Observing with the PACS Spectrometer

Part I

HERSCHEL CYCLE 1 OPEN TIME
OBSERVATION PLANNING WORKSHOP

HSC, ESAC
3-4 June 2010

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on behalf of the PACS ICC

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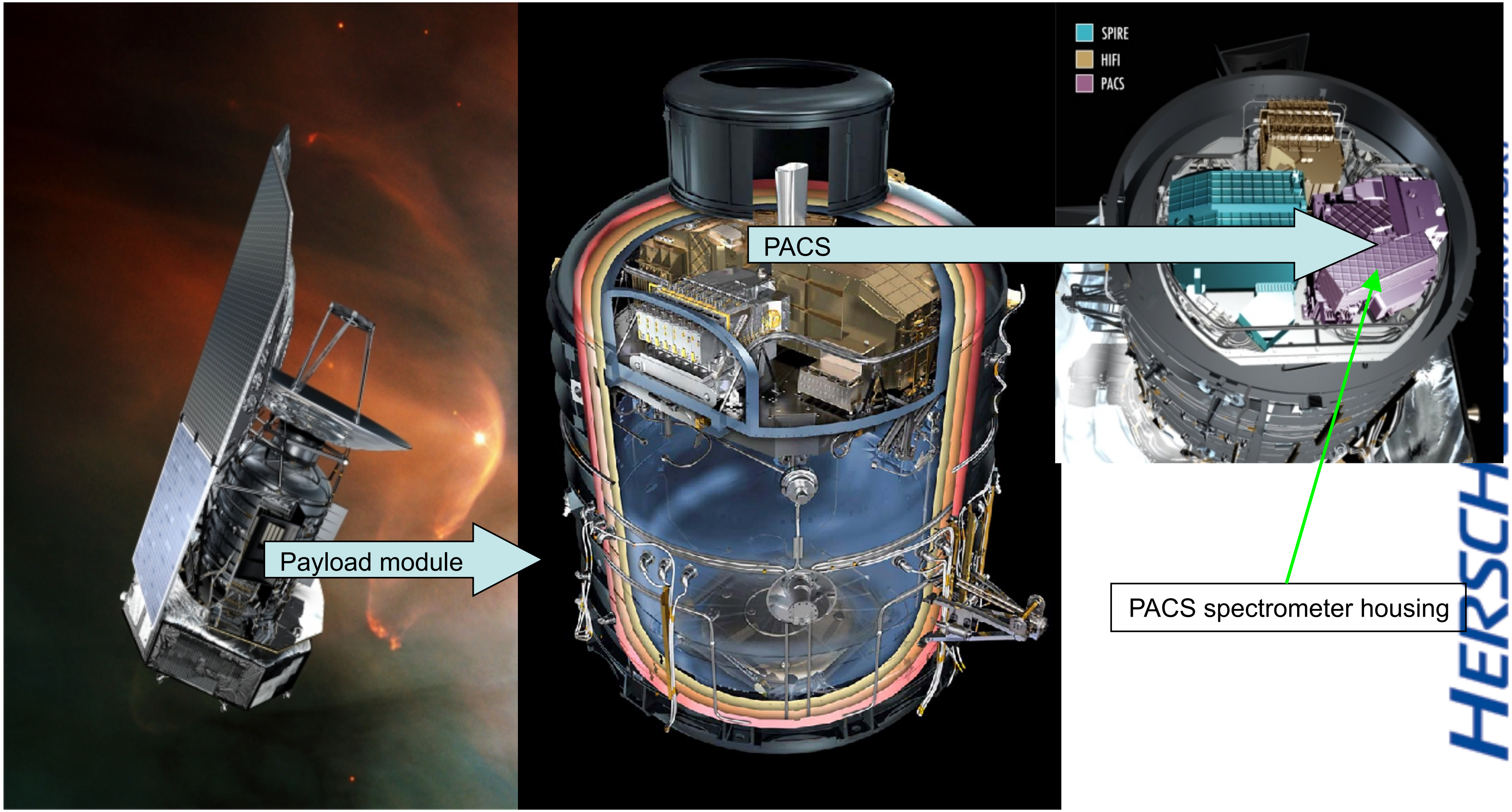
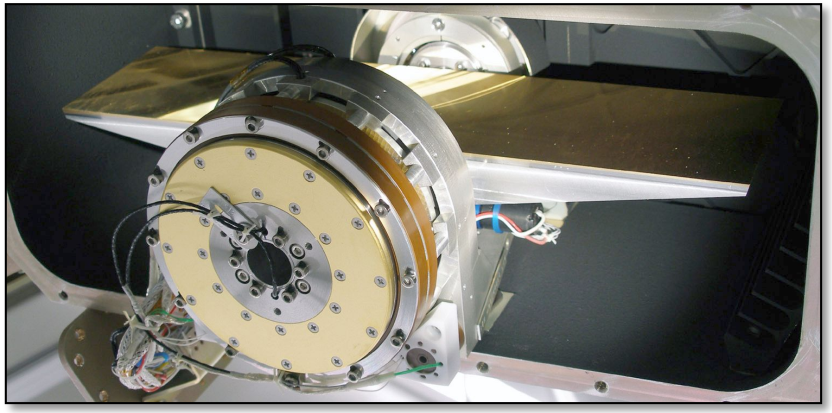
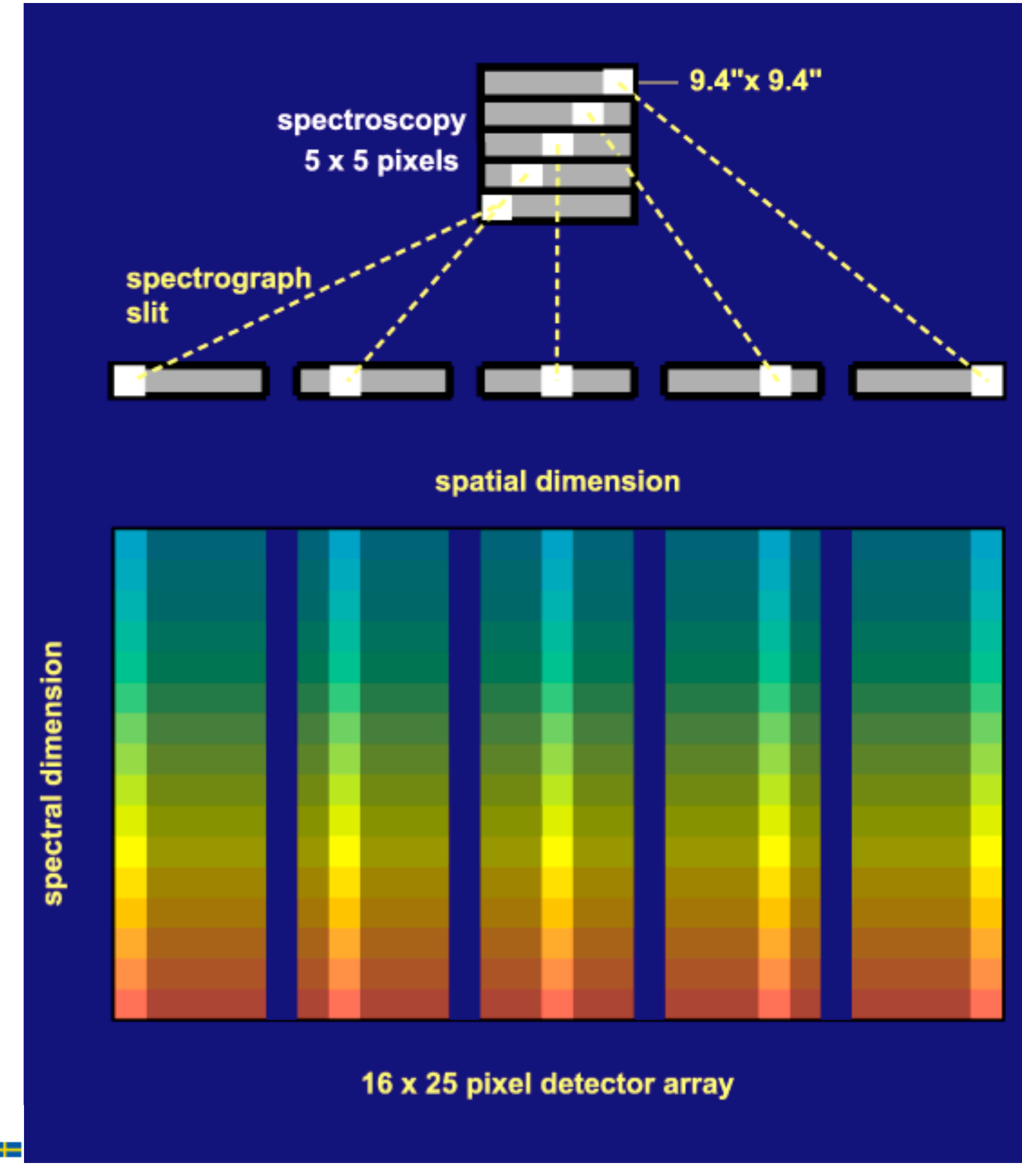
PACS Spectrometer concept



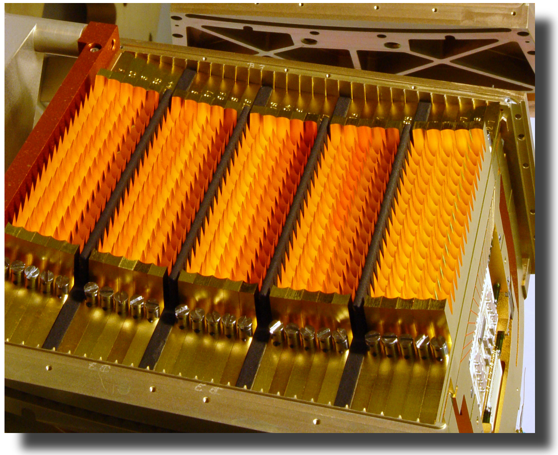
Integral-field concept



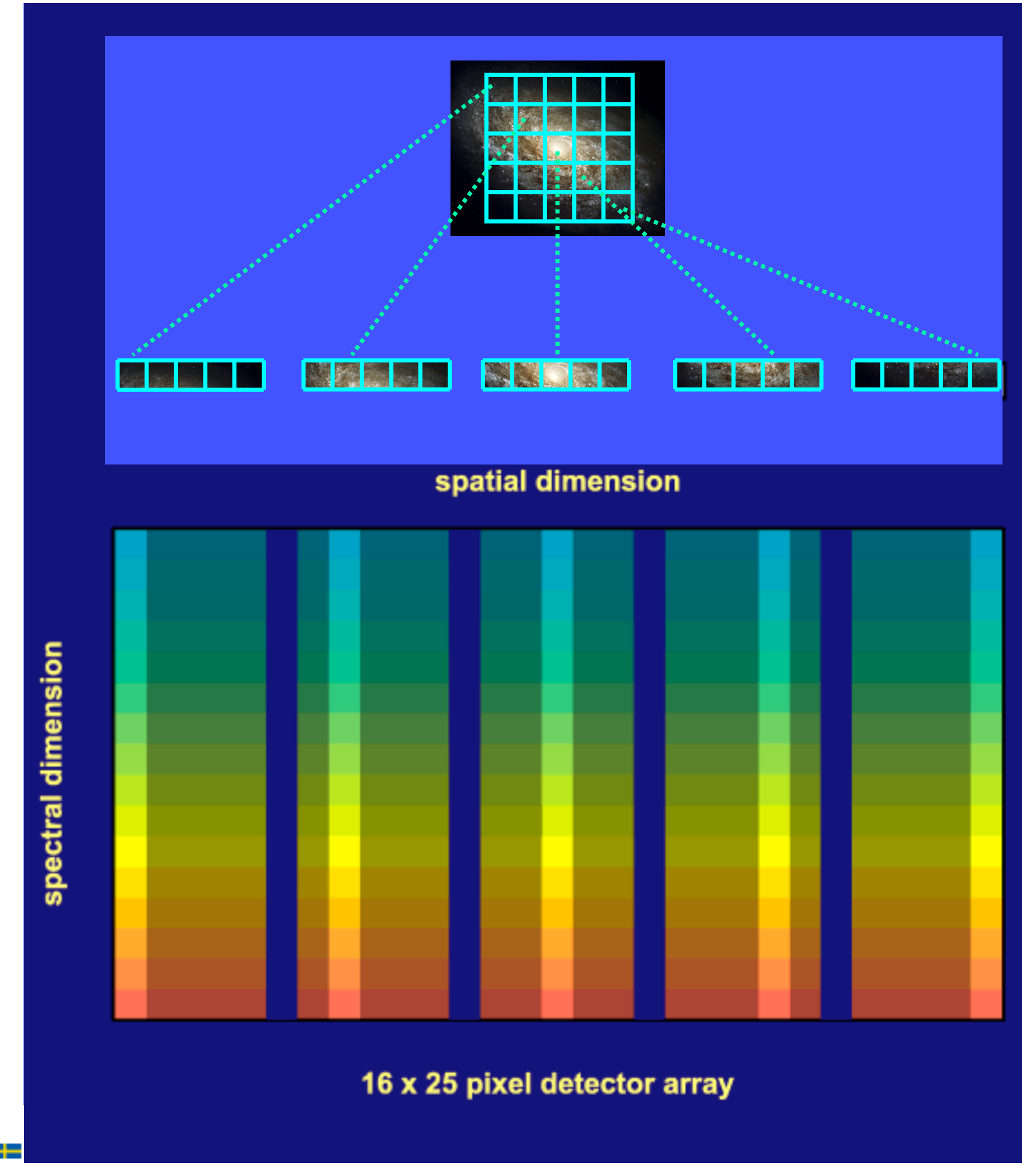


47"x47" (5x5 pixels) FOV rearranged via an image slicer on two 16x25 detector arrays

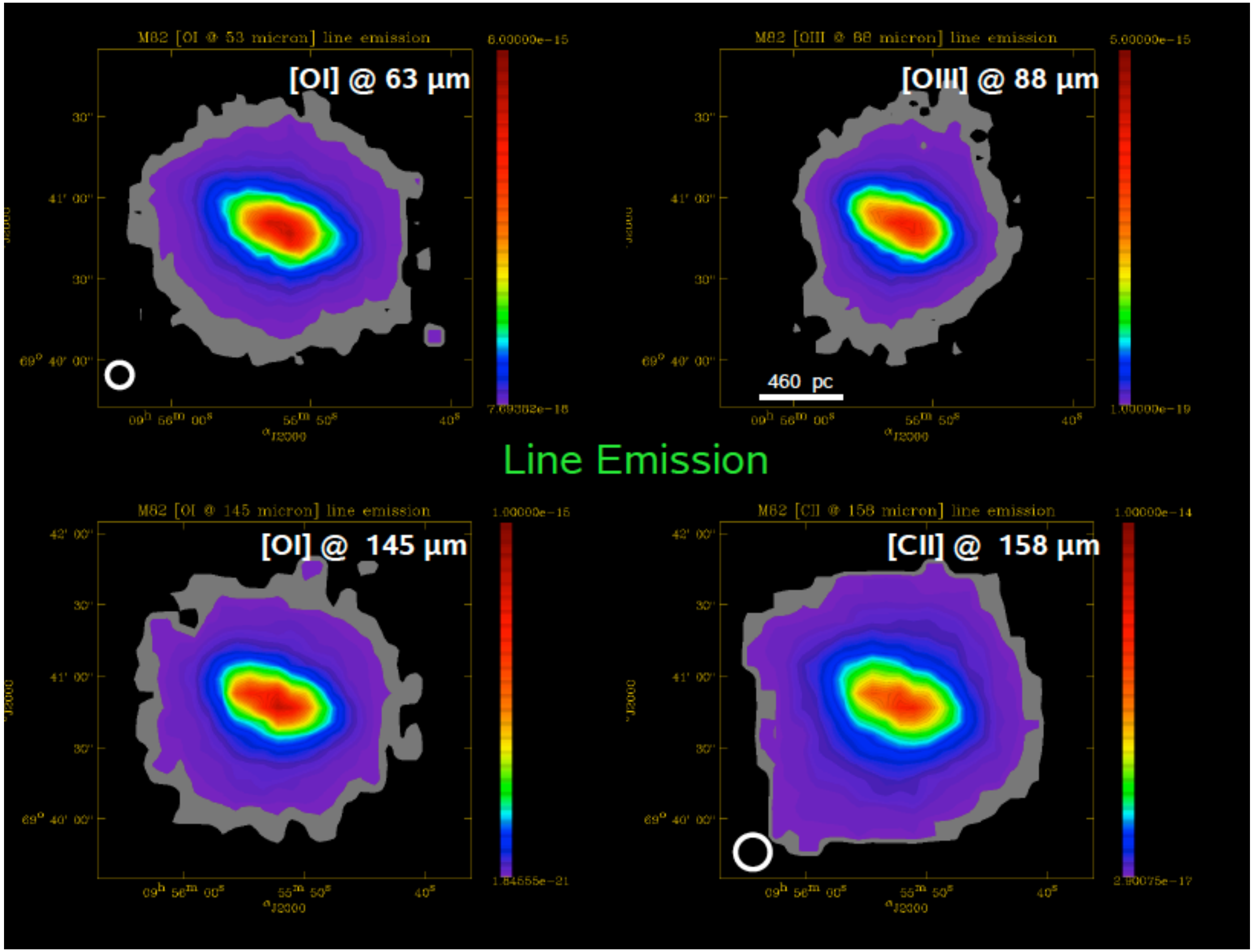
Integral-field concept



- Simultaneous 51-105 & 102-220 µm spectroscopy
- Performance:
  - λ/Δλ ~ 1500
  - Sensitivity:
    $\sim 5 \times 10^{-18} W/m^2$ (5σ, 1h)

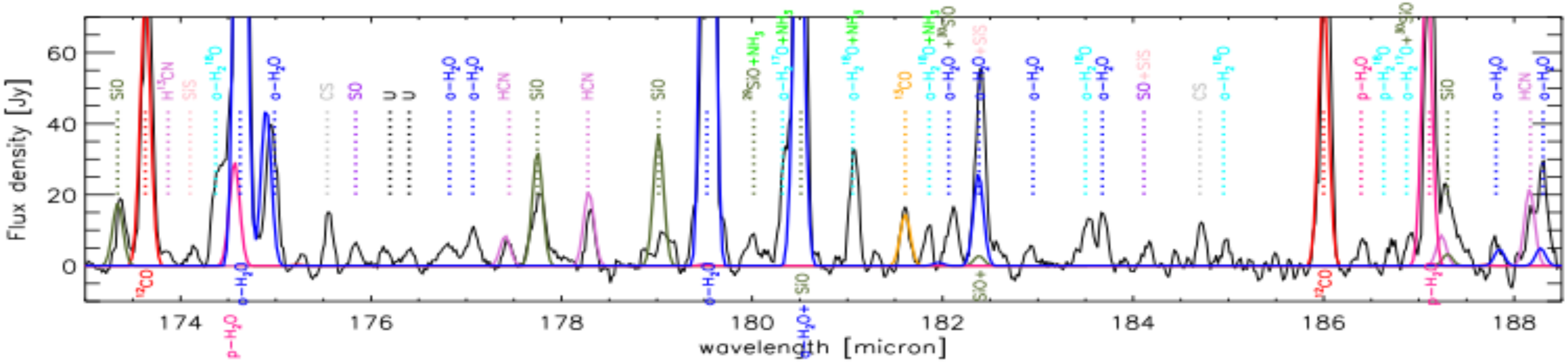


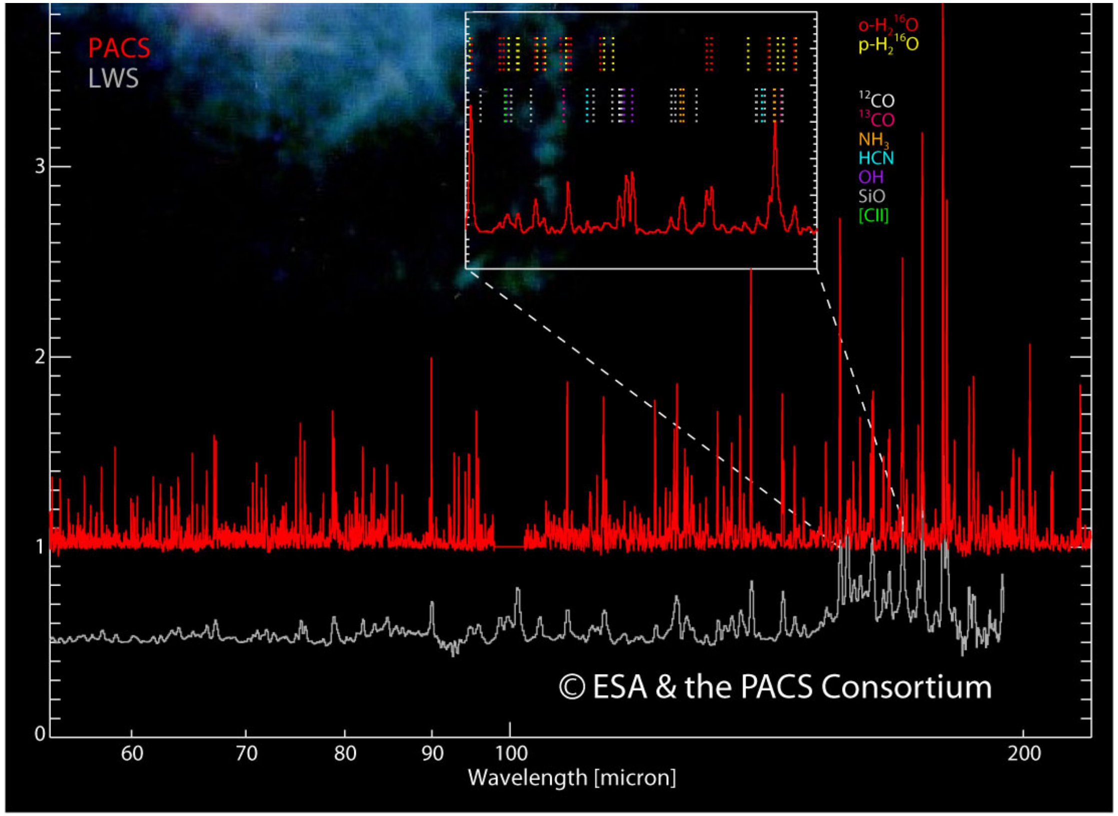
Spectroscopy with PACS



M82 PACS
line imaging
from the
SHINING team
(Contursi et al. 2010)

