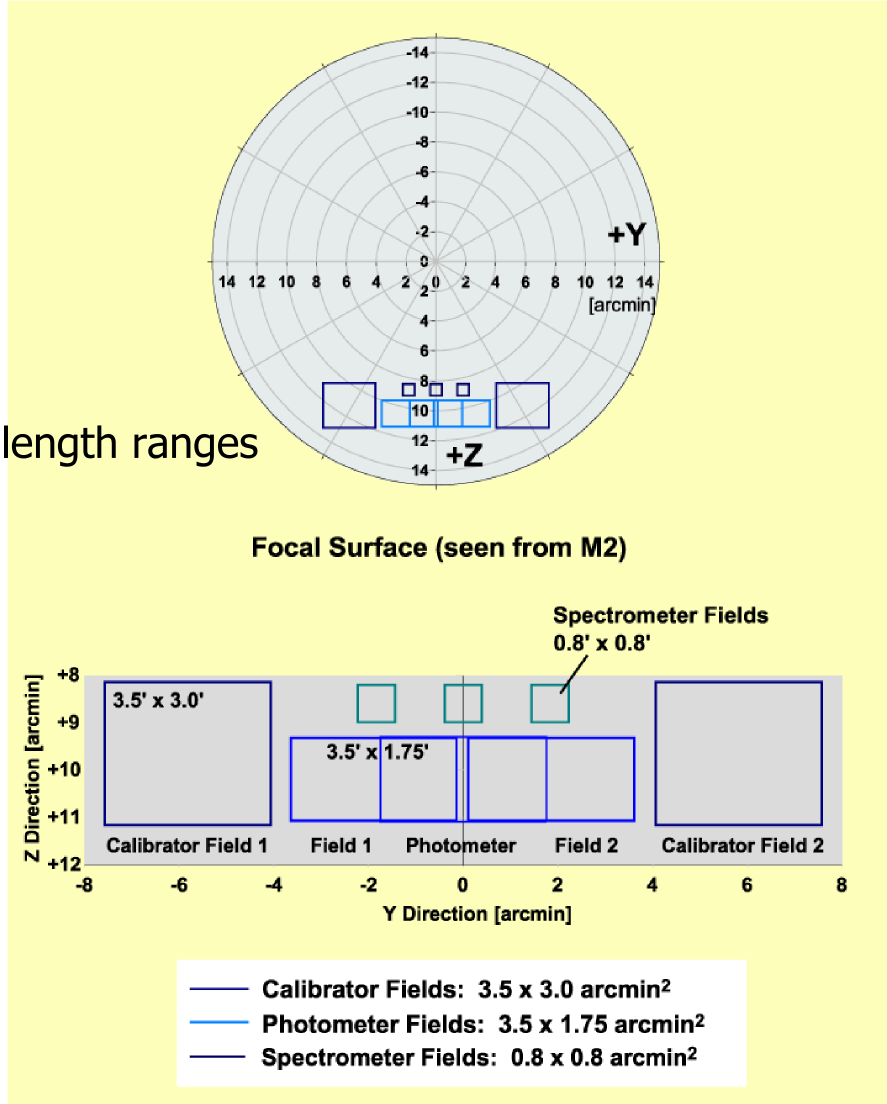
Line Spectroscopy and Mapping in Line Spectroscopy Mode with PACS

