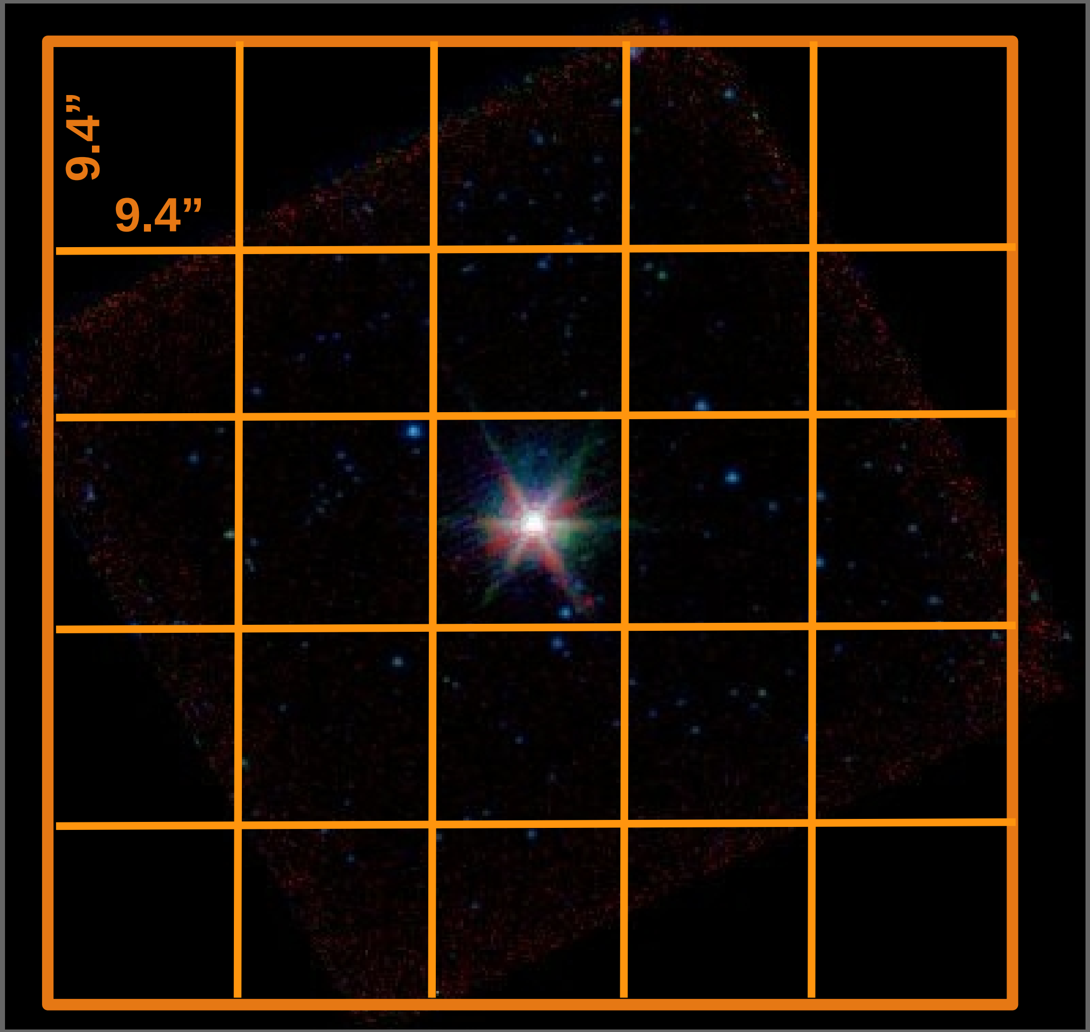
SHINING: Survey with Herschel of the INterstellar Medium in Infrared Nearby Galaxies

Contursi A., MPE Garching

<u>Sturm E. (P.I.)</u>, Christopher, N.; Davies, R.; Fischer, J.; Genzel, R.; González-Alfonso, E.; Graciá-Carpio, J.; Hailey-Dunsheath, S.; Jannsen A.; Lutz, D.; **<u>Poglitsch, A.</u>**; Sternberg, A.; Tacconi, L. J.; Veilleux S.; Verma, A.,

Guaranteed Time K-Project: ~300 hrs PACS spectrometer

PACS: IF Spectrometer, 47" x 47"' FOV from 55 to 200 µm
PSF=9"-13"



Spitzer/Irac image
of Mrk231

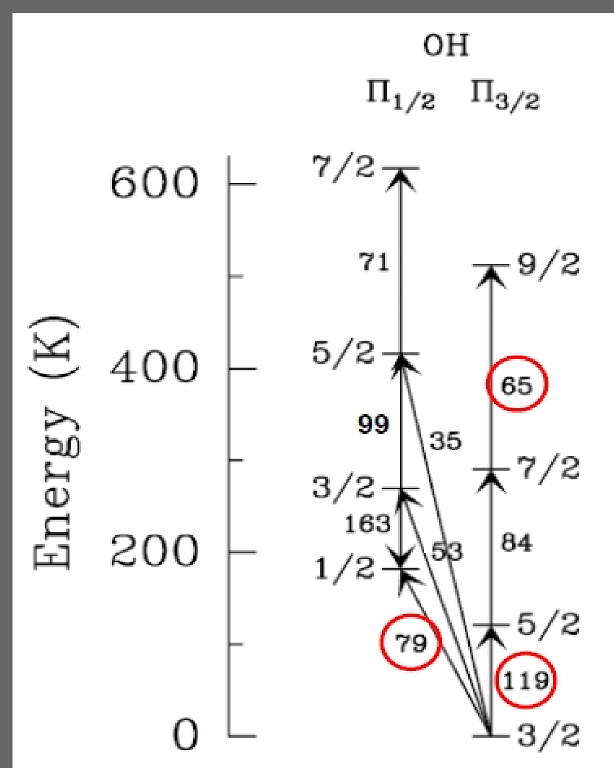
Guaranteed Time K-Project: ~300 hrs PACS

- Line survey of ~60 galaxies: AGN-ULIRGs, SB-ULIRGs, SB

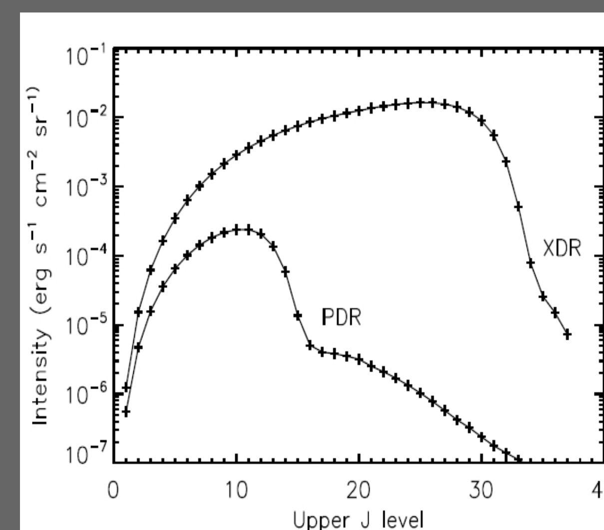
Fine Structure FIR Lines Ionized and neutral

Atomic line	$E_{\rm upper}$ K	$n_{\rm crit}$ [e] $\rm cm^{-3}$	$n_{\rm crit}$ [H] $\rm cm^{-3}$
[N III] 57μm	251	3×10^3	…
[O III] 52μm	441	4×10^3	…
[O III] 88μm	163	5×10^2	…
[N II] 122μm	188	3×10^2	…
[C II] 158μm	91	50	3×10^3
[O I] 63μm	228	…	5×10^5
[O I] 145μm	327	…	5×10^4

