SPIRE

THE SPIRE INSTRUMENT

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+ the SPIRE Consortium (Canada, Italy, France, Spain, Sweden, UK, USA)

- SCIENTIFIC GOALS
- INSTRUMENT DESIGN
- OBSERVING MODES
- PERFORMANCE ESTIMATION

SPIRE

The SPIRE Consortium

- Caltech/Jet Propulsion Laboratory, Pasadena, USA
- 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
- Laboratoire d'Astronomie Spatiale, Marseille, France
- Mullard Space Science Laboratory, Surrey, UK
- NASA Goddard Space Flight Center, Maryland, USA
- Observatoire de Paris, Meudon, Paris
- Queen Mary and Westfield College, London, UK
- UK Astronomy Technology Centre, Edinburgh, UK
- Rutherford Appleton Laboratory, Oxfordshire, UK
- Stockholm Observatory, Sweden
- Università di Padova, Italy
- University of Saskatchewan, Canada

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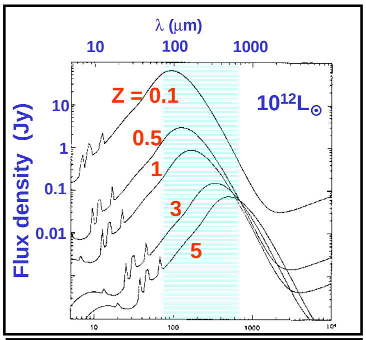
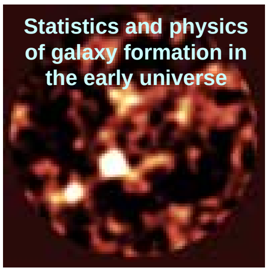
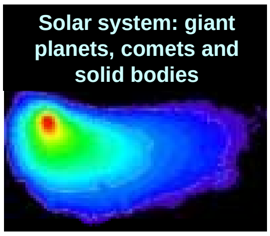
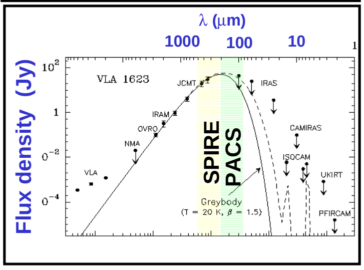
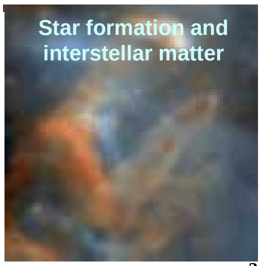
SPIRE Scientific Goals











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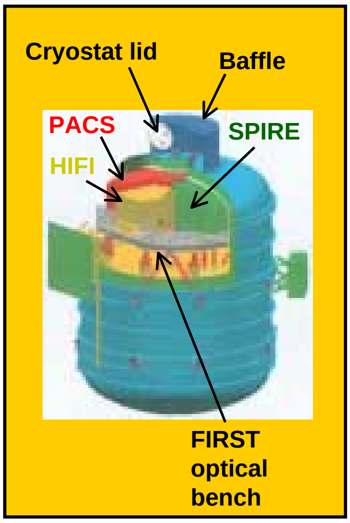
SPIRE Instrument Summary

- **3-band imaging photometer**
  - 250, 350, 500 µm (simultaneous)
  - $\lambda/\Delta\lambda \sim 3$
  - 4 x 8 arcminute field of view
  - Diffraction limited beams (17, 24, 35")
- **Imaging FTS**
  - 200 - 400 µm (goal 200 - 670 µm)
  - > 2 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%)
  - ^3He cooled detector arrays (0.3 K)
  - Feedhorn-coupled spider web NTD bolometers
  - Minimal use of mechanisms
    - Beam steering mirror; FTS mirror drive



