MIR/submm spectroscopy of active galaxies at Dome C

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Summary:

1. Accretion and AGNs dominate the energy budget of galaxies through their evolution
2. MIR spectroscopy: What we learned from ISO spectroscopy and what we are learning from Spitzer spectra
3. FIR spectroscopy: the example of NGC1068 & what we can do with Herschel
4. What can be done at the best ground based site

What science ?

measure separate luminosity functions for star formation and accretion in the Local Universe and during galaxy evolution

Why ?

To understand interplay of the two main emission mechanisms in galaxies during galaxy evolution

What technique ?

MIR/FIR/submm spectroscopy

What instrument ? (besides Herschel, JWST, SPICA…)

A dual channel MIR + FIR(200μm)& Submm telescope

What site ?

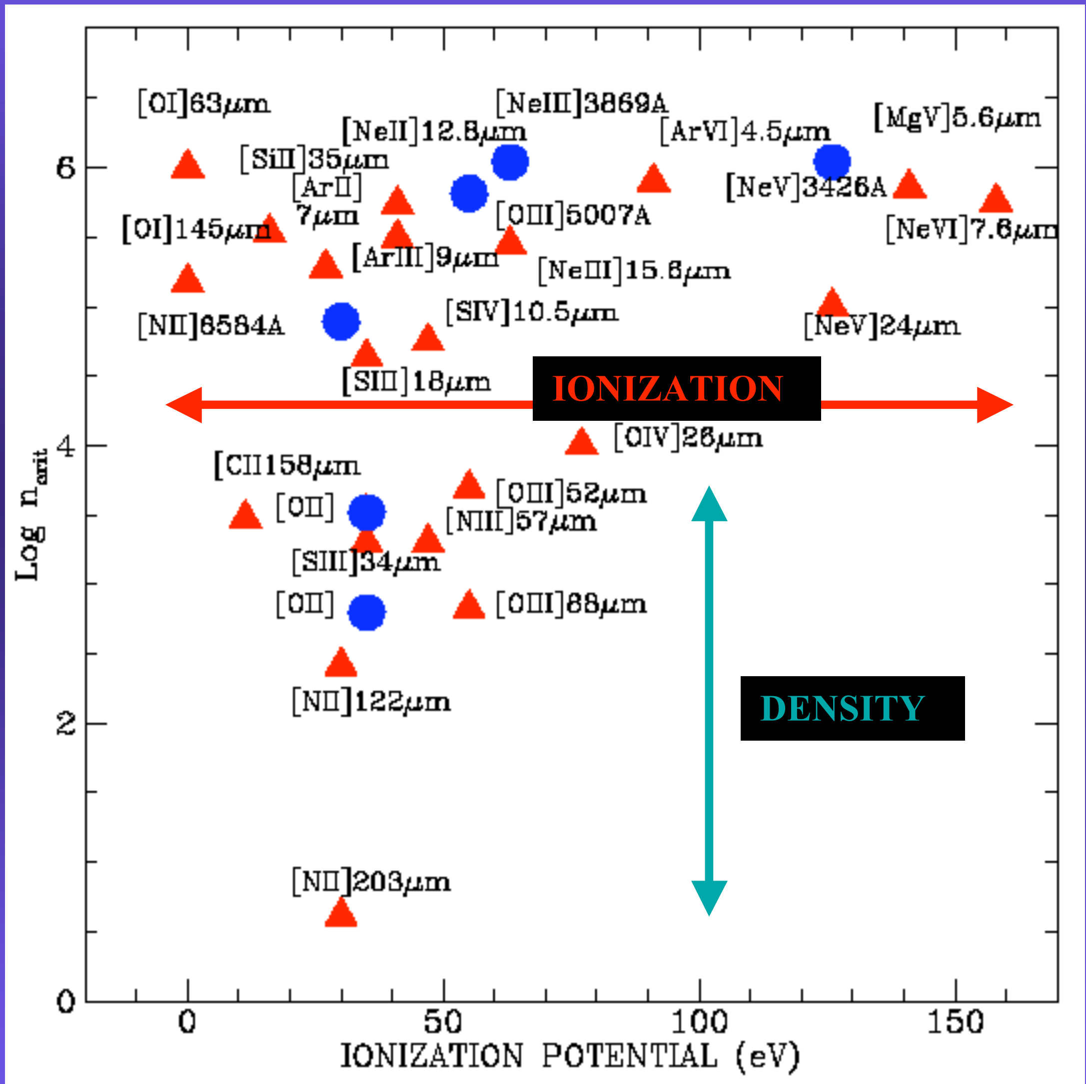
Of course Dome C !

….or maybe Dome A if really feasible and better…

Why infrared spectroscopy is better (than opt-UV) ?

1. can detect "obscured AGNs" (dust exctinction is much less severe)
2. can separate star formation from AGN emission
3. Contains many ionic FS lines well covering the parameter's space (e.g. density & ionization)
4. MIR include many H_2 lines and PAH features
5. FIR include many molecular lines (e.g. CO, OH, H_2O)

Infrared fine structure lines as nebular diagnostic tools



MID- & FAR-INFRARED fine structure lines trace:

density: 10^2-10^7 cm^{-3}

•Ionization potential : 0-150eV (NIR up to 400eV)

➔diagnostic diagrams emission line regions in galaxies:

NLR, ILR, CLR (near-IR)

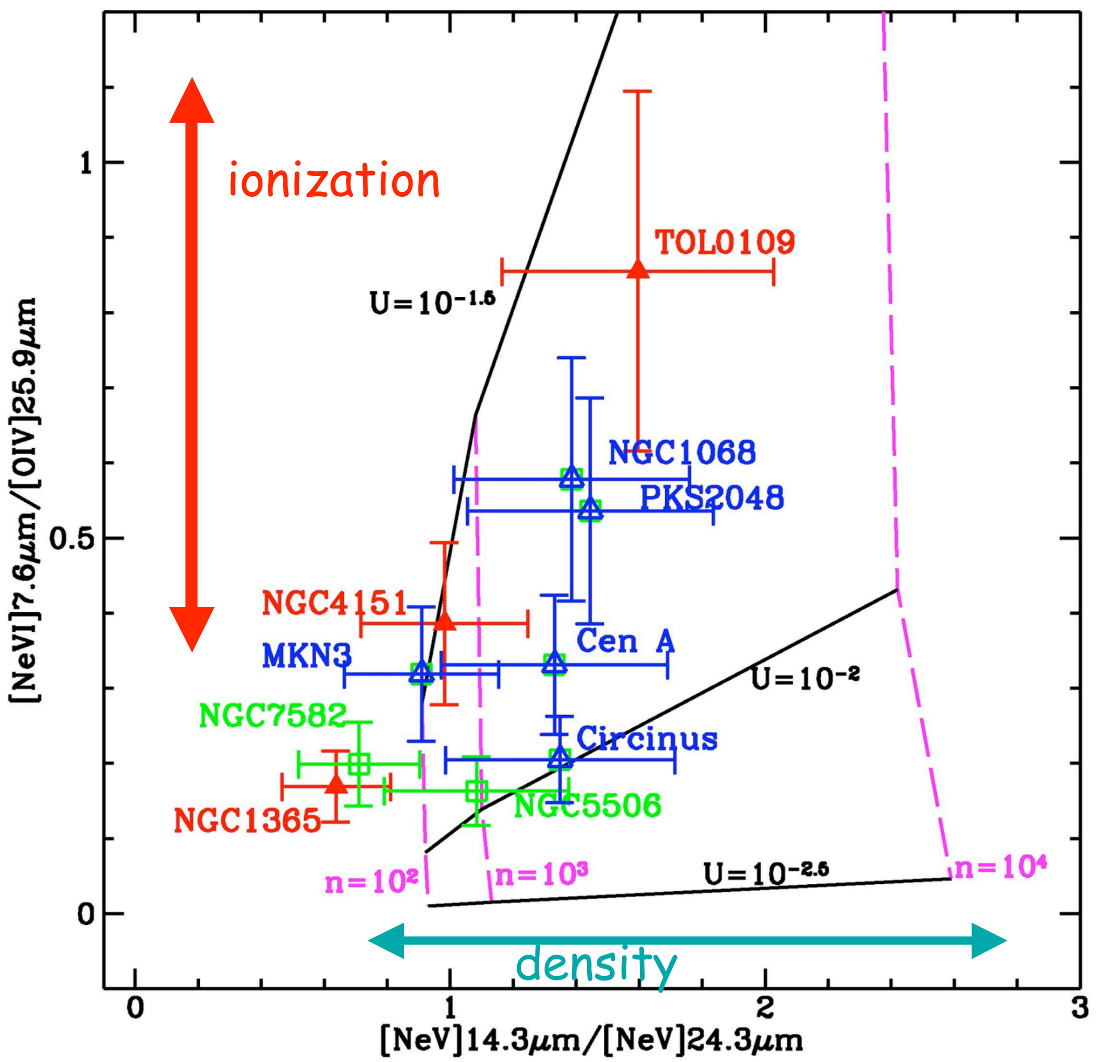
[Spinoglio & Malkan 1992,ApJ,399,504]

ISO-SWS DIAGRAM
[NeVI]7.6μm/[OIV]25.9μm vs [NeV]14.3μm}/[NeV]24.3μm

Lines excited only in the highly ionized AGN conditions - not from stellar ionization

➔[NeVI]7.6μm/[OIV] 25.9μm ionization tracer

➔[NeV] 14.3μm/ [NeV] 24.3μm density tracer



Seyfert 1s: (NGC1365, NGC4151, Tol0109), Seyfert 2s (MKN~3, Cen A, Circinus, NGC1068, PKS2048) and NLXR galaxies (NGC5506, NGC7582). The grid represents NLR models with ionizing spectrum with α=-1.0 and various densities and ionization parameters.

[Spinoglio et al.2000 iso conference]

Distinguish AGNs from starbursts with FIR F.S. lines

ISO-LWS DIAGRAM

[CII]158μm/[OI]63μm vs [OIII]88μm/[OI]63μm.

Seyfert 1s

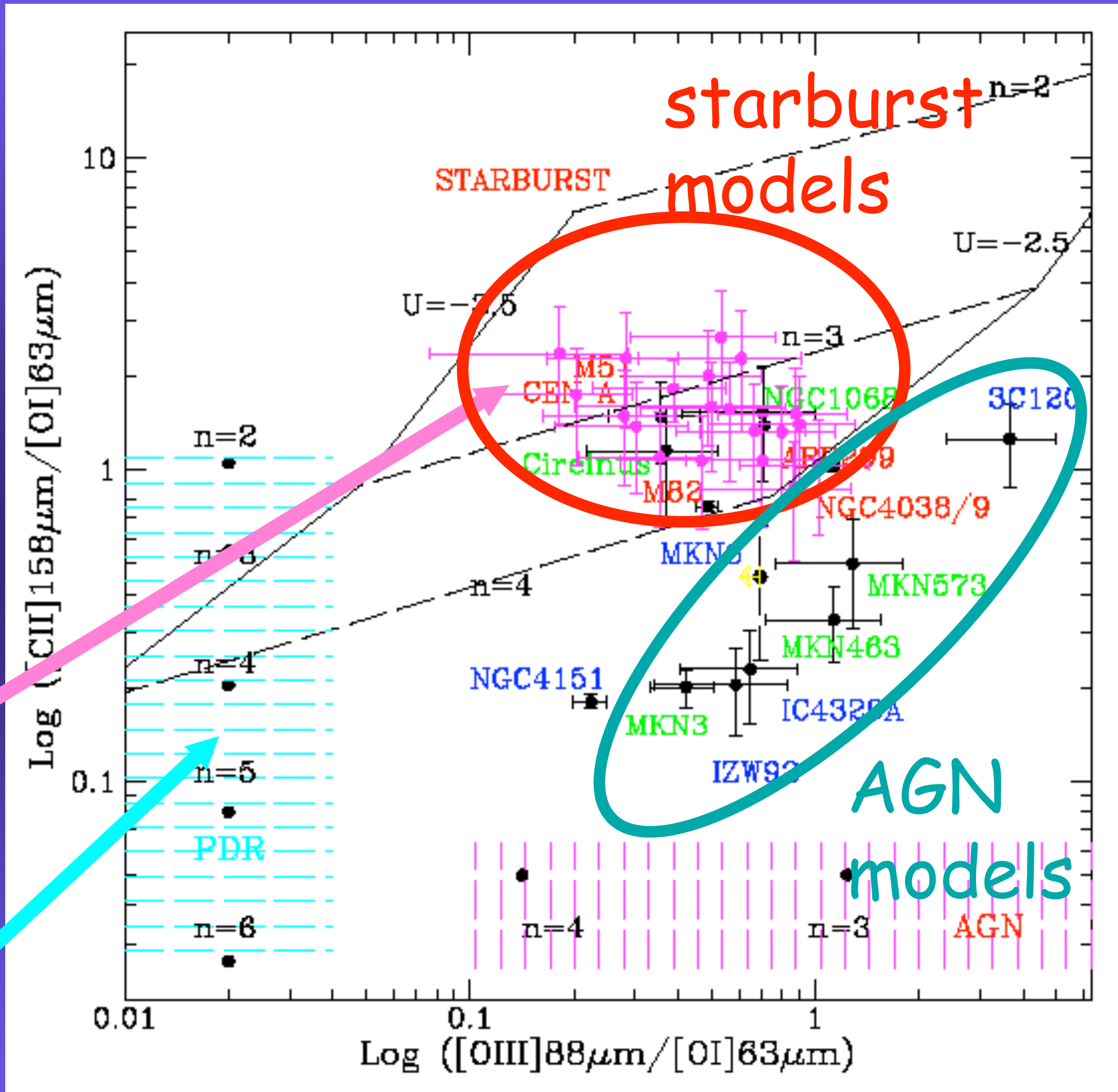
Seyfert 2s

(+ starburst component)

