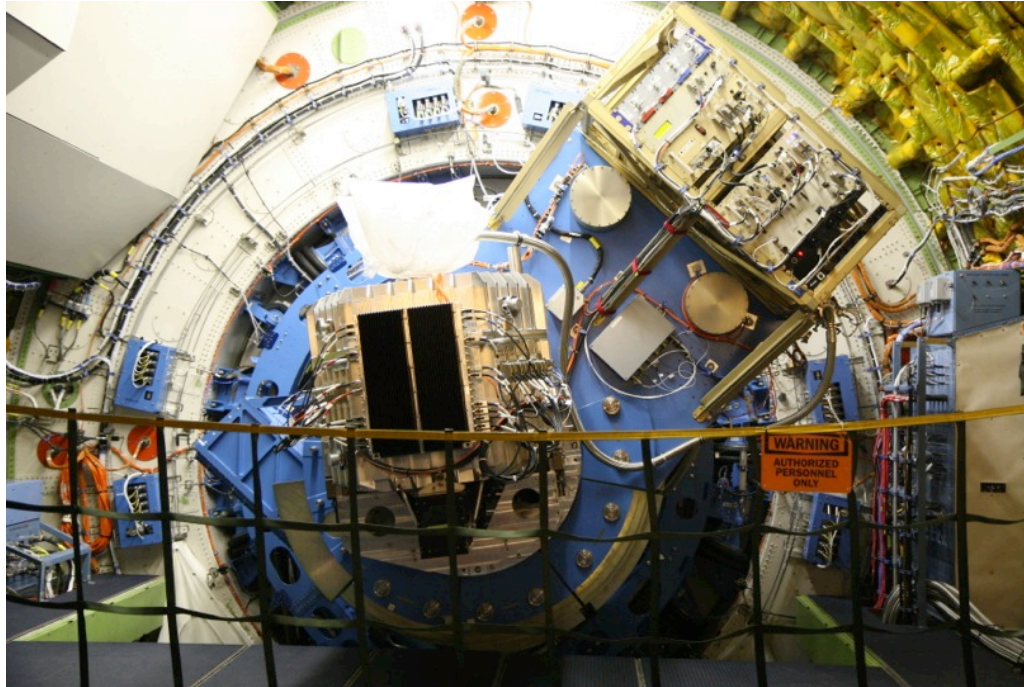




FIFI-LS Science Observations

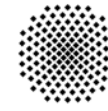


Leslie Looney
(Illinois)
+ FIFI-LS Instrument
& Science Team

The Team

S. Beckmann, A. Bryant, S. Colditz, C. Fischer,
F. Fumi, N. Geis, R. Hönle, C. Iserlohe, R. Klein,
A. Krabbe, L. Looney, A. Poglitsch, W. Raab,
F. Rebell, W. Vacca

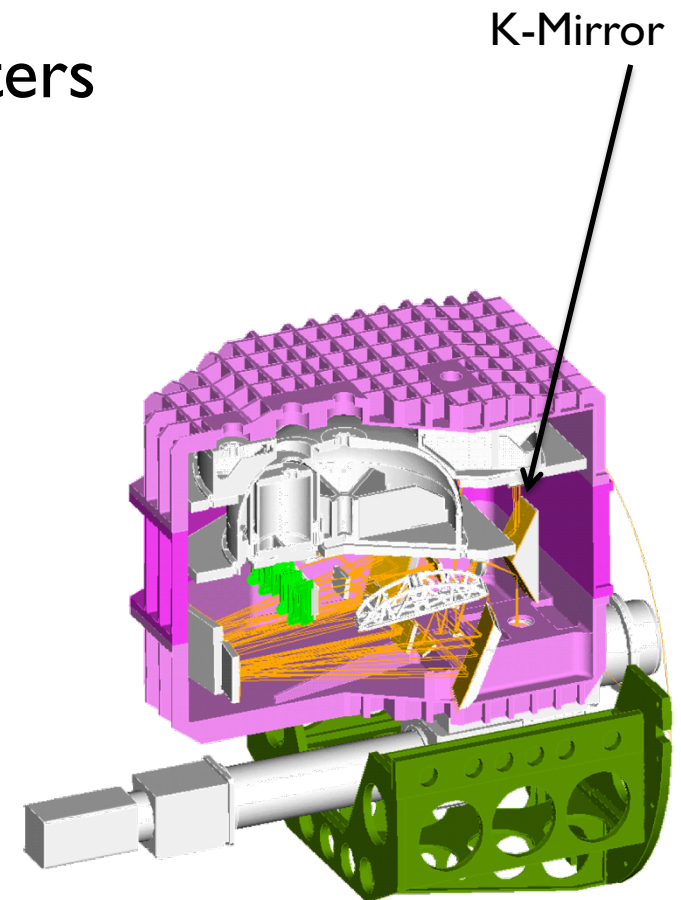
Special Guests:
M. Clarke, K. Hanna,
E. Starman, C. Trinh,
B. Wohler,

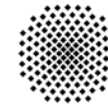


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aufgrund eines Beschlusses
des Deutschen Bundestages

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: $R=1000-2000$



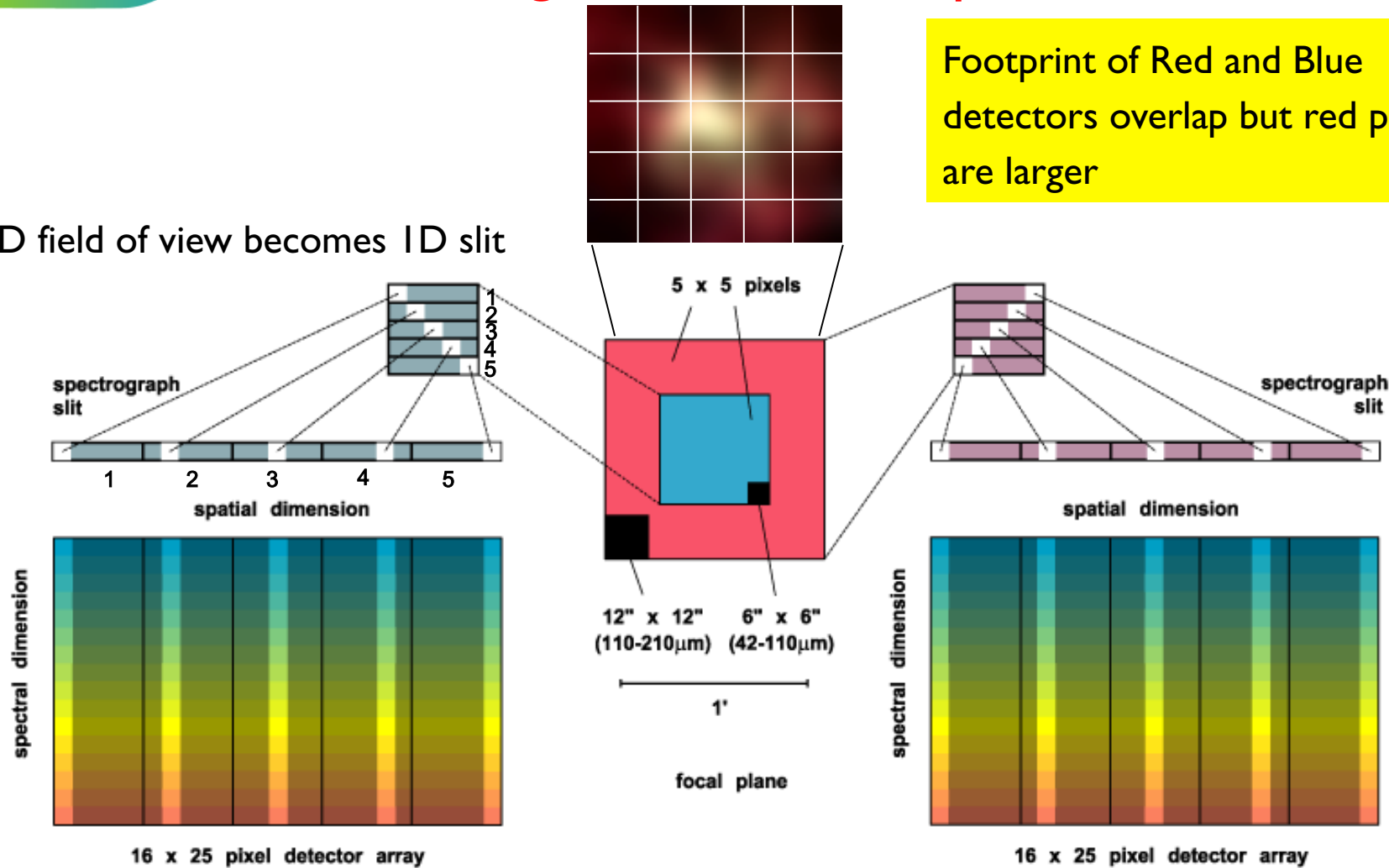


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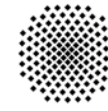
Integral Field Concept

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



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Main Observing Lines

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

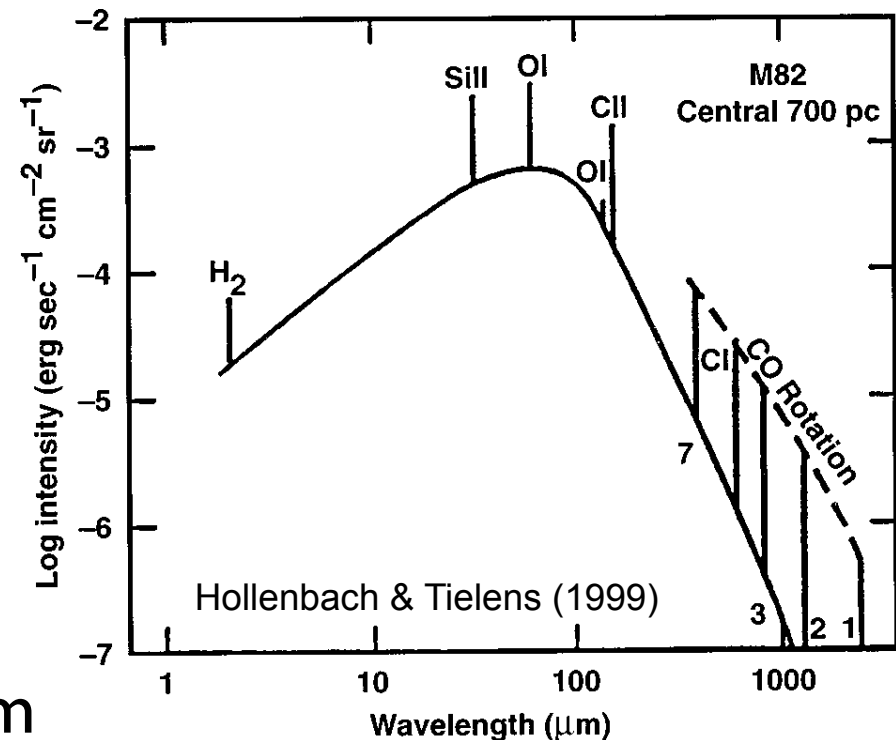
Main cooling lines of the interstellar gas in the FIFI-LS range:

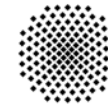
- [CII] $158 \mu\text{m}$
- [OI] $63.18 \mu\text{m}$, $145.4 \mu\text{m}$

In ionized regions:

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

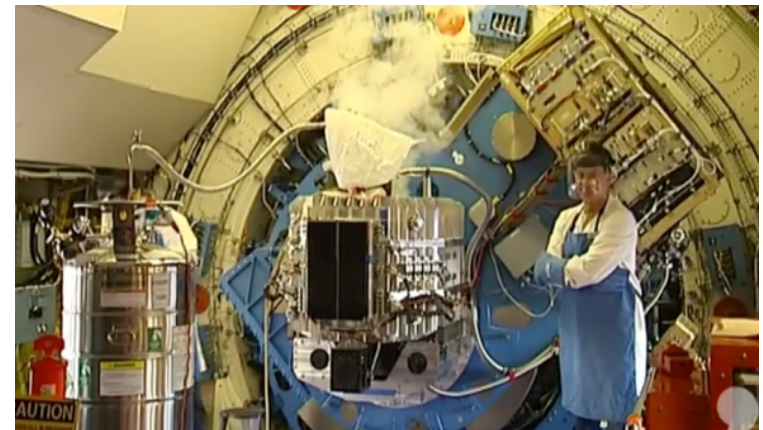
But also high- J CO lines, OH-lines etc.

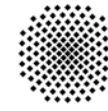




FIFI-LS Status

- 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





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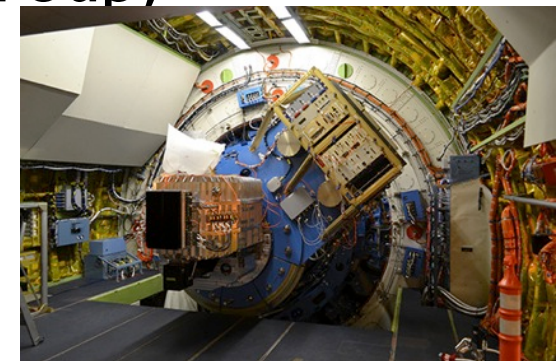
FIFI-LS In Flight Flexibility

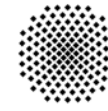
FIFI-LS observations fully editable in flight:
setups can be implemented
within minutes

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

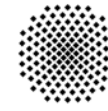
Incorporates parallel processing (huge increase in speed!)

Generates L2, L3, and L4 (multi-mission) data cubes

Incorporates nominal telluric corrections

Incorporates flux calibration for most wavelength settings





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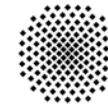
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Incorporates many of the lower level algorithms in the LabView reduction code written by R. Hoenle

Reproduces LabView results to within a few percent

Bad ramp detection is crucial as astronomical signal/sky $\leq 10^{-4}$



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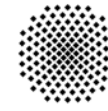
Works within existing DPS infrastructure (REDUX)

Allows steps to be performed sequentially by hand or automatically

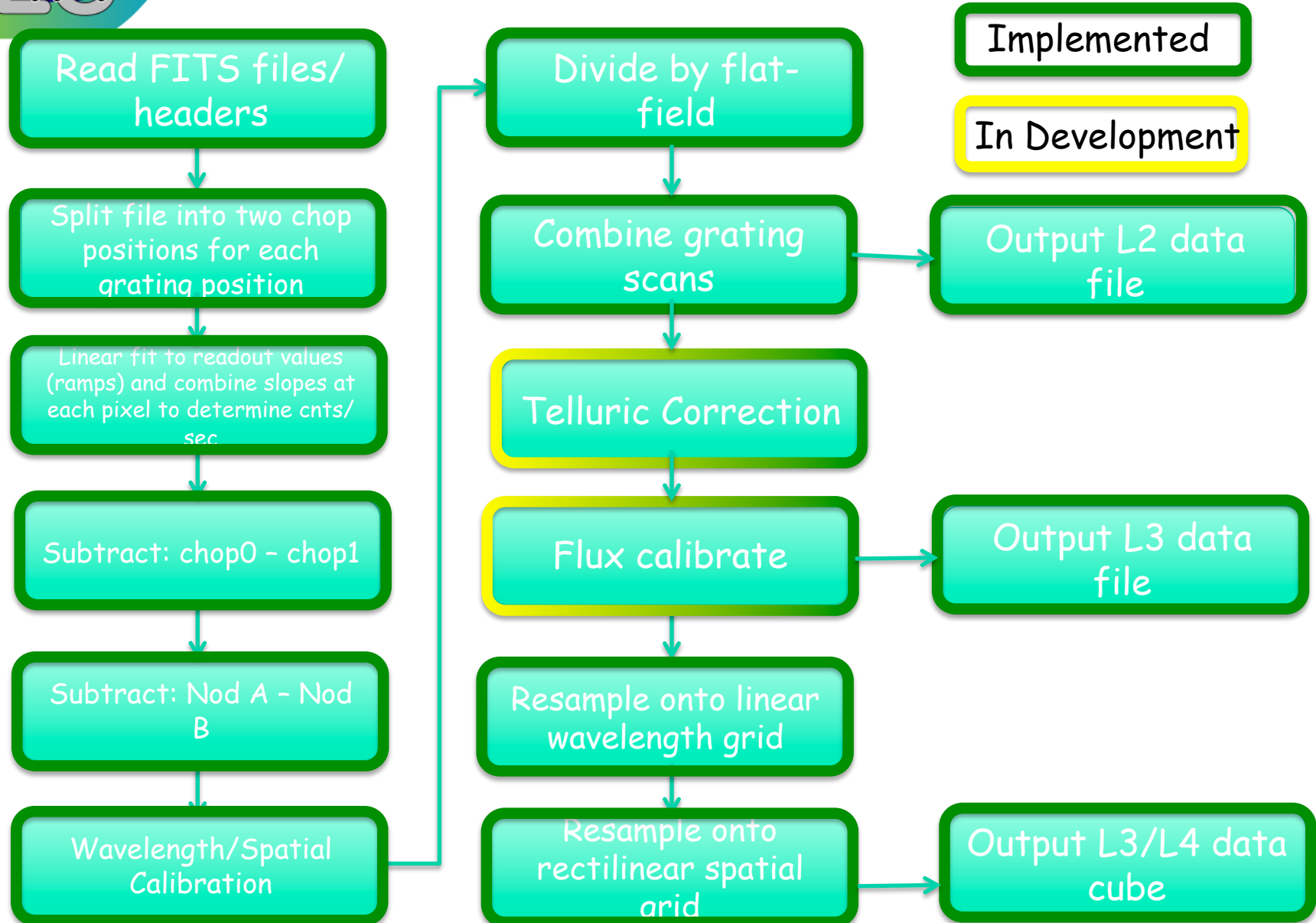
Displays results of each step when run manually



FIFI-LS Pipeline Steps:

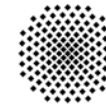


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Pipeline Example



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W43 at 158 μm

File Parameters Display

PIPE: FIFI_LS pipeline for FIFI_LS

Loaded files:
00028_043122_00001a_F022_W43_Act02_north_
00029_043210_00001a_F022_W43_Act02_north_
00030_043258_00002_F022_W43_Act02_north_
00031_043346_00003_F022_W43_Act02_north_
00032_043434_00004_F022_W43_Act02_north_
...
00200_054538_00050_F019_W43_Act01_30_2

More Info

Step Undo Reduce Reset

Step to:

Load Data Edit Param Run

Split Grating/Chop Edit Param Run

Fit Ramps Edit Param Run

Subtract Chops Edit Param Run

Combine Nods Edit Param Run

Lambda Calibrate Edit Param Run

Spatial Calibrate Edit Param Run

Apply Flat Edit Param Run

Telluric Correct Edit Param Run

Combine Scans Edit Param Run

Wave Resample Edit Param Run

Register Edit Param Run

Spatial Resample Edit Param Run

File View Zoom Range Scale ColorMap Buffer Cursor Help

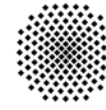
Current frame: 15 /60 Previous Next Send to buffer: 01 Done

X: 97.26, Y: 140.19, Z: 0.020545728

Done with reduction.



