PACS Observing strategy

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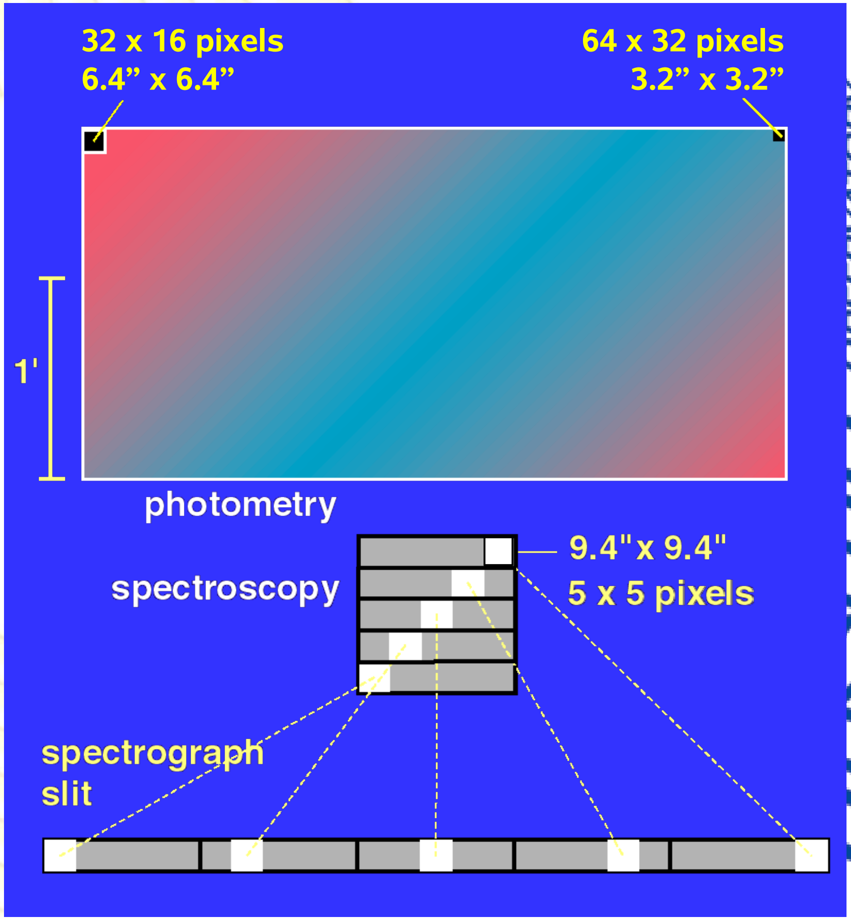
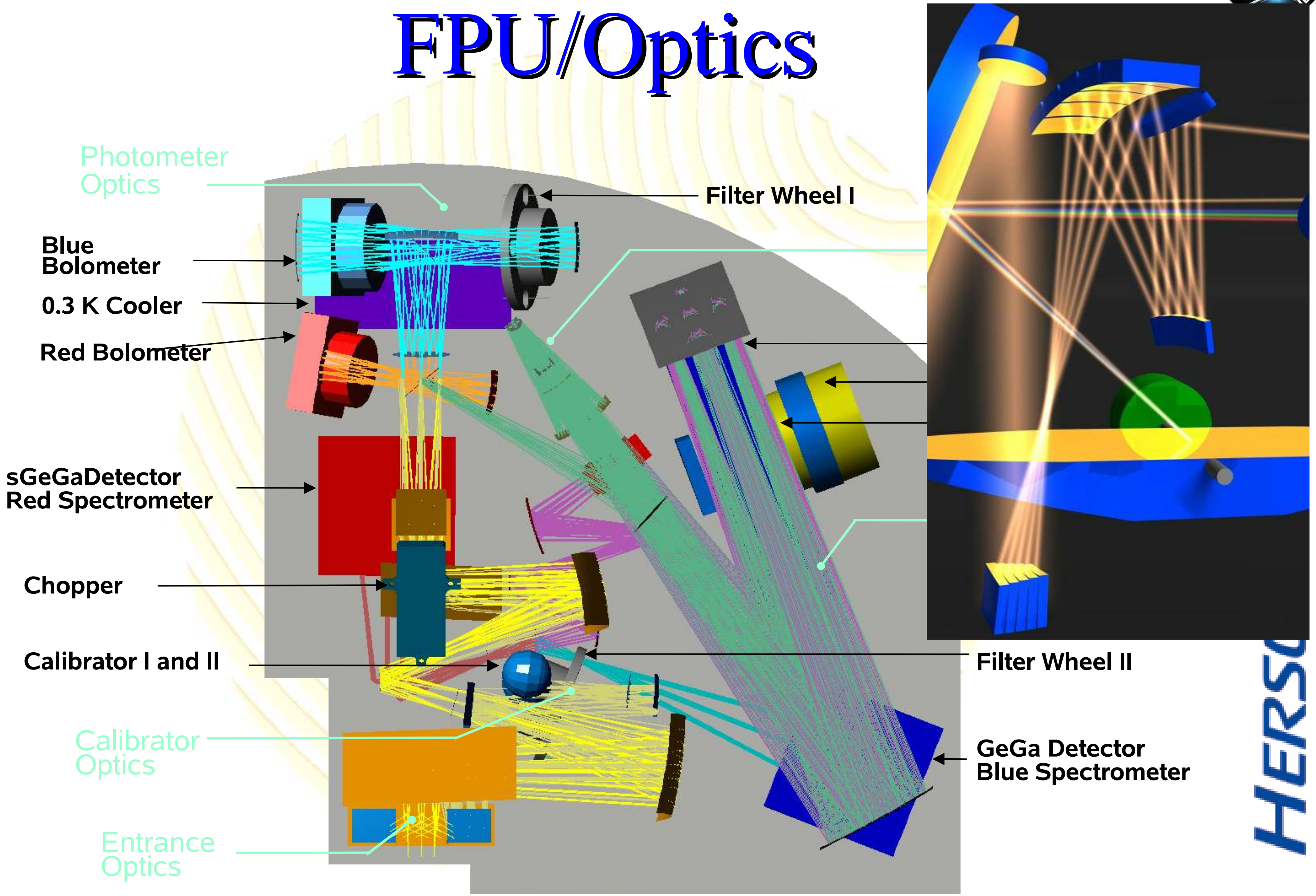
Instrument Concept

- **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 ~3-4 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



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

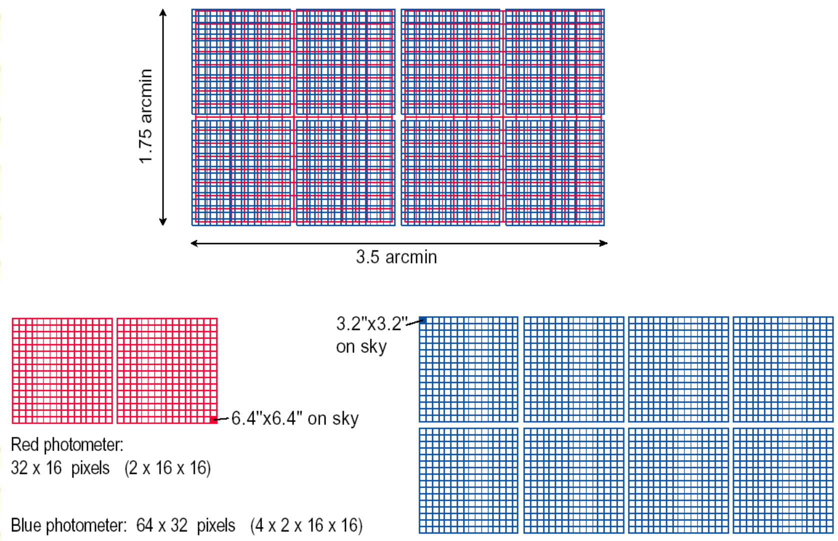
1. PACS photometer AOT

- Science with PACS photometer
  - *Sensitive mapping in 3 bands sampling the peak of SED for Embedded proto-stars*
  - *Re-emitted dust from AGNs and other extragalactic sources*
  - *Unprecedented spatial resolution at sub-mm wavelengths*

PACS Photometer

- *Relatively small rectangular 2x1 footprint, FOV = 3.5'x1.75'*

- *2 channels simultaneously imaged (dual-band):*
  - *Blue channel 64x32 array, pixel size = 3.2", **60-85 µm** or **85-130 µm***
  - *Red channel 32x16 array, pixel size = 6.4", **130-210 µm***

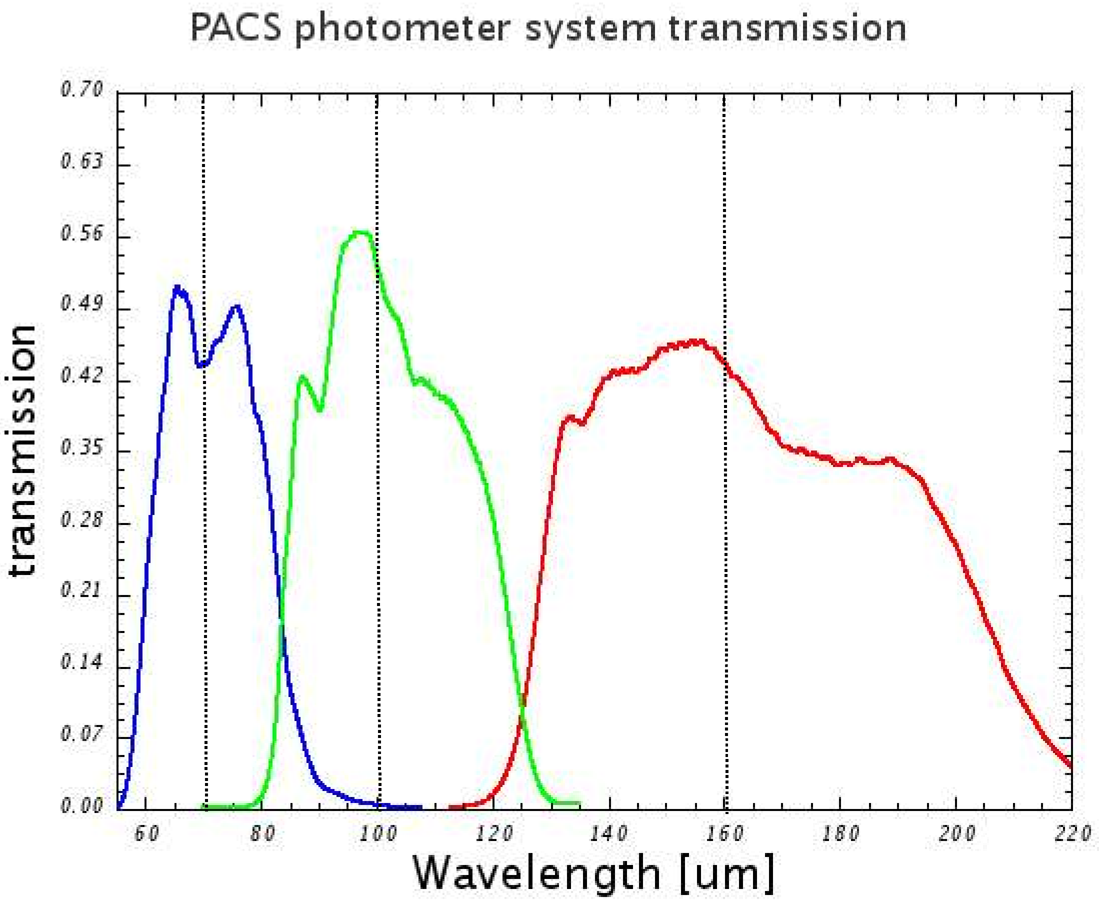


- *Sensitivity:*
  - *point source 5σ-1 hour*
    - *3.5 mJy at 70 and 100µm*
    - *5.0 mJy at 160µm*
  - *1sq.deg. to ~10mJy 5σ:*
    - *~ 40 hours at 70 and 100µm*
    - *~ 80 hours at 160µm*

- *PSF FWHM: 5.2", 7.7" and 12" in the 3 bands.*

- *On-board readout frequency : 40Hz*
- *On-board averaging, downloaded frequency : 10Hz, to stay within allocated 130kb/s rate.*

Photometer system transmission



75 µm (70 µm) | 110 µm (100 µm) | 170 µm (160 µm)

HERSCHEL SPACE OBSERVATORY

Photometer observing modes

General rules for which mode to use when :

- The size of mapped region usually determines which mode is more efficient
- 1. Point-source mode: unresolved single sources
- 2. Small-source mode: single source <1'-1.5' in size
- 3. Chopped raster: sources >1' and <12'
- 4. Scan maps: Source > 10'
- Exceptions : (always!)
  – You might want to use scan for area <12' if chopped negative beams do not suit your needs, esp. close to the confusion limit.
  – Use scan if you are worried about your off position.

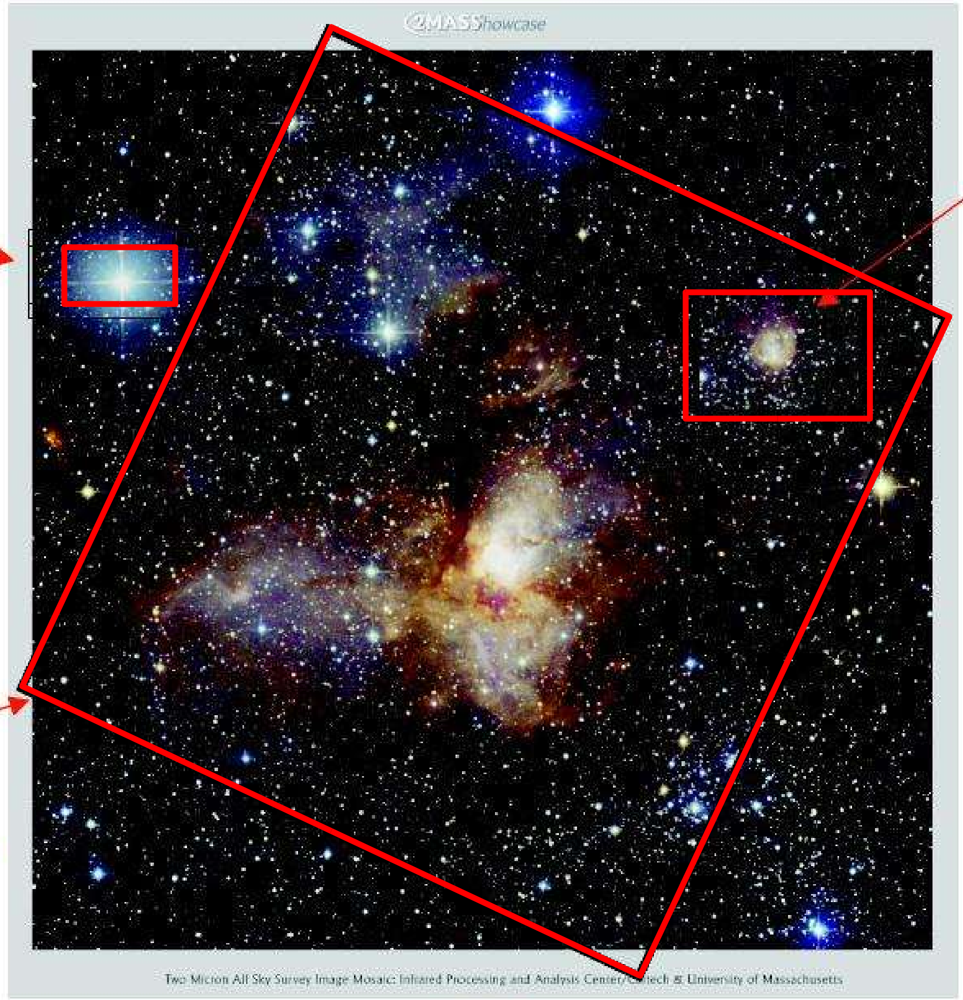
Photometer AOT concept

Point source photometry:

- 4-point chop/nod cycle
- Any orientation possible

Extended source Mapping:

- Scan or Raster
- Chopping optional with rasters



Small source photometry:

- Small MxN raster
- Chopping optional
- 2x field of view
- Fixed step sizes
- Any orientation

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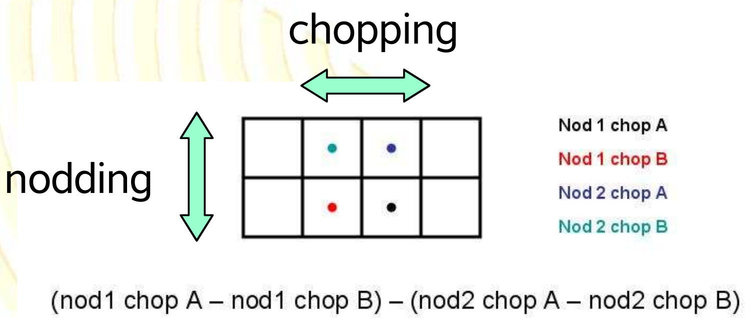
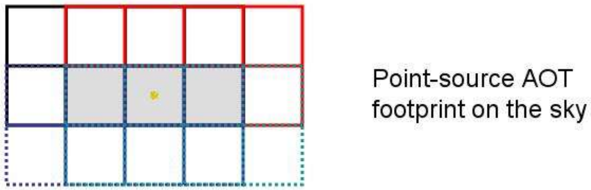
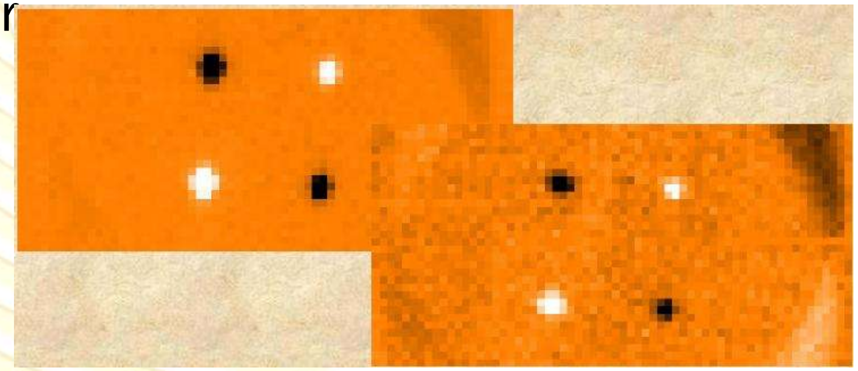
1.1 Point-source mode