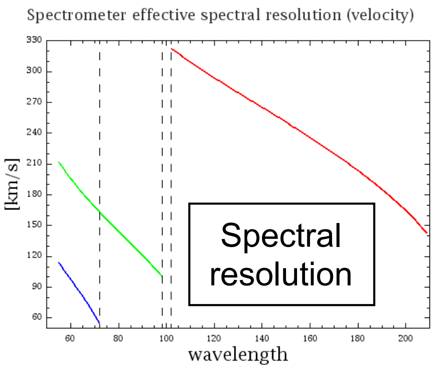
Spectroscopy with PACS

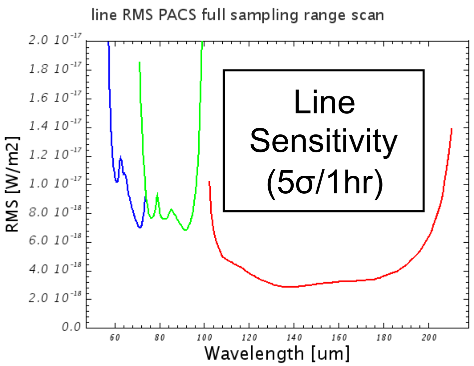


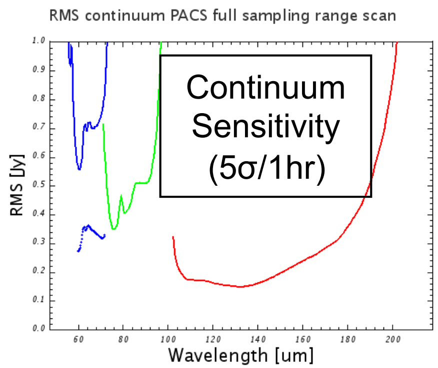


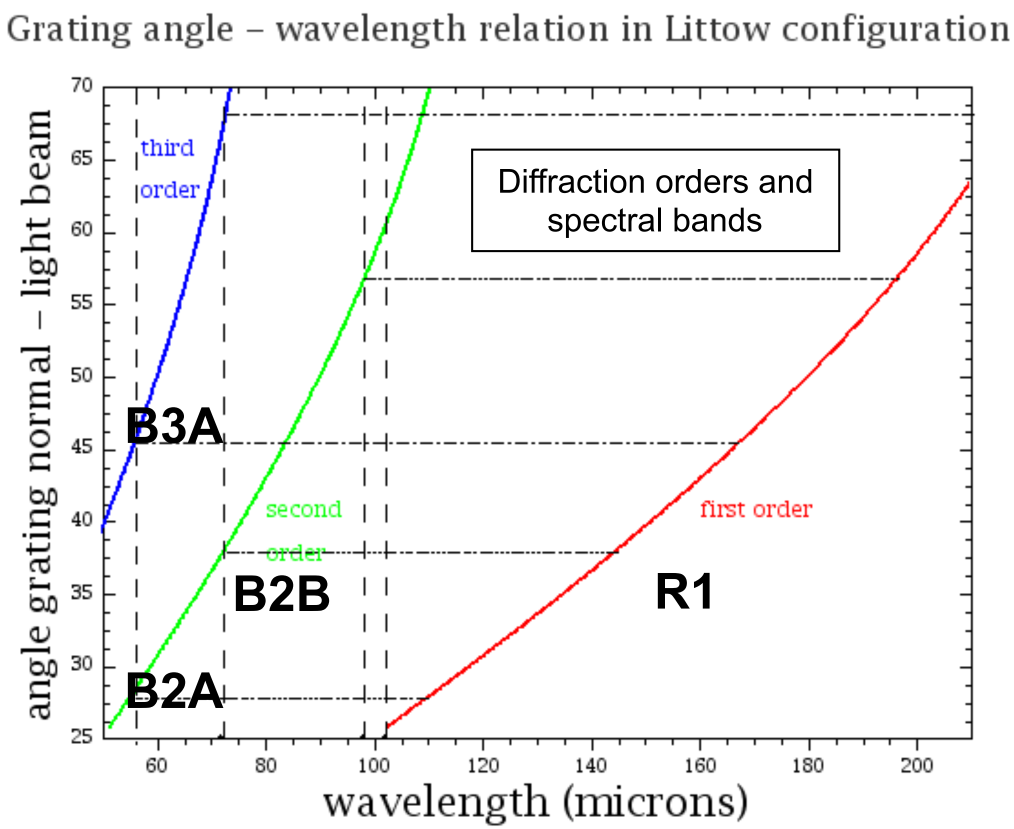
VY Canis Majoris
PACS full scan
From the MESS
team
(Royer et al. 2010)

PACS spectral bands

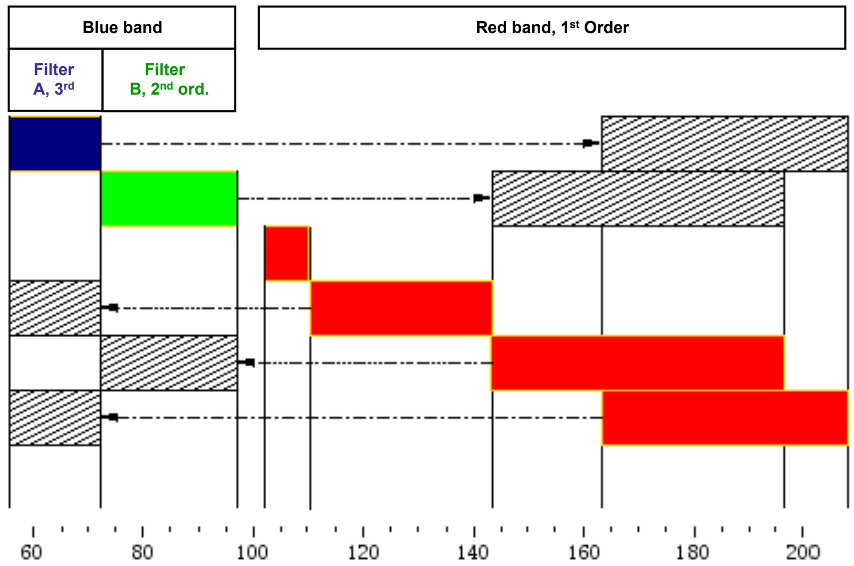






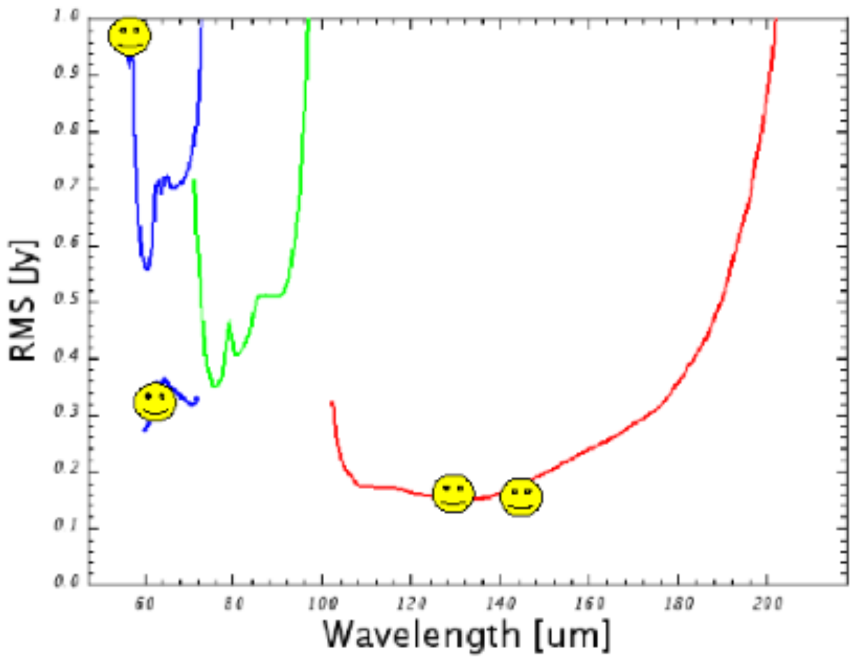


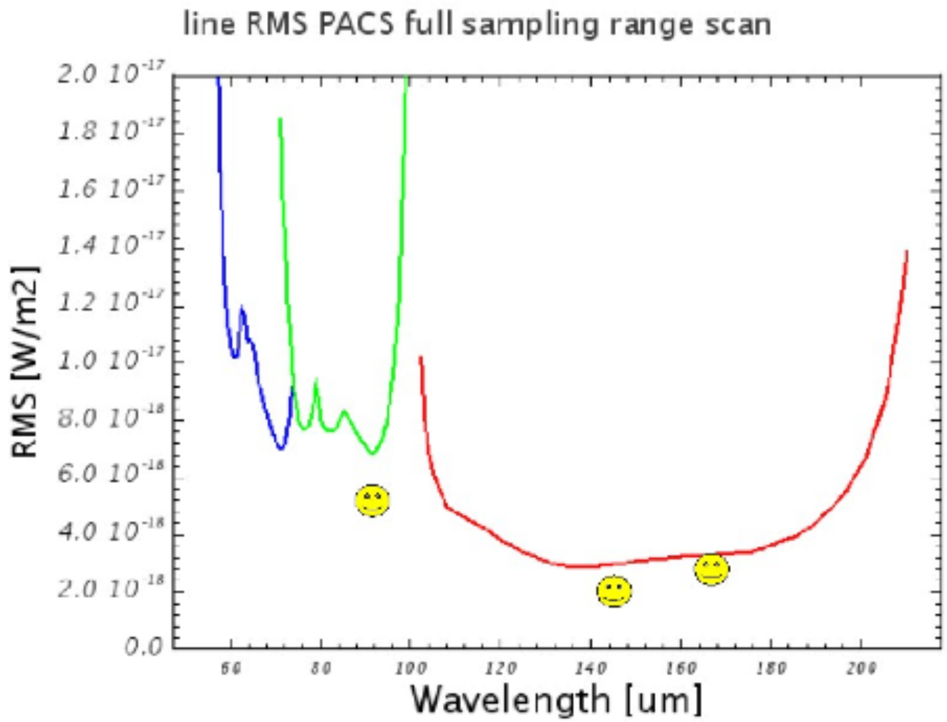
Nominal bands and parallel data



Spectrometer sensitivity

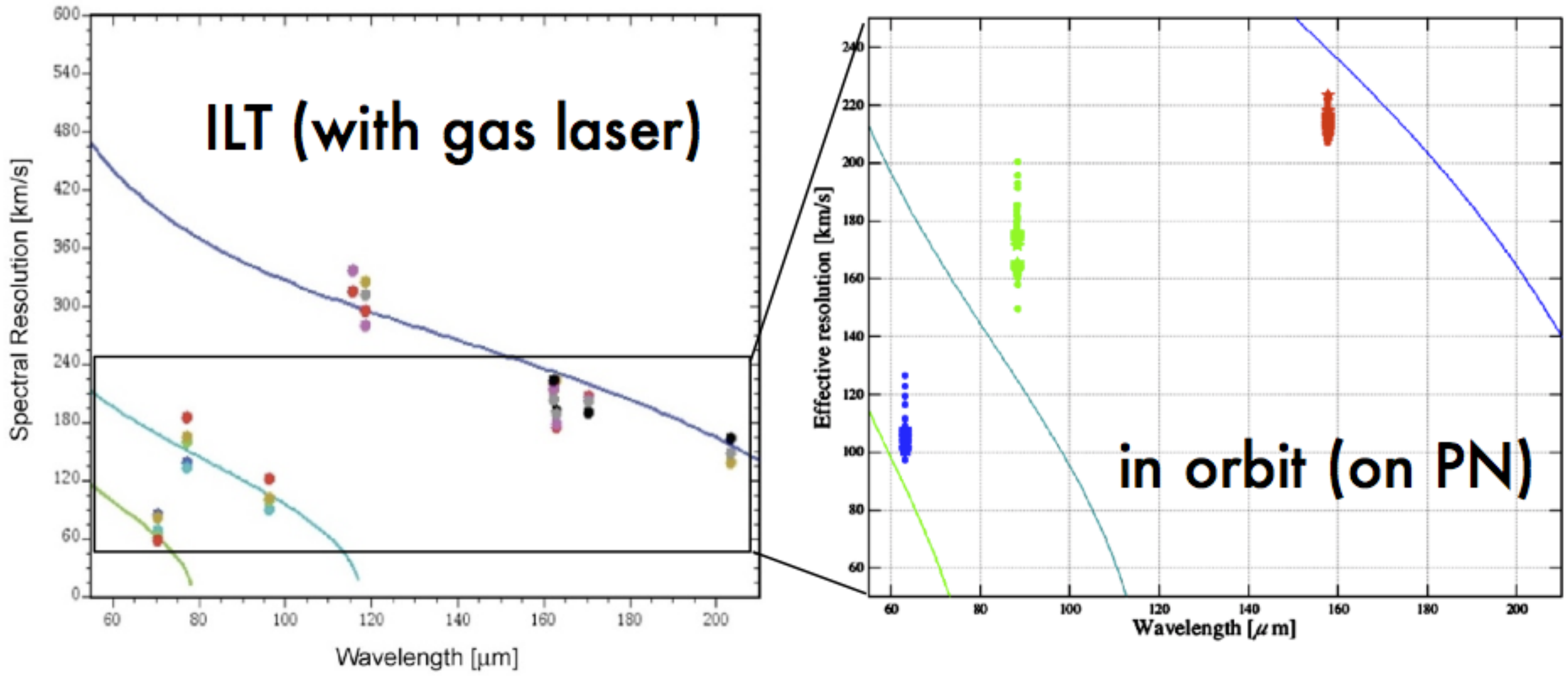
Recalculated 1σ continuum- and line sensitivities from actual exposure time to HSPOT exposure (~450sec per 1nod and 1up- down)





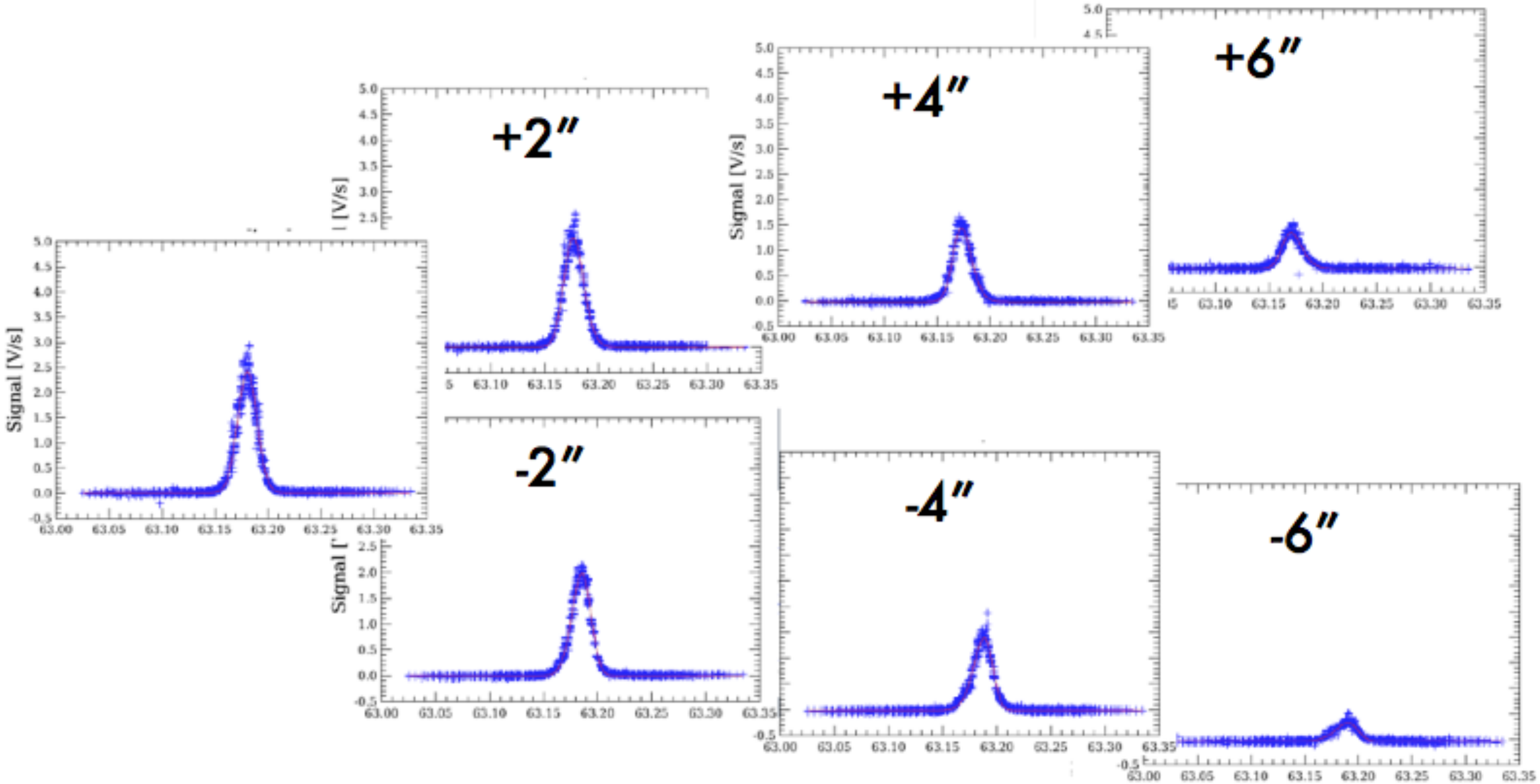
Spectrometer resolution

Measured resolution in fair agreement with lab test and calculated resolution



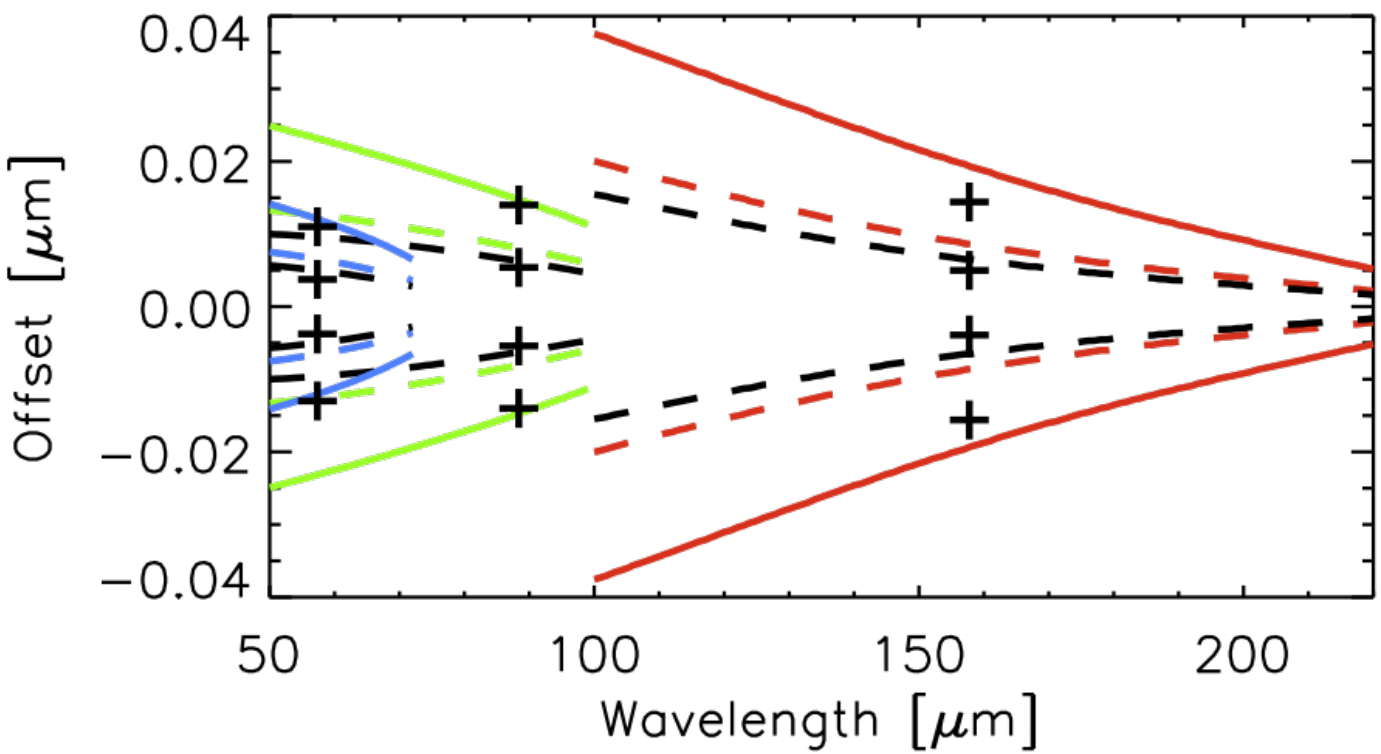
Spectrometer wavelength calibration and instrumental profile