starburst galaxies

sample of nearby normal galaxies

photodissociation Regions models

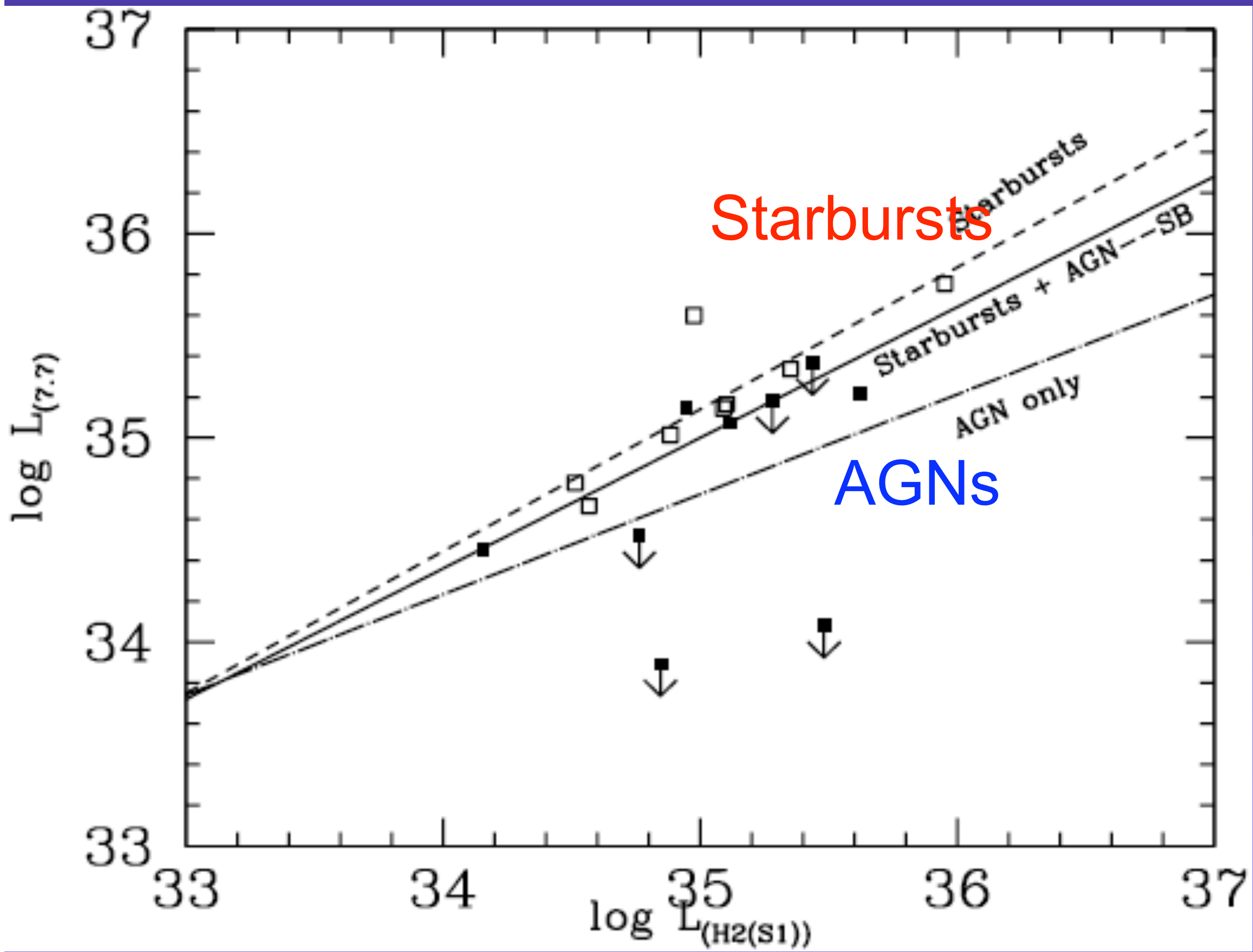


Herschel will populate this diagram

[Spinoglio et al 2004]

Other infrared diagnostic tools for AGNs vs starbursts

PAH luminosity L(7.7μm) vs. the $H_2S(1)$ luminosity for a starbursts and AGN. Open squares = Starburst filled squares = AGNs The lines represent the least square fits for: dashed line: starbursts, straight line: starbursts and AGN detections, long-dashed line AGN only (non-detection included).



PAH/H_2 high in Starburst: common origin of two emissions

PAH/He low in AGNs:

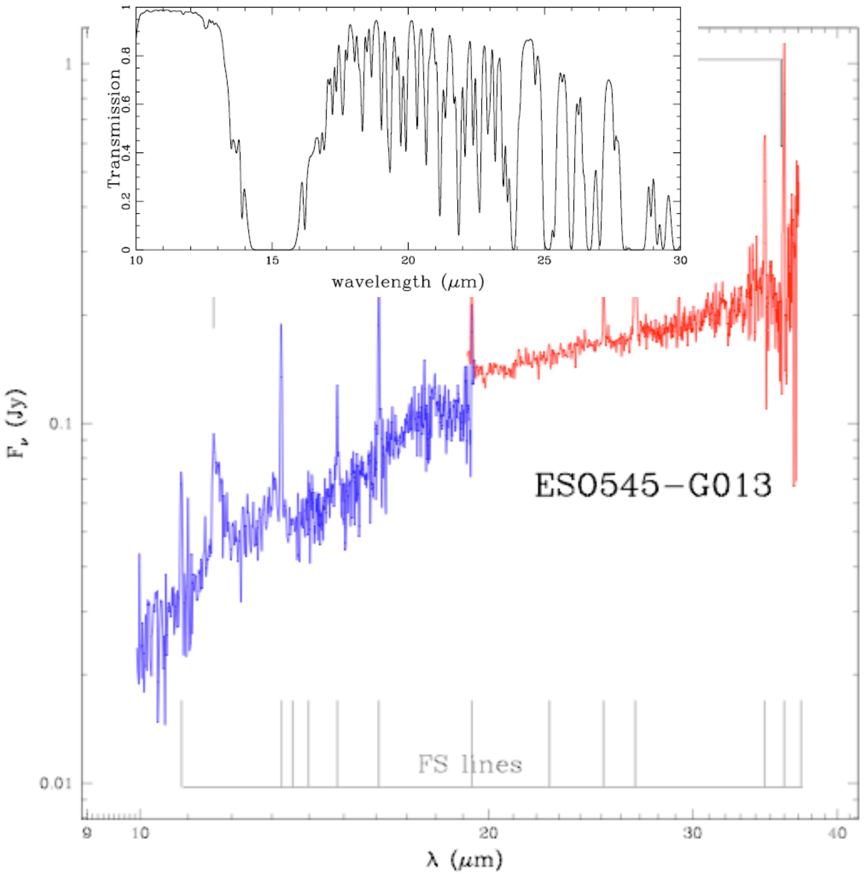
1. PAH are distroyed in the AGN field or
2. the AGN fiedl enhances H_2 emission

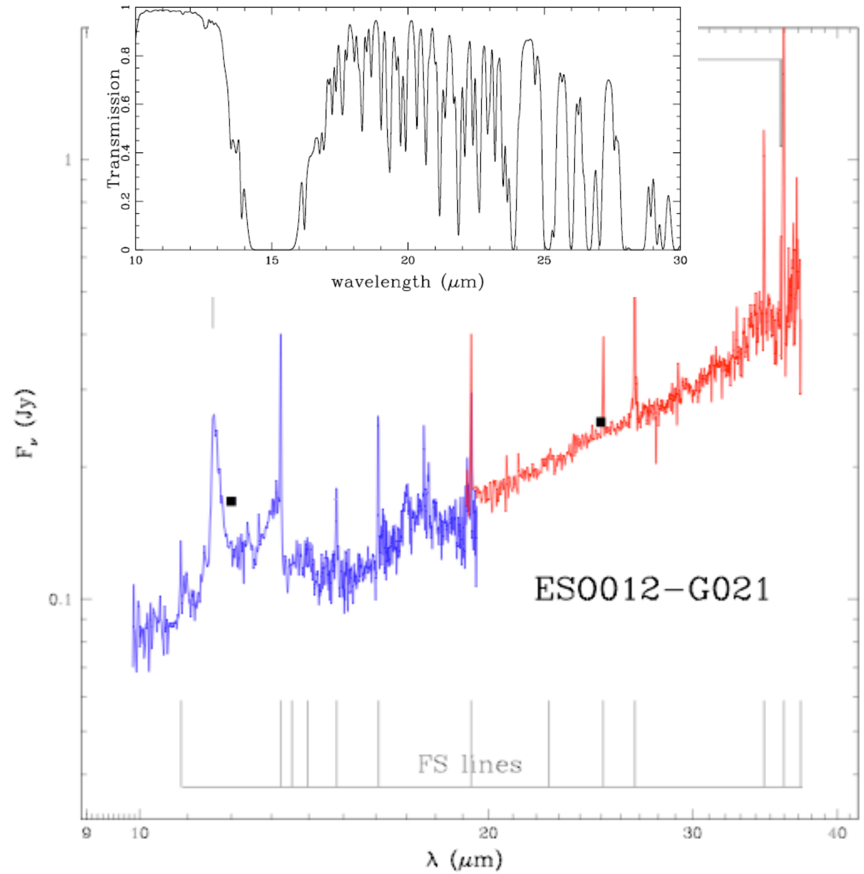
[Rigopoulou+ 2002, A&A389,374]

The role of Spitzer Spectroscopy

Measure the AGN and Starburst mid-IR lines (F.S.+H_2+PAH)

Extend the ISO-SWS results

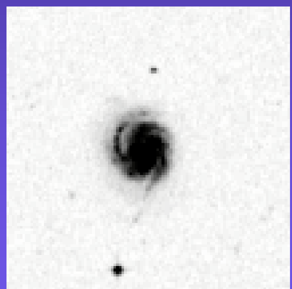




Spitzer spectra:

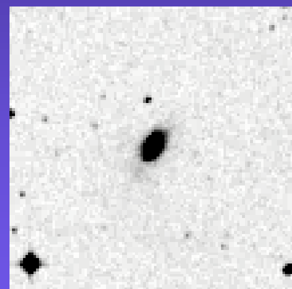
ESO 545- G 013

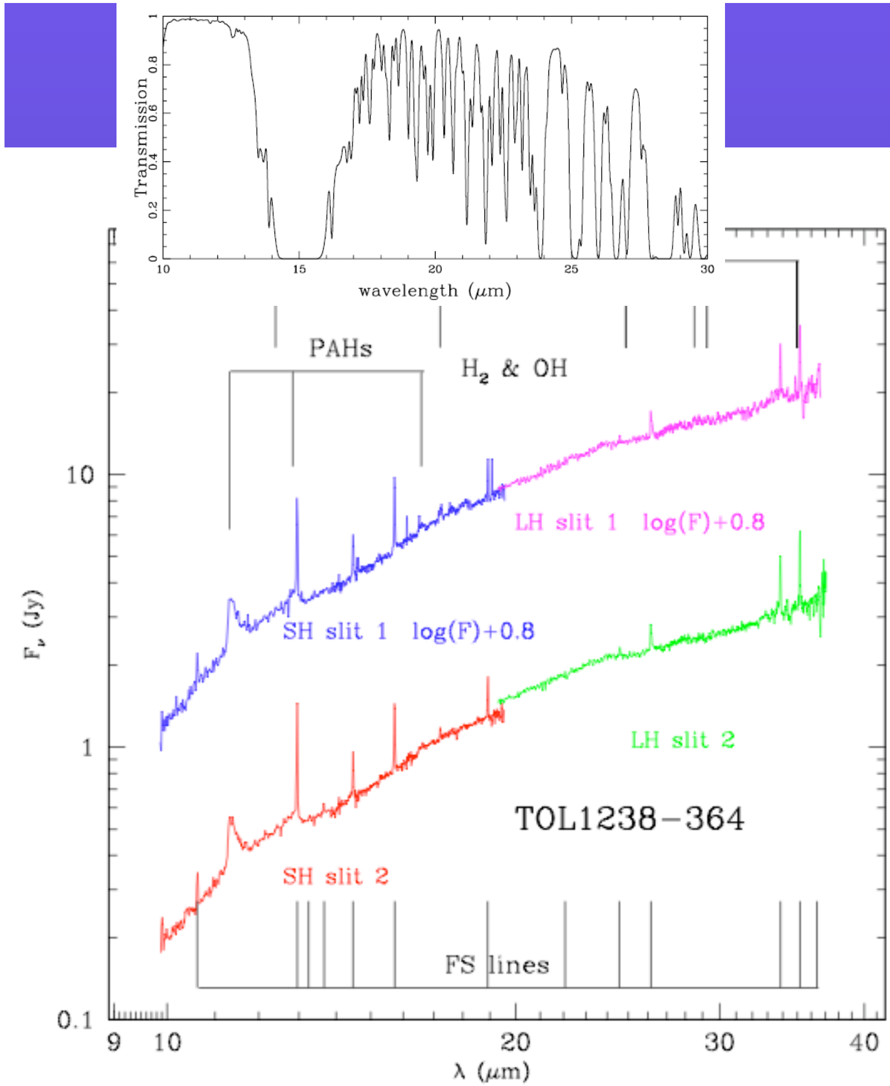
Z=0.0337 Sy1.8

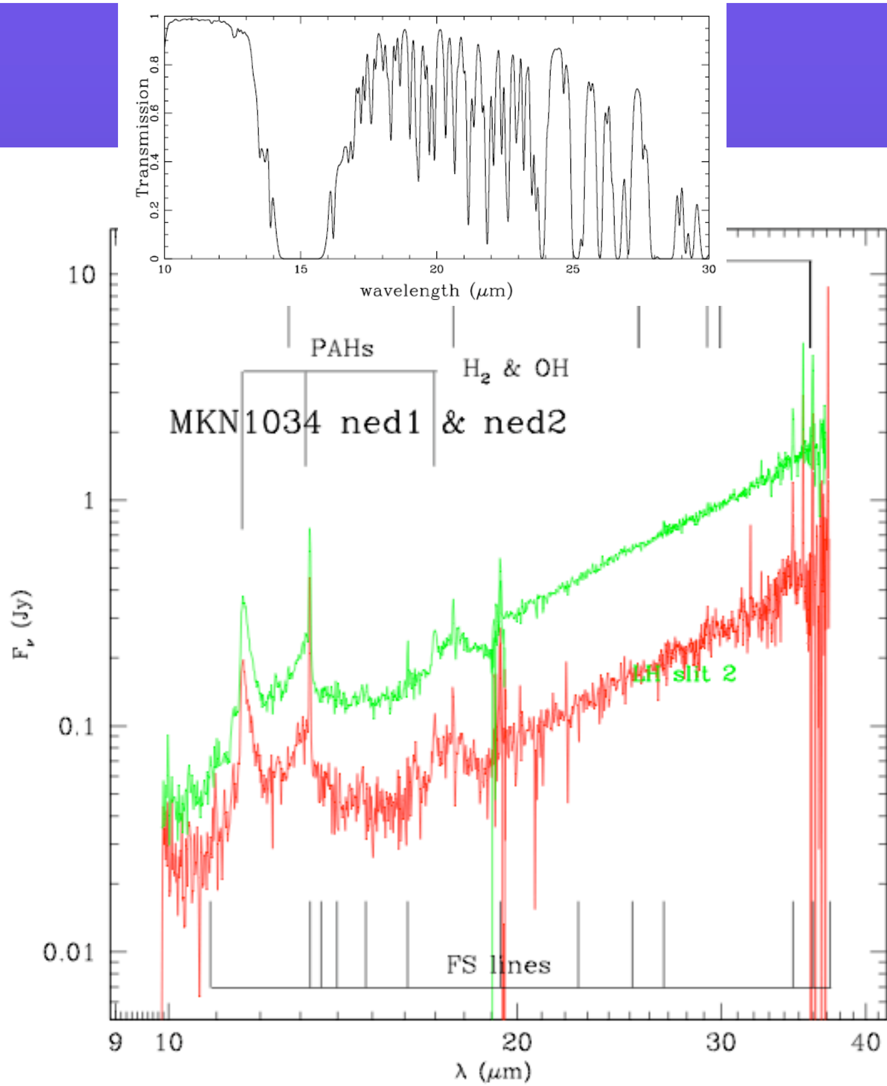


ESO 012- G 021

Z=0.0300 Sy1



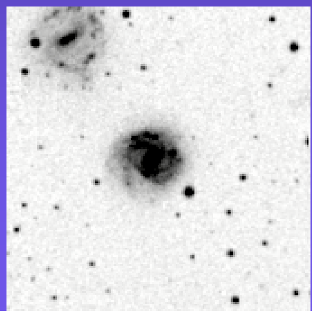




Spitzer spectra:

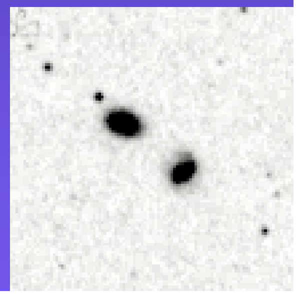
ESO 545- G 013

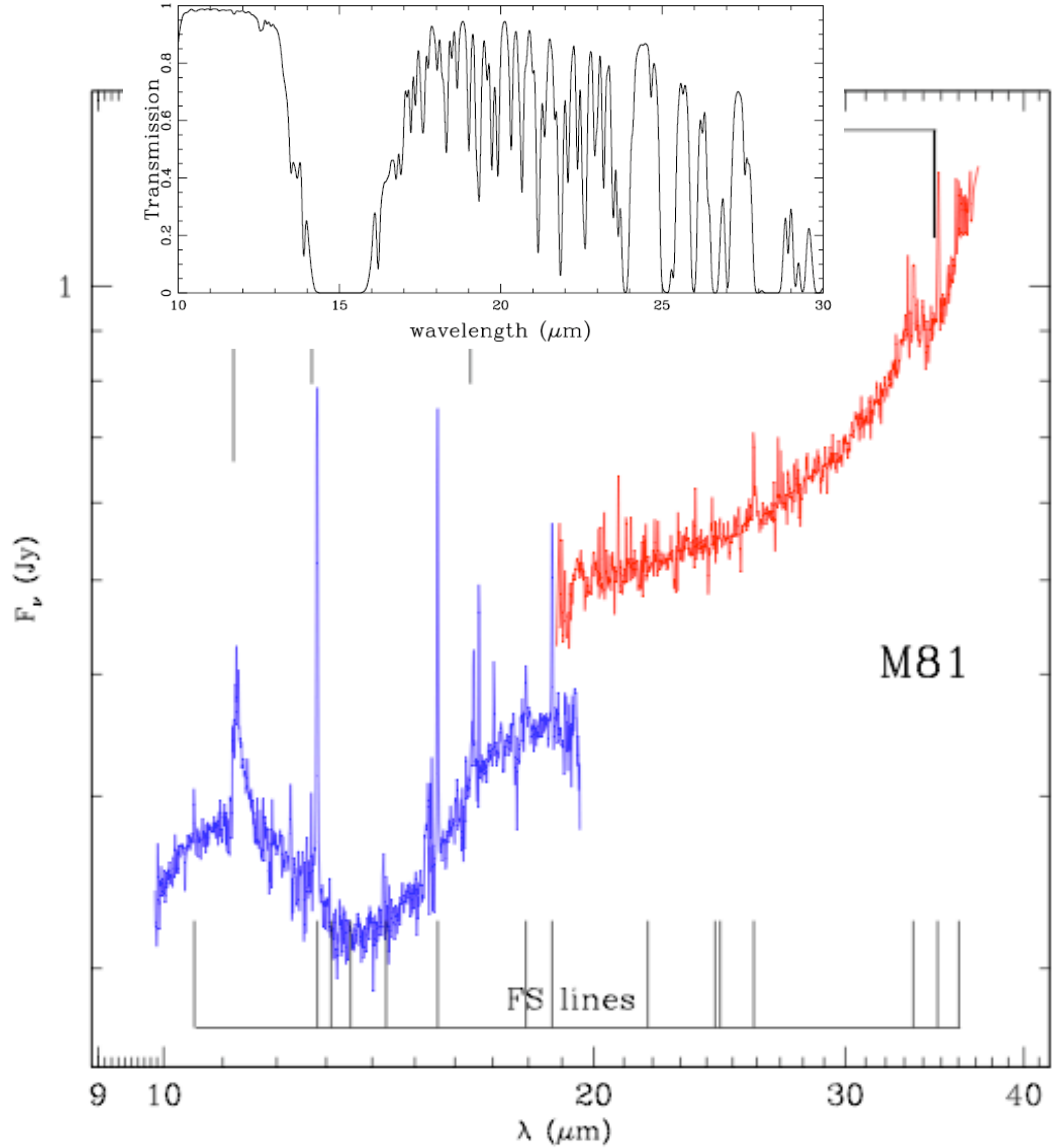
Z=0.0109 Sy2



MKN 1034

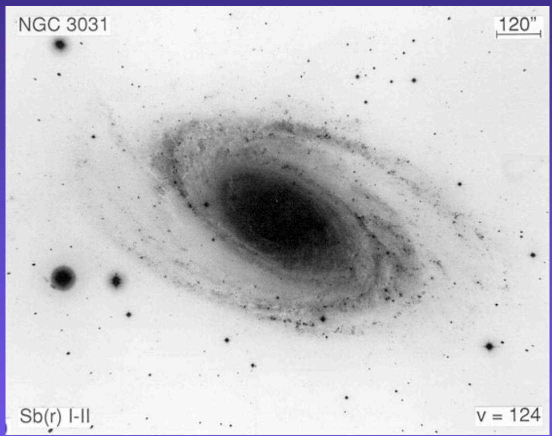
Z=0.0338 HII/Sy1





M81 LINER, z=0.0011

Line	intensity [W/cm^2]	S/N
[SIV] 10.51:	1.7546e-21 +/- 0.295	5.9
H2 12.27:	2.9641e-21 +/- 0.393	7.5
[NeII] 12.81:	2.7730e-20 +/- 0.049	56.
[NeIII] 15.55:	1.8356e-20 +/- 0.033	55.
H2 17.03:	2.3460e-21 +/- 0.269	8.7
[FeII] 17.93:	1.8065e-21 +/- 0.362	5.0
[SIII] 18.71:	6.4804e-21 +/- 0.277	23.
[FeII] 24.52:	5.8296e-22 +/- 2.59	2.25
[OIV] 25.89:	4.7251e-21 +/- 0.216	22.
[SIII] 33.48:	7.4343e-21 +/- 0.577	13.
[SiII] 34.81:	1.6755e-20 +/- 0.040	42.



Spitzer high.res. IRS data provided by Howard Smith, CfA

Spitzer results: SINGS spectra [Dale+2006, ApJ,646,161]

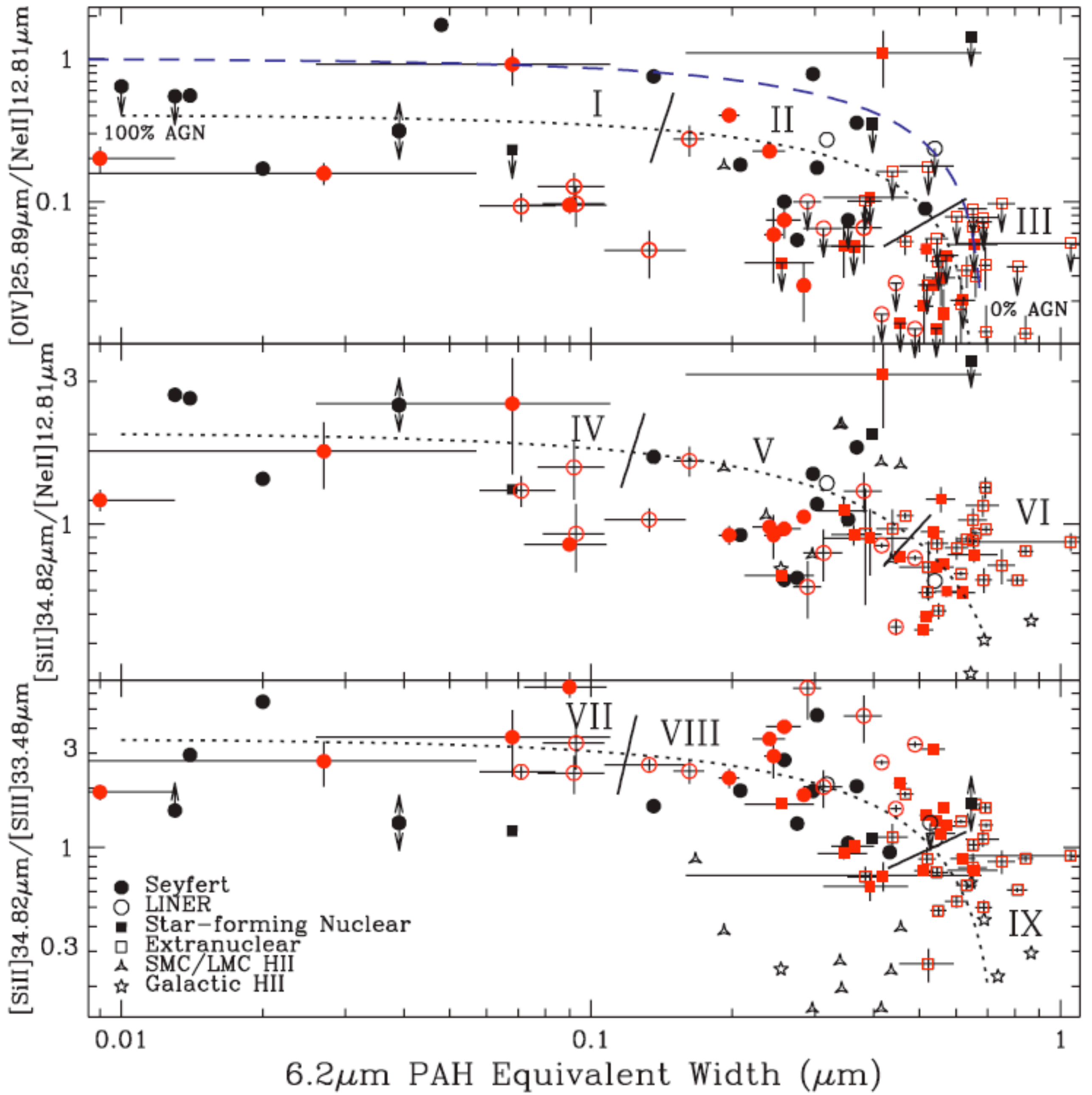
SINGS (Spitzer Infrared Nearby Galaxies Survey) sample (75 nearby galaxies spanning a wide range of morphologies, metallicities, luminosities, and star formation rates) spectra show:

mid-infrared diagnostics effectively constrain the dominant power source.

the combination of a high ionization line index and PAH strength is an efficient discriminant between AGNs and star-forming nuclei, confirming ISO results on starbursting and ultraluminous infrared galaxies (mainly from Genzel's group).

strong low-ionization cooling lines of X-ray–dominated regions like [Si II] 34.82μm can be used as excellent AGNs and star-forming sources discriminants.

Ratios of mid-IR f.s. lines vs 6.2μm PAH feature equivalent width.

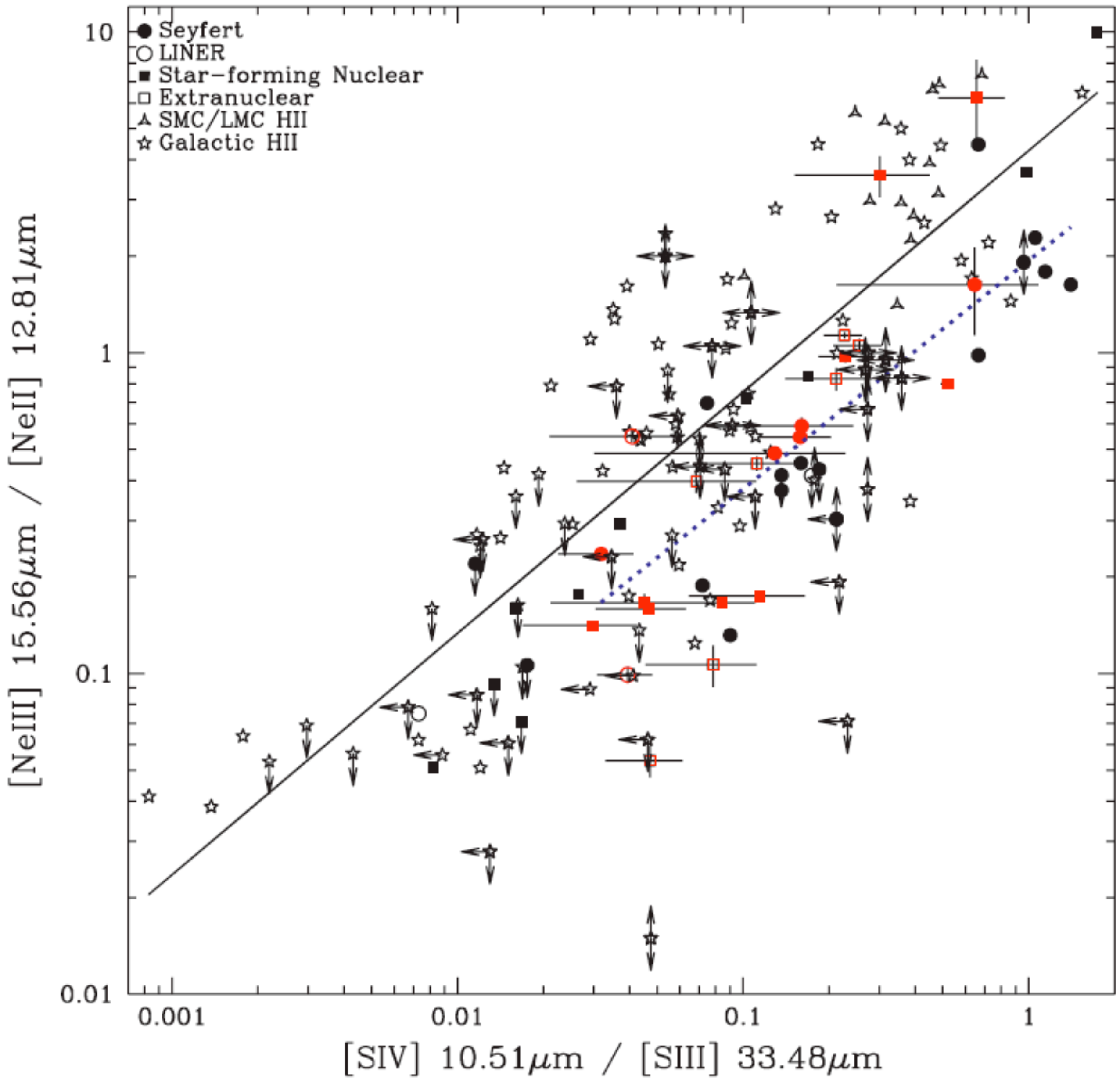


SINGS: red; archival: black.
Dotted lines = linear mixing models of a "pure" AGN and a "pure" star-forming source.
Dashed line = mixing model presented by Genzel et al. (1998).

Solid lines and Roman numbers show different emission regions (Seyfert galaxies, LINERs, star formation, see table).
[Dale+2006, ApJ,646,161]

Diagnostic diagram with neon and sulfur lines at different ionizations

(see, e.g., Verma et al. 2003).

