FIFI-LS Science Observations

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+ FIFI-LS Instrument & Science Team
The Team


Special Guests: M. Clarke, K. Hanna, E. Starman, C. Trinh, B. Wohler,
FIFI- LS: the Field-Imaging Far-Infrared Line Spectrometer

- Two parallel far-infrared spectrometers
  - **Blue 51-120 mm**
    - 5x5 pixel field of view: 6” pixels
  - **Red 115-203 mm**
    - 5x5 pixel field of view: 12” pixels
- Imaging spectrometer concept
  - 16 spectral pixels per spatial pixel
- Spectral resolution: R=1000-2000
Integral Field Concept

Footprint of Red and Blue detectors overlap but red pixels are larger

2D field of view becomes 1D slit

2D detector contains 3D data cube
Main Observing Lines

Mapping of FIR fine structure lines in galactic and extra galactic sources.

Main cooling lines of the interstellar gas in the FIFI-LS range:

- $[\text{CII}]$ 158 $\mu$m
- $[\text{OI}]$ 63.18 $\mu$m, 145.4 $\mu$m

In ionized regions:

- $[\text{OIII}]$ 51.81 $\mu$m, 88.36 $\mu$m

But also high-$J$ CO lines, OH-lines etc.

Hollenbach & Tielens (1999)
FIFI-LS Status

- 6 flight series to date (40 flights), including one southern deployment
- In Cycle 4: 16 out of 18 OT projects with clear detections: 3 projects able to add additional line measurement with in-flight assessment of SNR
- Flexible operations in flight
- In Cycle 4: 8 x 10h flights, less than 1h lost due to instrument issues
FIFI-LS In Flight Flexibility

FIFI-LS observations fully editable in flight: setups can be implemented within minutes

Can react to time lost or gained and other issues (e.g. coordinate offsets)

Quick look data with realistic SNR is available within minutes (thanks to the USRA pipeline group)

Guest Investigators flying proved beneficial for both the GIs and the FIFI-Team
Data Reduction Pipeline

Current version of IDL pipeline (v1.3.1) is stable, works well, and has been officially ‘released’

- Used extensively during flights to produce ‘Quick-look’ reductions
- Incorporates all known FIFI-LS observing modes, including ‘Total Power’ and ‘Focus Loop’
- Used to reduce OC2-F, OC3-B, OC3-K, OC4-B and OC4-F data
- Incorporates parallel processing (huge increase in speed!)
- Generates L2, L3, and L4 (multi-mission) data cubes
- Incorporates nominal telluric corrections
- Incorporates flux calibration for most wavelength settings

Pipeline Team: W. Vacca, M. Clarke, J. Holt -- ongoing development at USRA/DSI but L2/L3/L4 data available now
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Incorporates many of the lower level algorithms in the LabView reduction code written by R. Hoenle

- Reproduces LabView results to within a few percent
- Bad ramp detection is crucial as astronomical signal/sky ≤ 10⁻⁴
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- Reproduces LabView results to within a few percent
- Bad ramp detection is crucial as astronomical signal/sky ≤ 10^-4

Works within existing DPS infrastructure (REDUX)

- Allows steps to be performed sequentially by hand or automatically
- Displays results of each step when run manually

Pipeline Team: W. Vacca, M. Clarke, J. Holt -- ongoing development at USRA/DSI but L2/L3/L4 data available now
FIFI-LS Pipeline Steps:

1. Read FITS files/headers
2. Split file into two chop positions for each grating position
3. Linear fit to readout values (ramps) and combine slopes at each pixel to determine cnts/sec
4. Subtract: chop0 – chop1
5. Subtract: Nod A – Nod B
6. Wavelength/Spatial Calibration
7. Divide by flat-field
8. Combine grating scans
9. Telluric Correction
10. Flux calibrate
11. Resample onto linear wavelength grid
12. Resample onto rectilinear spatial grid
13. Output L2 data file
14. Combine grating scans
15. Output L3/L4 data cube
16. Output L3 data file

Implemented
In Development
Pipeline Example

W43 at 158 µm
Pipeline Example

W43 at 158 μm

W43 at 250 μm Herschel
Still the Atmosphere

63.18 micron [OI] line
FIFI-LS Search for CO$_2$ Ice

Team: Geoff Blake, Brandon Carroll, Brett McGuire, et al.
Pipeline Flux Calibration: ~20%
Fluxer: Data Cube of M42
NGC 2024

Part of the Orion B complex—good example of molecular cloud with an embedded HII region

Sharp ionization front at the boundary between the ionized and the molecular gas

Graf et al. (2013) find a high [CII] column density including an absorbing layer in front of the HII region and suspect non-LTE excitation component.
NGC 2024

Approximate FIFI-LS mosaic size 4.5’ x 3.5’
NGC 2024

VISTA J,H,K

© FIFI-LS Team
NGC 2024

VISTA J,H,K
Orion: Bar & Trapezium Region

Orion is standard location to test new instruments: important PDR region and overall template for Star Formation

Used to verify mapping and observing procedures with FIFI-LS

Multiple configurations and flights has made it a great test case for pipeline too
Orion Nebula

- Becklin-Neugebauer Object
- Trapezium Stars
- Orion Bar

Background image Spitzer by Thomas Megeath
Orion Nebula

- Becklin-Neugebauer Object
- Trapezium Stars
- Orion Bar

Background image Spitzer by Thomas Megeath
Orion Nebula

Becklin-Neugebauer Object

Trapezium Stars

Orion Bar

[CII] Emission @ 157.8 μm

Quicklook & I. FlatField applied

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Background image Spitzer by Thomas Megeath
Orion Nebula

Becklin-Neugebauer Object

Trapezium Stars

Orion Bar

[CII] Emission @ 157.8 µm

April 2014 & March 2015

Quicklook & I. FlatField applied

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Background image Spitzer by Thomas Megeath
The Orion Nebula by FIFI-LS

The continuum shows BN/KL, the bar and more of the cloud surrounding the HII region.

