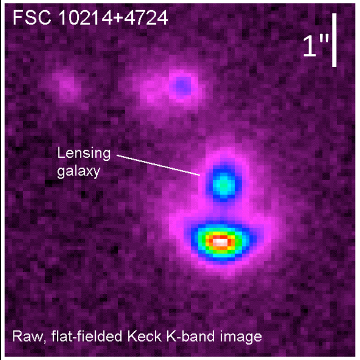
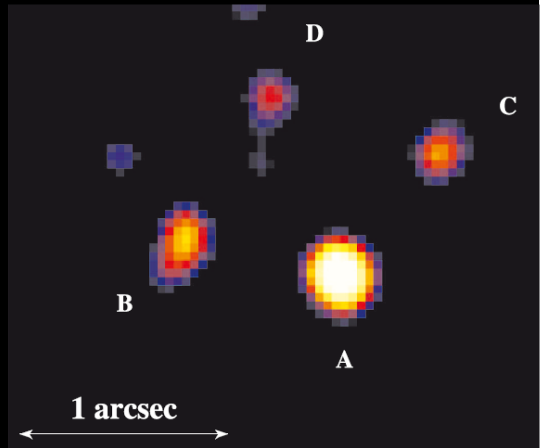
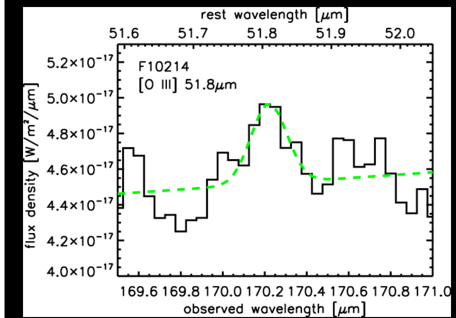
Far-infrared ISM diagnostics with Herschel spectroscopy

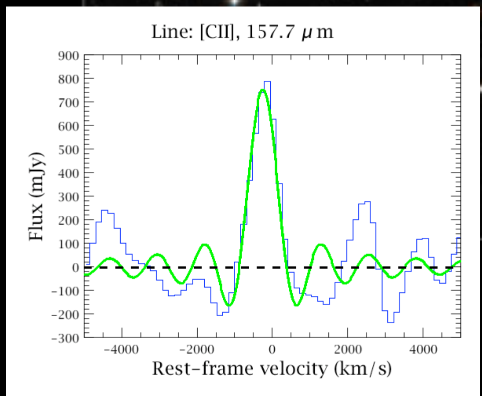


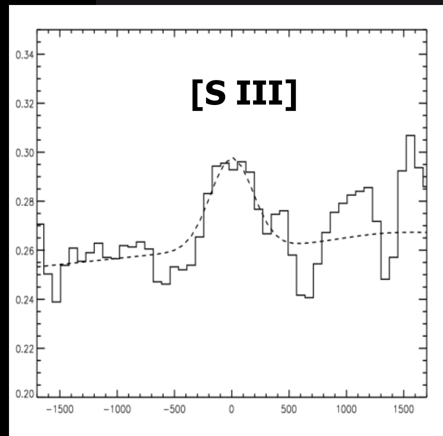
E. Sturm

MPE









Study of Infrared Bright Galaxies with Herschel FIR spectroscopy

nearby / resolved → **Spatial**

high z / unresolved → **Global/Temporal**

Spatial

- Spatially resolved PDR, XDR and HII diagnostics
- ISM properties as function of environment
- „calibration" of toolbox for use at high z

Global/Temporal

- global ISM properties and their evolution with redshift (PDR / XDR / HII modelling)
- different modes of star/galaxy formation (line deficits)
- feedback from star formation and AGN (outflows) on galaxy evolution / stimulation and quenching

➢ **Local calibration of toolbox**

➢ **Application to z~2**

➢ **Mid-IR diagnostics at z~3-4**

[CII]	158	µm	most important cooling lines of the atomic gas.
[OI]	63	µm	Probe the conditions in PDRs, i.e. the warm neutral
	145	µm	gas cloud surfaces which constitute a large fraction
			of the neutral medium in a galaxy.

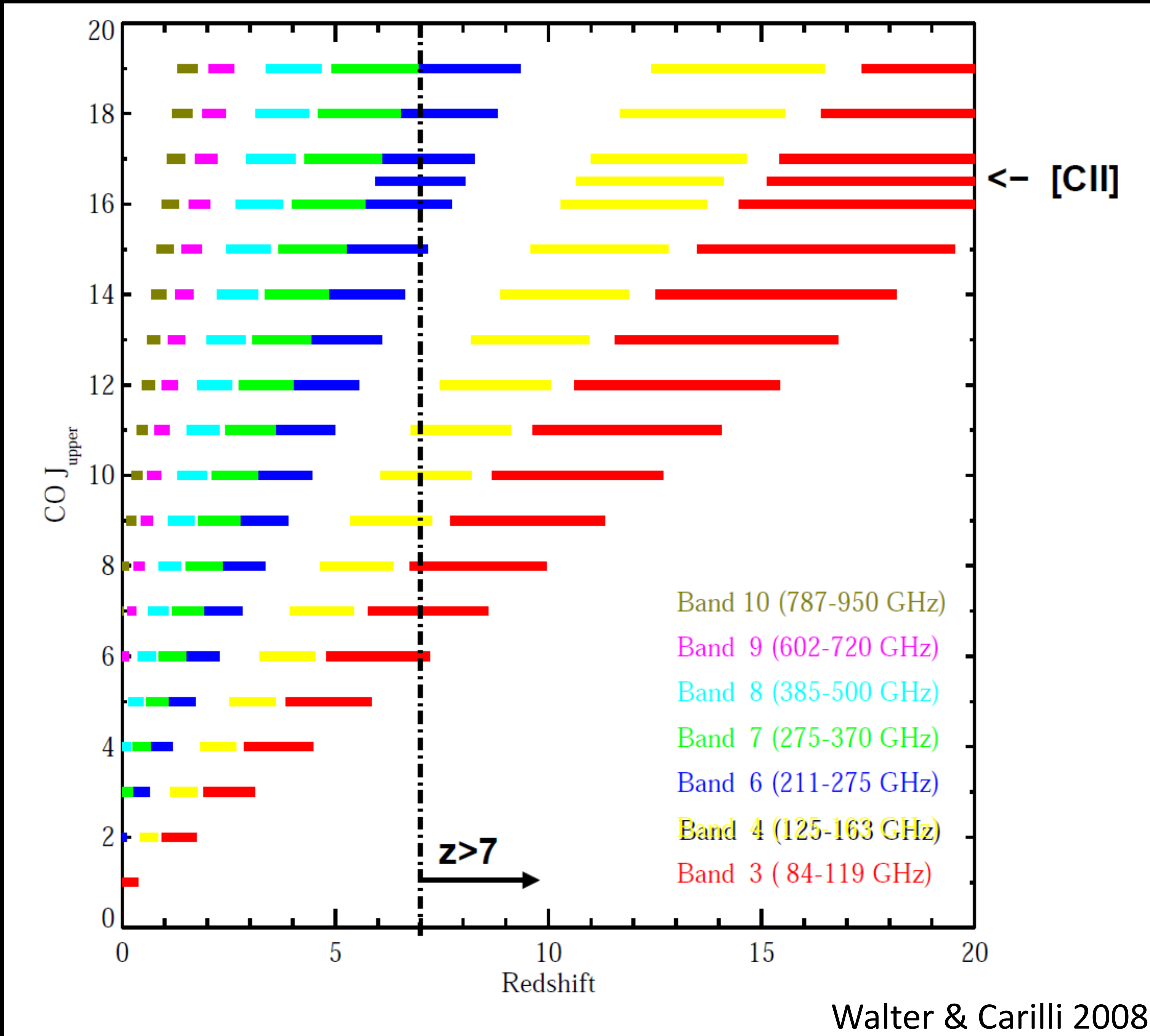
[NII]	122	µm	conditions in the ionized medium. Important diagnostics
[NIII]	204	µm	of absolute level and excitation of star forming (and AGN)
	57	µm	activity and of n_e @ low density (< 10^3 cm^{-3})
[OIII]	53	µm	(z>0.1)
	88	µm	

I) Spectral features

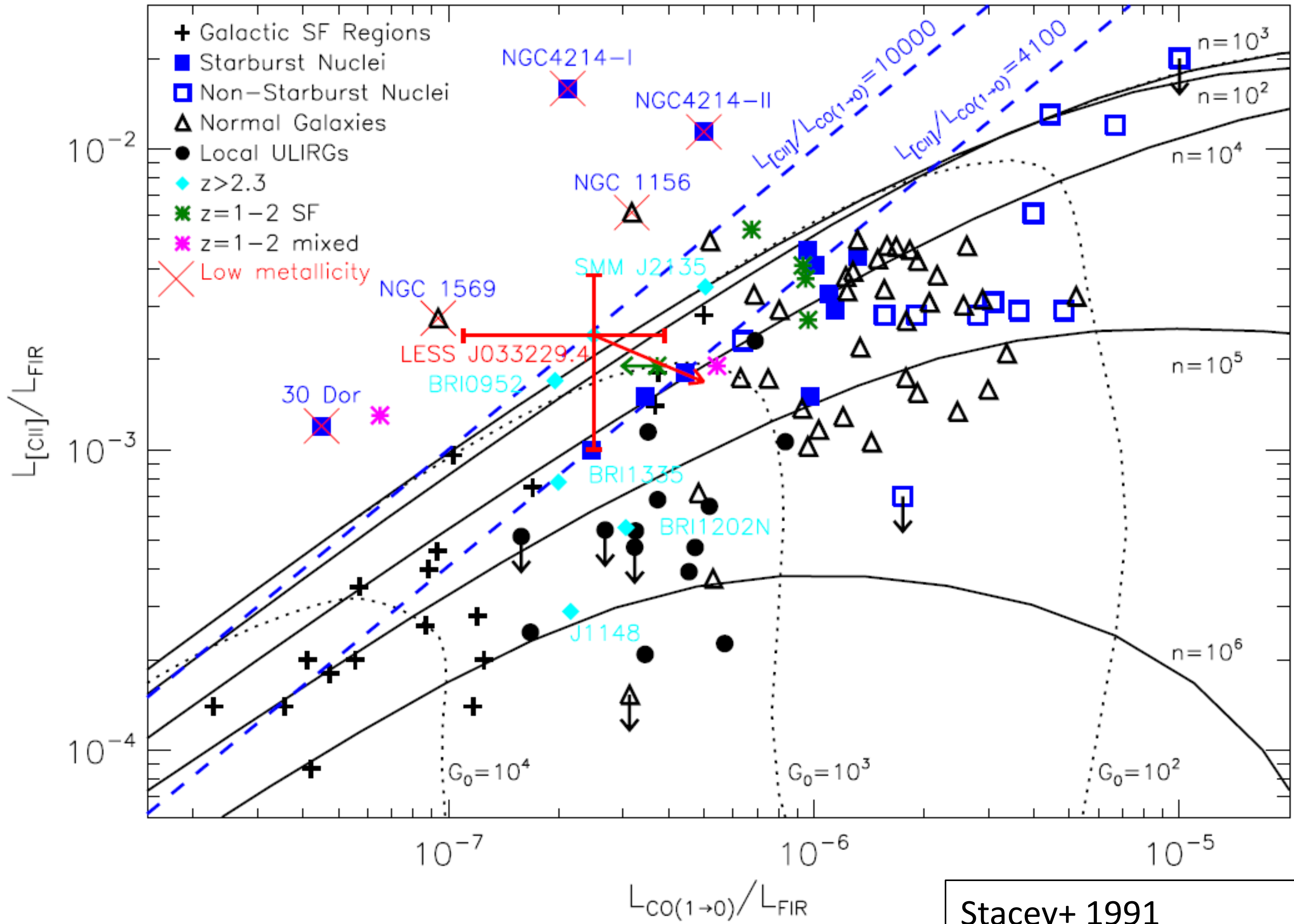
- SEDs (and broad ice and solid state features)
- Fine structure lines ([OIII], [NII], [NIII], [OI], [CII])
- Molecules (OH, H_2O, CO, NH_3 …)

II) Modeling

- HII region/photoionization diagnostics
- PDR and XDR modeling
- molecular radiative transfer modeling



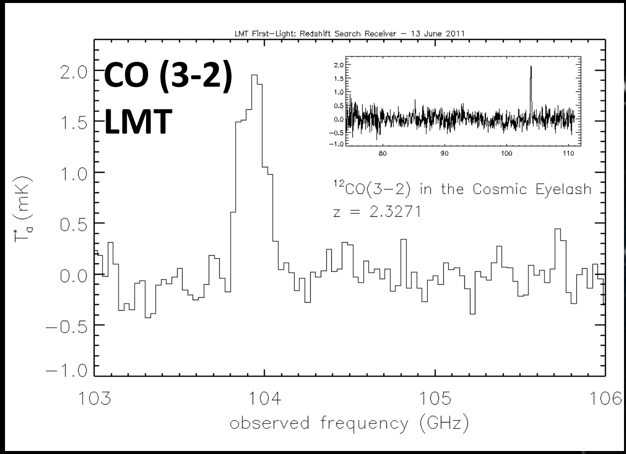
CO J_upper
Redshift
<- [CII]
z>7
Band 10 (787-950 GHz)
Band 9 (602-720 GHz)
Band 8 (385-500 GHz)
Band 7 (275-370 GHz)
Band 6 (211-275 GHz)
Band 4 (125-163 GHz)
Band 3 (84-119 GHz)
Walter & Carilli 2008

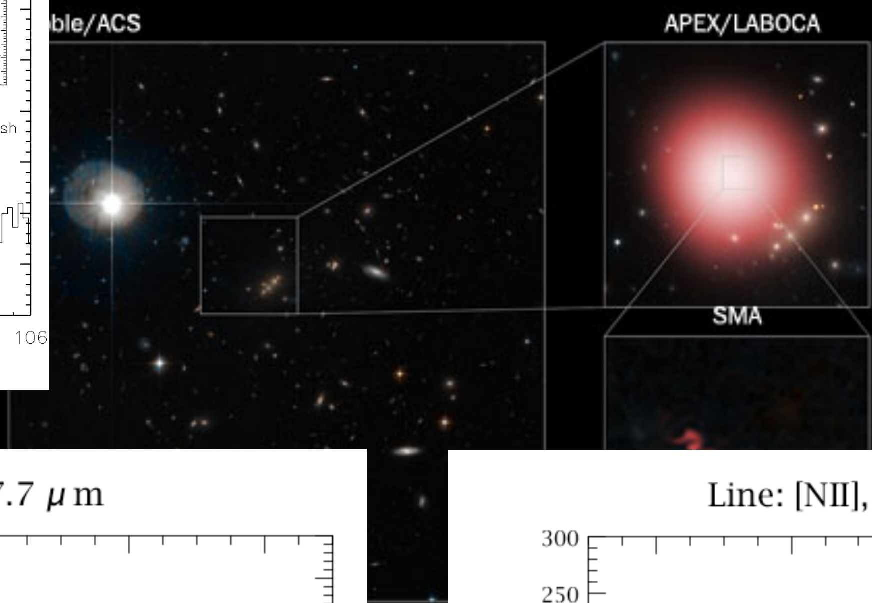


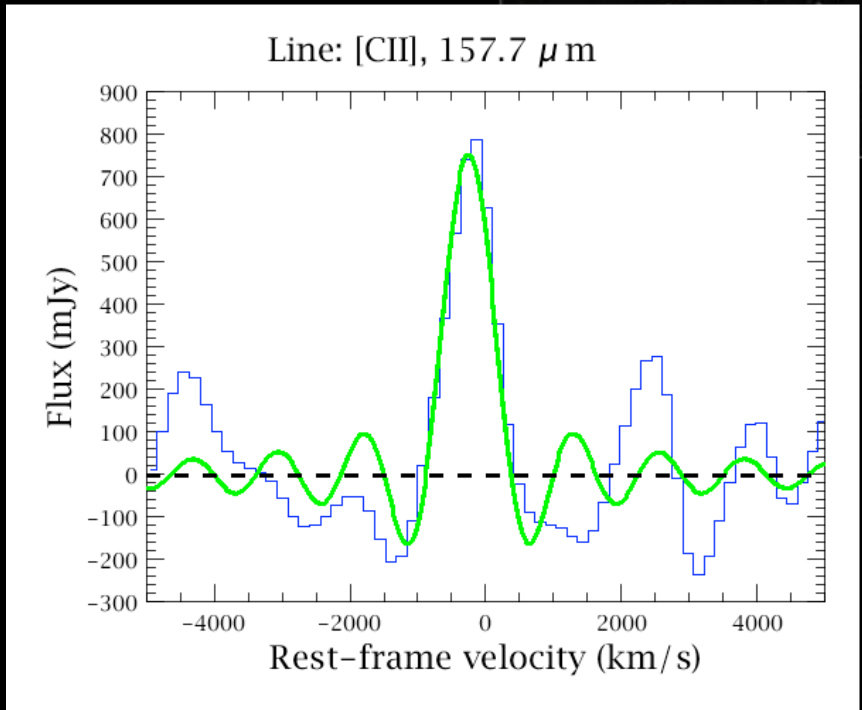
Stacey+ 1991
Hailey-Dunsheath + 2010
De Breuck+ 2011

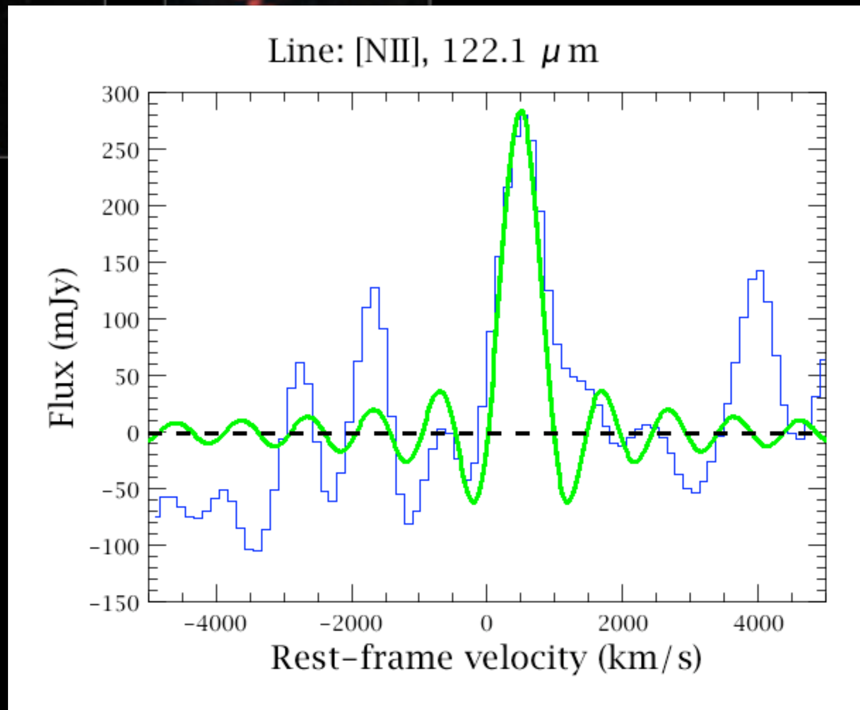
SMM J2135 (Cosmic Eyelash)

Strongly lensed SMG, z = 2.3



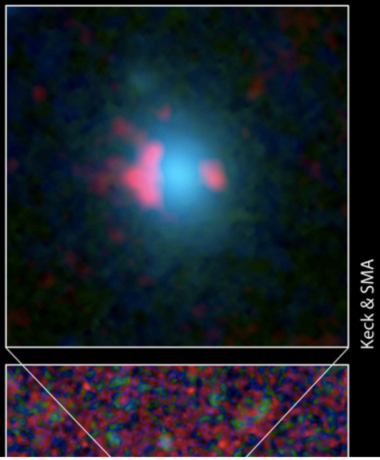






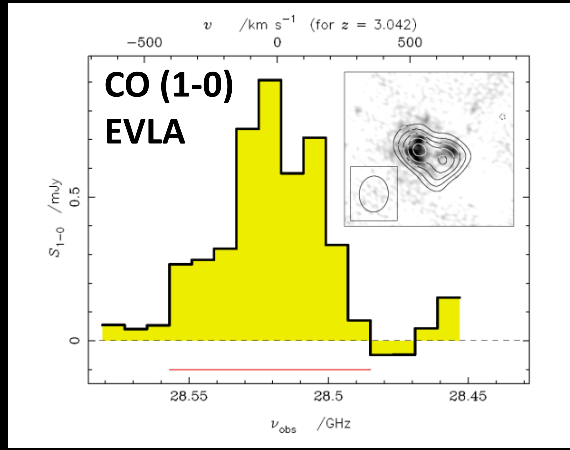
Ivison+ 2010 (SPIRE FTS)

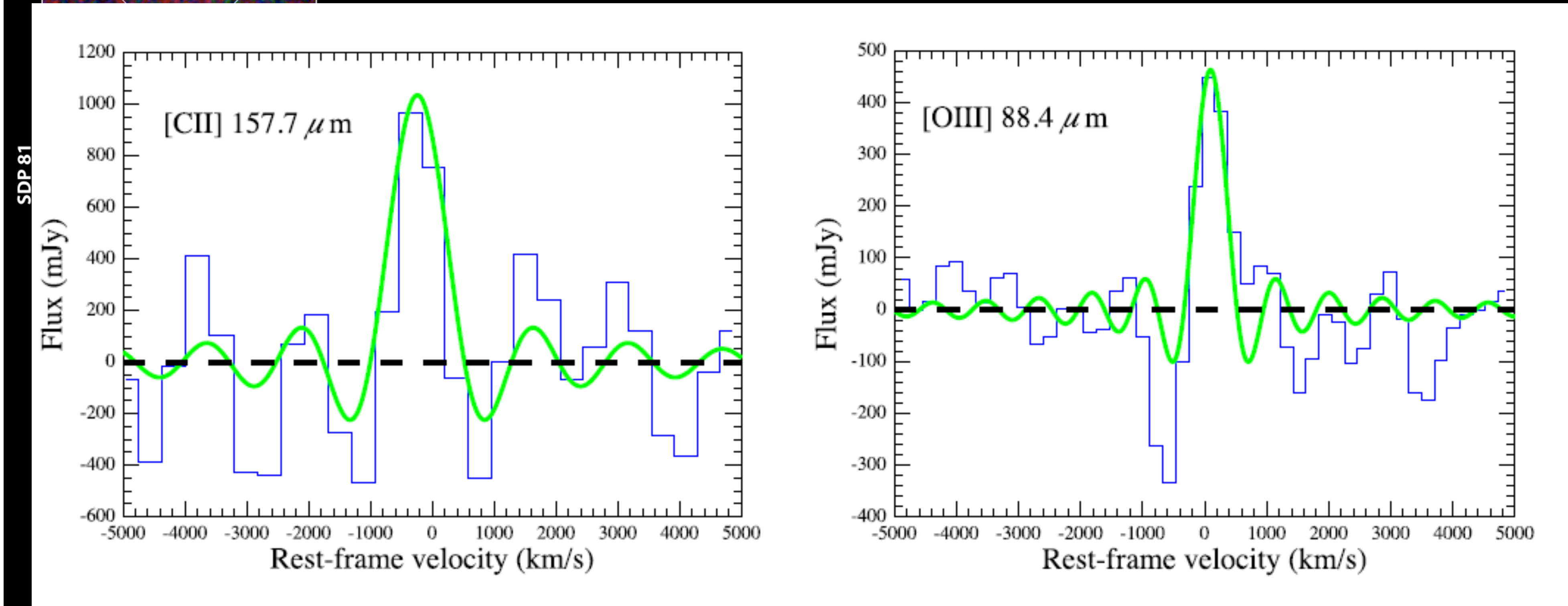
Ivison+ (priv. comm., SPIRE FTS)



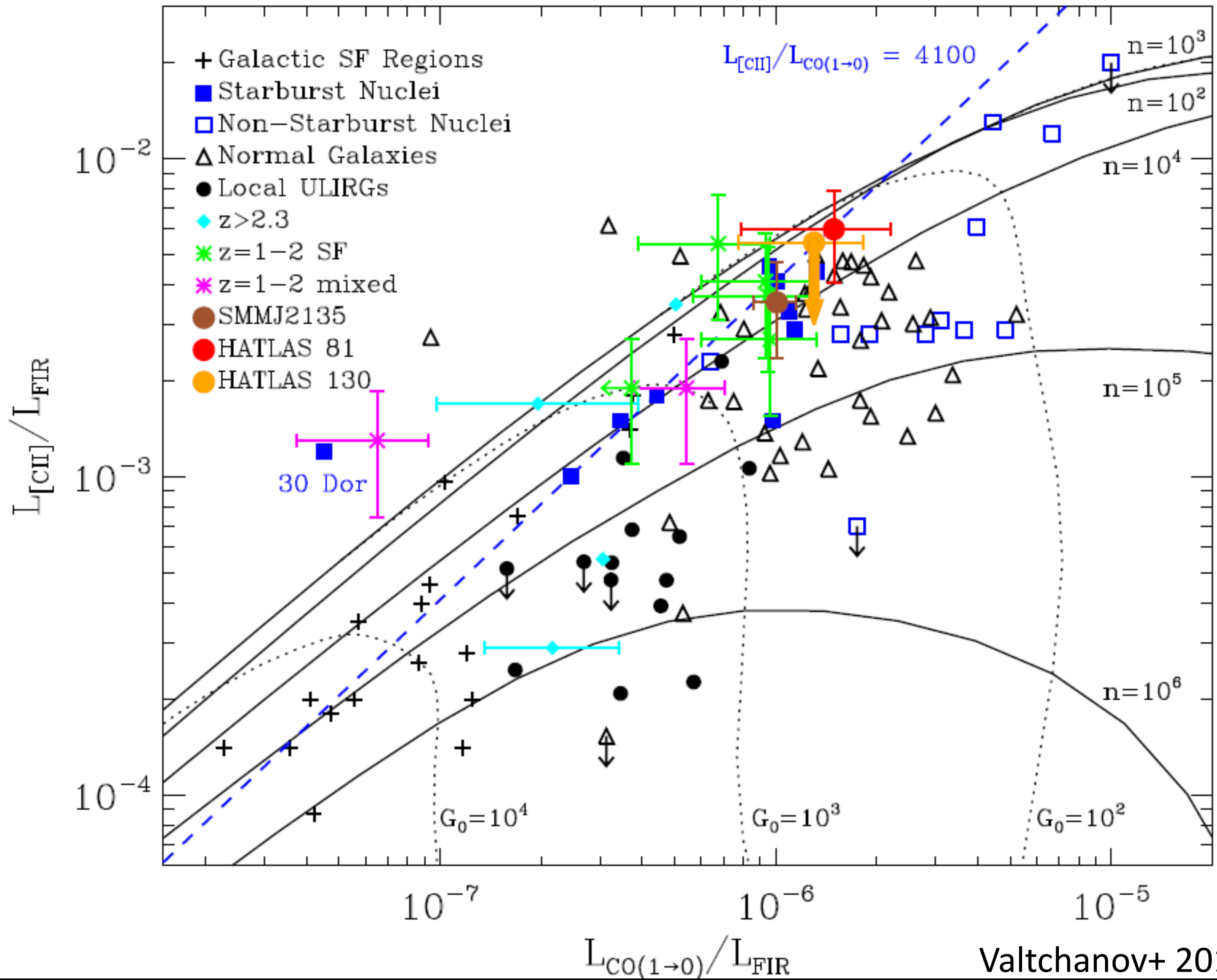
J090311.6+003906 (H-ATLAS SDP.81)

Strongly lensed SMG, z = 3.043 ± 0.012



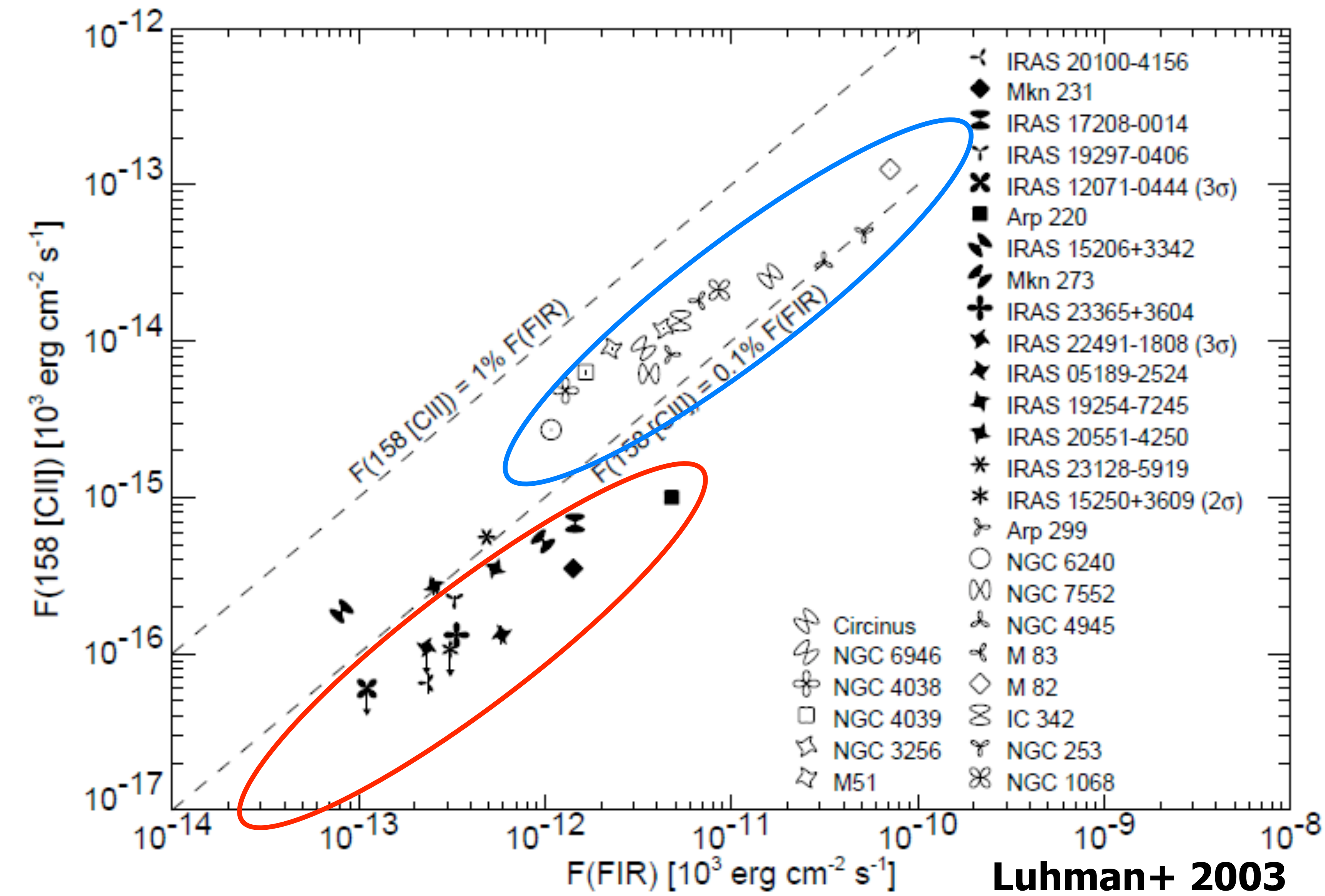


Valtchanov+ 2011 (SPIRE FTS)

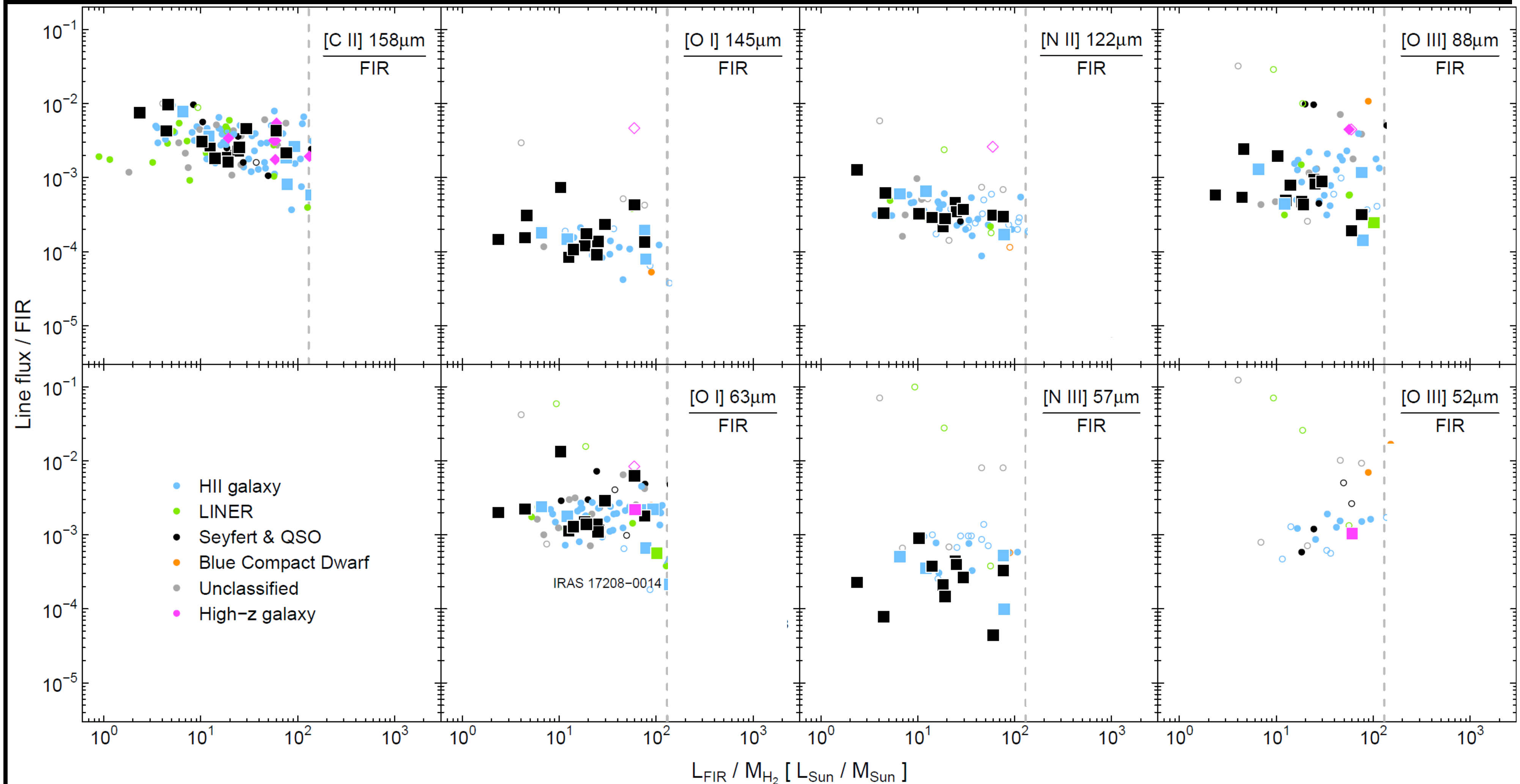


Valtchanov+ 2011

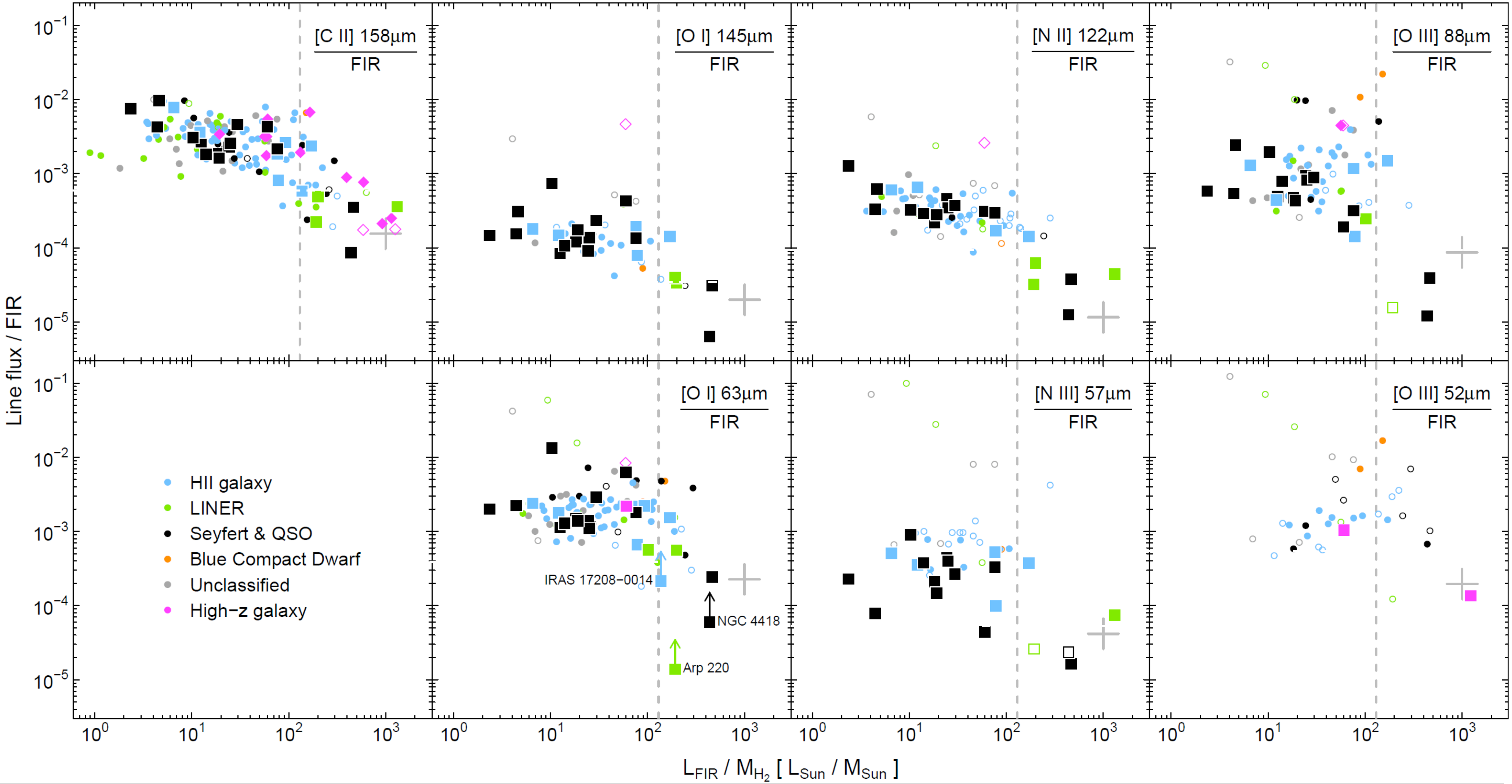
ISO's Heritage – The „CII deficit"