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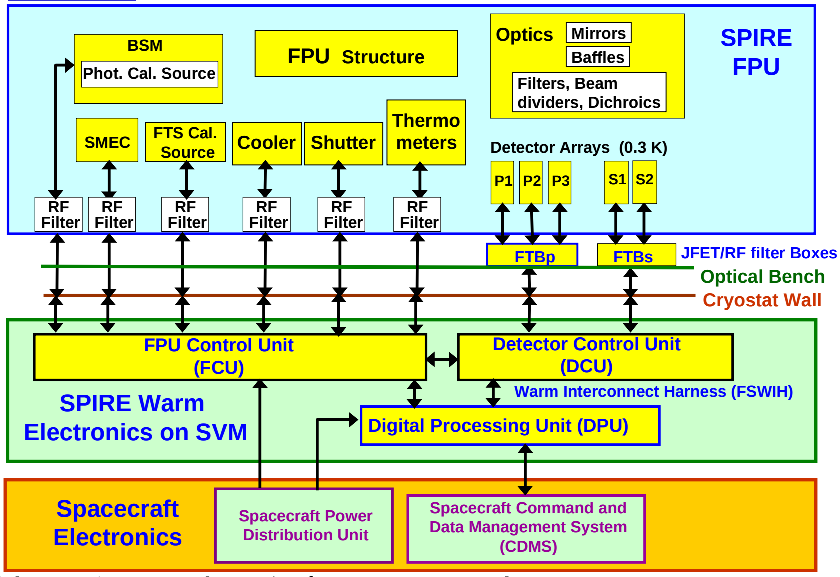
SPIRE Block Diagram



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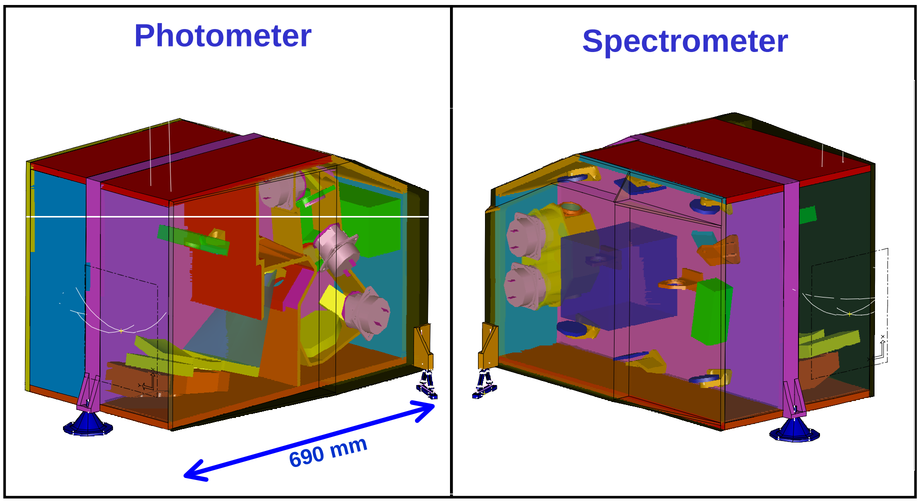
SPIRE FPU



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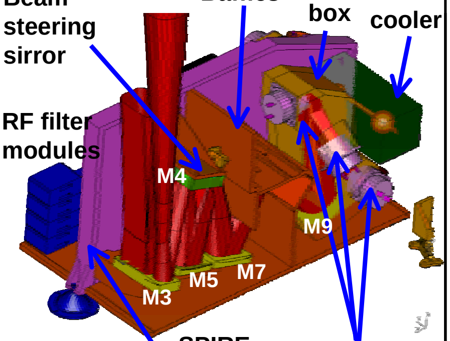
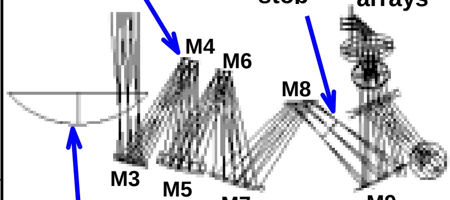
Photometer Layout and Optics





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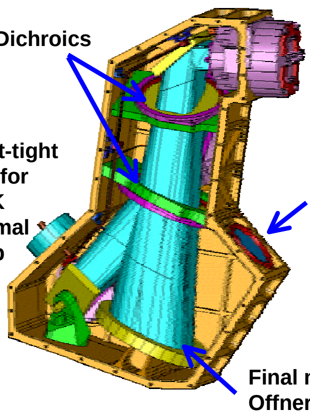
Photometer 2-K Box and 300-mK Straps



