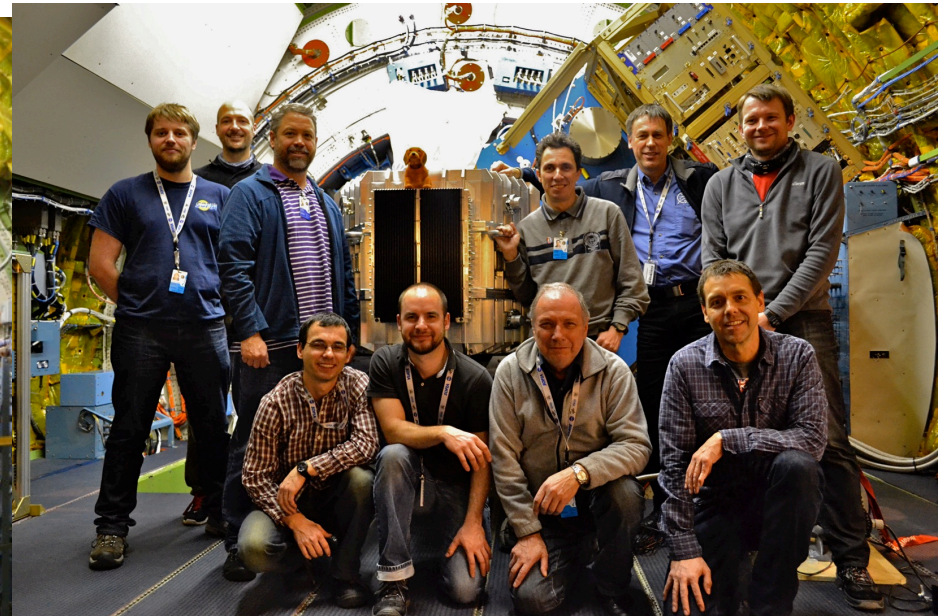
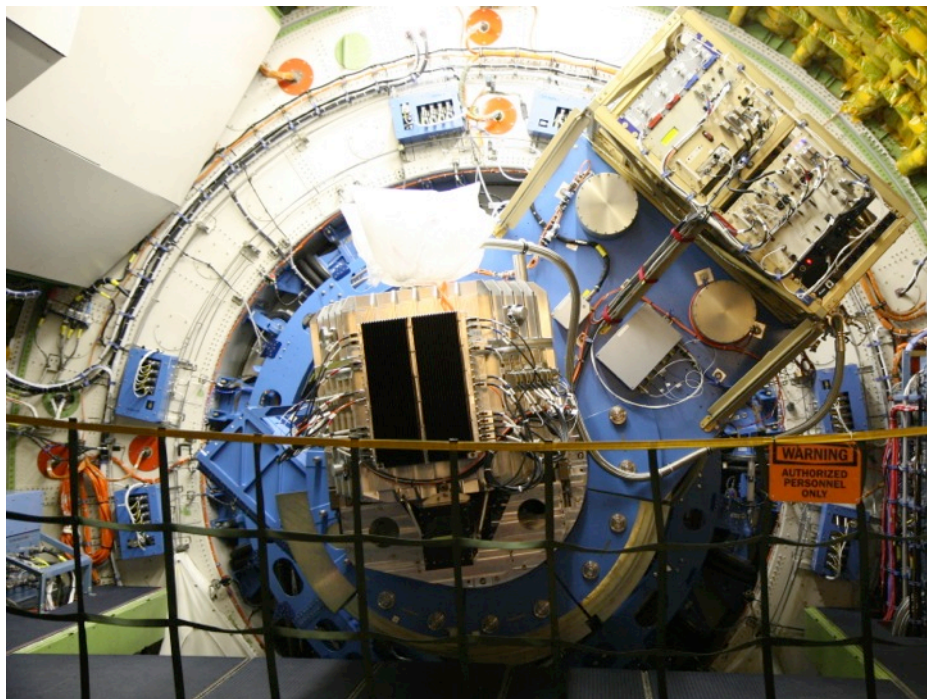


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des Deutschen Bundestages

# FIFI-LS Science Observations

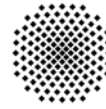


Randolf Klein  
(USRA/NASA Ames)  
+ FIFI-LS Instrument  
& Science Team





# Main Science Application



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des Deutschen Bundestages

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

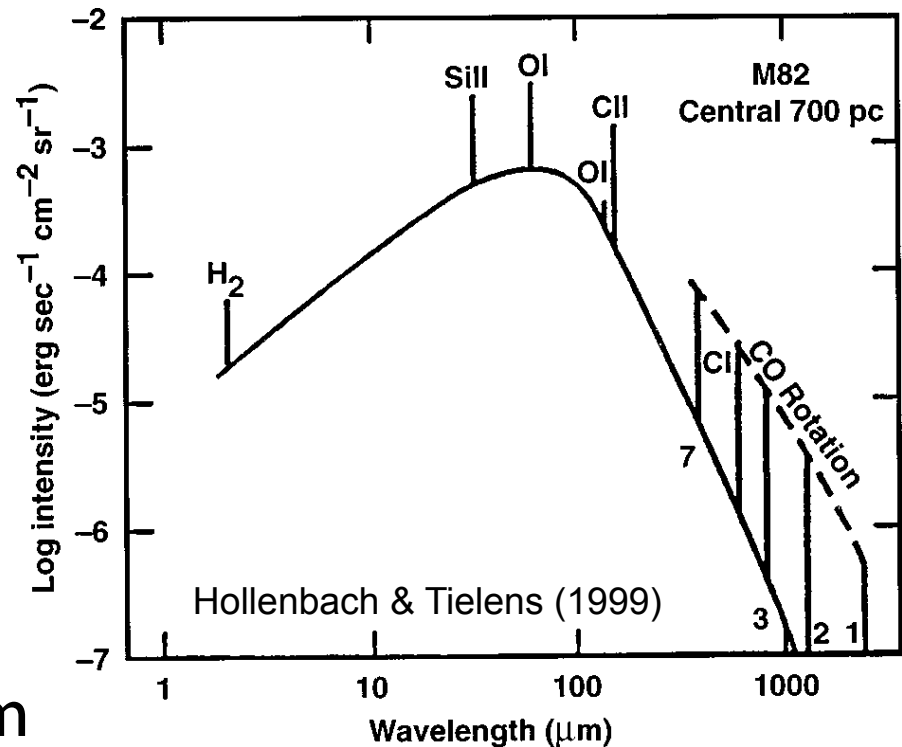
Main cooling lines of the interstellar gas in the FIFI-LS range:

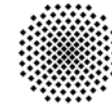
- [CII]  $158 \mu\text{m}$
- [OI]  $63.18 \mu\text{m}$ ,  $145.4 \mu\text{m}$

In ionized regions:

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

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





## Orion: Bar & Trapezium Region

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

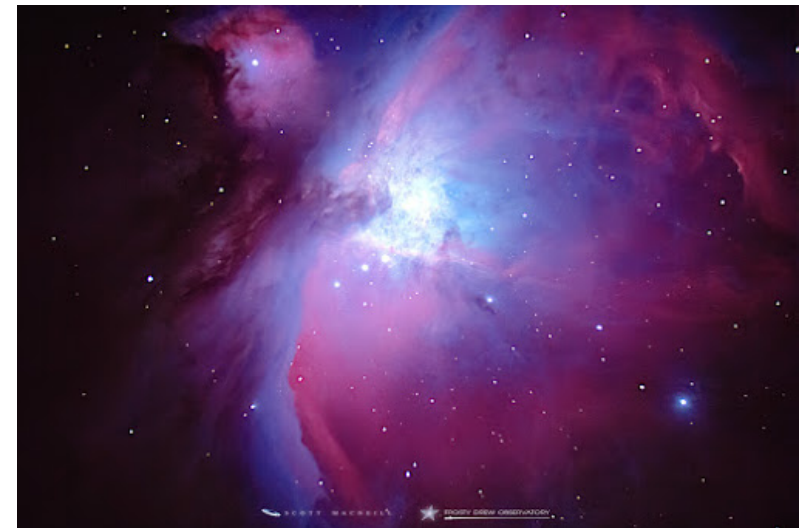
We used to verify mapping and observing procedures with  
FIFI-LS and to create a compelling data set

Whole region in:

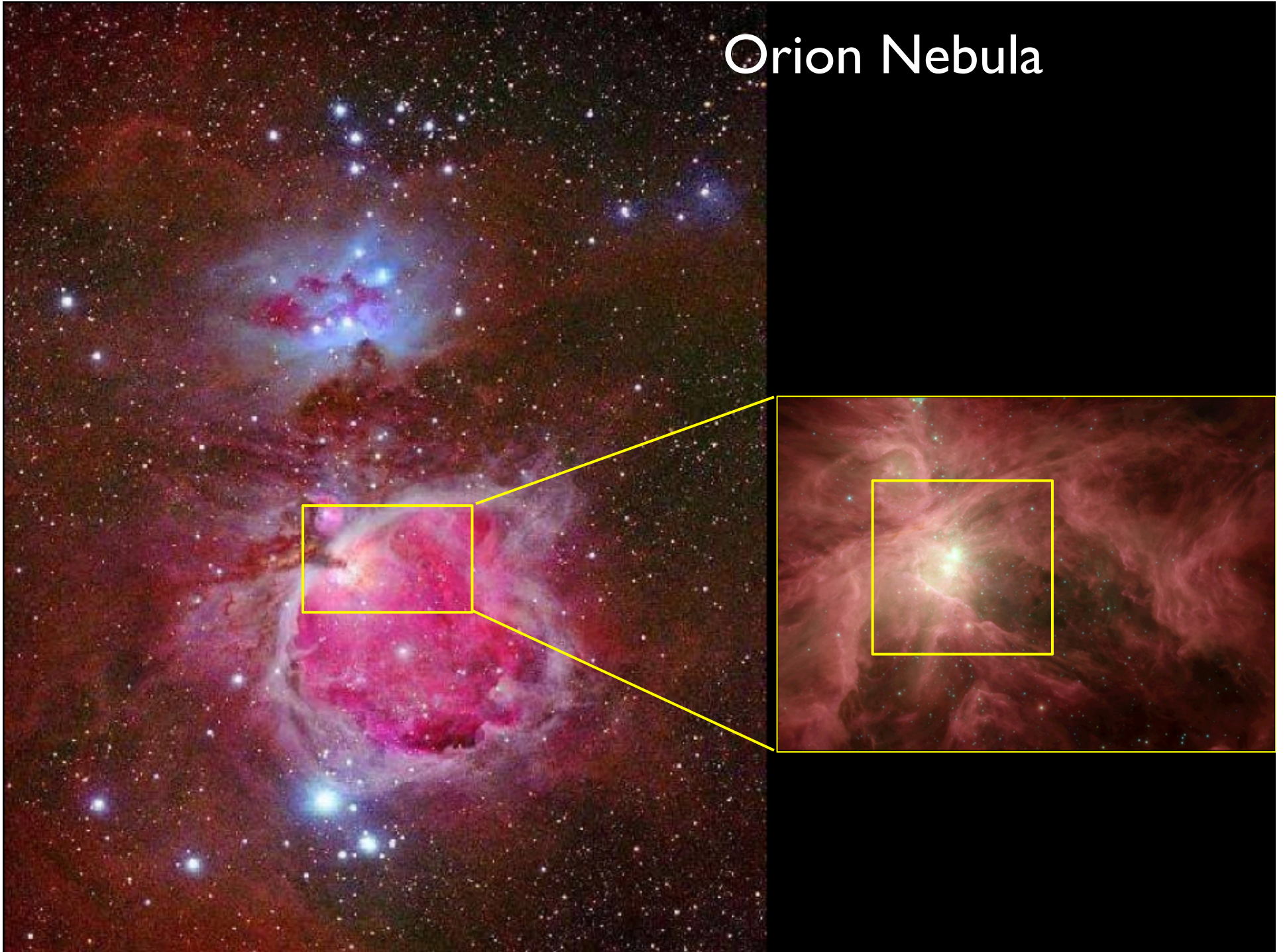
[OI] 63  $\mu\text{m}$ , [OI] 145  $\mu\text{m}$ ,  
[CII] 158  $\mu\text{m}$ , CO 118  $\mu\text{m}$

BN/KL: CO lines at: 69, 77, 87,  
163, 186, and 200  $\mu\text{m}$

BN/KL, Trapezium and Bar:  
[OIII] 52 & 88  $\mu\text{m}$ , [NIII] 57  $\mu\text{m}$ ,  
CO 118, 153 & 163  $\mu\text{m}$



