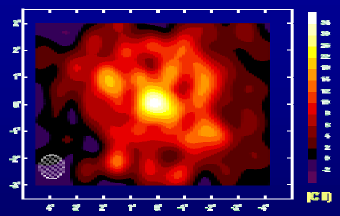
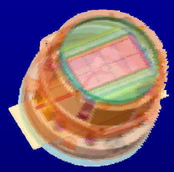
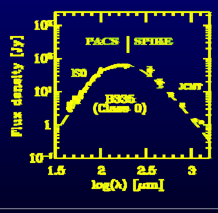
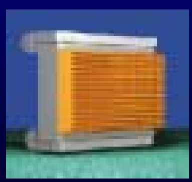
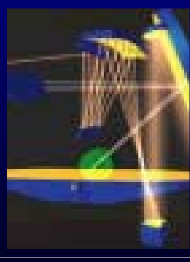
FIRST Photodetector Array Camera & Spectrometer (PACS)

Albrecht Poglitsch, MPE Garching

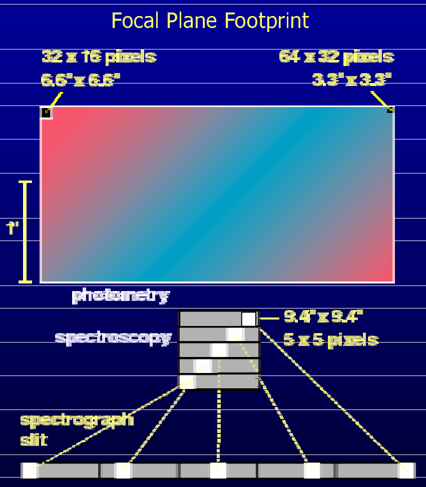



Science Requirements

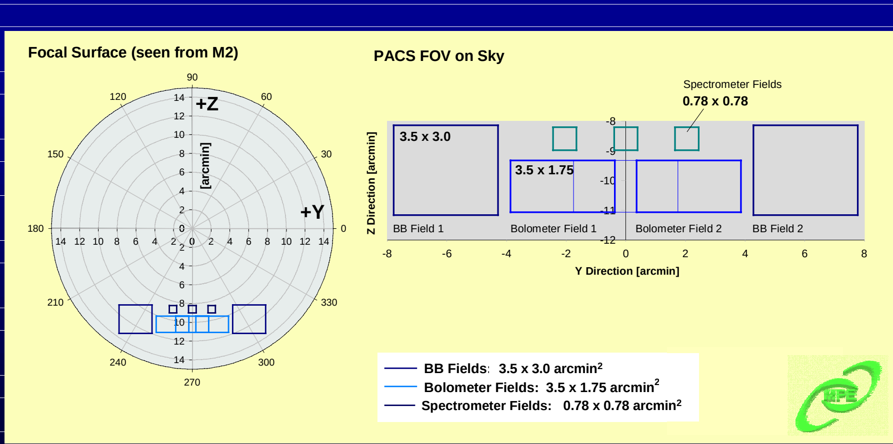
- Basis for PACS design
- Main scientific drivers
  - Investigations of the distant universe: galaxy formation and evolution - history of star formation and nuclear activity
  - Studies of star formation and the origin of the Initial Mass Function in our own Galaxy
  - Physics and chemistry of the interstellar medium, Galactic and extragalactic
  - Giant planets and the history of the Solar System
- Required observing capabilities
  - Imaging photometry in 3 bands in the 60 - 210μm range with requirements on sensitivity per detector and field of view
  - Imaging line spectroscopy in the 60 - 210μm (goal: 55 - 210μm) range with requirements on sensitivity per detector, spectral resolution and instantaneous bandwidth, and field of view

PACS In A Nutshell

- **Imaging photometry**
  - two bands simultaneously (60-90 or 90-130 μm and 130-210 μm) with dichroic beam splitter
  - two filled bolometer arrays (32x16 and 64x32 pixels, full beam sampling)
  - point source detection limit ~3 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 2...8 $\times 10^{-18}$ W/m^2 (5σ, 1h)



PACS Design: Focal Plane Footprint



Definition of the FOV for the Photometer

Rayleigh-Criterium:

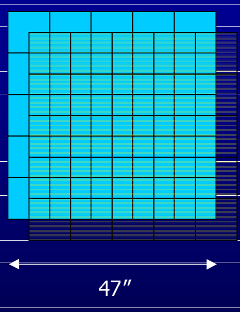
2 pixel per 1.2 λ/D at the diffraction limited wavelength

Detector	Pixel	FOV/Bolometer [arcmin]	FOV/Pixel [arcsec]	Diffraction Limited Wavelength [µm]
blue	32 x 64	**1.75 x 3.5**	3.3	87
red	16 x 32	**1.75 x 3.5**	6.6	174

Physical pixel size: 0.75 x 0.75 mm^2

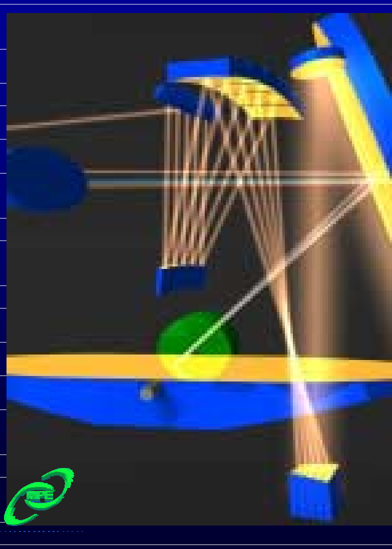
Definition of the FOV for the Spectrometer

- Pixel scale has to be a compromise
  - small number of spatial pixels limits field of view
  - diffraction introduced by image slicer does not allow full sampling
  - large wavelength range requires compromise
- Physical optics analysis shows that 9.4″/pixel gives low enough diffraction losses (15% at 175 µm) with acceptable spatial resolution/sampling
- Full spatial sampling in the long-wave band with two, slightly offset pointings

