Connecting Star Formation and AGN in active galaxies

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Eleonora Sani

Why?

- understanding galaxy formation and evolution
- star formation and metal enrichment history
- origin of nuclear activity in galaxies

Where?

- Composite (ULIRGs): active galaxies, starburst dominated with possible (obscured) AGN
- Seyfert: active galaxies, AGN dominated

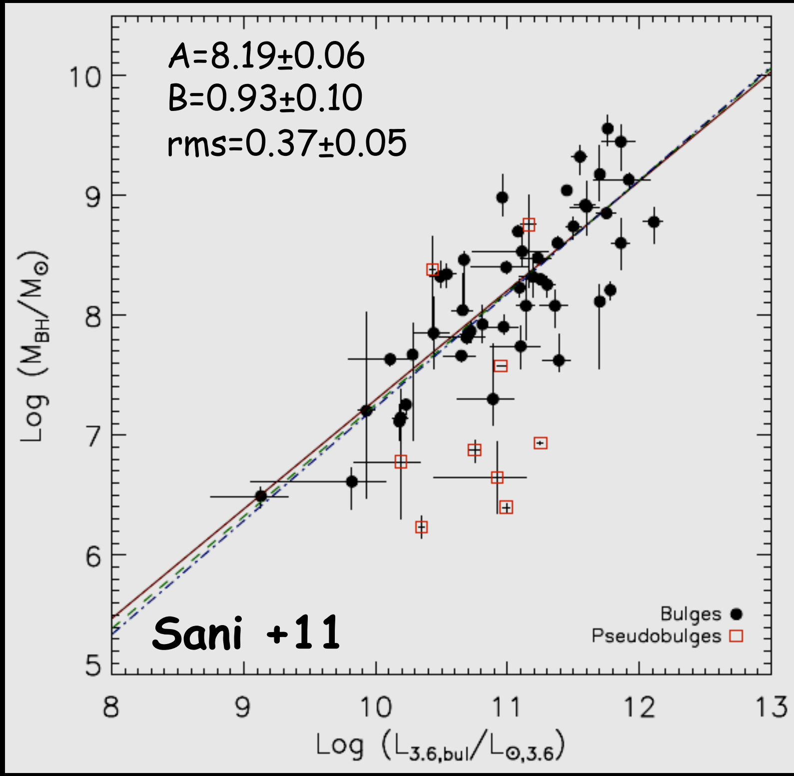
How?

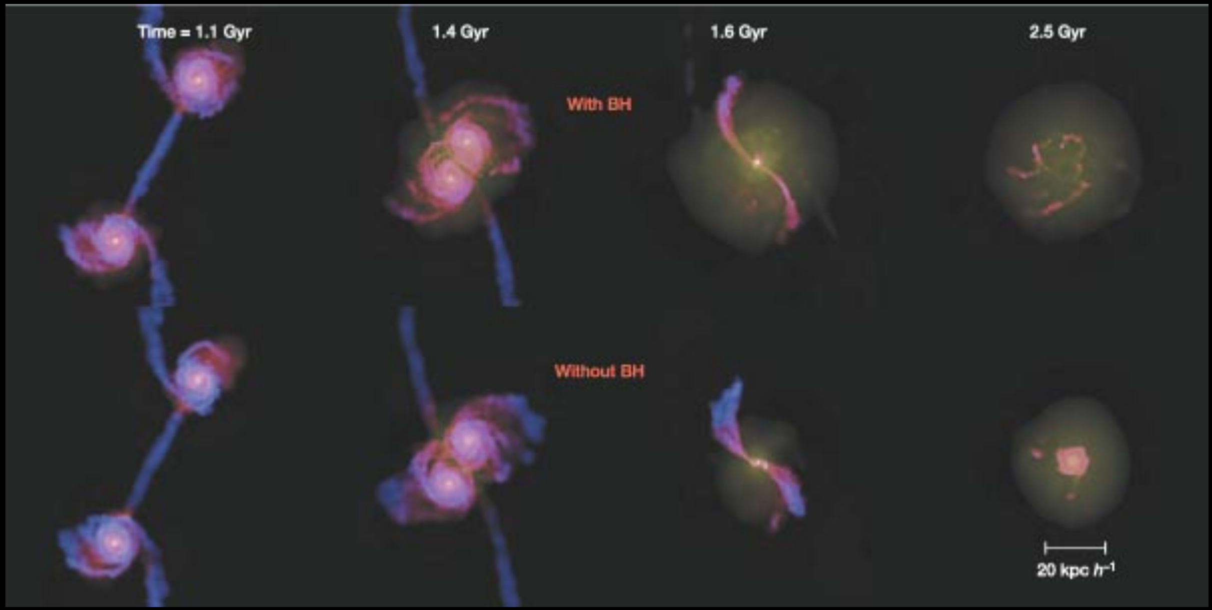
- different wavelengths
- Spectroscopy, imaging, interferometry
- Disentangle AGN/SF and/or resolve the source

AGN and SF connection

Evidence of a direct link between the formation of spheroids and the growth of the central black holes.

Ferrarese & Merritt ‘00,
Marconi & Hunt ’03,
Gebhardt +00,
Hu +09, Gultekin +09





In addition to generating a burst of SF, a merger leads to strong inflows that feed gas to the supermassive BH and power the quasar.
The energy released by the quasar expels enough gas to quench SF and further BH growth
(Di Matteo +05)

Related questions

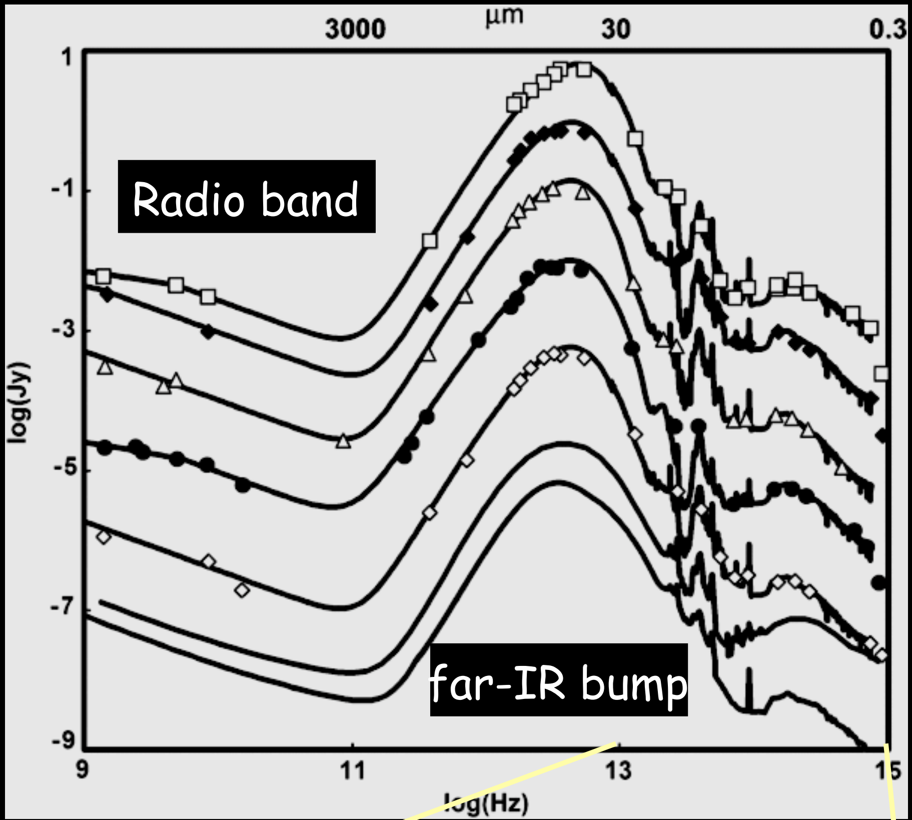
Introduction

AGN and SB SEDs

AGN and SB diagnostics in composite sources

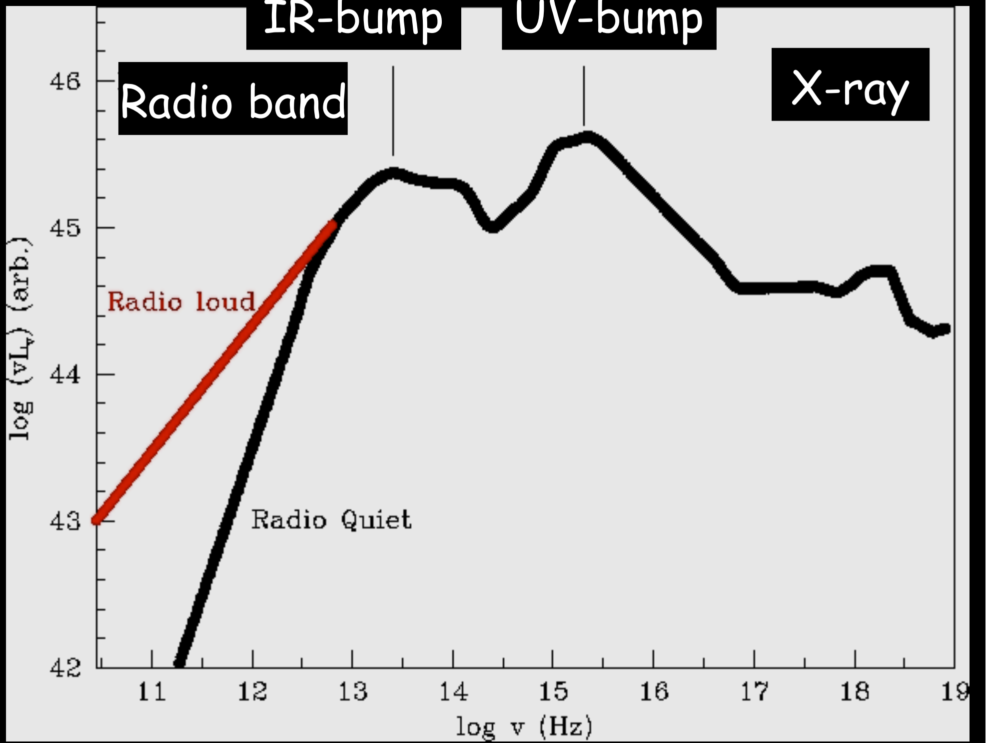
- ❑How the co-presence of AGN and SF alter the circumunclear environment?
- ❑Is the gas creating SF related to the Torus?
- ❑How does the gas get from 1kpc to central 10s of pcs?

SB and AGN emission

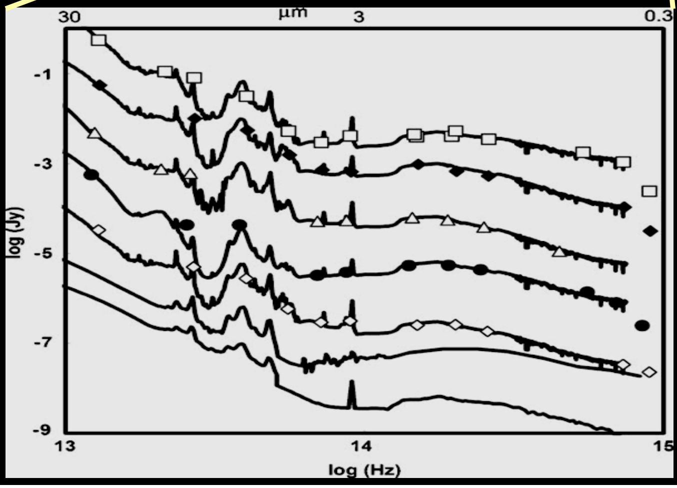


Starburst galaxies, Rieke et al. 2009

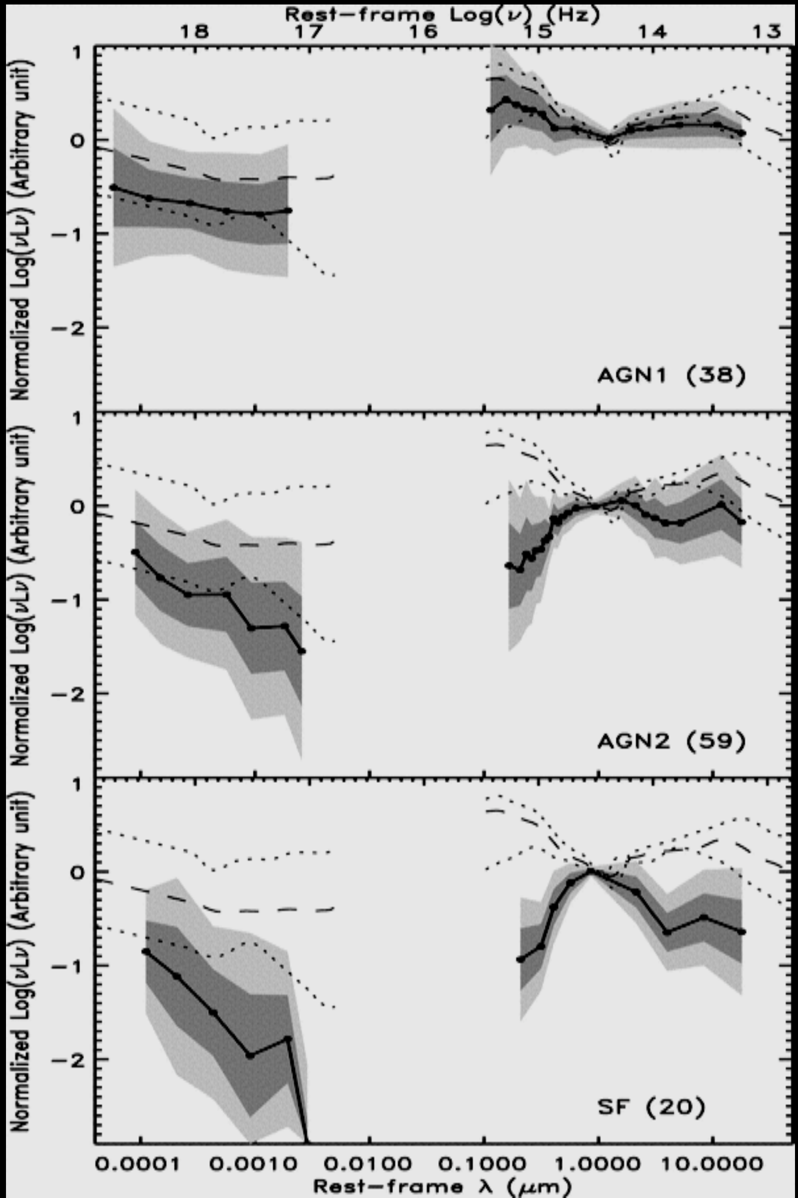
Type 1 quasars, Elvis et al. 1994



Opical
mid-IR
bands



AGN vs SB emission



Polletta et al. 2007

SEDs become increasingly

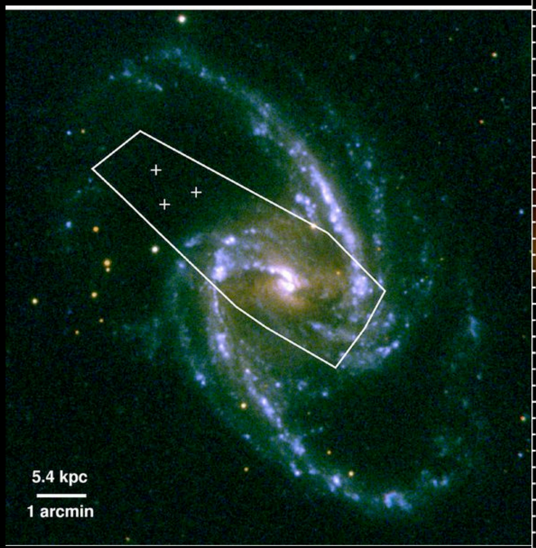
- warm in the IR ($1 < \lambda < 10$ μm)
- bright in the X-rays

