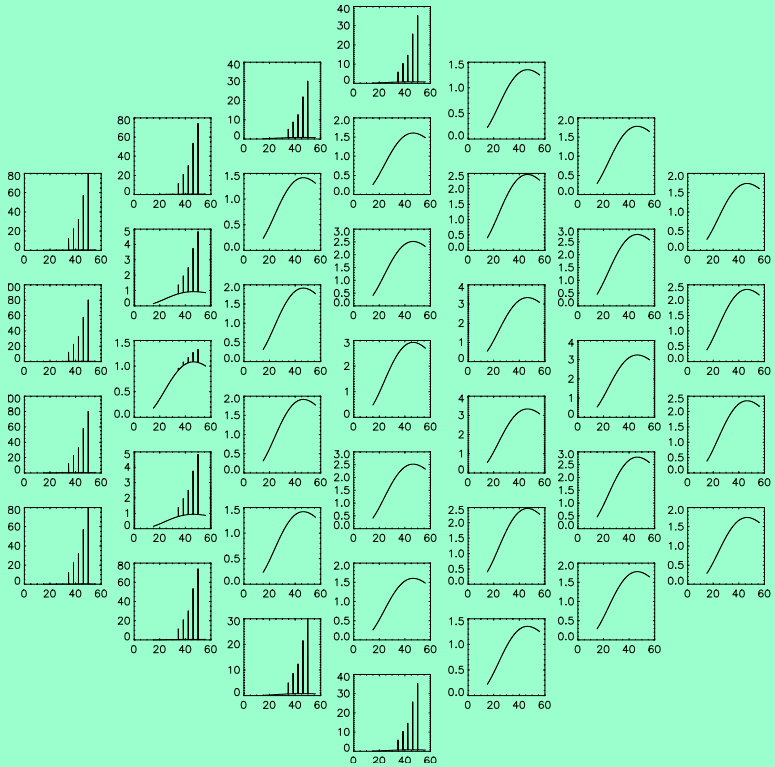
- Step-and-integrate:
  - 2nd port calibrator is off
  - Mirror stepped with integration at each position
  - Beam Steering Mechanism chops on sky

- Point source spectroscopy/spectrophotometry
  - Telescope pointing fixed
  - Background characterised by adjacent pixels

- Imaging spectroscopy
  - Beam steering mirror adjusts pointing between scans to acquire fully-sampled spectral image

FTS Mapping simulation





Sensitivity Estimates: Photometer

New sensitivities taking into account increased obscuration of telescope and lower estimate of detector sensitivity

Band (μm)		250	360	520
ΔS(5-σ; 1-hr) mJy	Point source (7-point)	2.7	3.5	4.2
	4' x 4' jiggle map	10	12	13
	4' x 8' scan map	7.6	9.2	11
Time (days) to map 1 deg.^{2} to 3 mJy 1-σ	Nominal case	2.1	3.0	3.9

Sensitivity Estimates: Spectrometer

Line spectroscopy $\Delta\sigma = 0.04$ cm^{-1}				
λ μm		200 - 315	315 - 500	500-670
ΔF (5-σ; 1-hr) W m^{-2} x 10^{-17}	Point source	5.9	5.5	5.5 - 7.7
	Fully-sampled 2.6' map	20	18	18 - 26

Low-resolution spectrophotometry $\Delta\sigma = 1$ cm^{-1}				
λ μm		200 - 315	315 - 500	500-670
ΔS (5-σ; 1-hr) (mJy)	Point source	200	180	180 - 260
	Fully-sampled 2.6' map	530	490	490 - 690

