Spectral Mapping with FIFI-LS and GREAT

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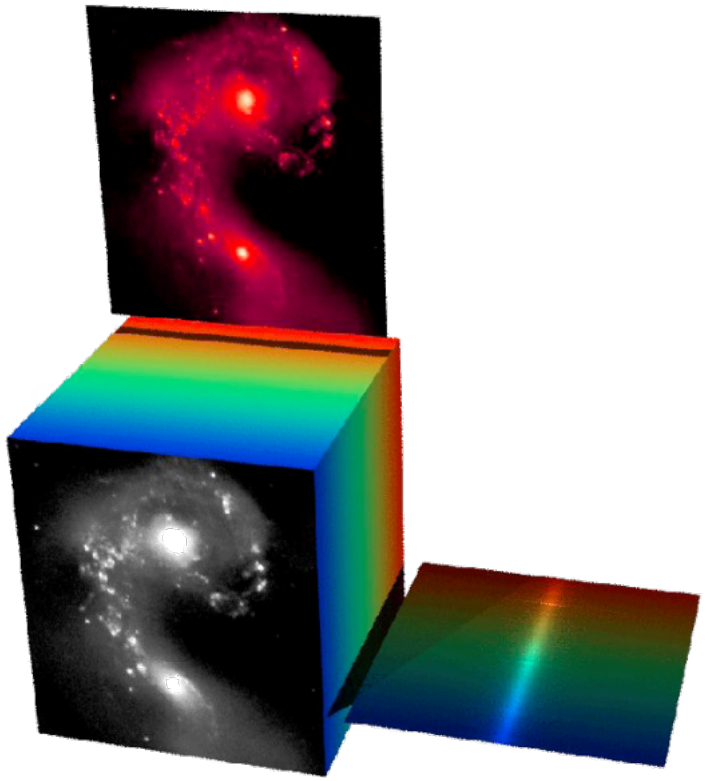
Spectral Mapping

Spectral Mapping results in a 3D-data cube

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

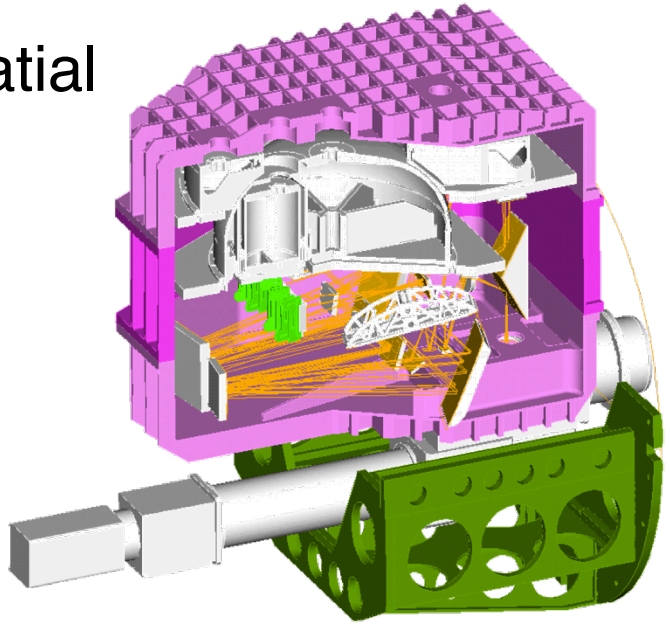


Instruments

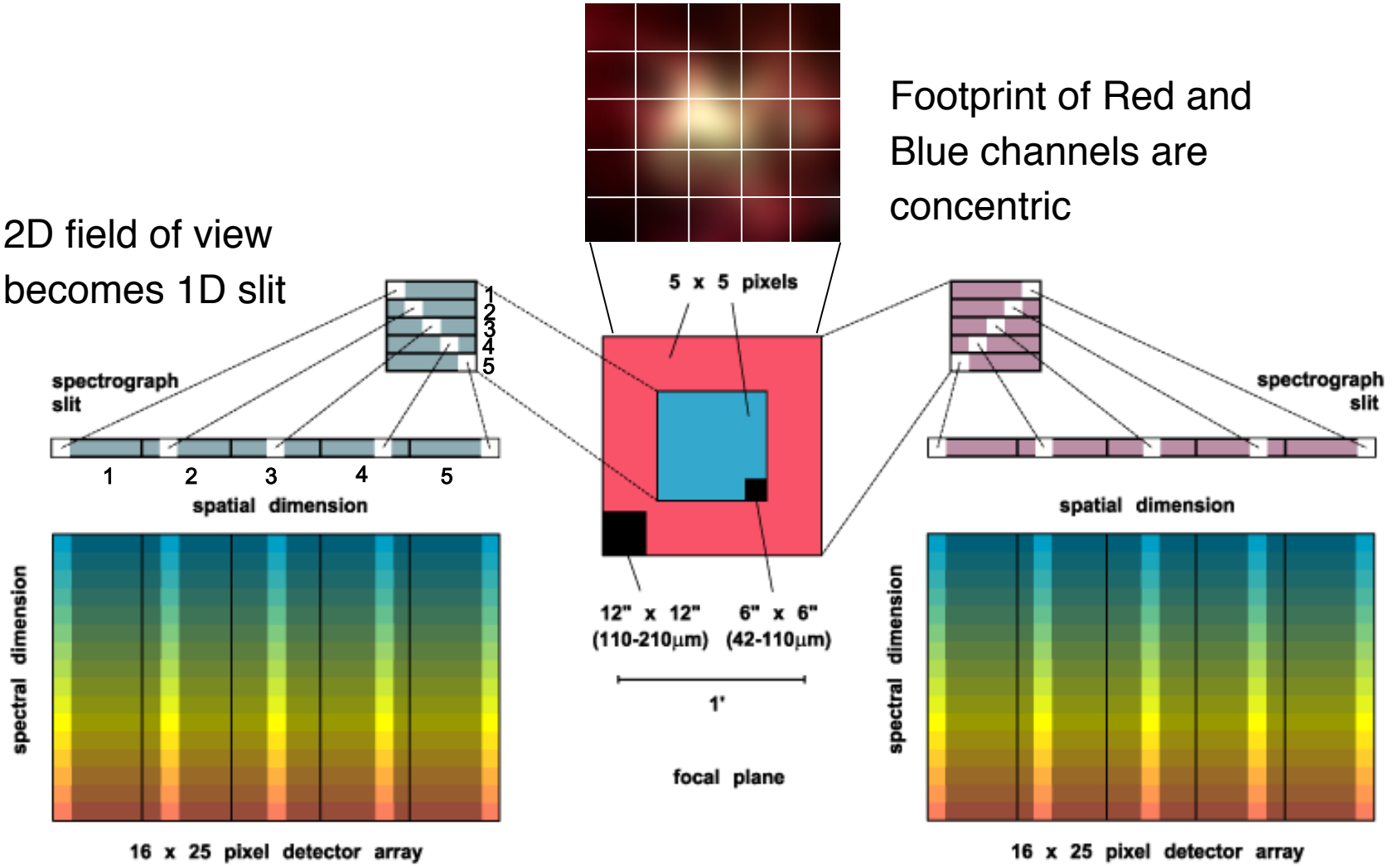
- **FIFI-LS** – Direct detection, 51 - 203 µm
  Grating spectrometer offering medium spectral resolution: R=500…2000
  Integral Field Unit
- **GREAT** – Heterodyne Receivers,
  High spectral resolution, R<10^7
  On-the-fly mapping
  Cycle 4 configurations: L1/L2, L2/H
  - L1: 1.25-1.52 THz / 240-197µm
  - 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