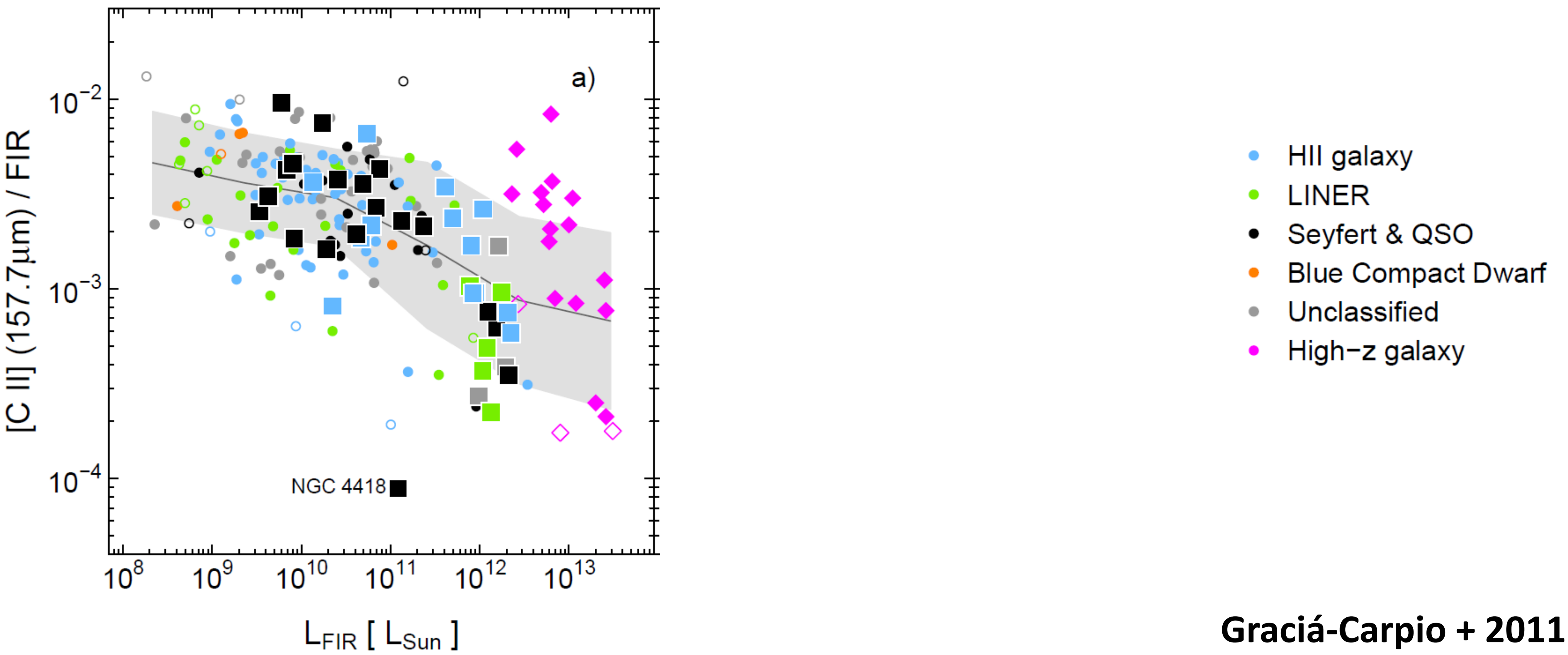


Luhman+ 2003


[C II] 158μm / FIR
[O I] 145μm / FIR
[N II] 122μm / FIR
[O III] 88μm / FIR
[O I] 63μm / FIR
[N III] 57μm / FIR
[O III] 52μm / FIR
IRAS 17208−0014
HII galaxy
LINER
Seyfert & QSO
Blue Compact Dwarf
Unclassified
High−z galaxy
Line flux / FIR
L_FIR / M_H2 [L_Sun / M_Sun]

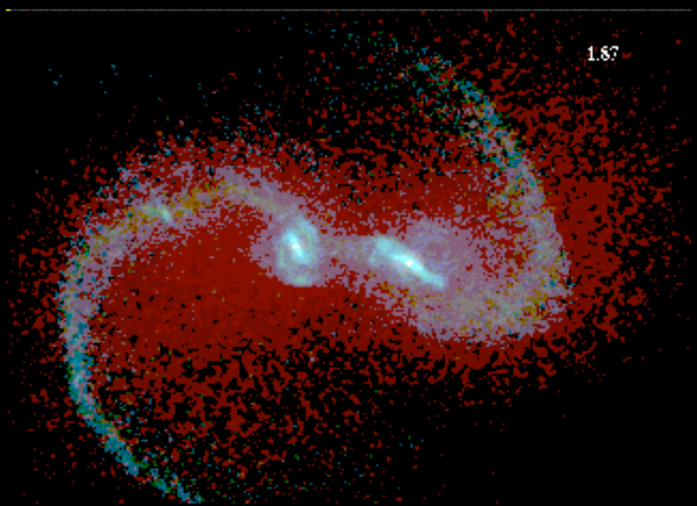
~~[C II] - deficiency~~ Line - deficiency

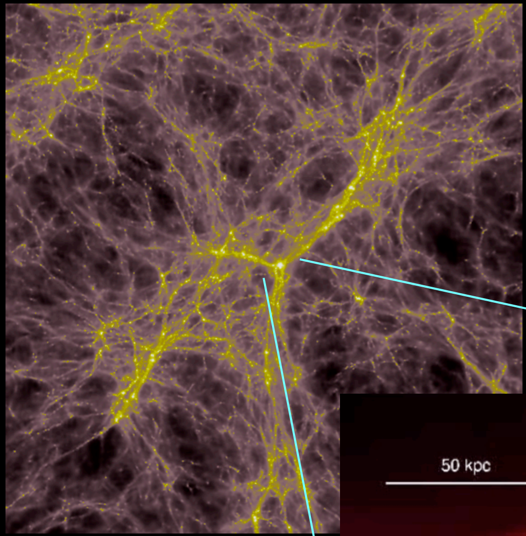


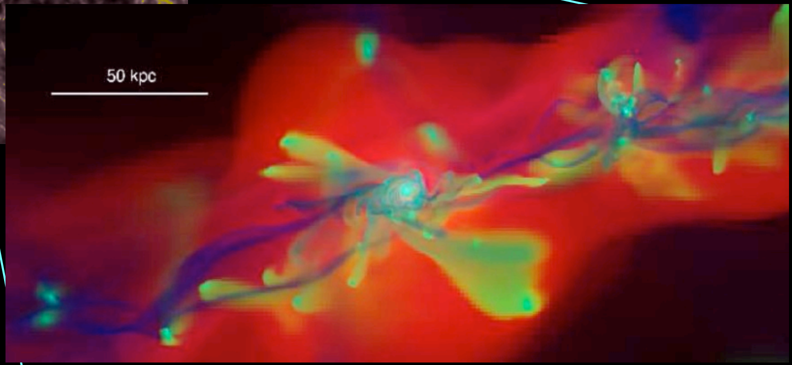


Graciá-Carpio + 2011

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





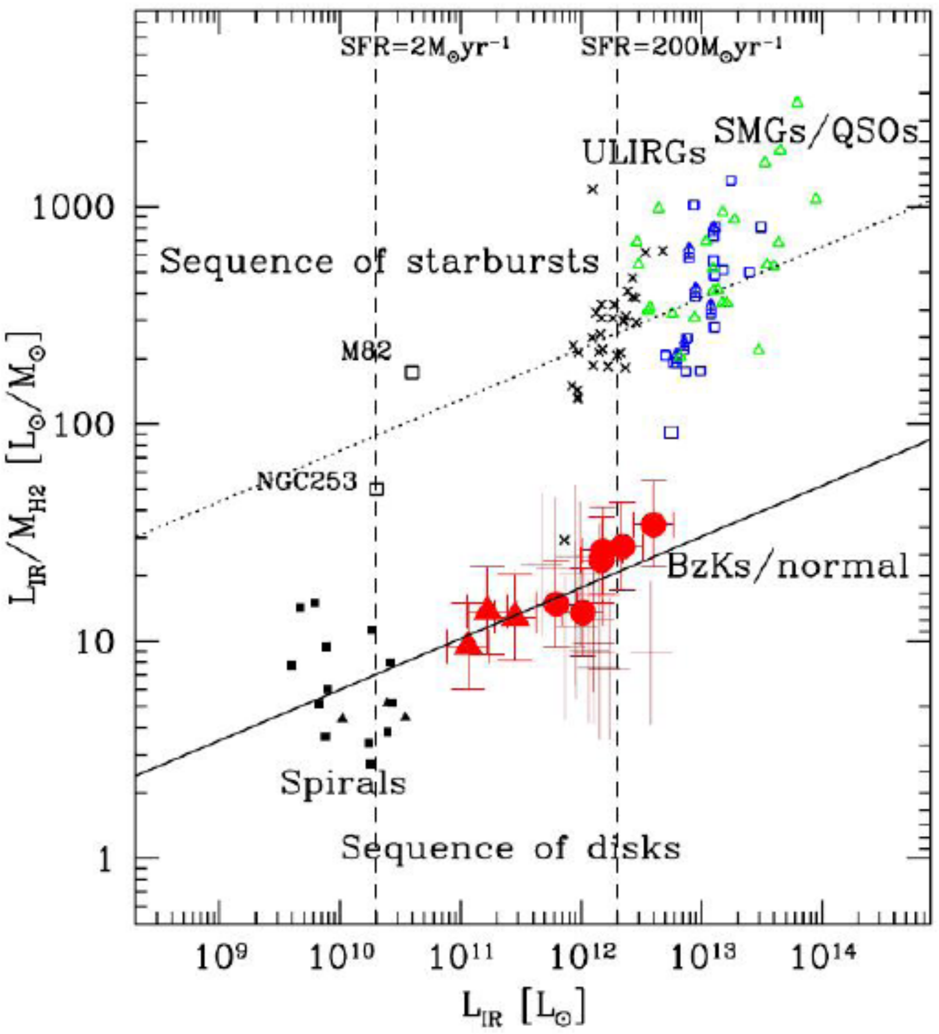


Major mergers

Kauffmann et al. 1993, Steinmetz & Navarro 2003, Hernquist, Springel, di Matteo, Hopkins et al. 2003-2006, Robertson & Bullock 2008

Minor mergers and steady accretion:

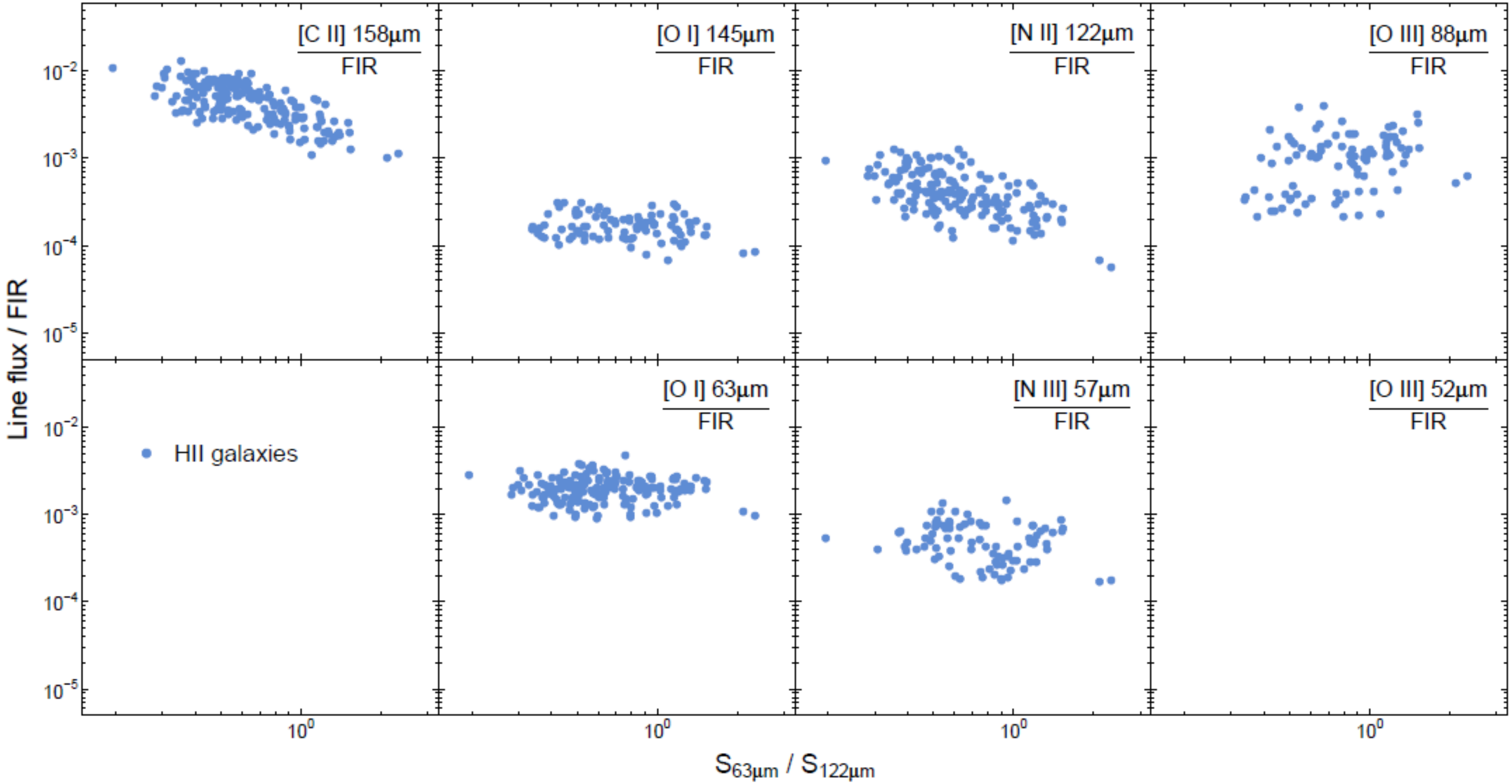
Dekel & Birnboim 2003,2006, Keres et al. 2005, Nagamine et al. 2005, Davé 2007, Kitzbichler & White 2007, Naab et al. 2007, Governato et al. 2008, Ocvirk et al. 2008, Dekel et al. 2009, Agertz et al. 2009



[Genzel et al. 2010, MNRAS 407: 2091]

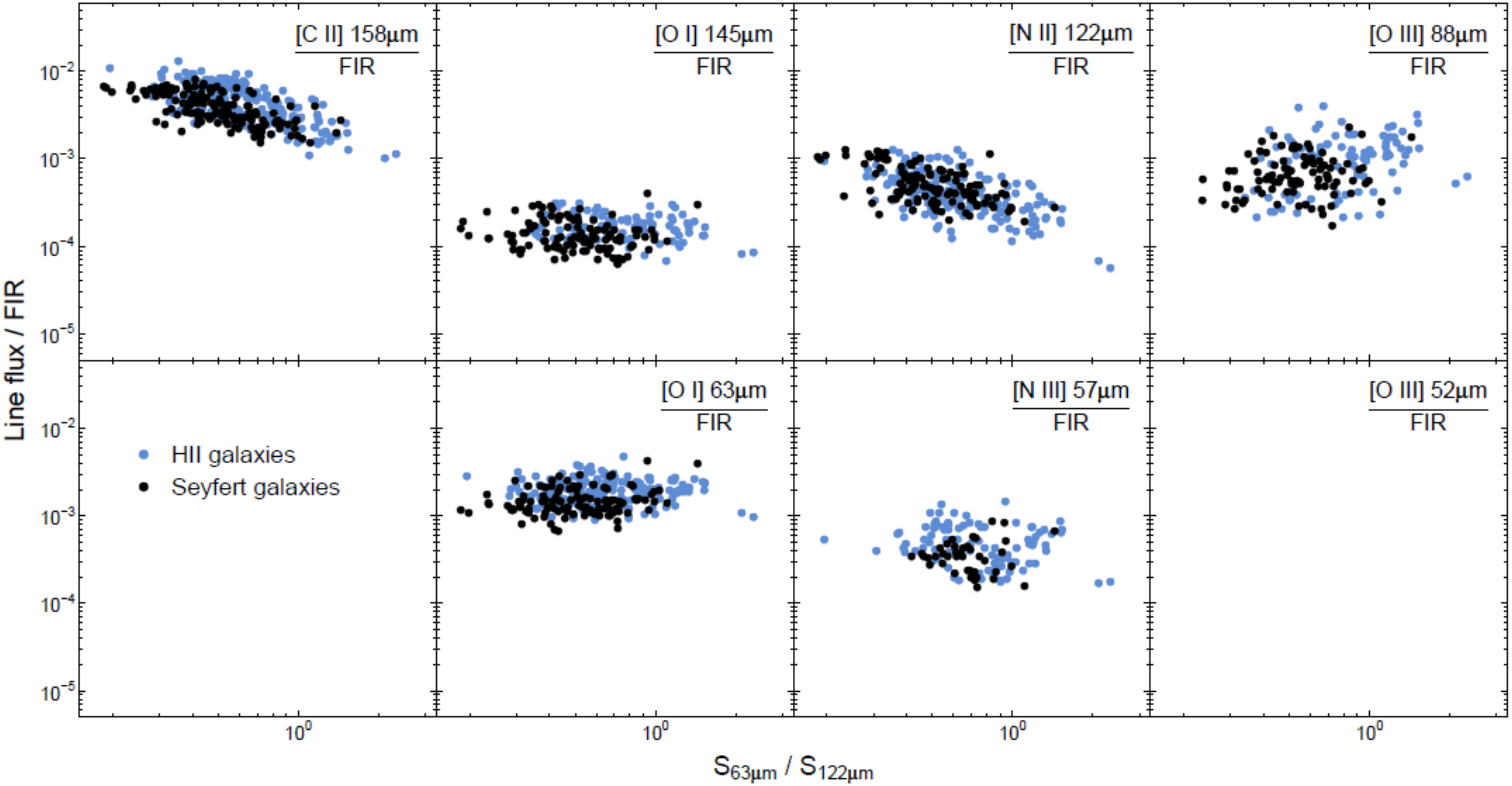
[Daddi et al. 2010, ApJ 714: L118]

Spatially resolved information



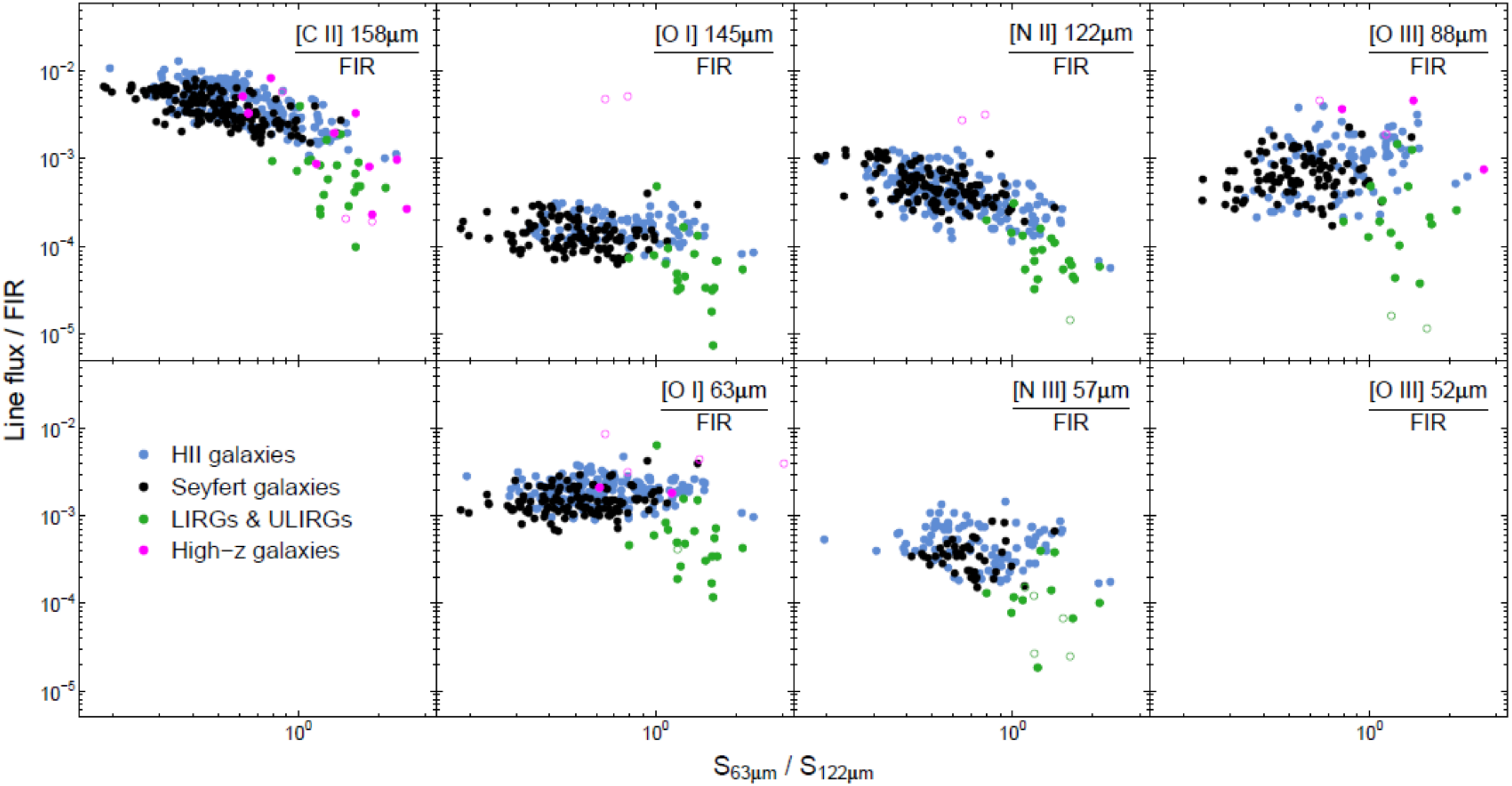
[Graciá-Carpio et al. in preparation]

Spatially resolved information



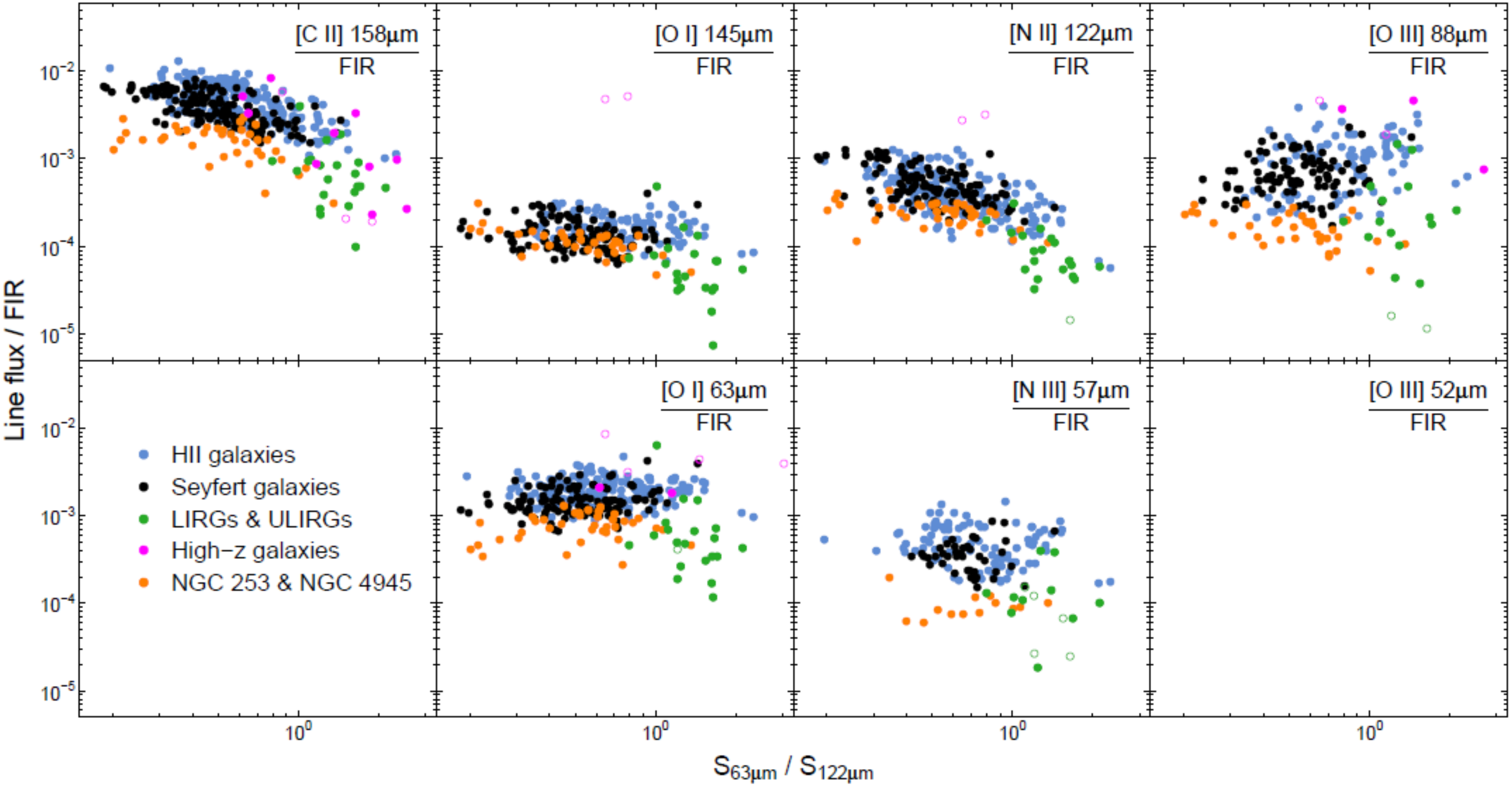
[Graciá-Carpio et al. in preparation]

Spatially resolved information



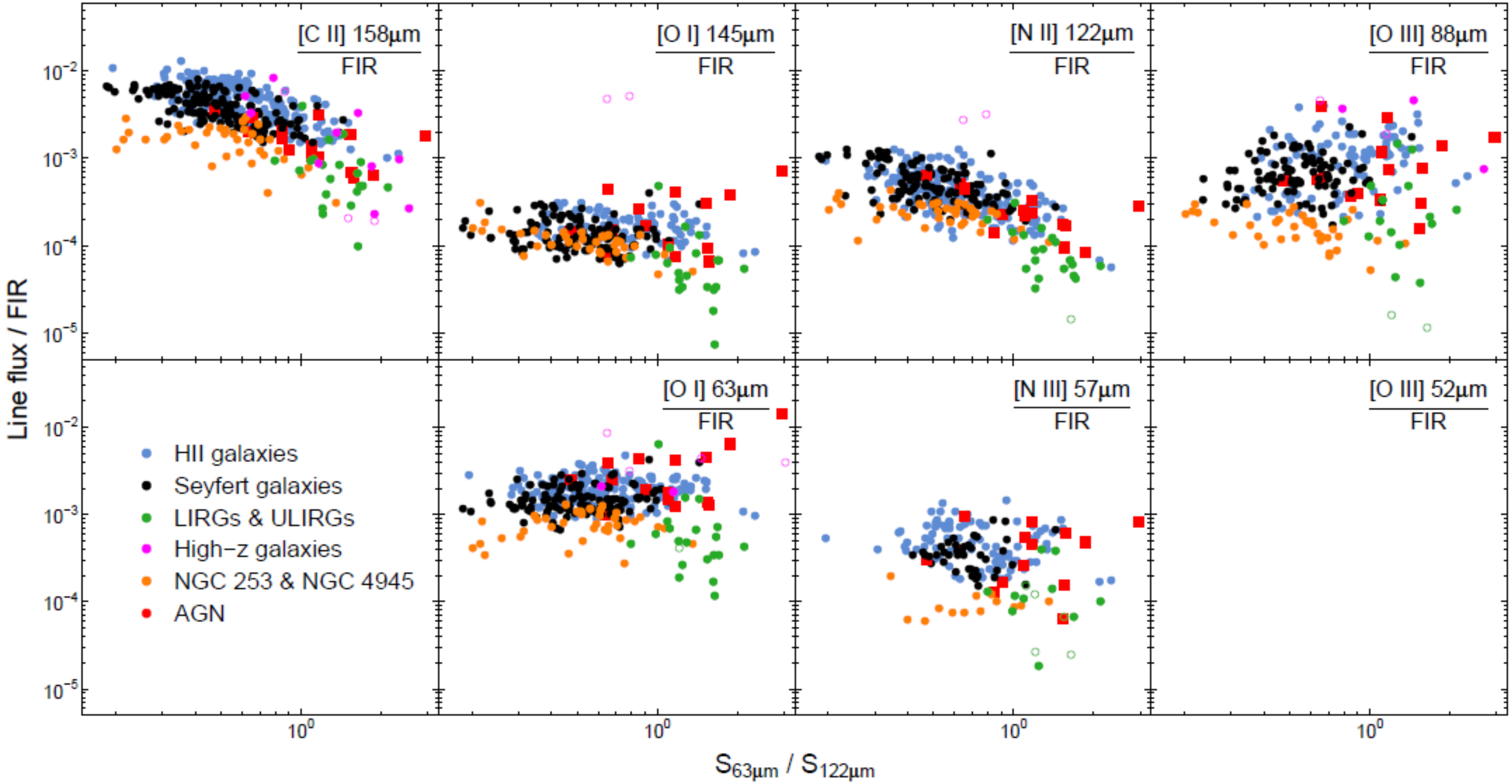
[Graciá-Carpio et al. in preparation]

Spatially resolved information



[Graciá-Carpio et al. in preparation]

Spatially resolved information

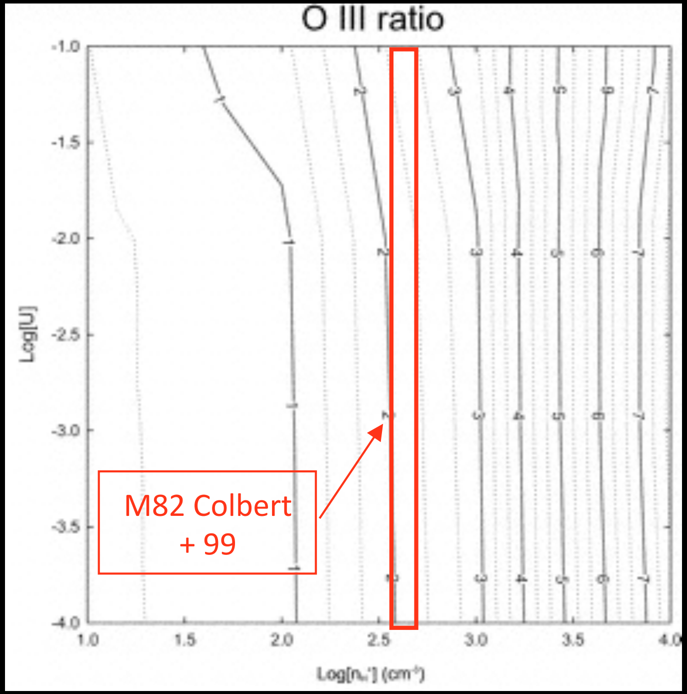


[Graciá-Carpio et al. in preparation]

PACS Spectroscopy: z ≈ 1

Name	z	Type	LFIR
MIPS J1428	**1.33**	**SB**	**2.8**
Abell 0370_01	0.72	Arc/SB	0.9
SMM J02399	1.06	Sey/LoBAL	1.8
SDSSJ1722	0.74	Sey2	1.3
ELAISCJ1640	1.10	QSO	2.6

- [O I]63μm, [O III]52, 88 μm
- Comparative to low z sample, spanning AGN, starbursts, low-Z, ULIRGs…