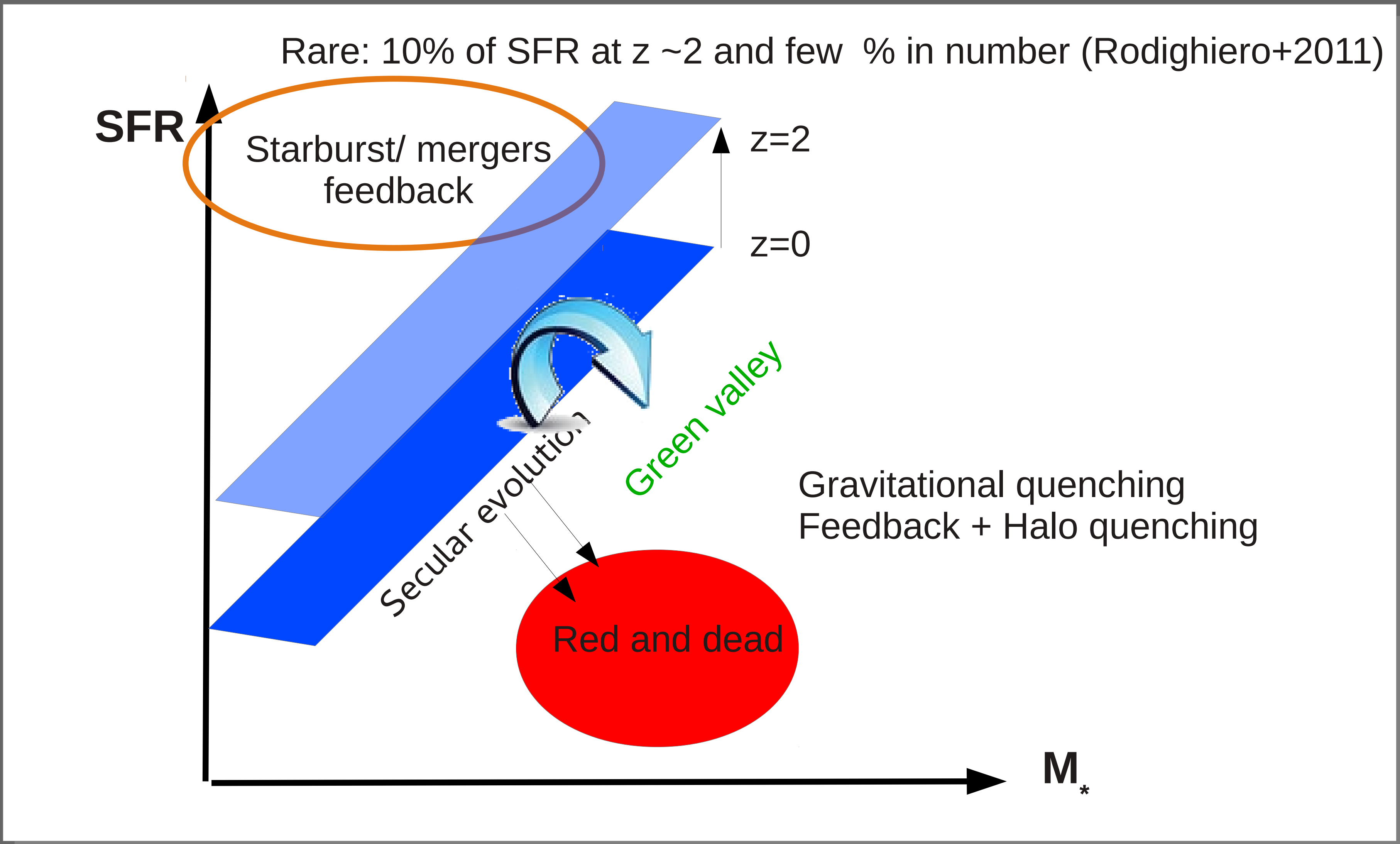
OH Molecule



High J (>13) CO lines



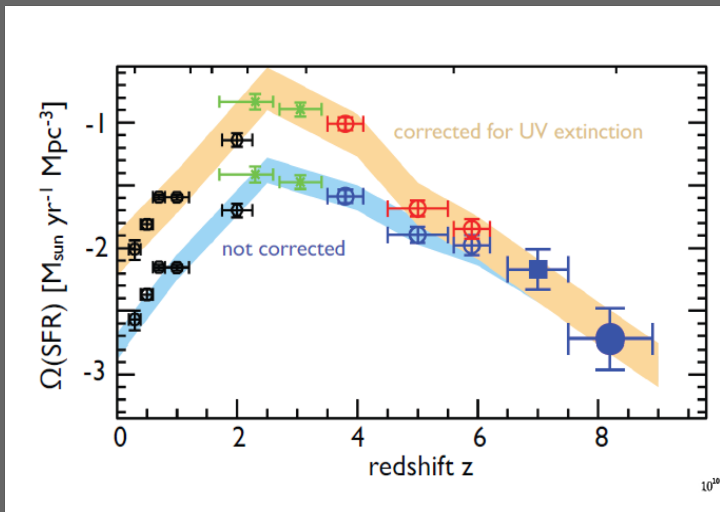
Quenching: feedback



Also environmental effects can be efficient in quenching SF

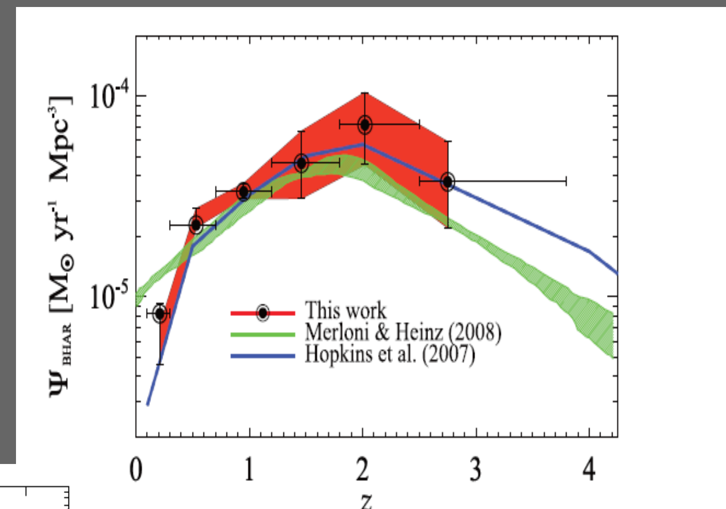
BHs/Galaxies coevolution

SFR density evolution

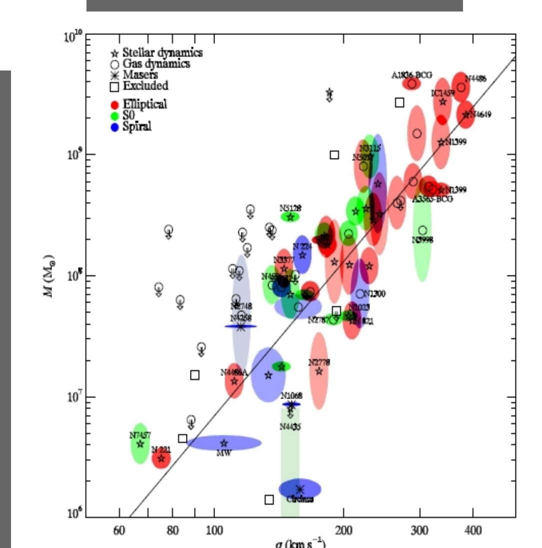


Bouwens+2010

BH accretion rate evolution



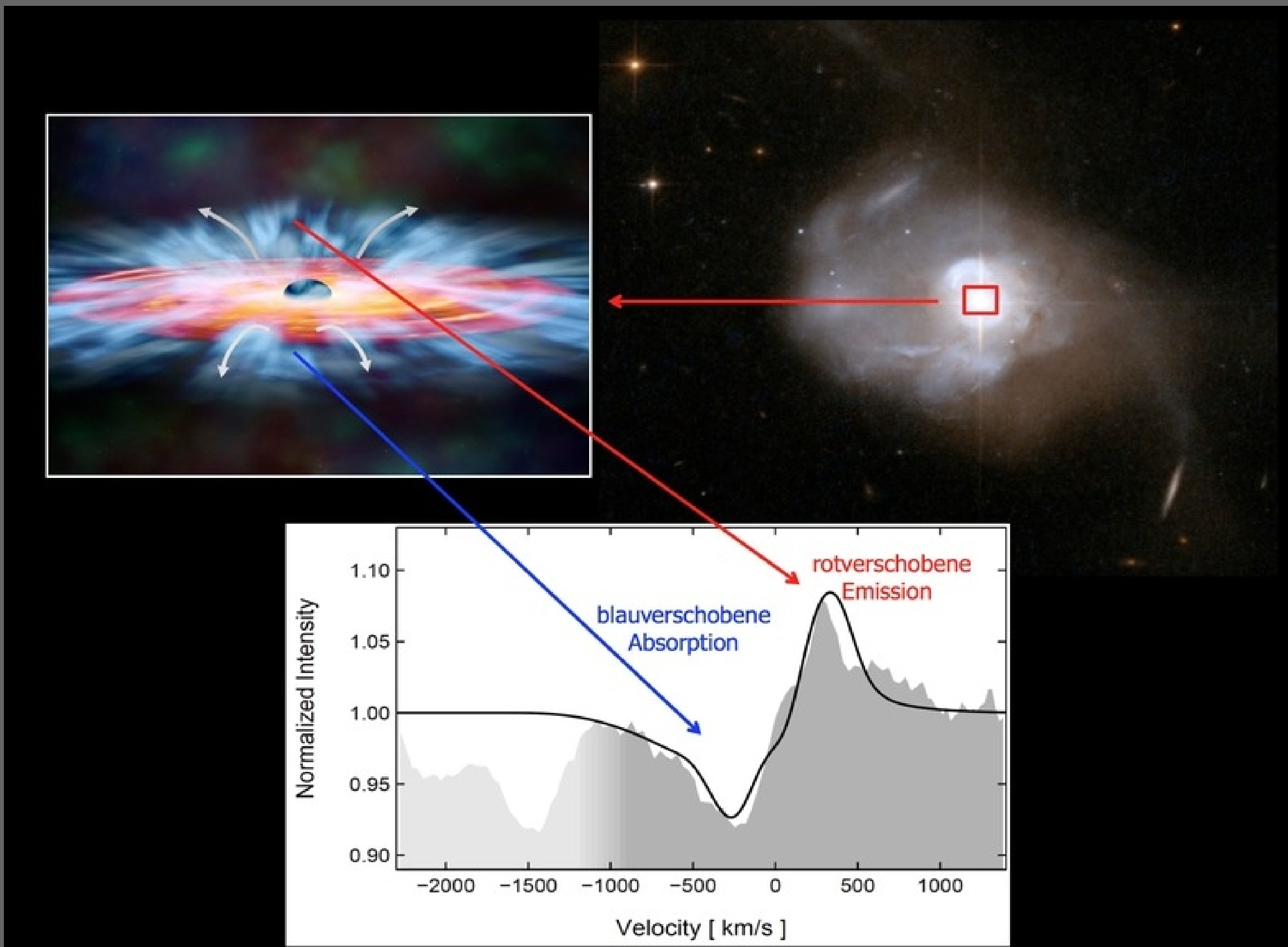
Delvecchio+2014



Gueltekin+2009

First suspect: AGN feedback

Molecular (OH) outflow in Mrk231

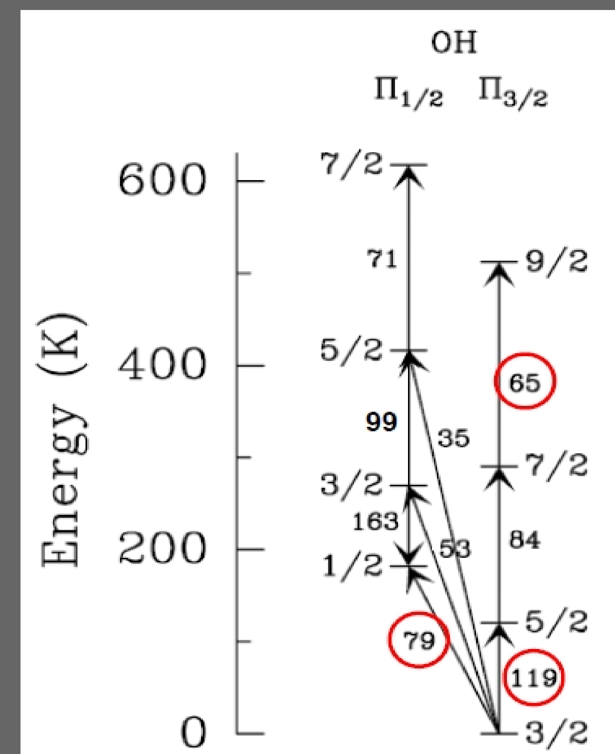


z=0.042

L_{IR}=3.2 x 10^{12} L_{sol}

70% AGN

Type 1 LoBAL AGN



First PACS detection of OH inverted Pcygni at 79 μm (Fisher+ 2010)

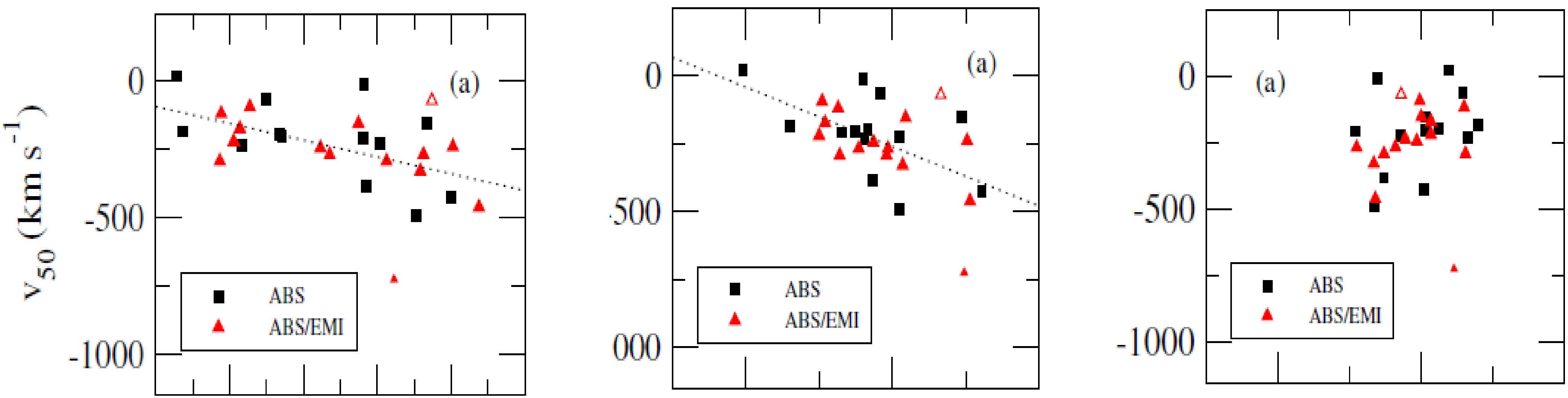
$V_{terminal}$ >~1000 km/s $M_{outflow}$ ~4.2 x 10^9 M_{Sun}

dM/dt=500-1200 M_{sol}/yr

SFR ~ 100M_{sol}/yr

Many other cases

- Strong molecular outflows observed in ~26 (out of ~37) warm and cold ULIRGs so far (Veilleux+2013) in OH 119 μm absorption
- Are the strong outflows driven by the AGN rather than by the star formation in these objects?



AGN Fraction
(Could derive from obscuration)

