Tracing AGN accretion and Star-Formation with far-IR lines

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+
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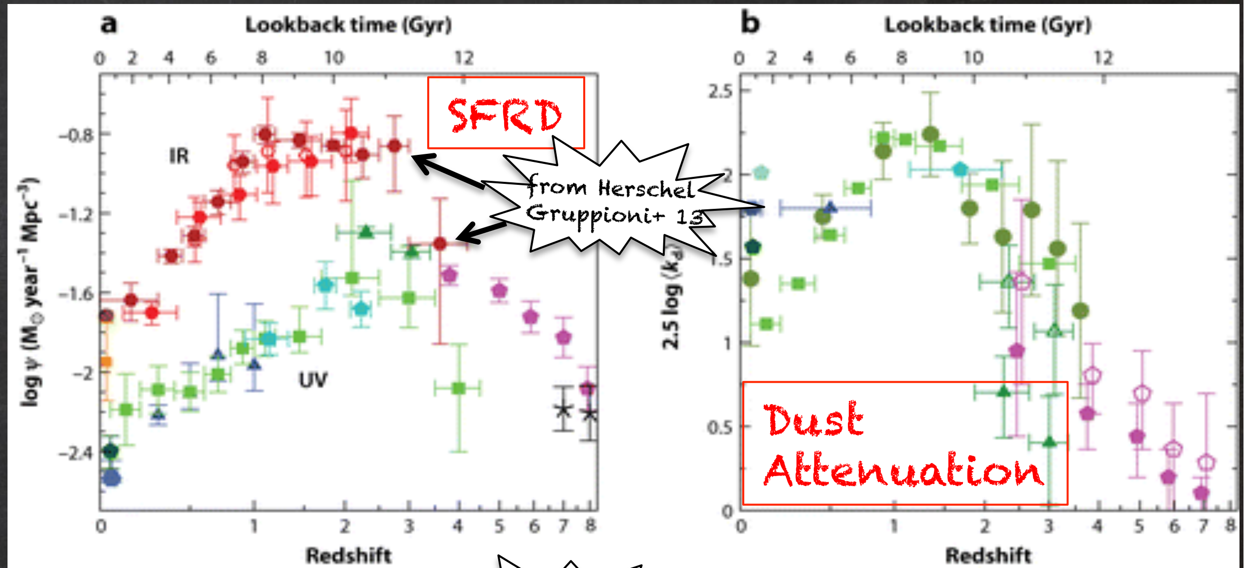
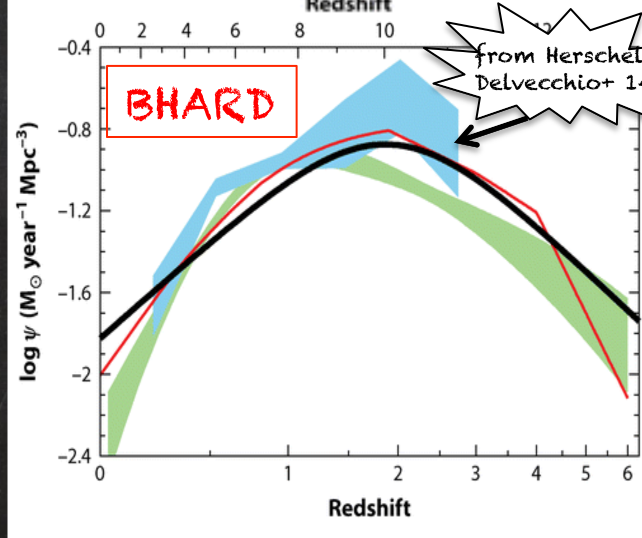
ALMA-Herschel Workshop - ESO, 2015 April 15-17

Co-eval growth of SMBHs and Host Galaxies





Madau P, Dickinson M. 2014.
Annu. Rev. Astron. Astrophys. 52:415–86

Dust enshrouded SF and AGN accretion

Both peak at z~2-3

Key AGN signatures: high-excitation fine structure lines

e.g. [NeV] 14.3 μm
[OIV] 26 μm

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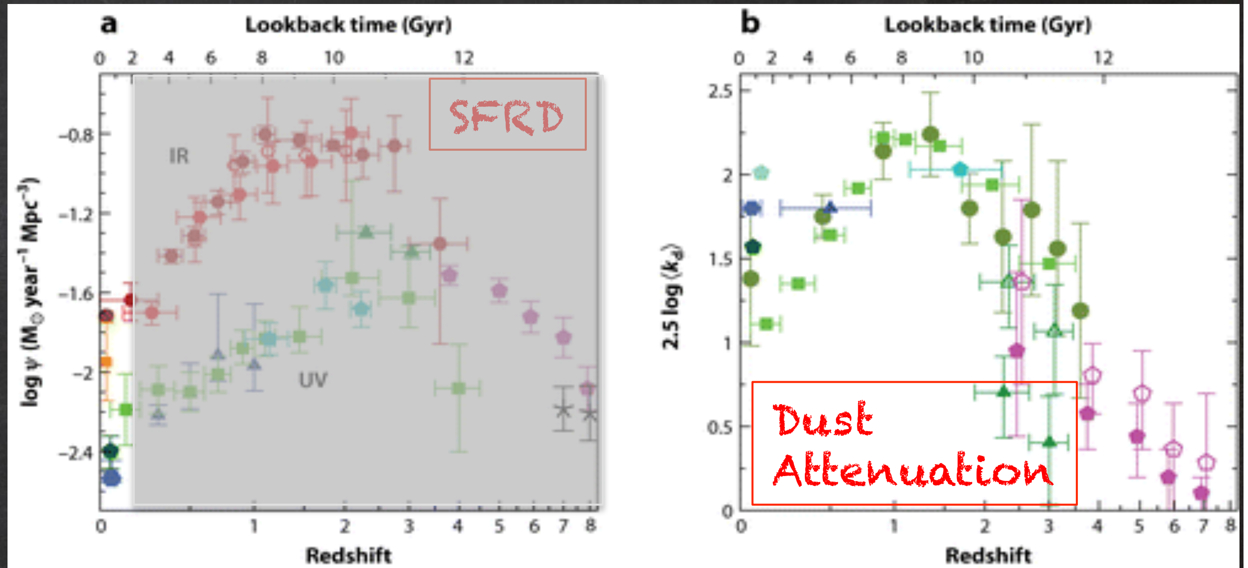

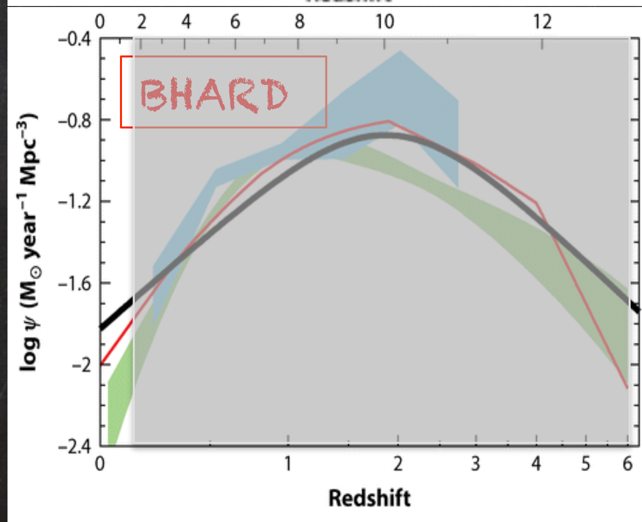

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Key Science

- The most dramatic phase of evolution for AGN and their host galaxies occurred between z~3 and the present day (84% of the age of the Universe) → obscured by dust

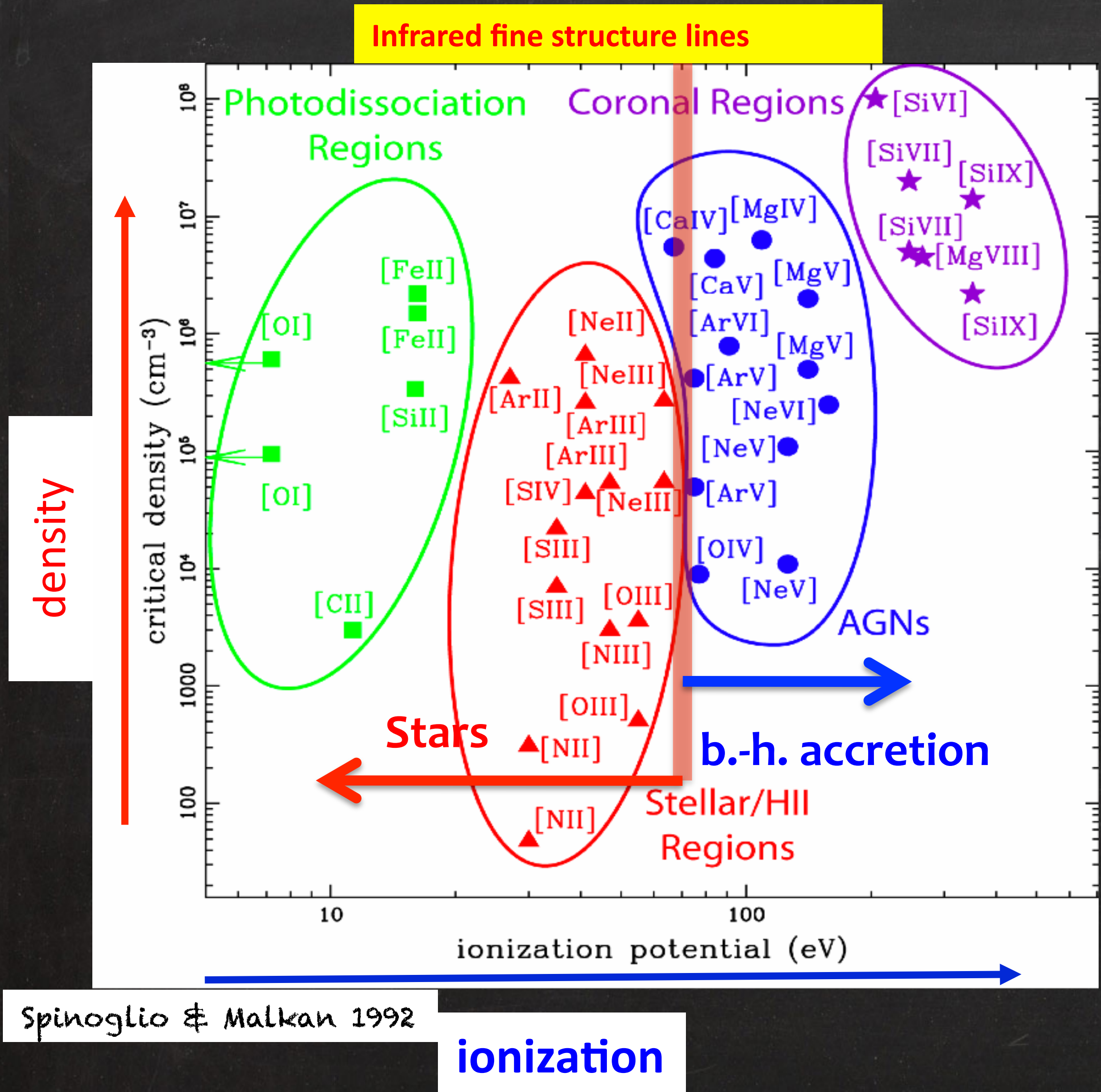
- Thermal continuum peak (T_{dust}, M_{dust}, L_{IR}, SFR) and the fine-structure lines of ionised atoms ([O III] 88μm, [C II] 158μm, ...) → far-IR ($0<z<3$)

- At $z > 3$ these enter into the ALMA range.