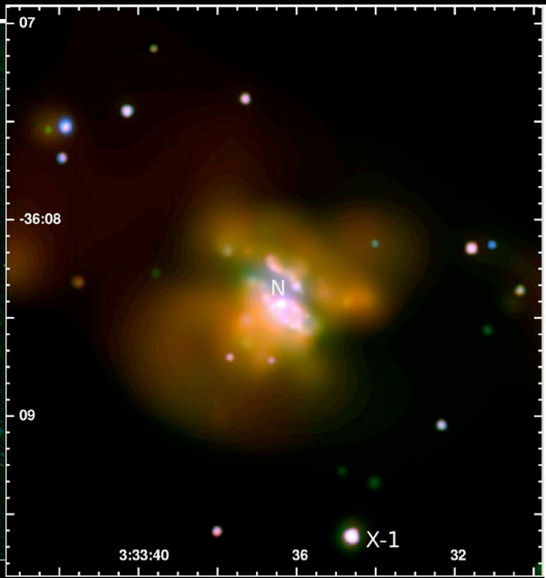
following the sequence:
SF → AGN2 → AGN1

Diagnostic performed in the X-ray and IR bands can highlight the main AGN-SB differences and where we have the most detailed information respectively

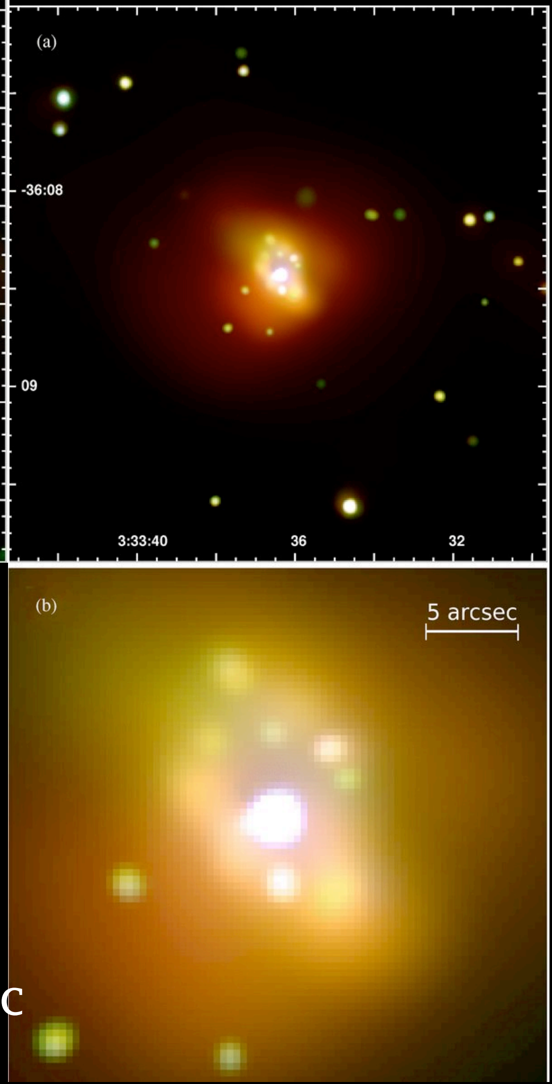
AGN and SF connection: X-ray & mid-IR

UV-XMM





Chandra
Red 0.3-0.65 keV
Green 0.65-1.5 keV
Blue 1.5-7.0 keV

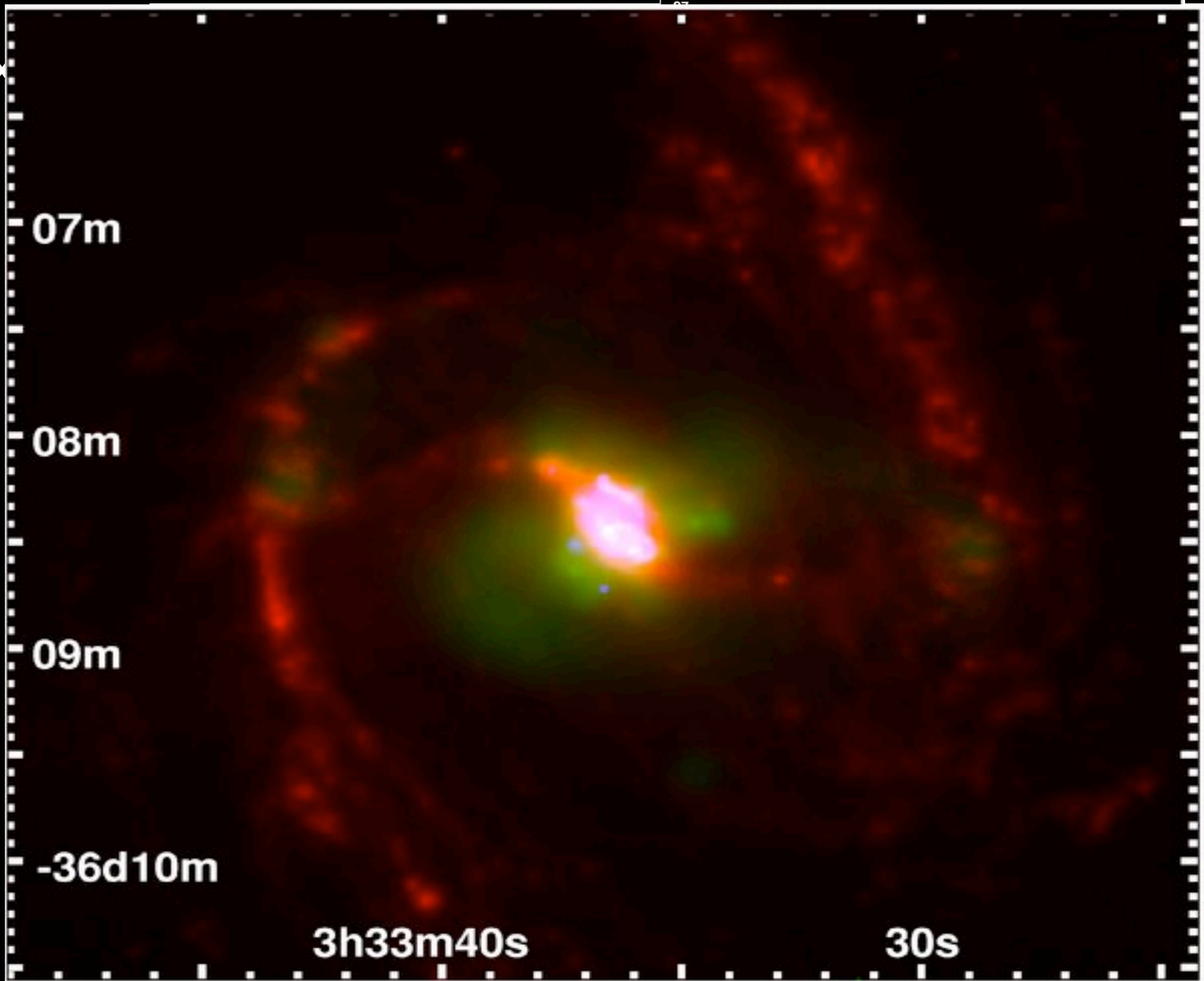


NGC 1365:
Type 1 AGN
SB on a spatial scale of ~3 kpc
(Wang et al. ‘09)

Red 0.3-1.5 keV
Green 1.5-3.0 keV
Blue 3.0-7.0 keV

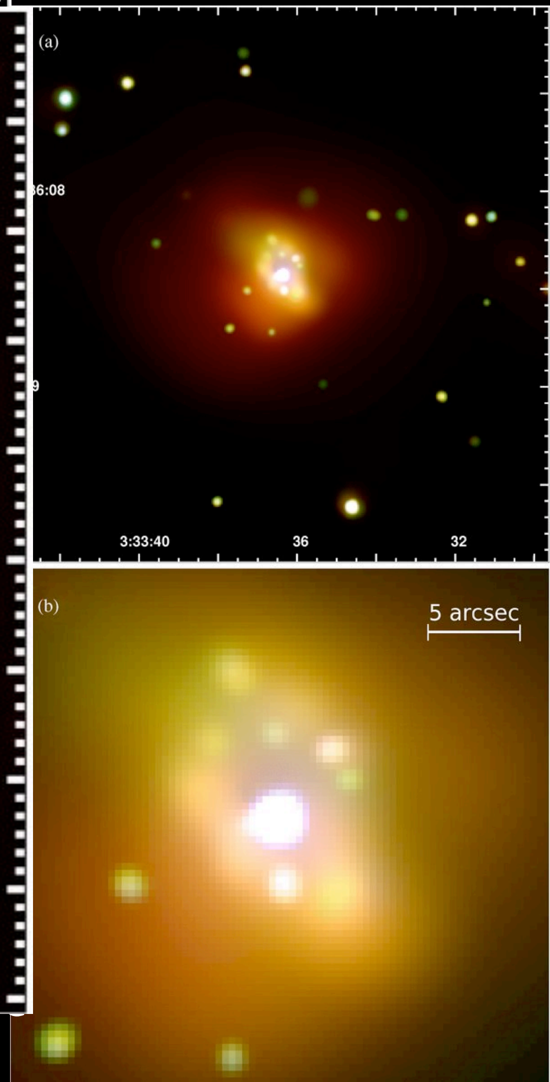
AGN and SF connection: X-ray & mid-IR

UV-X



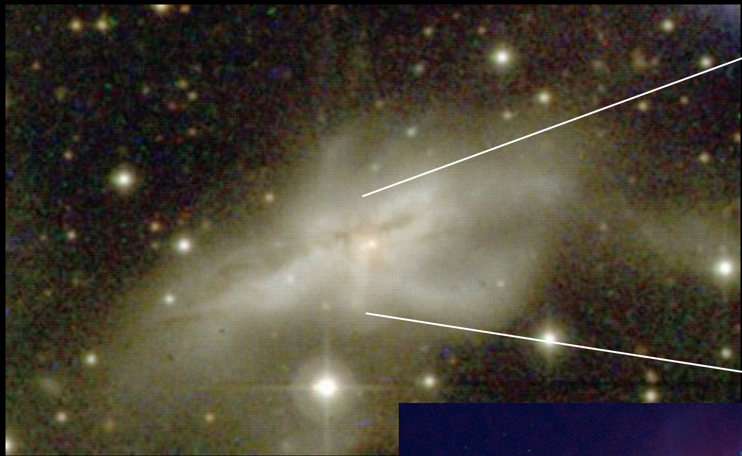
(Wang et al. '09)

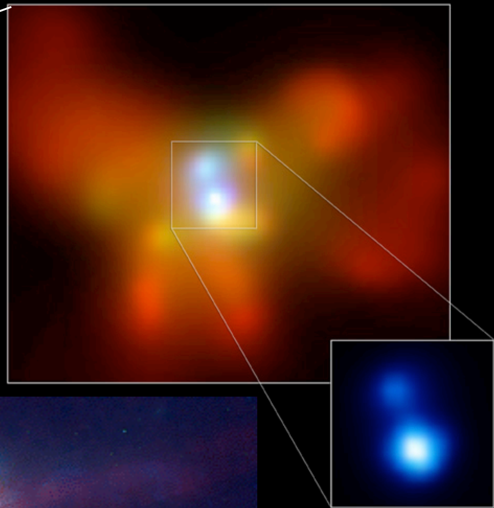
Chandra + Spitzer 8 μm



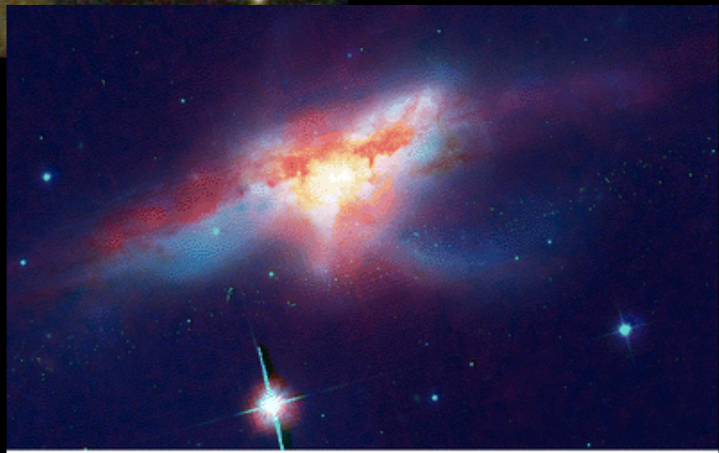
Red 0.3-1.5 keV
Green 1.5-3.0 keV
Blue 3.0-7.0 keV

AGN and SF connection: X-ray & mid-IR

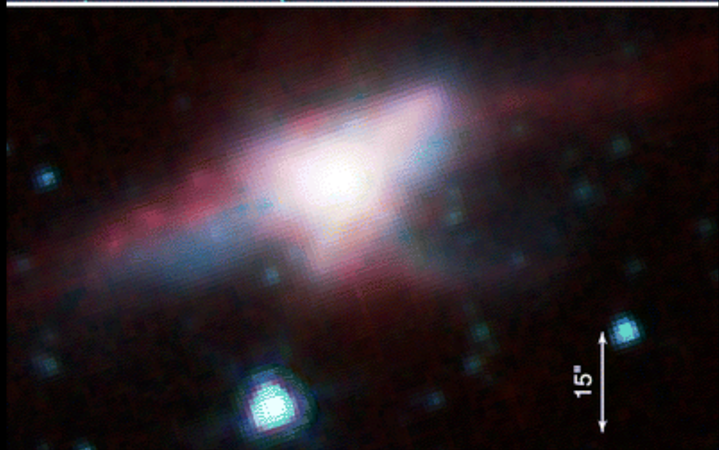




Double AGN
~2 kpc SB
Komossa et al. 2003



Optical/mid-IR:
Blue, B band
Green, I band
Red, 8 μm



Spitzer:
Blue, 3.6 μm
Green, 4.5 μm
Red, 8 μm

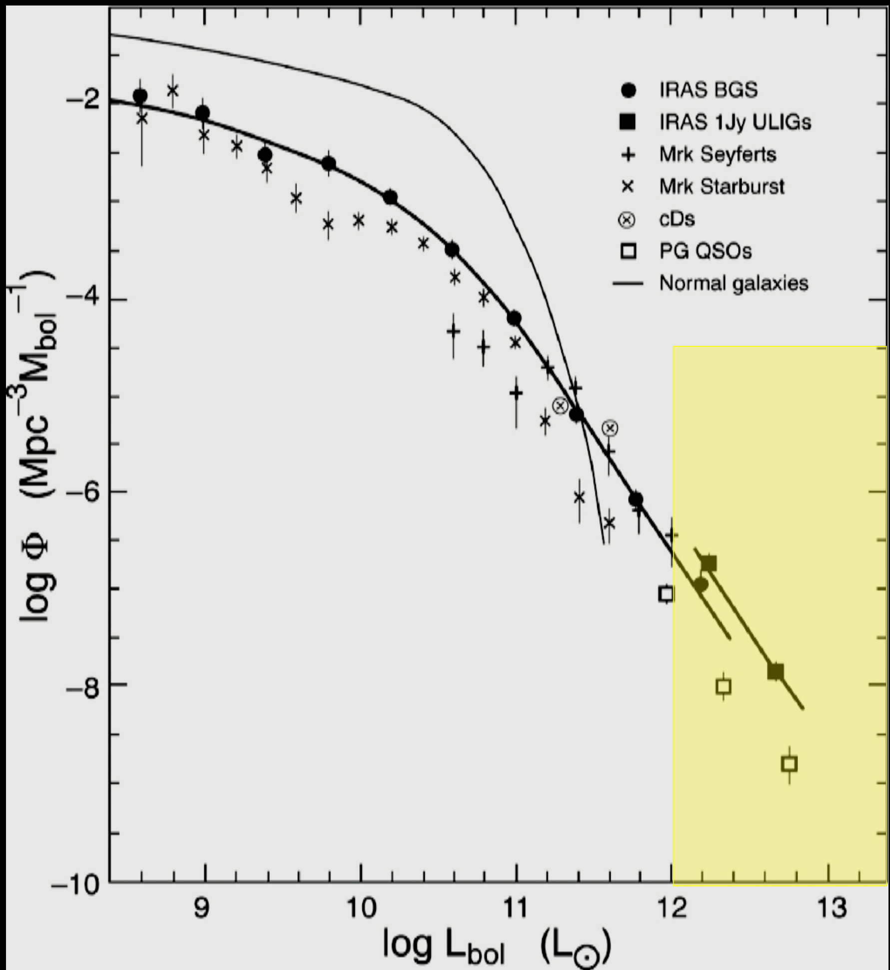
NGC6240 is experiencing a major merger and transitioning from a disk galaxy to a spheroid (Bush et al. '08)

