Line Spectroscopy and Mapping in Line Spectroscopy Mode with PACS

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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

Line spectroscopy with PACS
• **Line Spectroscopy: observation of individual line(s)**
  - Chop/nod or wavelength switching
  - Staring or mapping
  - $R \sim 1500$

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

Line spectroscopy with PACS
Line Spectroscopy in chop/nod – AOT implementation

![Graph showing line spectroscopy with PACS](image)
Line Spectroscopy in chop/nod – AOT implementation

![Graph showing line spectroscopy with PACS](image_url)
Line spectroscopy with PACS
First PACS (Laser) Line Spectrum!
Line spectroscopy with PACS
Line Spectroscopy in $\lambda$-switching – AOT implementation

Line spectroscopy with PACS
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)
Example 1:
Spectroscopic line survey of a galaxy (no mapping)
Herschel OT KP Workshop

20-21 February 2007

Line spectroscopy with PACS

Target: NGC3256, Type: Fixed Single, Position: 10h27m51.27s, -43d54m13.8s

Number of visible stars for the target: 17
Star tracker target: RA: 336.964 degrees Dec: 43.904 degrees

Wavelength Settings
Selection of wavelength ranges
Wavelength ranges: [55-72] and [105-210] microns (3rd + 1st orders)

PACS Line Editor

<table>
<thead>
<tr>
<th>Line Id</th>
<th>Wavelength</th>
<th>Redshift</th>
<th>Line Flux</th>
<th>Line Flux</th>
<th>Continuum</th>
<th>Line Width</th>
<th>Line Width</th>
<th>Line Range</th>
<th>Line Range</th>
</tr>
</thead>
<tbody>
<tr>
<td>NiII</td>
<td>57.000</td>
<td>57.53</td>
<td>334.00</td>
<td>10&lt;18</td>
<td>1.443.00</td>
<td>70.00</td>
<td>km/s</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>OI</td>
<td>63.000</td>
<td>63.59</td>
<td>3.349.00</td>
<td>10&lt;18</td>
<td>1.447.00</td>
<td>70.00</td>
<td>km/s</td>
<td>1</td>
<td></td>
</tr>
</tbody>
</table>

Observe 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

To control the absolute sensitivity consider to adjust the number of integration cycles.
Line spectroscopy with PACS
Line spectroscopy with PACS
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)

Line spectroscopy with PACS
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

Line spectroscopy with PACS

December 2008
Line spectroscopy with PACS

5 lines (2nd and 1st order), chop/nod, rep=1, cycle=1, medium throw, 3x1 map
**Some thoughts on chopping vs. wavelength switching**

### HSPOT decoding logic

**Minimum required OBS time = 216 [sec]**

### Observing time required

Minimum required OBS time: 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 (niongding) with 1 nod cycle.
- **Nod pattern**: nominal position A, or A→B, B→A, etc.

### Global AOT durations

**AOT total duration**: 405 [sec]

- **CalSlew (with overheads)**: 134 [sec]
- **SRC/REF (with overheads)**: 271 [sec]
- **HSPOT cost** + 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]**: 2.99E-18 [w/m2]
- **Total duration**: 240 [sec]
- **SRC+REF (no overheads)**: 88 [sec]
Some thoughts on *chopping* vs. *wavelength switching*

<table>
<thead>
<tr>
<th>Chop/nod</th>
<th>Wavelength switching</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>SpecLine summary</strong></td>
<td><strong>SpecLine summary</strong></td>
</tr>
<tr>
<td>Line: 158.0 [μm]:</td>
<td>Line: 158.0 [μm]:</td>
</tr>
<tr>
<td>● Continuum RMS at 158.0 [μm]: 212 [mJy]</td>
<td>● Continuum RMS at 158.0 [μm]: 173 [mJy]</td>
</tr>
<tr>
<td>● Line RMS at 158.0 [μm]: 2.93E-18 [W/m²]</td>
<td>● Line RMS at 158.0 [μm]: 2.39E-18 [W/m²]</td>
</tr>
<tr>
<td>● Total duration: 240 [sec]</td>
<td>● Total duration: 335 [sec]</td>
</tr>
<tr>
<td>● SRC+REF (no overheads): 88 [sec]</td>
<td>● SRC+REF (no overheads): 168 [sec]</td>
</tr>
</tbody>
</table>

Should be $173/\sqrt{2} = 123$ [mJy] !!!
And $1.7E-18$[W/m²]

See the „HSpot Known Problems“ AO Document
<table>
<thead>
<tr>
<th></th>
<th>advantage</th>
<th>disadvantage</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>chop/nod</strong></td>
<td>- preserve continuum</td>
<td>- not for large extended sources (&gt;6'x6&quot;), or crowded fields</td>
</tr>
<tr>
<td></td>
<td></td>
<td>- map orientation only via timing constraint *)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>- continuum lost</td>
</tr>
<tr>
<td></td>
<td></td>
<td>- z must be known precisely</td>
</tr>
<tr>
<td></td>
<td></td>
<td>- to be confirmed for faint sources</td>
</tr>
<tr>
<td><strong>λ-switching</strong></td>
<td>- also for extended or crowded fields</td>
<td></td>
</tr>
<tr>
<td></td>
<td>- map orientation can be chosen *)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>- less severe memory effects for bright lines ?</td>
<td></td>
</tr>
</tbody>
</table>

*) 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 \textit{pointed} vs. \textit{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  
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  
of absolute level and excitation of star forming (and AGN)  
activity and of \( n_e \) @ low density \(< 10^3 \text{ cm}^{-3} \)

[NIII] 57 µm

[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)