Pipeline Example

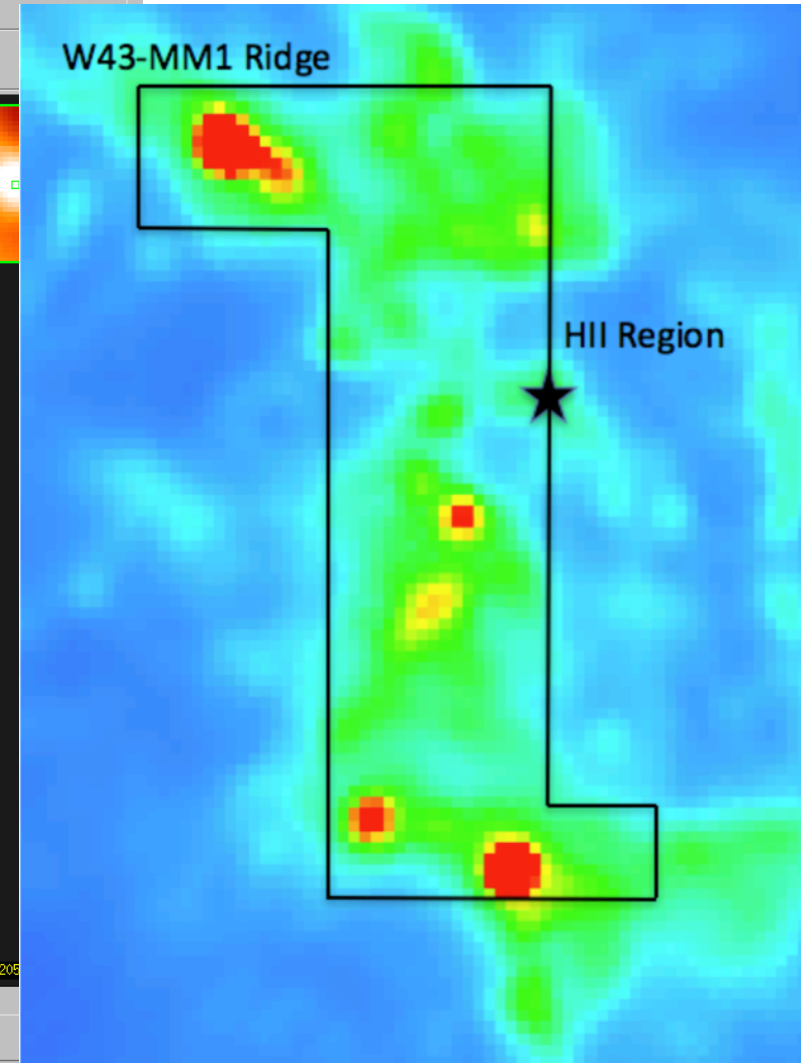


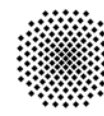
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und Technologie
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W43 at 158 μm

Done with reduction.

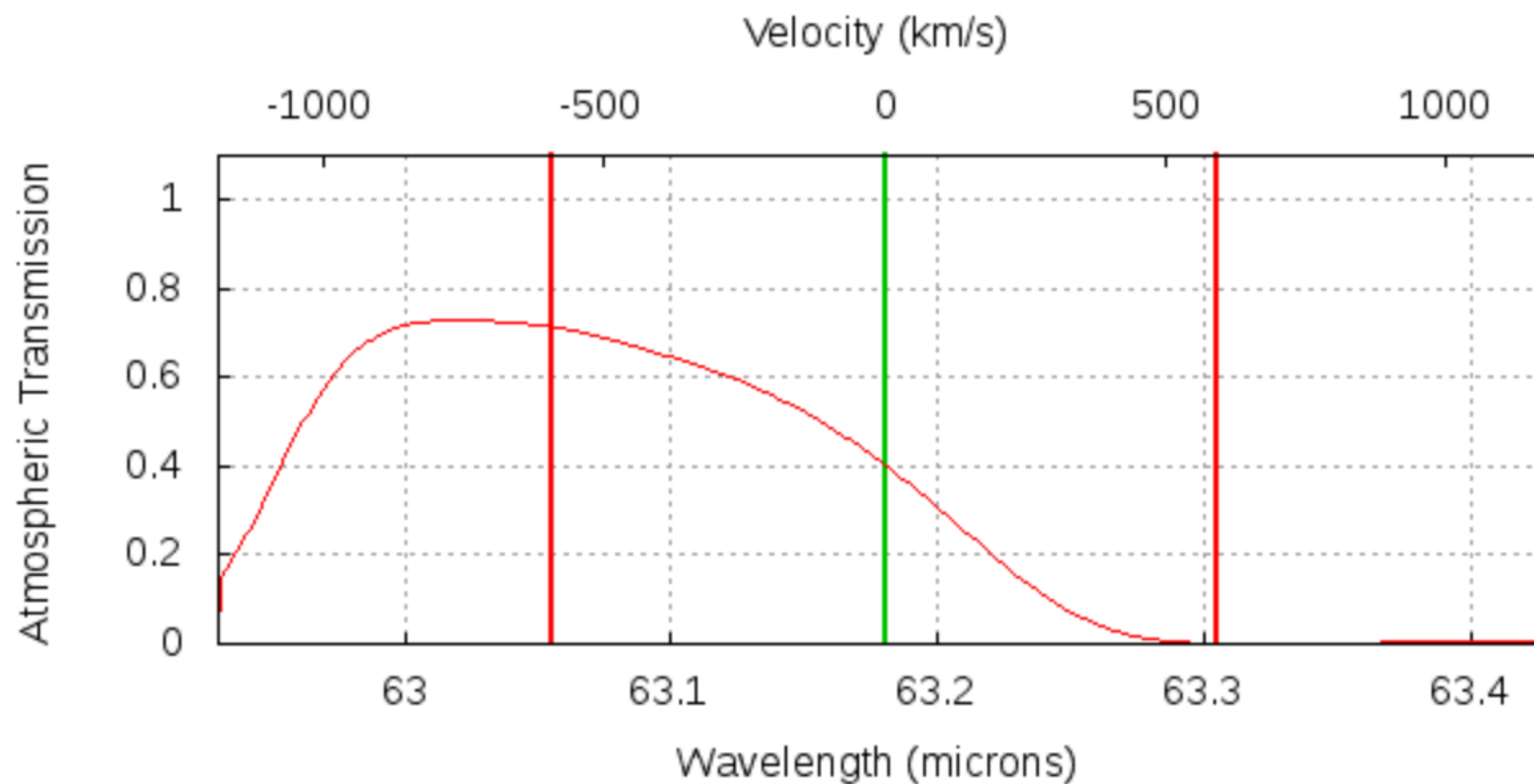
W43 at 250 μm Herschel



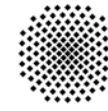


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Still the Atmosphere

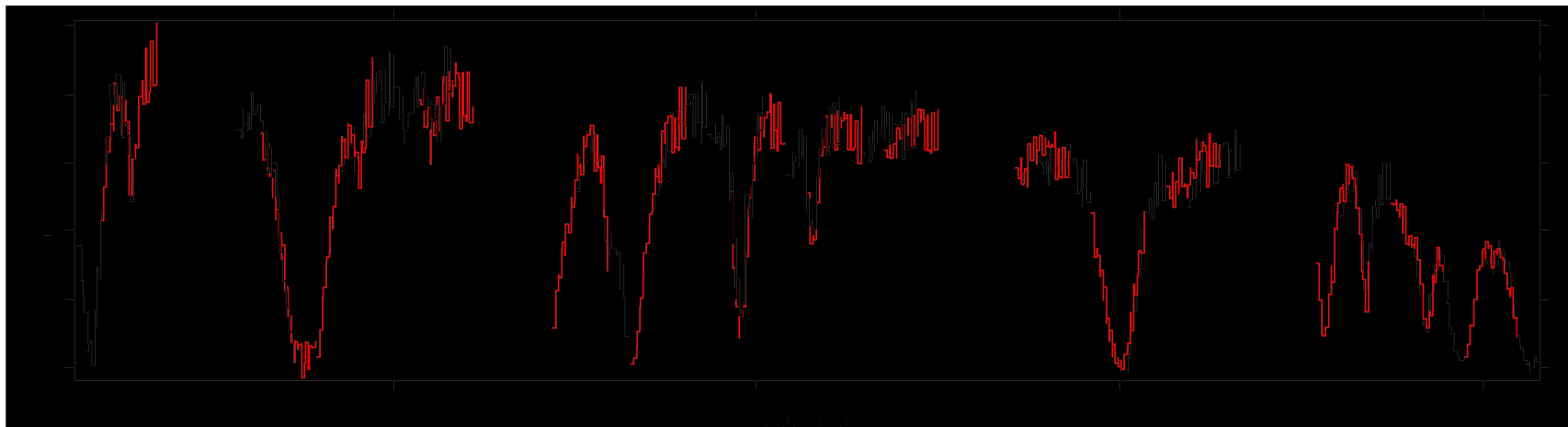
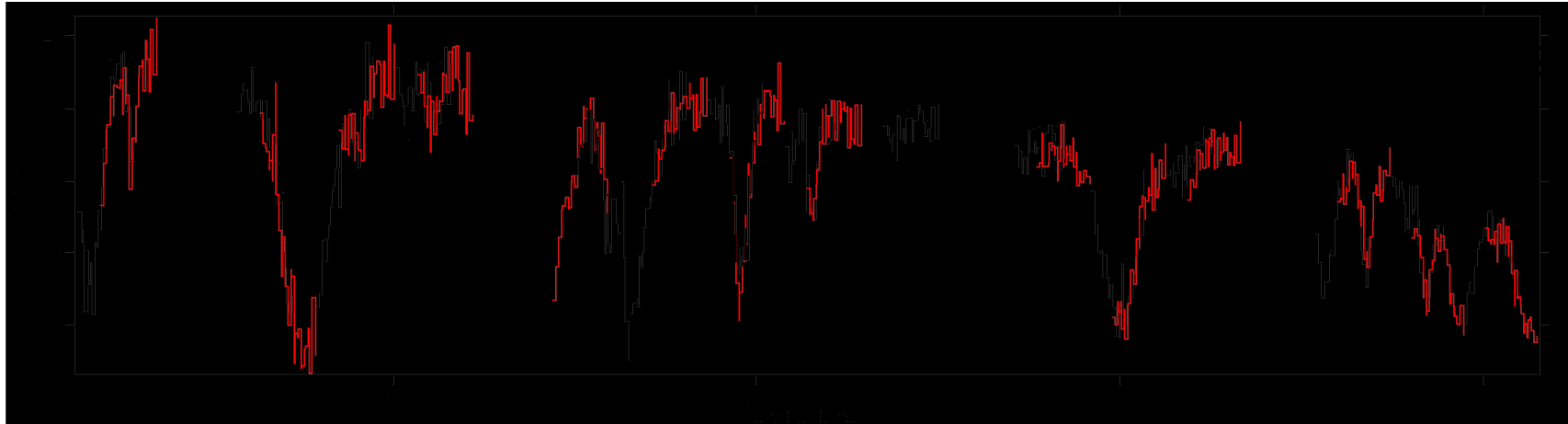


63.18 micron [OI] line

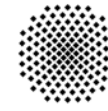


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FIFI-LS Search for CO₂ Ice



Team: Geoff Blake, Brandon Carroll, Brett McGuire, et al.

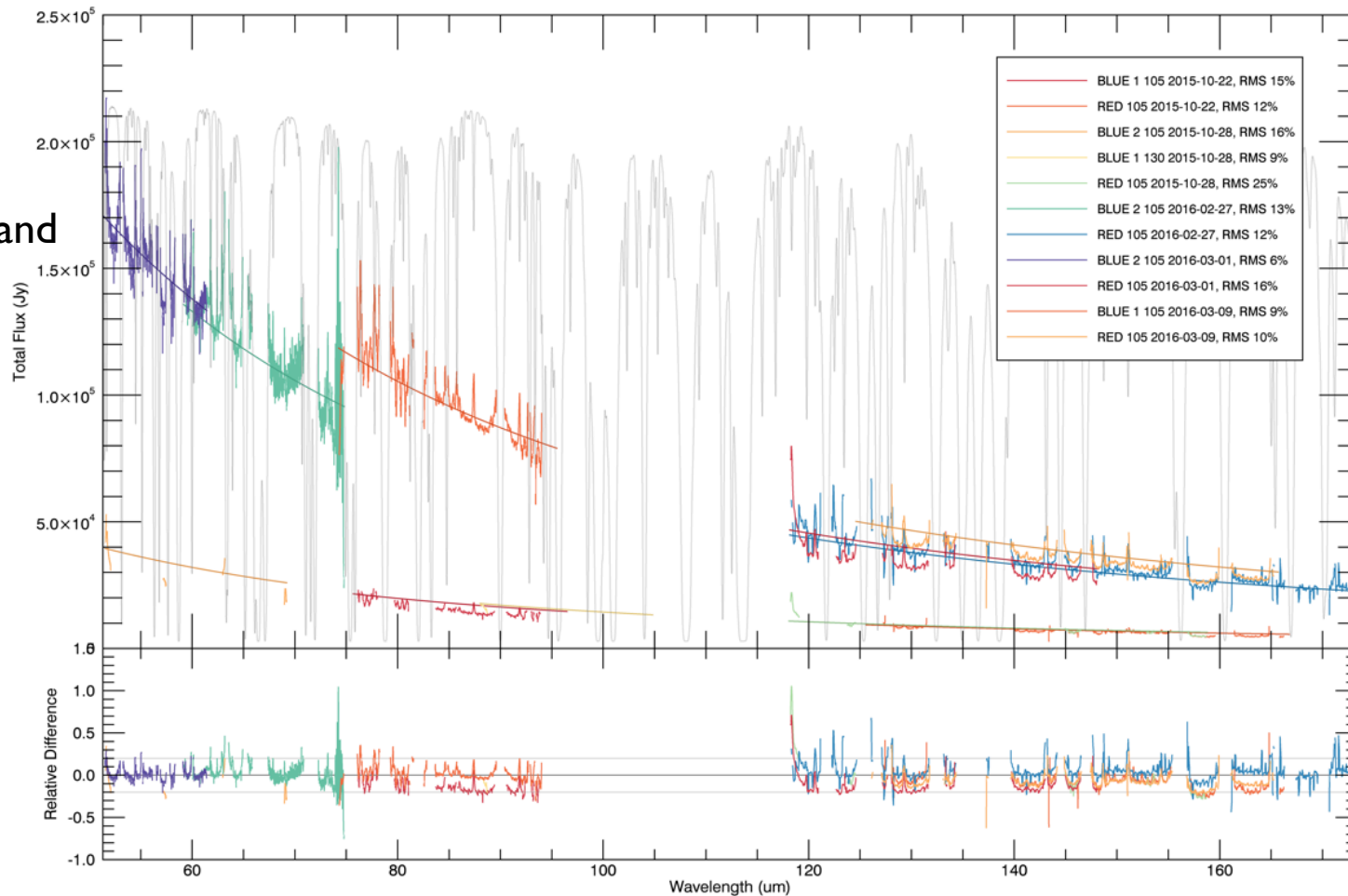


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Pipeline Flux Calibration: ~20%

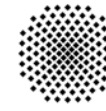
FIFI-LS Calibrated Mars Data vs. Model

Calibrated and
Model
Flux



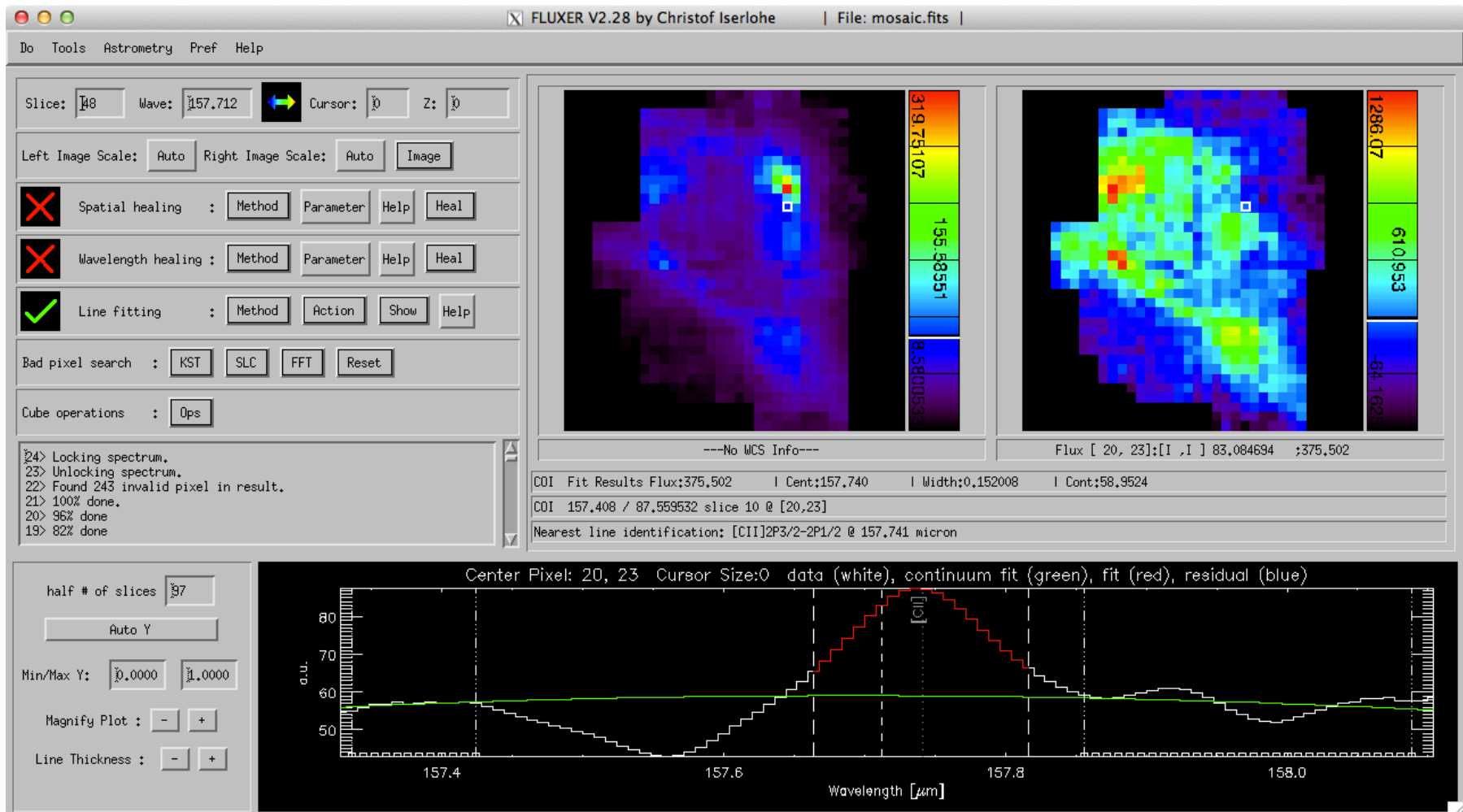
Residuals

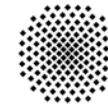
Wavelength



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Fluxer: Data Cube of M42





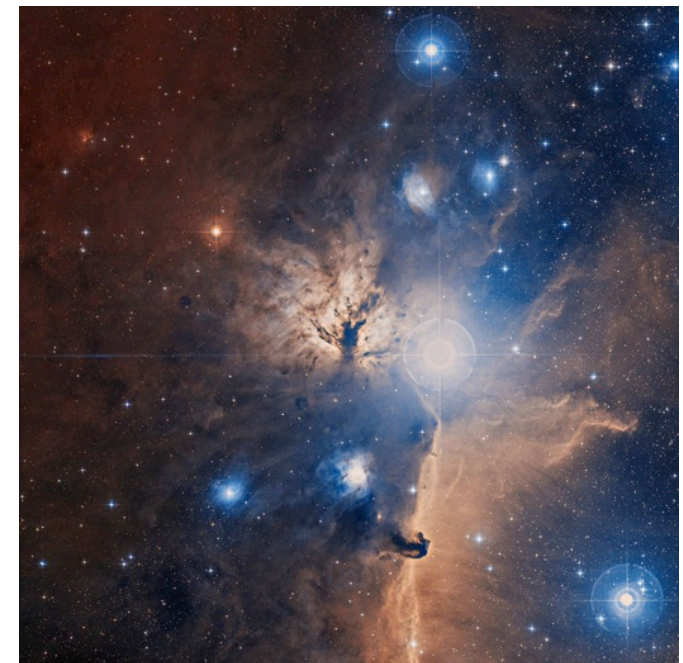
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NGC 2024