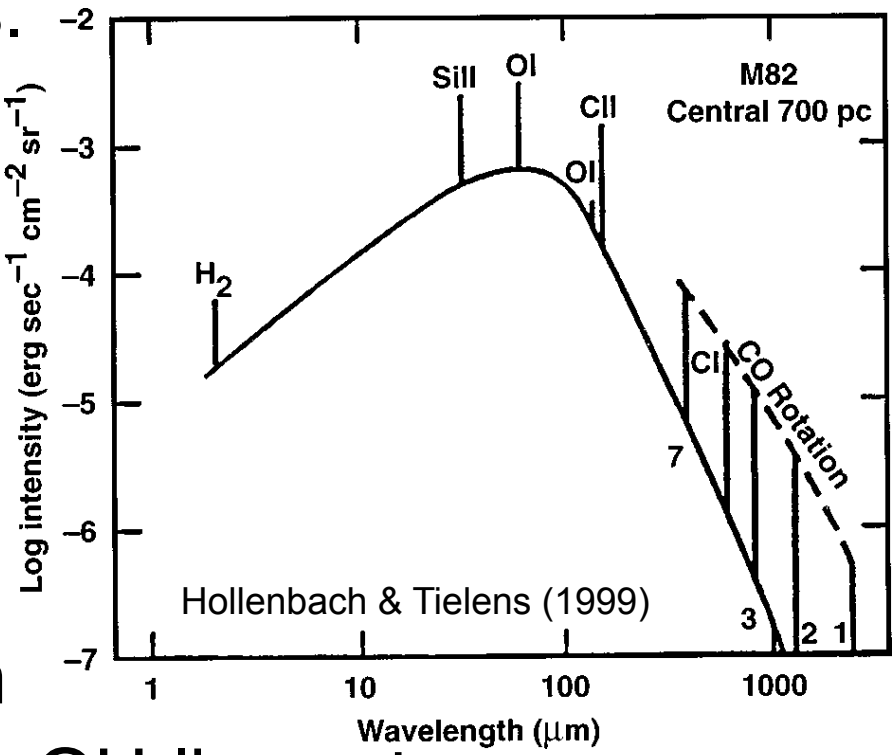
Integral Field Concept



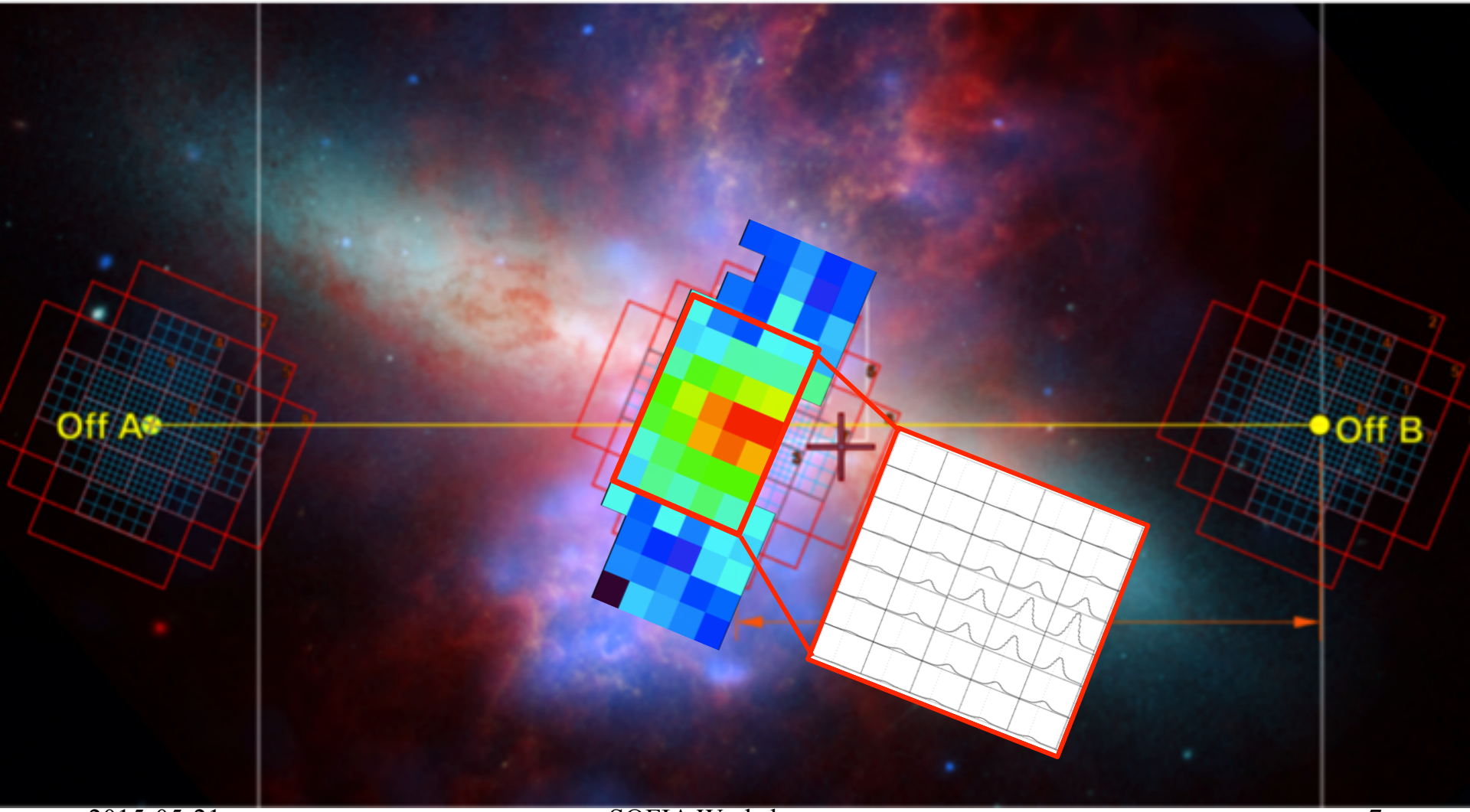
2D detector contains 3D data cube