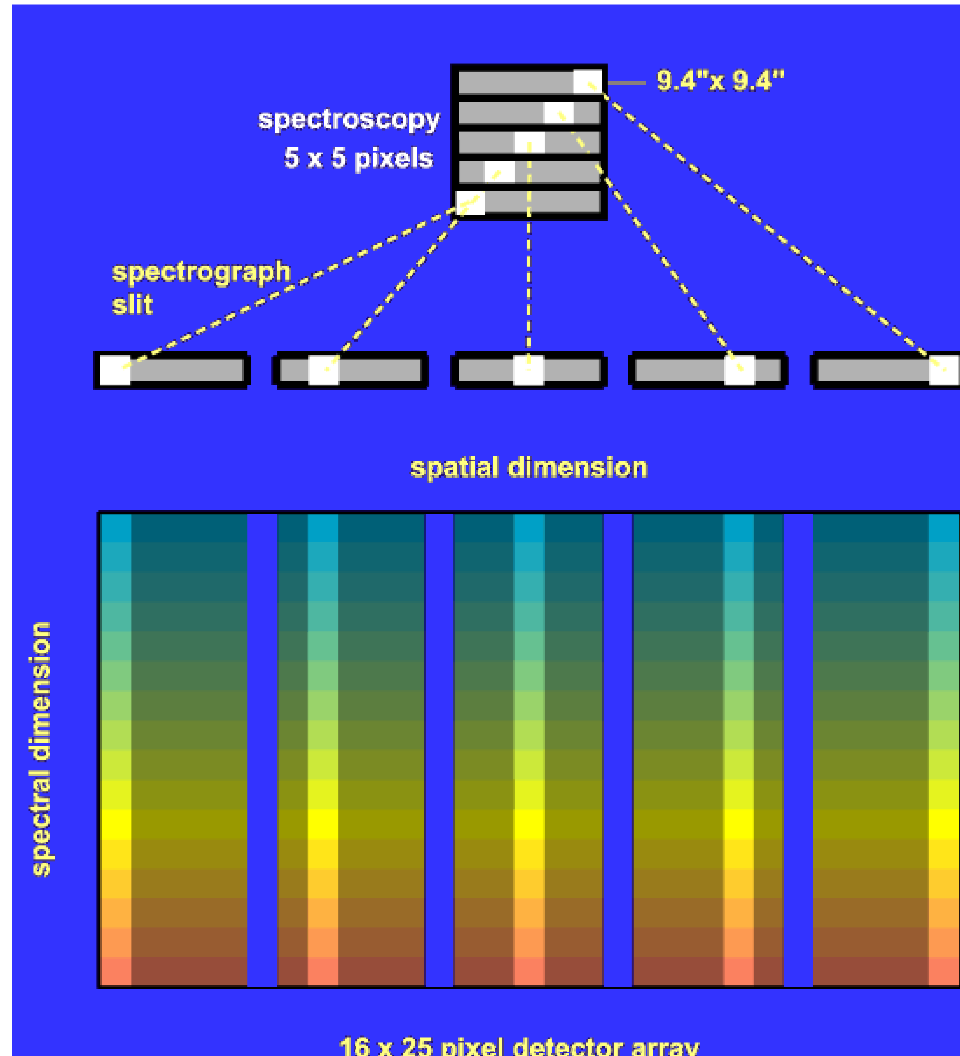
Eckhard Sturm
MPE

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

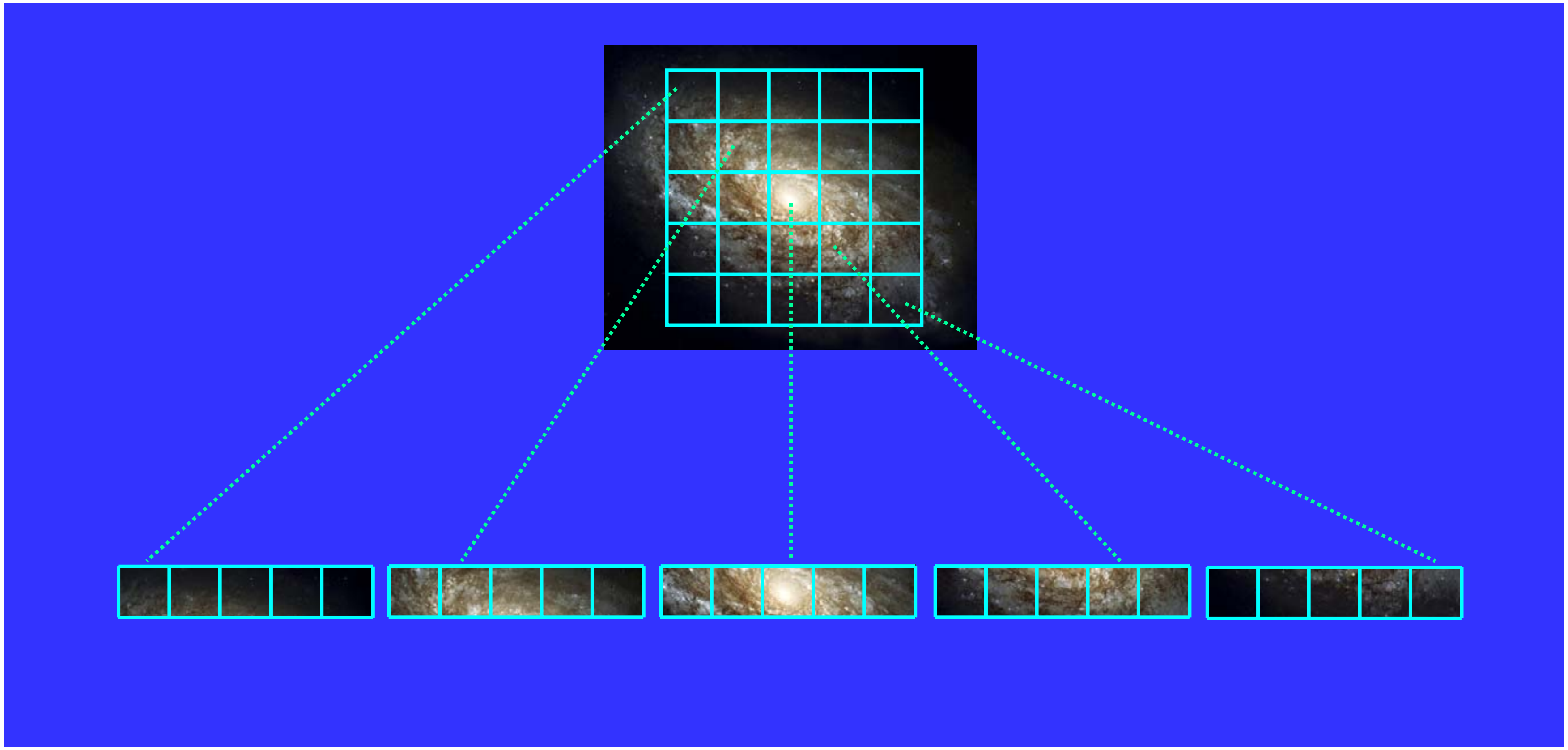


Spectrometer Observing Modes

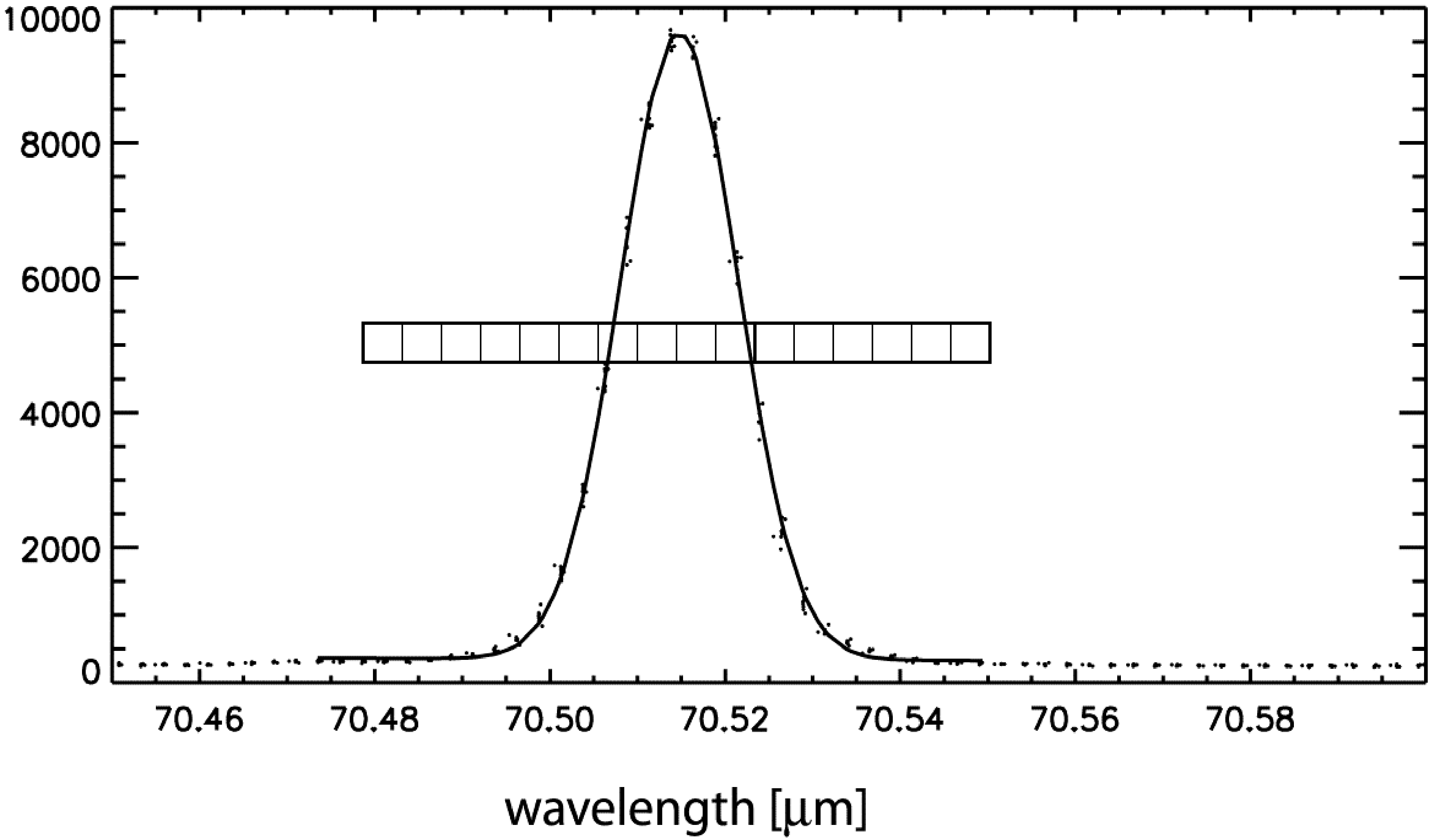


- **Line Spectroscopy: observation of individual line(s)**
  - Chop/nod or wavelength switching
  - Staring or mapping
  - R ~ 1500

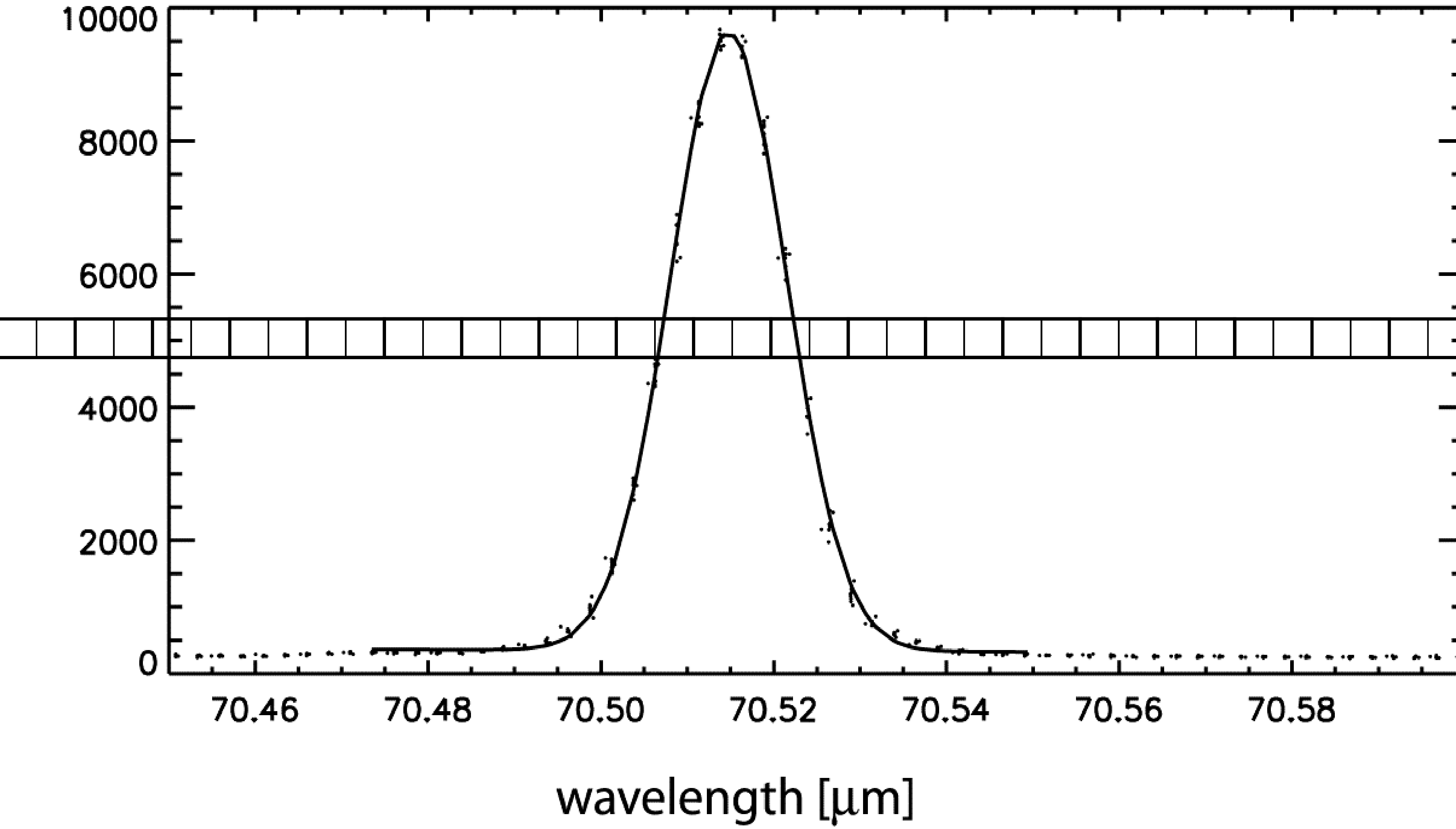
- **Range Spectroscopy: observation of extended range(s)**
  - Chop/nod or off position
  - Staring or mapping
  - SED mode
  - → *See presentation by J. Blommaert*

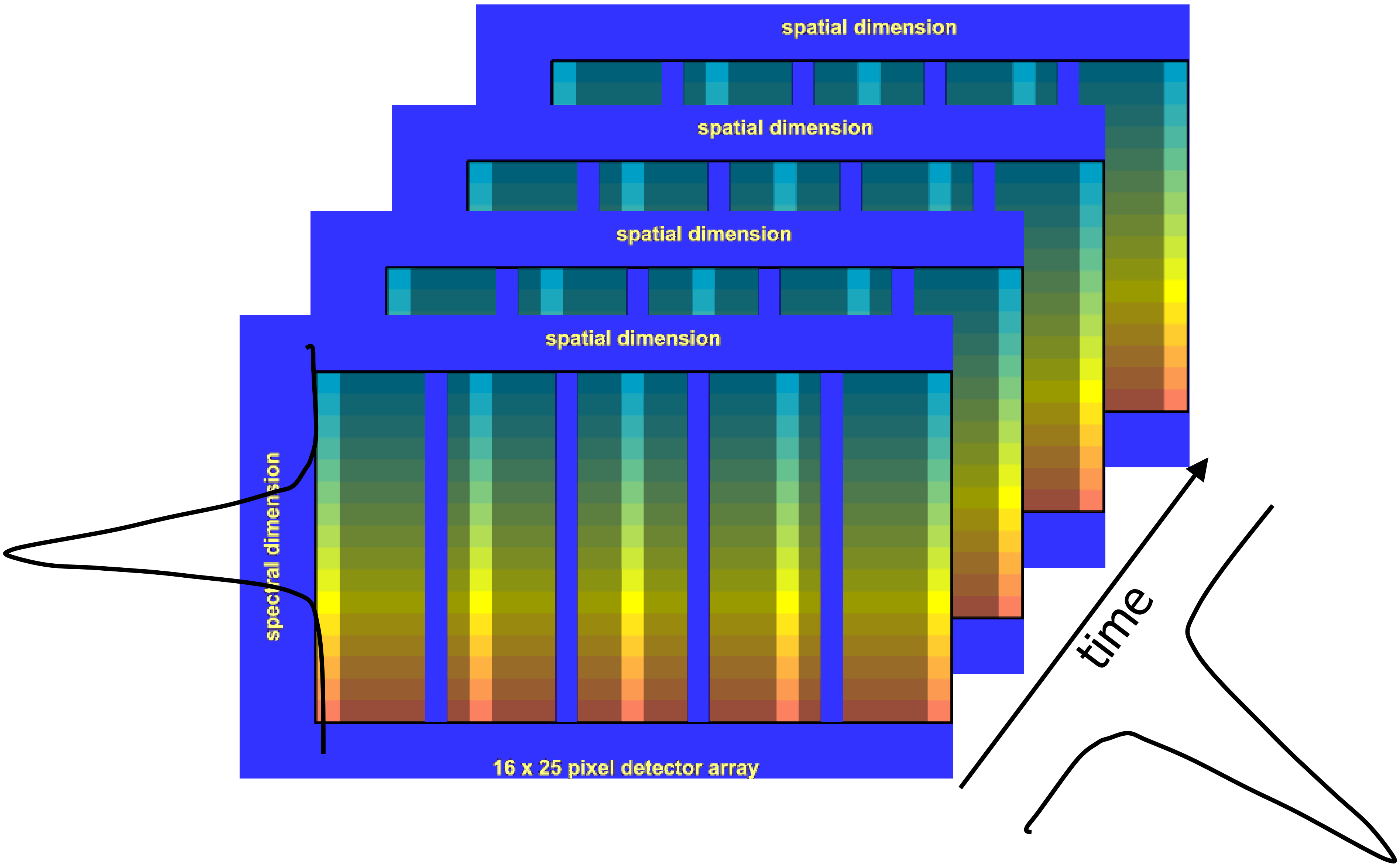


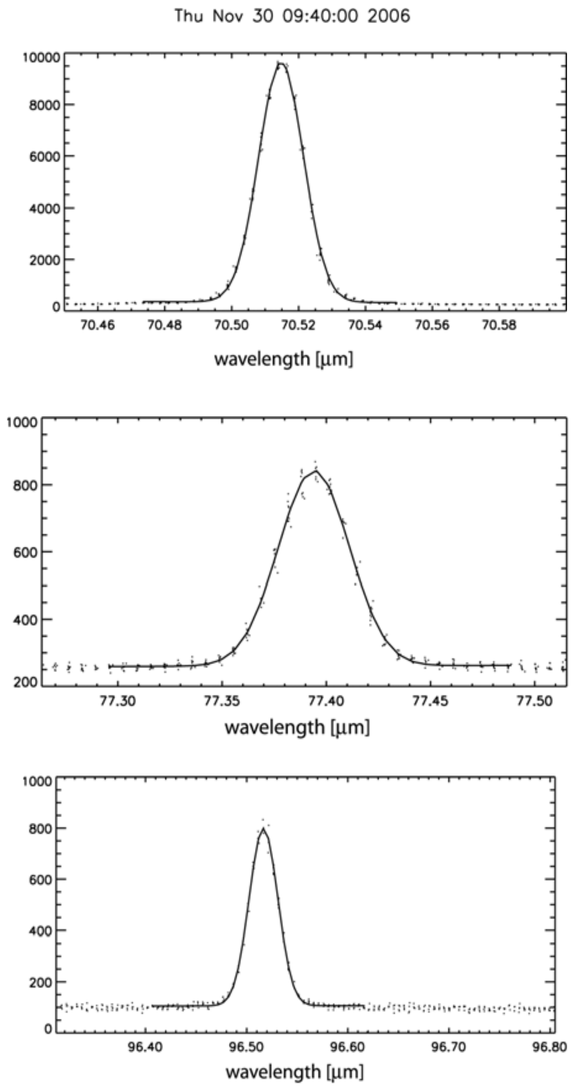
Line Spectroscopy in chop/nod – AOT implementation