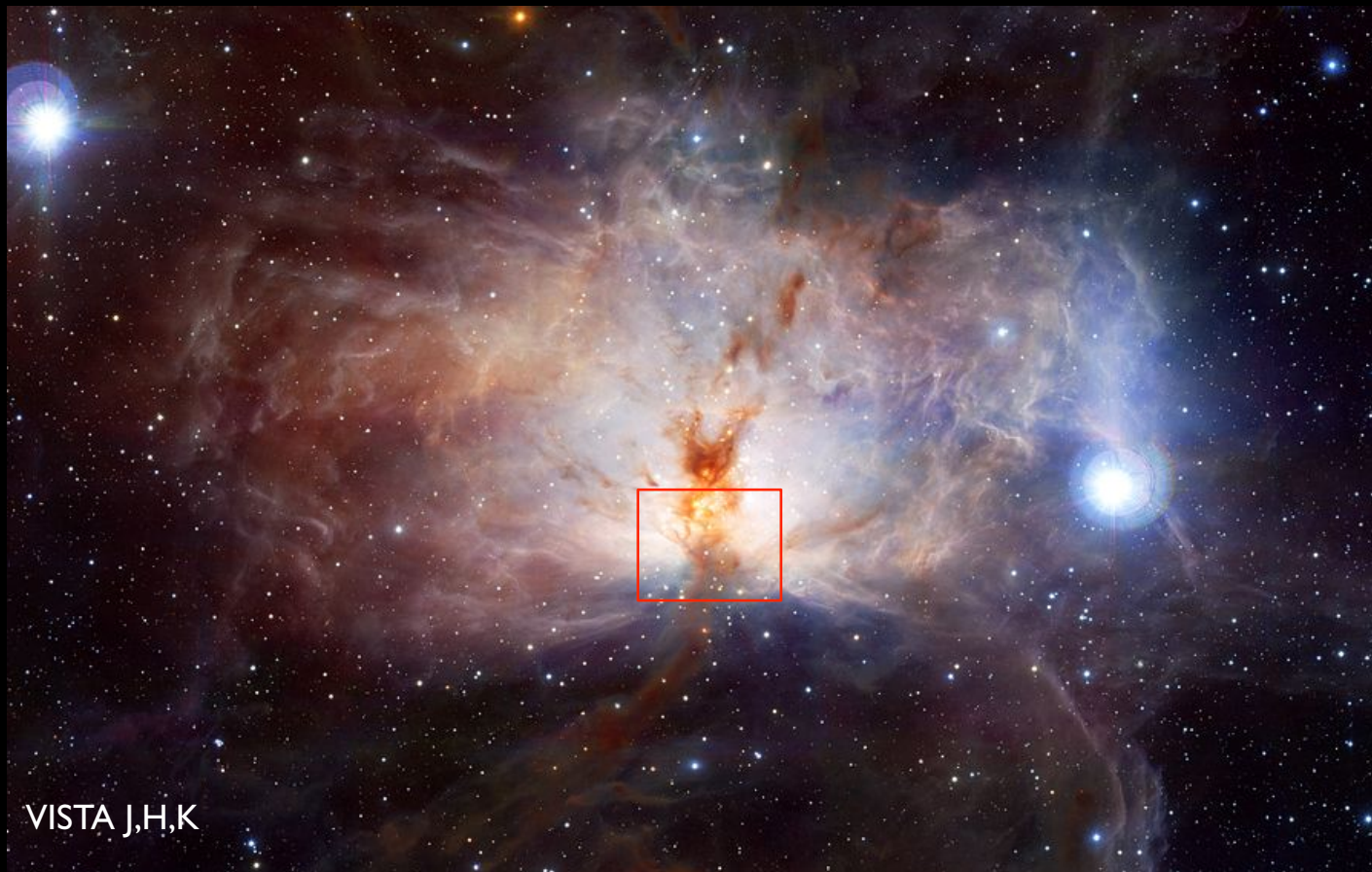
Part of the Orion B complex— good example of molecular cloud with an embedded HII region

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.



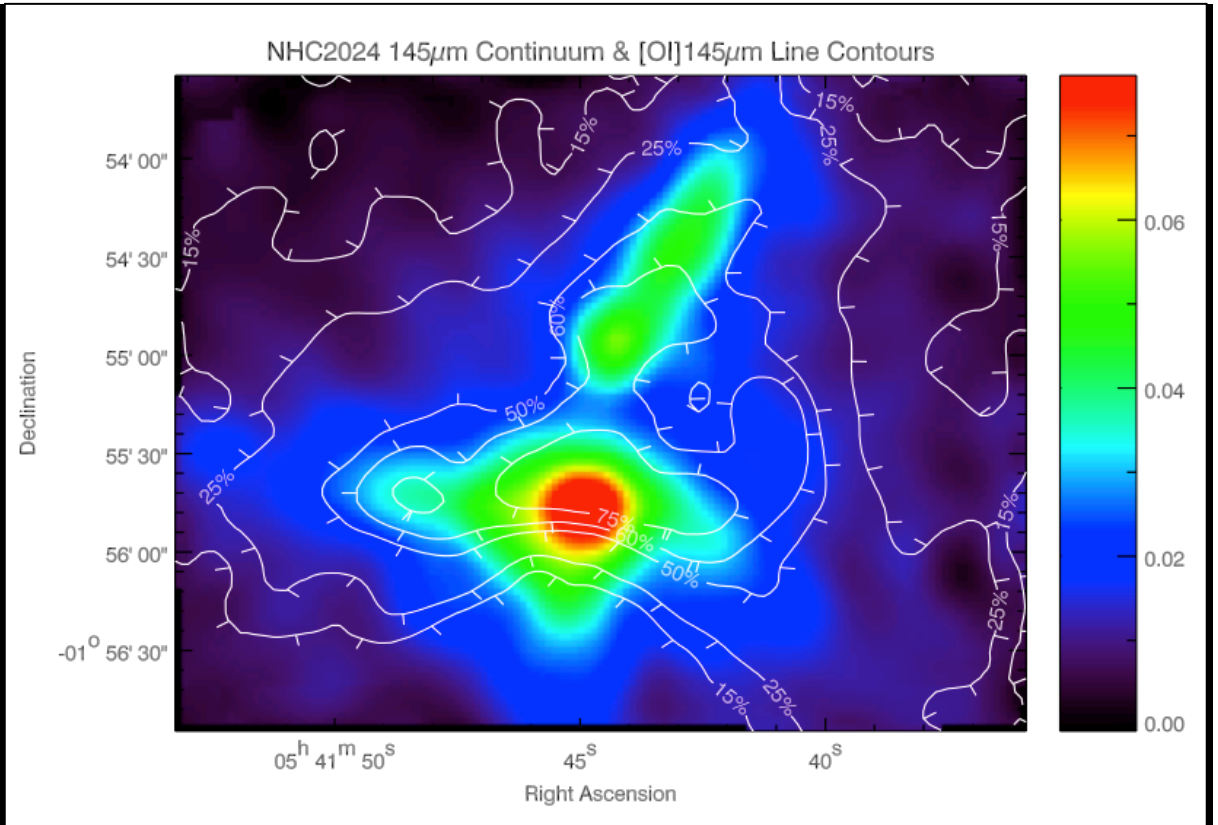
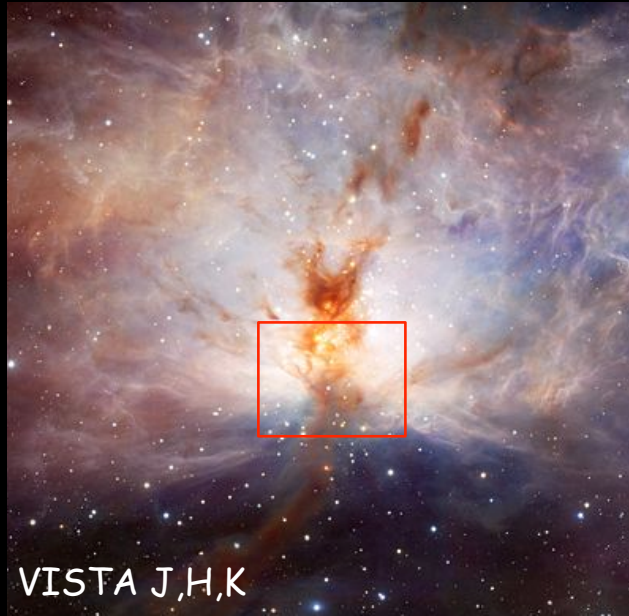
NGC 2024



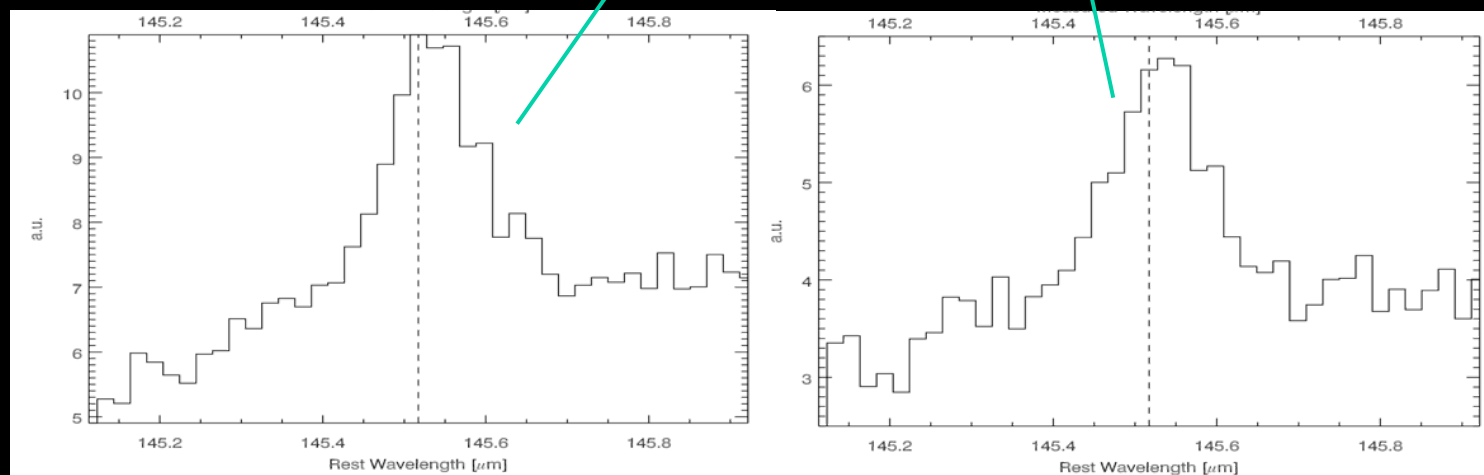
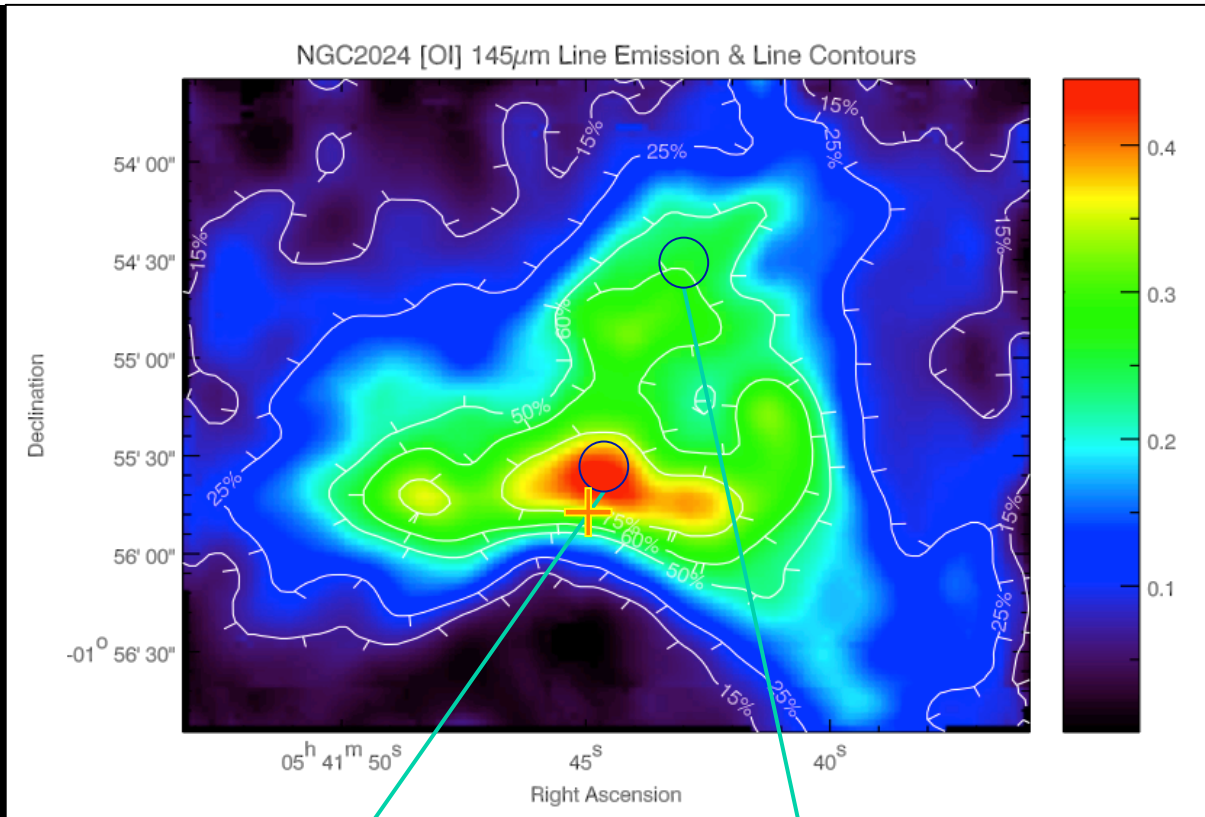
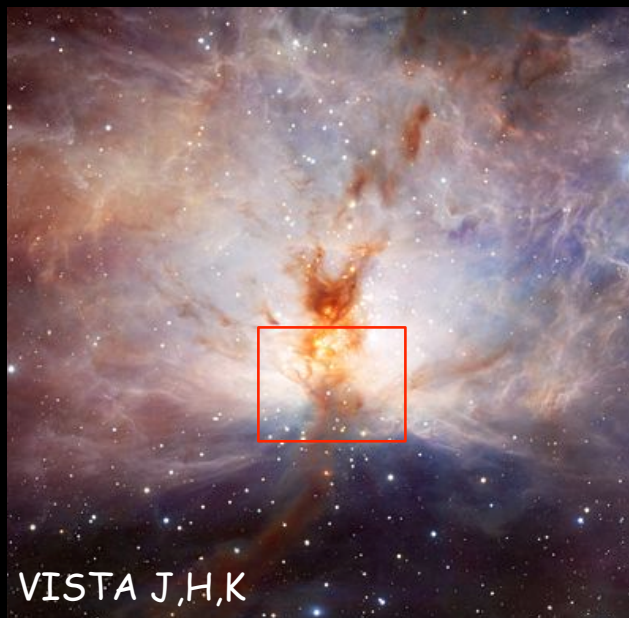
VISTA J,H,K

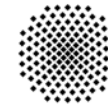
Approximate FIFI-LS mosaic size 4.5' x 3.5'

NGC 2024



NGC 2024





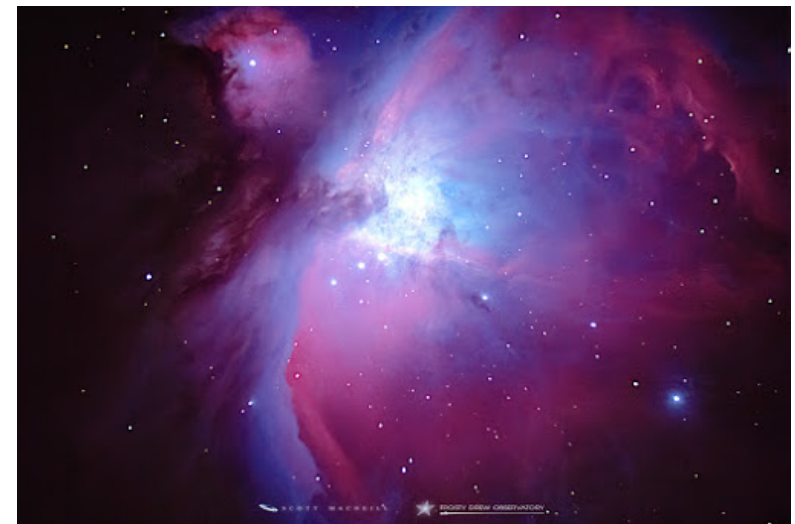
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Orion: Bar & Trapezium Region

