High resolution far-IR observations of obscured AGN

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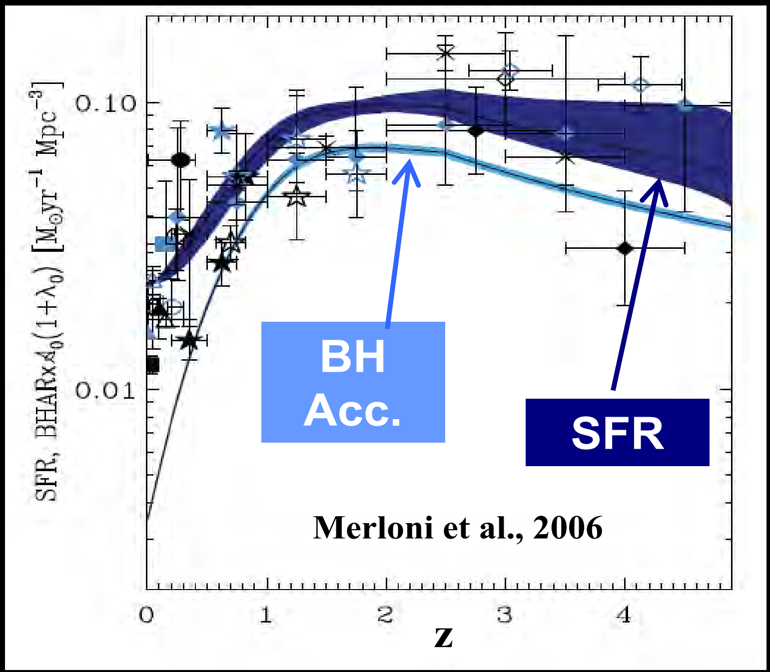
Talk Outline

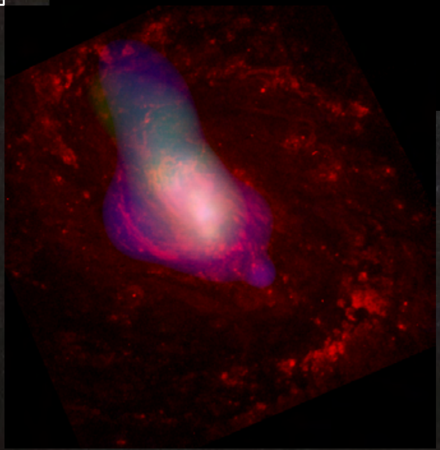
- AGN/Galaxy Co-evolution
- Dust Obscured AGN Phase: few cases
- Why high resolution observations in the far-IR?

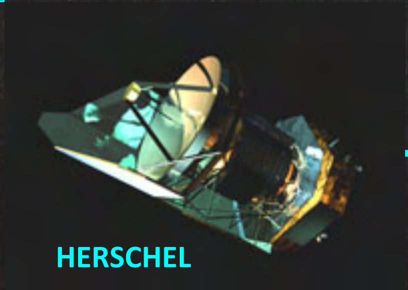
far-IR: what do we need to know?

Co-eval Growth of Black Holes and Host galaxies

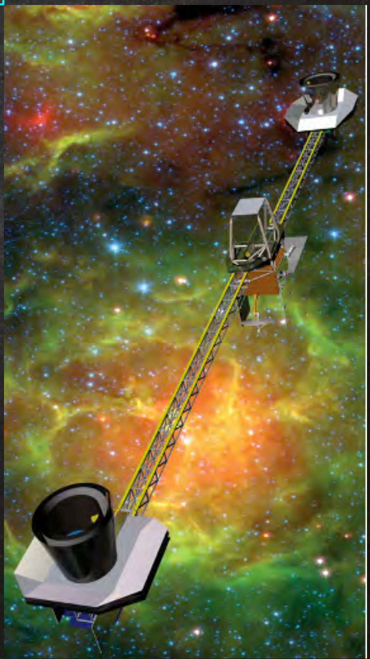


- Dust-enshrouded AGN accretion phase undergone by all galaxies?
- Need to compare evolution of BH mass function with galaxy mass and luminosity functions in large samples
- Must include heavily obscured AGN
- Both peak at z = 2 – 3, when most SF was in LIRGs – current data very limited
- Key AGN signature: high-excitation fine structure lines e.g., [NeV] 14.3 μm
  [OIV] 26 μm
- Line widths indicative of BH mass





Far-IR
High-resolution



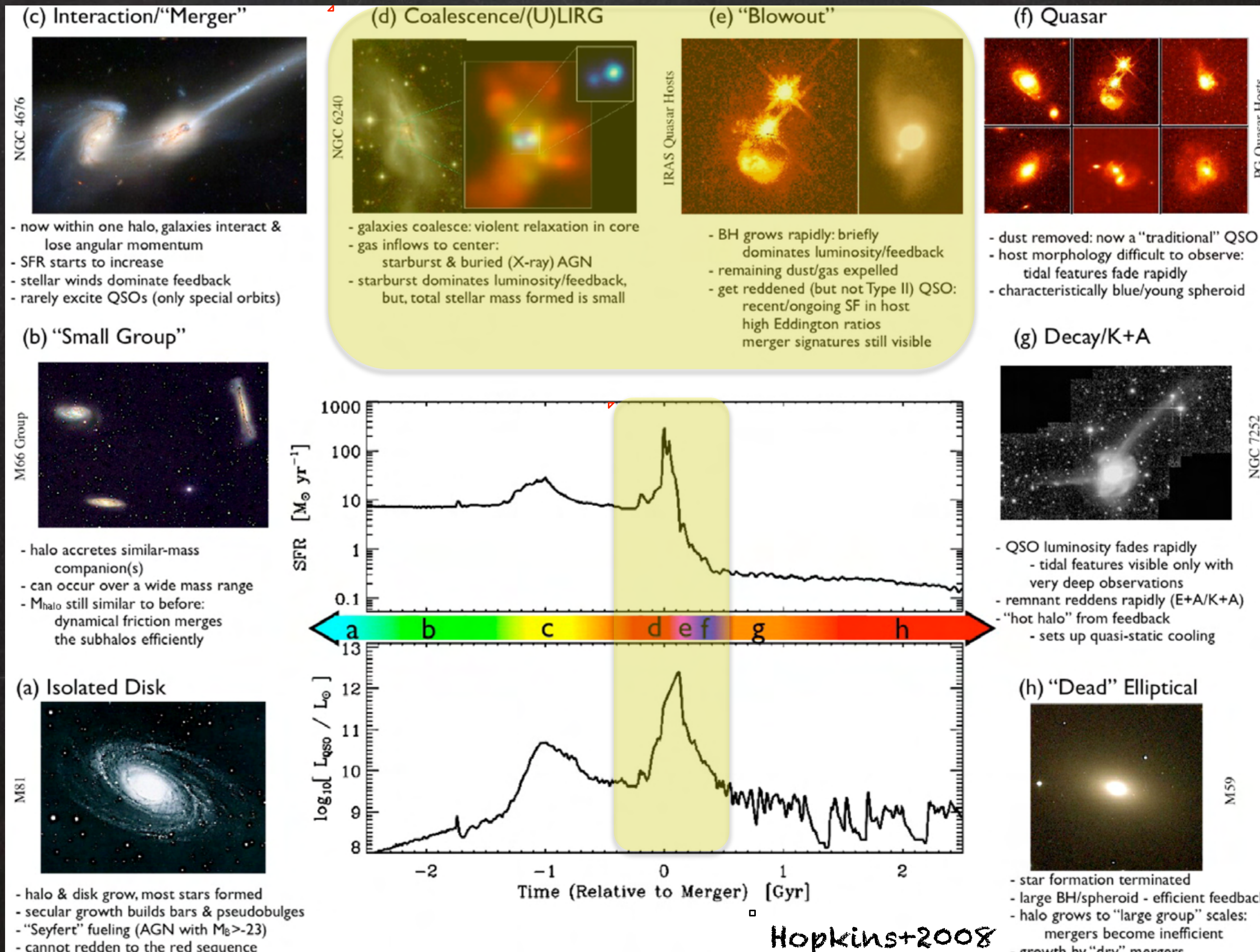
Key Science

- Energy budget of a galaxy throughout its evolution → interplay between accretion onto black holes in AGN, star-formation and the feedback related to both

- Much of this evolution is hidden by dust !!!
  -> Only rest-frame MIR/FIR spectroscopy is able to trace these physical processes.

- IR spectroscopy provides the diagnostics to distinguish between and quantify the two,
  → measuring the separate luminosity density due to accretion and star formation as a function of cosmic time.