- At lower z's must rely on Spitzer & Herschel

➡ FIND A LOCAL CALIBRATION WITH PHOTOMETRIC RESULTS & CONSIDER EVOLUTION DERIVED FOR HERSCHEL GAL'S & AGN

Why infrared spectroscopy is the best tool to isolate star formation and accretion?

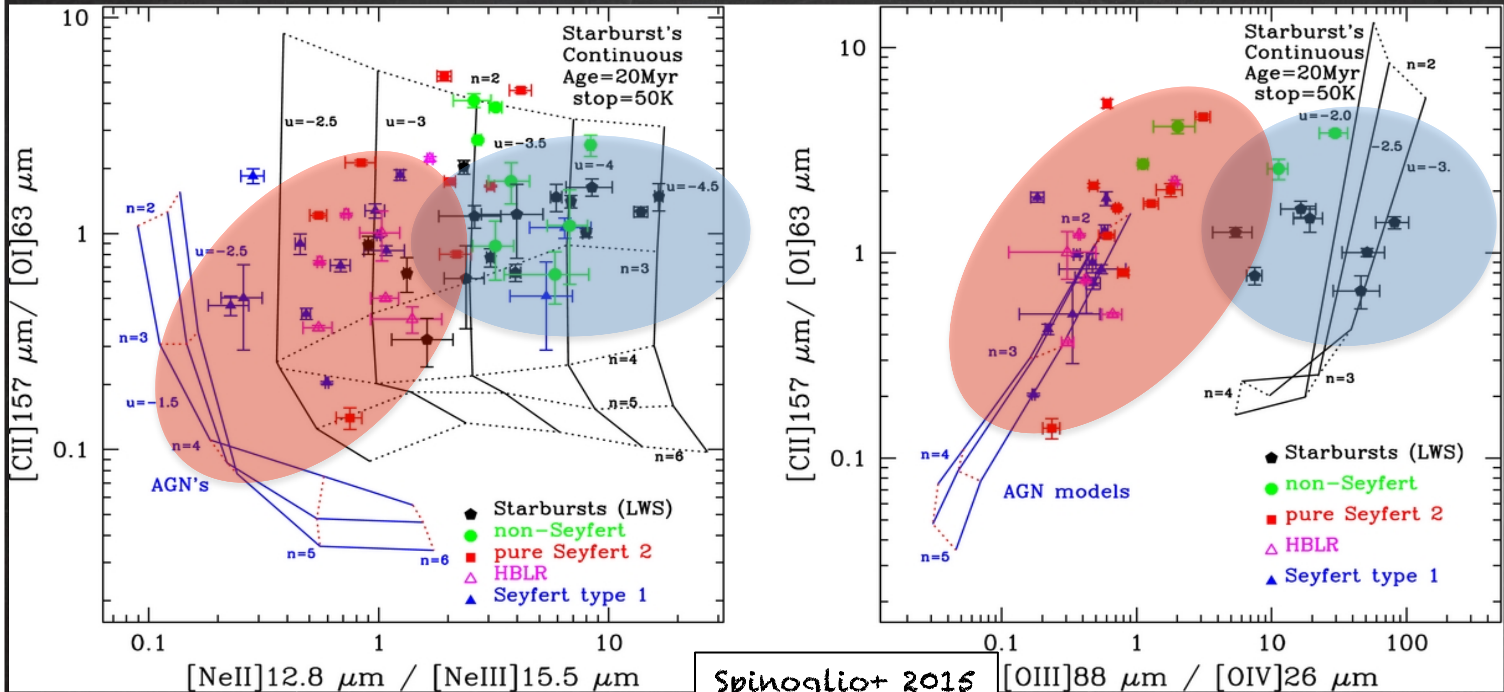


Spinoglio & Malkan 1992

IR fine structure lines:

- separate different physical mechanisms,
- cover the Ionization/density parameter space
- do not suffer from extinction

MIR and FIR lines as AGN/SB diagnostics



Spinoglio+ 2015

In the MIR:

[NeV]14.32 μm and [OIV]25.89 μm are the best AGN tracers

PAH EW are mostly tracing SF activity

The 3 strongest FIR lines can separate the 3 dominant energy sources in galaxies:

1. AGN: strong [OIII] (NLR), but also strong [OI] (enhanced in XDR and with n_{crit}~10^6 cm^{-3})

2. Starbursts: strong [CII] (PDRs) and [OIII] (HII regions)

3. Pure PDR: from the quiescent disk in the spiral galaxy: strong [CII] and [OI], but no [OIII]

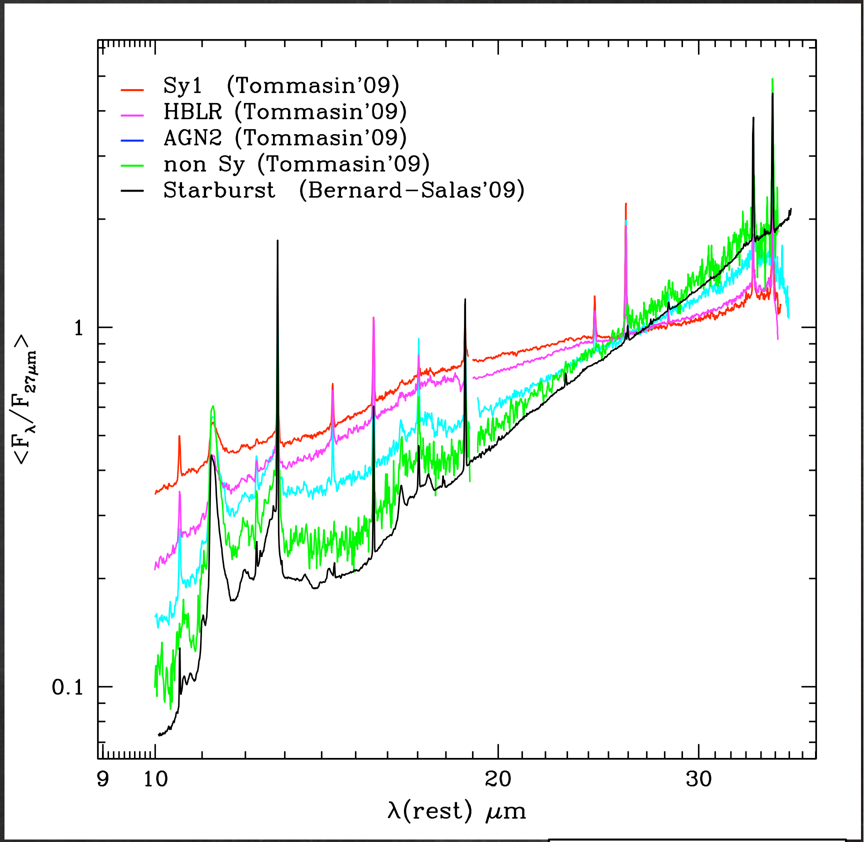
The Extended 12-μm Sample

★ 893 galaxies from the IRAS FSC-2: 12 μm flux limit > 0.22~Jy (Rush, Malkan & Spinoglio 1993)

★ 118 Seyfert galaxies (53 Seyfert 1 and qso, 63 Seyfert 2 and 2 blazar (13% of the total sample)

★ ISO spectra (Spinoglio, Andreani & Malkan 2002)

★ Spitzer IRS low (Wu+ 2009) and high resolution spectra (Tommasin+ 2010)



Tommasin+ 2010

★ PACS (Spinoglio+ 2014) of 26 and SPIRE spectra of 11 Seyfert (Pereira-Santaella+ 2013)

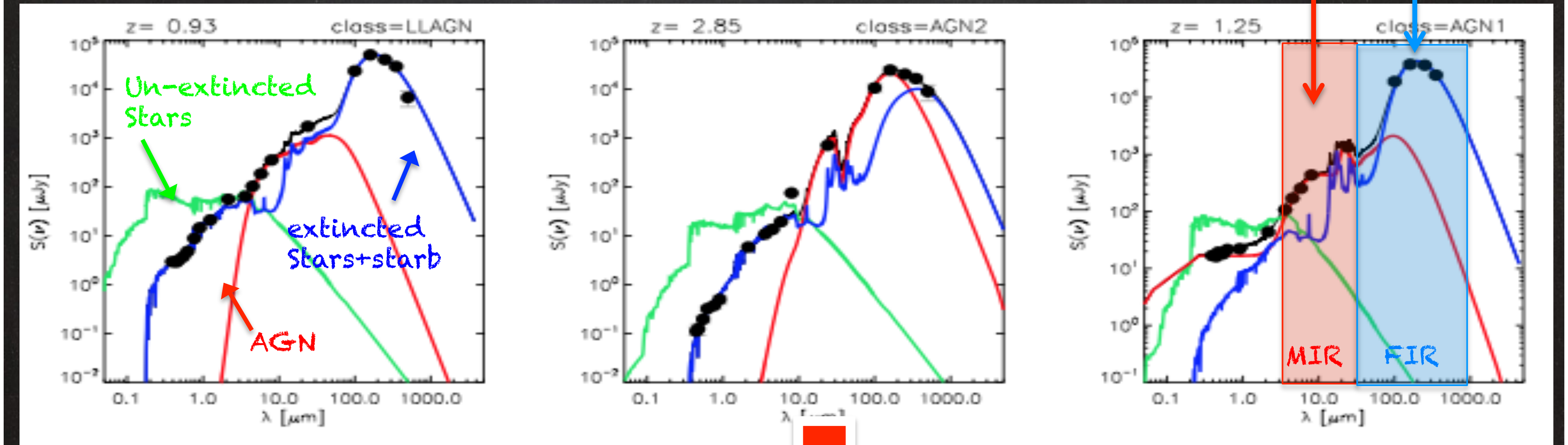
➔ Selected a sub-sample of 76 sources with good quality IRS spectra for SED analysis

Broad-band SED-fitting Decomposition

Modified MAGPHYS + AGN
(daCunha+08 + Feltre+12 => Berta+13):
Self-consistent link of the energy absorbed by dust in the UV-optical and dust emission in the MIR/FIR + torus emission