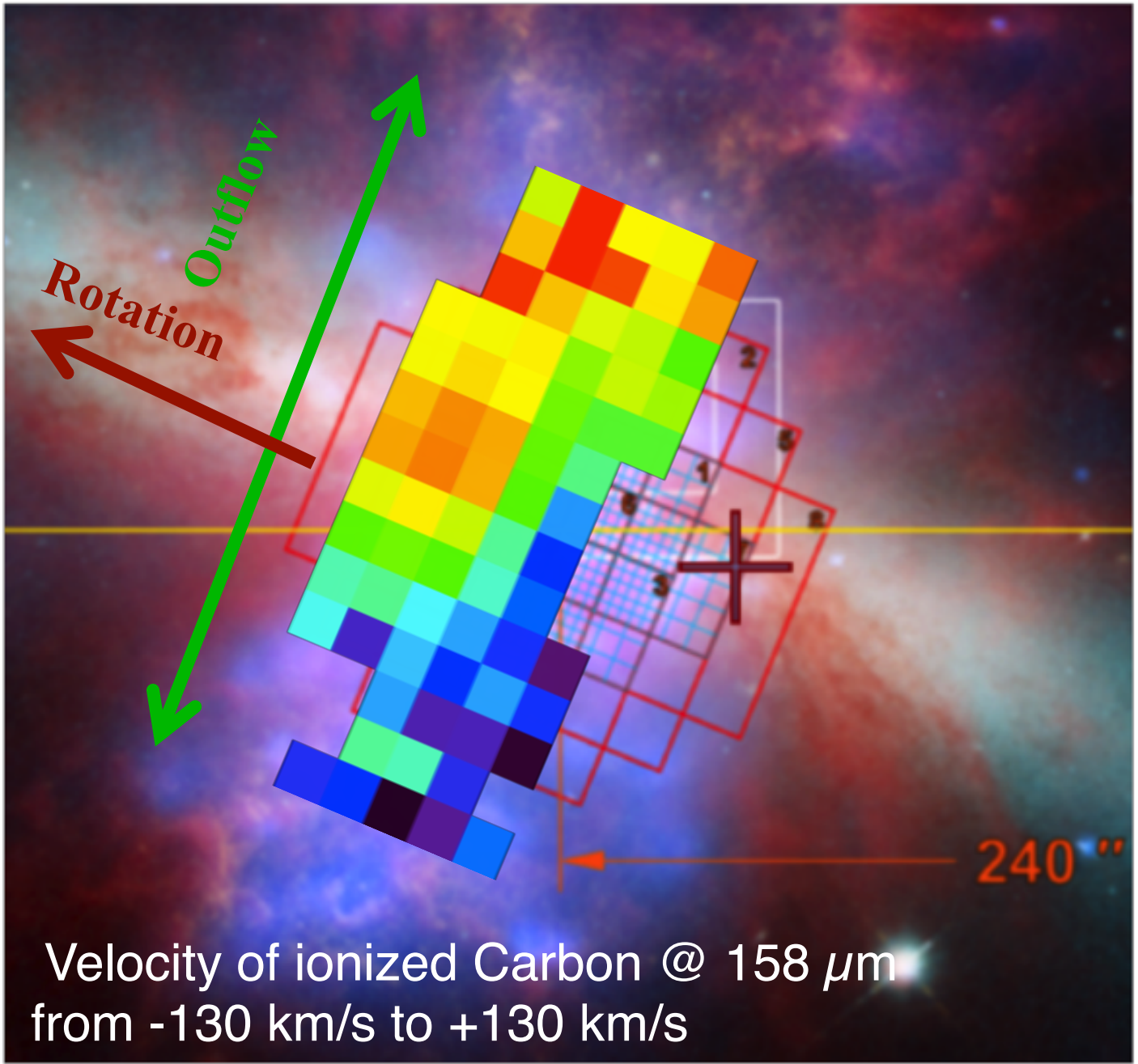
Science Case

- 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.