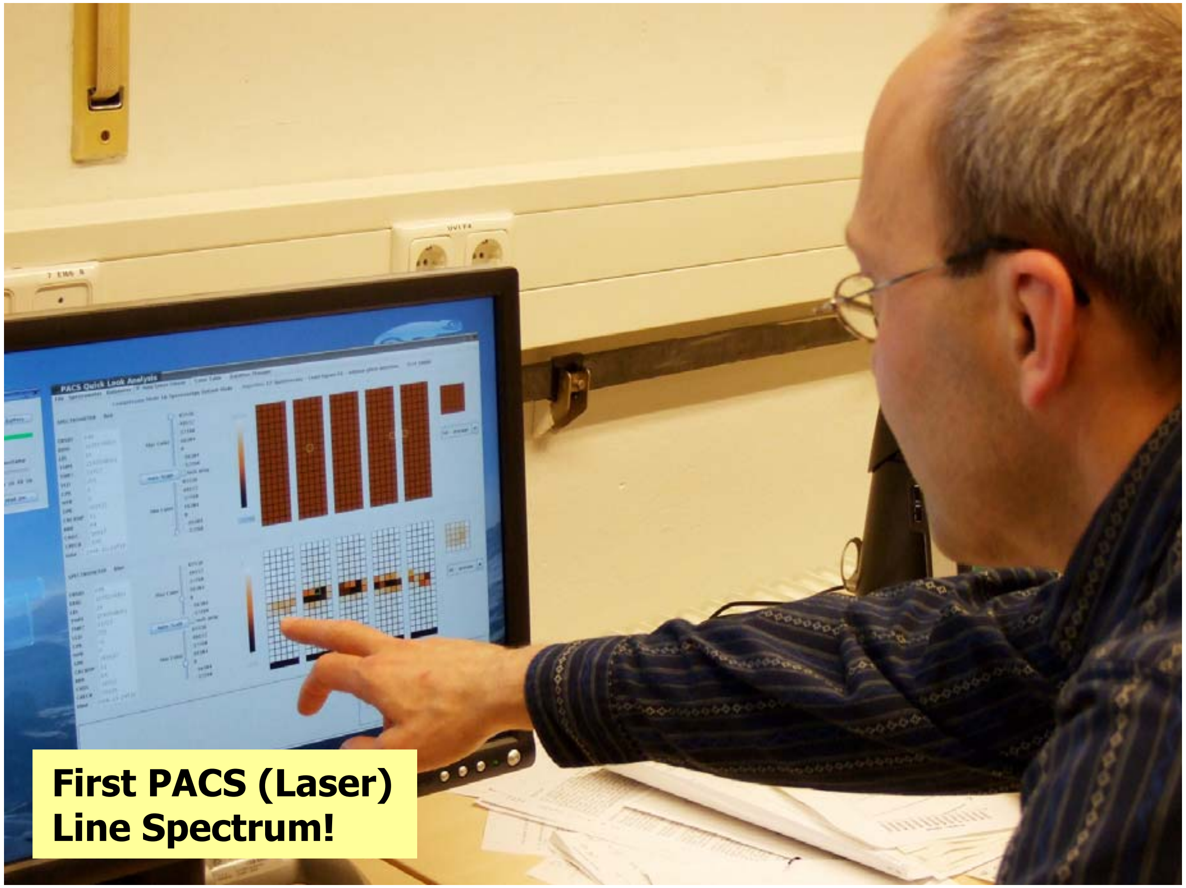


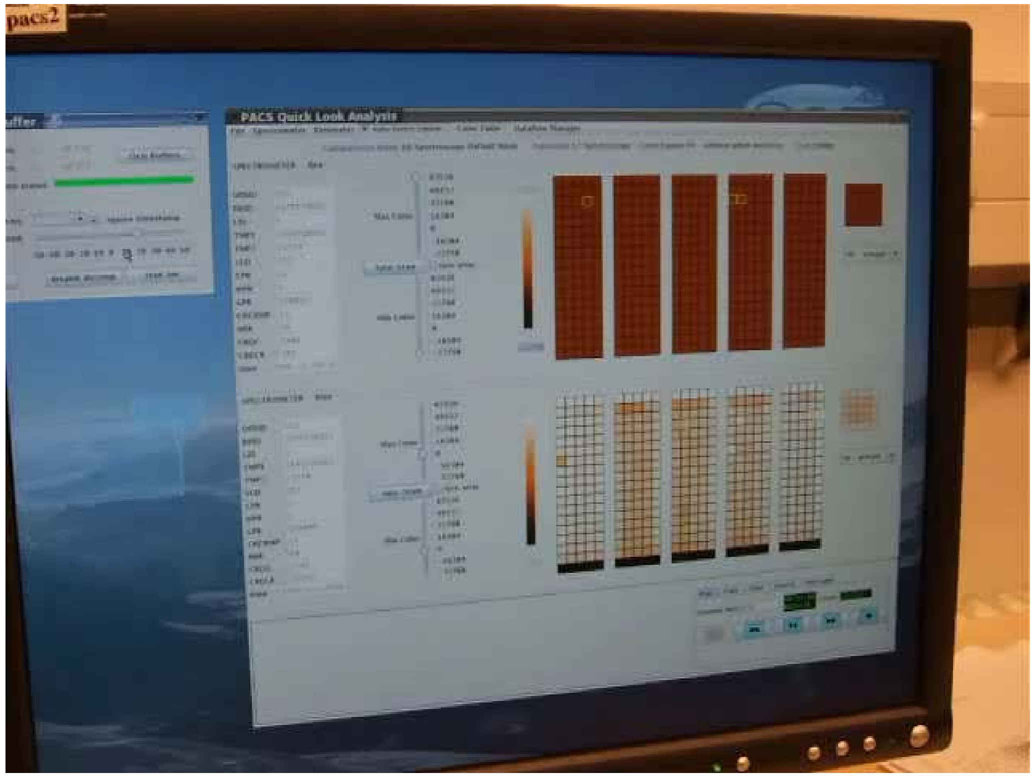
Line Spectroscopy in chop/nod – AOT implementation



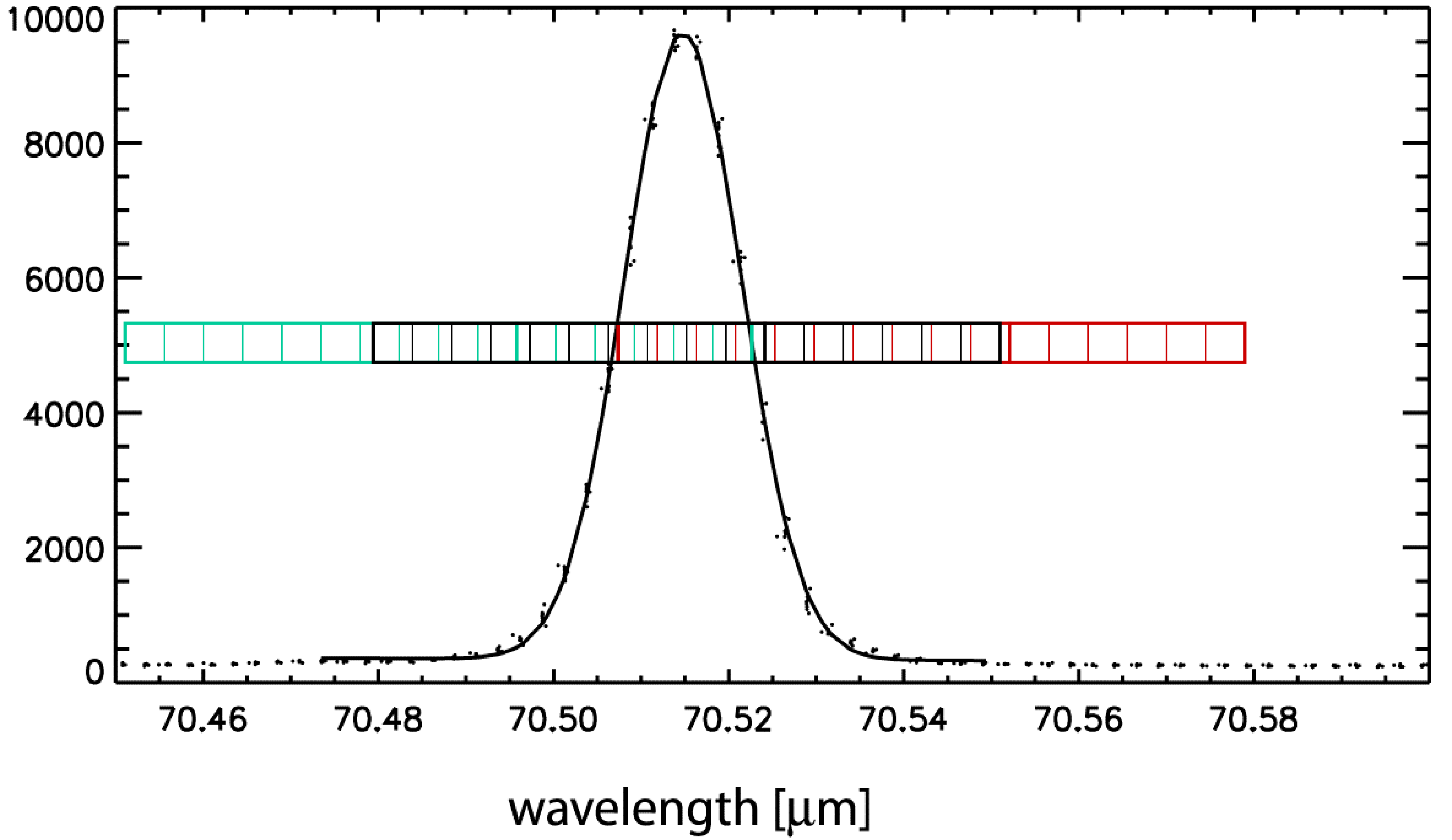

spatial dimension
spatial dimension
spatial dimension
spatial dimension
spectral dimension
16 x 25 pixel detector array
time

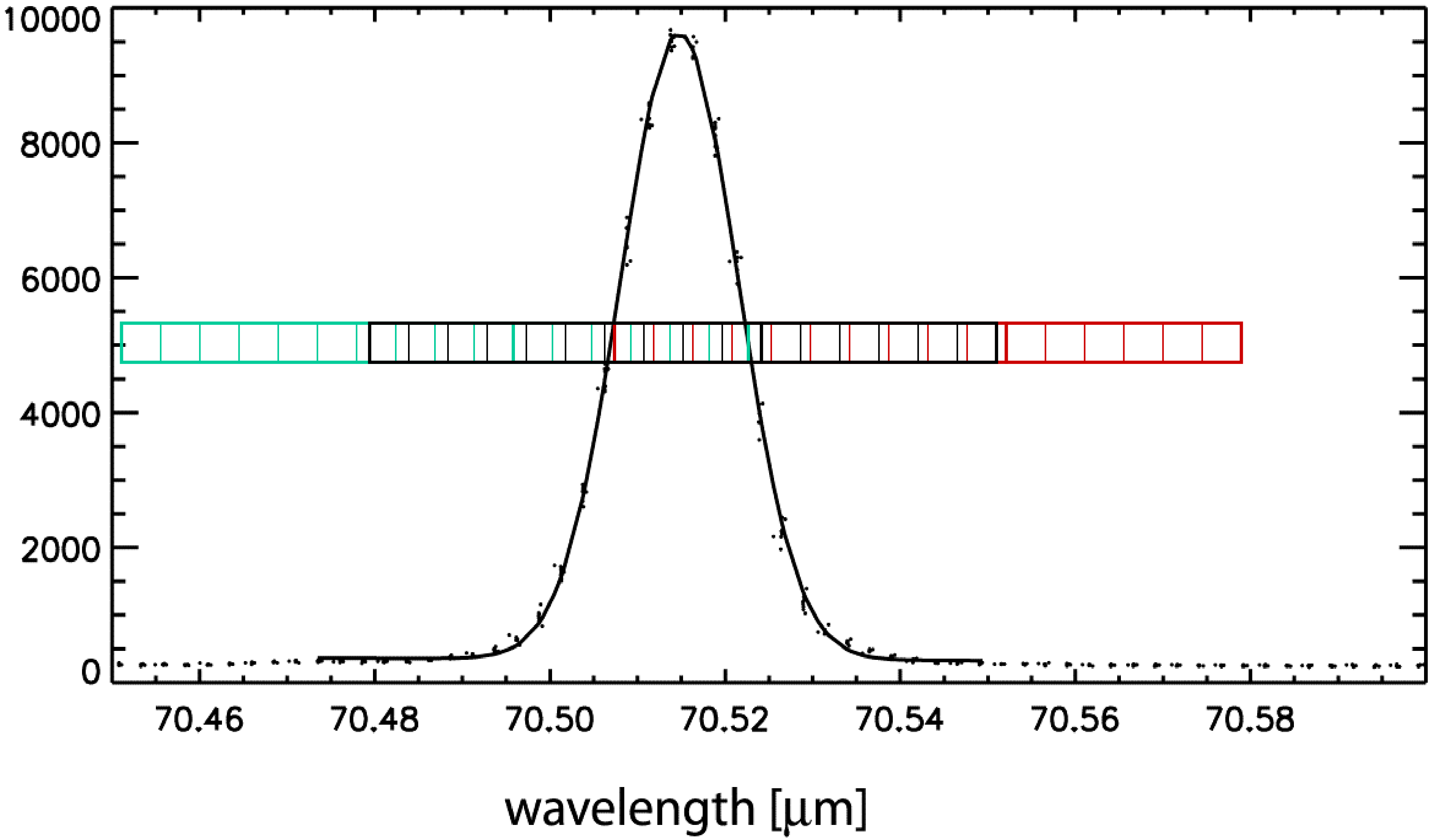

Thu Nov 30 09:40:00 2006
wavelength [µm]
wavelength [µm]
wavelength [µm]


