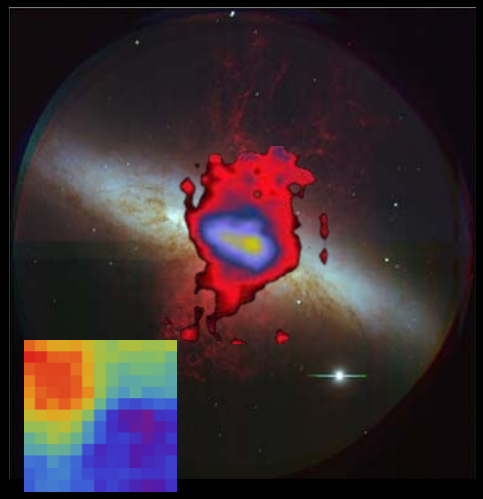
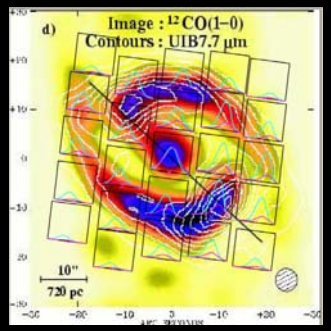
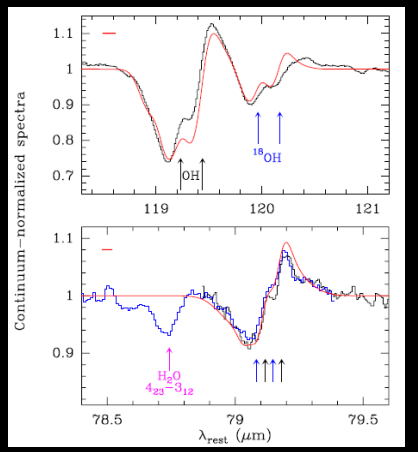
The ISM in Infrared Bright Galaxies - First Results from SHINING

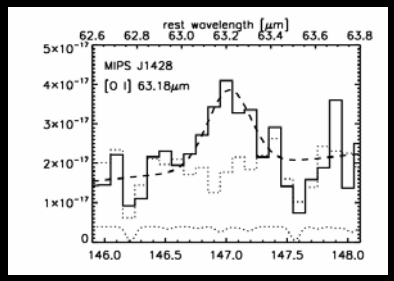


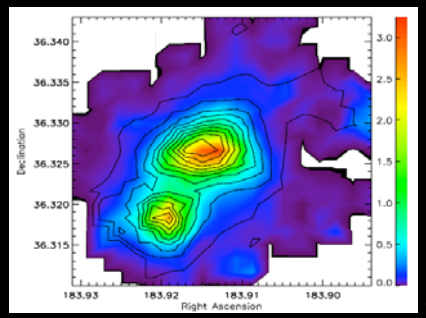


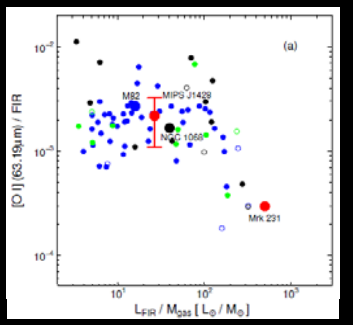
E. Sturm

for the SHINING Team

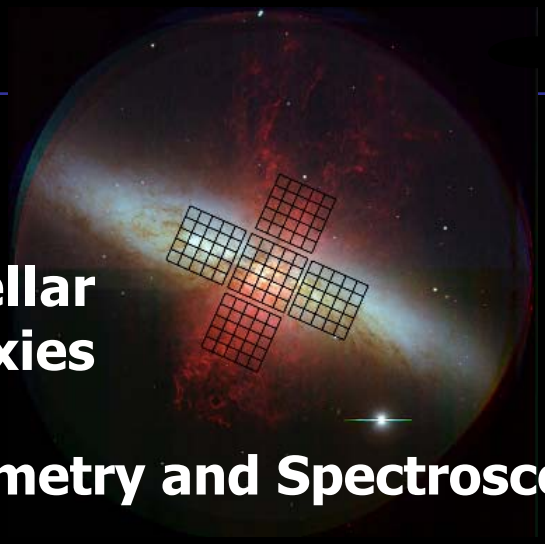




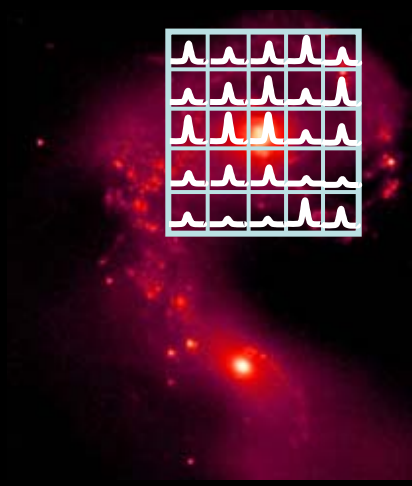




I) SHINING Goals



The **physical processes** in the **interstellar medium of local, infrared bright galaxies**

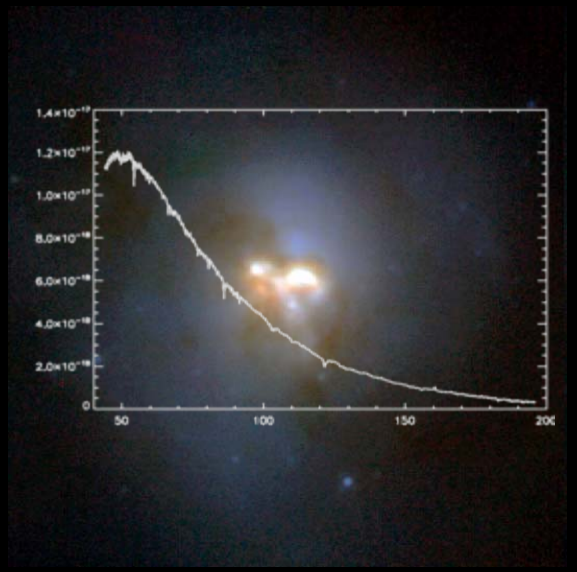


PACS (+ SPIRE) Photometry and Spectroscopy

Starbursts, AGN, ULIRGs

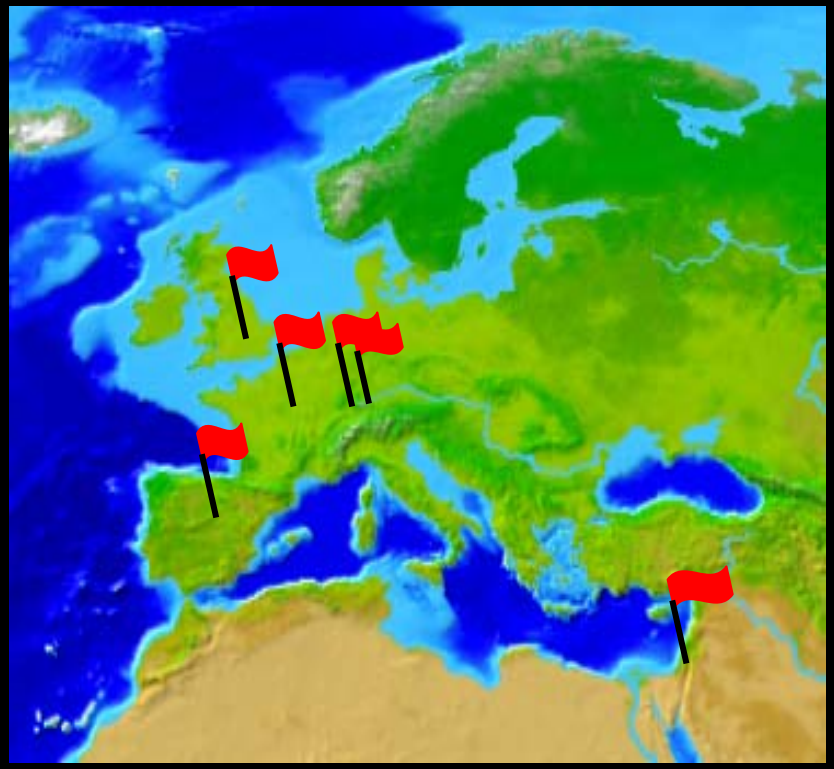
Interacting Galaxies

Dwarf Galaxies



The objects cover a wide parameter range in
- **luminosity**,
- **activity level**, and
- **metal enrichment**,

complemented by objects at **intermediate redshifts (1-3)**, i.e. at a more active epoch of star formation.



MPE: E. Sturm (PI), A. Contursi, R. Genzel, J. Graciá-Carpio, S. Hailey-Dunsheath, D. Lutz, A. Poglitsch, H. Feuchtgruber, L. Tacconi, J. de Jong

NRL/MPE: J. Fischer

Tel Aviv: A. Sternberg

Oxford: A. Verma, N. Christopher

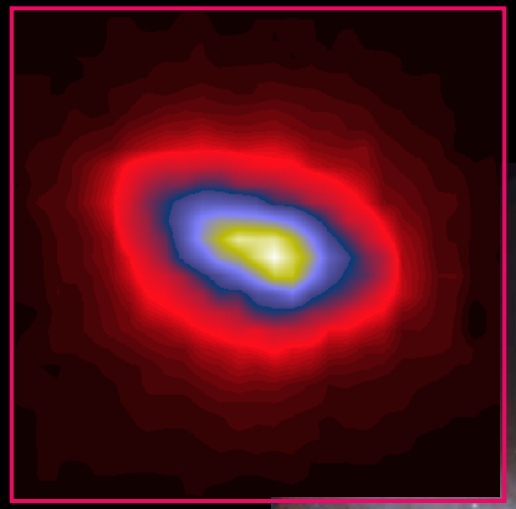
Madrid: E. González-Alfonso

CEA/IAP: S. Madden (Co-PI), M. Sauvage, L. Vigroux, Diane Cormier

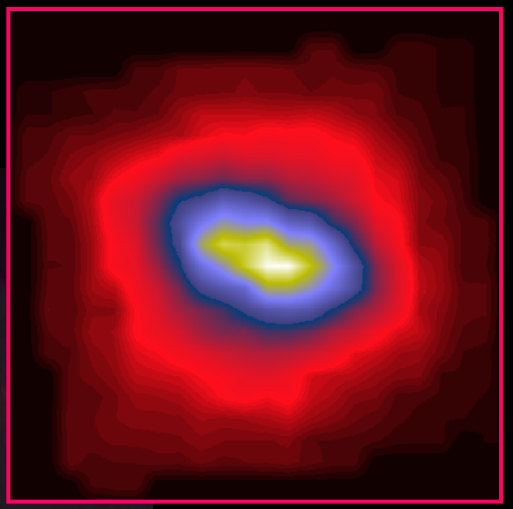
MPIA: U. Klaas (Co-PI), M. Nielbock, H. Linz, J. Schreiber, O. Krause, D. Lemke, E. Schinnerer, F. Walter

BochumUniv: M. Haas

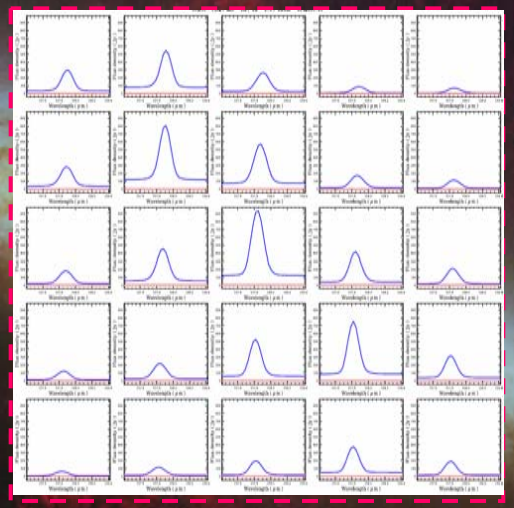
M82



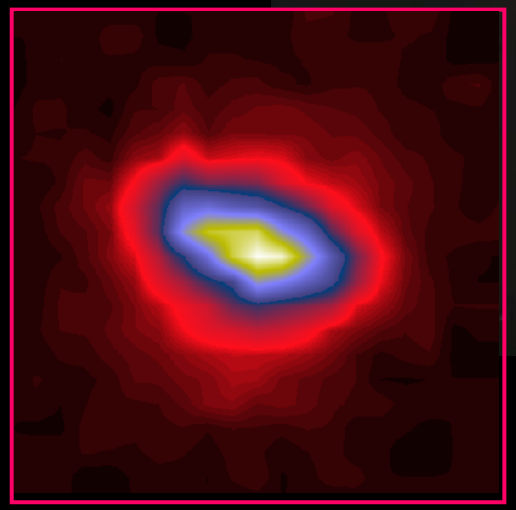
[O I] 63 μm



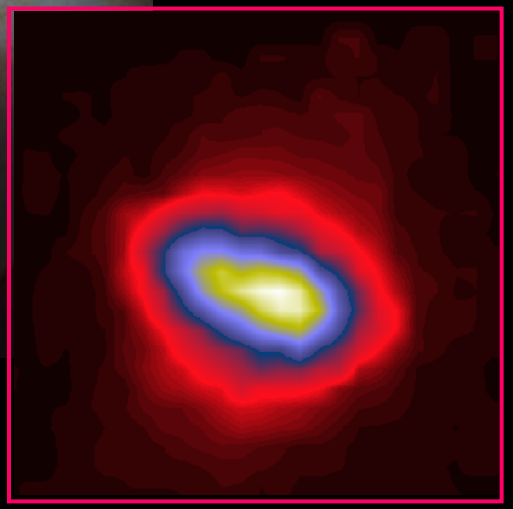
[C II] 158 μm



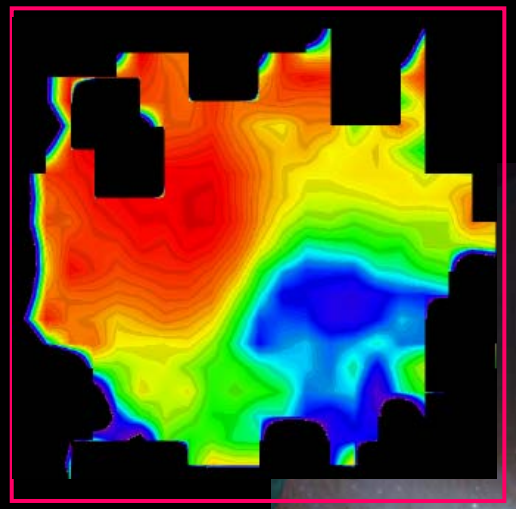
[O I] 145 μm



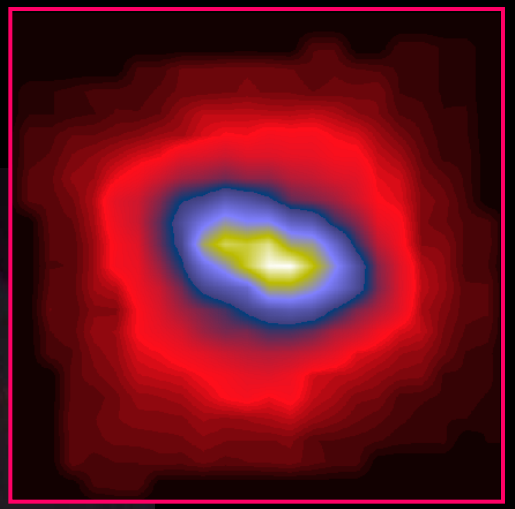
[O III] 88 μm



M82

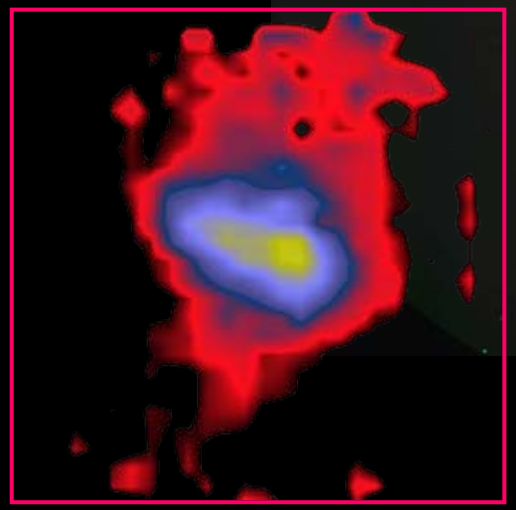


[O III] velocity

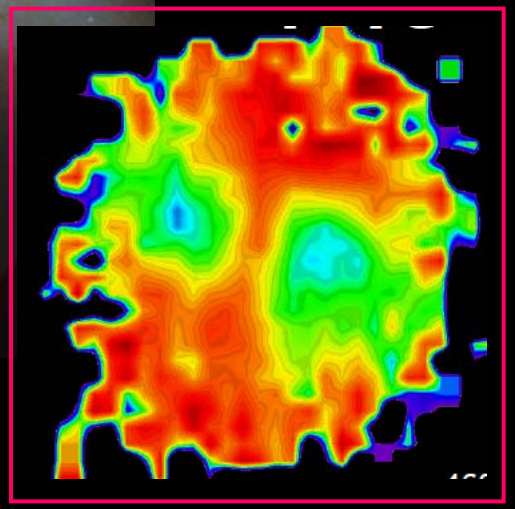


[C II] 158 μm

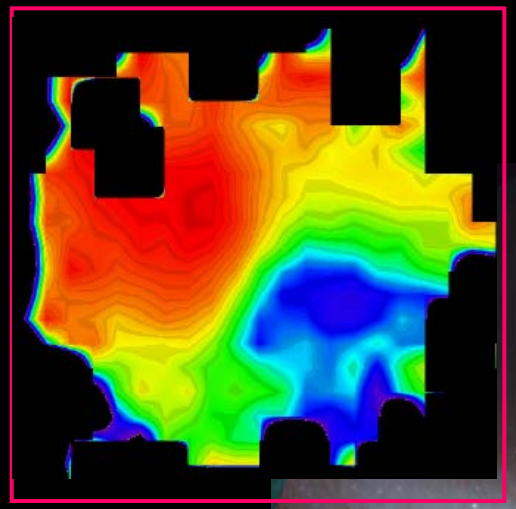
[O III] / [C II]