- 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.
- Possibility of dithering with chopper
- Minimum execution time: 5.5min (incl. 3min for slew)
- Predicted sensitivity (5σ):
  - 70/110 µm : 15mJy
  - 170 µm : 22 mJy







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1.2 Small-source photometry mode

- 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'x1.5'.
- Off-array chopping, nodding, dithering to fill gaps.
- Minimum execution time: 15min
  - (incl. all slew overheads).
- Predicted sensitivity (5σ):
  - 70/110 µm : 10mJy
  - 170 µm : 15mJy

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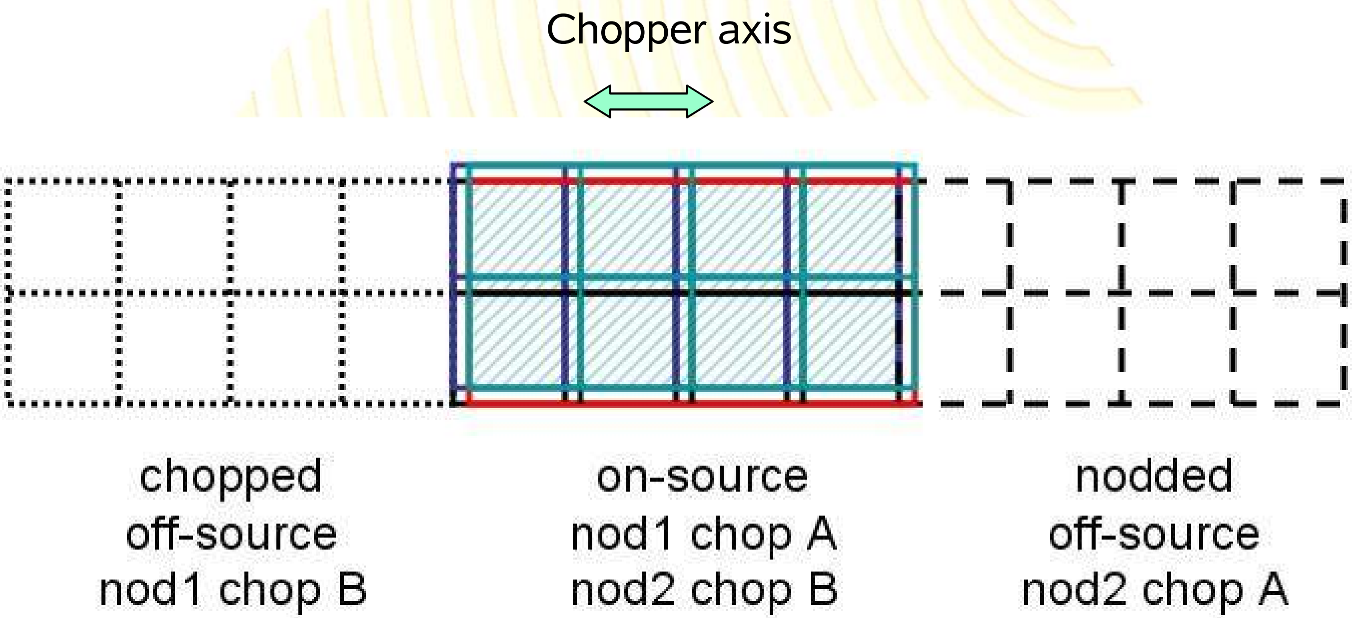
Small-source chopping/nodding



Double difference, to subtract telescope foreground

1.3 PACS large area mapping

- *However Herschel was designed to make large scale surveys : to map sources larger than the array size, or cover large contiguous areas of the sky (photometric surveys), two modes are available:*
  - *Raster mapping the satellite goes through a rectangular grid pattern of points in internal reference frame (that can be repeated).*

    Note: Rastering only with chopping (1/f noise)
  - *Scan mapping (without chopping): the satellite slews continuously along parallel lines at constant speed (10, 20 or 60 arcsec/s)*
    - *Filled arrays allow (almost) arbitrary scanning orientation*
    - *1 square degree in a few hours (at 10"/s)*

HERSCHEL SPACE OBSERVATORY

1.3.1 Raster mapping

- *Modulation of signal necessary because of 1/f noise*
- *Hence chopping imposed at 0.25Hz*
  - *Given by Allan variance (blue array), probably less later as compromise between blue and red detector*
- *Duration per raster point fixed at 64s (8 on/off cycles)*
- *Chopper-throw fixed at 3.5 arcmin, i.e one FOV (long side)*

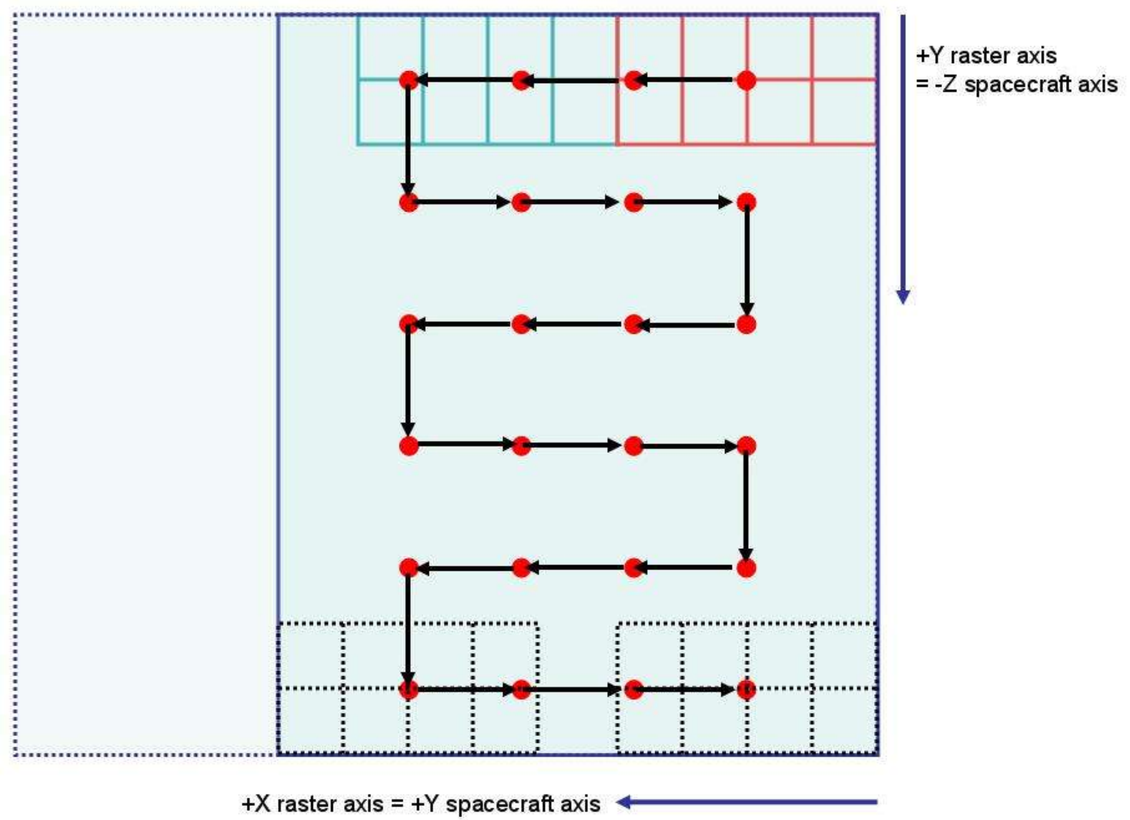
- *Raster mapping only allowed in instrument reference frame*

➔ *orientation depends on position angle of day of observation*

→ *to be immune against PA (position angle) rotation, it is advised to define square maps*

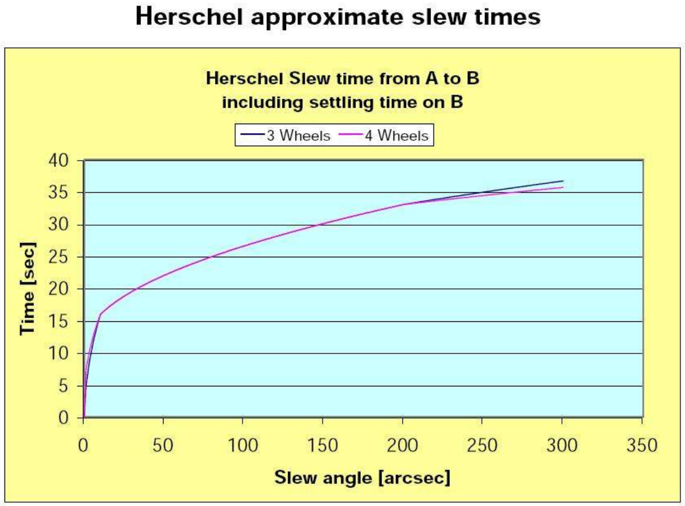
Raster mapping concept

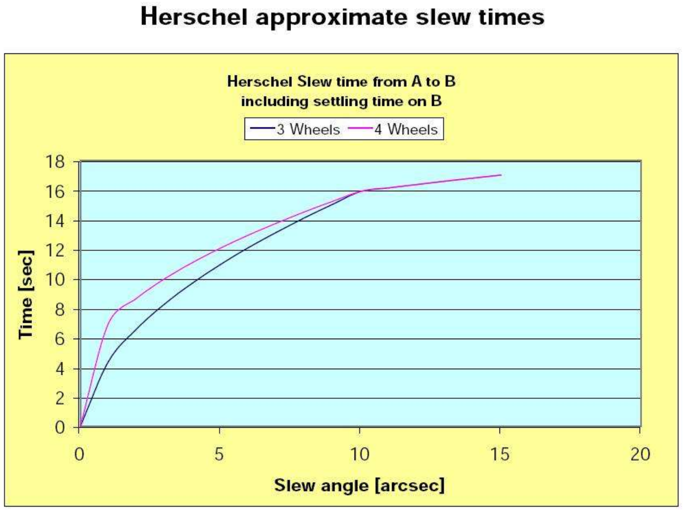
- **Map centered on the area mapped by the chop/on footprints**
- **SRPE=Spatial Relative Pointing Error**
  - **Current performance prediction = 2.0 arcsec,**
  - **Requirement/ goal: 1 arcsec**



Raster limitation 1: slew times overhead

- Observation efficiency limited by the duration of small slews between raster points,
  - typically of the order of 20-30 sec..
  - → ~⅓ of overheads for small slews





SPACE OBSERVATORY HERSCHEL

Raster limitations (2)

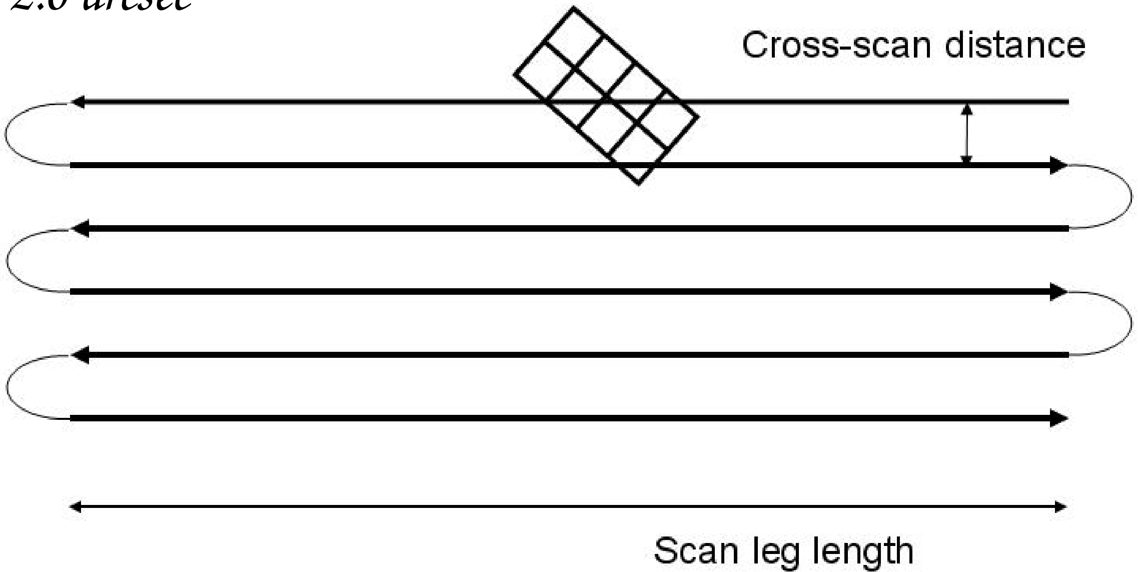
- *Chopping :*
  - *introduces negative sources/beams*
  - *degrades the sensitivity by $\sqrt{2}$ because of differential imaging*
  - *and another factor $\sqrt{2}$ because if sources seen only in one chop position (as half of the time spent on source).*

- *Only relatively small areas can be mapped, up to 10'x10' or 15'x15'*

→ *For larger area: scan mapping*

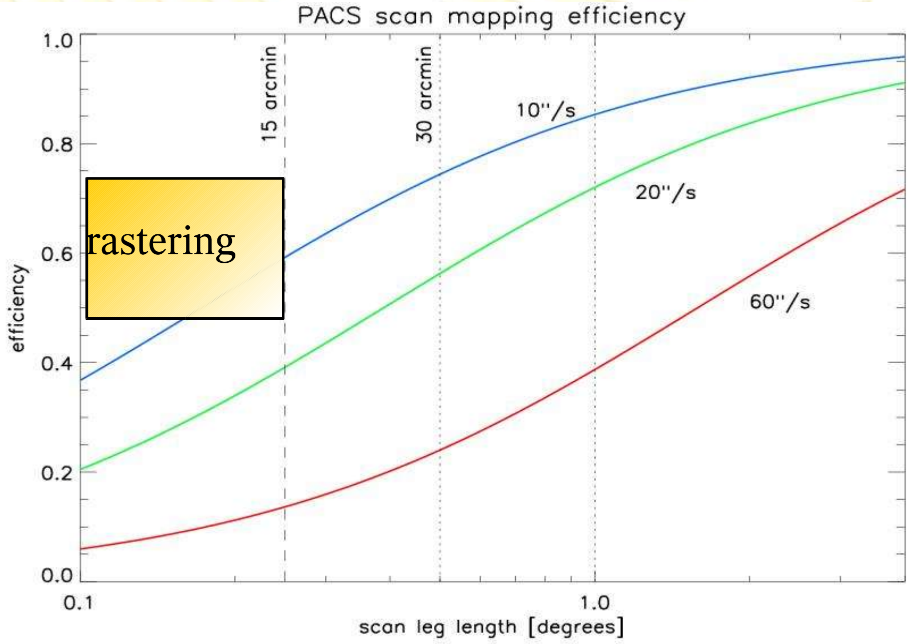
1.4 Scan mapping

- *For large areas up to several square degrees, no-chopping*
- *3 scan speeds*
  - *Slow : 10"/s, for extragalactic mapping/surveys*
  - *Medium: 20"/s, for larger areas >1 sq.deg*
  - *High: 60"/s, for galactic surveys*
- *PSF degradation :*
  - *Shift and broadening of the PSF because of electrical (and thermal) time constants and 10 Hz averaging: minimal at slow and medium speed*
  - *Significant impact at the high speed, broadening by a factor 2.*
- *SRPE along a line = 2.0 arcsec*



Scan mapping efficiency

- Large overhead for turn-around manoeuvre between scan legs
- Scan legs smaller than 15' are very inefficient.
- Significant reduction to be achieved for GT KP phase II entry and OT KP call by a factor ~2 at the expense of a marginal degradation of attitude accuracy along a scan leg.



Scan maps orientation

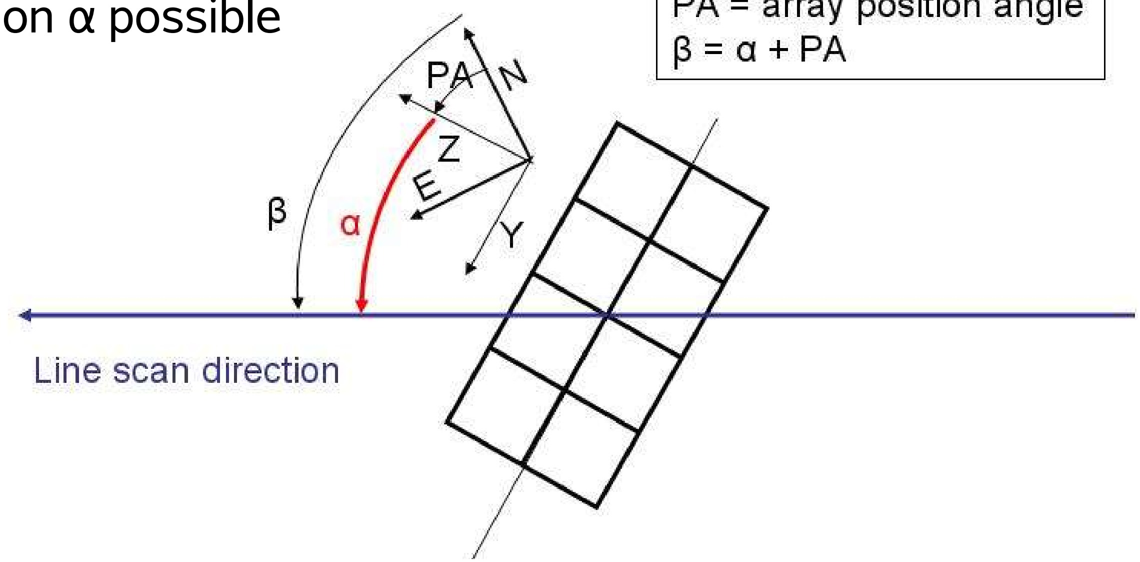
- *With filled array, no fixed magic angle like SPIRE*
- *Two types of scan maps*
  - *1/ in instrument reference frame*
    - *Advantage: control on the geometry of the scan map*
    - *Drawback: control on map orientation, only via constraints*
      - *orientation constraint or*
      - *timing constraint in HSpot (not advised)*
    - *Not always possible and 10mn penality*
    - *Hence maps shall be square*
  - *2/ in sky coordinates*
    - *Advantage: control on map orientation*
    - *Drawback : limited control on homogeneity of the scan map*
      - *but with PACS 'magic distance' : cross-scan distance of a blue matrix 51 arcse, the coverage is rather homogeneous, whatever the array to map angle*

Scan map orientation

- In reference frame "array" in HSpot
  - α fixed, constraint on β is possible
  - Selection of homogeneous coverage offered in HSpot.