MIR: for AGN

FIR: for SF

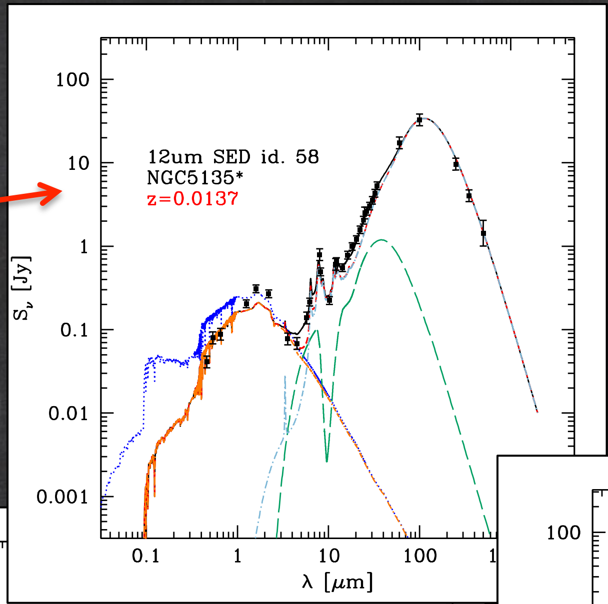


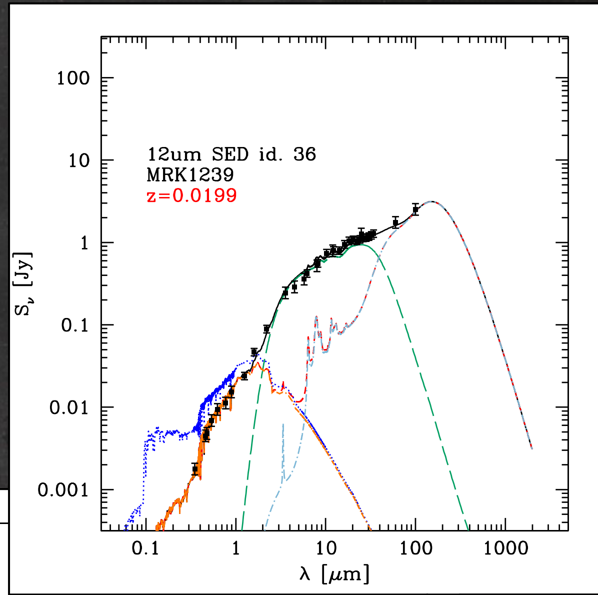
L_{ACC} from AGN torus model
L^{SF} from re-emitted stellar light
(L_{IR}[8-1000μm] is a proxy)

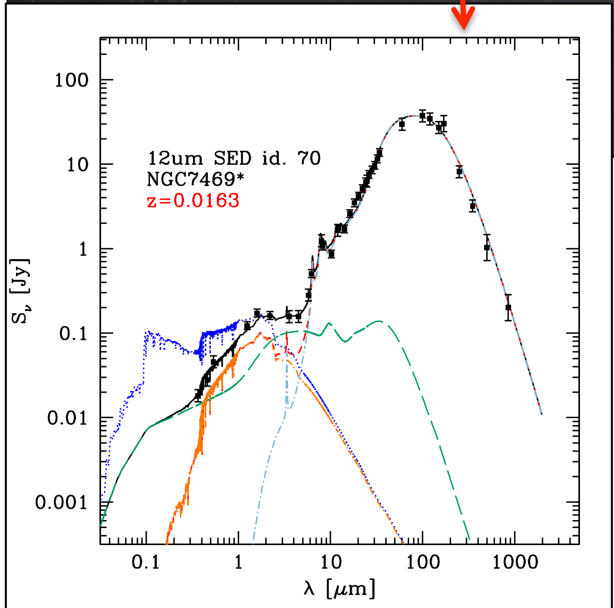
Broad-band SED-fitting Decomposition

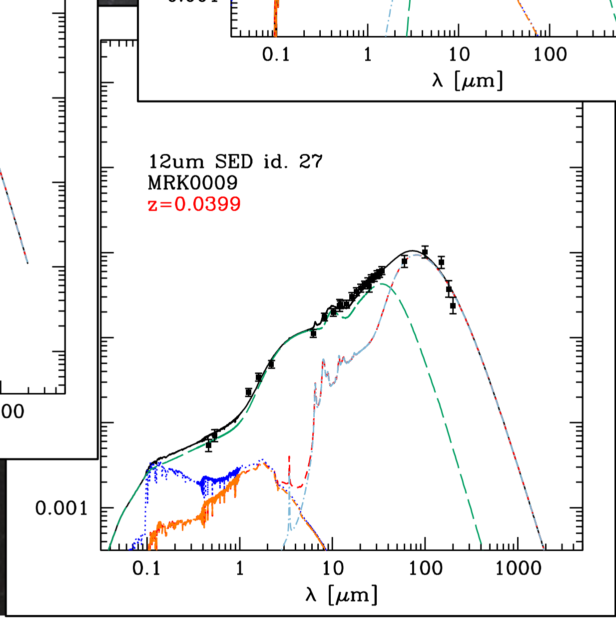
Modified MAGPHYS + AGN
(daCunha+08 + Feltre+12 => Berta+13)