Ultraluminous Infrared Galaxies

ULIRG — $L_{IR} > 10^{12} L_{sun}$

Milky Way — $L_{IR} \simeq 10^{10} L_{sun}$

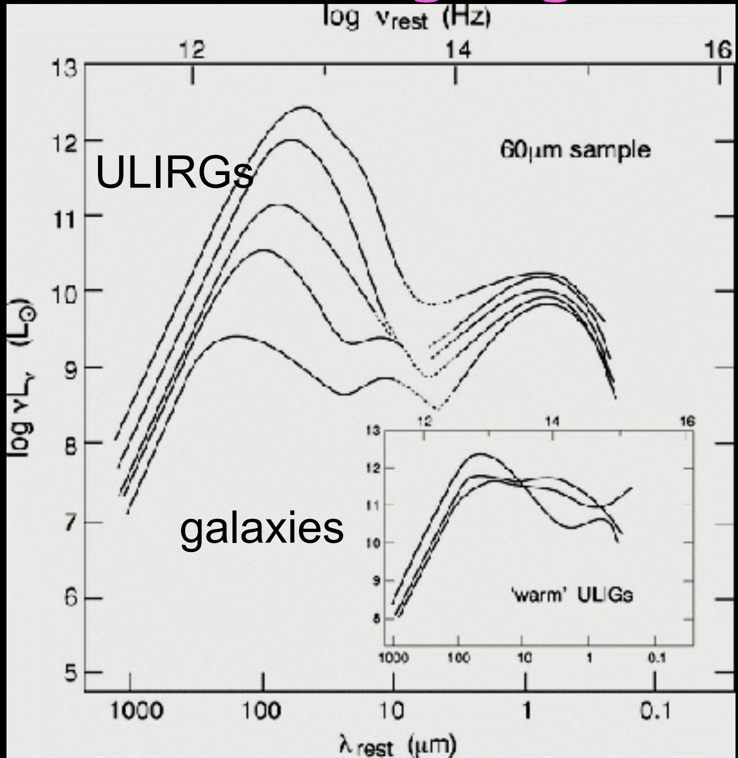
ULIRGs are the most luminous sources in the local Universe



ULIRGs are the local counterparts of high redhift sources dominating the submm background, and thus trace the star formation history of the Universe.

Possibly host obscured AGNs.
Thus ULIRGs are useful to infer the bolometric emission of the Universe and to study the local and far AGN population
(Sanders & Mirabel '96, Barger et al. '98)

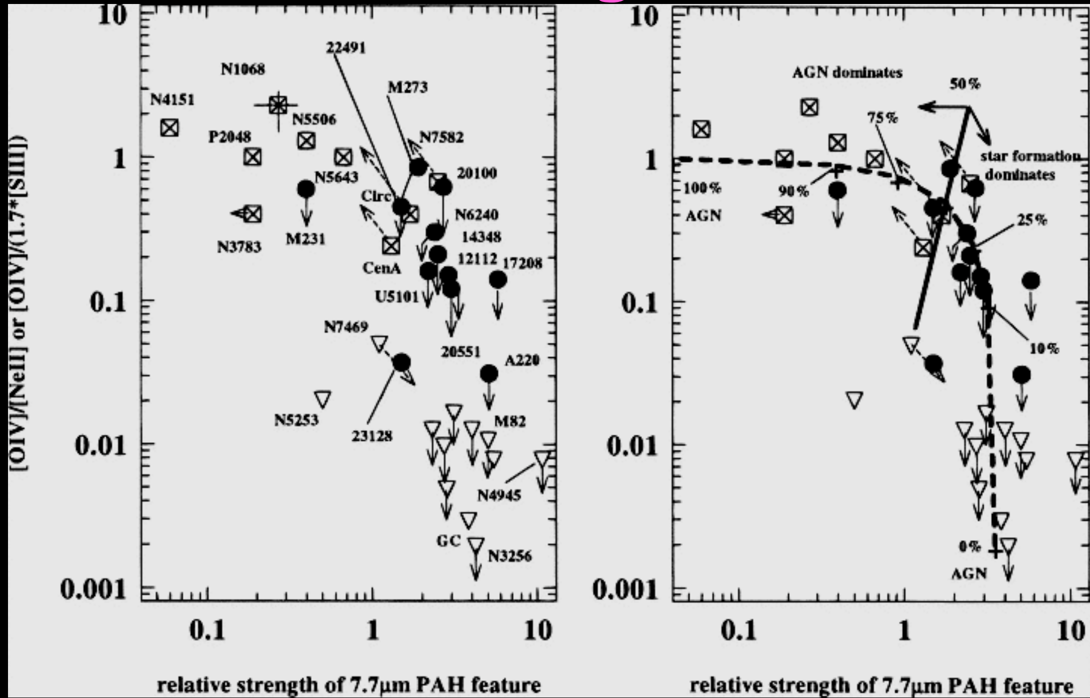
Disentangling ULIRGs: mid-IR diagnostics



Sanders & Mirabel 1996

warm ULIRG: $f_{25}/f_{60} > 0.3$

Fails in looking for AGNs embedded by large amount of cold dust



Genzel +98

Emission line diagnostic

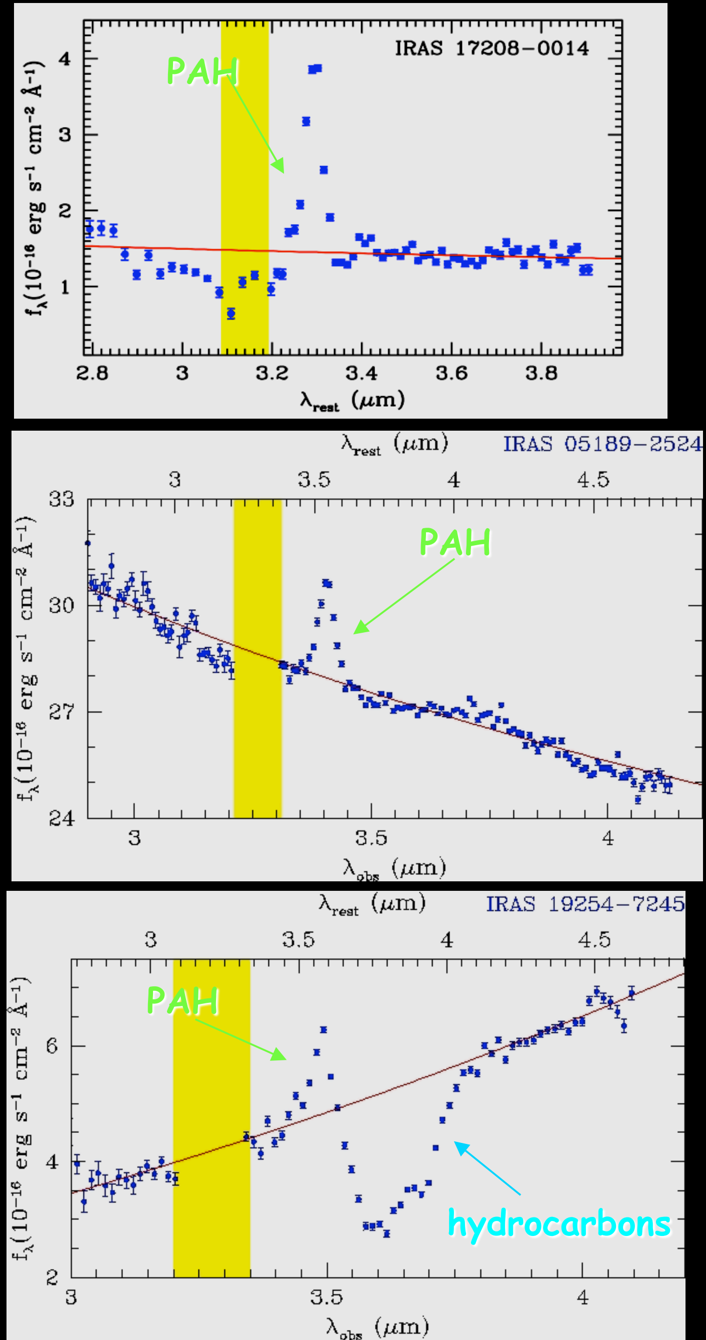
Need extinction correction

Limited extensibility to faint sources

Our aims:

- the *tuning* of diagnostic diagrams able to identify even faint/obscured AGNs
- *quantitatively* disentangle the relative AGN/SB contribution
- extendibility to *unclassified* sources
- extendibility to *high redshift* galaxies

Method: VLT/Subaru 3-4 μm spectral analysis



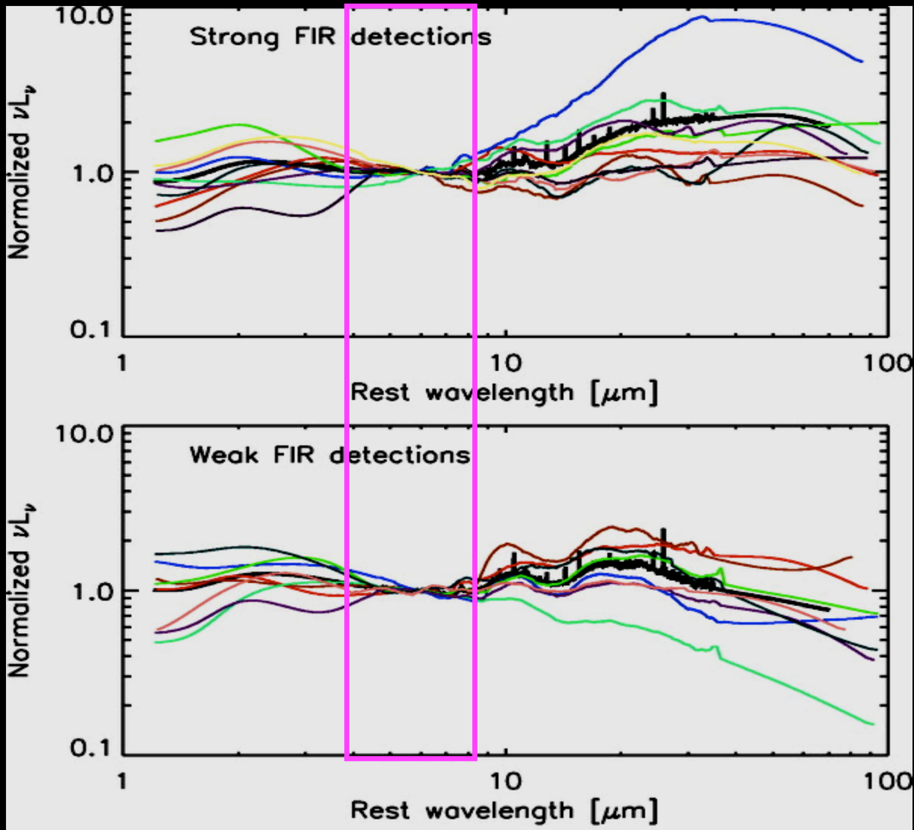
Flat continuum
$EW_{3.3} \sim 110$ nm
Pure SB

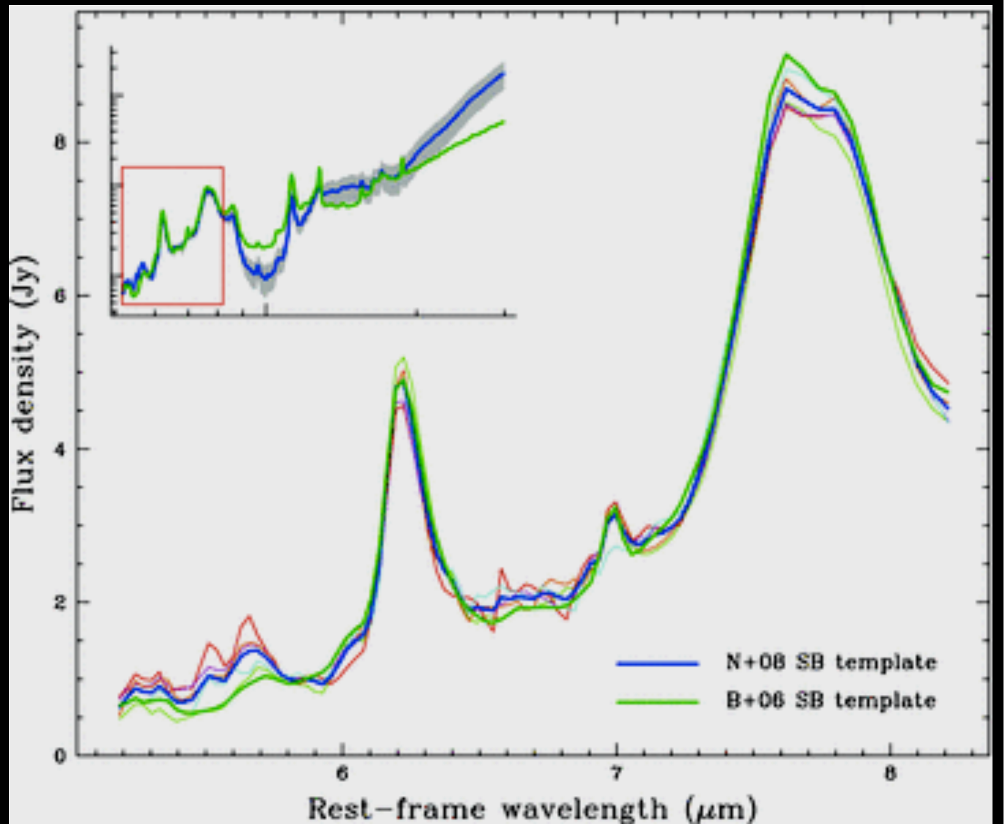
Flat continuum
$EW_{3.3} < 30$ nm
SB+AGN

Reddened continuum
$EW_{3.3} \sim 60$ nm
SB+reddening, absorption?