$Log(L_{AGN}/L_{SUN})$

$Log(L_{SB}/L_{SUN})$ ~ SFR

V_{50} = v below which 50% of the absorption takes place

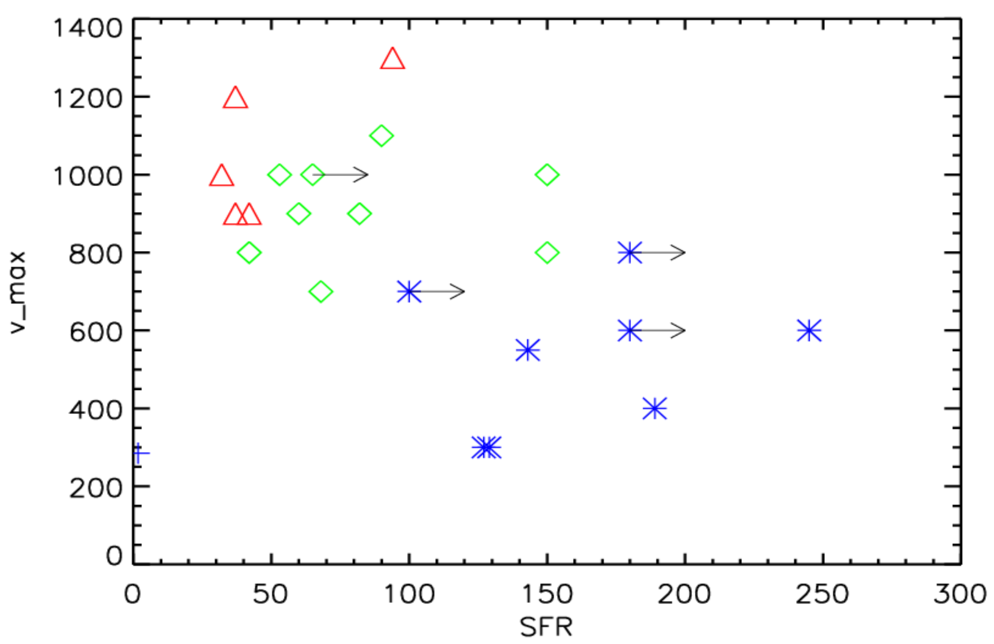
GTO+OT Program: Veilleux+2013

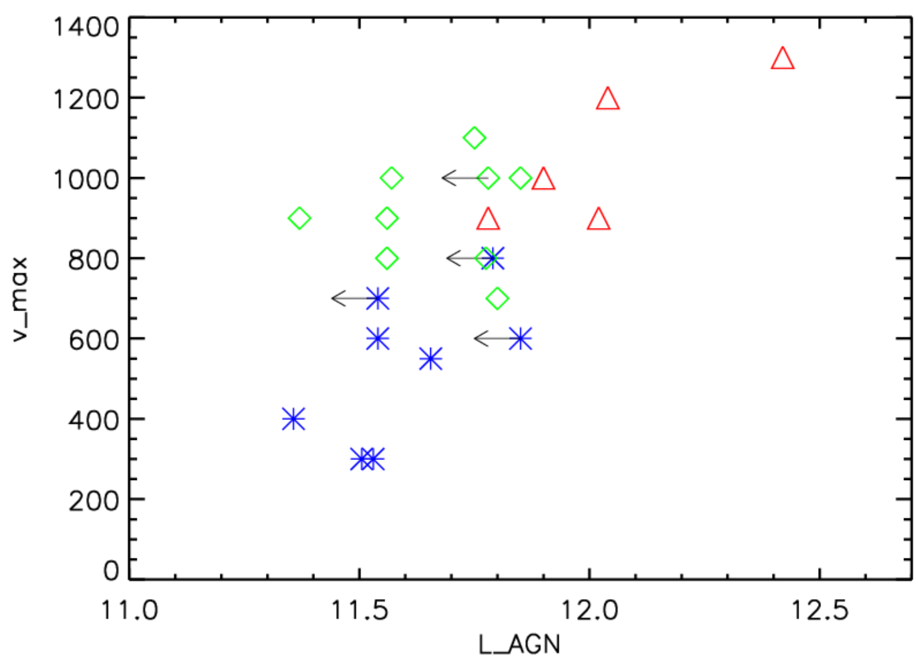
AGN versus Starbusts

AGN

ULRIGs

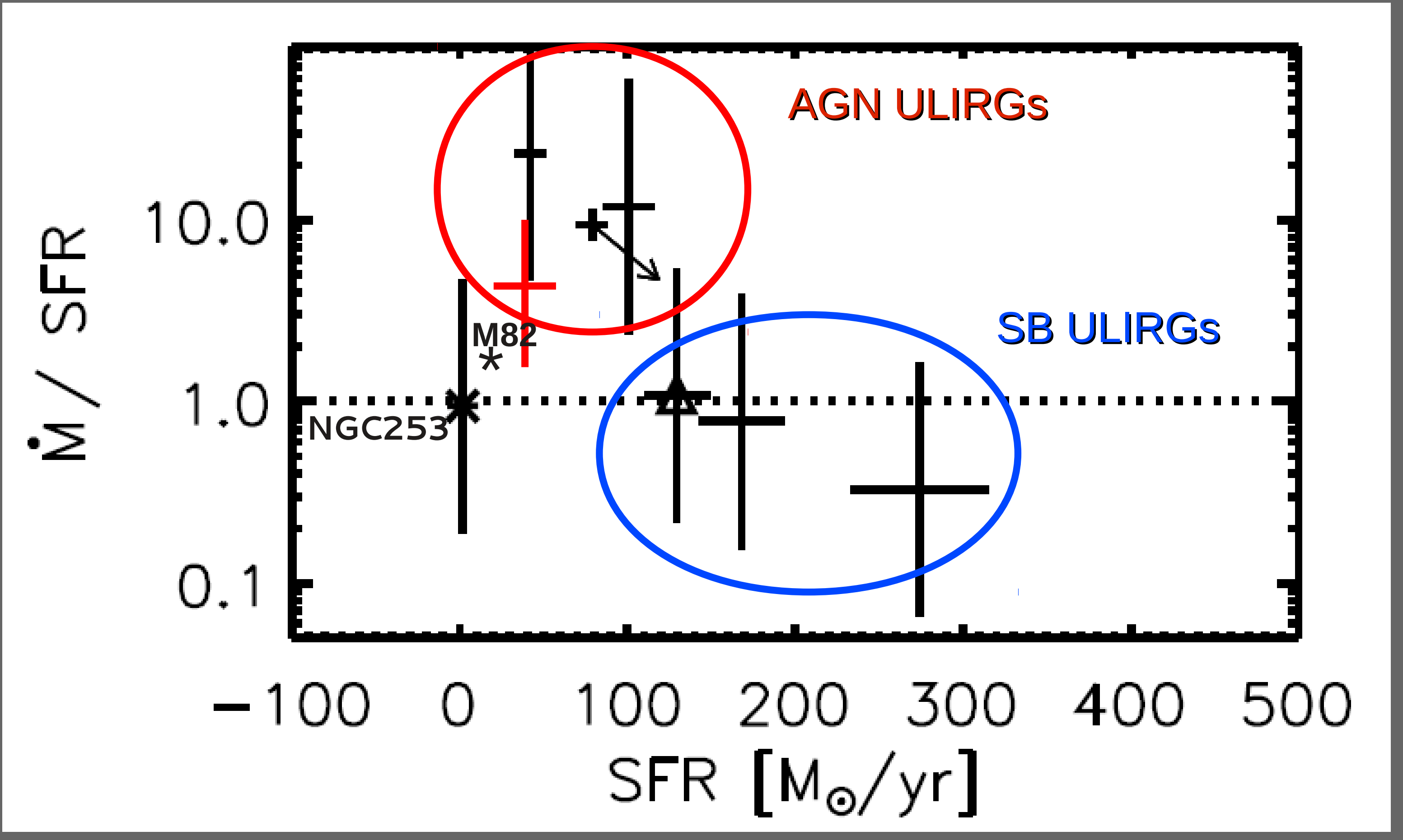
Starbursts





Updated from Sturm+2011

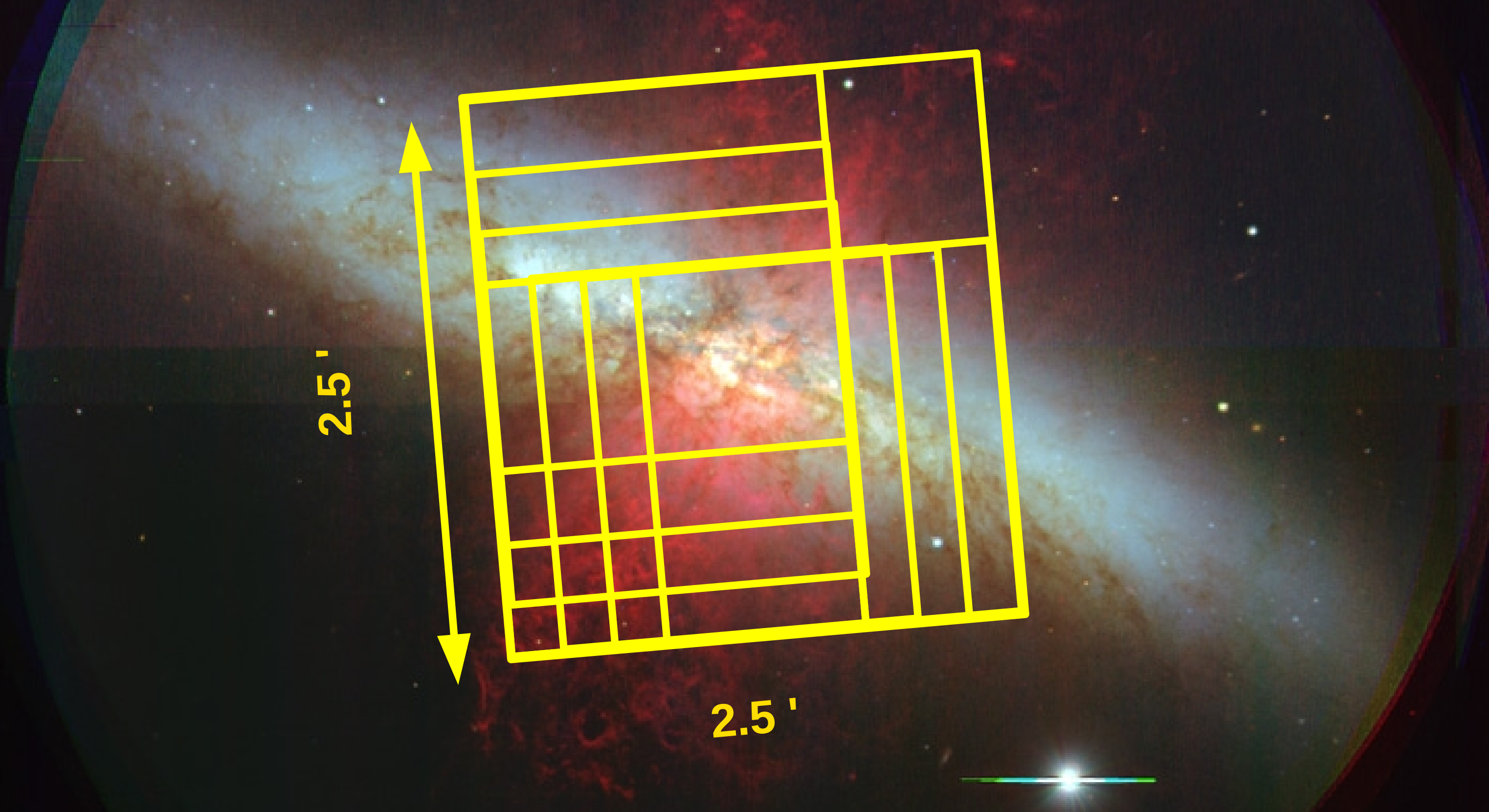
Quenching from AGN feedback?



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

Multiphase outflow: M82

PACS mapping of M82 in [CII], [OI 63,145 μm], [OIII] 88 μm

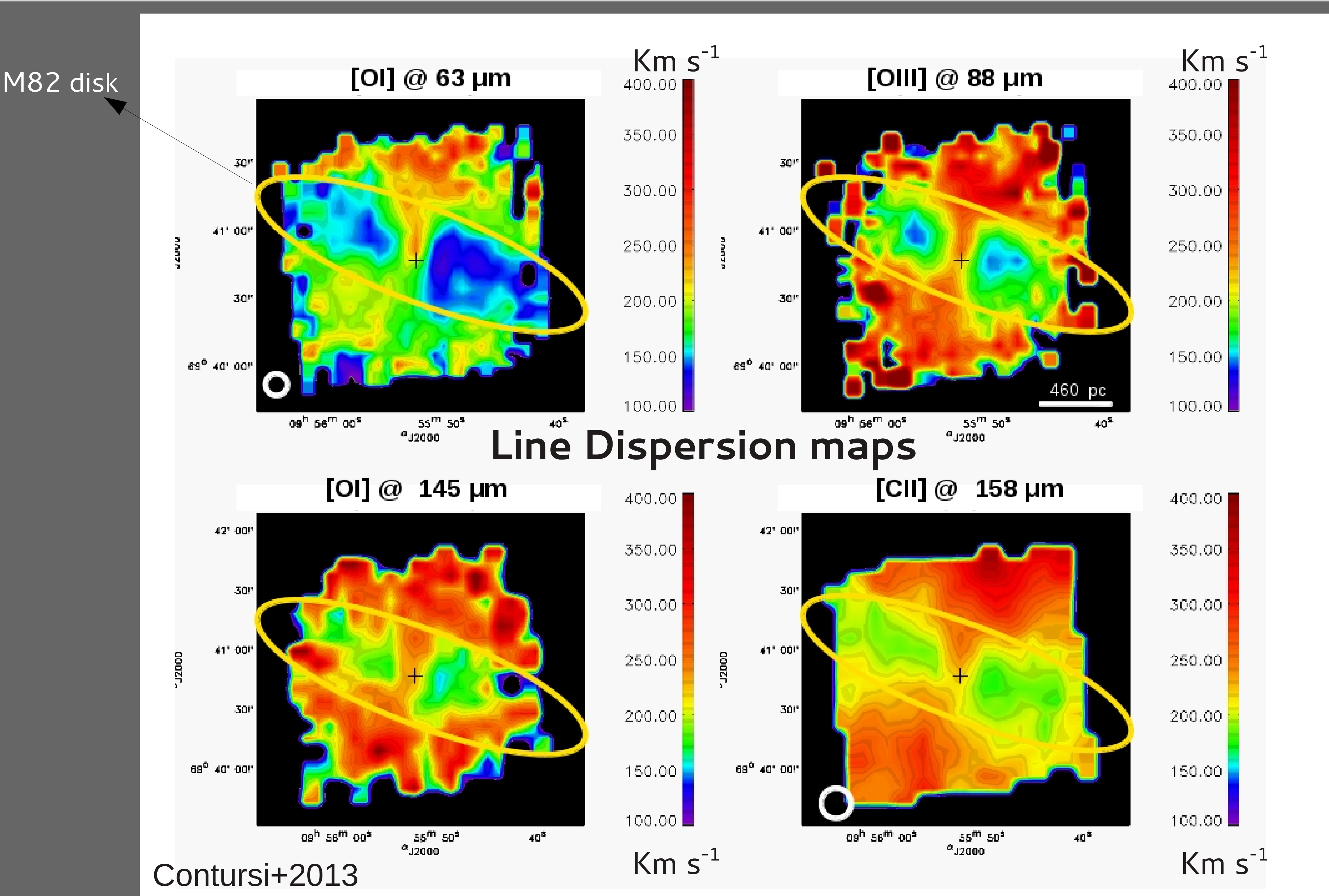


[CII], [OI] =main coolants of NEUTRAL gas

[OIII] = IONIZED gas

Spatial resolution ≈ 130 – 240 pc

Multiphase outflows: M82



Outflow velocities of different gas phases

gas phases	Outflow velocities Km/s	Reference
Neutral gas (PDR)	75	Contursi+2013
Ionized gas [OIII] 88 µm	75	Contursi+2013
Ionized gas Hα	600	Greve 2004
Molecular gas CO(1-0)	100	Walter+2002

- CO, PDR and [OIII] are coupled
- Warm ionized ($T \sim 10^4$ K) gas much faster
- PDR clouds in outflow fairly dense ($G_0 = 0.5\text{-}1 \times 10^3$, $n_H = 0.5\text{-}1 \times 10^3 cm^{-3}$, $T \sim 300$ K)
- SB luminosity sufficient to illuminate clouds in the outflow

Outflow velocities of different gas phases

gas phases	Outflow velocities	Reference
	Km/s	
Neutral gas (PDR)	75	Contursi+2013

Cold clouds from the disk are entrained into the outflow by the winds where they likely evaporate, surviving as small, fairly dense cloudlets.
[OIII] traces the ionized gas at the surface of these entrained clouds illuminated by the SB.

- PDR clouds in outflow fairly dense (G_0 = 0.5-1 x 10^3, n_H= 0.5-1 x $10^3 cm^{-3}$, T~300 K)
- SB luminosity sufficient to illuminate clouds in the outflow

Outflow Mass and Energy of various gas phases

Gas Phases	M	E_{kin}	$\dot{M}$	Reference
	10^8 $M_\odot$	10^{55} erg	$M_\odot$ /yr	
Cold molecular gas	3.3	3.3	33	Walter+ 2002
Warm molecular gas	0.0001	0.0001	0.001	Veilleux+ 2002
Ionized gas traced by Hα	0.06	2	3.6	Schopbell+1998
Neutral atomic gas	> 0.2-0.8	0.1-0.5	10-25	Contursi+2013

Outflow energetic of various gas phases

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- Molecular gas and PDR gas make most of the mass in the Outflow
- SFR_{M82} = 25 M_{sol}/yr (Förster-Schreiber+2003)
- Mass loading factor η~ 2

Further evidences of different parameters derived from different outflow phases.

- The velocities of outflowing molecular and atomic gas are similar but generally SMALLER than those of ionized gas (Sturm+11, Veilleux+13 and Contursi+13)

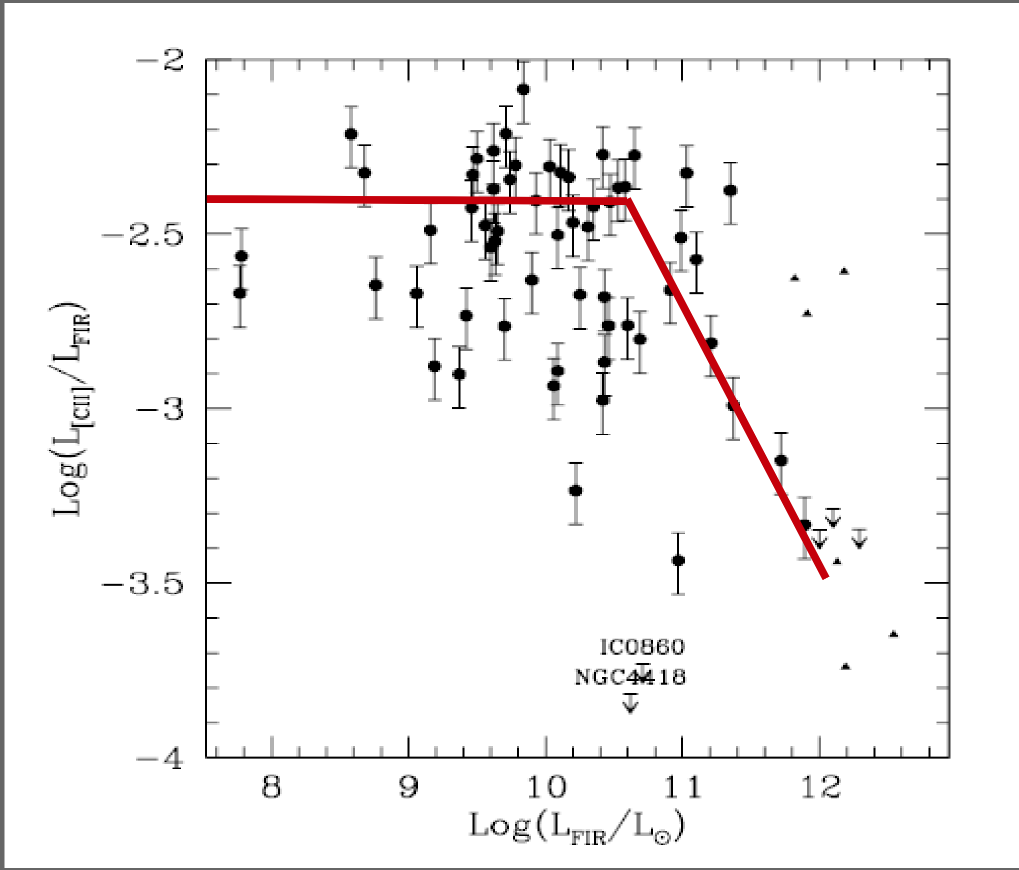
- Very recent ALMA observations of molecular lines (CO, HCN, HCO^{+}) In NGC1068 show molecular outflow rate 10 higher than those found from the Ionized gas (García-Burillo+2014).