First PACS (Laser)
Line Spectrum!


pacs2
PACS Quick Look Analysis

Line Spectroscopy in λ-switching – AOT implementation



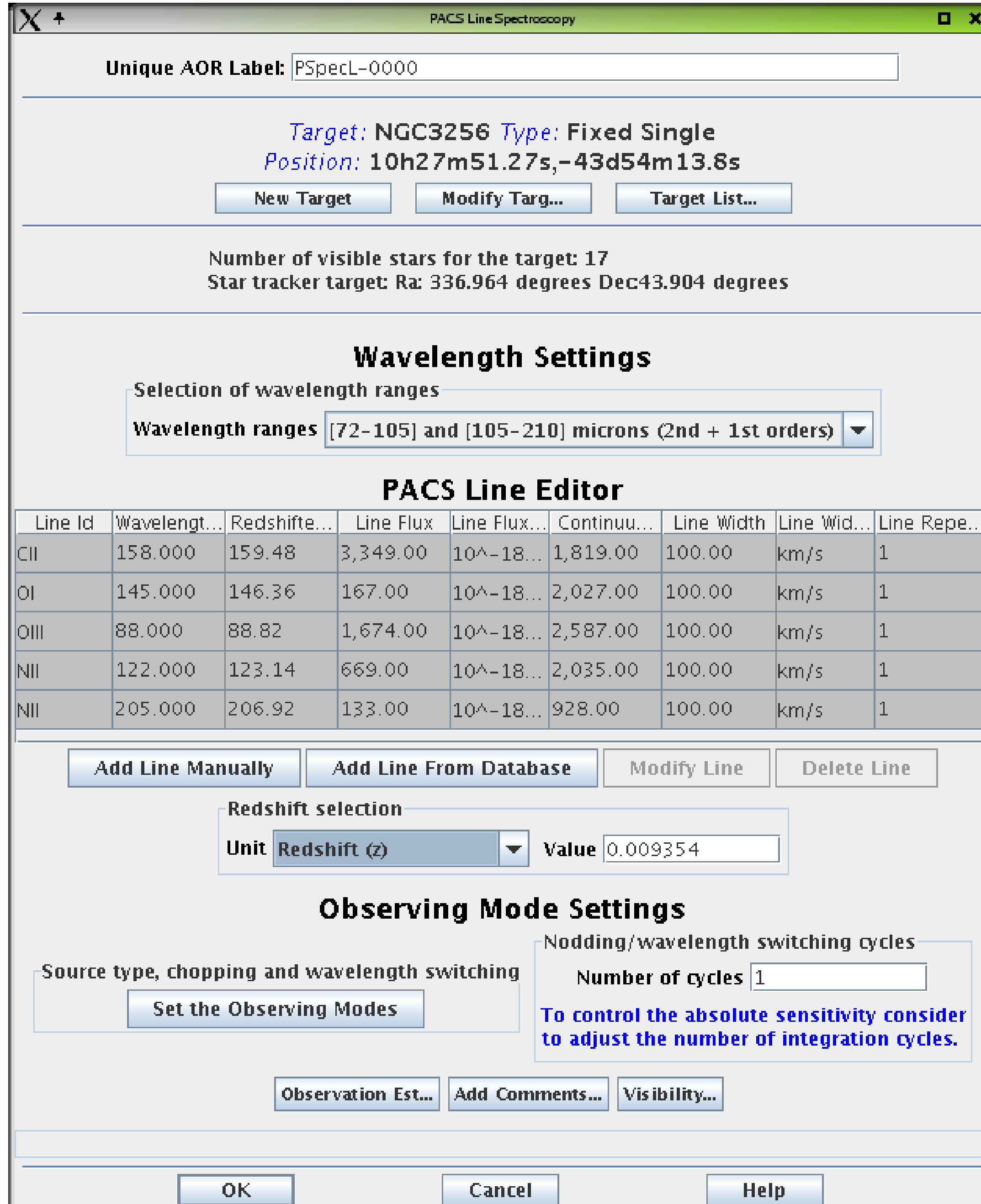

10000
8000
6000
4000
2000
0
70.46
70.48
70.50
70.52
70.54
70.56
70.58
wavelength [μm]

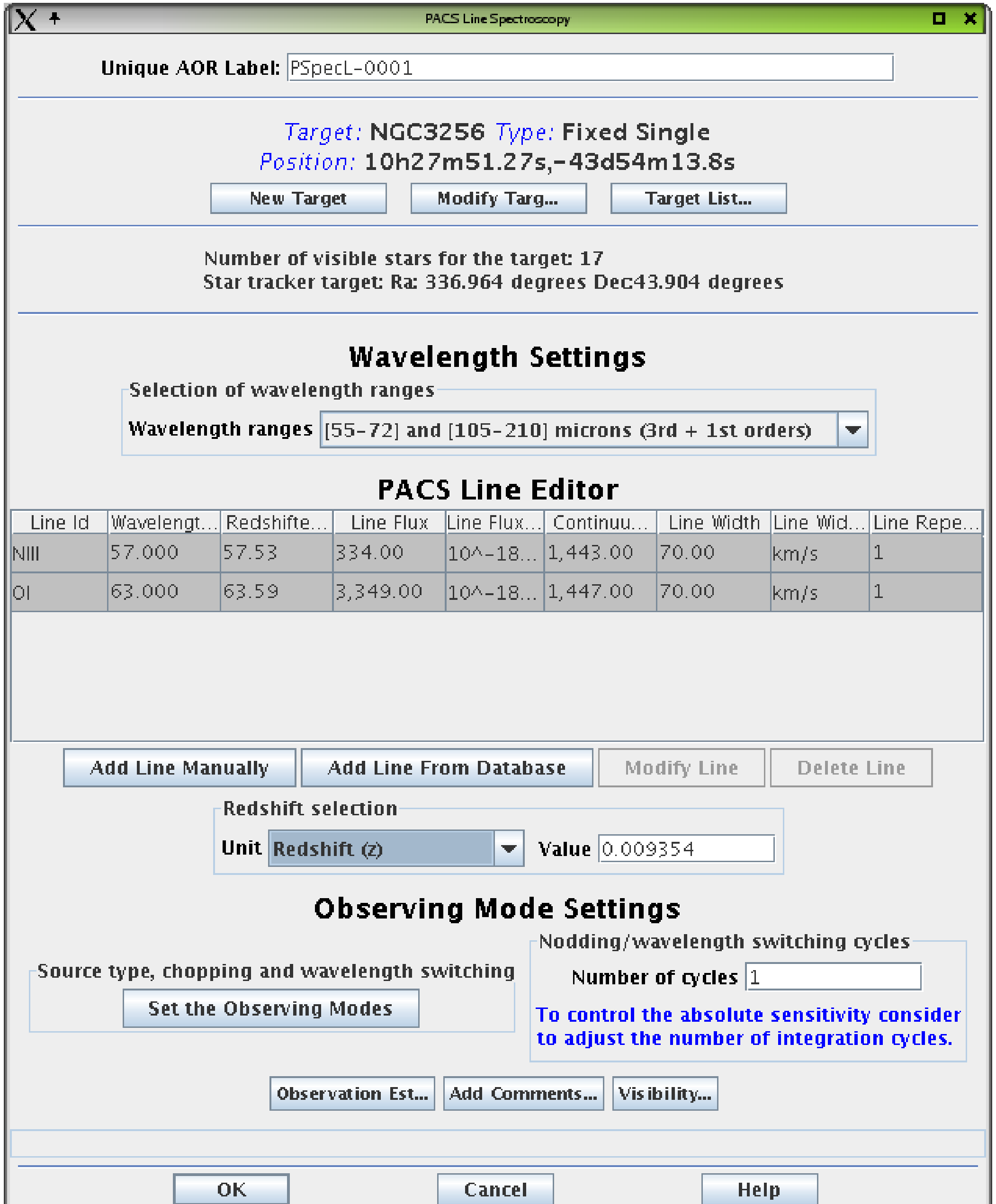
Spectrometer Observing Modes

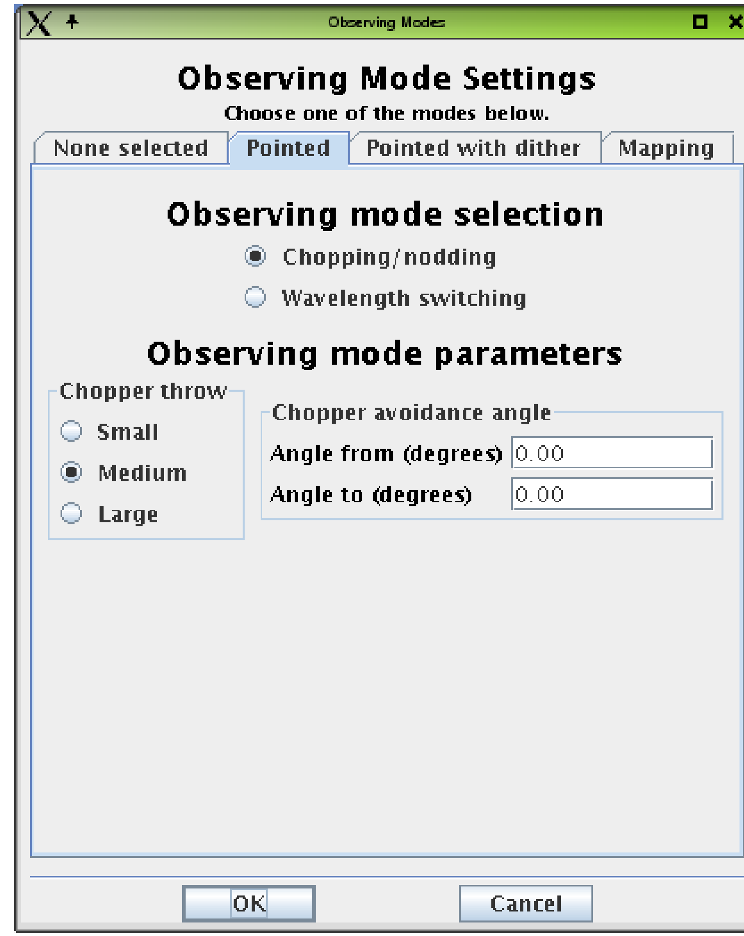
- **Line Spectroscopy: observation of individual line(s)**
  - Chop/nod or wavelength switching
  - POINTED: single satellite pointing
  - POINTED WITH DITHER: small spacecraft movements perpendicular to the chopper direction to compensate for slicer effects in case of slightly mispointed targets
  - 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
  - Spectral sampling >3 samples/FWHM (by small up/down scan)