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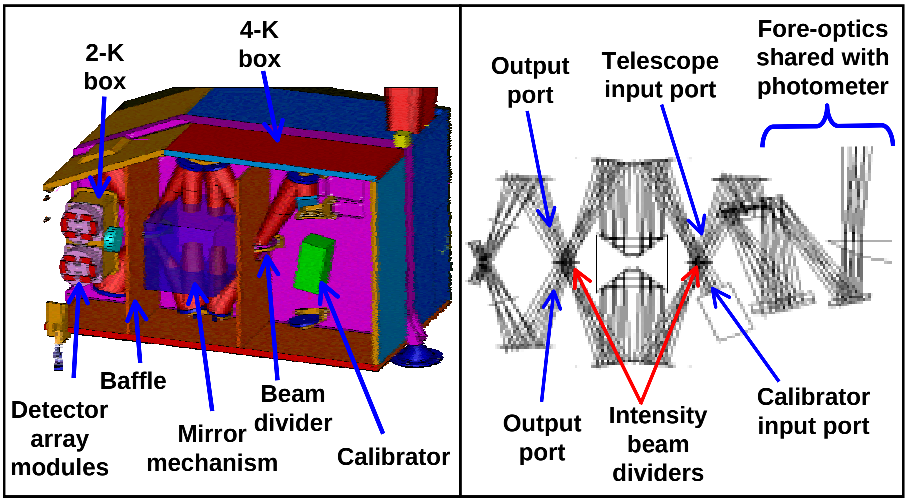
FTS Layout and Optics



Toledo Symposium, *The Promise of FIRST*, 11 - 15 December 2000 9

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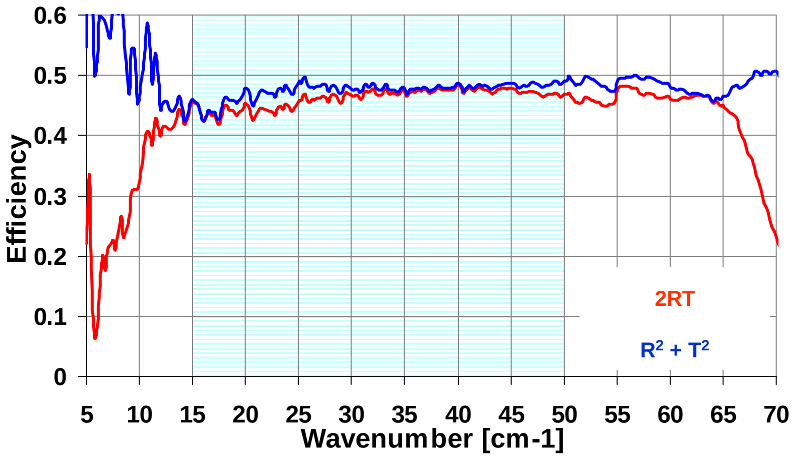
Prototype Broadband Beam Divider



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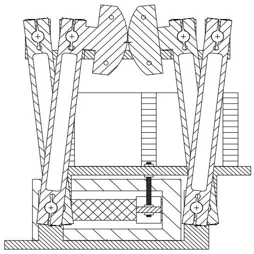
FTS Mechanism Design

- Double parallelogram with toothless gear
- Moiré fringe position measurement system (0.1 μm accuracy)
- Corner cube reflectors compensate for tilt and rotation
- - 0.3 -- +3.5 cm movement