AGN/Galaxy Formation & Co-evolution



Hopkins+2008

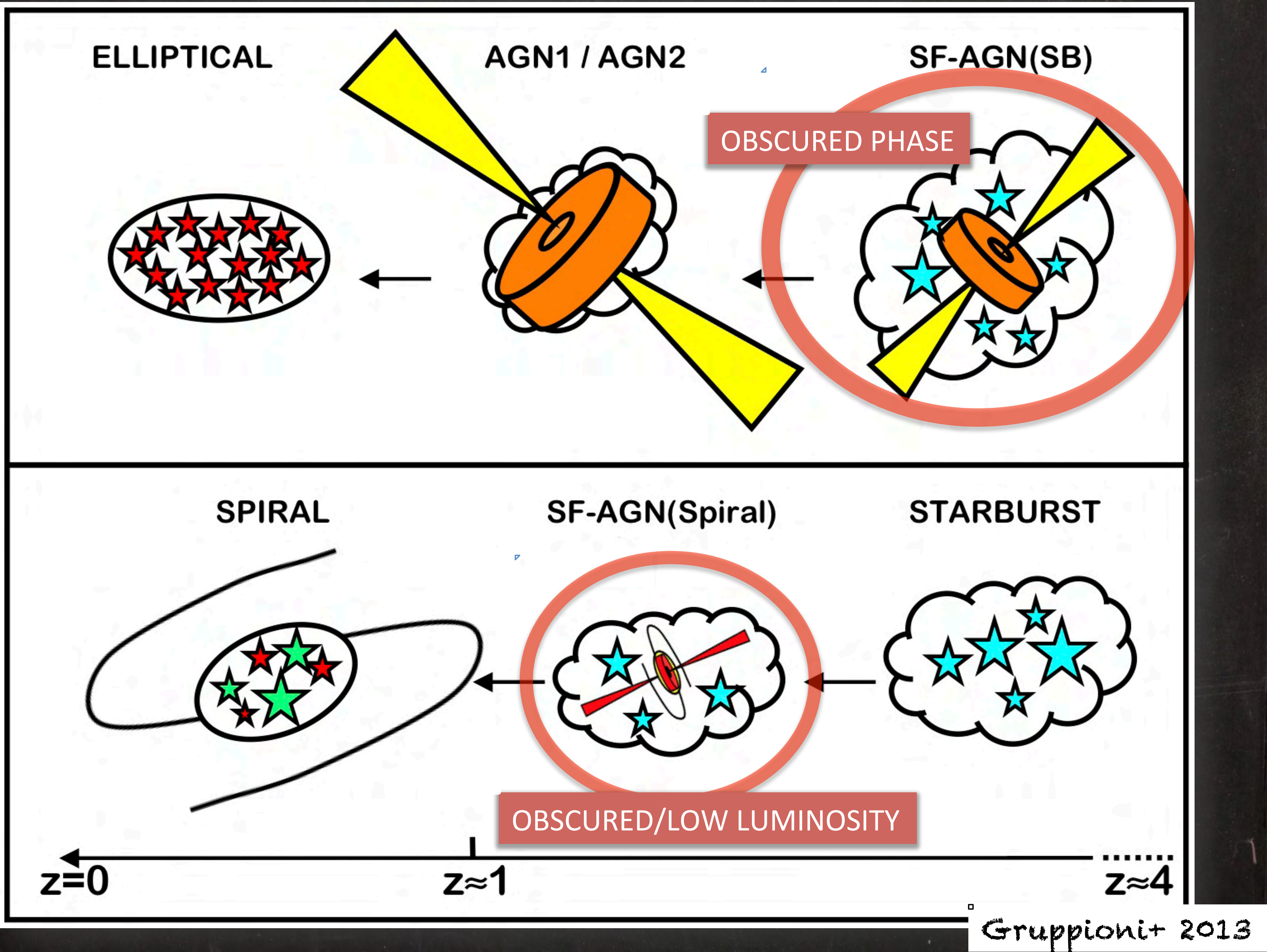
From Herschel (Galaxy evolution in the $0<z<4$ range; Gruppioni+13):

Twofold evolutionary scheme for IR gal's:

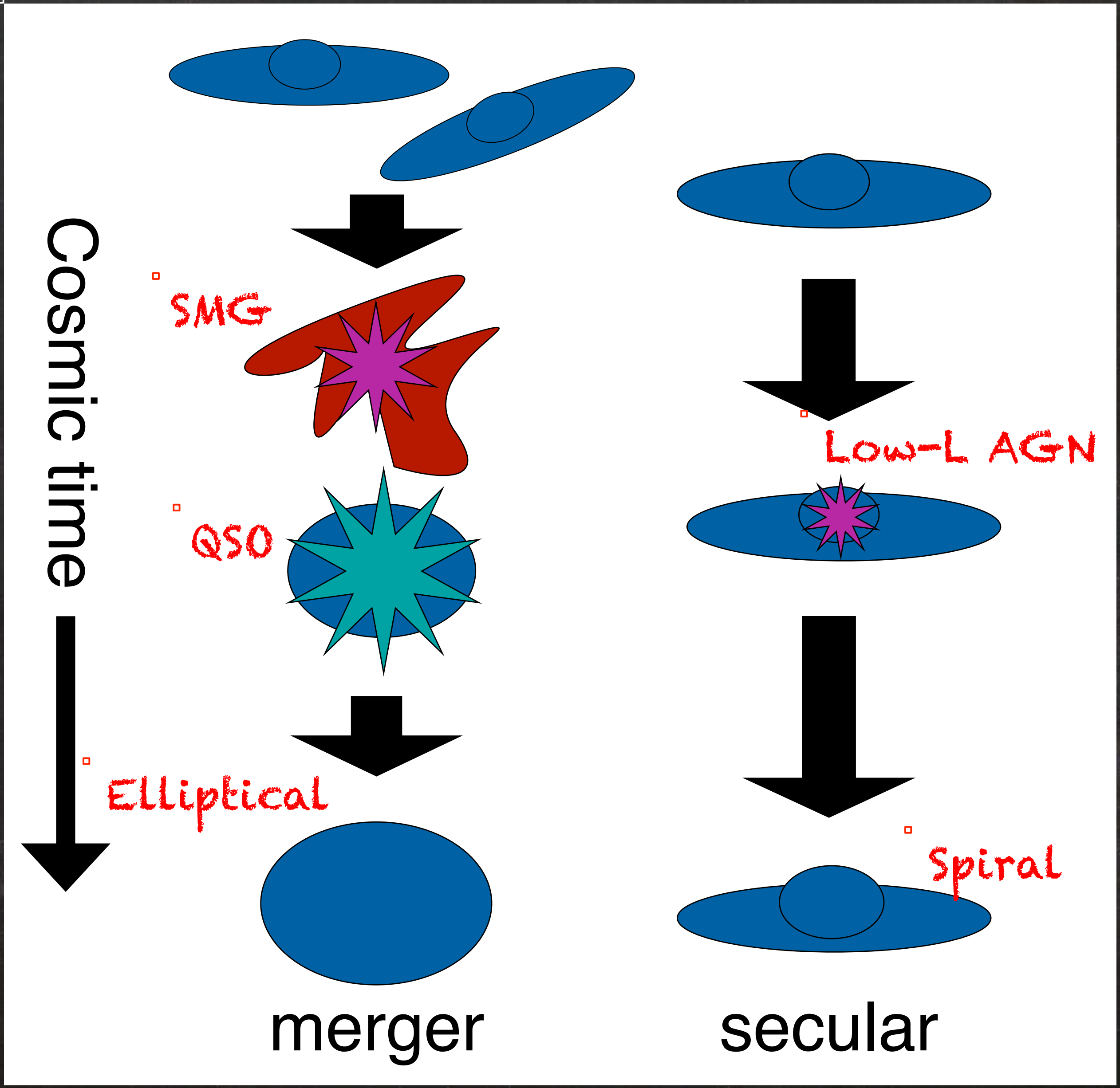
1) Obscured/Unobscured AGN-dominated sources detected in far-IR during an active starburst phase

➔ likely red spheroid.

1) low-L AGNs systems: in a (long-lasting) transition phase between moderate starbursts and steady spiral galaxies.


ELLIPTICAL
AGN1 / AGN2
SF-AGN(SB)
OBSCURED PHASE
SPIRAL
SF-AGN(Spiral)
STARBURST
OBSCURED/LOW LUMINOSITY
z=0
z≈1
z≈4
Gruppioni+ 2013

... same as from other studies

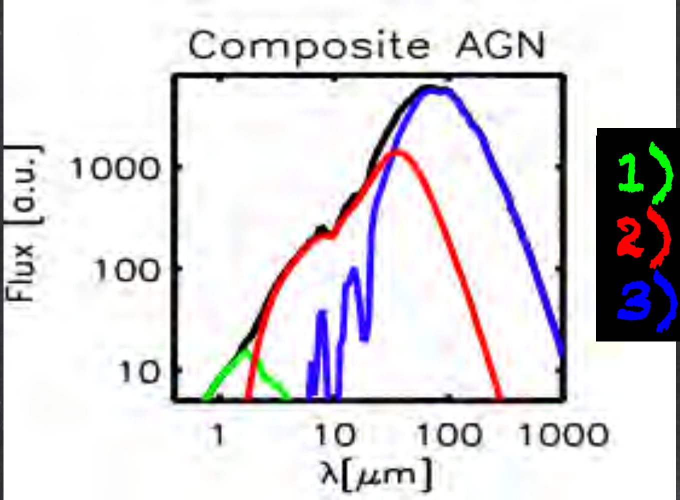


Alexander & Hickox 2012

→ AGN and galaxy co-exist in the same object

A simple way to estimate SFD and BHAR vs z:
→ Decompose template SEDs

SED de composition: χ^2 fitting procedure (see Hatziminaoglou et al. 08; Pozzi et al. 10)

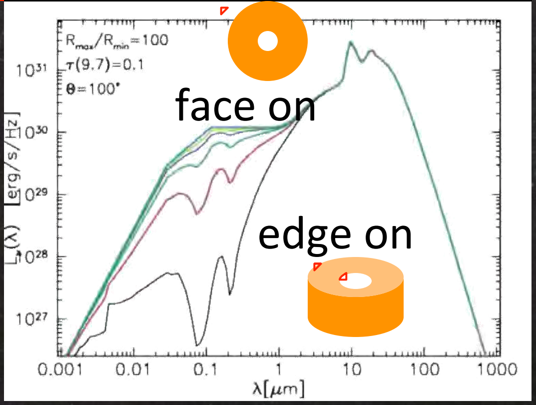


1) Evolved stars: opt/NIR
2) Nuclear: MIR
3) Starburst: FIR

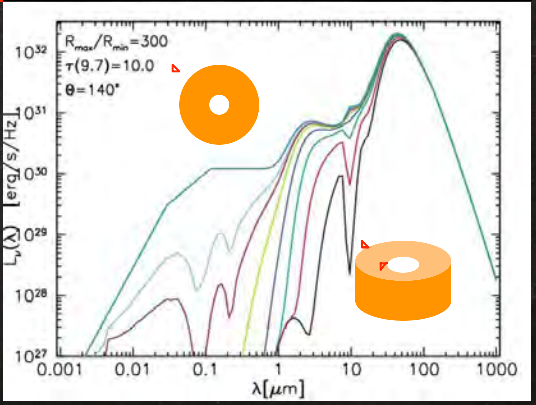
2) Nuclear (Fritz et al. 2006)