# Orion Nebula



# Orion Nebula

Becklin-  
Neugebauer  
Object

Trapezium Stars

Orion Bar



Hubble Space Telescope

# Orion Nebula

Becklin-  
Neugebauer  
Object

Trapezium Stars

Orion Bar

Background image Spitzer by Thomas Megeath



# Orion Nebula

April 2014 &  
March 2015

[CII] Emission  
@ 157.8  $\mu\text{m}$

© FIFI-LS Team

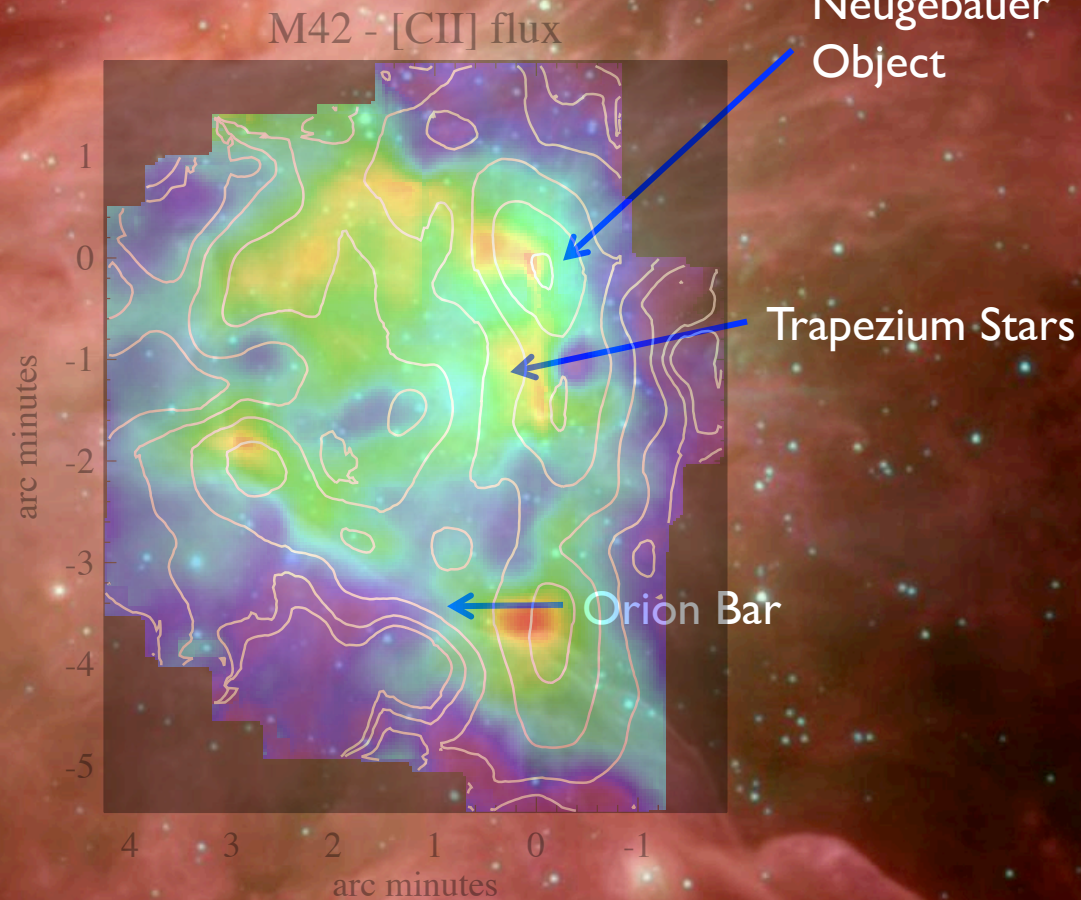


Image: linear stretch; log contours for 158 $\mu\text{m}$  continuum

Background image Spitzer by Thomas Megeath

# The Orion Nebula by FIFI-LS

M42 - continuum at 158 $\mu$ m

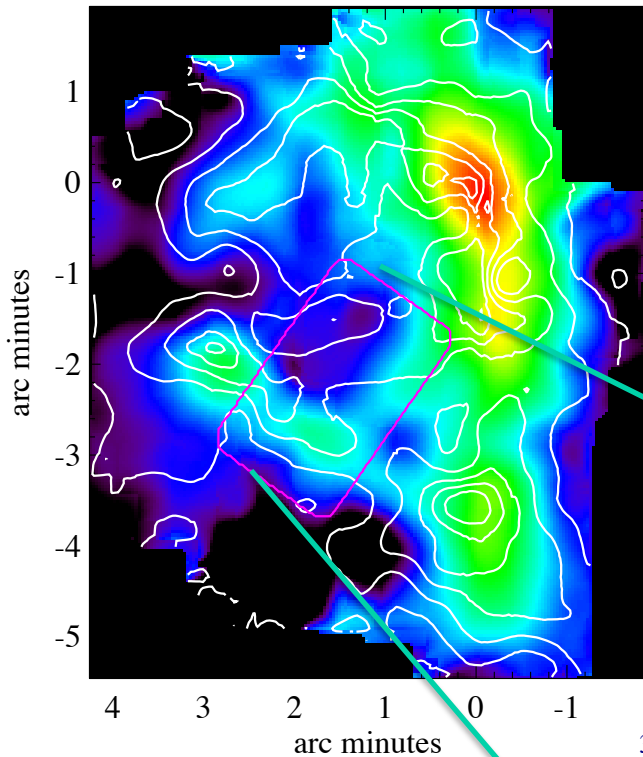


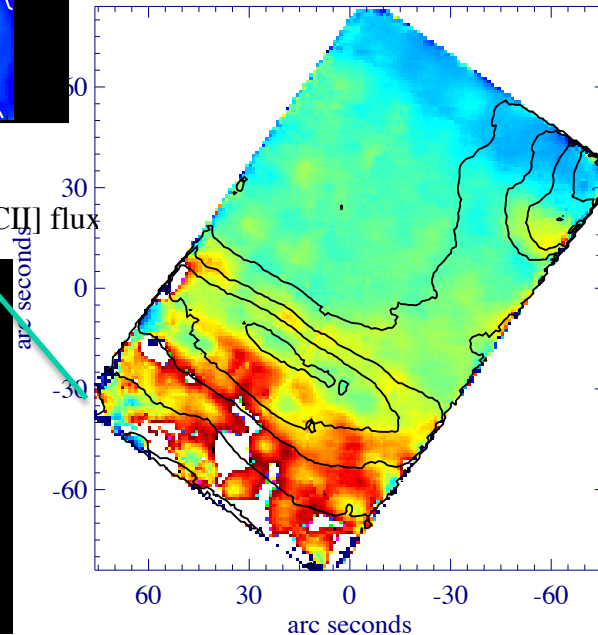
Image: log stretch; linear contours for [CII] flux

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

Preliminary results of the M42 observations.

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

[OIII] line ratio (r88/f52); 88 $\mu$ m cont



M42 - [CII] flux

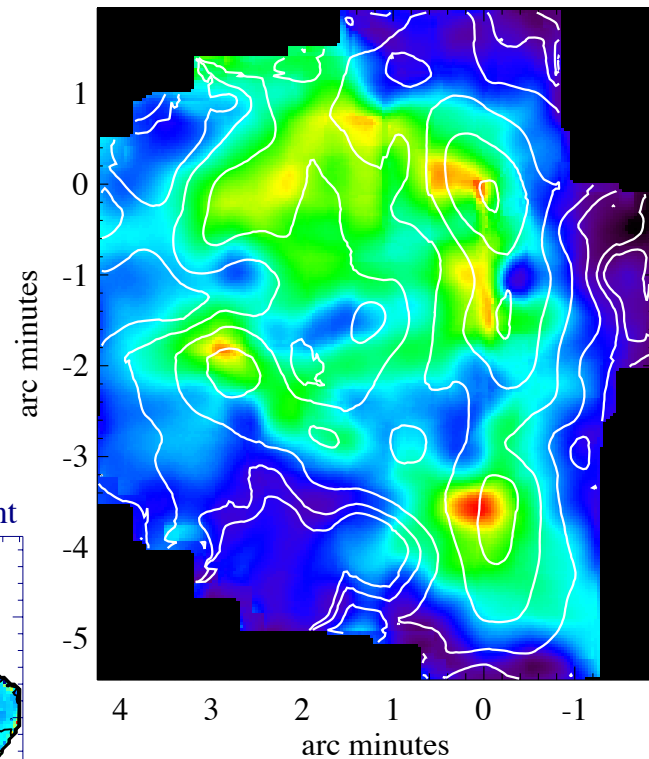
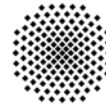


Image: linear stretch; log contours for 158 $\mu$ m continuum

The [CII] emission is prominent in the PDRs.





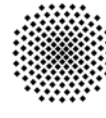
## MI7

Omega Nebula at  $\sim 2$  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)

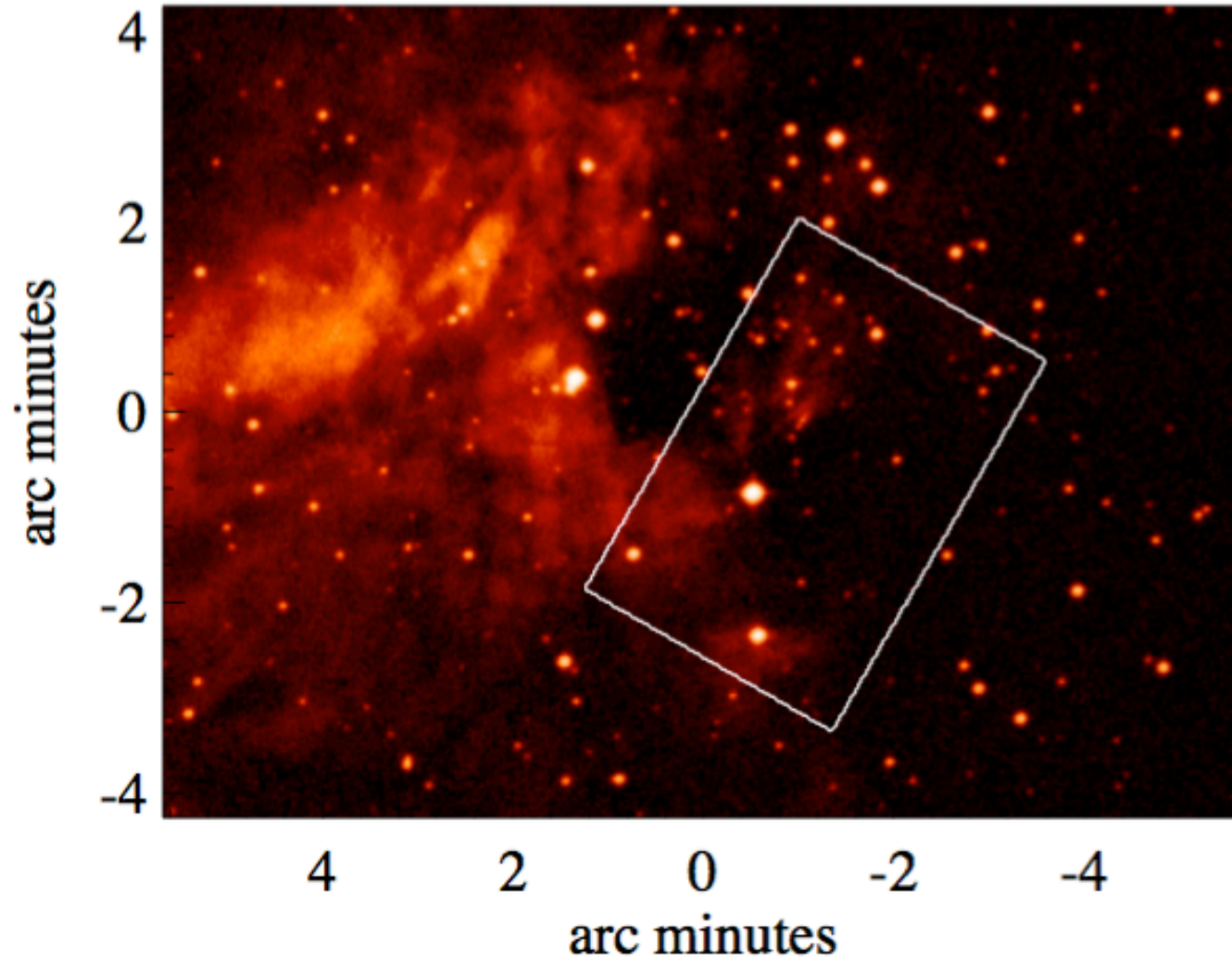
Our observations use multiple transitions to derive physical parameters of region.