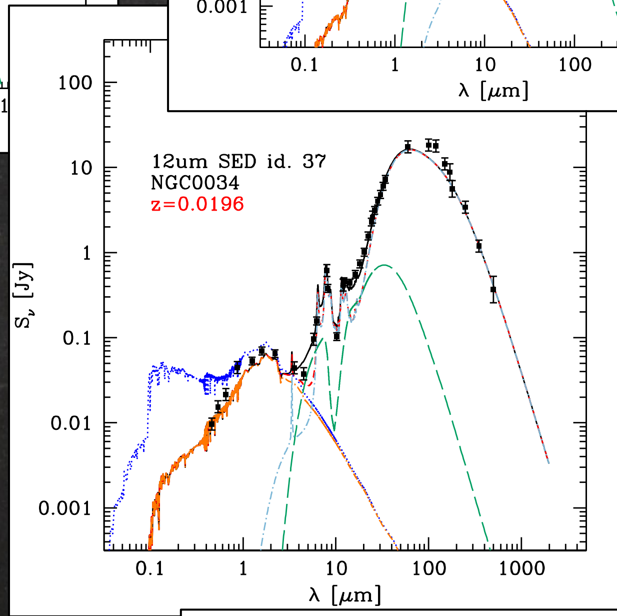
Some Examples of SED-decomposition



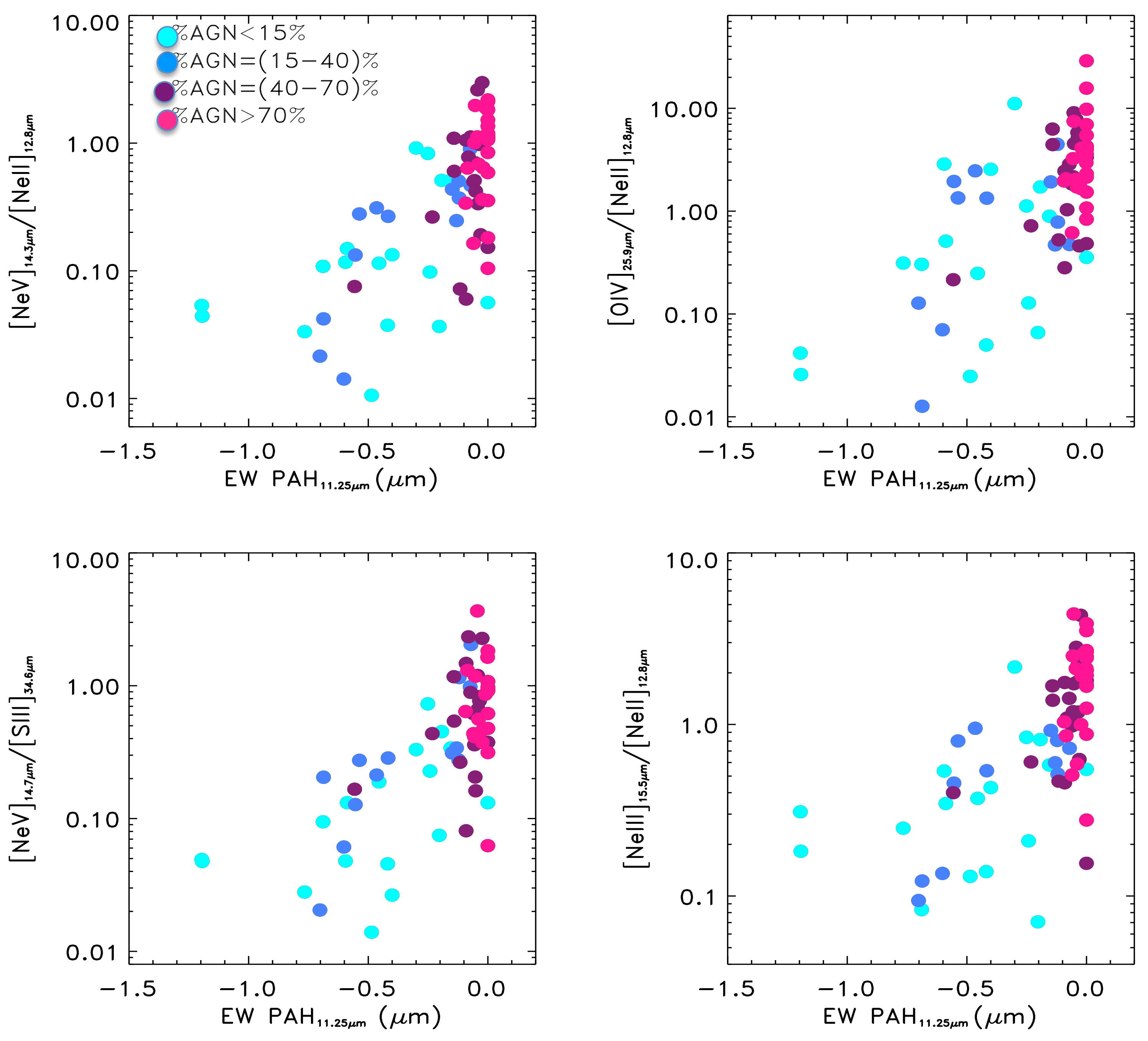




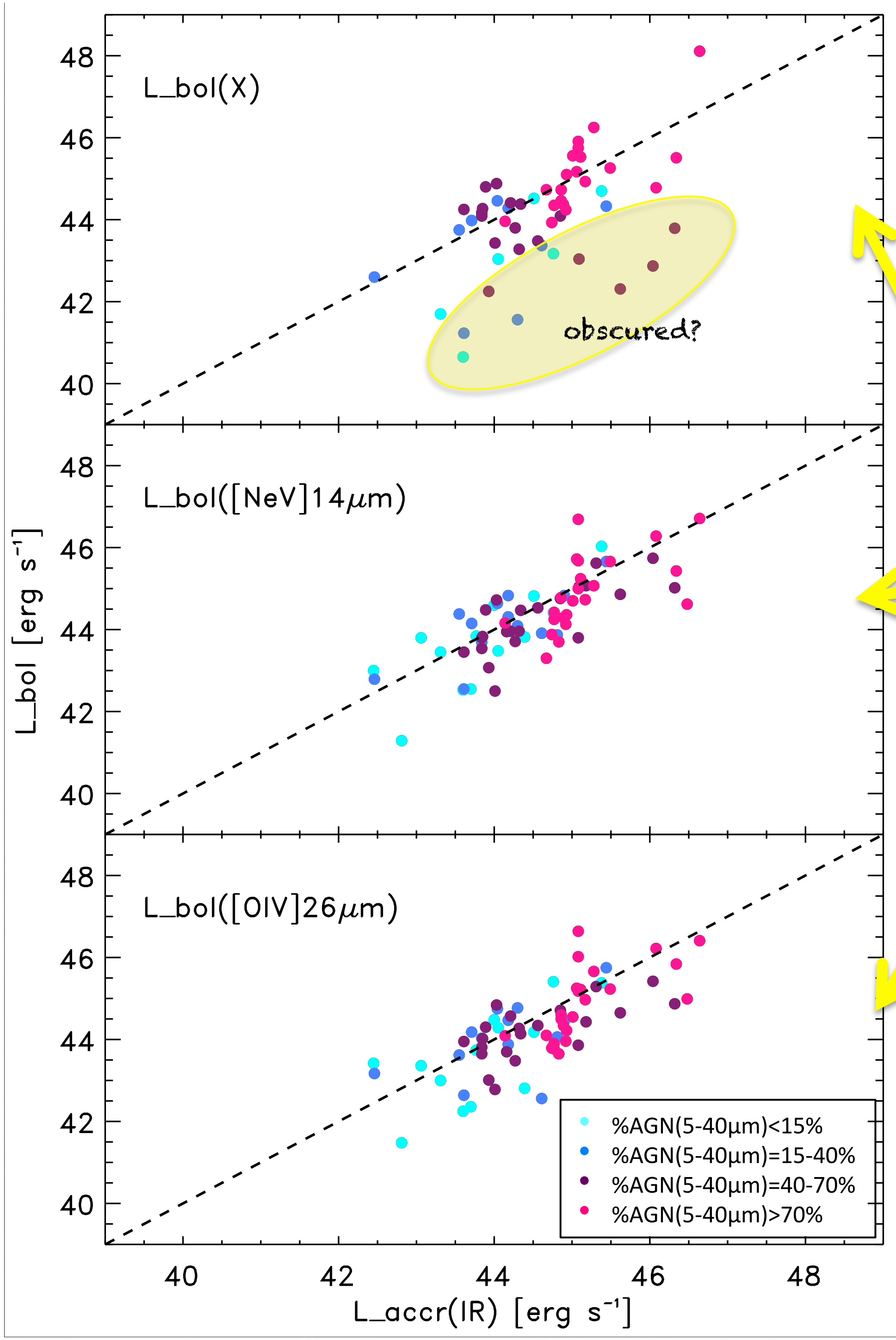




CG, Berta, Spinoglio+ 2015



%AGN<15%
%AGN=(15−40)%
%AGN=(40−70)%
%AGN>70%
[NeV]14.3μm/[NeII]12.8μm
[OIV]25.9μm/[NeII]12.8μm
[NeV]14.7μm/[SIII]34.6μm
[NeIII]15.5μm/[NeII]12.8μm
EW PAH11.25μm (μm)



L_{acc} derived from SED-fitting (= $L_{bol}^{AGN}(IR)$) compared with L_{bol}^{AGN} from other estimators (i.e. X-ray, [NeV], [OIV])

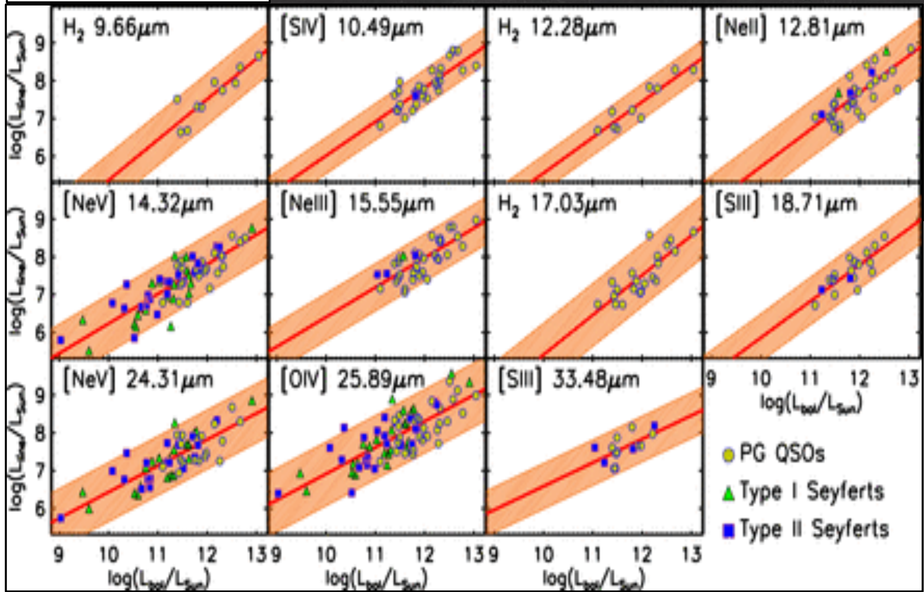
Very good Agreement!