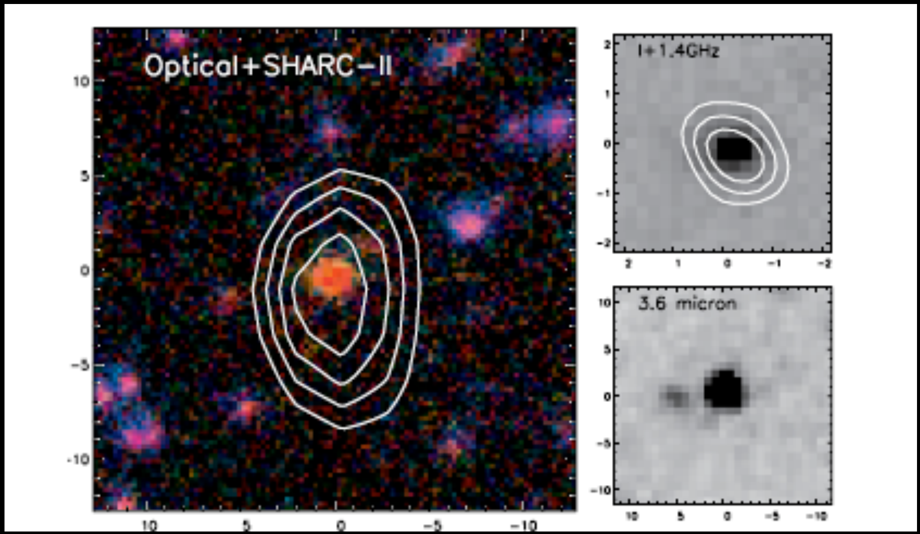


[OIII]52/[OIII]88

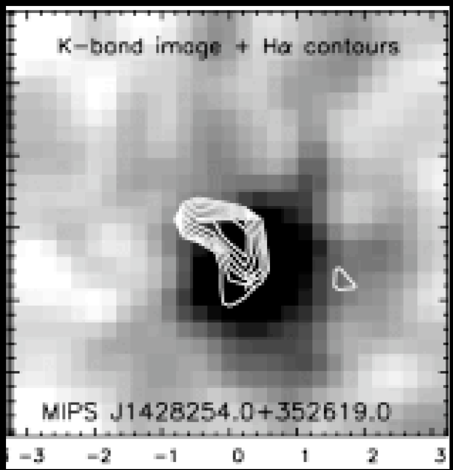
Good density diagnostic for HII regions with $n_H^+ > 10^2$ cm^{-3}

Abel et al. 05

MIPS J142824.0+352619



Borys et al. 06

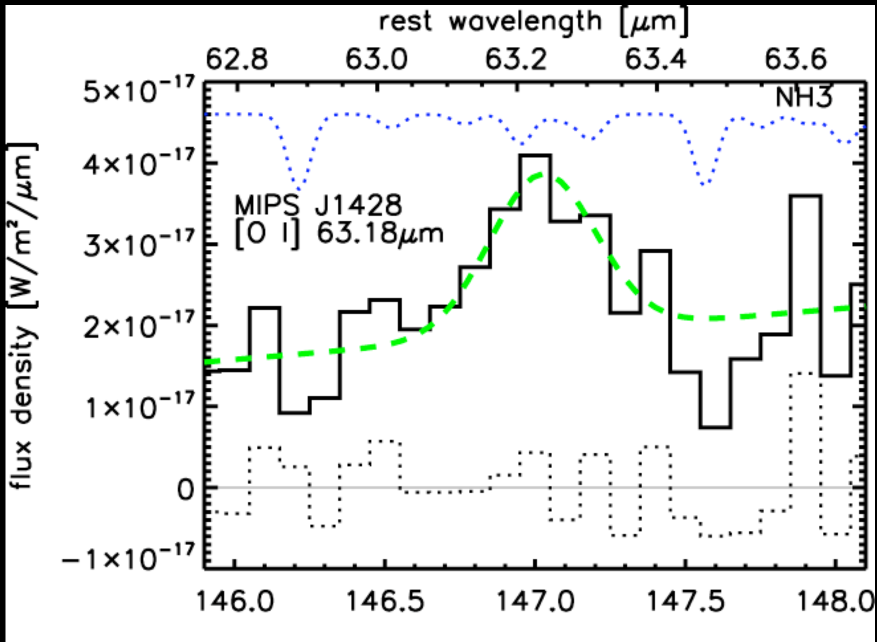


Swinbank et al. 06

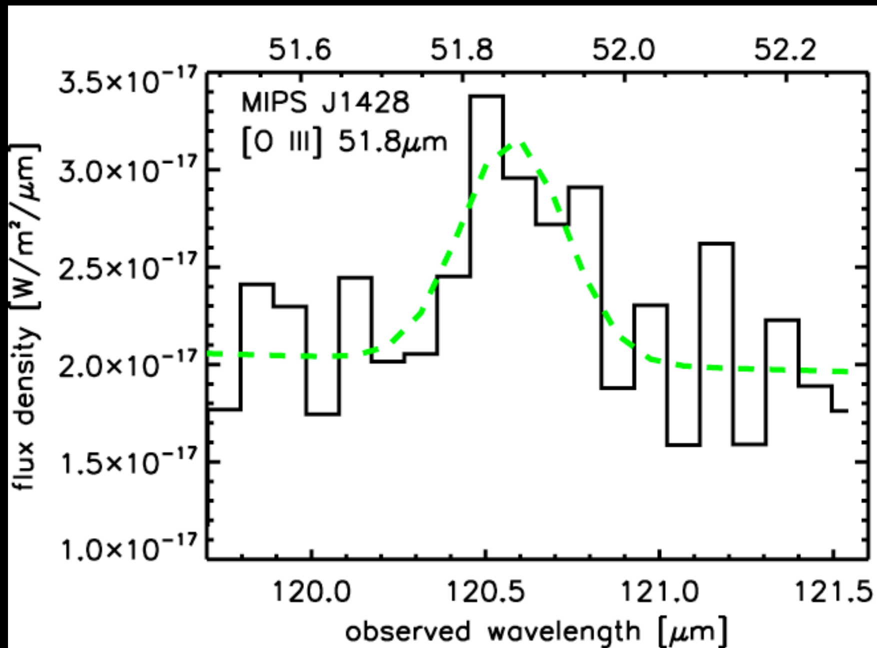
- A hyperluminous "Monster": Extreme Starburst at z=1.325 selected from Bootes (Borys et al. 06, Desai et al. 06)
- no AGN signatures
- Lensed by foreground z≈1 elliptical - μ<8 (Borys+ '06) & confirmed by CO
- L(FIR)=2.8 ± 0.7×10^{13}Lsol (lensed)
- Bright CO (3-2) & CO (2-1) detections (NRO, Iono+ '06b) M(H2) ~ 10^{11} $M_{\odot}$,

MIPS J142824.0+352619

[O I] 63 µm

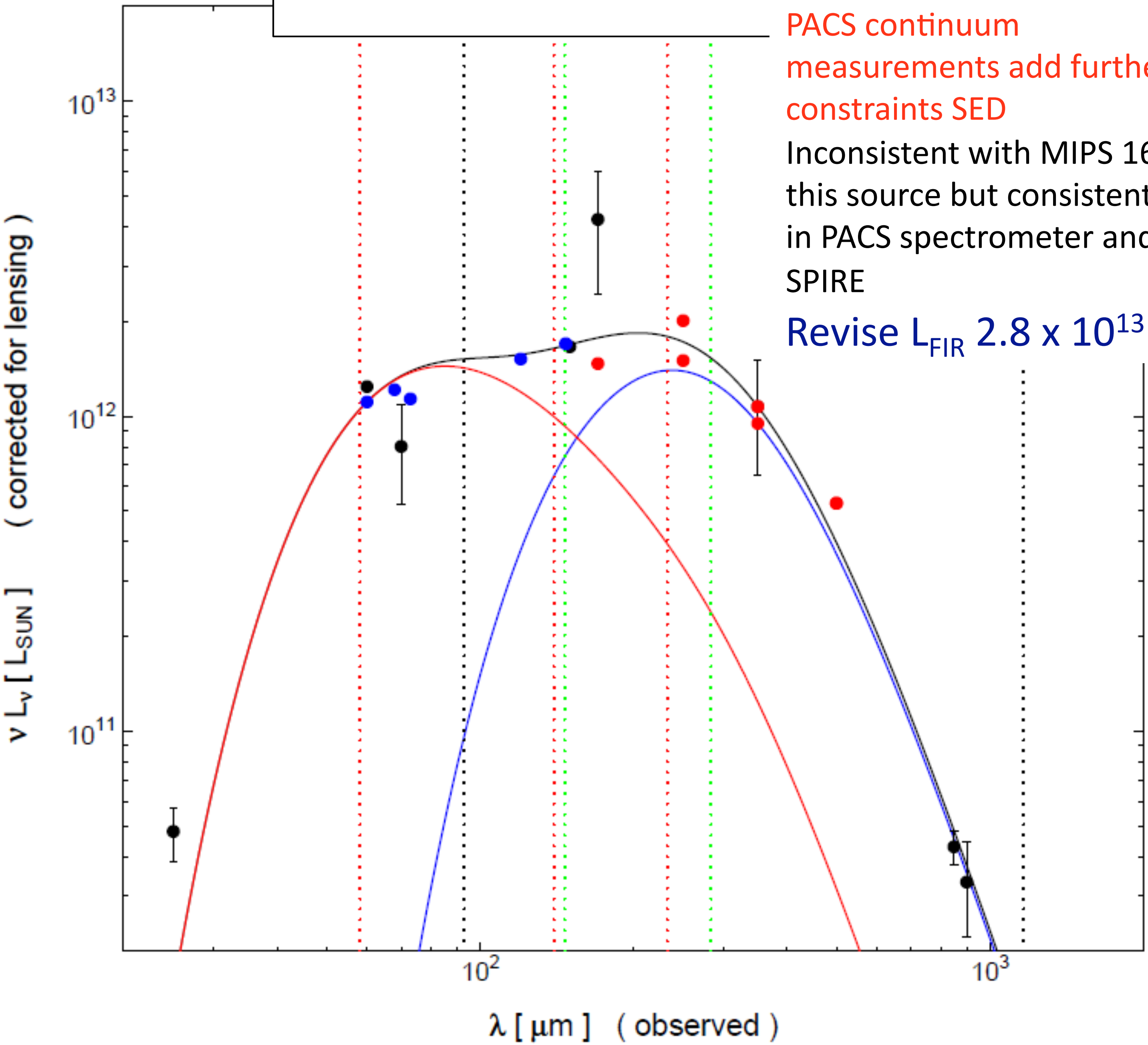


[O III] 52 µm



Sturm+ 2010

MIPSJ1428 SED

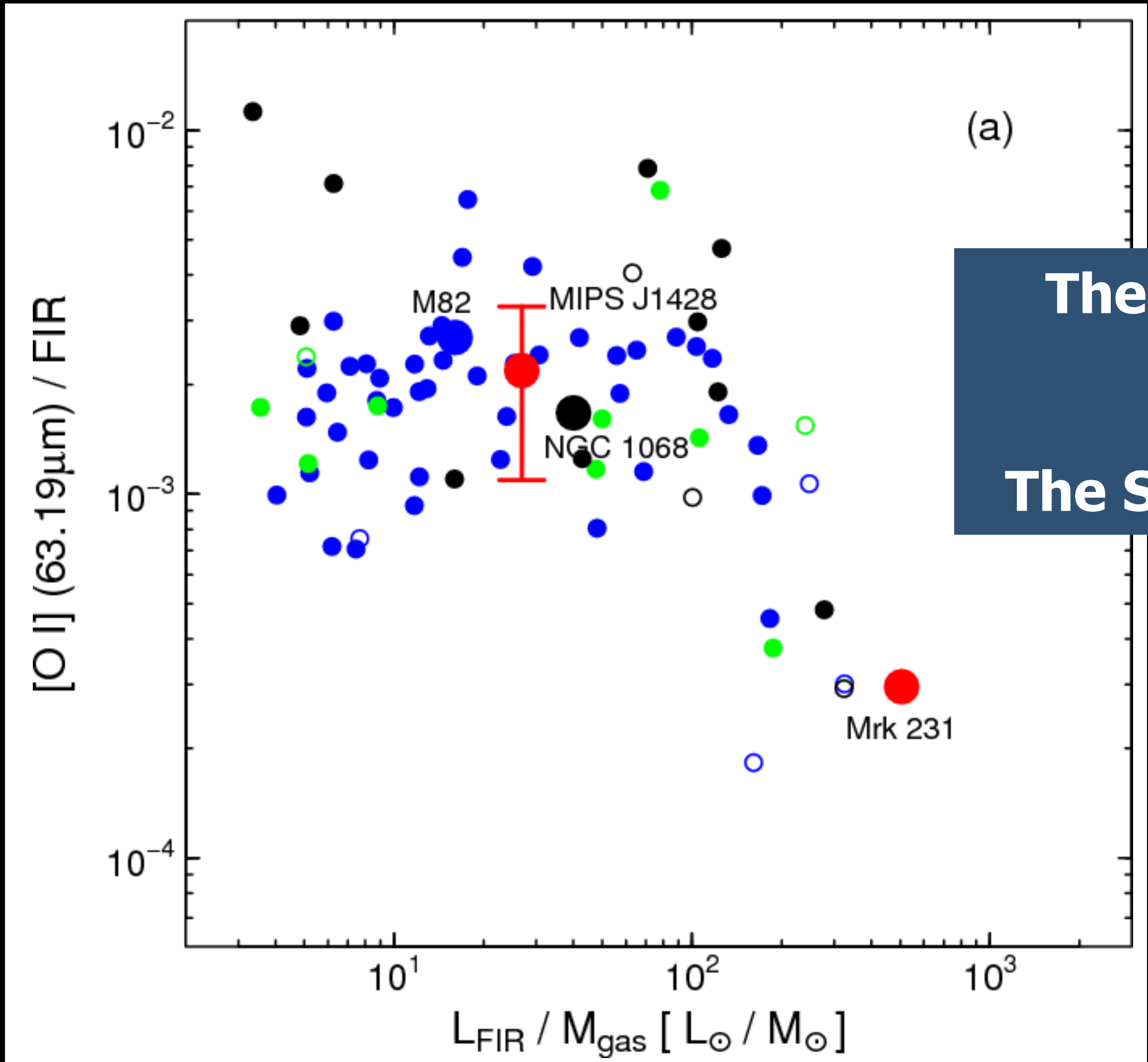


PACS continuum measurements add further constraints SED

Inconsistent with MIPS 160μm data on this source but consistent measurements in PACS spectrometer and bolometer, and SPIRE

Revise L_{FIR} 2.8 x 10^{13} $L_\odot$ to 1.3 x 10^{13} $L_\odot$

MIPSJ1428

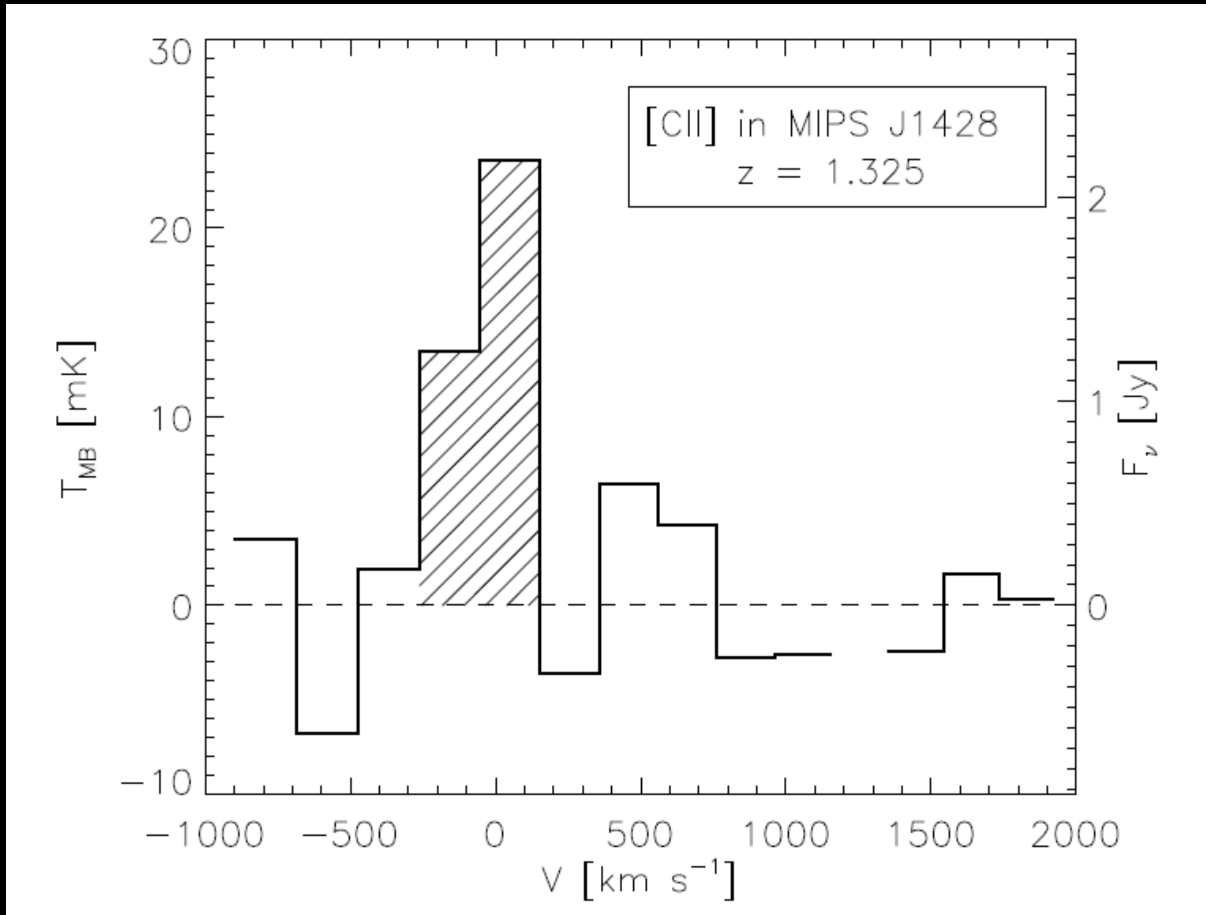


The Luminosity of a ULIRG

but

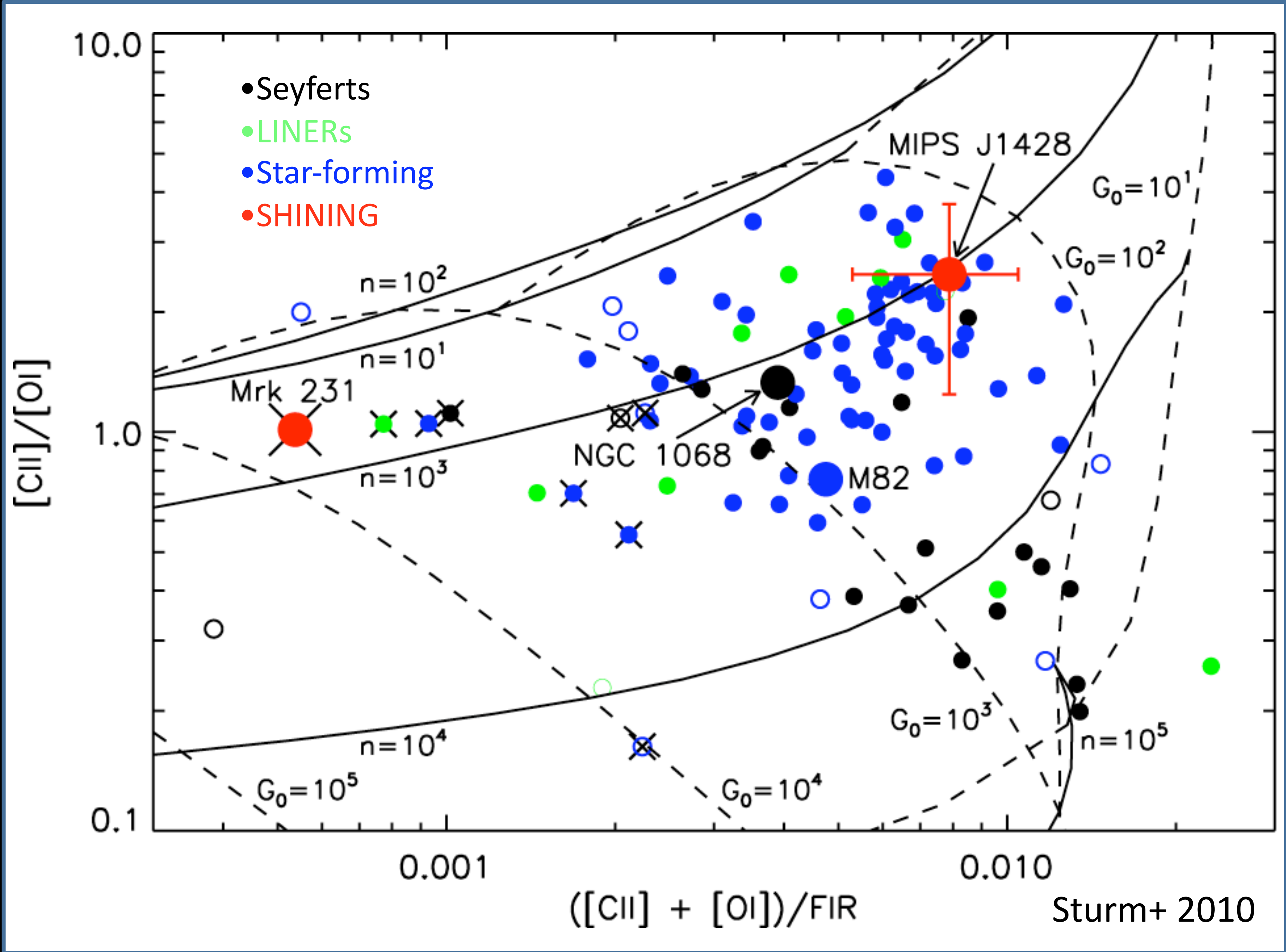
The SFE of a normal starburst

Sturm+ 2010

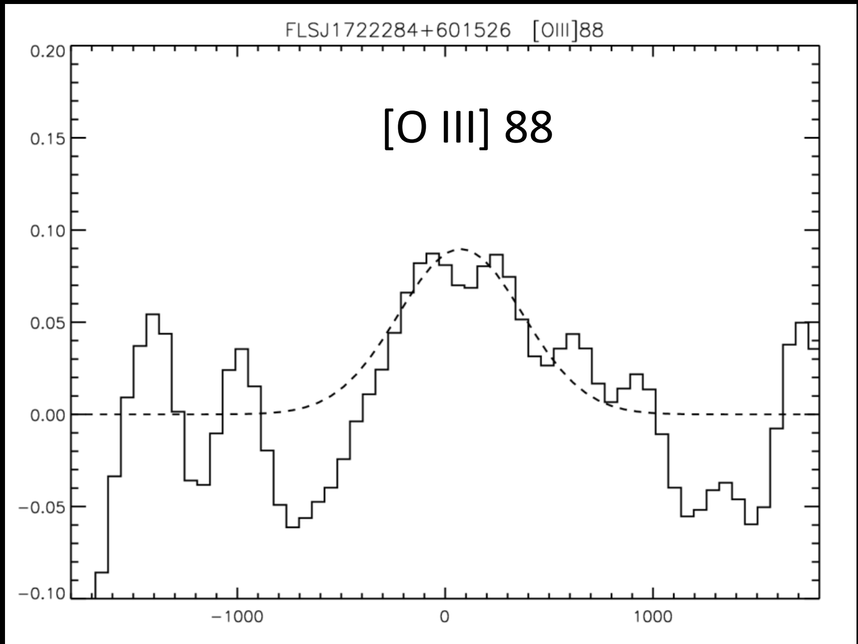


Hailey-Dunsheath + 2010 (ZEUS/CSO)

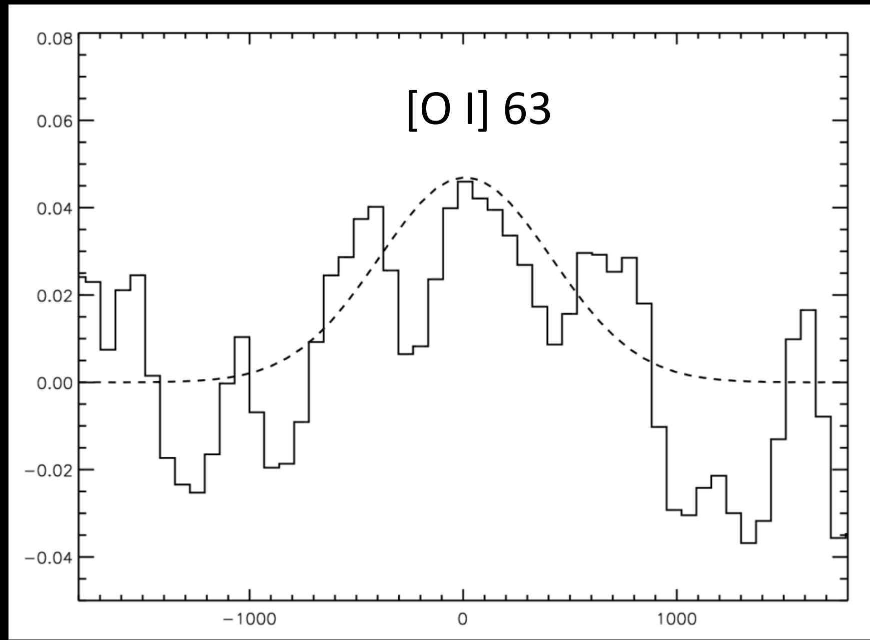
PDR diagnostic diagram



FLSJ172228.04+601526.0
Sy2, z=0,74



SMM J02396-0134
Sy/LoBAL, z=1.06



FWHM (CO) = 780 km/s (Greve + 2005)

PACS Spectroscopy: z ≈ 2 - 4

Name	*z*	*Type*	L_{IR} $10^{14} L_{\odot}$
IRAS F10214+4724	2.29	Sy2	5.1
SMM J14011+0252	2.57	SMG	1.1
Cloverleaf	2.57	QSO	8.1
APM 08279+5255	3.91	QSO	3.4

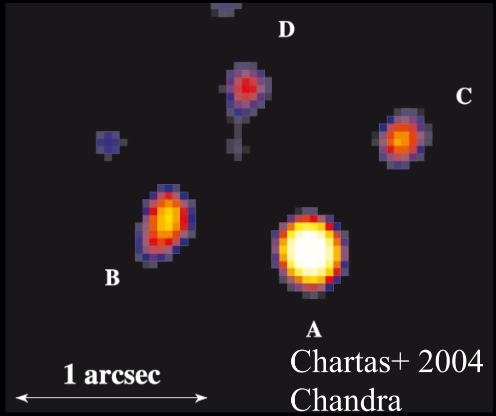
GTKP: The Dusty Young Universe, PI K. Meisenheimer

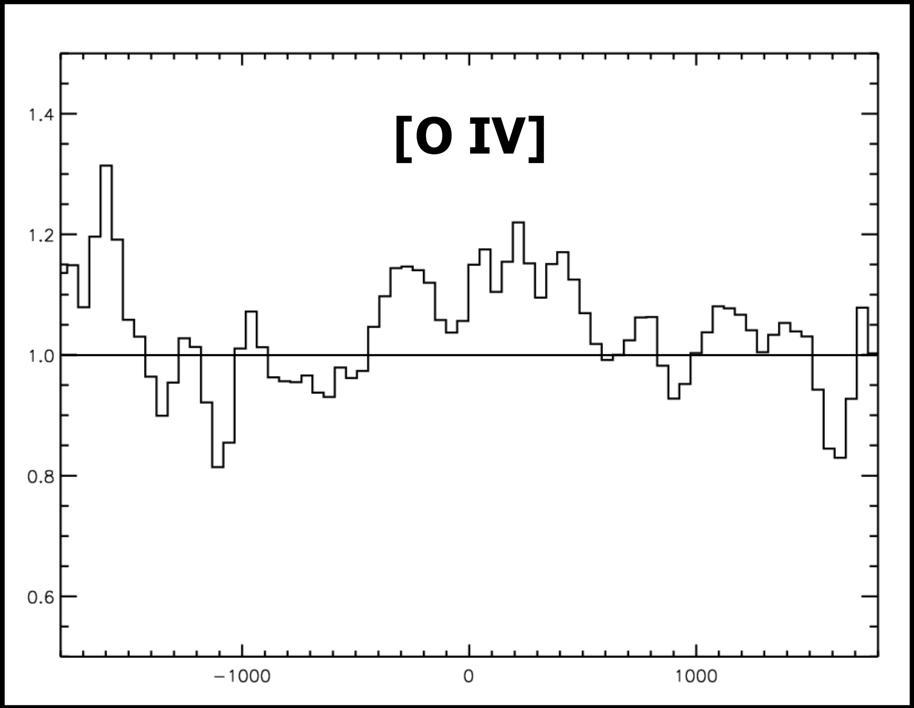
4 bright, lensed QSOs and SMGs

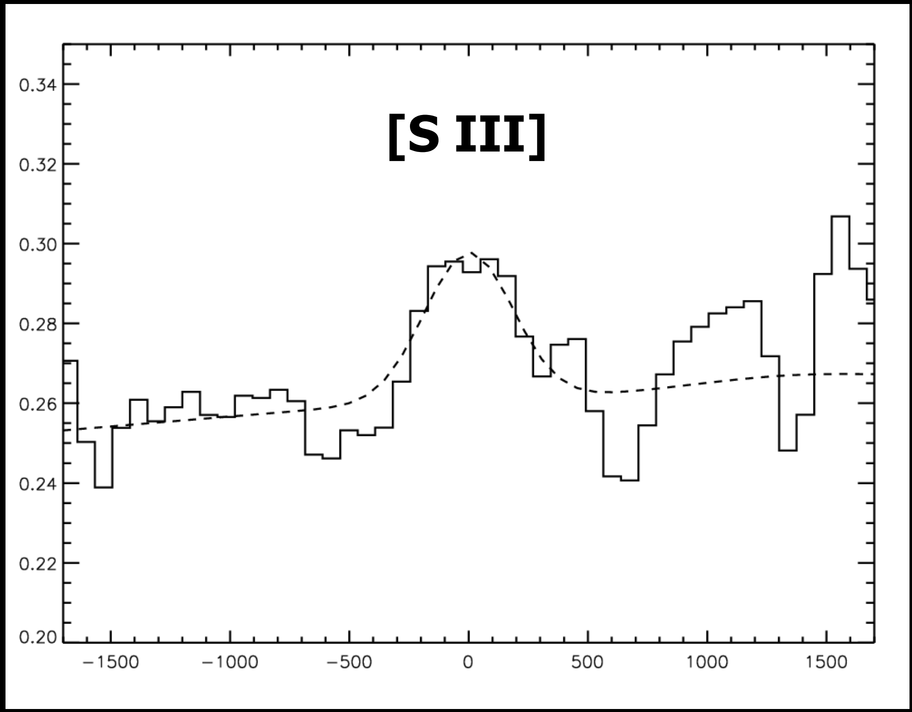
Redshifted [S III] 33.5 and [O IV] 25.9 ([S III]used as a proxy for [Ne II])
SIII (IP=23eV) traces low excitation gas, OIV(IP=55eV) traces high excitation gas
→ Starburst/AGN diagnostic