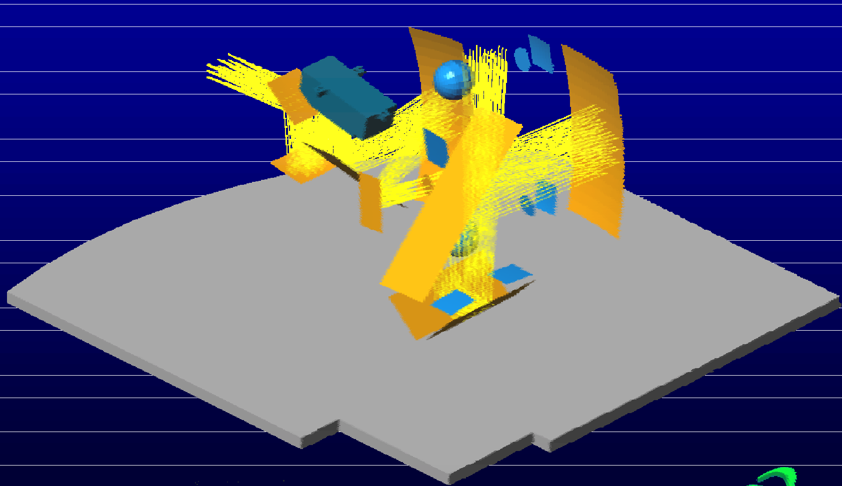


PACS Integral Field Line Spectrometer

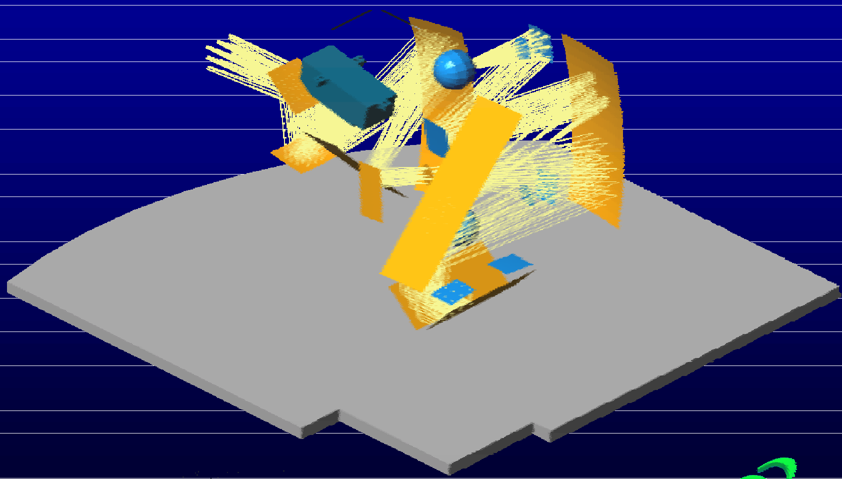
- Optical "image slicer" re-arranges 2-D field of view (5x5 pixels) along 1-D slit (1x25 pixels)
- Grating spectrograph disperses light
- Dispersed slit image is projected on 2-D detector array
- 16 spectral channels recorded simultaneously for each spatial element