Risaliti +06

Method: AGN and SB templates





Netzer et al. 2007

Nardini et al. 2008

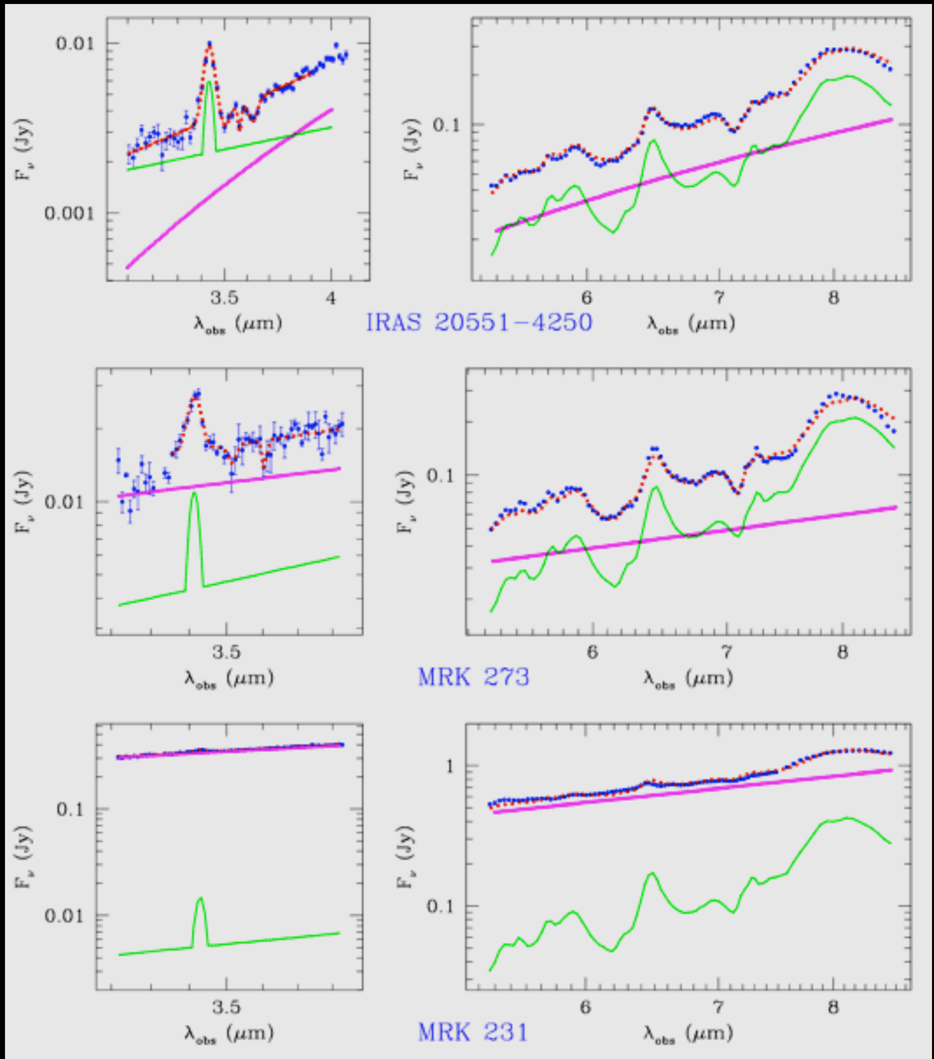
f_λ(AGN) is a powerlaw

f_λ(SB) PAH dominated spectrum

AGN and SB templates present the lowest dispersion in 3-8 μm waveband

Method: 3-8 μm spectral fitting

$$f_\lambda = \alpha f_\lambda(AGN) e^{-\tau(\lambda)} + (1-\alpha) f_\lambda(SB)$$



SB + reddened AGN

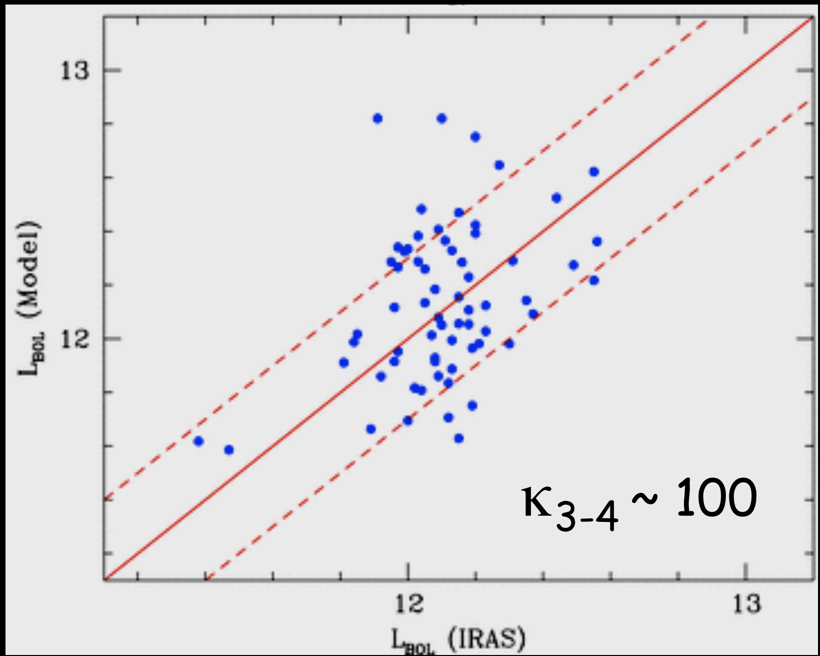
SB + unobscured AGN

Dominant AGN

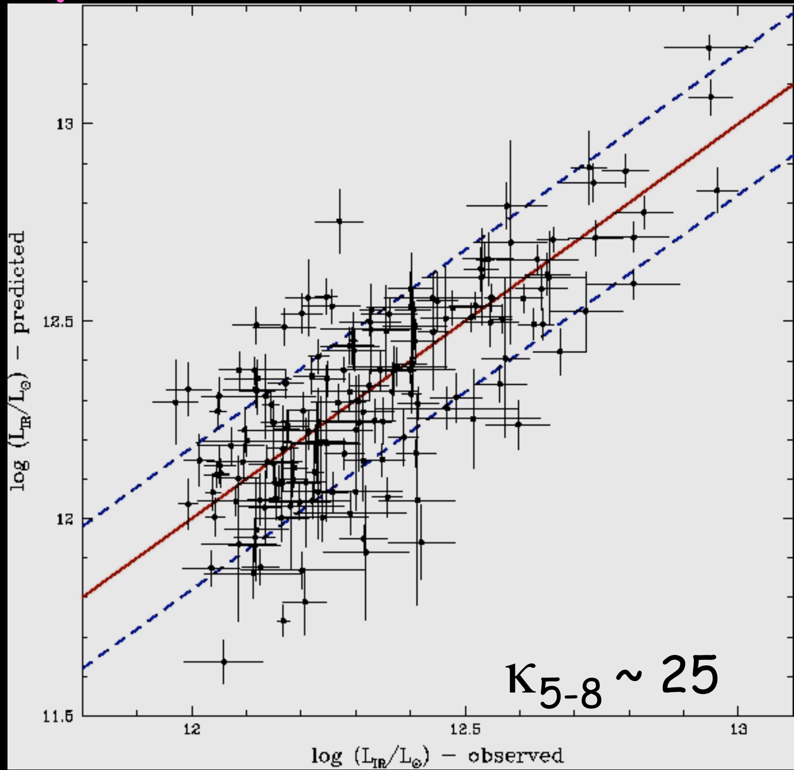
Differences are due to the different AGN contribution and its reddening/obscuration

Risaliti +06 Sani +08 Nardini +08 Nardini +09
Risaliti, Imanishi & Sani 2010

Method: sanity check



L-band analysis: 52 sources
Risaliti, Imanishi & Sani 2010

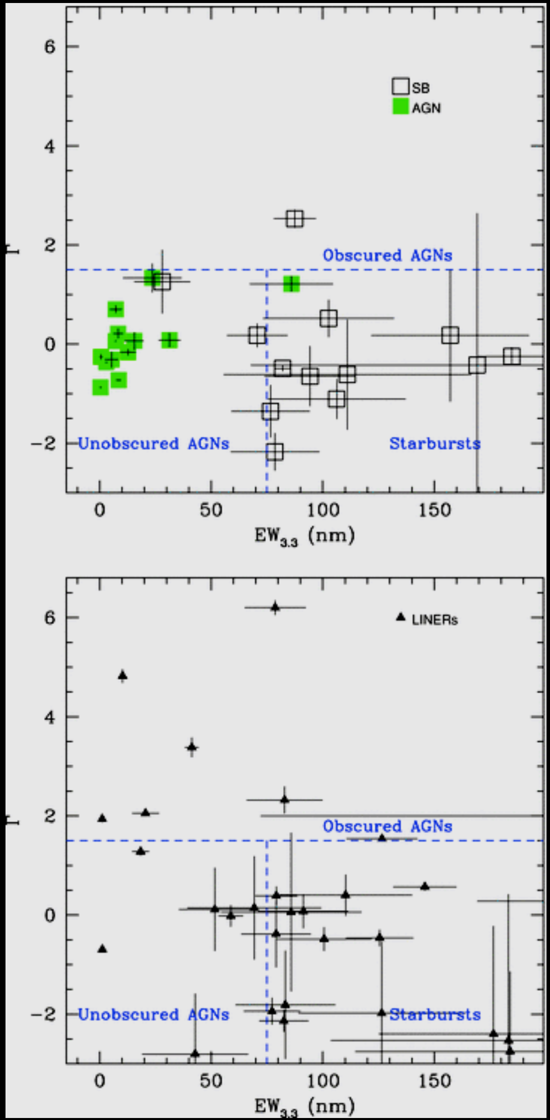


5-8 μm analysis: 164 sources
Nardini et al. 2009, Nardini et al. 2010 submitted

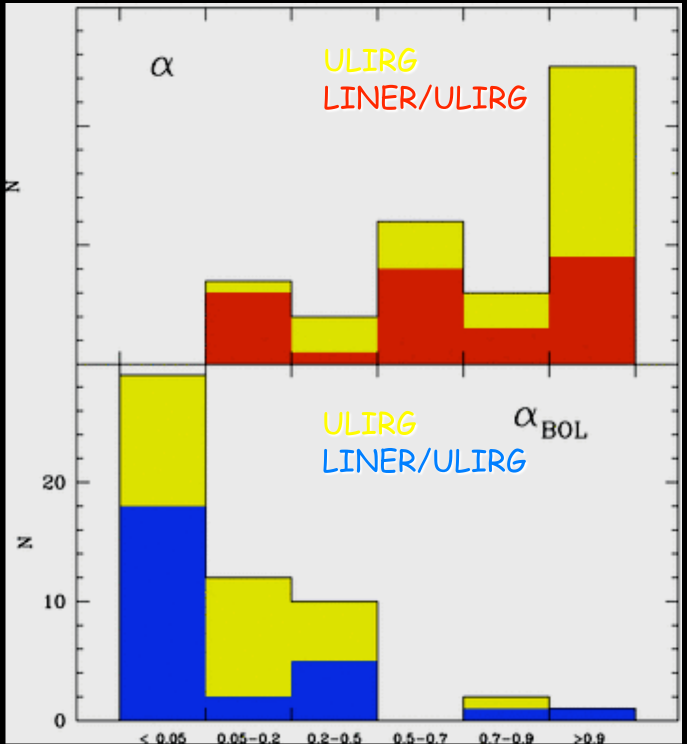
The actual 1σ dispersion is 0.18 dex (~50%),
and all the sources fall within ~0.3 dex from the exat match
Possible systematic errors:
- narrow waveband
- AGN/SB template (absorption features, flattening of the AGN continuum)
- Different extinction curve to model AGN obscuration

Application I: LINER/ULIRGs

VLT+Subaru: 55 ULIRGs, included 32 optically classified as LINERs



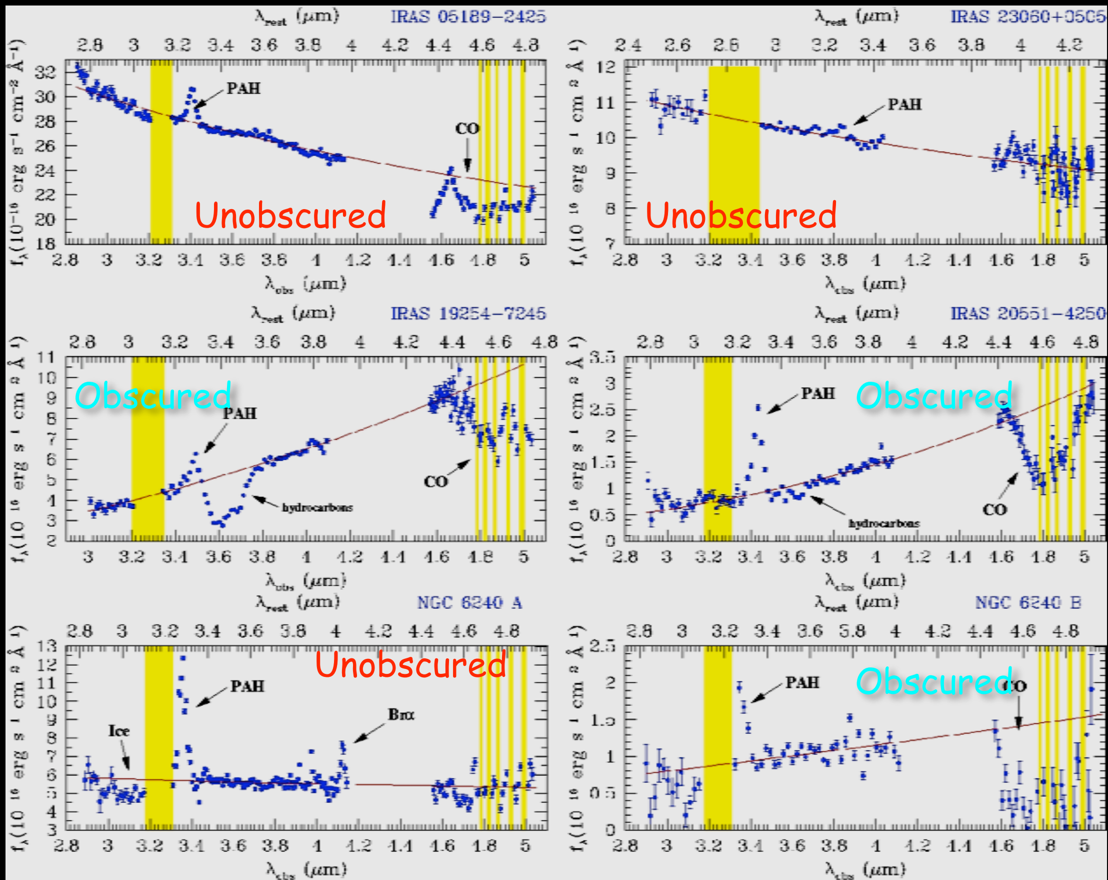
ULIRG sample:
AGN presence in >60%
LINER/ULIRG:
AGN presence in >30%

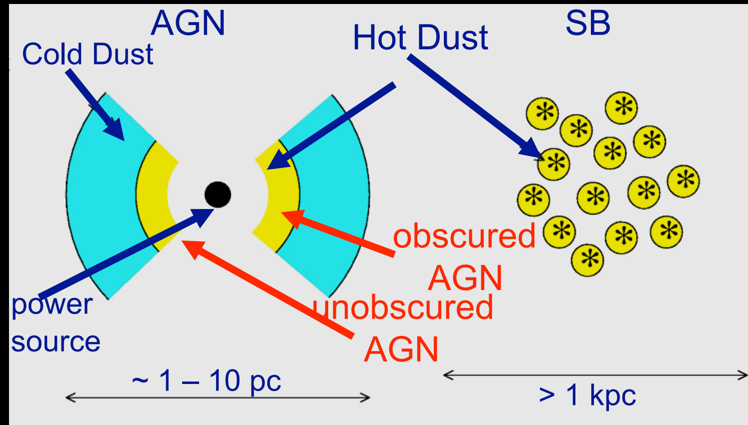


Coplete sample:
α>50% α_{bol}<20%
LINER/ULIRG:
α<30% α_{bol}<15%

Risaliti, Imanishi & Sani 2010

Gas & Dust properties in bright AGNs



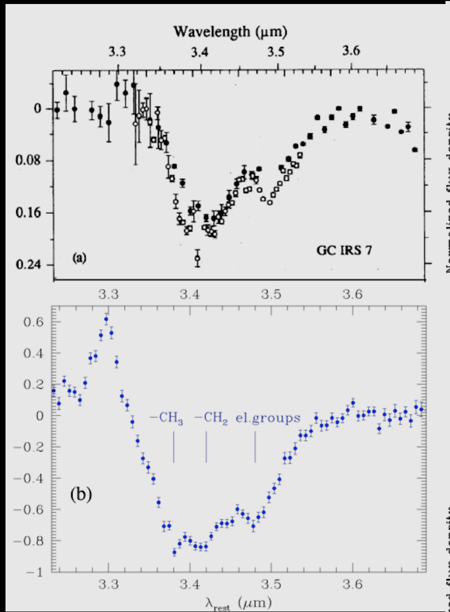


Sani et al. 2008

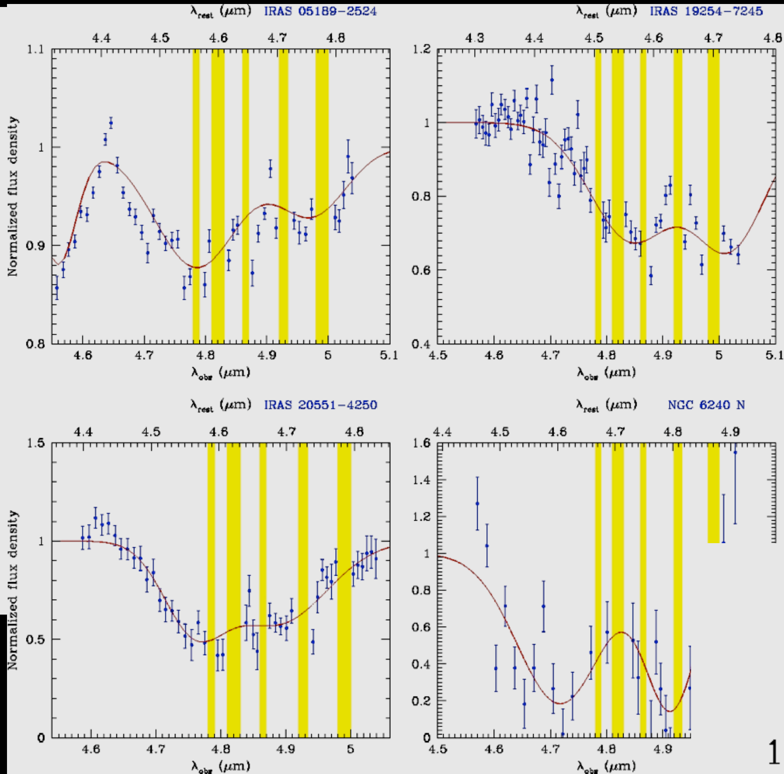
Unobscured ULIRG/AGN: flat continuum
no absorption features at 3.4 μm, 3.6 μm