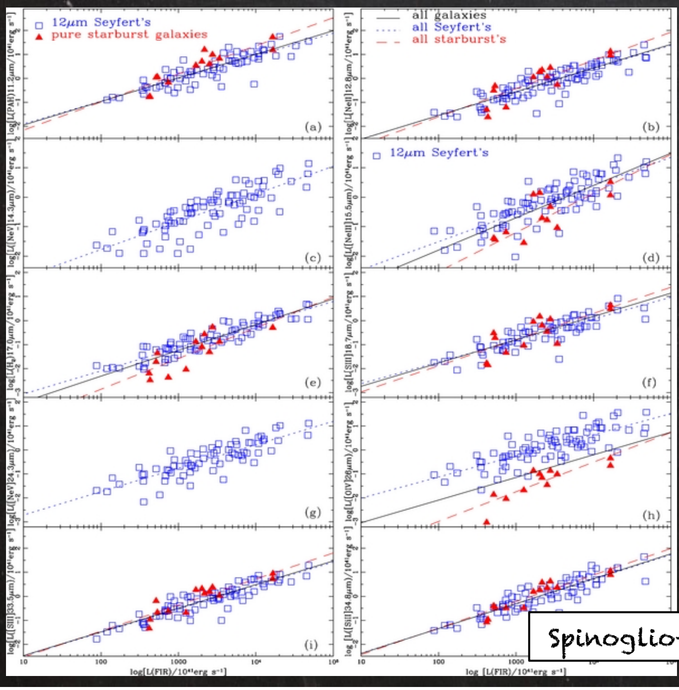
CG, Berta, Spinoglio+ 2015

New relations between L_{line} & L_{IR}/L_{acc}

Previous Works

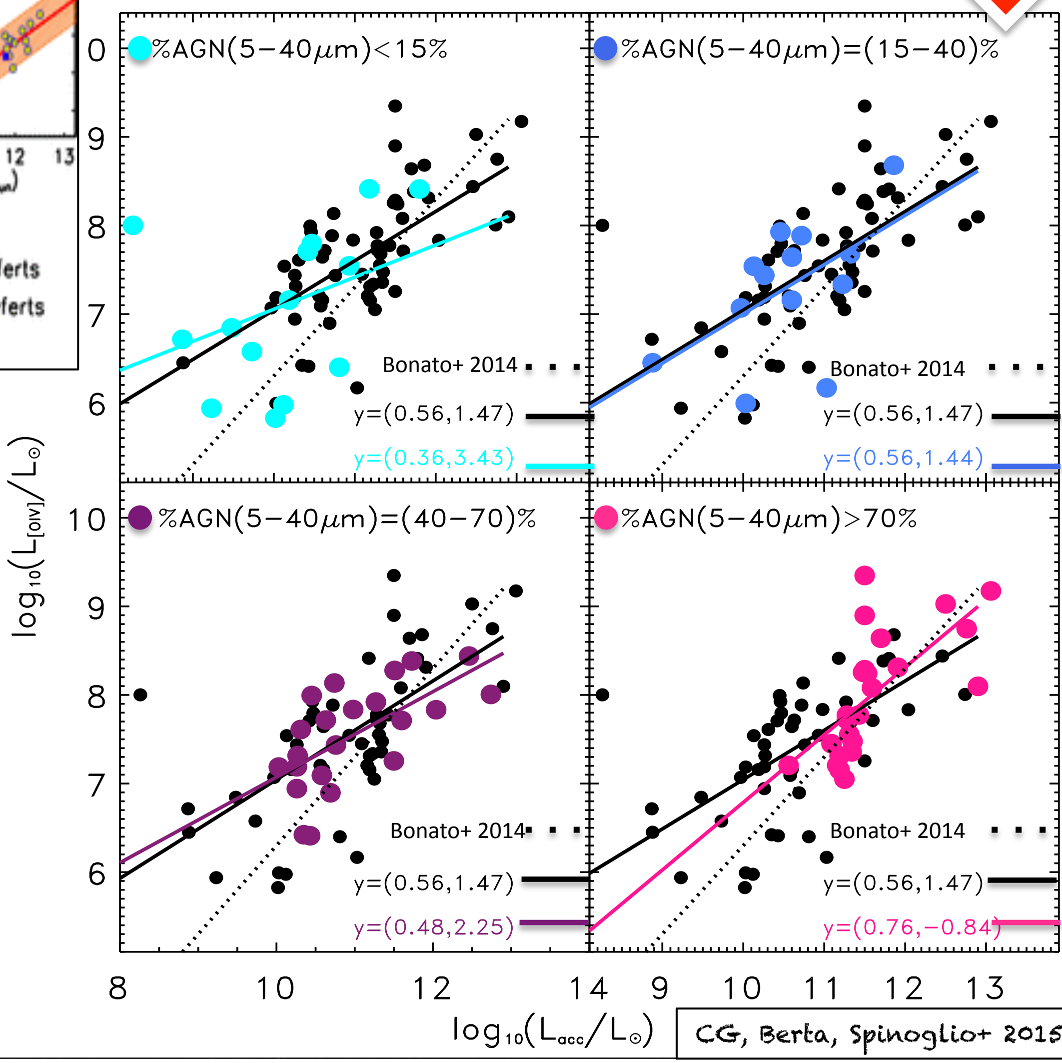
Bonato+ 2014



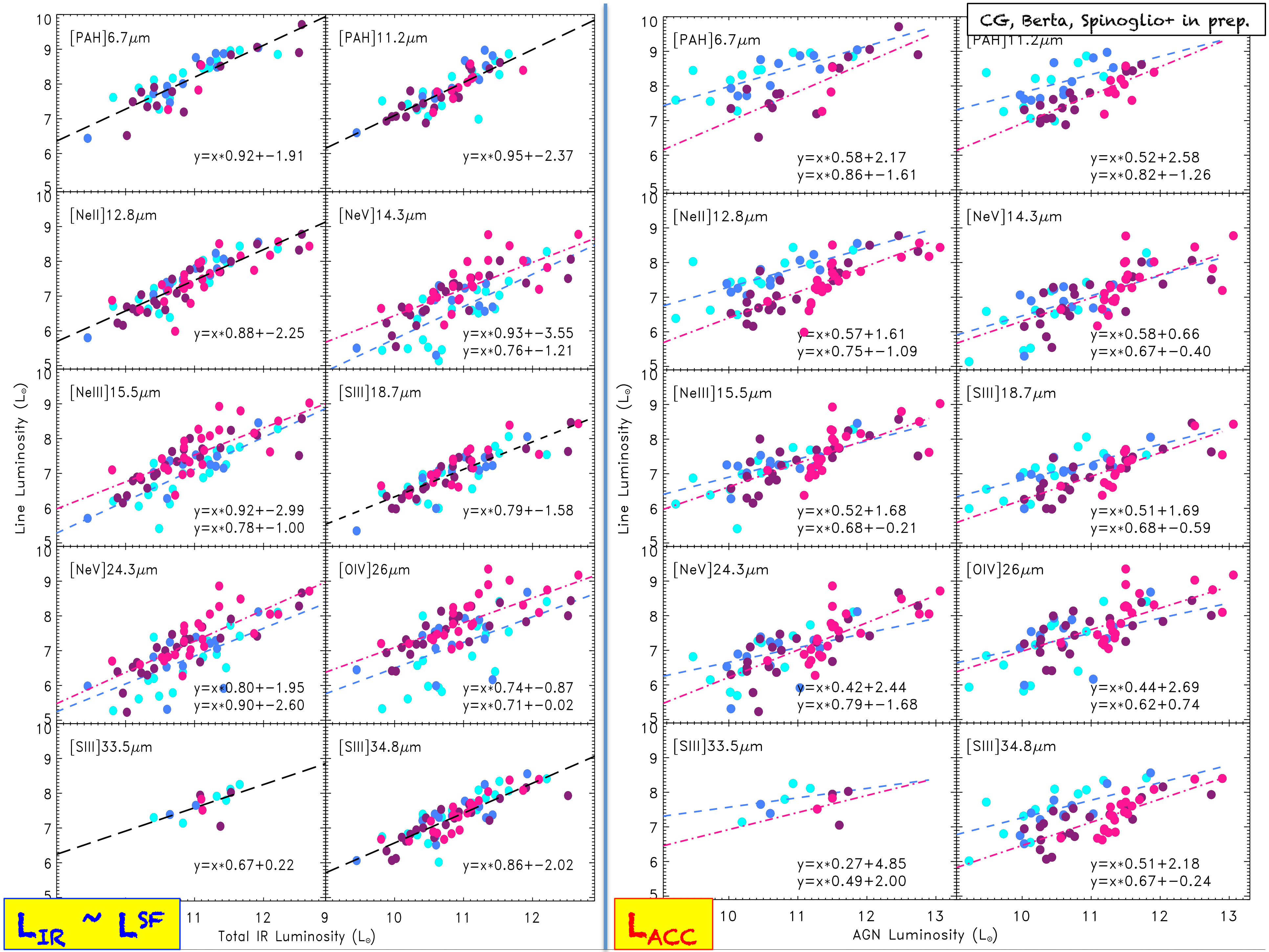


Spinoglio+ 2012

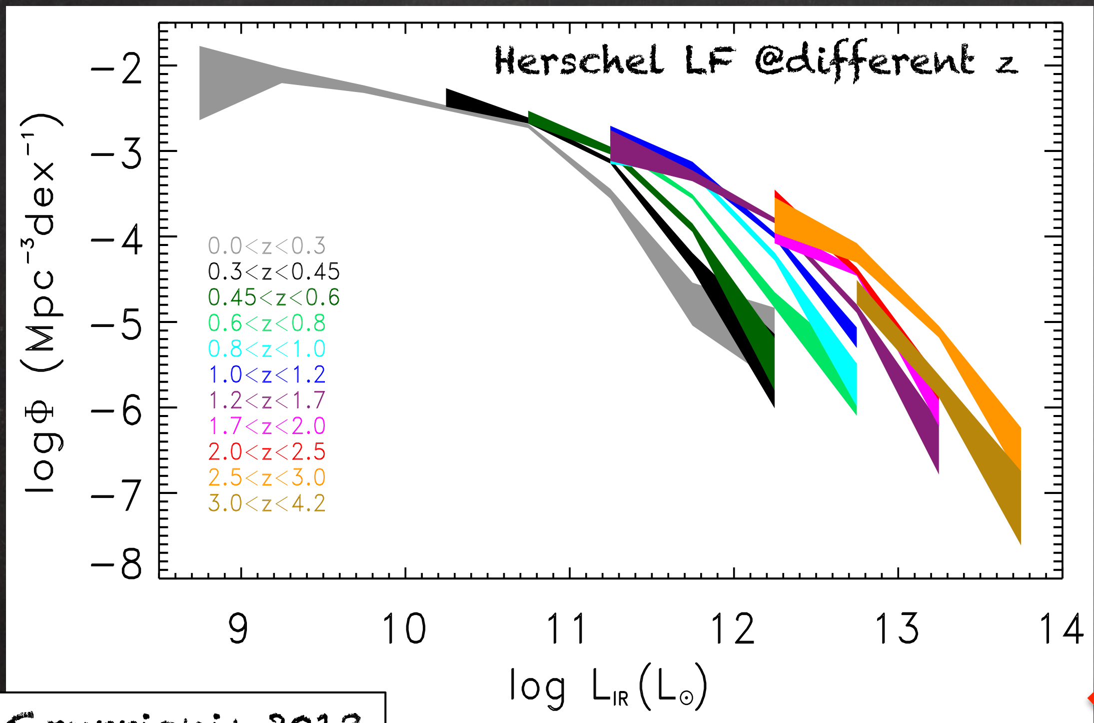
Example: $L_{[OIV]}$ vs. L_{acc}
slope steepens with increasing AGN% (@ 5-40μm)



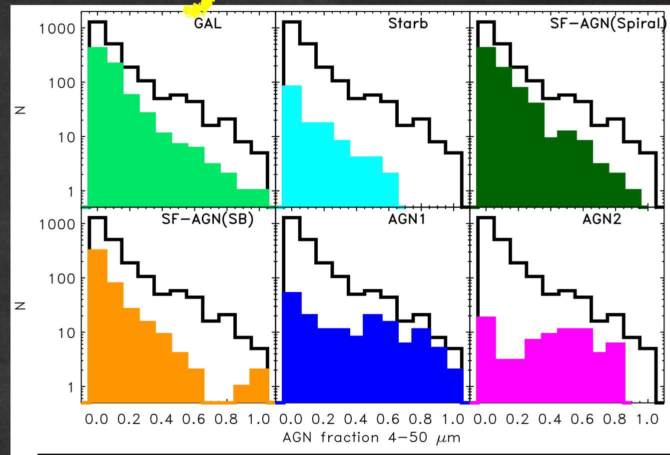
CG, Berta, Spinoglio+ 2015


CG, Berta, Spinoglio+ in prep.
[PAH]6.7μm
y=x*0.92+−1.91
[PAH]11.2μm
y=x*0.95+−2.37
[NeII]12.8μm
y=x*0.88+−2.25
[NeV]14.3μm
y=x*0.93+−3.55
y=x*0.76+−1.21
[NeIII]15.5μm
y=x*0.92+−2.99
y=x*0.78+−1.00
[SIII]18.7μm
y=x*0.79+−1.58
[NeV]24.3μm
y=x*0.80+−1.95
y=x*0.90+−2.60
[OIV]26μm
y=x*0.74+−0.87
y=x*0.71+−0.02
[SIII]33.5μm
y=x*0.67+0.22
[SIII]34.8μm
y=x*0.86+−2.02
Line Luminosity (L⊙)
Total IR Luminosity (L⊙)
L_IR ~ L^SF
[PAH]6.7μm
y=x*0.58+2.17
y=x*0.86+−1.61
[PAH]11.2μm
y=x*0.52+2.58
y=x*0.82+−1.26
[NeII]12.8μm
y=x*0.57+1.61
y=x*0.75+−1.09
[NeV]14.3μm
y=x*0.58+0.66
y=x*0.67+−0.40
[NeIII]15.5μm
y=x*0.52+1.68
y=x*0.68+−0.21
[SIII]18.7μm
y=x*0.51+1.69
y=x*0.68+−0.59
[NeV]24.3μm
y=x*0.42+2.44
y=x*0.79+−1.68
[OIV]26μm
y=x*0.44+2.69
y=x*0.62+0.74
[SIII]33.5μm
y=x*0.27+4.85
y=x*0.49+2.00
[SIII]34.8μm
y=x*0.51+2.18
y=x*0.67+−0.24
Line Luminosity (L⊙)
AGN Luminosity (L⊙)
L_ACC

mid-/far-IR line Luminosity Function

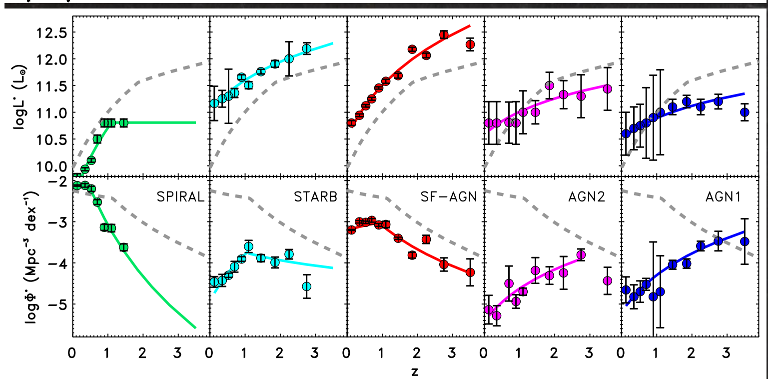


Gruppioni+ 2013



L_{line}-L_{IR} local relations for different AGN% applied to different Herschel populations