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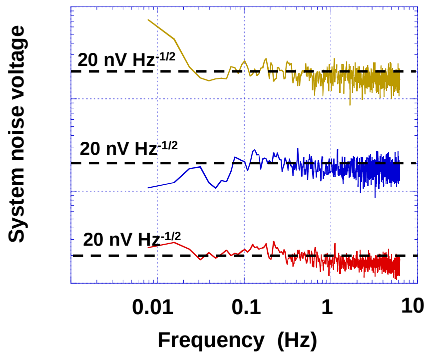
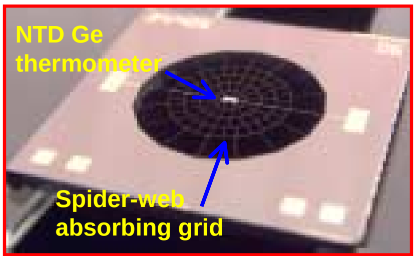
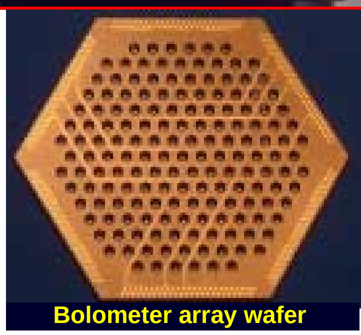
NTD Ge Bolometer Arrays (Caltech/JPL)

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

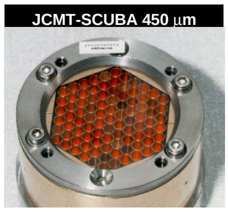




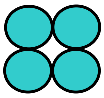


SPIRE — Sky Sampling with Feedhorn Arrays

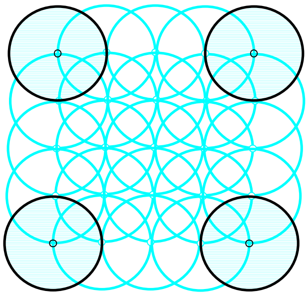
Full sampling of the image requires scanning or "jiggling" of the telescope pointing



Feedhorns adjacent in the focal plane



FWHM beams on the sky don't overlap



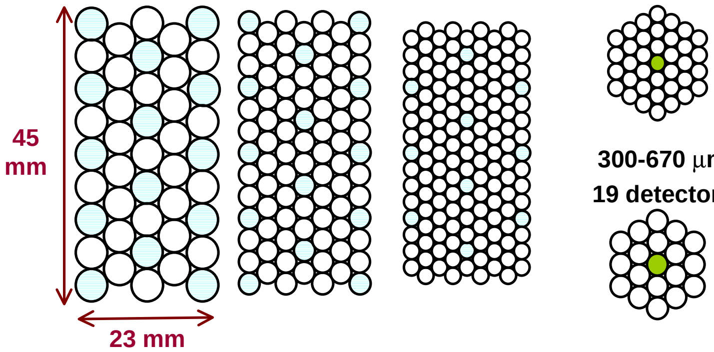
Beam FWHM = λ/D

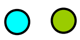
Beam separation = 2λ/D

16 pointings needed for fully-sampled image

SPIRE — Detector Arrays (2Fλ Feedhorns)

Photometer			Spectrometer
500 µm 43 detectors	350 µm 88 detectors	250 µm 139 detectors	200-300 µm 37 detectors 300-670 µm 19 detectors





⇒ Overlapping beams

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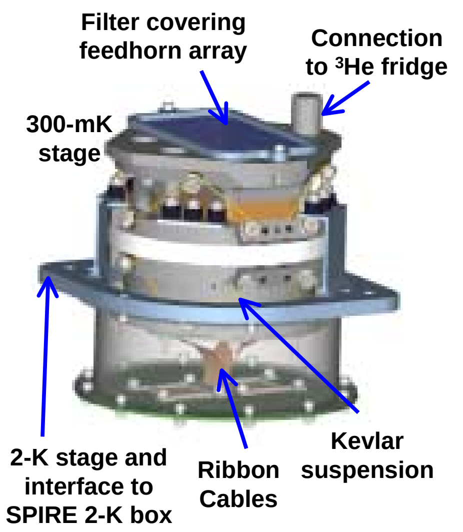
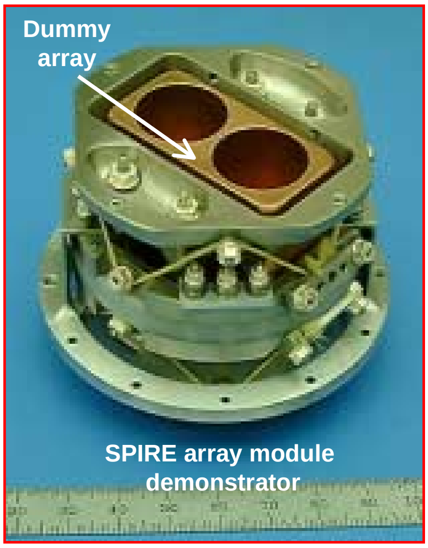
Bolometer Array Module