Obscured ULIRG/AGN: steep reddened continuum
hydrocarbons and CO absorption features

Gas & Dust properties in bright AGNs

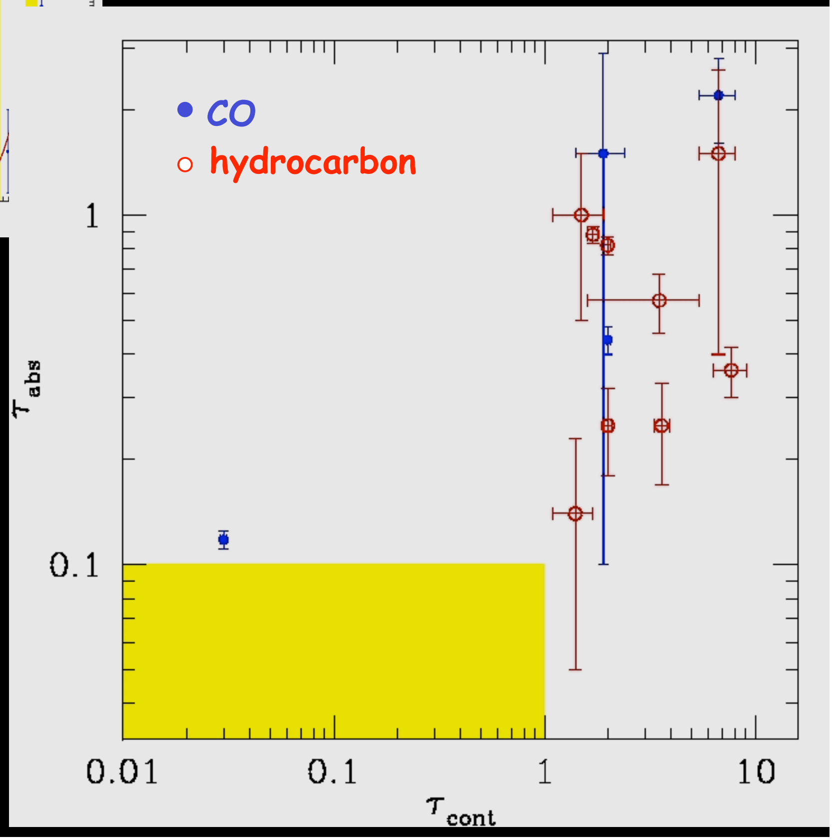


Risaliti +03, +06



Sani et al. 2008

Lutz et al. '04 do not detect gaseous CO in type 1 and 2 AGNs.
A different obscuration geometry and/or dust composition



Absorption features ⟺ Reddened continuum

No strict correlation

Different dust composition

Gas & Dust properties in bright AGNs

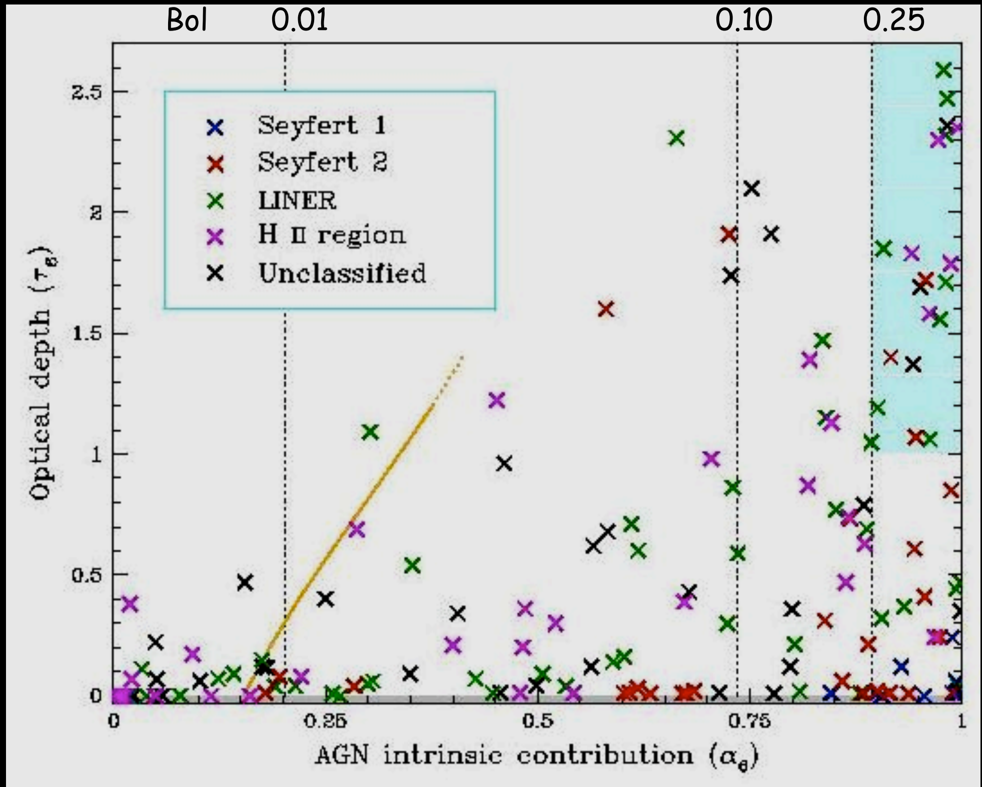
Source	N_H (10^{23} cm^{-2})	$A_L(X)$	$\tau_{3.4}$	$A_L(\tau_{3.4})$	τ_L	A_L(obs)
05189-2425	4	9	<0.02	<0.2	0	0
23060+0505	0.8	2	<0.03	<0.3	0	0
19254-7245	>10	20	0.8	9.6	2	2.2
20551-4250	8	17	1.5	18	>5	>6
NGC6240S	>10	20	<0.02	<0.2	0.3	0.4
NGC6240N	>10	20	<0.05	<0.5	1.4	1.5

Assuming
$N_H/A_V=1.9\text{x}10^{21}$ mag^{-1}cm^{-2}
Bohlin, Savage & Drake (1978)

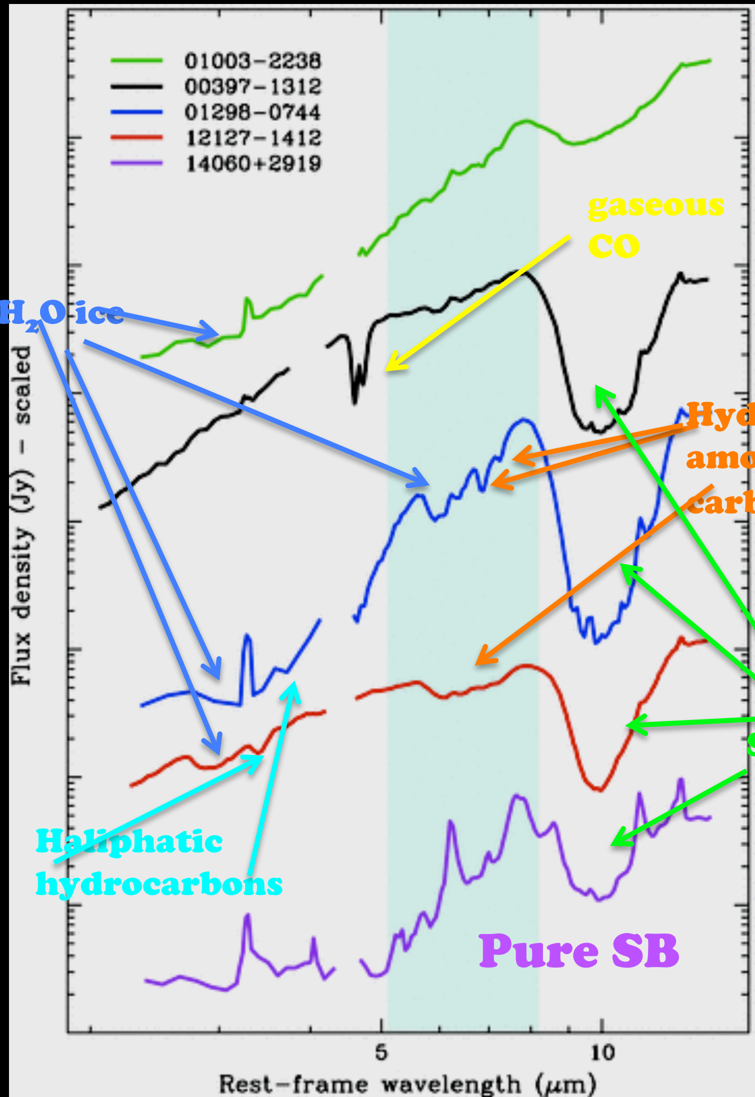
Assuming
$A_L=12\text{x}\tau_{3.4}$
Pendleton +94

- The gas-to-dust ratio is higher than in the Milky Way
- Non standard extinction curve

Looking for elusive AGNs



Nardini +10

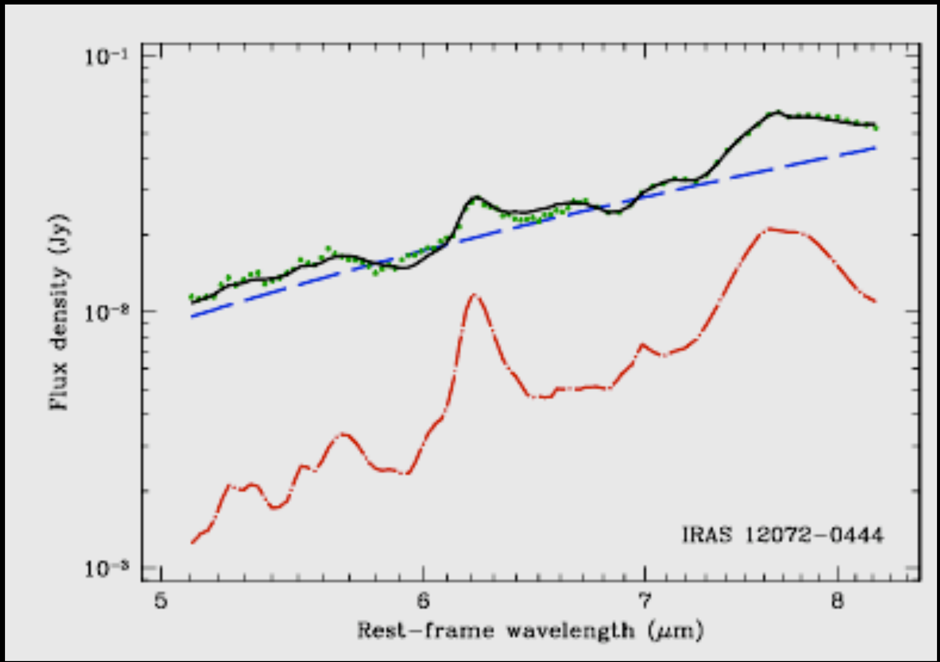


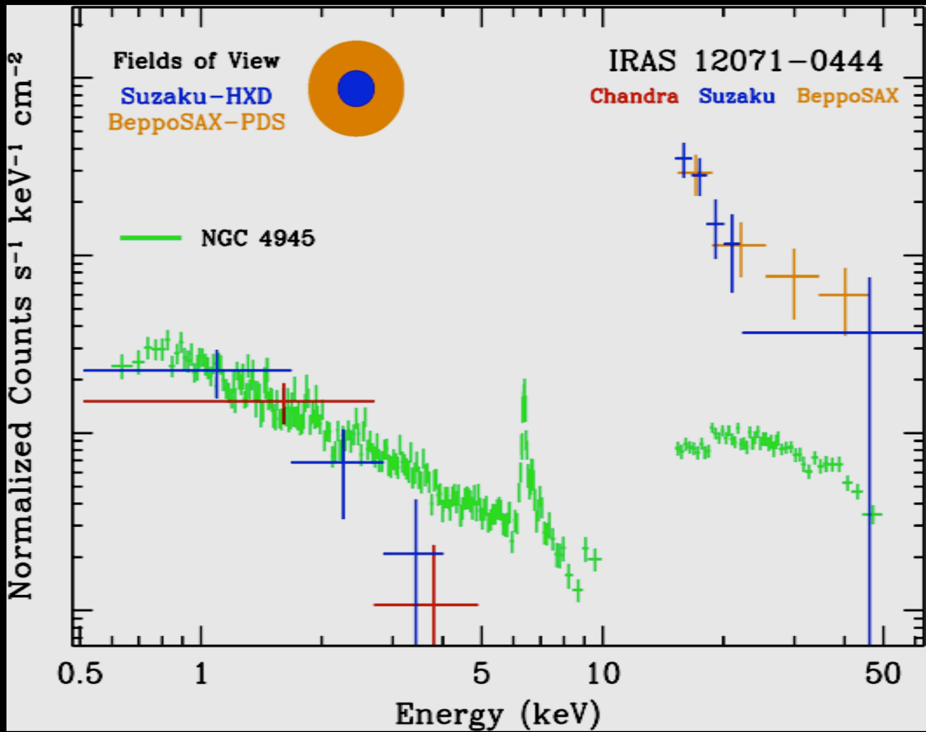
Elusive AGNs: significant emission, but highly obscured (α_{bol}>25%, τ_6>1)

Only 3 sources are classified as AGN (Sy2)