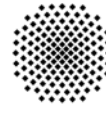




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# M17

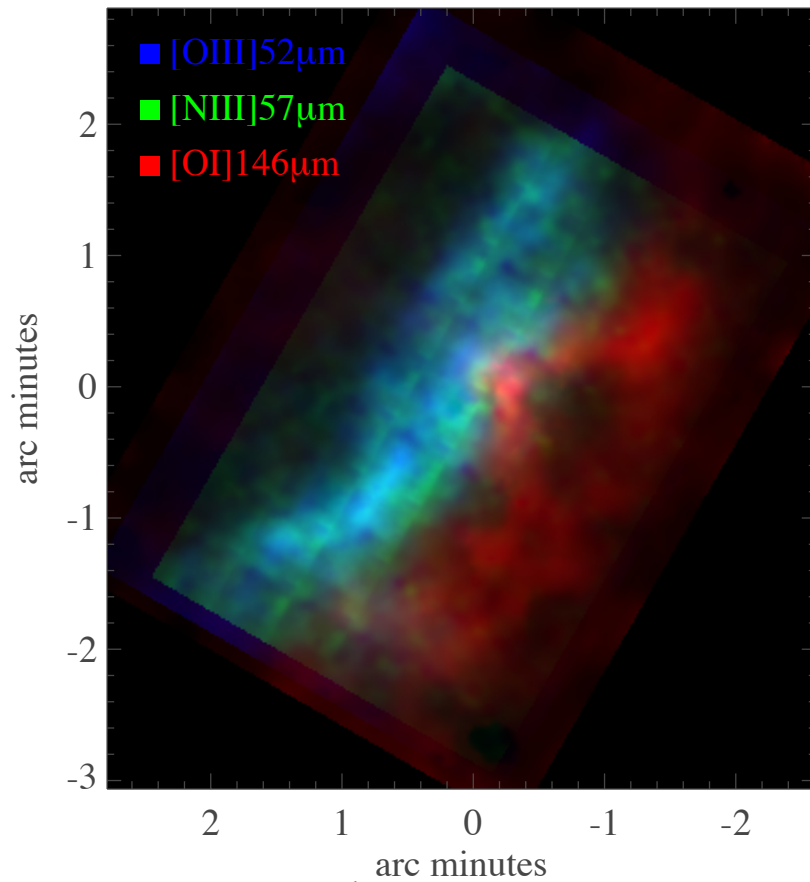




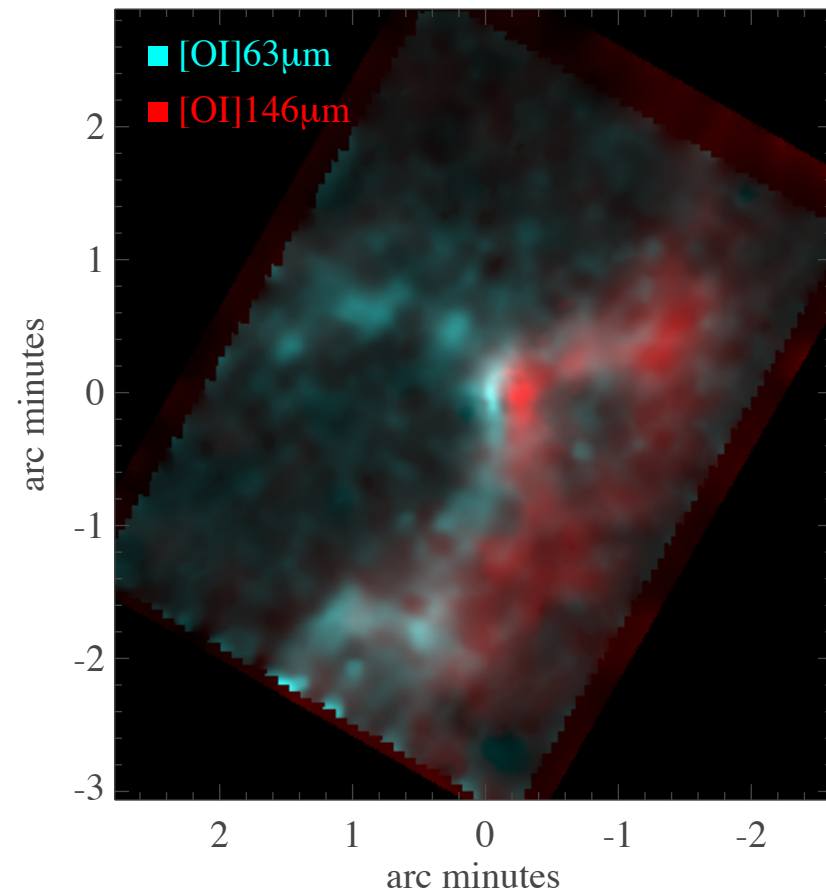
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des Deutschen Bundestages

# M17-SW

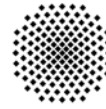
M17-SW Fine-structure Lines



M17-SW [OI] lines



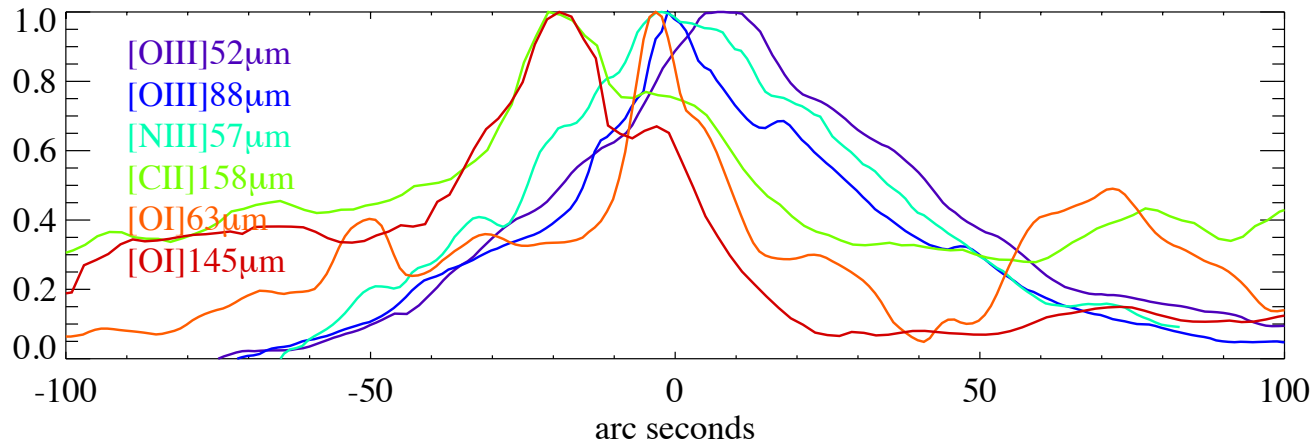
reference pos. R.A. 18<sup>h</sup>20<sup>m</sup>24<sup>s</sup>.82 DEC -16°11'34".9 (2000) reference pos. R.A. 18<sup>h</sup>20<sup>m</sup>24<sup>s</sup>.82 DEC -16°11'34".9 (2000)



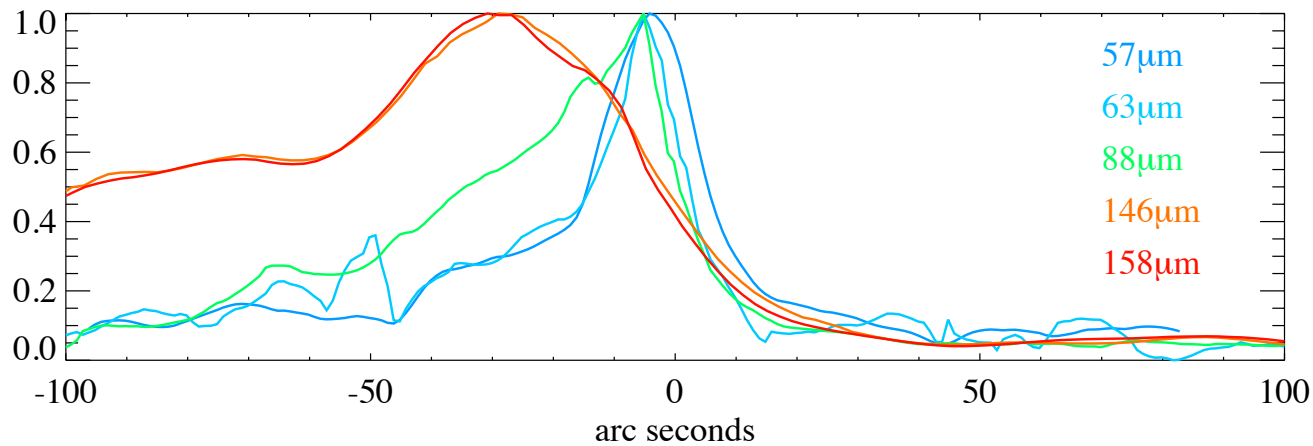
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# M17-SW

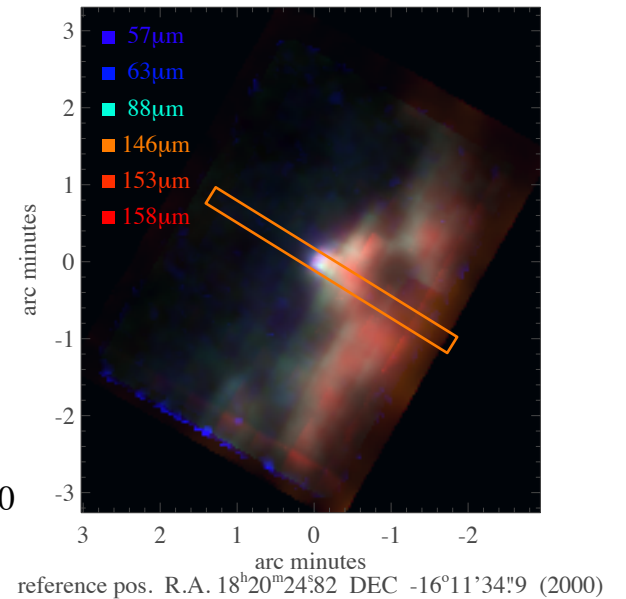
## Normalized Line Intensities



## Normalized Continuum Intensities



## M17-SW Continuum





# Circum Nuclear Disk

Observations: 2016 New Zealand  
 [CII] 157.741  $\mu\text{m}$  parallel with  
 [OI] 63.184  $\mu\text{m}$   
 Modified FIFI-LS Pipeline (B.Vacca/C.Fischer)  
 Fluxer by C. Iserlohe

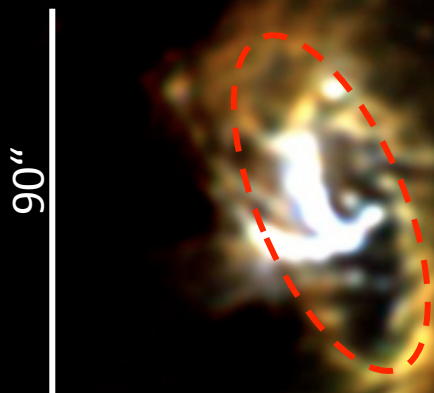
- Line: Intensity, Velocity, Width
- Narrow Band Continuum: Level, Tilt

## FIFI-LS

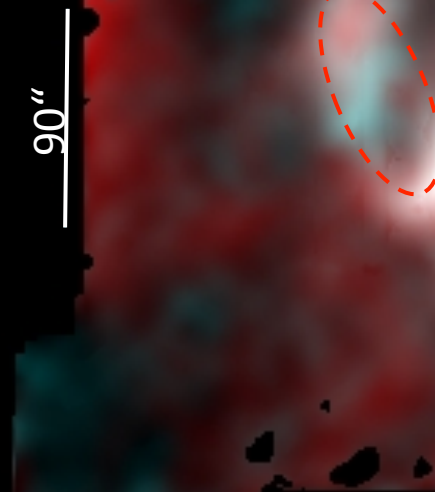
red: 158  $\mu\text{m}$  NB Continuum  
 blue: 63  $\mu\text{m}$  NB Continuum

SOFIA

Lau et al. 2013



FORCAST 19.7, 31.5, 37  $\mu\text{m}$  Continuum



© FIFI-LS Team

Krabbe et al. in prep.