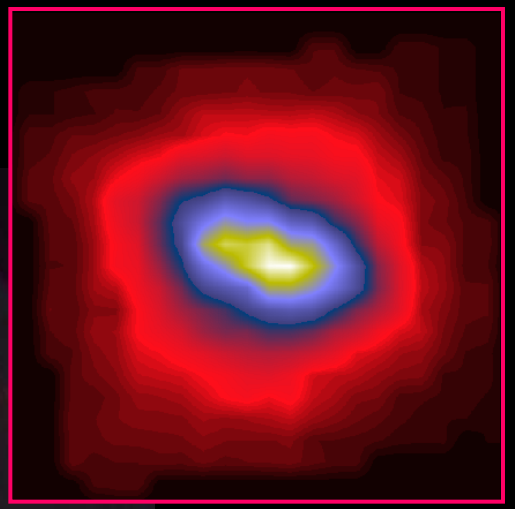
[O III] σ



M82

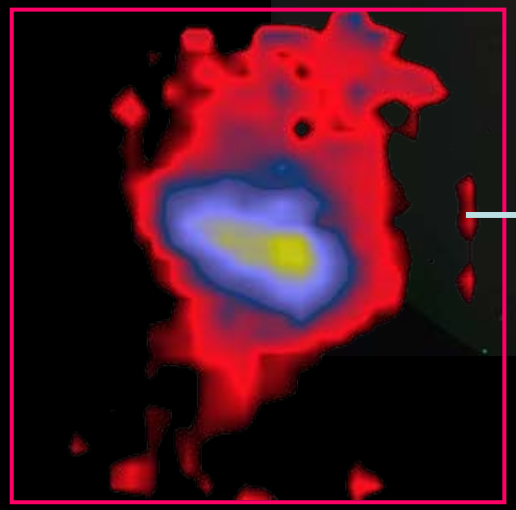


[O III] velocity

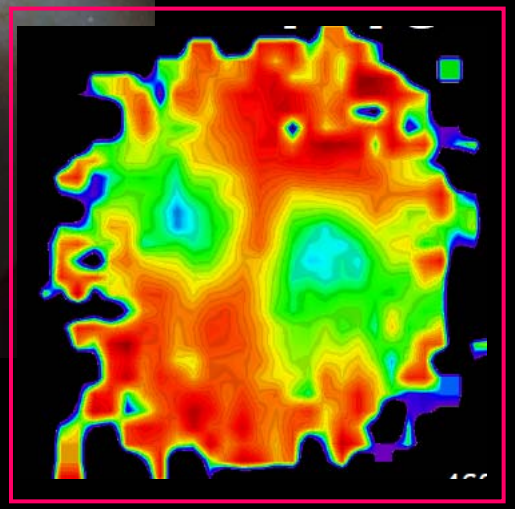


[C II] 158 μm

[O III] / [C II]

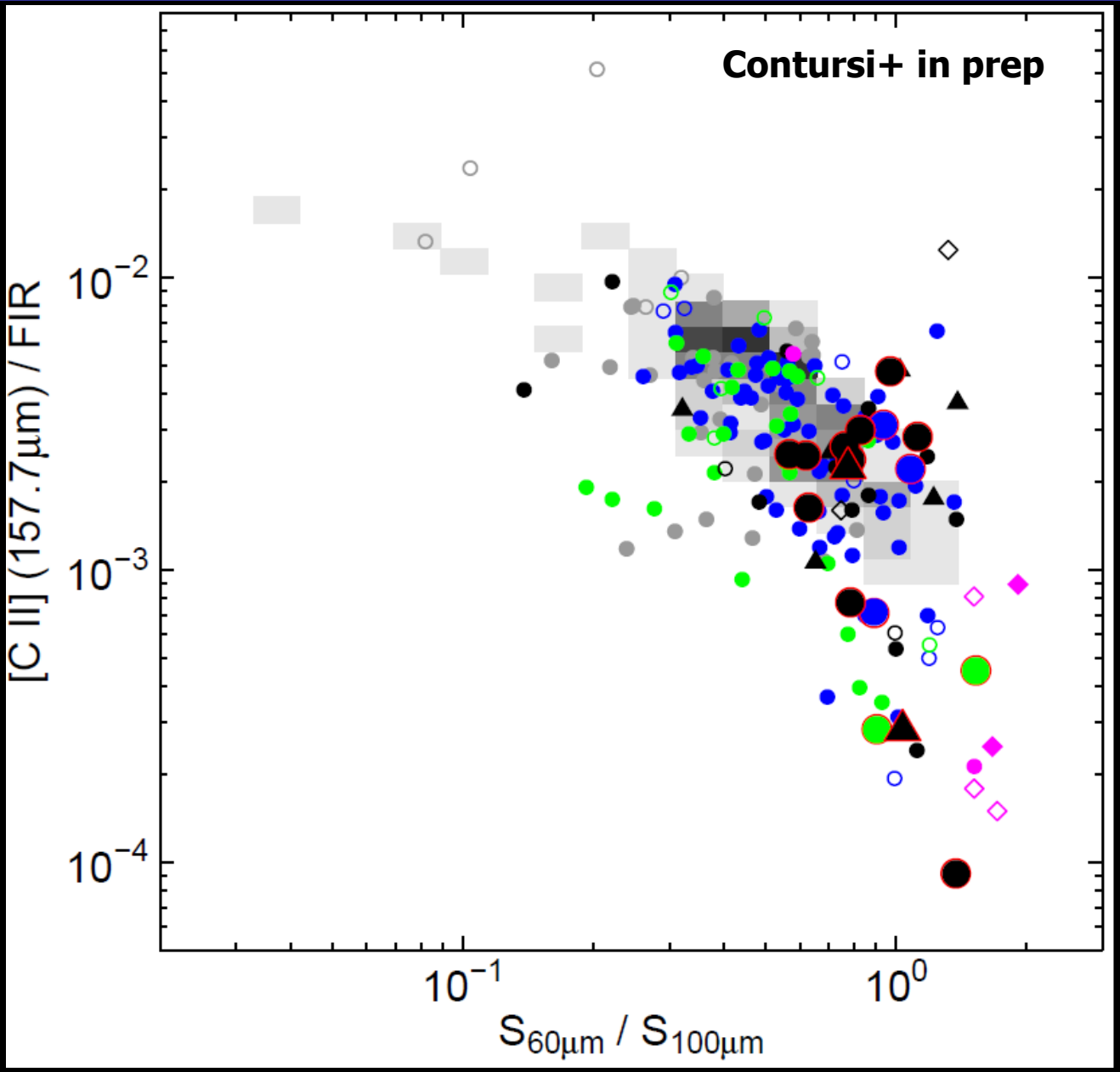


[O III] σ

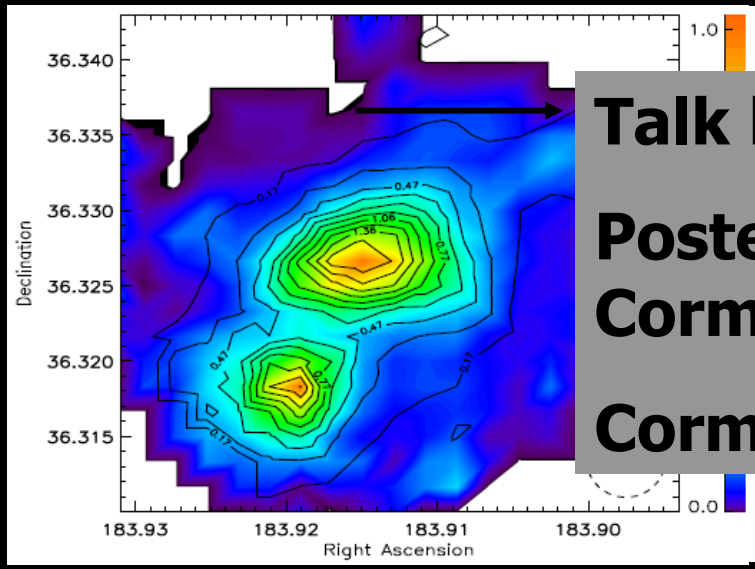


Talk by A. Contursi

Contursi+ in prep


Contursi+ in prep
[C II] (157.7μm) / FIR
10^{-2}
10^{-3}
10^{-4}
10^{-1}
10^{0}
$S_{60\mu m} / S_{100\mu m}$

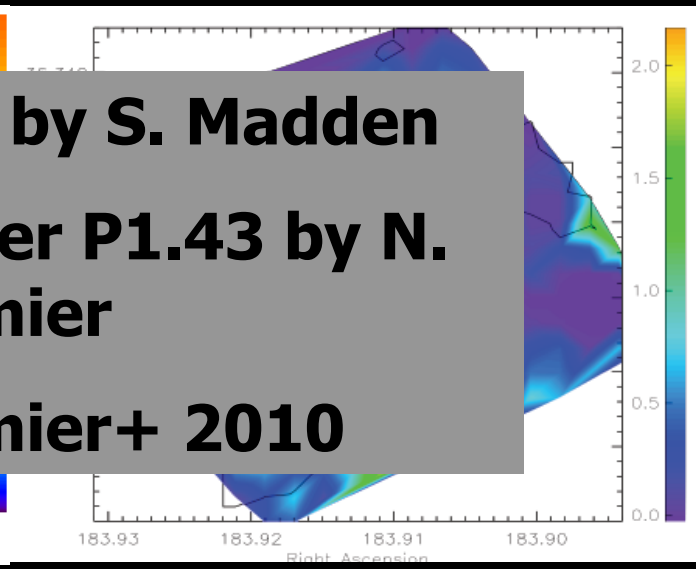
Dwarfs / Low metallicity - NGC 4214

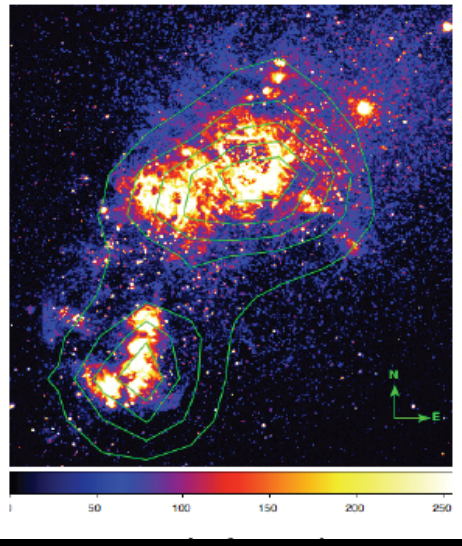


Talk by S. Madden

Poster P1.43 by N. Cormier

Cormier+ 2010





[O I] 63μm line with [C II] 158μm contours.

[O III] 88μm/ [C II] with [C II] contours.

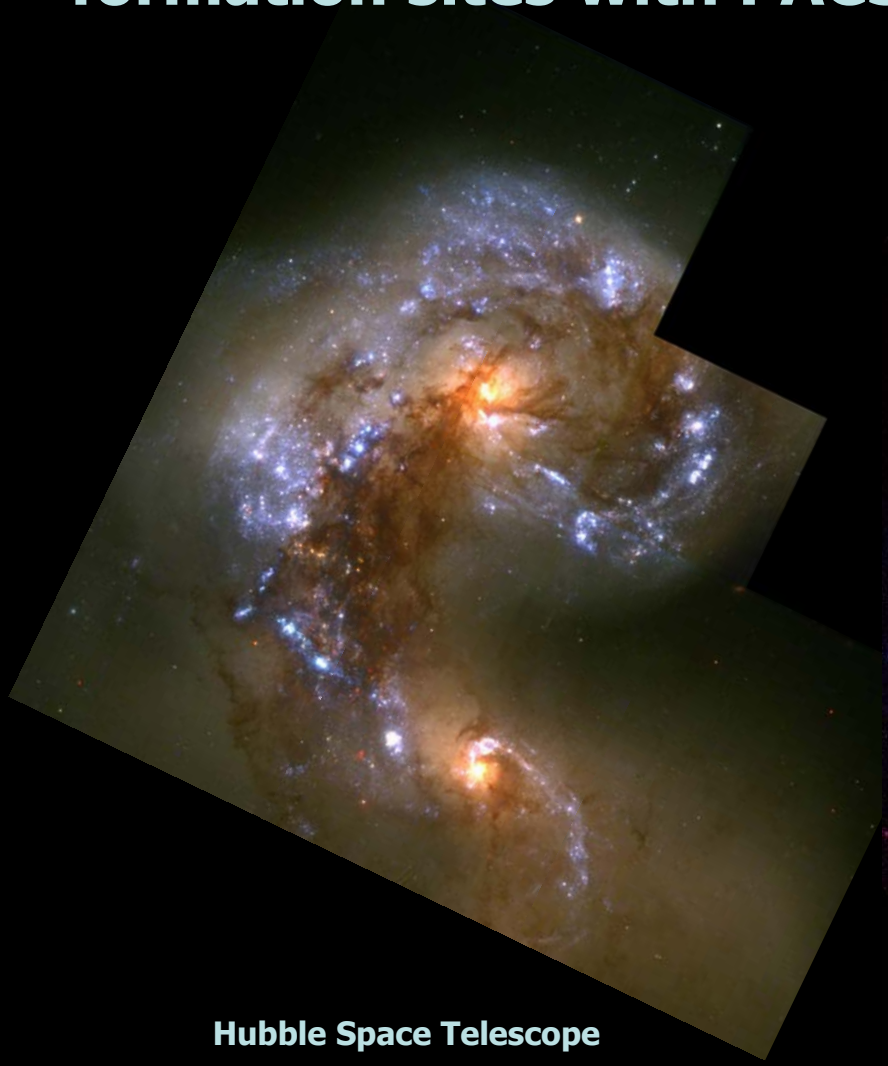
Optical HST image (Ubeda+ 2007) with [O III] 88μm contours.

Low metallicity + intense star formation →

- high [O III] / [C I]
- L(FIR lines) = 2% of L_{TIR}
- extreme CII/CO, ISM strongly affected by photodissociation

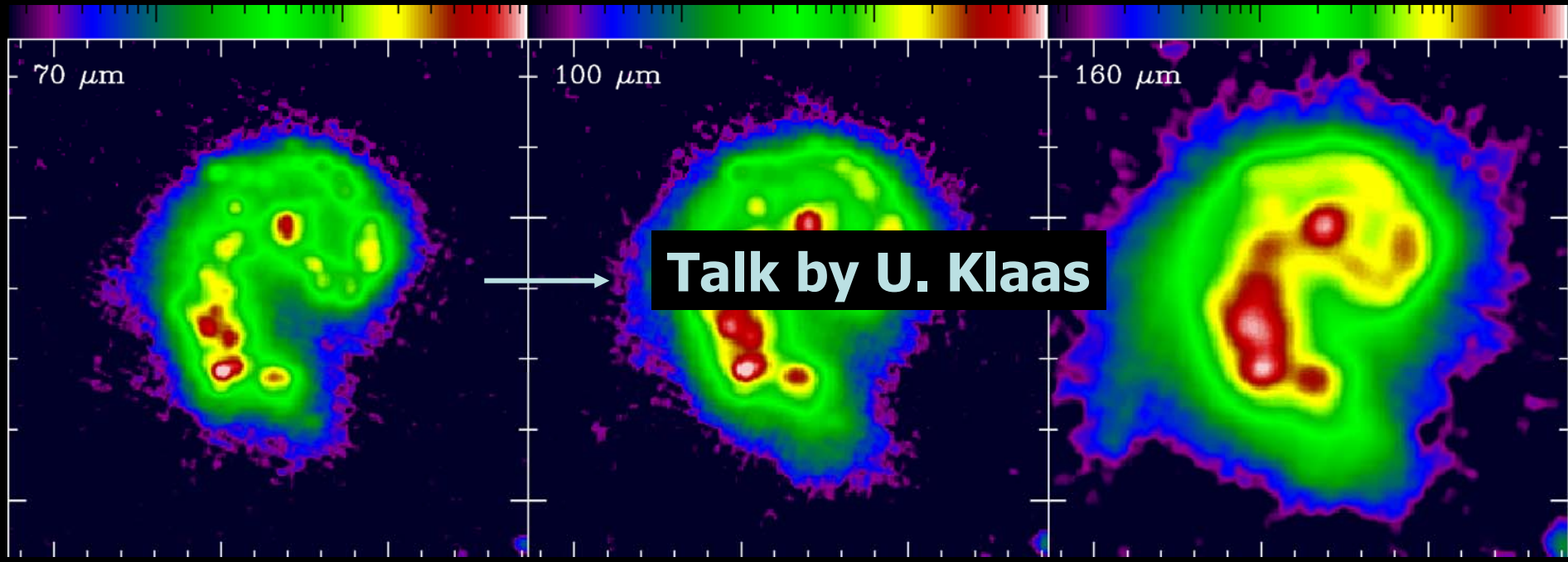
Irregular Magellanic type galaxy
2.9 Mpc away
Metallicity: 1/3 solar

Interacting galaxies – resolving the star formation sites with PACS photometry



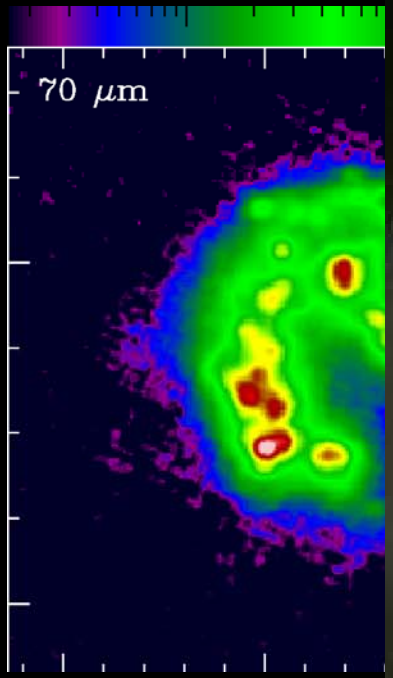
Hubble Space Telescope

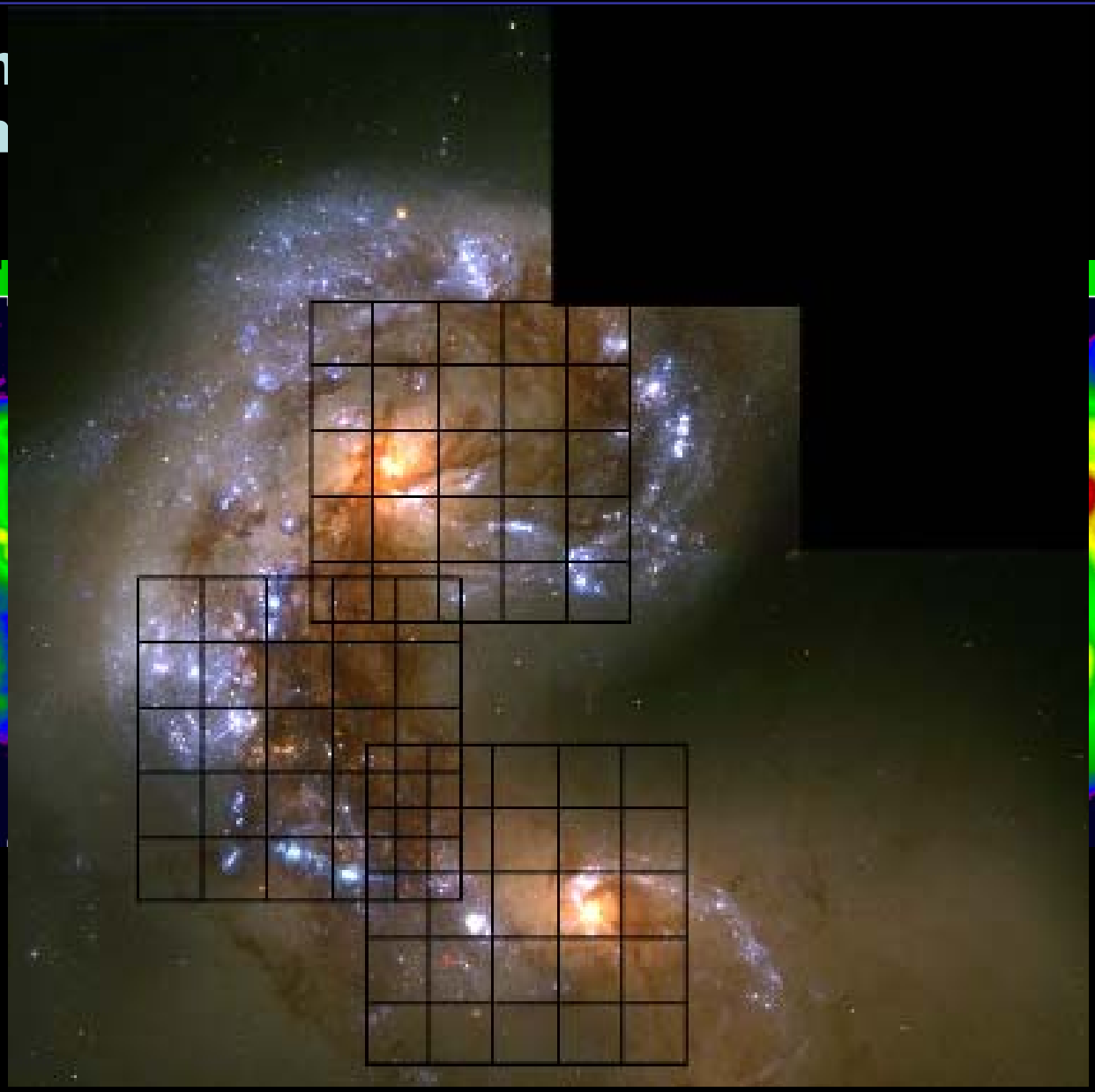
Interacting galaxies – resolving the star formation sites with PACS photometry