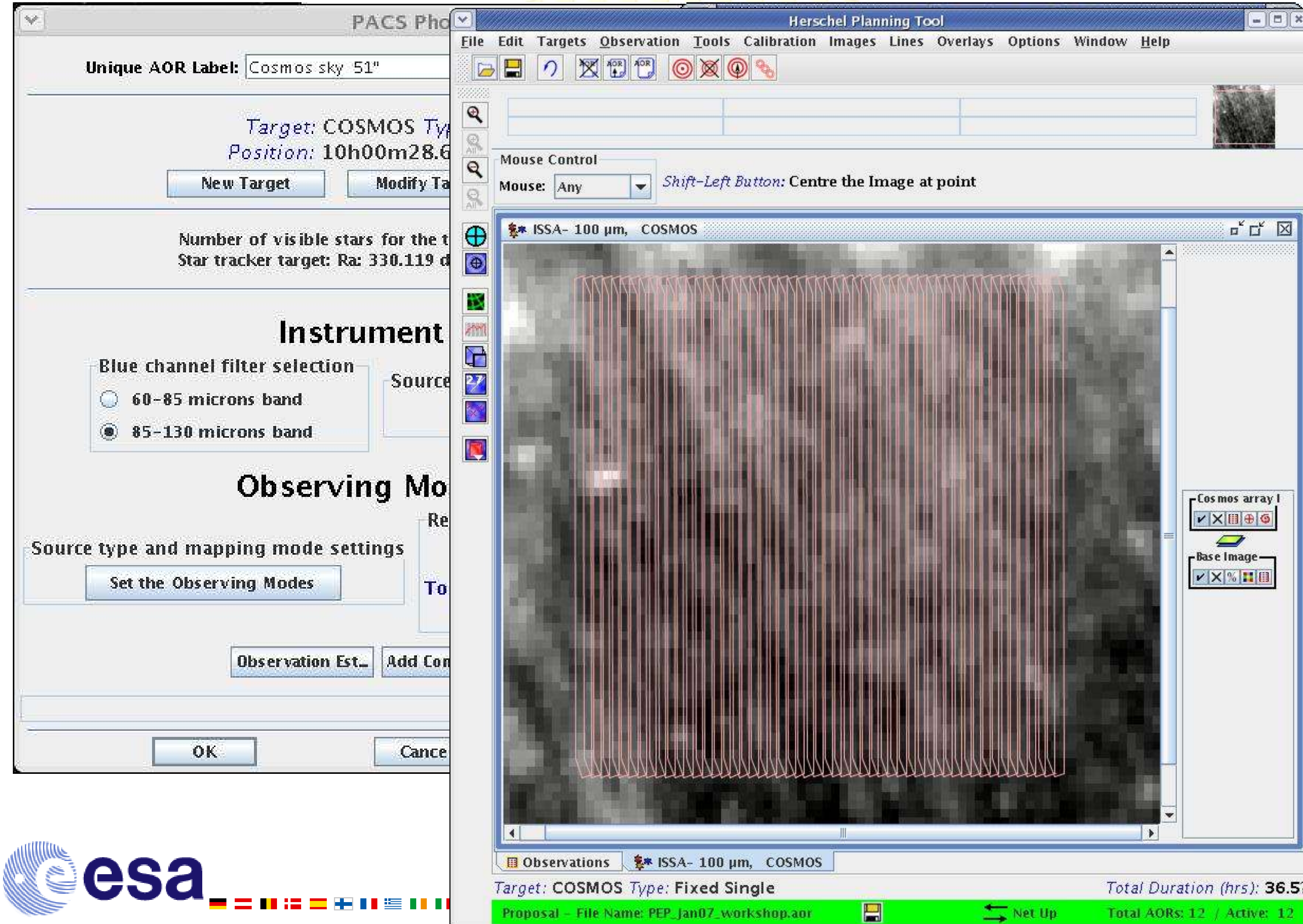
- Oriented in the sky, "sky" in HSpot
  - β fixed, constraint on α possible

α = array-to-map angle
β = map orientation angle
PA = array position angle
β = α + PA



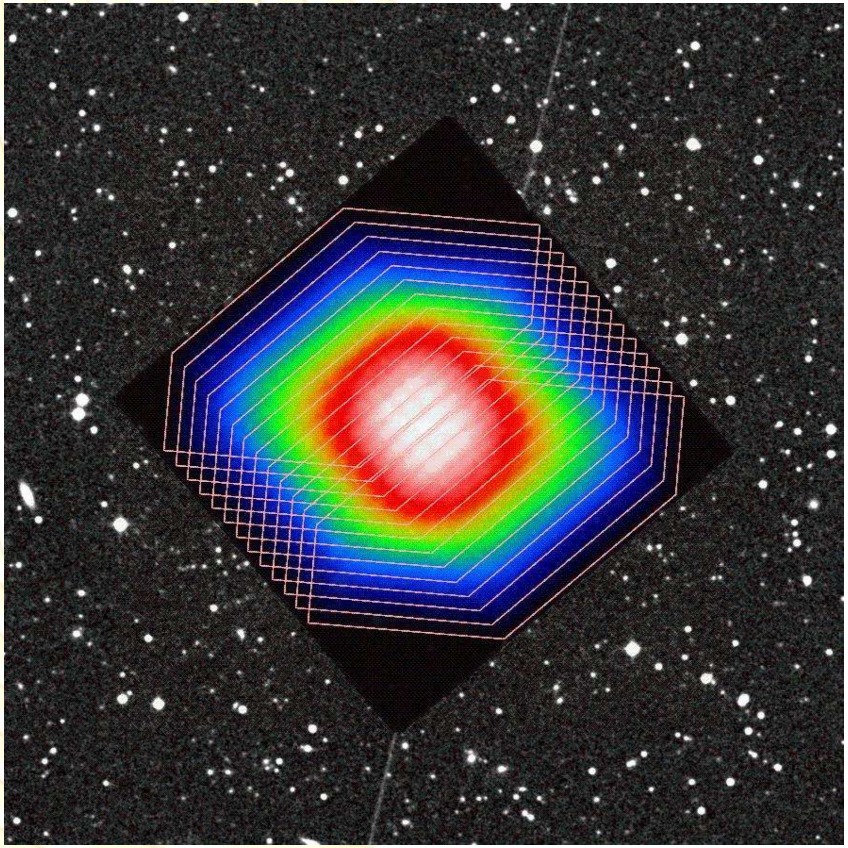
- Note: If α=45° then orthogonal coverage has same depth

Scan maps in HSpot



Exposure map

- Exposure map tool in HSpot (NHSC).
- Useful to check homogeneity
- *See tomorrow's demo.*



2. PACS spectroscopy AOTs

- Line Spectrosopy (of individual lines)
  - Line scan
  - Bright line scan
    - Similar to line scan with fewer grating steps (16 instead of 44)
  - Wavelength switching
- Range spectroscopy
  - User-defined range spectroscopy
    - 2 spectral sampling densities:
      - High :1/3 FWHM steps
      - Low: each wavelength seen by two different spectal pixels
  - SED spectroscopy (range spectroscopy applied to the entired observable spectrum)
    - only in low spectral (Nyquist) sampling

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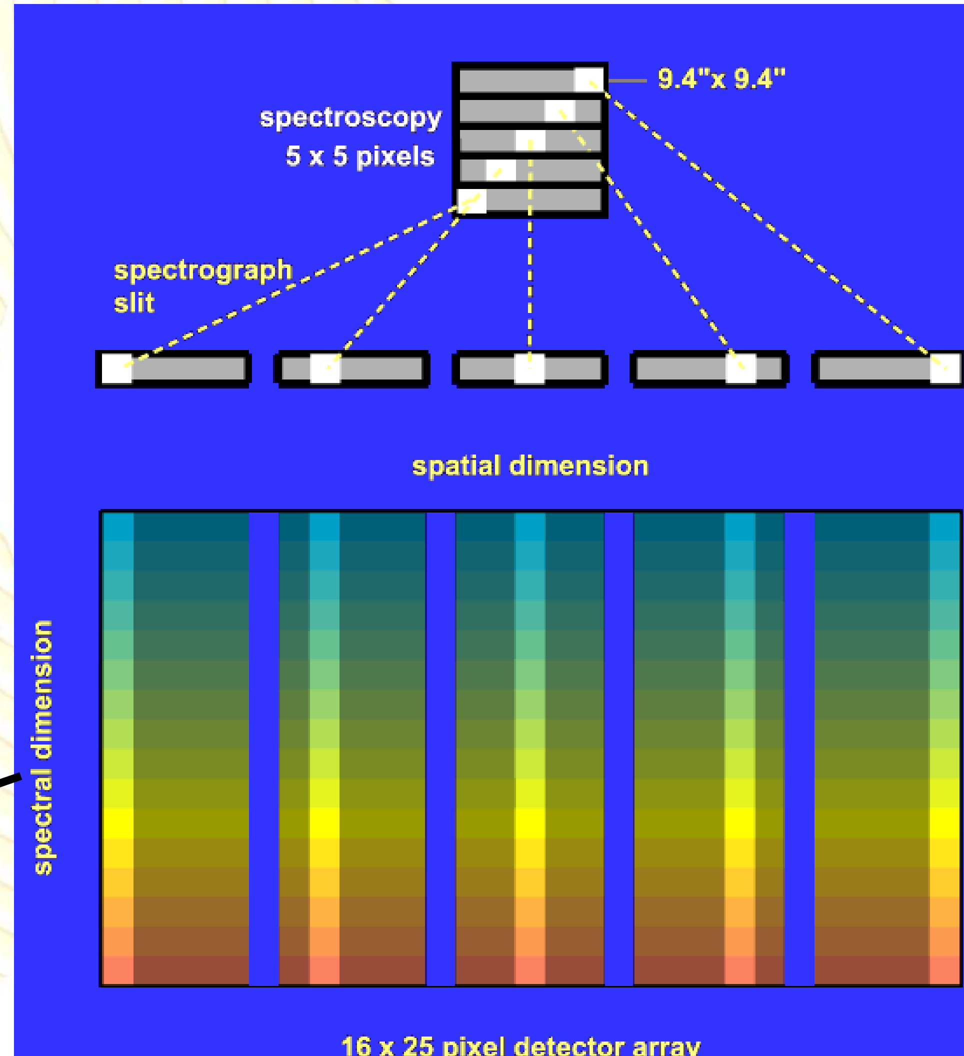
Spectrometer Observing Modes

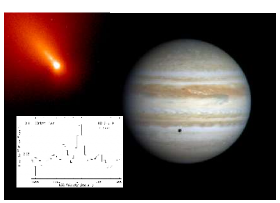
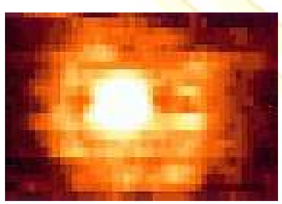
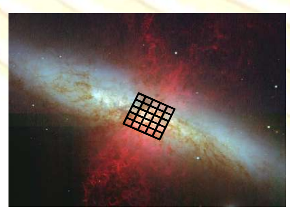
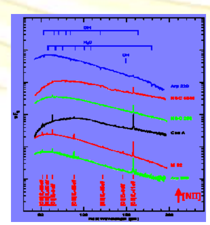
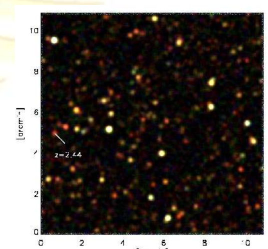
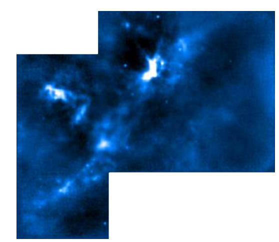
- **Line Spectroscopy: observation of individual line(s)**
  - Chop/nod or wavelength switching
  - Staring or mapping
  - R ~ 1500
- **Range Spectroscopy: observation of extended range(s)**
  - Chop/nod or off position
  - Staring or mapping
  - SED mode

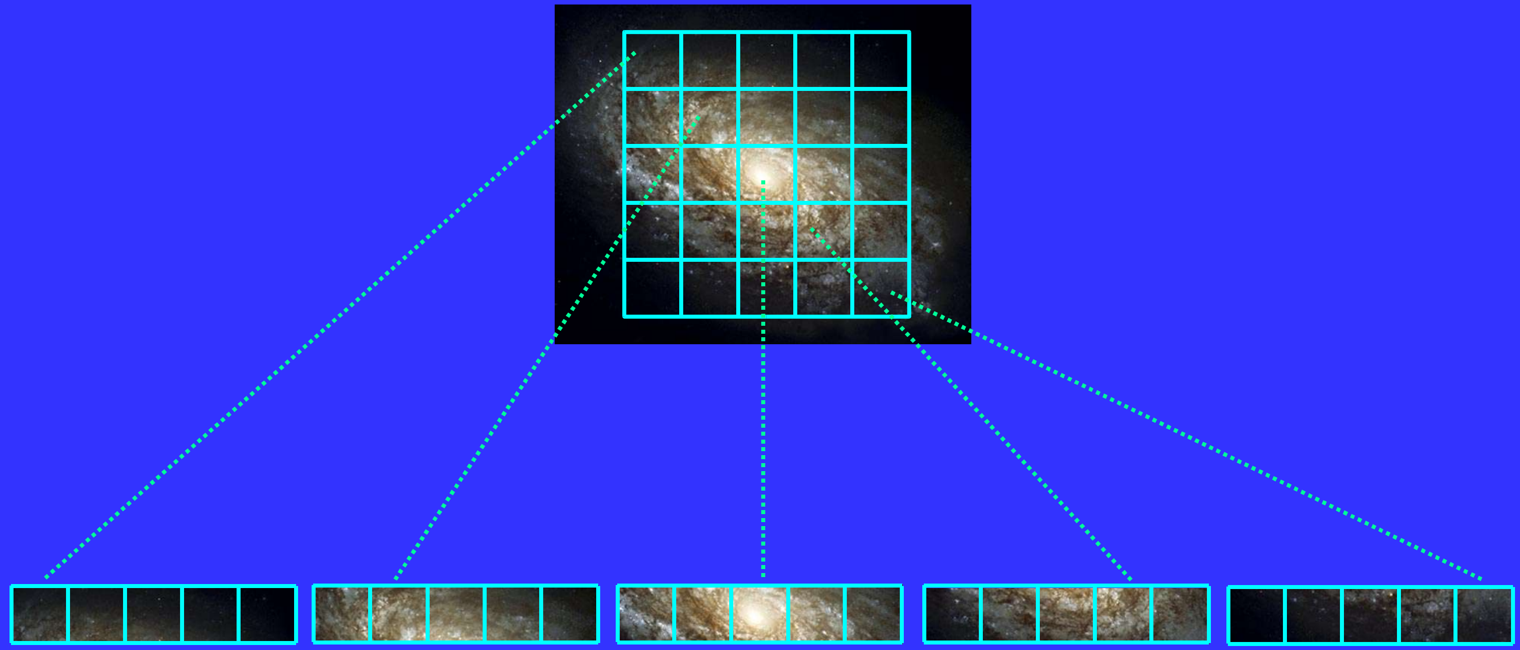


Instantaneous spectral coverage : 0.15 to 1 µm

Science with PACS Line Spectroscopy

- The opening of the 60-210 µm window by PACS to sensitive line spectroscopy at high spatial resolution will address a wide range of key questions of current astrophysics concerning the origins of stars, planetary systems, galaxies, and the evolution of the Universe
- The far-IR contains many spectral lines from atoms, ions and molecules. Largely unaffected by extinction they provide detailed information on UV radiation, density, temperature, velocities and abundances of ionized and neutral components of interstellar and circumstellar gas
- PACS is also intended to be an important driver for other projects which will explore adjacent spectral regions, such as JWST in the near/mid IR and ALMA in the mm domain