- direct light (opt/UV)
- re-emission (IR)
- scattered light

Low $\tau_{eq}(9.7\mu m) \Rightarrow$ Silicate feature in emission



High $\tau_{eq}(9.7\mu m) \Rightarrow$ Silicate feature in absorption



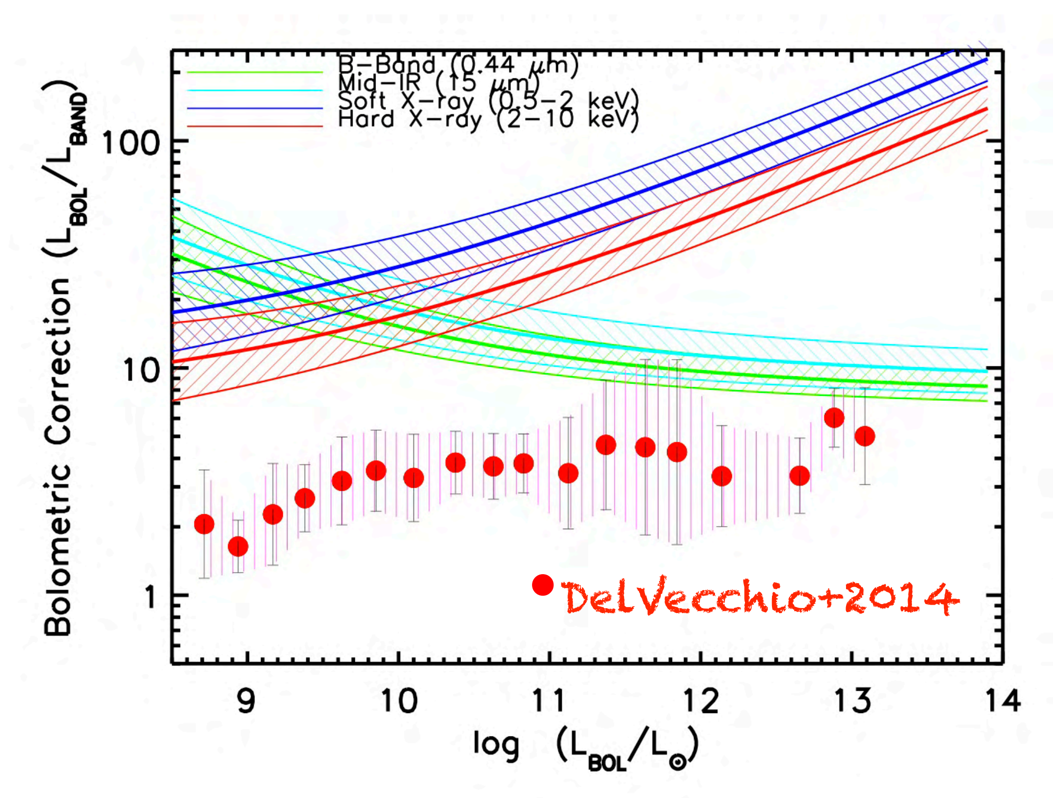
SED-decomposition : BHAR Density

$$K_{BOL} = \left[\frac{L_{accr,INPUT}}{L_{1-1000\,\mu m}} \right]_{BEST-FIT\,MODEL}$$

Almost 1 dex smaller than other bands

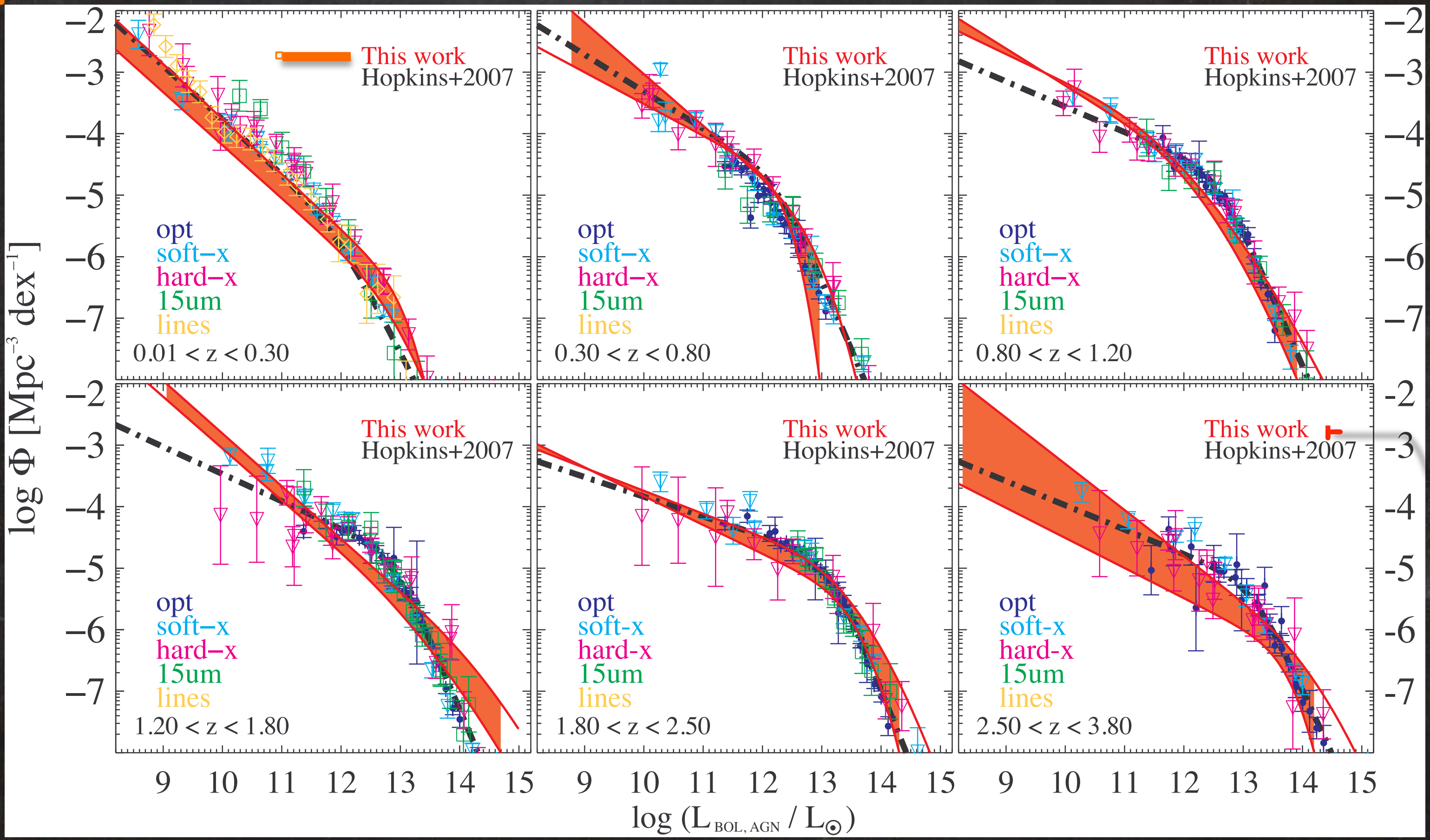
No dependance on bolometric luminosity (required by Hopkins+07 to match type I AGN LF in different bands. Mainly based on Richard+06 SED).

Weakness of IR relies on assumed torus model



SED-decomposition : BHAR LF

Agreement with Hopkins+07:
BUT Completely independent determination
=> first from far-IR



DelVecchio, Gruppioni+2014

SED-decomposition : BHAR Density

$$\Psi_{BHAR}(z) = \int_0^\infty \frac{(1-\varepsilon_{rad})L_{BOL,AGN}}{\varepsilon_{rad}c^2}\Phi(L_{BOL,AGN})\,d\log L_{BOL,AGN}$$

- **ASSUMPTION**

BH grows mainly by accretion

$L_{BOL} = \varepsilon\ c^2\ dM/dt$

ε = radiative efficiency

- **RESULTS**

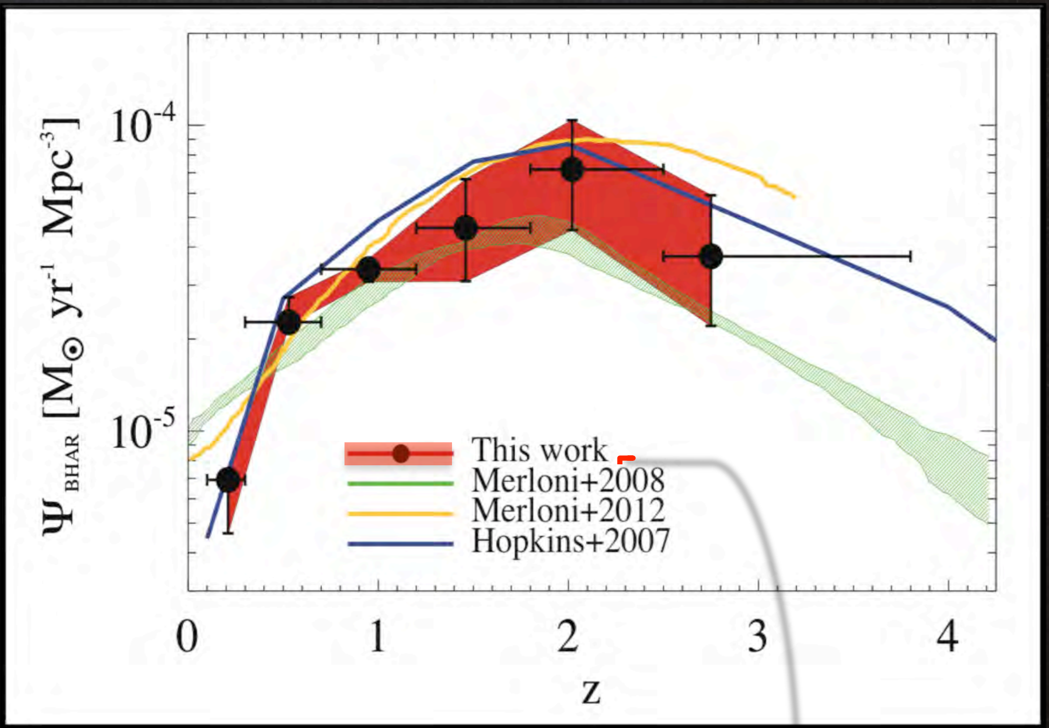
First time ψ_{BHAR} from IR

$\rho_{BH,0} = 4.2 \times 10^5\ M_\odot Mpc^{-3}$ (Shankar, 2009) → $\varepsilon = 0.08$