H1413+117 (Cloverleaf)
z = 2.558

Lensed Quasar

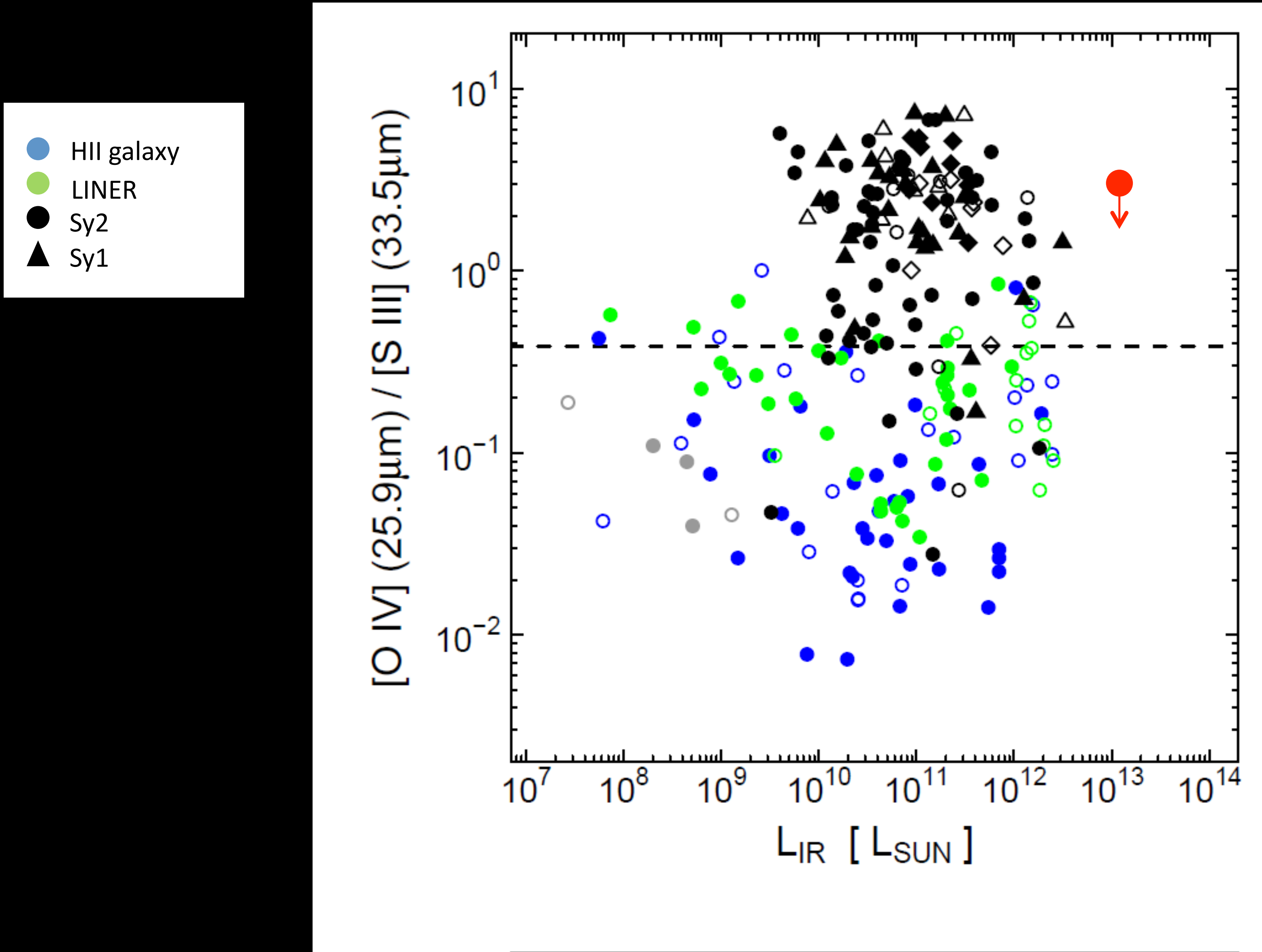


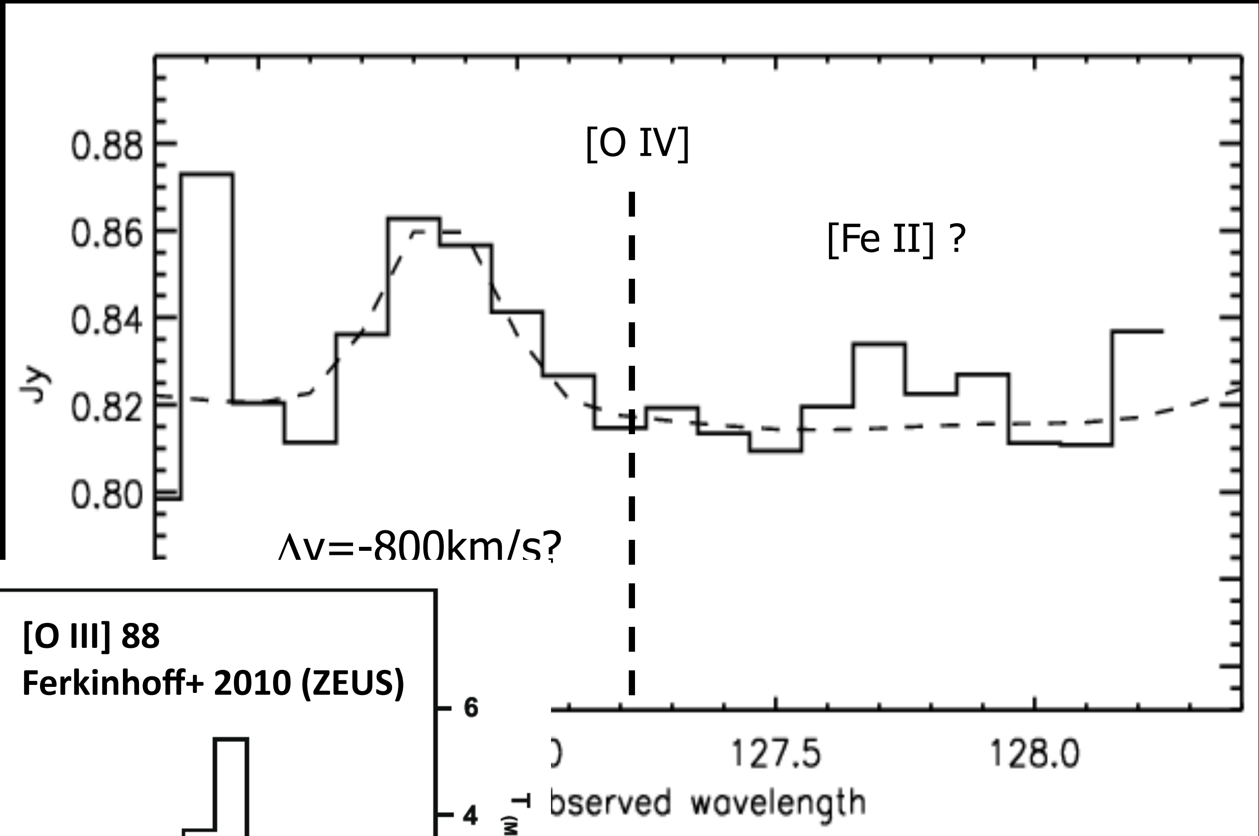


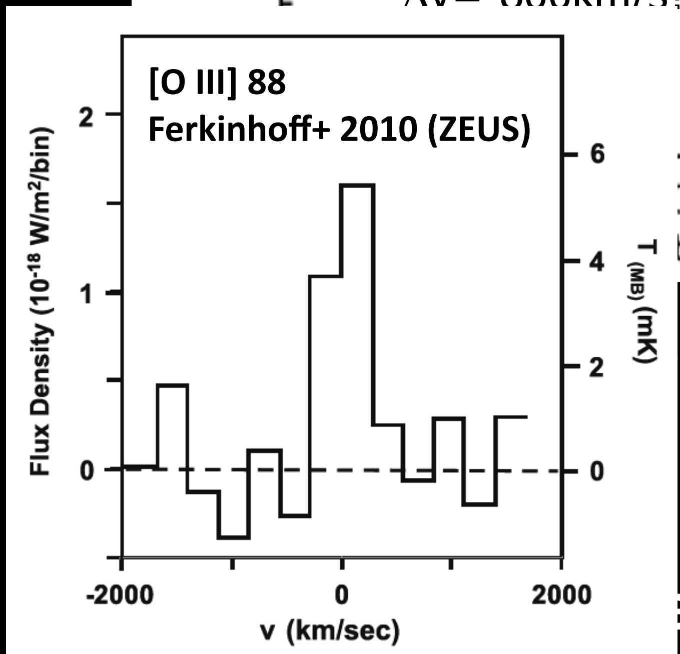


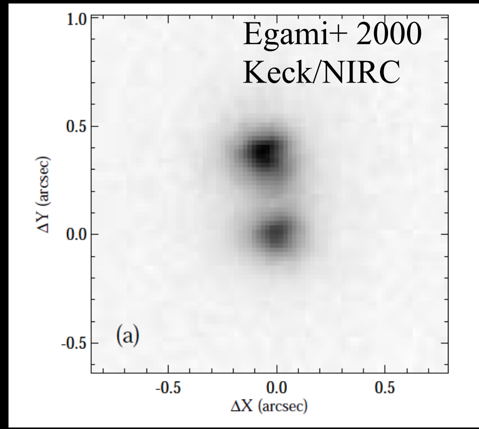
<6×10^{-18} W/m^2 , 4 hrs

2×10^{-18} W/m^2 , 1.2 hrs


HII galaxy
LINER
Sy2
Sy1
[O IV] (25.9μm) / [S III] (33.5μm)
10^1
10^0
10^{-1}
10^{-2}
10^7 10^8 10^9 10^{10} 10^{11} 10^{12} 10^{13} 10^{14}
L_{IR} [L_{SUN}]







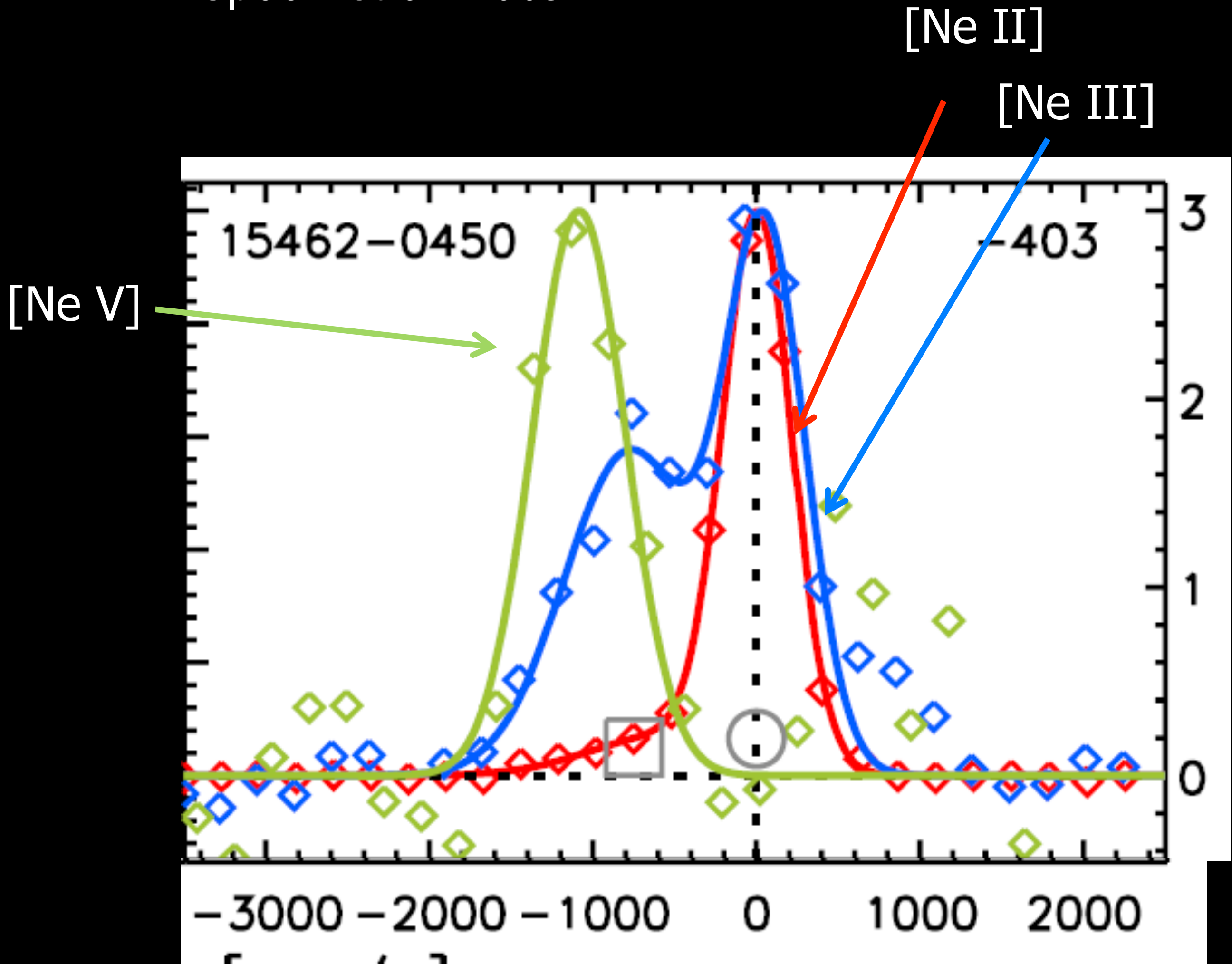
M 08279+5255

z = 3.91

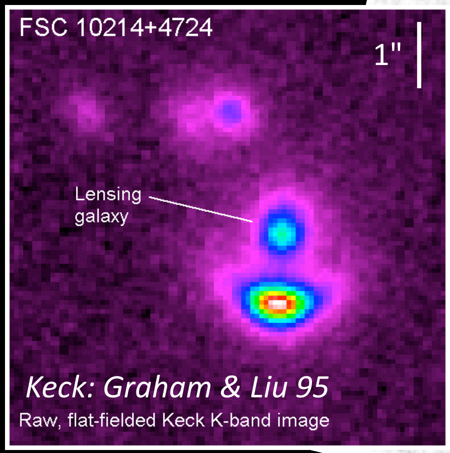
$(<)1.8\times10^{-18}$ W/m^2 , 3.5hrs

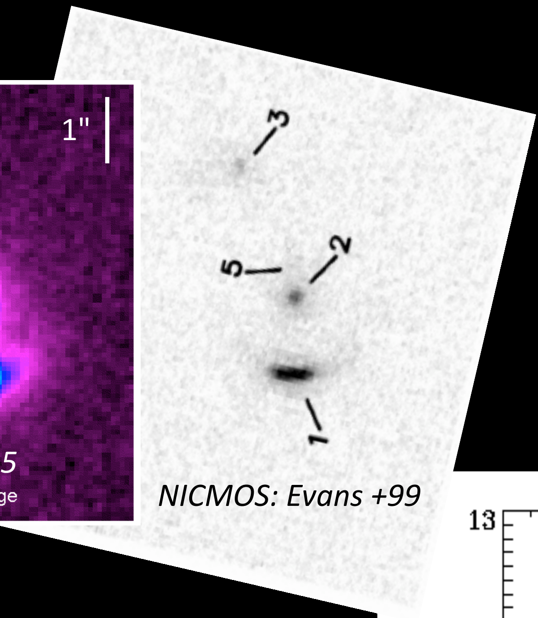
ensed Quasar

Spoon et al. 2009

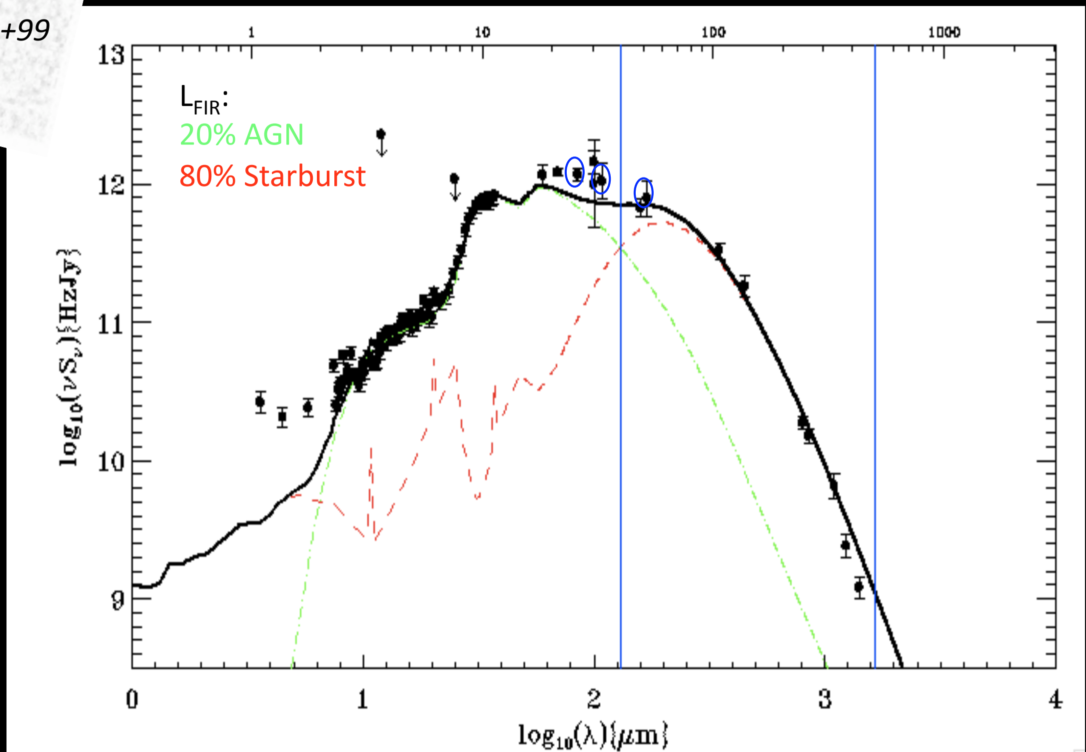


IRAS F10214+4724

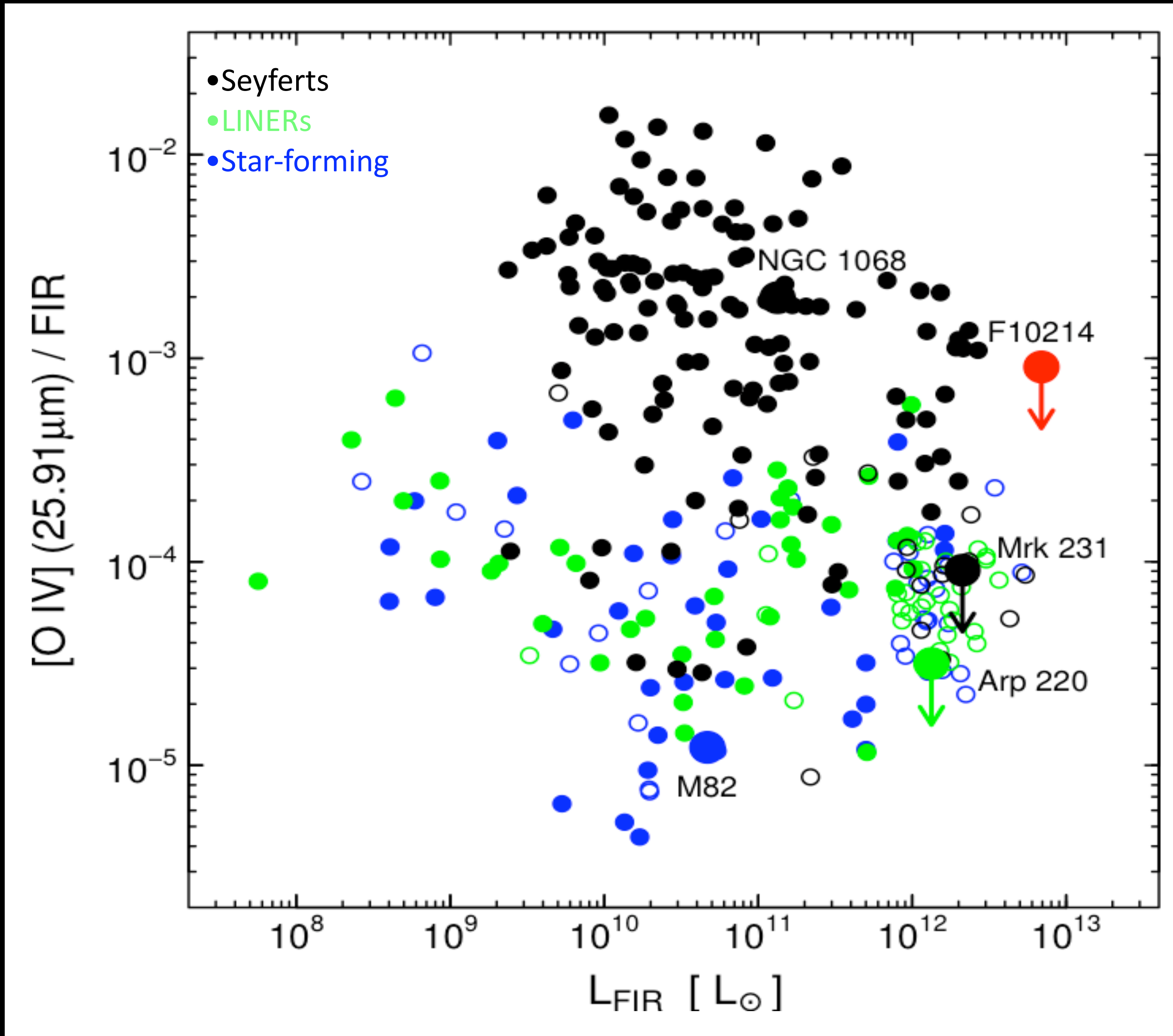


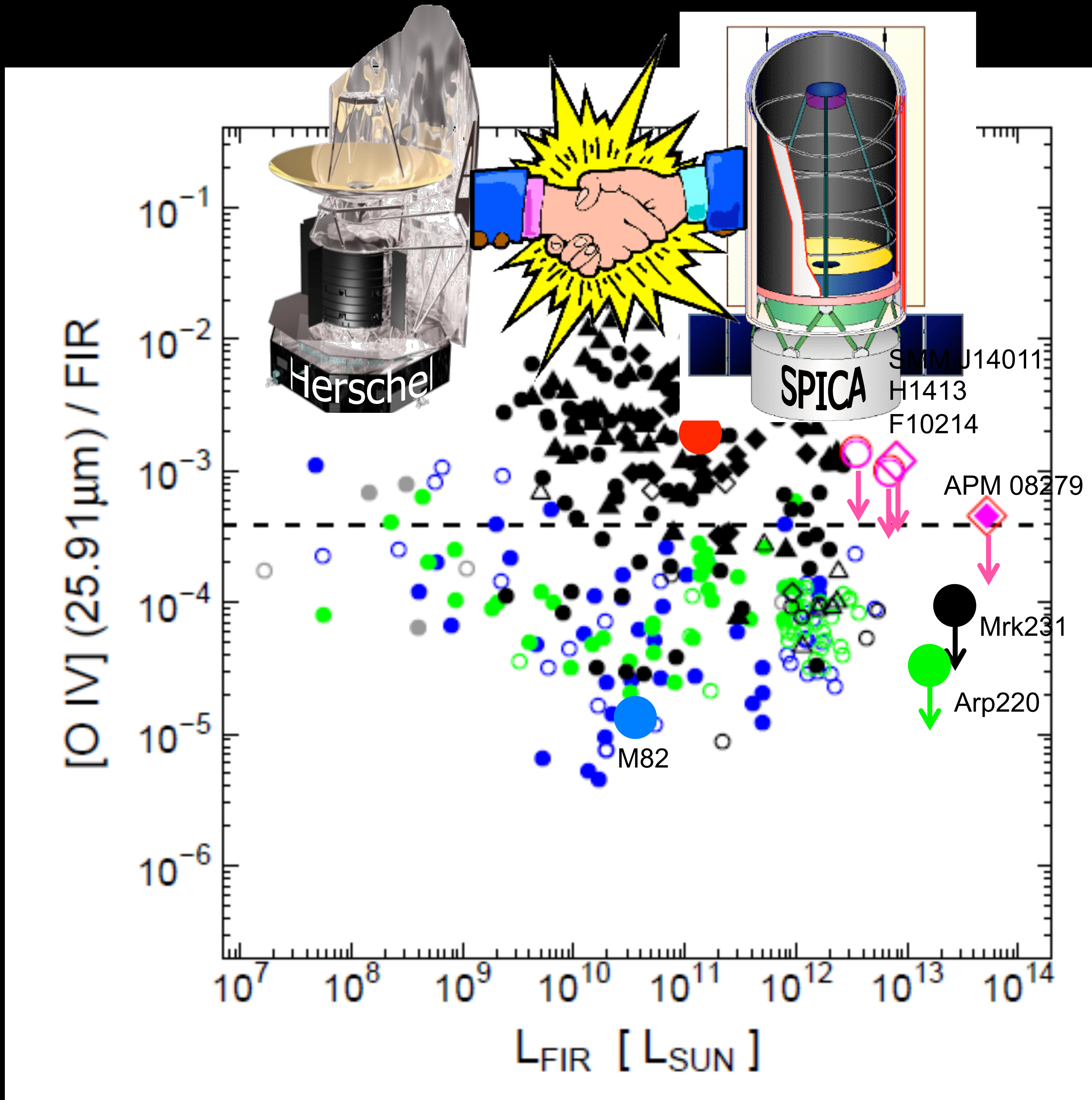


Well studied lensed z=2.29 HLIRG (Sy2)
Coeval star formation & AGN
Differential magnification AGN/Host ≈ 3



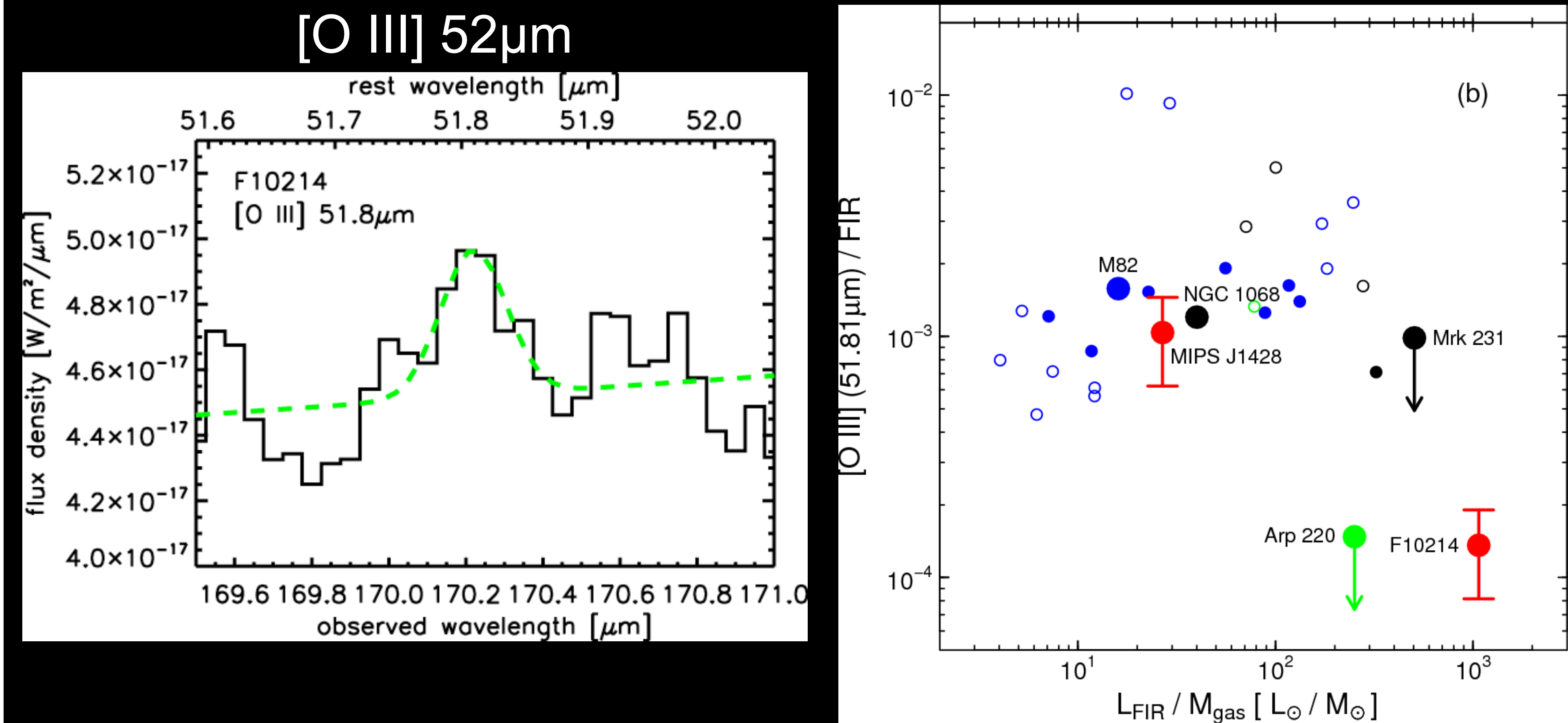
IRAS F10214+4724



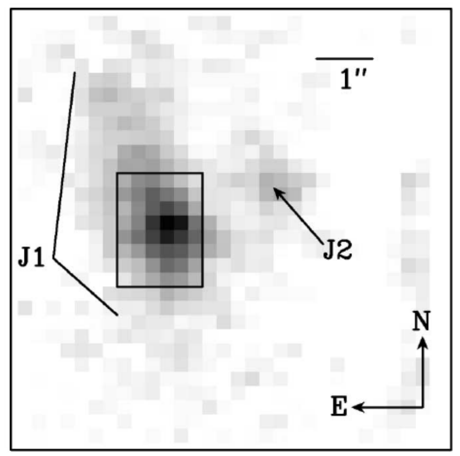

Herschel
SPICA
SMM J14011
H1413
F10214
APM 08279
Mrk231
Arp220
M82
[O IV] (25.91μm) / FIR
L_FIR [L_SUN]
10^-1
10^-2
10^-3
10^-4
10^-5
10^-6
10^7
10^8
10^9
10^10
10^11
10^12
10^13
10^14

IRAS F10214+4724

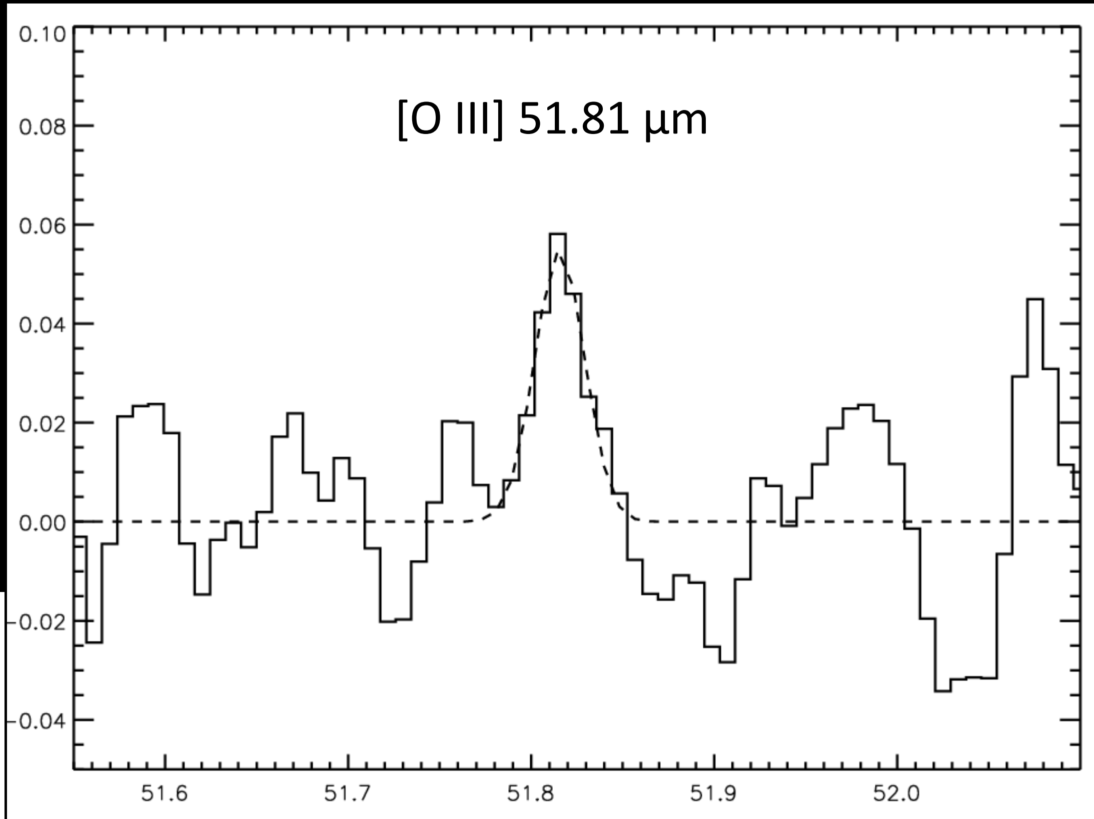
[O III] 52μm



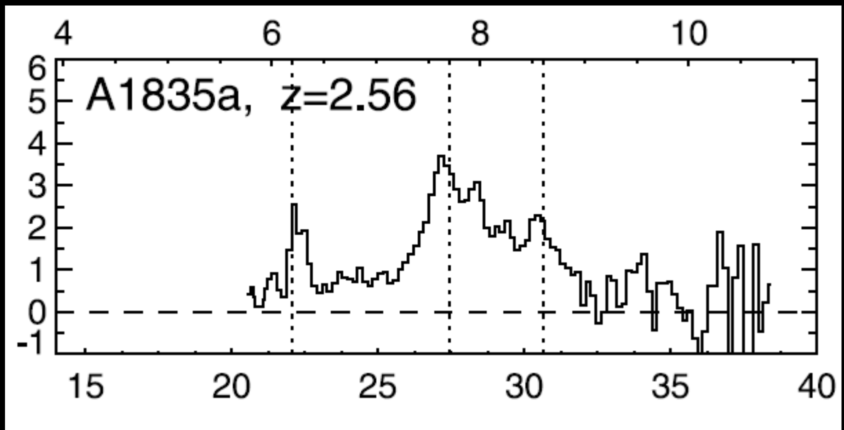
SMM J14011+0252
SMG at z=2.5652



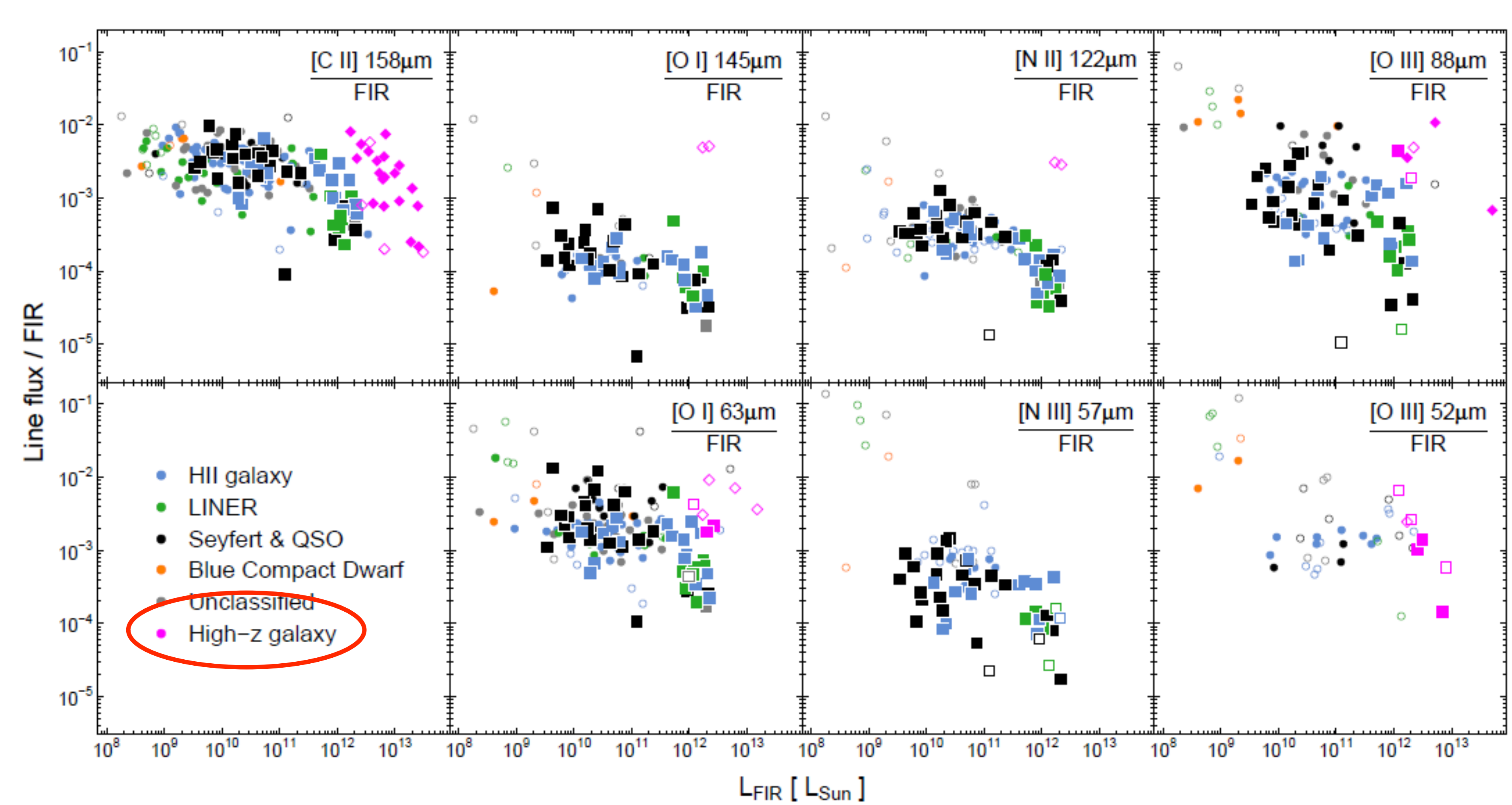
8“x8“ K-band continuum image (Tecza 2004)