- Wavelength shift + skew with source offset from slit center (cross-slit direction)
- Characterization + corrections underway
- Do not over-interpret line shapes in maps



Spectrometer wavelength calibration: dependence on slit position

Calculated wavelength offsets for point source positions: at the slit border (solid colour lines), for typical pointing errors up to 2" (dashed colour lines) and measured line centre offsets for ±1.5" (dashed black line and crosses) and slit border (black crosses) for three spectral lines on the point like planetary nebula IC2501.



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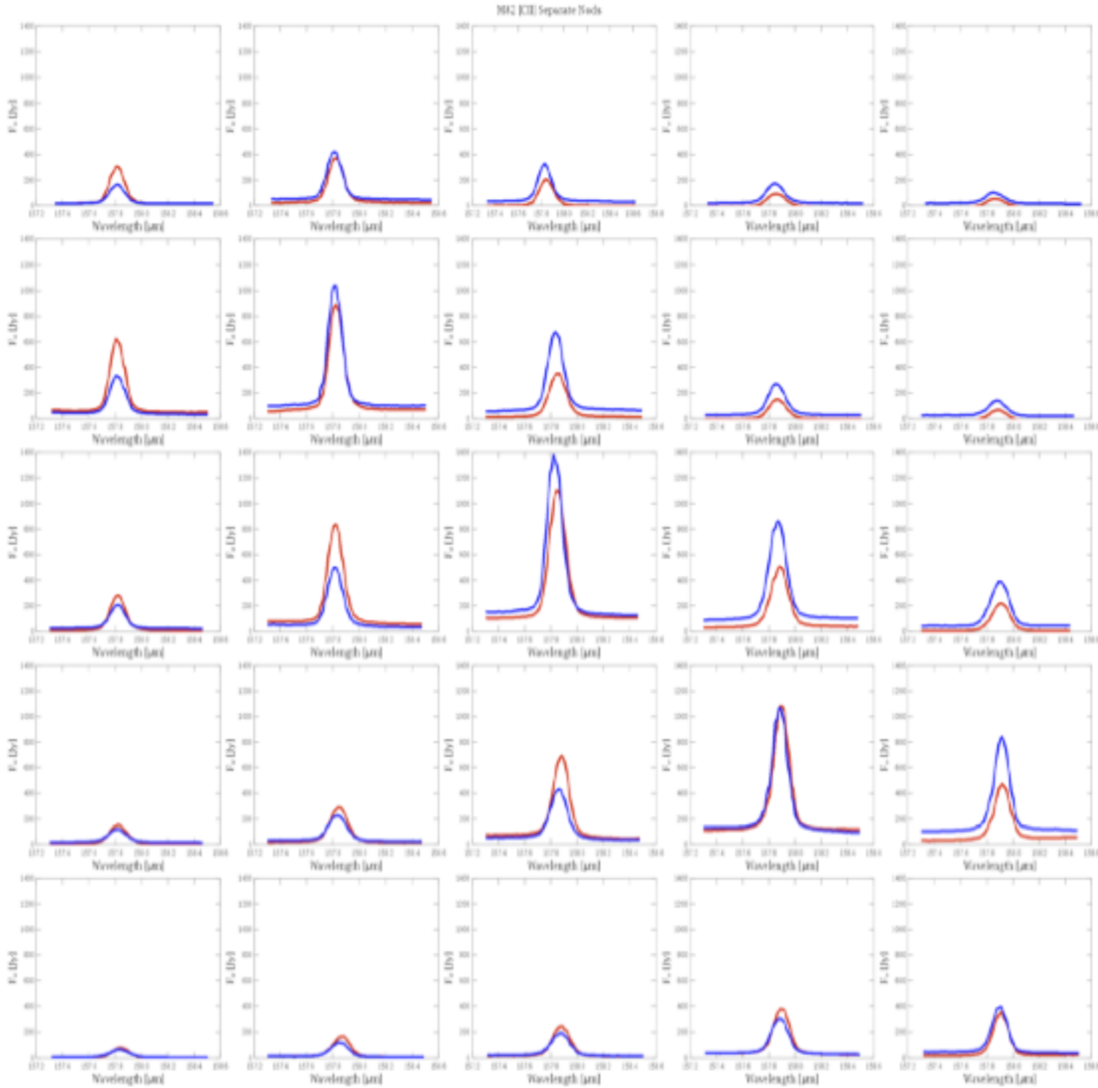
Pointing match chop/nod

• From (still limited) statistics, no problem for small chopper throw

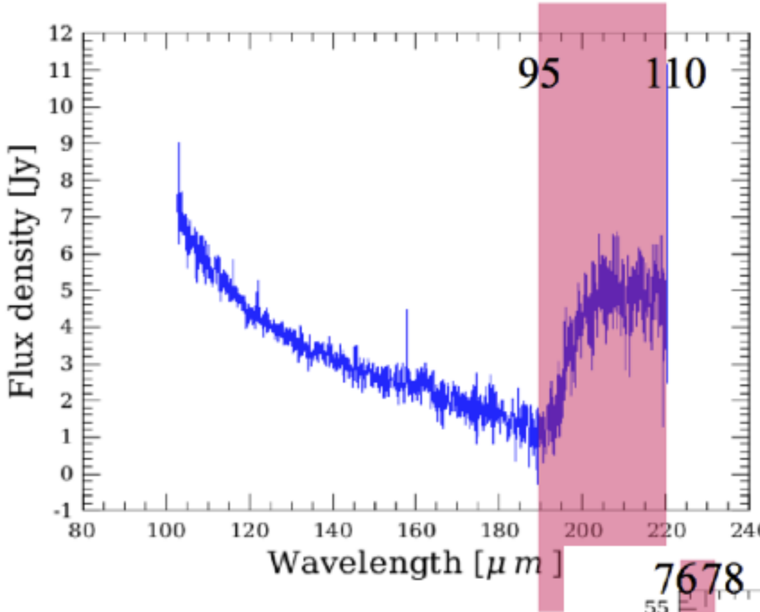
• With large chopper throw (±3'), APE seems to apply for "Nod A" and "Nod B" individually - sometimes ok, sometimes a problem

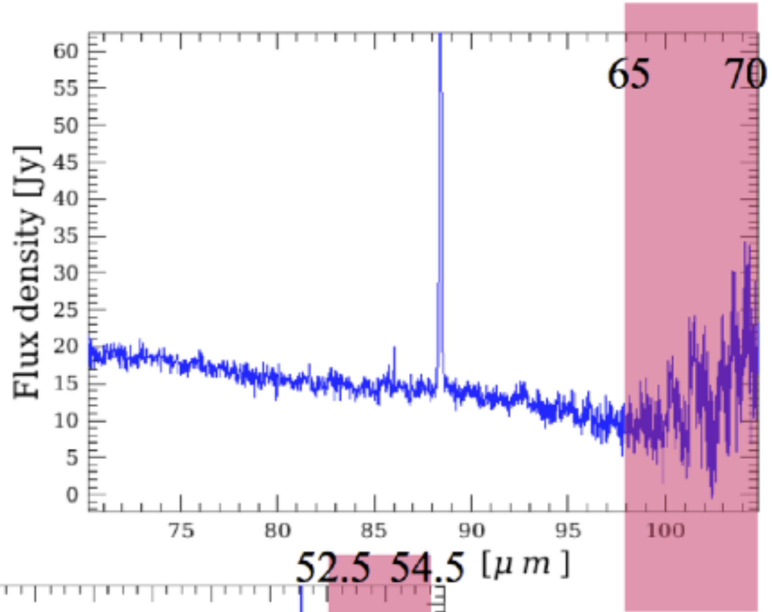
Note the pointing related effects on Nod A/B data (blue/red profiles):
- Line centres are shifted
- profiles may be skewed
- Inconsistent A/B fluxes per module

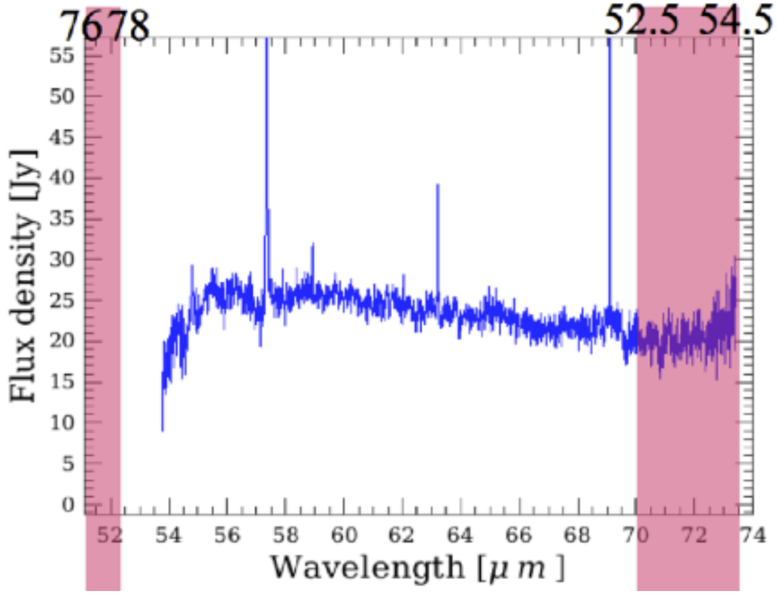
➔ ~5-15% spectrophotometric error (in integrated line flux)



Spectrometer “problem zones”: leakage







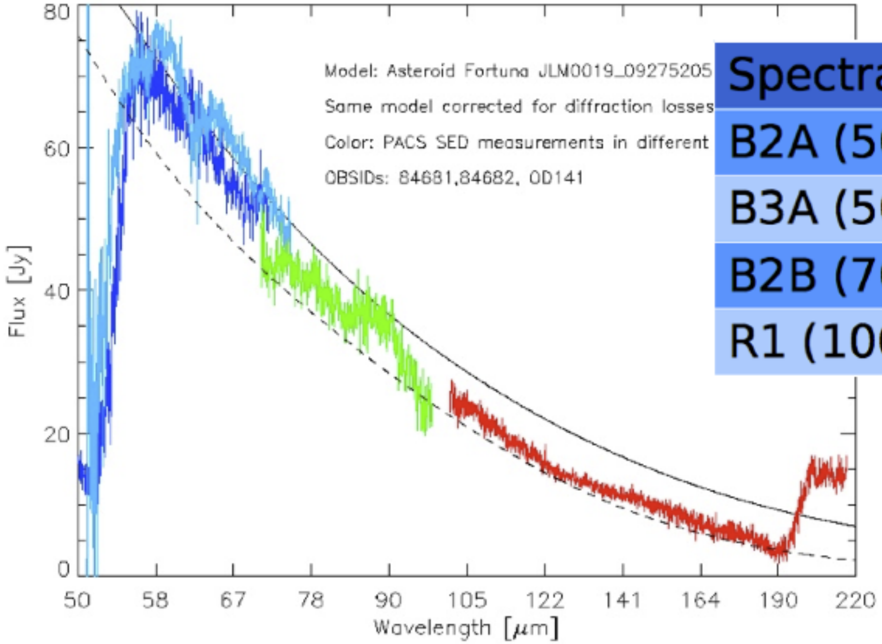
Leakage due to early dichroic cut-off and order-sorting filter transmission

➔Interpretation of spectral features in the leakage regions requires special attention

➔ More limited flux calibration accuracy

Spectrometer flux calibration

- Pipeline uses nominal absolute and relative spectral response from ground tests
- In-orbit measurements of flux calibrators (asteroids, Neptune, Uranus, fiducial stars) give first correction factors to ground calibration, yielding a 30% absolute error



Spectral band	Correction factor
B2A (50-70um)	1.3
B3A (50-70um)	1.3
B2B (70-100um)	1.3
R1 (100-220um)	1.1

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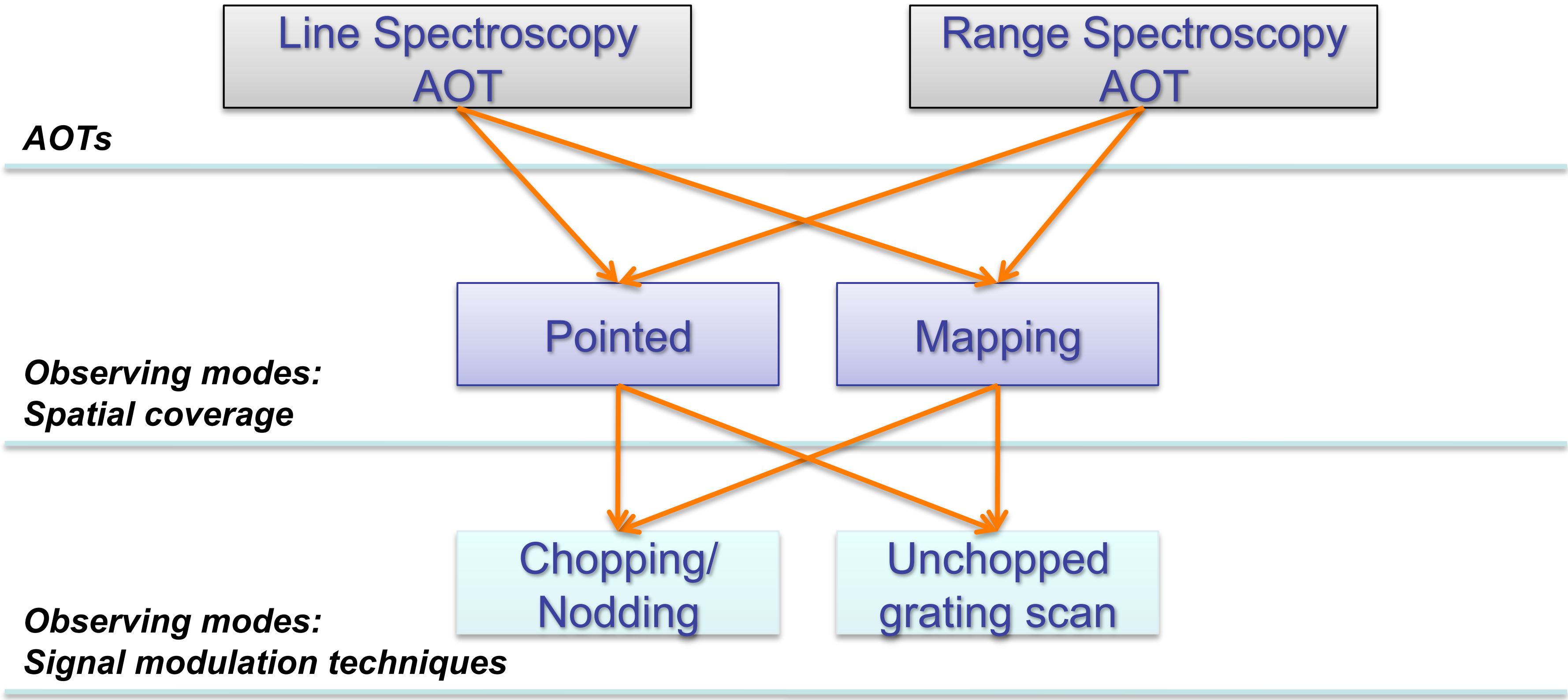
Spectrometer Astronomical Observing Templates (AOTs)



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Spectrometer Astronomical Observing Templates (AOTs)

- **Line Spectroscopy AOT:** ***observation of individual narrow lines***

Signal modulation Techniques

- **Chopping/nodding**
  - For isolated sources and rasters ≤ 5 arcmin
  - Variable grating sampling for faint and bright lines
- **Unchopped grating scan**
  - For observations of crowded fields and extended objects > 5 arcmin
  - Mandatory off-position

- **Range Spectroscopy AOT:** ***observation of broad lines, extended ranges or continuum***

Range definition

- **Range scan** (same concept as Line Spectroscopy) *for broad lines*
- **SED** mode *for full-range continuum*
- **Nyquist sampling** same as SED mode for restricted ranges *for long-range continuum and bright lines*

Signal modulation Techniques

- **Chopping/nodding**
  - For isolated sources and rasters ≤ 5 arcmin
  - For broad lines, multiple line coverage or continuum studies
- **Unchopped grating scan**
  - For observations of crowded fields and and extended objects > 5 arcmin

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Chop/nod vs. unchopped grating scan

- Chop-nod: **PACS standard mode**, classical approach when a reference field is observed all the time, alternated with the target.
- Unchopped: a **simple but fast (4x) grating scan** along wavelength with a reference background observed at a different time. *This – still unreleased - 2nd generation mode superseeds the wavelength-switching mode. Follow release guidelines: http://herschel.esac.esa.int/AOTsReleaseStatus.shtml*

- The chop-nod is applicable only when the reference target is distant less than 6' from the target. This is a physical limitation due to the chopper. The mapped area cannot be bigger than 5'x5'.

- The unchopped scan is, for this reason, the only choice available when observing extended sources or structured, crowded fields.