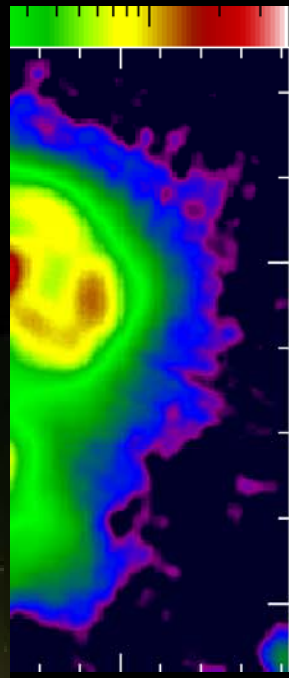


Klaas+ 2010

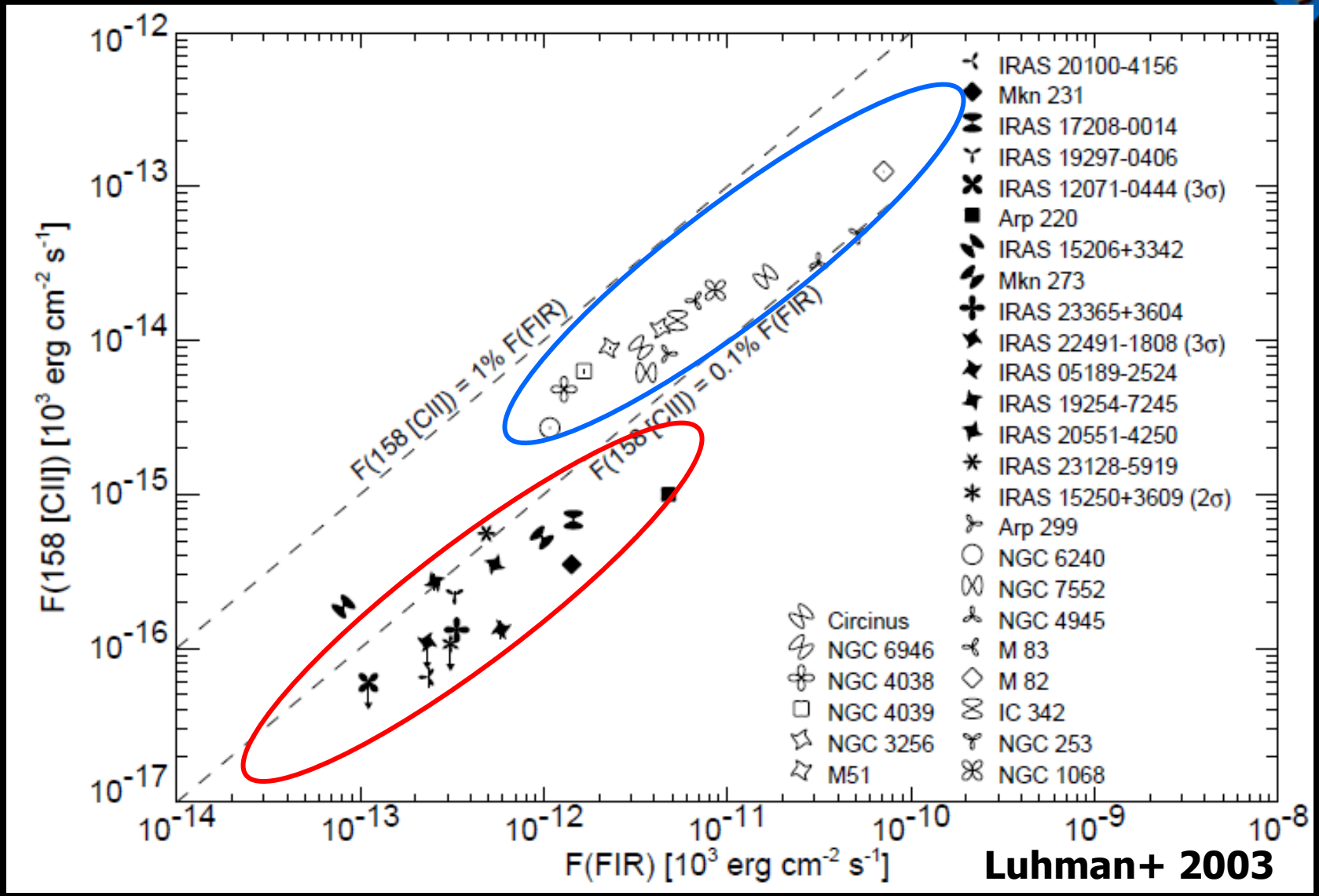
Interactin
formation

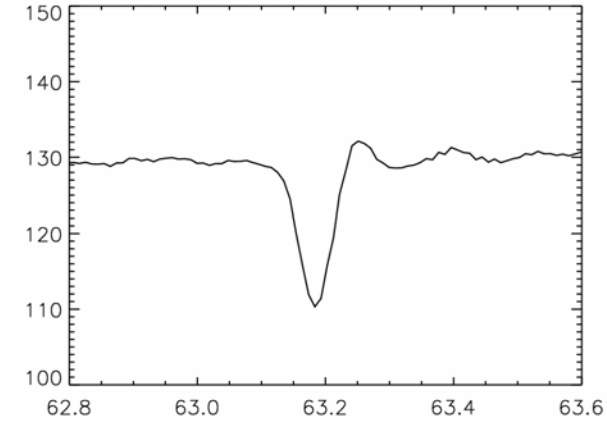


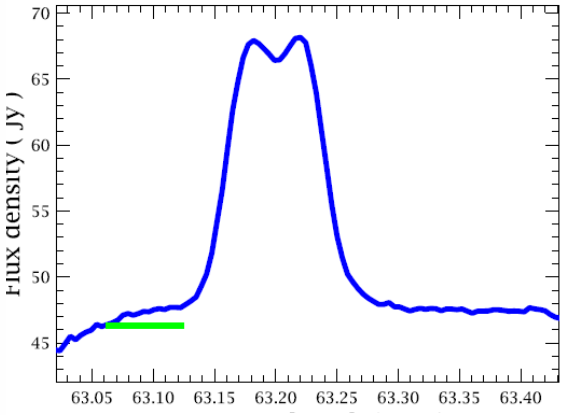




ISO's Heritage – The „CII deficit"




150
140
130
120
110
100
62.8
63.0
63.2
63.4
63.6


Flux density (Jy)
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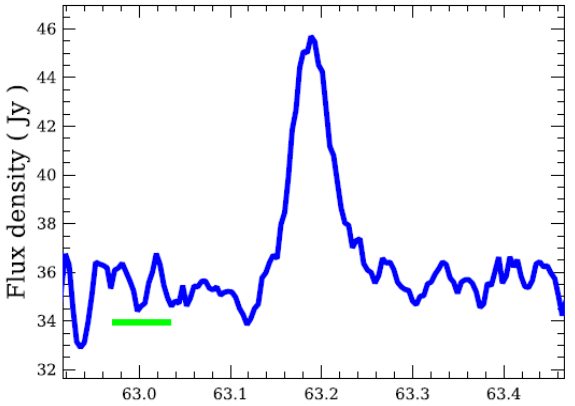
65
60
55
50
45
63.05
63.10
63.15
63.20
63.25
63.30
63.35
63.40


Flux density (Jy)
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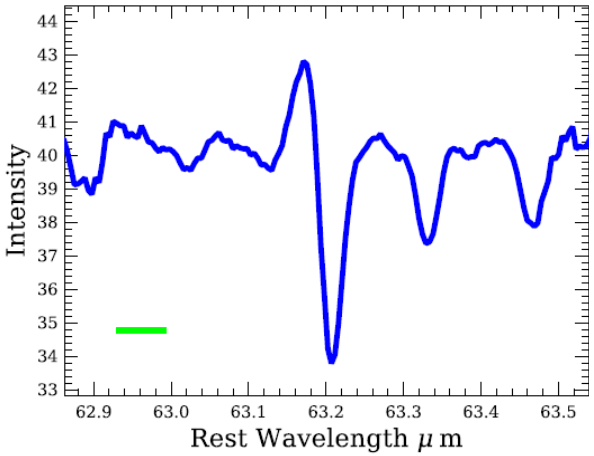
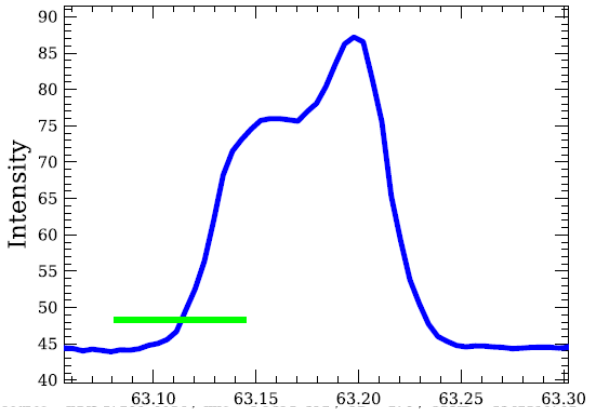
44
42
40
38
36
34
32
63.0
63.1
63.2
63.3
63.4


Intensity
44
43
42
41
40
39
38
37
36
35
34
33
62.9
63.0
63.1
63.2
63.3
63.4
63.5
Rest Wavelength μ m


Intensity
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85
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75
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65
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55
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45
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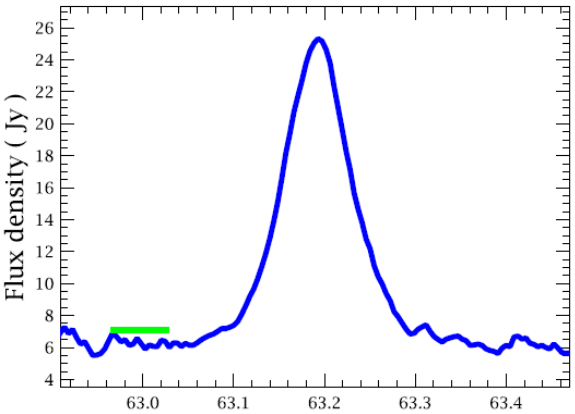
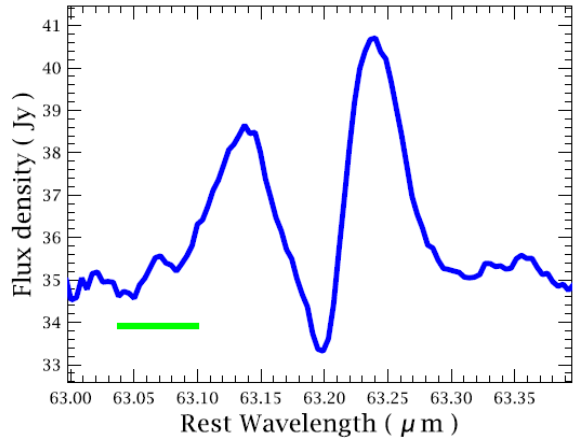
63.10
63.15
63.20
63.25
63.30


Flux density (Jy)
26
24
22
20
18
16
14
12
10
8
6
4
63.0
63.1
63.2
63.3
63.4

[O I] 63μm


Flux density (Jy)
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40
39
38
37
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63.00
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63.10
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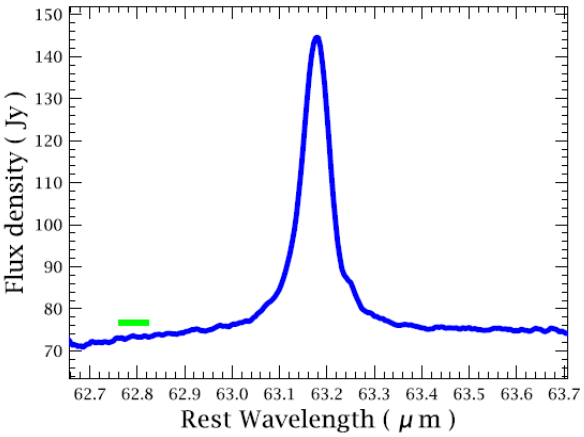
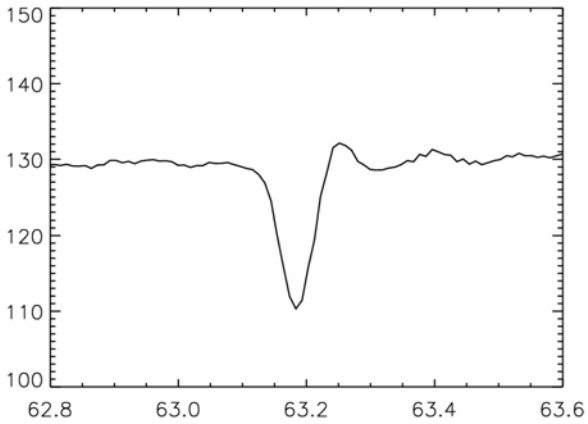
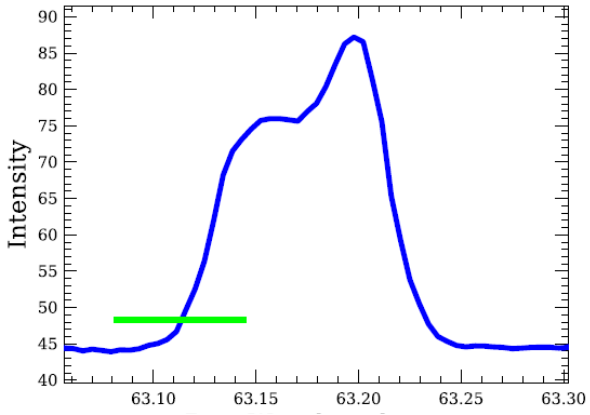
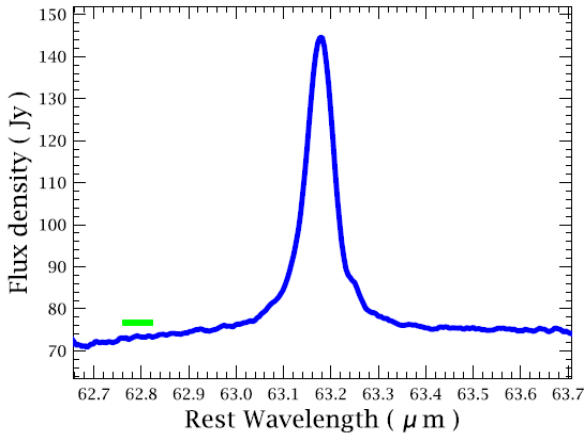
63.25
63.30
63.35
Rest Wavelength (μ m)

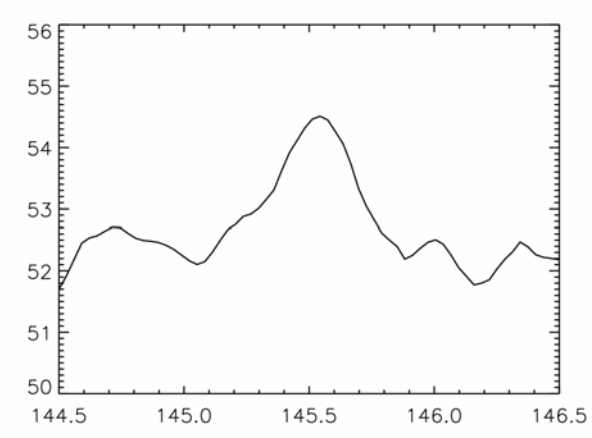

Flux density (Jy)
150
140
130
120
110
100
90
80
70
62.7
62.8
62.9
63.0
63.1
63.2
63.3
63.4
63.5
63.6
63.7
Rest Wavelength (μ m)

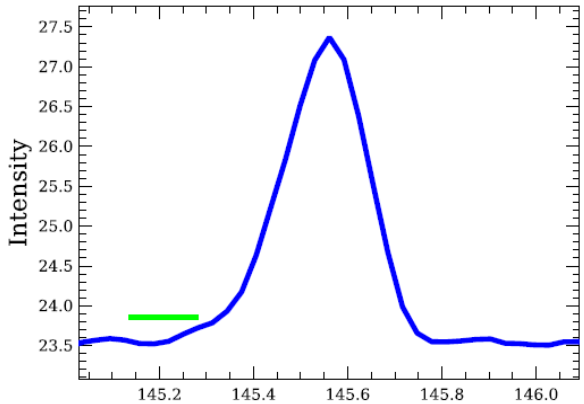

150
140
130
120
110
100
62.8
63.0
63.2
63.4
63.6


Intensity
90
85
80
75
70
65
60
55
50
45
40
63.10
63.15
63.20
63.25
63.30


Flux density (Jy)
150
140
130
120
110
100
90
80
70
62.7
62.8
62.9
63.0
63.1
63.2
63.3
63.4
63.5
63.6
63.7
Rest Wavelength (μm)

[O I] 63μm


56
55
54
53
52
51
50
144.5
145.0
145.5
146.0
146.5


Intensity
27.5
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26.5
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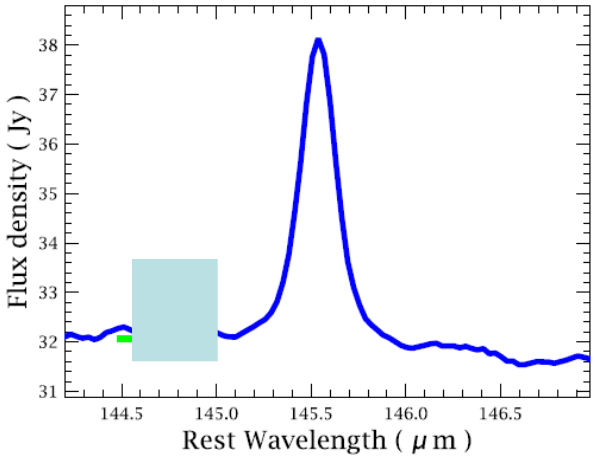
24.5
24.0
23.5
145.2
145.4
145.6
145.8
146.0