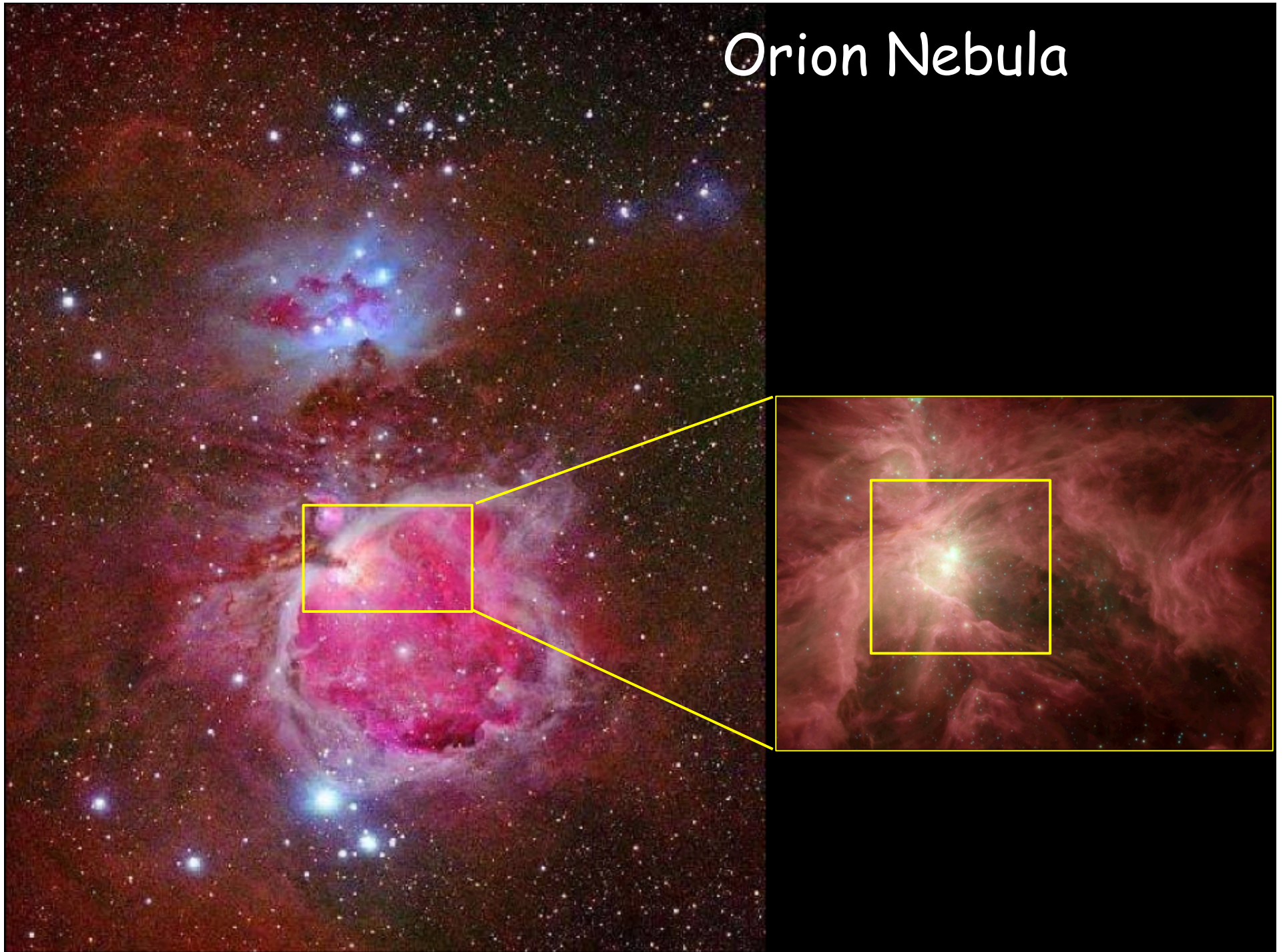
Orion is standard location to test new instruments:
important PDR region and overall template for Star
Formation

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



Orion Nebula

Becklin-Neugebauer Object

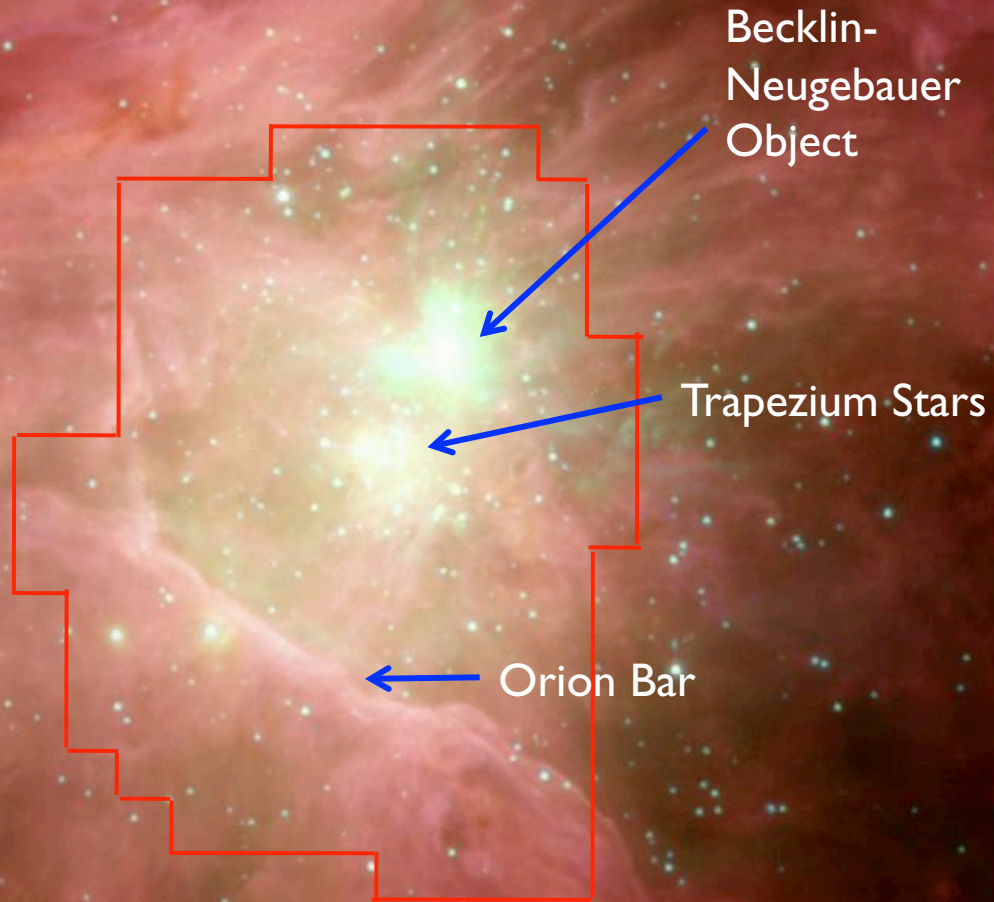
Trapezium Stars

Orion Bar



Hubble Space Telescope

Orion Nebula



Background image Spitzer by Thomas Megeath



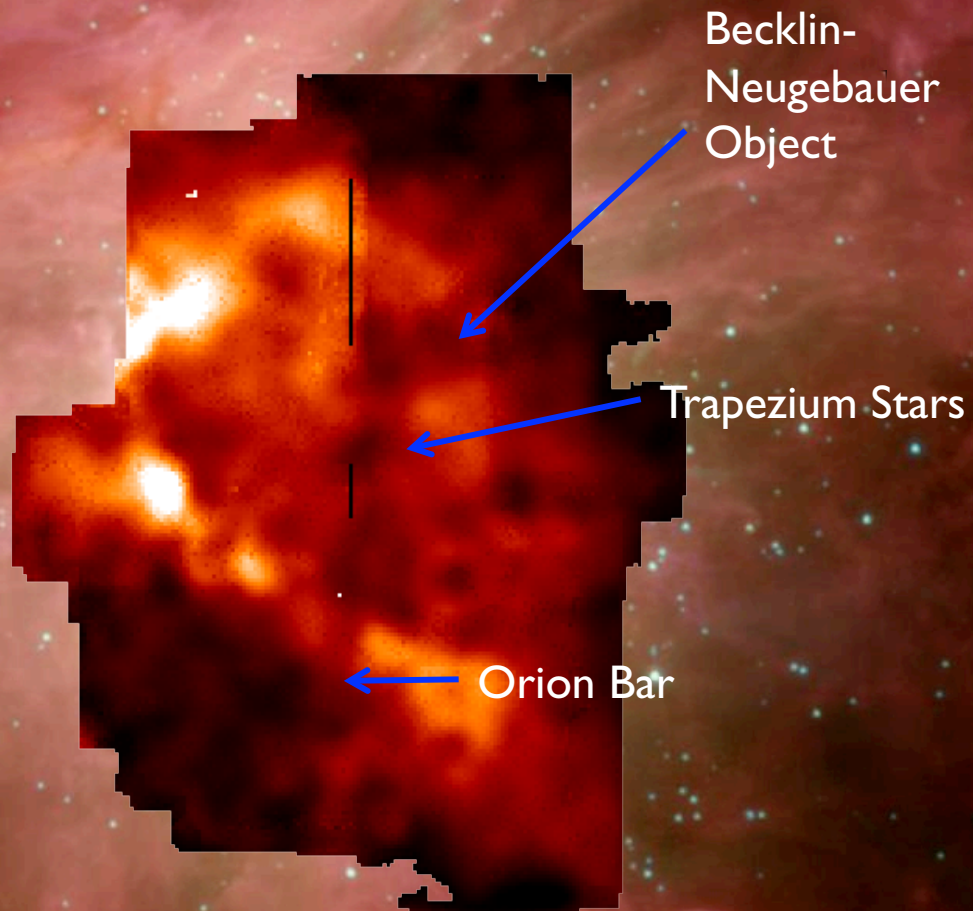
Orion Nebula

April 2014 &
March 2015

[CII] Emission
@ 157.8 μm

Quicklook &
I. FlatField
applied

© FIFI-LS Team



Background image Spitzer by Thomas Megeath

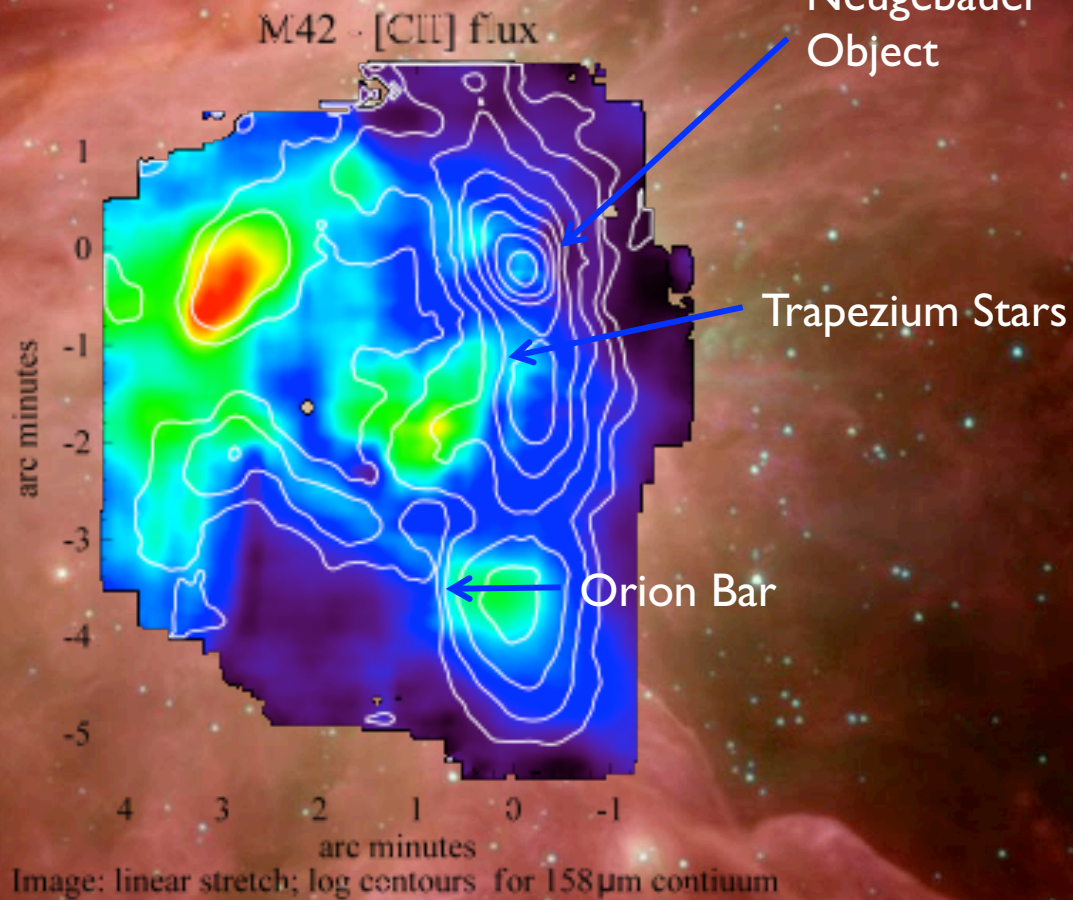
Orion Nebula

April 2014 &
March 2015

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Quicklook &
I. FlatField
applied

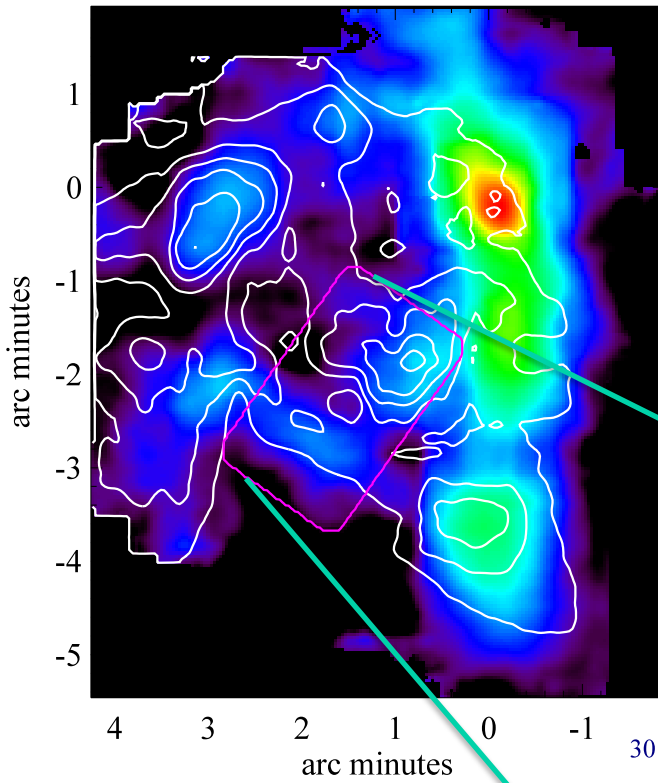
© FIFI-LS Team



Background image Spitzer by Thomas Megeath

The Orion Nebula by FIFI-LS

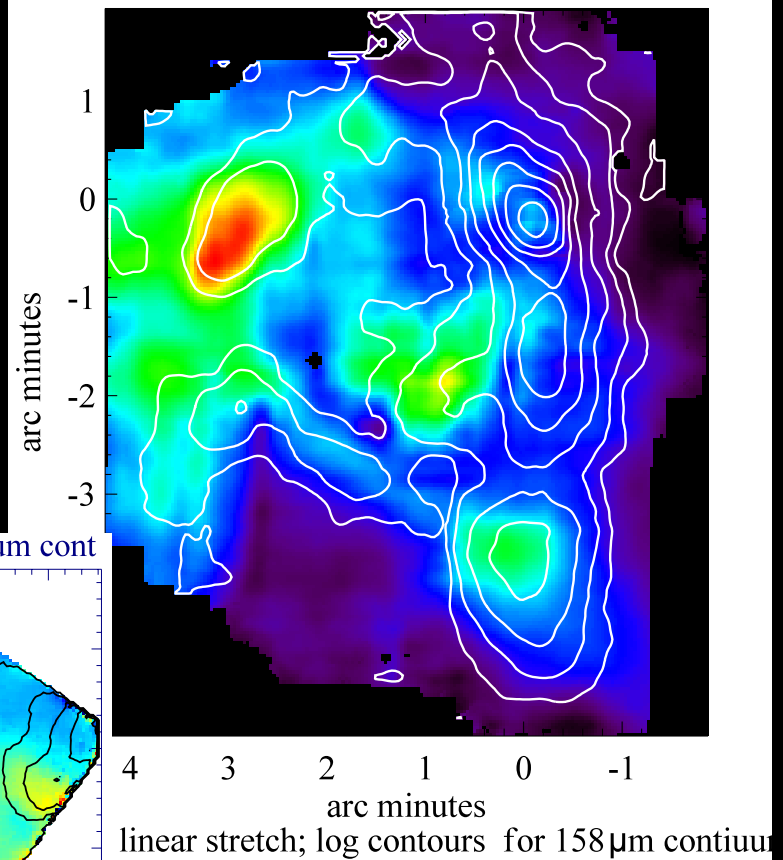
M42 - continuum at 158 μ m



Preliminary results of the M42 observations.

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

M42 - [CII] flux



[OIII] line ratio (f88/f52); 88um cont

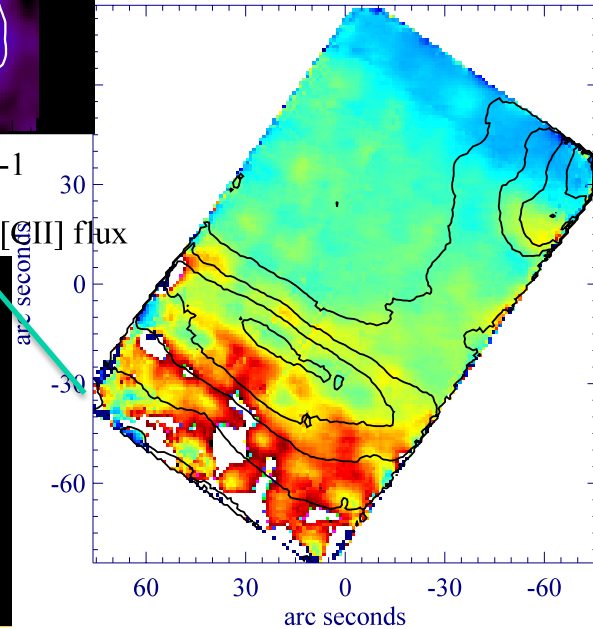


Image: log stretch; linear contours for [CII] flux

linear stretch; log contours for 158 μ m continuum

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

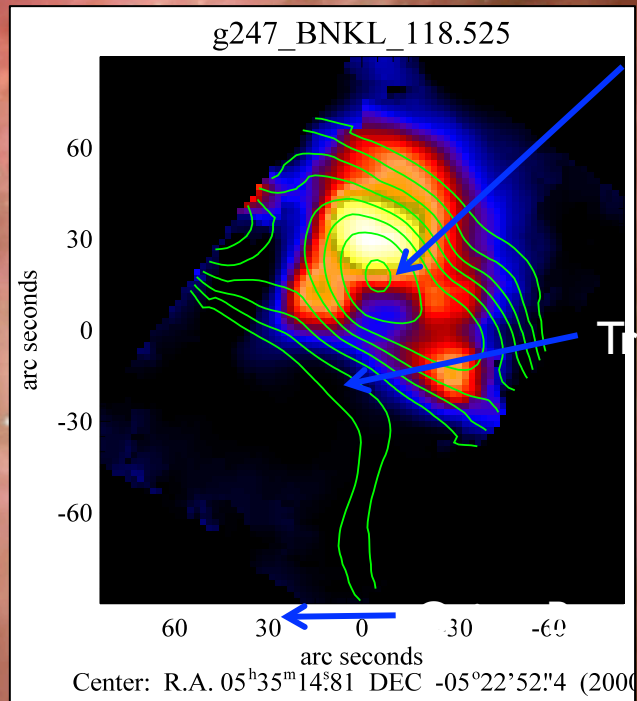
The [CII] emission is prominent in the PDRs.