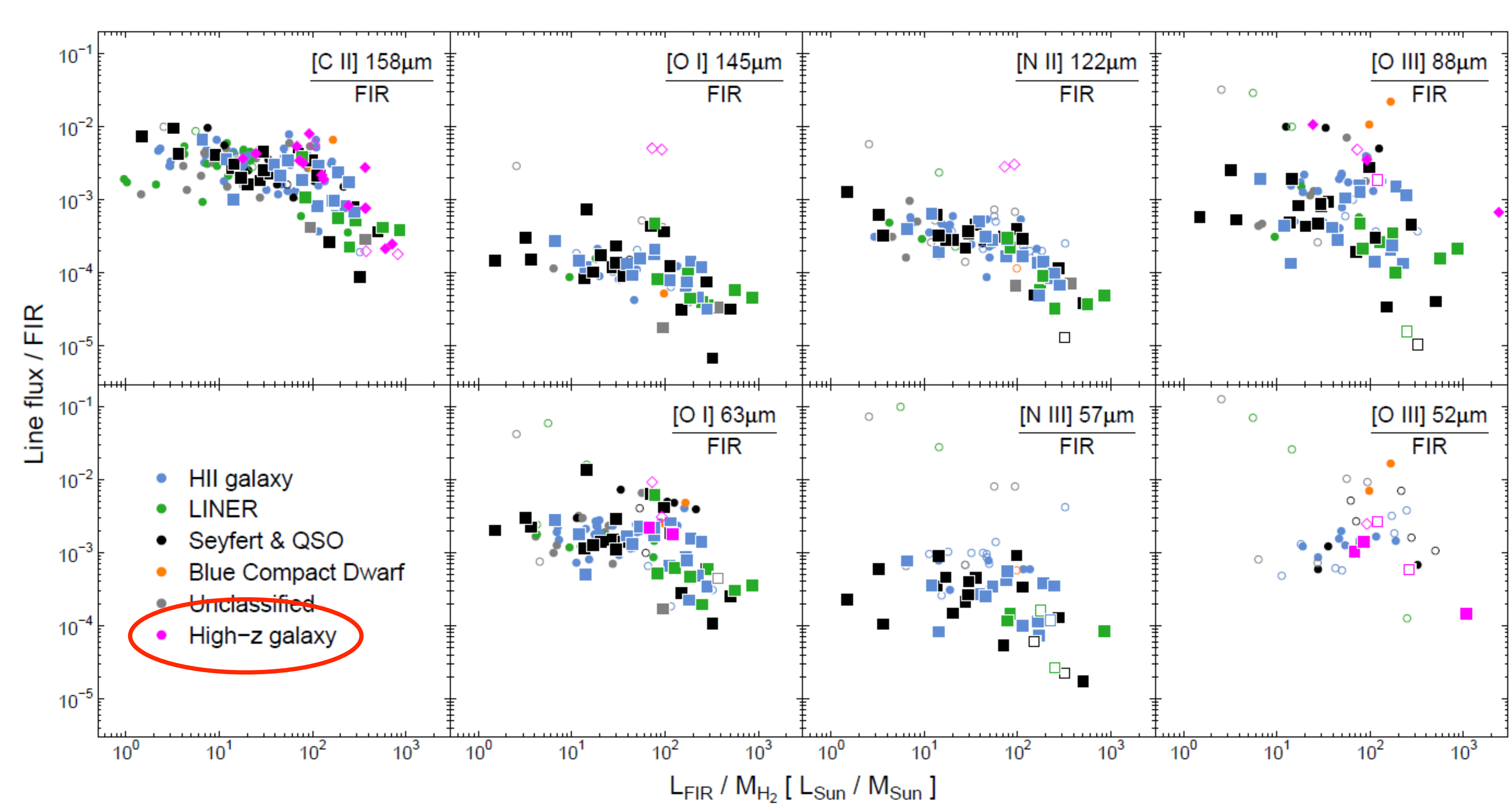


PACS spectrum (9“x9“ spaxel)



Spitzer spectrum (Rigby et al. 2008)


[C II] 158μm / FIR
[O I] 145μm / FIR
[N II] 122μm / FIR
[O III] 88μm / FIR
[O I] 63μm / FIR
[N III] 57μm / FIR
[O III] 52μm / FIR
HII galaxy
LINER
Seyfert & QSO
Blue Compact Dwarf
Unclassified
High−z galaxy
Line flux / FIR
L_{FIR} [L_{Sun}]



[C II] 158μm / FIR
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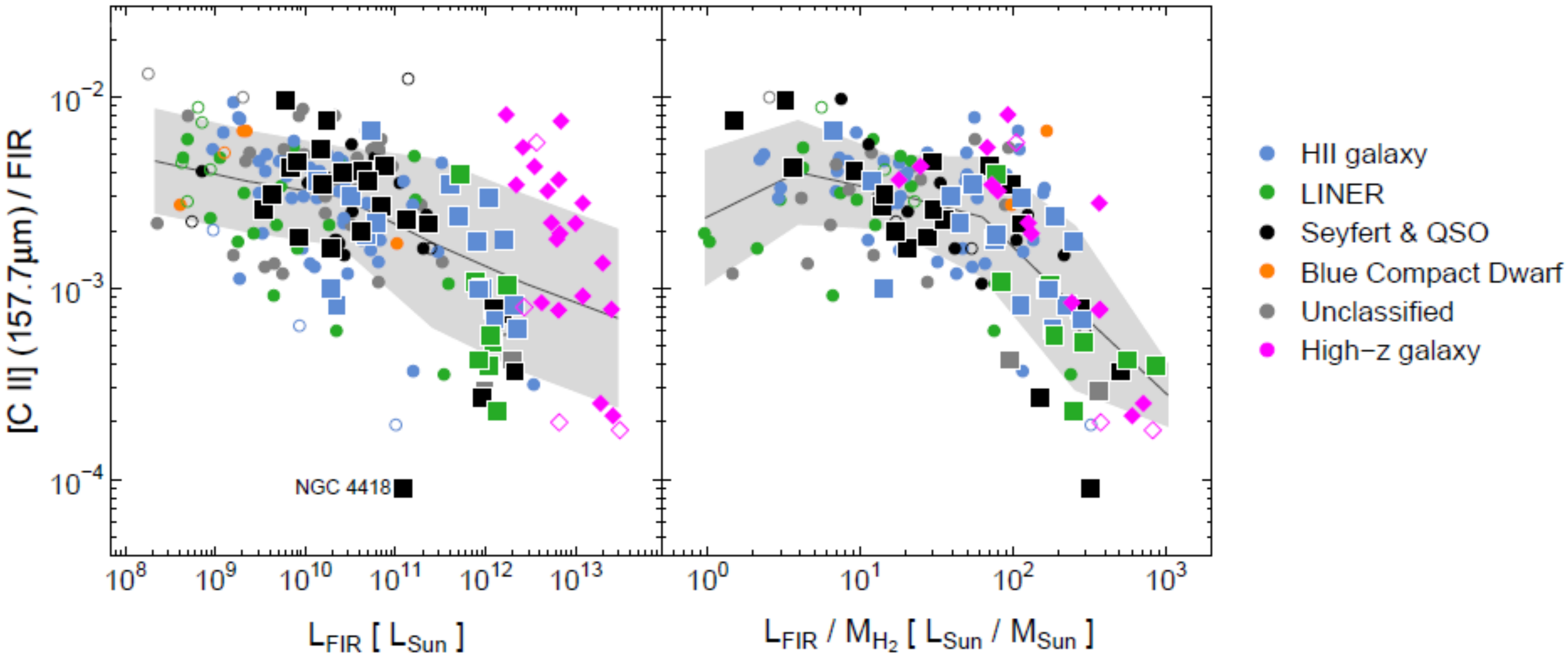
[O III] 88μm / FIR
[O I] 63μm / FIR
[N III] 57μm / FIR
[O III] 52μm / FIR
HII galaxy
LINER
Seyfert & QSO
Blue Compact Dwarf
Unclassified
High−z galaxy
Line flux / FIR
L_{FIR} / M_{H_2} [L_{Sun} / M_{Sun}]



[Graciá-Carpio et al. 2011, ApJ 728: L7]

[Brauher et al. 2008, ApJS 178: 280]

[Luhman et al. 2003, ApJ 594: 758]

[Ivison et al. 2010, A&A 518: L35]

[Stacey et al. 2010, ApJ 724: 957]

[Hailey-Dunsheath et al. 2010, ApJ 714: L162]

[Maiolino et al. 2009, A&A 500: L1]

[Walter et al. 2009, Nature 457: 699]

Herschel OT1 high-z spectroscopy projects

A PACS Redshift 1-2 Oxygen Survey: Leveraging the ZEUS [CII] Detections

Proposal ID: OT1_gstacey_3

Principal Investigator: Gordon Stacey

Time: 45.7 hours priority 1

Probing the Interstellar Medium of ULIRGs/SMGs at high redshift

Proposal ID: OT1_AVERMA_2

Principal Investigator: Aprajita Verma

Time: 77.3 hours priority 1

Characterising the ISM of bright, lensed star-forming galaxies across cosmic time with the SPIRE FTS

Proposal ID: OT1_rivison_1

Principal Investigator: Rob Ivison

Time: 94.1 hours priority 1

A Herschel Survey of [OI]63um in 1<z<2 Submillimetre Galaxies in the ECDFS: A Bridge to ALMA

Proposal ID: OT1_kcoppin_1

Principal Investigator: Kristen Coppin

Time: 26.3 hours priority 1

Measuring the PAH emission in a z=6.1 star forming Submillimetre Galaxy

Proposal ID: OT1_schapman_1

Principal Investigator: Scott Chapman

Time: 4.8 hours priority 1

SPIRE Spectroscopy of the Brightest High-Redshift Submillimeter Galaxies

Proposal ID: OT1_dmarrone_1

Principal Investigator: Daniel Marrone

Time: 4.1 hours priority 1

Spectroscopy of a Highly Magnified Galaxy Behind the Bullet Cluster

Proposal ID: OT1_agonza02_1

Principal Investigator: Anthony Gonzalez

Time: 12.8 hours priority 1

Characterizing the Interstellar Medium in 'Normal' High Redshift Galaxies

Proposal ID: OT1_driecher_1

Principal Investigator: Dominik Riechers

Time: 24 hours priority 2

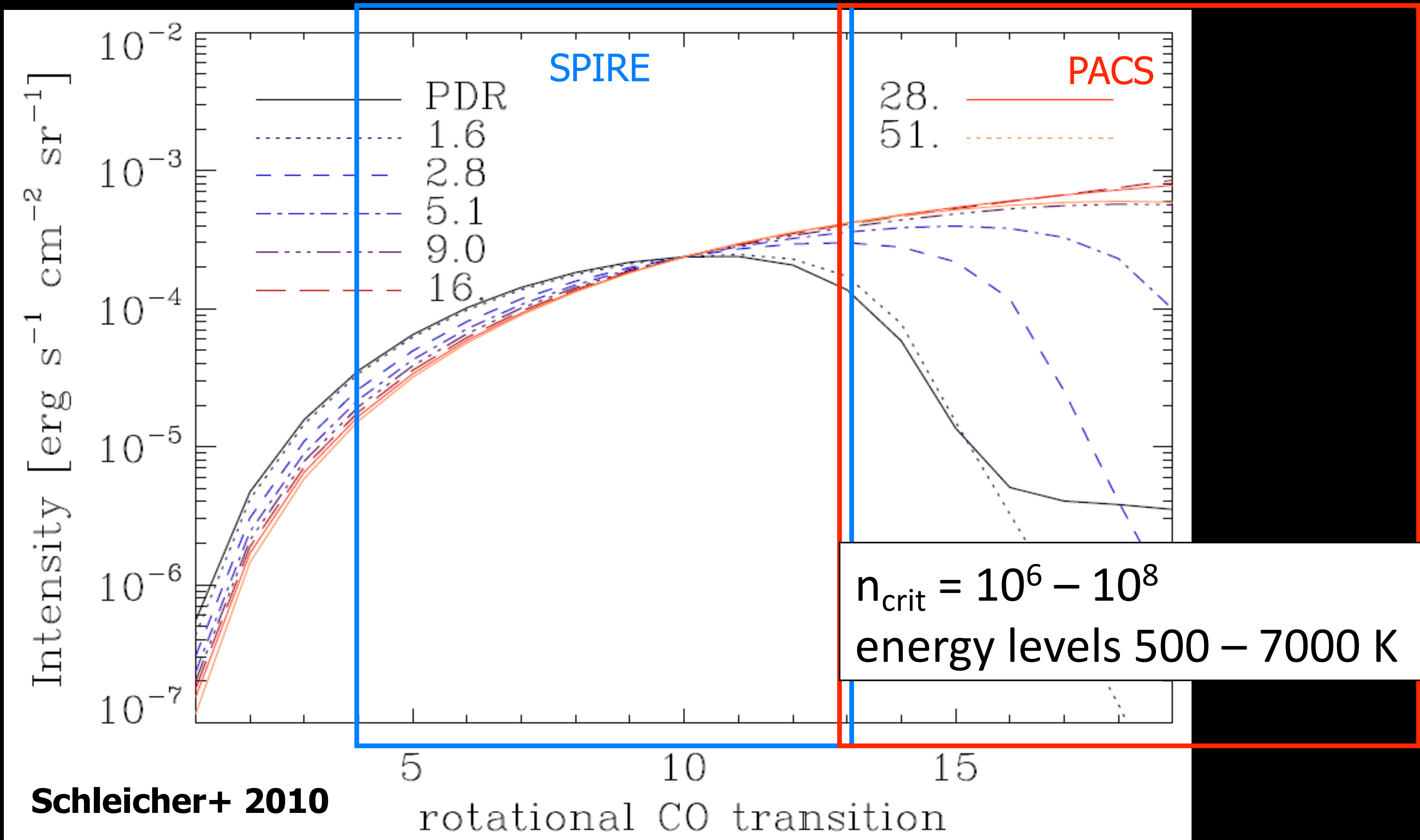
Resolved Herschel photometry and line spectroscopy for the brightest lensed galaxy at z~2

Proposal ID: OT1_jrigby_1

Principal Investigator: Jane Rigby

Time: 19.2 hours priority 1

High J CO - the new toy

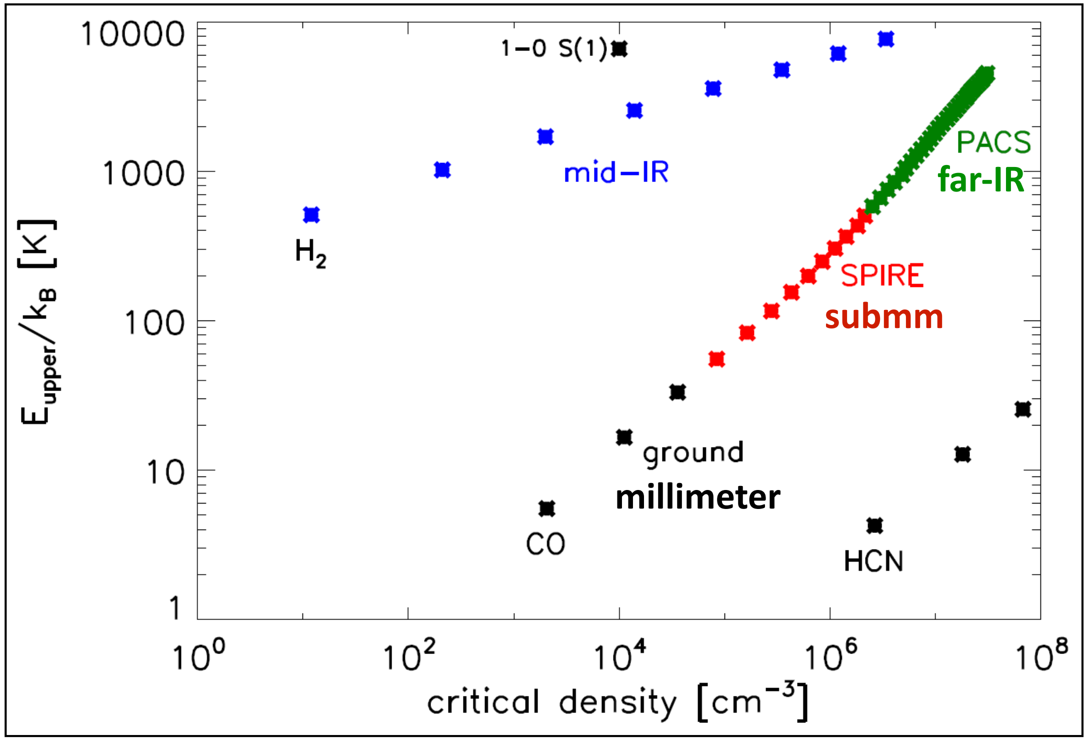


$n_{crit} = 10^6 – 10^8$
energy levels 500 – 7000 K

Extragalactic High-J CO

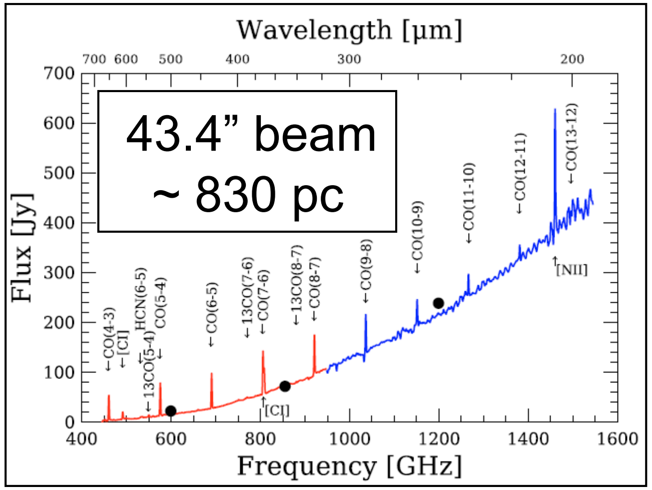
High-J CO --> A new probe of warm and dense molecular gas

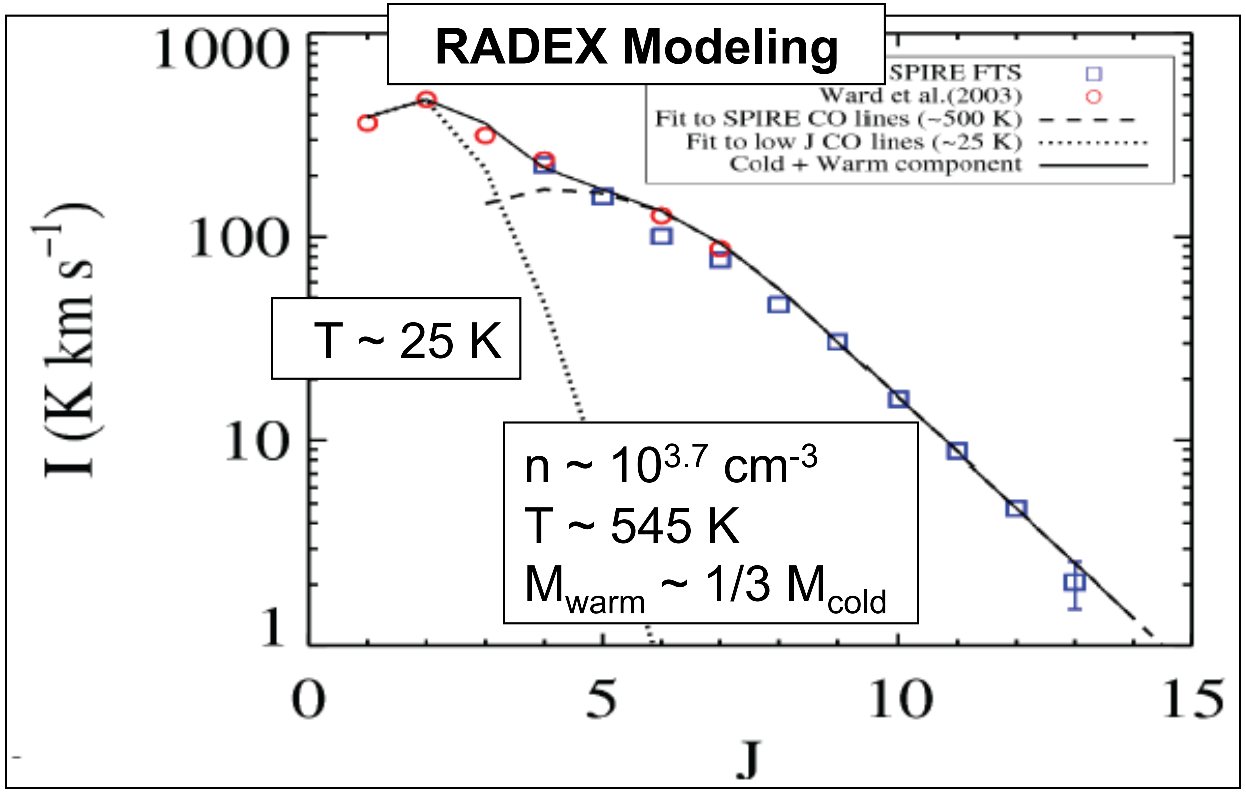
- SB and AGN feedback
  - UV/X-ray (AGN torus)
  - Cosmic rays
  - Outflows, jets
- Mergers, galactic dynamics



- Methods
  - Galactic templates
  - Non-LTE radiative transfer
  - PDR/XDR/shock models
- Literature Data
  - **M82** and **Mrk 231** (SPIRE-FTS)
- SHINING – PACS observations of nearby IR-bright galaxies
  - Full range scans of 5 templates (**NGC 1068**)
  - 1 – 2 high-J CO lines in ~10 starbursts, ~20 Seyferts, ~20 ULIRGs

M82 (Panuzzo+10)





CO(6-5) and CO(7-6) brighter than PDR predictions

⇒ not tracing UV-heated gas

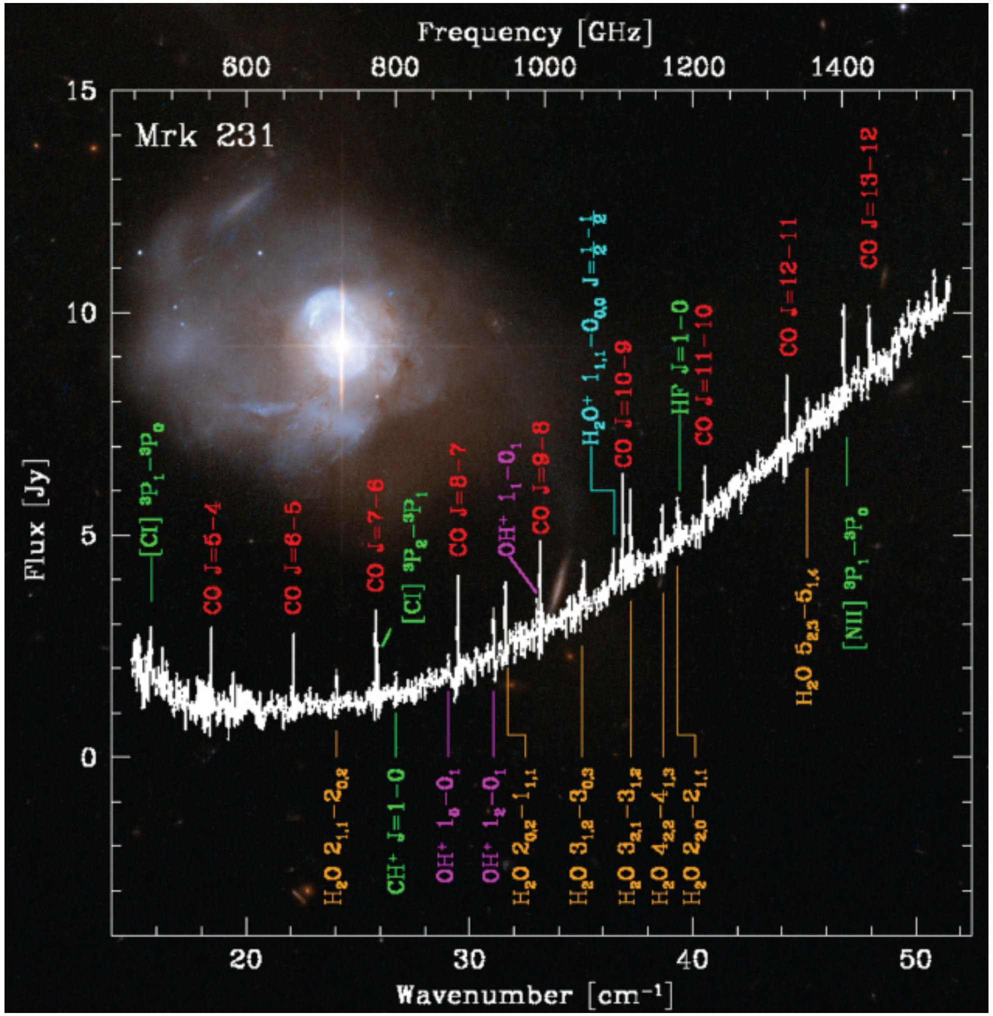
- T ~ 545 K consistent with H_2 S(0)/S(1) ratio --> **$L/M \sim 2.6\ L_{sun}/M_{sun}$**
- Cosmic ray density too low
- Dissipation of turbulence

  ⇒ stellar wind and supernovae

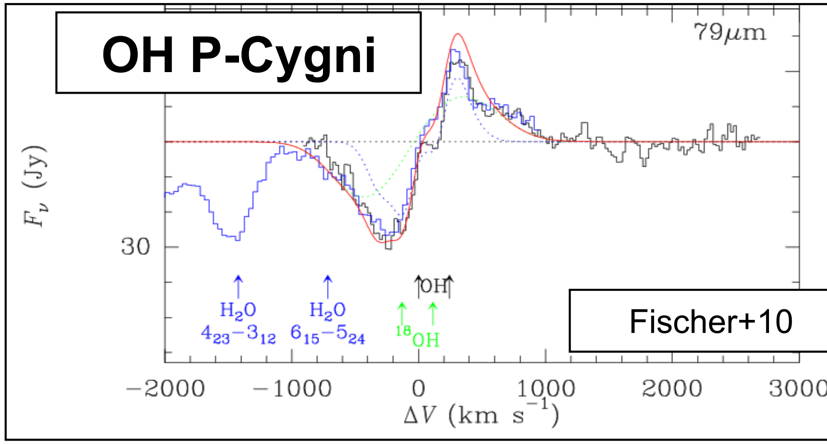
Mac Low 99, Pan & Padoan 09

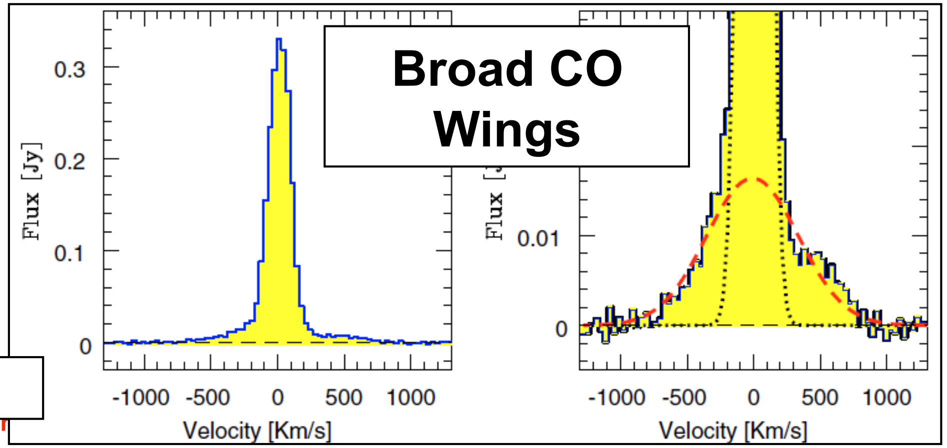
$$\frac{L}{M} = 0.42\frac{v_{\rm rms}^3}{\Lambda_d} = 1.10\left(\frac{v_{\rm rms}}{25\ km\ s^{-1}}\right)^3\left(\frac{1\ \rm pc}{\Lambda_d}\right)\frac{\rm L_\odot}{\rm M_\odot},$$

Mrk 231 (van der Werf+10 – HerCULES)



- Most luminous ULIRG in RBGS: L_{IR} = 4 x 10^{12} L_{sun}
- Optical BAL QSO
- AGN accounts for ~ 70% of L_{bol}
- Molecular outflows: V ~ 1000 km/s

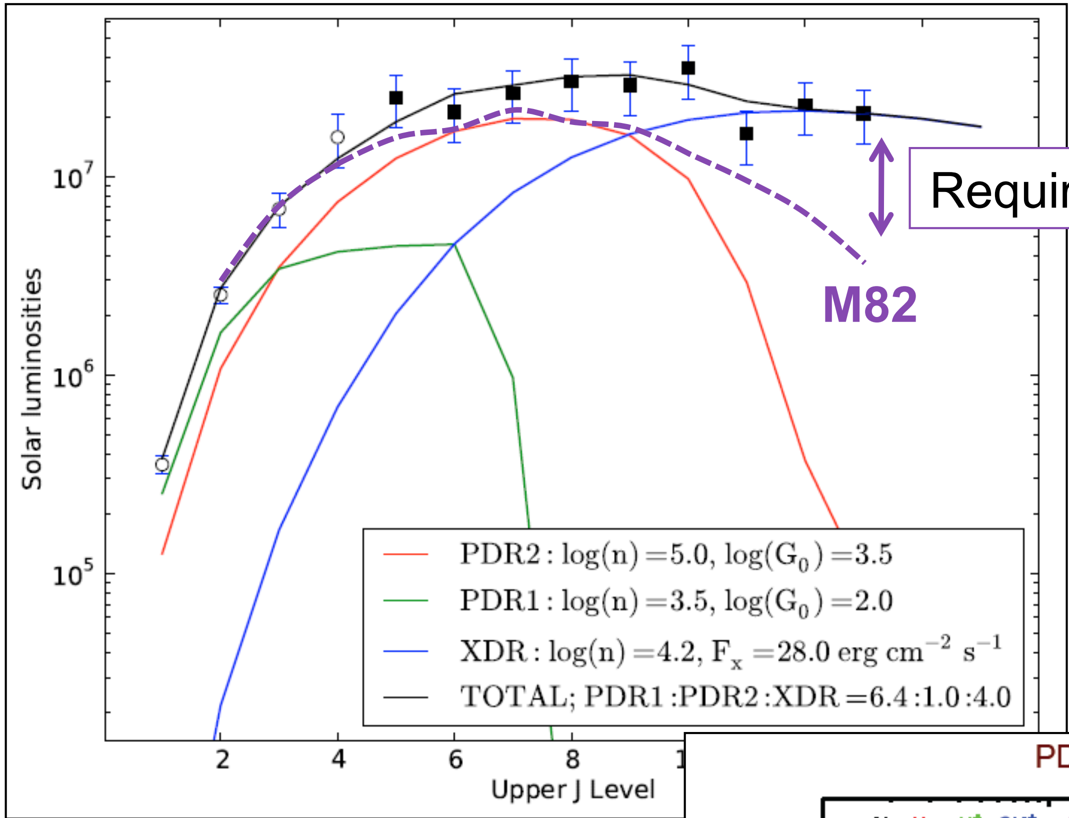




Feruglio+10

- All 9 CO lines, [CI], [NII]
- 7 lines of H_2O
- OH^+, H_2O^+, CH^+, HF

Mrk 231 (van der Werf+10 – HerCULES)



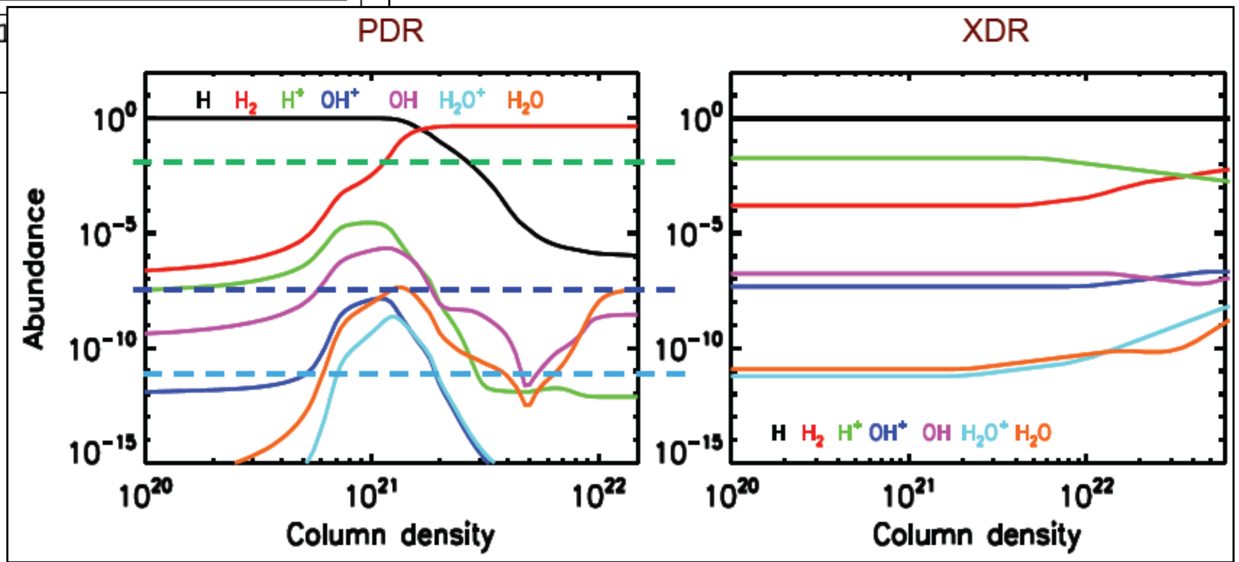
Require a 3rd component for highest-J

- PDR/XDR models (Meijerink +05,+07)
- High-G_0, high-n PDR
  - Half the molecular gas in the vicinity of O5 or earlier stars (~0.7% of disk volume)
  - Half the dust would be ~ 170 K
  - Not account for OH^+, H_2O^+ abundances > 2 x 10^{-10}