[O I] 145µm


Flux density (Jy)
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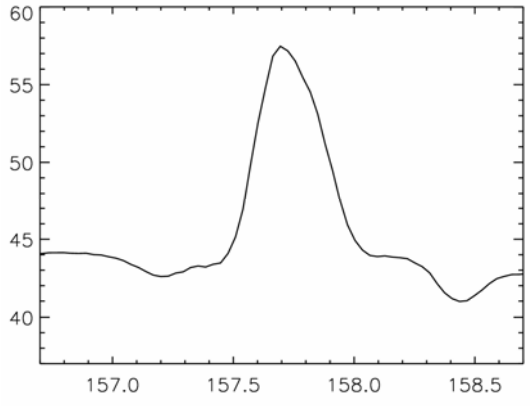
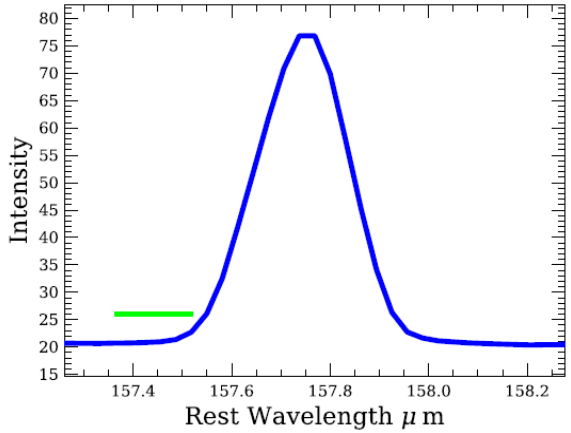
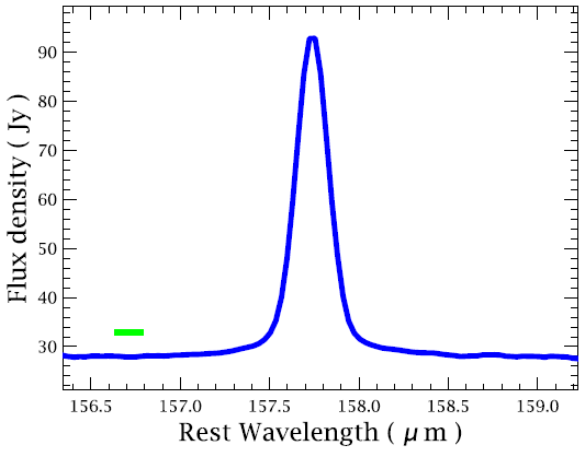
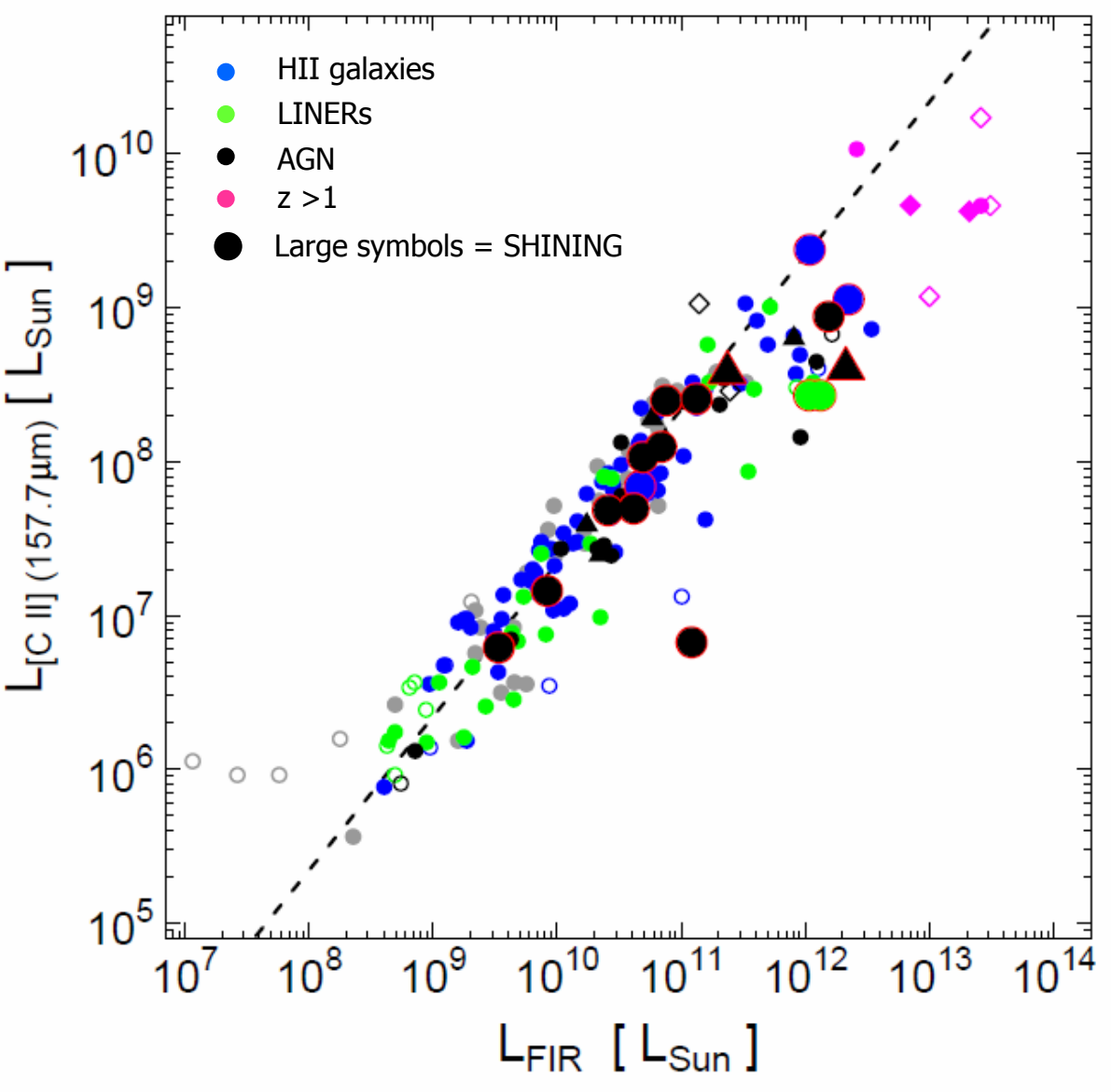
37
36
35
34
33
32
31
144.5
145.0
145.5
146.0
146.5
Rest Wavelength (µm)

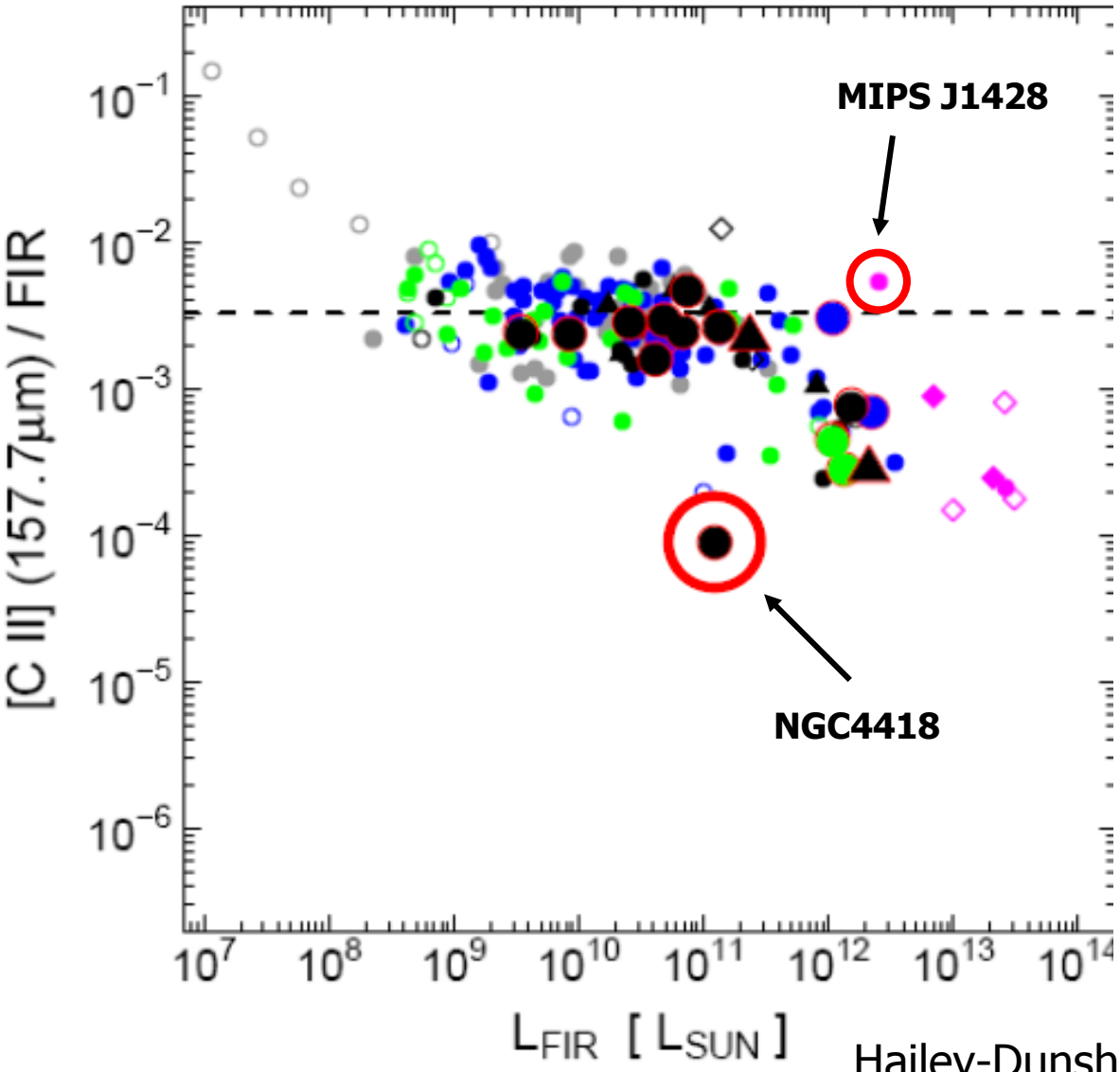

60
55
50
45
40
157.0
157.5
158.0
158.5


Intensity
80
75
70
65
60
55
50
45
40
35
30
25
20
15
157.4
157.6
157.8
158.0
158.2
Rest Wavelength μm


Flux density (Jy)
90
80
70
60
50
40
30
156.5
157.0
157.5
158.0
158.5
159.0
Rest Wavelength (μm)

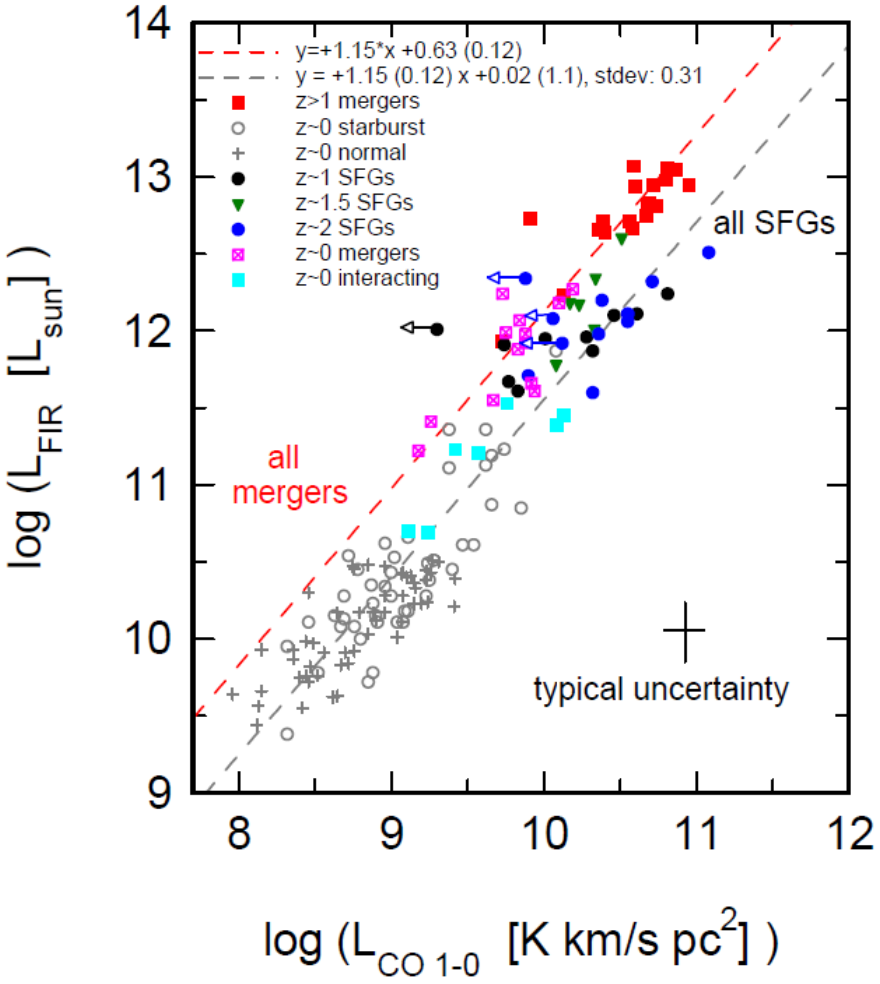
[C II] 157μm

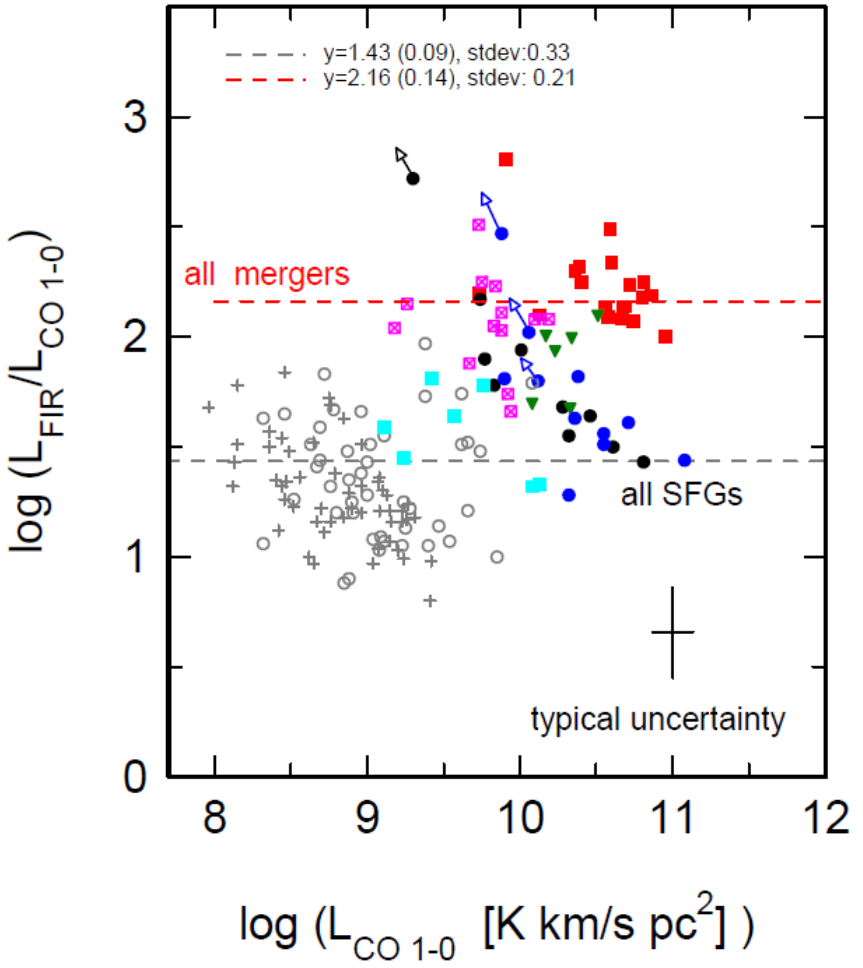

HII galaxies
LINERs
AGN
z >1
Large symbols = SHINING
$L_{[C\ II]}$ (157.7μm) [L_{Sun}]
L_{FIR} [L_{Sun}]
10^5
10^6
10^7
10^8
10^9
10^{10}
10^{11}
10^{12}
10^{13}
10^{14}



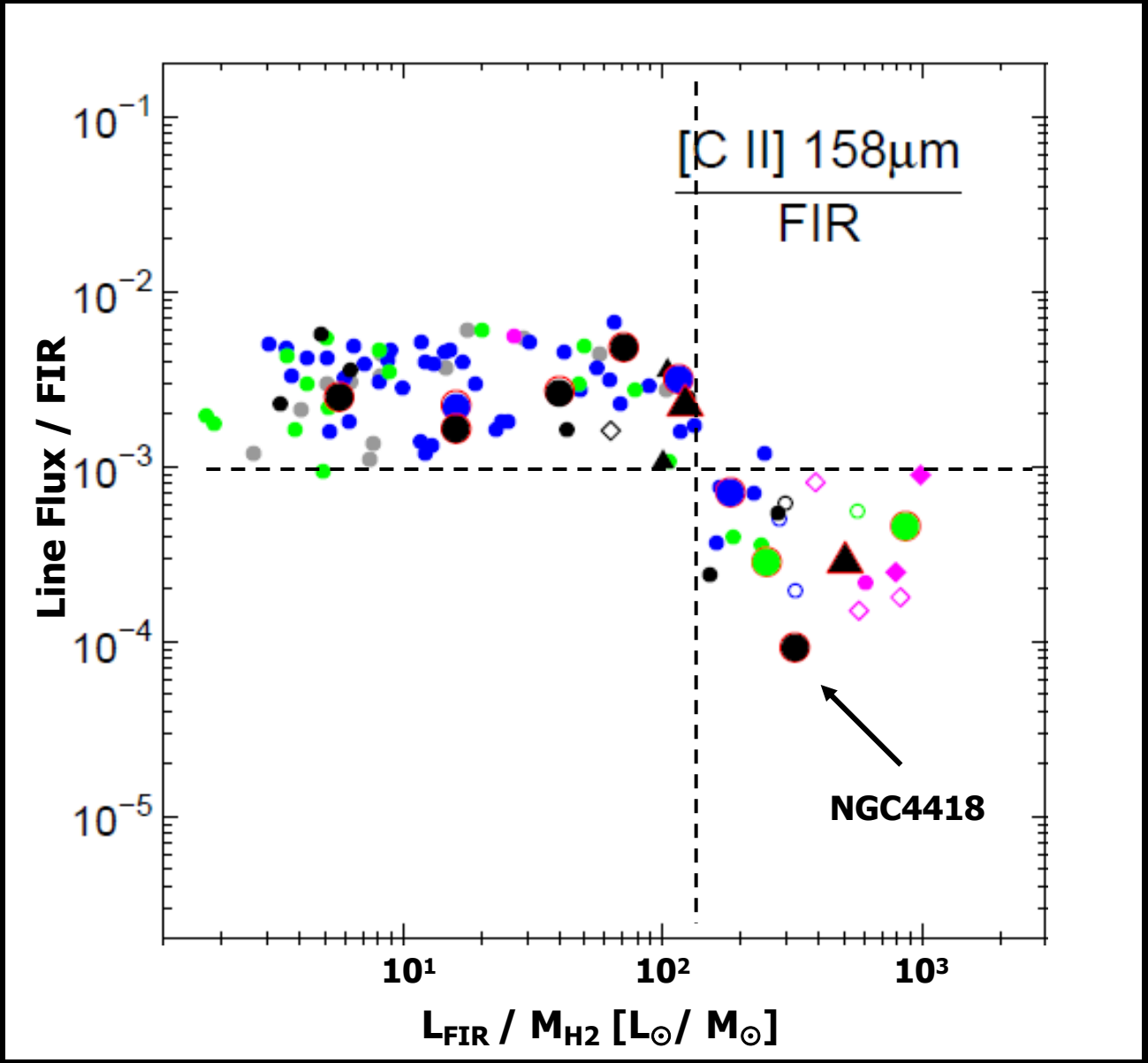
Hailey-Dunsheath+ 2010 and in prep.