Universität Stuttgart

Stratospheric Observatory for Infrared Astronomy

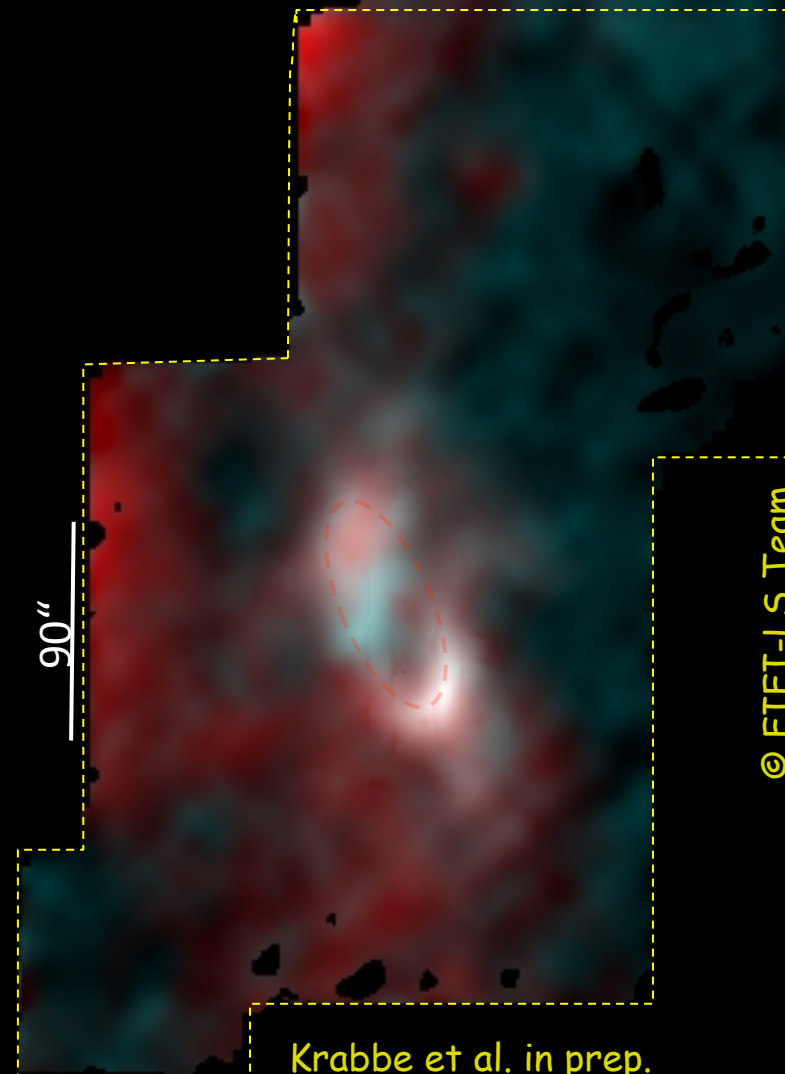
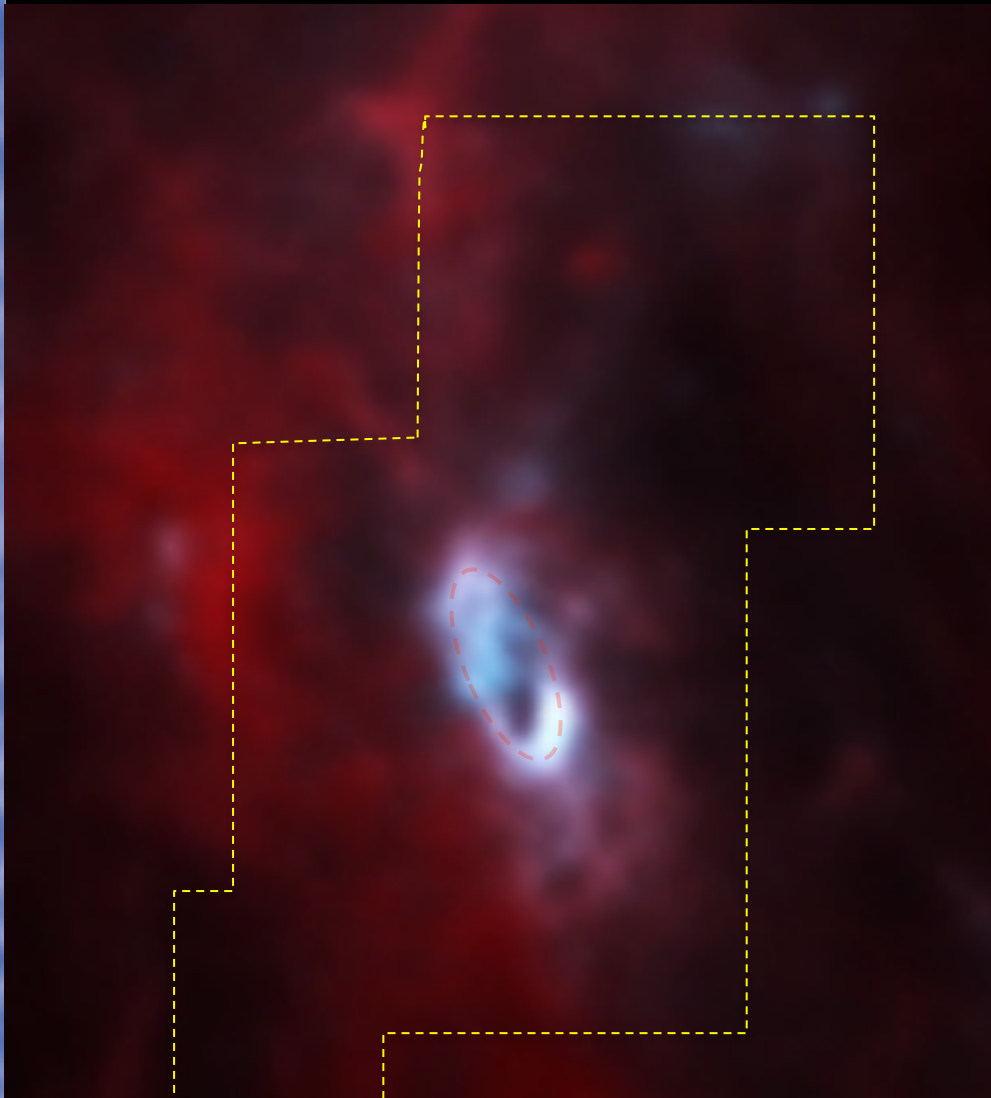
# Circum Nuclear Disk

PACS Bolometer

red: 160 $\mu$ m BB Continuum  
blue 70 $\mu$ m BB Continuum

# FIFI-LS

red: 158 $\mu$ m NB Continuum  
blue: 63 $\mu$ m NB Continuum



© FIFI-LS Team

Krabbe et al. in prep.



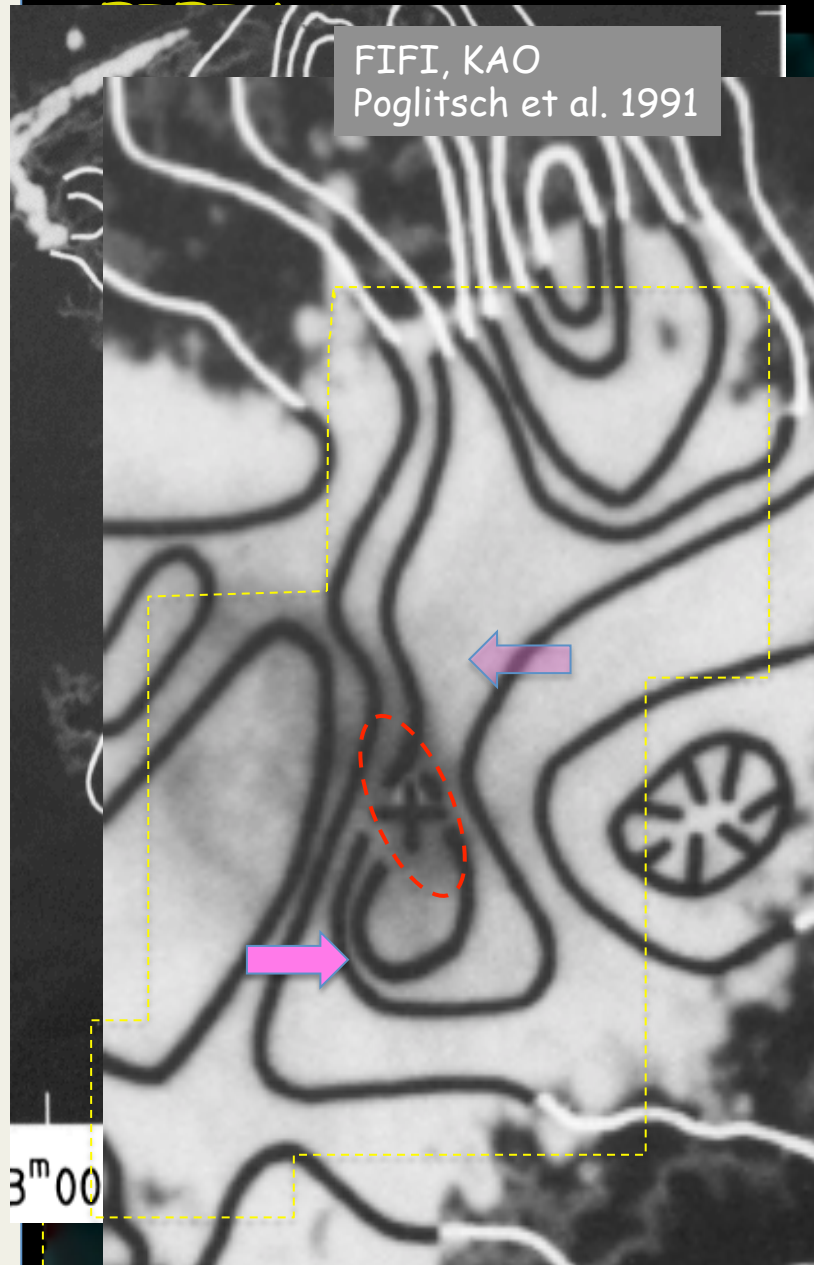
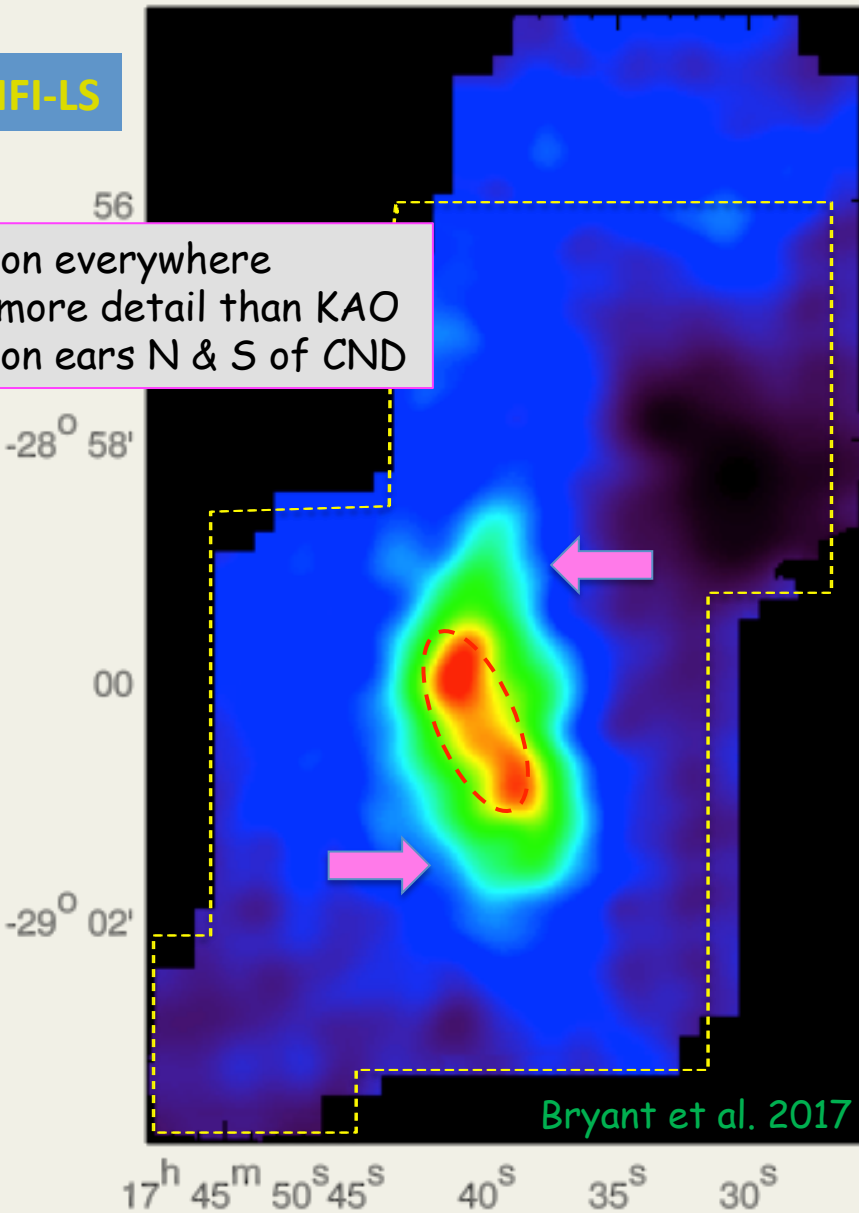
ronomy