See also posters on…

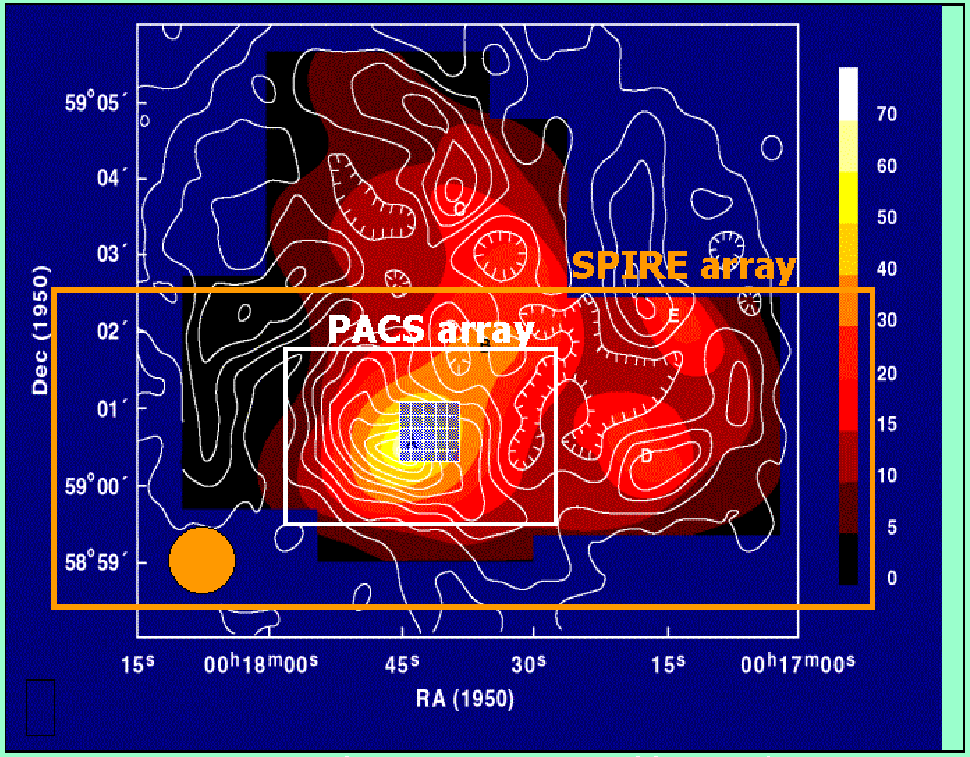
- First results from SPIRE CQM testing (Lim et al)
- Thermal design of the SPIRE instrument (Goizel and Griffin)
- Hi-Gal survey – proposed FIR/Sub-mm survey of the galactic plane to |l|<2.5 deg (Babar et al)
- SPIRE ICC – how the data and observations will be handled (Clements et al)

- Effects of thermal fluctuations on Planck HFI sensitivity (Fereday)

Some Key Programmes Involving SPIRE

- **SPIRE + PACS photometry and spectroscopy of galaxies**
  - Detailed SEDs and dust properties
  - Metallicity variation and evolution
  - AGN vs. starburst
  - Testing unified schemes
  - Templates for high-redshift studies

IC10 (D ~ 1Mpc)

