Spectral Mapping with FIFI-LS and GREAT

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Spectral Mapping results in a 3D-data cube

- P-V-diagrams
- Line intensity maps
- Velocity maps

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• **FIFI-LS** – Direct detection, 51 - 203 μm
  Grating spectrometer offering medium spectral resolution: R=500…2000
  Integral Field Unit

• **GREAT** – Heterodyne Receivers, 
  High spectral resolution, R<10^7
  On-the-fly mapping
  Cycle 4 configurations: L1/L2, L2/H
  – L1: 1.25-1.52 THz / 240-197μm
  – L2: 1.81-1.91 THz / 166-157μm, incl. [CII]
  – H: 4.7448 THz / 63.1837 μm [OI]
**FIFI-LS**

- Far-infrared spectrometer employing two parallel channels operating simultaneously:
  - **Blue 51-120 μm**
    - 5x5 pixel field of view: 6” per spatial pixel
  - **Red 115-203 μm**
    - 5x5 pixel field of view: 12” per spatial pixel
- Imaging spectrometer concept
- Each channel: 5x5 spatial pixels
- 16 spectral pixels per spatial pixels
- Spectral resolution: R=500-2000
Integral Field Concept

Footprint of Red and Blue channels are concentric

2D detector contains 3D data cube
Science Case

- Mapping of **FIR fine structure lines** in galactic and extra galactic sources.
- Main cooling lines of the interstellar gas in the FIFI-LS range:
  - [CII] 158μm
  - [OI] 63.18μm, 145.4μm
  - In ionized regions:
    - [OIII] 51.81μm, 88.36μm
    - But also high-J CO lines, OH-lines etc.

![Graph showing Log intensity vs. Wavelength (μm)](image)

Hollenbach & Tielens (1999)
M82 – [CII] 158µm
Velocity of ionized Carbon @ 158 µm from -130 km/s to +130 km/s
Time Estimate: M82

- Expected flux eg. from KOA, ISO, or Herschel observations
- Here from Herschel PACS-S: Central 2’x2’ with PACS-S
- Expected integrated line flux for [CII]: [C II]158µm
  $\sim 2 \times 10^{-17}$ W/m$^2$ per PACS-S spaxel in outer regions
- PACS-S spaxel is 9.7”x9.7”
- FIFI-LS red spaxel: 12”x12” -> 1.5 times larger
- Expected flux per FIFI-LS spaxel: $3 \times 10^{-17}$ W/m$^2$
FIFI-LS Time Estimator

Input Parameters

- Observatory Altitude (in feet; < 60000 ft):
  - 38000 ft

- Water Vapor Overburden (in microns; 0 if unknown):
  - 0

- Telescope elevation (between 20 and 60 deg):
  - 40

- Signal to Noise Ratio / Integration Time (minutes):
  - 5

- Wavelength (in microns, between 51 and 203):
  - 157.741
  - 3.0e-17
  - 219
  - 1500

- Source:

- Velocity correction (source VLSR, in km/s):

- Band width:

- Comment:

Conservative default values

Required user input

https://atran.sofia.usra.edu/cgi-bin/fifi-ls/fifi.cgi
FIFI-LS Time Estimator

M82 Example

Velocity (km/s)

Atmospheric Transmission

Wavelength (microns)
FIFI-LS Time Estimator

List of parameters inserted:
- Observatory Altitude (in feet; < 60000 ft): 38000 ft
- Water Vapor Overburden (in microns; 0 if unknown): 0
- Telescope elevation (between 20 and 60 deg): 40
- Signal to Noise Ratio / Integration Time (s): 5 SNR
- Wavelength (in microns, between 40 and 200): 157.741
- Source: 3e-17 line (in W/m^2)
- Velocity correction (source VLSR, in km/s): 219
- Band width: 1500 km/s

List of parameters derived:
- Velocity corrected wavelength (in microns): 157.856
- Plot wavelength range (in microns): 157.054 - 158.659
- Interpolated values from data table:
  - MDLF = 2.085e-17 (W/m^2);
  - MDCF = 0.570 (Jy);
  - bandwidth = 0.802 (microns);
  - I = 1.000
  - alpha = 0.775
- Atmospheric transparency:
- Integration time: t_on = 18.870 minutes

Result
MDL/CF: minimum detectable line/continuum flux (4σ in 15 t_on)
Mapping

- $t_{on}=19\text{min}$
- Consider overlap: 3x3 map positions spacing of $\frac{1}{2}$ a red array or 30” or 2.5 pixels (super-resolution)-> Map size 2’x2’ in red
  - Corners covered once -> SNR: 2.9
  - Sides covered 3x -> SNR: 5
  - Center covered 9x -> SNR: 8.7
- $t_{on}=19\text{min}$ coverage, i.e. SNR of 5, in sides. Therefore $19/3=6.3\text{min}$ on-source time, per position -> $9\times 6.3=57\text{min}$ or $3420\text{s}$ total on-source time.
- Symmetric Chop -> overhead: x1.7 or 97min Total time: 154+5 min or 9534s (SPT)
- Blue map full coverage, no overlap
  Let’s assume that 6.3min per position is sufficient for a blue pointing.
## Sofia Proposal Tool (SPT)