WARNING

Outflows are multi-phases and energetic, terminal velocities and outflowing mass rates may vary depending on the observed phase

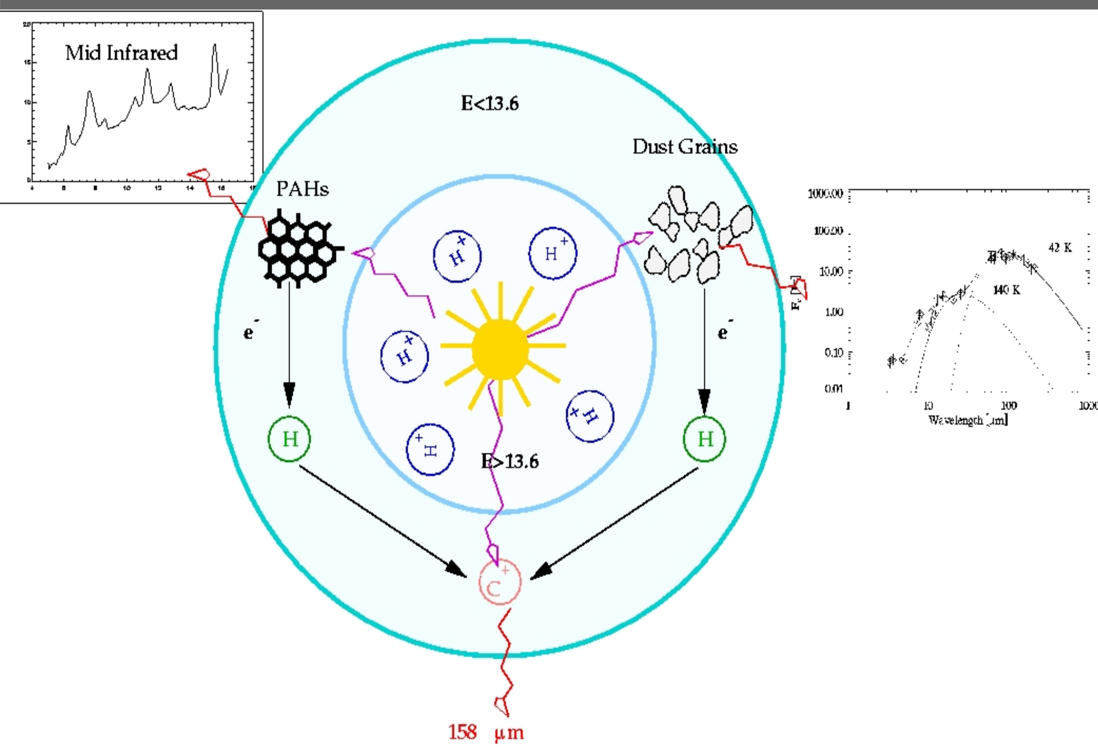
The "[CII] deficit"

Before Herschel



Malhotra+2001 Luhman+ 2003

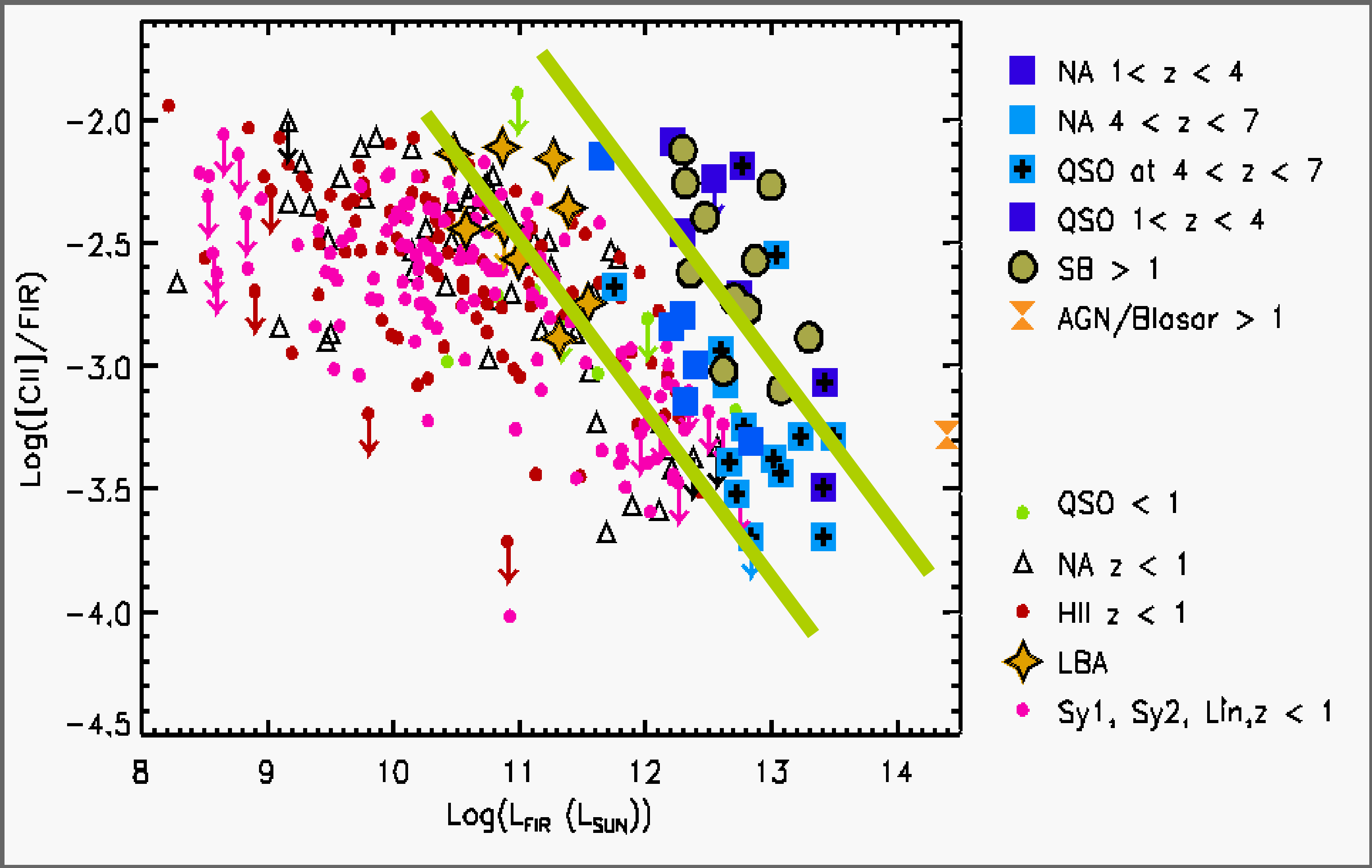
The *"[CII] deficit"* : an open issue



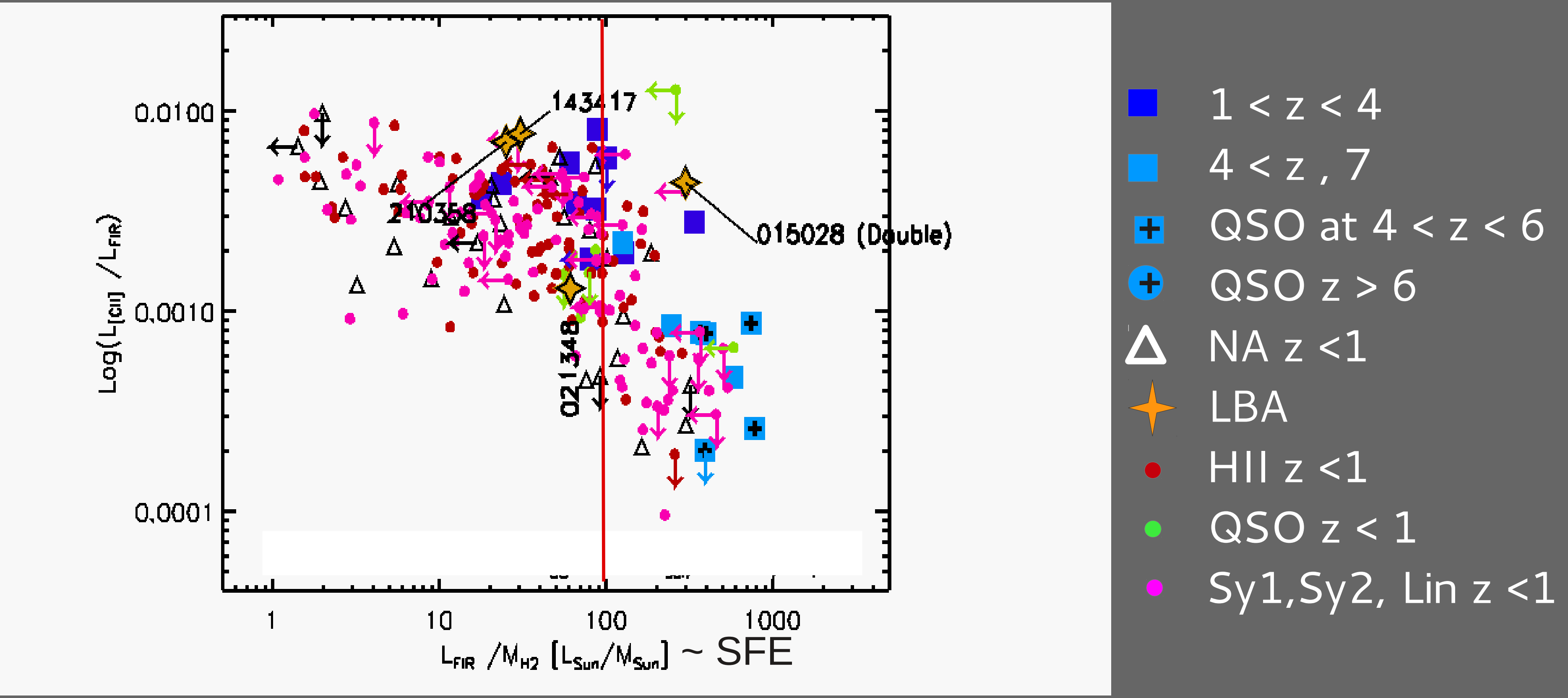
Photoelectric effect on grain: the smaller the more efficient

- Grain ionization degree increases in FIR luminous (warm) sources
- [CII] optically thick: this means $N_H \sim 3x\ 10^{23}\ cm^{-2}$ in each cloud and stronger [OI 63 μm] line deficit (not observed at ISO time)
- Dusty HII regions: photons are absorbed by dust more than in "normal" HII regions producing extra FIR not corresponding to extra [CII] from PDRs