M82 – [CII] 158μm

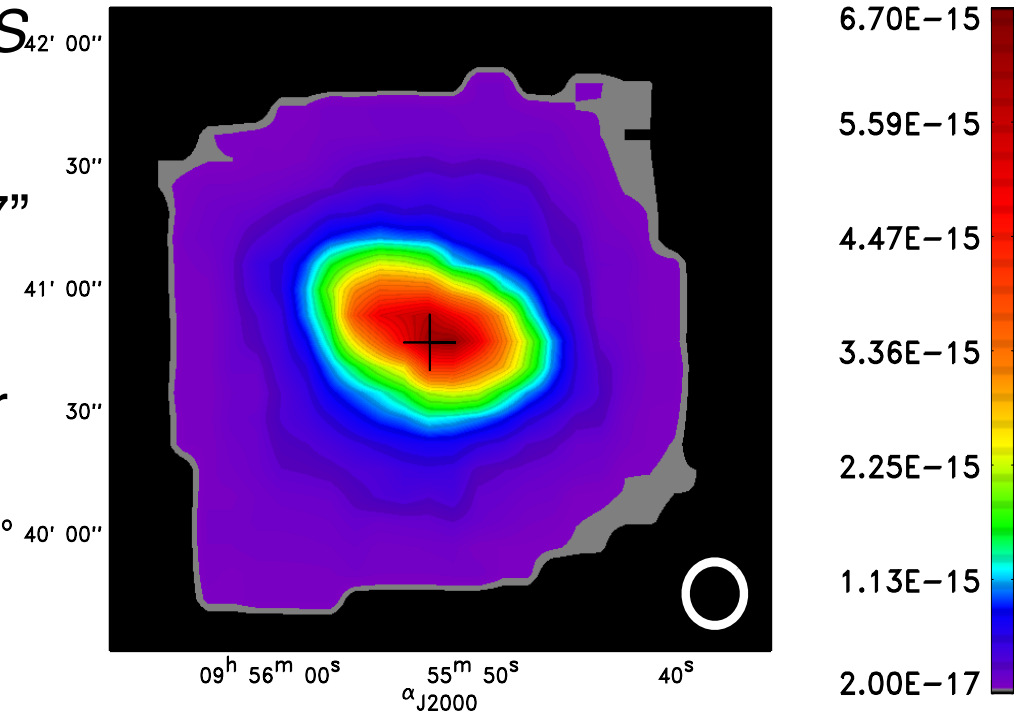




Velocity of ionized Carbon @ 158 μm
from -130 km/s to +130 km/s

Time Estimate: M82

- Expected flux eg. from KOA, ISO, or Herschel observations
- Here from Herschel PACS-S: Central 2'x2' with PACS-S Contursi et al. A&A 549, A118 (2013)
- Expected integrated line flux for [CII]: [C II] 158μm ~2x10^{-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: 3x10^{-17} W/m^2