IRAS 12071-0444

Nearby ULIRG, z=0.128, L_{IR}~9x10^{45} erg/s



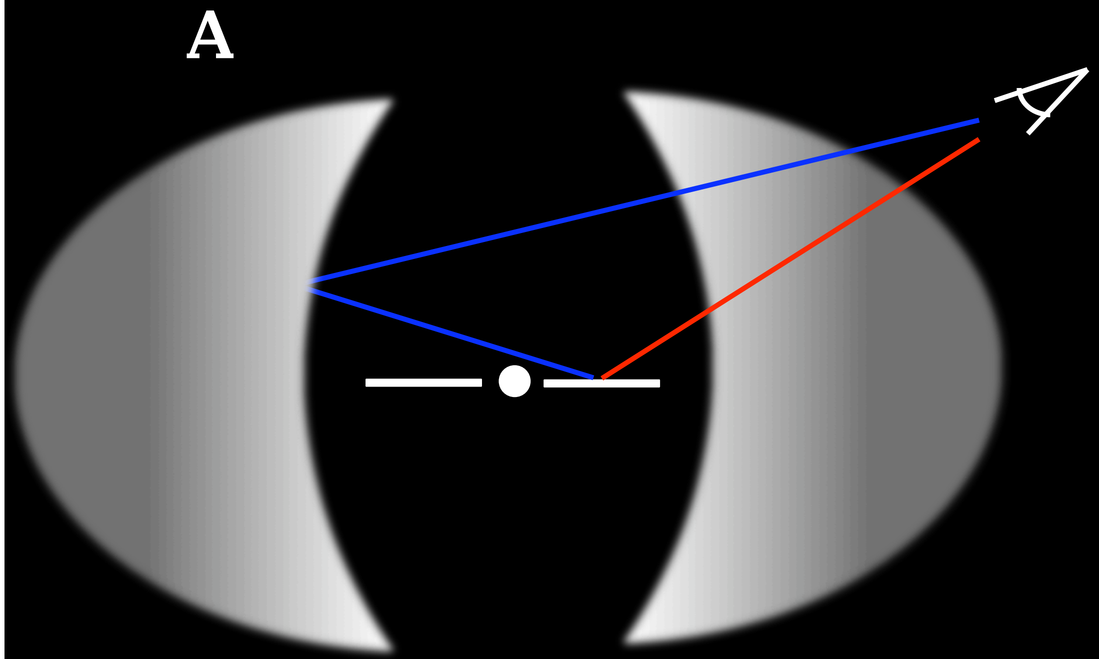


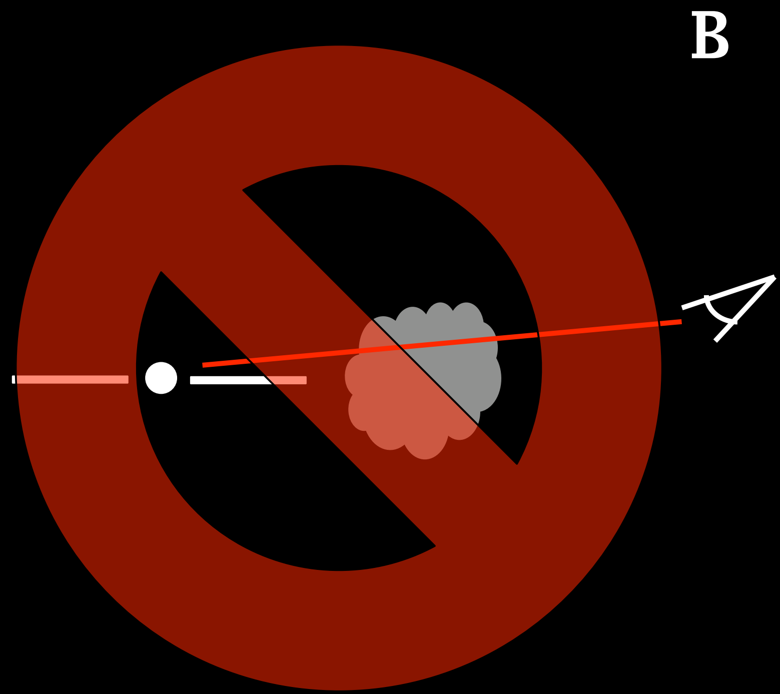
- 2-10 keV emission consistent with a pure SB process
- No Fe Kα detection
- Direct emission detected above 20 keV
- Absorbed powerlaw with:

N_H=3.5x10^{24} cm^{-2}

L_{2-10}^{int}~7x10^{44} erg/s (~10% of the bolometric emission)

IRAS 12072-0444: a CT type 2 QSO





Multiwavelength analsys
IR: reddened cont + PAH
Optical: Seyfert 2
X-ray: Compton thickness
No reflection

No Comptonization
Cocoon-like structure

Questions

✓How the co-presence of AGN and SF alter the circumunclear environment?

- The chemical composition is NOT constant among ULIRGs
- NO standard gas-to-dust ratio
- Cocoon-like absorber

❑Is the gas creating SF related to the Torus?

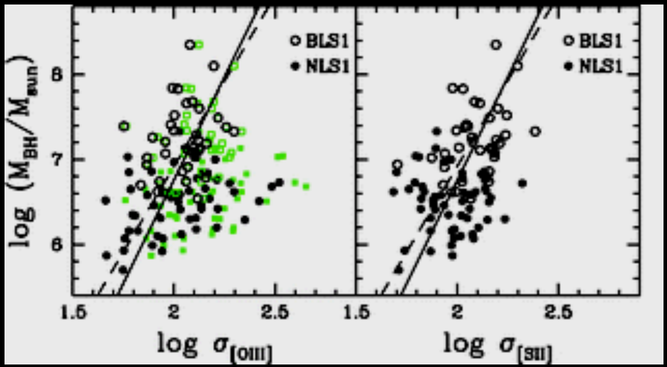
❑How does the gas get from 1kpc to central 10s of pcs?

SF & BH accretion: Narrow Line Seyfert 1 galaxies

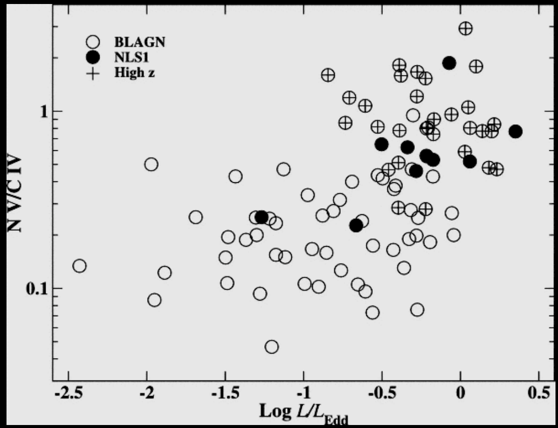
Optically defined: H_β FWHM ~ 500-2000 km/s
$[OIII]/H_\beta < 3$
(Osterbrock & Pogge 1985, Vèron-Cetty & Vèron 2001)

Properties: $FeII/H_\beta > 2$
steep X-ray spectra, soft X-ray excess
rapid and strong X-ray variability
low M_{BH}, high L/L_{Edd}

NLS1s in the contest of AGN-Starburst connection:



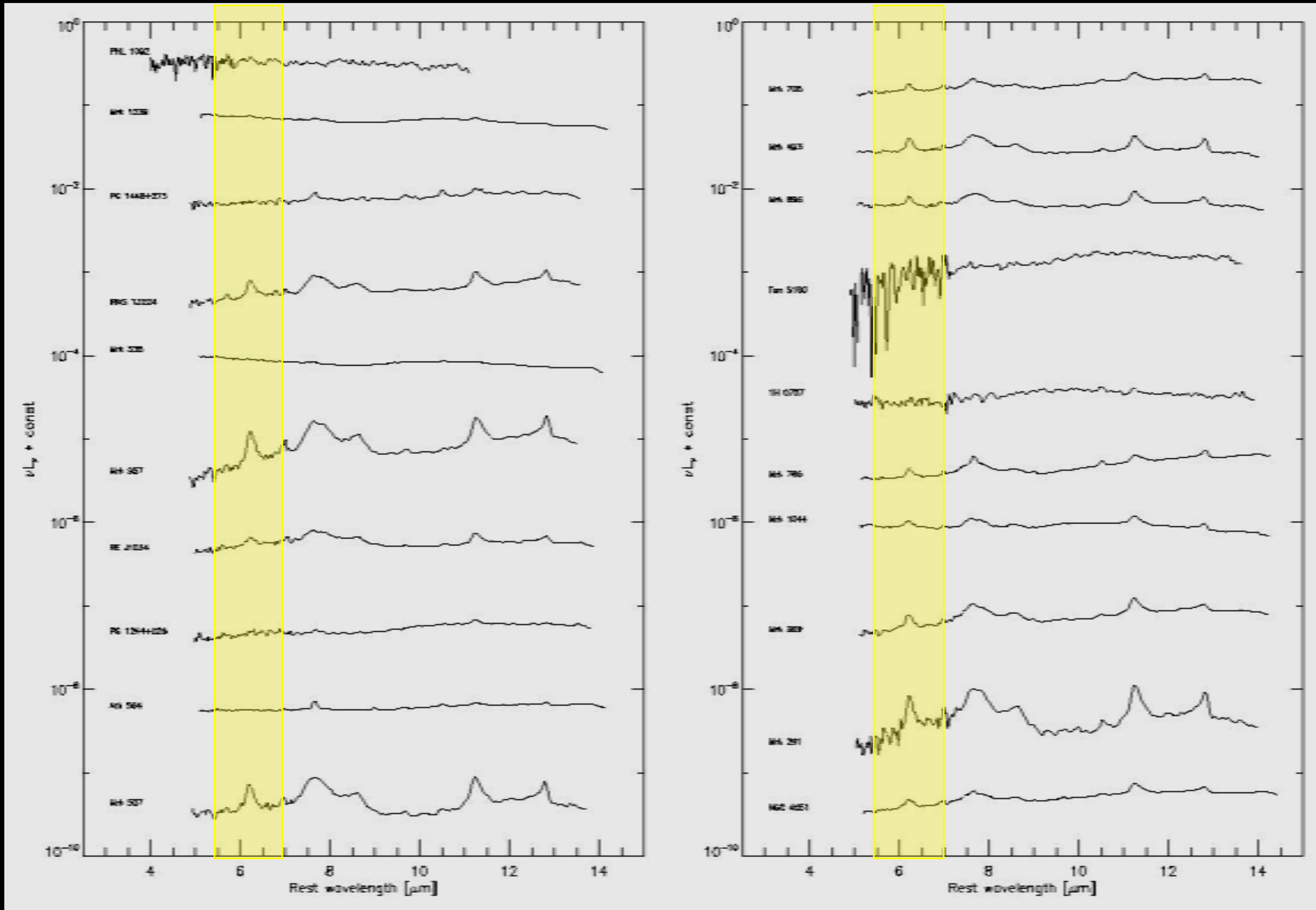
NLS1s lie on the M_{BH}-σ relation
(Komossa & Xu 2007)



NLS1s have high L/L_{Edd} and high metallicity
(Shemmer et al. 2004)

ULIRG nature of some NLS1:
ULIRG/AGNs radiate at 50% Edd rate.
(Tacconi et al. 2002)

20 well known NLS1: z<0.1 (except PHL 1092),
spanning NLS1 class properties over several order of magnitude



Decomposition of low res. spectra through a Power law (AGN) + Starburst template

$L_{PAH} \sim 10^{39} - 10^{41}$ erg/s

Unbiased NLS1 + BLS1 samples

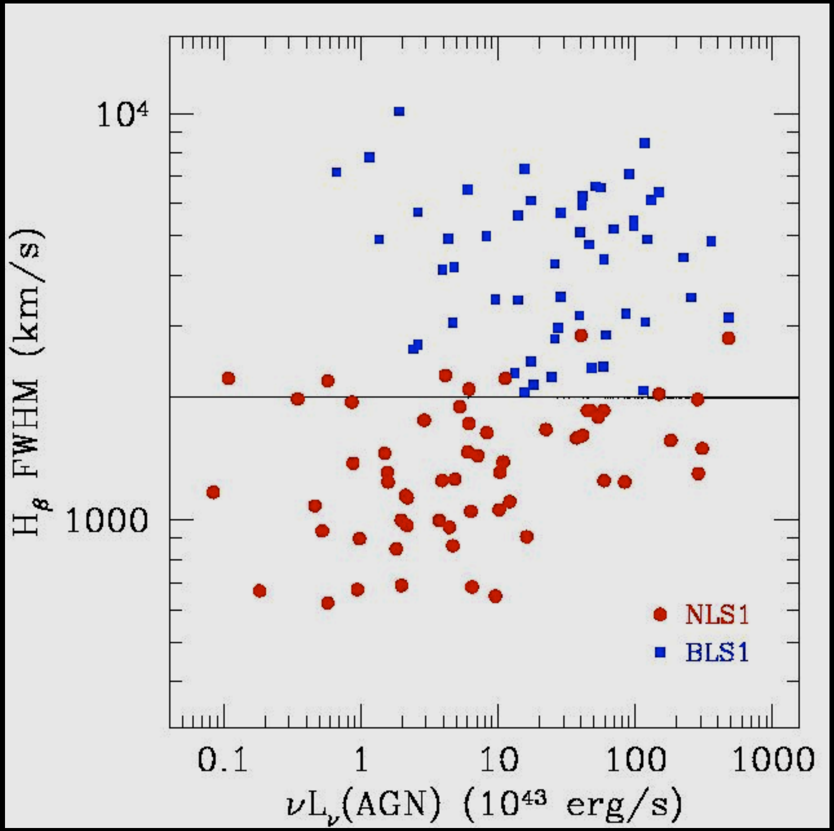
Catalogue of Quasars and Active Nuclei (12th edition Vèron-Cetty & Vèron 2006)
z < 0.2: cover 2 orders in D_L , 6 orders in L(AGN) maintaining good quality
Exclude Sy 1.5, 1.8, 1.9 to avoid optical biases toward type 2 objects
Exclude Radio Loud objects with synchrotron dominated mid-IR spectra

Check

-some NLS1 have FWHM>2000 km/s
but: have all the other NLS1 properties
and are included in well known NLS1 samples
-all BLS1 with FWH <2000 km/s are excluded

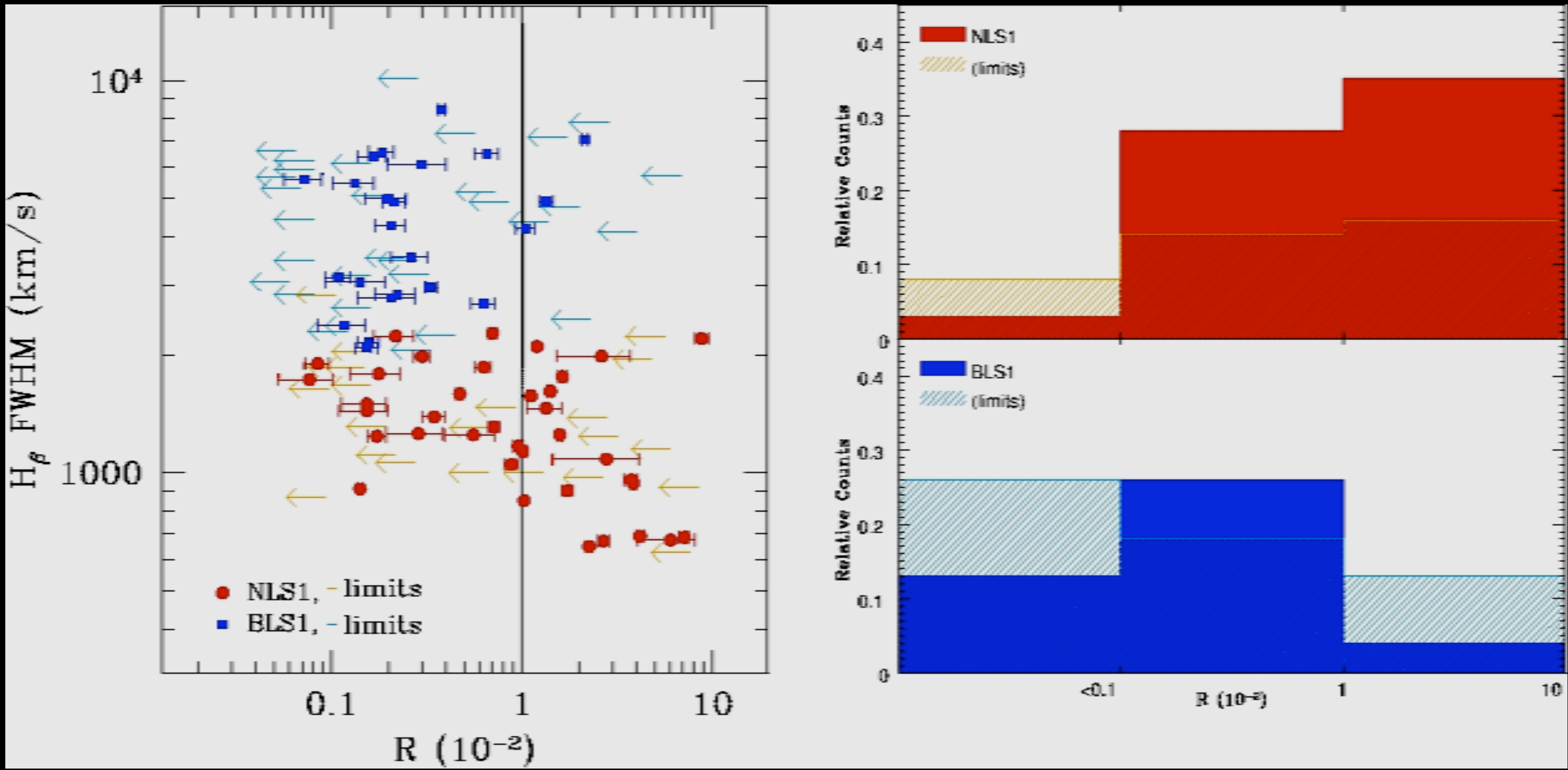
Note: lack of BLS1 in the lower luminosity range..