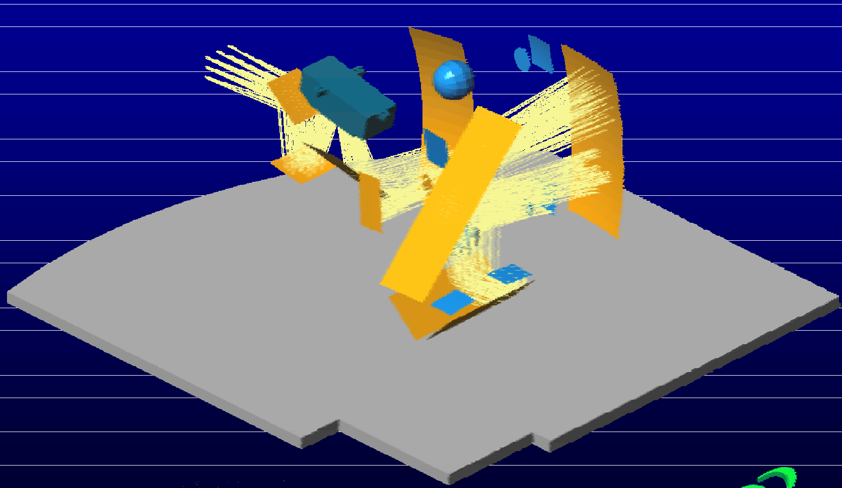
PACS FPU



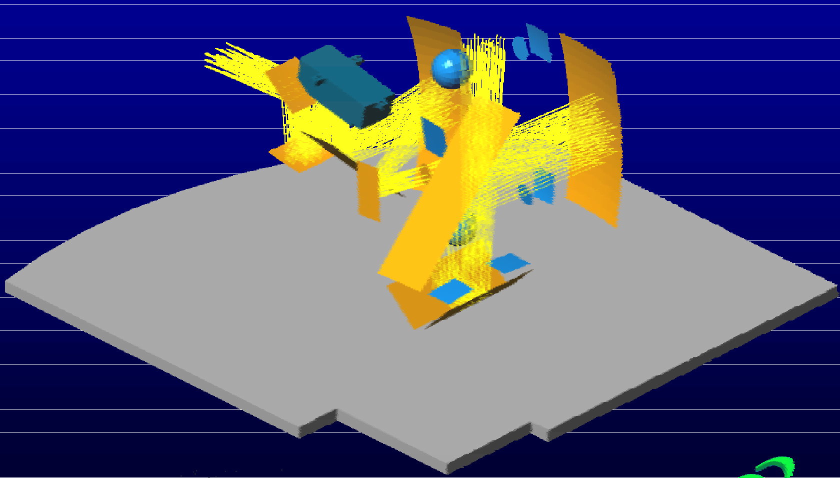
PACS FPU



PACS FPU



PACS FPU



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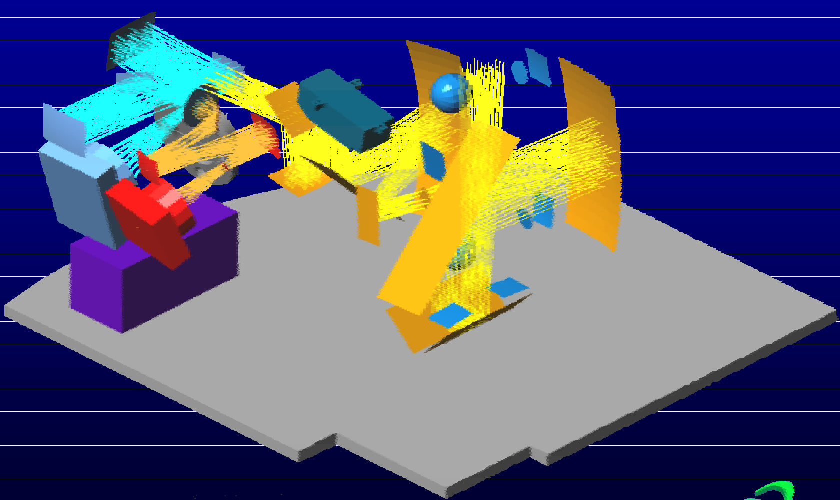
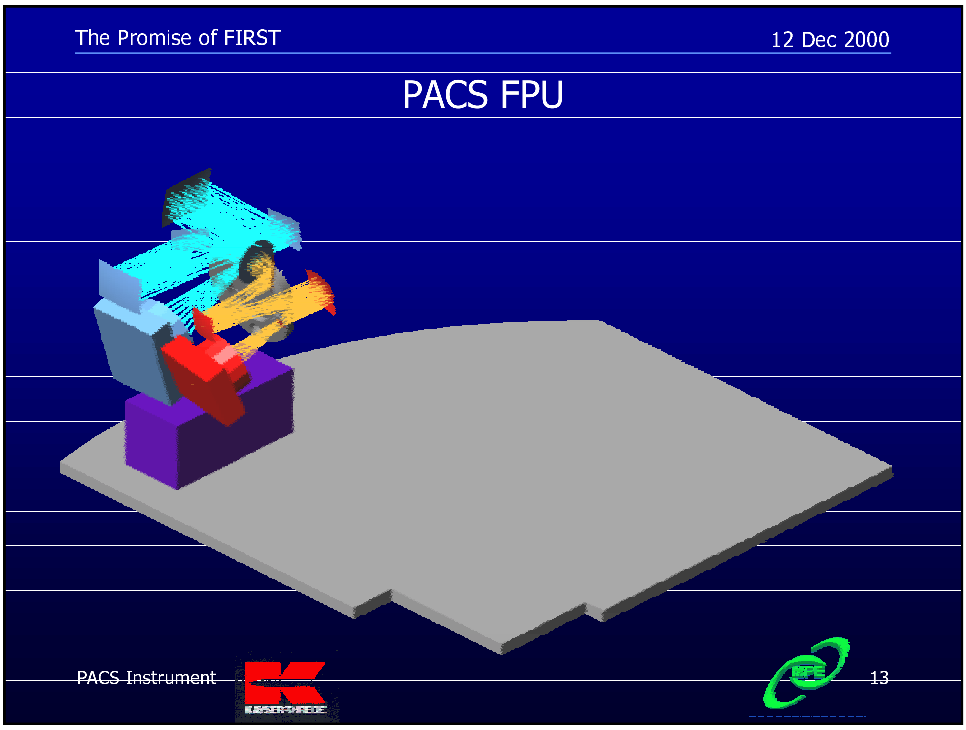
PACS FPU