$0<z<3$

$\psi_{BHAR,IR} \sim \psi_{BHAR,X}$

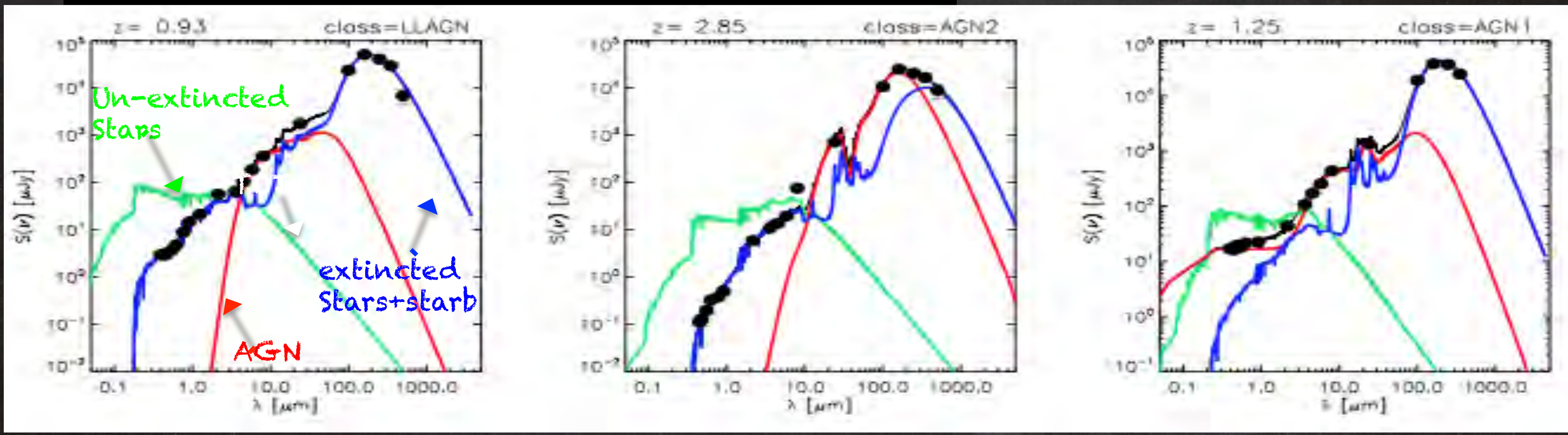
(consistent with Merloni+2012 & Hopkins+2007)



DelVecchio, Gruppioni +2014

BUT: sources classified on photometric basis only (SED-fitting)

MAGPHYS + AGN
(daCunha+08 + Fritz+06 => Berta+12)

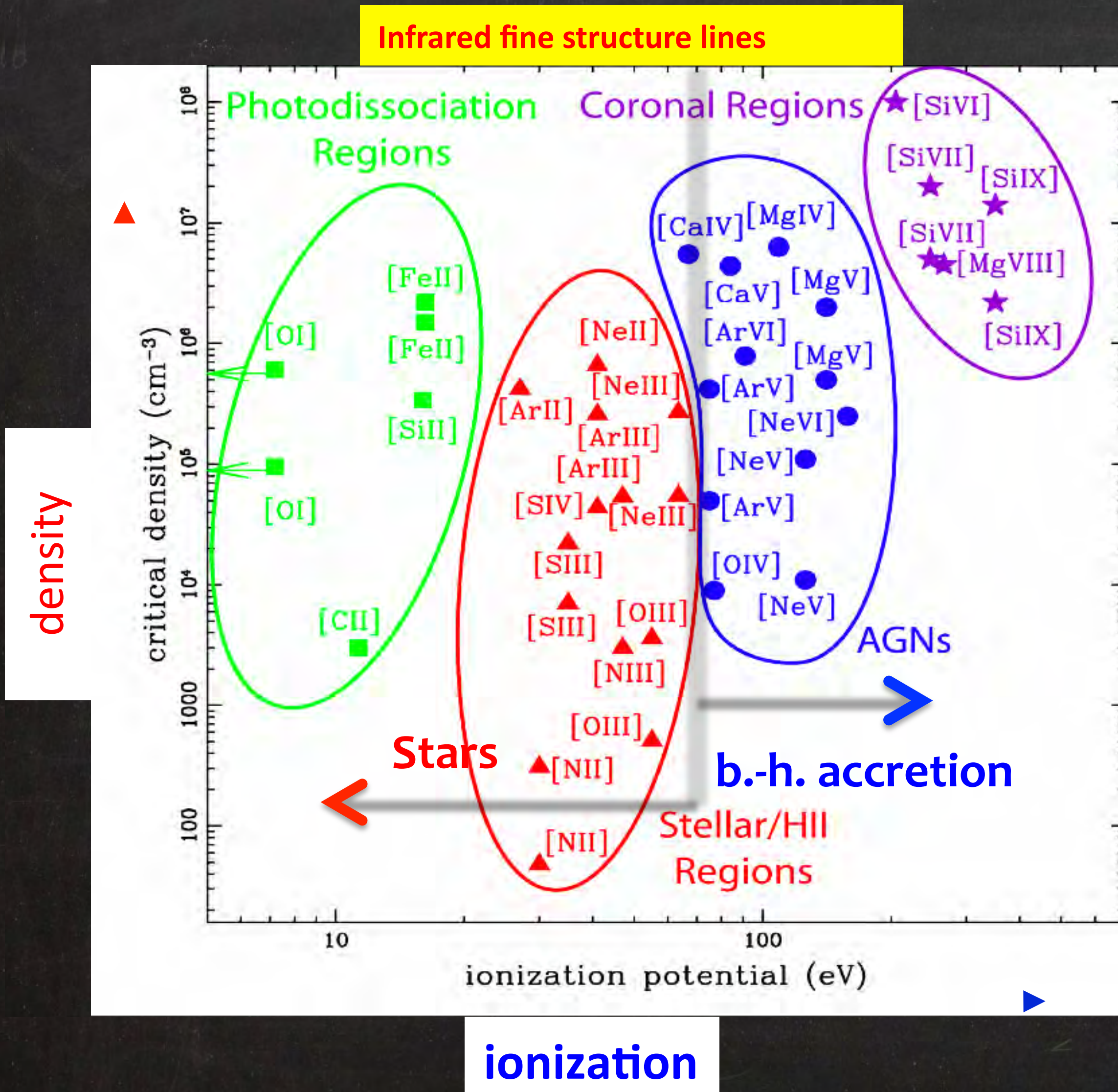


Large degeneracies in the AGN models

NEED for spectroscopic classification unaffected by obscuration

NEED for high angular resolution for resolving AGN and its effects on gas

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



IR fine structure lines:

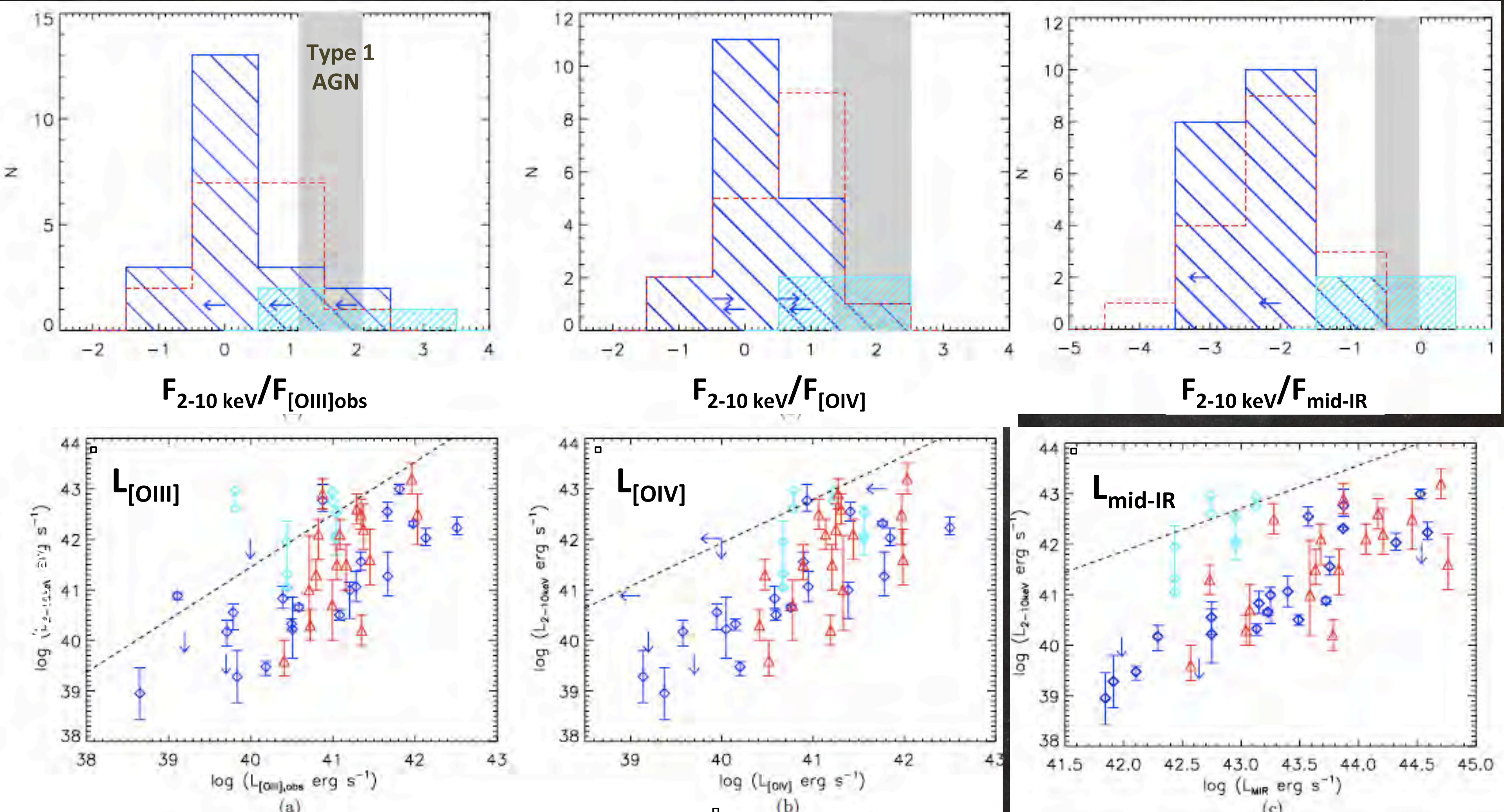
- separate different physical mechanisms,