The *"[CII] deficit"* at low and high z

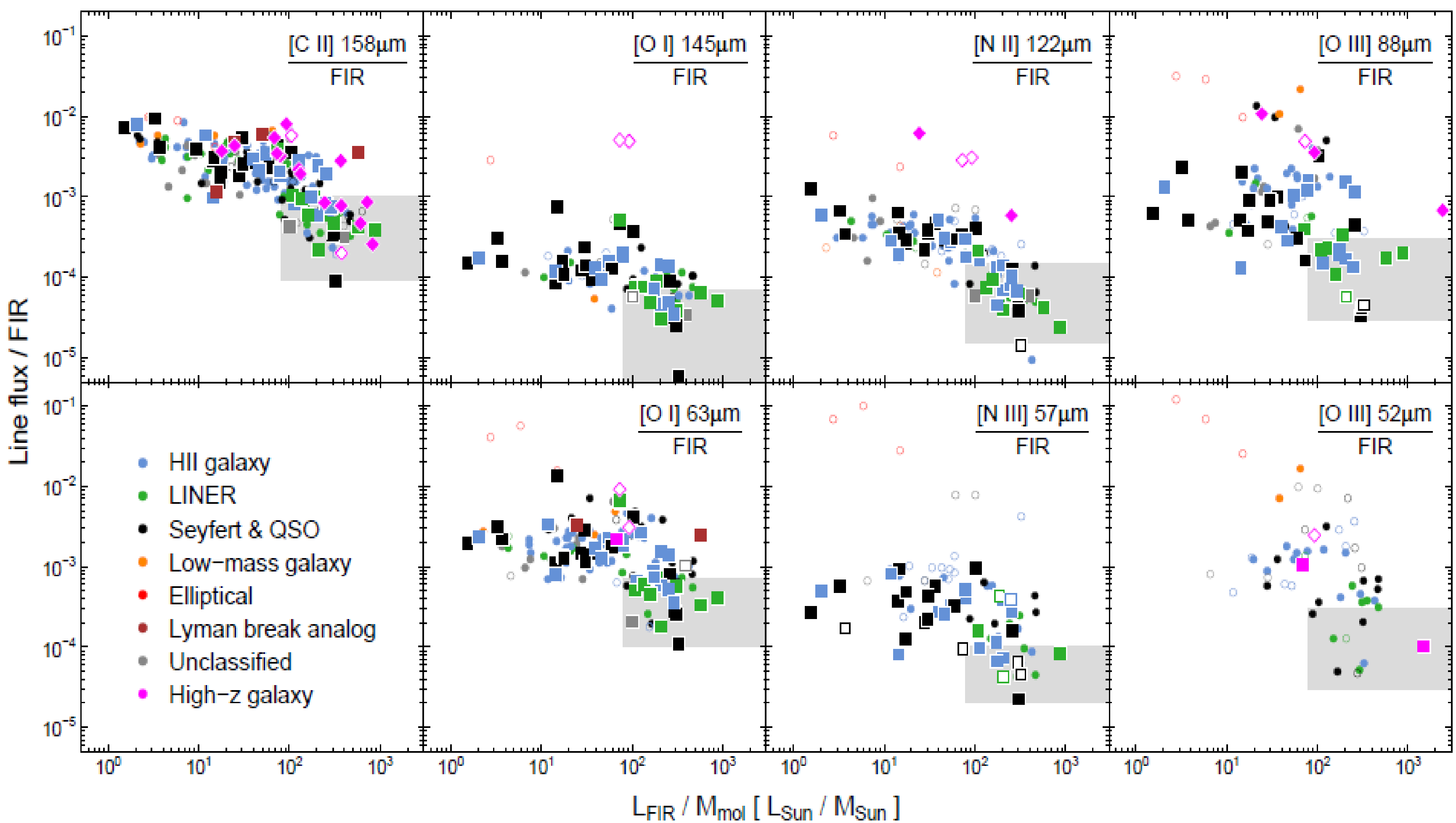


The *"[CII] deficit"* : universal at all z



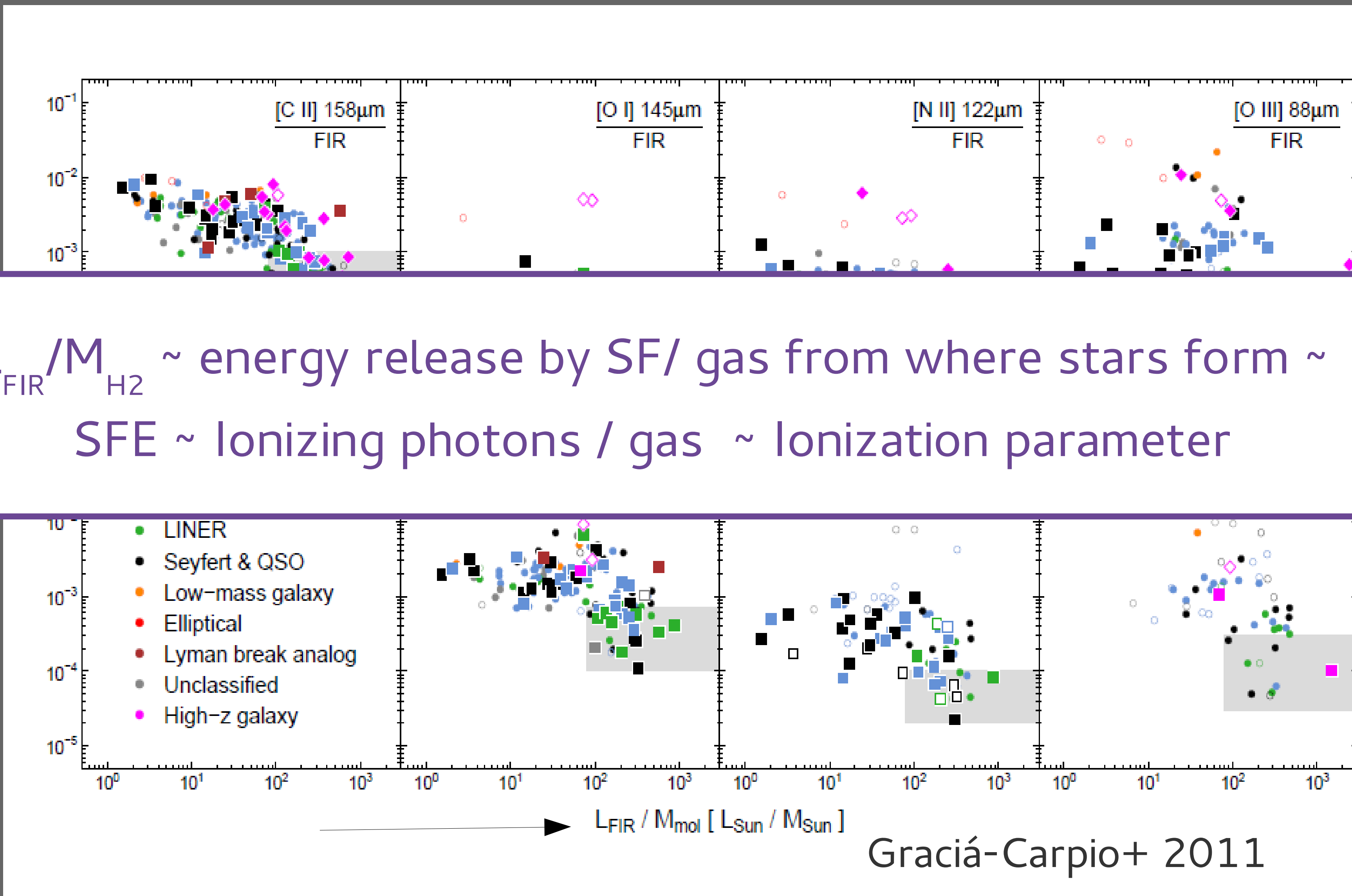
- [CII] deficit becomes universal at all z when plotted against L_{FIR}/M_{H2}

The *"[CII] deficit"* becomes a line deficit



Graciá-Carpio+ 2011

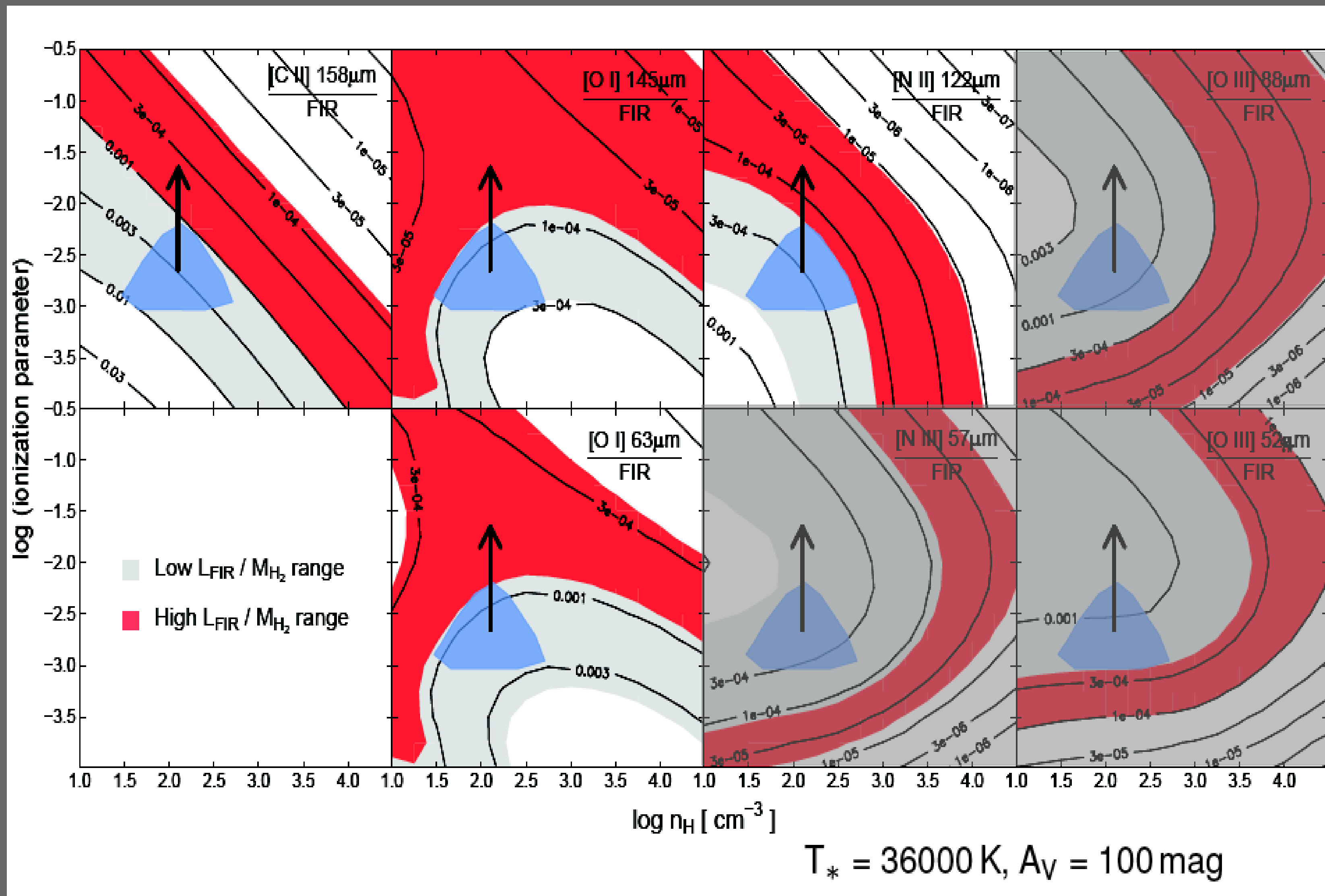
The *"[CII] deficit"* becomes a line deficit



L_{FIR}/M_{H2} ~ energy release by SF/ gas from where stars form ~ SFE ~ Ionizing photons / gas ~ Ionization parameter

Graciá-Carpio+ 2011

The *"[CII] deficit"* becomes a line deficit



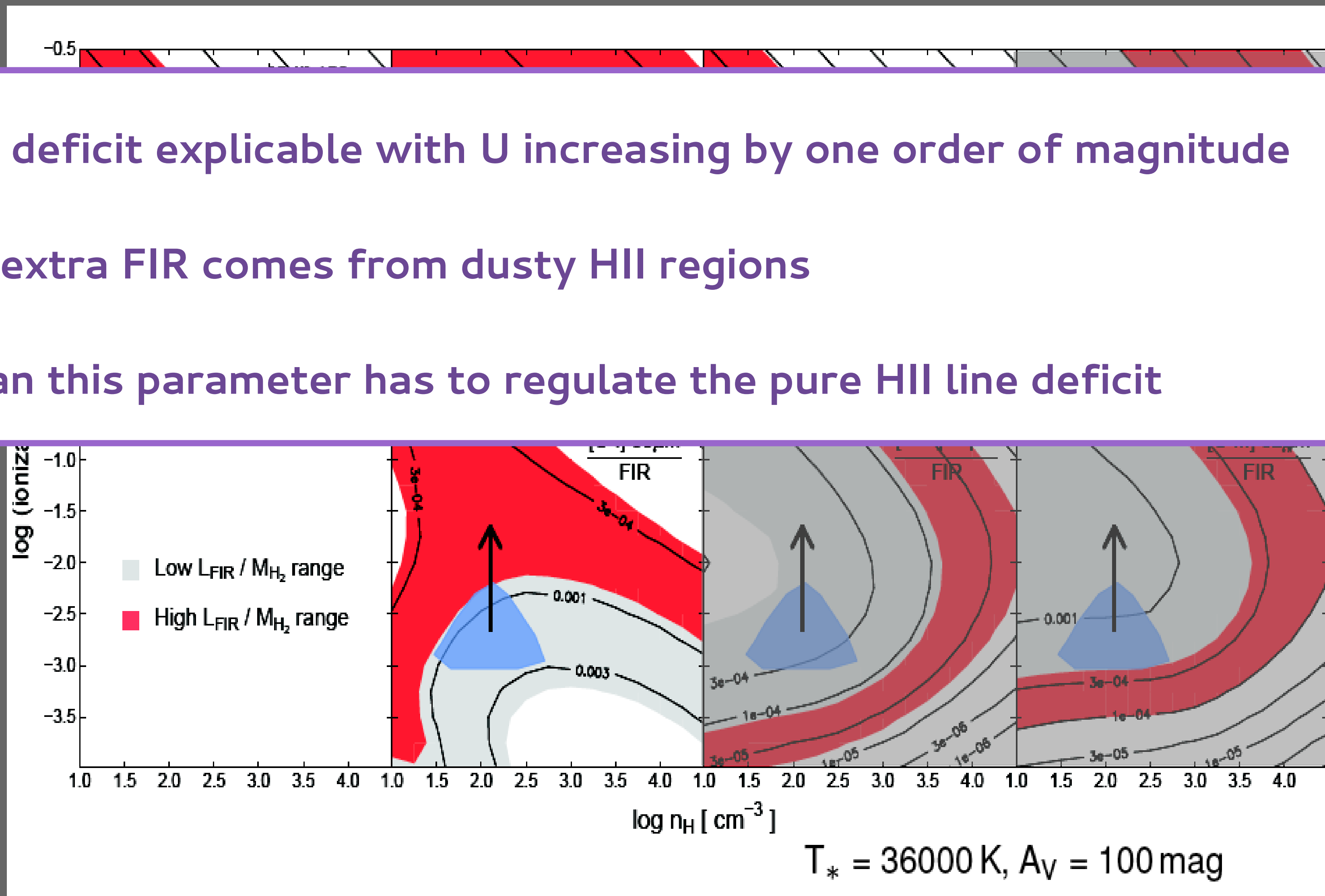
Cloudy Models
Graciá-Carpio+ 2011

The *"[CII] deficit"* becomes a line deficit

PDR line deficit explicable with U increasing by one order of magnitude

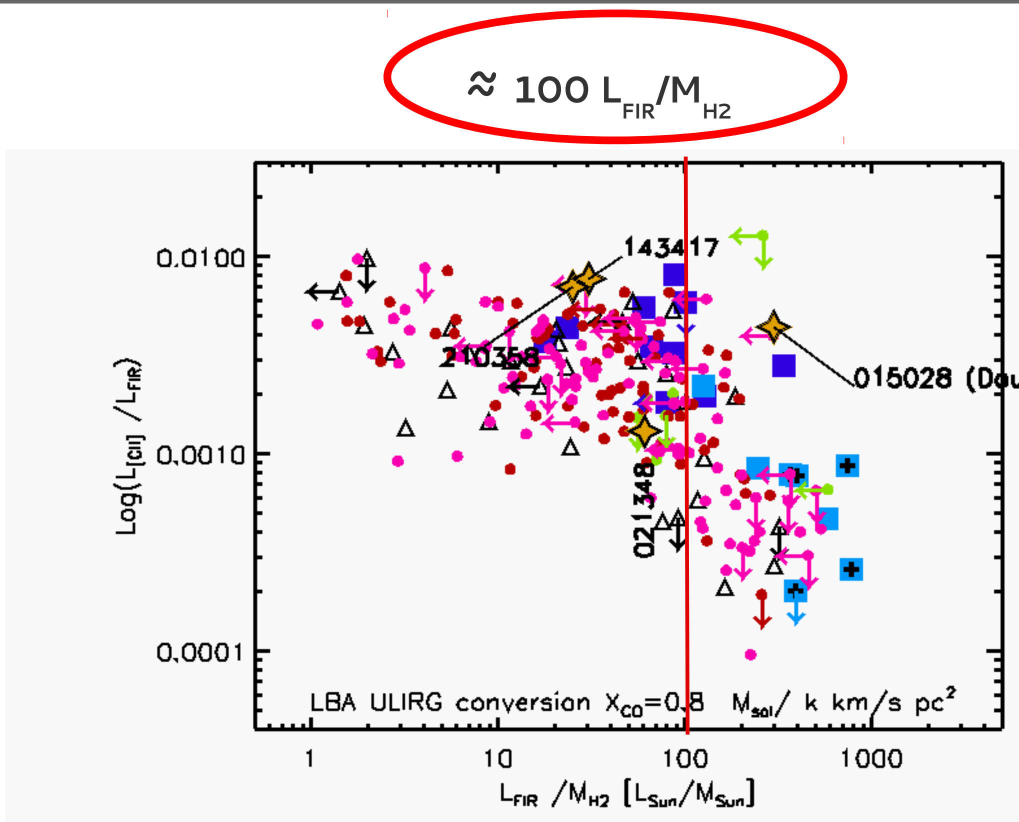
In these extra FIR comes from dusty HII regions