Considerations about chop/nod mode

- Source flux is derived applying the **double-differential scheme**:
  F(observed) = [NodA(on-off)] + [NodB(on-off)] / 2 = [(T2+F(source)-T1] + [(T1+F(source)-T2] / 2 = F(source),
  where T1 and T2 are the telescope background fluxes at the two chopper positions
- Differential **on-off signal is very stable** even after instantaneous response changes (glitches), very efficient de-glitching of the raw signal
- The chop-nod mode is **suitable for faint- as well as bright targets**, PACS offers this mode **in the entire dynamic range** (i.e. flux calibrated)
- **Continuum** can be recovered, **as well as line fluxes**
- **On-source positions are not identical for Nod A and B** (explained later)
- The chop-nod technique **could be used for very extended regions** IF the sky background has a constant gradient over the scale 2x the chop throw, and it is homogeneous at the scale of the spectrometer footprint (i.e. the 25 spaxels see very similar background levels)

Advantages of unchopped scan

The unchopped scan has a certain number of advantages wrt the Chop-nod:

- of course, makes possible observing lines in extended sources

- the same region of the telescope mirror is observed and the **same optical path is used when the grating is moving**, so that we don't need any nodding (…but we need off-position)

- **transients are usually negligible** (except in case of very bright lines) while, in chop-nod, the continuous chopping produces transients. Flux calibration will be different in the two modes.

- the observations are **time-efficient**: the off position is observed for a shorter time in case of long observations.

- it is possible to **map strips at any sky angle**

Disadvantages of unchopped scan

The unchopped scan mode has also a certain number of disadvantages wrt the chop-nod technique:

- **not recommended for faint lines**, target lines needs to be above typically ~1 Jy peak-to-continuum and the **continuum level can be recovered in a reliable way only for bright sources**, i.e. at a minimum continuum level of ~ 20-30 Jy (>10-20% of the telescope background)
- **dark is computed from the calibration block**, while in chop-nod a simple subtraction on-off gets rid of the dark in a more accurate way (there are transients, anyway ...).
- it is not possible to follow the response variation with time in unchopped scan as in chop-nod where there is a constant reference to the off-position. So, **the background subtraction is not precise as in chop-nod**.
- *Anyway, in case of faint background, a more precise estimate is probably available from broad-band photometry.*

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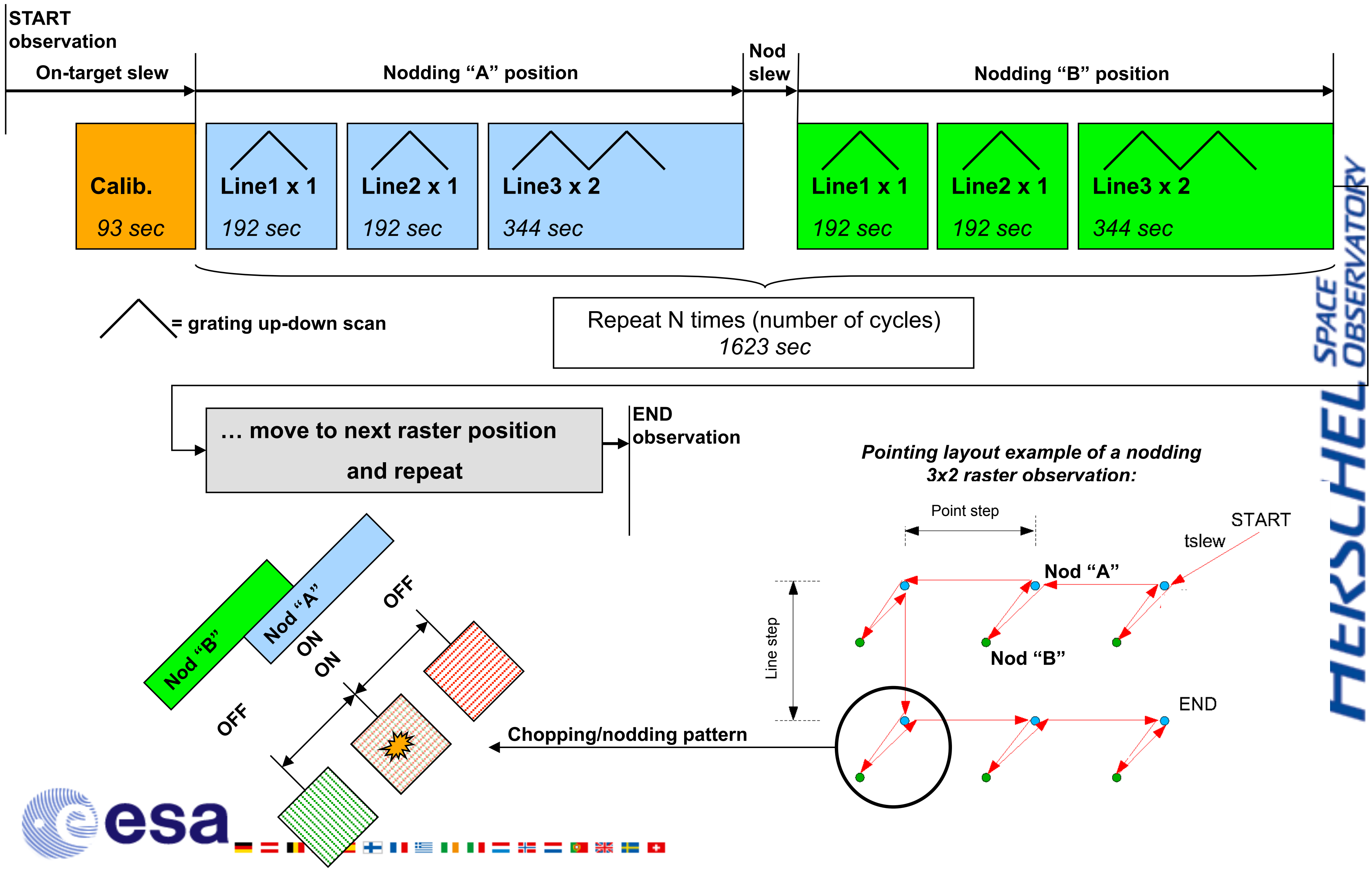
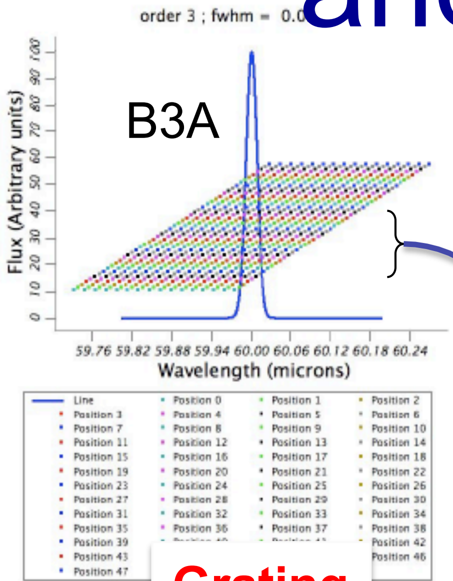
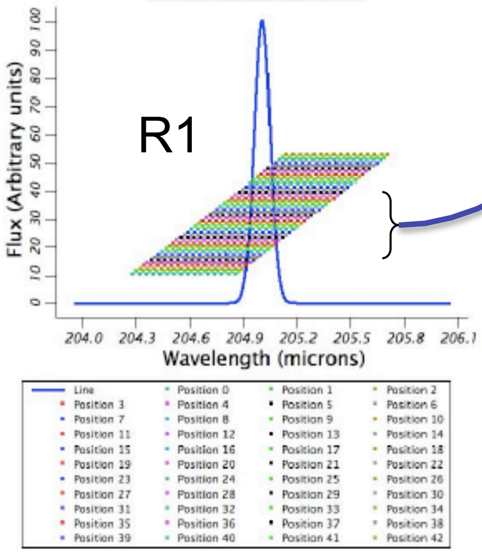
Chop/nod AOT blocks: 3 lines



Chop/nod AOT blocks: grating and chopper movements



Grating

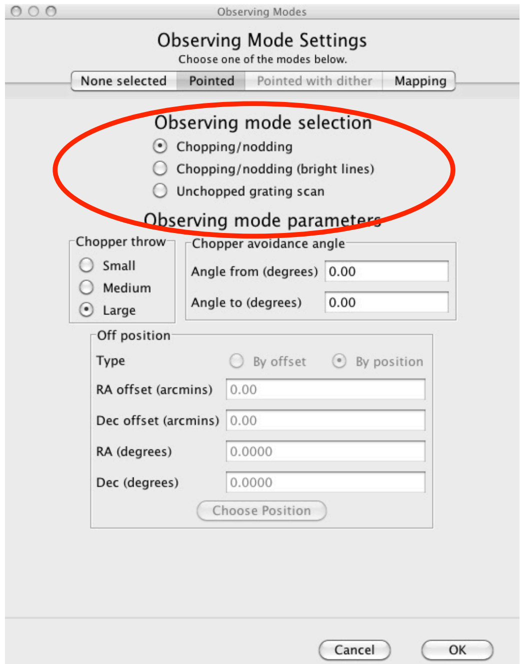


Standard (faint line) mode: Grating step sizes are 48, 46, and 43 in B3A, B2B, and R1

~1/3 FWHM for every pixel (spectral res. element)

Bright line mode: only the 10 central positions

Not every pixel could see the entire line profile



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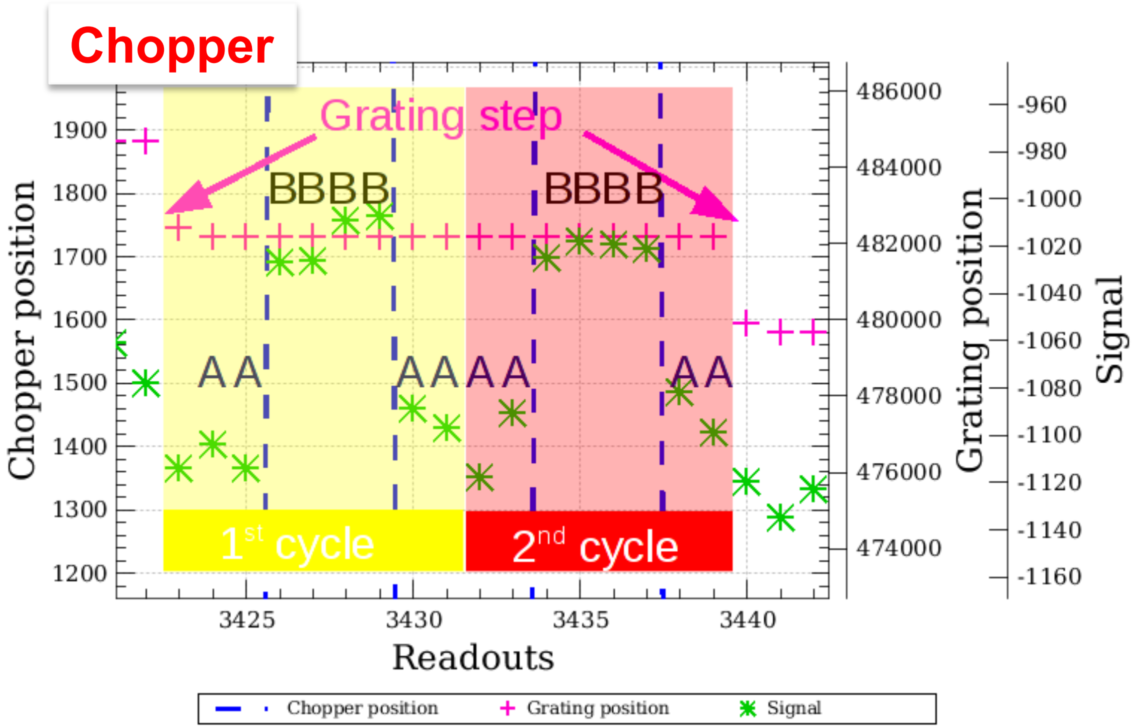
Chop/nod AOT blocks: grating and chopper movements

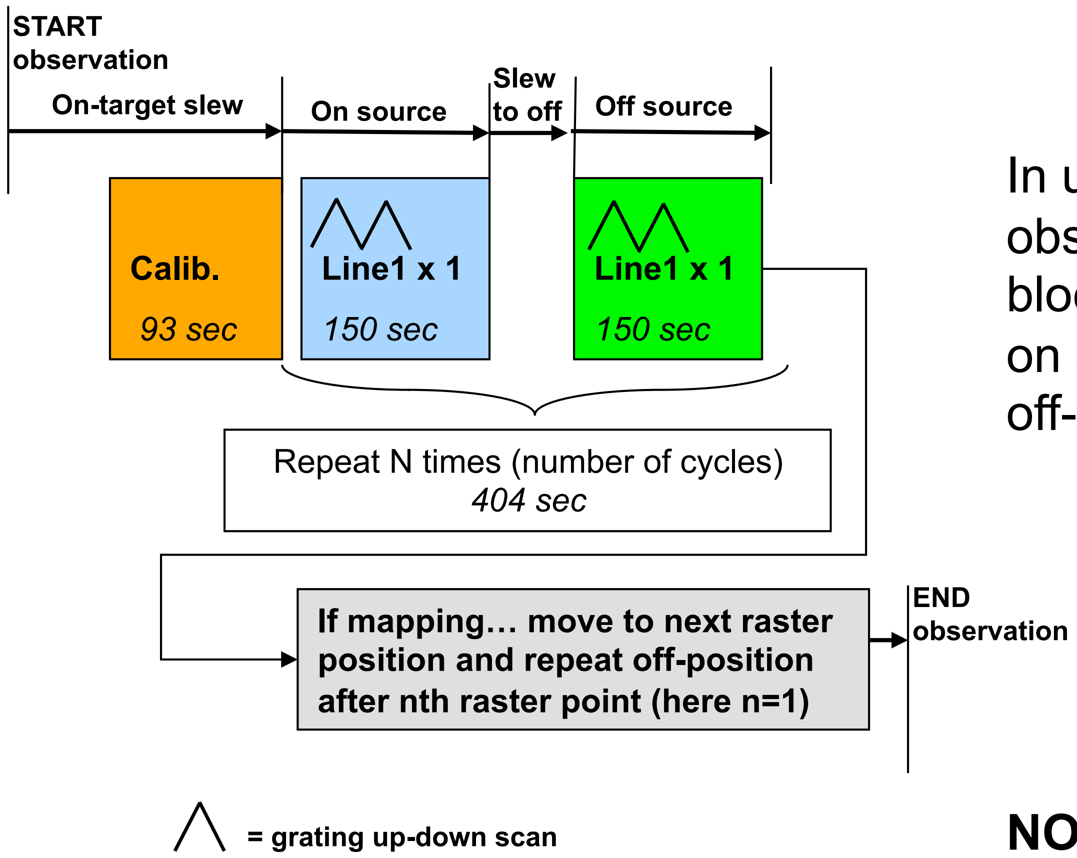
Duration per grating position: [8 integrations] x [1/8 sec integration time] x [2 ABBA cycles] = 2 seconds



On every grating poistion:

- *16+1 readouts (ramps)*
- *1 readout takes 1/8 second*
- *2 chopper ABBA cycles*

Unchopped AOT blocks: 1 line



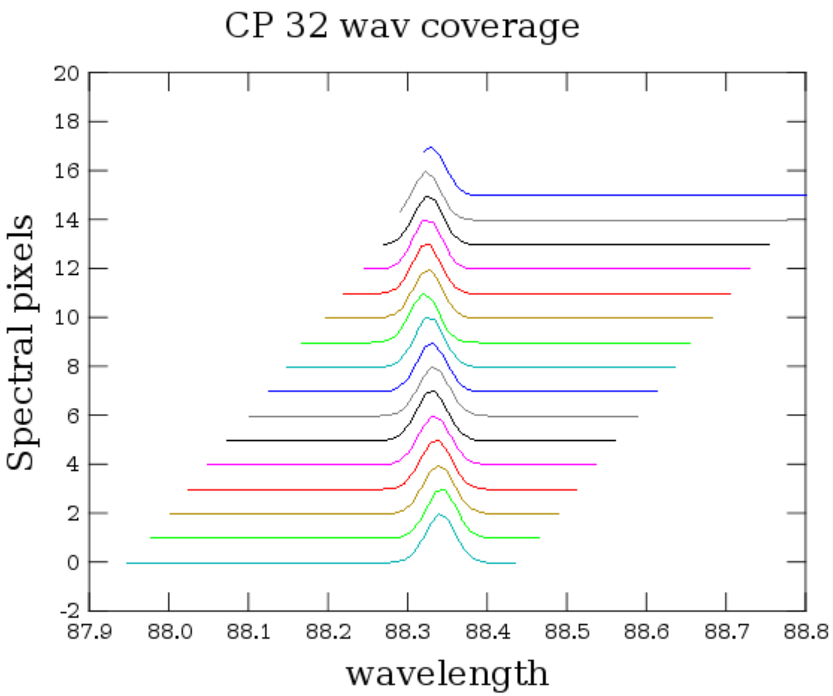
In unchopped scan, the minimum observations consists of a calibration block, two up-down wavelength scans on source and two up-down scans off-source.

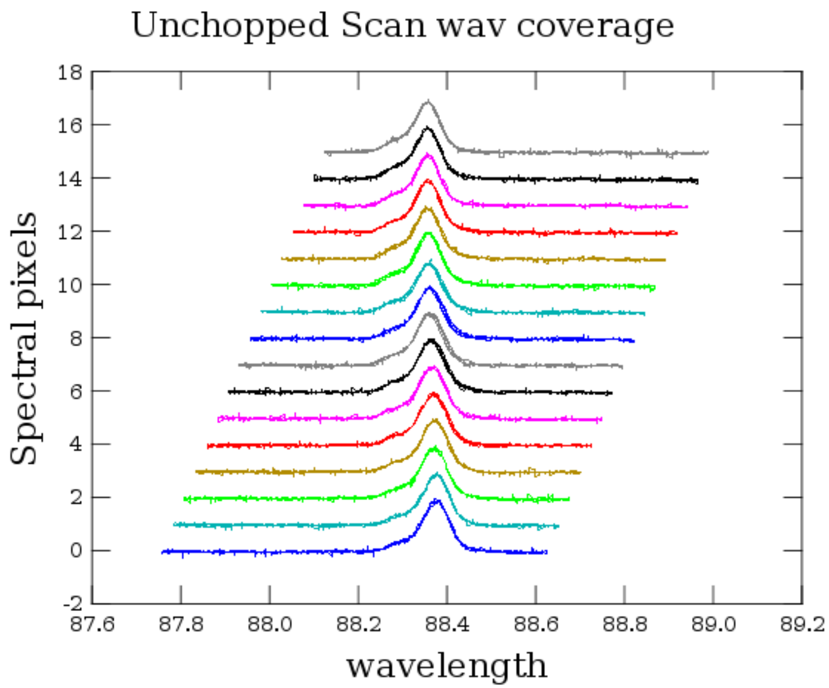
NOTE: the number of grating steps is fixed 75 in all bands!