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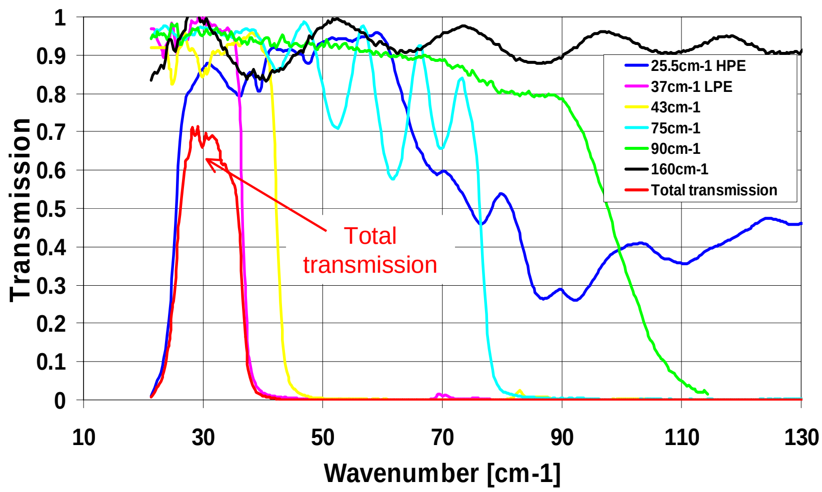
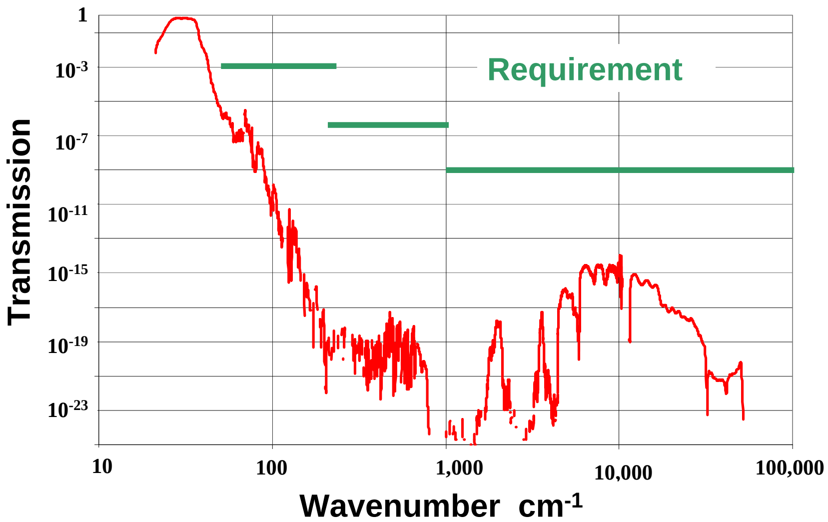
350 μm Filtering Scheme



SPIRE — Filter Out-of-Band Rejection

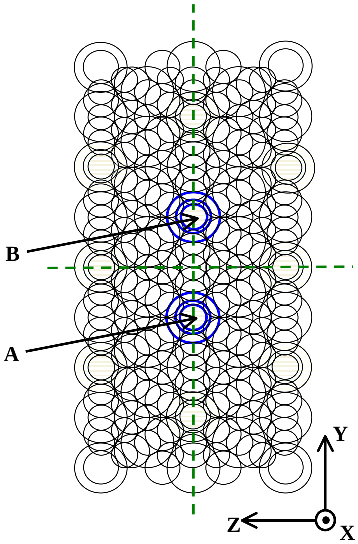


SPIRE — Photometer Observing Modes

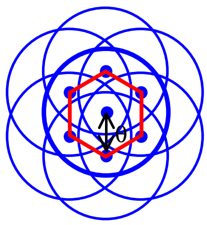
- **Point source photometry:**
  - Beam steering mirror chops 125” between overlapping sets of detectors
  - Seven-point jiggle can be done if desired
- **Field mapping:**
  - Beam steering mirror chops up to 4’ and performs 64-point “jiggle”
  - Available fov = 4’ x 4’
- **Scan mapping:**
  - Beam steering mirror not operated
  - Telescope drift scanning at up to 60”/second
  - Scan angle wrt array axis set to give full spatial sampling