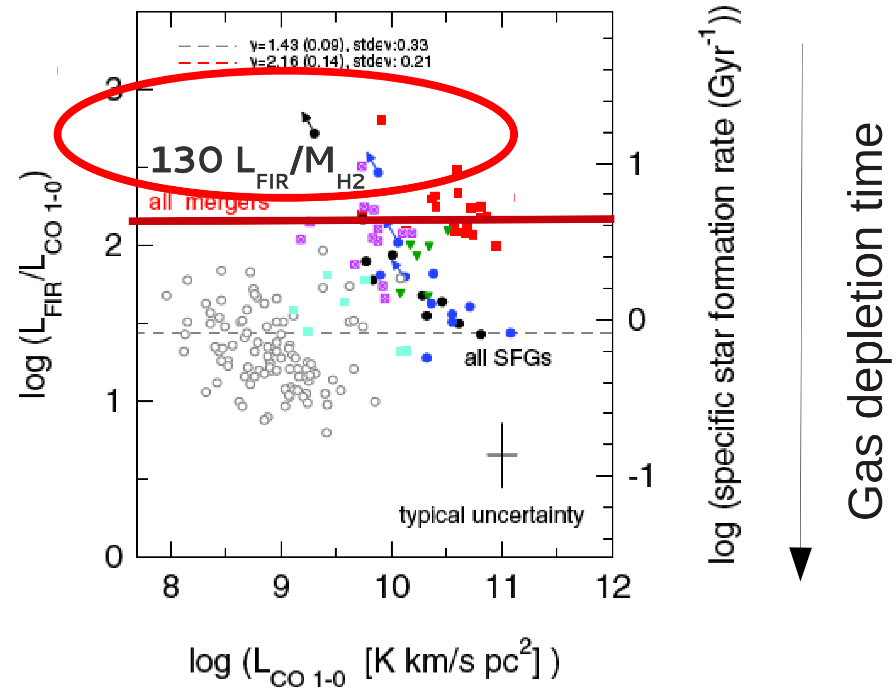
More than this parameter has to regulate the pure HII line deficit



Cloudy Models
Graciá-Carpio+ 2011

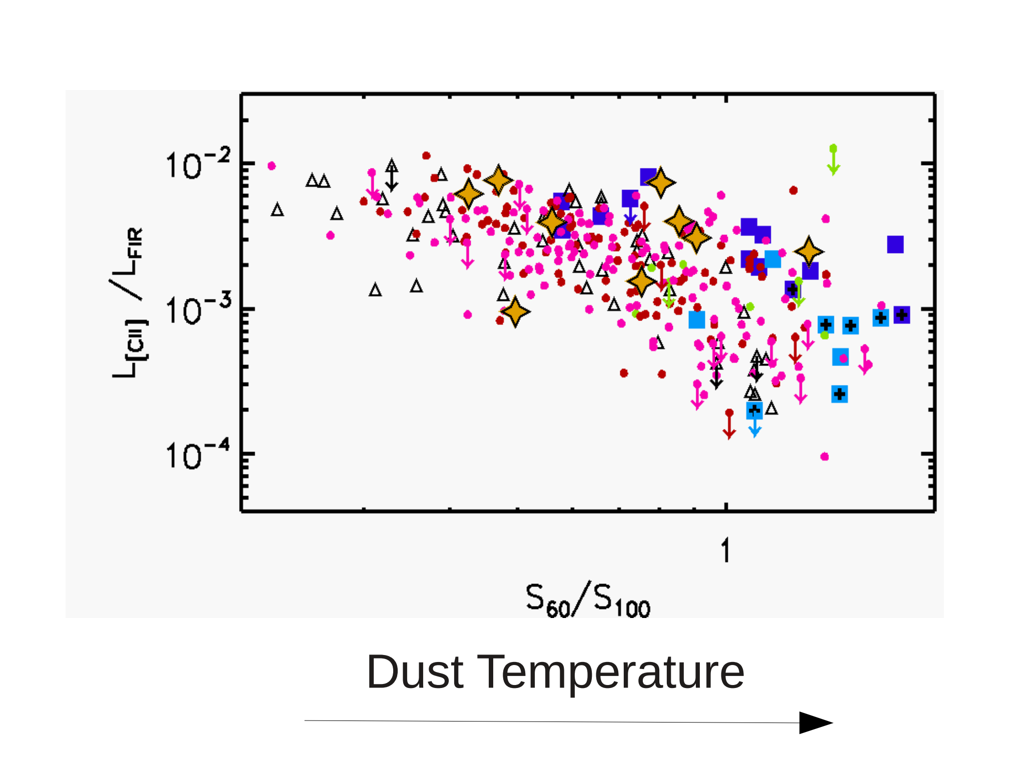
The "*[CII] deficit*" : high SFE

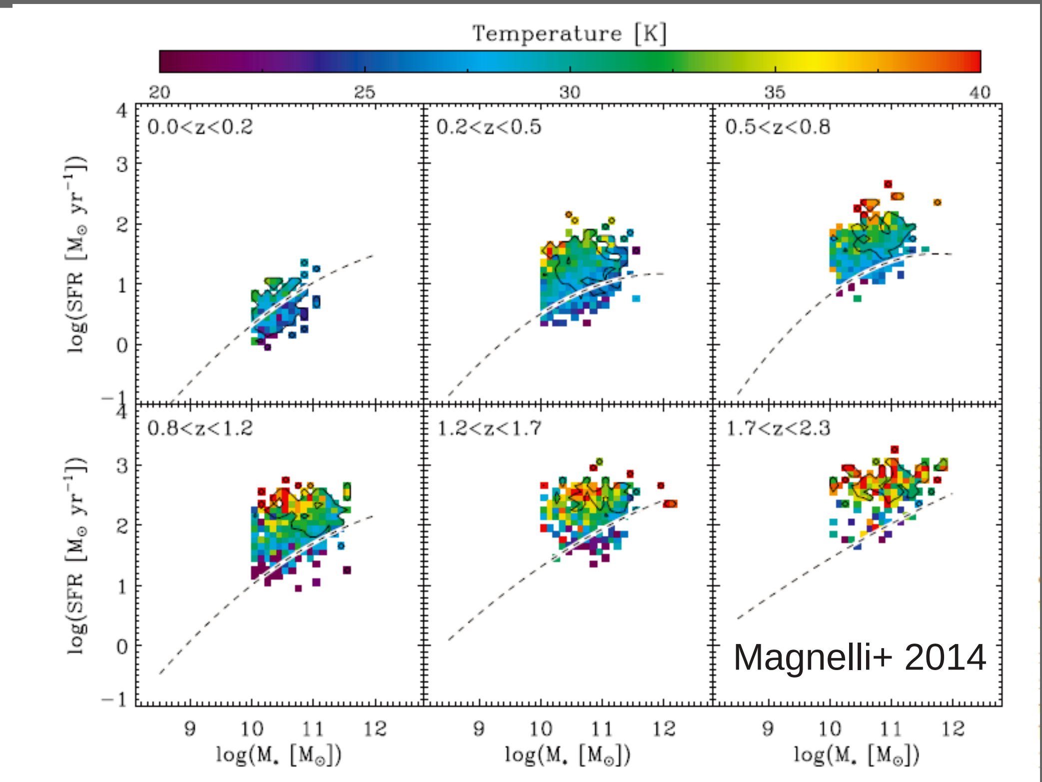




Independent on their redshift, galaxies with high SFE and high dust temperatures tend to have weaker lines compared with their FIR continuum. Dusty burst phase of SF

The "*[CII] deficit*" : where on the MS?





Galaxies having SF in a dusty burst with high efficiency (10%) have high dust temperatures, PDR line deficit and they likely lie above the MS.

Lyman Break Analogs (LBAs)

- Ultra compact UV luminous galaxies at $0.1 < z\ 0.3$ selected to have LUV > 2 x 10^{10} L_{sol} (Heckman+ 2005).

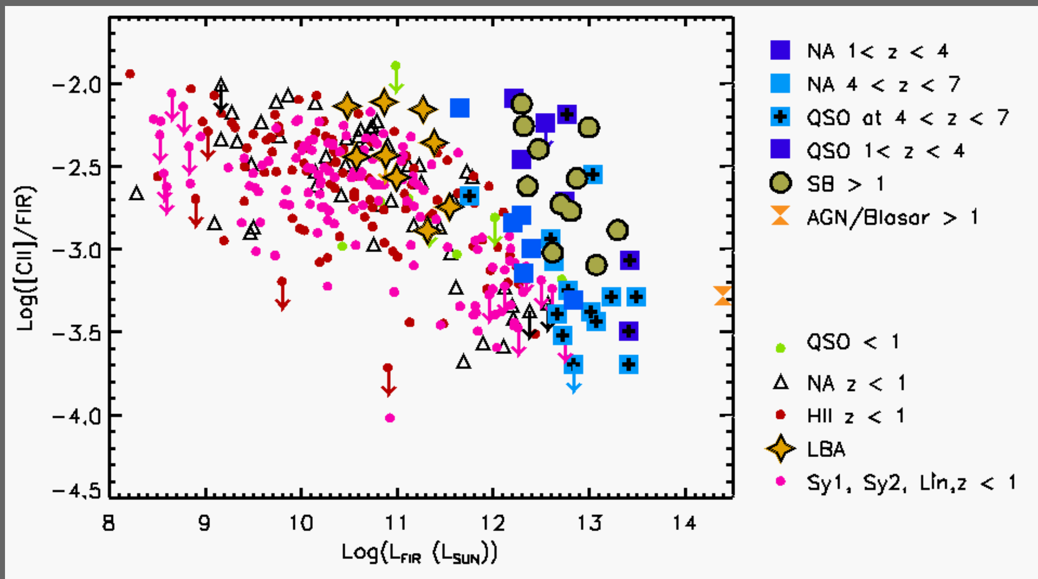
- They are **rare** in the Local Universe

- **If AGN present not dominant**

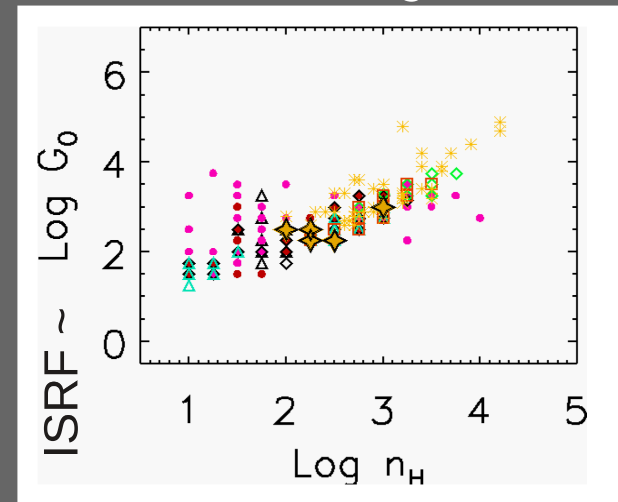
- Share many properties with LBGs (Heckman+2005), such as
  - -UV luminosities
  - -surface brightness
  - -stellar mass
  - -SFR
  - - metallicity
  - -gas velocity dispersion higher than in normal SF galaxies