FIFI-LS Time Estimator

Input Parameters

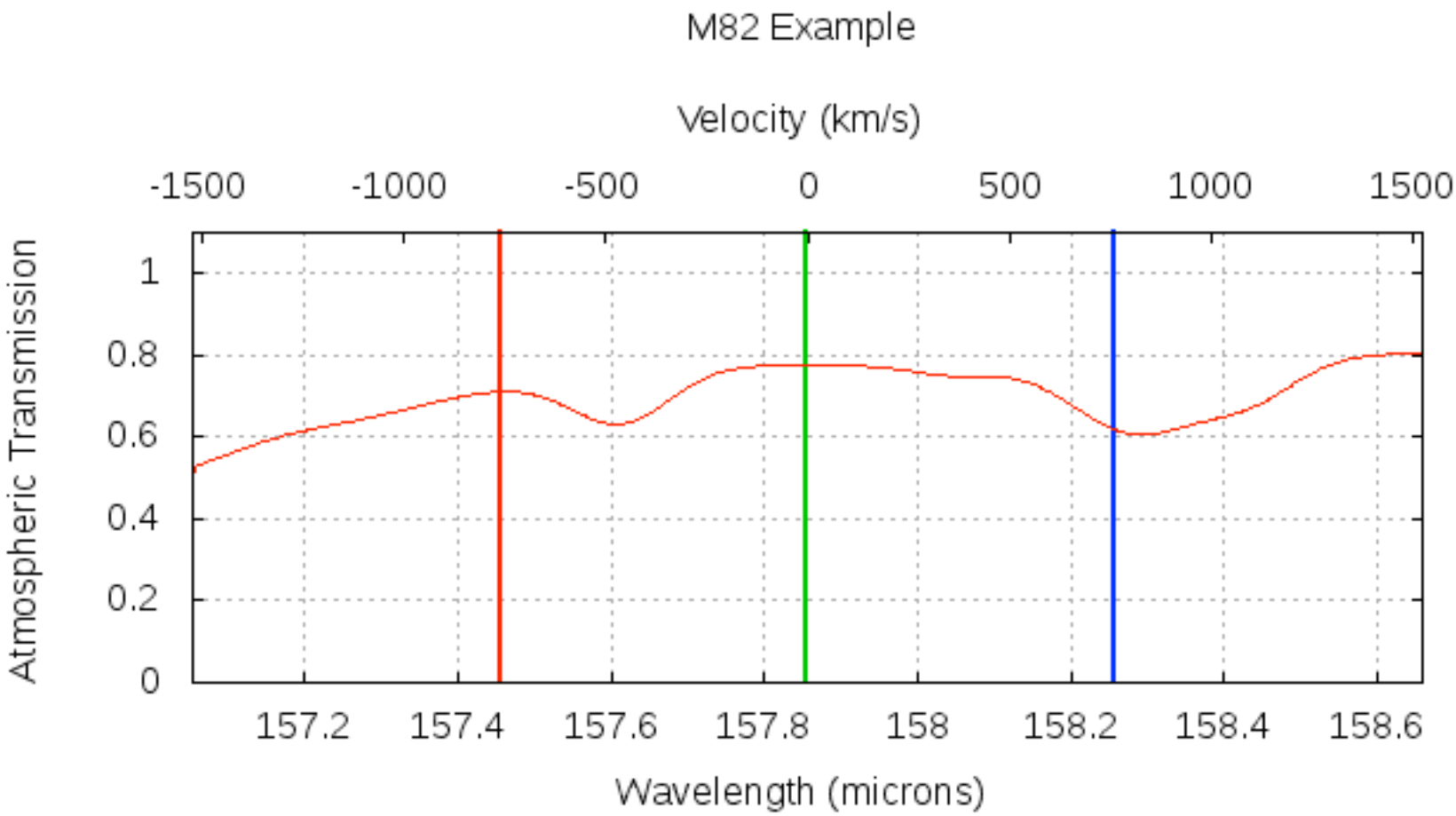
Observatory Altitude (in feet; < 60000 ft):	38000	(•) ft ( ) m
Water Vapor Overburden (in microns; 0 if unknown):	0	
Telescope elevation (between 20 and 60 deg):	40	
Signal to Noise Ratio / Integration Time (minutes):	5	(•) SNR ( ) Total Int. Time
Wavelength (in microns, between 51 and 203):	157.741	
Source :	3.0e-17	(•) line (in W/m^2) ( ) continuum (in Jy)
Velocity correction (source VLSR, in km/s):	219	
Band width :	1500	(•) km/s ( ) microns
Comment :	M82 Example	

Conservative default values

Required user input

https://atran.sofia.usra.edu/cgi-bin/fifi-ls/fifi.cgi

FIFI-LS Time Estimator



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); l = 1.000
Atmospheric transparency :	alpha = 0.775
Integration time :	t_on = 18.870 minutes

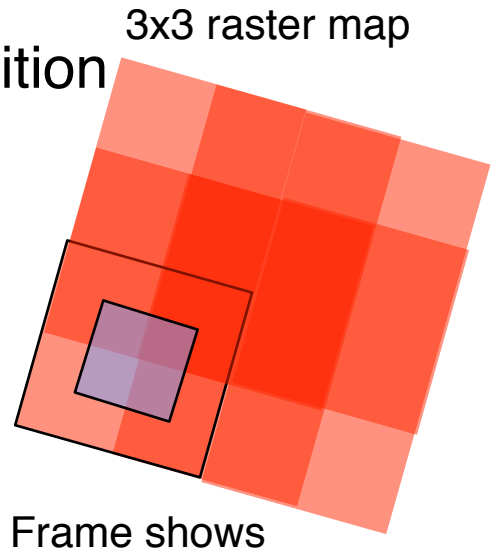
Inter-mediate results

Result

MDL/CF: minimum detectable line/continuum flux (4σ in 15 t_{on})

Mapping

- **t_{on}=19min**
- Consider overlap: 3x3 map positions spacing of ½ 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}=19min coverage, i.e. SNR of 5, in sides. Therefore 19/3=6.3min on-source time, per position -> 9x6.3=57min or **3420**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.



Frame shows single blue & red FOV

Sofia Proposal Tool (SPT)