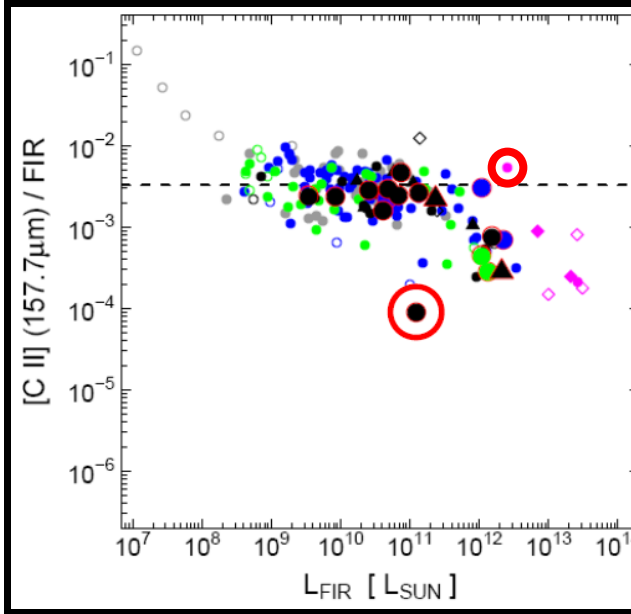
The roles of Major Mergers vs. Steady Accretion, and the SFE



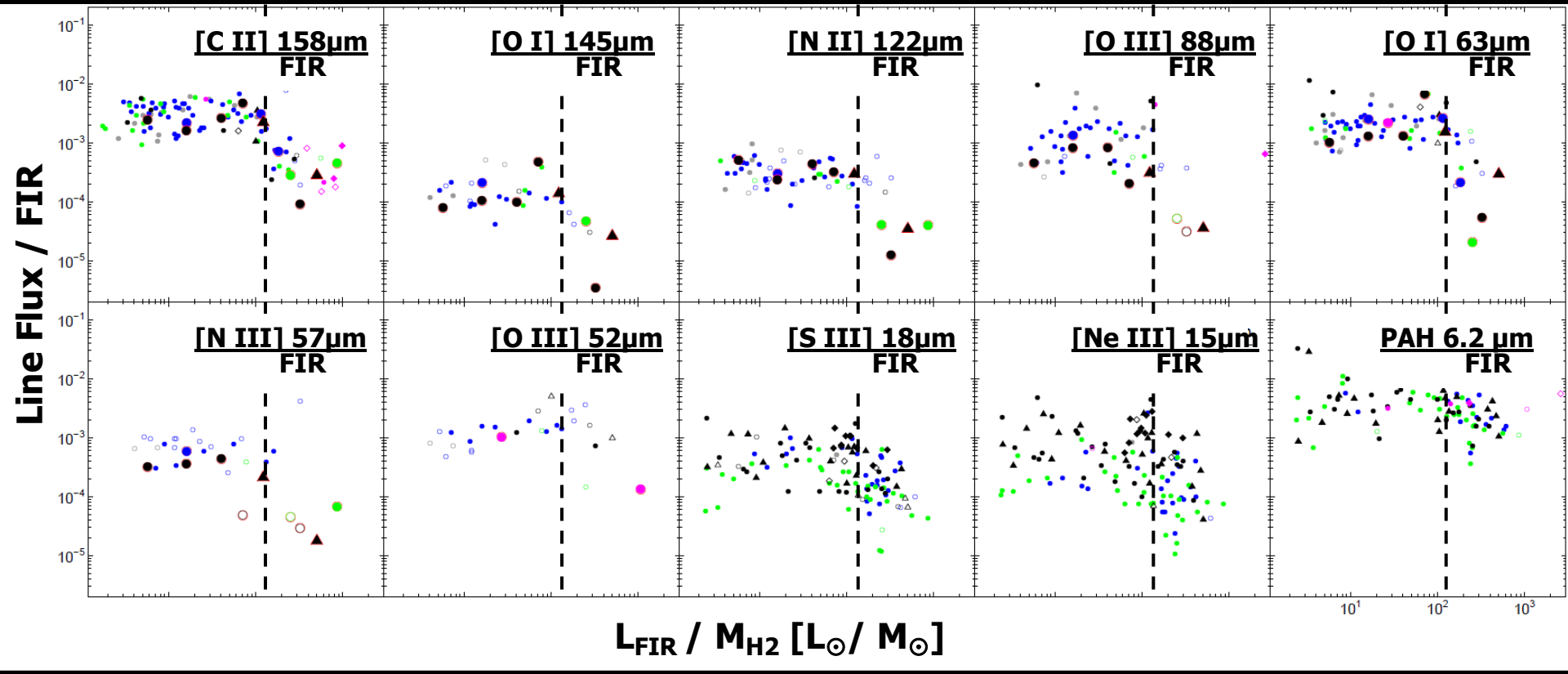


Genzel et al. 2010, Tacconi et al. 2010

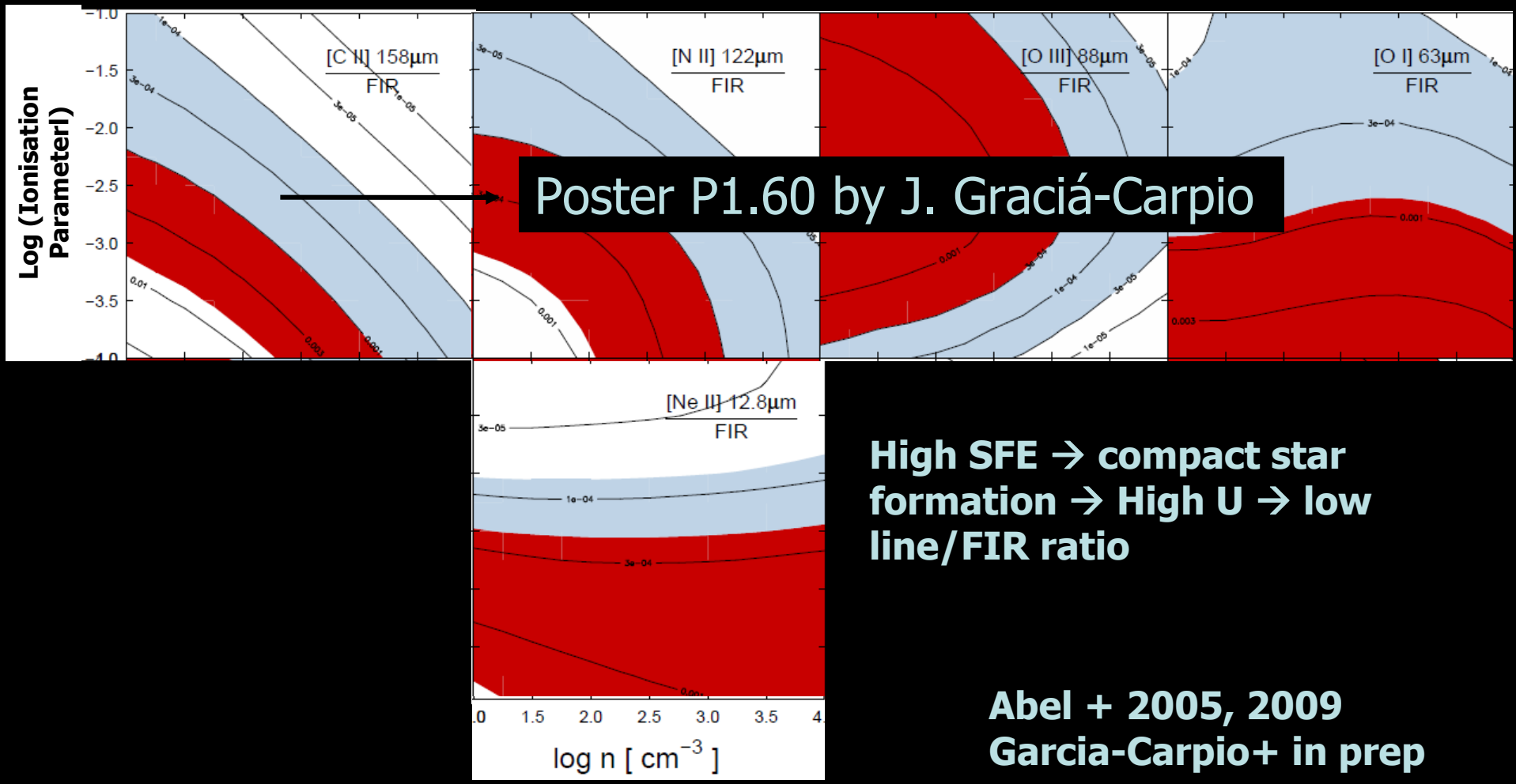

[C II] 158μm
FIR
Line Flux / FIR
10^{-1}
10^{-2}
10^{-3}
10^{-4}
10^{-5}
10^{1}
10^{2}
10^{3}
NGC4418
L_{FIR} / M_{H2} [$L_\odot$/ $M_\odot$]


[C II] (157.7μm) / FIR
10^{-1}
10^{-2}
10^{-3}
10^{-4}
10^{-5}
10^{-6}
10^{7}
10^{8}
10^{9}
10^{10}
10^{11}
10^{12}
10^{13}
L_{FIR} [L_{SUN}]

~~[C II] - deficiency~~ Line - deficiency



CLOUDY modelling



Poster P1.60 by J. Graciá-Carpio

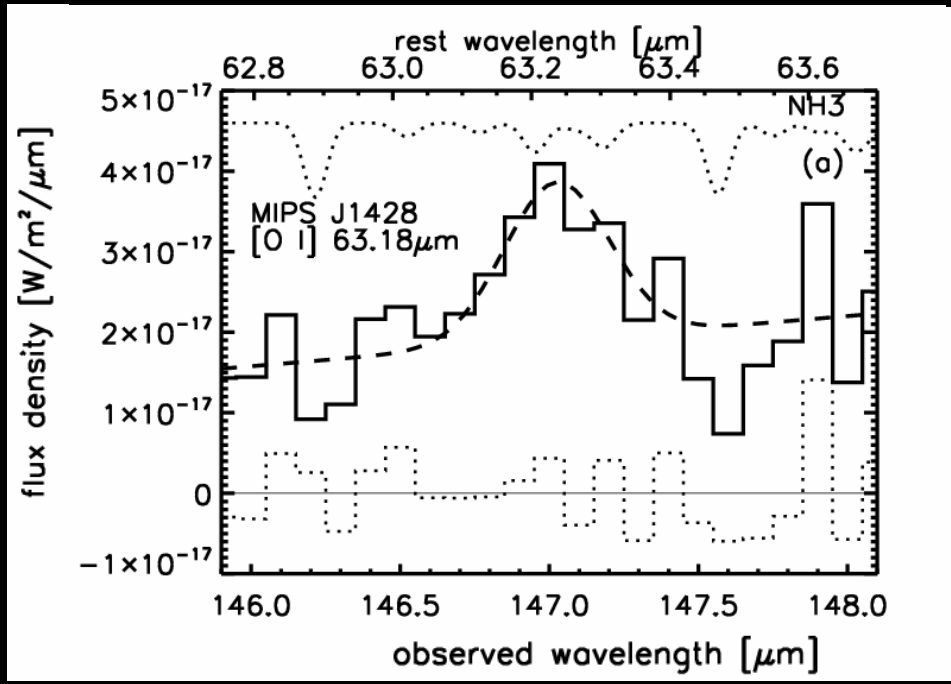
High SFE → compact star formation → High U → low line/FIR ratio

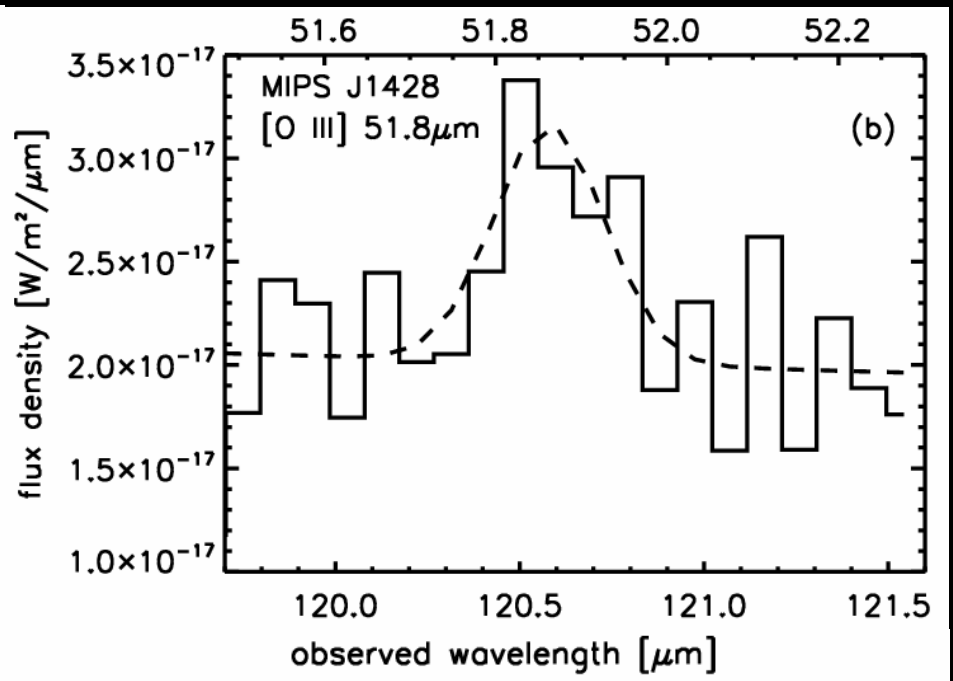
Abel + 2005, 2009
Garcia-Carpio+ in prep