Wavelength coverage

The wavelength coverage is slightly broader in unchopped scan

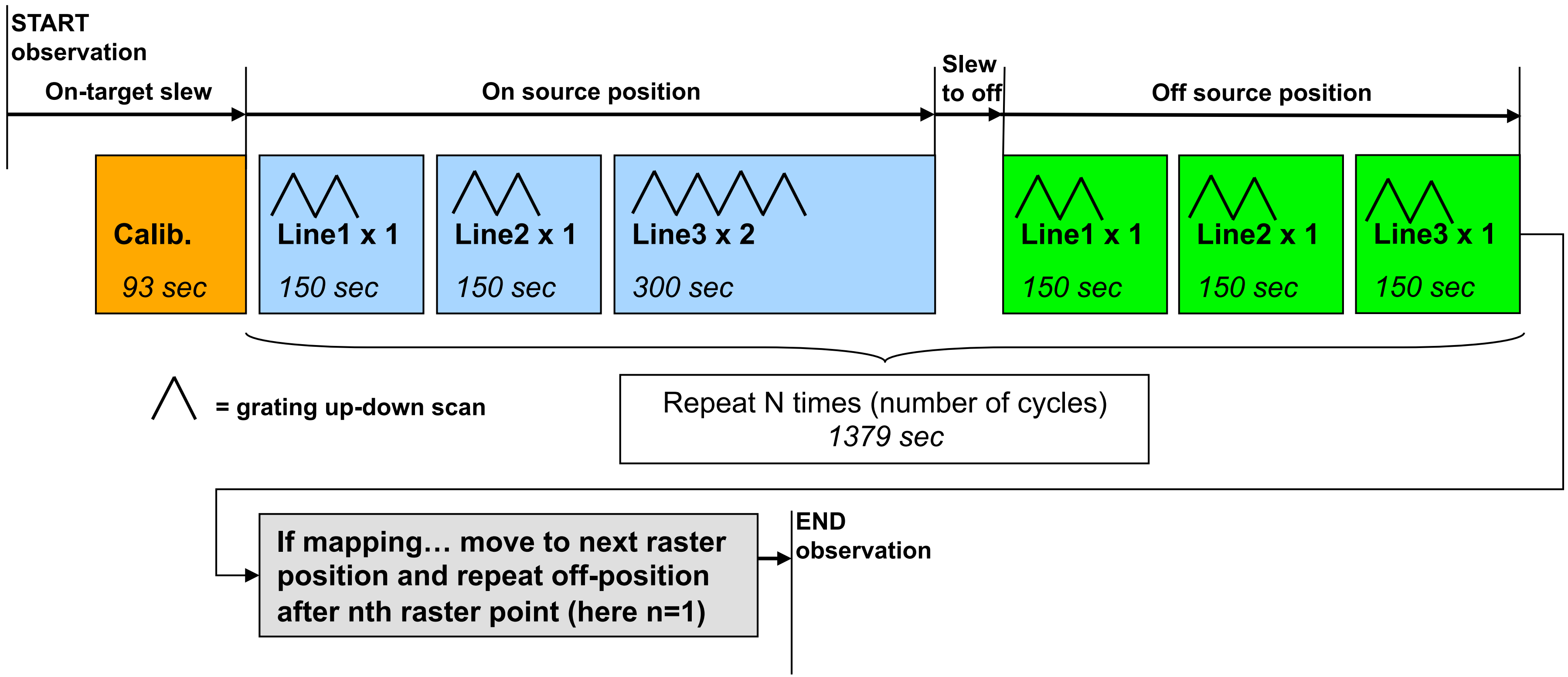
The number of grating steps is 75 in unchopped scan, while it is 48, 46, and 43 in B3A, B2B, and R1, respectively, for chop/nod.





This allows a better coverage of the continuum around the line and better data reduction. In the example, an asymmetric line has been observed with unchopped scan.

Unchopped AOT blocks: 3 lines



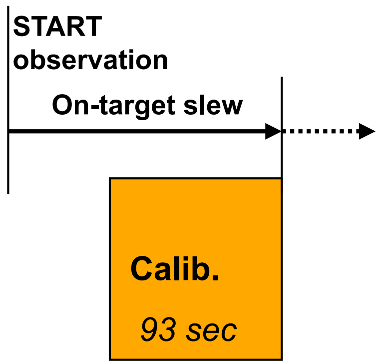
In the off-position, all lines repeated only once (two internal scans)!

Time efficiency

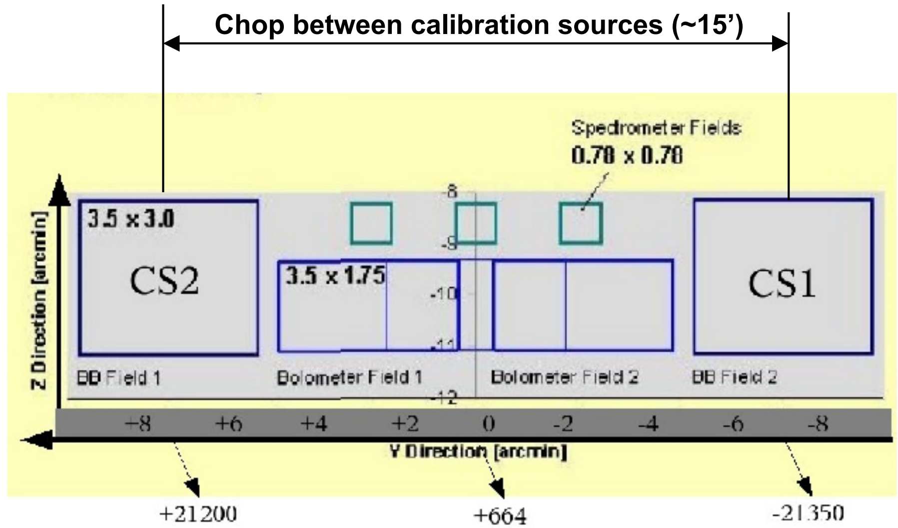
The time estimator provides a conservative estimate of the time spent
On source. It does not know about the subtleties of data reduction.
For instance, in chop/nod for each 17 ramps which correspond to a step
Of a grating scan, the first is considered as overhead but can be used.
In the case of unchopped scan, the initial ramp of each grating step is
considered as overhead, although it can be safely used.
The following estimates give in brackets the values using the
“overhead” ramp not considered by the time estimator.

		ON [s]	Total [s]	Efficiency (on/total)
chop/nod	1 repeat	172(180)	582	0.29 (0.31)
	2 repeats	344(365)	948	0.36 (0.38)
	3 repeats	516(547)	1314	0.39 (0.42)
unchopped	1 repeat	150(187)	582	0.26 (0.32)
	2 repeats	300(374)	769	0.39 (0.48)
	3 repeats	450(562)	957	0.47 (0.58)

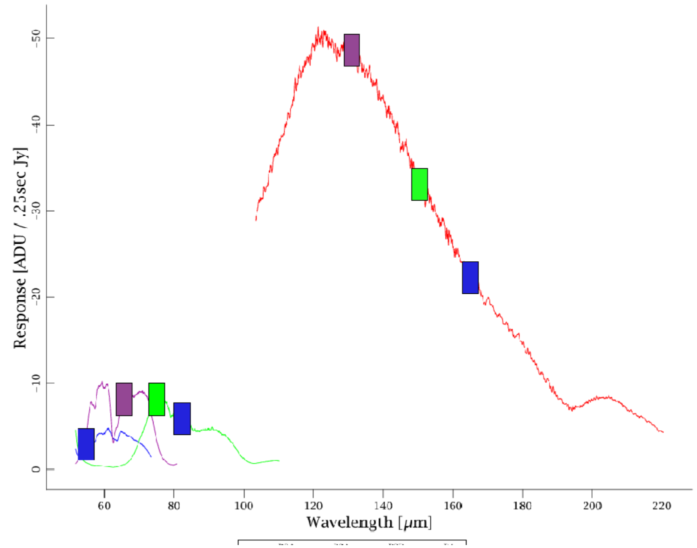
AOT calibration block



- On-target slew calibration block(s) on key wavelengths
- Calibrate the response and dark on one point of the RSRF, we believe the RSRF does not change (a lot) over the mission lifetime
- Chopping between the calibration sources (no grating movement)
- Homogeneous dataset over the entire mission lifetime
- One key wavelength per diffraction order:
  - flat part of the RSRF
  - close to the most frequently used lines



Key wavelengths
on the Relative Spectral Response Function (RSRF)



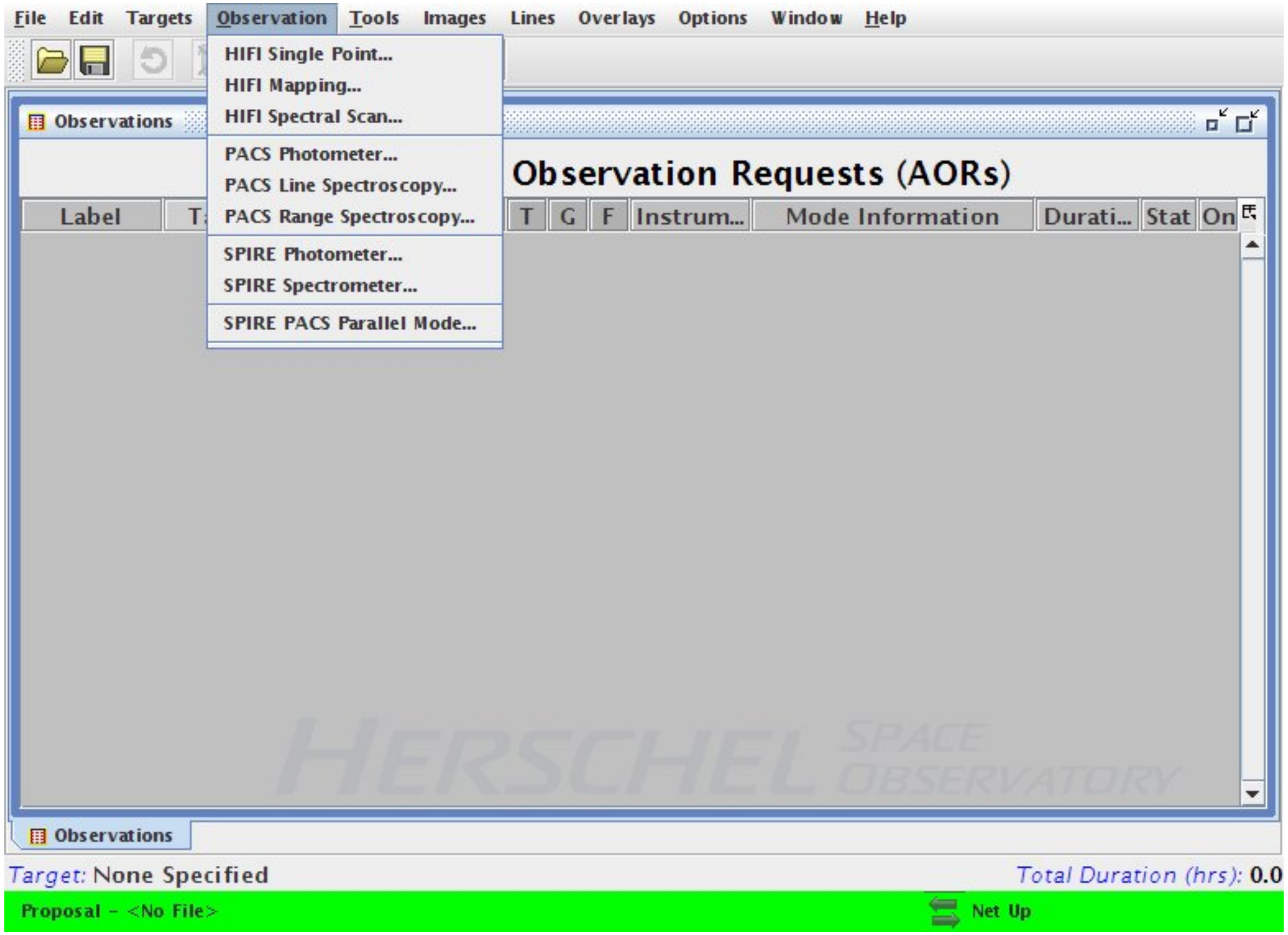
How to do it in Hspot?

- First select target
- Choose which “blue” order? $3^{rd}+1^{st}$ or $2^{nd}+1^{st}$

  Note that if you have target lines in all three orders you will need 2 separate AORs
- Choose a line (manual or from list)
- Enter continuum and line flux — saturation will trigger capacitance change to adjust the dynamic range — warning in PACS time estimator message
- Select the Observing Mode
- If applicable: set up the mapping parameters
  - raster step sizes (follow guidelines of the PACS Observers Manual)
  - map orientation

Step by step…

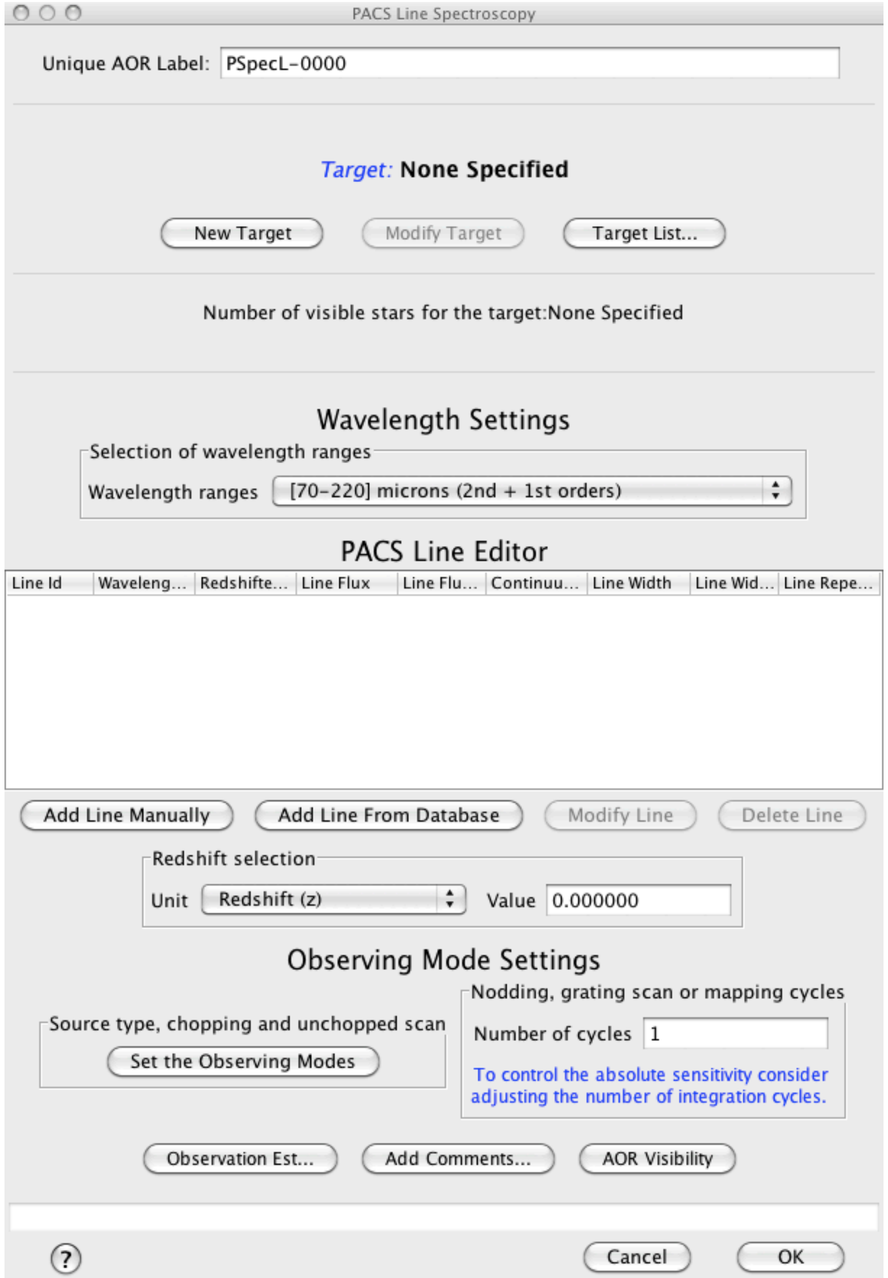
Once opened HSPOT, choose the AOT (PACS Line- or Range Spectroscopy)



Step by step…

The AOT pup-up window appears. We can choose a name for the AOR, then select the wavelength band to observe one or more lines.

See Hspot general presentation on target selection…



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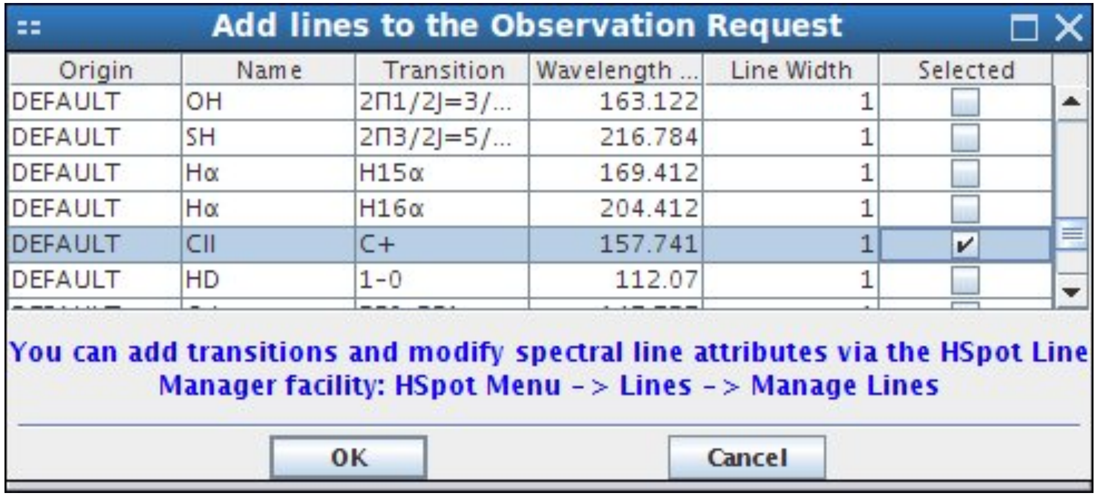
Step by step…

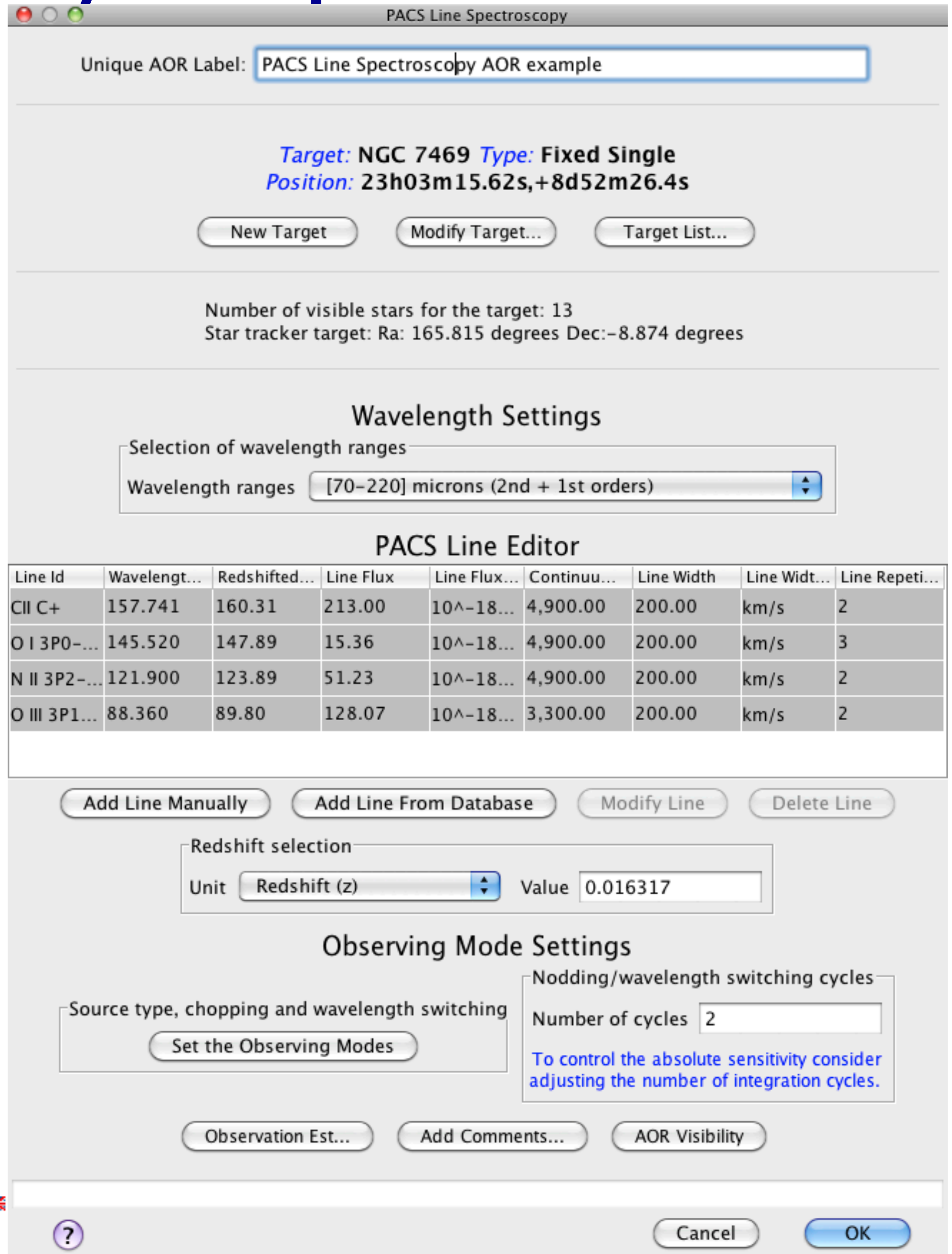
One can add a line manually or using the database. In this example, we use the database and select the C II+ line. Remember to select the box. Only highlighting the line does not select it.