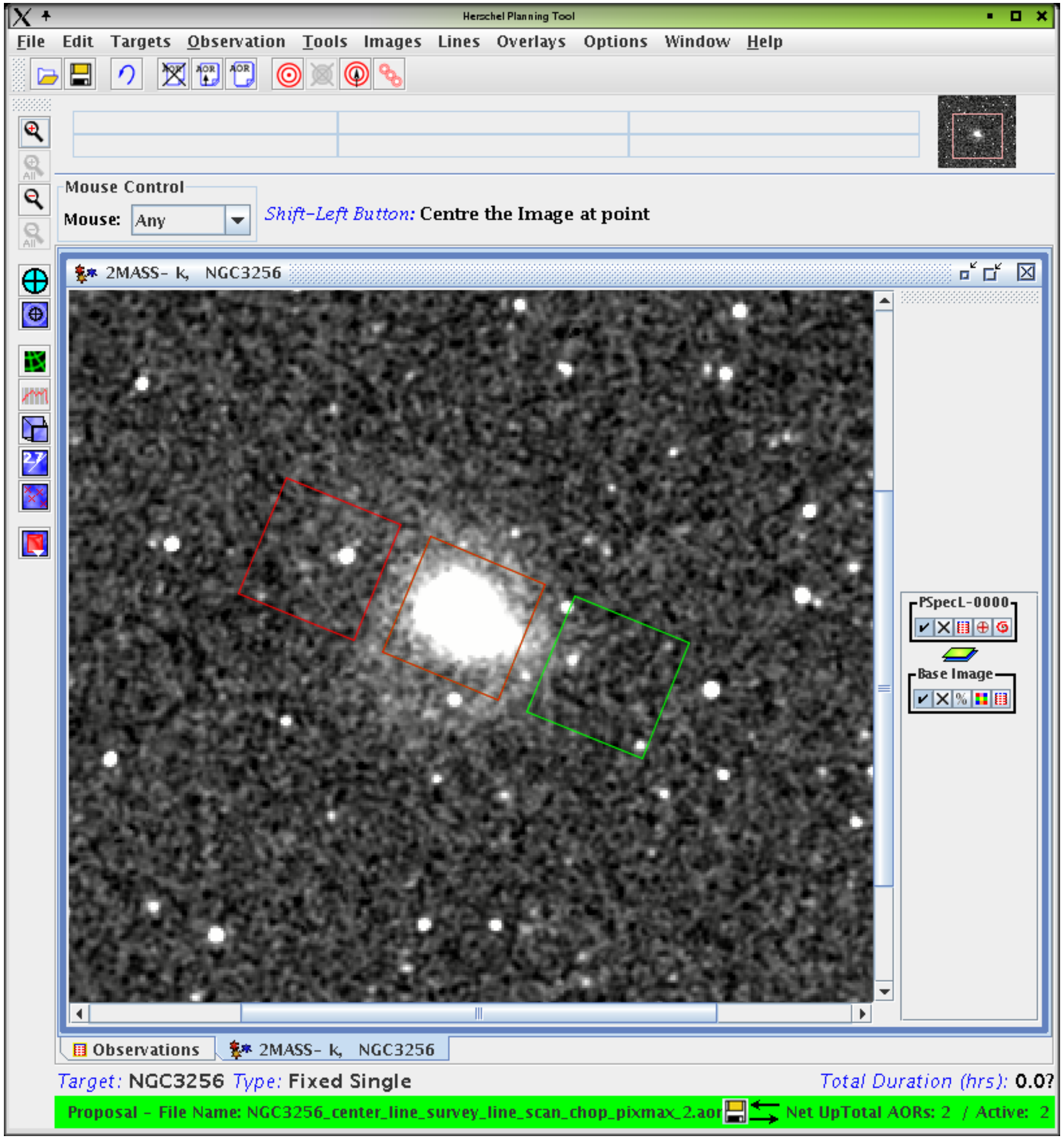
Example1:

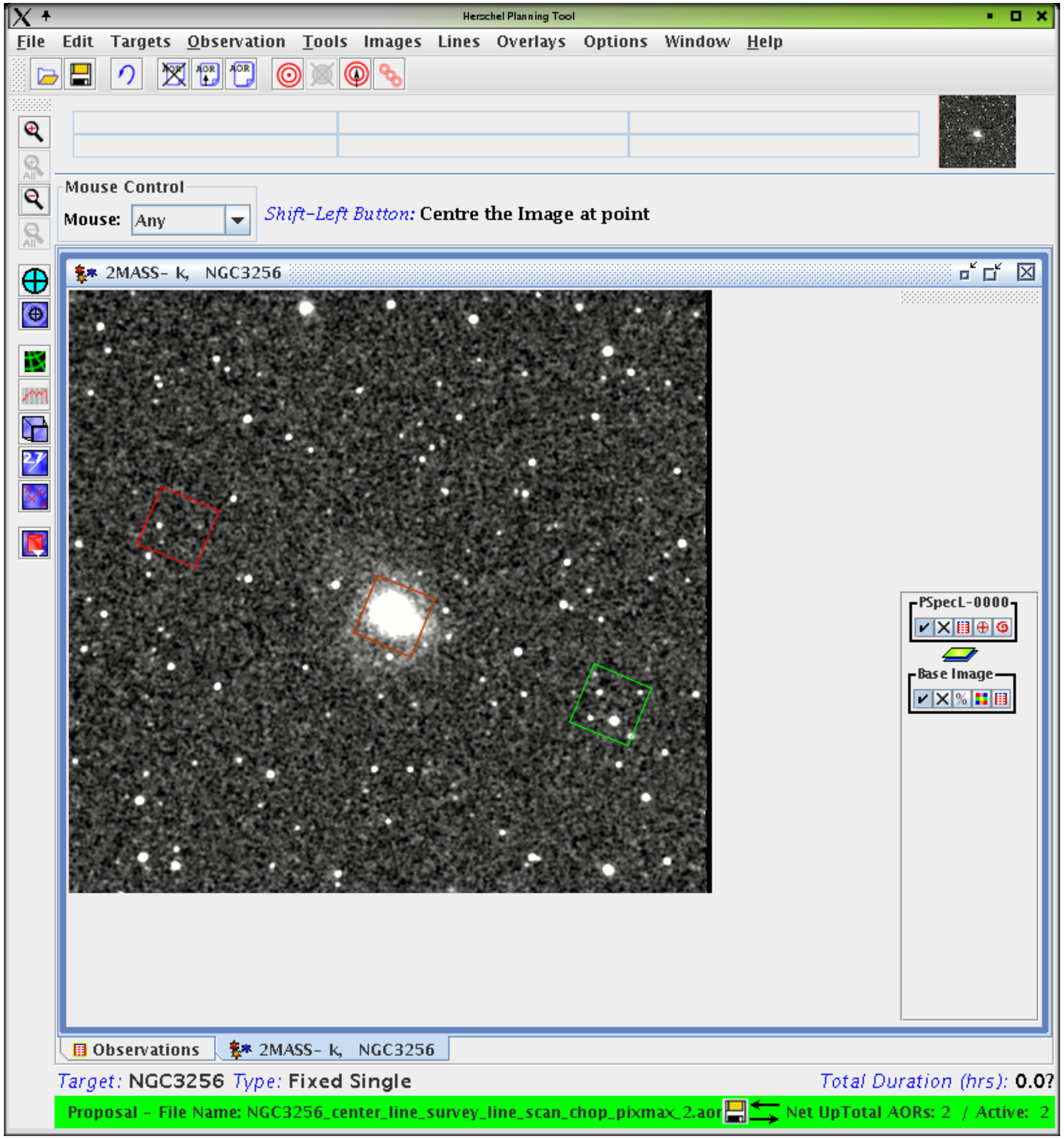
Spectroscopic line survey of a galaxy (no mapping)



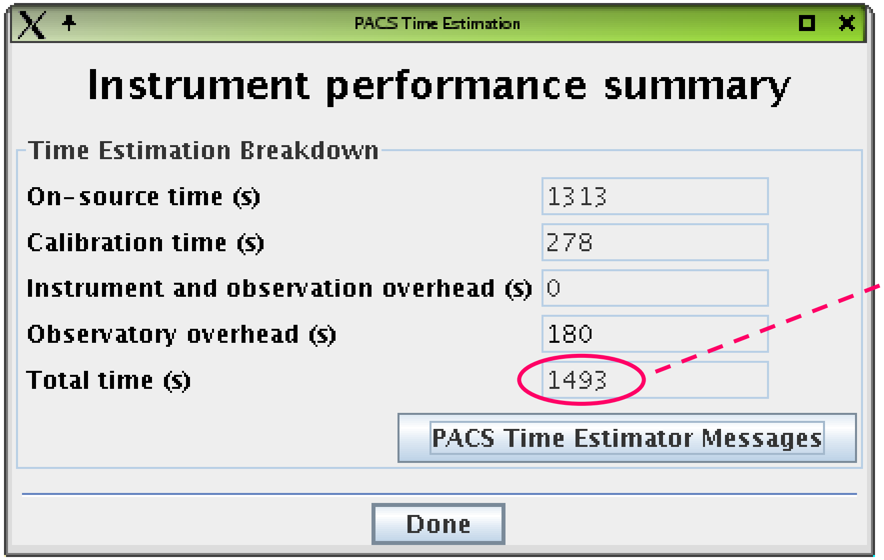

PACS Line Spectroscopy
Unique AOR Label: PSpecL-0001
Target: NGC3256 Type: Fixed Single
Position: 10h27m51.27s,-43d54m13.8s
New Target
Modify Targ...
Target List...
Number of visible stars for the target: 17
Star tracker target: Ra: 336.964 degrees Dec43.904 degrees
Wavelength Settings
Selection of wavelength 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

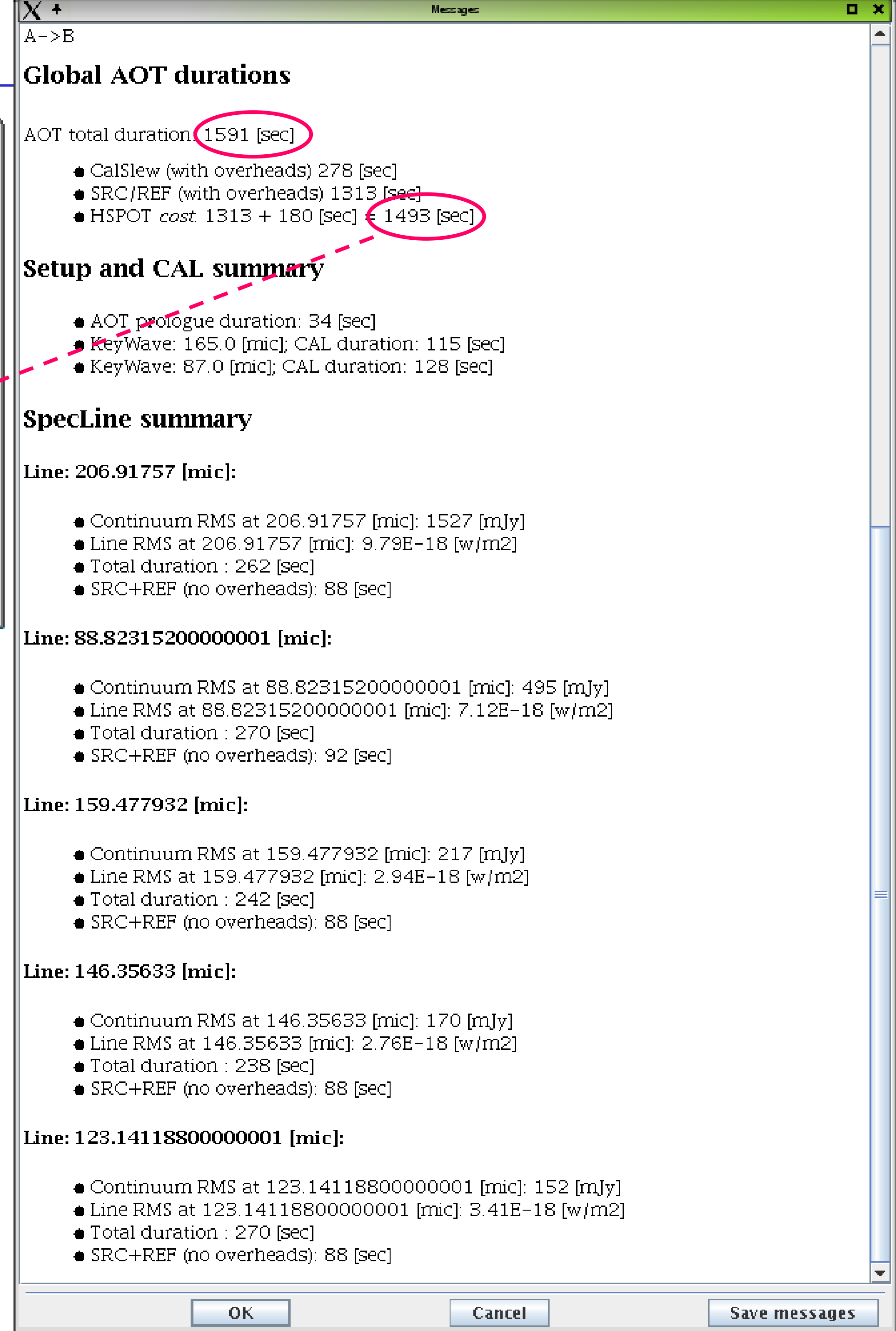

Observing Modes
Observing Mode Settings
Choose one of the modes below.
None selected
Pointed
Pointed with dither
Mapping
Observing mode selection
Chopping/nodding
Wavelength switching
Observing mode parameters
Chopper throw
Small
Medium
Large
Chopper avoidance angle
Angle from (degrees) 0.00
Angle to (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): 0.07
Proposal - File Name: NGC3256_center_line_survey_line_scan_chop_pixmax_2.aor
Net UpTotal AORs: 2 / Active: 2