Stratospheric Observatory for Infra

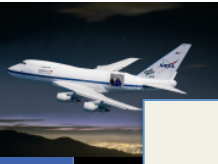
FIFI-LS

[CII] 158 $\mu$ m Line Emission

- Emission everywhere
- Much more detail than KAO
- Emission ears N & S of CND

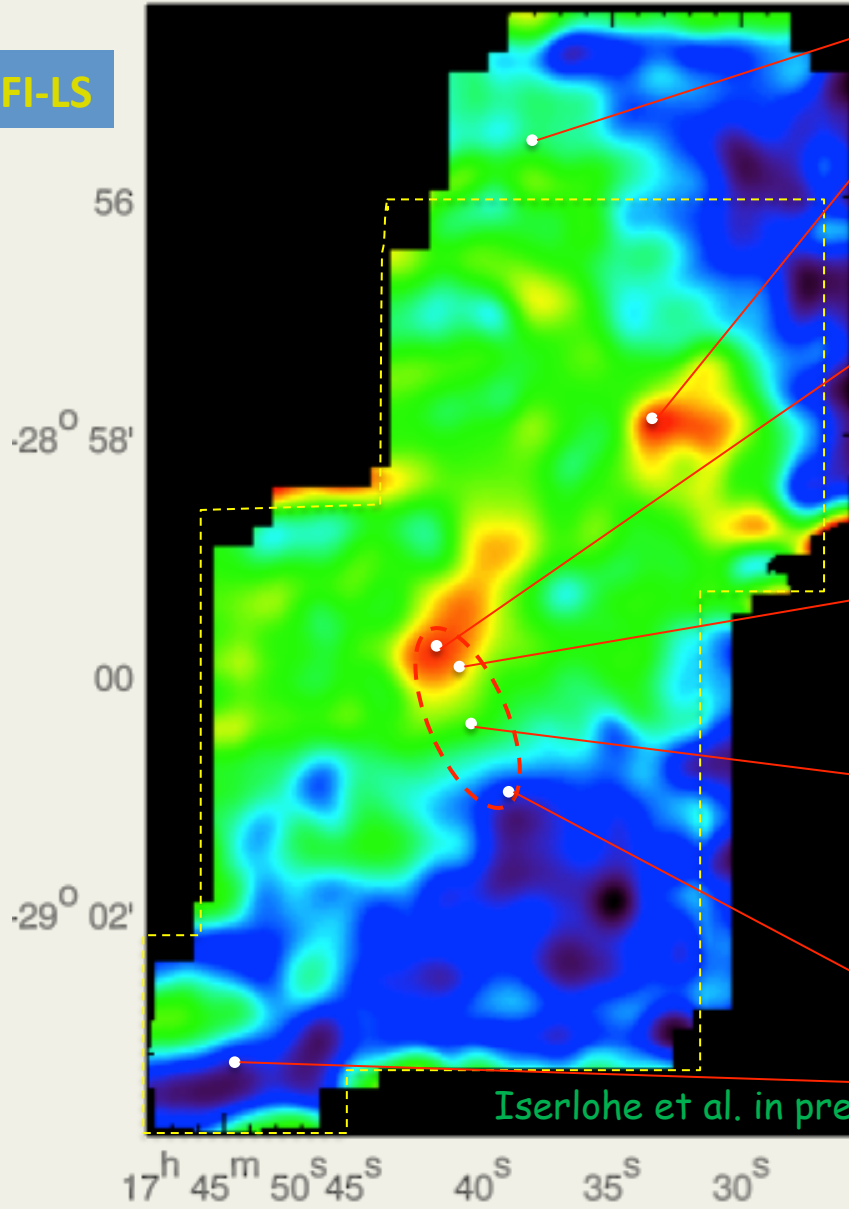


Krabbe et al. in prep.



FIFI-LS

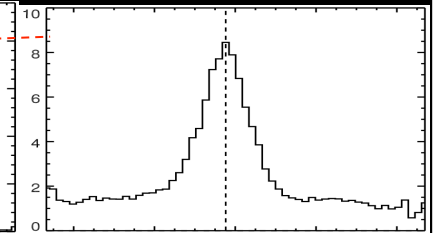
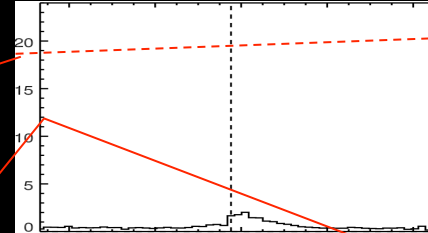
[CII] 158μm Velocity



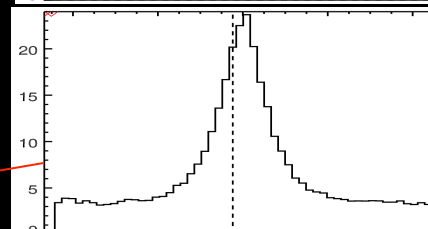
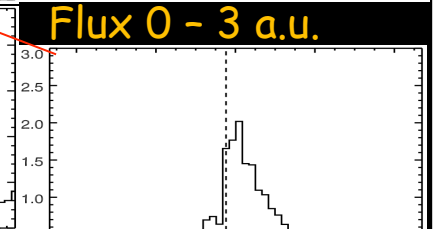
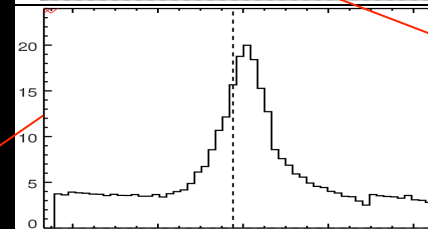
Iserlohe et al. in prep.

Flux 0 - 24 a.u.

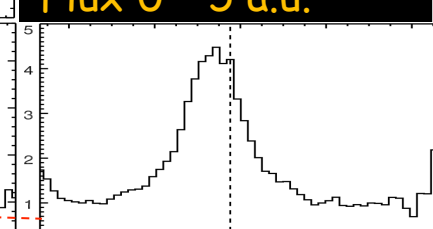
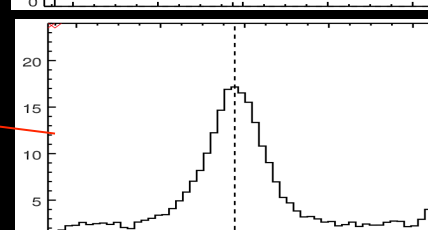
Flux 0 - 10 a.u.



Flux 0 - 3 a.u.



Flux 0 - 5 a.u.



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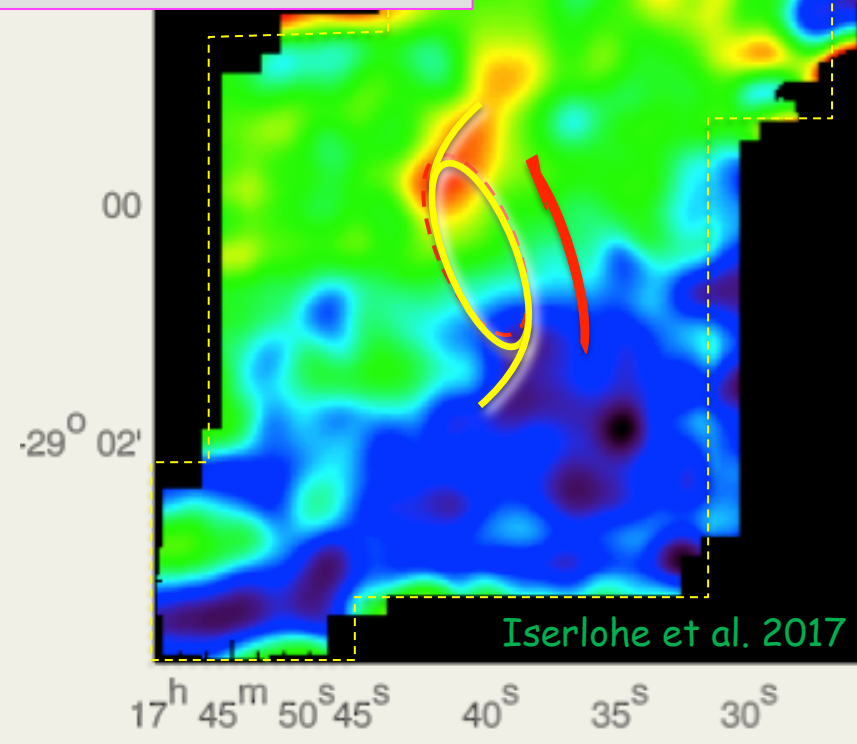
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[CII] 158μm Velocity

Stretch ±100 km/s

56

- Rotating ring at center
- Peculiar motions outside (not a big rotating disk)
- Ring-Bar supported by v-field & CND rotation



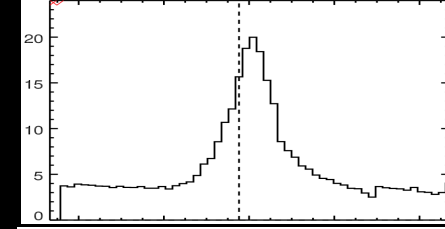
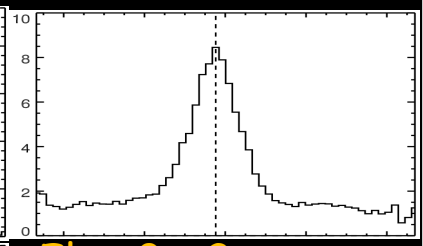
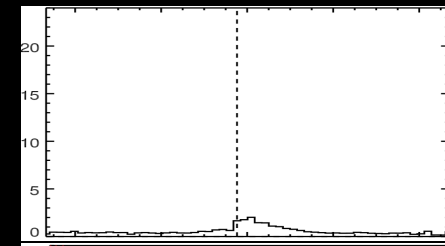
Iserlohe et al. 2017

Stratospheric Observatory for

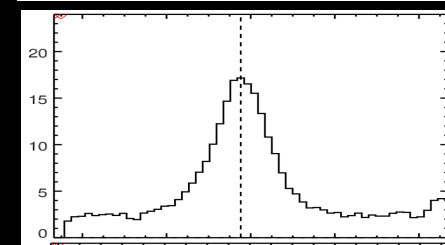
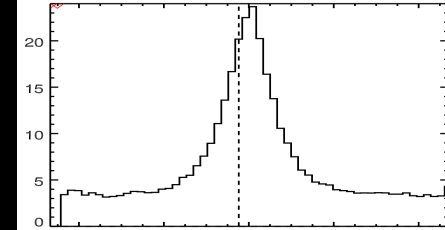
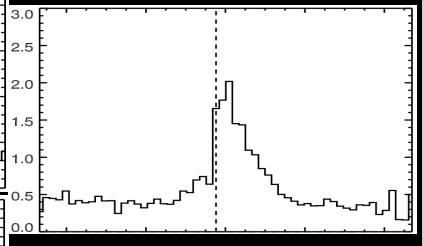
Asilo

Flux 0 - 24 a.u.

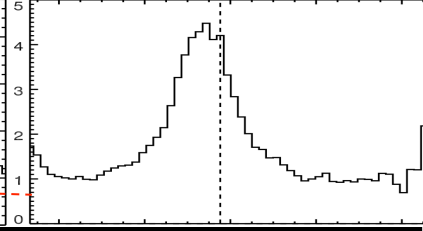
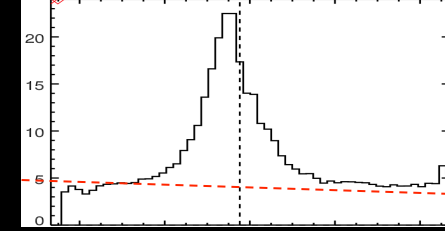
Flux 0 - 10 a.u.



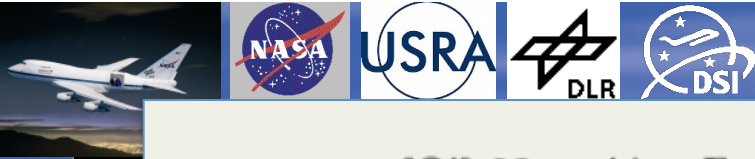
Flux 0 - 3 a.u.



Flux 0 - 5 a.u.