Orion Nebula

CO 22-21 @ 118 μm

Becklin-
Neugebauer
Object

Trapezium Stars

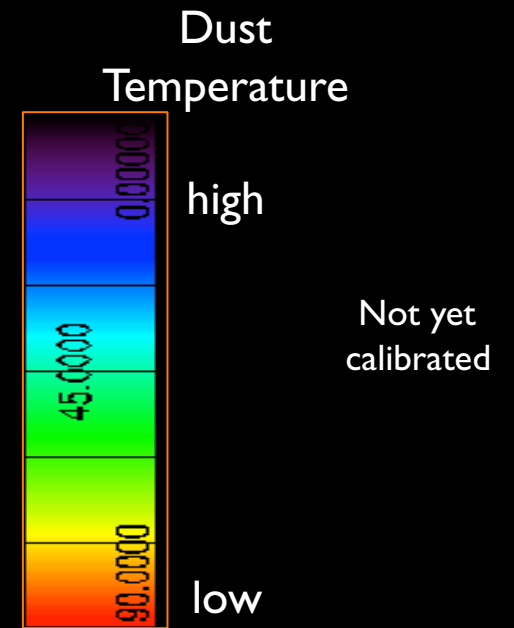
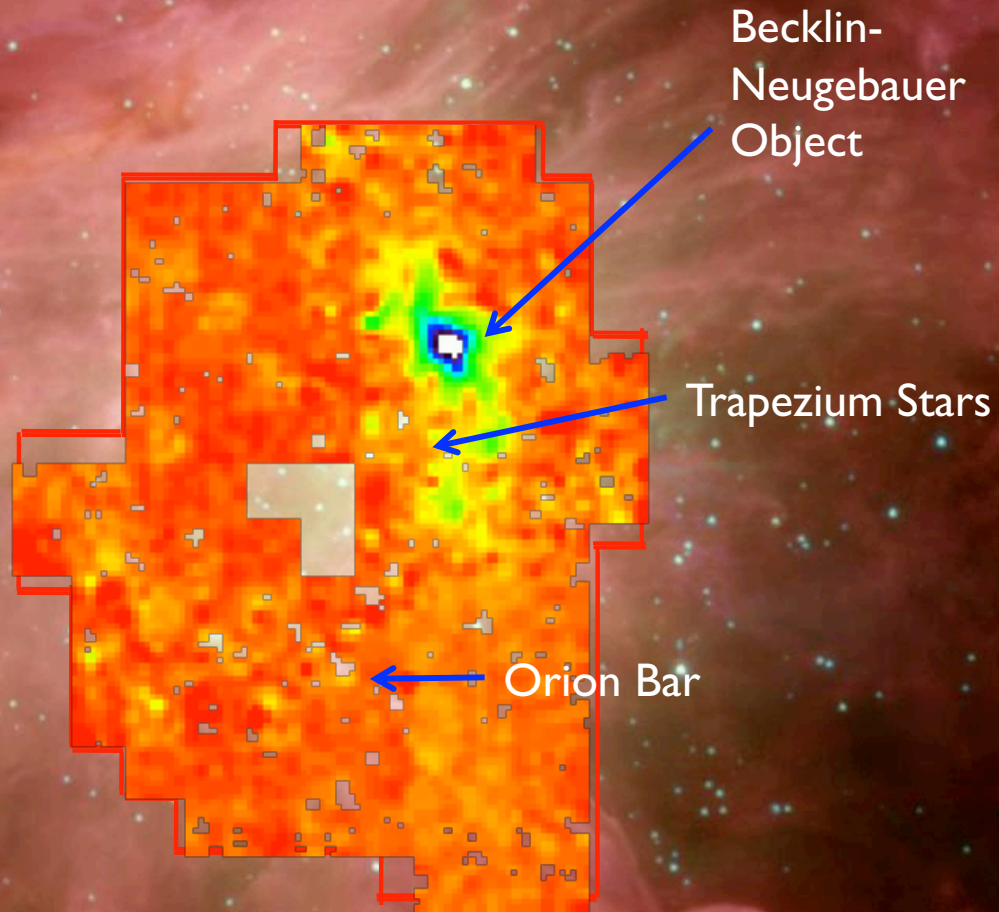


© FIFI-LS Team

Color: Lineflux
Contour: Continuum

Background image Spitzer by Thomas Megeath

Orion Nebula



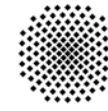
Based on continuum slope @ 118 μm

© FIFI-LS Team

Background image Spitzer by Thomas Megeath

April 2014 &
March 2015





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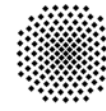
MI7

Omega Nebula at ~ 2 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-Beaupuits et al. 2015)

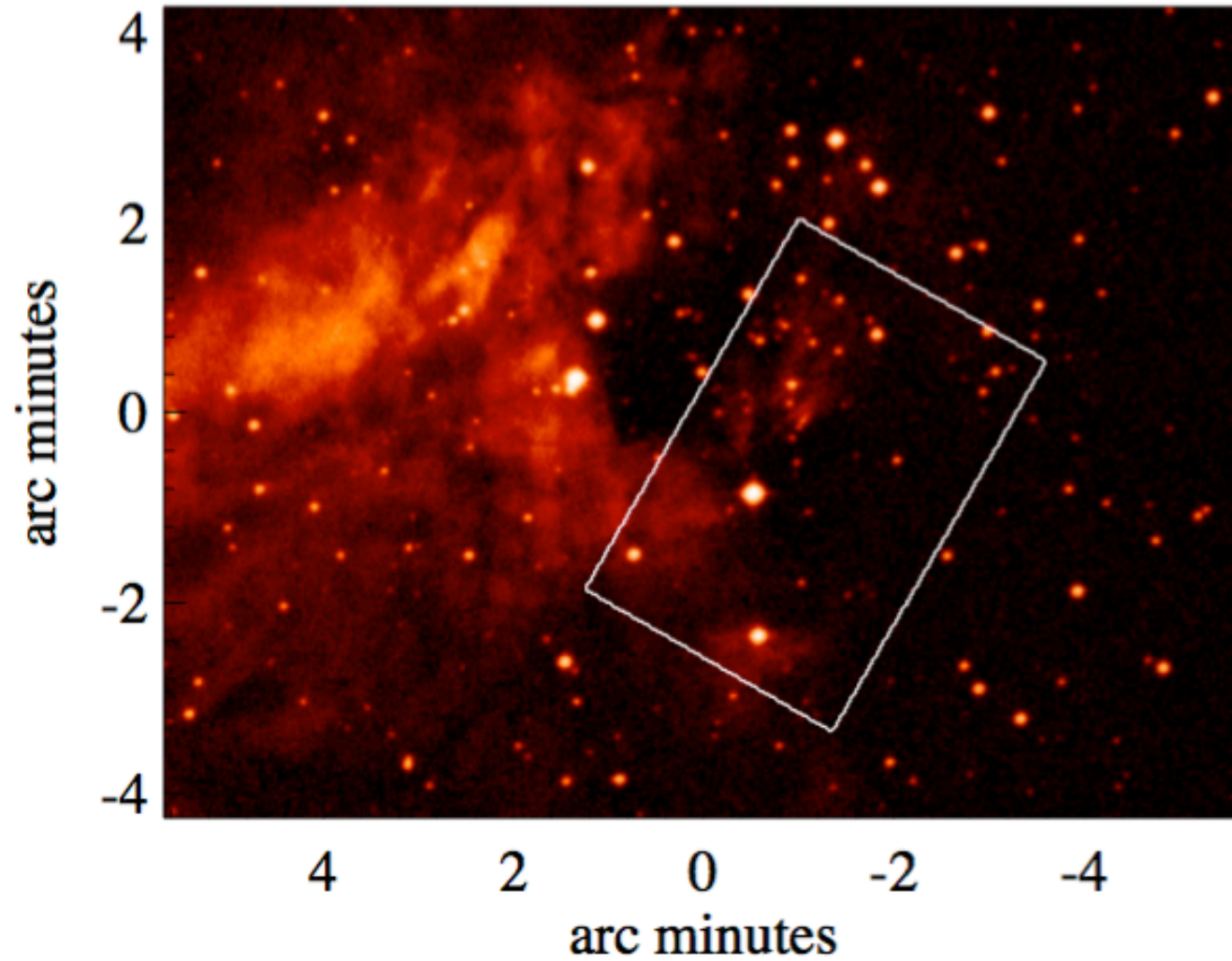
Our observations use multiple transitions to derive physical parameters of region.

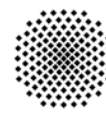




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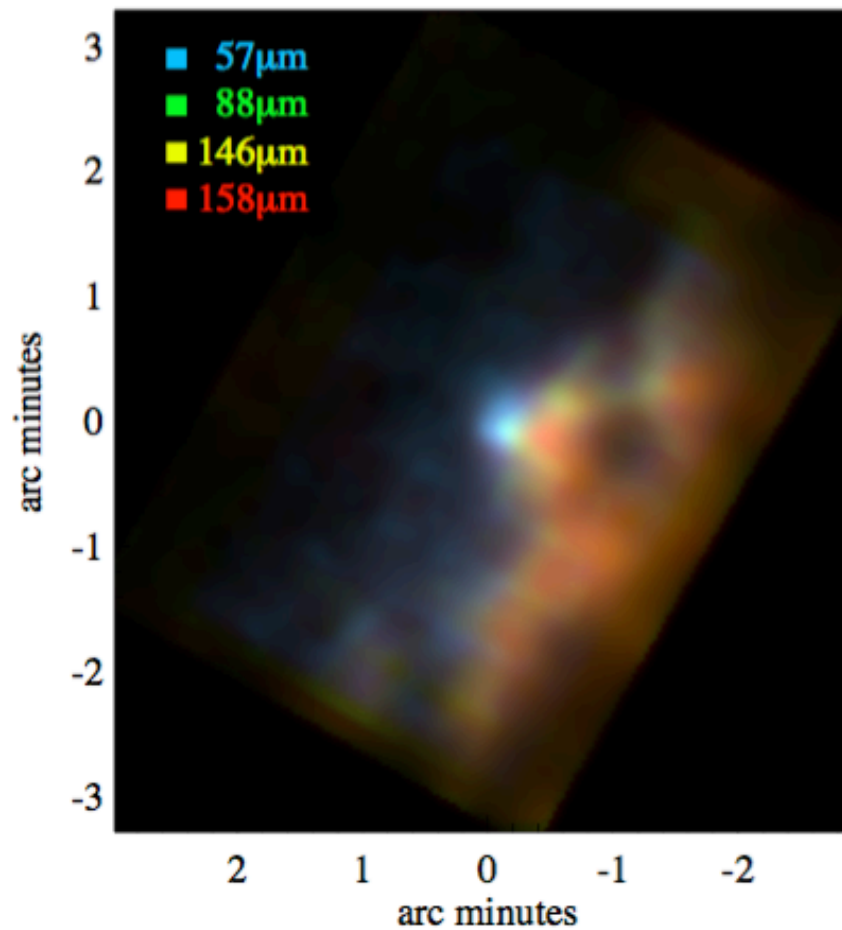
M17



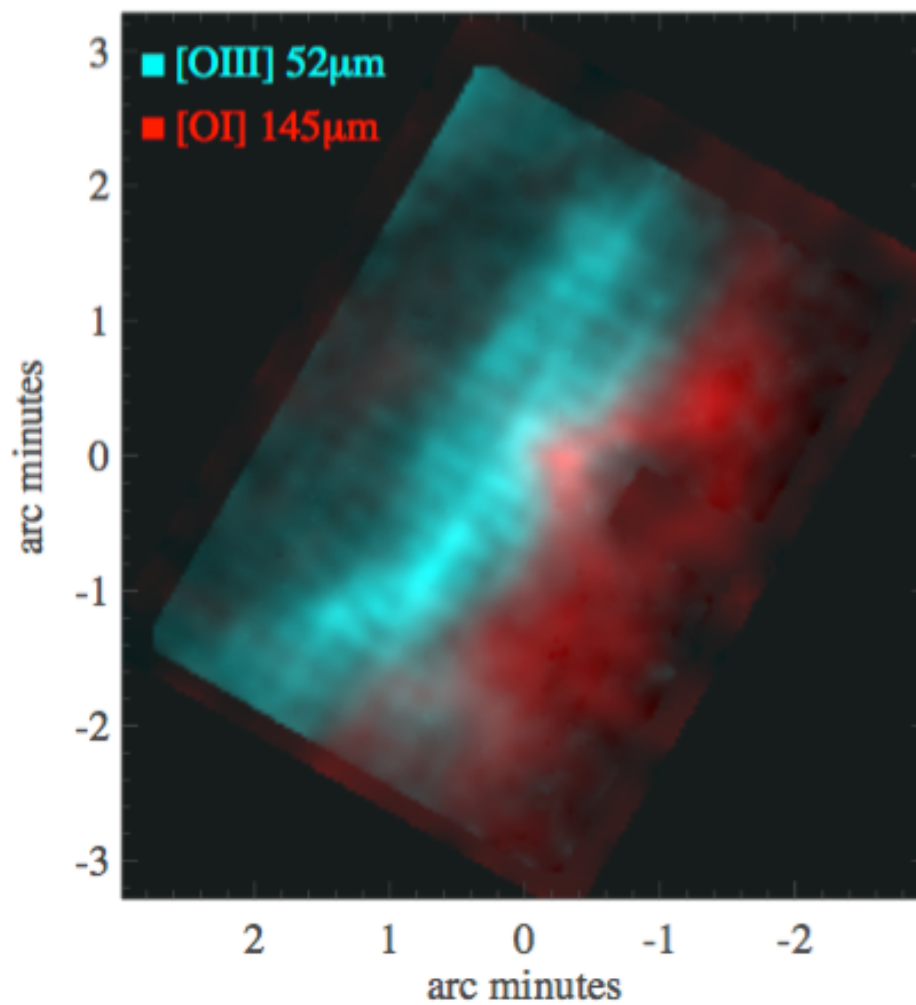


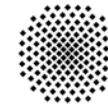
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M17-SW



M17-SW





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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

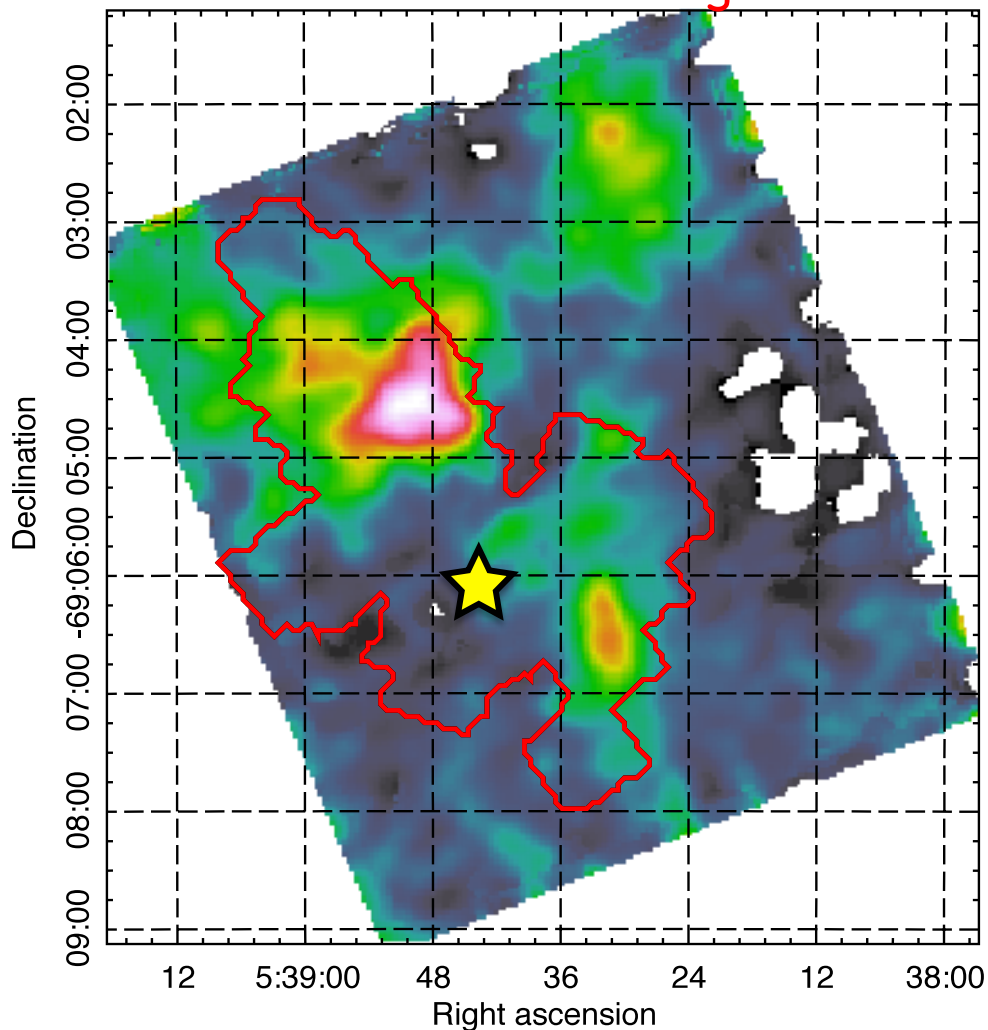




[CII] 158 μ m

Background image: FIFI-LS

Red contour: PACS coverage



Thesis work from
Melanie Chevance
Tele-talk on
30Dor Sept 28th!