Physical conditions of PDRs in LBAs

No [CII] deficit

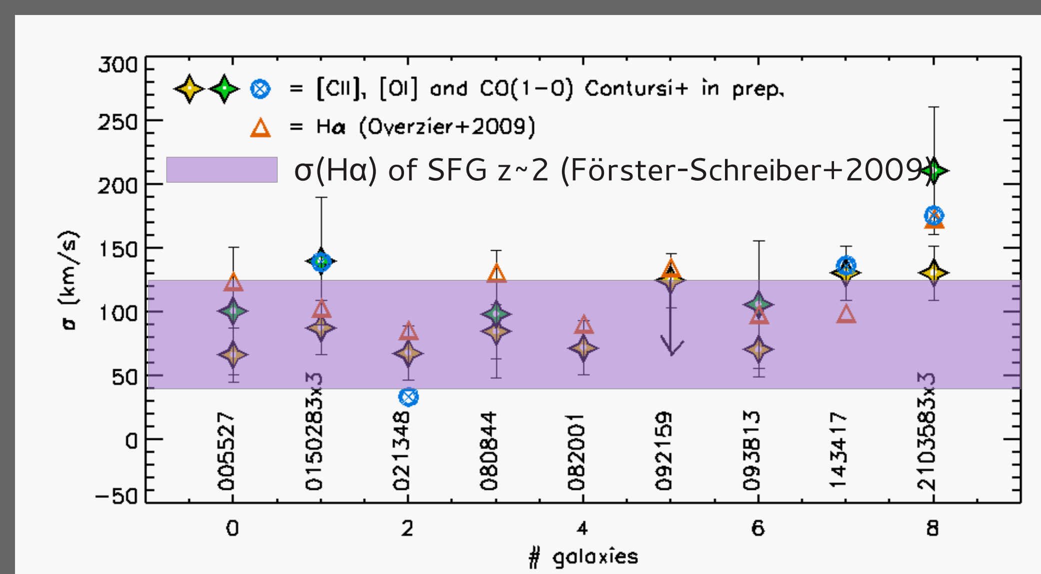


G_0 and n as in normal galaxies disks

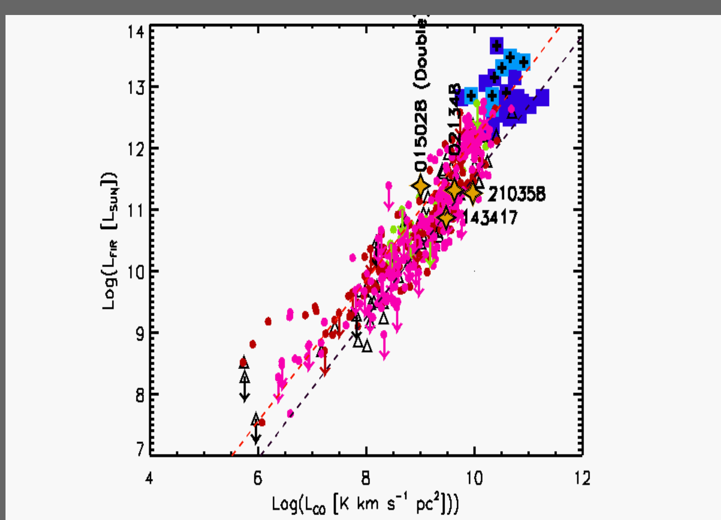


Same $\sigma_{dispesion}$ in CO, Hα, [CII] and [OI] high

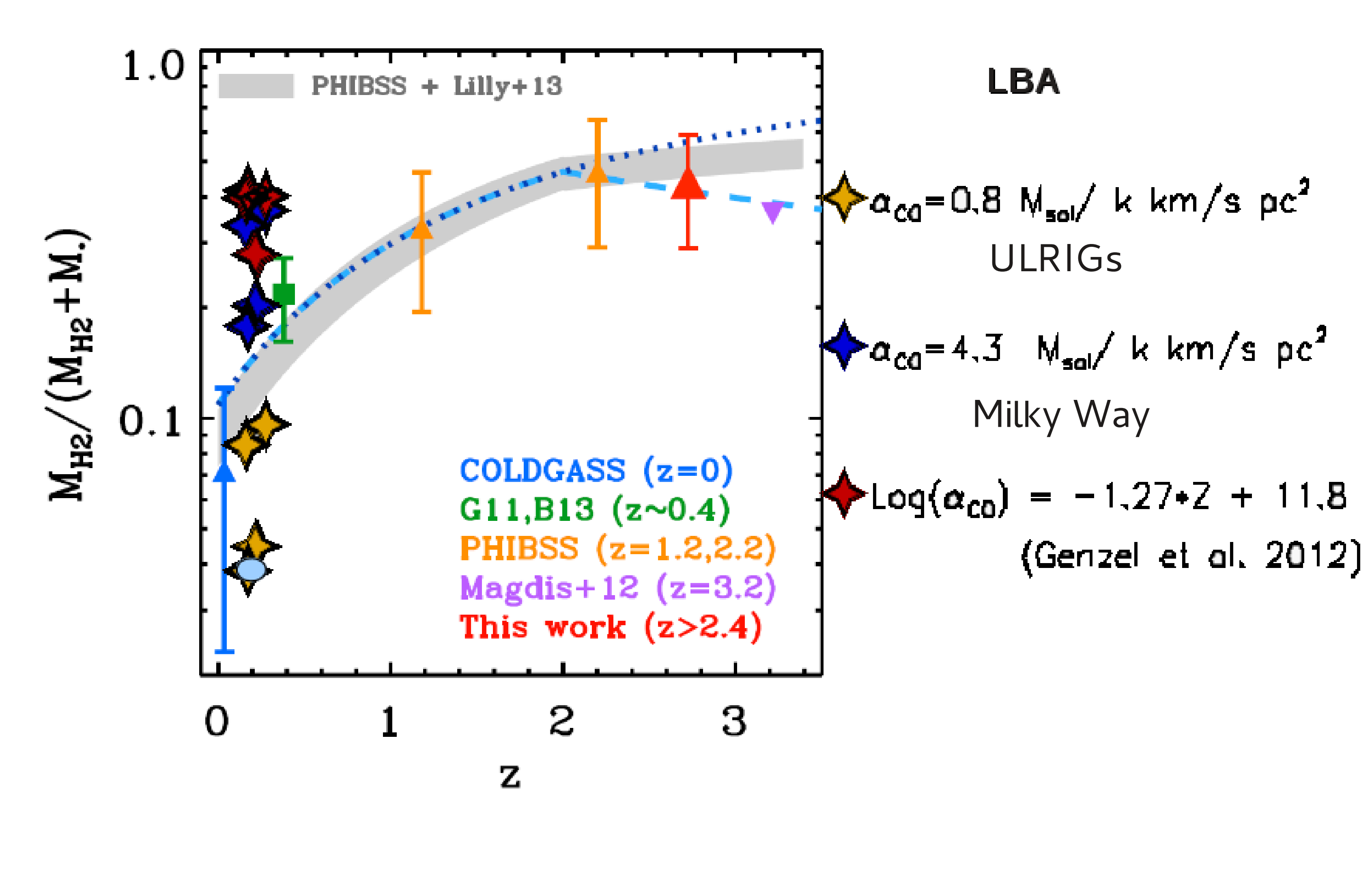
As in z~2 SFGs



KS of Star Forming galaxies



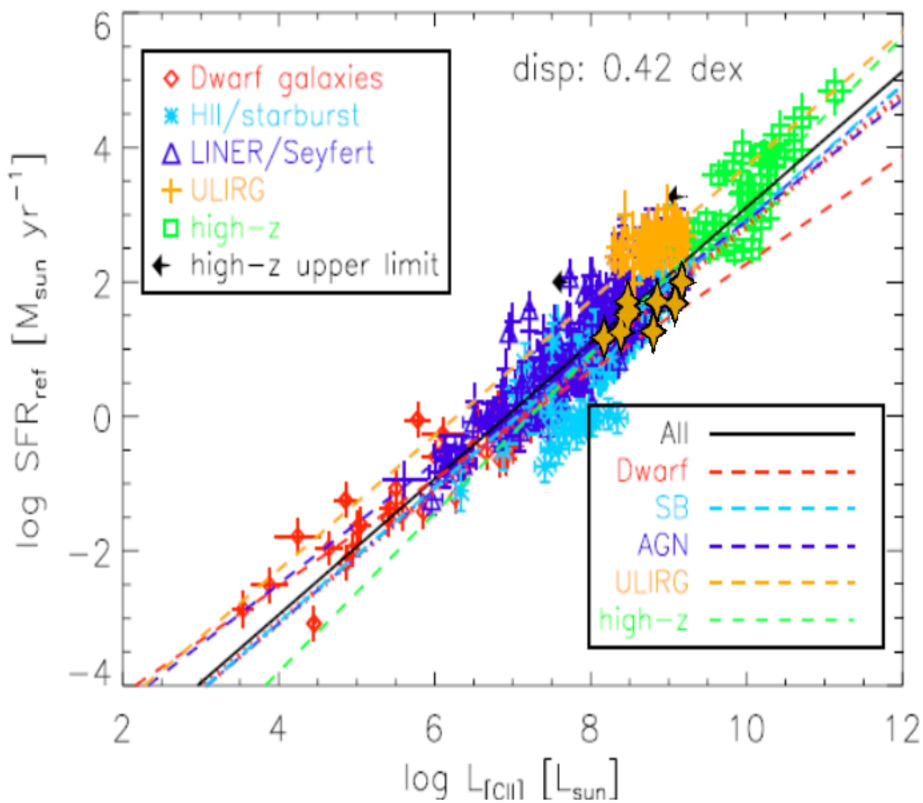
Physical conditions of gas in LBAs



Contursi+ in prep.

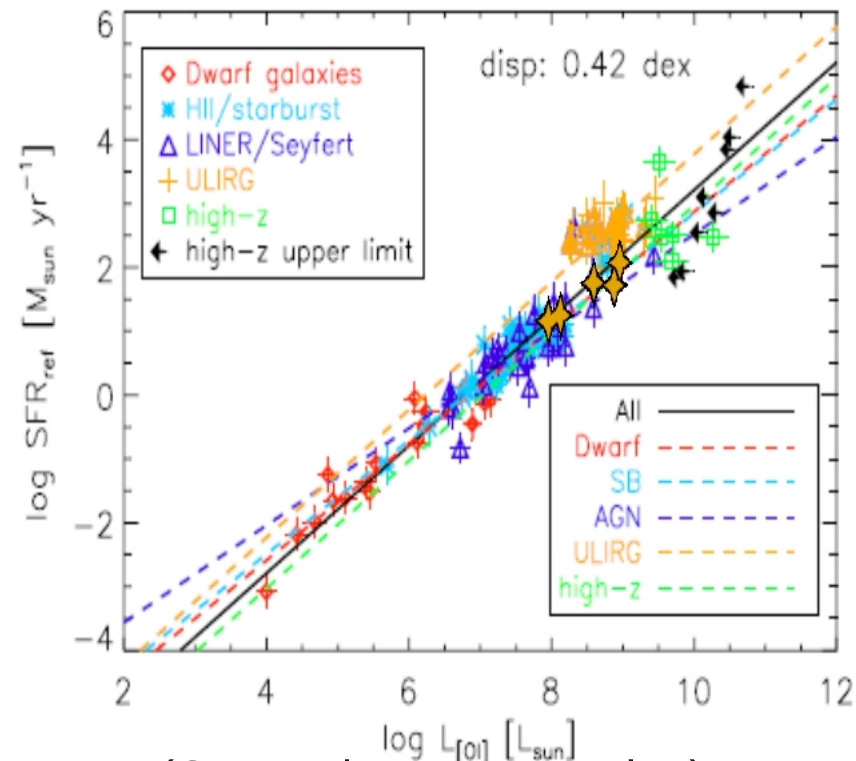
Is [CII] in LBAs a good SFR tracer?

SFR-[CII]



De Looze+2014

SFR-[OI 63μm]



LBAs (Contursi+ In preparation)

- LBAs are not CII deficient and follow the overall SFR-CII relation

High J CO lines

- Original aim was to probe tours in AGN (Krolik & Lepp 1989)

- H_2 ro-vibrational and rotational lines are the main coolants of very dense (n> 10^5) cm^{-3} and hot (T~10^3 K) gas, but they are extincted

- High (J> 13) CO lines arise from states 500-7000 K above ground, have critical densities of ~10^{6-8} cm^{-3} BUT are less extincted.

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- H_2 ro-vibrati
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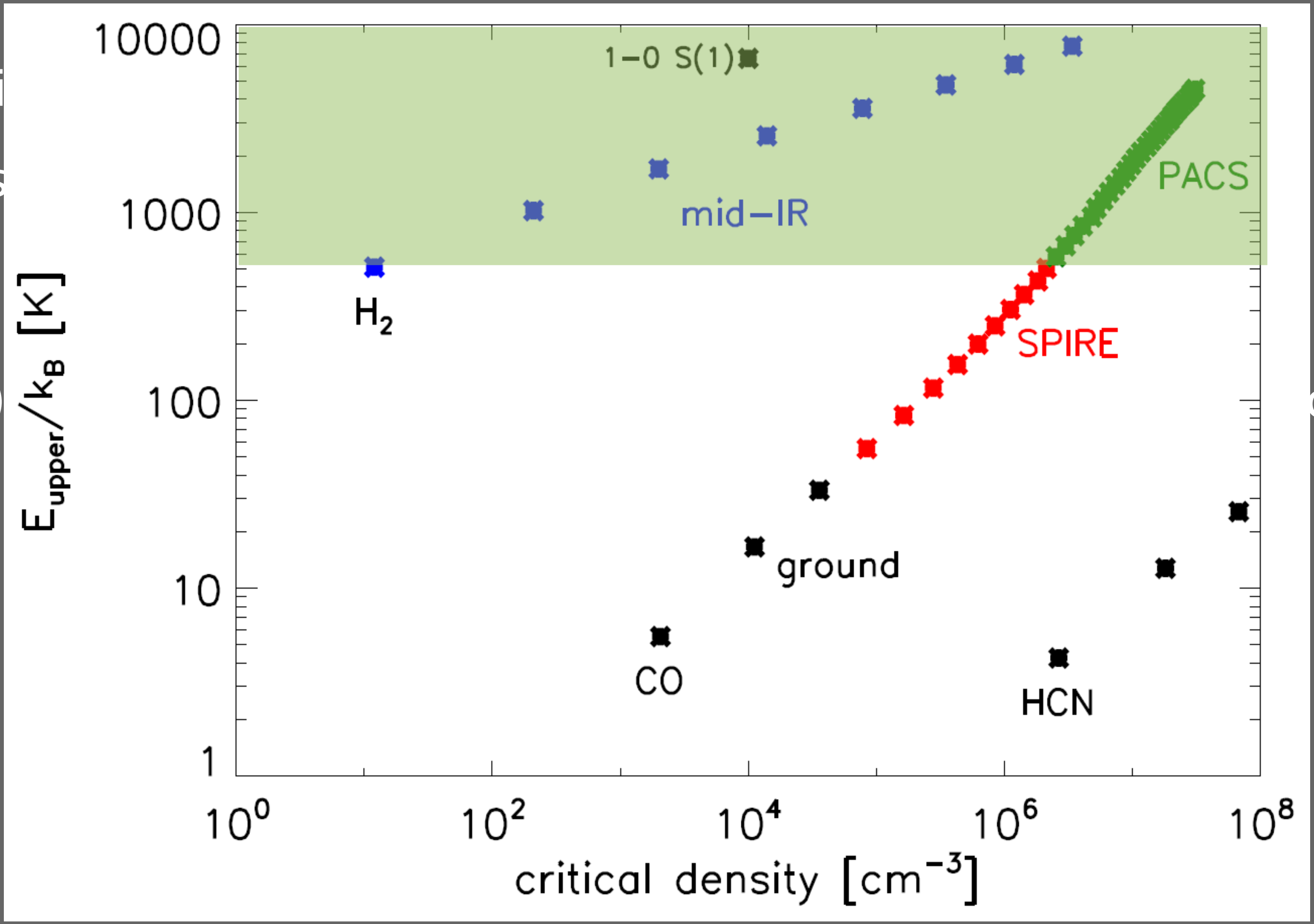
  have critical



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- Ideal to probe the AGN Xray dominated regions (XDRs)