Different evolutions found for different populations

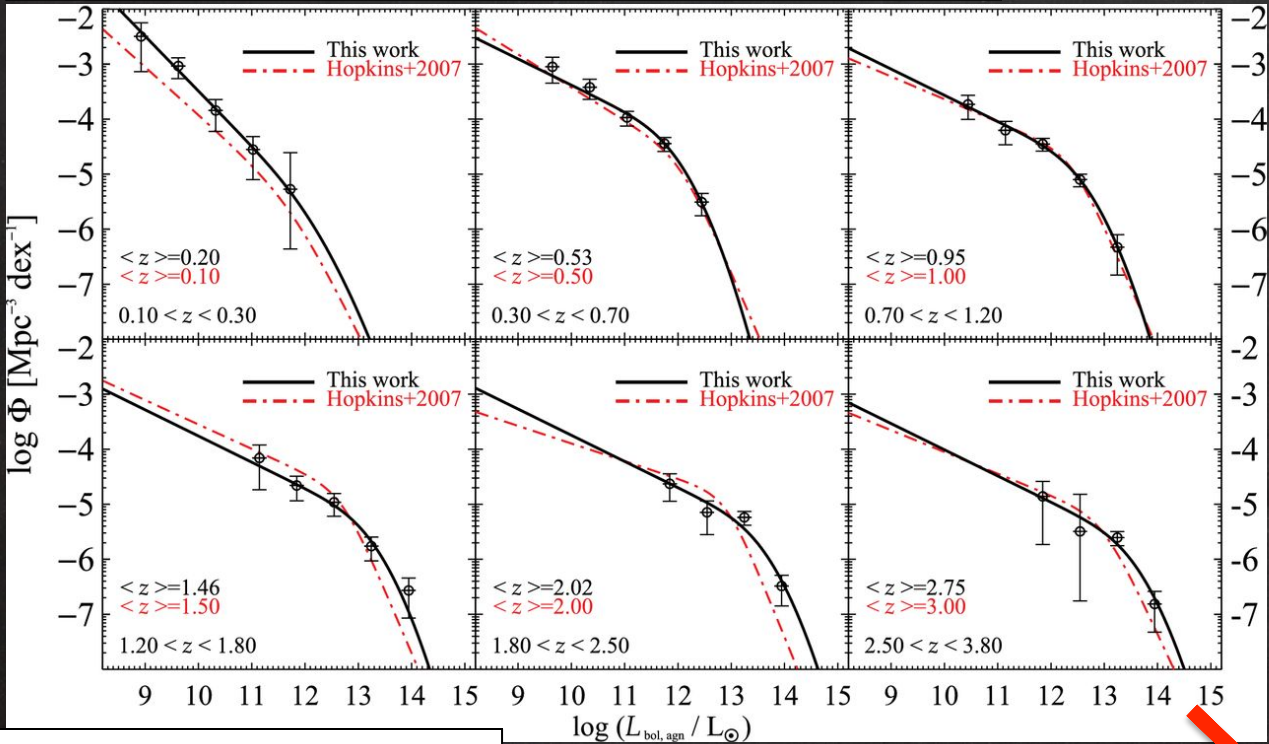


Apply different evolutions to different IR populations

Line Luminosity Function

mid-/far-IR line Luminosity Function

Herschel BH accretion Function @different z



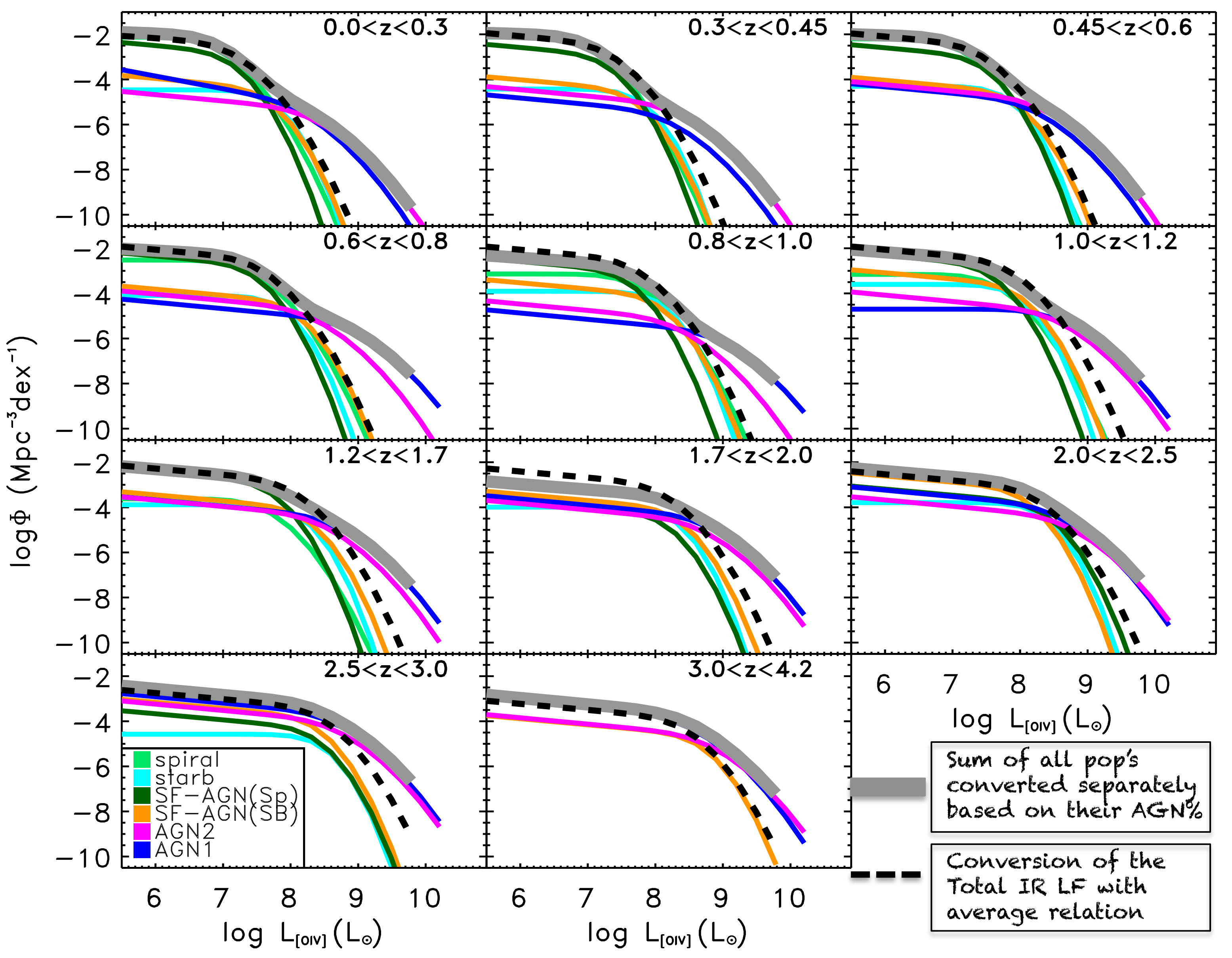
Delvecchio, CG+ 2014

L_{line}-L_{ACC} local relations

Apply BH accretion function evolution

AGN Line Luminosity Function

mid-/far-IR line Luminosity Function



CG, Berta, Spinoglio+ in preparation

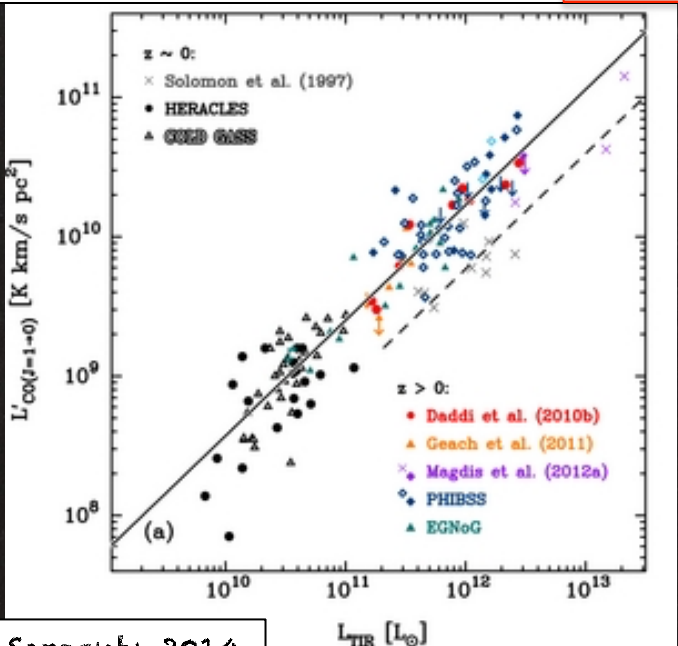
CO Luminosity Function

(Vallini, CG et al., in preparation)

- Start from Herschel LFs and different pop.'s evolutions (Gruppioni+ 2013)
- use Sargent+ 2014 $L'_{CO(1-0)}$ - L_{IR} relation for normal galaxies
- and Greve+ 2014 $L'_{CO(J+1-J)}$ - L_{IR} relations for Starbursts/(U)LIRGs/AGN

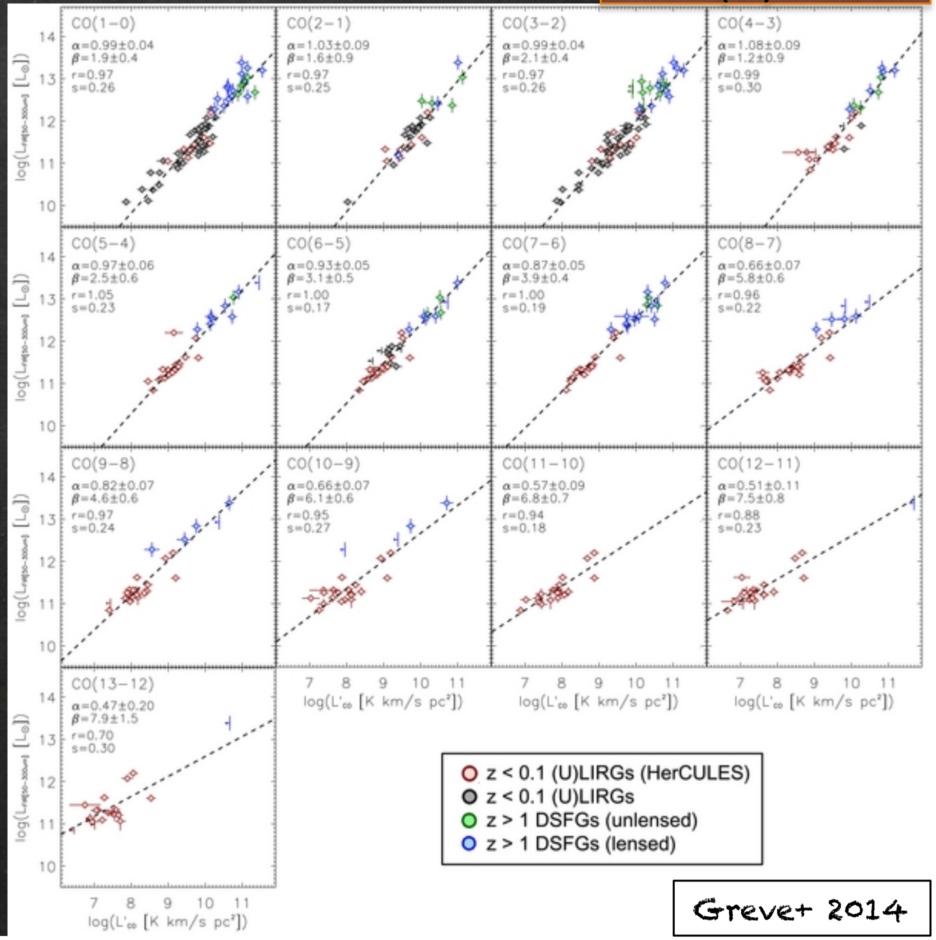
$$\log\left(\frac{L'_{CO(J=1\to0)}}{\mathrm{K\,km\,s^{-1}\,pc^2}}\right) = \alpha_1 + \beta_1 \log\left(\frac{L_{IR}}{L_\odot}\right), \quad \text{with} \quad (1)$$

$(\alpha_1;\beta_1) = (0.54 \pm 0.02; 0.81 \pm 0.03)$ for normal galaxies.