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

Chevance et al. 2016

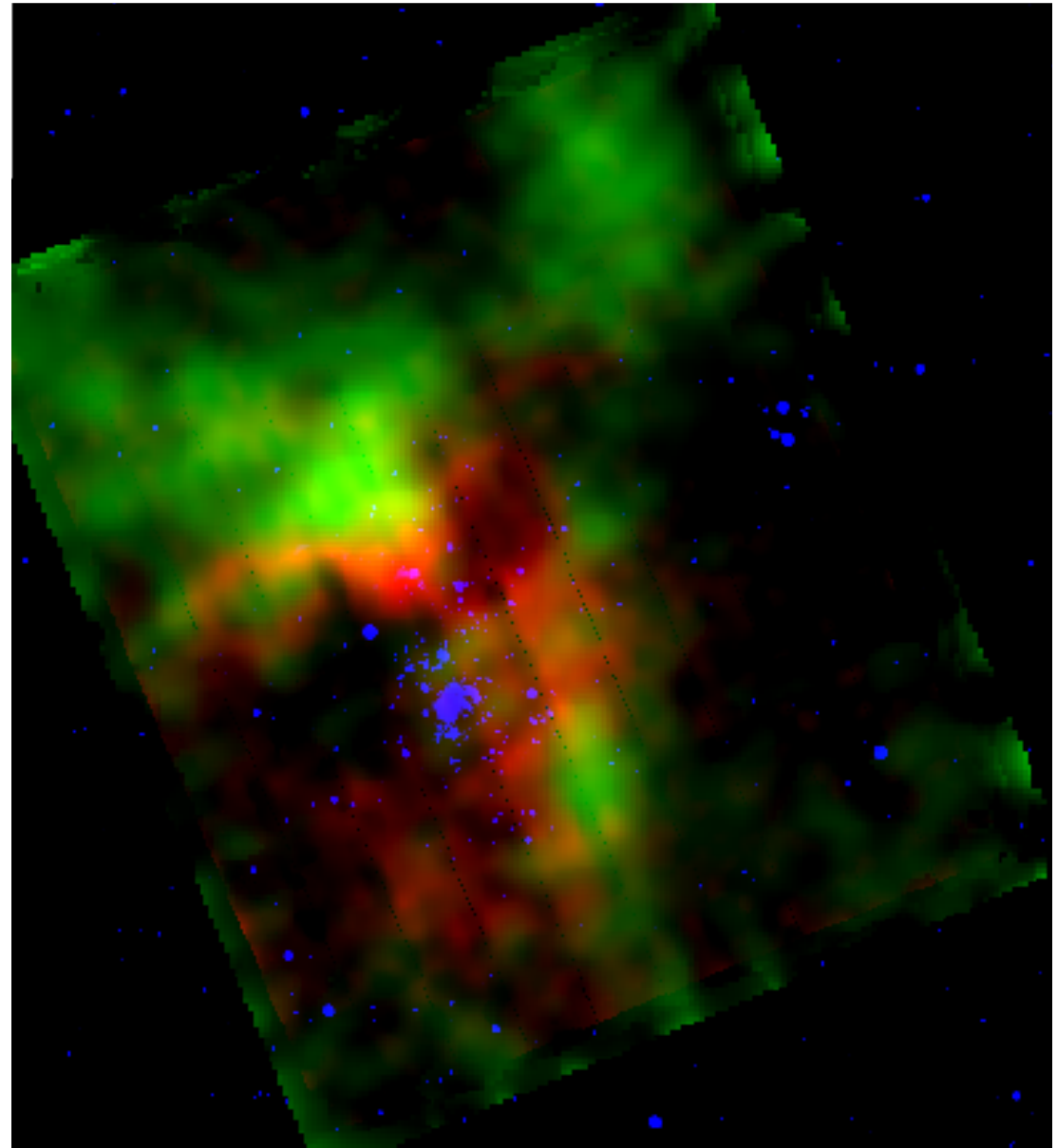


30 Dor



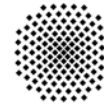
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des Deutschen Bundestages

FIFI-LS [OIII] 88 μ m
FIFI-LS [CII] 158 μ m
VISTA J band



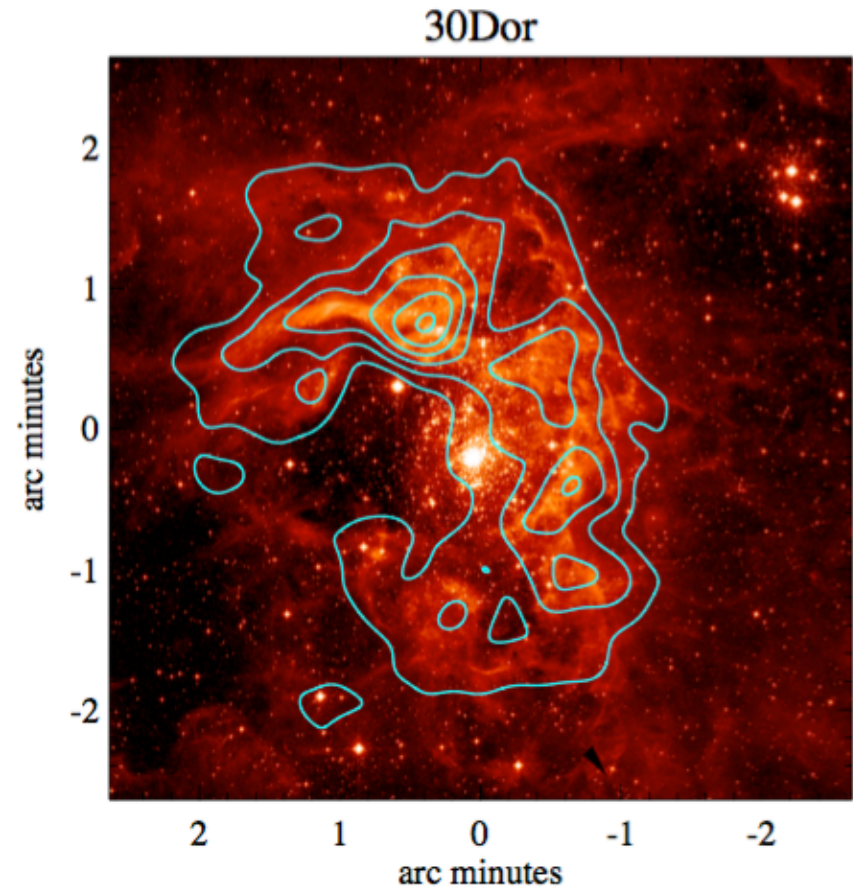
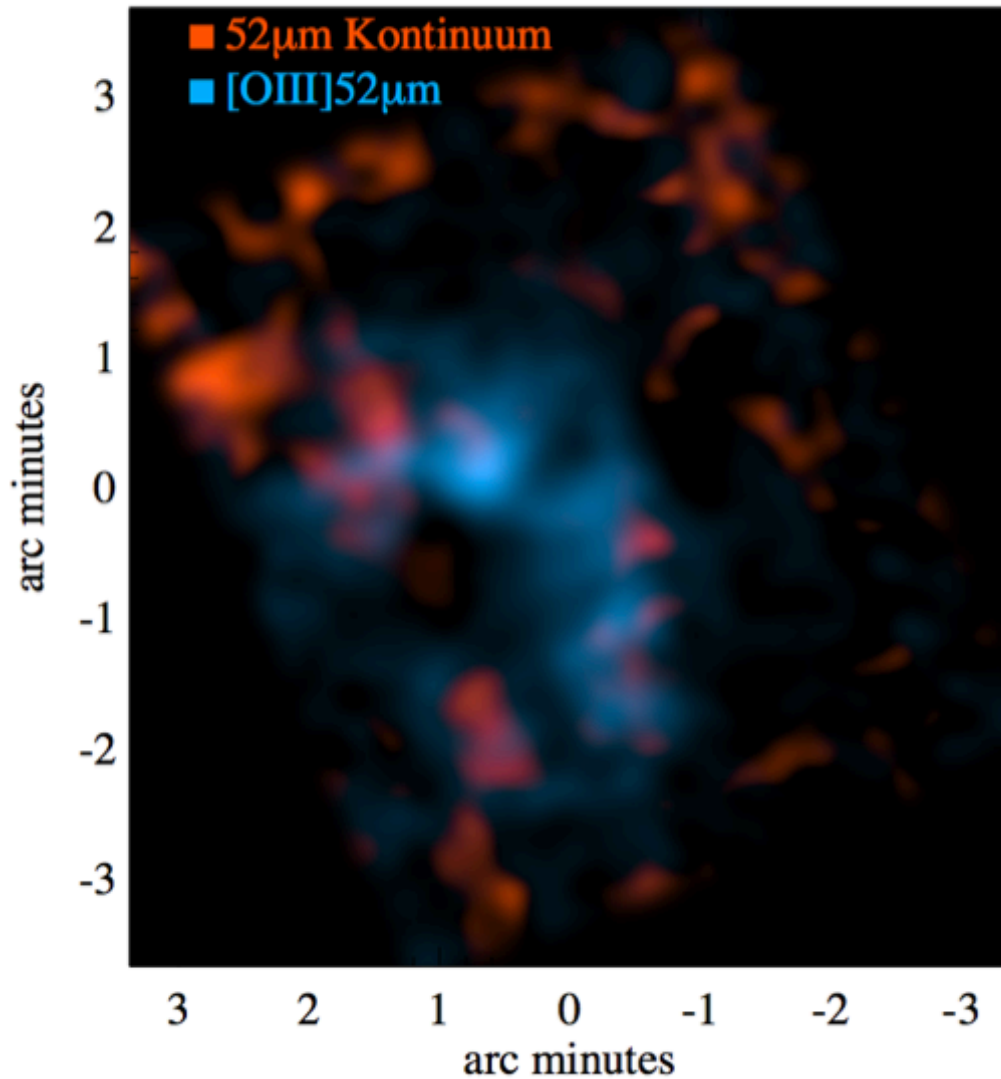


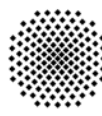
[OIII] Observations



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30Dor

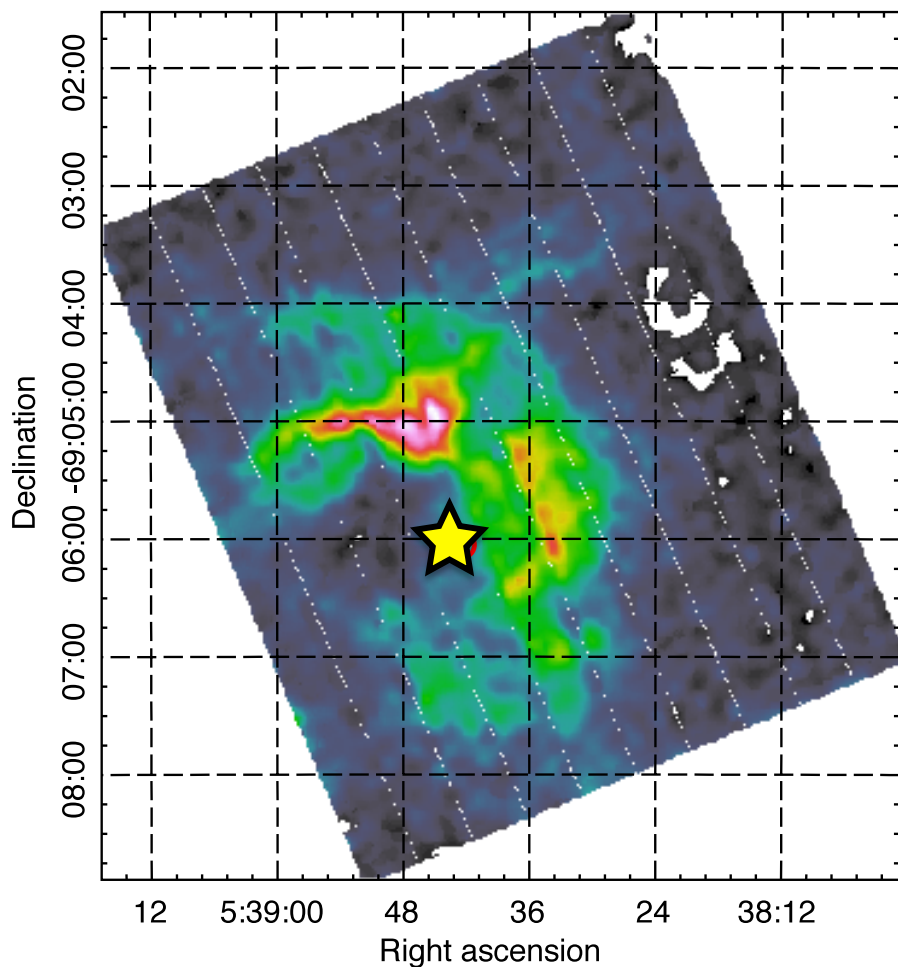




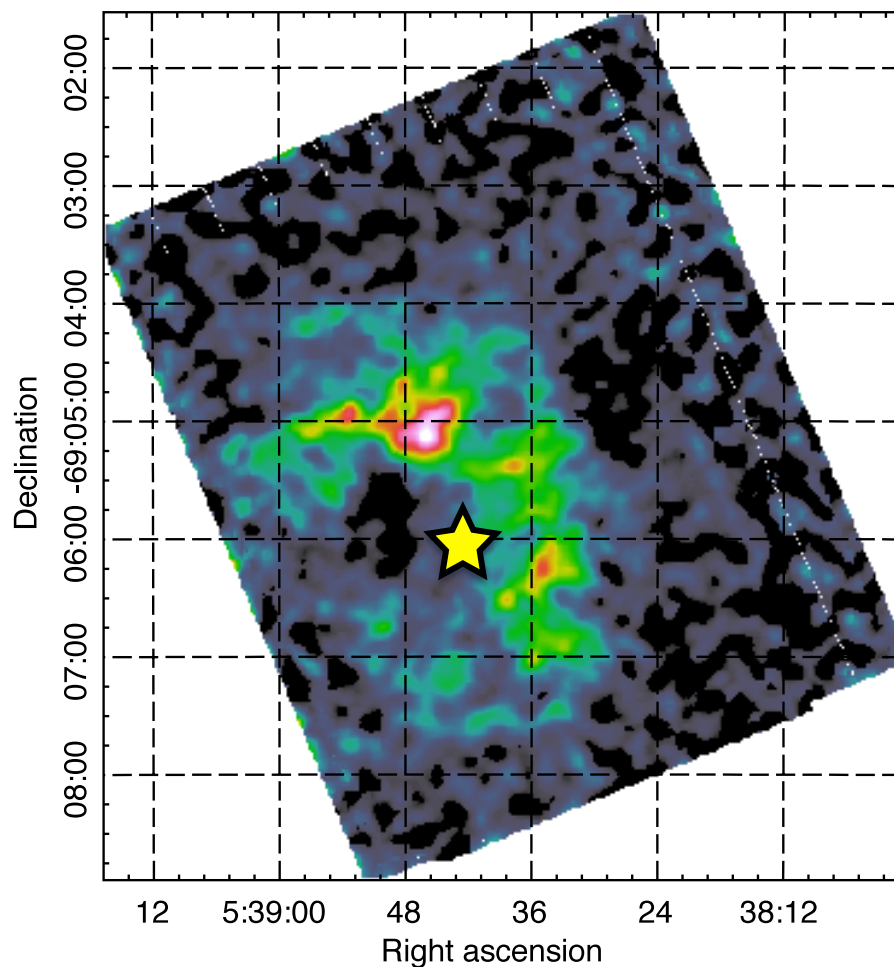
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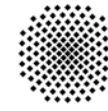
FIFI-LS observations of 30Dor

[OIII] 88 μ m



[OIII] 52 μ m





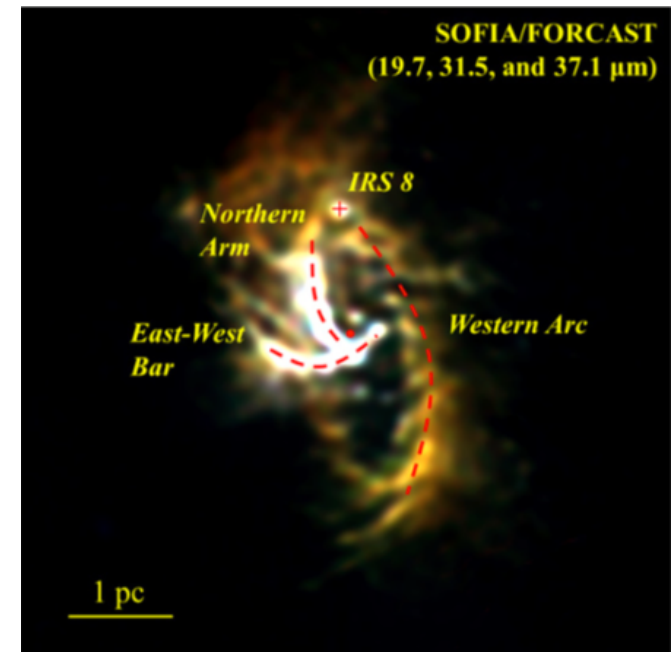
Galactic Center

Galactic center harbors the circumnuclear disk

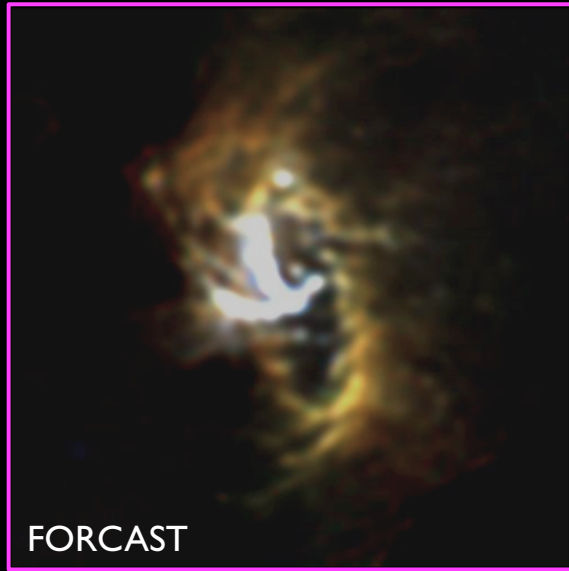
Torus of warm dense gas surrounding the central supermassive blackhole—
informs accretion process

FORCAST continuum observations revealed details of CND edge.