Step by step…

Back in the AOR window, the selected line appears in the list. At this point, Fill the PACS Line Editor table, and insert the redshift of the object.

To change the number of repetition on one line, double click on the line.



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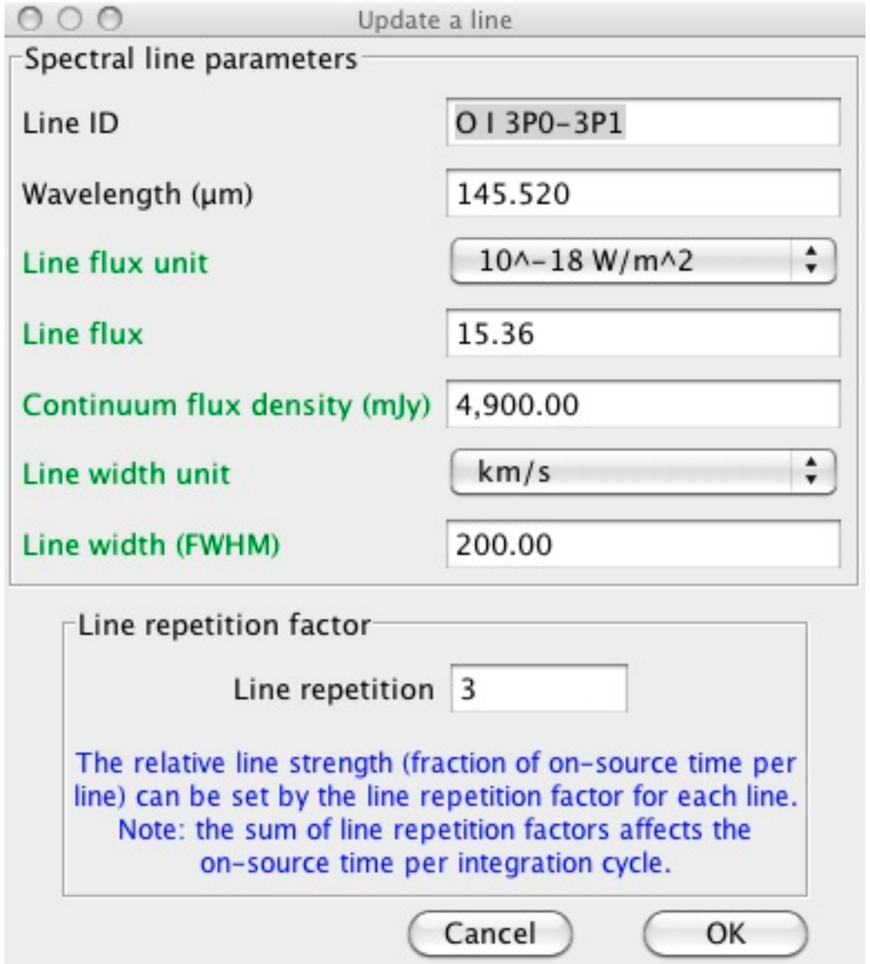
Step by step…

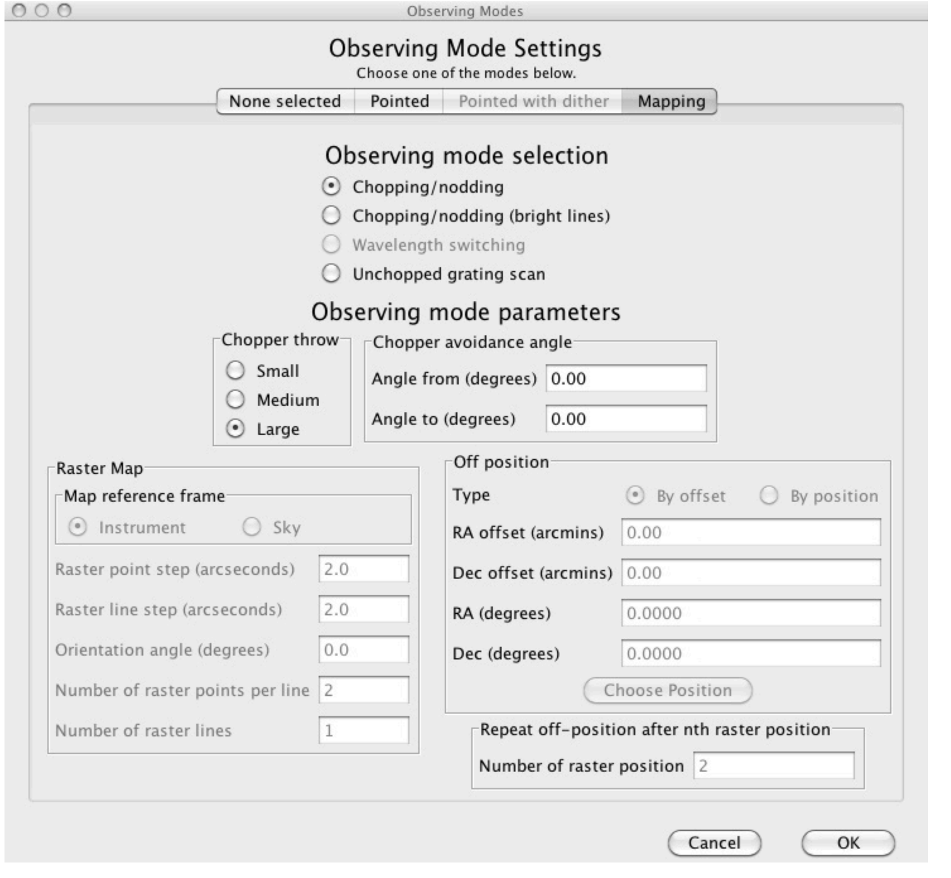
Click on a line: all the information about the selected line appears.

Values entered here are copied into the Line Editor



Step by step…

Once back in the AOR window, you are ready to choose the observing mode. Click on the button and a new window appears.



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Part II tomorrow:

- Spectrometer focal plane geometry
- Mapping strategies
- Range spectroscopy: use of parallel ranges
- Sensitivity estimates, use of repetitions and cycles
- Flux estimates and saturation limits
- *AOR design: hands-on session*

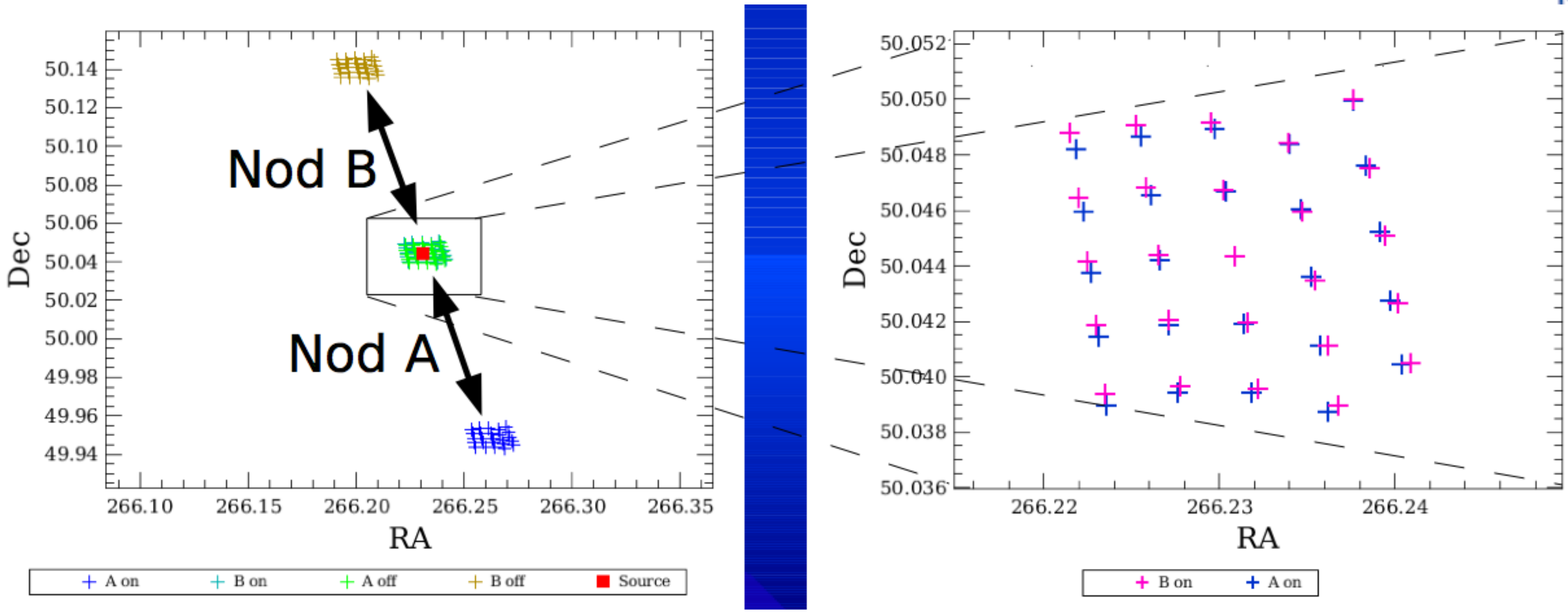
Observing with the PACS Spectrometer

Part II

Spectrometer focal plane geometry

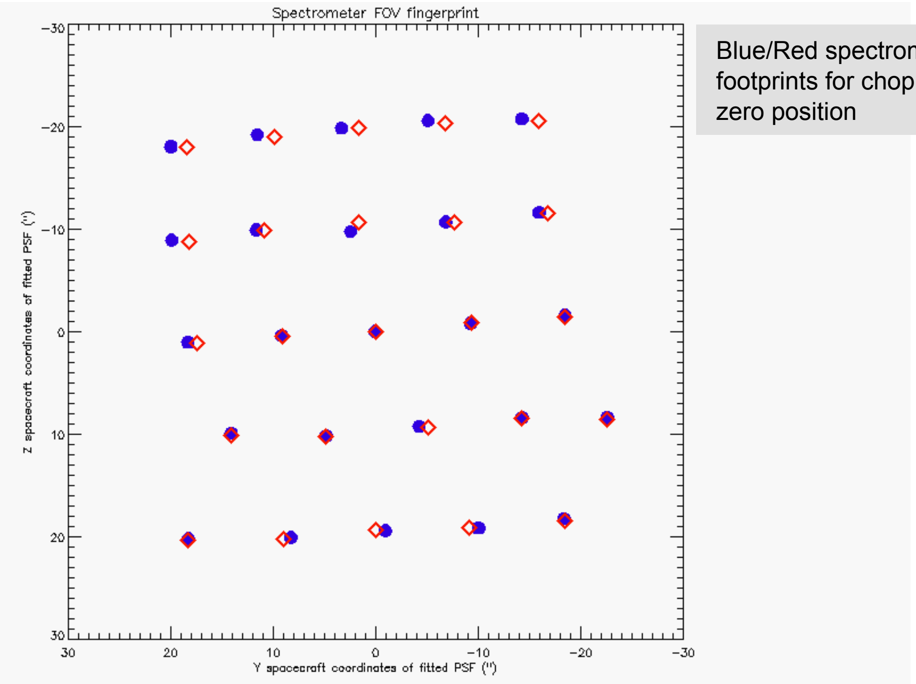
Nodding skew angle has been optimised for the central spaxel (**spa**tial pi**xel**)
Other spaxels do not see along the same LoS for the two nod positions

- either use the central spaxel only and apply point-source correction factor
- or recover flux from the resampled Nod A+B/2 cube

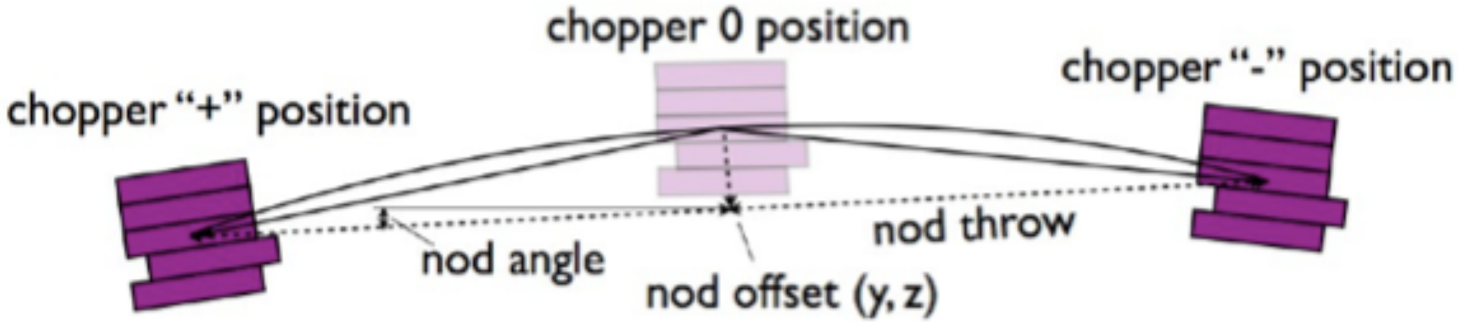


Focal plane geometry

- Apparent field-rotation increasing with chopper throw
- Use “Small” (1.5’) chopper throw if possible (for point sources)
- If you suspect your source is not a point-source or you are very unsure of its position to 1-2”, probably best NOT to use POINTED mode, but a fully sample mapping mode.

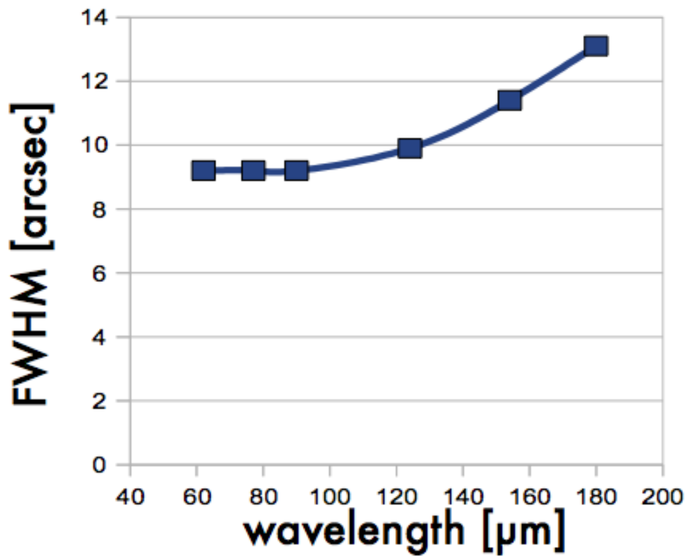


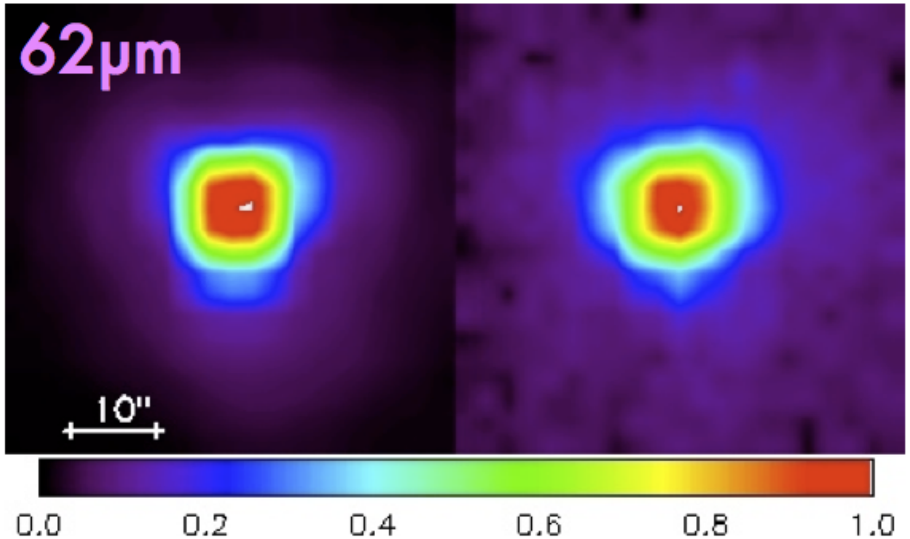
Blue/Red spectrometer footprints for chopper zero position

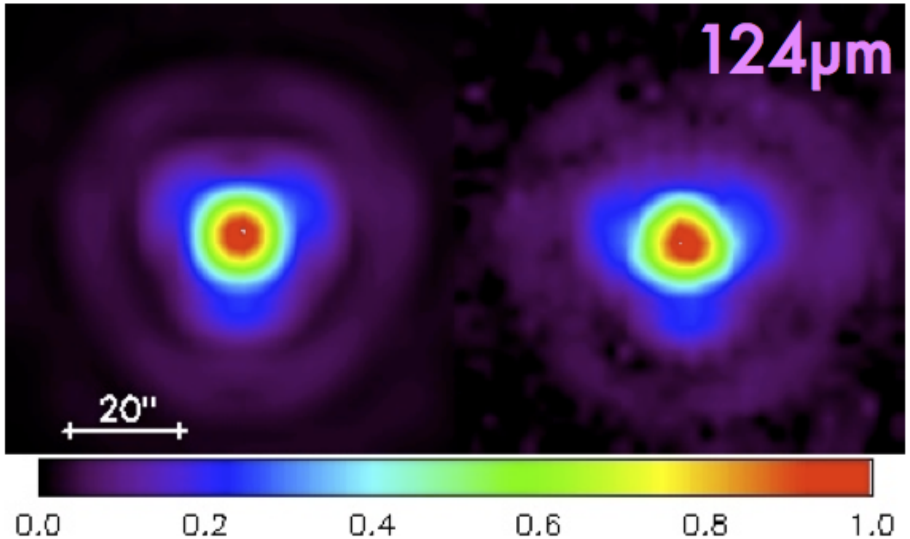


Spectrometer PSF

- Modeled/measured at 62μm and 124μm /on Neptune
- "Trifoliate" structure, also seen in photometer

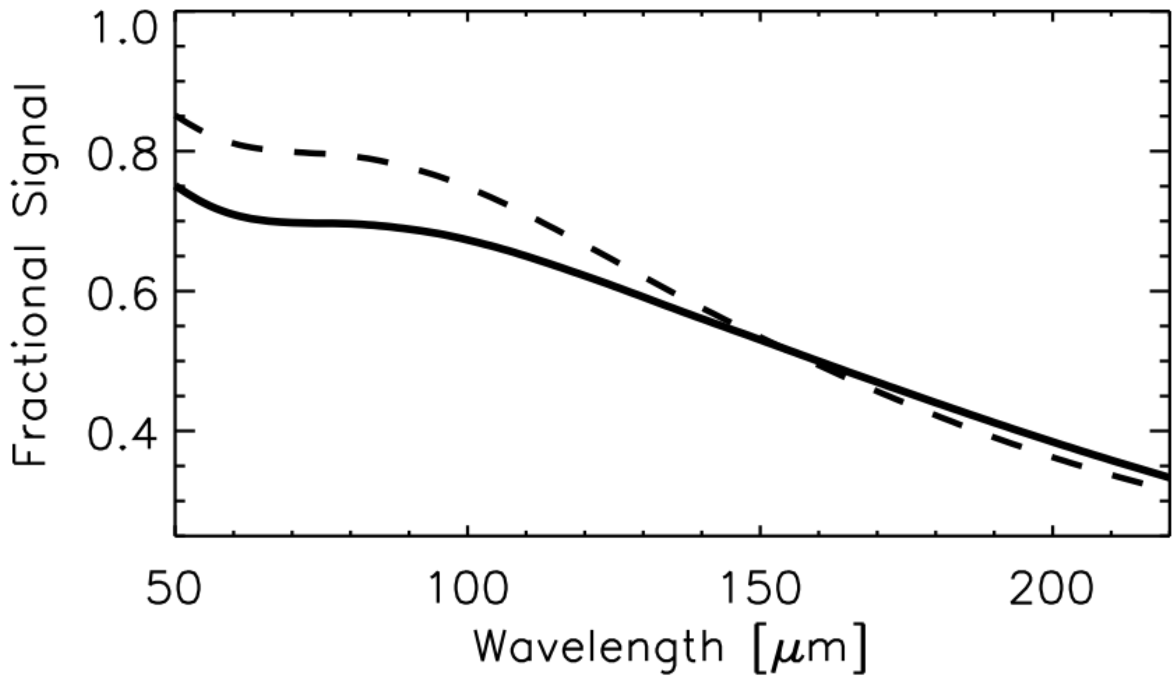






Spectrometer “beam efficiency”

- Fraction of PSF seen by (centered!) 9.4”x9.4” spatial pixel varies with wavelength
- Point source correction table available in HIPE



Mapping strategies

- **Raster map step sizes have been optimized, based on the focal plane geometry and PSF**
- **Sky mosaics:**

  For raster maps with stepsize greater than 30" (i.e tiling the sky rather than oversampled rasters) there are no particular recommendations for step sizes. Typical step sizes are 47" (no overlap between the different raster positions) and 38" (approximately one row or column of spatial pixels overlap between the different raster positions).