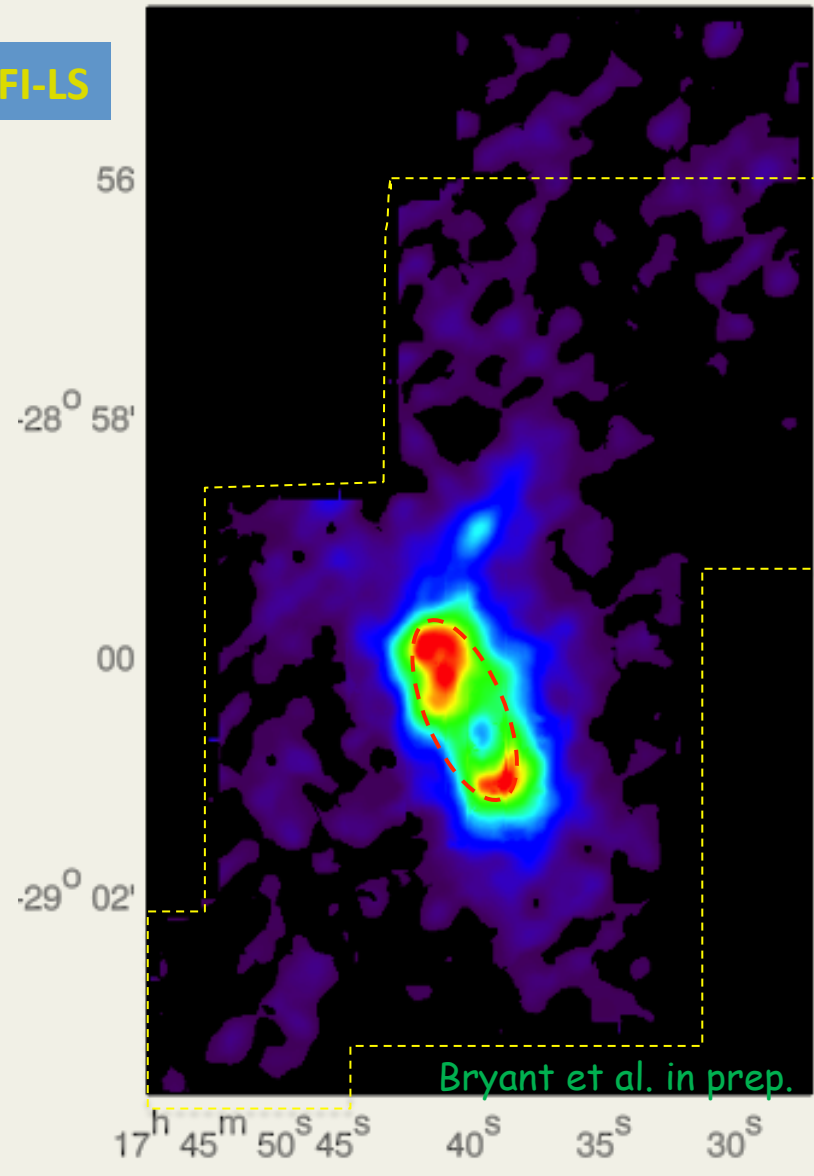


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FIFI-LS

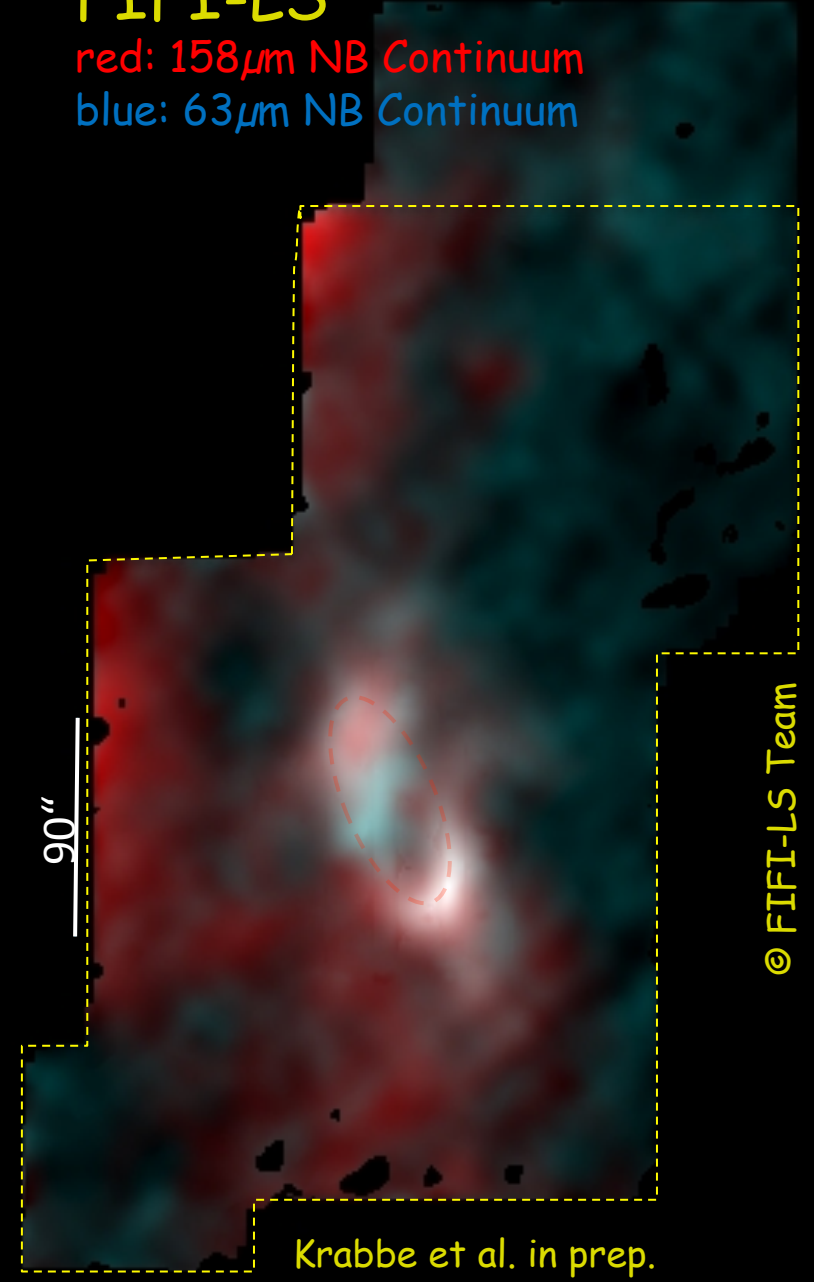
[OI] 63μm Line Emission



Bryant et al. in prep.

FIFI-LS

red: 158μm NB Continuum  
blue: 63μm NB Continuum



Krabbe et al. in prep.

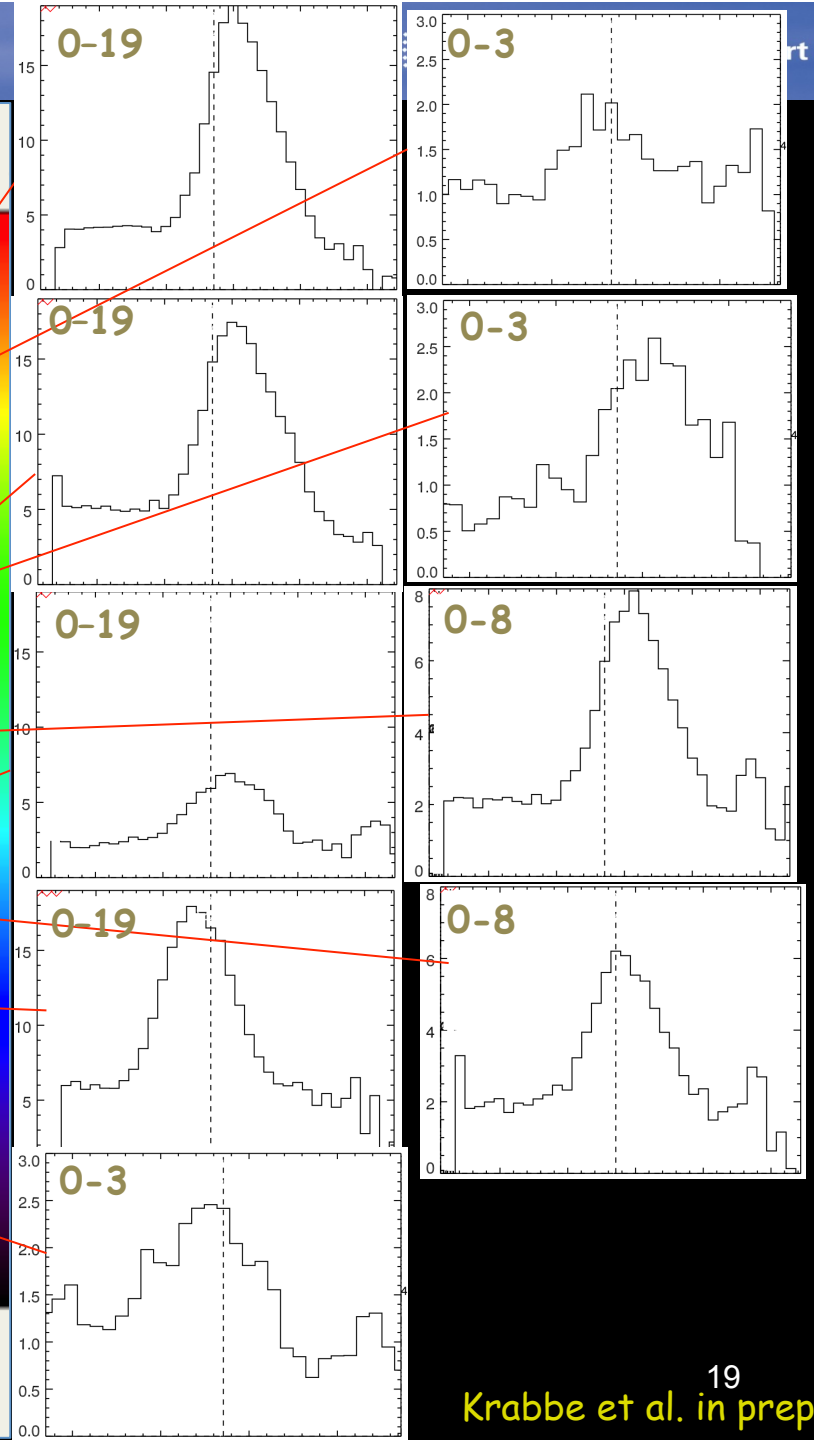
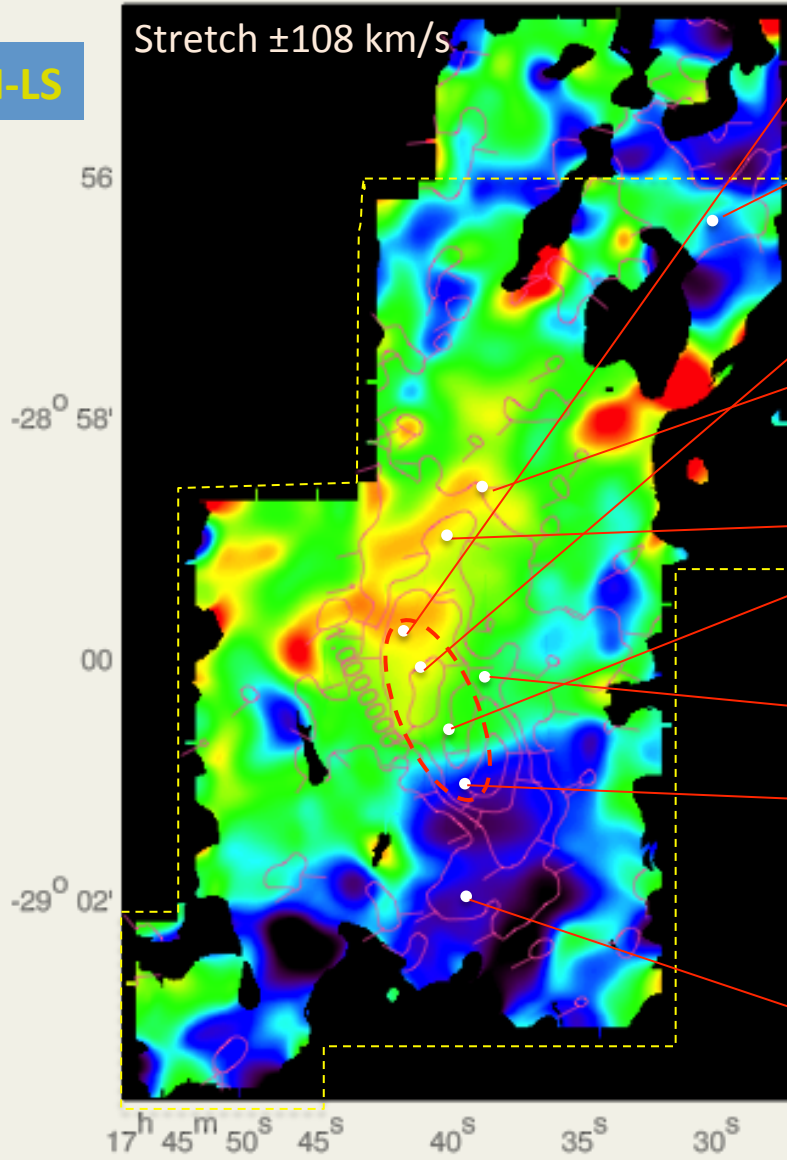
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FIFI-LS

[OI] 63 $\mu$ m Velocity & Continuum Contours 0.5, 1, 1.5,

Stretch  $\pm 108$  km/s



© FIFI-LS Team



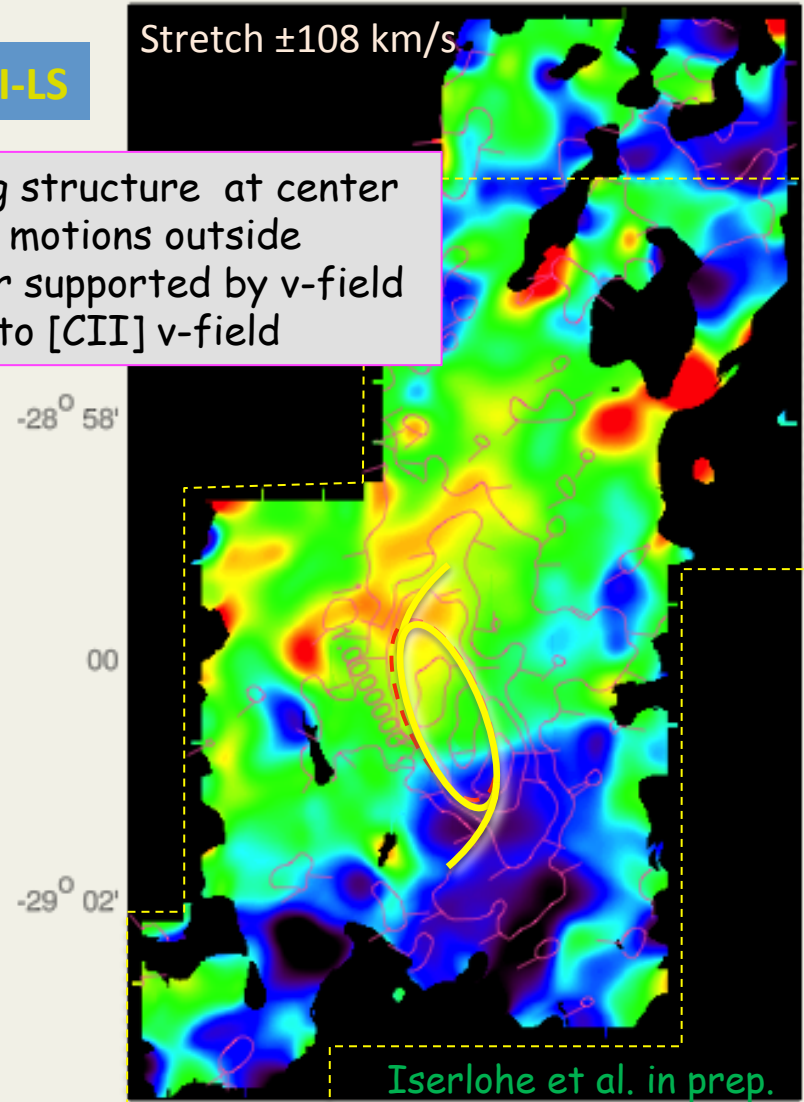
Stratospheric Observatory for Infrared Astronomy