Kinematics can provide detailed view



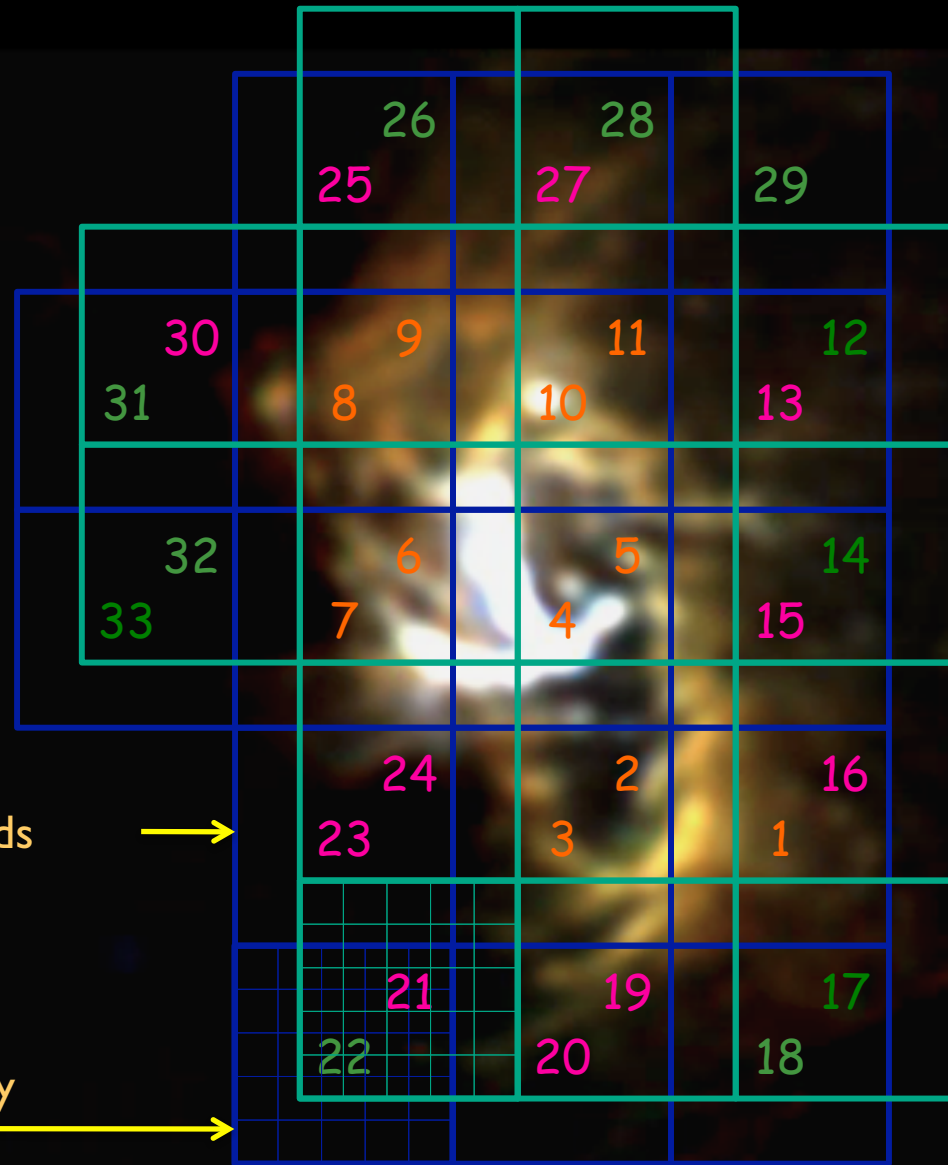
FIFI-LS GC



- 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



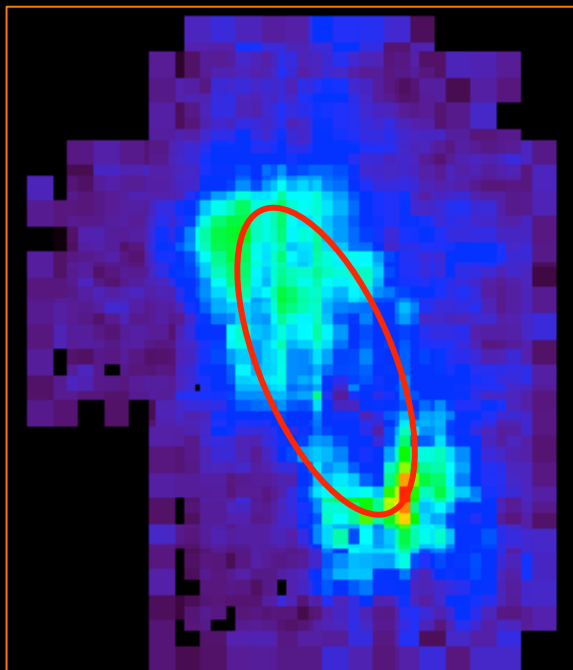
FIFI-LS mosaic

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

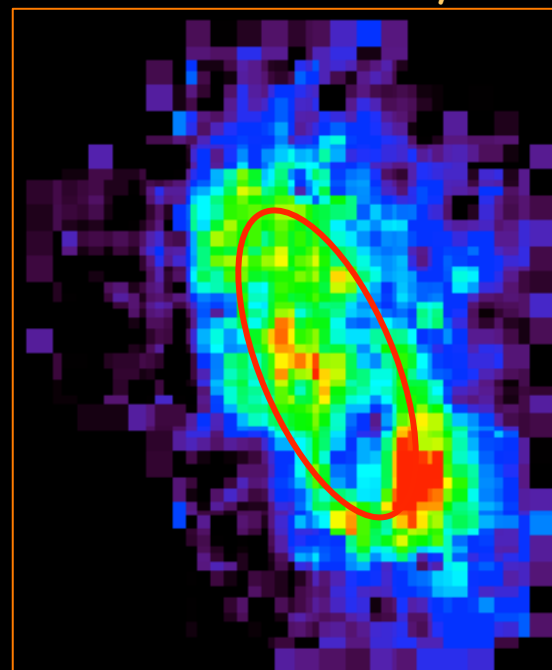
FIFI-LS GC



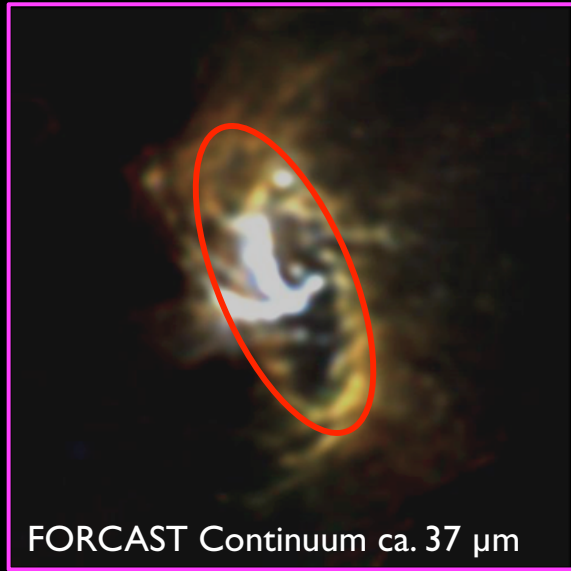
[OI] @ 63 μm



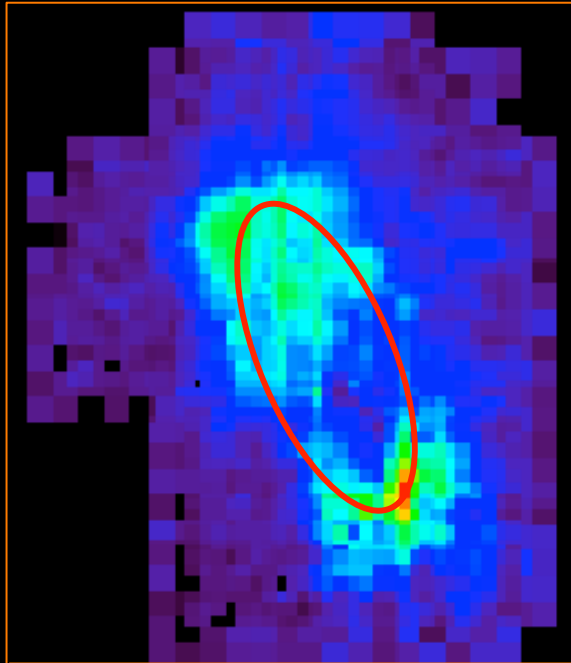
Continuum @ 63 μm



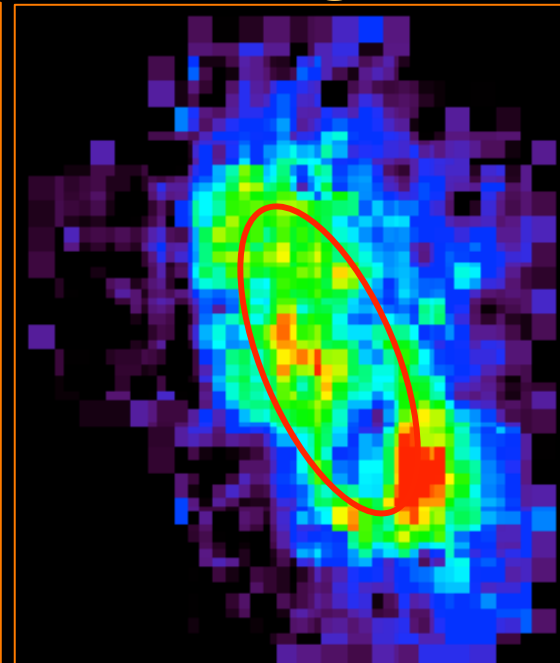
FIFI-LS GC



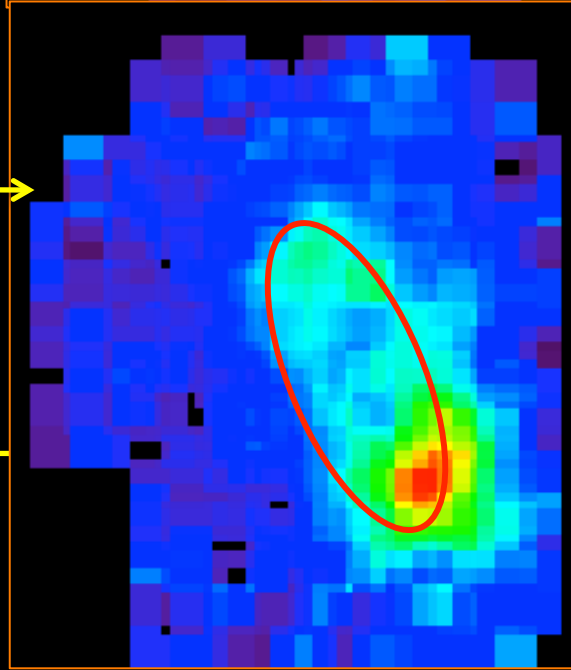
[OI] @ 63 μm



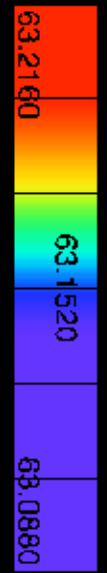
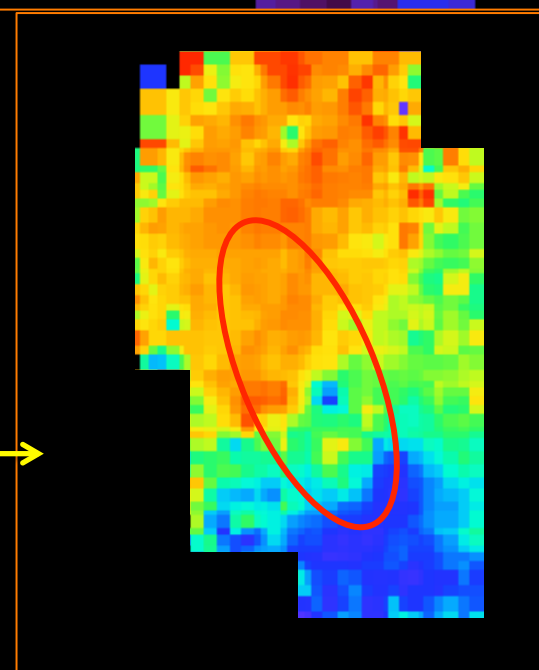
Continuum @ 63 μm



[OI] @ 145 μm



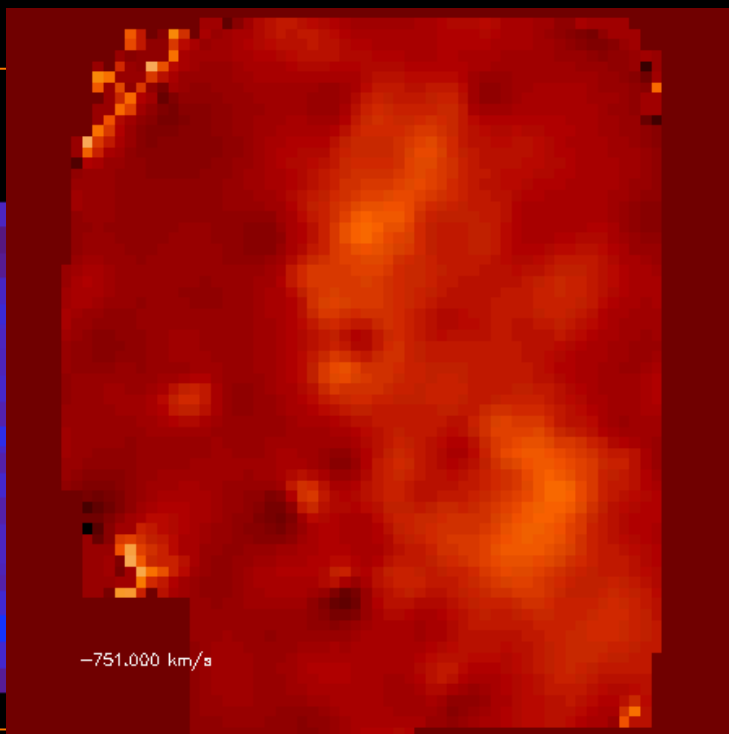
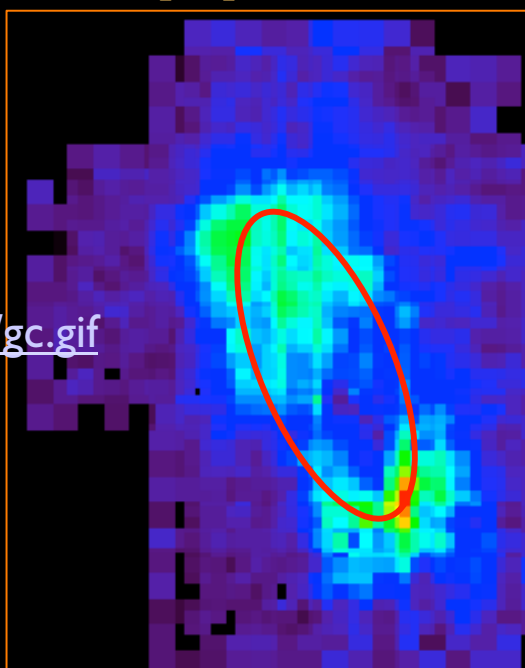
[OI] @ 145 μm
velocity



FIFI-LS GC

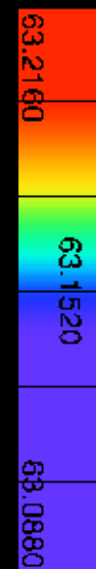
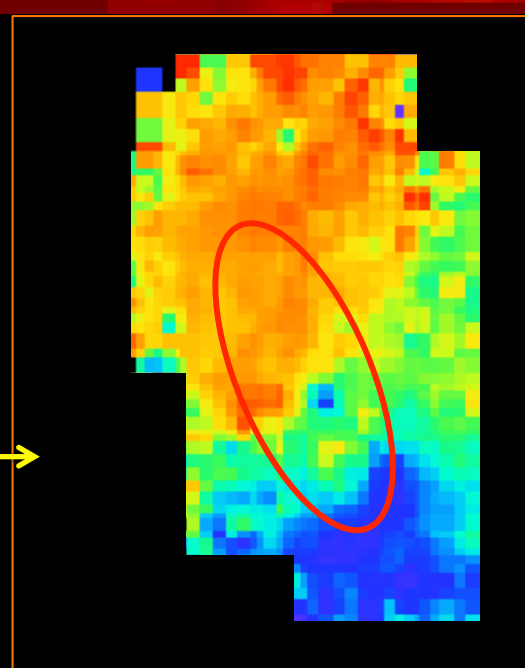
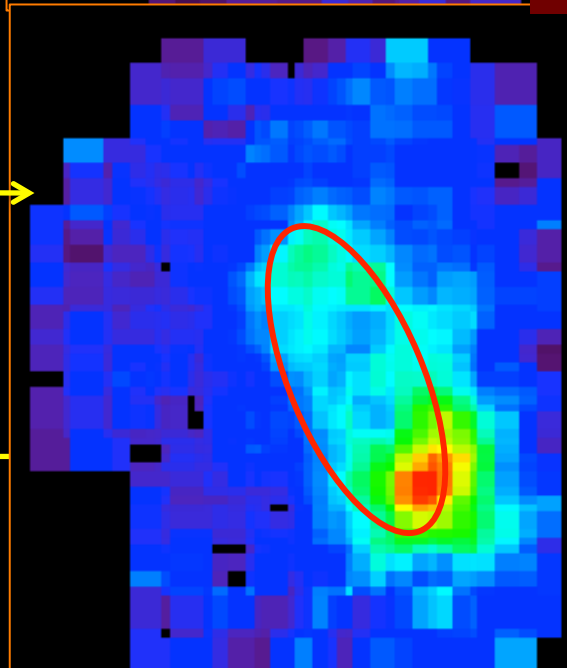
<http://eeyore.astro.illinois.edu/gc.gif>

[OI] @ 63 μm



[OI] @ 145 μm

[OI] @ 145 μm
velocity





M82

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

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

Clouds in outflow evaporate into small, dense cloudlets



Contursi et al. 2012

SOFIA &
FIFI-LS

M82 Galaxy



North up, east left

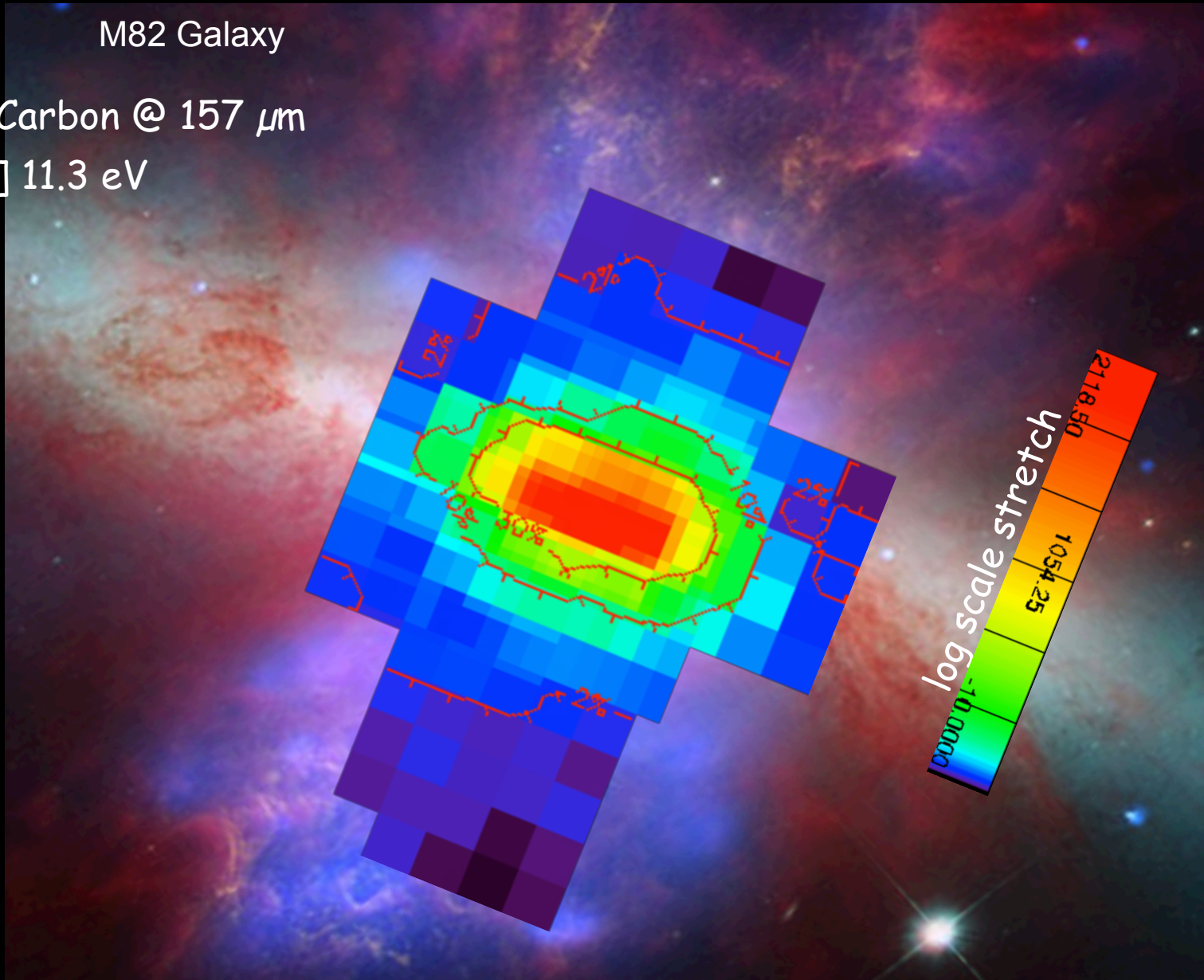
Background image: HST, Spitzer & Chandra