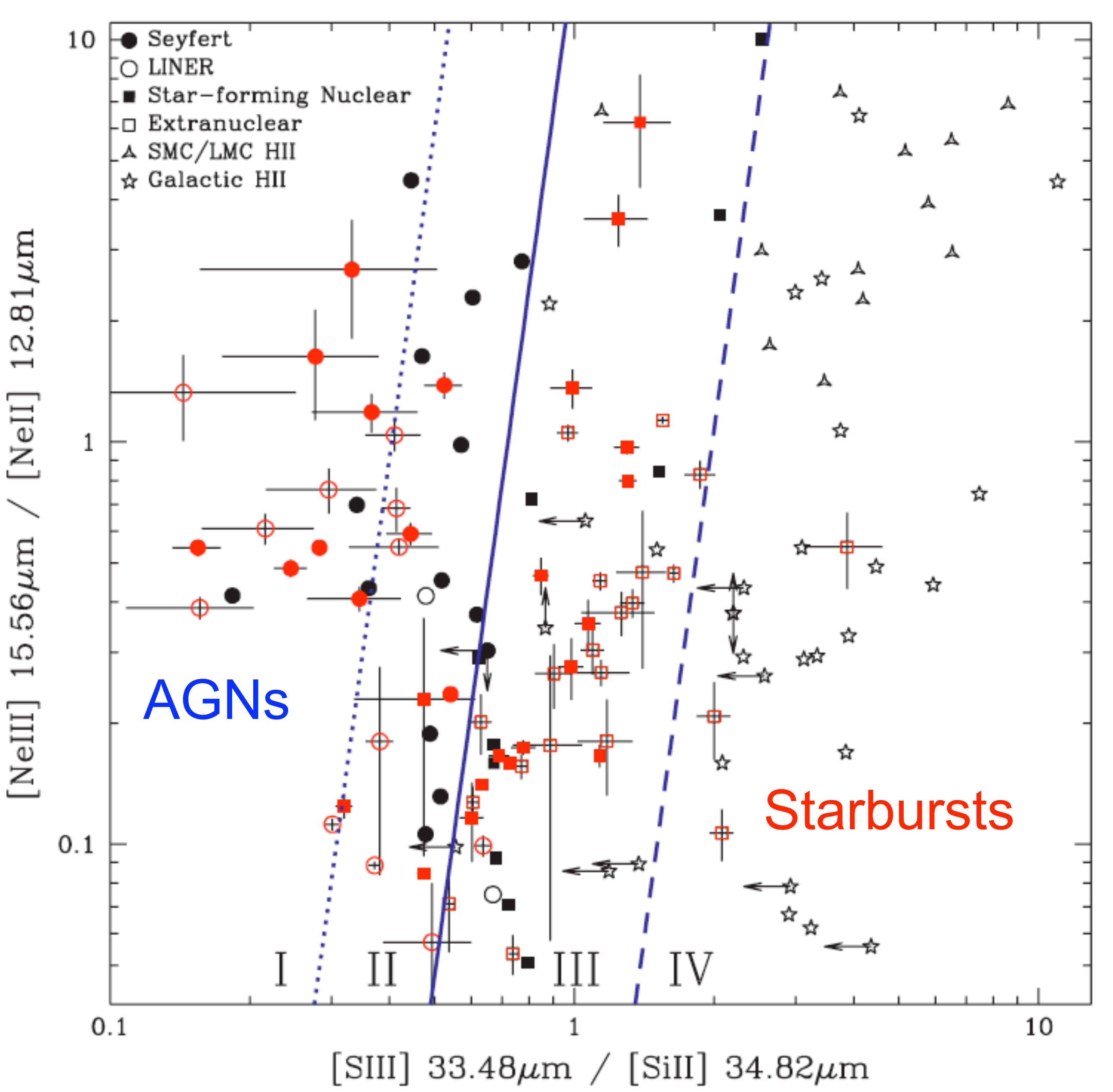


The solid line = linear fit to the detections of star-forming nuclei and HII regions

the dotted line = linear fit to the Seyfert detections.

[Dale+2006, ApJ,646,161]

Neon, sulfur, and silicon diagram covering different ionizations.



The lines and Roman numbers delineate regions distinguished by Seyfert galaxies, LINERs, star formation, etc.

[Dale+2006, ApJ,646,161]

Low Ionization Narrow Emission Region galaxies= LINERs

Spitzer spectra of IR-bright and IR-faint LINERs

[Sturm+ 2006, ApJL & astro-ph/0610772]

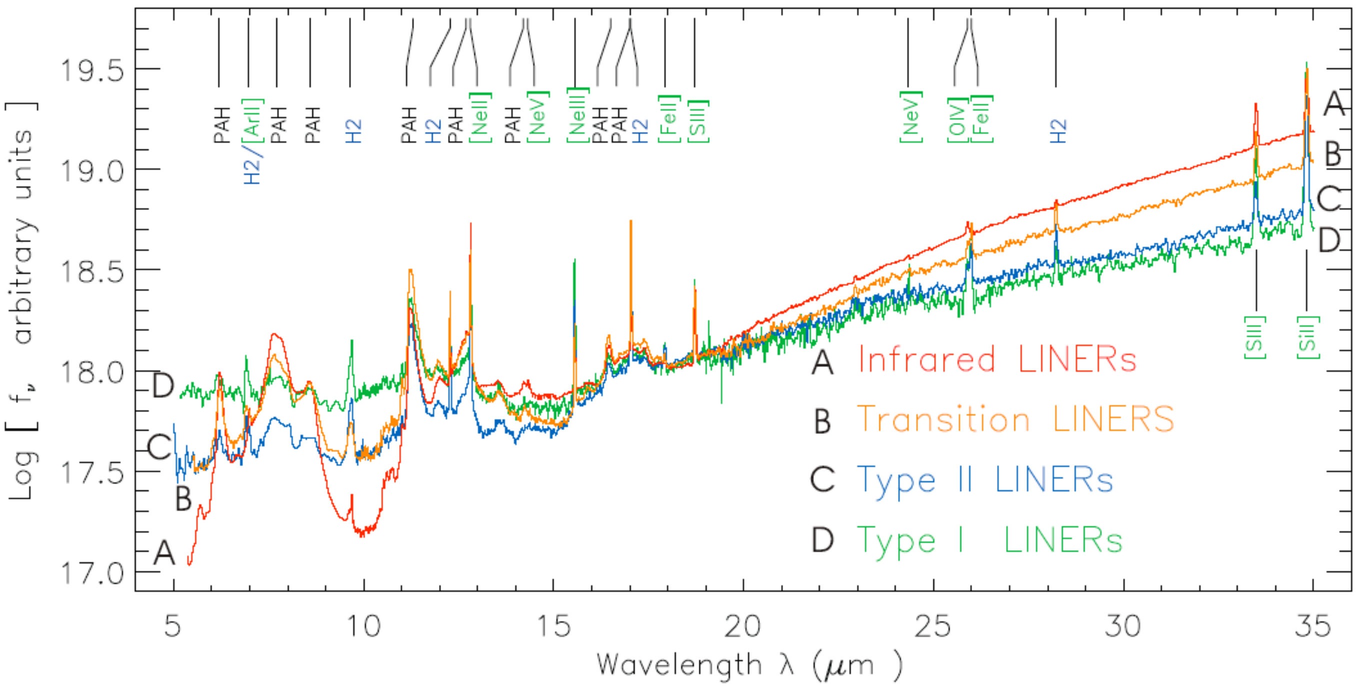
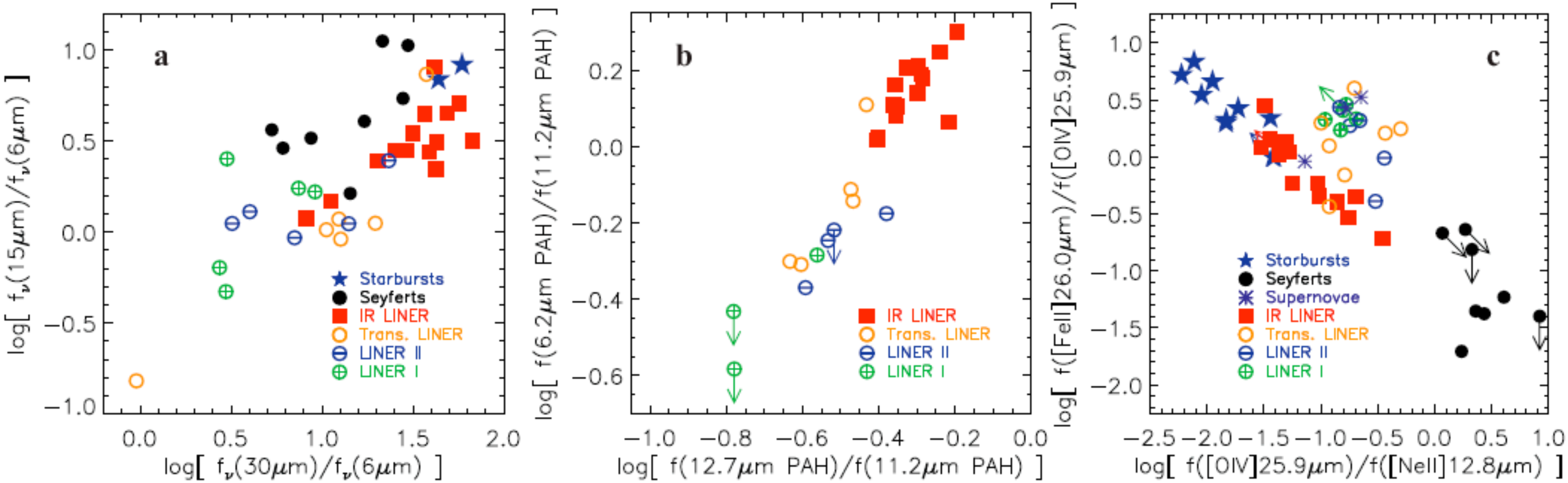


Fig. 1.— Composite spectra (normalized at 19μm) of the 16 IR-luminous LINERs (red) and the IR-faint LINERs (green: 5 Type 1 LINERs, blue: 6 Type 2 LINERs, yellow: 6 Transition Type).



What we expect from Herschel Spectroscopy ?

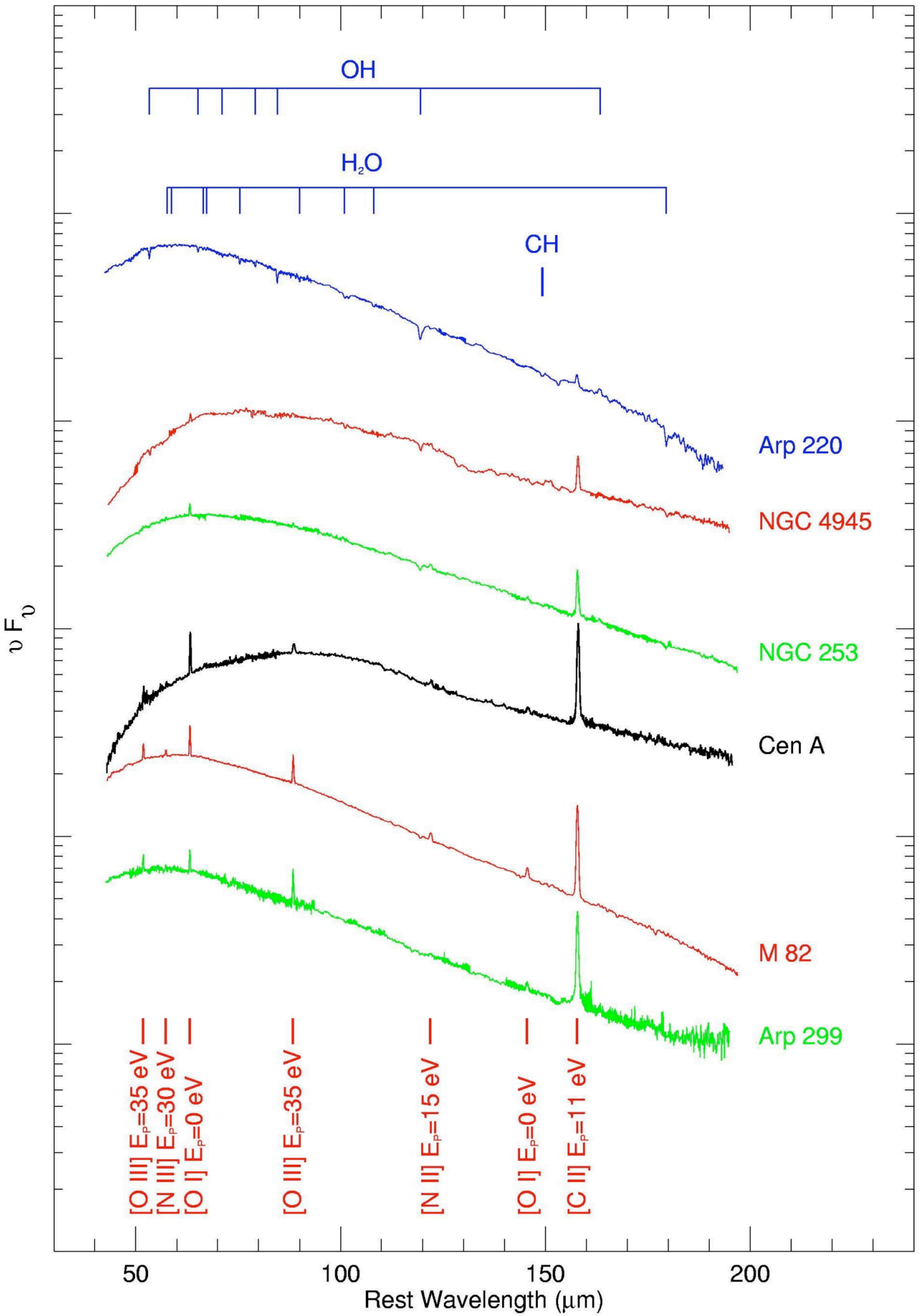
Extend the pioneering work done with ISO-LWS to local active galaxy samples

What we learned from ISO-LWS spectra :

LWS: dramatic progression in ionic/atomic fine-structure emission line and molecular/atomic absorption line. (Fischer et al '99)

Arp 220:
absorption in lines of OH, H_2O, CH, NH, NH_3, and in [OI]63μm
faint emission in [CII]158μm line.
high IR radiation density (Gonzàlez-Alfonso et al 2004).

NGC 1068:
79, 119 and 163μm OH rotational lines in emission (not in absorption as in every other galaxy yet observed) probably originated in the nucleus. (Spinoglio et al. 2005).