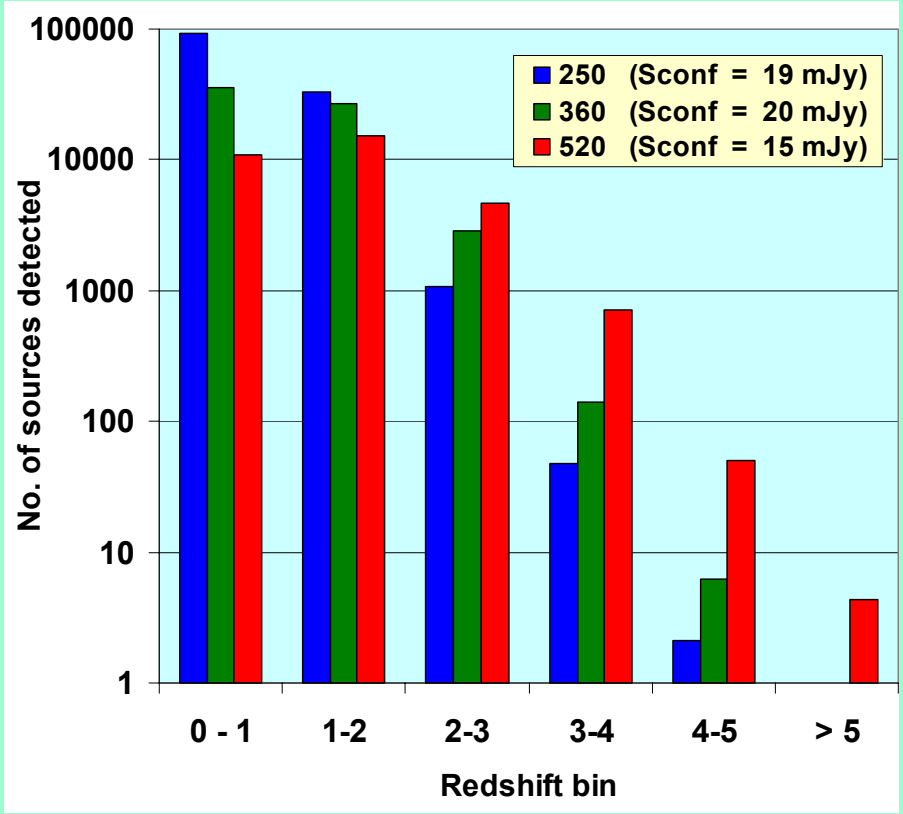


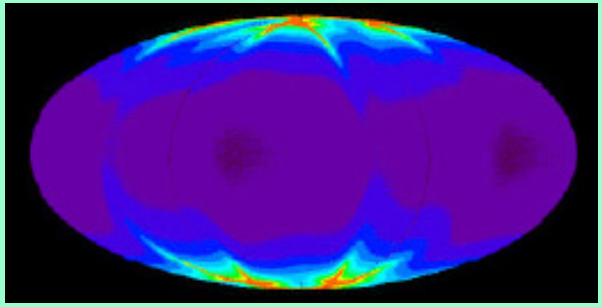
Contours: HI; Color 158 mu CII Madden et al 1997

Some Key Programmes Involving SPIRE

- **SPIRE + PACS extragalactic surveys (deep, medium, shallow)**
  - Unbiased survey of high-z dusty star-forming galaxies missed by optical and near-IR survey
  - Detection of many thousands of galaxies
  - Test models of number counts galaxy spectra, luminosity, and SF history out to z = 5

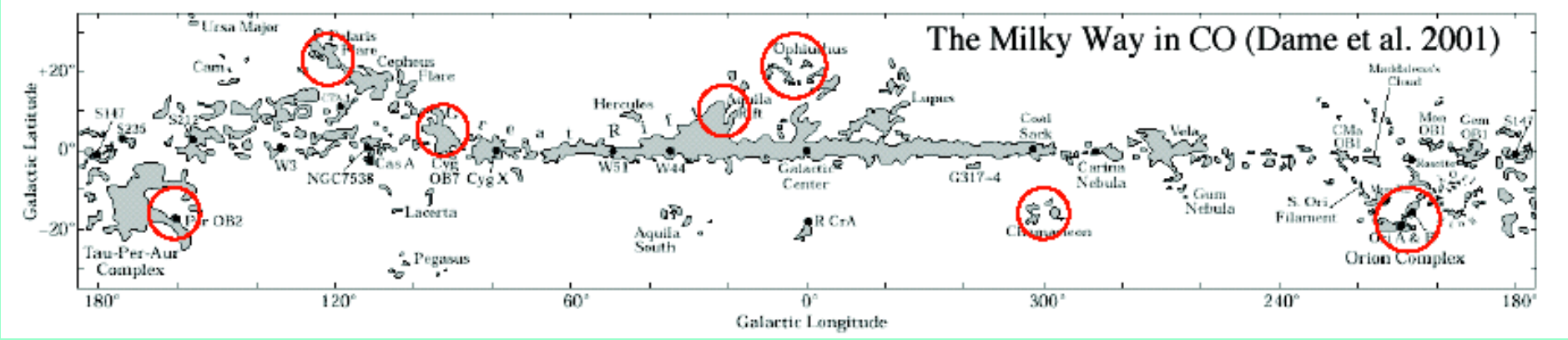
- Large-scale structure in the high-redshift universe
- Follow up spectroscopic observations: redshifts, physics and chemical evolution