SPIRE — 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
- Chop without jiggling is OK if the pointing is accurate enough (~ 1.5”)

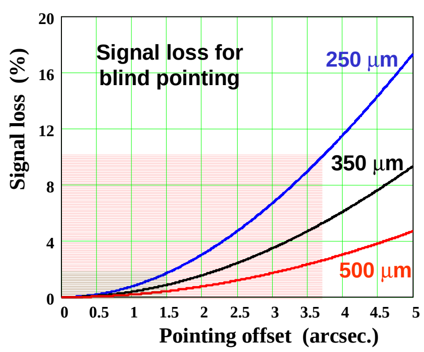


SPIRE — 7-point Jiggle Map



- 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



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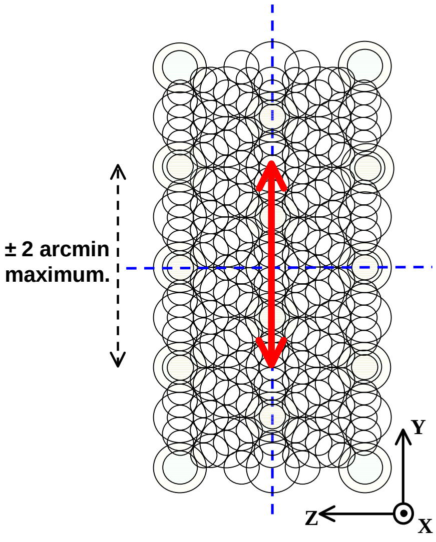
Field Mapping

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



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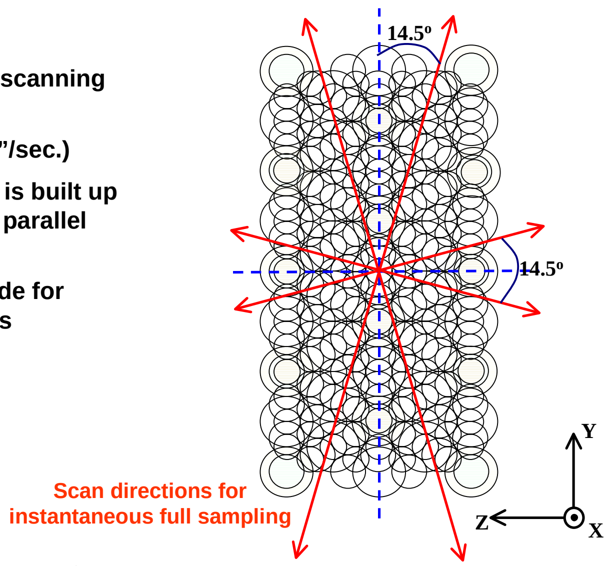
Scan Mapping

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



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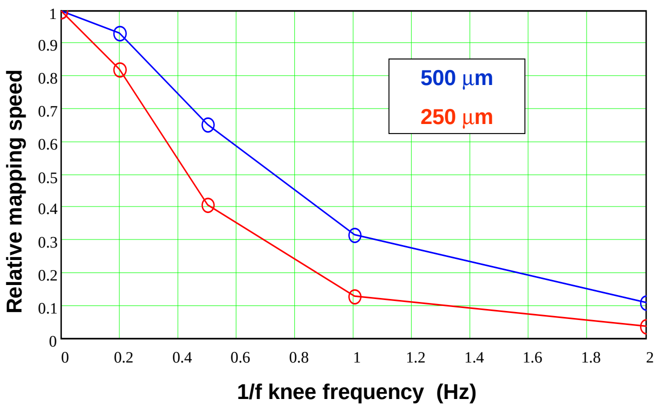
Simulations of scanning without modulation: need for good 1/f stability



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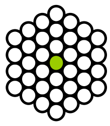
FTS Observing Modes