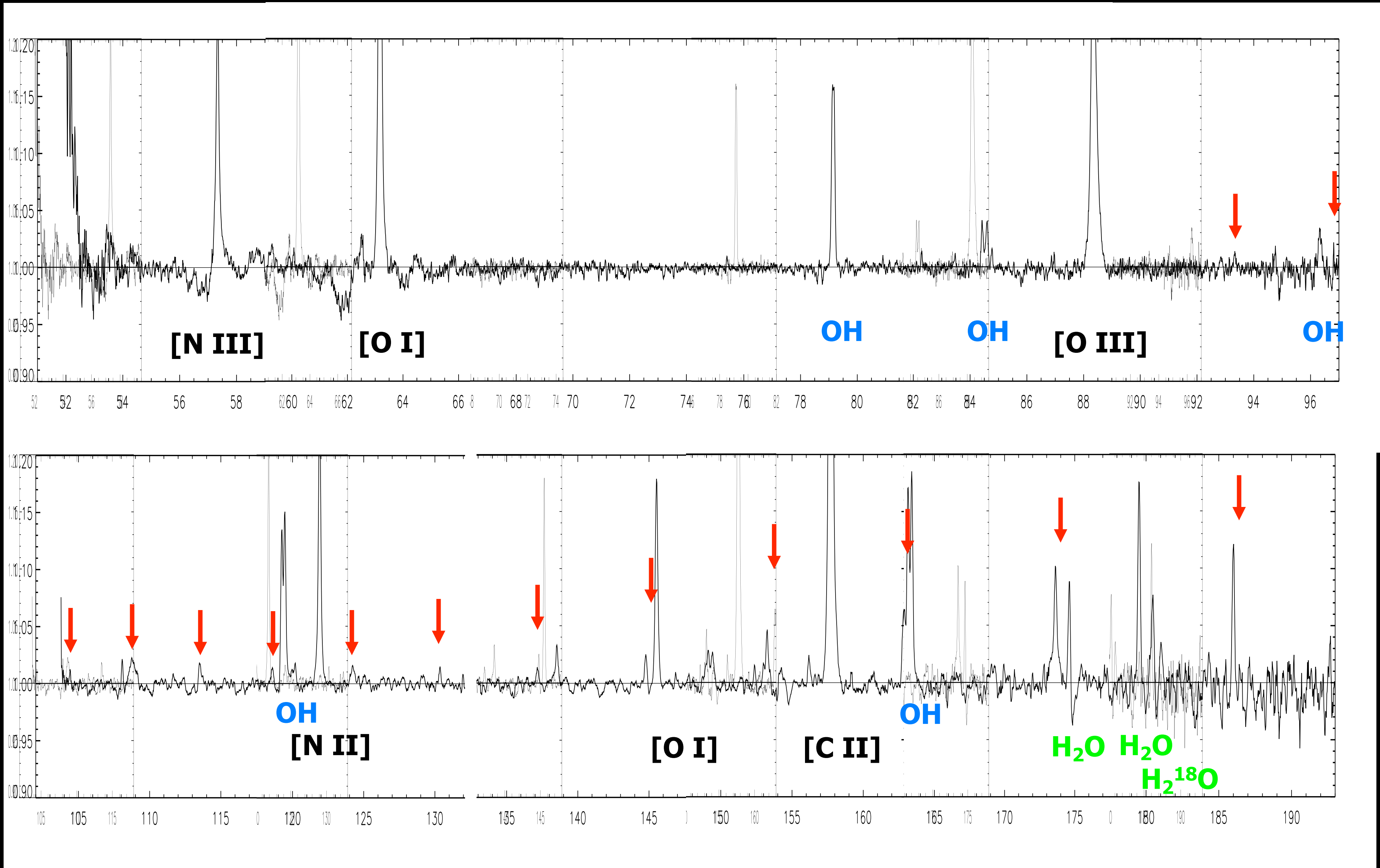
$$H^+ + O \rightarrow O^+ + H$$

$$O^+ + H_2 \rightarrow OH^+ + H$$

$$OH^+ + H_2 \rightarrow H_2O^+ + H$$



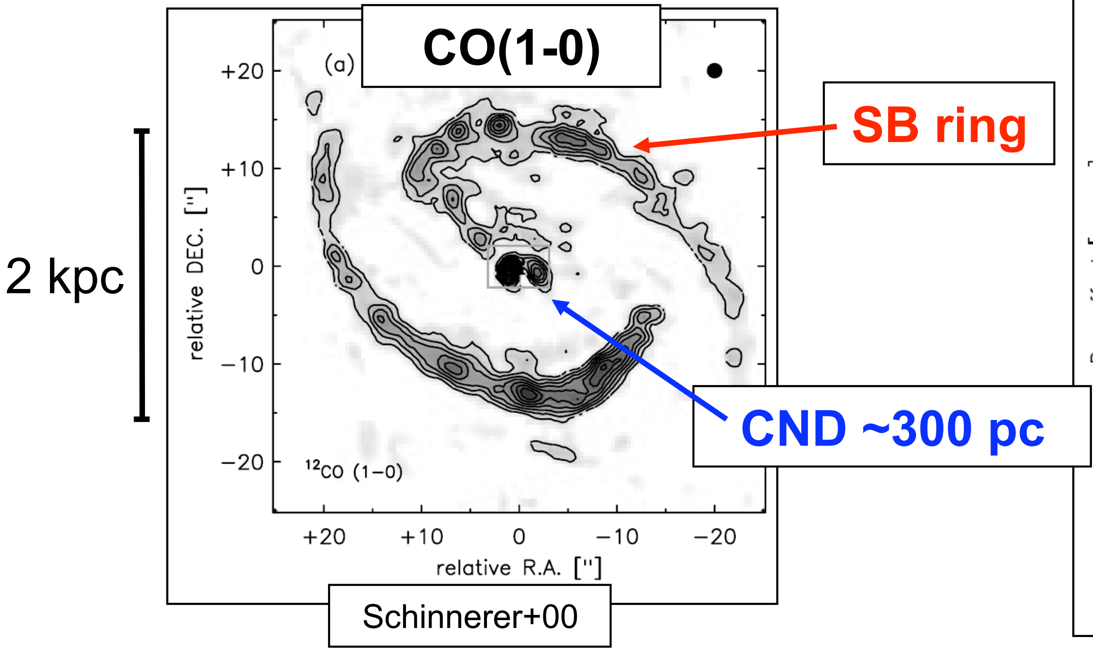
NGC 1068

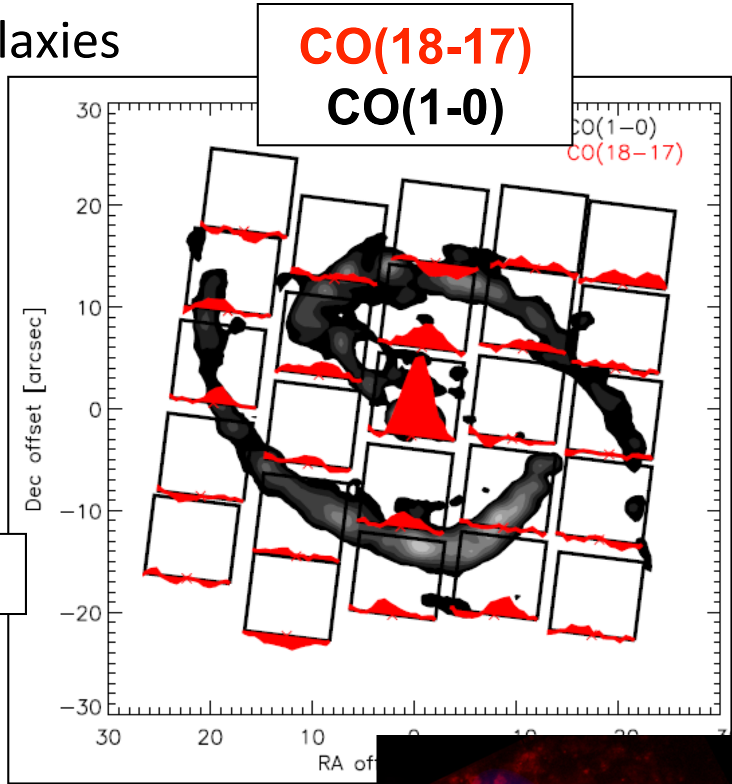


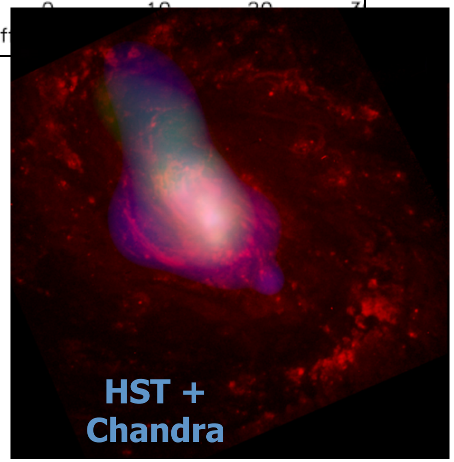
NGC1068 central spaxel

NGC 1068 – Molecular Gas

- SHINING PI E. Sturm
- PACS spectroscopy of nearby IR bright galaxies

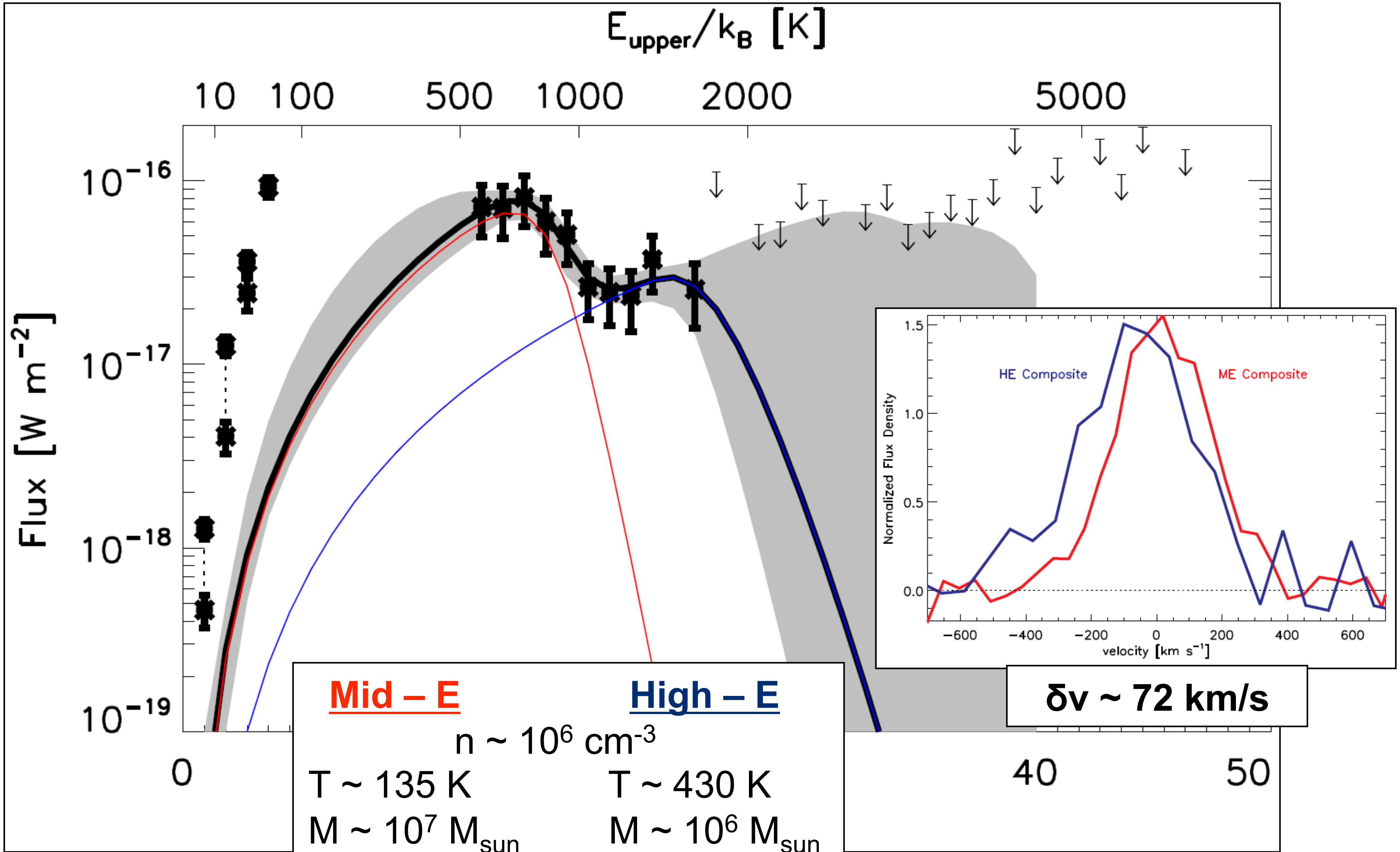






- x10 CO lines --> **First extragalactic far-IR CO**
- Atomic fine-structure lines ([CII], [OI], [NII], [OIII], [NIII])
- OH, H_2O, **OH^+, H_2O^+**, …
- Molecular emission concentrated in central spaxel

CO Line SED – LVG Modeling



Mid – E

High – E

n ~ 10^6 cm^{-3}

T ~ 135 K | T ~ 430 K

M ~ 10^7 M_{sun} | M ~ 10^6 M_{sun}

~ M_{cold}

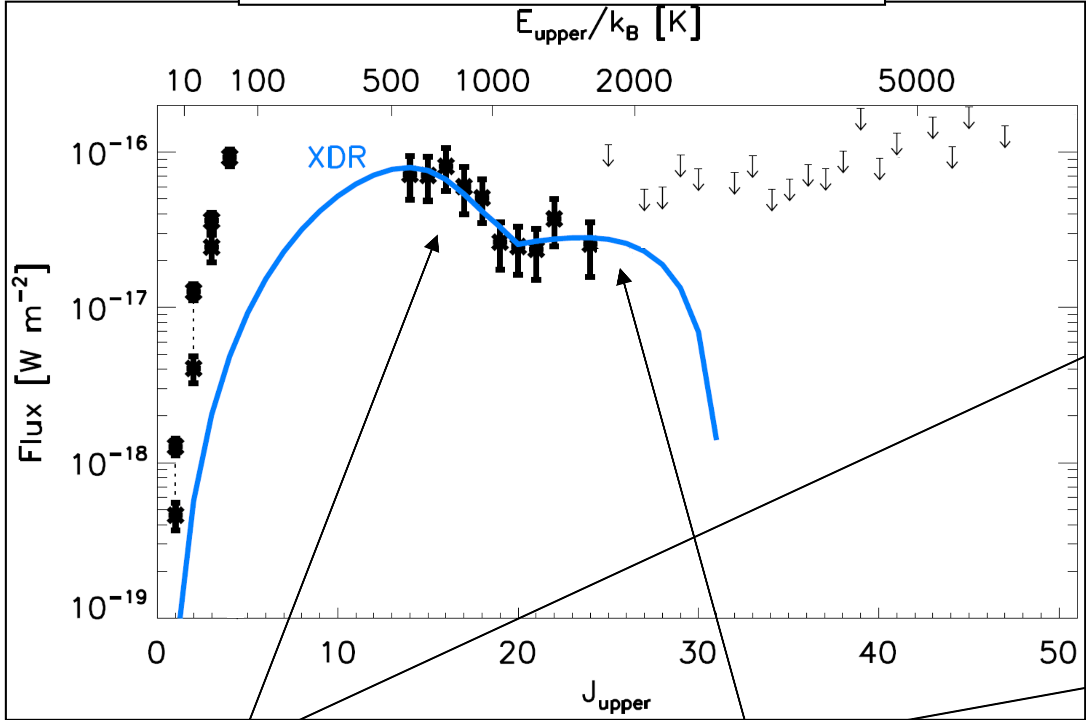
δv ~ 72 km/s

Hailey-Dunsheath+ in prep.

XDR Modeling

AGN: $L_X \sim 10^{43} - 10^{44}$ erg/s

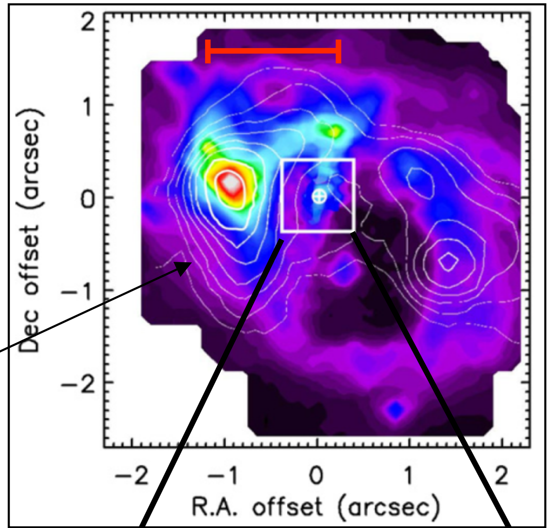
XDR models of Meijerink+05+07

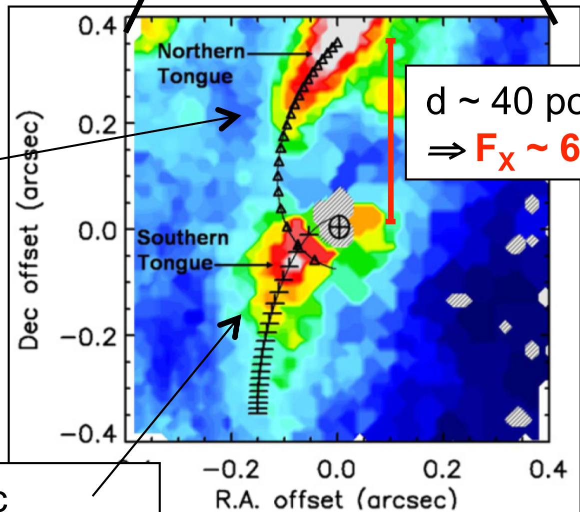


F_X = **16 erg/cm²/s** (**ME**)
$n = 10^{6.5}$ cm^{-3}
$A_{XDR} \sim$ **(160 pc)²**

F_X = **160 erg/cm²/s** (**HE**)
$n = 10^{5.5}$ cm^{-3}
$A_{XDR} \sim$ **(25 pc)²**

d ~ 100 pc
⇒ **F_X ~ 10 – 100**





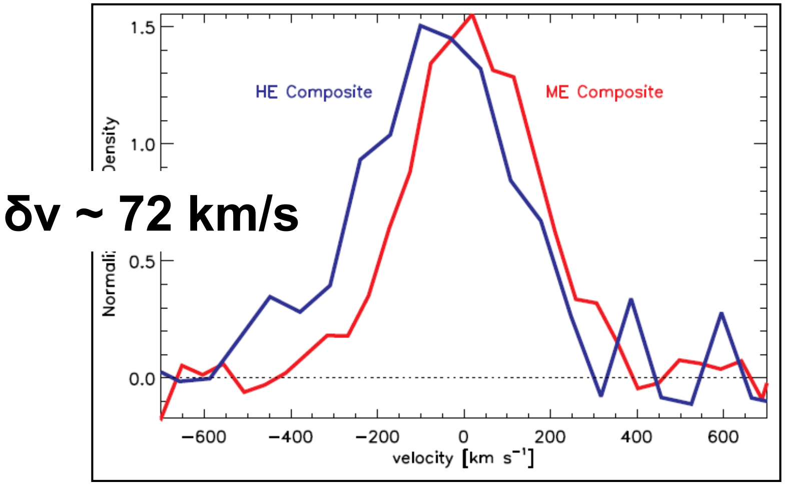
d ~ 40 pc
⇒ **F_X ~ 60 – 600**

d ~ 10 pc
⇒ **$F_X \sim 10^3 - 10^4$**
⇒ **not likely**

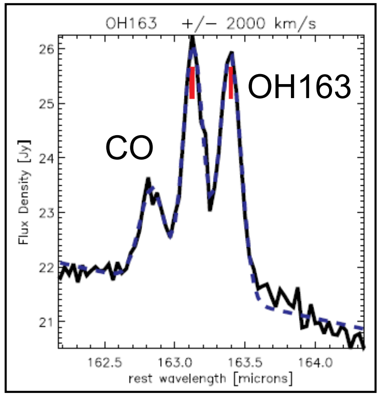
Hailey-Dunsheath+ in prep.

XDR vs Shock Chemistry

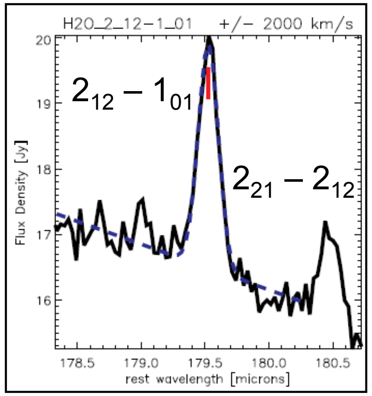
- Reproduce the CO SED with 2 shocks: **n ~ 10^5 – 10^6 cm^{-3}, v ~ 20 – 30 km/s**



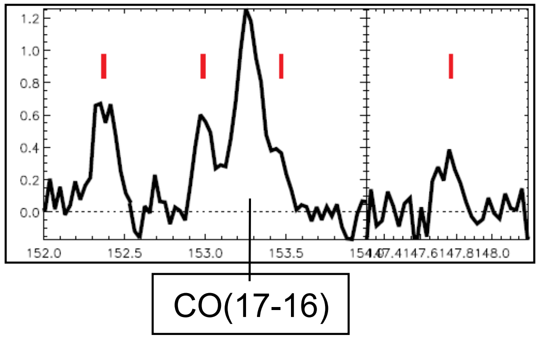
OH



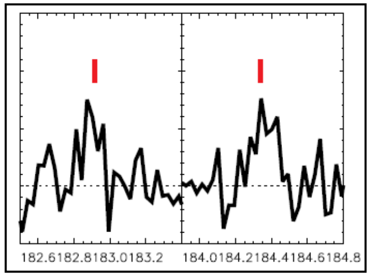
H_2O



OH^+ (2-1)



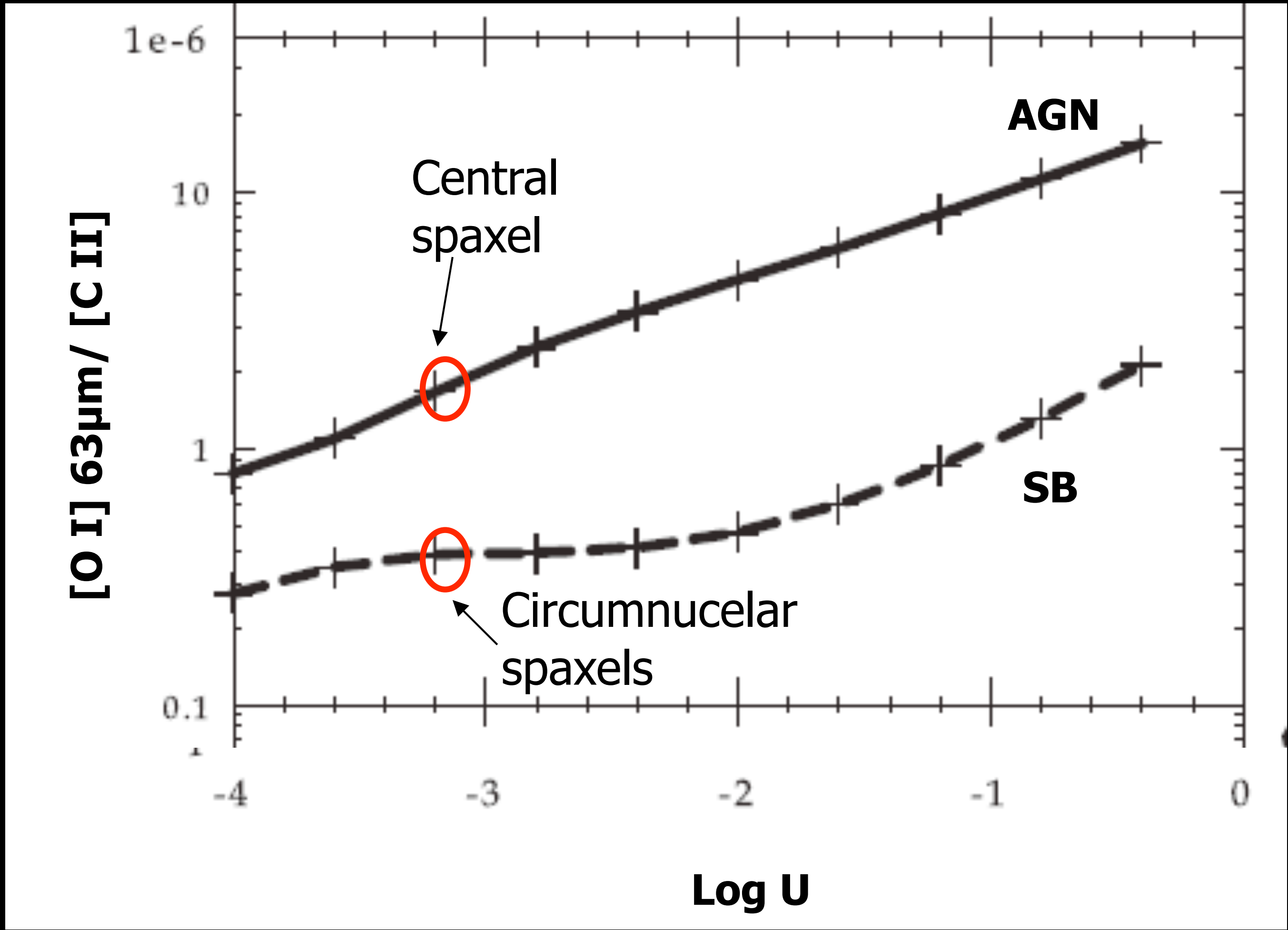
p-H_2O^+ $2_{12} - 1_{01}$



- OH, H_2O, OH^+, H_2O^+ **at v_{sys}**
  - X(OH) ~ 2 x 10^{-6}
  - X(OH^+) > 5 x 10^{-9}
  - X(H_2O^+) > 10^{-9}
- Shocks
  - All oxygen goes to H_2O – Need **H_2O + hv --> OH + H** to produce OH
  - Need **H^+** to produce OH^+, H_2O^+ through **ion-molecule** reactions**--> X-rays**
- XDRs generate high columns of OH, OH^+, H_2O^+ --> **prefer XDR for ME**
- For HE, ancillary lines are much weaker --> no constraint

Hailey-Dunsheath+ in prep.

Shocks vs. XDR ?



Abel+ 2009

Garcia-Burillo + 2010

SiO and CN ➔ XDR rather than shock

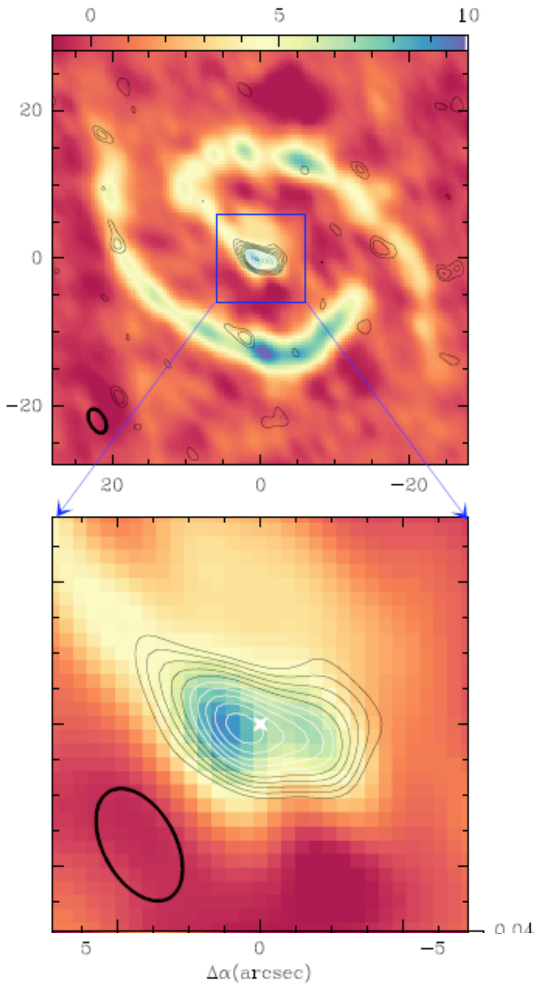


Fig. 2. **a)** (*Upper panel*) The SiO integrated intensity map (contour levels are 3σ to 12σ in steps of 1σ=0.082 Jy km s^{-1} beam^{-1}) is overlaid on the CO(1–0) integrated intensity map of S00 (color scale as shown in units of Jy km s^{-1} beam^{-1}). **b)** (*Middle panel*) The same as **a)** but showing a zoomed view on the inner 12″ around the AGN (identified by the cross). **c)** (*Lower panel*) The SiO map contours are overlaid on the 3 mm continuum map (color scale) of Fig. 1. The SiO beam is shown in all the panels by an ellipse.

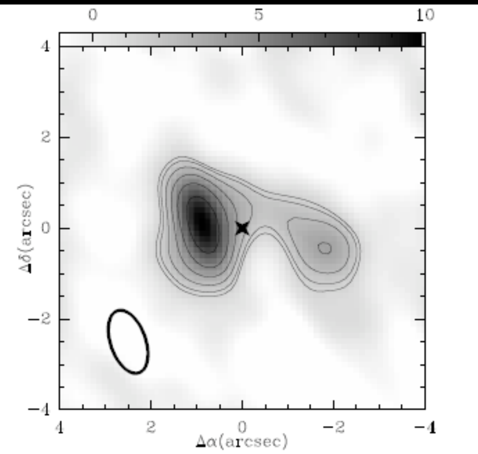


Fig. 3. The CN integrated intensity map. Contour levels are 3σ, 4σ, 6σ, 9σ, 13σ to 25σ in steps of 6σ, with 1σ=0.40 Jy km s^{-1} beam^{-1}. The AGN is identified by the cross and the CN beam is shown by an ellipse.

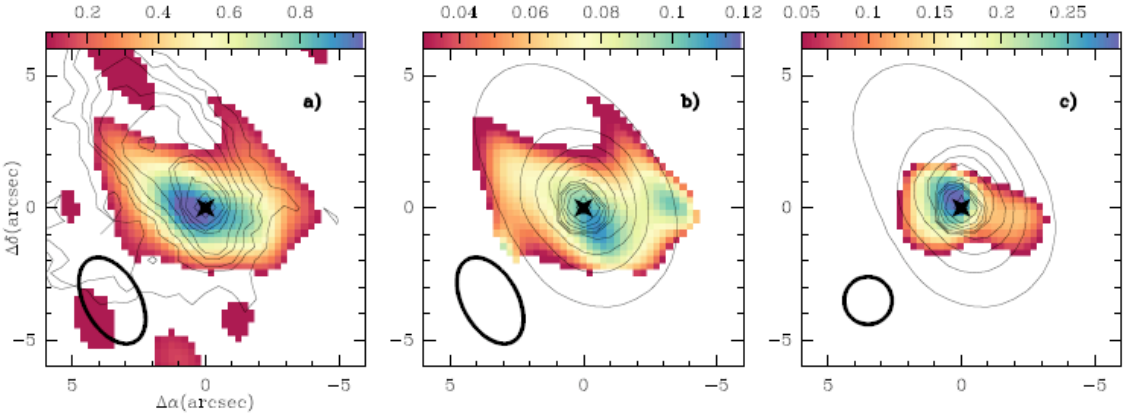
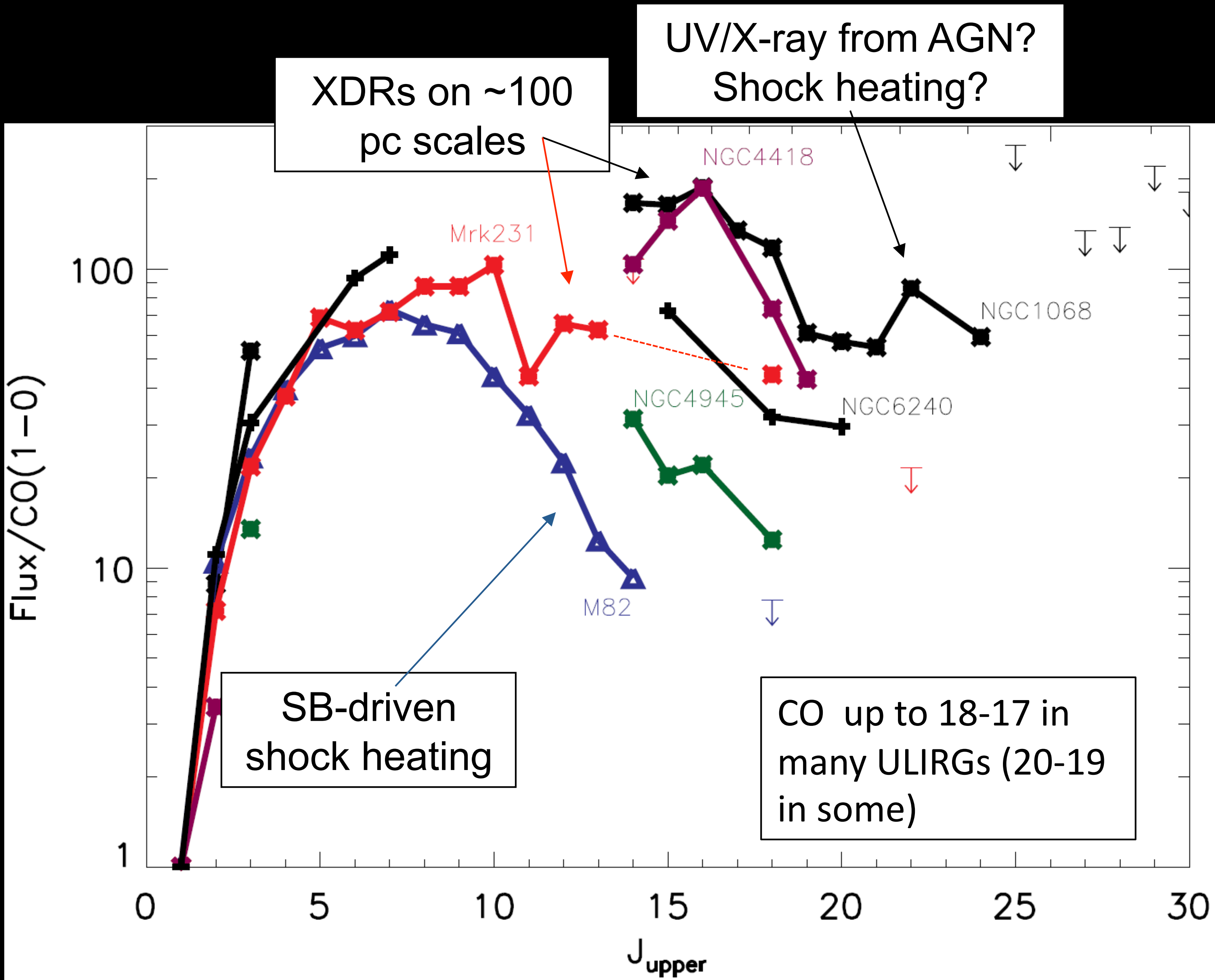
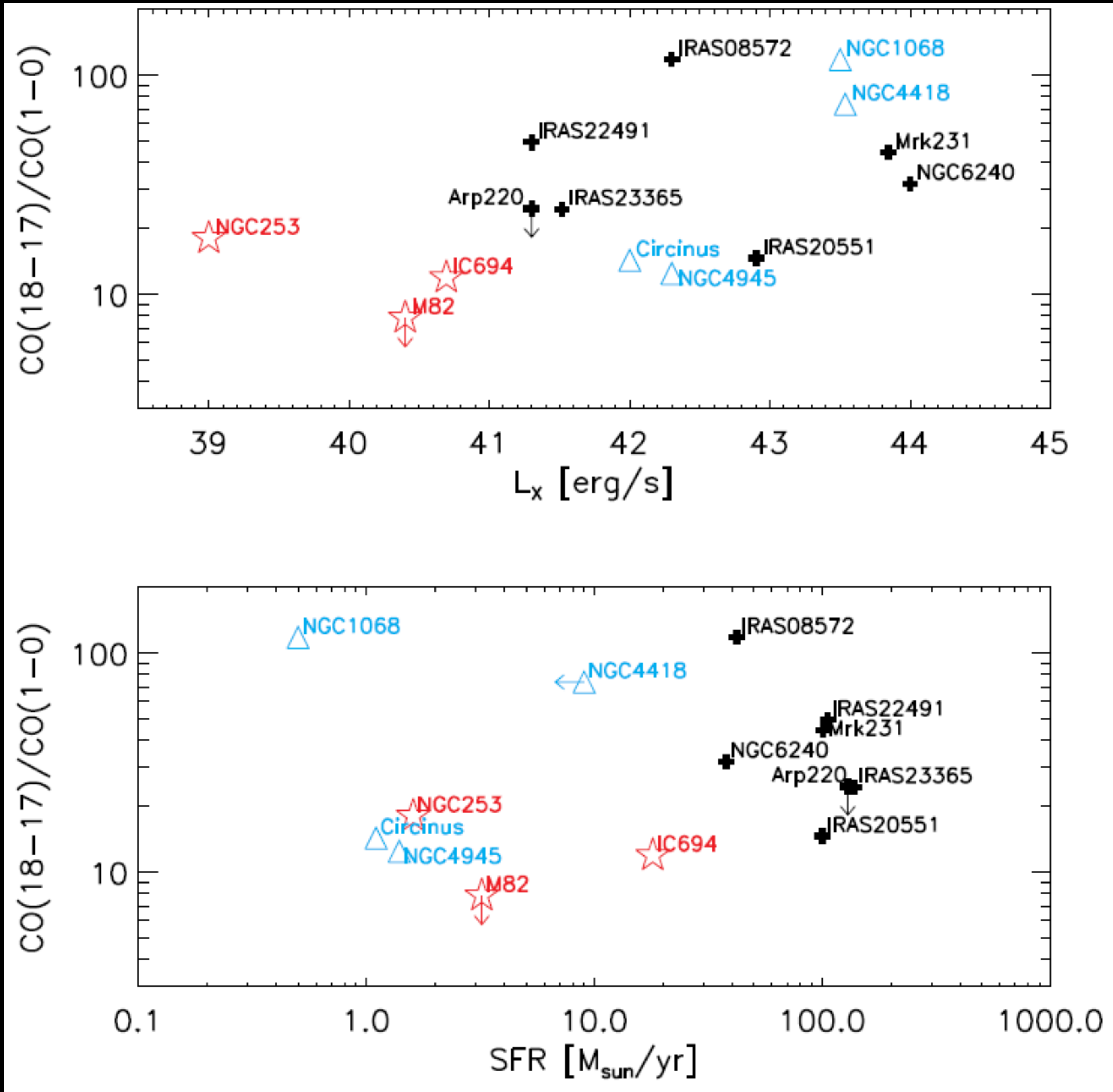