Spectroscopy of luminous galaxies at z>1

[O I] 63μm

[O III] 52μm

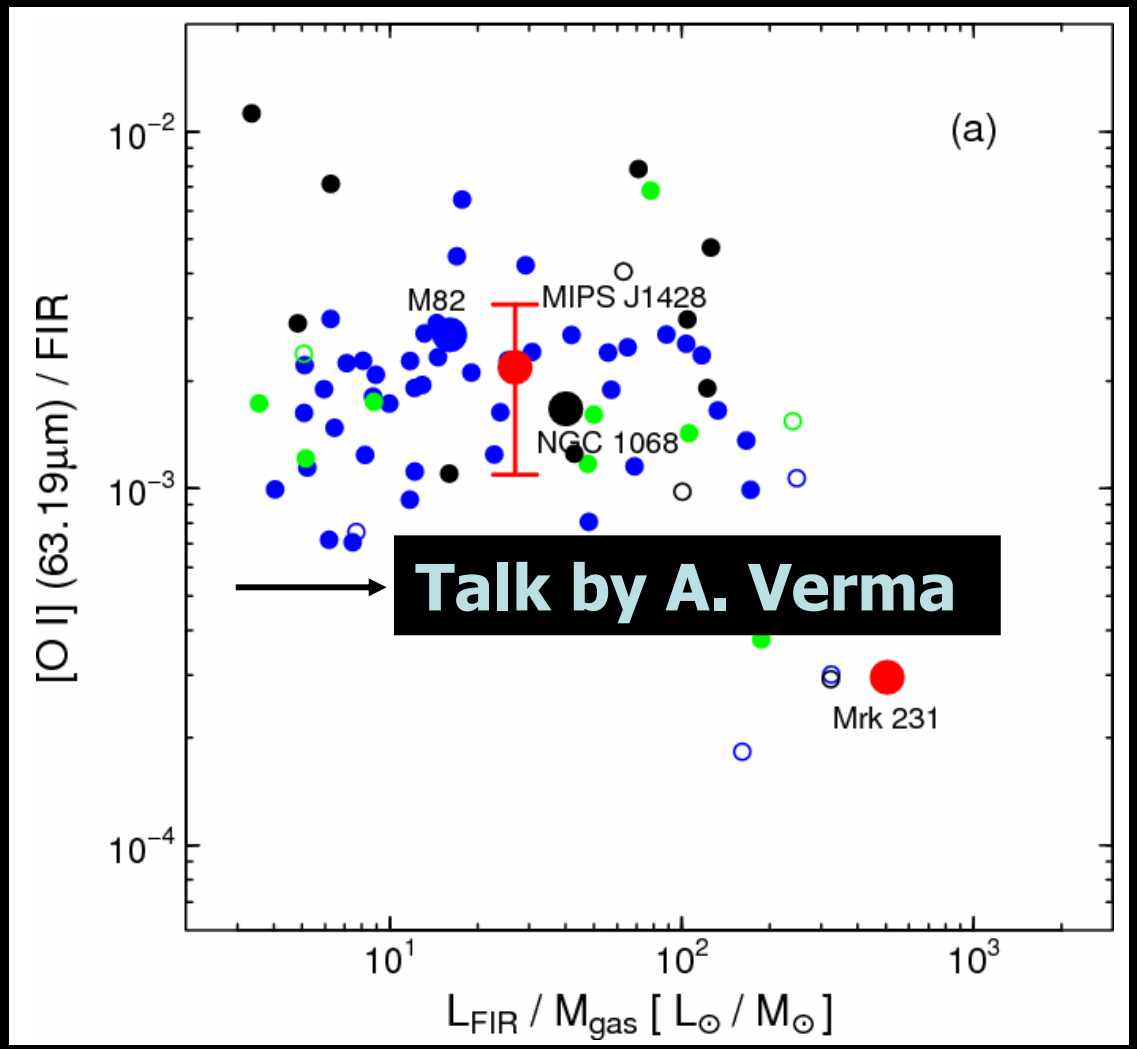




MIPSJ142824.0+352619

z = 1.32

MIPSJ142824.0+352619
z = 1.32



The Luminosity of a ULIRG

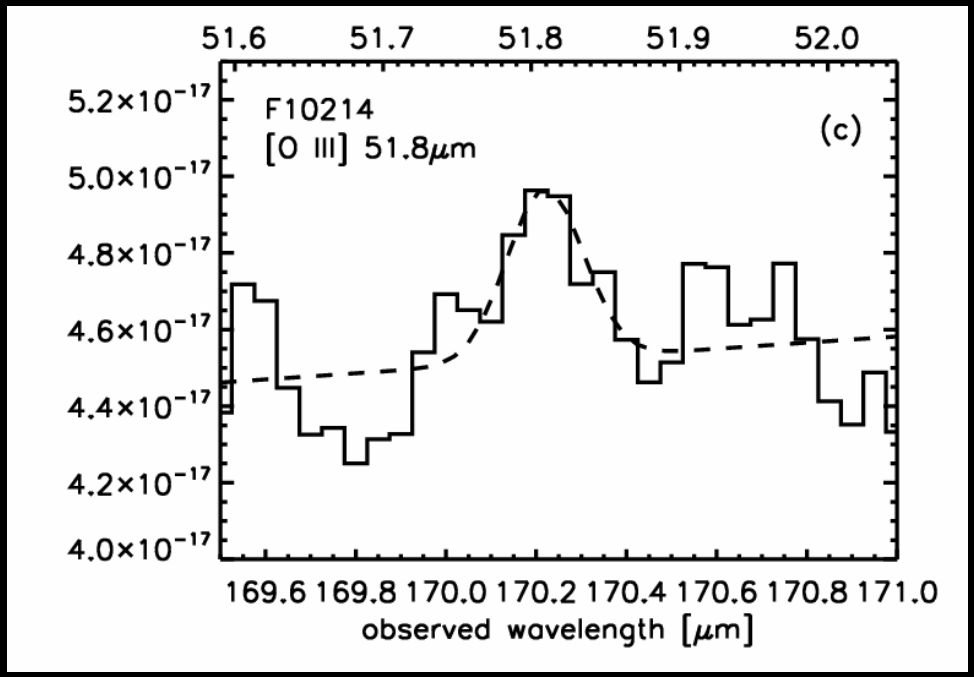
but

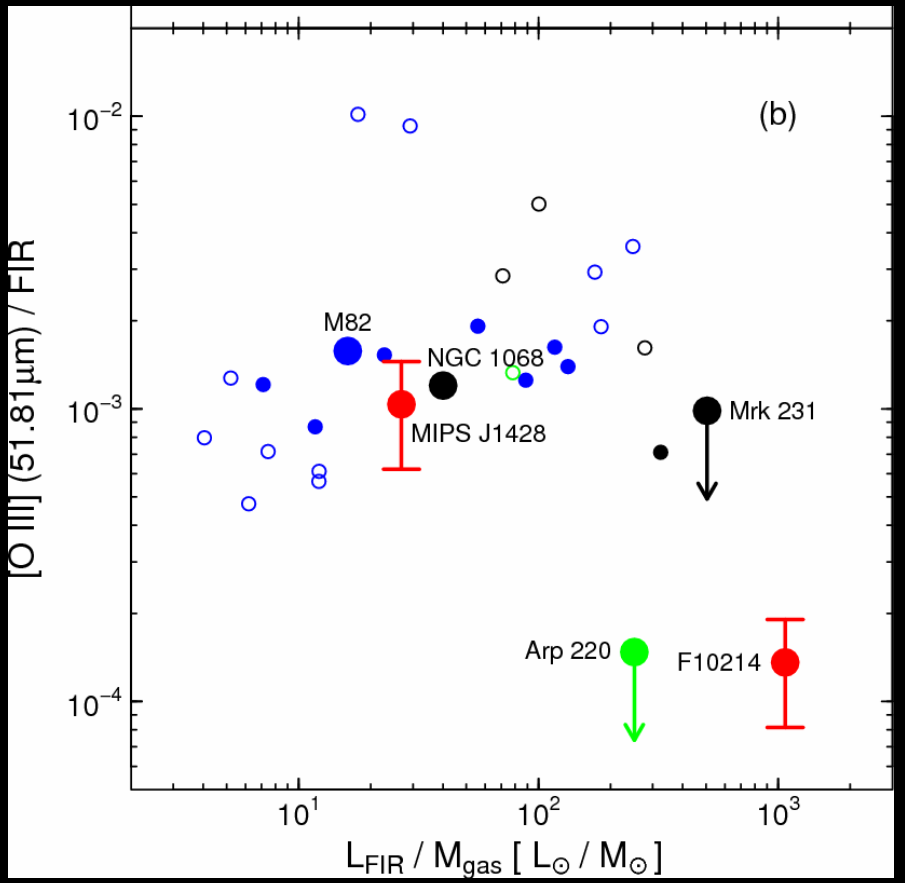
The SFE of a normal starburst

Sturm et al. 2010

Spectroscopy of luminous galaxies at z>1

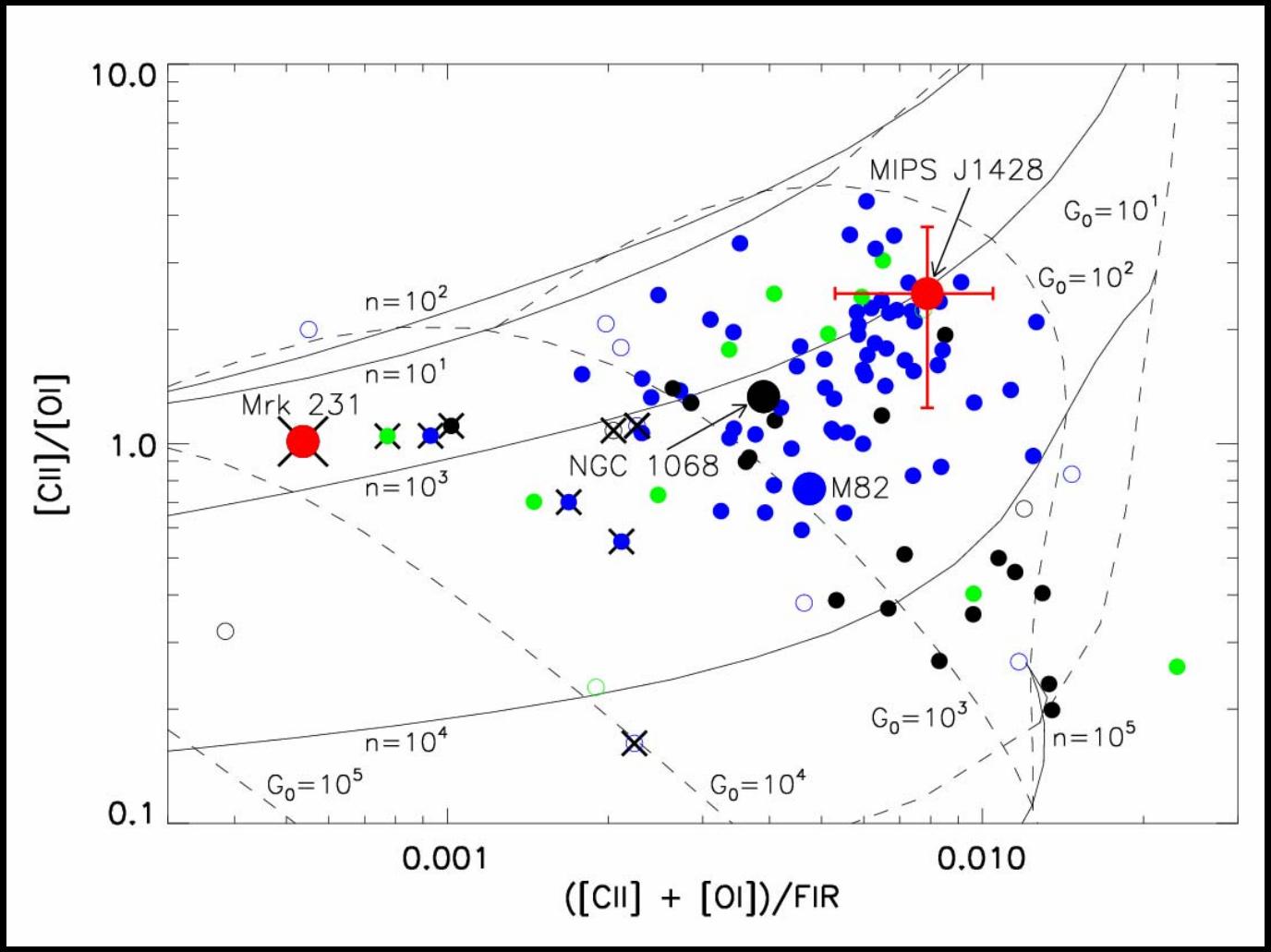
[O III] 52μm





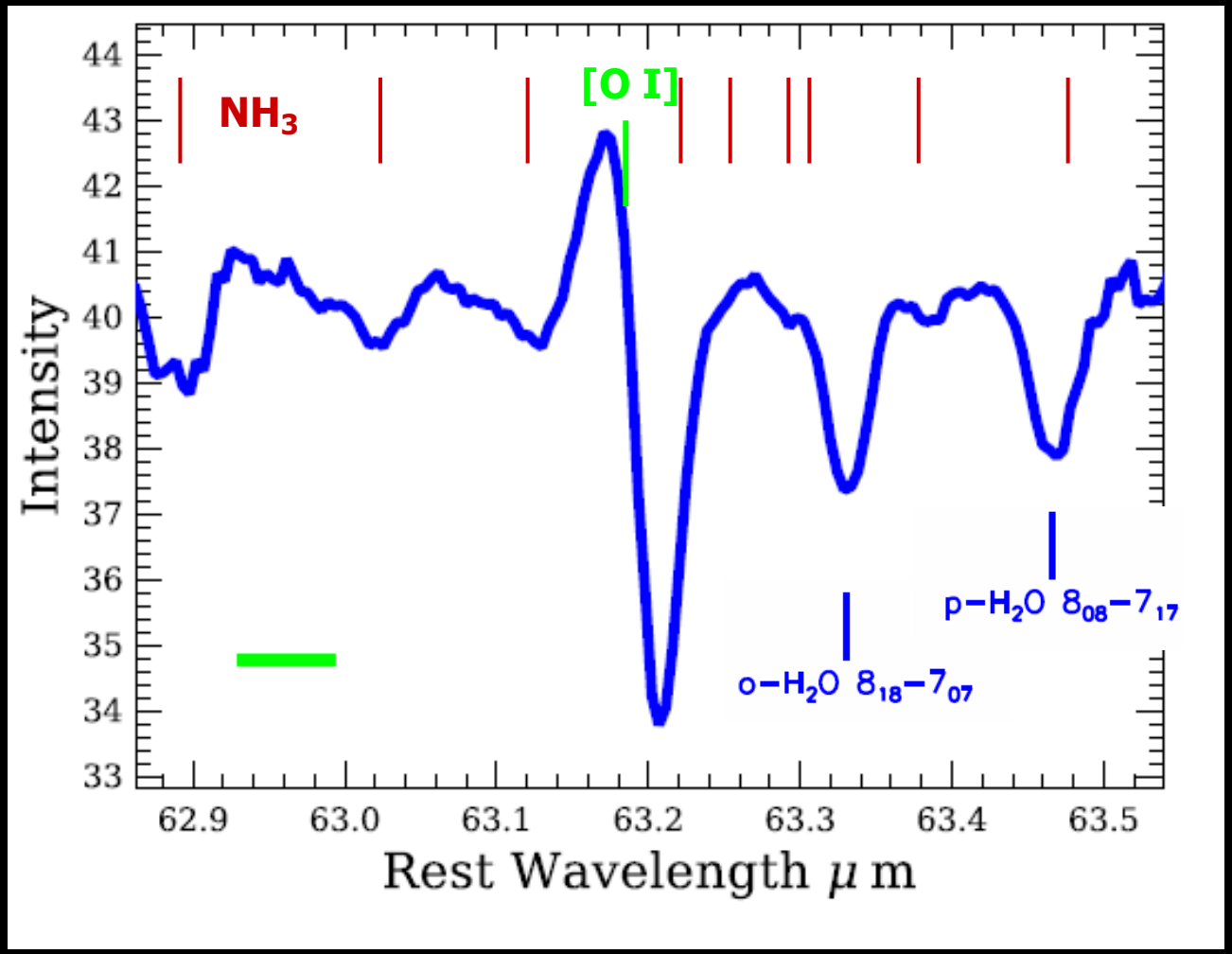
IRAS F10214+4724
z = 2.2855

Spectroscopy of luminous galaxies at z>1

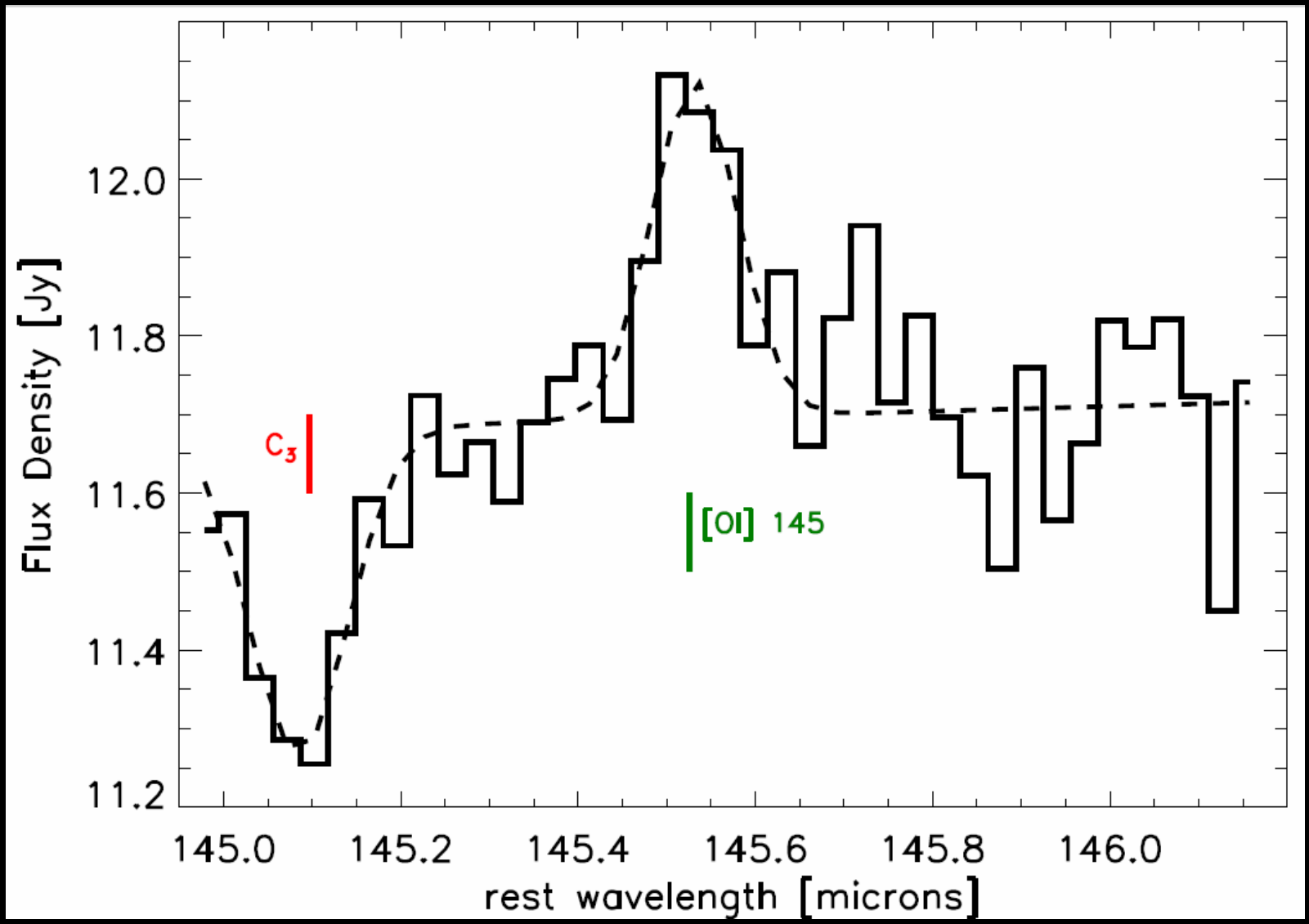


Sturm+ 2010

Molecules



NGC4418

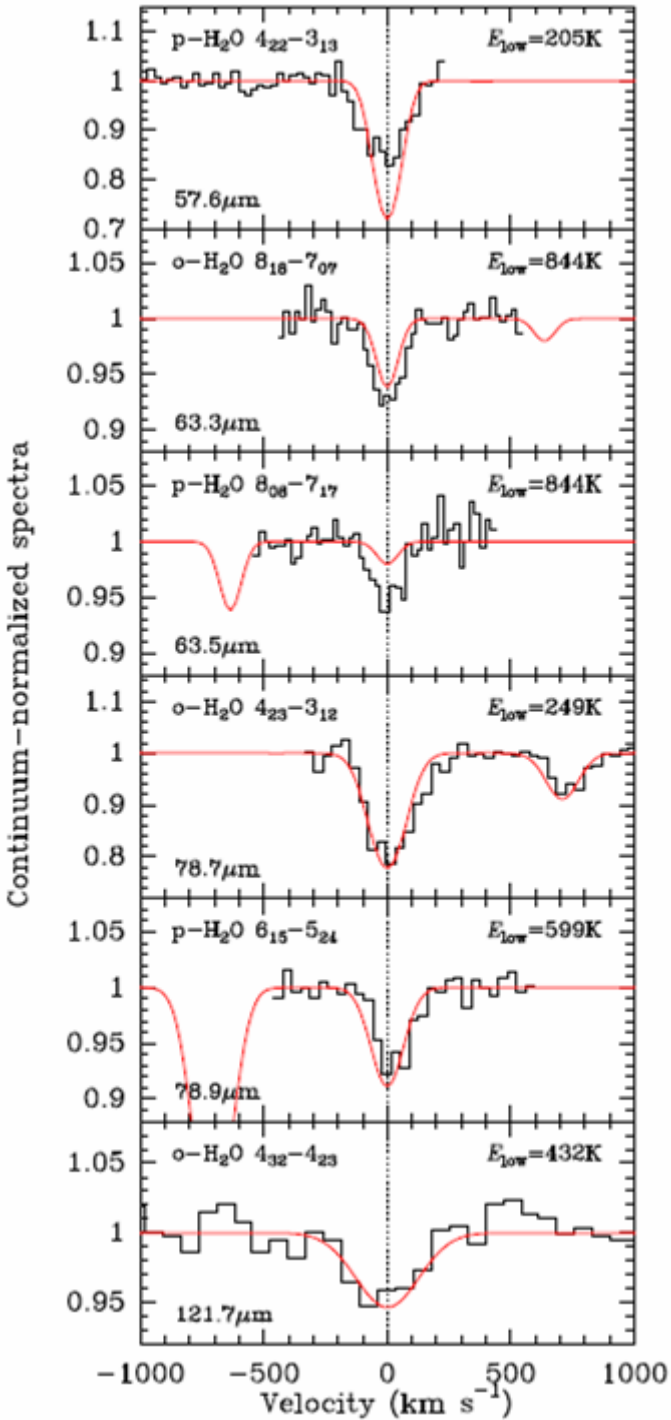

Flux Density [Jy]
12.0
11.8
11.6
11.4
11.2
C3
[OI] 145
145.0
145.2
145.4
145.6
145.8
146.0
rest wavelength [microns]

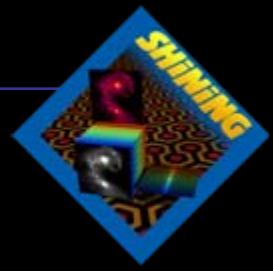
NGC 4418 – a unique extragalactic astro-chemical laboratory

- $N(H_2O) = 10^{19}$ cm^{-2}
- covering factor 50%
- High critical density lines – radiatively pumped

→ Poster P1.48 by S. Hailey-Dunsheath

Hailey-Dunsheath+ in prep.