The case of NGC 1068

What we have learned from ISO spectroscopy:

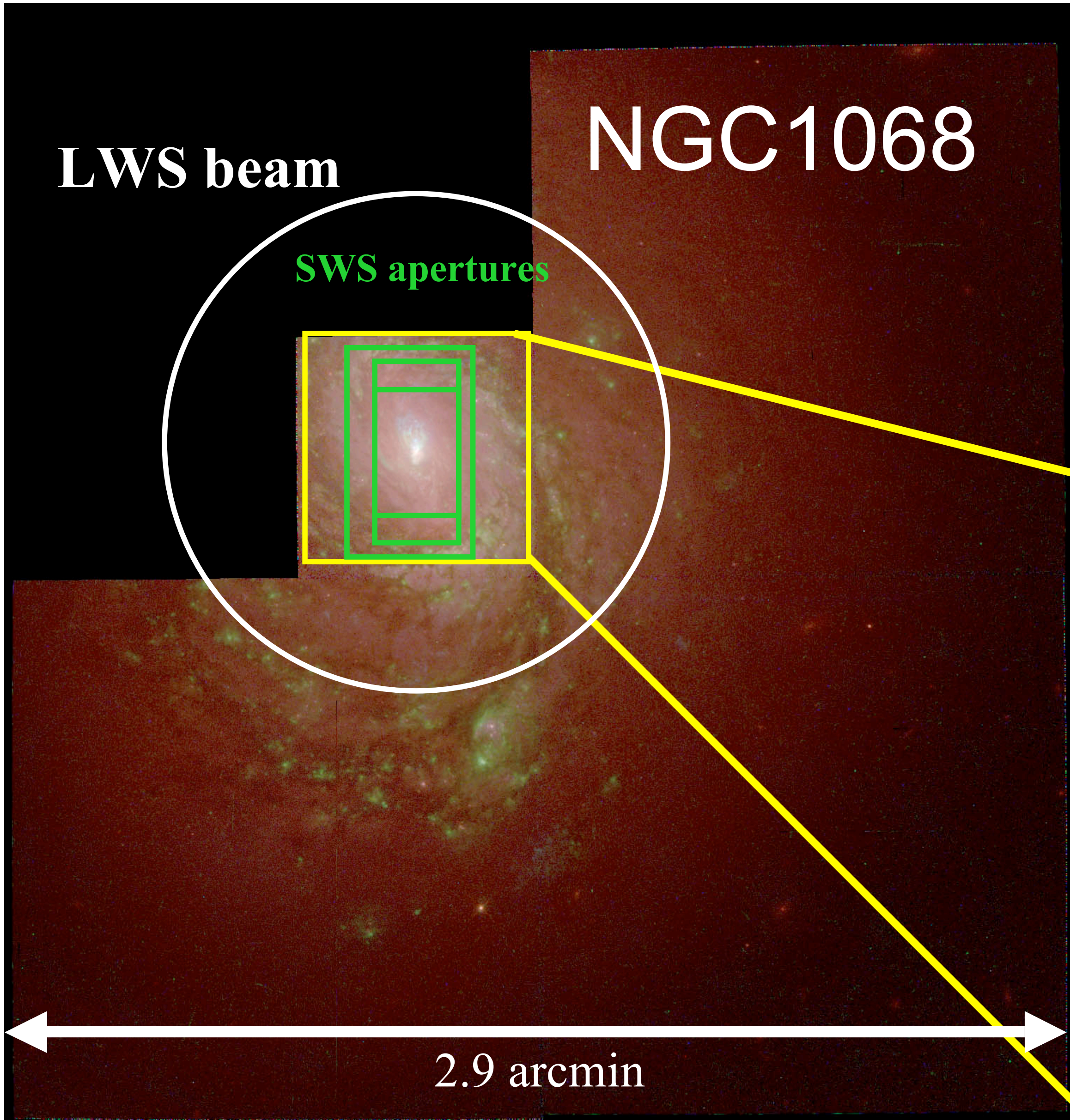
- continuum and the line emission have been modeled

- spectroscopic separation of starburst from AGN component using the mid & far-IR spectrum and photoionization models

- first detection of 3 far-IR OH lines all in emission in extragalactic objects

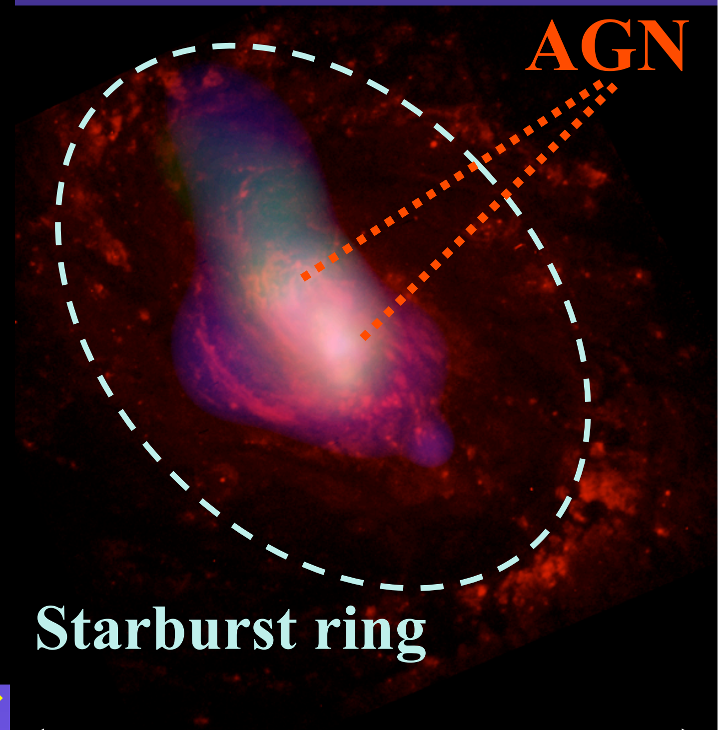
- radiative tranfer models show that the OH lines are nuclear in origin

LS+ E. Gonzalez-Alfonso, H.Smith, J. Fischer & M. Malkan, [Spinoglio et al.2005]



CHANDRA image overlayed on a HST image (X-ray: green 0.4-0.8 keV, blue 0.8-1.3 keV; optical: red)

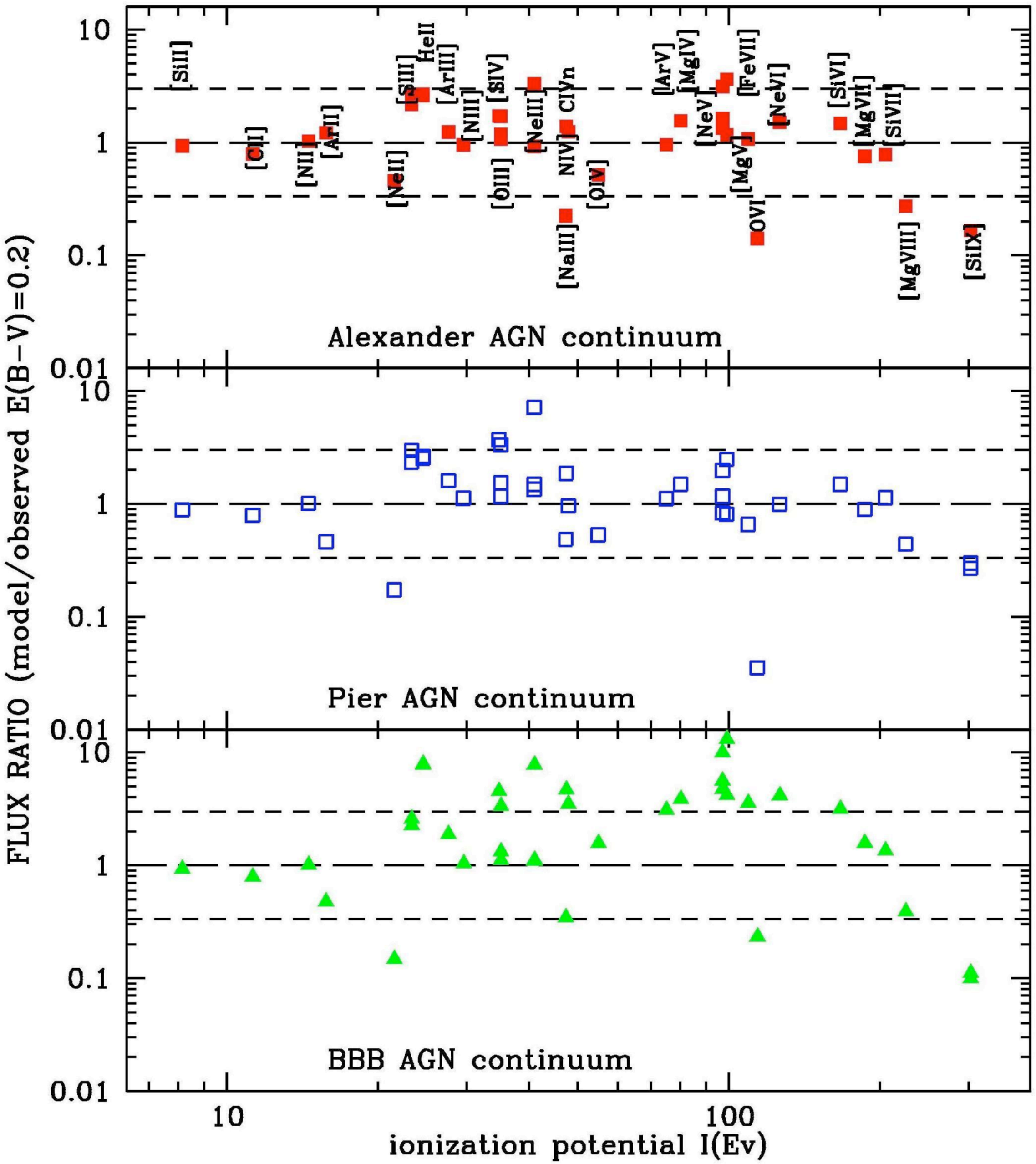
X-ray: P.Ogle et al.; Optical: A.Capetti et al.



36 arcsec

HST three-colour image of the WFPC2 camera ([OIII], Hα+[NII], wide-band 791nm filter)

GOAL of Mid-IR/FIR spectroscopy: separate AGN & starburst



COMPOSITE MODELS

AGN + Starburst models of NGC1068.

Line fluxes change with the AGN input ionizing spectrum:

■ Alexander et al. reduced χ^2 =11.7

line fluxes reproduced within 2.0±1.3

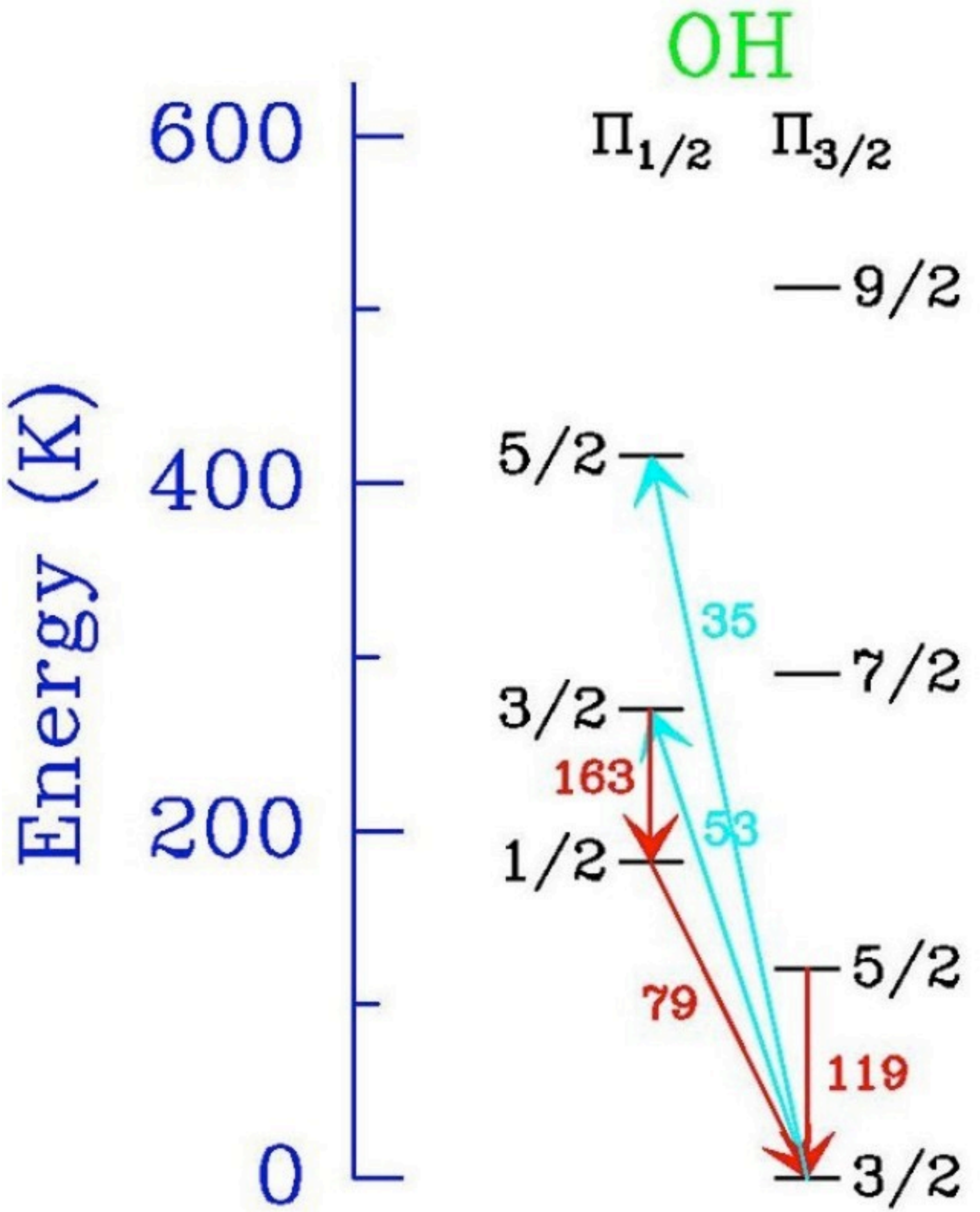
□ original Pier et al. χ^2 =17.1

big blue bump χ^2 = 177

starburst model with n_H=100 cm^{-3} Log U=-3.5

[Spinoglio et al 2005,ApJ]

Energy levels diagram of OH



Rotational levels up to 600K

Red: lines detected in NGC1068:

fundamental at 119µm (in-ladder) and at 79 µm (cross ladder) the 163µm line (the lowest transition of the $2\Pi_{1/2}$ ladder).

Blue: the 35 and 53µm lines important in the radiative excitation.

NGC 1068 is the only extragal. source observed with ISO where the 119µm ground-state line is detected in emission. The 79µm line is detected in some sources in emission and in other in absorption, whereas the 163µm line is always in emission.

Modeling the OH line emission

The 119µm emission cannot be explained in terms of OH excitation through absorption of 35µm and 53µm dust photons, because there would be strong emission in other OH far-infrared lines that are not detected.

- The 119µm line is excited through collisions.

  ➔ warm and dense region where the OH abundance is high.