59 NLS1s + 54 BLS1s



Results: H_β vs PAH

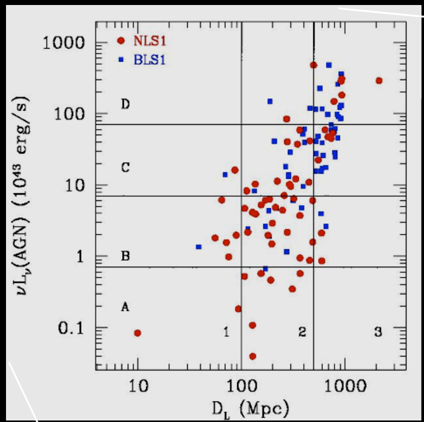
H_β FWHM and $R=L(PAH)/\nu L_\nu(AGN)$ are intrinsic and independent quantities.
Two distinct populations of type 1 AGNs

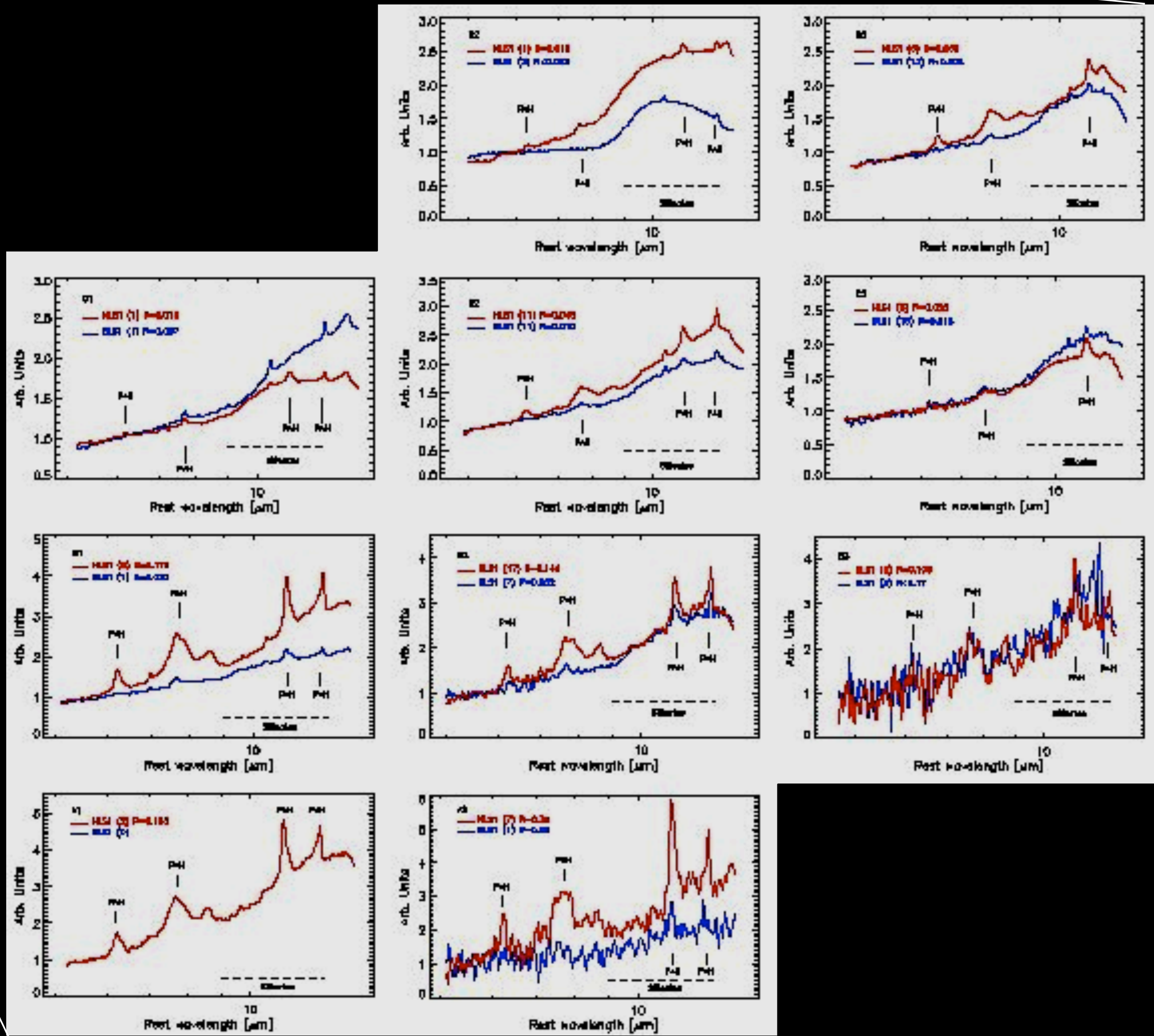


Sani et al. 2010

- -Larger R values indicate a larger relative SF contribution to the MIR spectrum.
- -PAH detection rate larger in NLS1 than in BLS1.
- -The majority of detections for NLS1s correspond to the strongest SF (R>1).
- -R values for BLS1 are mostly upper limits

Biases control: stacked spectra





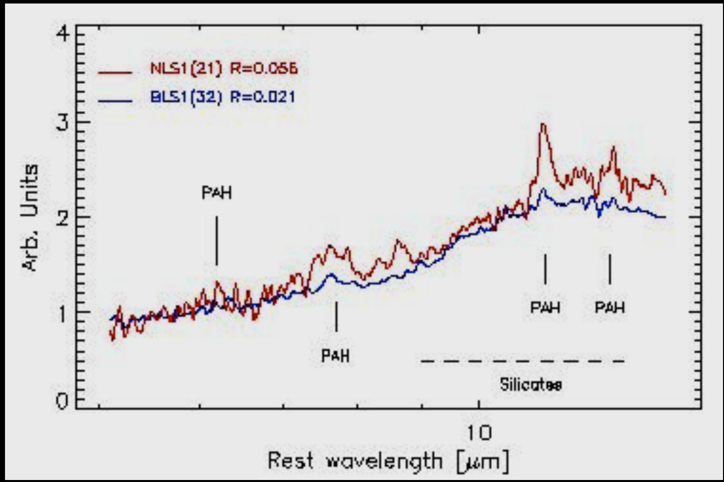
$F_{SB}=R_{NLS1}/R_{BLS1}$

$F_{SB}>2$
except in A1, B3

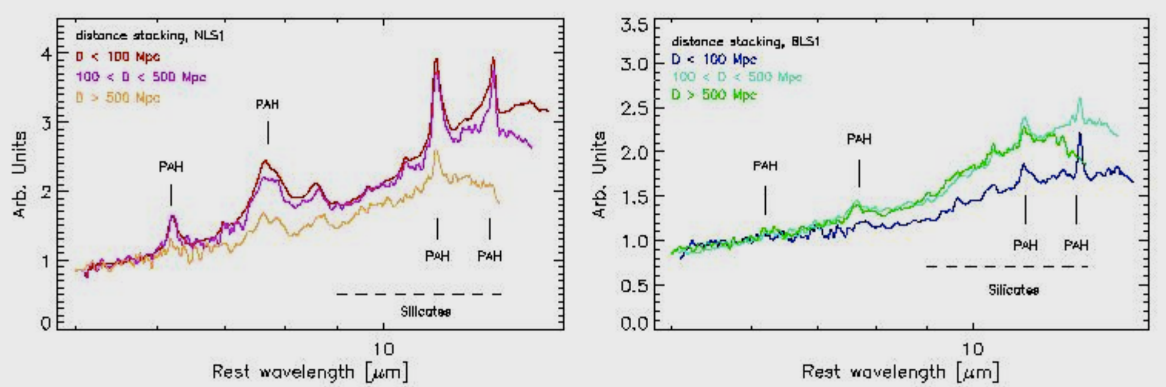
Further check end confirmation

Stacked spectra for sources with NO
6.2 PAH detection in the individual spectrum:

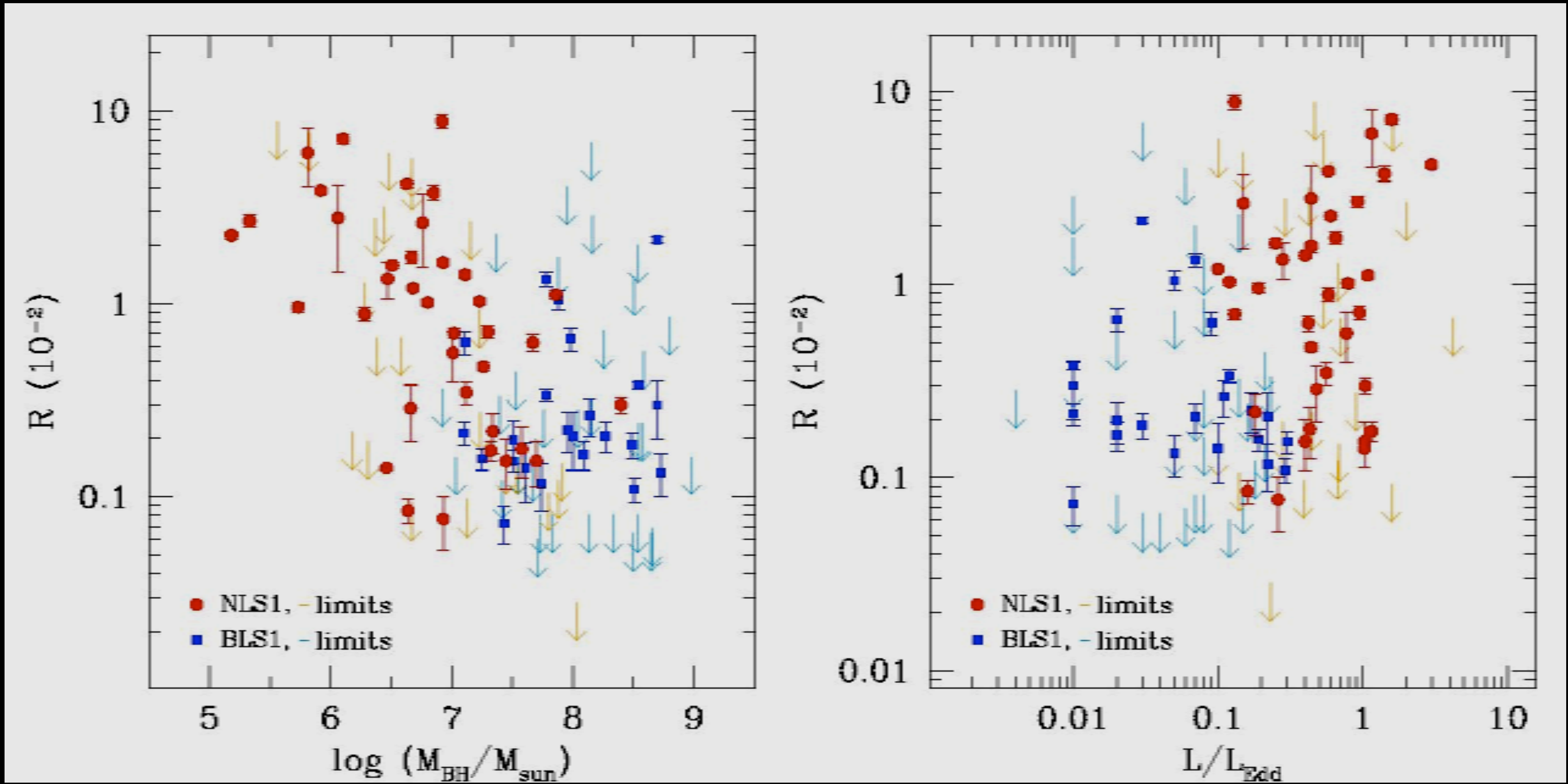
F_{SB}=2.6±0.5



Stacking zones are collapsed along the luminosity axis



AGN fuelling and SF connection



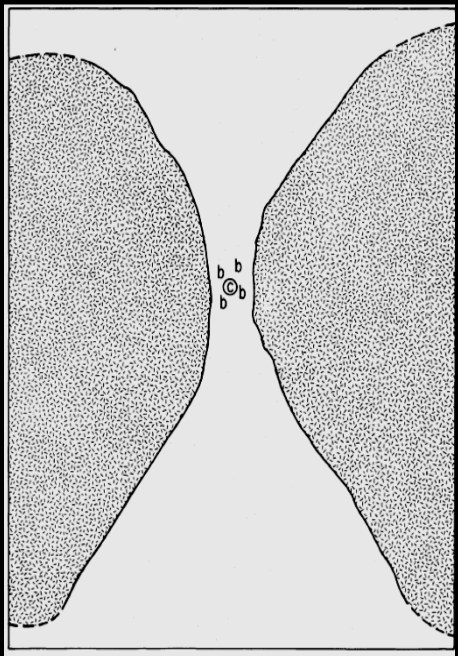
Sani +10

-SF increases with decreasing BH masses and increasing Eddington ratios
-NLS1s only occupy the regions of extreme values

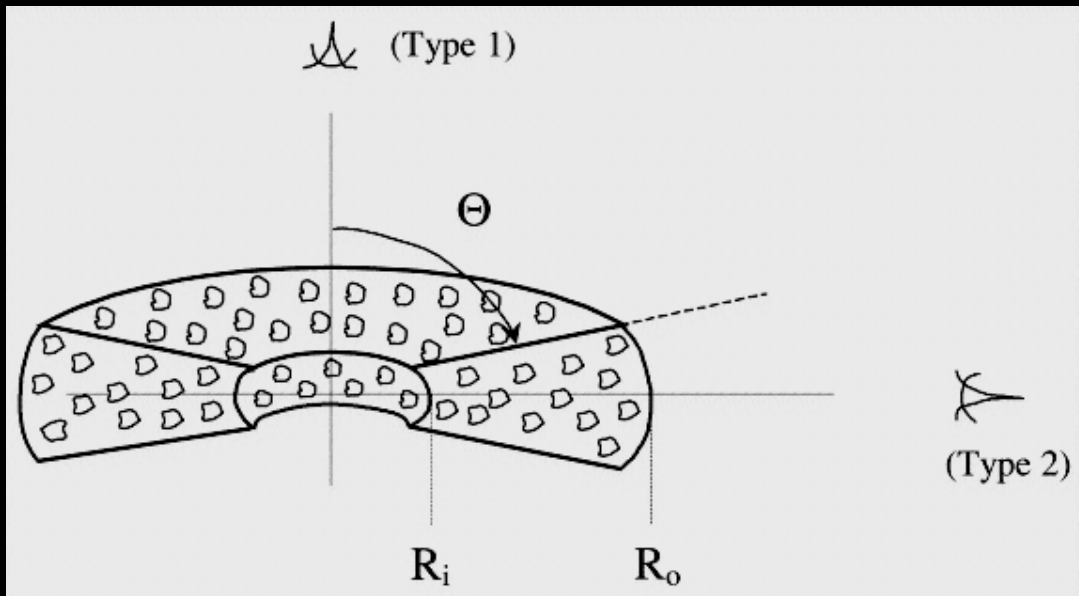
Torus Properties

- molecular gas and dust
- optically thick: it obscures the AGN if viewed edge on
- compact: tens of parsecs of radial extension
- vertically extended: several parsecs

(provide collimation for ionized gas)