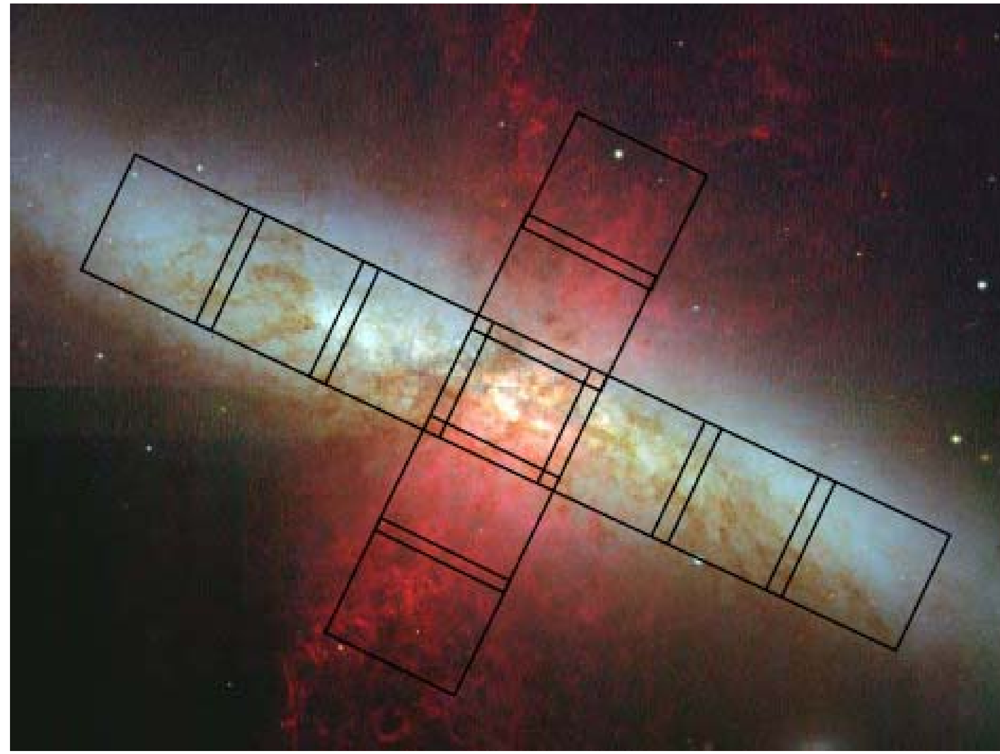


5 lines (2nd and 1st order), chop/nod, rep=1, cycle=1, medium throw

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

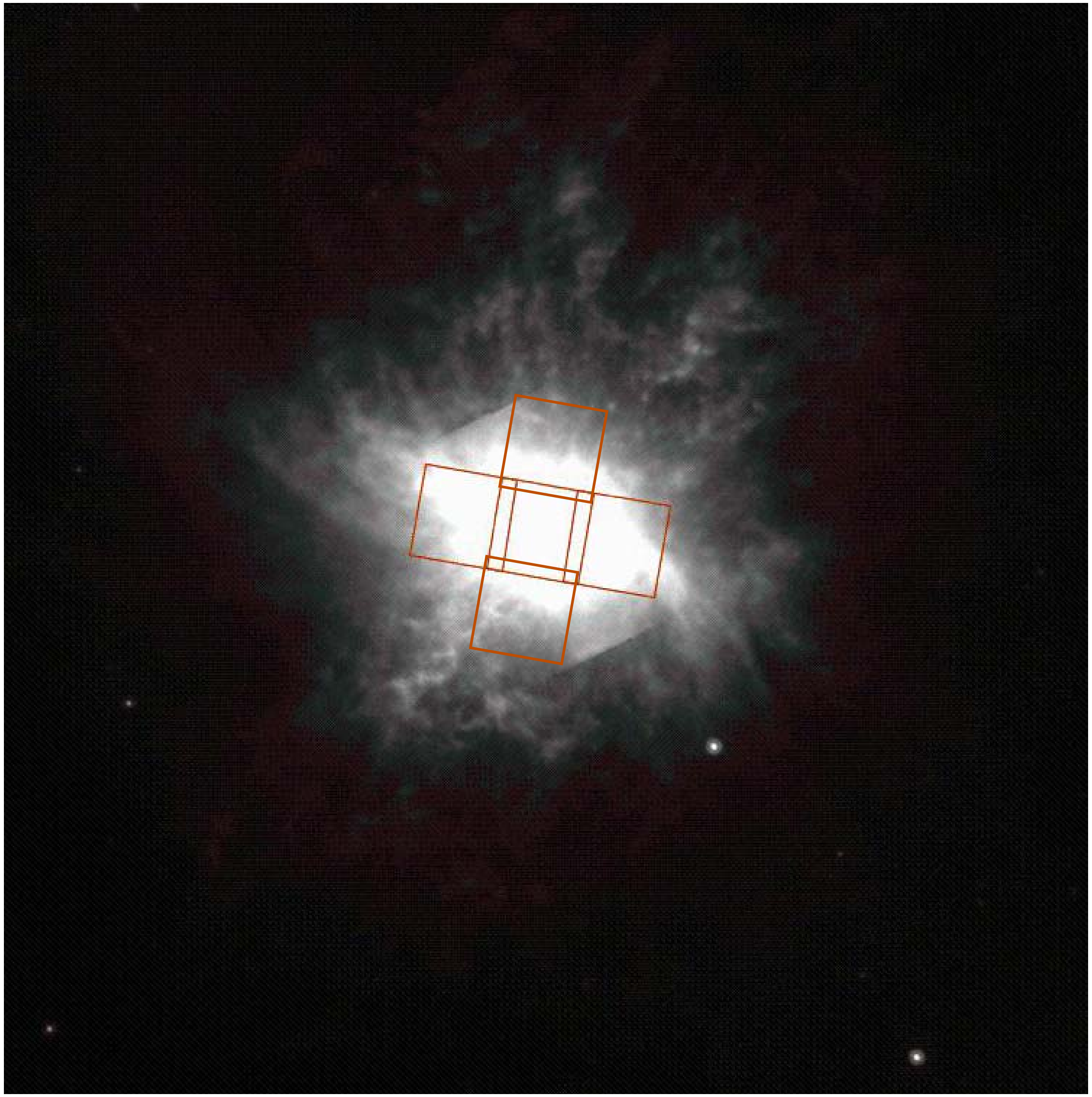
Example2:

Spectroscopic line mapping of a galaxy (M82)



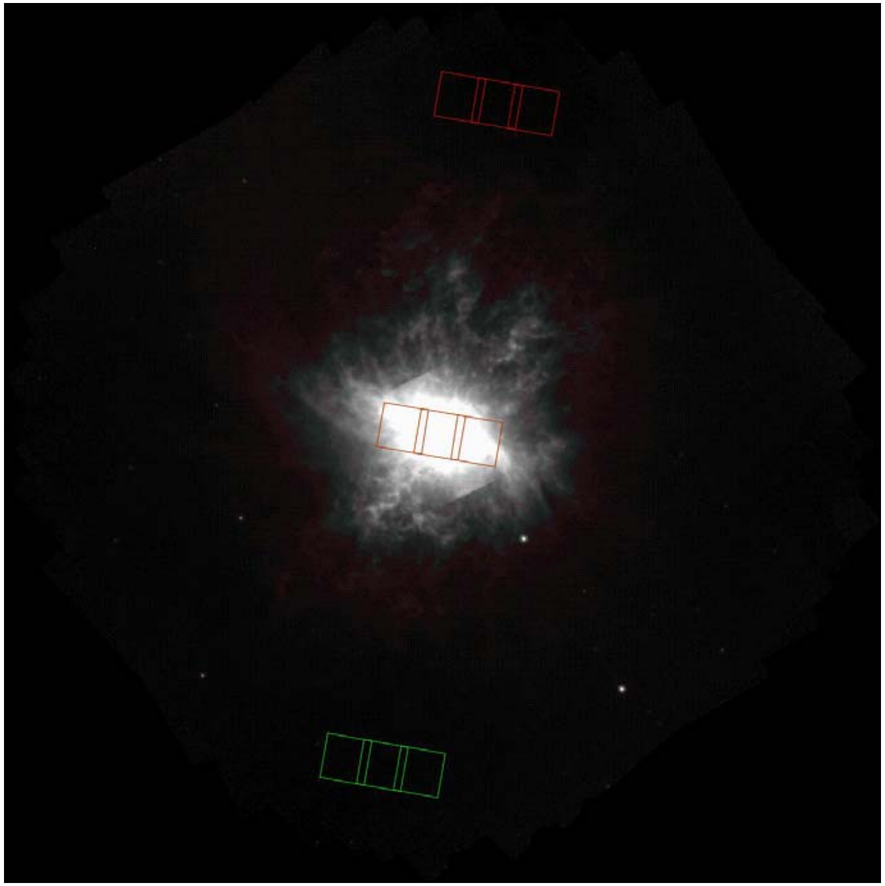
E.g. map transition from the central starburst to the molecular ring to quiescent disk along major axis in NIII/NII.