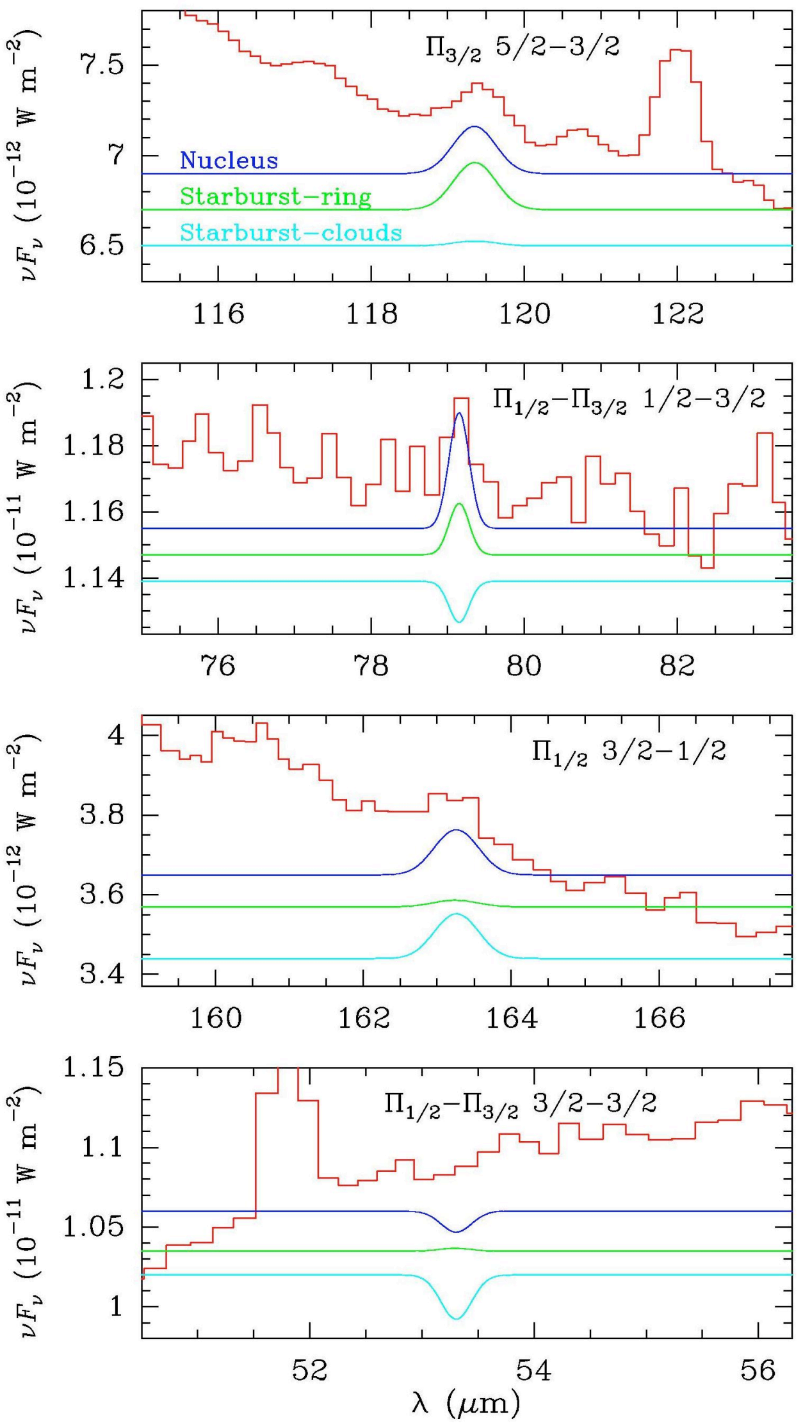
- The 163µm line is radiatively excited.

- The 79µm line may be excited through both mechanisms.

The OH 119µm line can be originated from:

- The nuclear region, with 2×10^7 Mo of warm gas (80 K), an average density of $n(H_2) = 5 \times 10^5 cm^{-3}$, and an OH abundance of $\approx 10^{-5}$.

- The starburst region, if ≈ 5% of the associated mass (≈ 8×10^7 Mo) is warm (≈100 K), dense (a few $\times 10^5$ cm-3), and rich in OH ($X(OH) \approx 2 \times 10^{-6}$).



Radiative transfer non-local, non-LTE models of the OH lines (Gonzàlez-Alfonso & Chernicharo) for the nuclear and the starburst region, with radiative and collisional OH excitation.

Nuclear models can explain the emission in the three OH lines.

Starburst models, assuming a low influence of the FIR emission on the OH excitation, fit the 119μm line, but underestimate the other two lines (see green spectra).

Starburst models with an ensemble of clouds, with influence of FIR continuum on OH excitation, predict the 119 and 79μm lines very weak or in absorption when the 163μm line is fitted.

➔ some contribution from the extended starburst cannot be ruled out

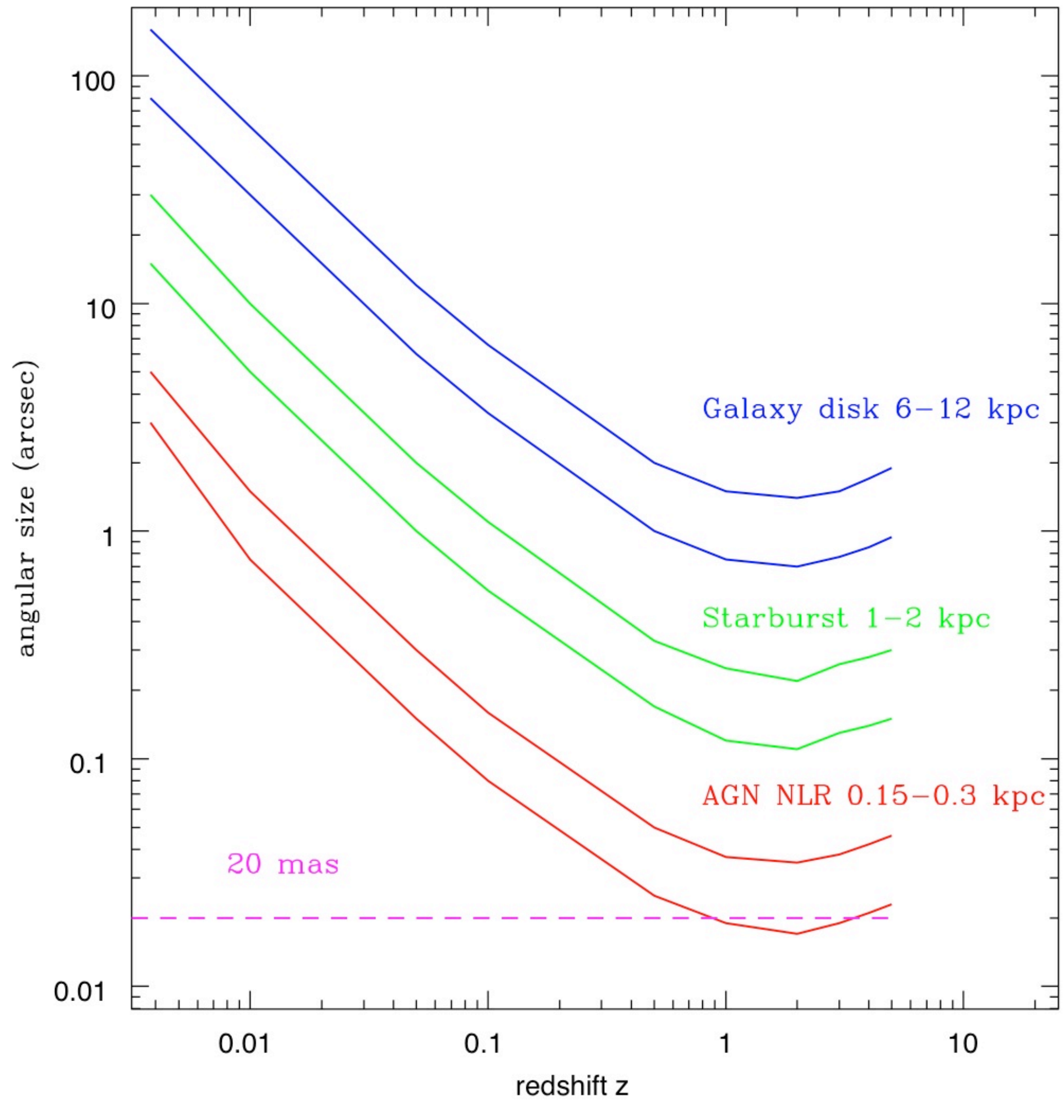
➔ the bulk of the OH emission arises in the nuclear region.

➔ the high OH abundance needed suggests the presence of an X-ray dominated region.

Herschel spatial resolution will not be able to resolve different emission line regions not even in local active galaxies:

PACS@60um: 8 arcsec

PACS @160um:23 arcsec



Angular resolution as a function of redshift needed to resolve

- an AGN narrow line region of 150-300pc

- a circumnuclear starburst of 1-2kpc

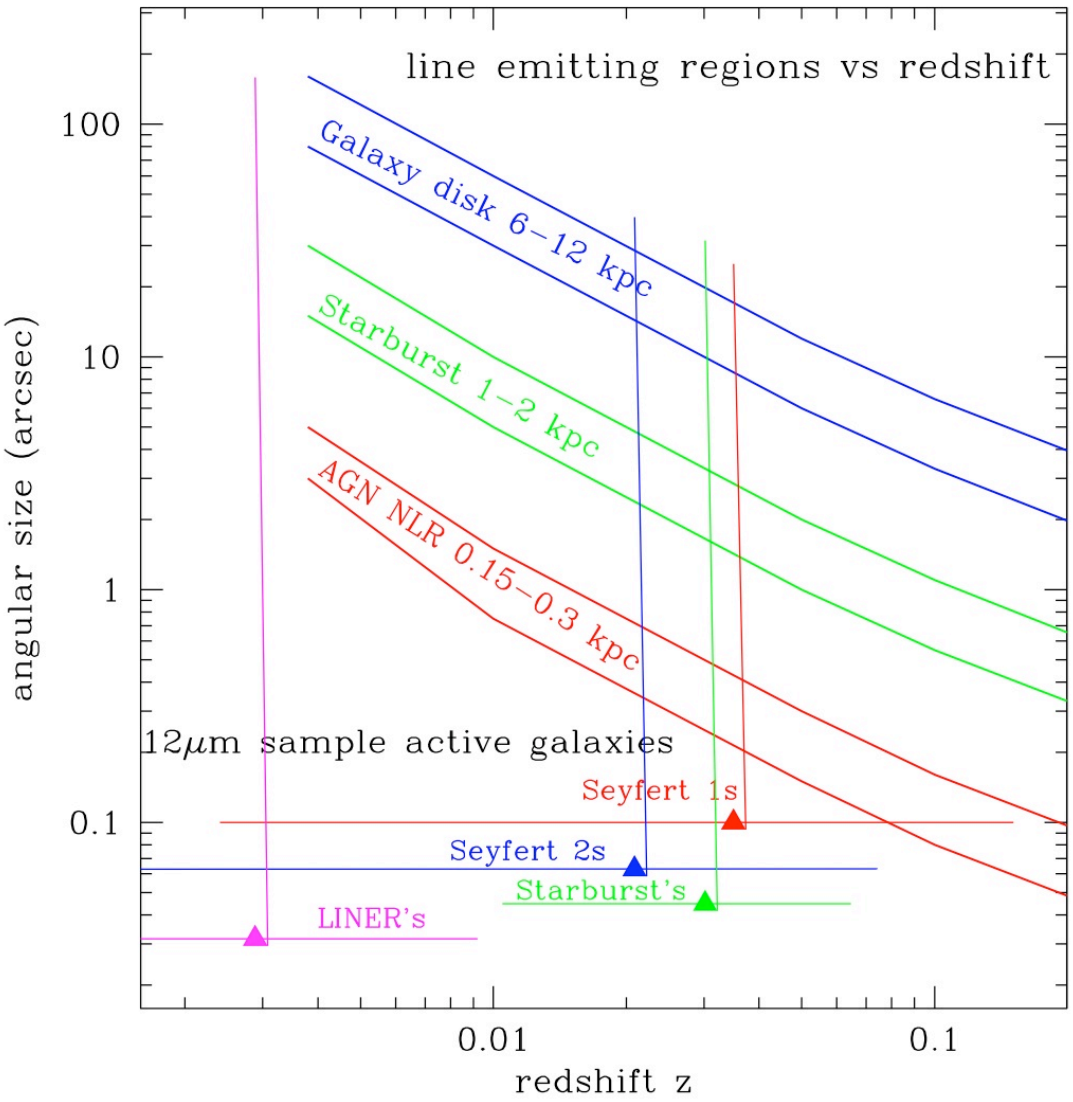
- a galactic disk of 6-12 kpc

Assuming:

Ho=71km/s/Mpc

Ωm=0.27

Ωvac=0.73



For local active galaxies, a resolution of:

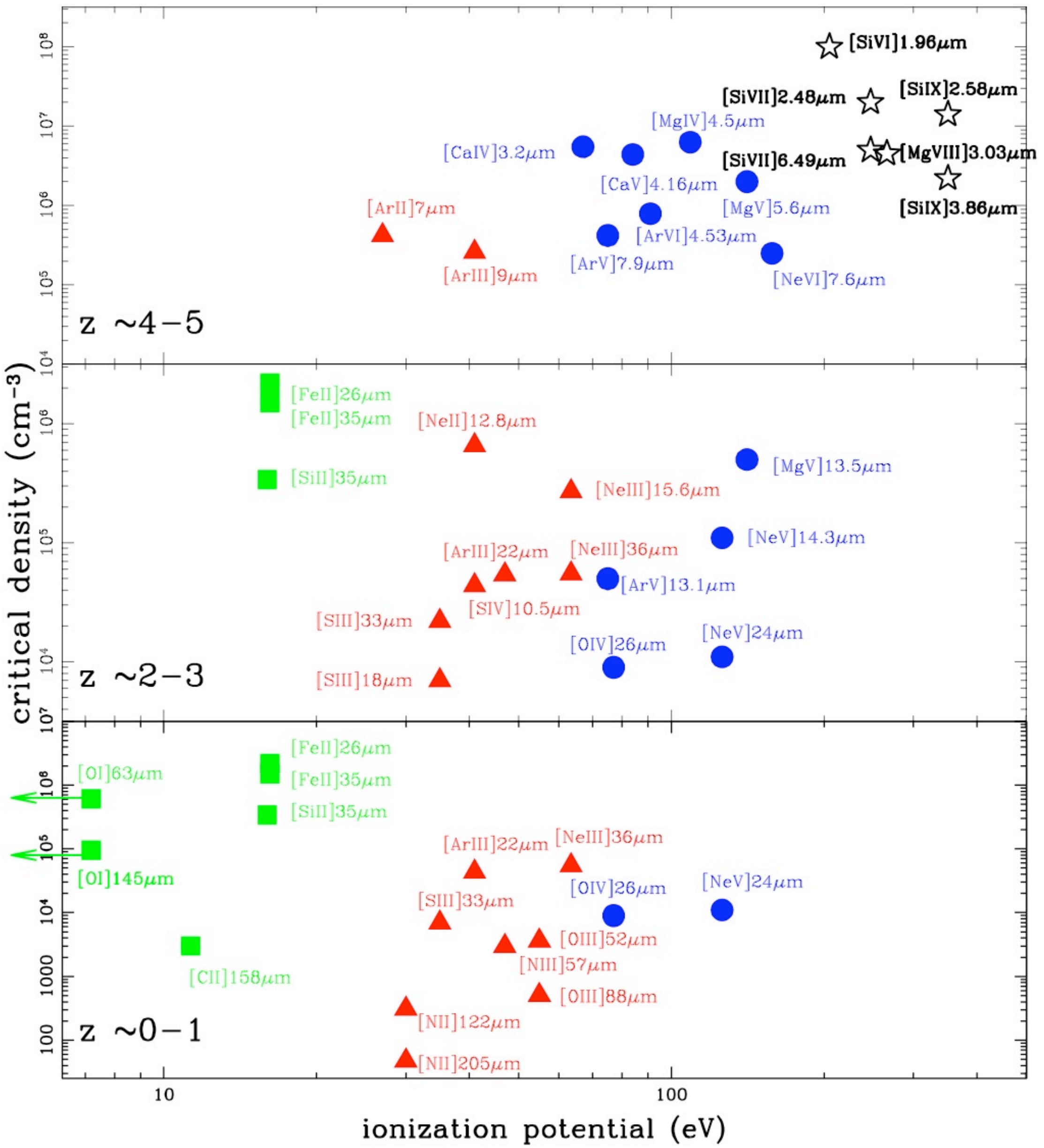
-1-5 arcsec is adequate to resolve the closest AGN narrow line regions

- a few arcsec (1-10) the circum-nuclear starbusts

Spectroscopy will be needed to separate the emission components !

At least before any interferometric instrument (e.g. FIRI from the space proposed for CV 2015-2025)

Fine structure lines shifted in the mid-IR/FIR as a function of z



FS lines measure density and ionization of the gas. from:

- the photodissociation regions (PDR),

- the stellar ionization in HII/starburst regions,

- the AGN ionization

- the high ionization of coronal type emission.