- **Nyquist sampling map of extended objects:**

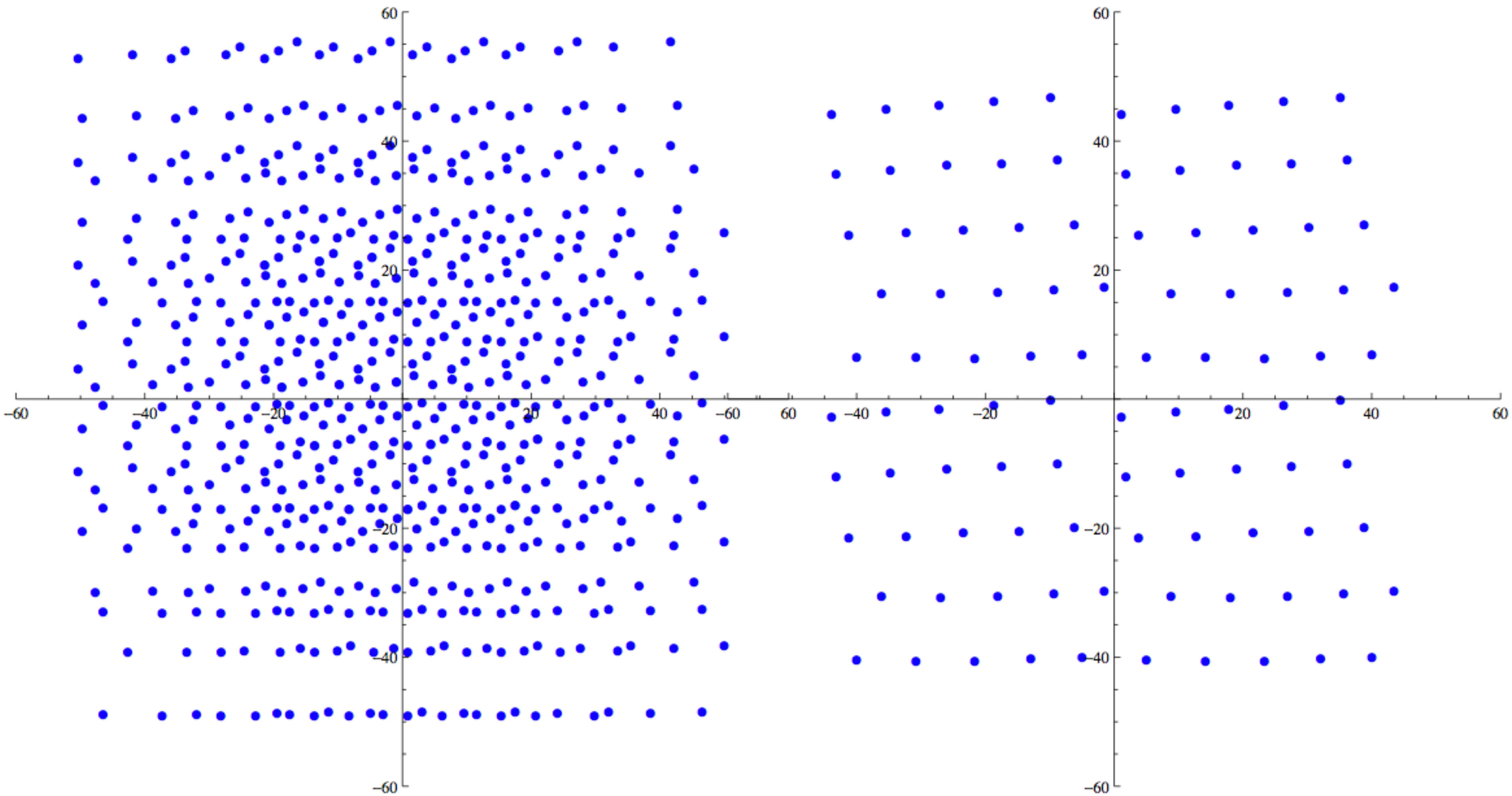
  For extended objects, mapping with oversampling, i.e. with step size smaller than one spaxel, may be very time consuming. Therefore this mapping strategy is suggested with step sizes larger than one spaxel, but such that the beam is Nyquist sampled. **Blue: point step=16.0", line step =14.5" Red: point step=24.0", line step =22.0”**

- **Full PACS spatial resolution of compact objects:**

  In order to map the sky at full PACS spatial resolution, step sizes smaller than a spaxel have to be used. Since this increases the observing time, this mode is strongly suggested to be used only for mapping point-like or almost point-like objects. **Blue: 3x3 raster with step size equal to 3.0" in both directions Red: 2x2 raster with step size equal to 4.5" in both directions**

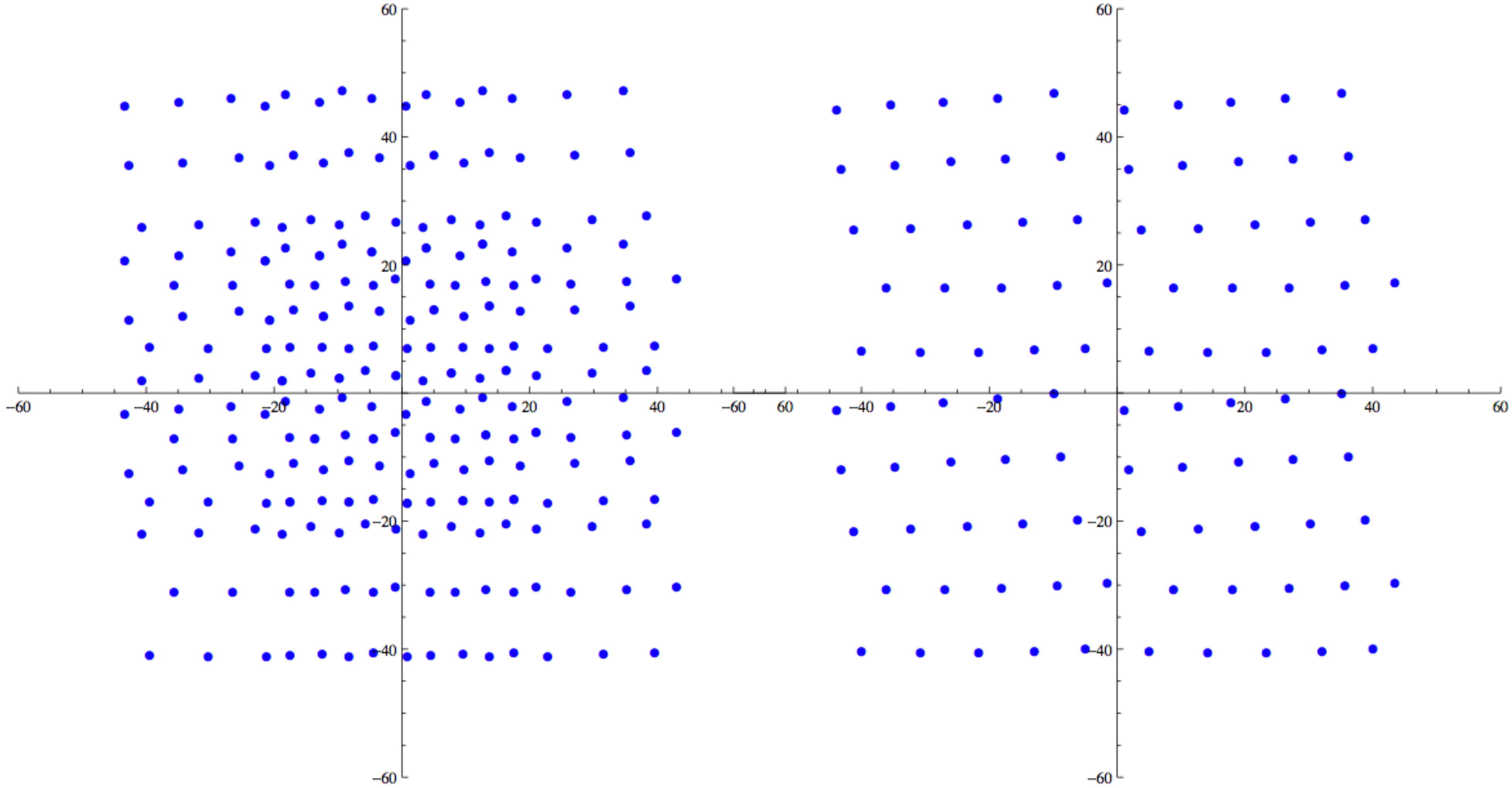
Mapping strategies

5x5 “Nyquist sampling” (short-λ) vs. 2x2 “Sky mosaic”

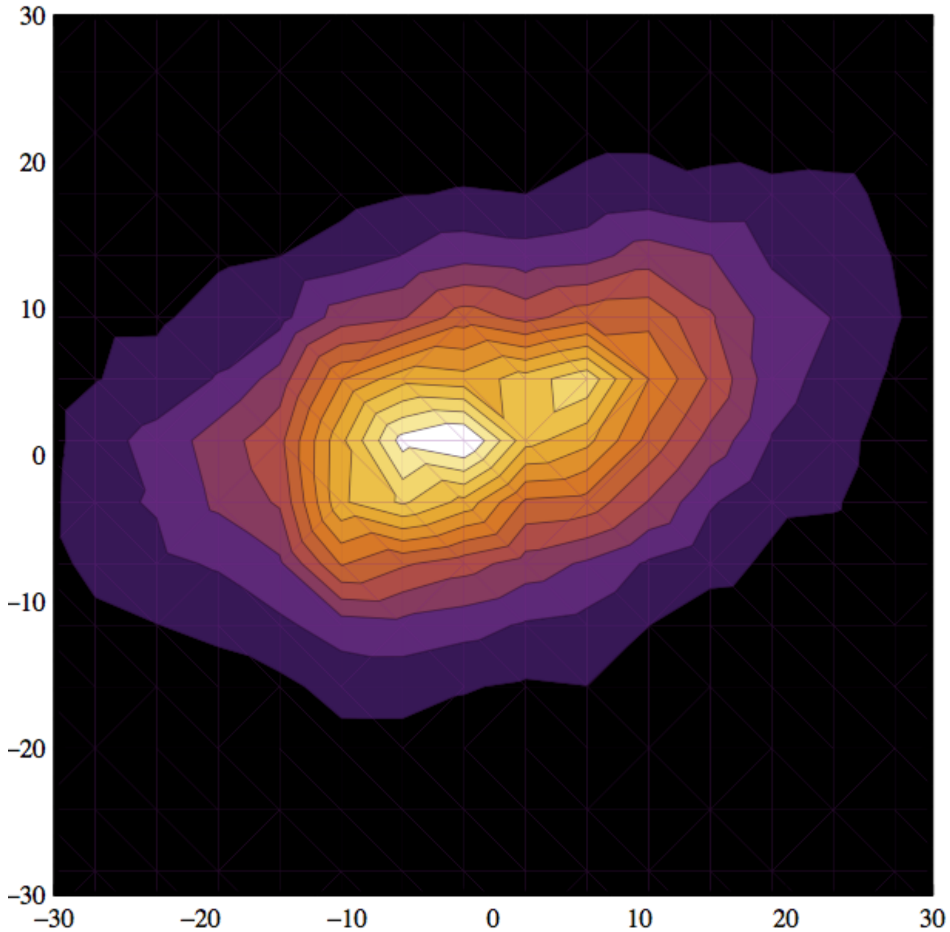


Mapping strategies

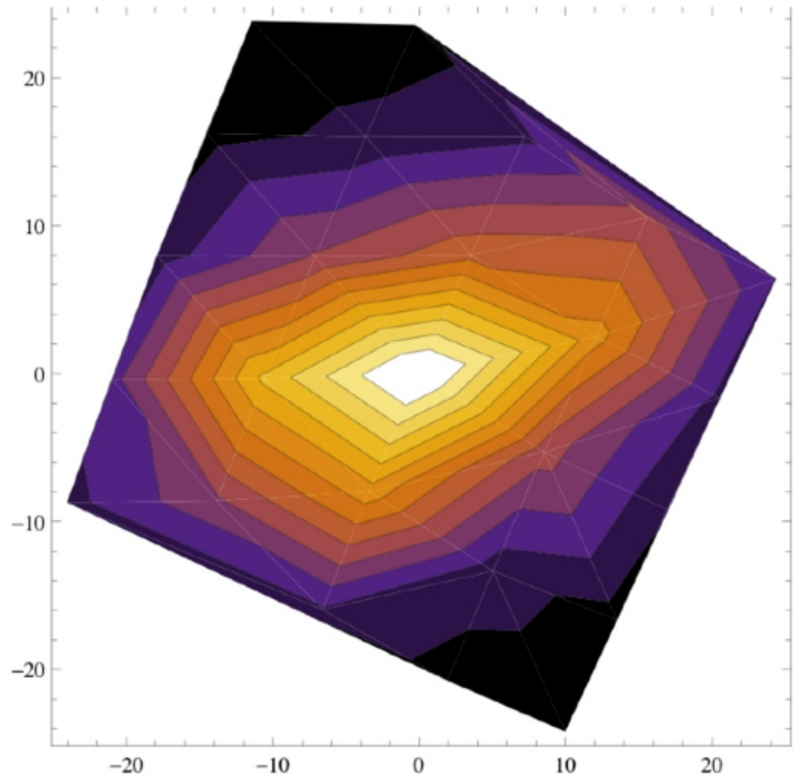
3x3 “Nyquist sampling” (long-λ) vs. 2x2 “Sky mosaic”



Pointed vs. full resolution mapping



M82 [O I] 63μm



Map reconstruction under construction (in HIPE)

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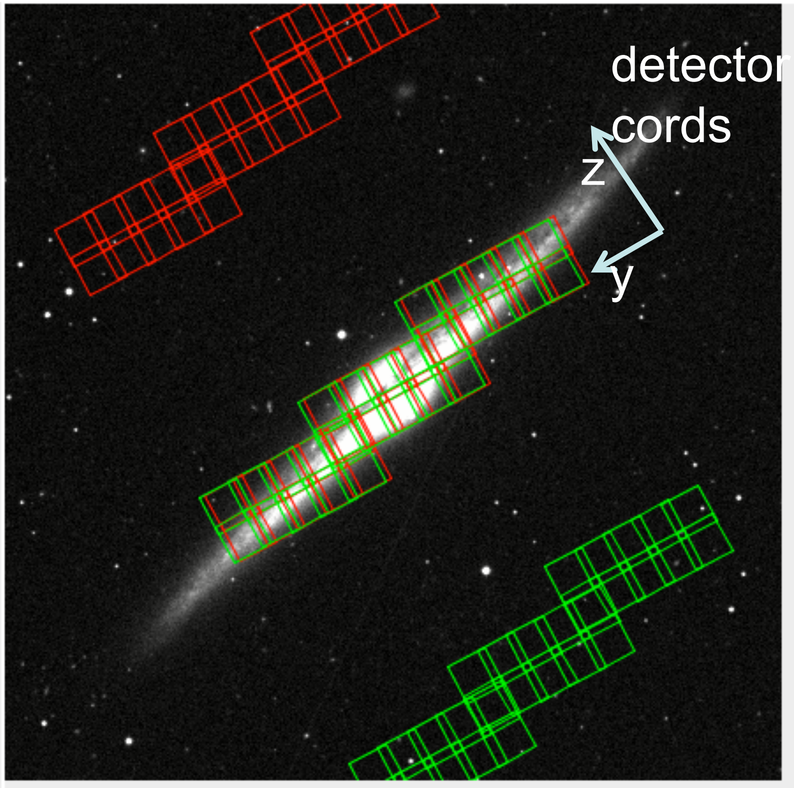
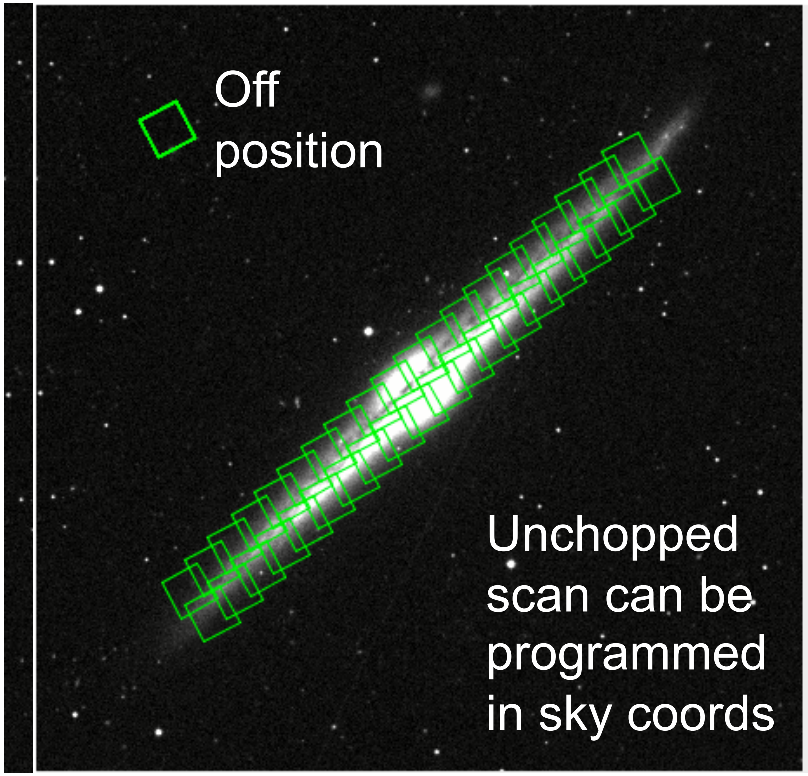
Map orientation angle

- The **recommended raster step/line size settings have been optimised only for zero degree map orientation in instrument coordinates**. In case of applying sky reference frame then optimal spatial sampling cannot be guaranteed because the PACS footprint rotation with respect to the raster line orientation depends on the position angle of the detectors footprint (determined by the day of the observation). The sky reference frame can be selected only in unchopped grating scan mode. Please note, in unchopped grating scan mode the HSpot default option is 'sky' reference, but we highly advise to switch to 'instrument' mode.
- **SKY frame:** In unchopped grating scan mode, if an AOR **raster covers an elongated area (e.g. a nearby edge-on galaxy)** then the observer might have no other option than using sky reference frame and turn the raster to the right direction. If the target is at higher ecliptic latitude then you may select instrument reference frame and put a time constraint on the AOR.
- **INSTRUMENT frame:** Chopped rasters cannot be rotated with a specific orientation angle, the chop direction is hard-coded in instrument reference frame with zero angle orientation (i.e. the chop direction is perpendicular to a raster line). If the target is at higher ecliptic latitude then put a time constraint on the AOR. This way the array and the whole raster can be rotated to the desired angle by a time dependent array position angle.

Map orientation angle





Chop-nod mapping is limited to instrument plane (chops along z axis). Limited ability to map a feature without multiple AORs = 4.1hrs 3 x (38 x 38” 5 x 2 raster) one line!