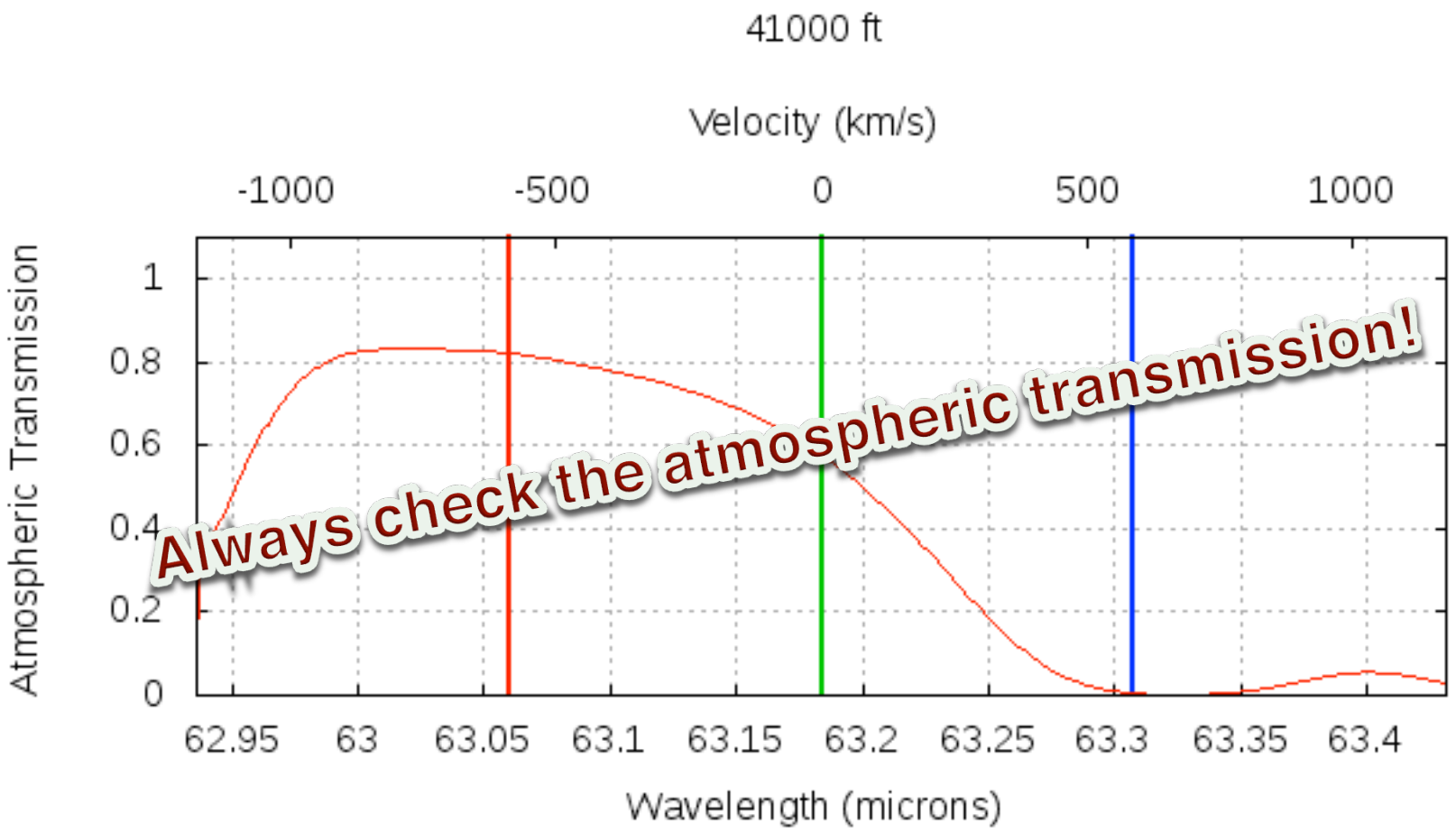
Observation 1: M82 of Phase I Proposal 04_0013 (testsubmission)

Instrument:	FIFI-LS				
Target Name:	M82				
Source Type:	Sidereal			SIMBAD ☑	NED ☐
NAIF ID:		NAIF ID Selection List			
Coordinates:	Galactic ☐	RA/GalLong: 9 55 52.43		DEC/GalLat: 69 40 46.93	
Proper Motion ("/yr) :	RA: 0			DEC: 0	
Instrument Mode:	SYMMETRIC_CHOP	Overheads - Constant (secs): 300.0		+ Factor: 1.7	
Wavelengths (microns):	Blue Channel: 52			Red Channel: 158	
Width of Spectrum (km/s):	Blue Channel: 1500			Red Channel: 1500	
Integration Time (secs):	3420	Alternate Overhead: 0	Default Overhead: 6114.0	Duration: 9534.0	
Map Area:	2.0 arcmin	X	2.0 arcmin		
Order of Observation:					
Priority:	Medium				
Time Critical Observation:	☐				
First Critical Time, From :		To:			
Second Critical Time, From :		To:			