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PACS Instrument
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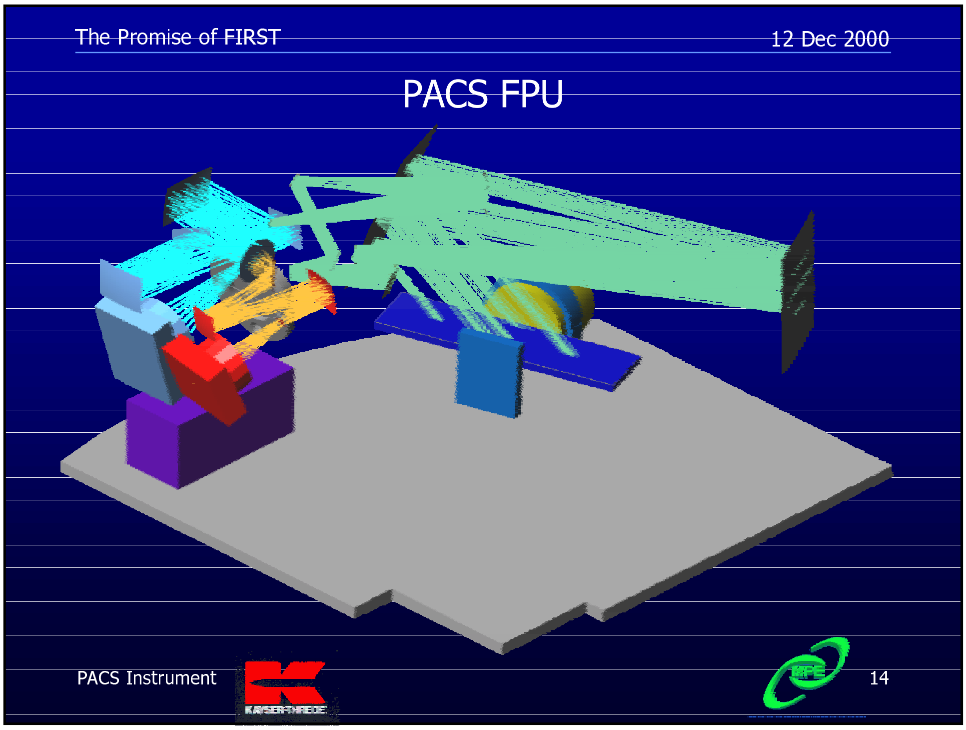
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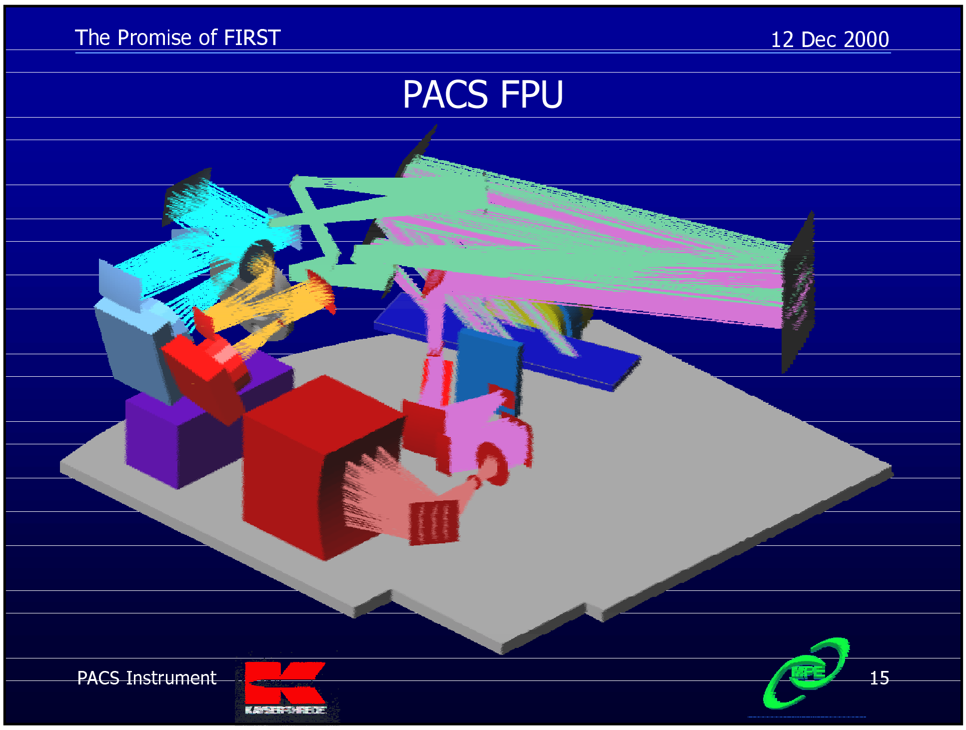
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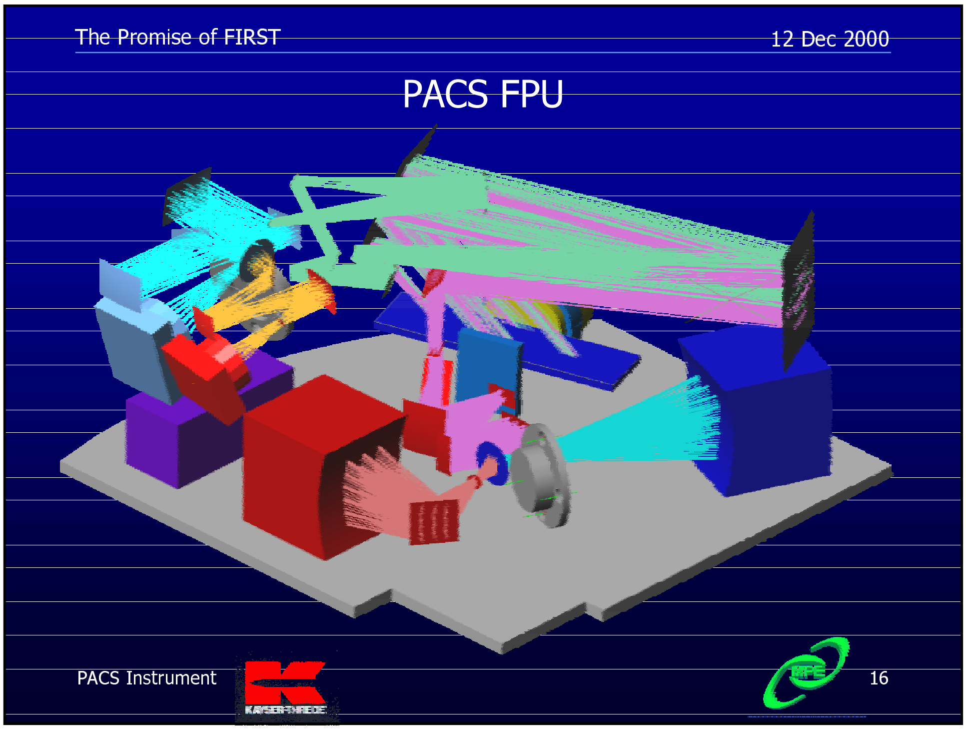
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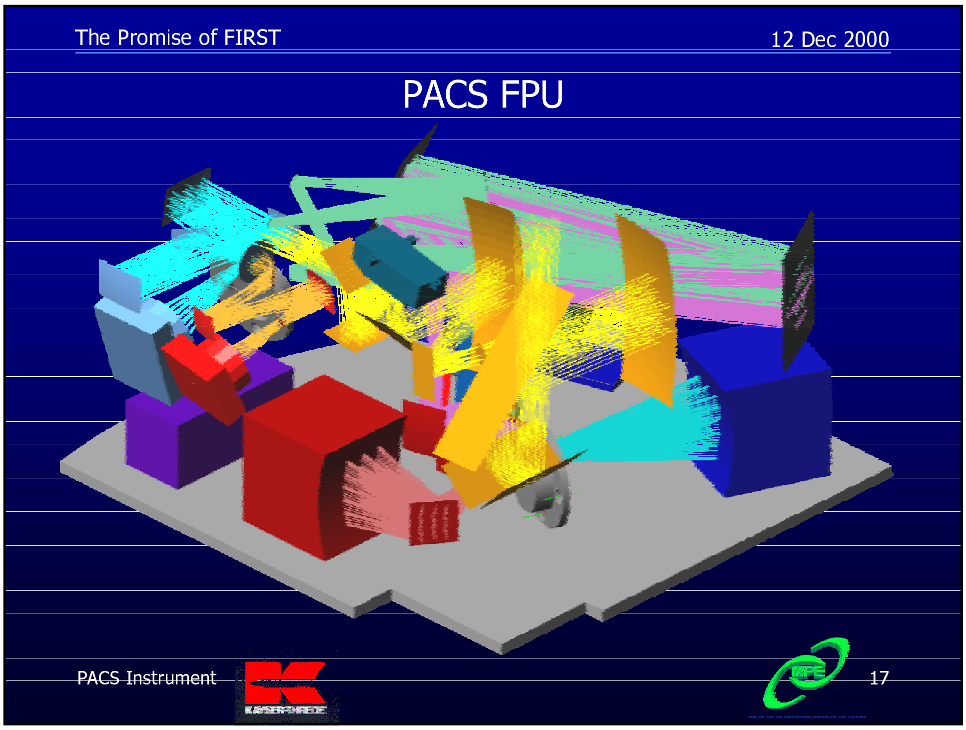
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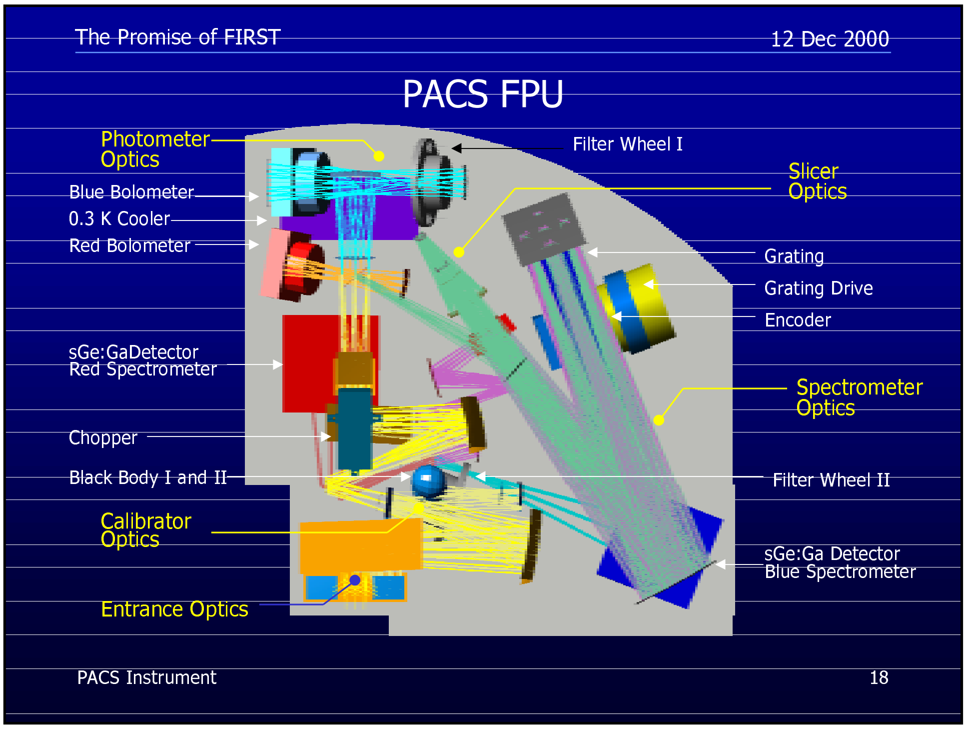
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PACS FPU
Photometer Optics
Blue Bolometer
0.3 K Cooler
Red Bolometer
sGe:GaDetector Red Spectrometer
Chopper
Black Body I and II
Calibrator Optics
Entrance Optics
Filter Wheel I
Slicer Optics
Grating
Grating Drive
Encoder
Spectrometer Optics
Filter Wheel II
sGe:Ga Detector Blue Spectrometer
PACS Instrument
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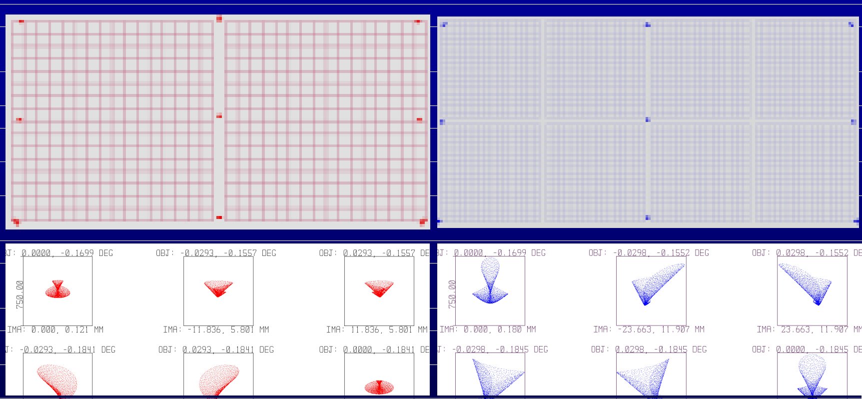
Photometer Image Quality