The [CII] emission is prominent in the PDRs.

Preliminary results of the M42 observations.

Below:
The [OIII] line ratio varies from the HII region into the bar: $T_e \sim 10^4 K; N_e \sim 10^3 cm^{-3}$
Orion Nebula

CO 22-21 @ 118 \( \mu \)m

Becklin-Neugebauer Object

Trapezium Stars

Background image Spitzer by Thomas Megeath
Orion Nebula

- Becklin-Neugebauer Object
- Trapezium Stars
- Orion Bar

Based on continuum slope @ 118 μm

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April 2014 & March 2015

Background image Spitzer by Thomas Megeath
Omega Nebula at \( \sim 2 \text{ kpc} \) is classic layered PDR region– nearly edge on (importance of feedback on star formation)

More recently, testbed of clumpy structures, especially with large magnetic field measurements (e.g., Pérez-Beauvuits et al. 2015)

Our observations use multiple transitions to derive physical parameters of region.
30 Doradus

30 Doradus in the LMC contains a super star cluster (R136)—feedback of the ISM in starburst environment (and lower metallicity)

Herschel results of important cooling lines are insufficient as extent of many e.g., [CII] are wide spread, so incomplete picture

Important to quantify CO-dark gas near R136 as indicator other regions
Thesis work from Melanie Chevance
Tele-talk on 30Dor Sept 28th!

- 90% of [CII] from PDRs
- [CII] ~0.1 to 1% of FIR luminosity
- High porosity -- small clumps of PDR clouds

Chevance et al. 2016
30 Dor

FIFI-LS [OIII] 88μm
FIFI-LS [CII] 158μm
VISTA J band
[OIII] Observations
FIFI-LS observations of 30Dor

[OIII] 88µm

[OIII] 52µm
Galactic Center

Galactic center harbors the circumnuclear disk

Torus of warm dense gas surrounding the central supermassive blackhole—inform accretion process

FORCAST continuum observations revealed details of CND edge.

Kinematics can provide detailed view

Lau et al. 2013
FIFI-LS GC

FORCAST

52 μm [OIII]
57 μm [NIII]
63 μm [OI]
88 μm [OIII]
145 μm [OI]
153 μm CO 17-16
157 μm [CII]
186 μm CO 14-13

33 mosaic fields

FOV blue array

FIFI-LS mosaic

FIFI-LS paper being led by Stuttgart grad student Aaron Bryant as part of thesis
FIFI-LS GC

FORCAST Continuum 37 \( \mu \)m

[OI] @ 63 \( \mu \)m

Continuum @ 63 \( \mu \)m
FIFI-LS GC

[OI] @ 63 μm

[OI] @ 145 μm

http://eeyore.astro.illinois.edu/gc.gif

[OI] @ 145 μm velocity
M82

Good example of galactic outflow, which are important for feedback and also the evolution of the super massive blackhole.

Hershel observations imply clouds from disk are captured by outflow into the wind

Clouds in outflow evaporate into small, dense cloudlets

Contursi et al. 2012
M82 Galaxy

Background image: HST, Spitzer & Chandra

North up, east left

© FIFI-LS Team
M82 Galaxy

Ionized Carbon @ 157 µm  
[CII] 11.3 eV

Background image: HST, Spitzer & Chandra  © FIFI-LS Team
M82 Galaxy

Ionized Carbon @ 157 µm

$[\text{CII}]$ 11.3 eV

Velocity from -200 km/s to +200 km/s

Background image: HST, Spitzer & Chandra

© FIFI-LS Team
M82 Galaxy

Ionized Carbon @ 157 μm

Background image: HST, Spitzer & Chandra

© FIFI-LS Team
M82 Galaxy

Oxygen [OIII] @ 52 µm

Background image: HST, Spitzer & Chandra

© FIFI-LS Team
M82 Galaxy

Oxygen [OIII] @ 52 µm

Background image: HST, Spitzer & Chandra
Upgrade Possibilities

• New entrance filter
  ~50% more transmission is possible for [OIII] 52 μm line

• Making the internal calibration source usable
  Better flat fields for improved data quality and more flexible observing modes faster mapping

• Details, details, details …..
  …… electronics upgrades, ghost hunt, observing modes
Summary

- FIFI-LS pipeline is working well and quickly producing good data on flights and now amplitude calibrated Level 4 maps.
- FIFI-LS is able to map large regions quickly, providing continuum and useful diagnostic lines in two separate bands simultaneously.
- We have many presented examples of important observations for variety of science cases—next step is to publish these data:
  - NGC 2024
  - Orion KL
  - M17
  - 30 Dor
  - GC
  - M87