$H_2{}^{16}O$ $H_2{}^{18}O$ H_2O^+ H_2D^+ H_3O^+

^{16}OH ^{18}OH OH^+ OD^-

CO

CH

NH NH_3

HF

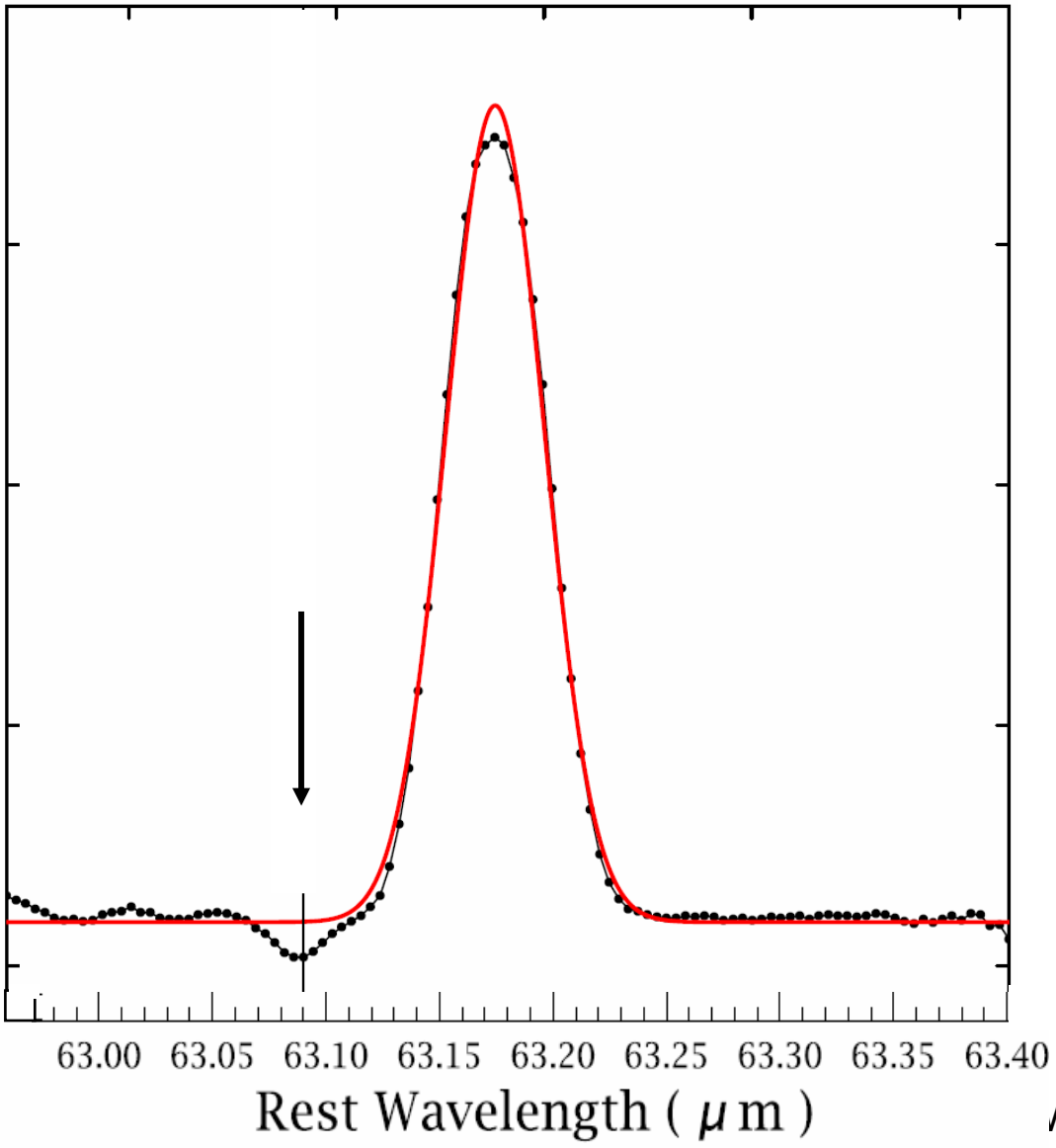
HCN

PH

C_3

Catalogue of (tentatively) identified molecules in PACS spectra of IR-bright galaxies – so far.

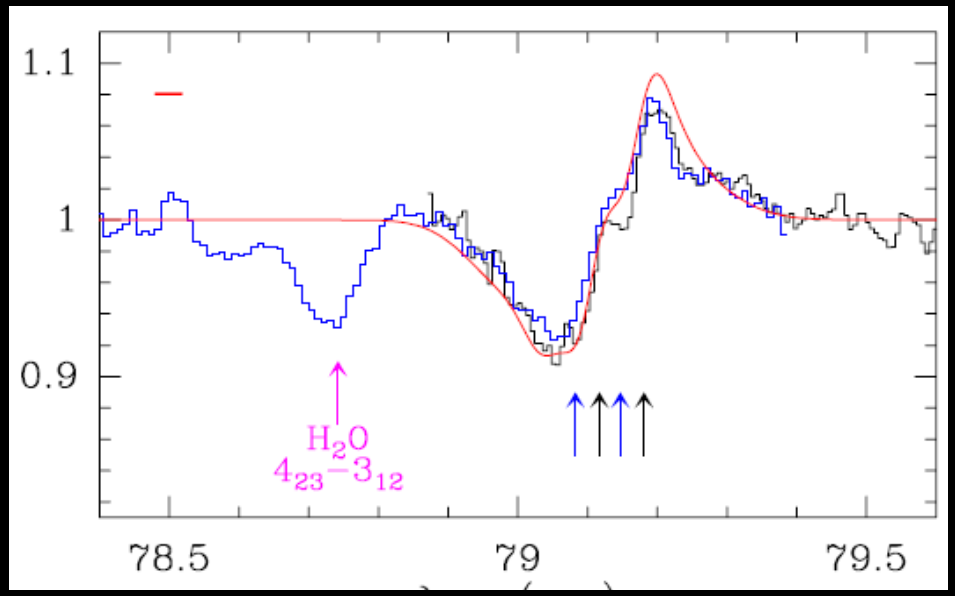
→ Poster P1.57 by E. González-Alfonso

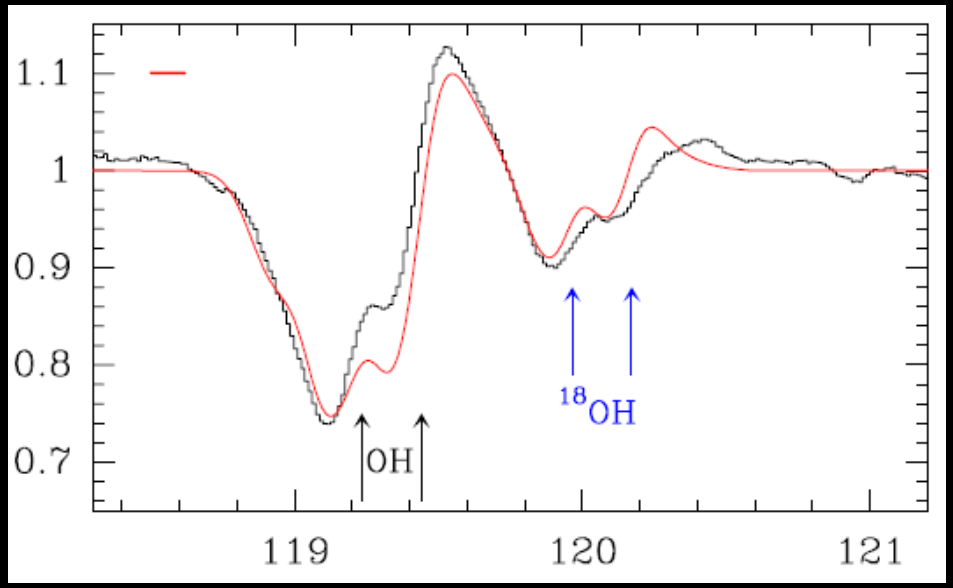


[O I] in the Milky Way, seen in absorption in the line of sight to the Circinus Galaxy (close to the galactic plane)

wavelength!

OH – Massive molecular outflow in Mrk 231
AGN feedback at work ?

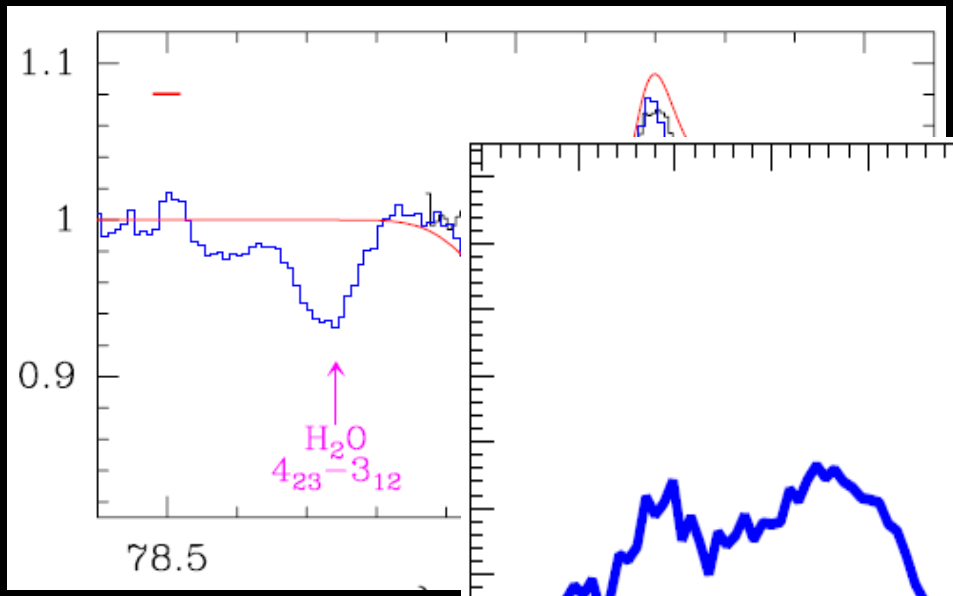


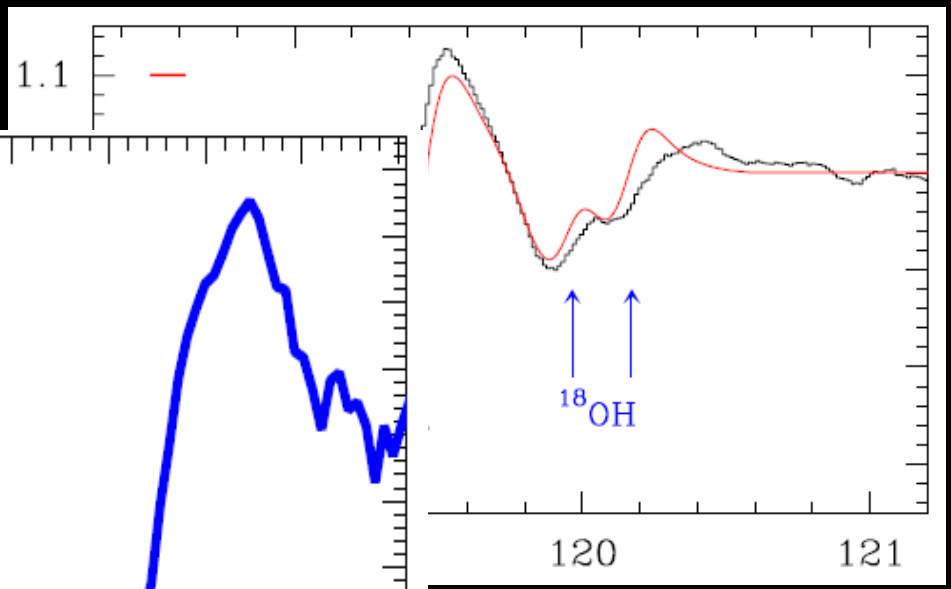


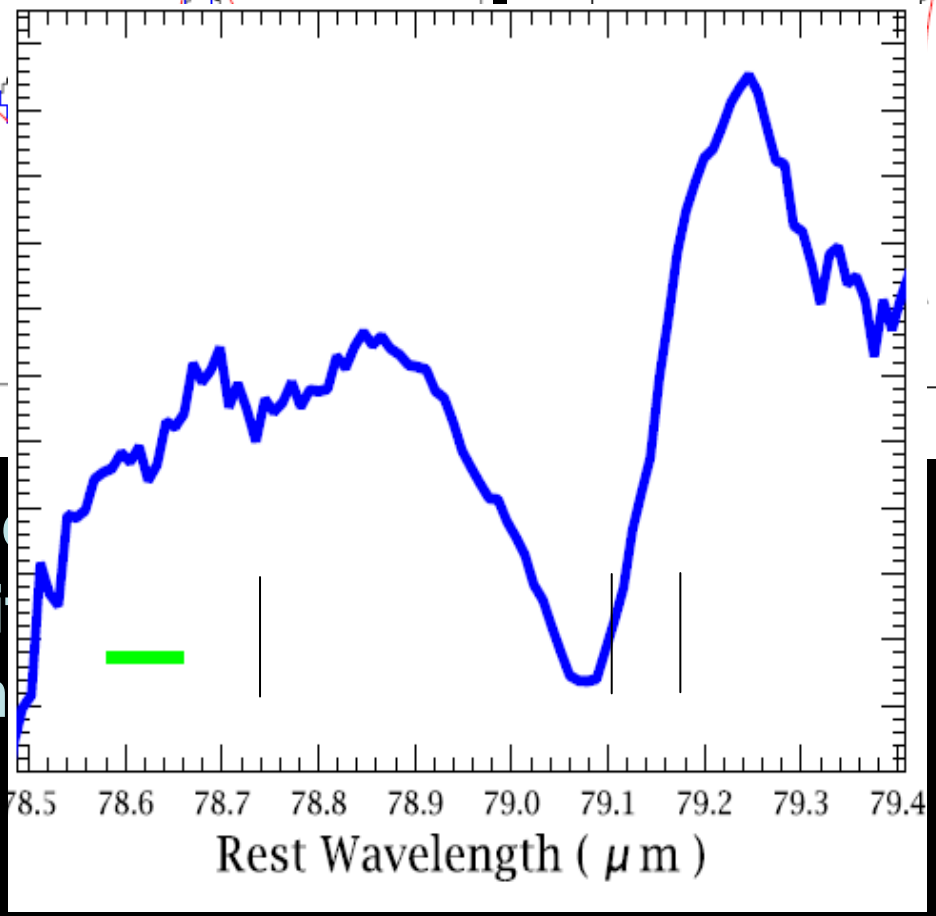
outflow mass of 7×10^7 $M_\odot$
outflow velocities of -1400 km/s
Mechanical energy ≥ 10^{56} ergs

→ Talk by J. Fischer

OH – Massive molecular outflow in Mrk 231
AGN feedback at work ?