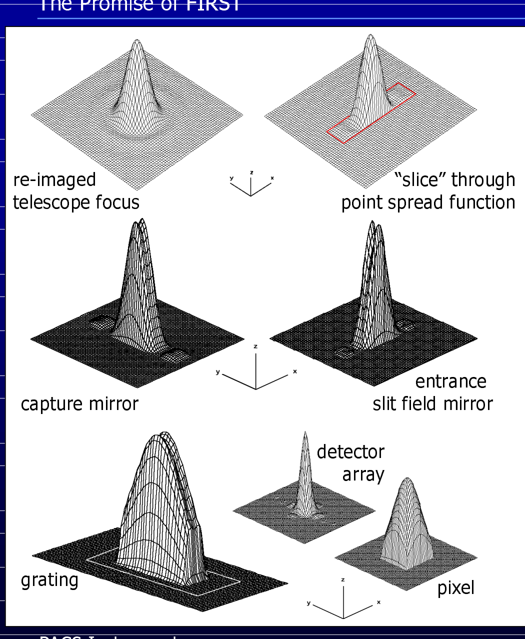


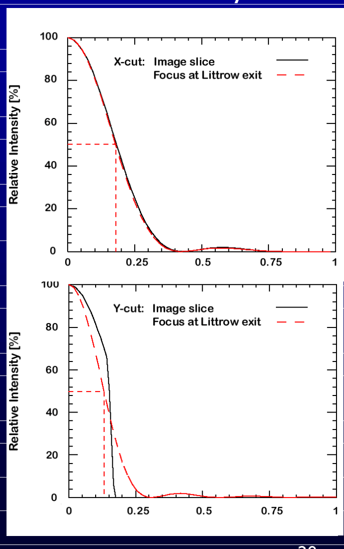
Aberrations of full optical train (telescope + PACS) included

- Strehl ratio 0.99
- Distortion < 1 pixel

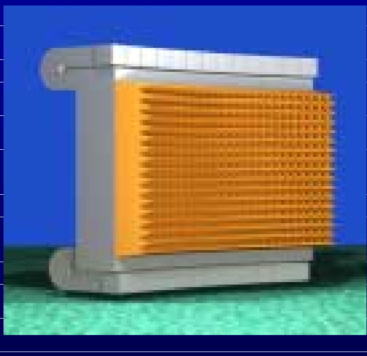
- Strehl ratio >0.95
- Distortion < 1 pixel

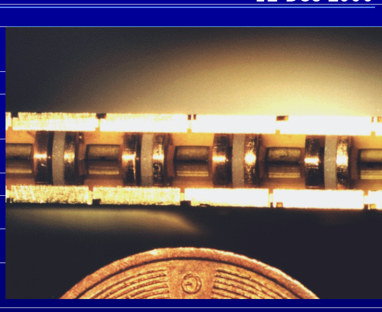
PACS Spectrometer Diffraction Analysis



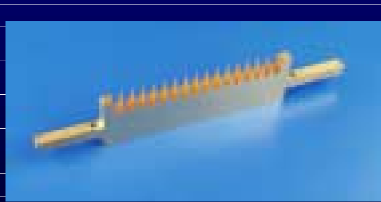


PACS Ge:Ga Photoconductor Arrays





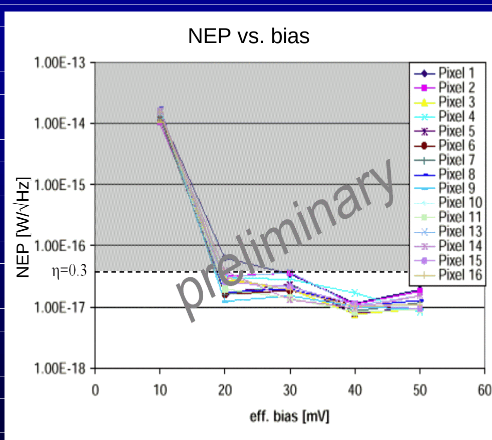
16 pixel stressed detector module



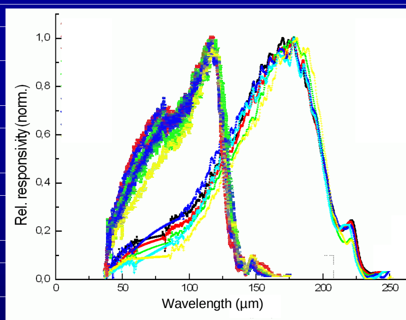
Feed optics: light cone array

- 16x25 pixel filled arrays
  - 25 linear modules
  - integrated cryogenic readout electronics