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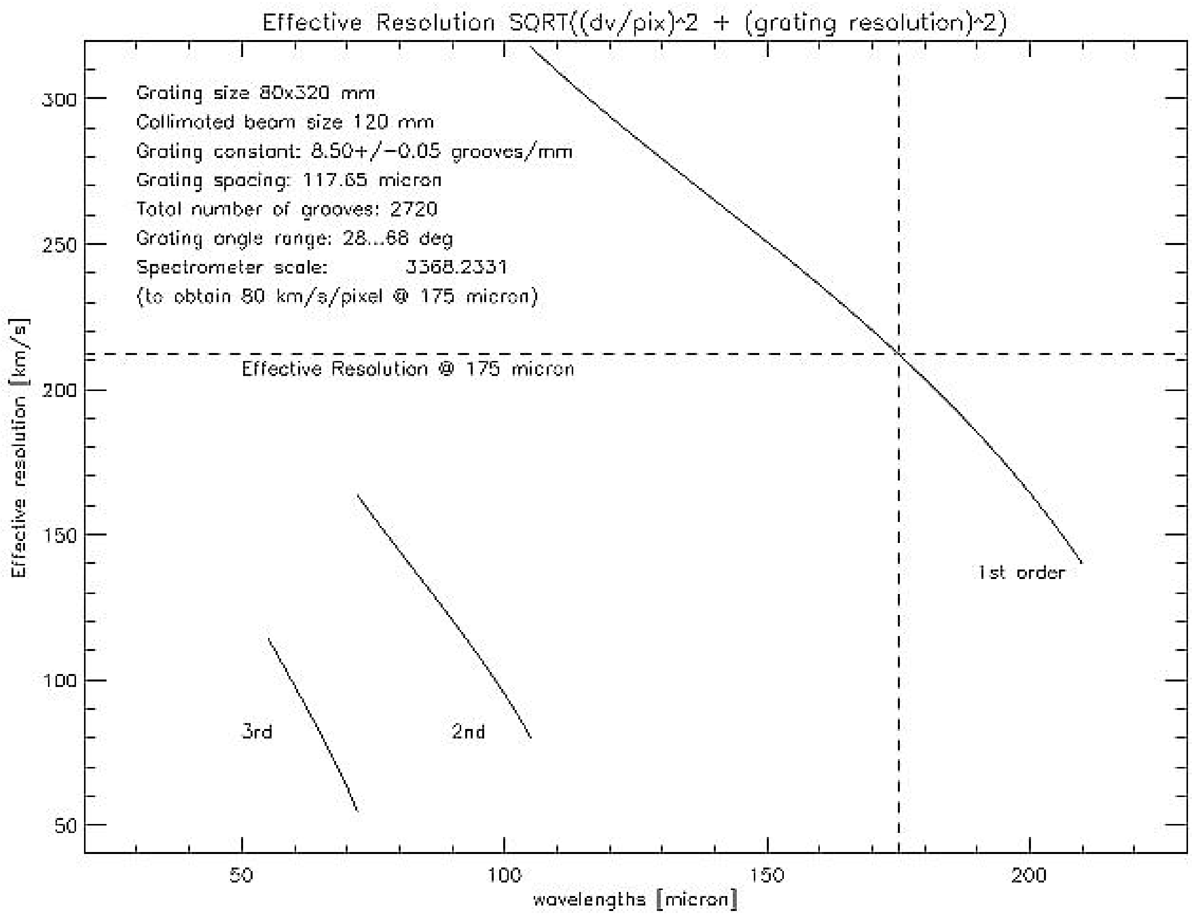
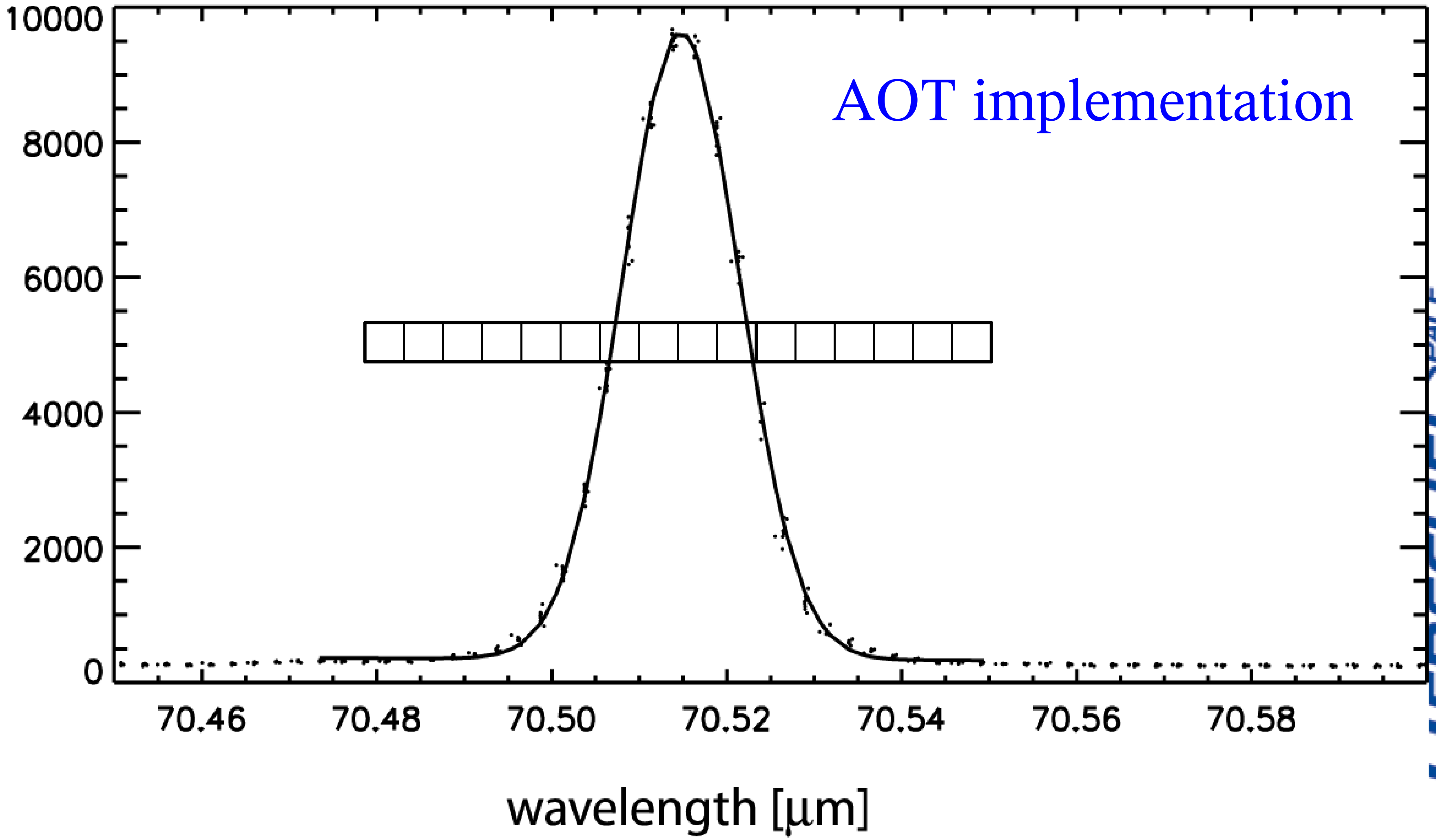
Spectral resolution

$\lambda/\delta\lambda$ = 940-5500

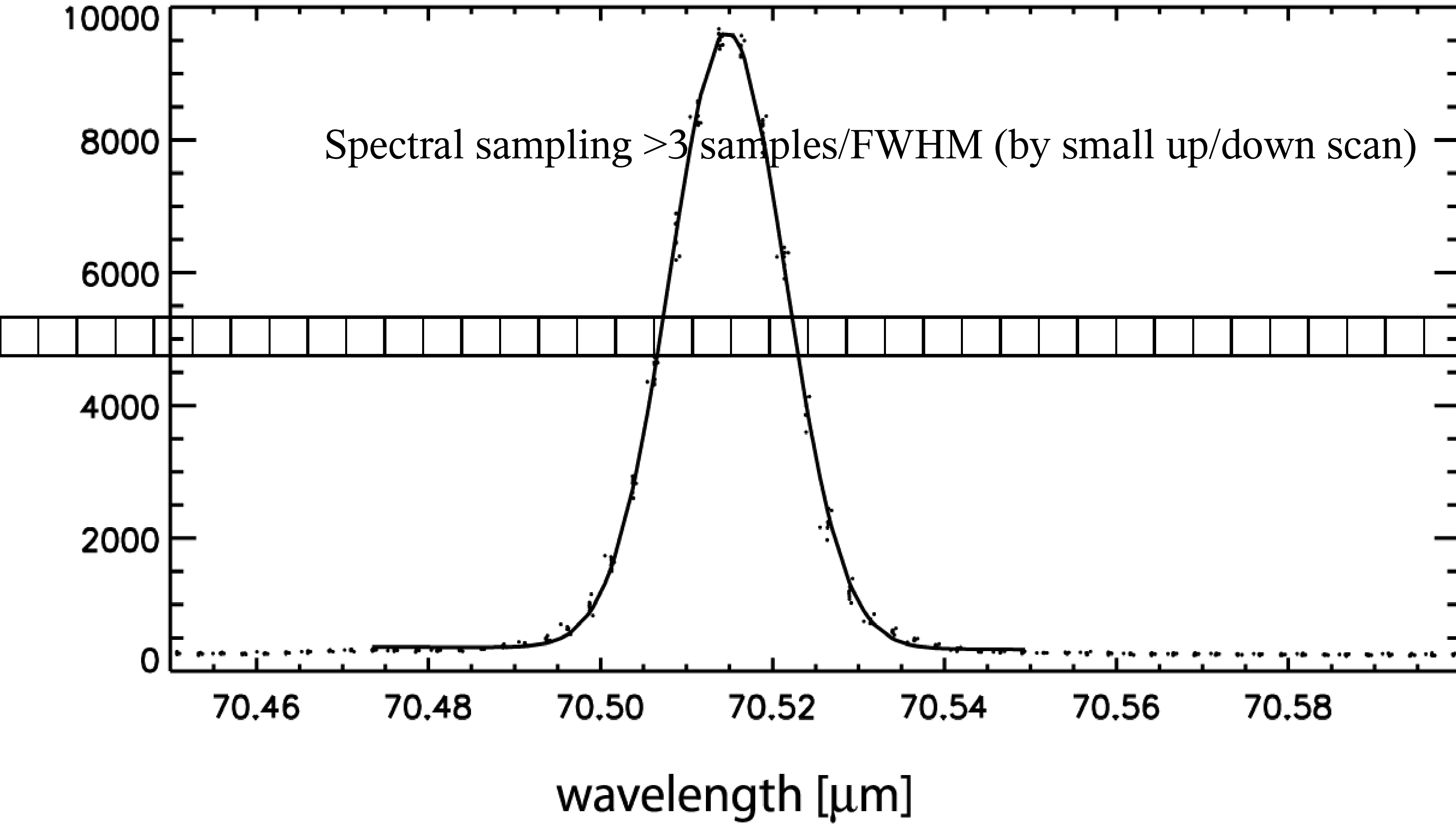
c $\delta\lambda/\lambda$ = 55-320 km/s

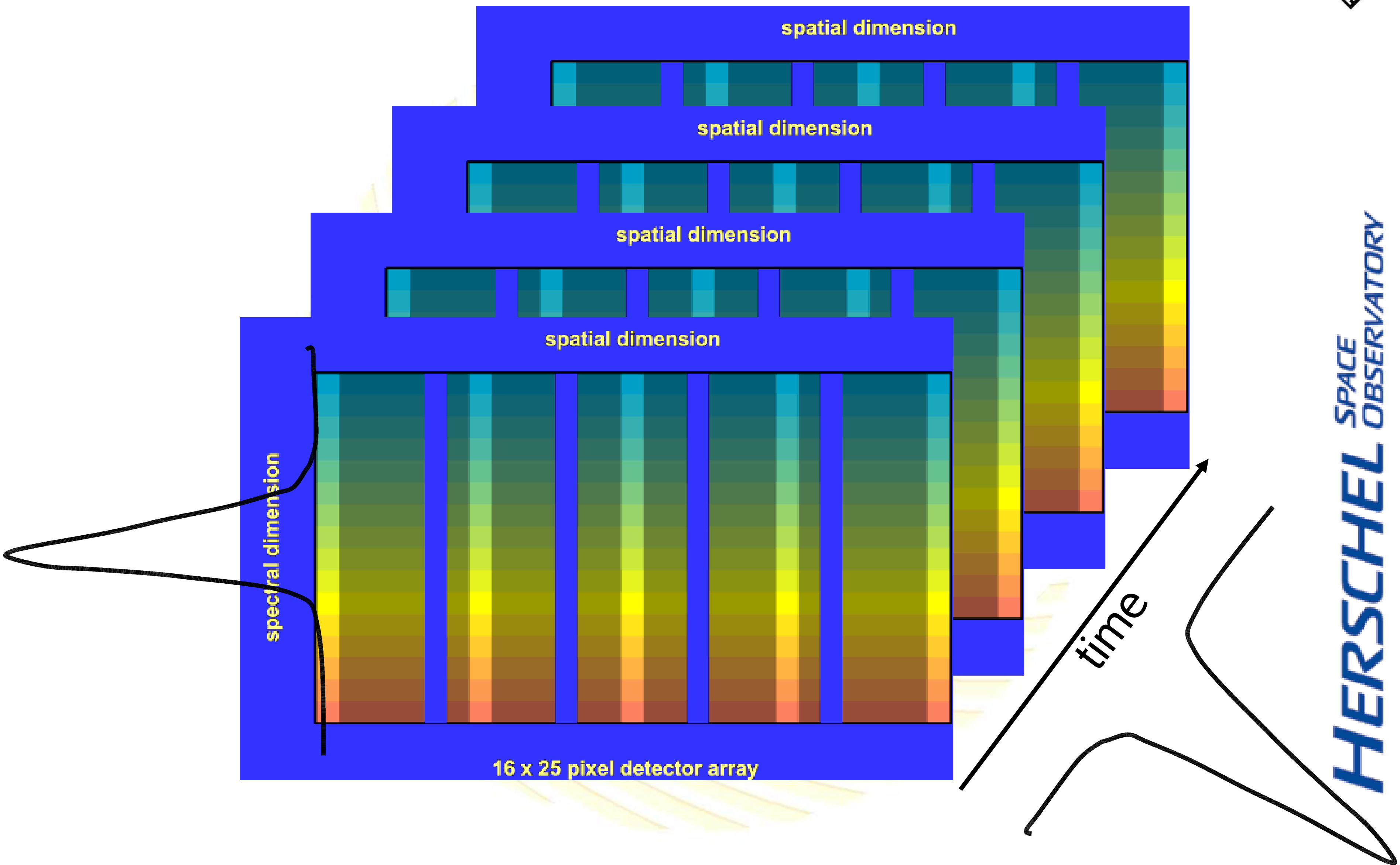


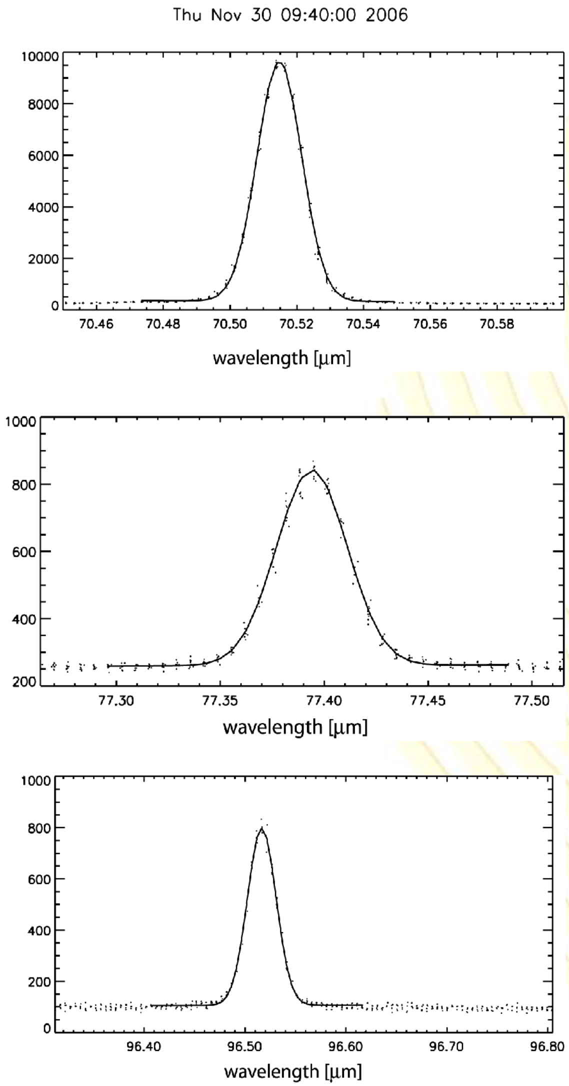
2.1 Line Spectroscopy in chopping/nodding