### Observation 1: M82 of Phase I Proposal 04_0013 (tests submission)

<table>
<thead>
<tr>
<th>Instrument</th>
<th>FIFI-LS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Target Name</td>
<td>M82</td>
</tr>
<tr>
<td>Source Type</td>
<td>Sidereal</td>
</tr>
<tr>
<td>Coordinates</td>
<td>Galactic</td>
</tr>
<tr>
<td></td>
<td>RA: 05 55 52.43</td>
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<tr>
<td></td>
<td>DEC: 06 40 46.93</td>
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<tr>
<td>Proper Motion</td>
<td>RA: 0</td>
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<tr>
<td></td>
<td>DEC: 0</td>
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<tr>
<td>Instrument Mode</td>
<td>SYMMETRIC_CHOP</td>
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<tr>
<td>Overheads</td>
<td>Constant (secs):</td>
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<tr>
<td></td>
<td>300.0</td>
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<tr>
<td></td>
<td>+ Factor: 1.7</td>
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<tr>
<td>Wavelengths</td>
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<td></td>
<td>Red Channel: 158</td>
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<tr>
<td>Width of Spectrum</td>
<td>Blue Channel: 1500</td>
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<tr>
<td></td>
<td>Red Channel: 1500</td>
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<tr>
<td>Integration Time</td>
<td>3420 (total)</td>
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<tr>
<td>Map Area</td>
<td>2.0 X 2.0</td>
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<tr>
<td>Order of Observation</td>
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<tr>
<td>Priority</td>
<td>Medium</td>
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<tr>
<td>Time Critical Observation</td>
<td></td>
</tr>
<tr>
<td>First Critical Time, From:</td>
<td>To:</td>
</tr>
<tr>
<td>Second Critical Time, From:</td>
<td>To:</td>
</tr>
</tbody>
</table>
The [OI] 63μm line

41000 ft

Velocity (km/s)

Atmospheric Transmission

Always check the atmospheric transmission!
FIFI-LS Observing Modes

- **Symmetric Chop** (see example)
  With matched nod -> symmetric off-positions
  Max chop throw $\theta < 5'$ for $\lambda < 120 \mu m$ & $\theta < 4'$ for $\lambda < 63 \mu m$
  Overhead: 170% (assumes long integration times)

- **Asymmetric Chop**
  Needs reference position
  Overhead: 430% (assumes long integration times)

- **Bright Object**
  Asymmetric chop with two on-positions per nod-cycle
  Overhead: 500% (assumes $t_{on} \approx 5s$)

- **Spectral Scan** (*shared risk!*)
  Several microns wide spectral features
Fluxer http://hera.ph1.uni-koeln.de/~ciserlohe/Fluxer/fluxer.html
GREAT – M17-SW

- Example: 3’x4’ on-the-fly map of M17-SW
- [C II] at 1900.5369 GHz (157.7 μm)
- $^{12}$CO $J=13–12$ at 1496.9229 GHz (200.3 μm)
- Continuously taking data while moving over the source
- 6 strips, 224” long, 4x 8”=32” high
- 8” sampling (half beam at 1.9 THz). -> 28 points per line

J.P. Prez-Beauquists et al.
1s integration per point -> 8”/s scanning speed
• *Scan should not exceed 60s*
• Reference position $\sqrt{28s} \approx 5s$
• One line -> 28s+5s=33s
• 4x6=24 lines
• Total integration time: 24x33s=792s
• 100% + 2min overhead (SPT)
• 1704s (28min)
• Time estimator:
  1s x 1km/s -> ~3K rms
• No repeat of map necessary.

J.P. Pérez-Beauquuits et al.
## Observation 1: M17 SW of Phase I Proposal 04_0013 (test submission)

<table>
<thead>
<tr>
<th>Instrument:</th>
<th>GREAT</th>
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<td>Target Name:</td>
<td>M17 SW</td>
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<tr>
<td>Source Type:</td>
<td>Sidereal</td>
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<tr>
<td>Coordinates:</td>
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<tr>
<td>Proper Motion (&quot;/yr&quot;):</td>
<td>RA: 0, DEC: 0</td>
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<td>Configuration:</td>
<td>GRE_H</td>
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<td>Spectral Element 1:</td>
<td>GRE_L2</td>
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<td>Frequencies (GHz):</td>
<td>Bandpass L1: 4744.8, Bandpass L2: 1900.5</td>
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<tr>
<td>Velocity (Km/s):</td>
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<td>Instrument Mode:</td>
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<td>Integration Time (secs):</td>
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<td>Map Area:</td>
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<td>Time Critical Observation:</td>
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<tr>
<td>First Critical Time, From:</td>
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</tr>
<tr>
<td>Second Critical Time, From:</td>
<td></td>
</tr>
</tbody>
</table>

**Total**: 1704.0
upGREAT

- Low frequency array (LFA)
- 7 pixel array both polarizations (currently only one polarization at a time)
- Current tuning range: $1.9005 \pm 0.003$ THz [CII] line $\pm 500$km/s
- 7 (maybe both pol.) pixel each more sensitive than L2 -> ~ order of magnitude more efficient mapping than GREAT L2
  Currently on SOFIA for commissioning
- Cycle 4 combination: LFA/L1
  L2/H may be replaced by LFA/H
- Stay tuned for updates on June 8
upGREAT mapping example

Fig. 3.2.4. Mapping scheme for IC1396E, for subfields A (top left) to D (bottom right). Red lines are array pixels for the first OTF lines.

Note to TO: FFJ tracking on reference will be fine.

Note: due to tracking issues in large field, the scripts for C and D have been split.