- Mirror scan rate = 1 mm s^{-1}
- Signal frequency range 6 - 20 Hz
- Maximum scan length = 3.5 cm (14 cm OPD)
- $\Delta\sigma$ = 0.04 - 2 cm^{-1} by adjusting scan length
- Calibrator in second port nulls telescope background

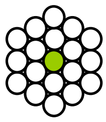
- Point source spectroscopy/spectrophotometry
  - Telescope pointing fixed
  - Background characterised by adjacent pixels

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

200-300 µm
37 detectors



300-670 µm
19 detectors



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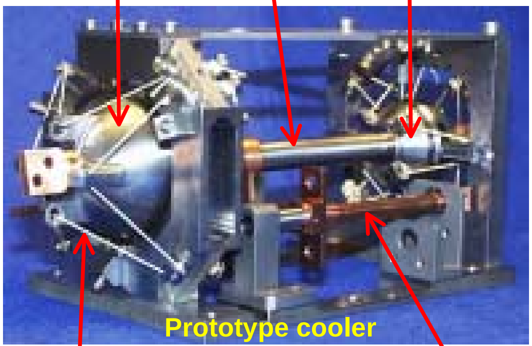
^{3}He Cooler

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



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Estimated Instrument Sensitivity

Photometry (all bands)

Flux density (mJy, 5-σ; 1 hr)

Point source	4.0 (req.)	2.0 (goal)
Map (4'x 4')	16 (req.)	8.0 (goal)

FTS: Spectroscopy 200 - 400 μm Δσ = 0.04 cm^{-1}

Line flux (W m^{-2} x 10^{-17}, 5-σ; 1 hr)

Point source	6.0 (req.)	3.0 (goal)
Map	18 (req.)	9.0 (goal)

FTS: Spectrophotometry 200 - 400 μm Δσ = 1 cm^{-1}

Flux density (mJy, 5-σ; 1 hr)

Point source	200 (req.)	100 (goal)
Map	600 (req.)	300 (goal)

FTS sensitivity declines by factor of ~ 2 between 400 and 670 μm

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Protostars and YSOs: Spectral Coverage and Capabilities

- **Unbiased surveys of nearby molecular clouds**
- **Complete census of protostellar condensations within ~ 1 kpc**
- **Temperature and density distributions**
- **Total luminosities**
- **Dust properties**
- **Star formation rate and efficiency**
- **Initial mass function**

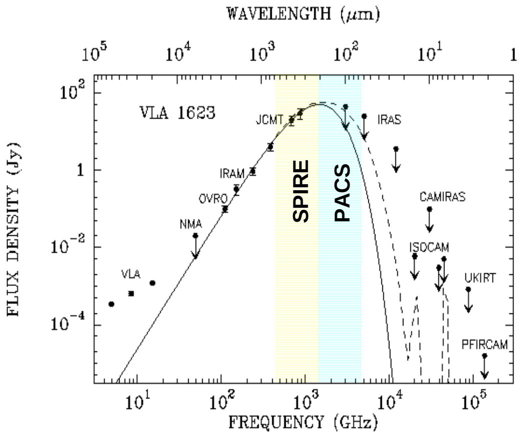

Figure by Philippe André

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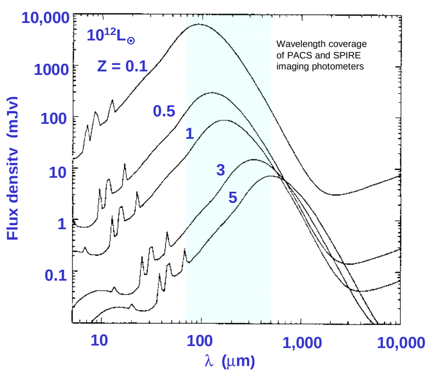
High-Redshift Galaxy Surveys with FIRST

- **Unbiased survey of population of high-z dusty star-forming galaxies missed by current (and future) optical and near-IR surveys**
- **Large-scale structure in the high-redshift universe**
- **Star-formation history in galaxies at z out to 5**