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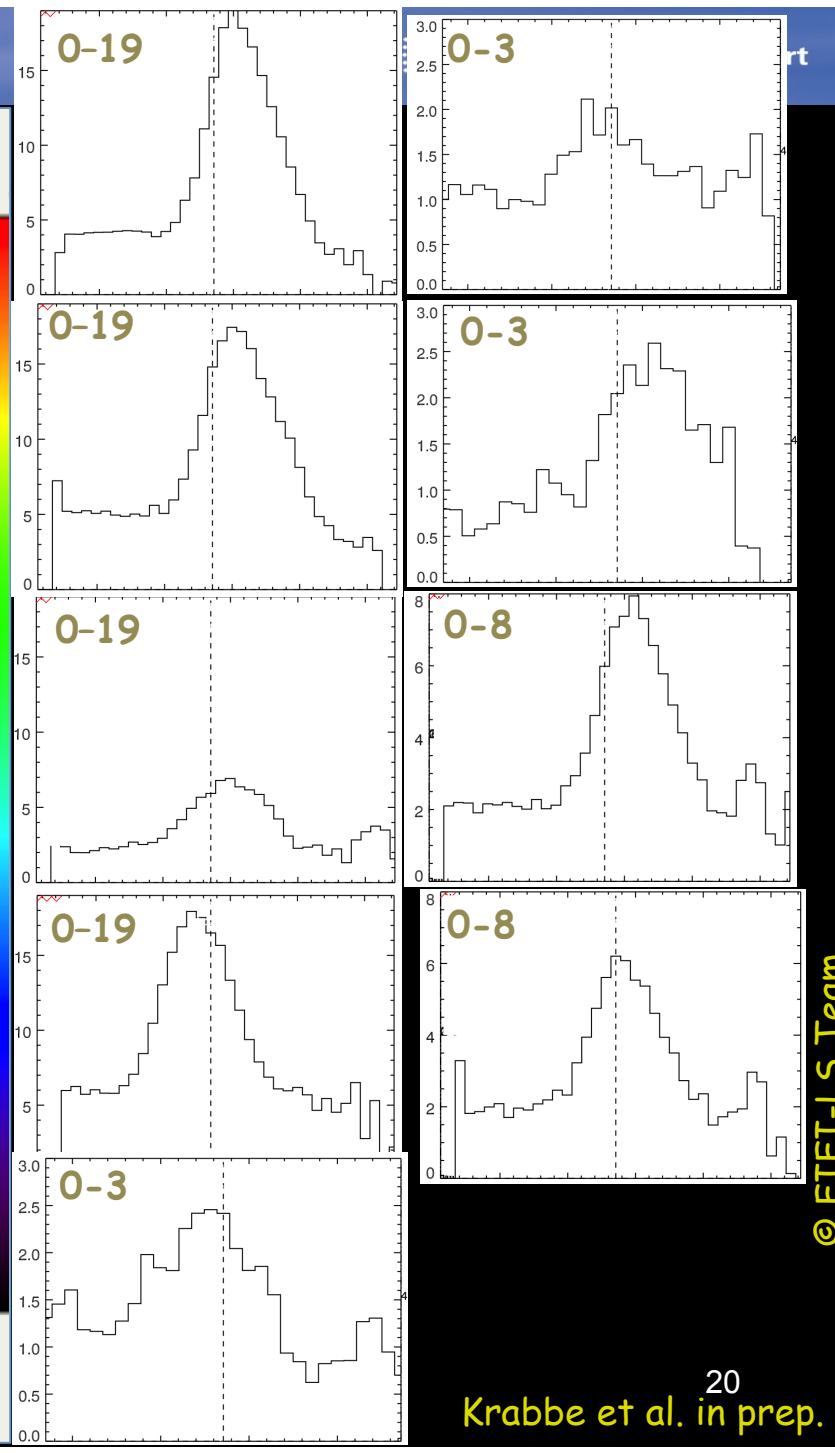
[OI] 63 $\mu$ m Velocity & Continuum Contours 0.5, 1, 1.5,

Stretch  $\pm 108$  km/s

- Rotating structure at center
- Peculiar motions outside
- Ring-Bar supported by v-field
- Similar to [CII] v-field



Iserlohe et al. in prep.



Asilo

20  
Krabbe et al. in prep.

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## 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



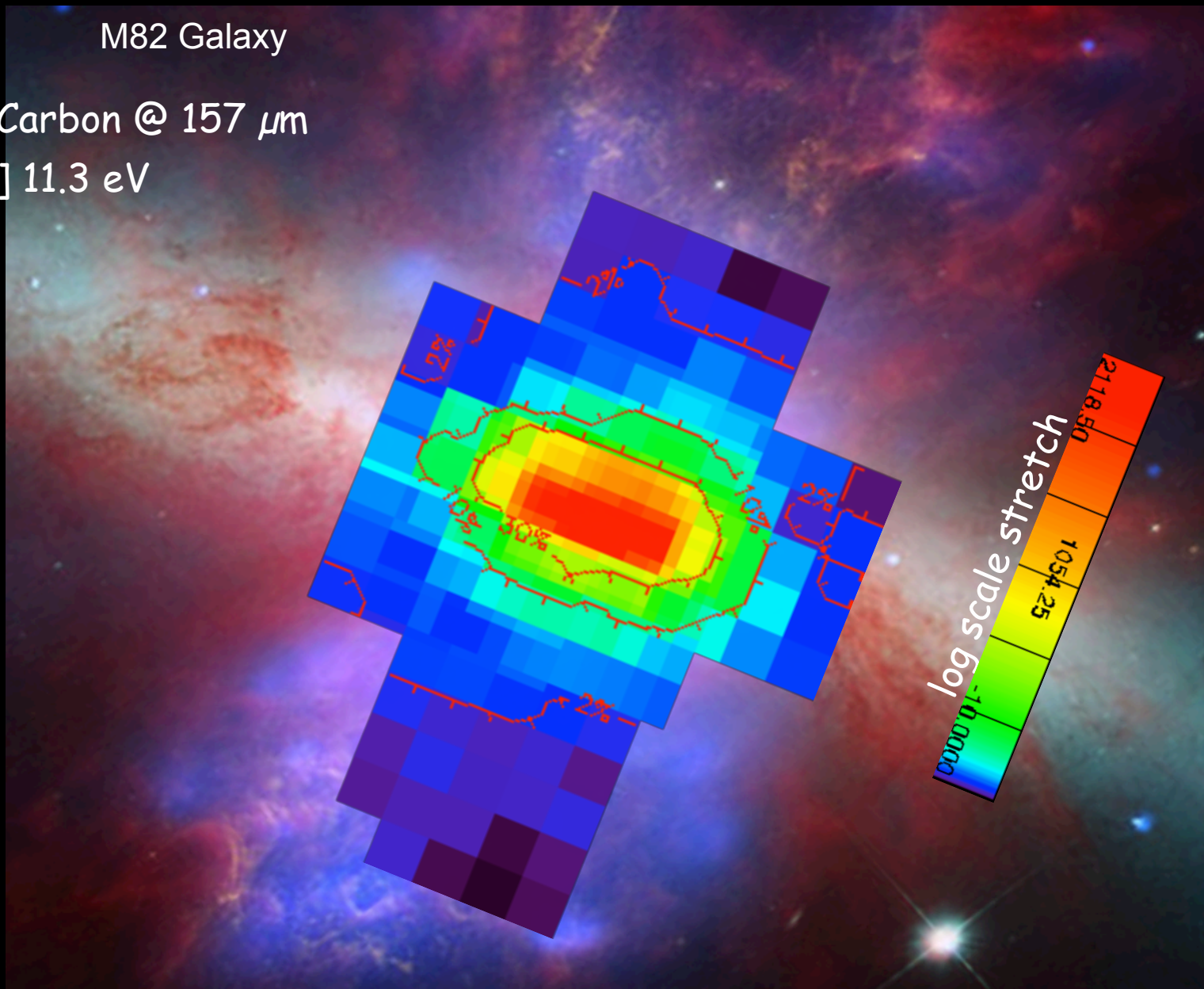
North up, east left

Background image: HST, Spitzer & Chandra

© FIFI-LS Team

M82 Galaxy

Ionized Carbon @ 157  $\mu\text{m}$   
[CII] 11.3 eV



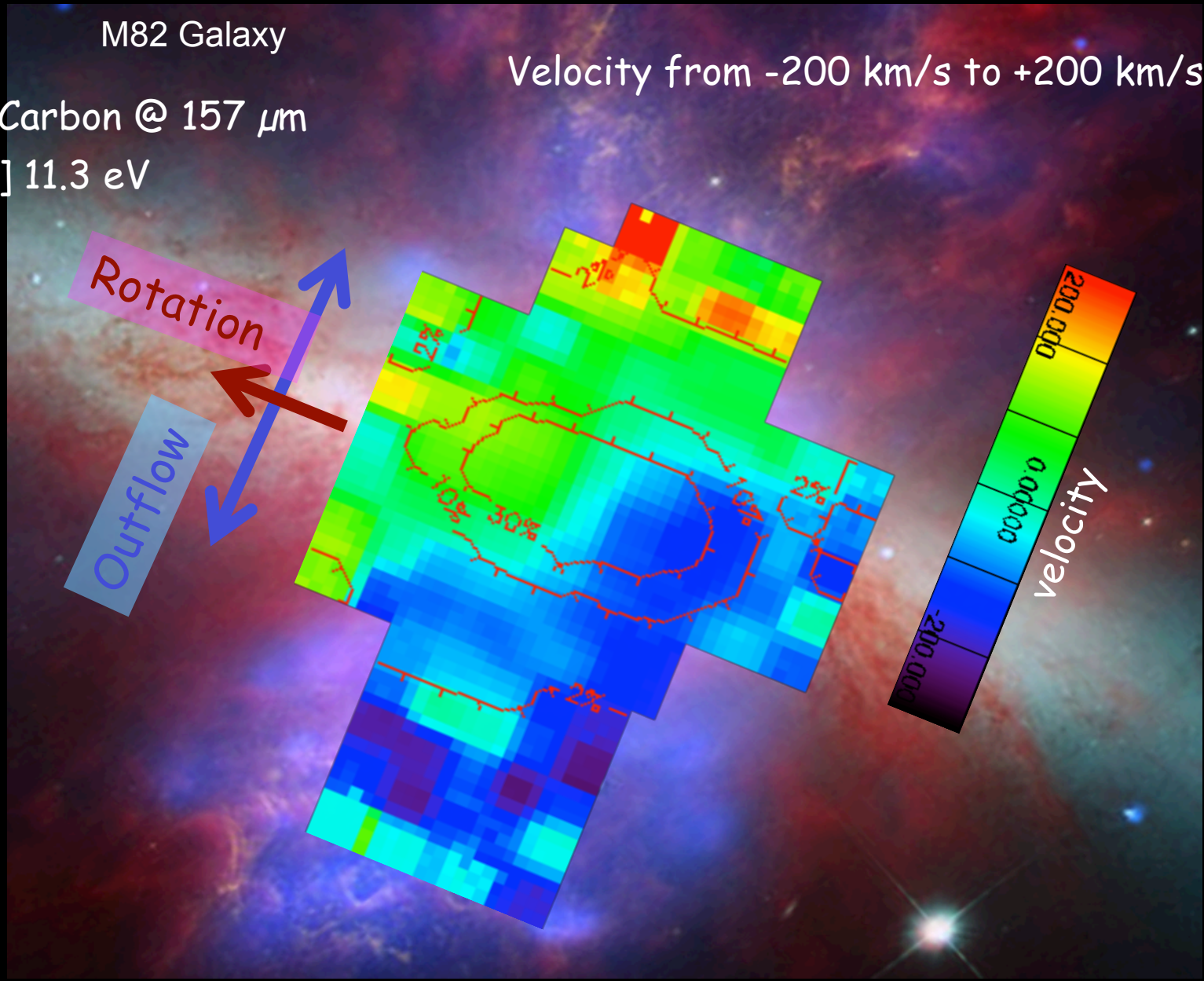
Background image: HST, Spitzer & Chandra