High J CO lines

- H_2 ro-v
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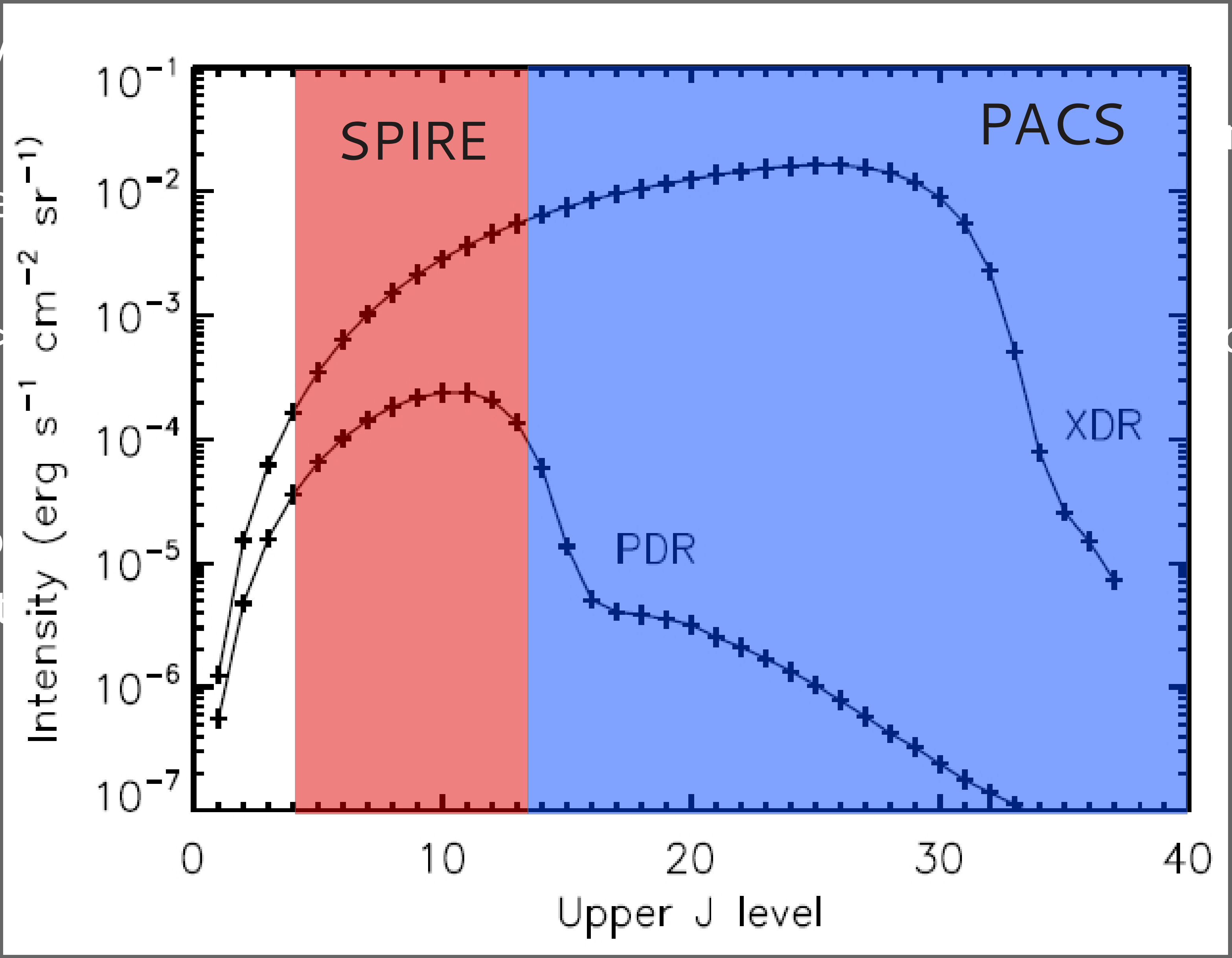
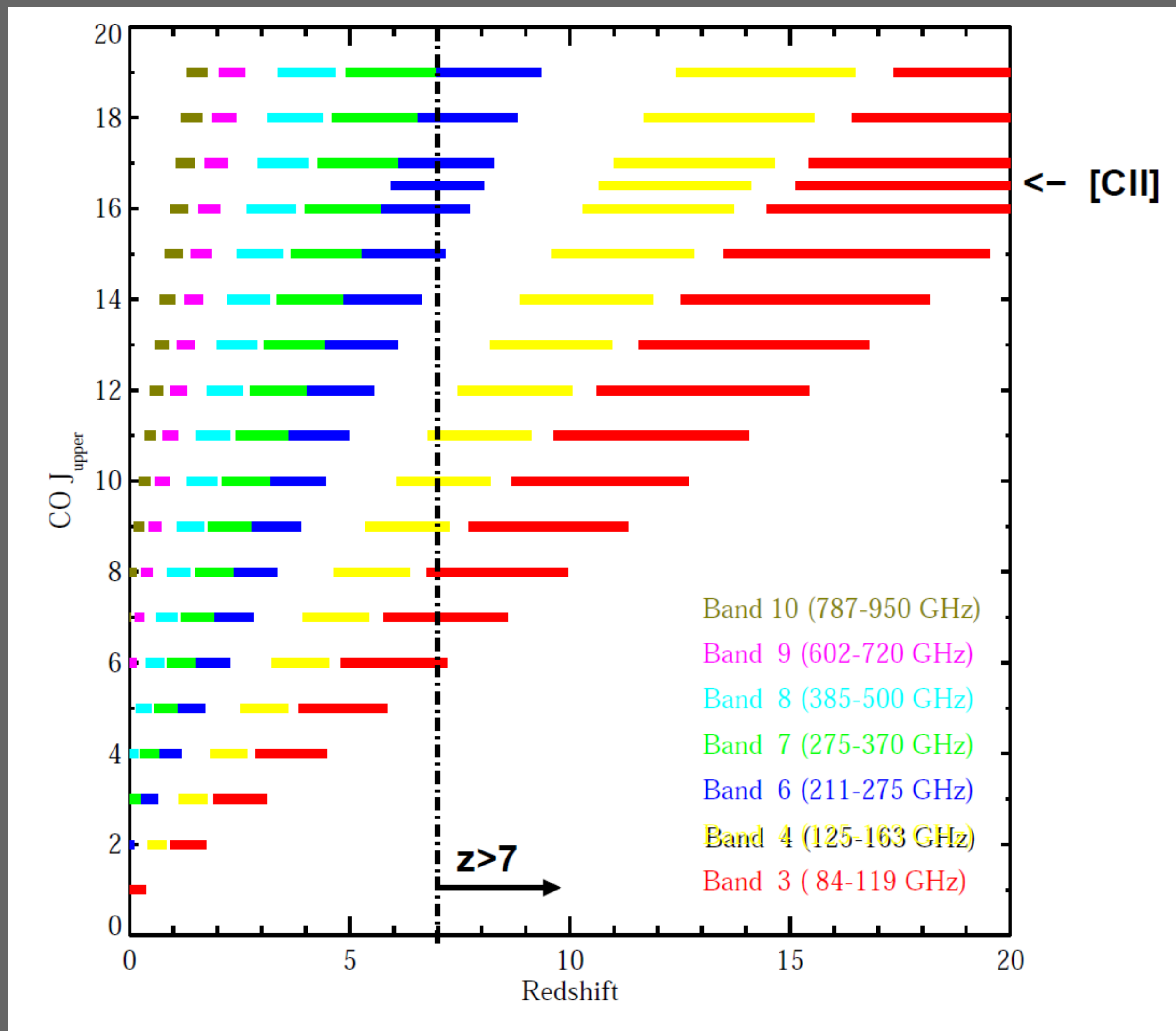


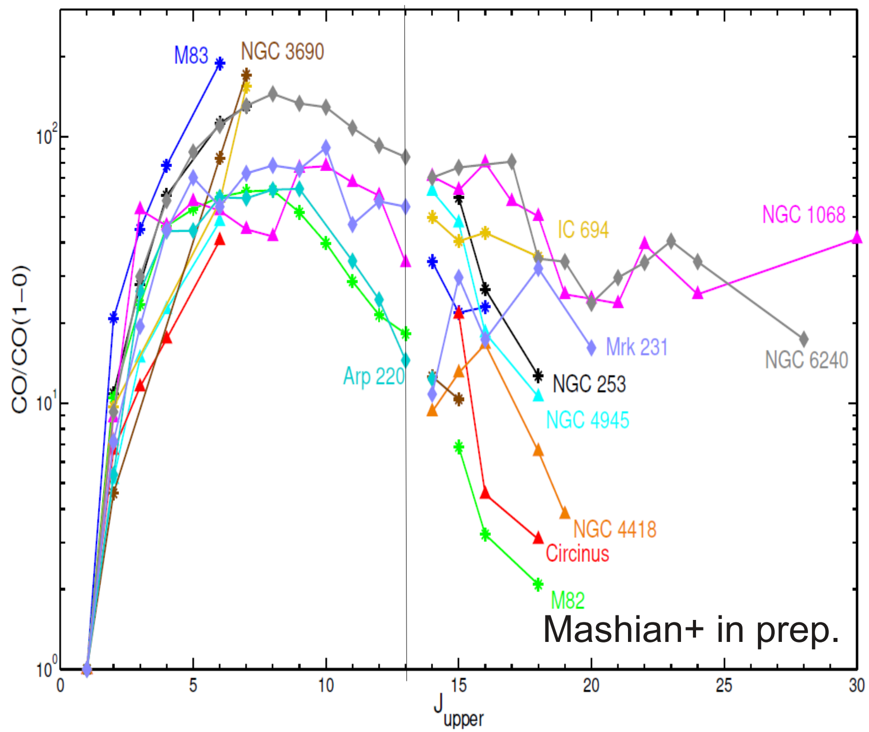
High J CO(1–0) lines

These are the lines one gets with ALMA for very high (z > 7) galaxies

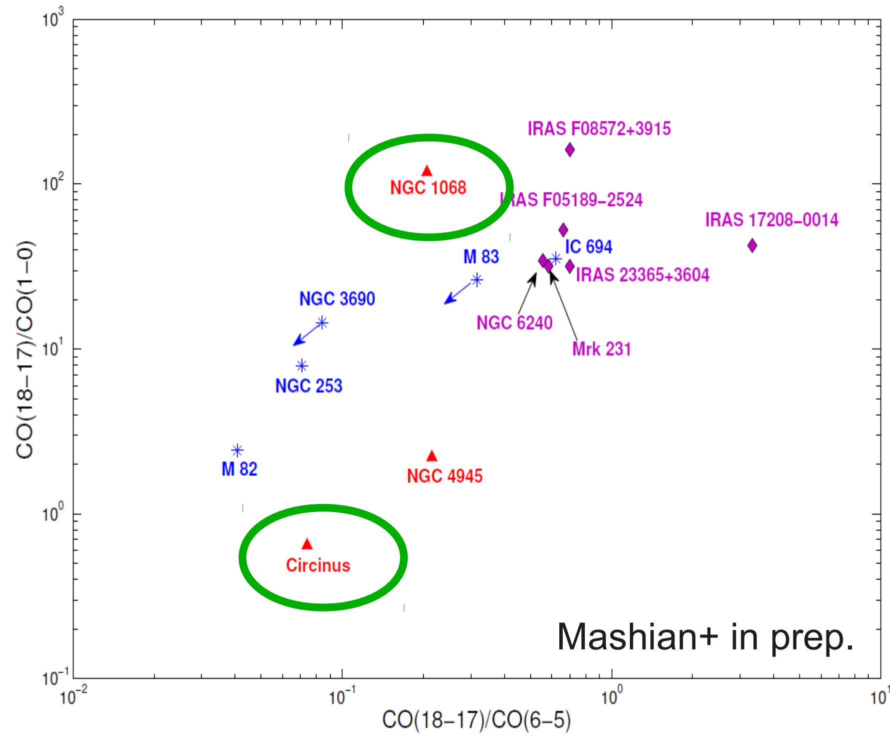


High J CO(1–0) lines

CO SLED PACS/SPIRE sample



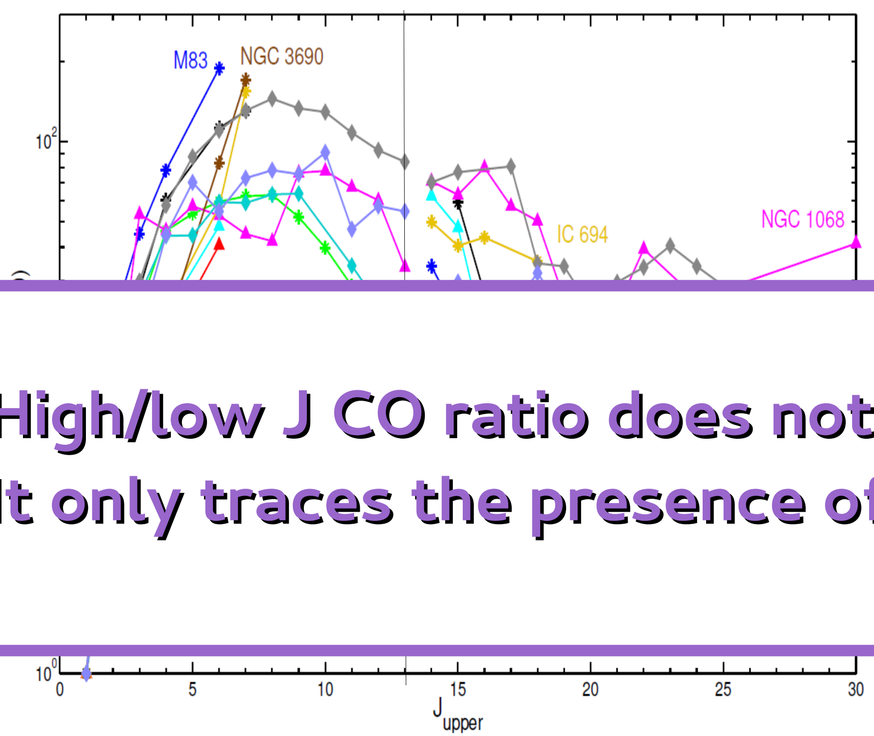
Diagnostic diagram



- Starburst
- Seyfert
- ULIRGs (SB and AGNs)

High J CO(1–0) lines

CO SLED PACS/SPIRE sample



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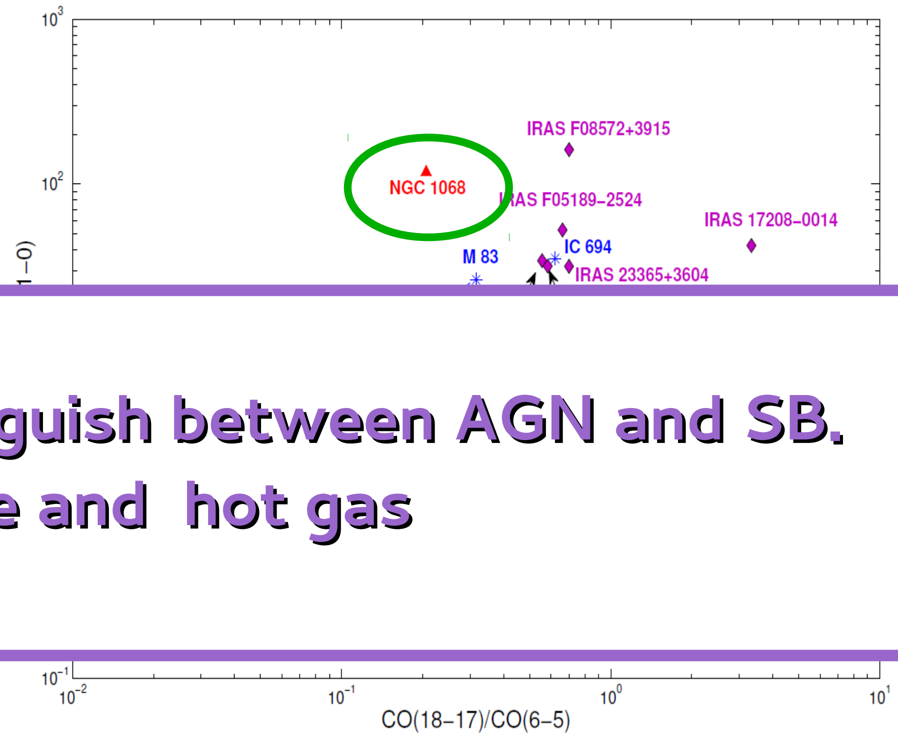

High/low J CO ratio does not distinguish between AGN and SB.
It only traces the presence of dense and hot gas

- Starburst
- Seyfert
- ULIRGs (SB and AGNs)

Summary

- Powerful high velocities molecular outflows detected in OH:
  - Are quite common in local ULIRGs.
  - Are mainly AGN driven.
  - Have high outflow mass load factor where AGN dominates.
  - Imply short time scale for expelling the cold gas (SFR reservoir)
    QUENCHING in act?

- Many outflows gas phases with different kinematics are often present
  In M82 CO,PDR lines and [OIII] 88 μm line are coupled and much slower
  Than hot wind fluid.
  The cold gas is entrained by the wind, where survives in dense, small clouds.
  Clod and neutral gas are the more massive components of the outflow
  Important for deriving mass loading factors.

Summary

- [CII] deficit extends to all fine structure FIR lines for high SFE ~U at all z. These conditions are met in merger induced Starburst galaxies, that lie above the KS relation for "normal" galaxies, and above the MS.
  This explanation though is not sufficient to account for the pure HII lines deficit. Towards a two component phase model

- Is [CII] a good SFR tracer (and a redshift machine) for high-h z MS galaxies? Observations of local Lyman Break Analog galaxies show that these are not [CII] deficient and that they follow the local [CII]-SFR relation.

- Observations of very high (J>13) CO lines show that they do not trace the presence of AGN as expected, rather the presence of dense and warm gas.