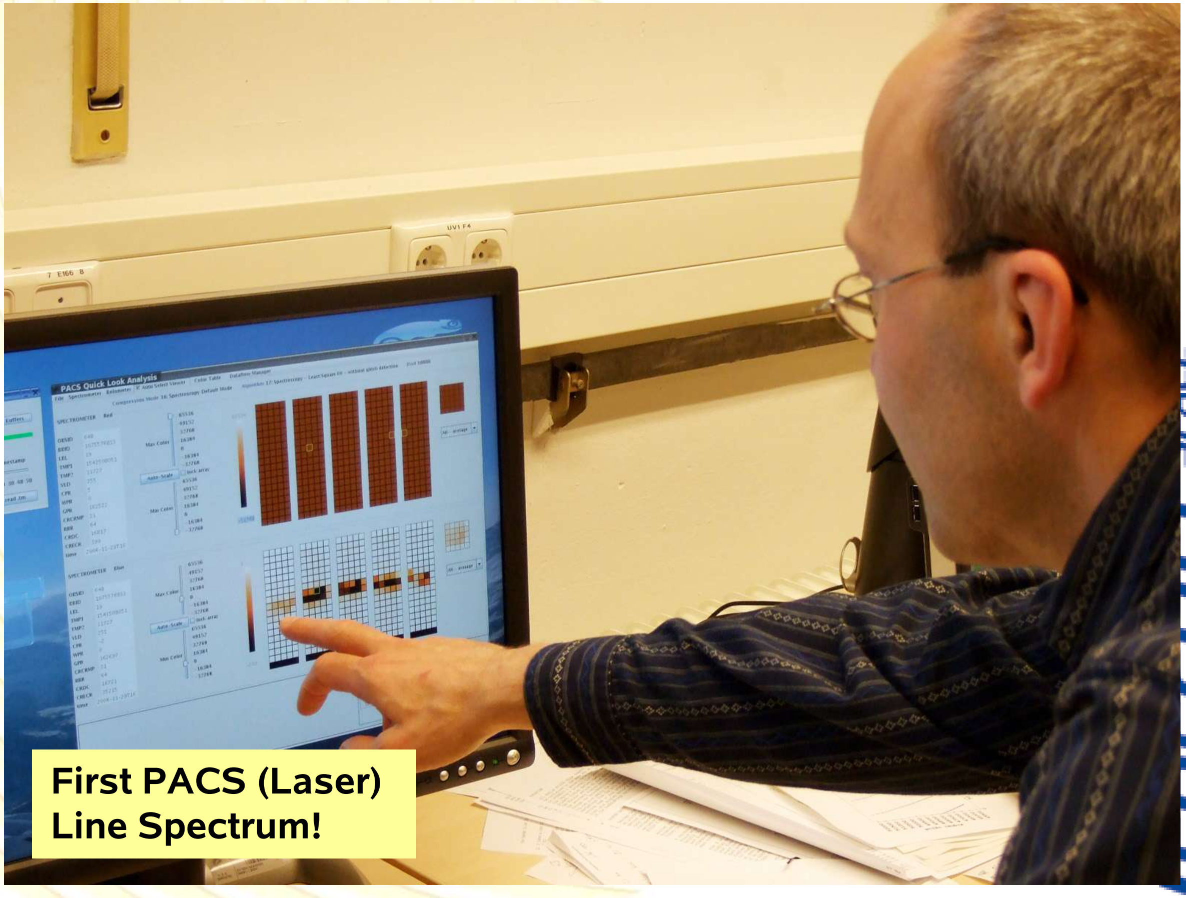


Line Spectroscopy in chop/nod – AOT implementation

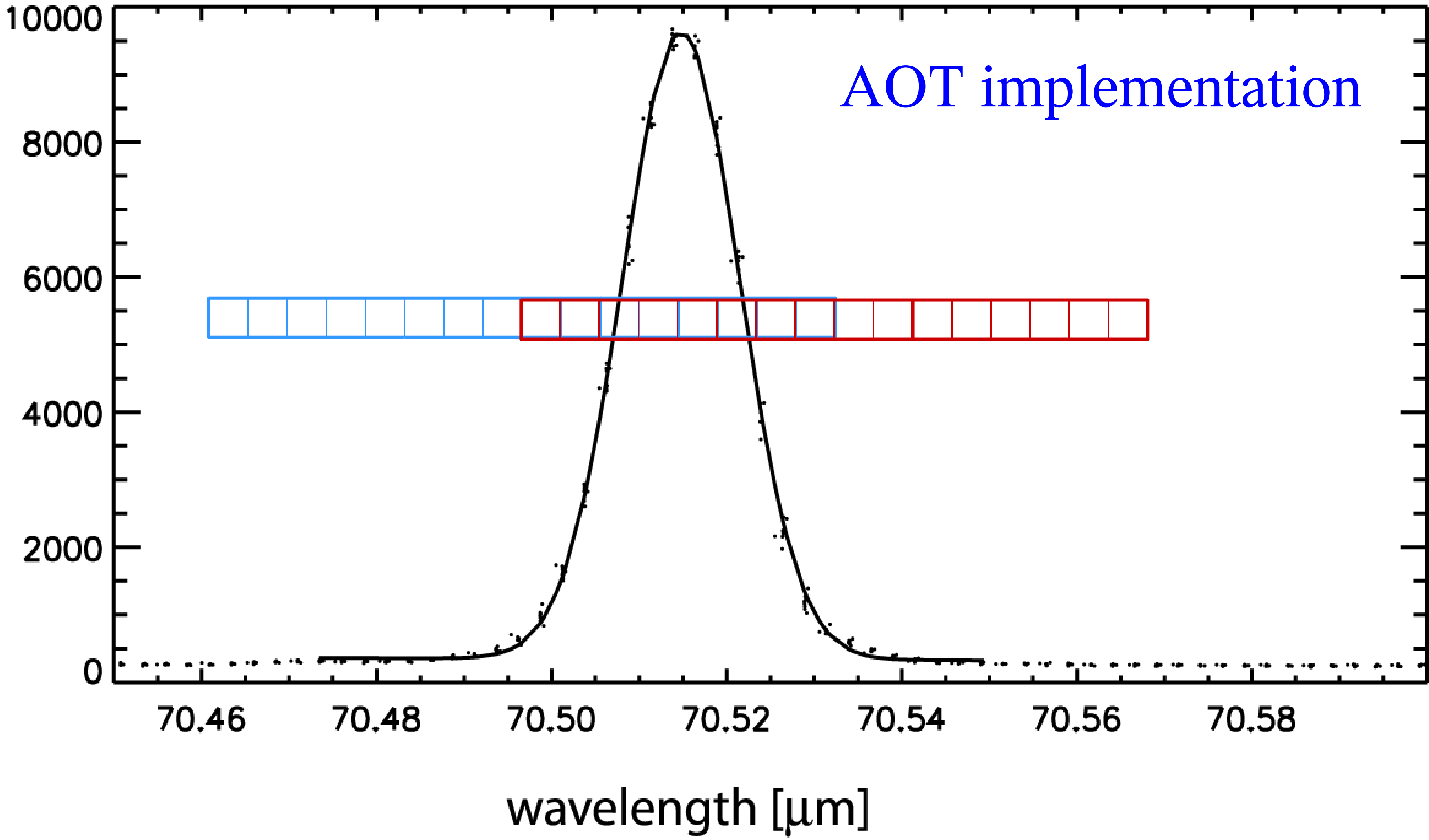



spatial dimension
spatial dimension
spatial dimension
spatial dimension
spectral dimension
16 x 25 pixel detector array
time

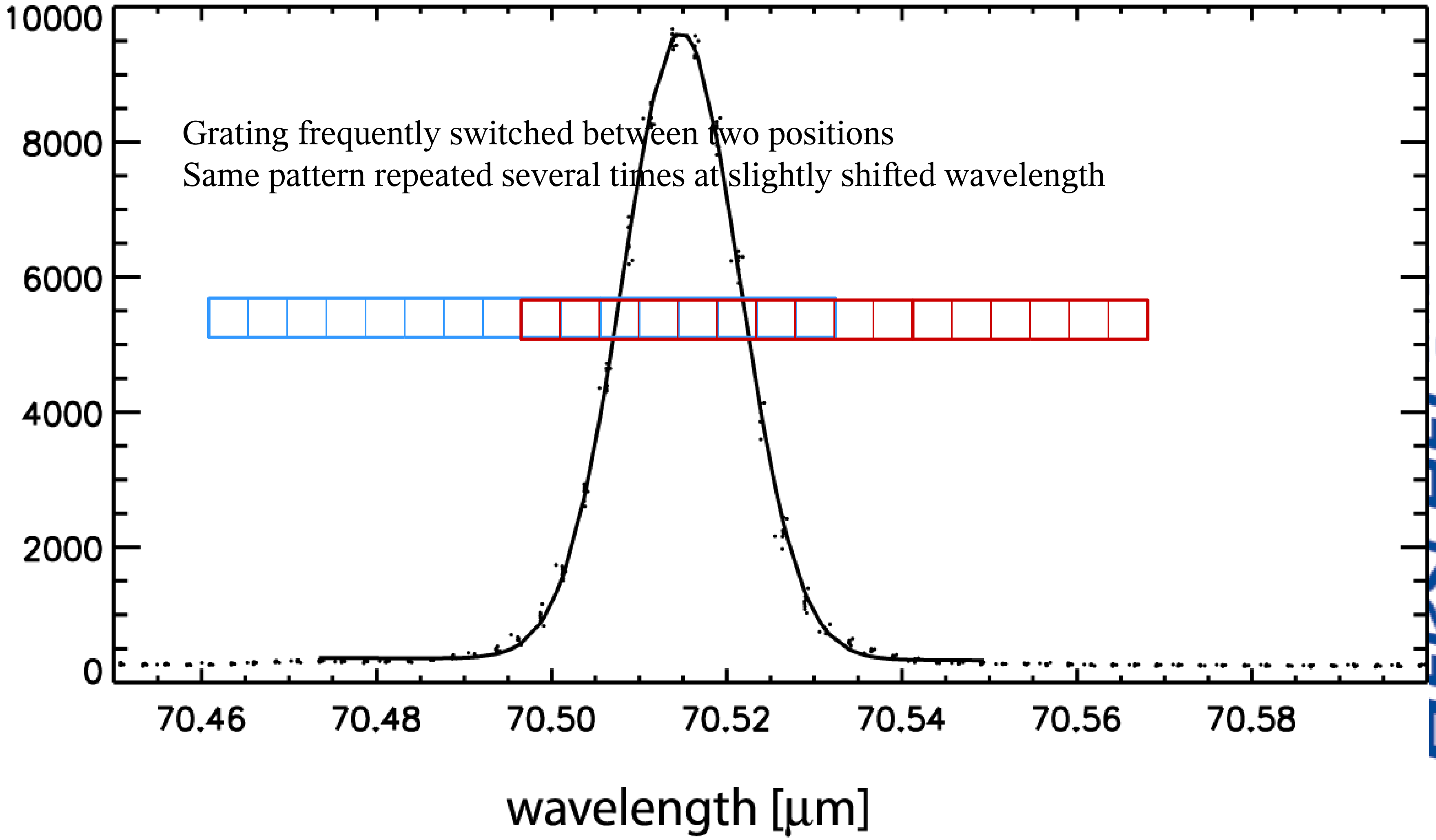

Thu Nov 30 09:40:00 2006
10000
8000
6000
4000
2000
0
70.46 70.48 70.50 70.52 70.54 70.56 70.58
wavelength [µm]
1000
800
600
400
200
77.30 77.35 77.40 77.45 77.50
wavelength [µm]
1000
800
600
400
200
0
96.40 96.50 96.60 96.70 96.80
wavelength [µm]


First PACS (Laser)
Line Spectrum!

2.2 Line Spectroscopy in λ-switching



Line Spectroscopy in λ-switching – AOT implementation



Line spectroscopy pointing modes

- *POINTED: single satellite pointing*
  - *with chopping/nodding except in wavelength switching*
  - *Fixed chopper throw: 1, 3 and 6 arcmin*
- *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 6 arcmin to allow for clean chopper off-positions for each raster point*
  - *map parameters in instrument coordinate system except in wavelength switching*

– ***Order 1 : 102 – 210 μm***
– ***Order 2 : 72 – 96 μm***
– ***Order 3 : 55 – 72 μm***

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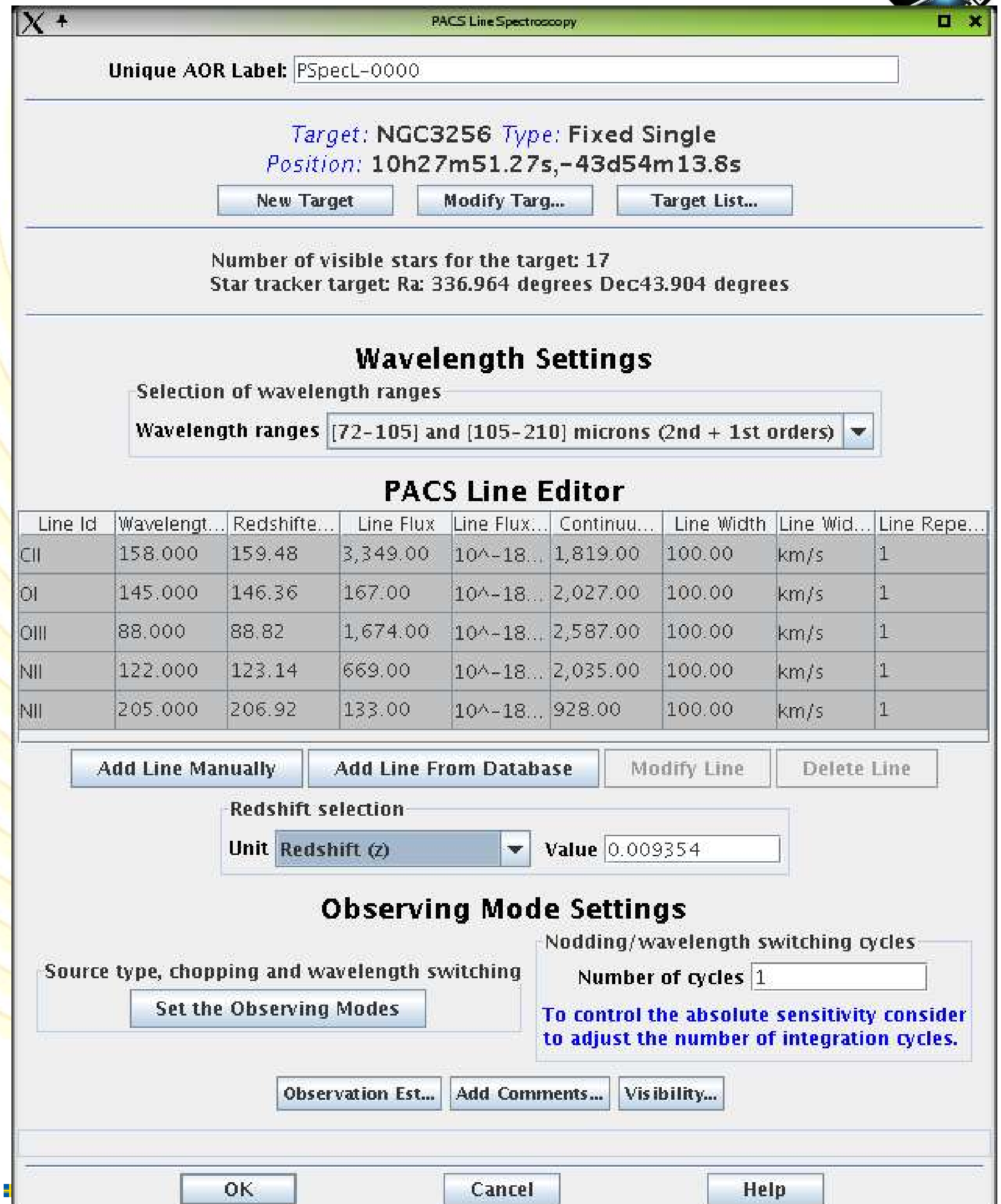
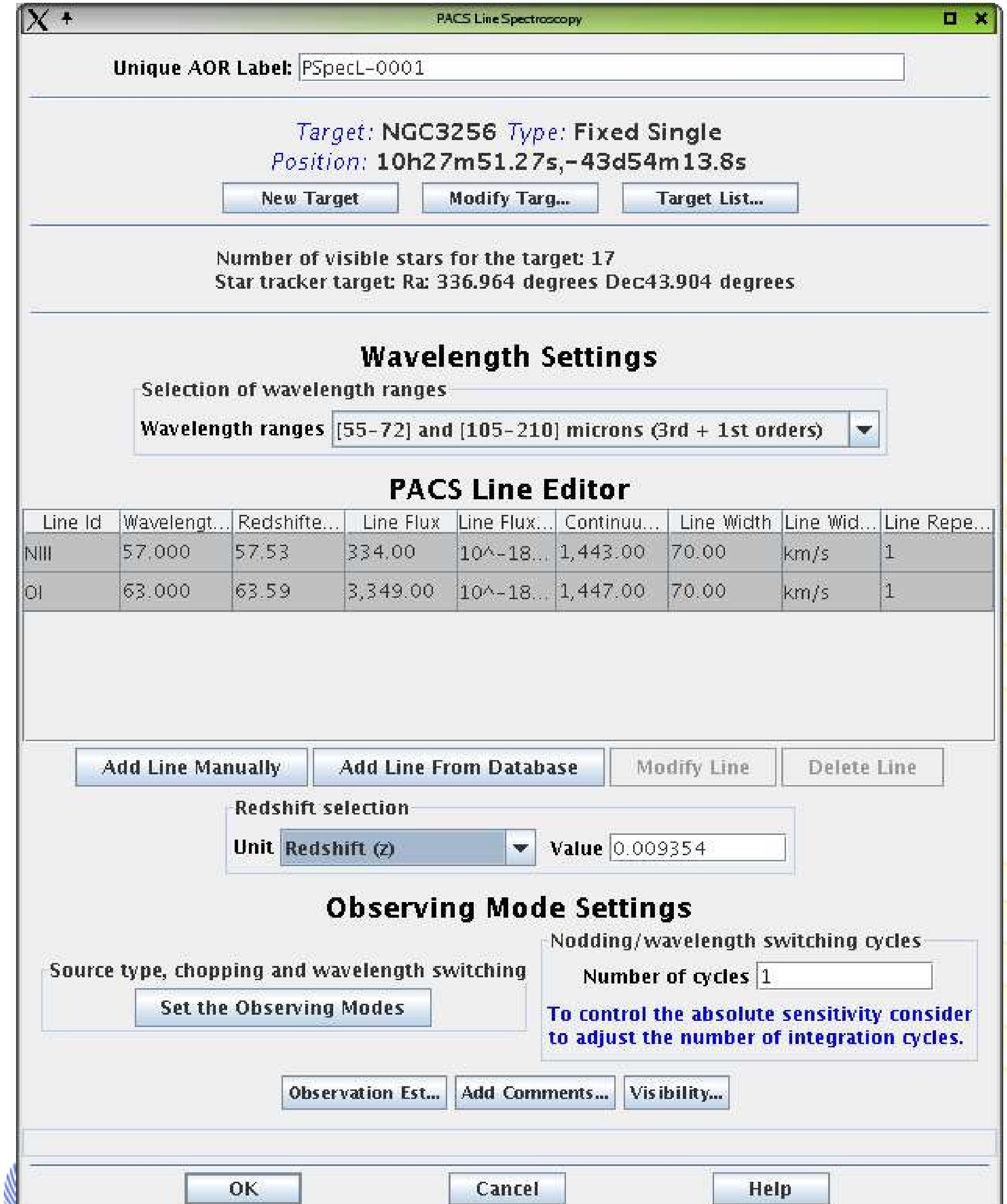
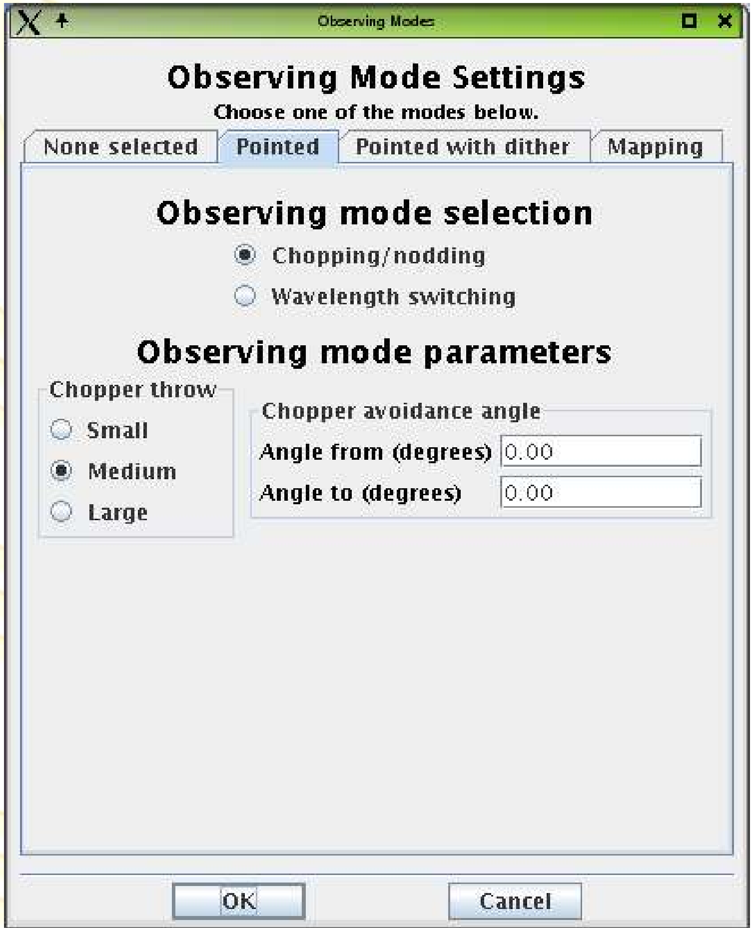
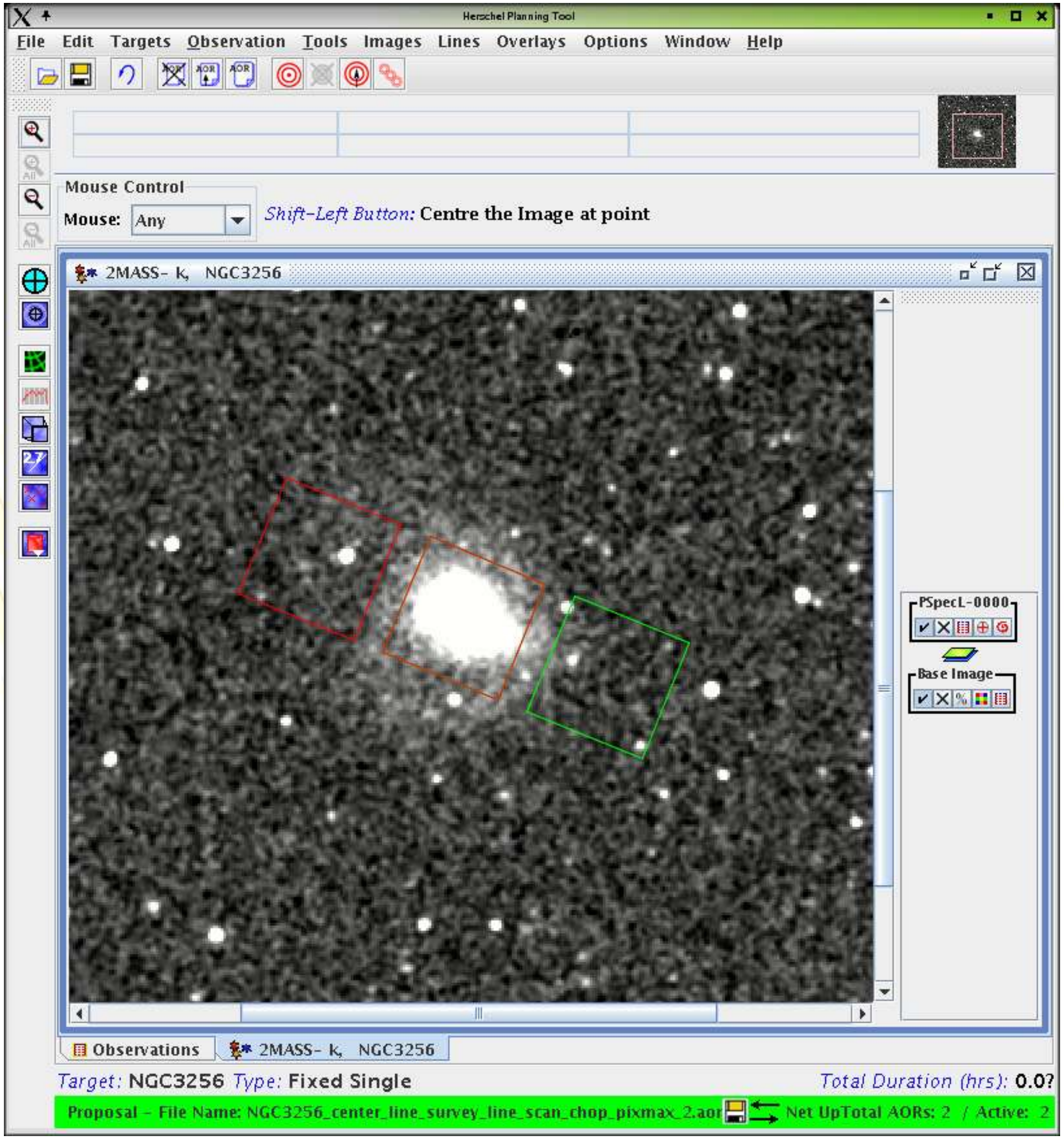
Example1:

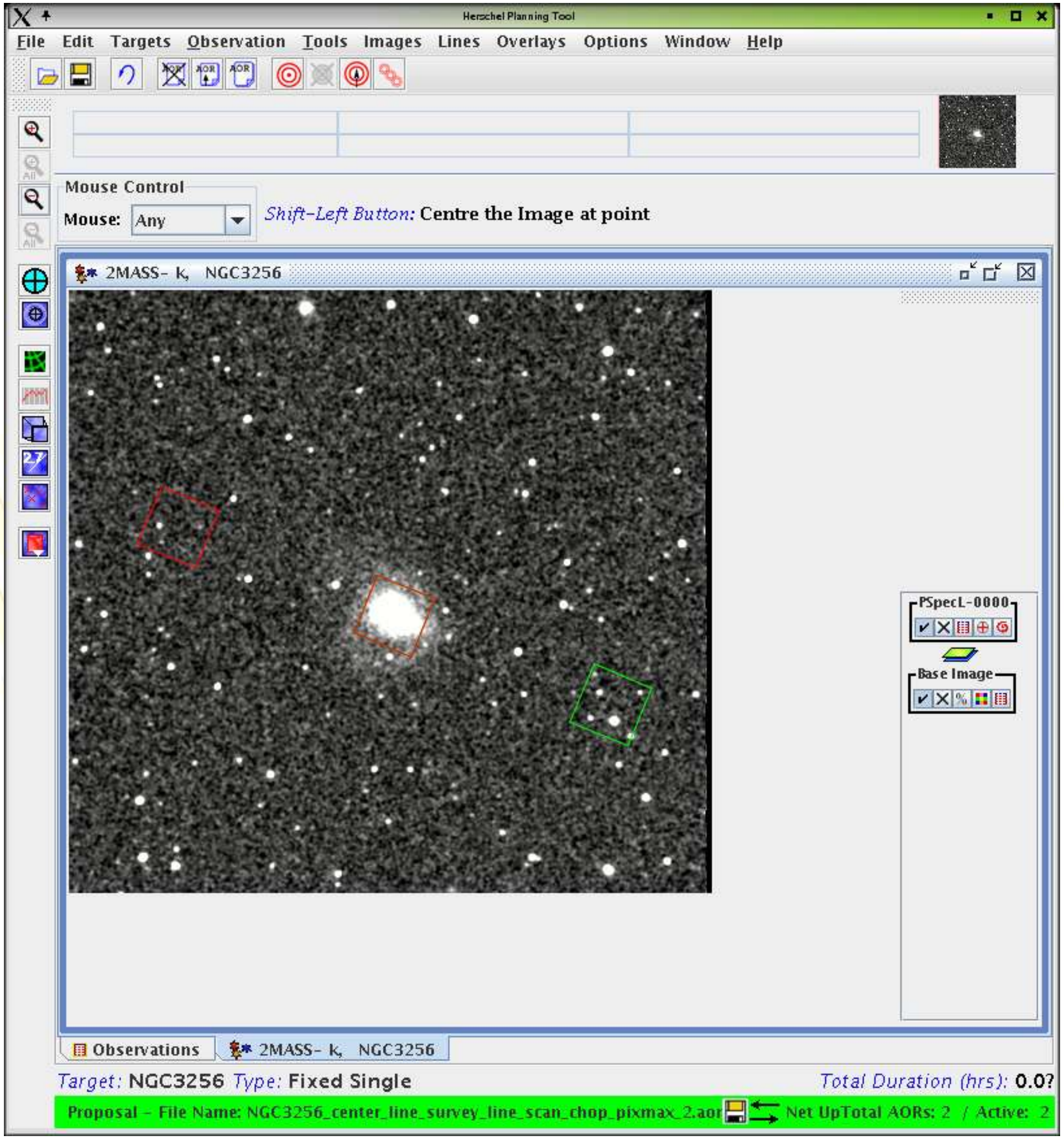
Spectroscopic line survey of a galaxy (no mapping)

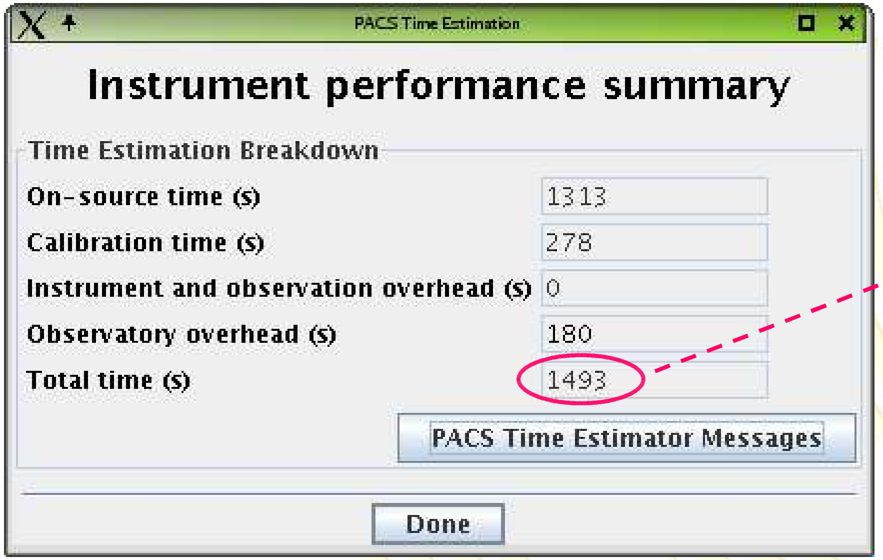


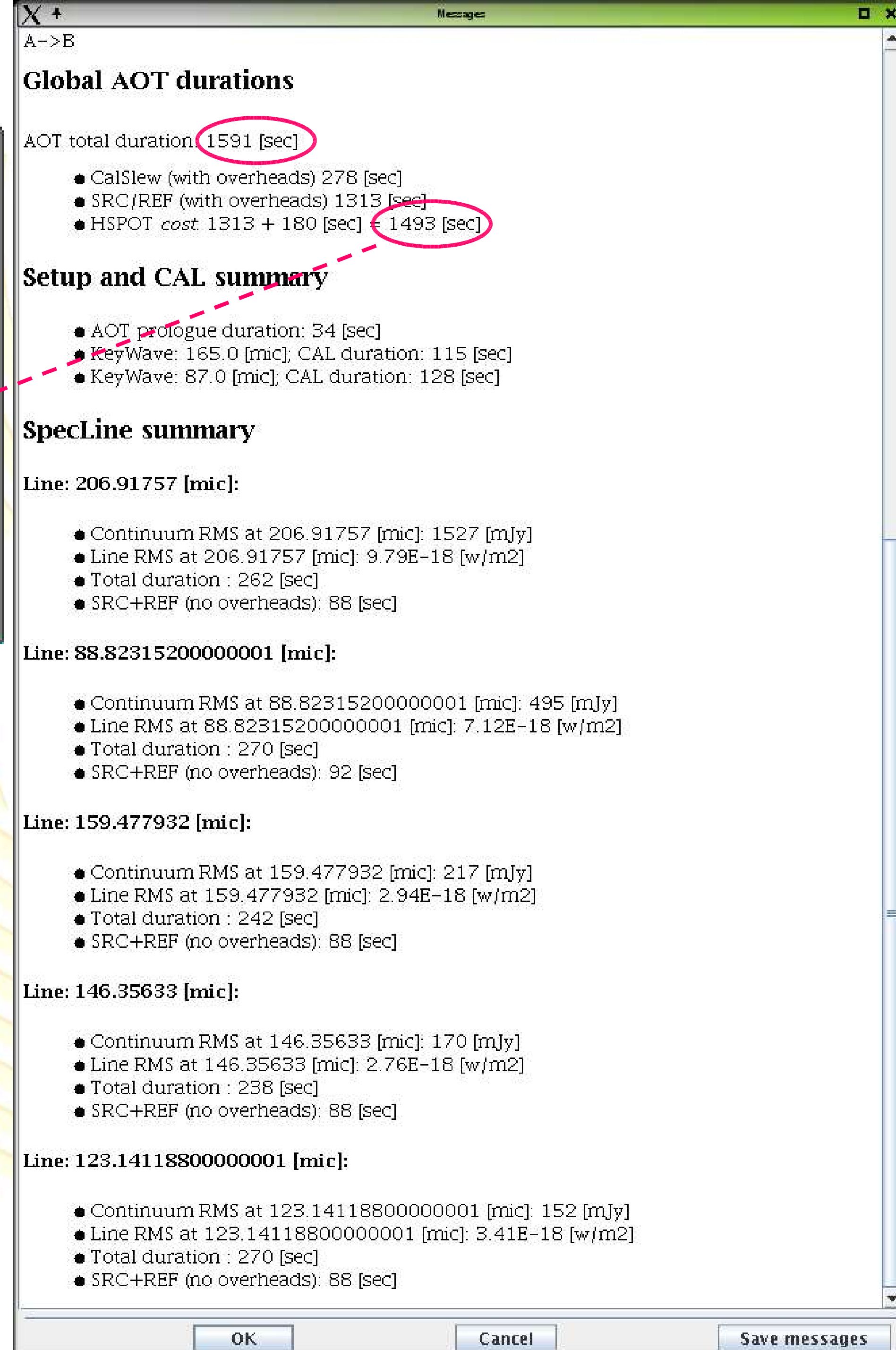

PACS Line Spectroscopy
Unique AOR Label: PSpecL-0001
Target: NGC3256 Type: Fixed Single
Position: 10h27m51.27s,-43d54m13.8s
New Target
Modify Targ...
Target List...
Number of visible stars for the target: 17
Star tracker target: Ra: 336.964 degrees Dec43.904 degrees
Wavelength Settings
Selection of wavelength ranges
Wavelength ranges
[55-72] and [105-210] microns (3rd + 1st orders)
PACS Line Editor
Line Id
Wavelengt...
Redshifte...
Line Flux
Line Flux...
Continuu...
Line Width
Line Wid...
Line Repe...
NIII 57.000 57.53 334.00 10^-18... 1,443.00 70.00 km/s 1
OI 63.000 63.59 3,349.00 10^-18... 1,447.00 70.00 km/s 1
Add Line Manually
Add Line From Database
Modify Line
Delete Line
Redshift selection
Unit
Redshift (z)
Value
0.009354
Observing Mode Settings
Source type, chopping and wavelength switching
Set the Observing Modes
Nodding/wavelength switching cycles
Number of cycles
1
To control the absolute sensitivity consider
to adjust the number of integration cycles.
Observation Est...
Add Comments...
Visibility...
OK
Cancel
Help


Observing Modes
Observing Mode Settings
Choose one of the modes below.
None selected
Pointed
Pointed with dither
Mapping
Observing mode selection
Chopping/nodding
Wavelength switching
Observing mode parameters
Chopper throw
Small
Medium
Large
Chopper avoidance angle
Angle from (degrees)
0.00
Angle to (degrees)
0.00
OK
Cancel


Herschel Planning Tool
File Edit Targets Observation Tools Images Lines Overlays Options Window Help
Mouse Control
Mouse: Any
Shift-Left Button: Centre the Image at point
2MASS- k, NGC3256
PSpecL-0000
Base Image
Observations
2MASS- k, NGC3256
Target: NGC3256 Type: Fixed Single
Total Duration (hrs): 0.0?
Proposal - File Name: NGC3256_center_line_survey_line_scan_chop_pixmax_2.aor
Net UpTotal AORs: 2 / Active: 2


Herschel Planning Tool
File Edit Targets Observation Tools Images Lines Overlays Options Window Help
Mouse Control
Mouse: Any
Shift-Left Button: Centre the Image at point
2MASS- k, NGC3256
PSpecL-0000
Base Image
Observations
2MASS- k, NGC3256
Target: NGC3256 Type: Fixed Single
Total Duration (hrs): 0.0?
Proposal - File Name: NGC3256_center_line_survey_line_scan_chop_pixmax_2.aor
Net UpTotal AORs: 2 / Active: 2



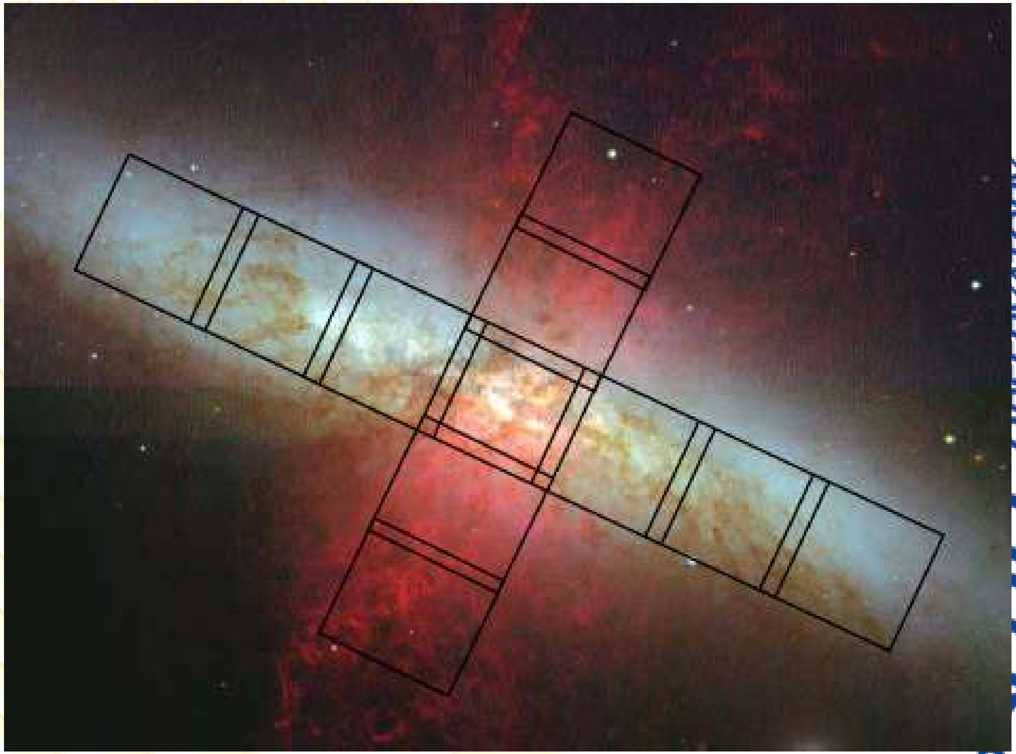


5 lines (2nd and 1st order), chop/nod, rep=1, cycle=1, medium throw

(to this the time for the 2 lines in 3rd order has to be added - concatenation)