PACS Photoconductor Modules



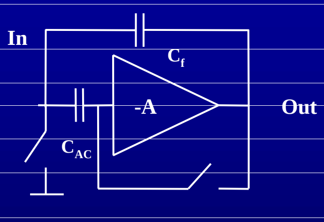
T=1.7K, P=9x10^{-14}W, t_{int}=1 s, C_{int}=10 pF



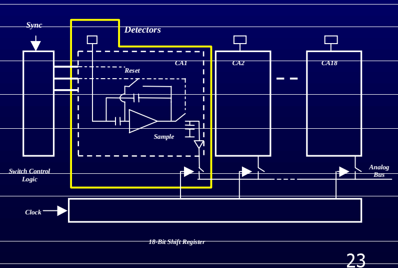
- Ge:Ga photoconductors
  - unstressed: 40 - 120µm
  - stressed: 110 - 210µm
  - background-limited in both, photometry and spectroscopy, if amplifier noise is low enough

PACS Cryogenic Readout Electronics

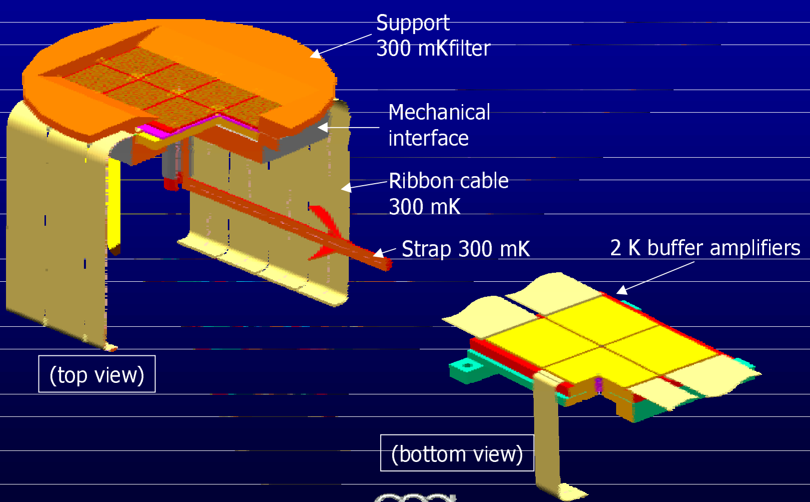
- Capacitive feedback transimpedance amplifier (CTIA) for each pixel, based on AC-coupled inverter stage in silicon CMOS technology
- 16 CTIAs multiplexed on each CRE chip for each linear detector module
- CRE chips integrated in detector modules
- Amplifier noise compatible with background-limited performance in spectroscopy