t_{on}

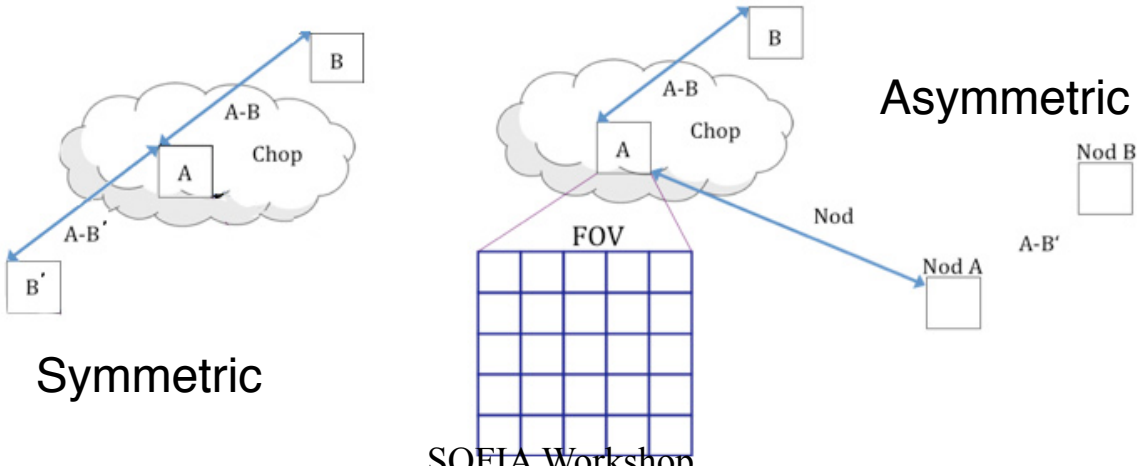
t_{total}

The [OI] 63µm line

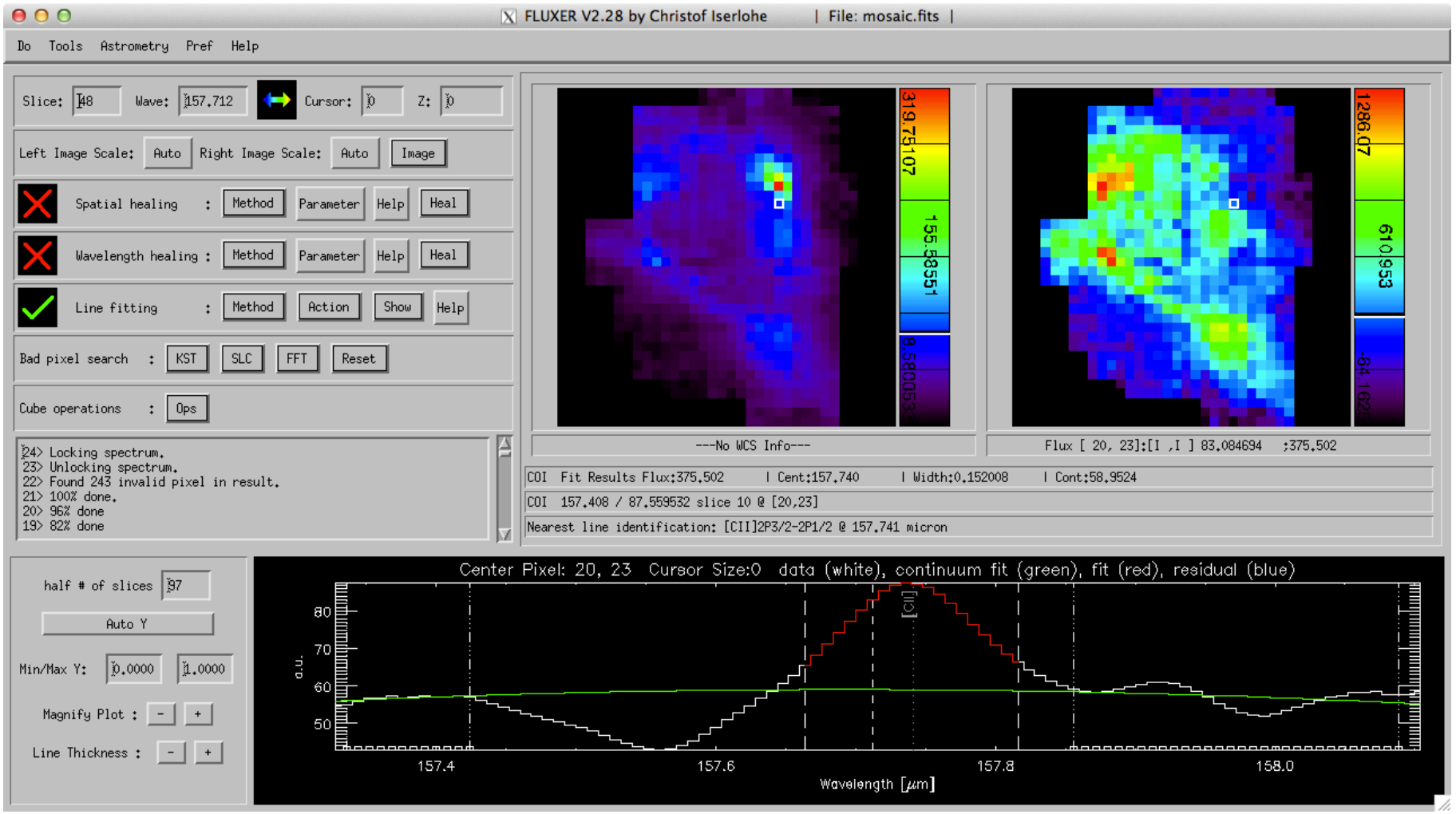


FIFI-LS Observing Modes

- **Symmetric Chop** (see example)
  With matched nod -> symmetric off-positions
  Max chop throw θ < 5' for λ<120μm & θ < 4' for λ < 63μm
  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