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

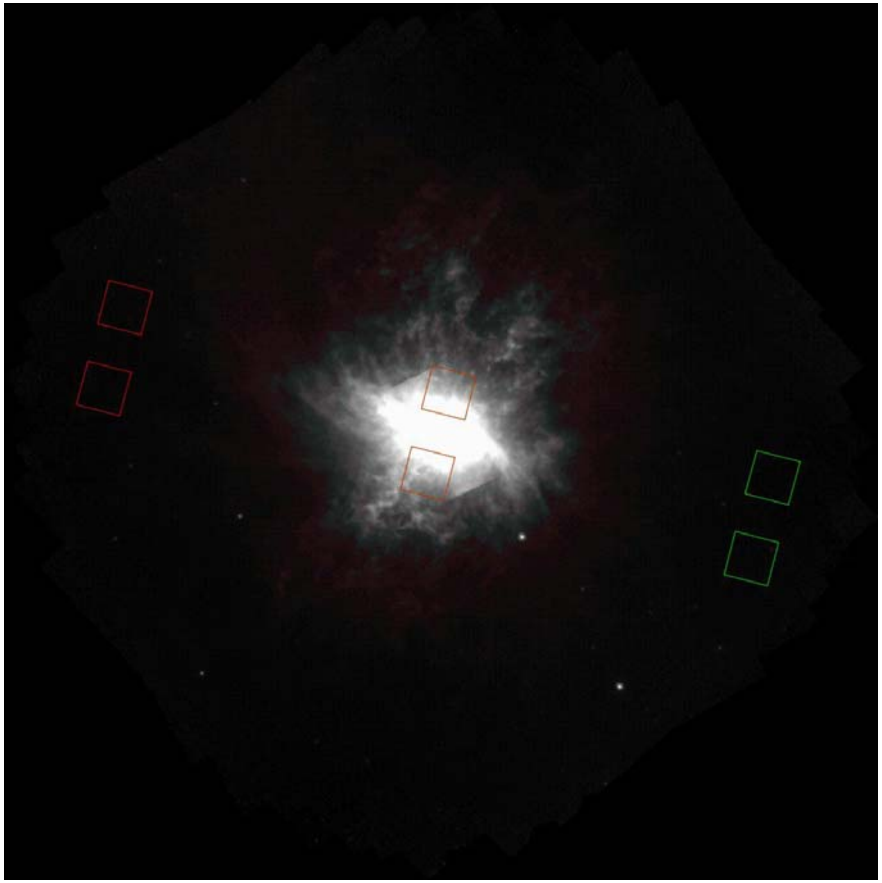


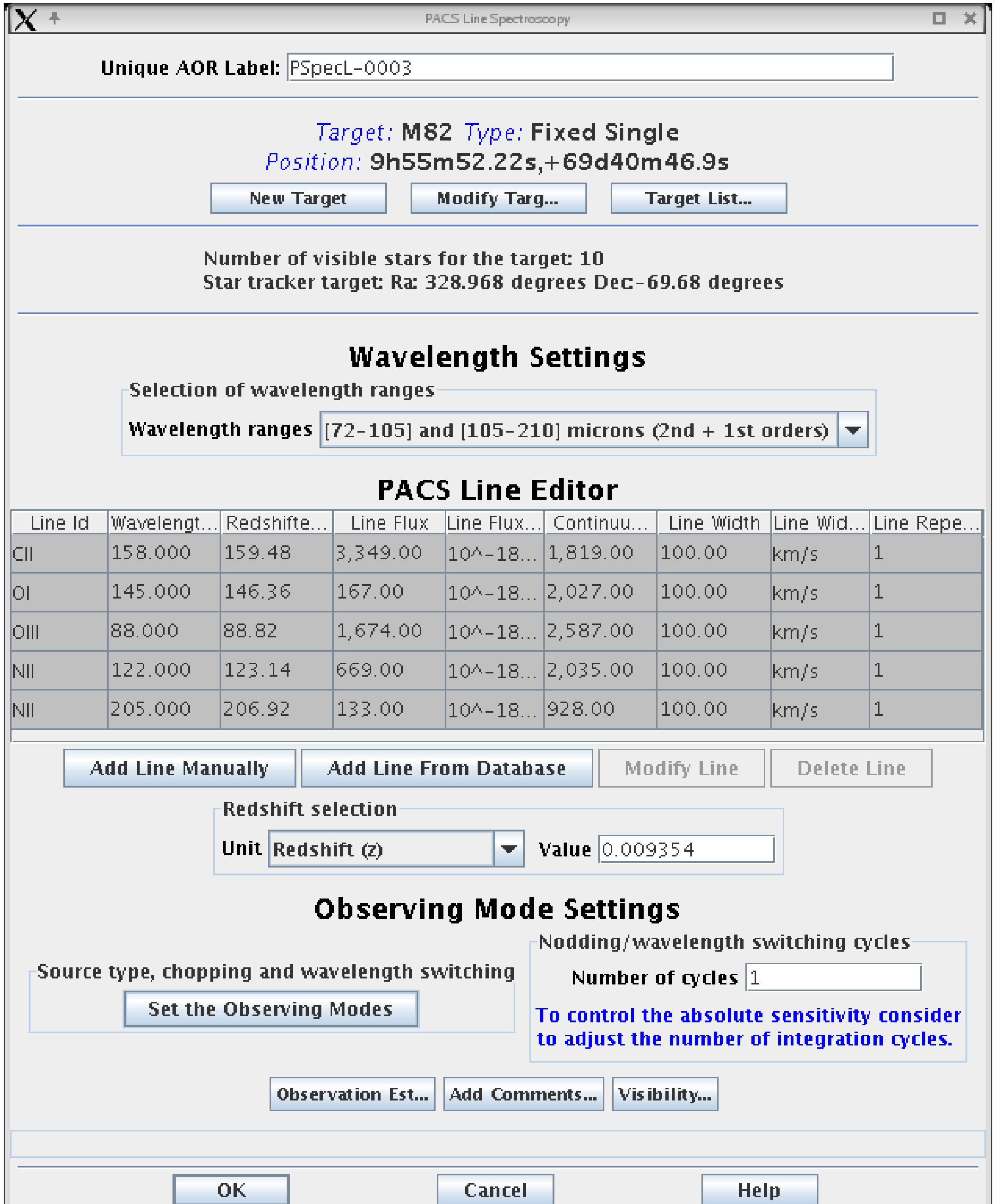
Line spectroscopy with PACS

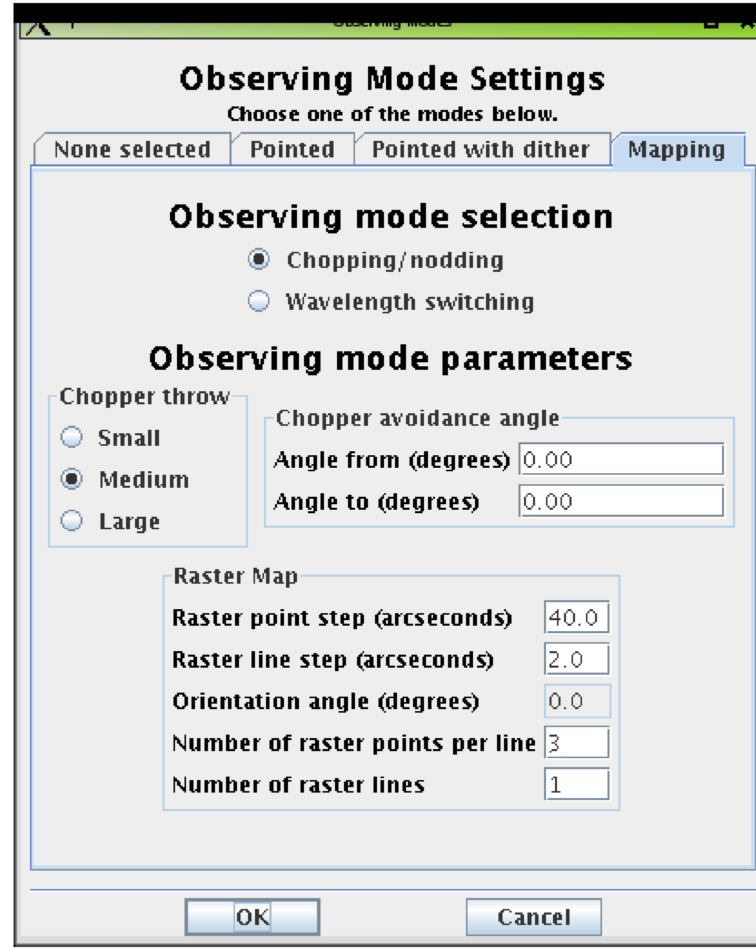
September 2008

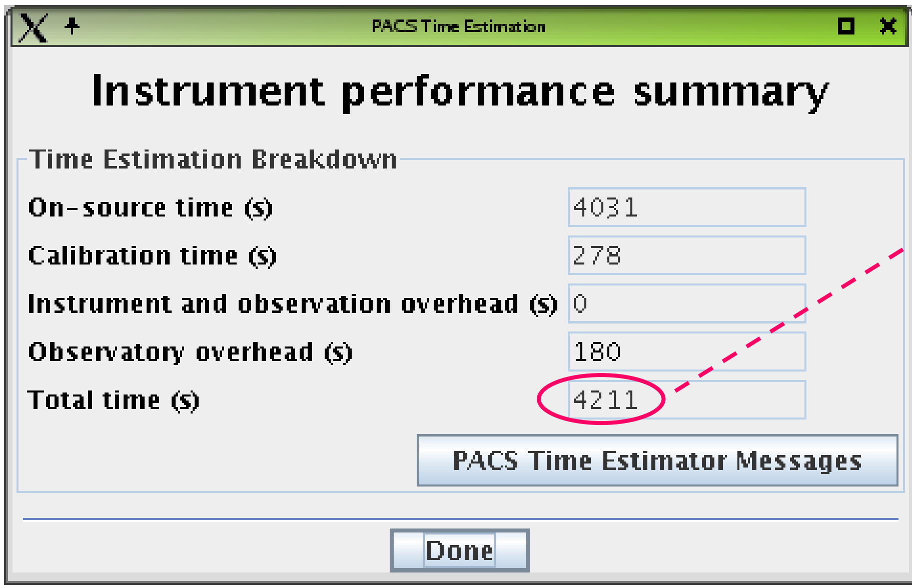


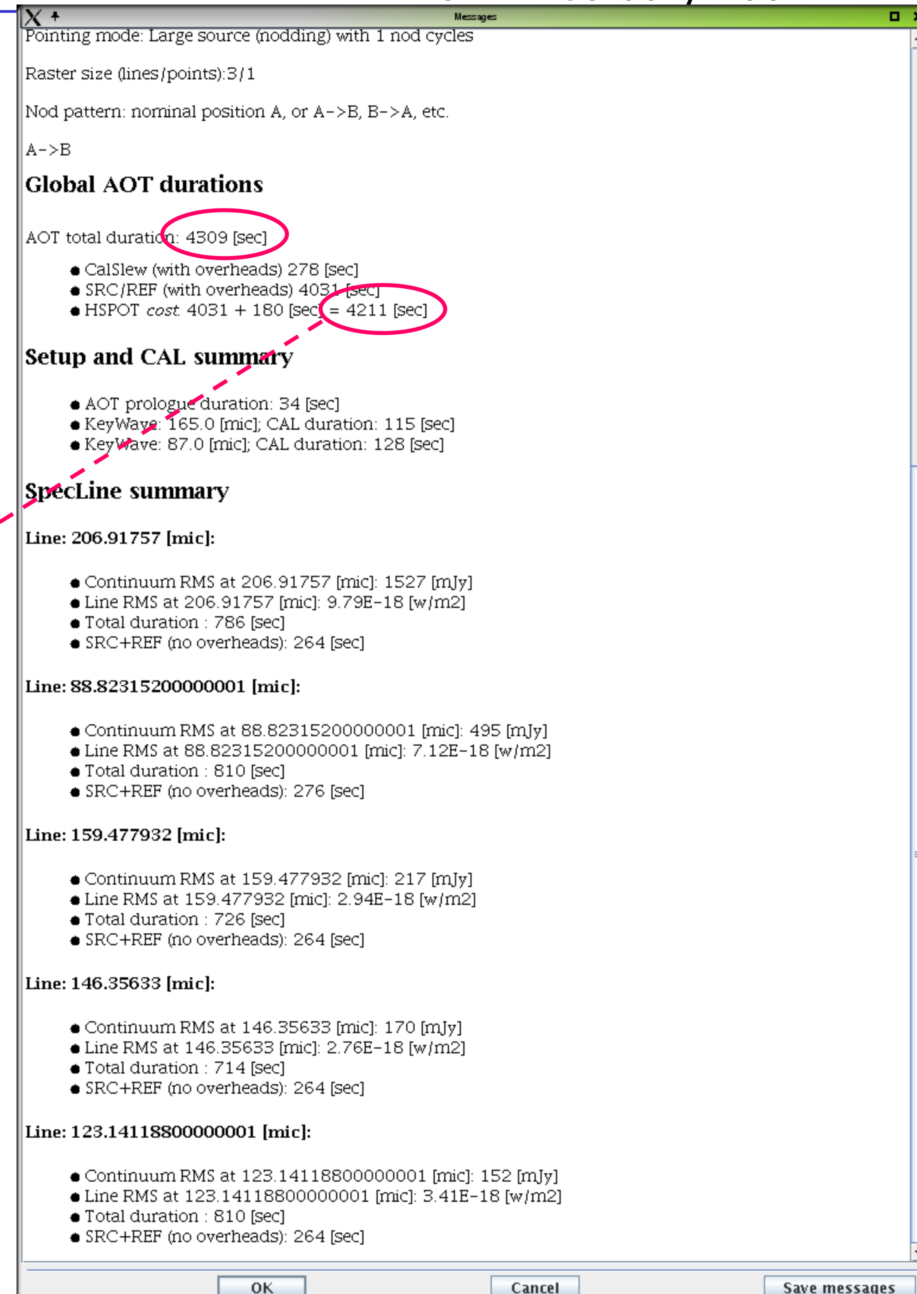
December 2008




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

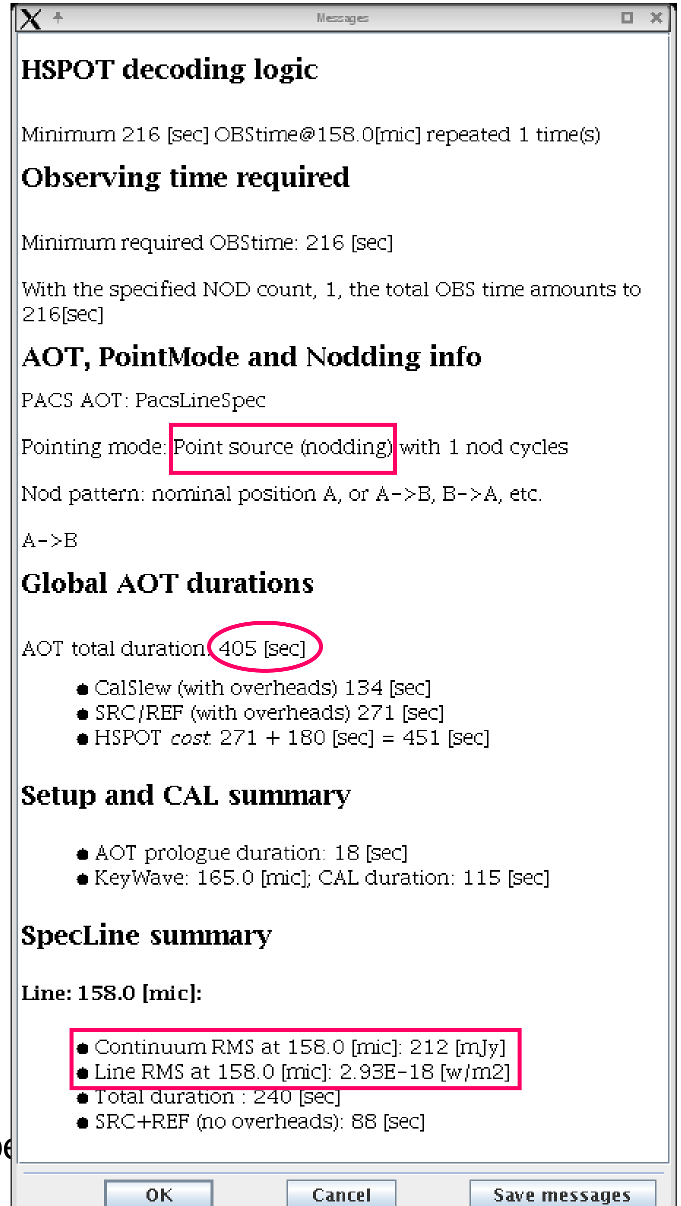

Observing Mode Settings
Choose one of the modes below.
None selected
Pointed
Pointed with dither
Mapping
Observing mode selection
Chopping/nodding
Wavelength switching
Observing mode parameters
Chopper throw
Small
Medium
Large
Chopper avoidance angle
Angle from (degrees)
0.00
Angle to (degrees)
0.00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

Some thoughts on *chopping* vs. *wavelength switching*



Messages

HSPOT decoding logic

Minimum 216 [sec] OBStime@158.0[mic] repeated 1 time(s)

Observing time required

Minimum required OBStime: 216 [sec]

With the specified NOD count, 1, the total OBS time amounts to 216[sec]

AOT, PointMode and Nodding info

PACS AOT: PacsLineSpec

Pointing mode: Point source (nodding) with 1 nod cycles

Nod pattern: nominal position A, or A->B, B->A, etc.

A->B

Global AOT durations

AOT total duration: 405 [sec]

- CalSlew (with overheads) 134 [sec]
- SRC/REF (with overheads) 271 [sec]
- HSPOT *cost*: 271 + 180 [sec] = 451 [sec]

Setup and CAL summary

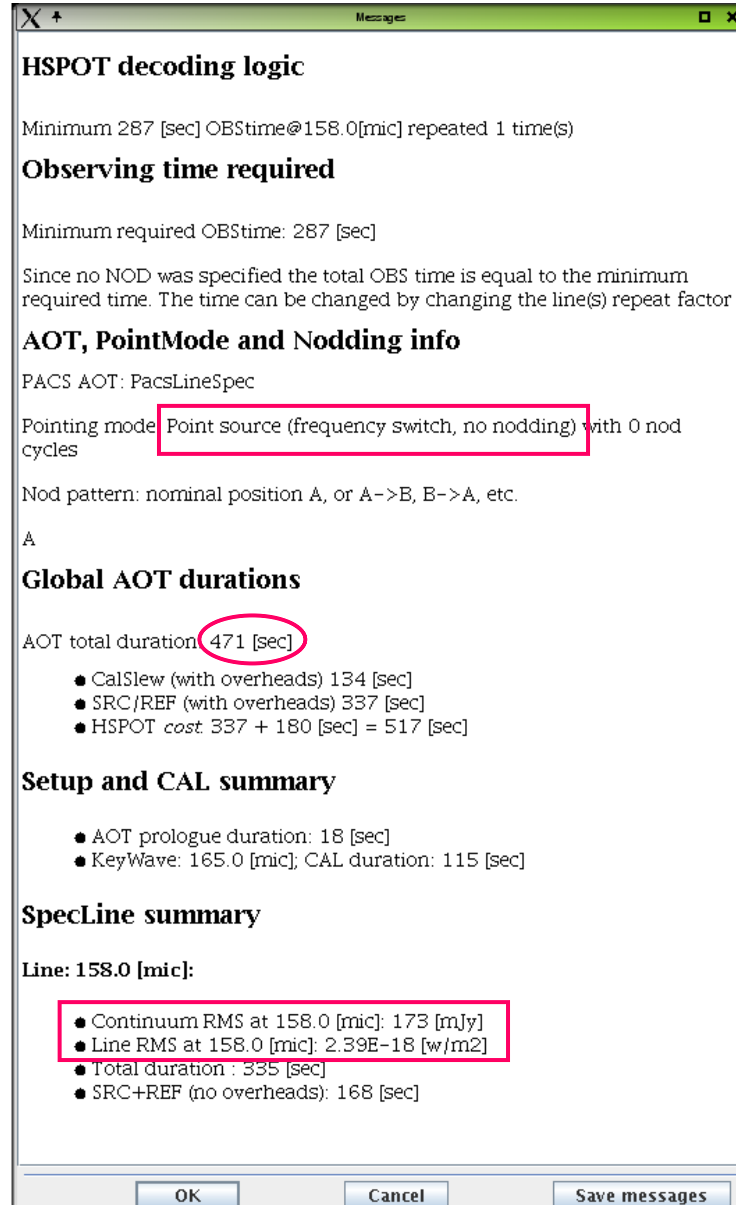
- AOT prologue duration: 18 [sec]
- KeyWave: 165.0 [mic]; CAL duration: 115 [sec]

SpecLine summary

Line: 158.0 [mic]:

- Continuum RMS at 158.0 [mic]: 212 [mJy]
- Line RMS at 158.0 [mic]: 2.93E-18 [w/m2]
- Total duration : 240 [sec]
- SRC+REF (no overheads): 88 [sec]

OK Cancel Save messages



Messages

HSPOT decoding logic

Minimum 287 [sec] OBStime@158.0[mic] repeated 1 time(s)

Observing time required

Minimum required OBStime: 287 [sec]

Since no NOD was specified the total OBS time is equal to the minimum required time. The time can be changed by changing the line(s) repeat factor

AOT, PointMode and Nodding info

PACS AOT: PacsLineSpec

Pointing mode: Point source (frequency switch, no nodding) with 0 nod cycles

Nod pattern: nominal position A, or A->B, B->A, etc.

A

Global AOT durations

AOT total duration: 471 [sec]

- CalSlew (with overheads) 134 [sec]
- SRC/REF (with overheads) 337 [sec]
- HSPOT *cost*: 337 + 180 [sec] = 517 [sec]

Setup and CAL summary

- AOT prologue duration: 18 [sec]
- KeyWave: 165.0 [mic]; CAL duration: 115 [sec]

SpecLine summary