- cover the Ionization/density parameter space

- do not suffer from extinction

Spinoglio & Malkan (1992)

[OIII], [OIV], and mid-IR as proxies of AGN intrinsic emission



Sey 2s: SDSS-[OIII] and 12μm sample – La Massa+11 (see also Weaver+10)

Underlying thought: [OIII], [OIV], mid-IR continuum are nearly isotropic AGN indicators

Why high-resolution far-IR spectroscopy?

- 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)

- [Only at z > 3 these enter into the ALMA range.]

- A spatial resolution of 0.1" samples sub-kpc structure at any redshifts

(dusty torus: 1-10 pc; gas inflow: <100-1000 pc)

Why high-resolution far-IR spectroscopy?

- AGN are identified in the rest-frame mid-IR through high-excitation lines and by hot dust re-radiating the absorbed primary AGN emission.

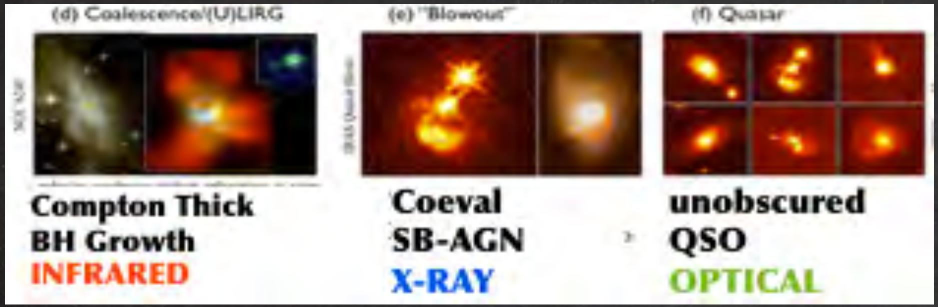
→detect Compton-thick sources (NH > 10^{24} cm^{-2}) that largely escape X-ray surveys (even at hard X-ray)

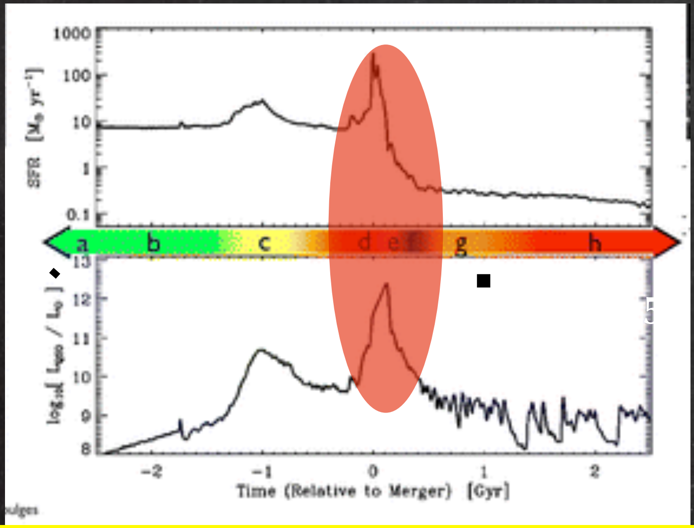
- Low- and intermediate-luminosity (Seyfert-like) AGNs are completely diluted within starburst galaxies

- moderate star formation is difficult to detect in powerful quasar host galaxies.

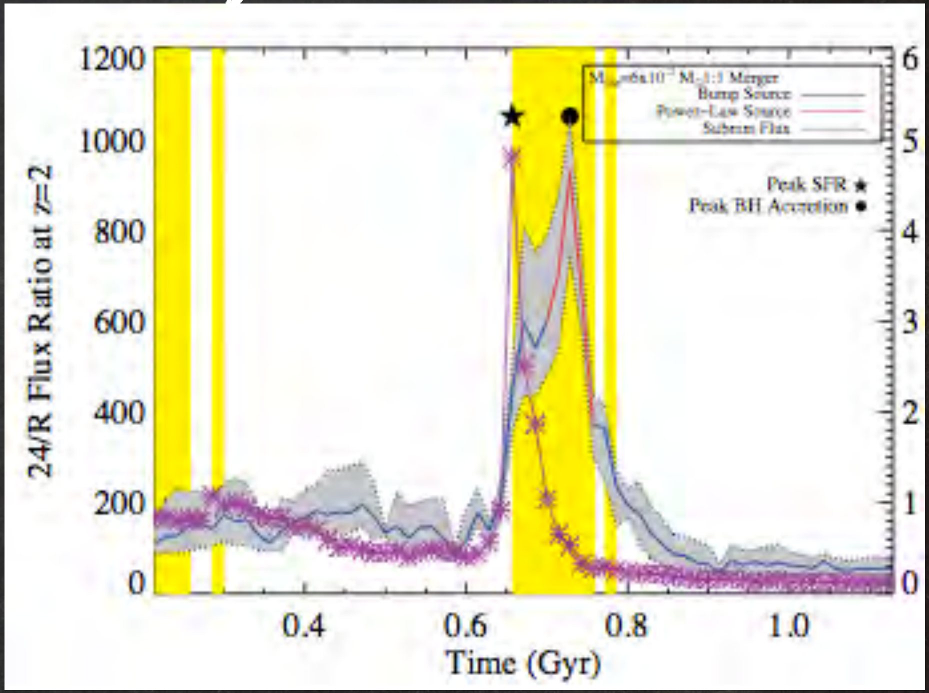
Finding the "sweet spot" for feedback

Hopkins et al. 2008 (see also Lamastra+2013)