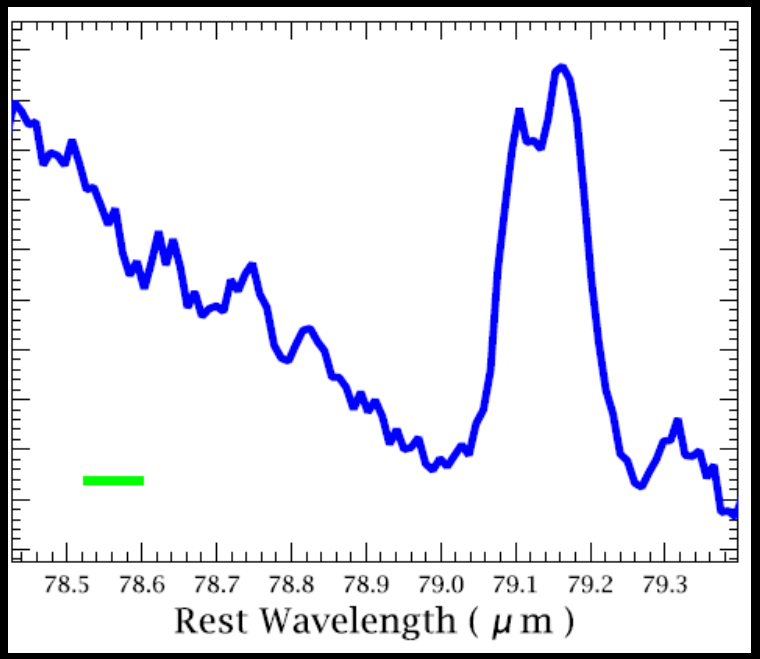


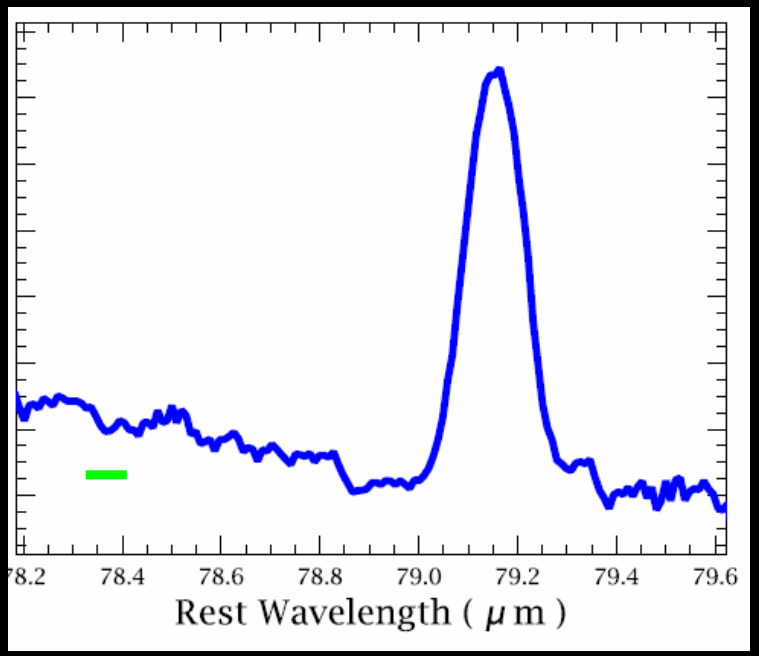




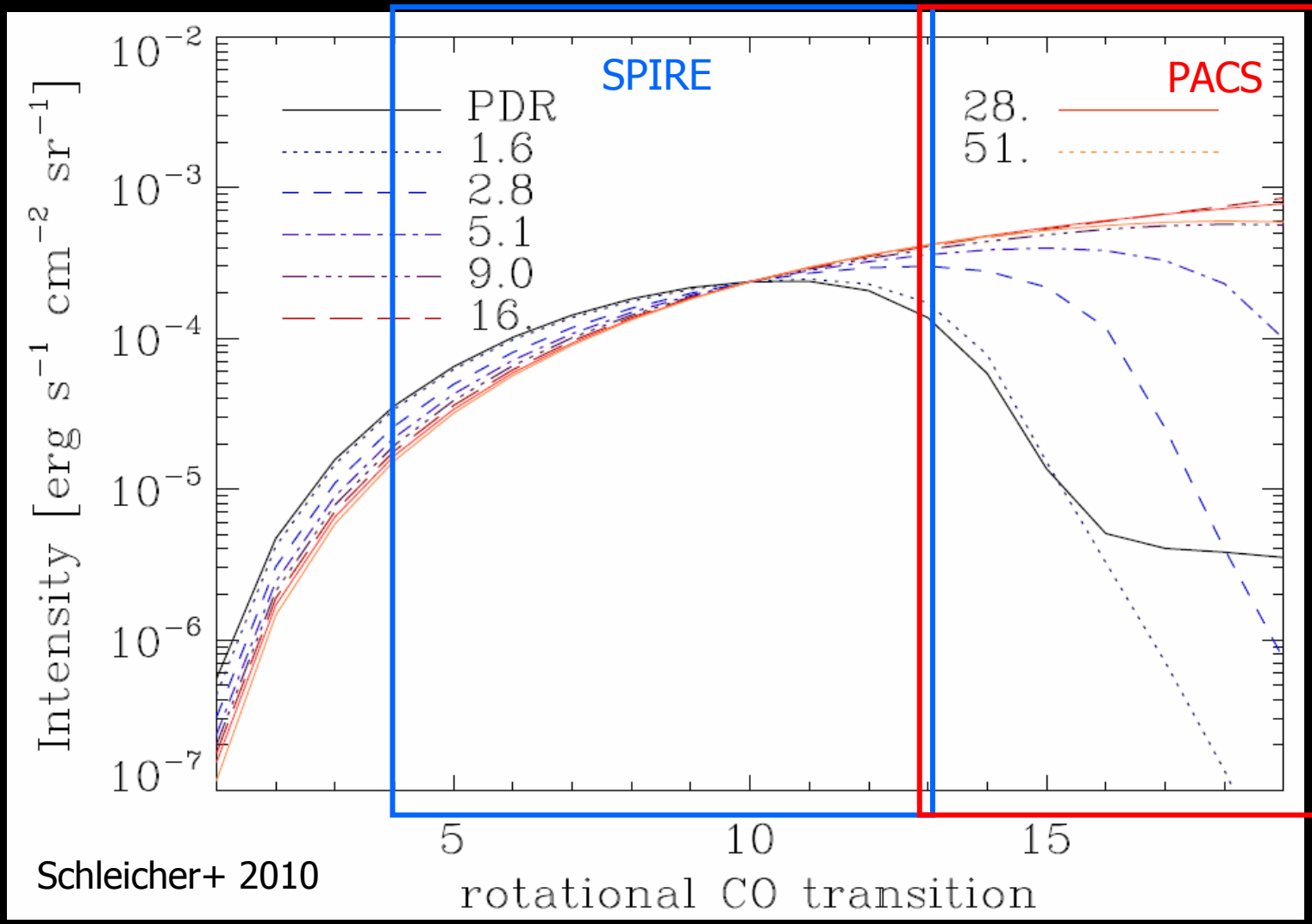
outflow mass (
outflow velocit
Mechanical en

Compare: OH in Seyfert Galaxies:

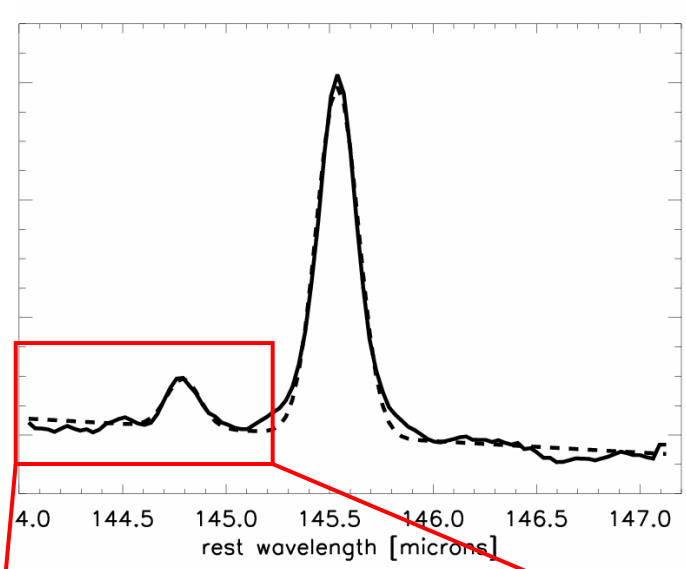


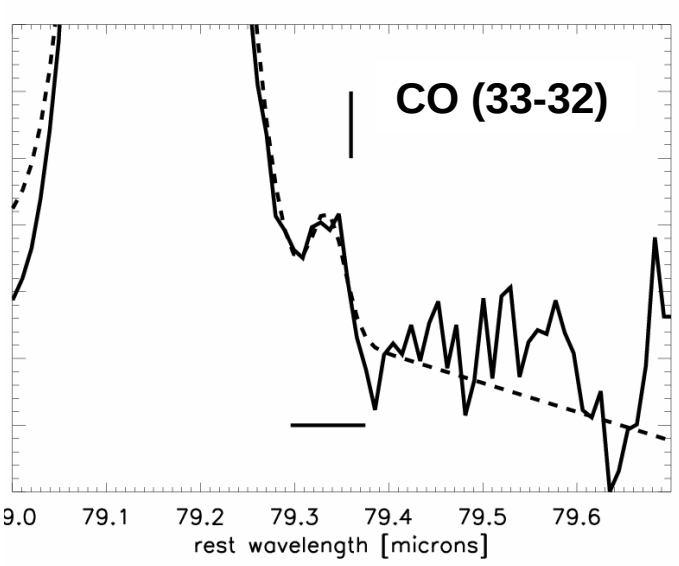


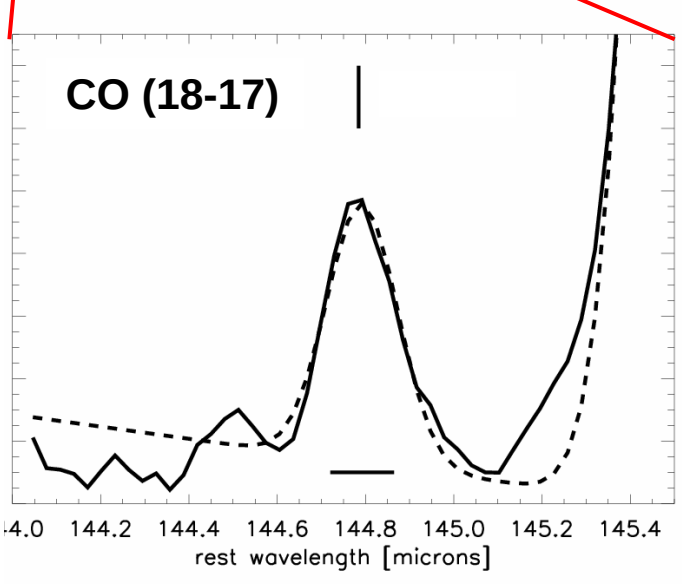
High J CO - the new toy

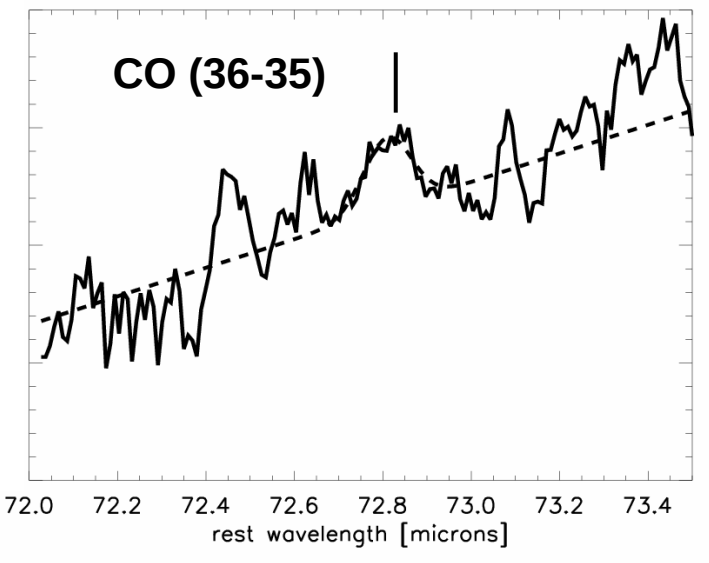


Schleicher+ 2010

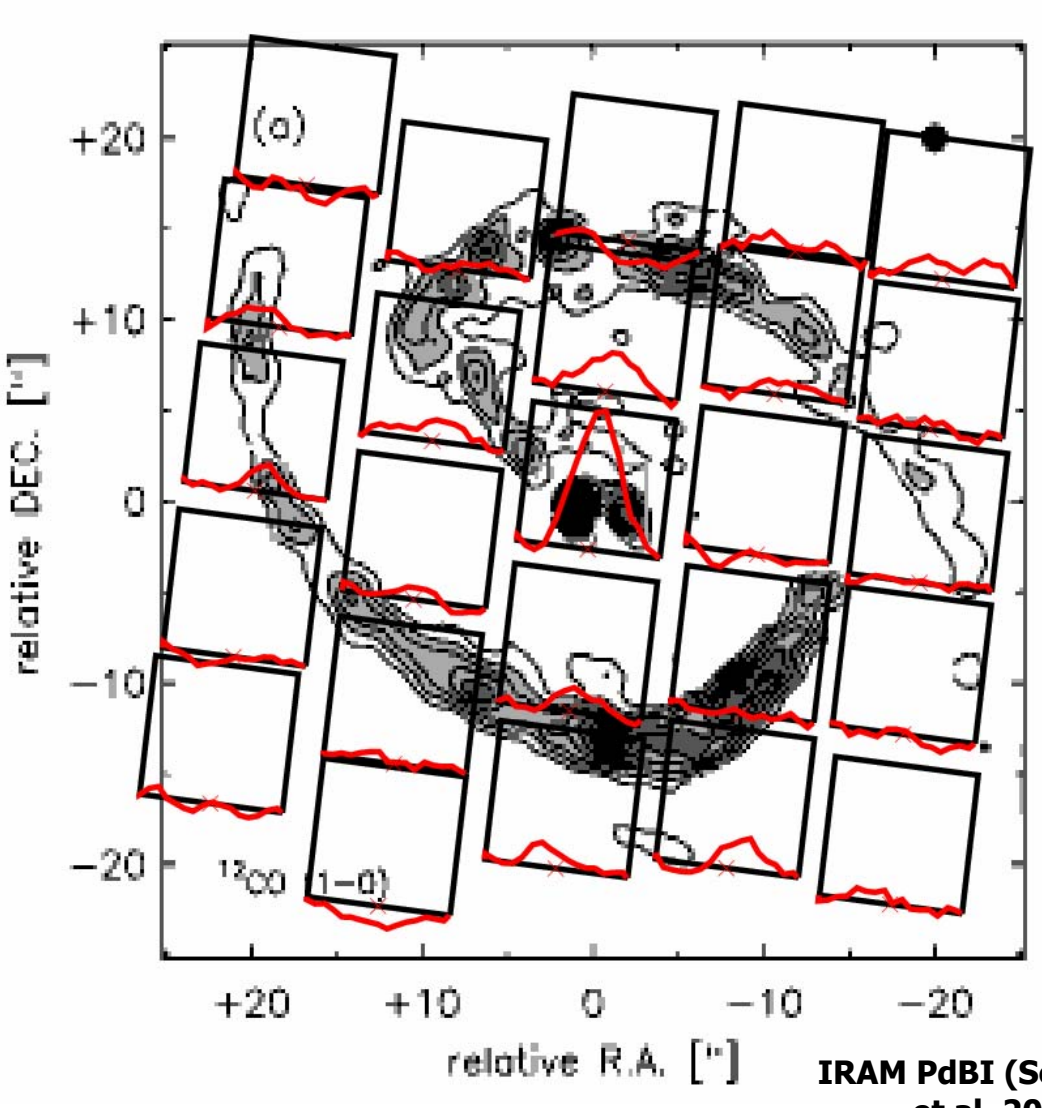

4.0
144.5
145.0
145.5
146.0
146.5
147.0
rest wavelength [microns]


CO (33-32)
9.0
79.1
79.2
79.3
79.4
79.5
79.6
rest wavelength [microns]

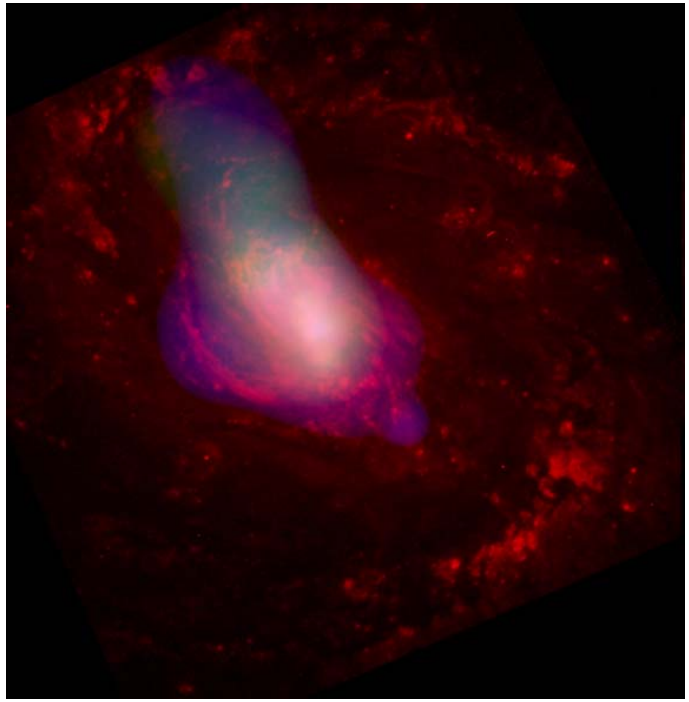

CO (18-17)
4.0
144.2
144.4
144.6
144.8
145.0
145.2
145.4
rest wavelength [microns]


CO (36-35)
72.0
72.2
72.4
72.6
72.8
73.0
73.2
73.4
rest wavelength [microns]

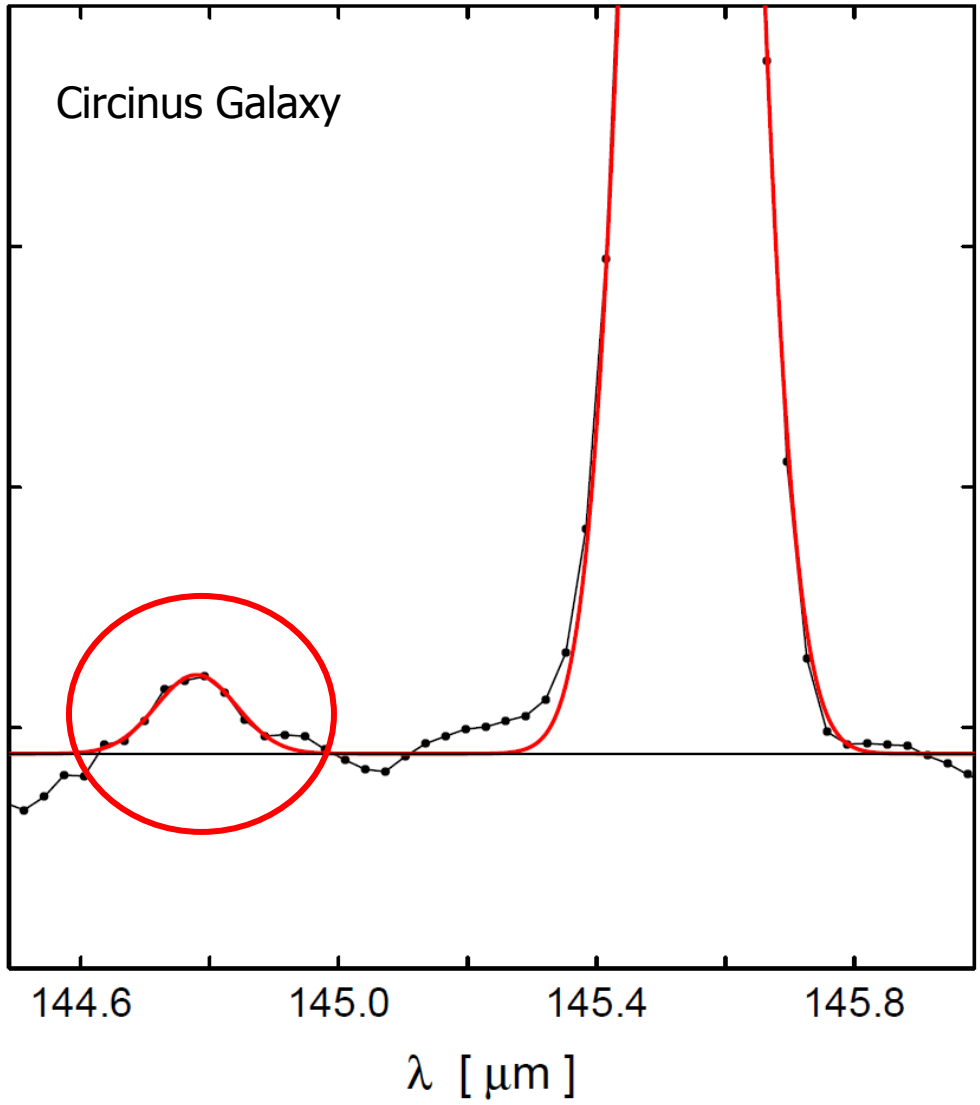
CO (18-17) vs. CO (1-0)

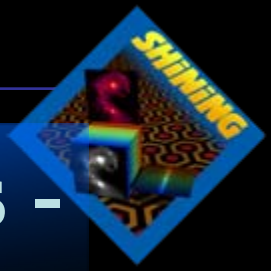


IRAM PdBI (Schinnerer et al. 2003)



HST + Chandra


Circinus Galaxy
144.6
145.0
145.4
145.8
λ [μm]



The ISM in Infrared Bright Galaxies - First Results from SHINING

1) Rich harvest of FIR diagnostic lines and images in starbursts, AGN, ULIRGs, at different redshifts, metallicities, and interaction stage, with spatial and kinematic information

2) Global Line/FIR deficiency at high L_{FIR}/M_{mol} – high ionization paramter ?

3) Molecules galore – complex astro-chemistry and ISM processing

4) Massive molecular outflows – AGN feedback ?

5) High J CO Lines in AGN – cooling the torus ?

The ISM in Infrared Bright Galaxies - First Results from SHINING

Talks by

-A. Contursi

-S. Madden

-U. Klaas

-A. Verma

-J. Fischer

Posters by

-S. Hailey-Dunsheath (P1.48)

-J. Graciá-Carpio (P1.60)

-D. Cormier (P1.43)

-E. González-Alfonso (P1.57)

A&A papers by

-Fischer+
(Mrk231)

-Cormier+
(NGC4214)

-Klaas+
(Antennae photom.)

-Sturm
(high-z ULIRGs)