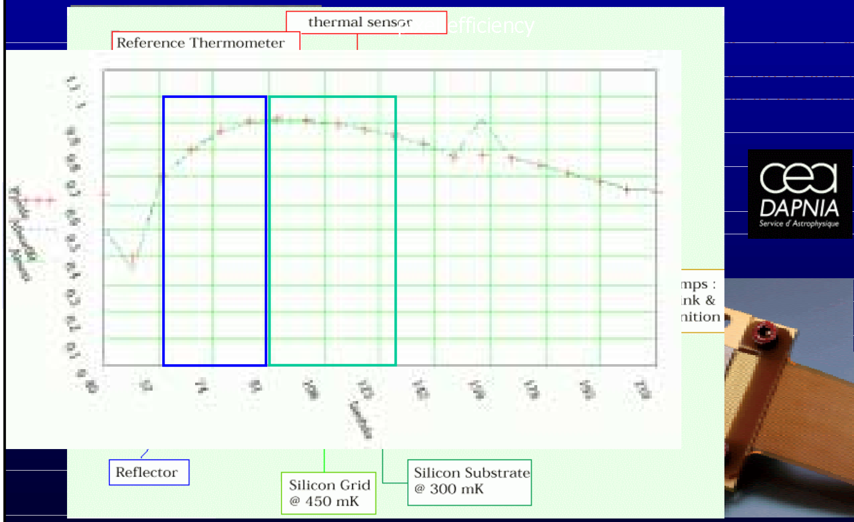
CTIA architecture



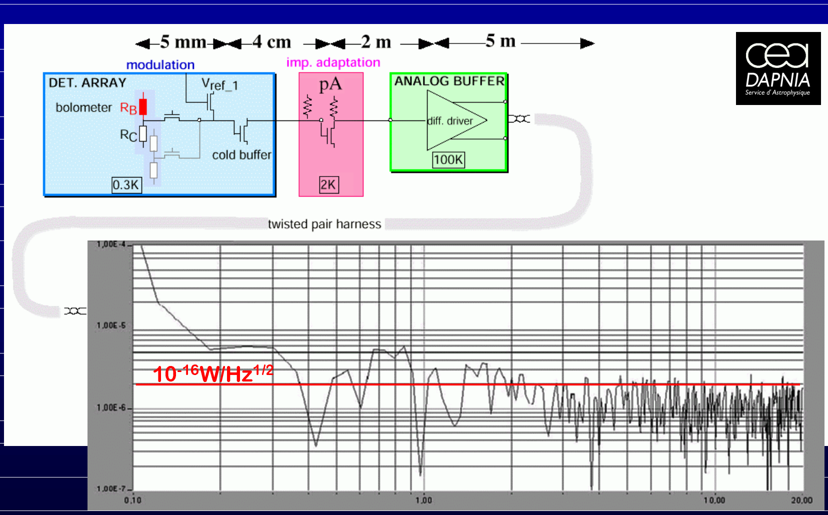
Bolometer Array Assembly



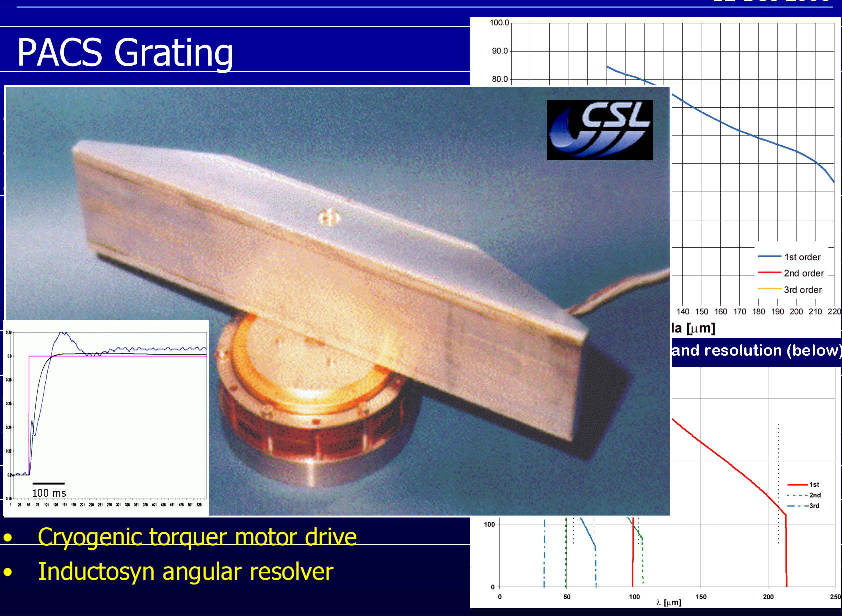
Bolometer Arrays: 16x16 Subarray



Bolometer Readout & Performance



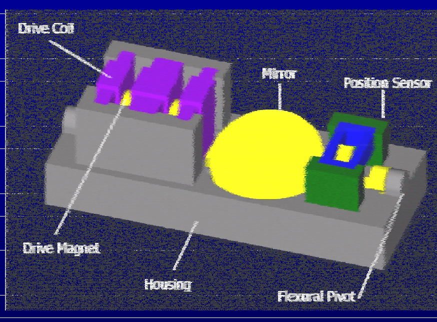
PACS Grating

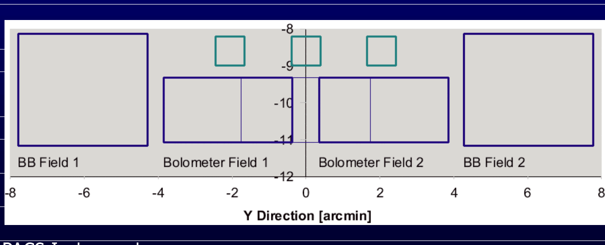


- Cryogenic torquer motor drive
- Inductosyn angular resolver

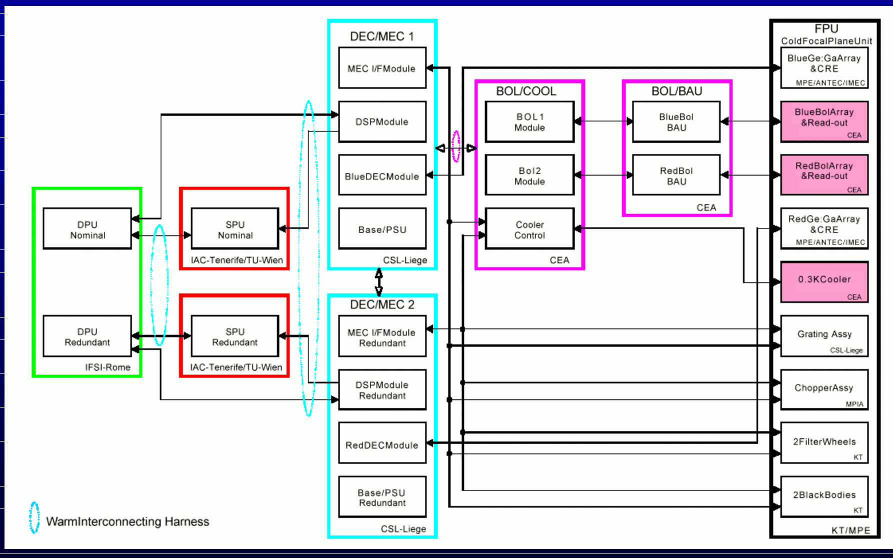
PACS Chopper

- Chopper with variable throw and arbitrary waveform used for spatial modulation and for observation of internal calibration sources
- Electromagnetic linear drive
- Monolithic flexural pivots
- Magnetoresistive position sensors
- Duty cycle > 80%





Instrument Units and Subsystem Responsibilities



Observing Modes

- Observing modes are combinations of *instrument modes* and *satellite pointing modes*
- Instrument modes:
  - dual-band photometry
  - single-band photometry
  - line spectroscopy
  - range spectroscopy
- Pointing modes:
  - stare/raster/line scan
  - with/without nodding

Dual-Band Photometry

- Both arrays operating
  - full spatial sampling in each band
  - long-wave array imaging 130-210μm band
  - short-wave array imaging 60-90 or 90-130μm band
    - sub-band selected by filter
- Standard mode for PACS as prime instrument
- Observing parameters
  - chopper mode (off/on; waveform, throw)
  - pointing parameters (stare/raster/scan;nod)
  - integration time per pointing

Single-Band Photometry

- One array operating
  - long-wave array imaging 130-210μm band
    or
  - short-wave array imaging 60-90 or 90-130μm band
- Standard mode for PACS/SPIRE parallel mode
- Observing parameters
  - chopper mode (off/on; waveform, throw)
  - pointing parameters (stare/raster/scan;nod)
  - integration time per pointing

Line Spectroscopy

- One or two arrays operating
  - observation of individual lines
  - long-wave array in 105-210µm band
  - short-wave array in 57-72 or 72-105µm band
  - wavelength in primary band determines wavelength in secondary band
- Observing parameters
  - scan width (default 0)
  - chopper mode (off/on; waveform, throw)
  - pointing parameters (stare/raster/scan;nod)
  - integration time per pointing

Range Spectroscopy

- Two arrays operating
  - observation of extended wavelength ranges
    - continuous scan (full resolution) or steps (SED sampling)
  - long-wave array in 105-210µm band
  - short-wave array in 57-72 or 72-105µm band
- Observing parameters
  - start- and end wavelength
  - resolution mode
  - chopper mode (off/on; waveform, throw)
  - pointing parameters (stare/raster/scan;nod)
  - integration time per pointing

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Parameters of PACS Instrument Model

optical element	efficiency	
	photometry	spectroscopy
Lyot stop	0.9	0.9
filters	0.4	0.4
mirrors	0.85	0.74
slicer diffraction	-	0.85
grating	-	0.65

level	T (K)	ε	effective transmission		relative bandwidth	
			photometry	spectroscopy	photometry	spectroscopy
telescope	80	0.04	0.31	0.15	$2.5^{-1}/2.2^{-1}$ (a)	1700^{-1}
baffle	65	0.01	0.34	0.16	$2.5^{-1}/2.2^{-1}$ (a)	1700^{-1}
"15 K" optics	15	0.05	0.34	0.16	$2.5^{-1}/2.2^{-1}$ (a)	1700^{-1}
"4 K" optics	5.5	0.15	760/190 (b)	4 (b)	1.5^{-1}	1.5^{-1}

(a) Values for the photometry modes from 60-90 / 90-130 μm and 130-210 μm, respectively.

(b) The formal transmission of >1 takes into account the acceptance solid angle of the light cones / bolometer pixels which differs from the beam solid angle.