Two lines parallel to x-axis and two parallel to y-axis have ratios that measure the ionization and the density of the gas in the region (see, e.g., Spinoglio & Malkan 1992).

Spectroscopy is not limited by confusion like photometric imaging: the sources will be resolved because of the different redshift

Fine-structure line detection

At what redshift we can detect the lines ISO detected in NGC1068 ?

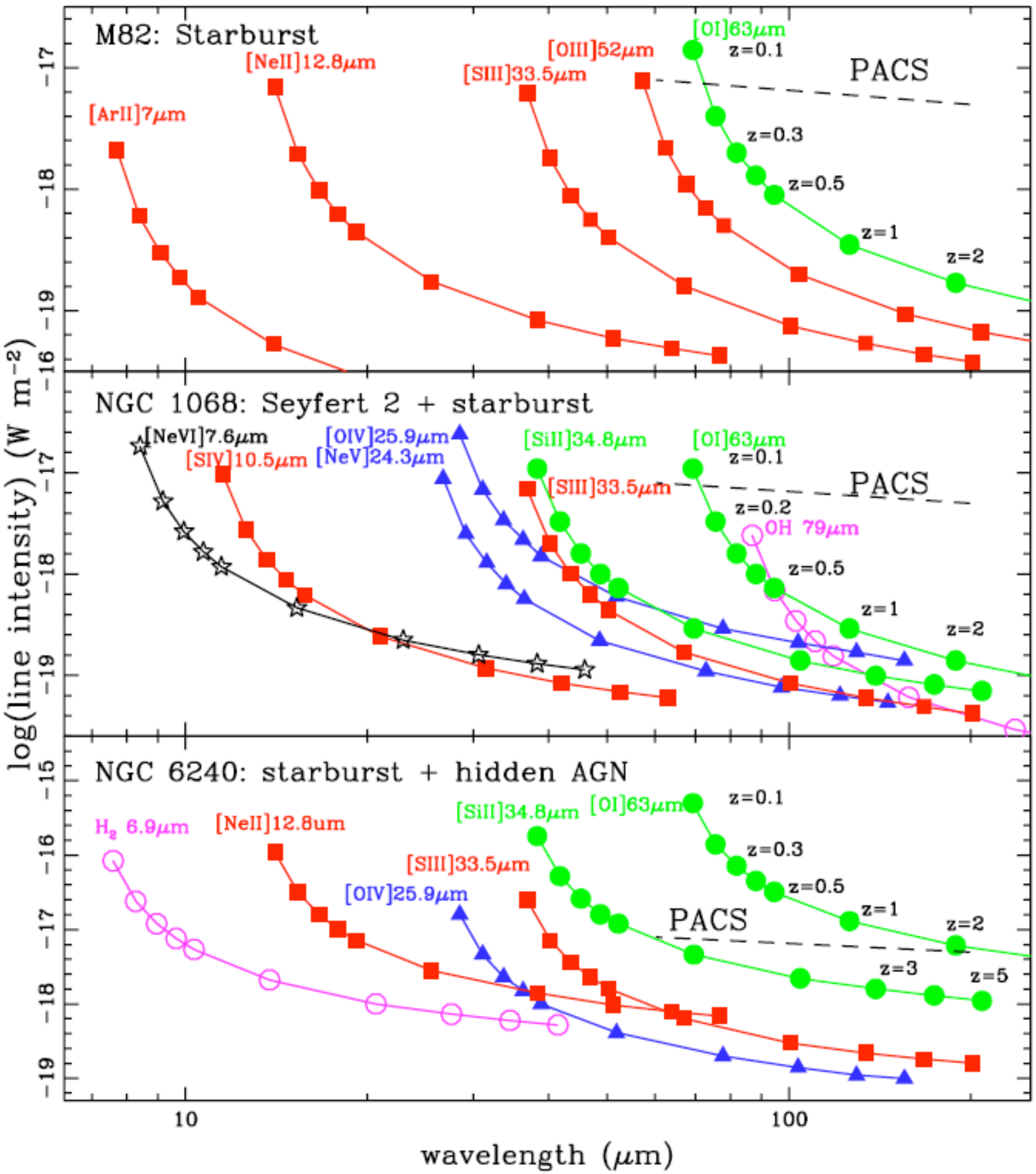
Einstein-De Sitter model Universe, with $\Omega_\Lambda = \Omega vac = 0$ and $\Omega = \Omega M = 1$, Ho=75 km/s/Mpc

luminosity distances with : $D_L(z) = 2c/Ho\,[1+z - \sqrt{(1+z)}]$

We derived the line fluxes in W/m^2, assuming that the line luminosities scale as the bolometric luminosity and choosing two cases:

A) luminosity evolution proportional to the $(z+1)^2$, consistent with *Spitzer* up to redshift z=2 (Pérez-Gonzalez et al 2005, ApJ, 630, 82).

B) no luminosity evolution



Expected line intensities of fine structure lines tracing:

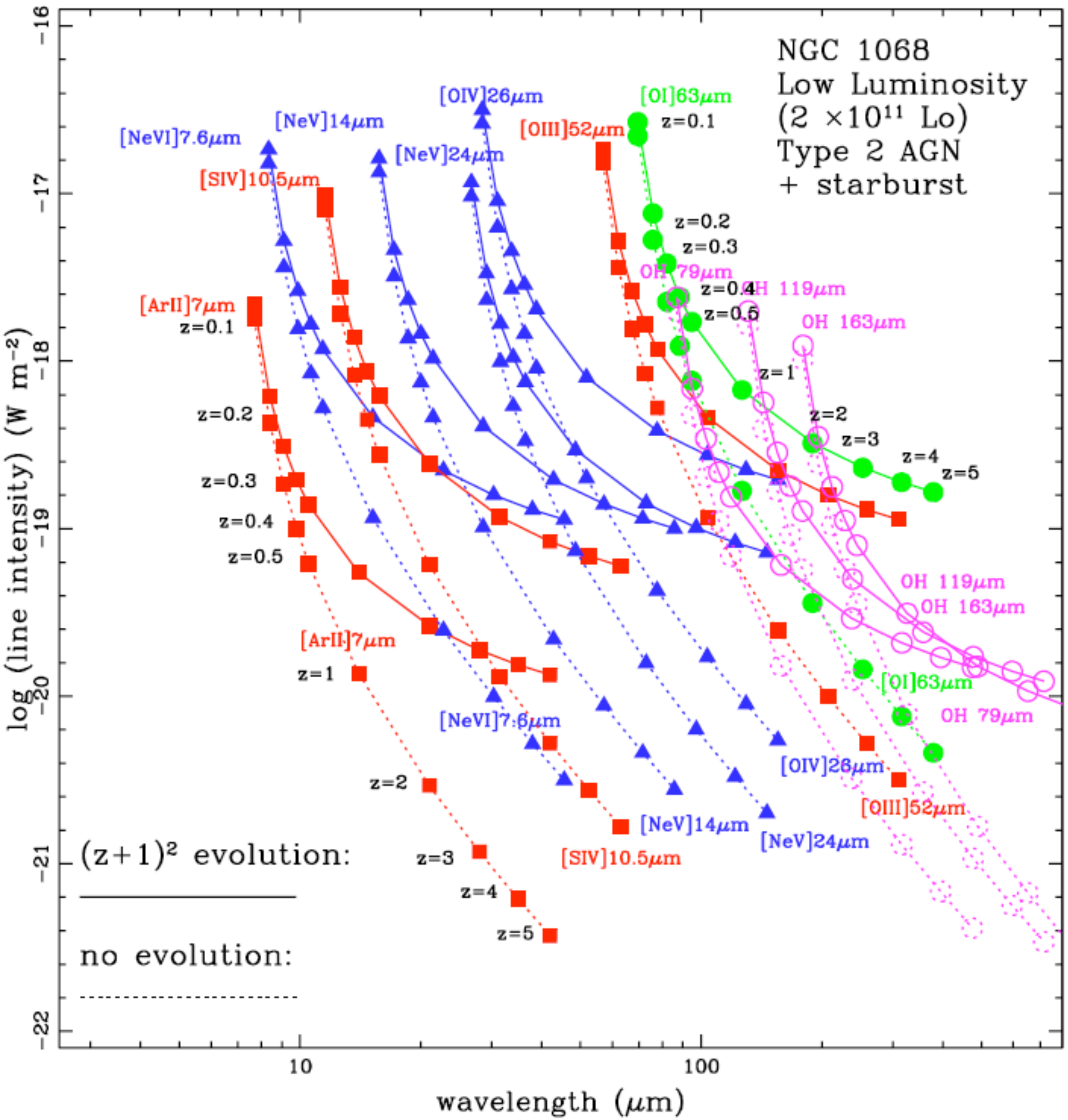
Stars

AGNs

PDRs

Molecular material

As a function of redshift for 3 template objects



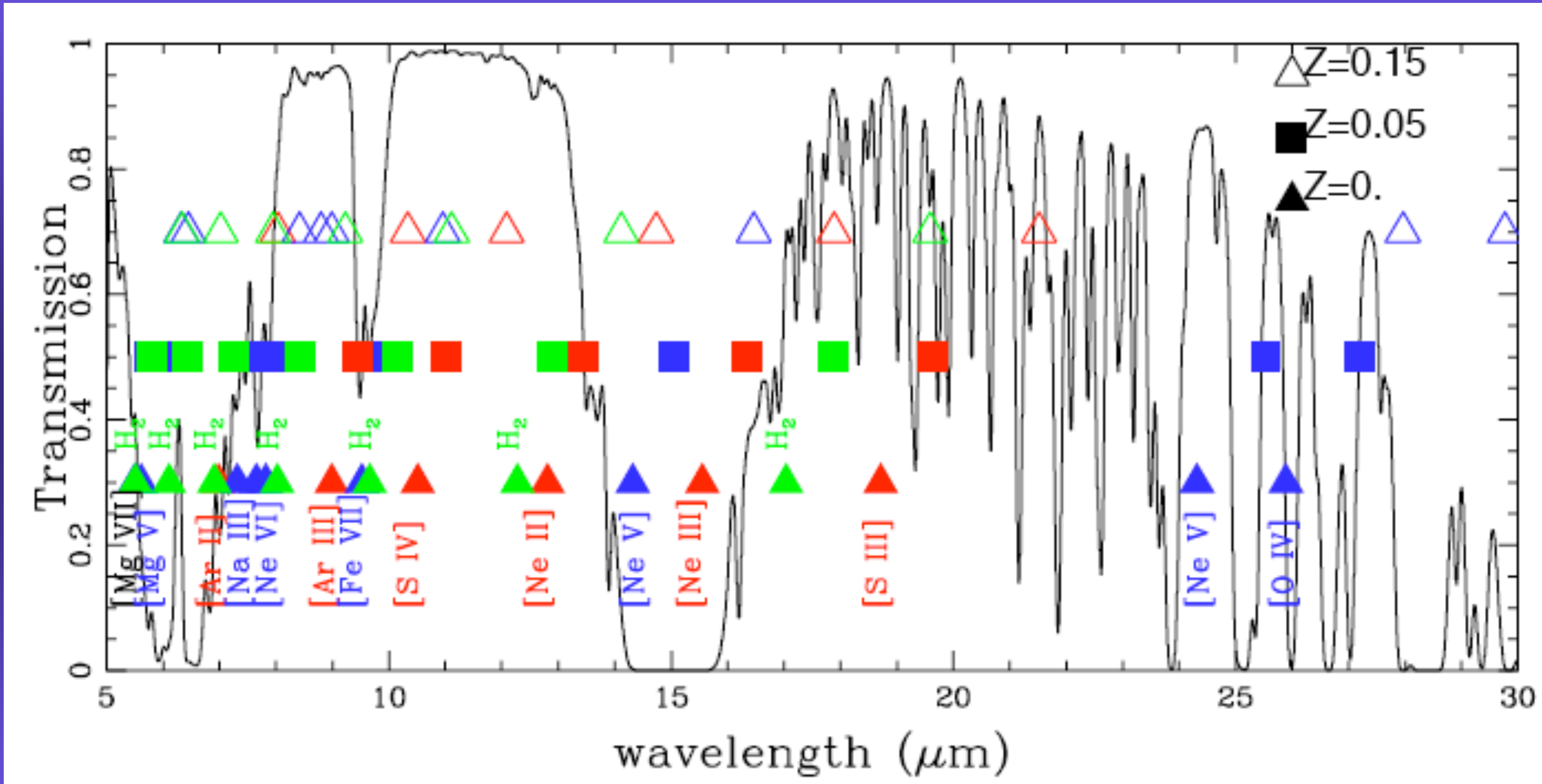
NGC 1068 as a template (type 2 AGN + starburst)

As a function of z for two evolutionary models:

___ $L \propto (z+1)^2$

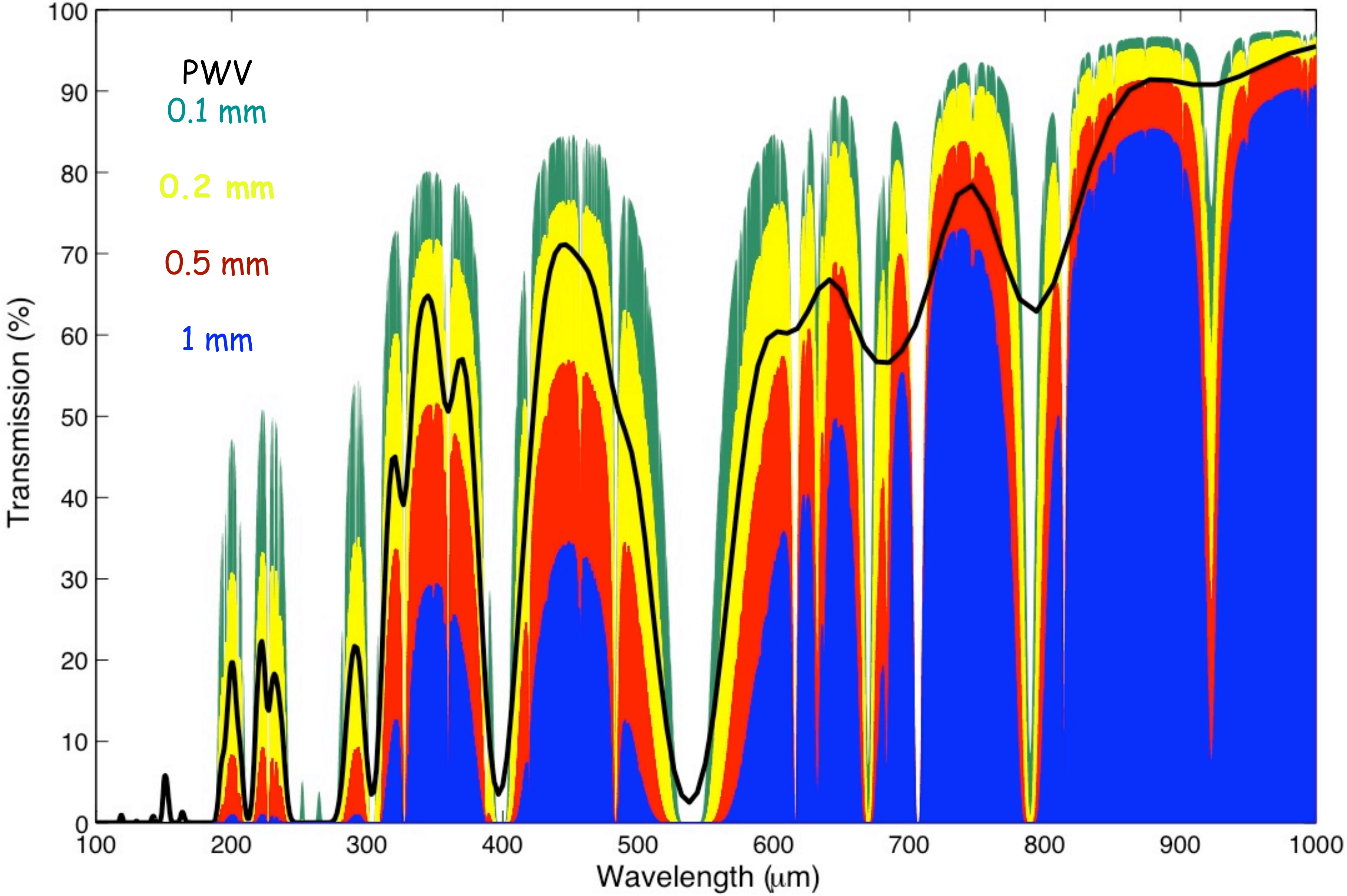
..... no evolution

5-30um range: what lines can be observed

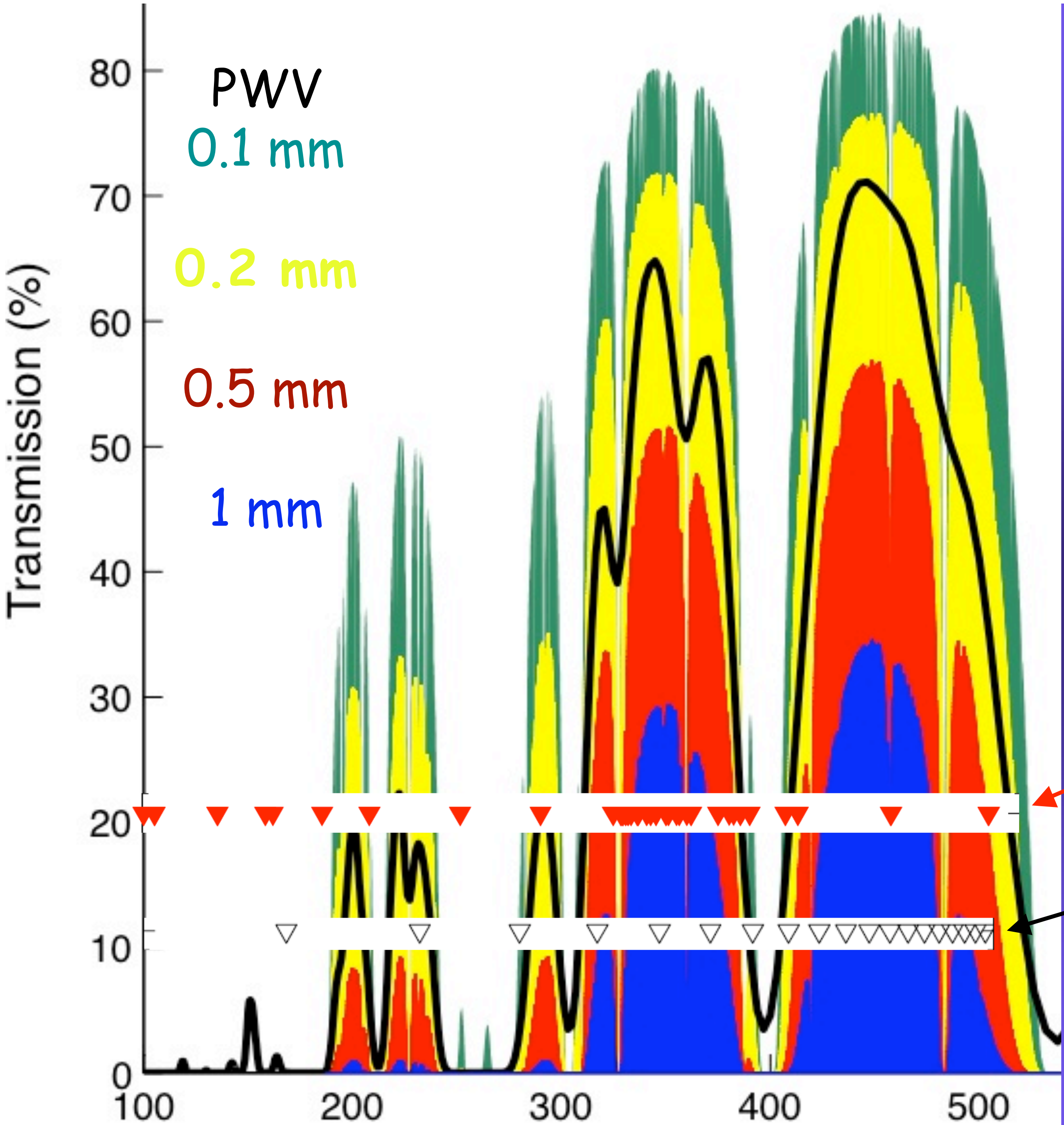


Transmission at Mauna Kea with pwv=1mm with positions of stellar lines (red), AGN (blue) molecular H2(green)

Three values of redshift z=0., z=0.05 and z=0.15 are given



PWV
0.1 mm
0.2 mm
0.5 mm
1 mm
Transmission (%)
Wavelength (μm)
0
10
20
30
40
50
60
70
80
90
100
100
200
300
400
500
600
700
800
900
1000



Critical atmospheric windows:

200μm

230μm

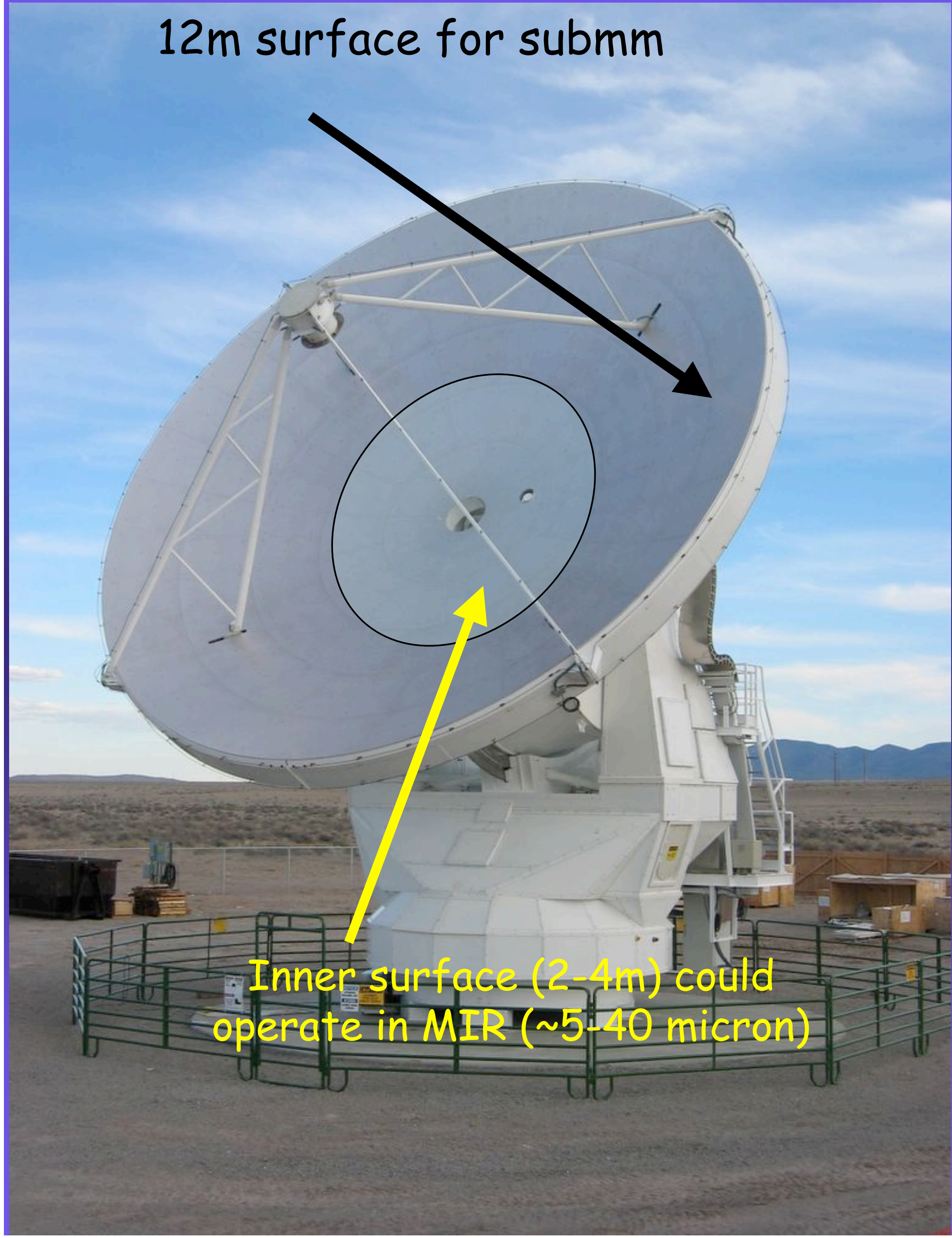
280μm

350μm

450μm

OH LINES

CO LINES



From a dual channel type telescope (see Olmi presentation) capable to work in the MIR (5-40μm) and submillimeter: 200, 350, 450μm

⇒ We will be able to do spectroscopy in a site like Dome C (TBC) where the best atmospheric windows are open

⇒ Understand real transparency and stability of the windows

conclusions

- MIR/FIR/submm spectroscopy traces the physical processes obscured by dust

- Goal: measure separate “accretion” and “star formation” luminosity functions in the Local Universe and during galaxy evolution as a function of redshift

- local universe: MIR traces AGNs, FIR/submm traces Star Formation + possibly X-ray illuminated circumnuclear regions (tori?)

- even in Loc.Univ. SPECTROSCOPY is needed to separate starburst from AGN

- At high z: near-IR and MIR shifted into MIR/FIR: possible to trace evolution through the AGN versus SF content in the energy budget

- At high z: very high spatial resolution (interferometer?) or high sensitivity spectroscopy would be needed => large flux collectors (easier from the ground)

- Dome C MIR/submm spectroscopy can be complementary to space observations

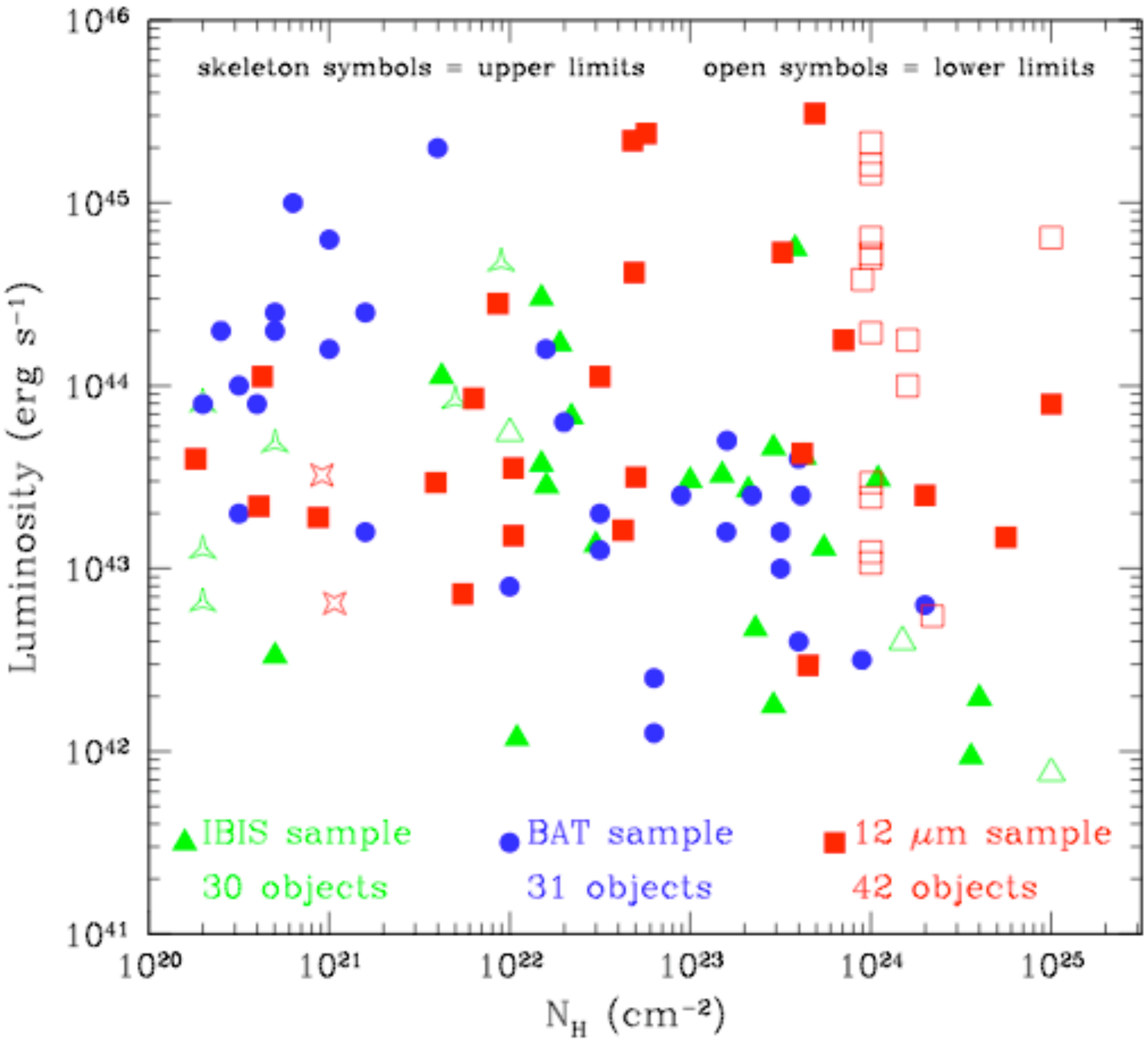
Herschel Open Time Key Project:
HERLOGAL= Herschel Survey of Local galaxies Activity

technique:

- -collect Herschel spectra on 12um selected Seyfert galaxies (~120) + hard-X rays selected Seyferts (SWIFT-BAT + Integral-IBIS samples) (~60)
- - Complement with complete spectral Spitzer coverage at High Resolution (10-40um)

aims:

- - measure local Universe separate luminosity functions for "accretion" and "star formations" processes
- - find through FIR atomic & molecular spectra effects of AGNs on the circumnuclear physics of Seyfert's
- - characterize OBSCURATION: searching for correlations of NH (as measured at hard-X-rays) with Luminosity, with Ratio AGN/S (from ionic lines), with "tori" molecular lines.



Luminosity-NH diagram for the Seyfert galaxies to be observed with HERLOGAL

The combination of 12μm selected + Hard X-rays selected Seyfert galaxies well cover the parameter's space.

Mid-IR line ratio diagrams

X-axis line ratio measures the ionization, Y-axis measure the density.

Grids: AGN models with α=-1 and -2 power law ionizing continuum to model Seyfert type 1 and 2 NLRs, resp., different densities and ionization parameters