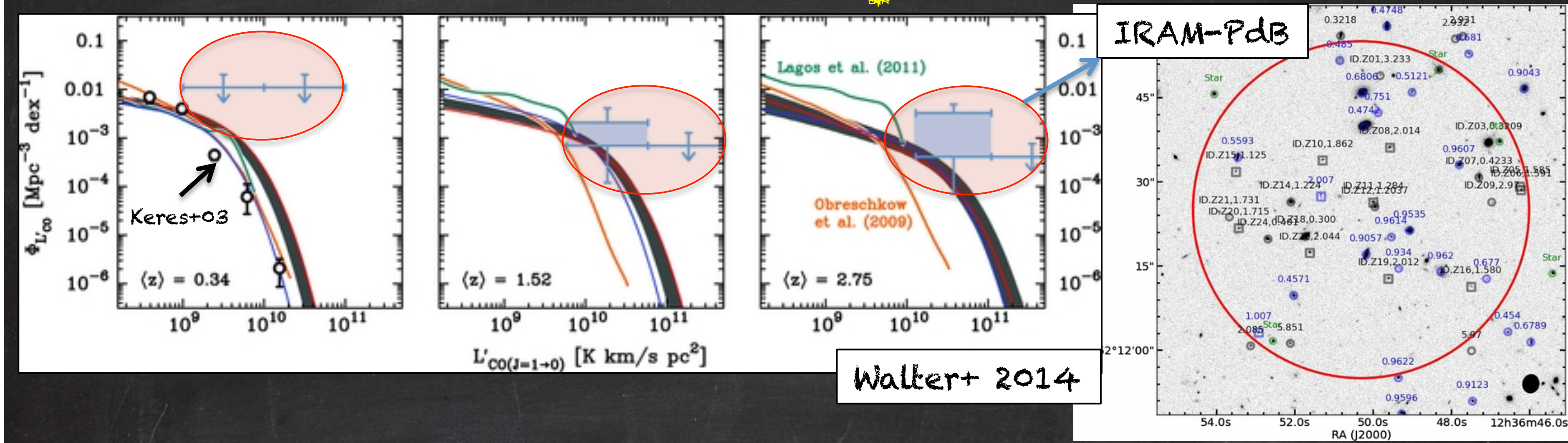
Sargent+ 2014

for (U)LIRGs

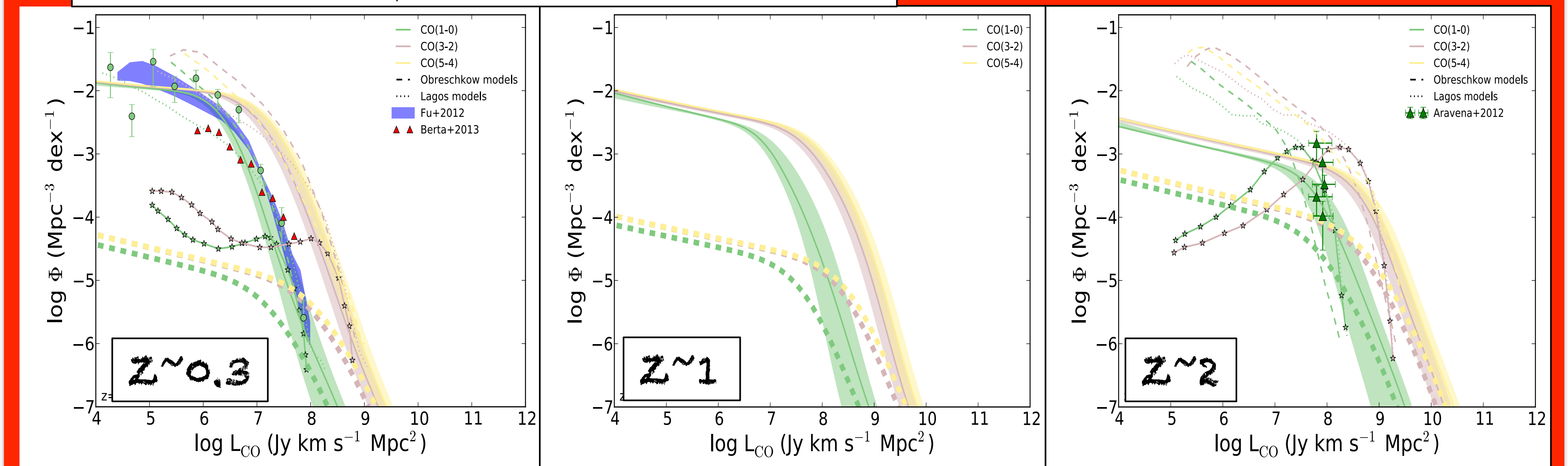


Greve+ 2014

CO Luminosity Function



CO LF derived from the Herschel IR LF



Vallini, CG et al., in prep. (A)

CO-line Luminosity Function

→ FUTURE CO SURVEYS with ALMA

- 2013.1.00146.S - PI: Fabian Walter

A Molecular ALMA Deep Field in the UDF
(CO spectral scan of band 3 -> >20 srcs below the knee of the LF)

- 2013.1.00718.S - PI: Manuel Aravena

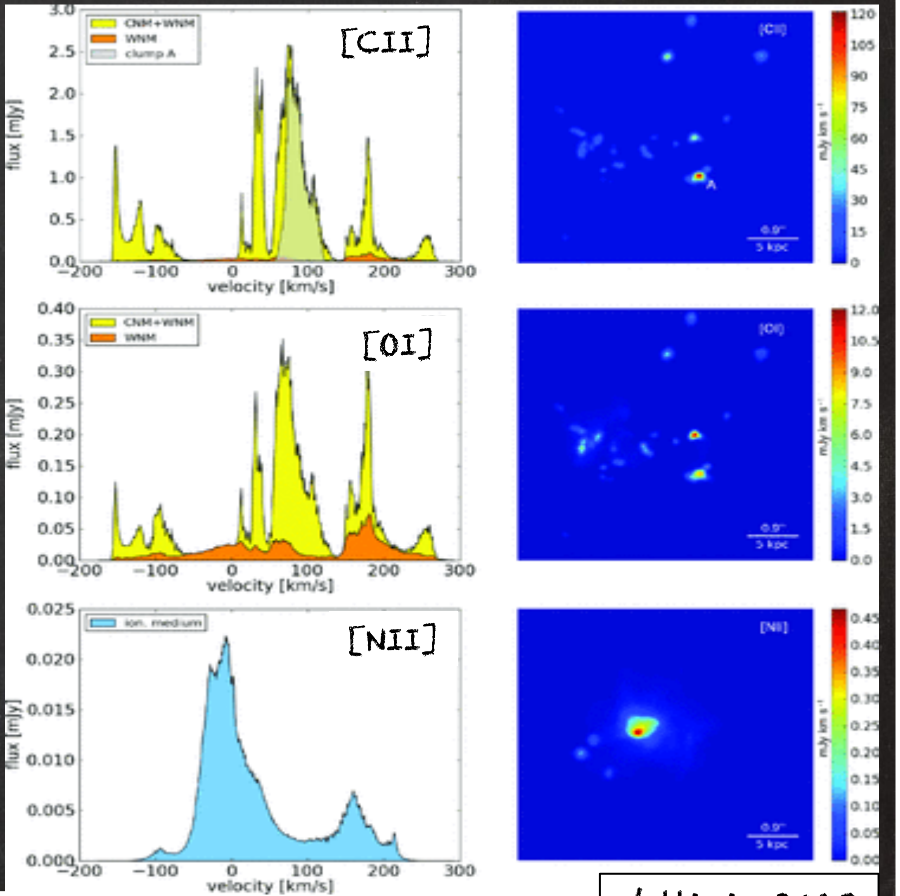
An ALMA 1.3 mm spectroscopic survey in the Hubble Ultra Deep Field
(deep CO/[CII] spectral scan and ultra-deep continuum imaging Of 1 arcmin^2 in the UDF using ALMA in band-6 -> >25 CO emitters and 30 continuum sources H2 mass limit of 2.5×10^9 $M_\odot$ and FIR luminosities of 1×10^{11} $L_\odot$ 5-σ)

- Cycle 3 Proposal of CO/[CII] spectral scan of ~1 arcmin^2 in ALMA band-7 ([CII] intensity mapping at z~5 and removal of CO contaminants (CO(4-3),(5-4),(6-5),(7-6) at z = 0.45, 0.82, 1.18, 1.54) - PI: L. Vallini

Simulation of far-IR and sub-mm lines

- High resolution, radiative transfer cosmological simulations of galaxies with a multi-phase ISM model

- expected intensity of several far-IR emission lines for different values of the gas metallicity, (Vallini+ 2013)