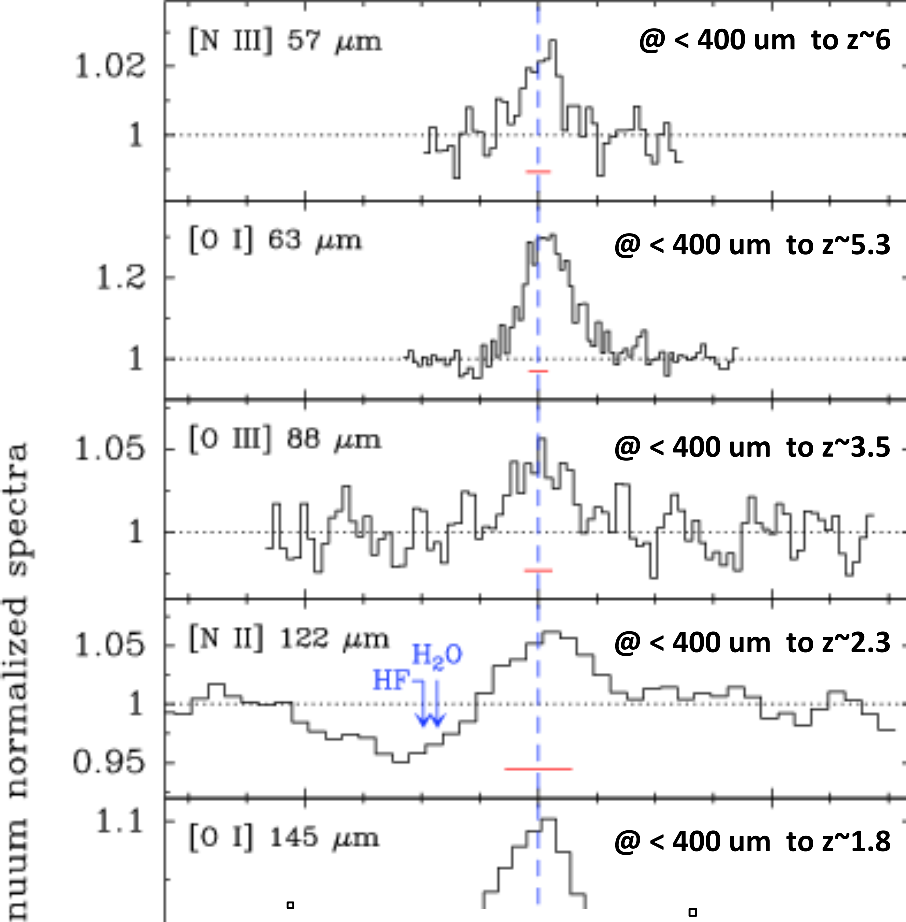


Narayanan et al. 2010

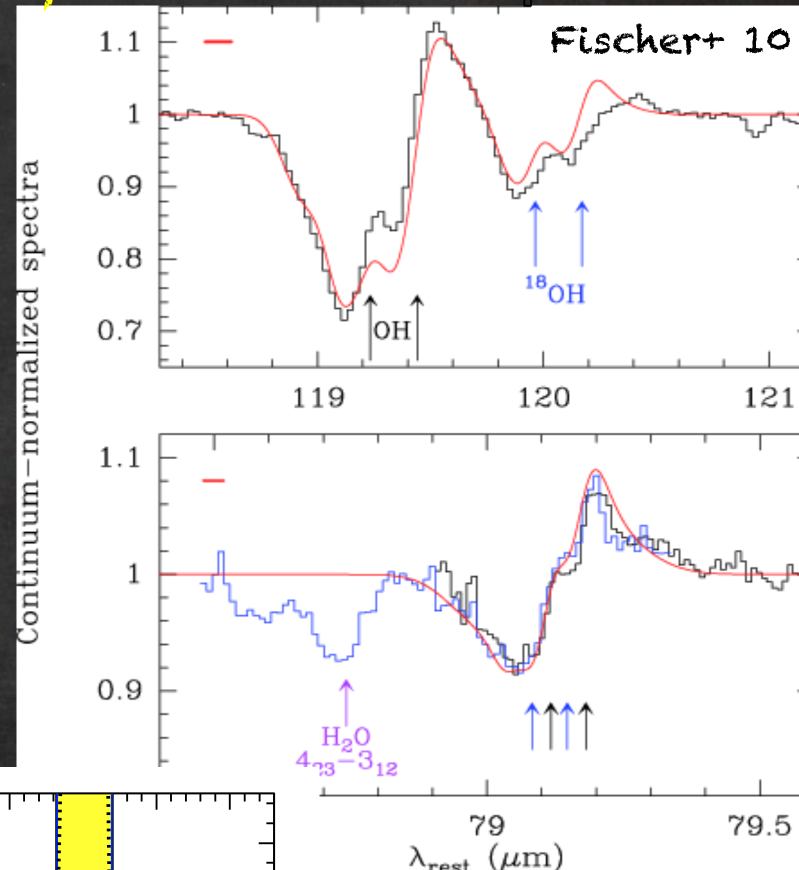


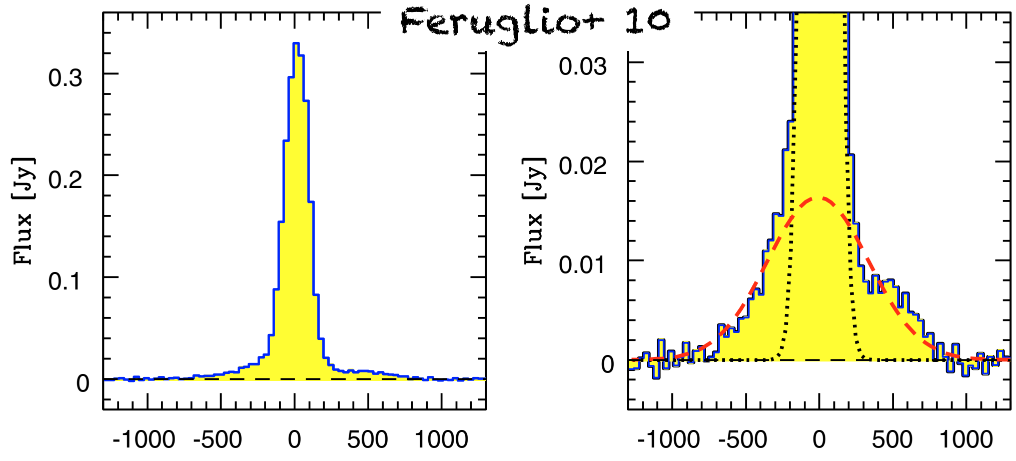
MERGERS MODEL PREDICTIONS/IMPLICATIONS:

.1) blow-out/feedback phase very short (≲ 100 Myr) - RARE !
.2) BH growth and SF almost "simultaneous"
.3) blow-out/feedback phase X-ray obscured (torus+host ISM)
.4) blow-out/feedback phase IR bright



Mrk231 → caught in the act of feedback

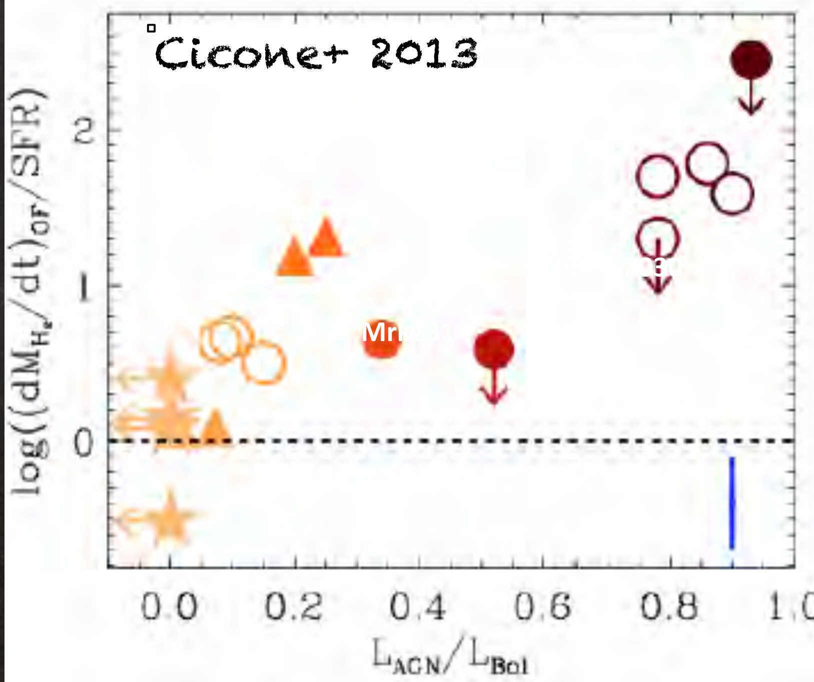




Fischer+10: P-Cygni profiles in OH lines, with broad blue-shifted absorption

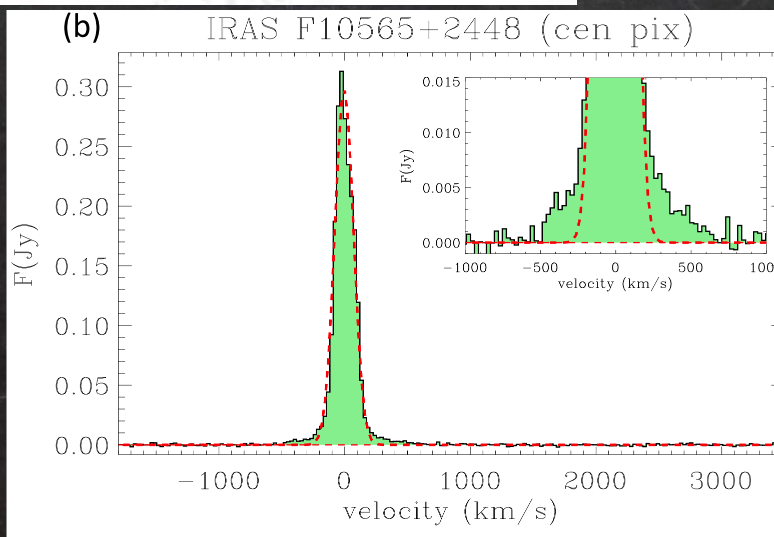
Feruglio+10: broad CO Line

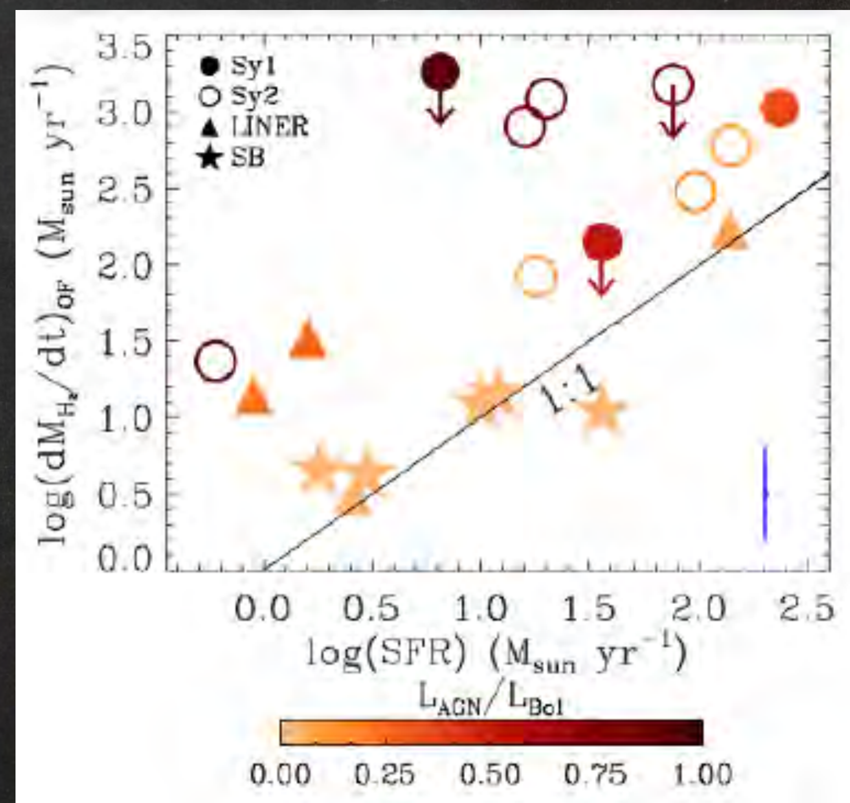
→AGN driven outflow



Similar studies in nearby ULIRGs

1) AGN dominated sources have higher mass outflow rate than SB dominated sources, and higher than that predicted from the SFR





2) detection rate of CO broad wings/outflow higher for objects with already reported OH outflows!