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M82 Galaxy

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

Ionized Carbon @ 157  $\mu\text{m}$   
[CII] 11.3 eV



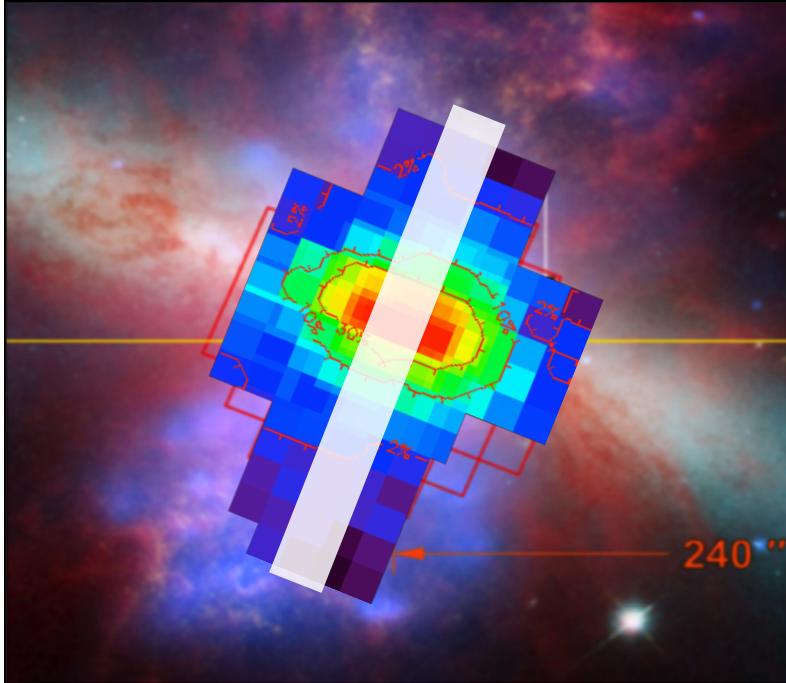
Background image: HST, Spitzer & Chandra

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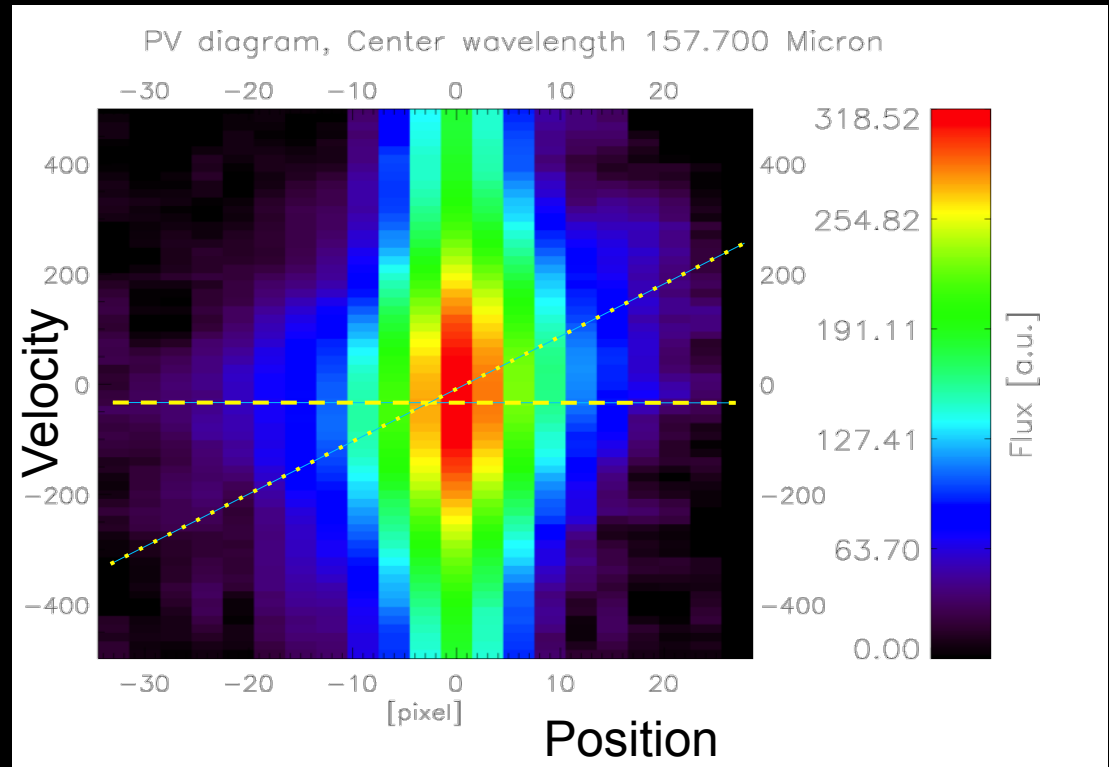


# M82 Galaxy

## Ionized Carbon @ 157 $\mu\text{m}$



## Position-velocity diagram



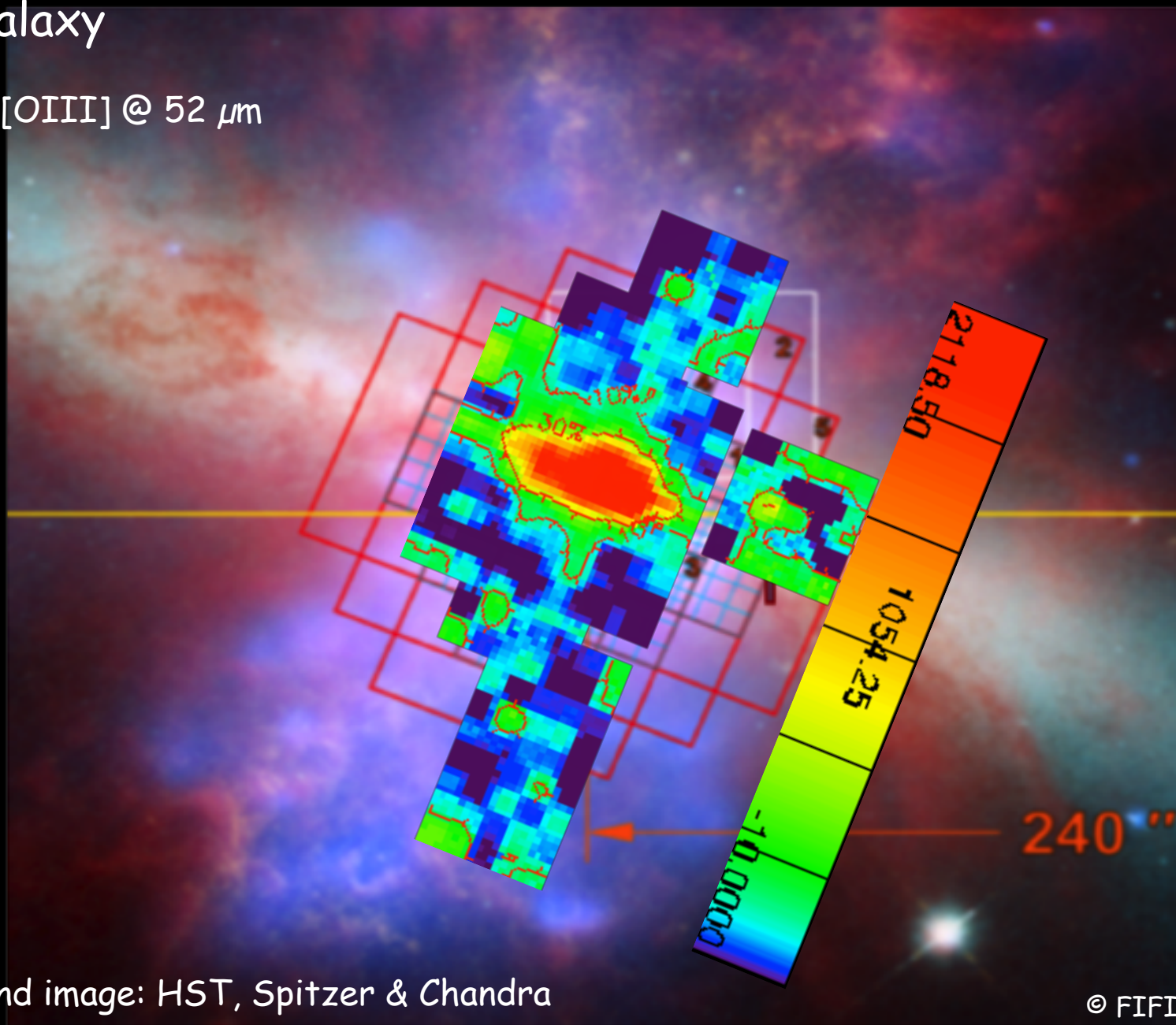
Velocity from -400 km/s to +400 km/s

Background image: HST, Spitzer & Chandra

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# M82 Galaxy

Oxygen [OIII] @ 52  $\mu\text{m}$

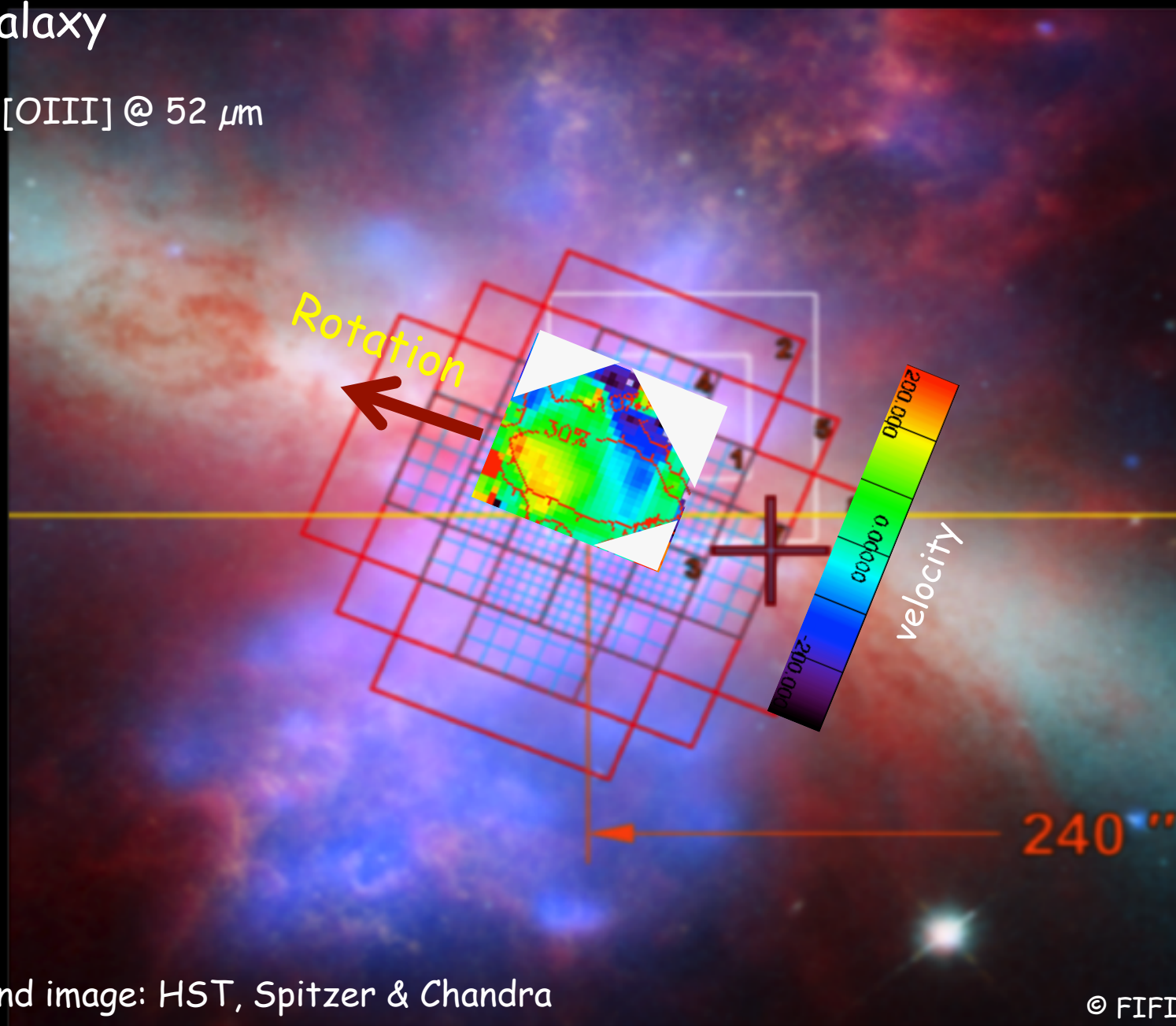


Background image: HST, Spitzer & Chandra

© FIFI-LS Team

# M82 Galaxy

Oxygen [OIII] @ 52  $\mu\text{m}$



Background image: HST, Spitzer & Chandra

© FIFI-LS Team



## Summary

- FIFI-LS can observe all the important cooling lines in the FIR
- With its two independent spectrometers it can observe two wavelengths simultaneously
- FIFI-LS maps large regions quickly, providing continuum and line fluxes
- As facility instrument on SOFIA, FIFI-LS is available to the astronomical community.

You!

Thank You