After Guiderdoni et al. MNRAS 295, 877, 1998

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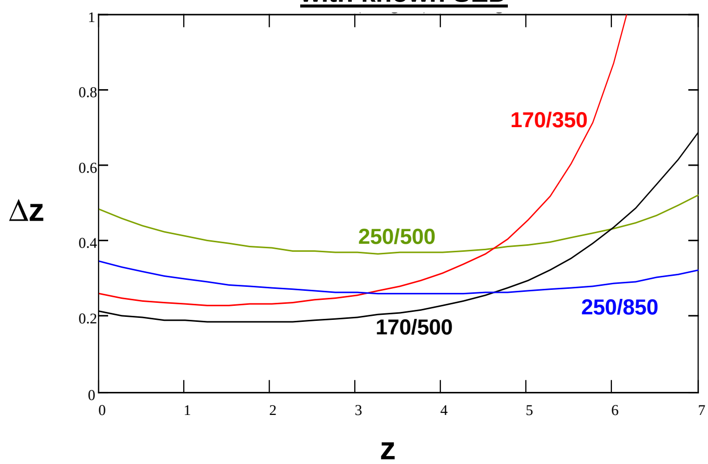
Photometric Redshifts

Δz for 5-σ measurement of flux density ratio
with known SED



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SPIRE Large-Area Survey Sensitivity

λ (μm)	FWHM (arcsec.)	5σ; 1hr limit (scan-map mode) (mJy)	Confusion limit (1 source per 40 beams) (mJy)	Time to reach confusion limit for one field at 5-σ (min.)	Time to map 1 sq. deg. to confusion limit (days)
250	18	7.3	19	9	1.3
350	25	7.4	20	8	1.2
500	36	7.4	15	14	2.1

Confusion limits are from the models of M. Rowan-Robinson (*Ap. J., in press*)

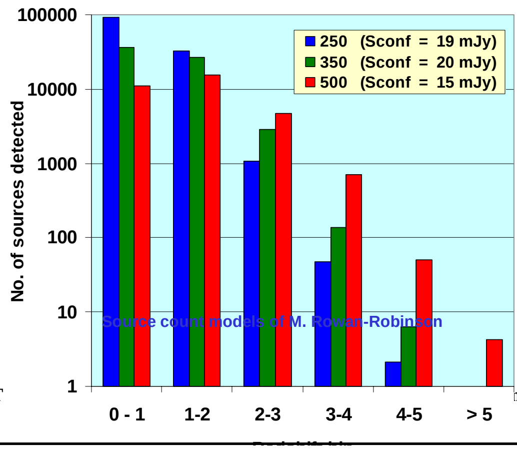
Assumptions
- Scan-map mode
- 90% observing efficiency
- 21 hrs observing/day
- 25% field overlap
- 75% detector yield

SPIRE — Survey Strategy

- SPIRE confusion limit is ~ 15 - 20 mJy: reached at 5-σ over the full 4 x 8 arcmin fov in < 15 minutes in 3 bands simultaneously
  ⇒ wide area rather than small ultra-deep surveys
- Observations of smaller areas with PACS imaging photometer
- Multi-wavelength survey near peak of the red-shifted SED
  → total luminosities; photometric redshifts estimation
- Follow-up with SPIRE FTS and other instruments for physics and SEDs of brighter sources:
  e.g.:
  - SPIRE FTS can reach 1-200 mJy (5-σ) per spectral element with $\lambda/\Delta\lambda$ ~ 20 in 1 hr
  - PACS spectrometer can detect diagnostic lines to distinguish AGN from starburst in several hours
- Example of Planck HFI Survey follow-up:
  - DECS: 2 ~ 14º x 14º (total ~ 400 sq. deg.) maps near ecliptic poles
  - Detection thresholds: (850, 545, 350) μm: (100, 220, 220) mJy
  - SPIRE ~ 2-3 week survey of the same area: improved positions, and sensitivity (5-σ detection thresholds ~ 100 mJy) and extended spectral coverage

SPIRE — Possible SPIRE Survey and Outcome

- 100 sq. deg.
- Confusion-limited
- 1 - 200 days
- $\Delta S_{5\sigma}$ < 15 mJy



1,300 sources/sq. deg.
660 sources/sq. deg.
320 sources/sq. deg.