Unchopped grating scan in RA/Dec Coords. 38 x 38 “ 20 x 2 raster at orientation = 135 degrees = 3.7 hrs clock time

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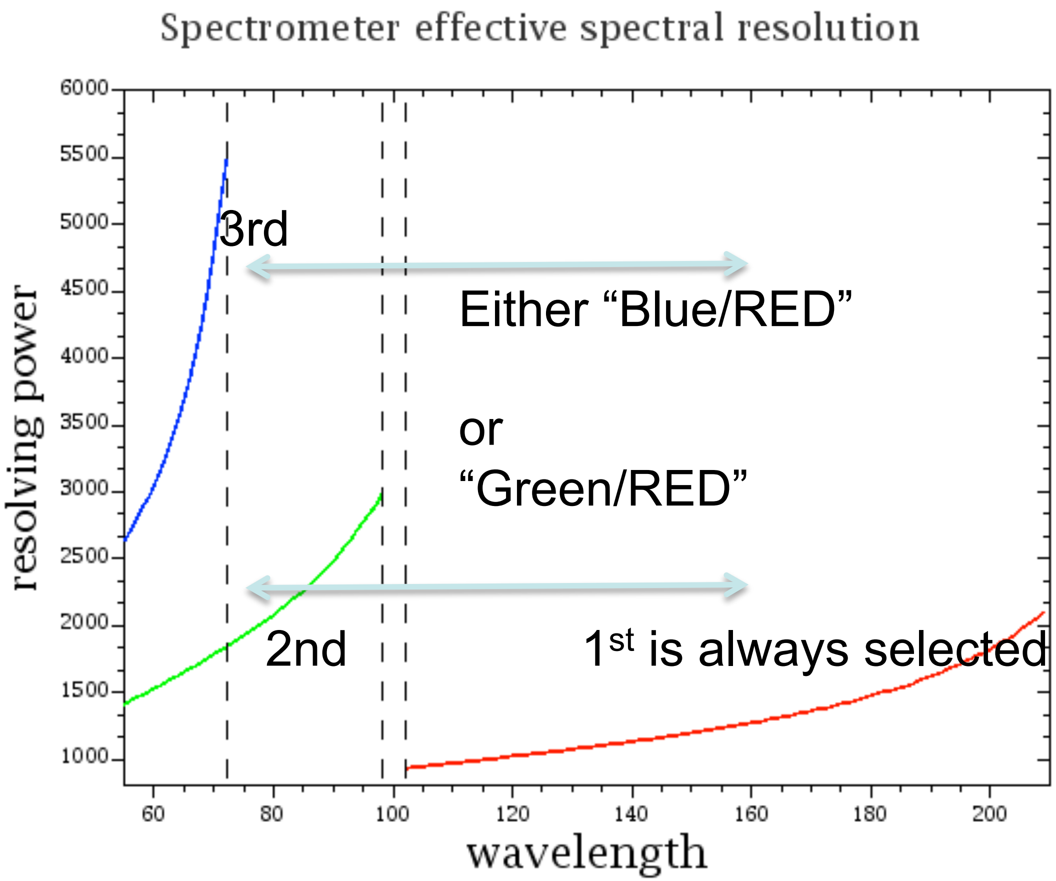
Range spectroscopy: use of parallel ranges



You can only select in any one AOR either the 2nd or 3rd order paired with 1st order

You can select multiple lines per AOR—for each line scanned you will get "for free" an observation in the blue or red band (e. g. If request 2nd/1st order modes and you observe [CII]158μm, you will "simultaneously" get "blue" observation at 158/2 = 79μm

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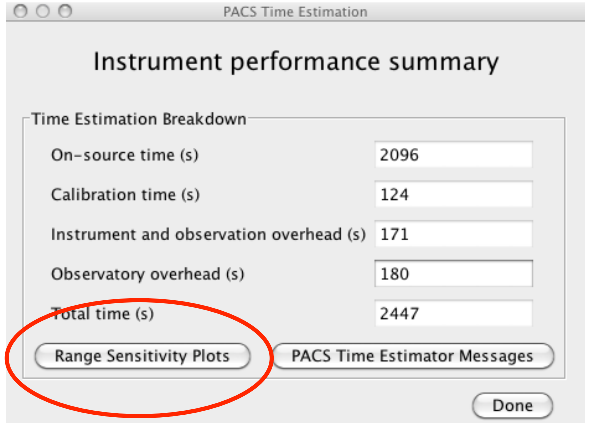
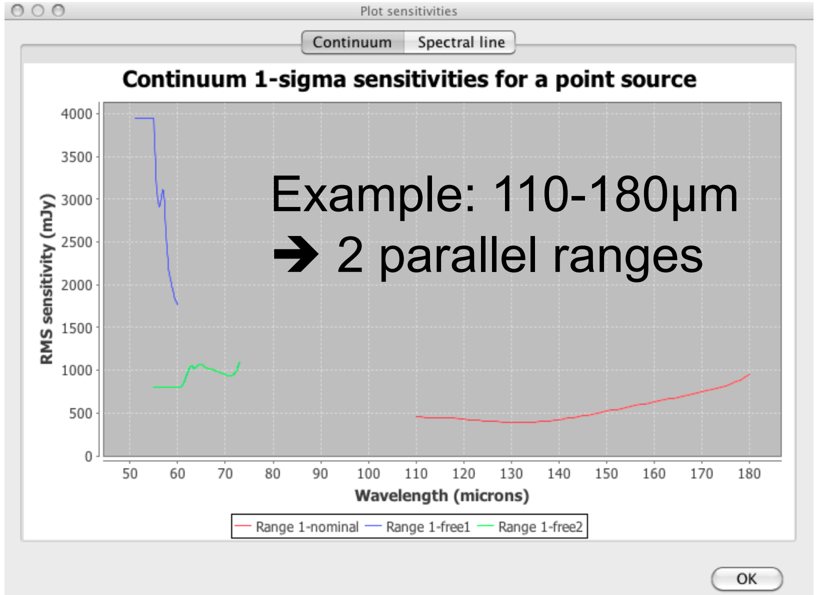
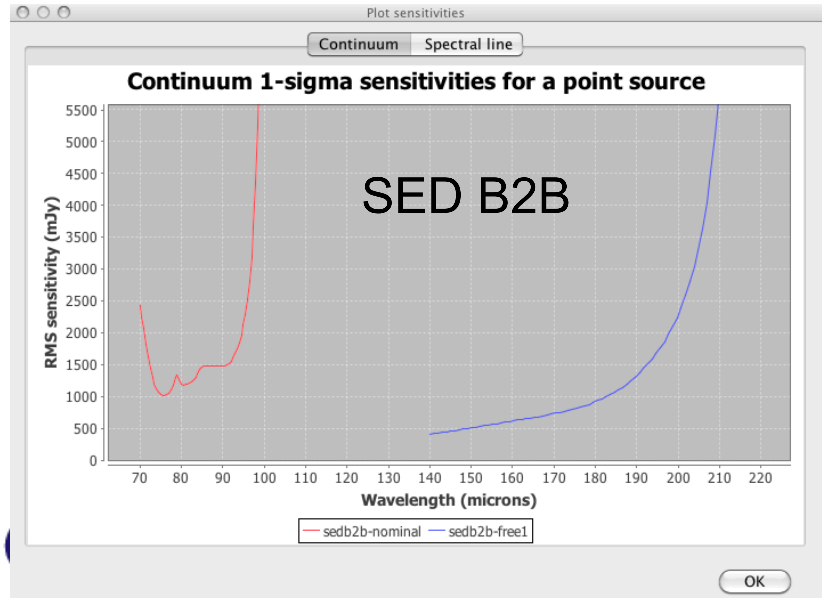
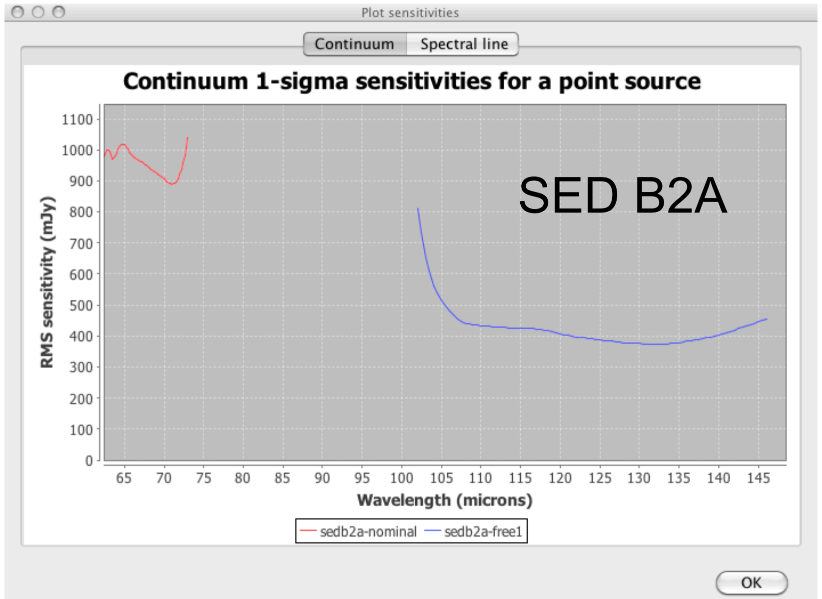
Range spectroscopy: use of parallel ranges





HSpot calculates the parallel ranges
Sensitivities are for individual ranges!
➔ take into account for observation design

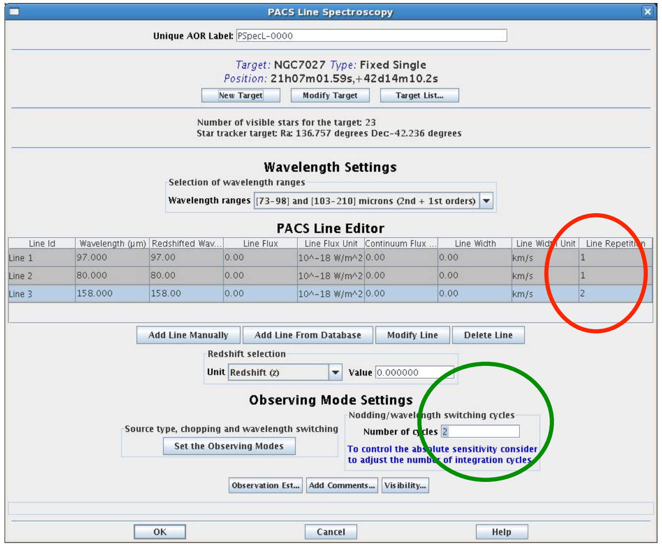




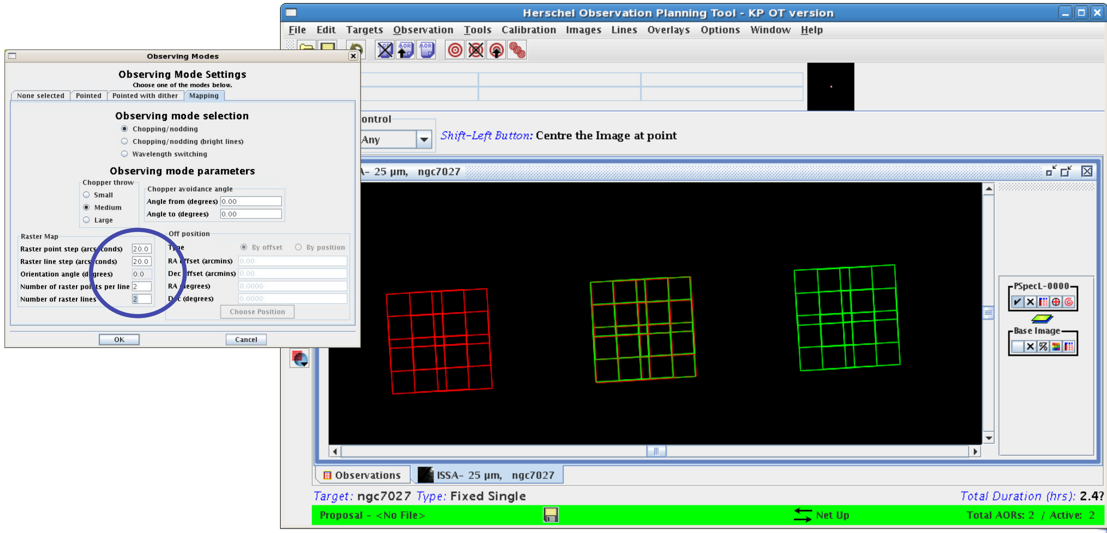
Repetition factors … and how blocks are defined in HSpot

Nodding blocks

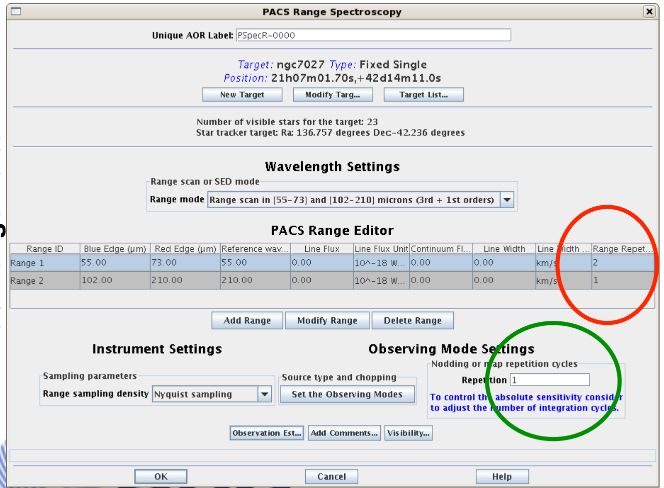
PACS Line Editor



Pointing blocks



PACS Range Editor



Depth of the observation is set via repetition factors:

- *Line/Range repetition **for relative** Line/Range strength, total number of repetitions is ≤ 10 to limit the maximum block duration*
- *Nodding/grating/mapping cycles define how many times a block has to be repeated. Adjust the **absolute observing depth.***
- Overlap between pointing blocks (d1, d2 step size < 47”), this is not taken into account in sensitivity estimation

Repetition factors vs. observing cycle vs. complete AOR

If you have one weak line (say [NII]205mm) and one strong one [CII]158, you can increase the number of repetitions on the [NII] line at the expense of the brighter line. e. g. 9 reps [NII], and say 1 rep for [CII]. If you need more time on both lines you can then increase the number of cycles.

- Single pointing mode 1 line, 2 repetions

Total time = 952s (on source*=688s, cal=129s)

- Single pointing 1 line, 2 cycles

Total time = 985s (on source 688s) Extra inst. overhead of 33s!

- Single pointing 1 line, 1 rep, 2 AORs

Total time = 2 x 586 (on 688s; cal=2 x 129) = 1172s

but you get 2 cal blocks..very inefficient..

Repetitions have less overhead than cycles.

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Time estimation and S/N calculation

PACS Time Estimation

Instrument performance summary

Time Estimation Breakdown

On-source time (s)	384
Calibration time (s)	122
Instrument and observation overhead (s)	61
Observatory overhead (s)	180
Total time (s)	625

PACS Time Estimator Messages

Done

Global AOT durations

AOT total duration: 567 [sec]

- CalSlew (with overheads) 122 [sec]
- SRC+REF (with overheads) 445 [sec]
- **AOT cost** (includes time for slewing to source): 445 + 180 [sec] = 625 [sec]

LINE setup and CAL summary

- AOT prologue duration: 26 [sec]
- KeyWave: 60.0 [μm]; CAL duration: 93 [sec]

SpecLine summary

O I 3P1-3P2: 63.18 [μm]:

- FWHM at current wavelength: 87.5 [km/s] or 0.018 [μm]
- Continuum RMS: 572 [mJy]
- Continuum S/N: 1,746.46
- Line RMS: 9.22E-18 [w/m2]
- Line S/N: 62.88
- Total duration (SRC+REF+PACS overheads): 420 [sec]
- SRC+REF (no overheads): 384 [sec]

Attention!!

The Capacitance has changed from the default value 0 to the higher value 4 due to high flux density in one or several requested lines

This will cause a loss of sensitivity in the faintest lines. Please refer to the User's manual, and/or to the PacsLineSpec Release notes for more informations

Observing time for O I 3P1-3P2

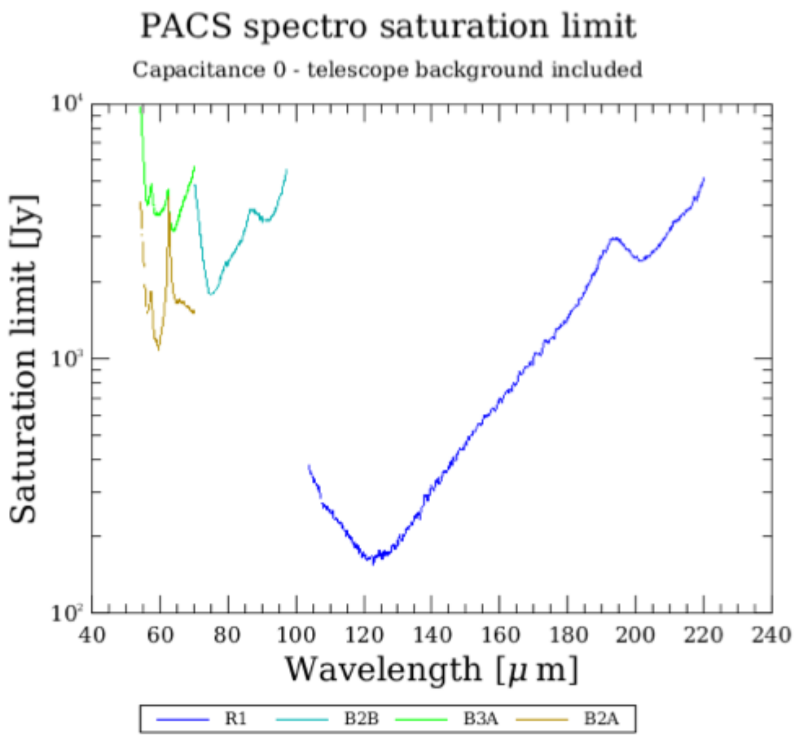
Estimated SRC+REF time: 384 [sec] for 63.185 [μm] with line repeated 1 time(s)

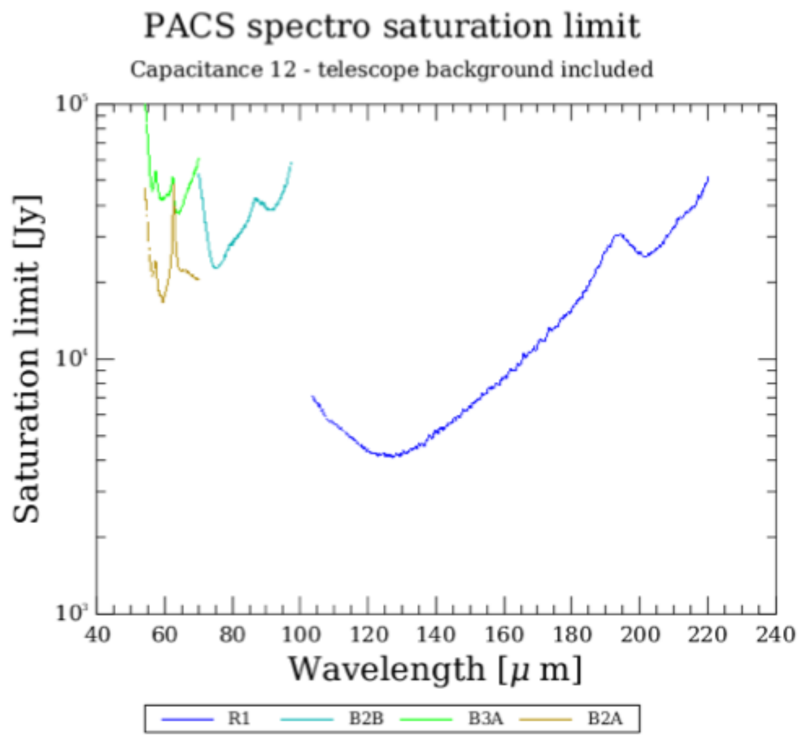
Accumulated SRC+REF time estimation

IF ENTERED FLUX TOO LARGE: HSPOT WILL REQUEST A NEW GAIN BY CHANGING CAPACITANCE. SATURATION OCCURS FOR VERY HIGH FLUX > 2x10^3 Jy!

Saturation limits

Continuum limits with the smallest and largest integration capacitor: saturation happens if the flux per resolution element is above limits for the highest capacitor (telescope background is included)





For range spectroscopy, the expected flux at the maximum response is extrapolated via a Rayleigh-Jeans law from the reference wavelength and corresponding flux estimate. The appropriate integrating capacitance of the CRE is then chosen for the entire observation to avoid saturation.