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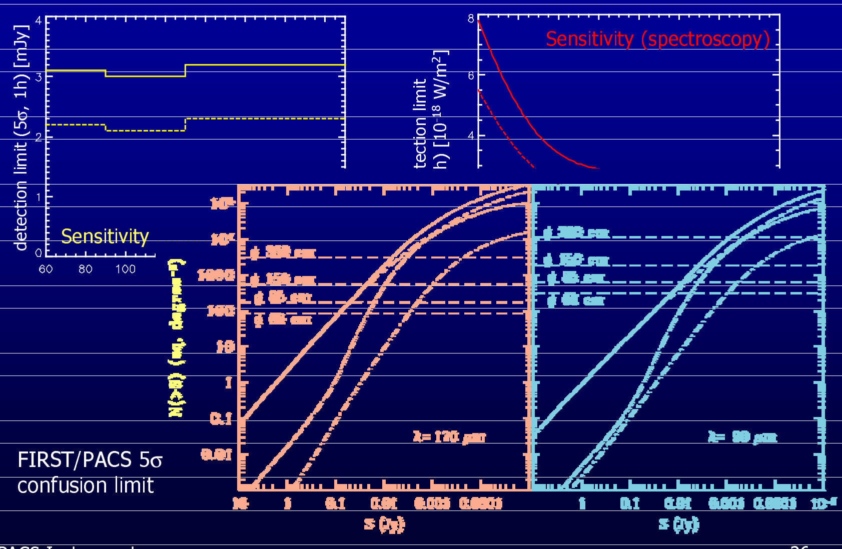
PACS Sensitivity



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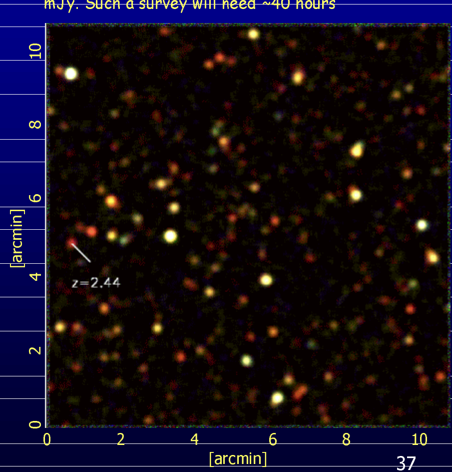
Deep extragalactic surveys

- Characterize the obscured part of high redshift star and galaxy formation, especially in the range z~1-3 where most star formation happened and most metals formed.
- Resolve the cosmic FIR background
- Multiwavelength information essential for starburst/AGN discrimination and redshift indication.
- PACS spatial resolution crucial to beat confusion and for identification.
- Photometric/spectroscopic followup.
- Example: A 1000 hour dual-band PACS survey to 5σ depths of 10mJy at 110μm and 170μm will cover ~15 square degrees and detect tens of thousands of galaxies.

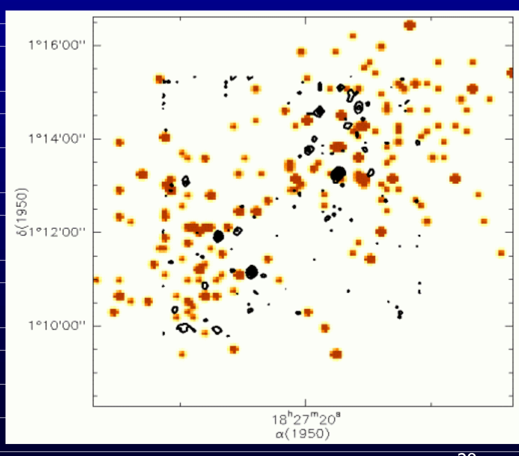
Simulated deep PACS survey of 10^{-5}sr at 75, 110, 170 μm (false colors) to a 1σ limit of 0.7, 0.7, 0.5 mJy. Such a survey will need ~40 hours



IMF in cores and clusters

- Understanding the origin of the stellar mass distribution
- Efficient mapping of large areas to get good statistics
- Good SED coverage including maximum to get accurate masses/luminosities
- Probing down to equivalent brown dwarf masses
- Individual cores observable in few hours
- 3-band survey to the same limit for 6 star forming regions within 500pc (total 12 sq. degree): ~500 hours

Serpens core - PACS 100 μm simulation 0.08 $M_\odot$, 5σ limit - 2 hours map, 2 hours SED photometry



Spatially resolved study of the ISM in galaxies

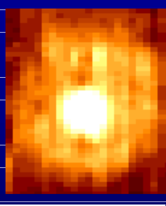
- What is the nature and distribution of the various gas and dust phases?
- How do these vary in galaxies of different types and metallicity?
- What are the heating/cooling mechanisms and the relation to energy sources (star formation / AGN)?
- Observations: Deep FIR imaging and spectroscopic mapping of galaxies
- Time: Several hours for broad-band imaging and spectroscopic mapping in [CII] / [OI] of a nearby large galaxy like M83.
- Spatial resolution decisive in separating nuclei / arms / interarms / star forming complexes

M31 175μm: Haas et al. 1998

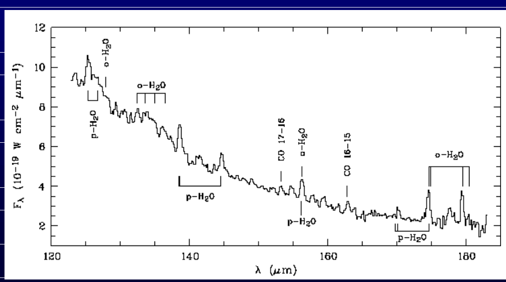
Stellar mass loss

- Establish mass loss history through high resolution imaging of dust shells
- 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 other species participating in the initial chemistry of the escaping gas.

Y CVn ISOHOT 90μm: Izumiura et al. 1997



W Hya ISO-LWS: Barlow et al. 1996



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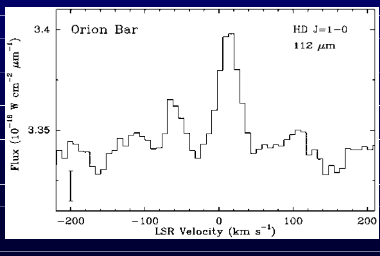
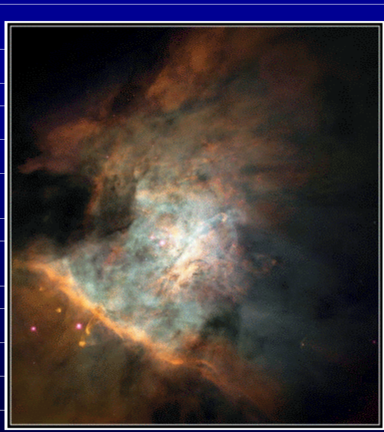
HD

- Estimate baryon density – ratio D/H
- HD observable from solar system to galaxies
- Survey of 18 Galactic PDRs within 1.1kpc. Integration times for spectra between 1min and 4h, total 28 hours





Wright et al. (1999)

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