© FIFI-LS Team

M82 Galaxy

Ionized Carbon @ 157 μm

[CII] 11.3 eV



Background image: HST, Spitzer & Chandra

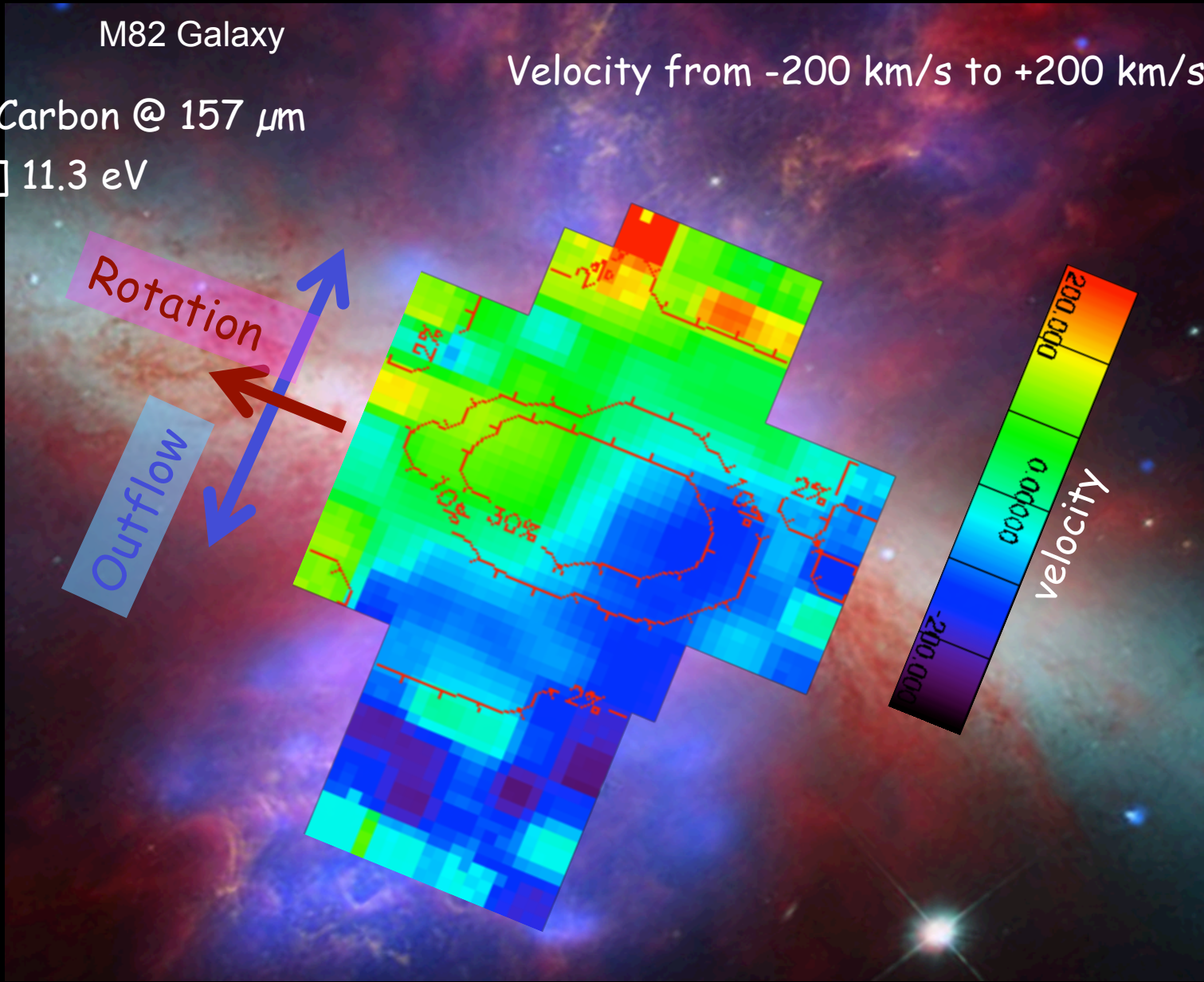
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M82 Galaxy

Ionized Carbon @ 157 μm

[CII] 11.3 eV

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

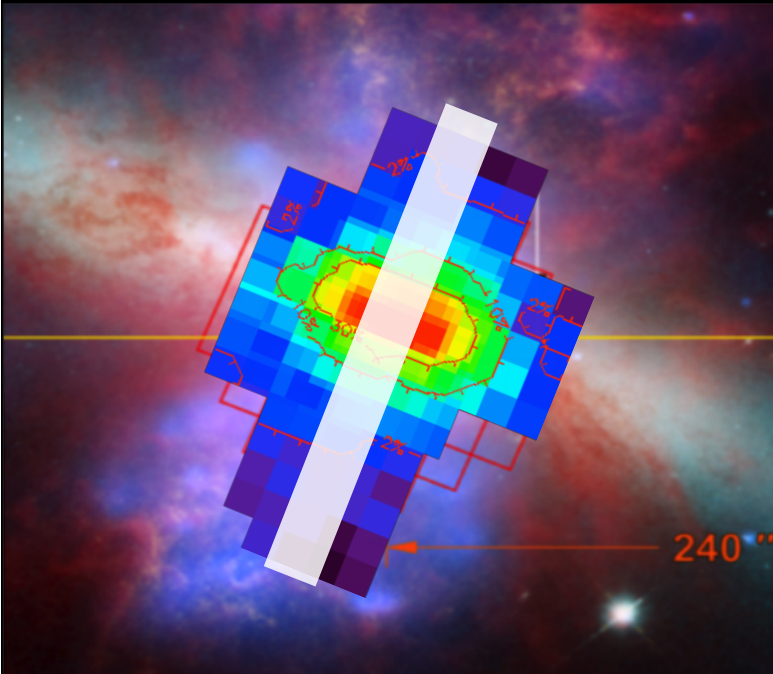


Background image: HST, Spitzer & Chandra

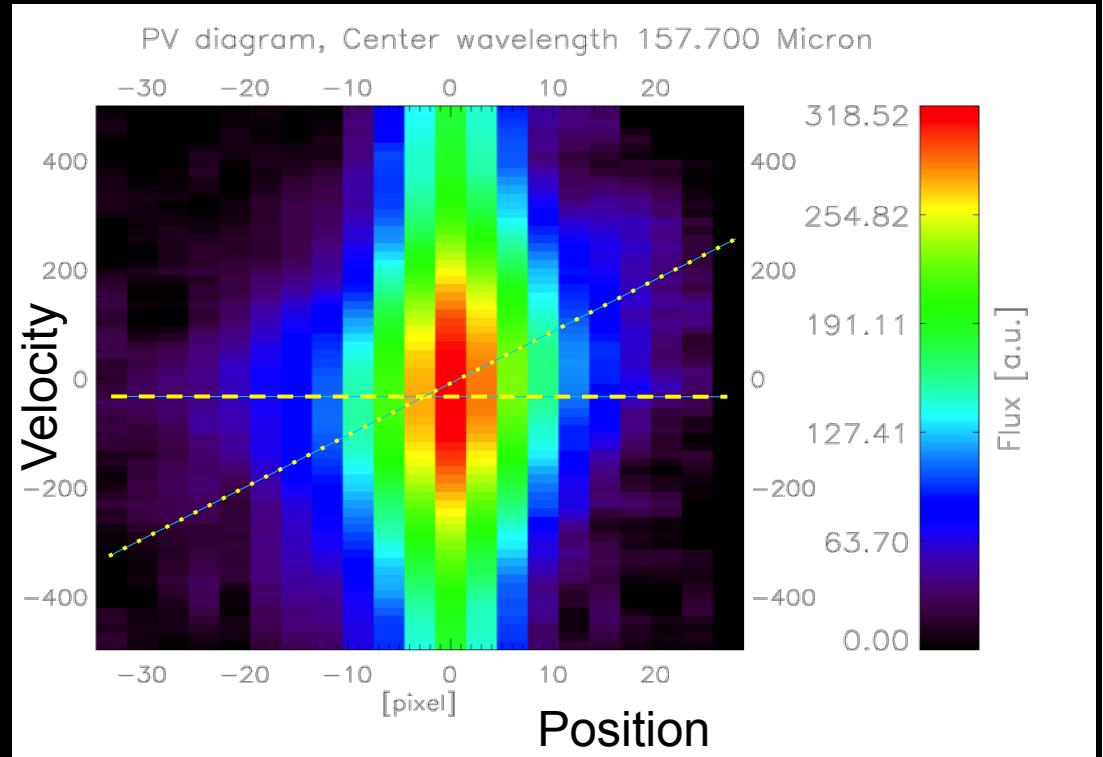
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M82 Galaxy

Ionized Carbon @ 157 μm



Position-velocity diagram



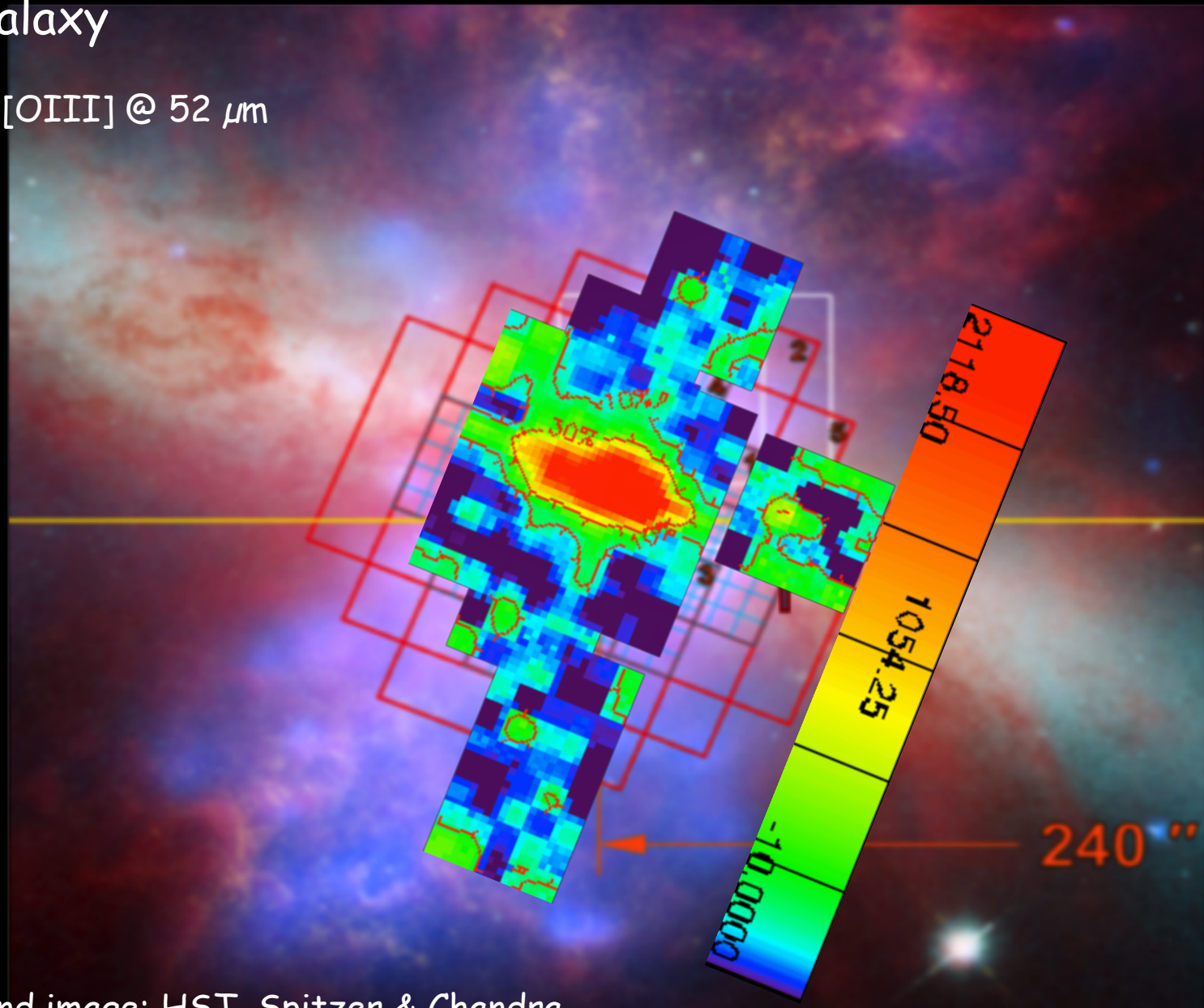
Velocity from -400 km/s to +400 km/s

Background image: HST, Spitzer & Chandra

© FIFI-LS Team

M82 Galaxy

Oxygen [OIII] @ 52 μm

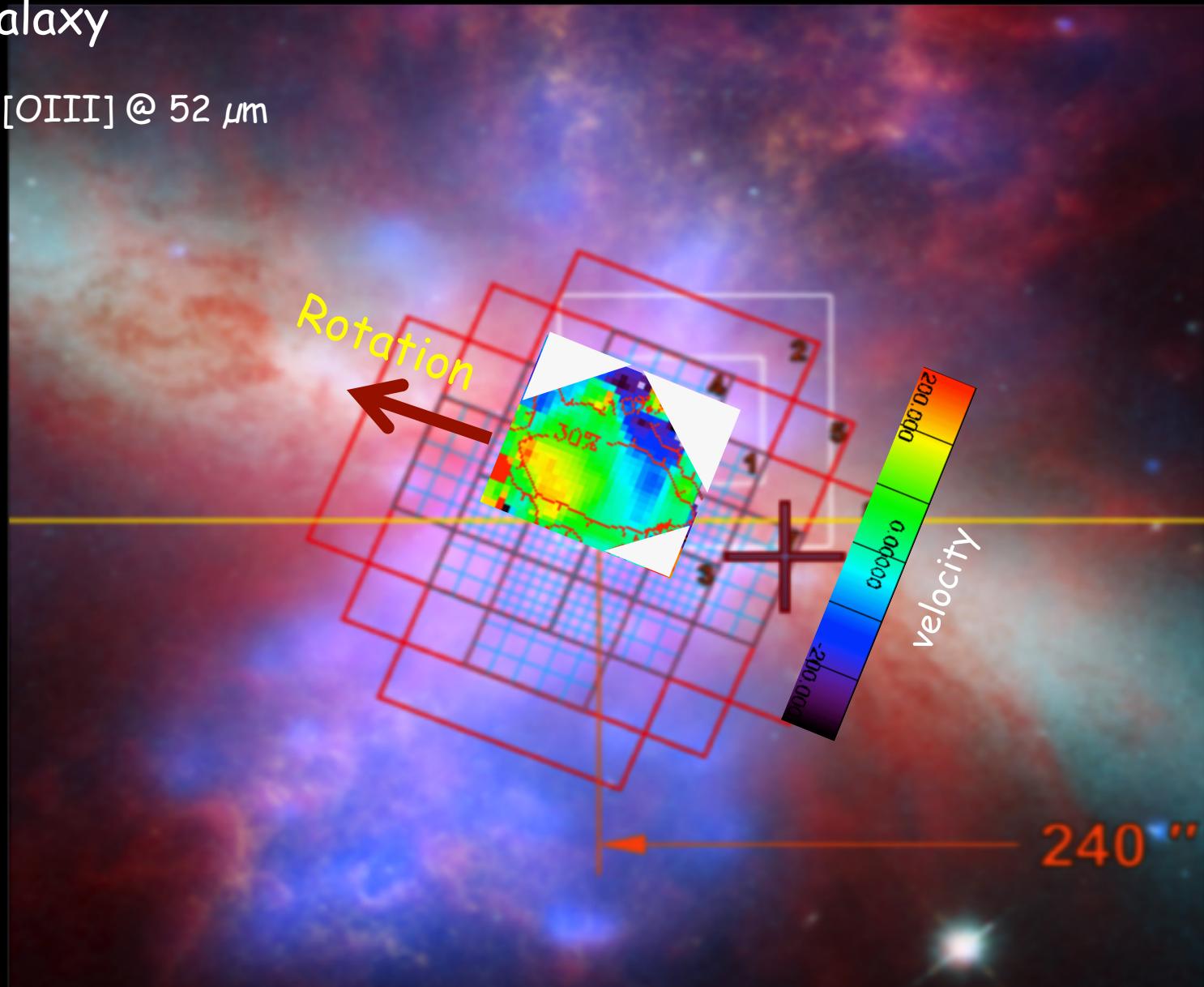


Background image: HST, Spitzer & Chandra

© FIFI-LS Team

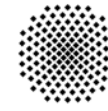
M82 Galaxy

Oxygen [OIII] @ 52 μm



Background image: HST, Spitzer & Chandra

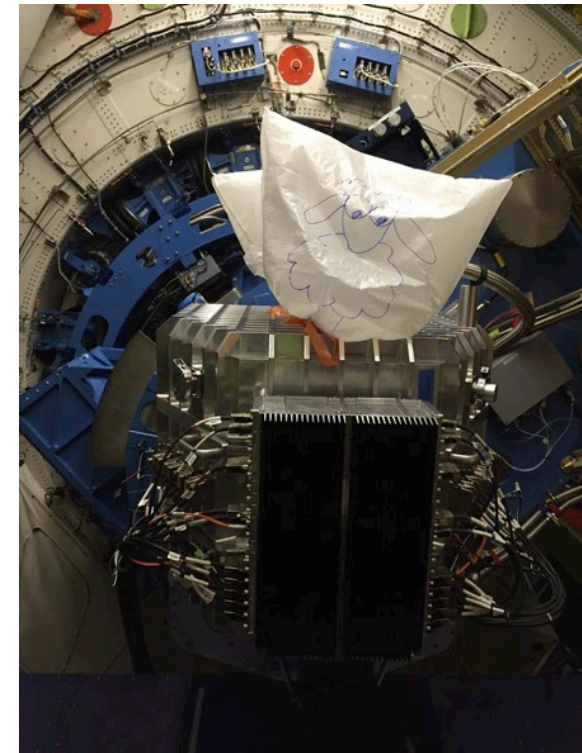
© FIFI-LS Team

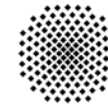


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Upgrade Possibilities

- 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