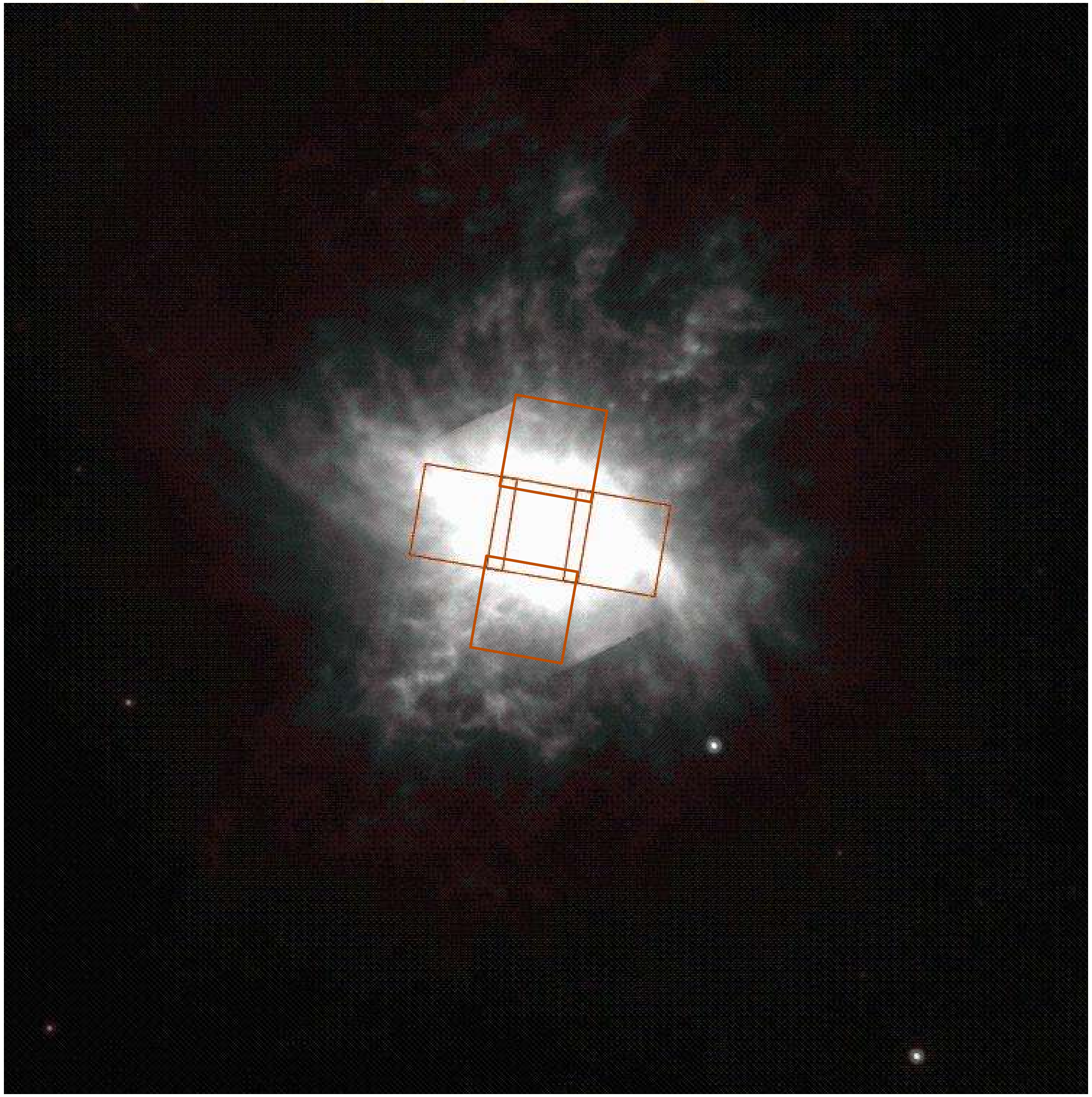
Example2:

Spectroscopic line mapping of a galaxy (M82)

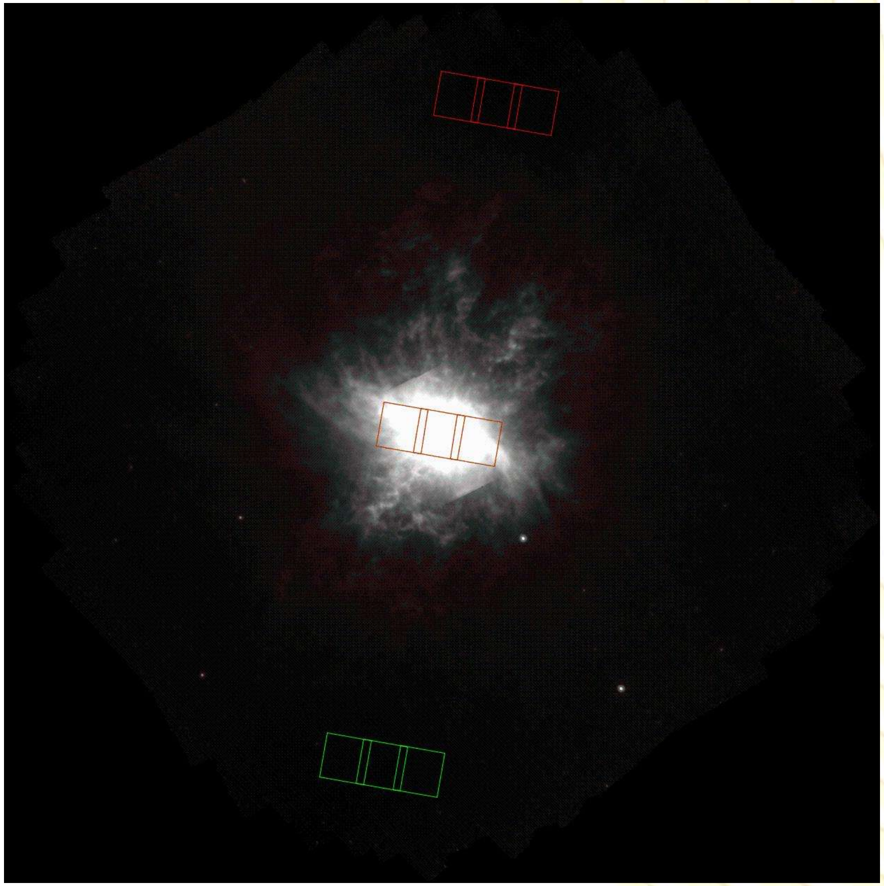


E.g. map transition from the central starburst to the molecular ring to quiescent disk along major axis in NIII/NII.

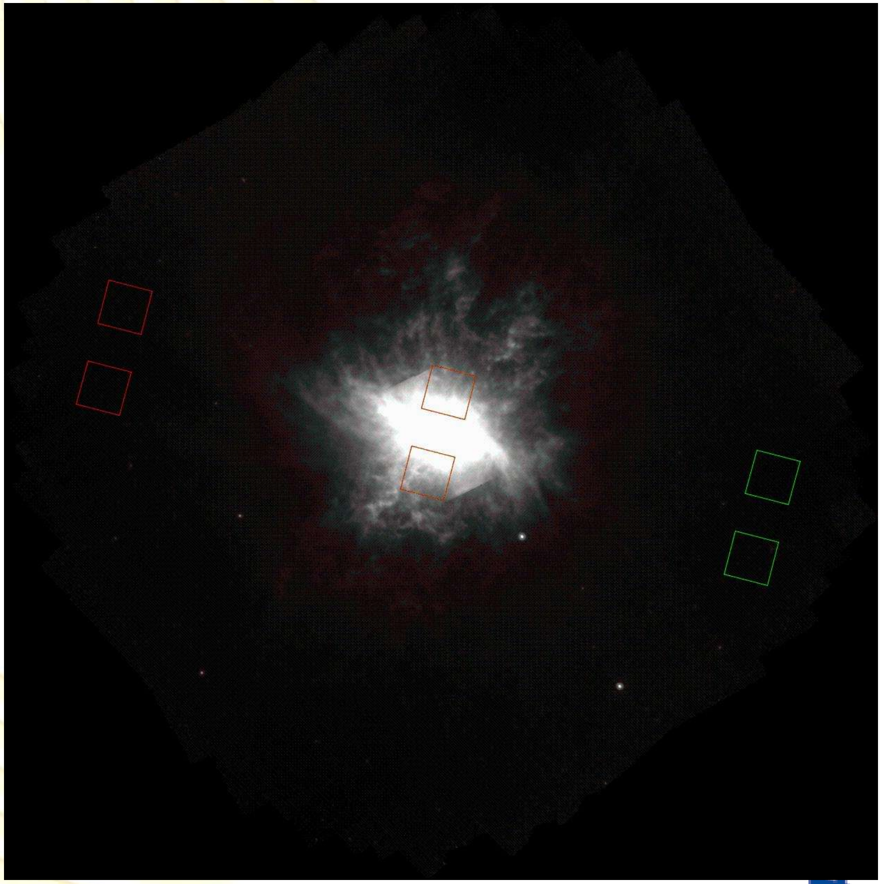
E.g. map cooling of gas and shock vs. ionization along super wind outflow in CII/OI