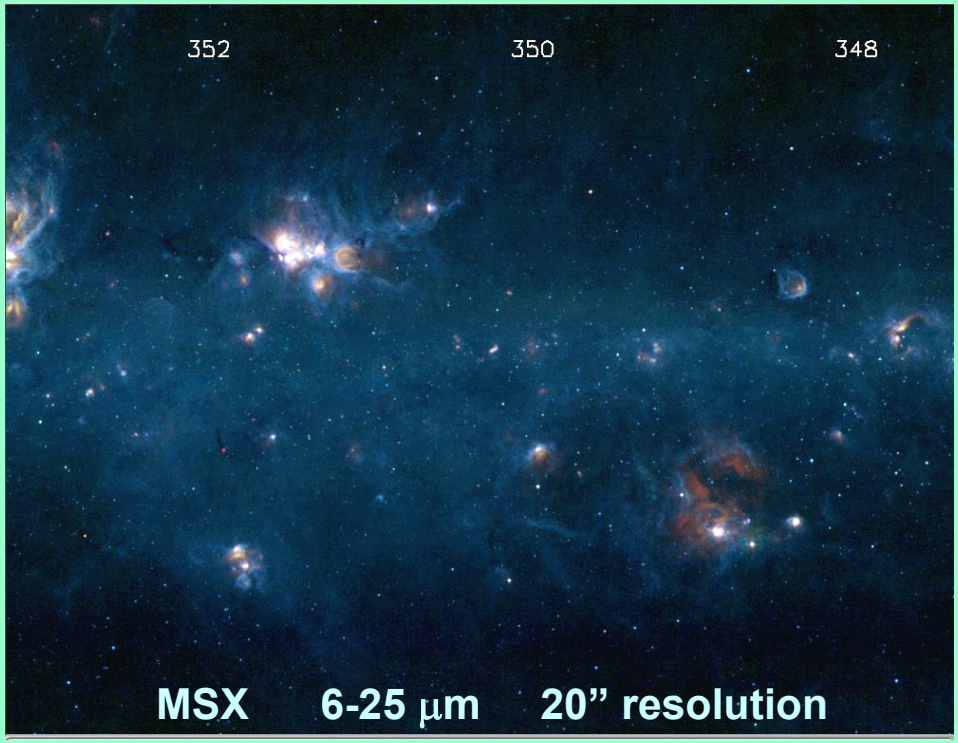




Some Key Programmes Involving SPIRE

- **SPIRE + PACS survey of nearby molecular clouds**
  - Complete samples of protostars and pre-collapse condensations down to $M_{proto} \sim 0.03\ M_{\odot}$ and d ~ 1 kpc
  - Mass function down to brown dwarf mass regime
  - SED coverage of spectral peak
  - Accurate mass, luminosity, temperature
  - Lifetimes of different evolutionary stages
  - Temperature and density profiles
  - Initial conditions for collapse



Some Key Programmes Involving SPIRE

- **Compete multi-band galactic plane survey to ~100 mJy rms**
  - Census of all observable galactic star forming regions
  - Wide range of masses and evolutionary stages
  - Triggered star formation
  - Global properties of the ISM dust and molecular clouds
  - Supernova remnants; PMS star mass ejection
  - See poster by Ali et al.