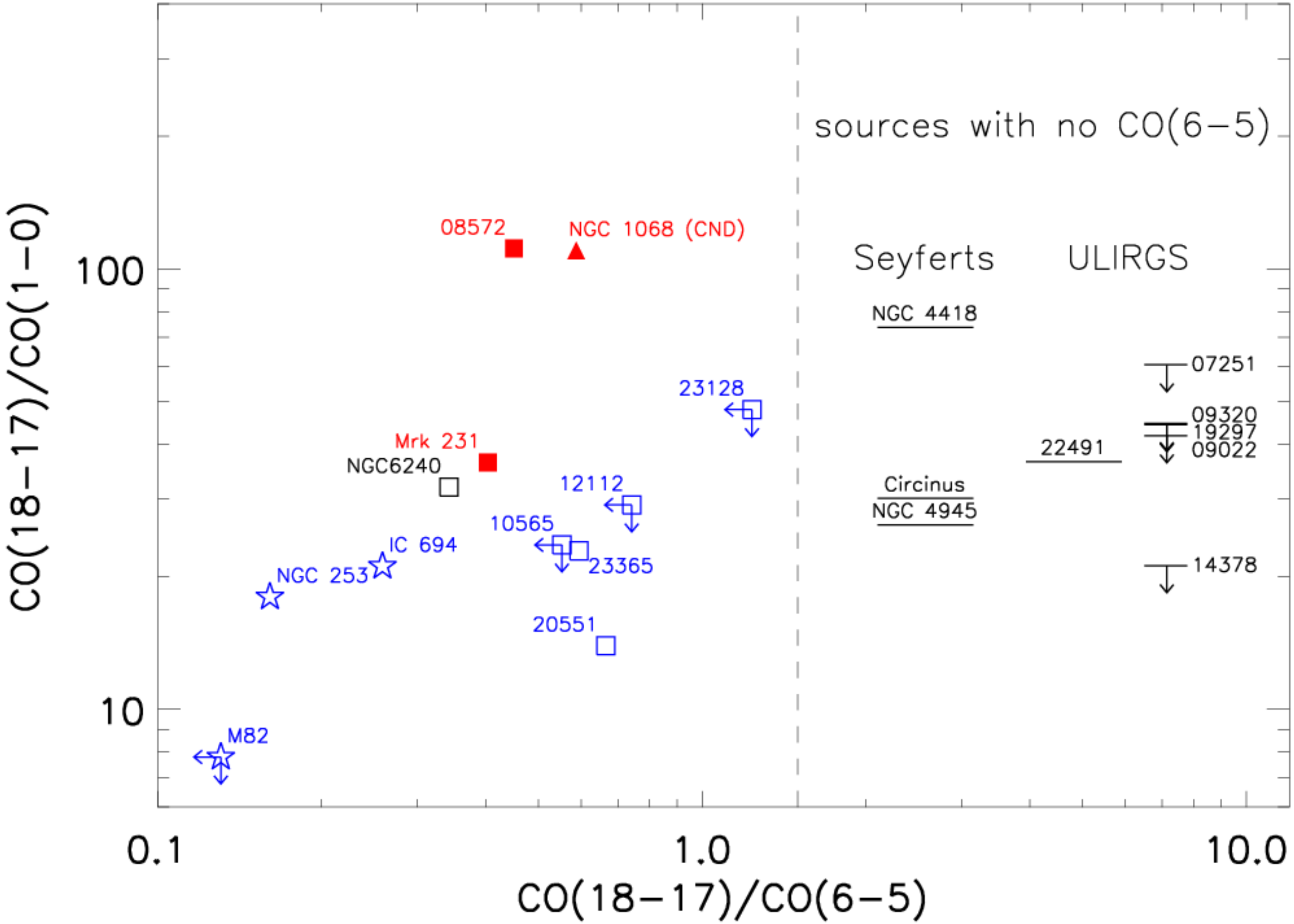
Fig. 12. **a)** (*Left panel*) The Chandra X-ray image of NGC 1068 (contours:15, 30, 50, 100, 200, 400, 600, 1000, 2000 and 3000 counts) obtained in the 0.25–7.5 keV band by Young et al. (2001) is overlaid on the PdBI SiO map (color scale in units of Jy km s^{-1} beam^{-1}). **b)** (*Middle panel*) The X-ray image obtained in the 6–8 keV band by Ogle et al. (2003) (contours: 0.2, 0.5, 1, 2, 4, 8, 15, 25, 40, 80 and 100 counts) is overlaid on the SiO(2–1)/CO(1–0) brightness temperature ratio (color scale) at the SiO spatial resolution. **c)** (*Right panel*) Same as **b)** but with the X-ray image obtained in the 6–8 keV band overlaid on the CN(2–1)/CO(1–0) ratio (color scale) at the CO spatial resolution. Ellipses show beams of SiO and CO as in Fig. 9.



XDRs on ~100 pc scales
UV/X-ray from AGN? Shock heating?
NGC4418
Mrk231
NGC1068
NGC4945
NGC6240
M82
SB-driven shock heating
CO up to 18-17 in many ULIRGs (20-19 in some)
Flux/CO(1−0)
100
10
1
0
5
10
15
20
25
30
J upper



CO(18−17)/CO(1−0)
100
10
IRAS08572
NGC1068
NGC4418
IRAS22491
Mrk231
NGC6240
Arp220
IRAS23365
NGC253
Circinus
IRAS20551
IC694
NGC4945
M82
39
40
41
42
43
44
45
Lx [erg/s]
CO(18−17)/CO(1−0)
100
10
NGC1068
IRAS08572
NGC4418
IRAS22491
Mrk231
NGC6240
Arp220
IRAS23365
NGC253
Circinus
IRAS20551
IC694
NGC4945
M82
0.1
1.0
10.0
100.0
1000.0
SFR [Msun/yr]

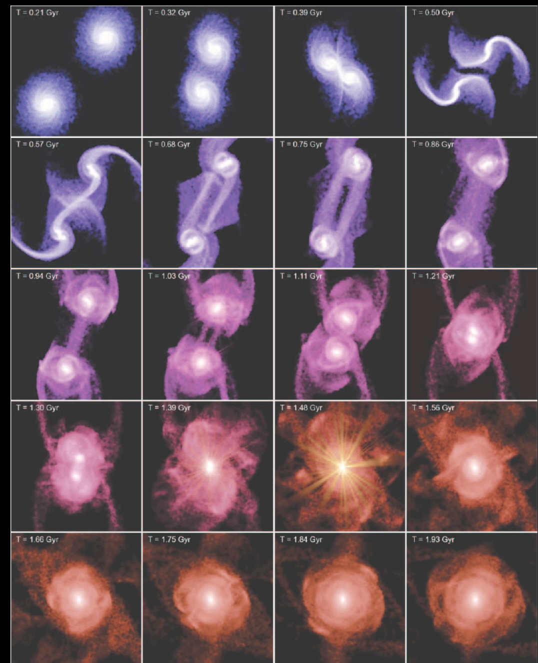

sources with no CO(6−5)
08572
NGC 1068 (CND)
Seyferts
ULIRGS
100
NGC 4418
07251
23128
09320
19297
09022
22491
Mrk 231
NGC6240
12112
Circinus
NGC 4945
10565
IC 694
NGC 253
23365
14378
20551
10
M82
0.1
1.0
10.0
CO(18−17)/CO(6−5)
CO(18−17)/CO(1−0)

Starburst- and AGN-Driven Outflows

Feedback from the **Starburst**

- Mass-metallicity relation of galactic bulges
- galaxy luminosity functions
- enrichment of IGM and ICM

Feedback from the **AGN**



Hopkins+2006

- merger → ULIRG → QSO → elliptical
- quenching of star formation
- BH-spheroid mass relation
- blue cloud vs. red sequence

Tracing Molecular Outflows

Outflows almost exclusively studied in ionized/atomic tracers

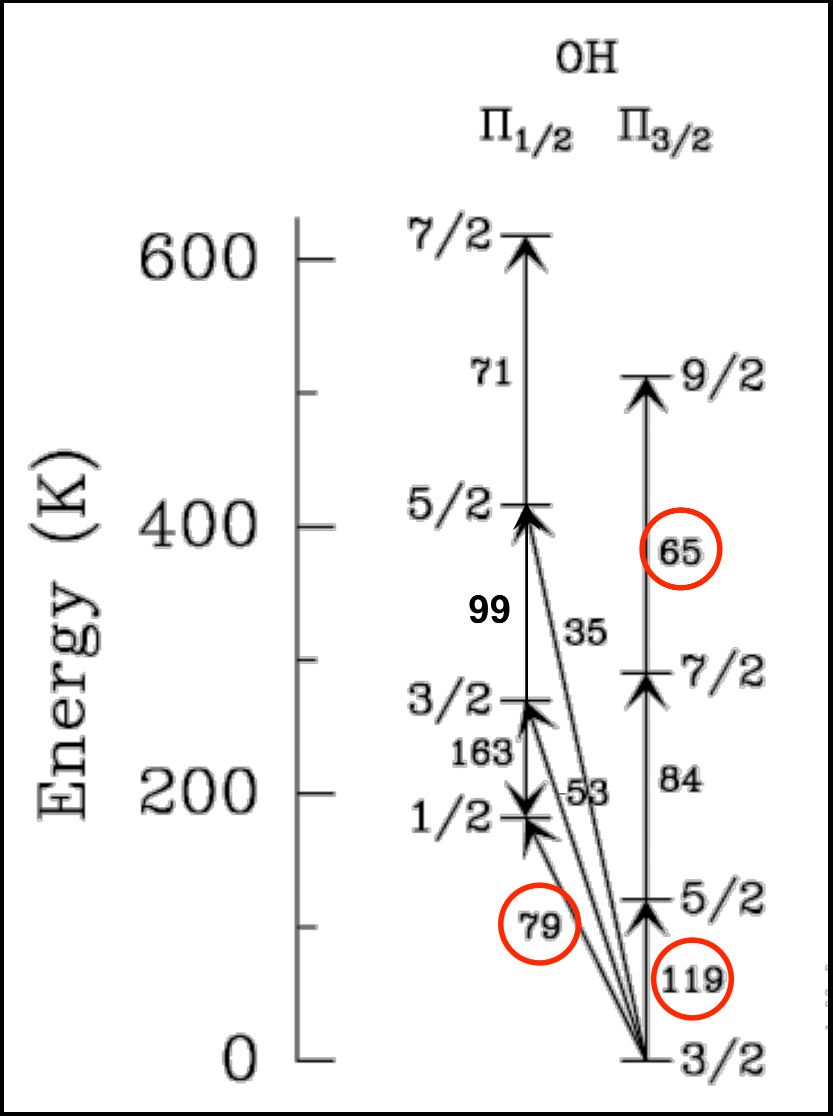
What about molecular gas?

OH molecule

- Ground state far-IR transitions (79 µm, 119 µm) plus higher enegy level tansitions (e.g. 65 µm)

Herschel/PACS

- Excellent far-IR sensitivity
- ~100 km/s resolution
- wavelength coverage: 55 – 200 µm



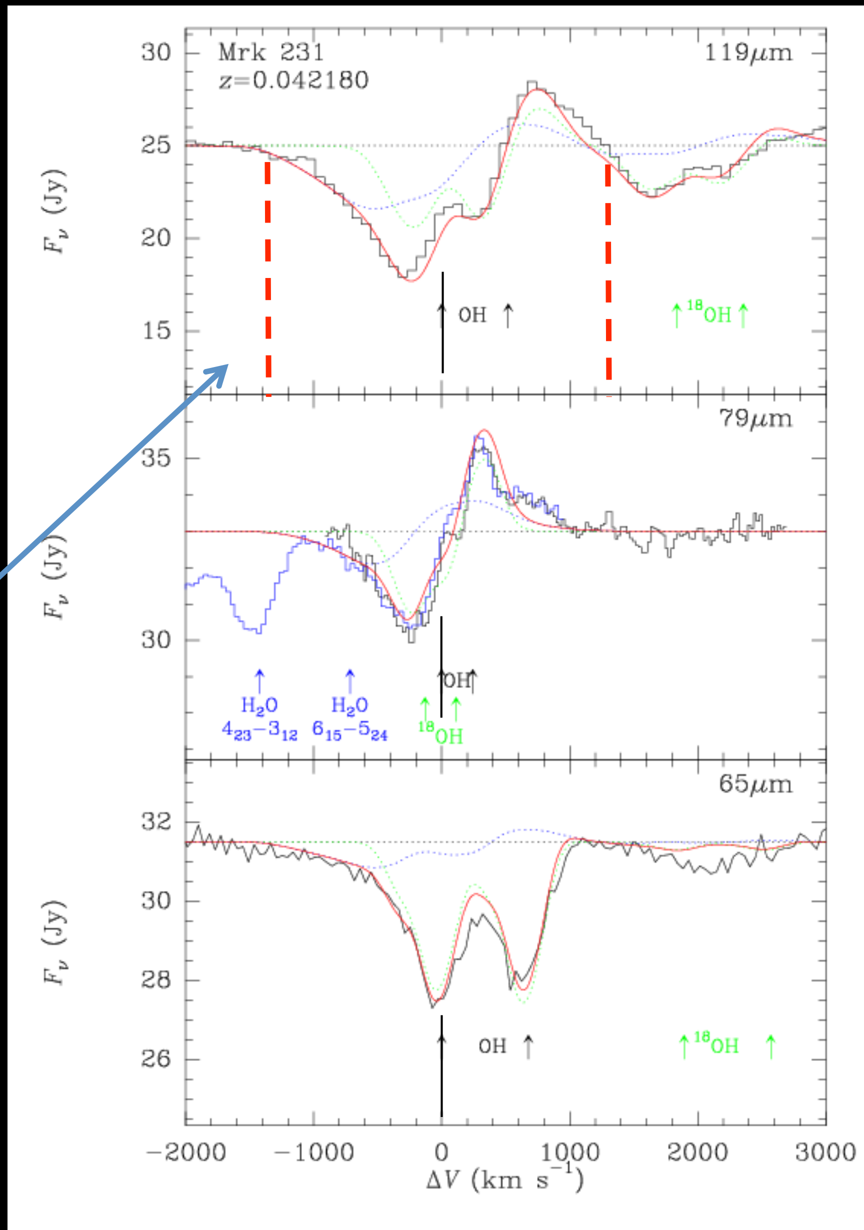
Mrk 231

$L_{IR} = 3.2 \times 10^{12}\ L_\odot$ (70% AGN)

Type 1 LoBAL AGN

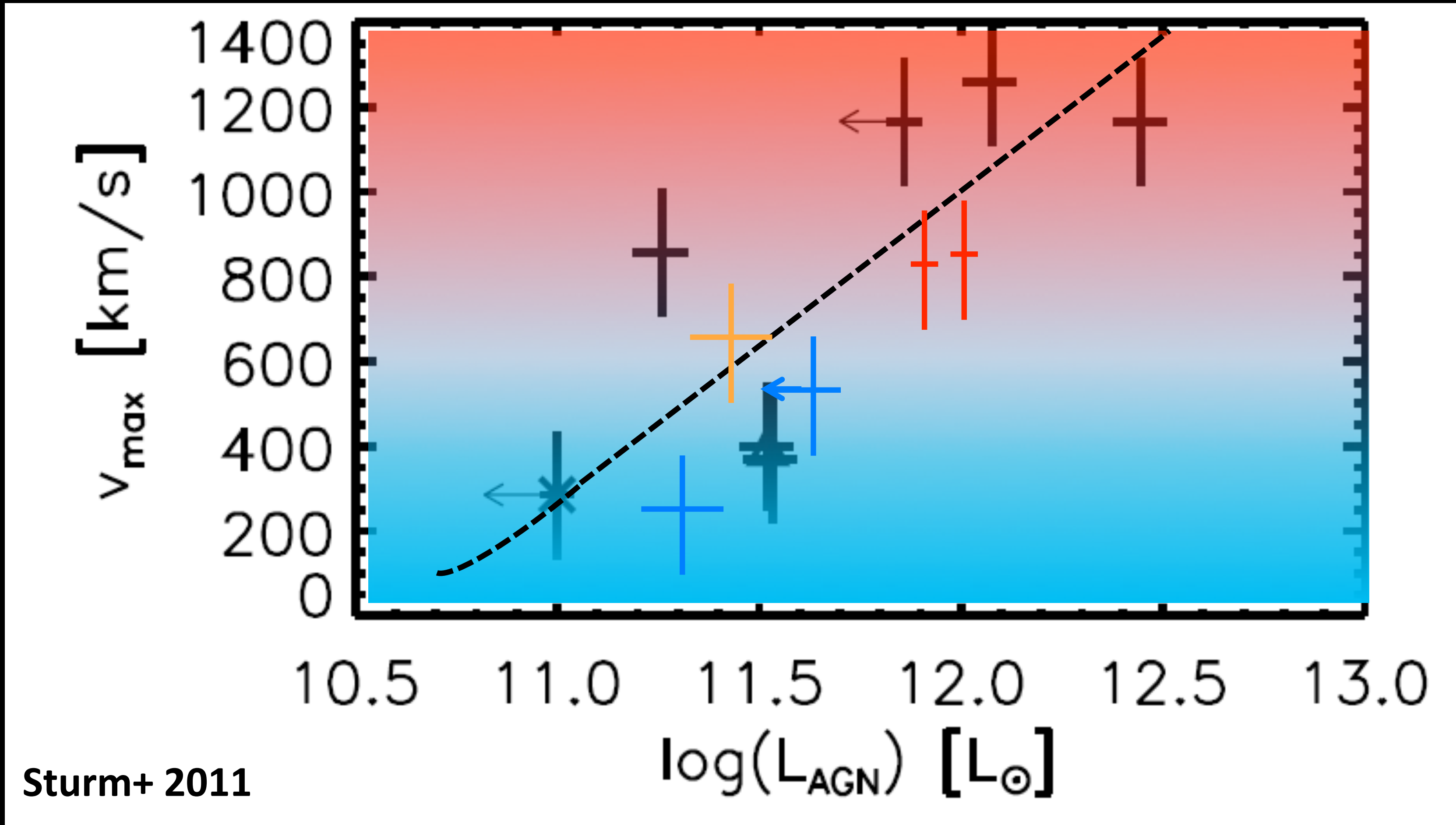
P-Cygni profile with blue-shifted absorption and red-shifted emission

$\Delta v \sim$ 1,170 km/s



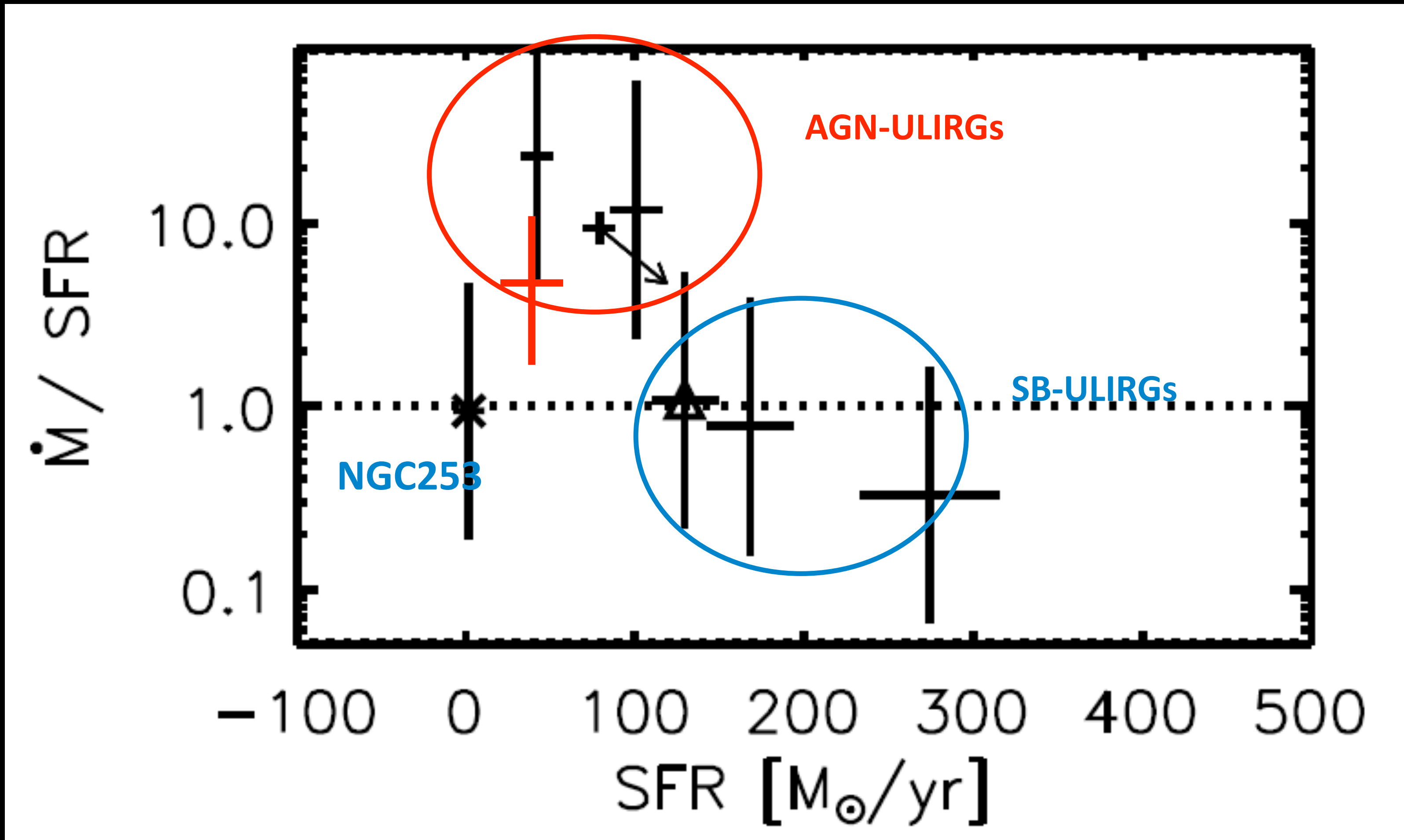
Fischer + 2010

Are the strong outflows driven by the AGN rather than by the star formation in these objects?

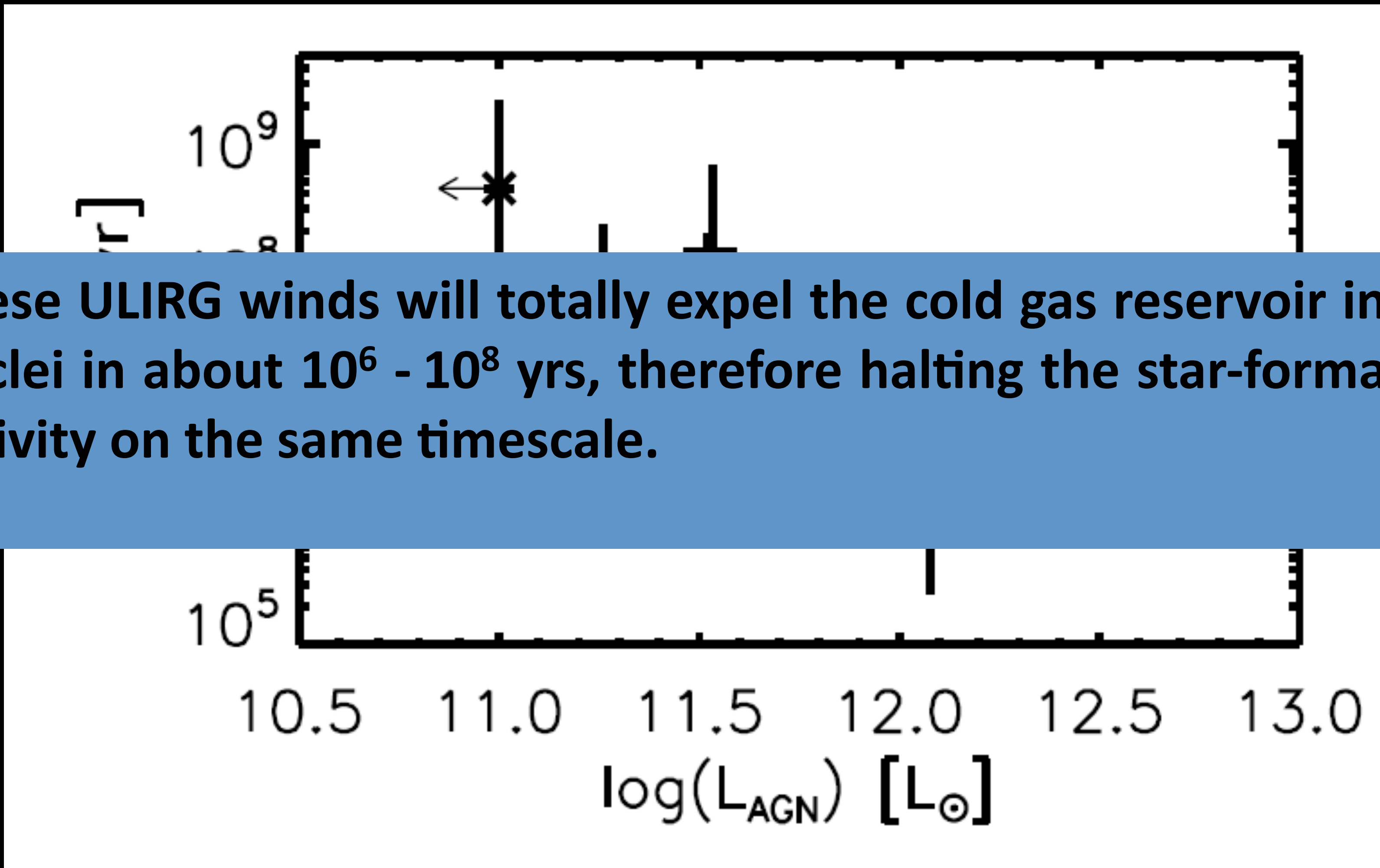


SNe driven → v(outflow) < 500 km/s (e.g. Martin 2005, Thacker+ 2006)

Does the outflow carry sufficient molecular gas to remove the star formation fuel and actually quench the star formation?



Sturm+ 2011

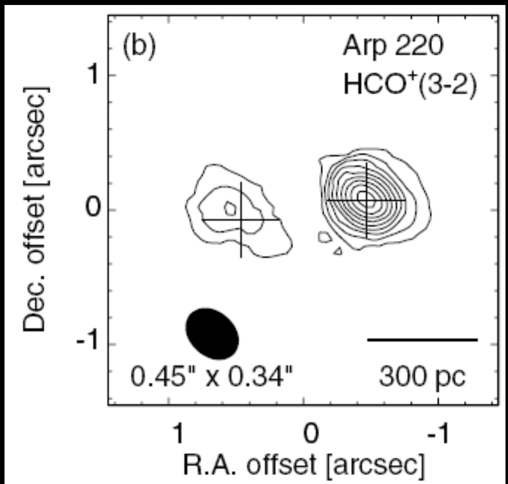


These ULIRG winds will totally expel the cold gas reservoir in the nuclei in about 10^6 - 10^8 yrs, therefore halting the star-formation activity on the same timescale.

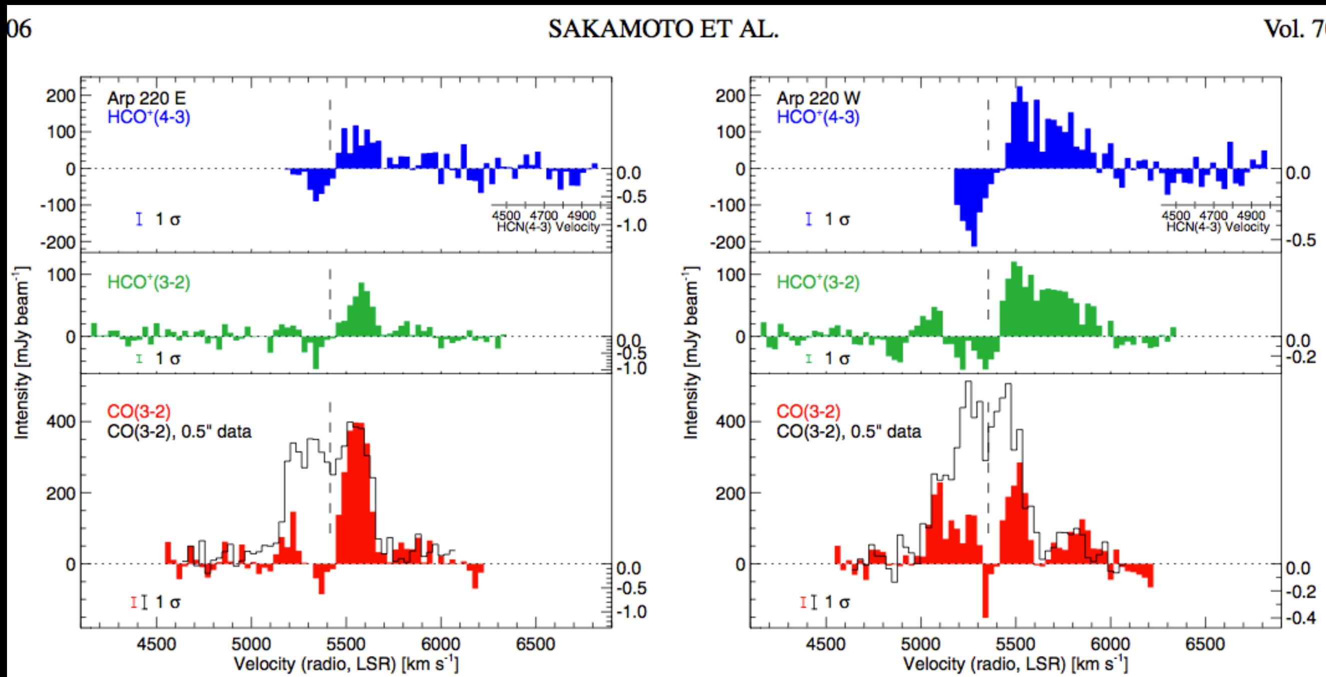
Sturm+ 2011

Outflows almost exclusively studied in ionized/atomic tracers

Few molecular studies, e.g. Sakamoto+ 2009 (Arp220):

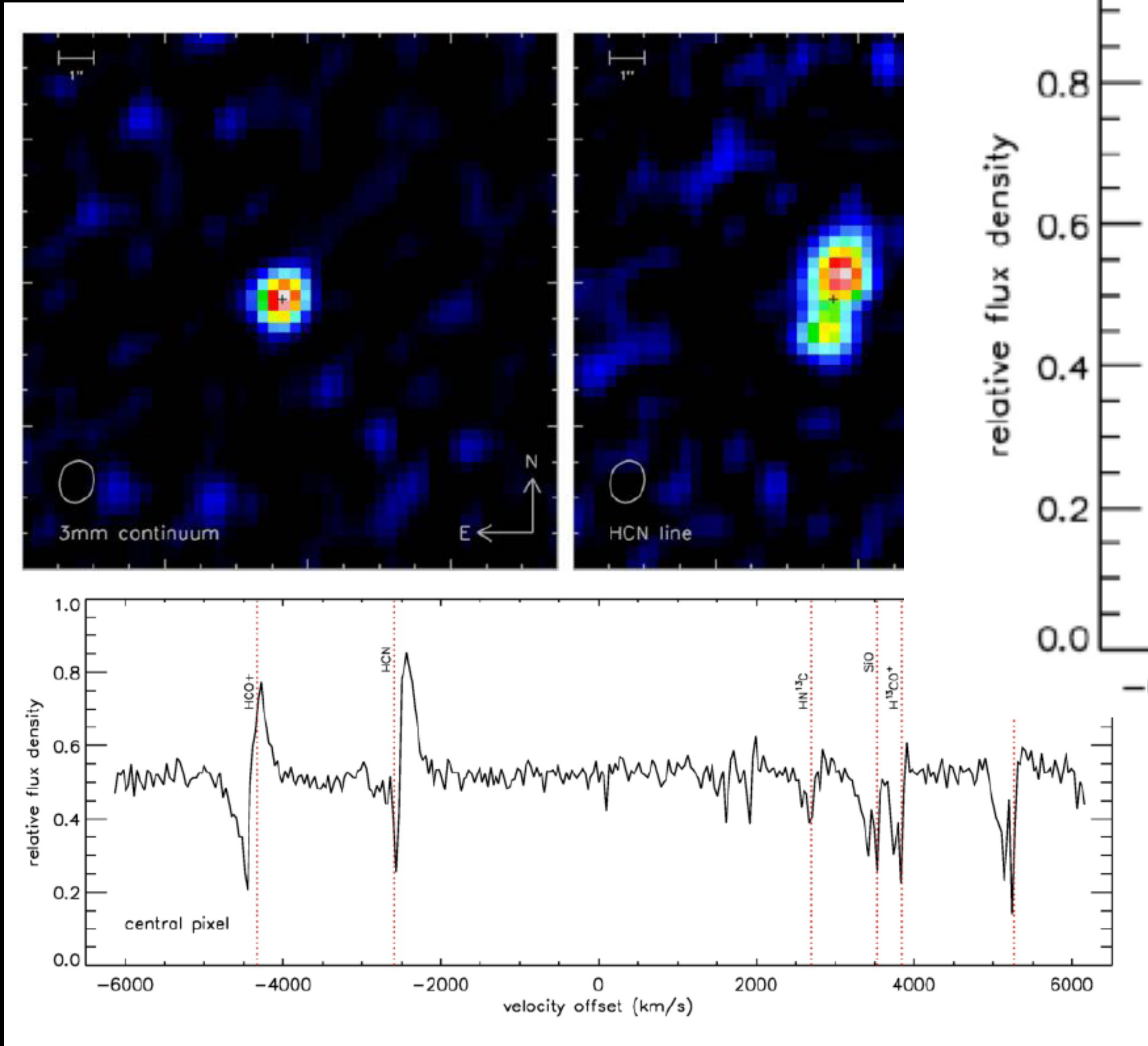


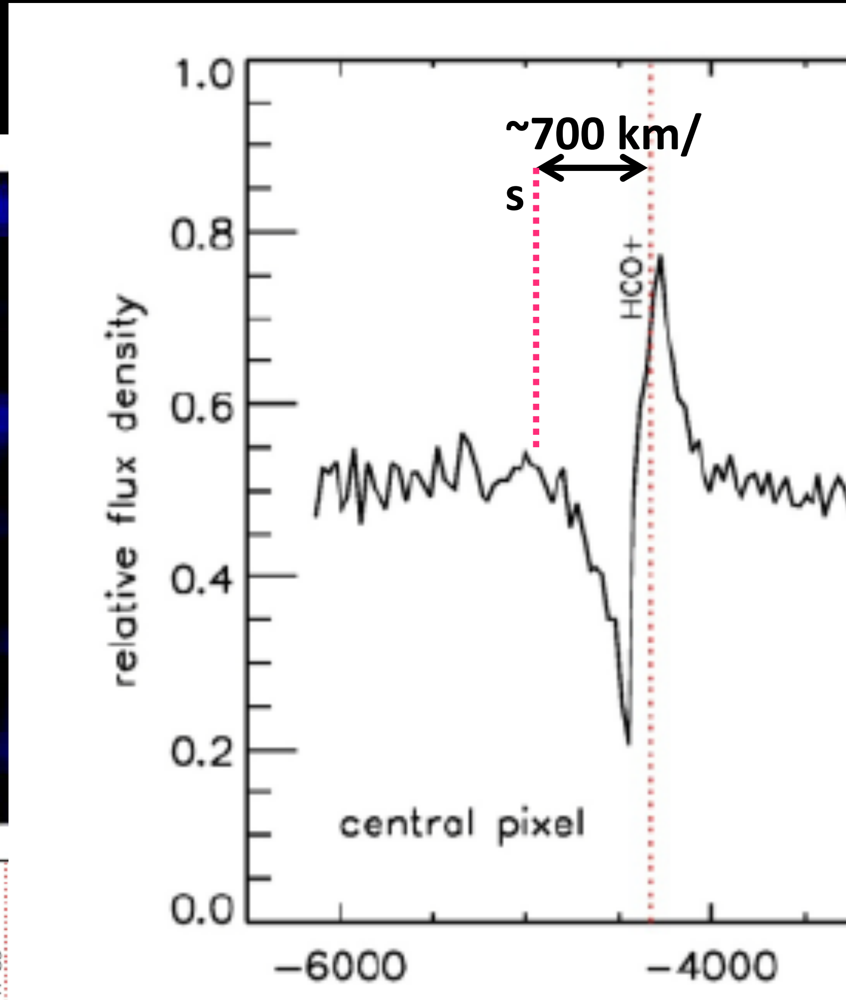
Sakamoto+2009



HCO+ shows ~100 km/s P Cygni profiles in both nuclei

NC3079 (Sy2)