Best targets to look for / detect outflows:

coevolution models (Xshooter rationale):

- X-ray luminous, obscured and “dusty”

Cicone+13 (observational results):

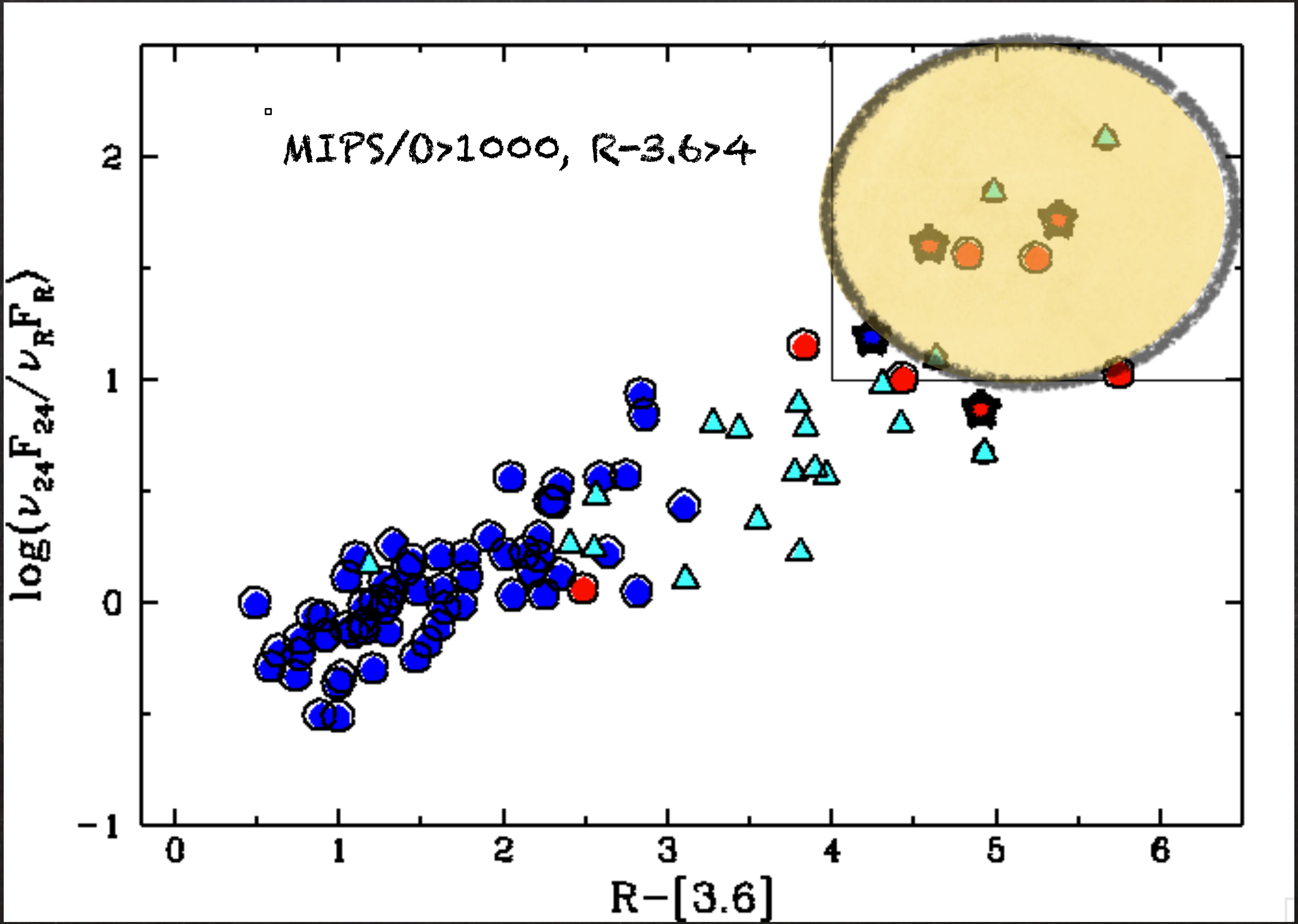
high SFR and/or AGN presence

Mrk 231:

* SFR=235 Msun/yr
* L(AGN)=45.72 (34%)
* L’(CO)=10.15
* Type 1 (BAL!!)
* evidence of outflows from other lambda (OH, spectrum SPIRE)

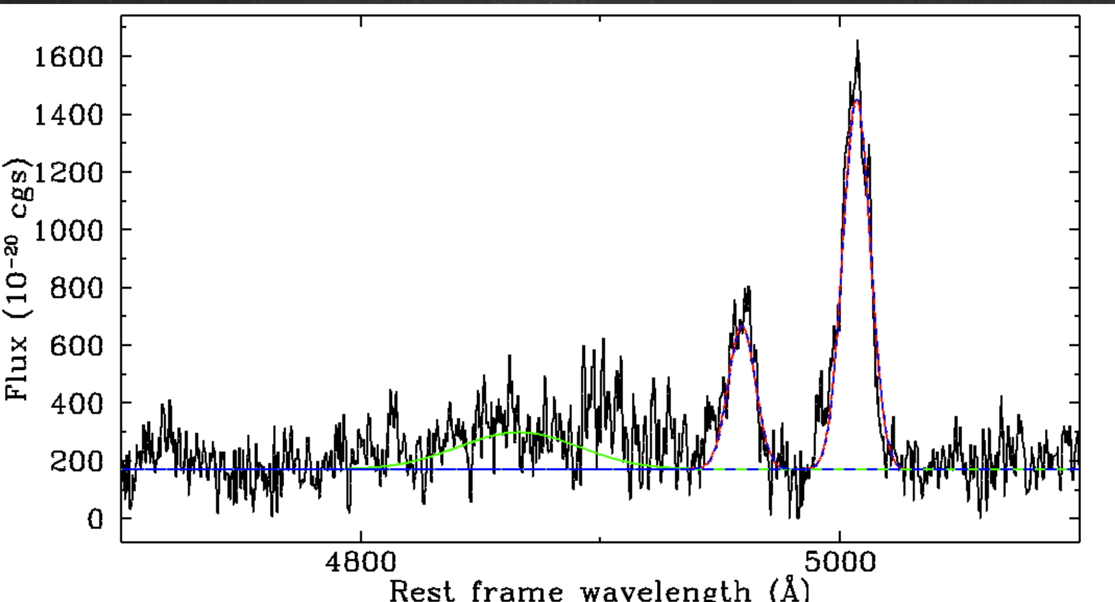
z~1.5 analogous of Mrk231

Mid-IR/Near-IR to optical Colour Selection
(e.g. Fiore+ 2008)



z~1.5 analogous of Mrk231 in COSMOS

XID 2028

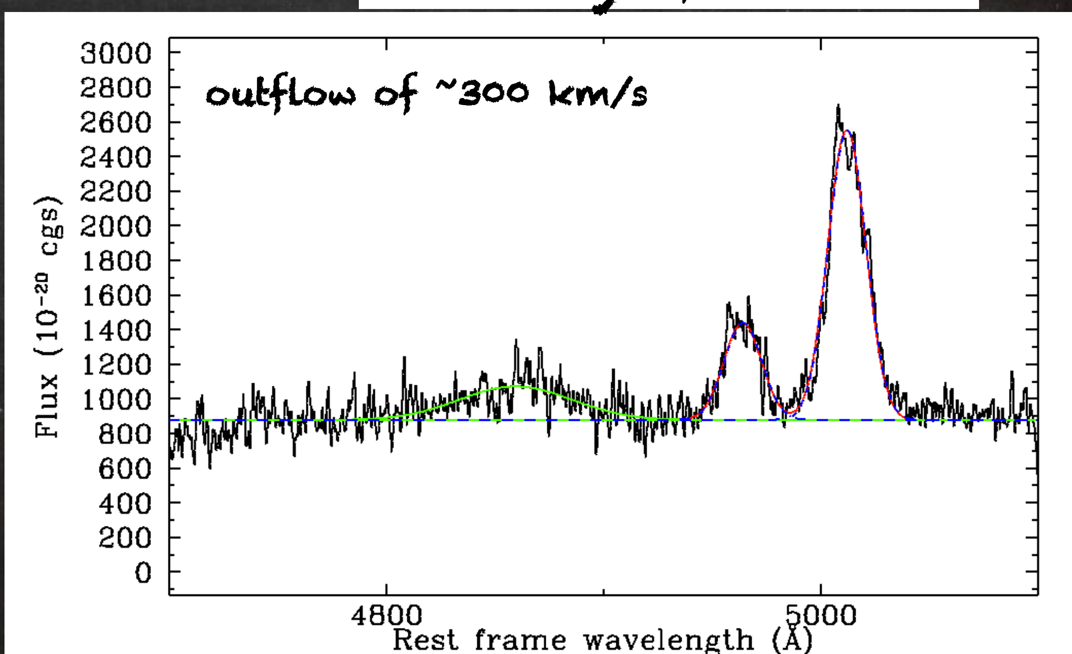


logLx~45
logLIR=12.47
SFR~500 Msun/yr
Type 1.8 (broad Hα)
evidence of outflow:
FWHM([OIII])=810 km/s

Courtesy of M. Brusa

XID 5321

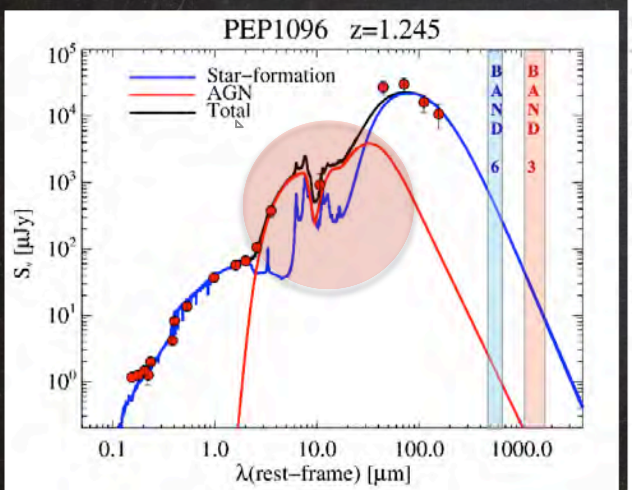
logLx=45
logLIR=12.2
SFR~350 Msun/yr
Type 1.8 (broad Hα)
evidence of outflow:
FWHM([OIII])=1200 km/s