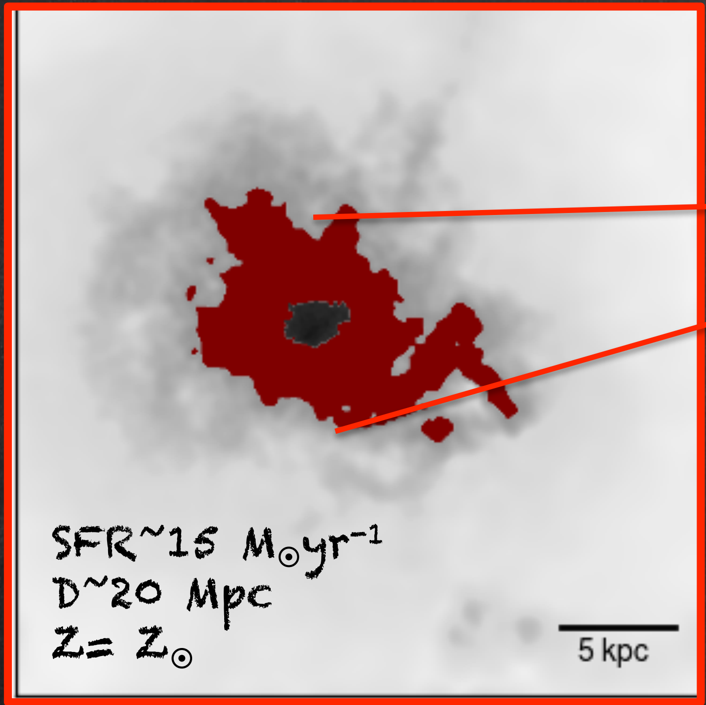


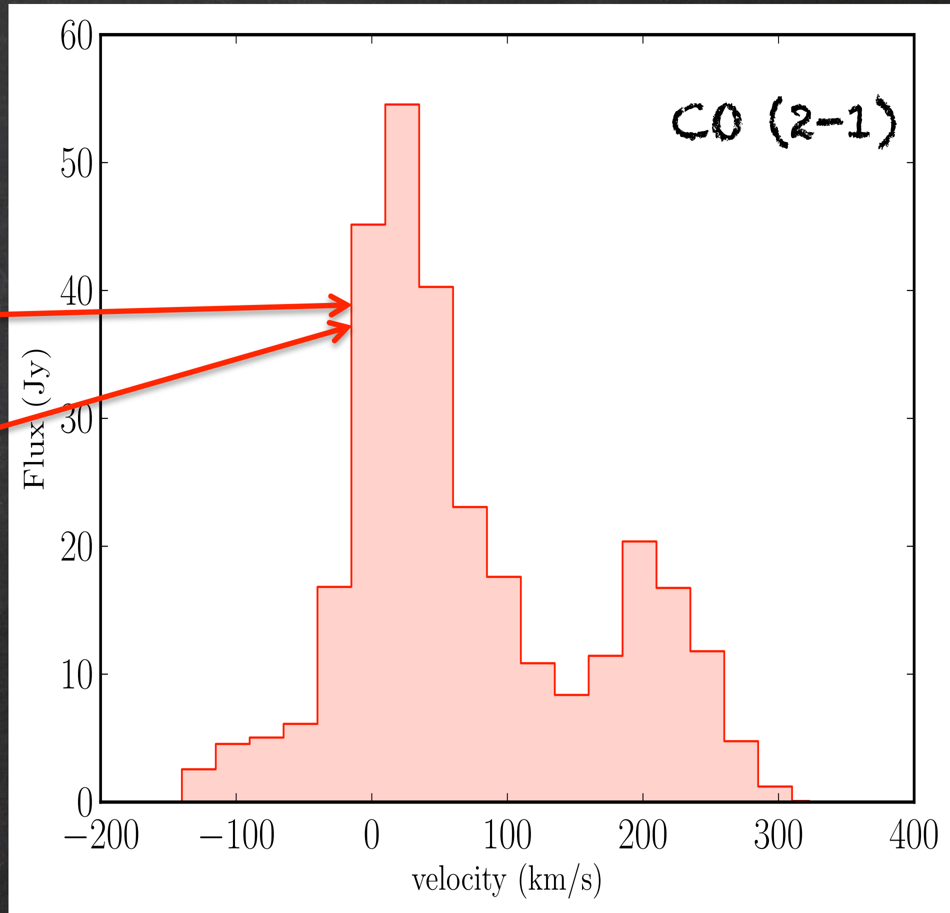
Vallini+ 2013

→ Work in progress:
Calibrate the model at different z's (typical SFR, M*, populations + different Z) based on Herschel/ALMA data and study how the ISM in galaxies evolves (diffuse, PDR, XDR)

→ *Vallini, CG et al. (A), in preparation*

CO (2-1) emission from NGC 1365





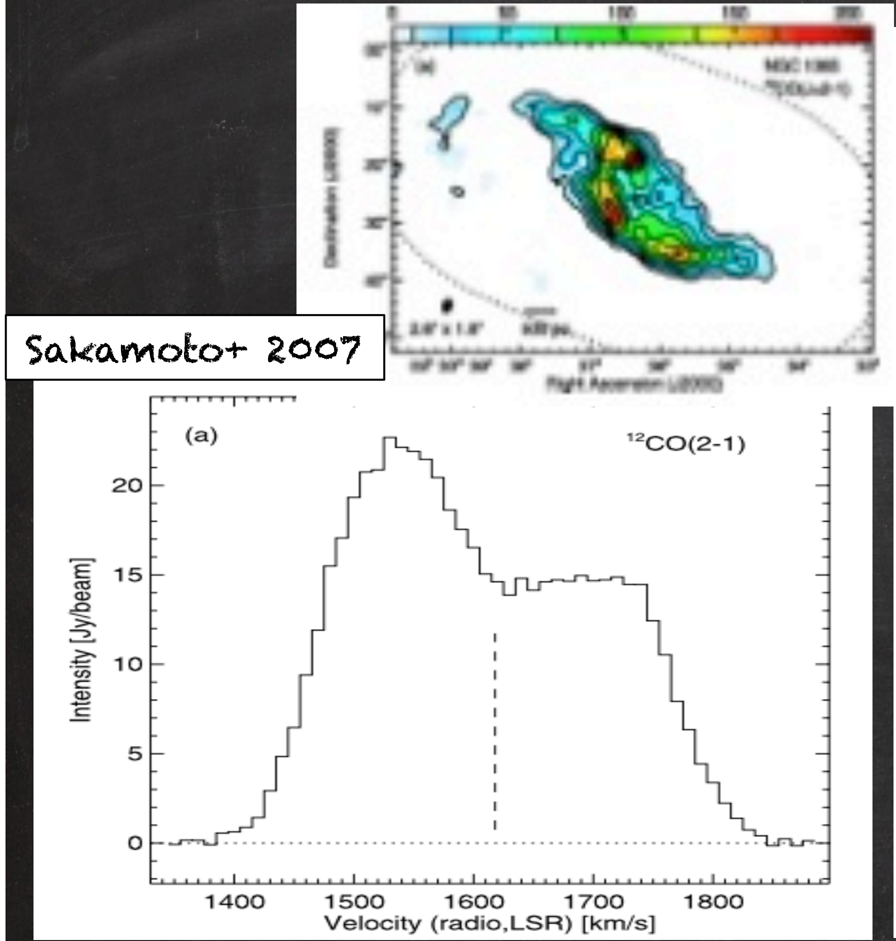
Input:
SFR, Z, age of stellar population

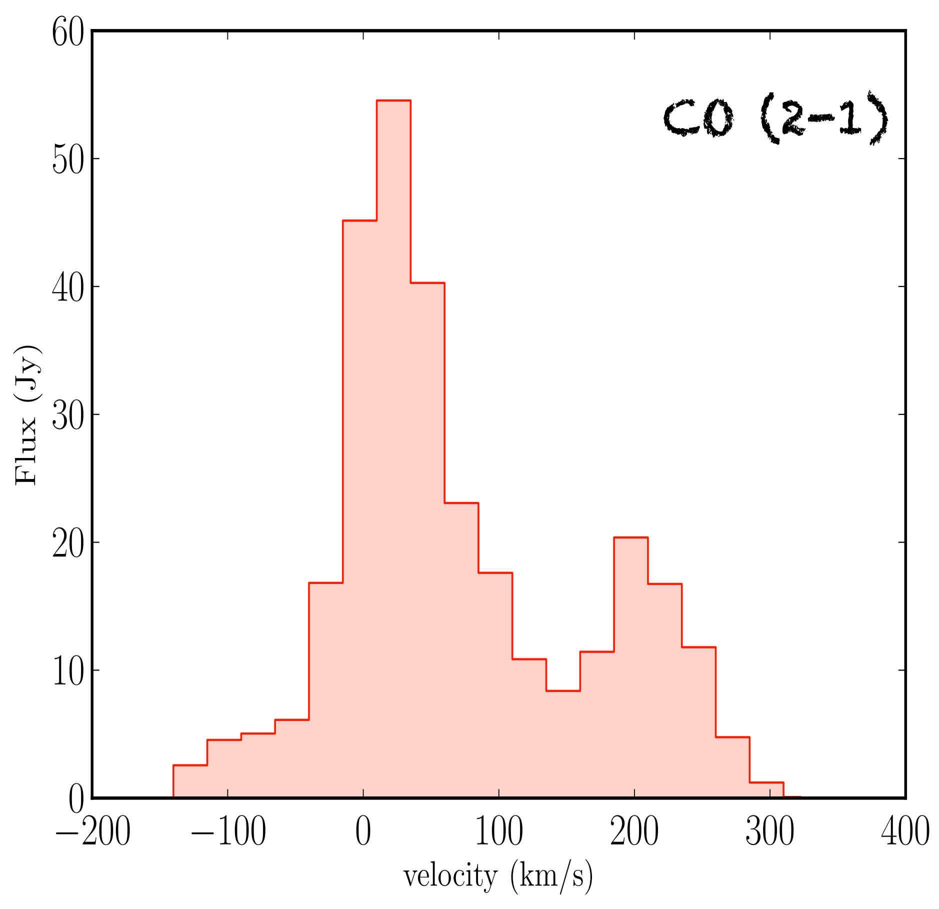
UCL_PDR

Output:
CO, [OI], [CII] lines

→ *Vallini, CG et al. (B), in preparation*

CO (2-1) emission from NGC 1365





Input:
SFR, Z, age of stellar population

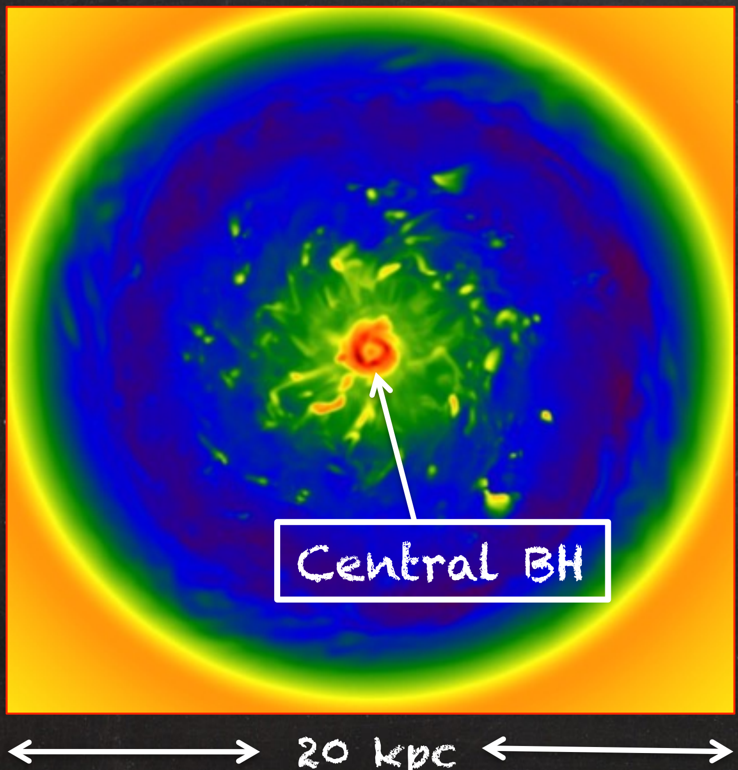
UCL_PDR

Output:
CO, [OI], [CII] lines

→ Vallini, CG et al., 2015b in preparation

Work in Progress:
Single galaxy with AGN

Courtesy: A. Aykutalp



Hydrodynamical simulation with ENZO
(http://enzo-project.org)
up to physical scales of 15 pc

+

Radiative transfer with CRASH
(Maselli, A., Ferrara, A. & Ciardi, B. 2003)

+

Coupling with PDR + XDR codes
(e.g., UCL_PDR + Meijerik & Spaans XDR)

Effect of the AGN and gas density on the luminosity of FIR lines

Vallini, CG et al. (B), in prep.

Conclusions

★ We have considered a well studied sample of local Seyfert galaxies (the extended 12-μm sample) with different % of AGN to:

- Apply a new SED decomposition technique to derive L_{ACC}, L_{SF} and the fraction of IR luminosity due to AGN

- Derive new relations: MIR/FIR fine structure line L - L_{IR}/L_{acc}

★ We have applied the new relations to the Herschel LFs and BH accretion function to derive line LFs at different z's

★ We have applied L_{CO}-L_{IR} relations from the literature to derive the CO LFs from the Herschel ones

-> to be checked with forthcoming ALMA survey data

★ We have developed a new model to simulate the far-IR and sub-mm lines -> calibrate on local data and at different z to study how the ISM in galaxies evolves