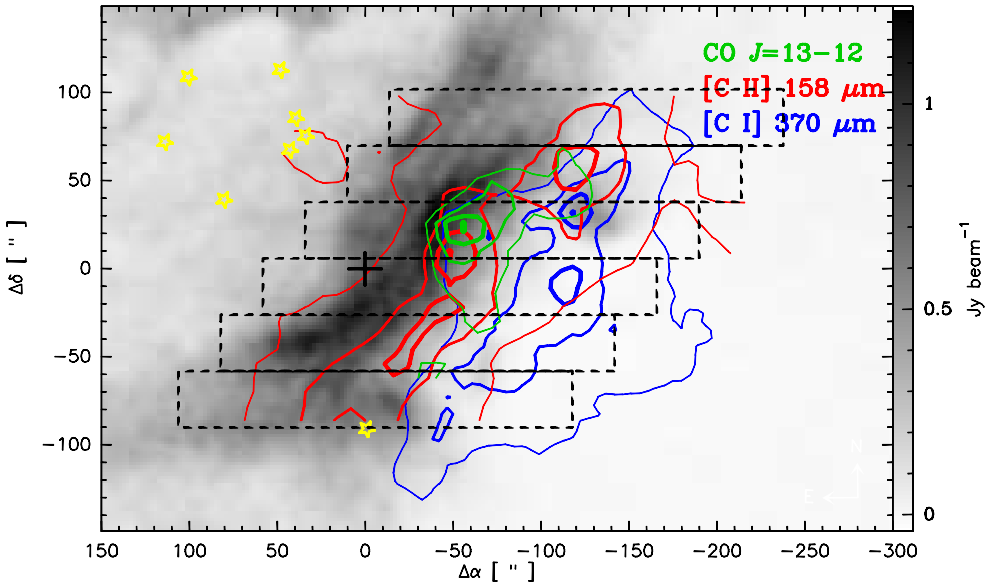
Data Cube of M42



Fluxer `http://hera.ph1.uni-koeln.de/~ciserlohe/Fluxer/fluxer.html`

GREAT – M17-SW

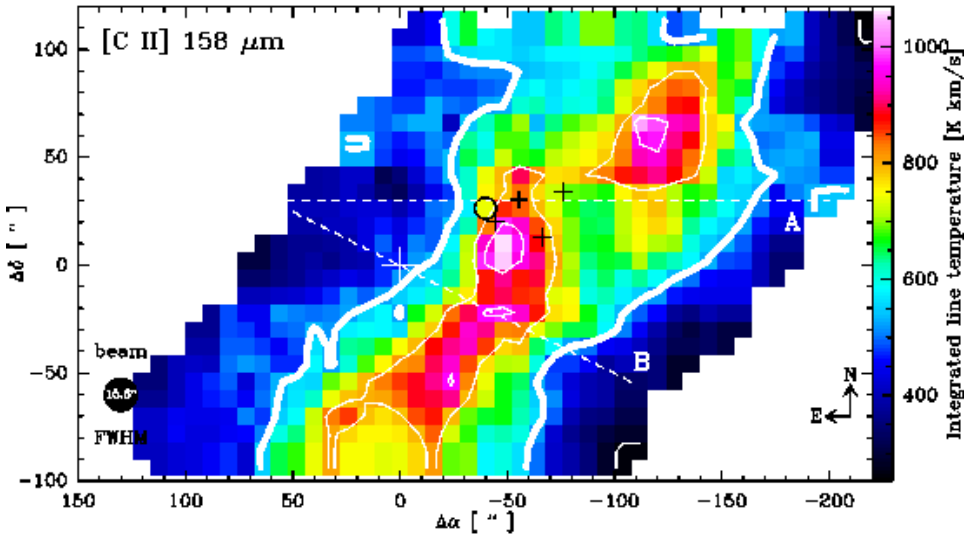
- Example: 3'x4' on-the-fly map of M17-SW
- [C II] at 1900.5369 GHz (157.7 μm)
- ^{12}CO *J*=13–12 at 1496.9229 GHz (200.3 μm)
- **Continuously taking data while moving over the source**
- 6 strips, 224" long, 4× 8"=32" high
- 8" sampling (half beam at 1.9 THz). -> 28 points per line



J.P. Prez-Beaupuits et al.
A&A 542, L13 (2012)

GREAT – M17-SW

- 1s integration per point -> 8”/s scanning speed
- *Scan should not exceed 60s*
- Reference position √28s ≈ 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-Beaupuits et al.
A&A 542, L13 (2012)

GREAT SPT

Observation 1: M17 SW of Phase I Proposal 04_0013 (testsubmission)

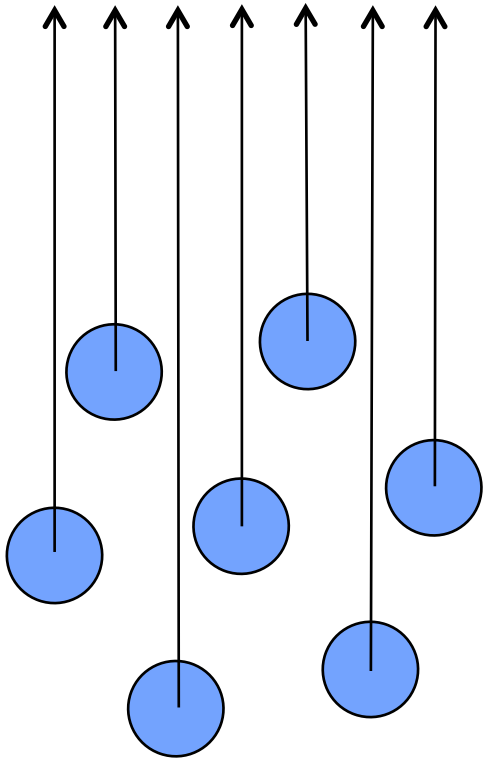
Instrument:	GREAT		
Target Name:	M17 SW		
Source Type:	Sidereal	SIMBAD ☑	NED ☐
NAIF ID:		NAIF ID Selection List	
Coordinates:	Galactic ☐	RA/GalLong: 18 20 23.10	DEC/GalLat: -16 11 43.00
Proper Motion ("/yr) :	RA: 0	DEC: 0	
Instrument:	Configuration: DUAL_CHANNEL	Spectral Element 1: GRE_H	Spectral Element 2: GRE_L2
Frequencies (GHz):	Bandpass L1: 4744.8	Bandpass L2: 1900.5	
Velocity (Km/s):	-20	Reference Frame: LSR	
Instrument Mode:	OTFMAP_PSW	Overheads – Constant (secs): 120.0	+ Factor: 1.0
Integration Time (secs):	792	Alternate Overhead: 0	Default Overhead: 912.0
Map Area:	3 arcmin	X 4 arcmin	
Order of Observation:			
Priority:	Low		
Time Critical Observation:	☐		
First Critical Time, From :		To:	
Second Critical Time, From :		To:	

t_{on}

t_{total} = Duration: 1704.0

upGREAT

- Low frequency array (LFA)
- 7 pixel array both polarizations (currently only one polarization at a time)
- Current tuning range: 1.9005 ± 0.003 THz [CII] line ± 500km/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



Approx.
beam pattern and
scanning directions

upGREAT mapping example