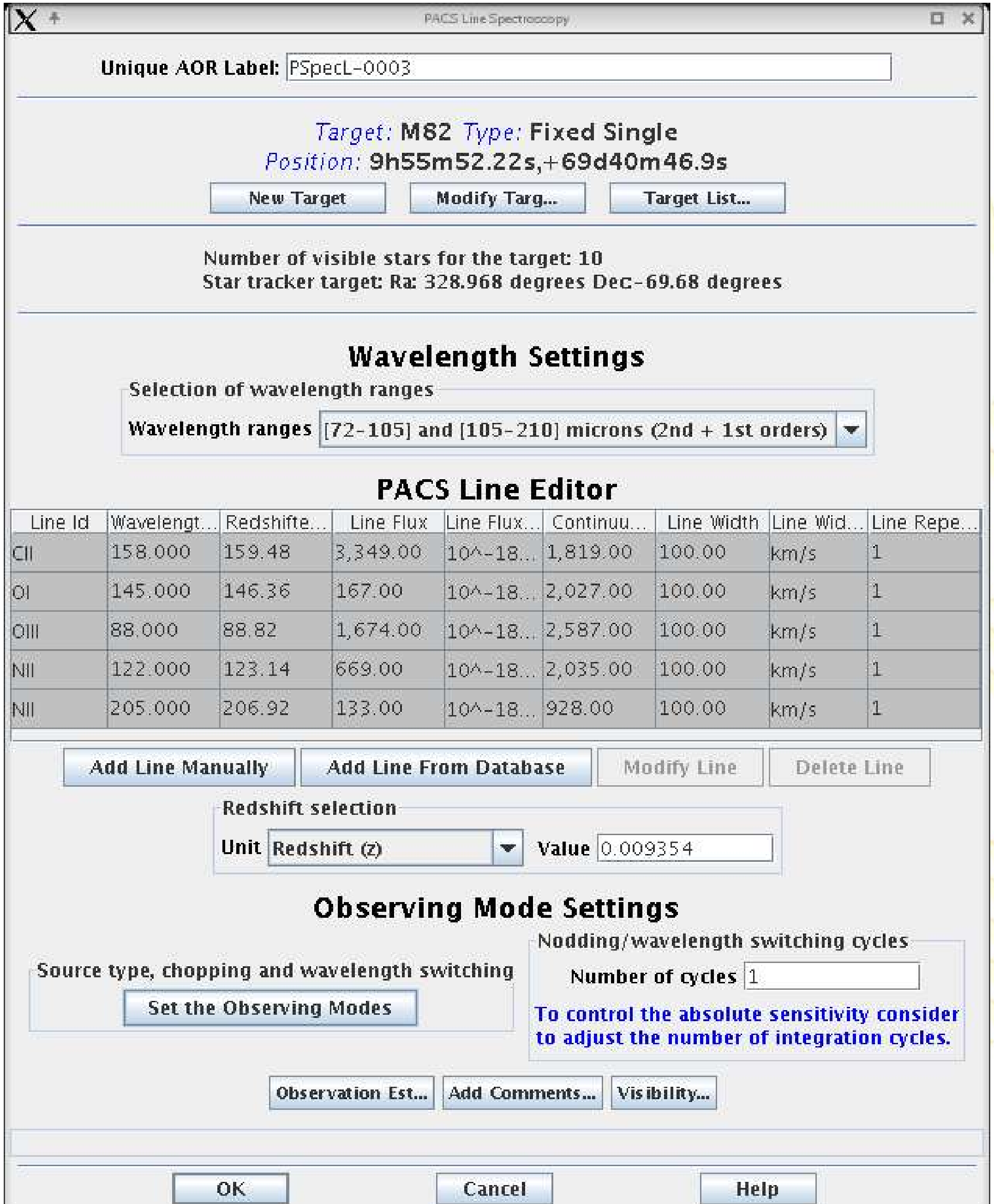


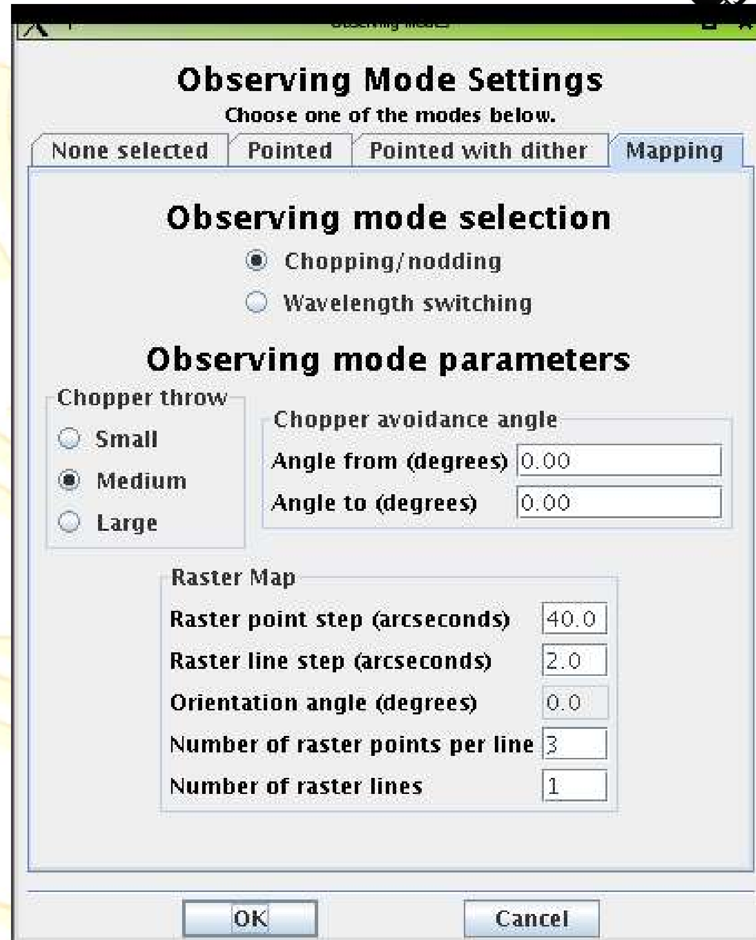
September 2008

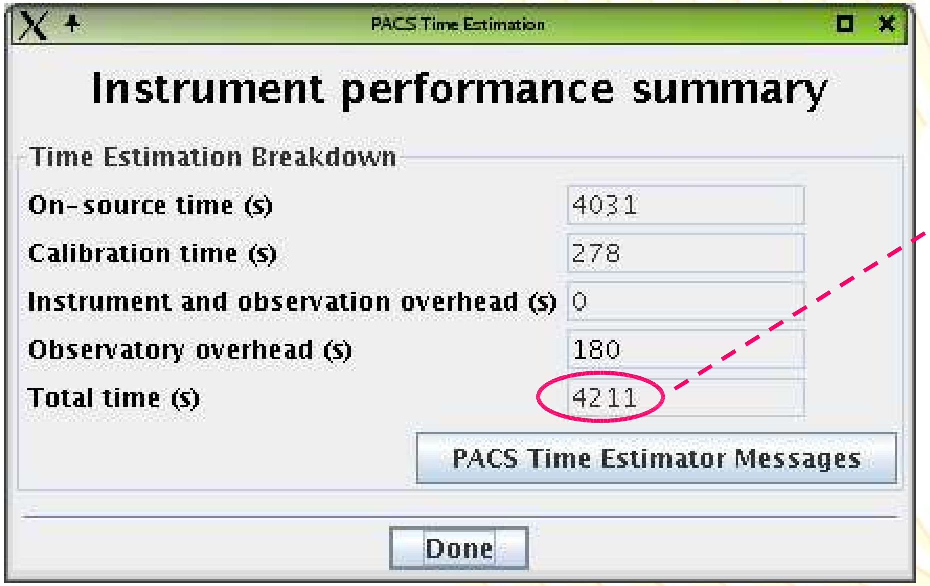


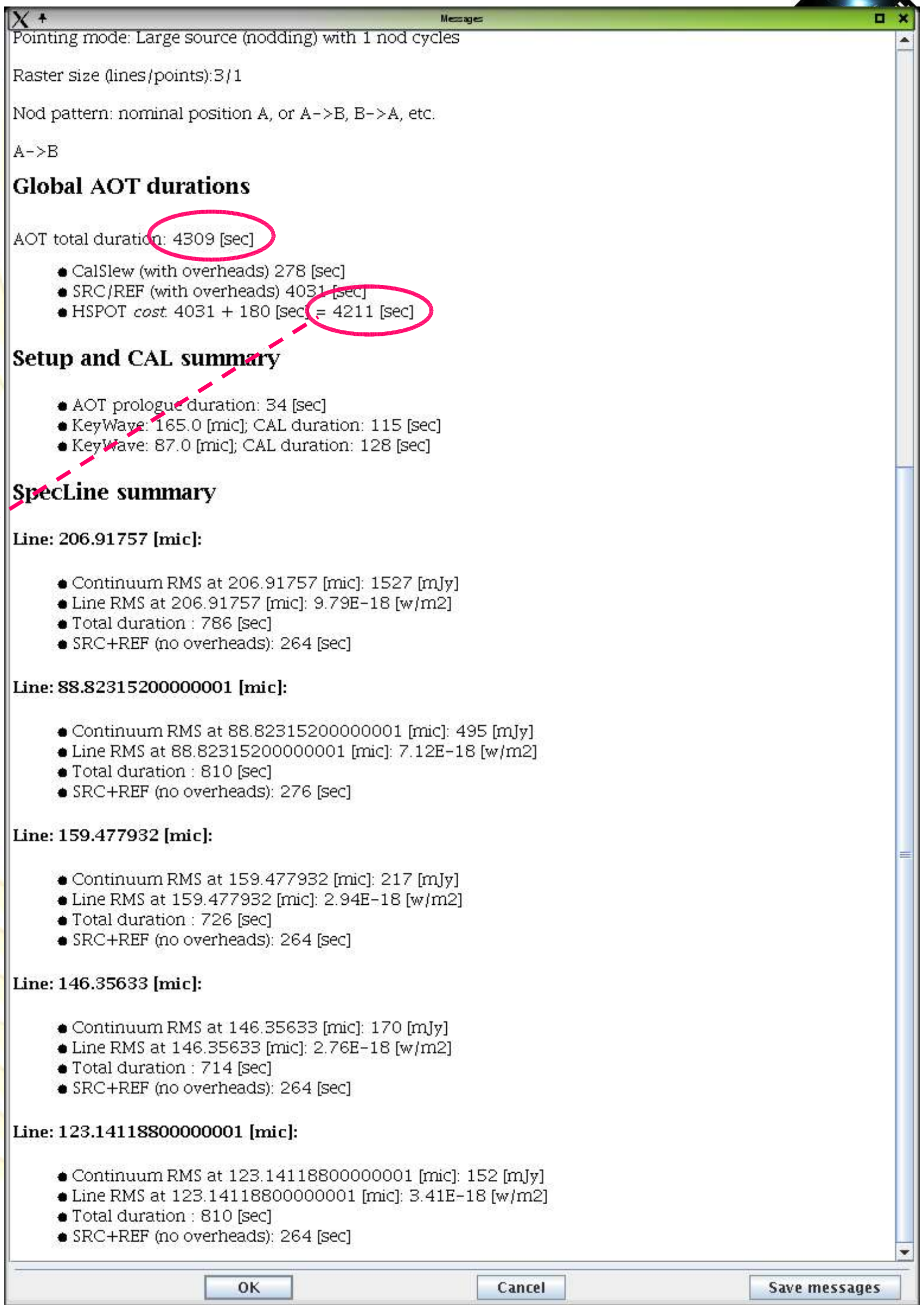
December 2008




PACS Line Spectroscopy
Unique AOR Label: PSpecL-0003
Target: M82 Type: Fixed Single
Position: 9h55m52.22s,+69d40m46.9s
New Target
Modify Targ...
Target List...
Number of visible stars for the target: 10
Star tracker target: Ra: 328.968 degrees Dec-69.68 degrees
Wavelength Settings
Selection of wavelength ranges
Wavelength ranges [72-105] and [105-210] microns (2nd + 1st orders)
PACS Line Editor
Line Id | Wavelengt... | Redshifte... | Line Flux | Line Flux... | Continuu... | Line Width | Line Wid... | Line Repe...
CII | 158.000 | 159.48 | 3,349.00 | 10^-18... | 1,819.00 | 100.00 | km/s | 1
OI | 145.000 | 146.36 | 167.00 | 10^-18... | 2,027.00 | 100.00 | km/s | 1
OIII | 88.000 | 88.82 | 1,674.00 | 10^-18... | 2,587.00 | 100.00 | km/s | 1
NII | 122.000 | 123.14 | 669.00 | 10^-18... | 2,035.00 | 100.00 | km/s | 1
NII | 205.000 | 206.92 | 133.00 | 10^-18... | 928.00 | 100.00 | km/s | 1
Add Line Manually
Add Line From Database
Modify Line
Delete Line
Redshift selection
Unit Redshift (z)
Value 0.009354
Observing Mode Settings
Source type, chopping and wavelength switching
Set the Observing Modes
Nodding/wavelength switching cycles
Number of cycles 1
To control the absolute sensitivity consider
to adjust the number of integration cycles.
Observation Est...
Add Comments...
Visibility...
OK
Cancel
Help


Observing Mode Settings
Choose one of the modes below.
None selected
Pointed
Pointed with dither
Mapping
Observing mode selection
Chopping/nodding
Wavelength switching
Observing mode parameters
Chopper throw
Small
Medium
Large
Chopper avoidance angle
Angle from (degrees) 0.00
Angle to (degrees) 0.00
Raster Map
Raster point step (arcseconds) 40.0
Raster line step (arcseconds) 2.0
Orientation angle (degrees) 0.0
Number of raster points per line 3
Number of raster lines 1
OK
Cancel





5 lines (2nd and 1st order), chop/nod, rep=1, cycle=1, medium throw, 3x1 map

Chopping/nodding vs wavelength switching

	advantage	disadvantage
chop/nod	- preserve continuum	- not for large extended sources (>6‘x6‘), or crowded fields - map orientation only via orientation constraint
λ-switching	- also for extended or crowded fields - map orientation can be chosen - slightly more sensitive as target always on array - less severe memory effects for bright lines ?	- continuum lost - z must be known precisely - *mode to be confirmed for faint sources*

pointed vs. pointed with dither

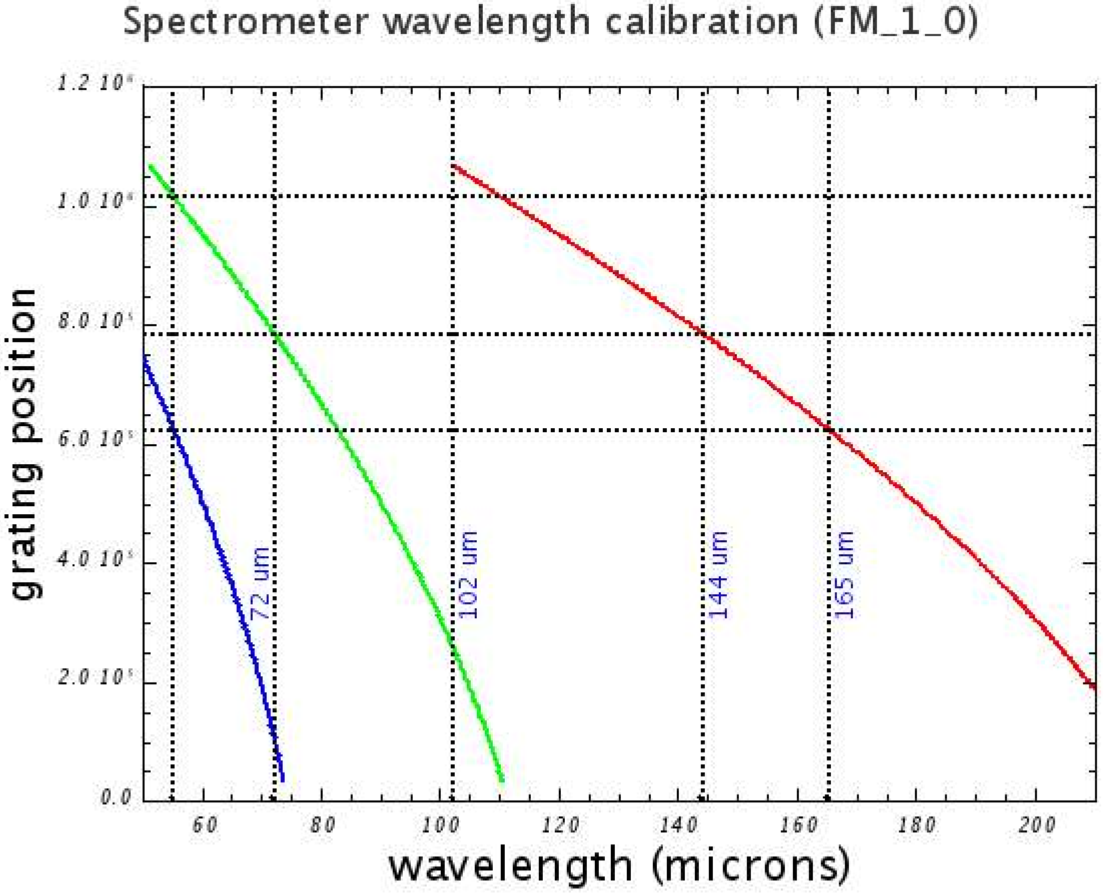
- flux reconstruction of (faint) point sources might be improved with dither if the source position is uncertain, and/or the source is slightly extended (pointing uncertainty!)
- small raster might be better, anyway, in these cases
  - 2x2 raster, 4.5“ arcsec step size.
- clear guidelines cannot be given at this point in time
- the exact dither/map pattern and the overlap between pointings, is perhaps not overly important (pointing uncertainty! data processing needs to start from after-the-fact reconstructed pointing information anyway)

3. Range spectroscopy

- Same basic idea as in line spectroscopy
-
  - on a wider, user-defined spectral range
  - possibility to use lower grating sampling density
  - SED mode to cover whole PACS wavelength range
  - Same pointing modes

Parallel ranges

Different grating orders are observed simultaneously in red and blue detector



<u>order 1+2</u>

102-210 μm

// : 71- 96 μm

<u>order 1+3</u>

102-210 μm

// : 55 - 73

Parallel ranges: examples

- Range scan 60-70 µm [order 3]
  - yields 'for free' range in order 1 : 180-210µm
- Range scan 72-80 µm in [order 2]
  - yields 'for free' range in order 1 : 144-160µm
- Range scan 120-180 µm [order 1]
  - If range [71-98] is selected, yields for free :
    - 71-90 µm [order 2]
      [order selection filter: cut-off short of 72µm]
  - If range [55-73] is selected, yields for free :
    - 60-73 µm in 'extended' 2nd order and
    - 55-60 µm in order 3.
- All parallel ranges and sensitivities returned by HSpot, graphically

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Full range scan in SED modes.

- PACS full range scan
  - 2 concatenated AORs as no filter wheel change allowed in one aor,
  - pre-defined full range scans
- SED red [71-210] µm, in 1st and 2nd order :
  - order 1 : 102-210 µm
  - order 2 : 71 - 98 µm
    - [order selection filter: cut-off short of 72µm, and dichroic at 98µm]
- SED blue [55-73] µm in 3rd order and partially 1st :
  - order 3 : 55 – 73 µm
  - order 1 : 165 – 219 µm
- SED blue high (continuum) sensitivity in extended 2nd order :
  - order 2 : 60 – 73 µm
  - order 1 : 120 – 146 µm

HERSCHEL SPACE OBSERVATORY

Two spectral sampling densities

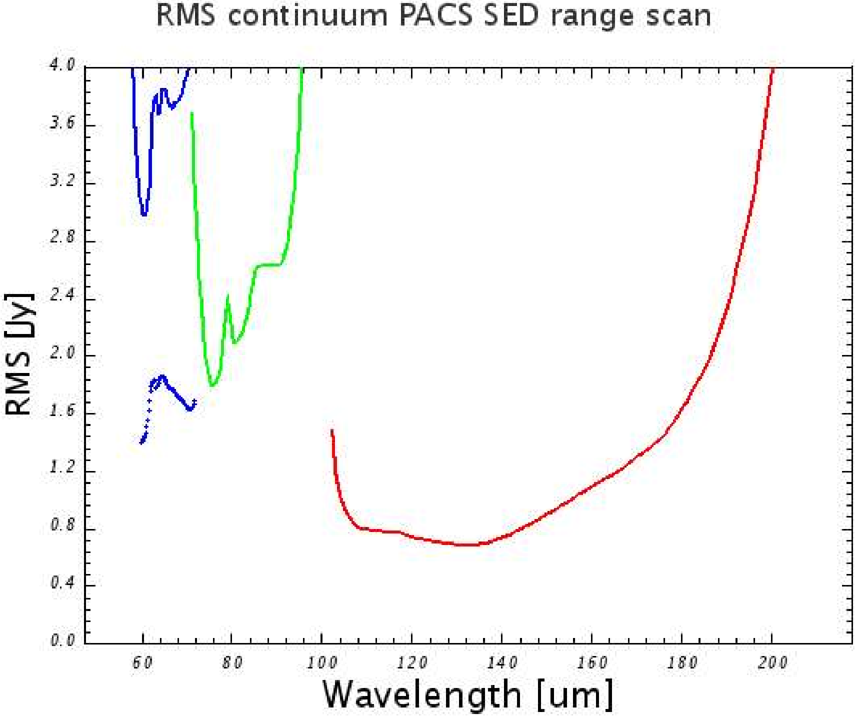
- Nyquist sampling
  - Unresolved line FWHM Nyquist sampled
  - Nyquist considering all 16 spectral pixel
  - This sampling is chosen for SED mode (PACS full range AOR)

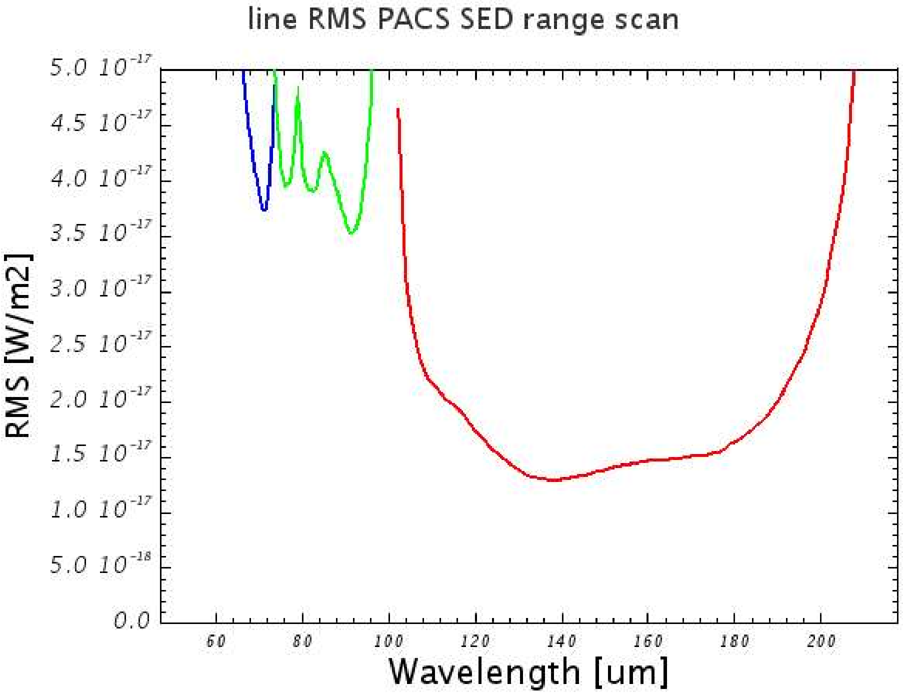
- High Sampling
  - Spectral sampling as in line spectroscopy
  - ~3 samples per FWHM in every detector

Nyquist sampling (SED)

- 4 scans in 1 telescope nod cycle
  - 1 up / 1 down wavelength direction
  - Repeated on 2nd nod position
- Duration, e.g. full range
  - 102 - 210 µm (71-98 for free) : 1121 s ("SED red")
  - 55 – 73 µm (extra 165-219 free): 847 s ("SED blue")
  - → Repetition factor 2: so total PACS range in 1hour.
- Sensitivity (line / continuum)
  - Varies over wavelengths
  - Increase S/N : repeat nod cycle

SED predicted sensitivities





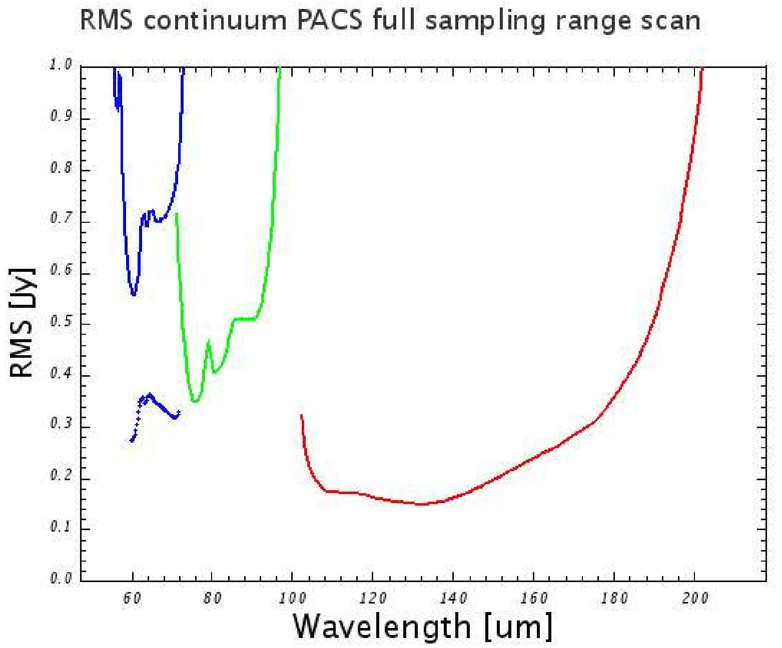
High sampling

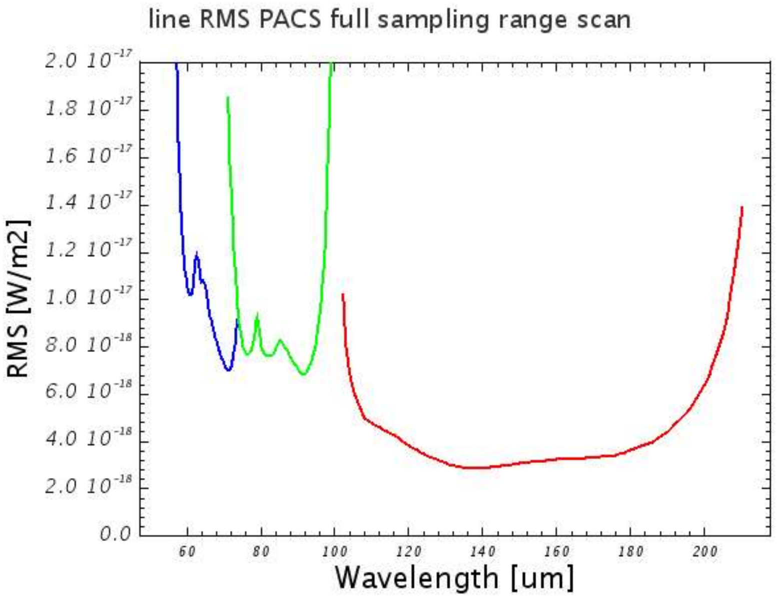
- 4 scans in 1 telescope nod cycle
  - 1 up / 1 down wavelength direction
  - Repeated on 2nd nod position
- Duration, e.g. full range
  - 102 - 210 µm (71-98 for free) : ~18611 sec
  - 55 – 73 µm (extra 165-219 free): ~17151 sec

  →total: ~10 hours
- Sensitivity (line / continuum)
  - Varies over wavelengths
  - Increase S/N : repeat nod cycle

HERSCHEL SPACE OBSERVATORY

High-sampling predicted sensitivity





Questions ?

- PACS Observer's Manual :

http://herschel.esac.esa.int/ao_kp_documentation.shtml

- Herschel Helpdesk:

http://herschel.esac.esa.int/esupport/