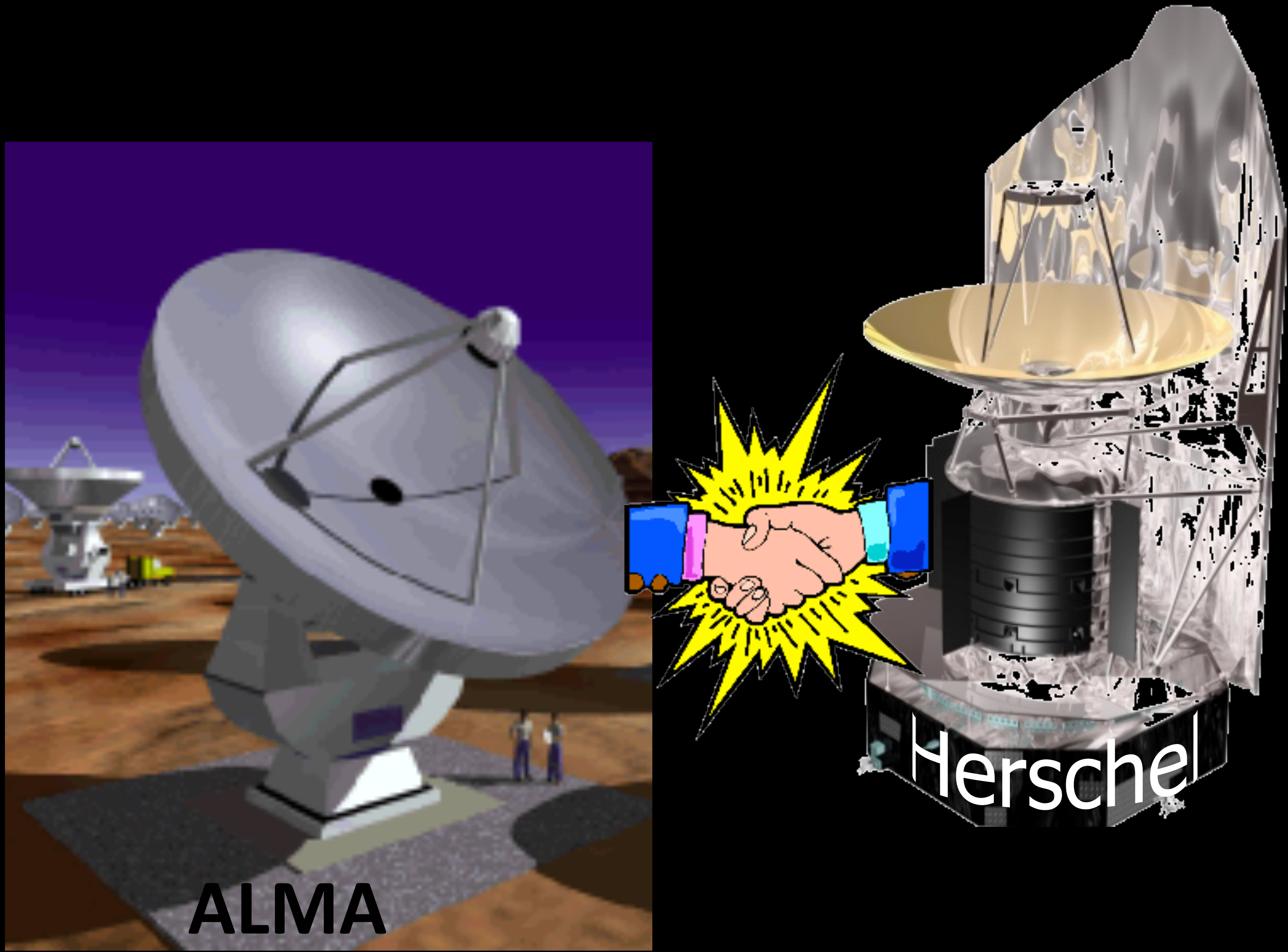




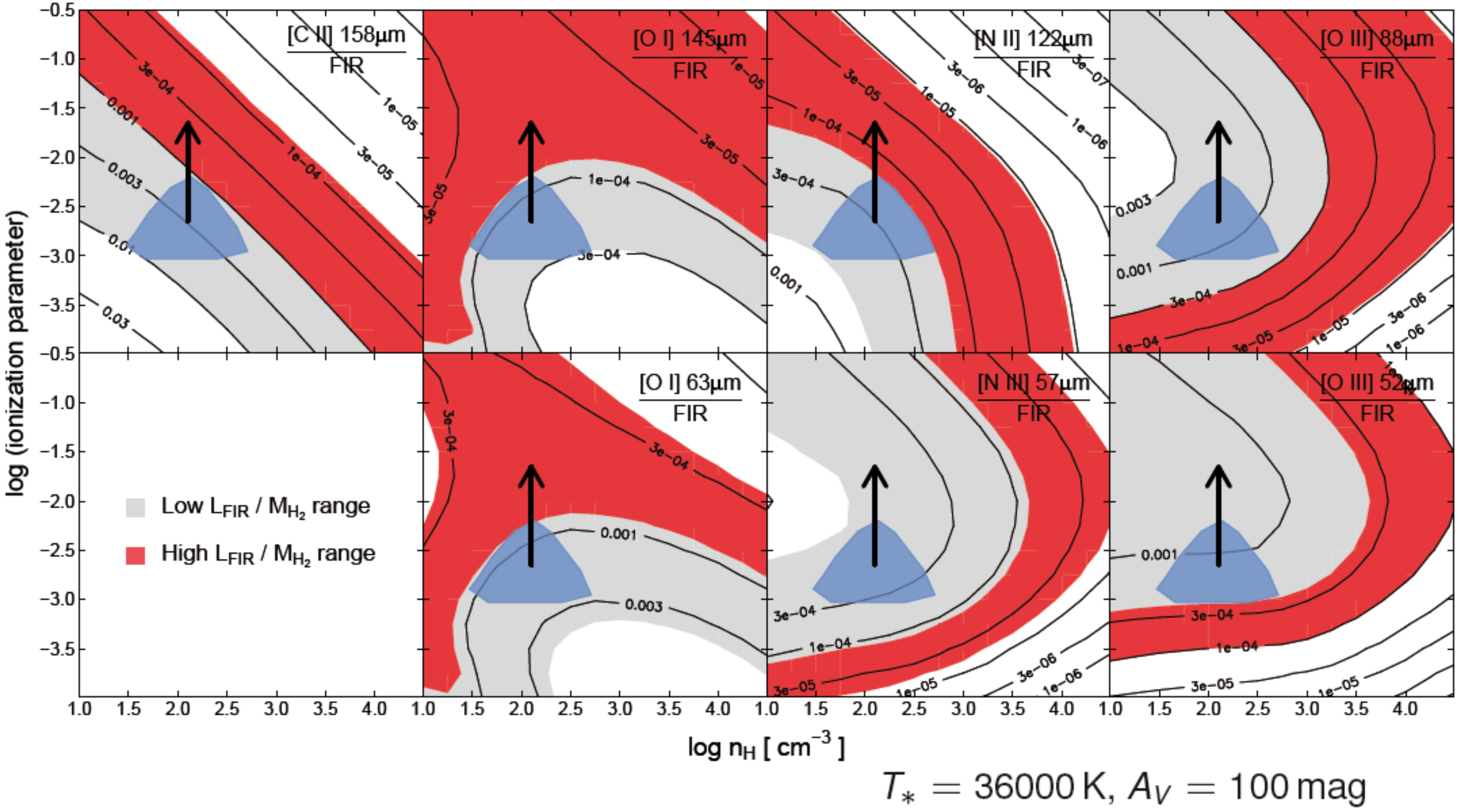
IRAM HCN and HCO^+
Davies + in prep

(Mid- and) far-infrared spectroscopic diagnostics of local and distant IRBGs

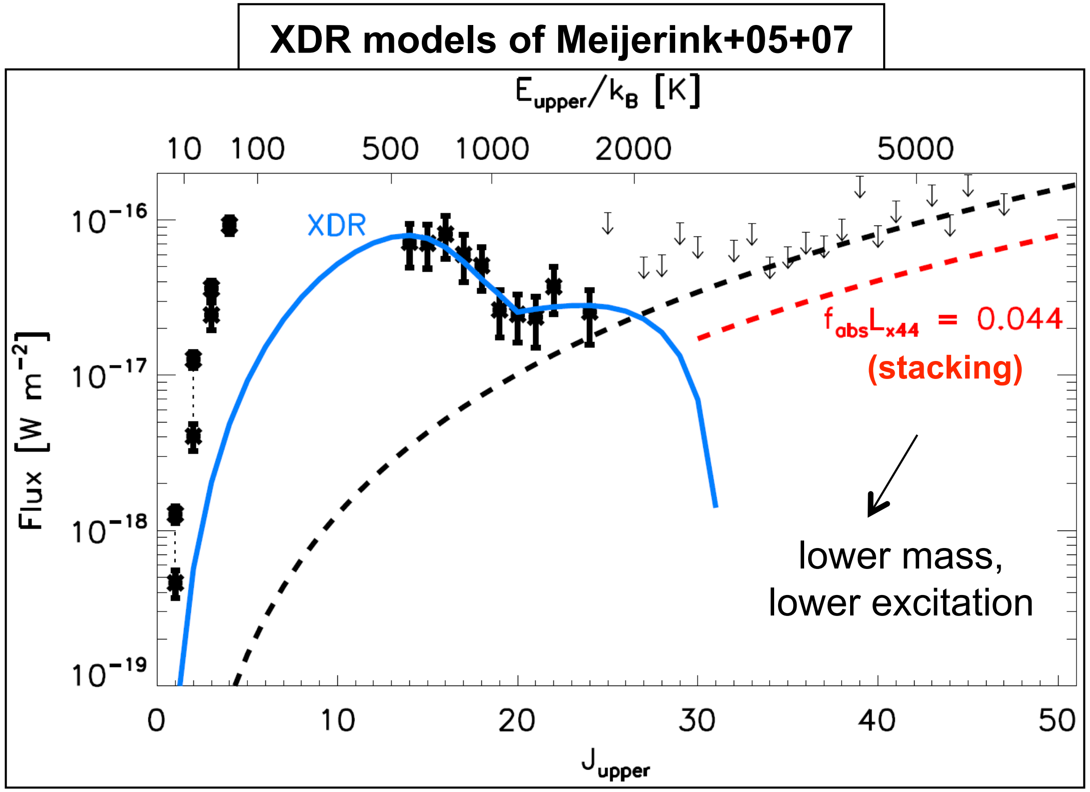
1) Calibration of FIR toolbox
   - quantification of AGN contribution: better done at (rest) mid-IR
   - global Line/FIR deficiency at high $L_{FIR}/M_{mol\ tracing}$ different modes of star formation (major merger vs. steady accretion)
2) FIR diagnostics at high z
   - first time PDR/HII diagnostics at high redshifts
3) New FIR diagnostics
   - high-J CO Lines in Starbursts and AGNs – PDR vs. XDR (shocks, CR,…)
   - OH as tracer of outflows (and inflows) and negative AGN feedback

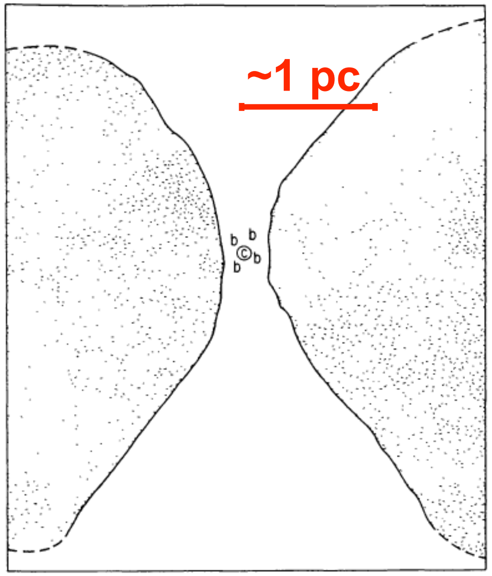

ALMA
Herschel

Backup slides


[C II] 158μm / FIR
[O I] 145μm / FIR
[N II] 122μm / FIR
[O III] 88μm / FIR
[O I] 63μm / FIR
[N III] 57μm / FIR
[O III] 52μm / FIR
Low L_FIR / M_H2 range
High L_FIR / M_H2 range
log (ionization parameter)
log n_H [cm^-3]
T_* = 36000 K, A_V = 100 mag

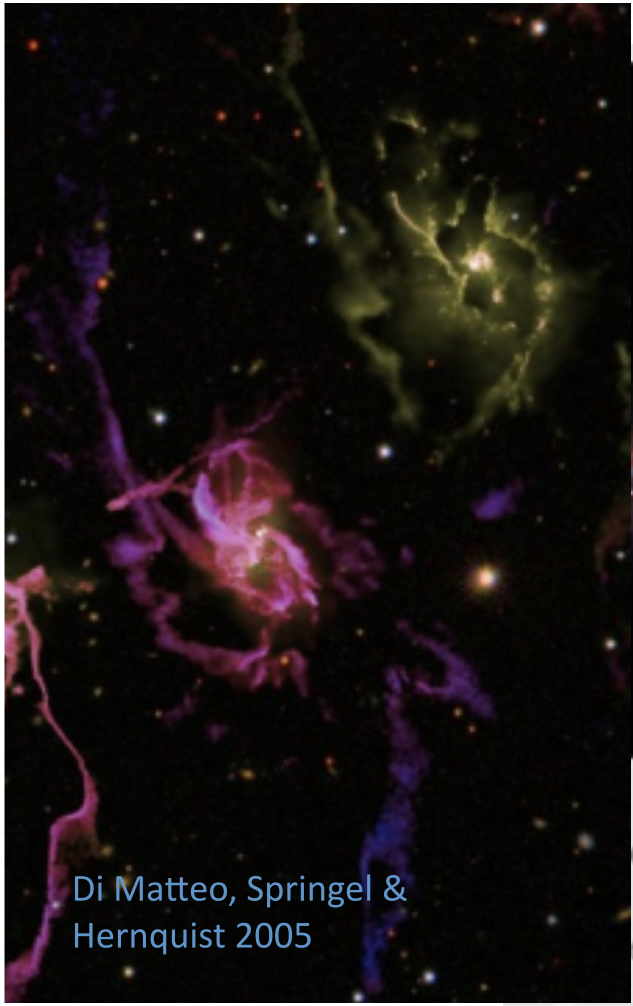
XDR Modeling – where's the torus?

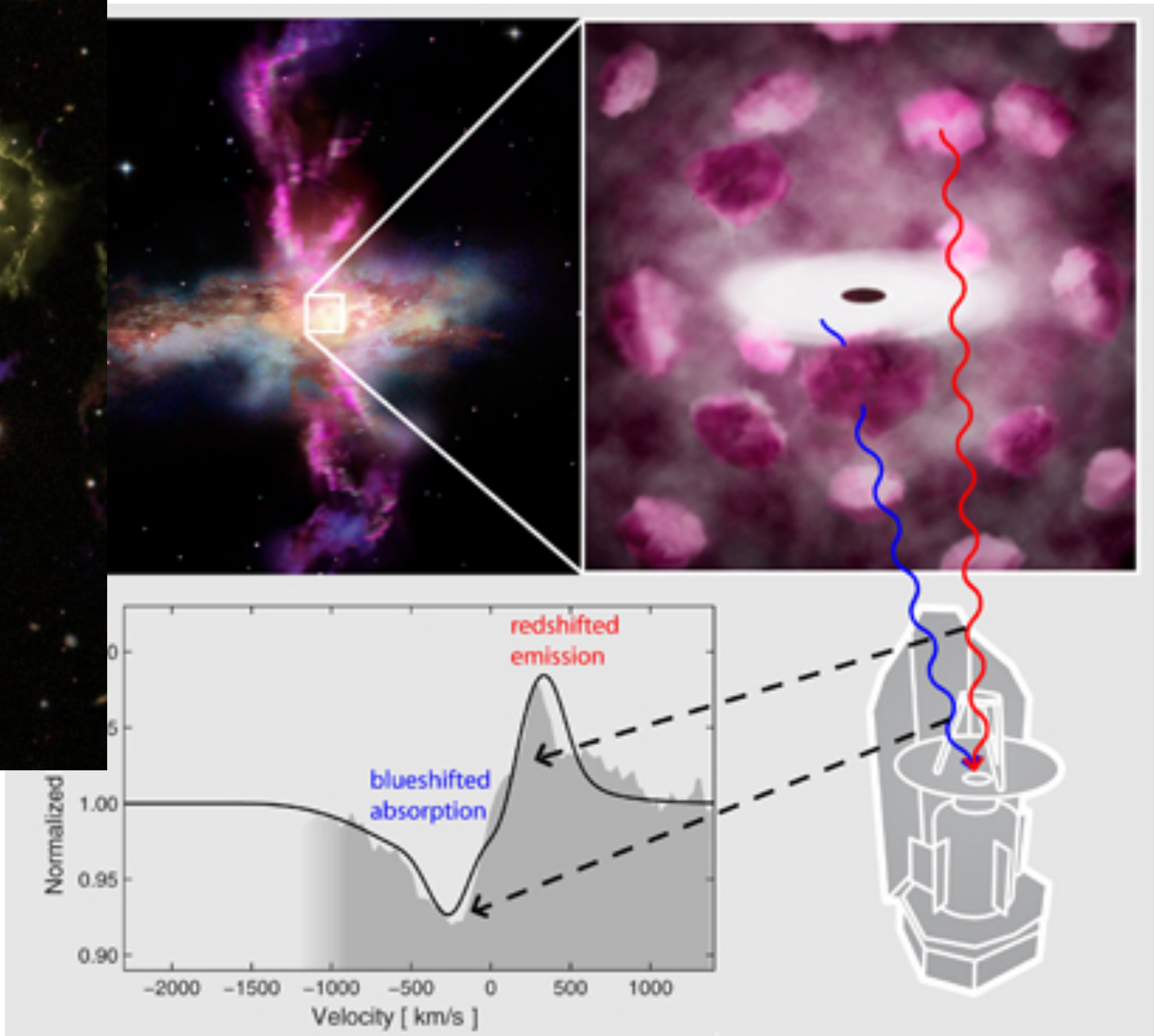




Antonucci 93

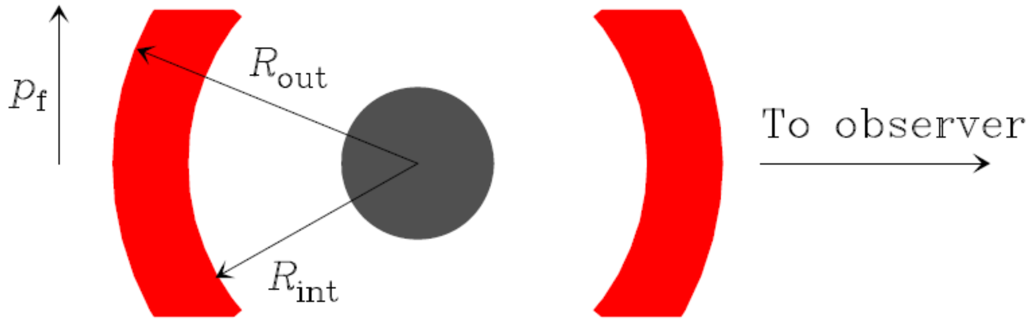
- Krolik+Lepp 89 – FIR CO lines from the Torus
  - Molecular gas ~ 1 pc from $L_X \sim 10^{44}$ erg/s source
  - ***⇒ Measured limit is 2.5 times weaker than predicted (modulo geometry, intrinsic luminosity …)***





Artists conception
©ESA

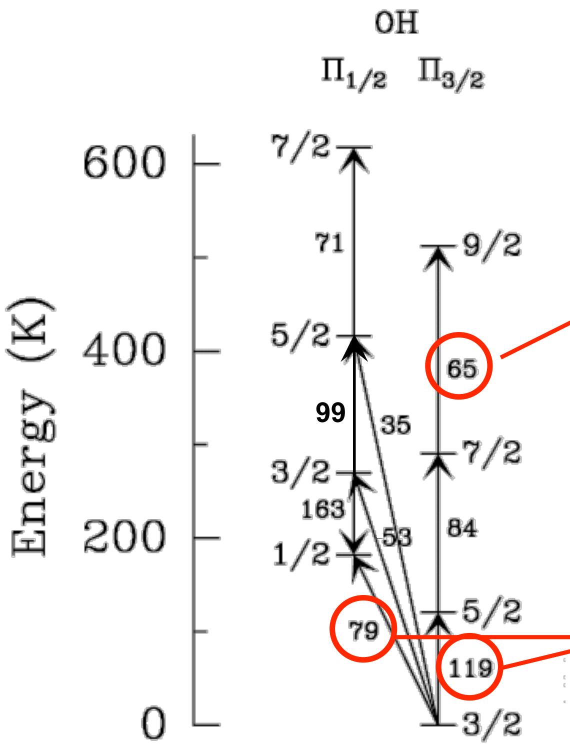
Mass and Energetics – Model

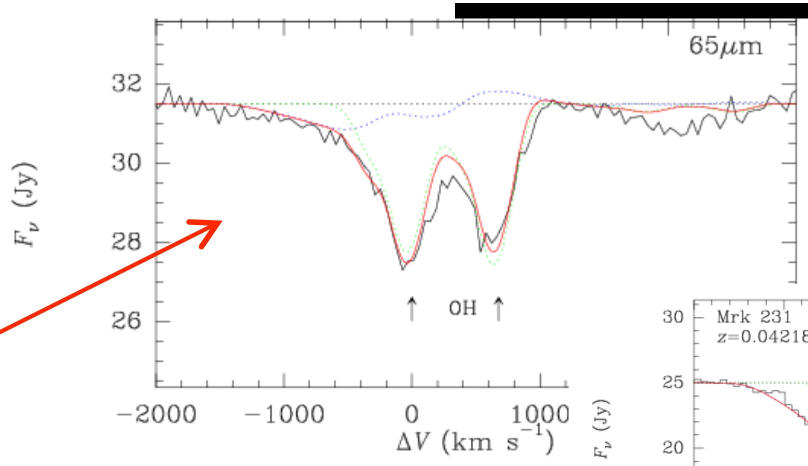


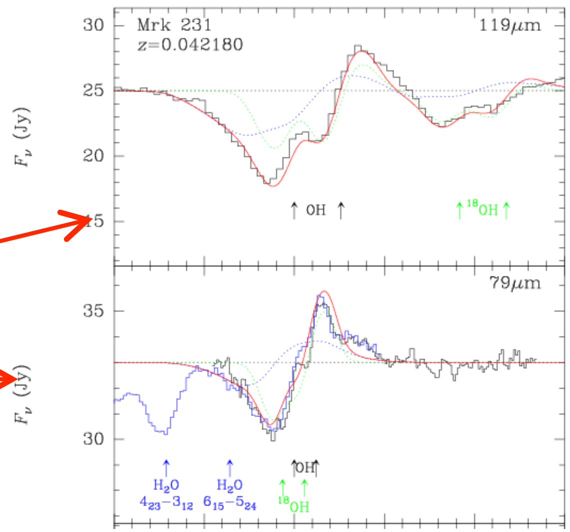
$$M \sim \frac{N(OH)}{X(OH)} R^2$$

$$\dot{M} = \frac{M}{t_{dyn}} \sim \frac{N(OH)}{X(OH)} \frac{R^2}{\Delta R} v$$

$$t_{dyn} = \frac{R_{out} - R_{int}}{v}$$

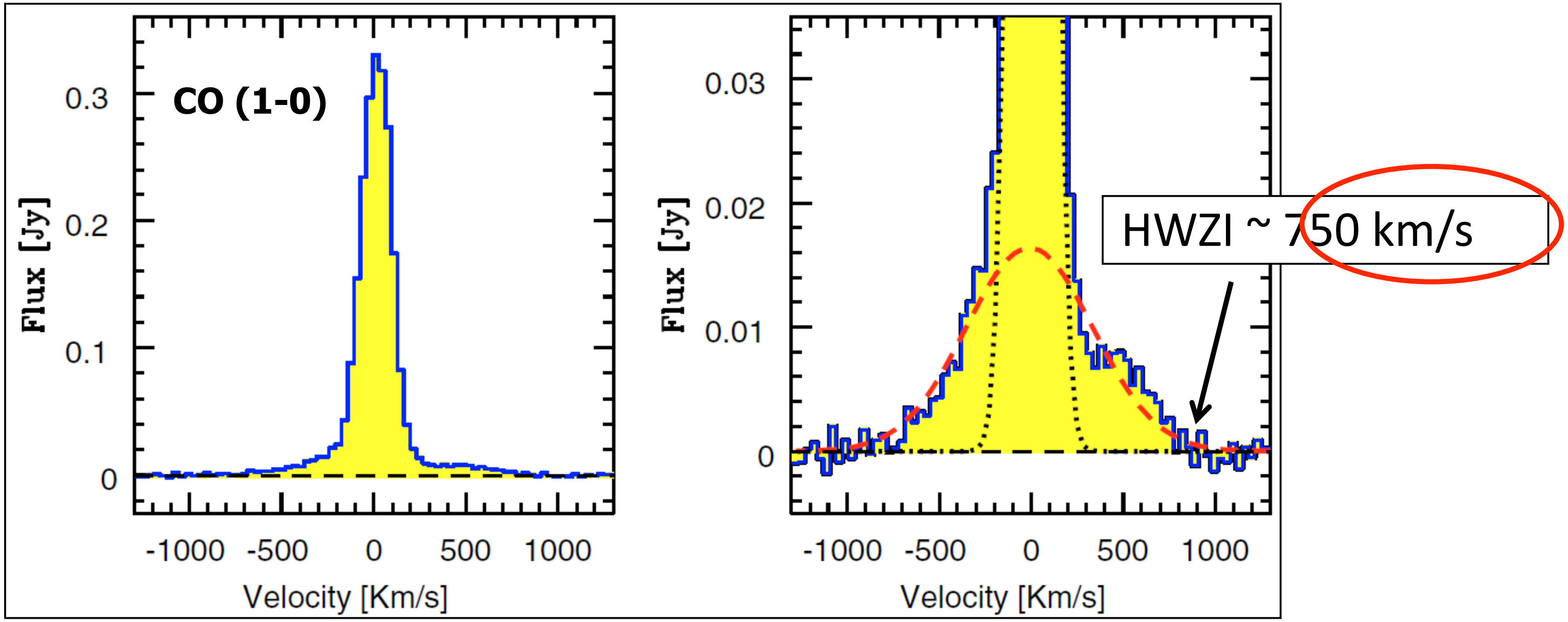


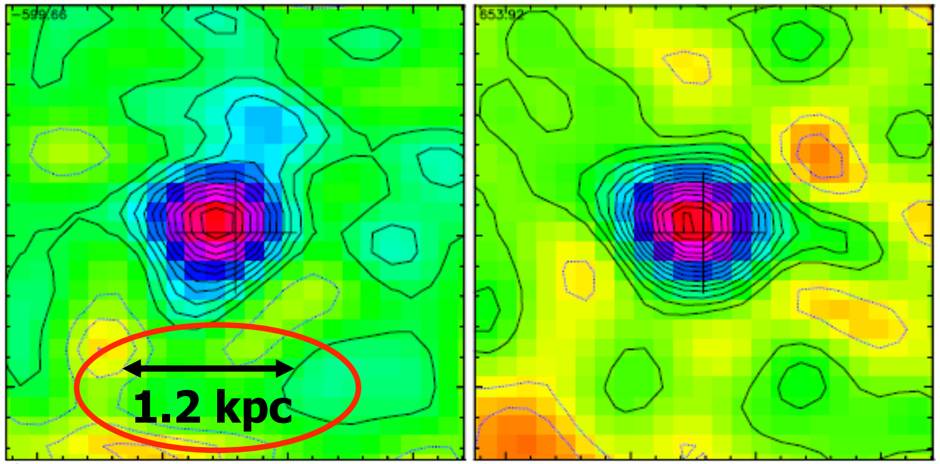




González-Alfonso & Cernicharo 1999

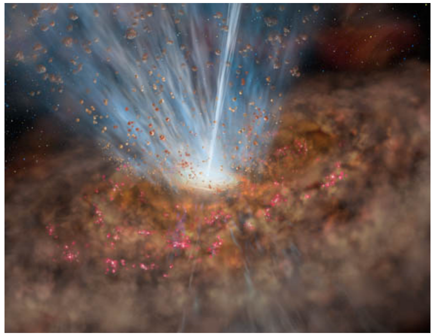
Mrk 231 – CO Outflow



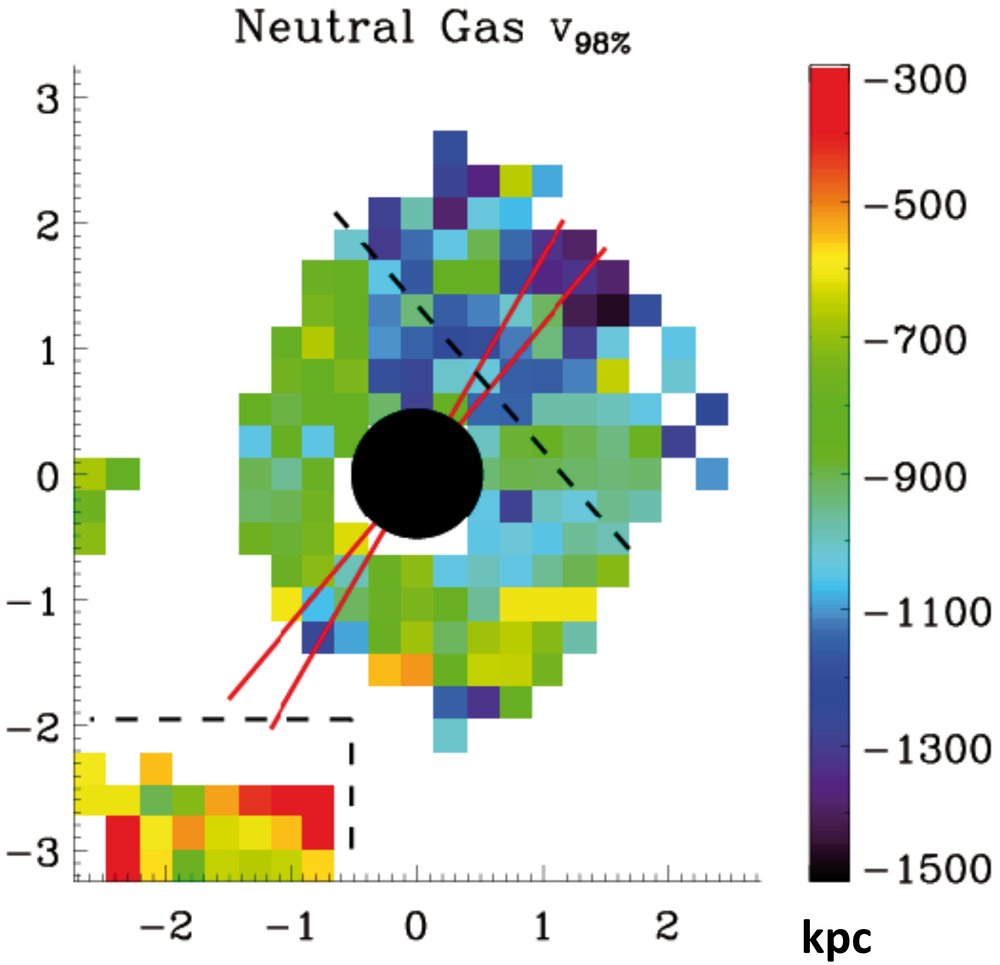


outflow mass of 5.8 x 10^8 $M_\odot$

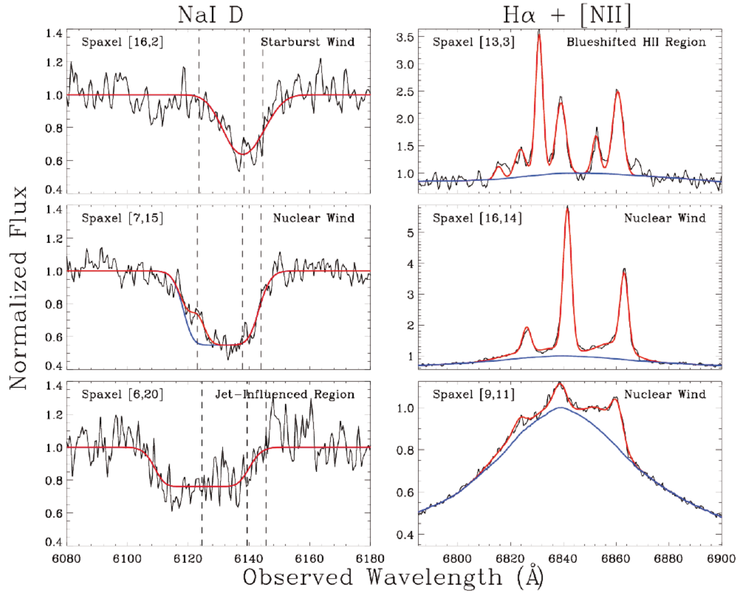
outflow rate of ~700 $M_\odot$/yr



Mrk 231 – Na I D Outflow



- Wide angle outflow (i.e. only minor contribution from jet)
- Outflow velocity up to ~1100 km/s
- 2-3 kpc extension



Rupke & Veilleux 2011
Gemini GMOS