Line: 158.0 [mic]:

- Continuum RMS at 158.0 [mic]: 173 [mJy]
- Line RMS at 158.0 [mic]: 2.39E-18 [w/m2]
- Total duration : 335 [sec]
- SRC+REF (no overheads): 168 [sec]

OK Cancel Save messages

Some thoughts on *chopping* vs. *wavelength switching*

Chop/nod

SpecLine summary

Line: 158.0 [mic]:

- Continuum RMS at 158.0 [mic]: 212 [mJy]
- Line RMS at 158.0 [mic]: 2.93E-18 [w/m2]
- Total duration : 240 [sec]
- SRC+REF (no overheads): 88 [sec]

Wavelength switching

SpecLine summary

Line: 158.0 [mic]:

- Continuum RMS at 158.0 [mic]: 173 [mJy]
- Line RMS at 158.0 [mic]: 2.39E-18 [w/m2]
- Total duration : 335 [sec]
- SRC+REF (no overheads): 168 [sec]

Should be 173/sqrt(2) = 123 [mJy] !!!
And 1.7E-18[w/m2]

See the „HSpot Known Problems“ AO Document

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

*) *note: array orientation only via timing constraint in any case*

- Observing times are similar (for similar RMS) *)

- a fast line spectroscopy mode may be introduced; if so, this might be done for line switching only

- **both modes need to be tested (ILT and PV) for confirmation of sensitivity and further consolidation of guidelines!**

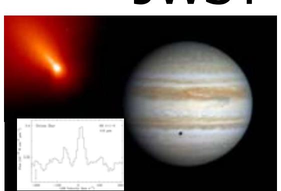
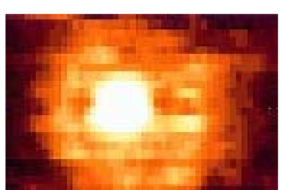
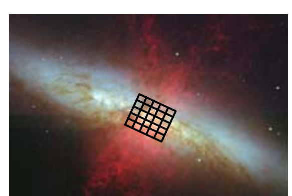
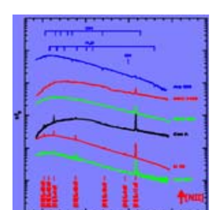
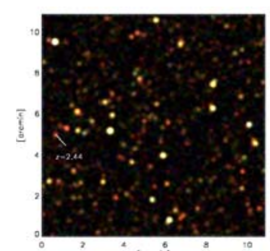
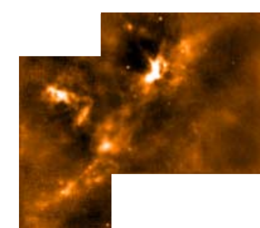
*) *note: In wavelength switching mode the sensitivity returned by HSpot is underestimated by sqrt(2) (i.e. RMS values really are lower by this factor)*

Some thoughts on *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
- 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)

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

Important lines (Star formation/ISM tracers) in the FIR

[CII]	158 µm	most important cooling lines of the atomic gas.
[OI]	63 µm	Probe the conditions in PDRs, i.e. the warm neutral
	145 µm	gas cloud surfaces which constitute a large fraction of the neutral medium in a galaxy.
[NII]	122 µm	conditions in the ionized medium. Important diagnostics
	204 µm	of absolute level and excitation of star forming (and AGN)
[NIII]	57 µm	activity and of n_e @ low density (< 10^3 cm^{-3})
[OIII]	53 µm (z>0.1)	
	88 µm	

Molecular lines (e.g. OH, H2O, CO), ice features (water ice at 62 µm), (crystalline) silicates (e.g. fosterite at 69 µm), …

Extinction ~ 1/10 of mid-IR (ISO-SWS, Spitzer-IRS)

Photoionization models (e.g. Cloudy, Ferland et al.), PDR models (e.g. Hollenbach & Tielens; Kaufman; Sternberg & Dalgarno)