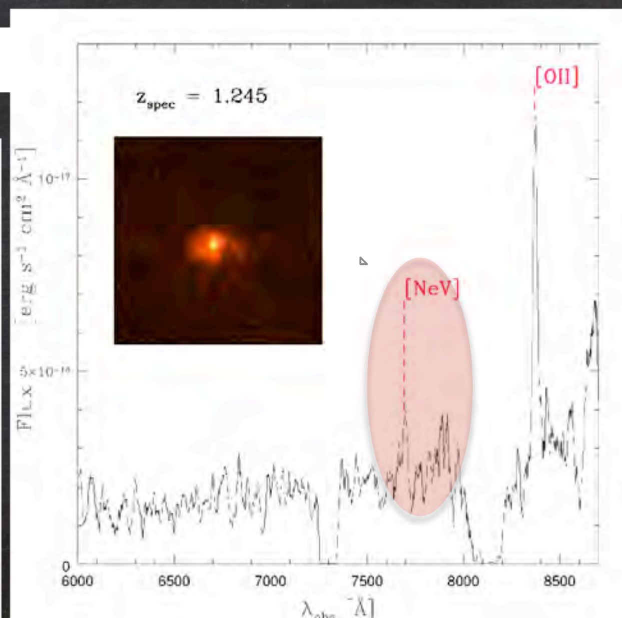


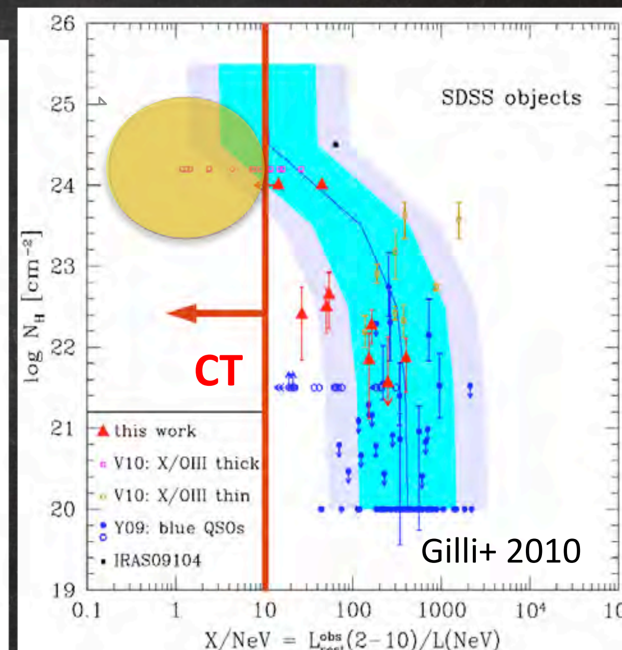
Herschel Compton Thick AGN (undetected in X-ray)

Herschel has discovered sources showing unambiguous evidence for the presence of a powerful, buried AGN that are not detected in X-rays (even in the deepest exposures)

I. DelVecchio et al., in prep.



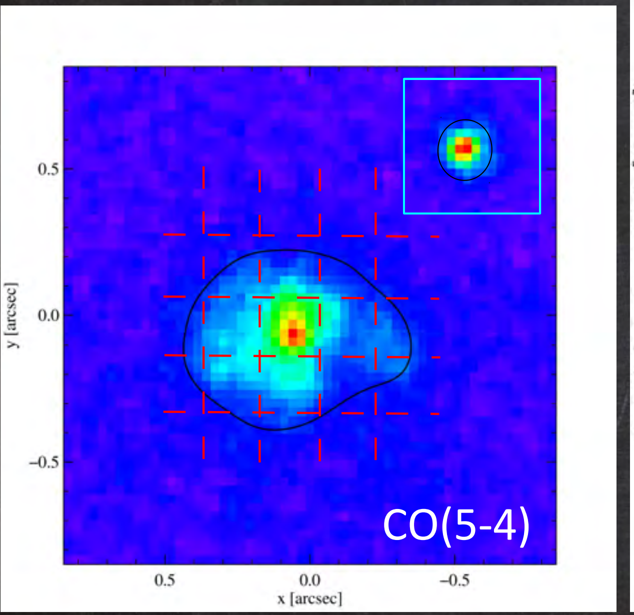




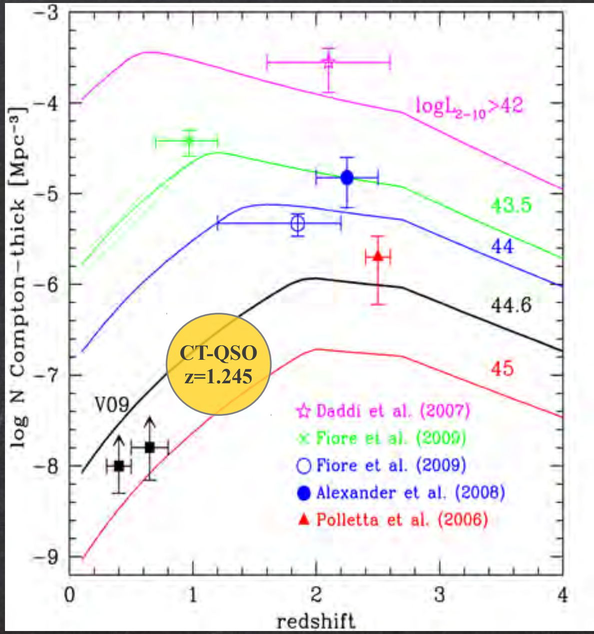
ID-PEP	z	SFR [$M_\odot$ yr^{-1}]	LogM* [$M_\odot$]	$logL_{FIR}$ [$L_\odot$]	$logL_{bol;agn}$ [$L_\odot$]	$logL_{[2-10];intr}$ [erg s^{-1}]	$logL_{1.4GHz}$ [W Hz^{-1}]
1096	1.245	125	11.08	12.30	12.91	44.7	24.3

Herschel Compton Thick AGN (X-ray undetected) in COSMOS

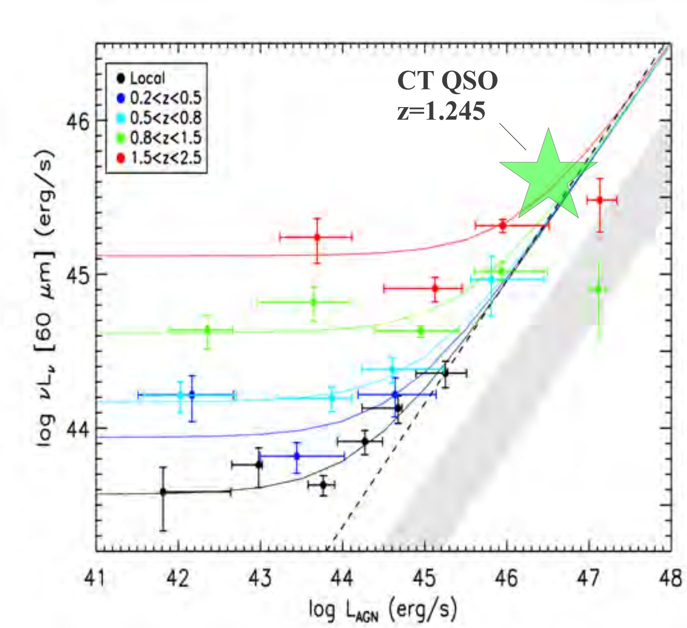
Spatially resolved CO line



Space density of CT AGN



AGN vs SF luminosity



The intrinsic X-ray luminosity expected is $L_{2-10;intr}$ $10^{44.73}$ erg/s

The presence of a high degree of obscuration is also suggested by the relatively low (<10) X-to-[NeV] flux ratio observed for this source (Gilli+ 2010

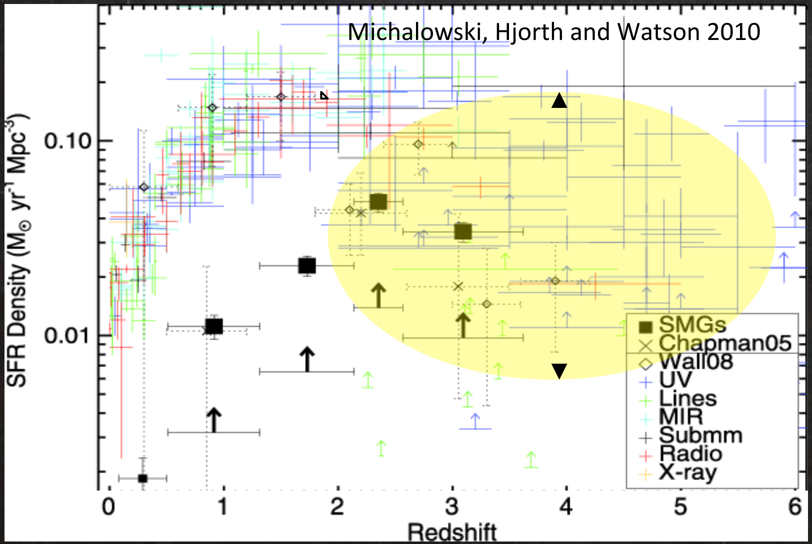
I. DelVecchio et al., in prep.

The role of far-IR high-resolution imaging and spectroscopy

Herschel is well suited to surveying large regions of the sky, detecting thousands of obscured sources

→high angular resolution images in far-IR spectral line and continuum, <0.1" in size, crucial in disentangling AGN from SF activity, constraining M_{gas}, M_{dust}, NH

put strong constraints on ρ_{SFR} and Ψ_{BHAR} vs. z at 1<z<3



Large spread:

optical/UV
→ correct for extinction

Sub-mm
→ z-distrib., completeness

Key Requirements

- ★ medium/high spectral resolution (>2000-3000) over a wide wavelength range (30-400 μm) to detect the diagnostic and interstellar gas cooling lines up to high-z;

- ★ high angular resolution (≲ 0.1 arcsec) to:

  - measure the molecular gas mass and study the gas kinematics on sub-Kpc scales

  - spatially resolve the gas column density

  - constrain the size of dusty torus

  ➔ verify whether the host gas density in the nuclear region is large enough to produce the high degree of obscuration inferred from multi-band diagnostics

- ★ high sensitivity (~few μJy) to detect z > 3 galaxies (when most of the building takes place).