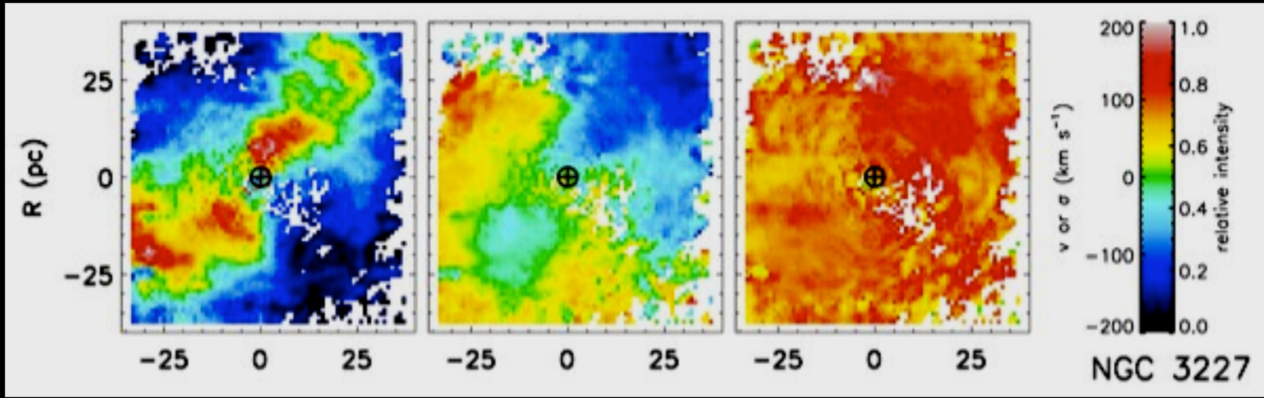
Antonucci & Miller '85



Nenkova +02

Focus on the geometrical structure

Radial distribution of molecular gas

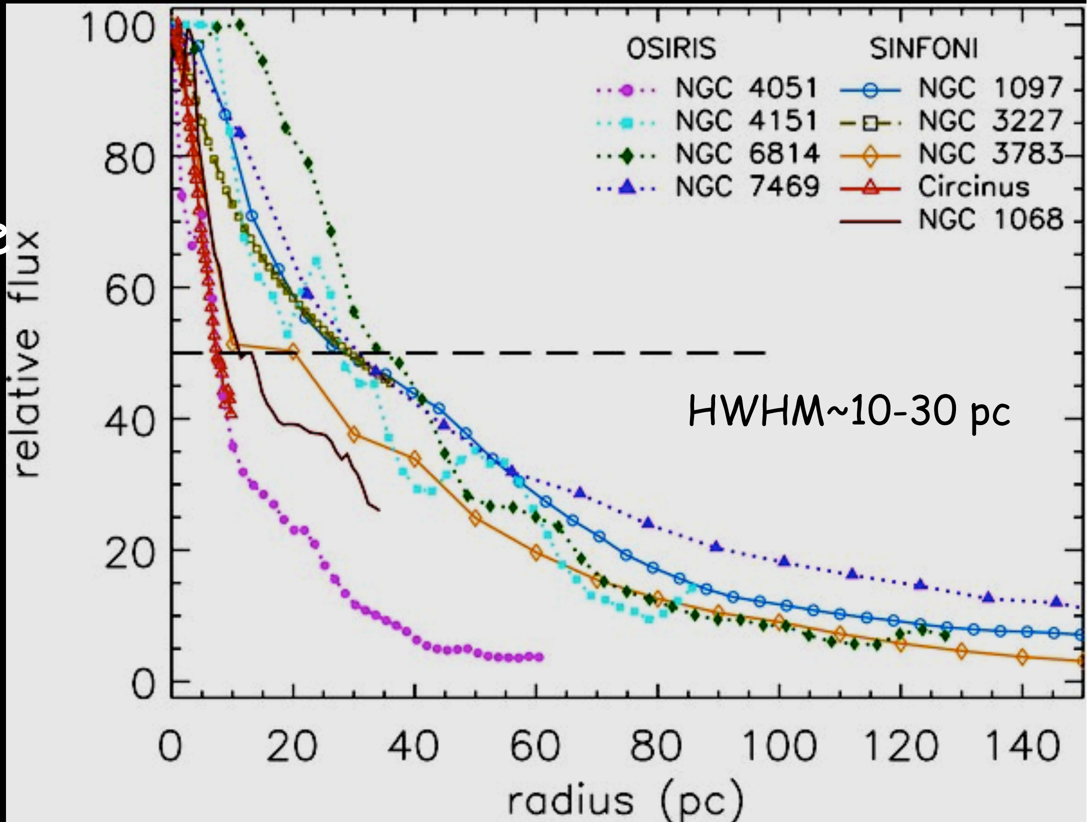


1-0S(1) H_2 traces warm gas:

- compact concentration of the gas in the nucleus

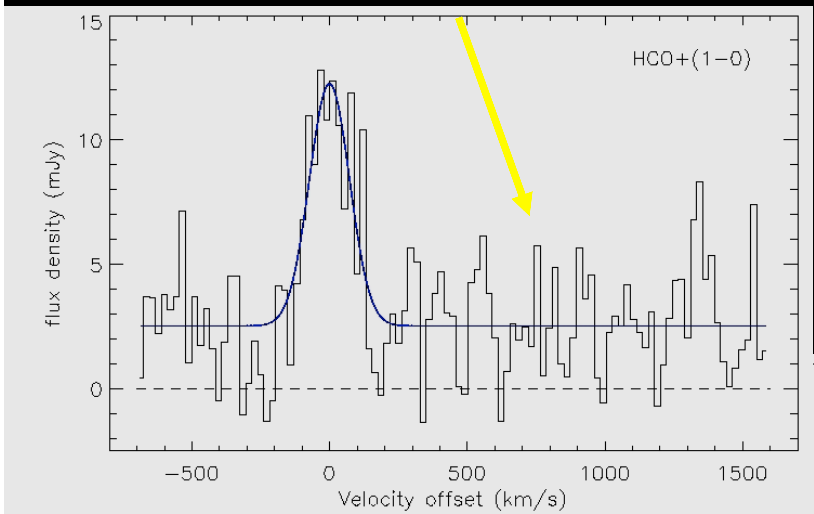
inner region is a high surface brightness concentration of a larger scale structure

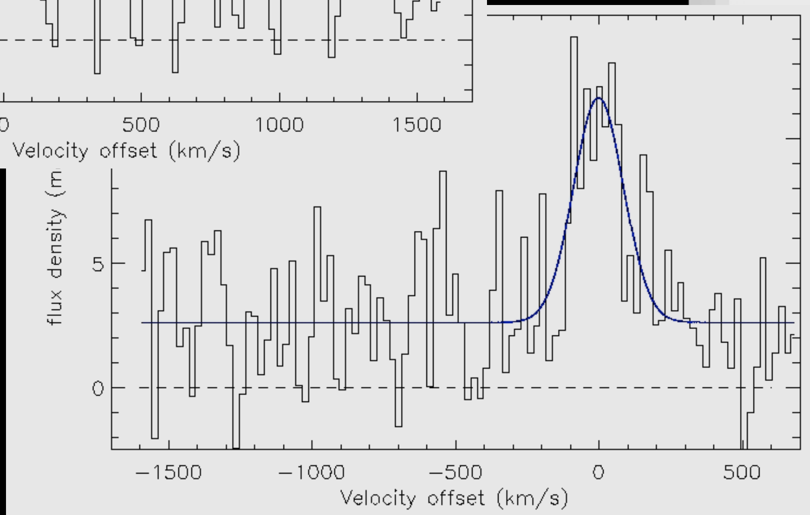
Hicks+09

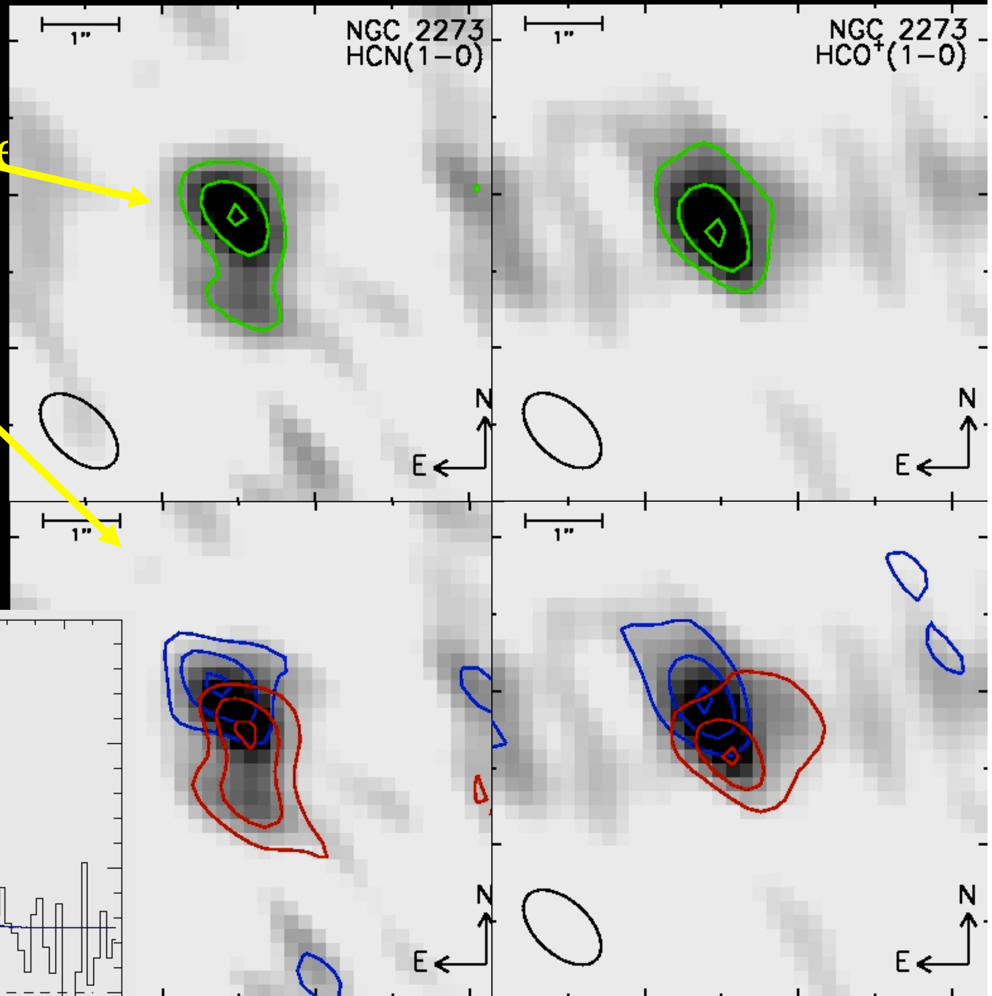


Dynamical state of the dense gas

HCN observations probe dense > $3x10^4$ cm^{-3} gas
~1" resolution from PdBI – NGC 3227, 2273, 4051, 6951
(now also NGC 3079, 5033, 6764)
Directly observable constraints:
- major & minor axis size +PA
separation + PA of the red/blue channe
- integrated line width







Sani +11 (sumitted)

Dynamical state of the dense gas

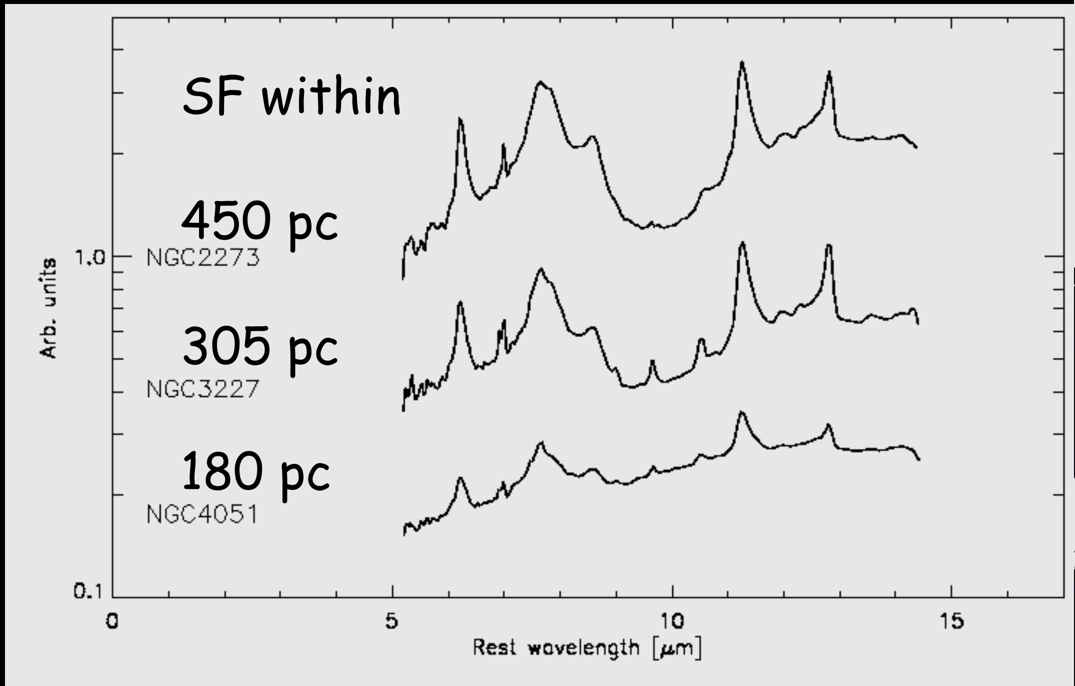
Use DYSMAL (Cresci +09, Davies +11)
-Inclined disk
-Elliptical beam (beam smearing is a key aspect of dynamical modeling)

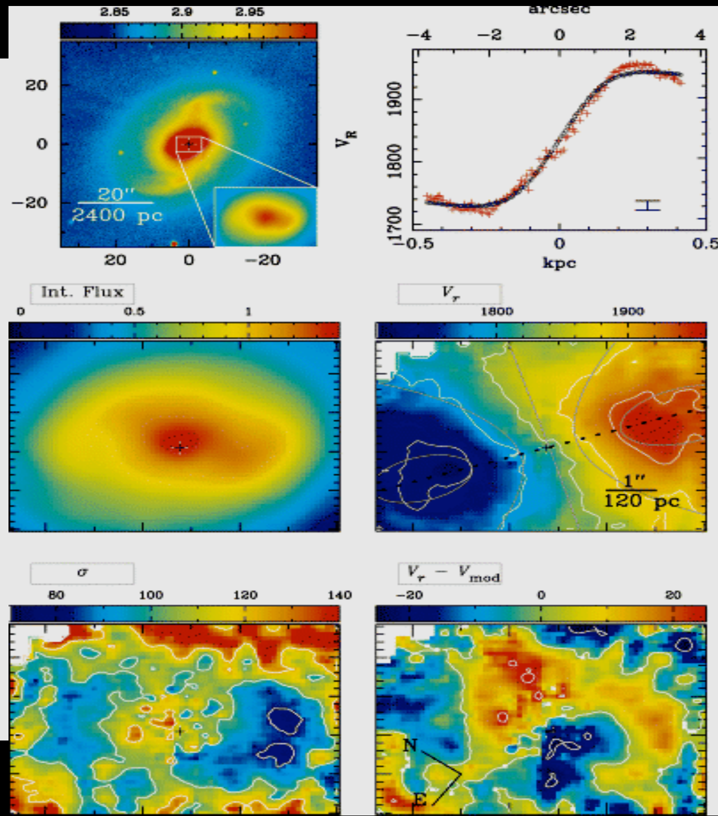
Thin disk
-Gaussian and uniform distribution yield similar results
-Line width is only ~2/3 of that observed

Thick disk
-Can reproduce all observed characteristics
-Dispersion is due to a combination of beam smearing of velocity gradients as well as $V/\sigma \sim R/H \sim 2\text{-}3$
-Intrinsic dispersion is 25-50 km/s for HCN and HCO+ (about ~50% of H_2 1-0S(1) reported by Hicks+09)

Toomre Q parameter: $Q/Q_c > 1$ always, i.e. dense gas is turbulent with NO ongoing SF

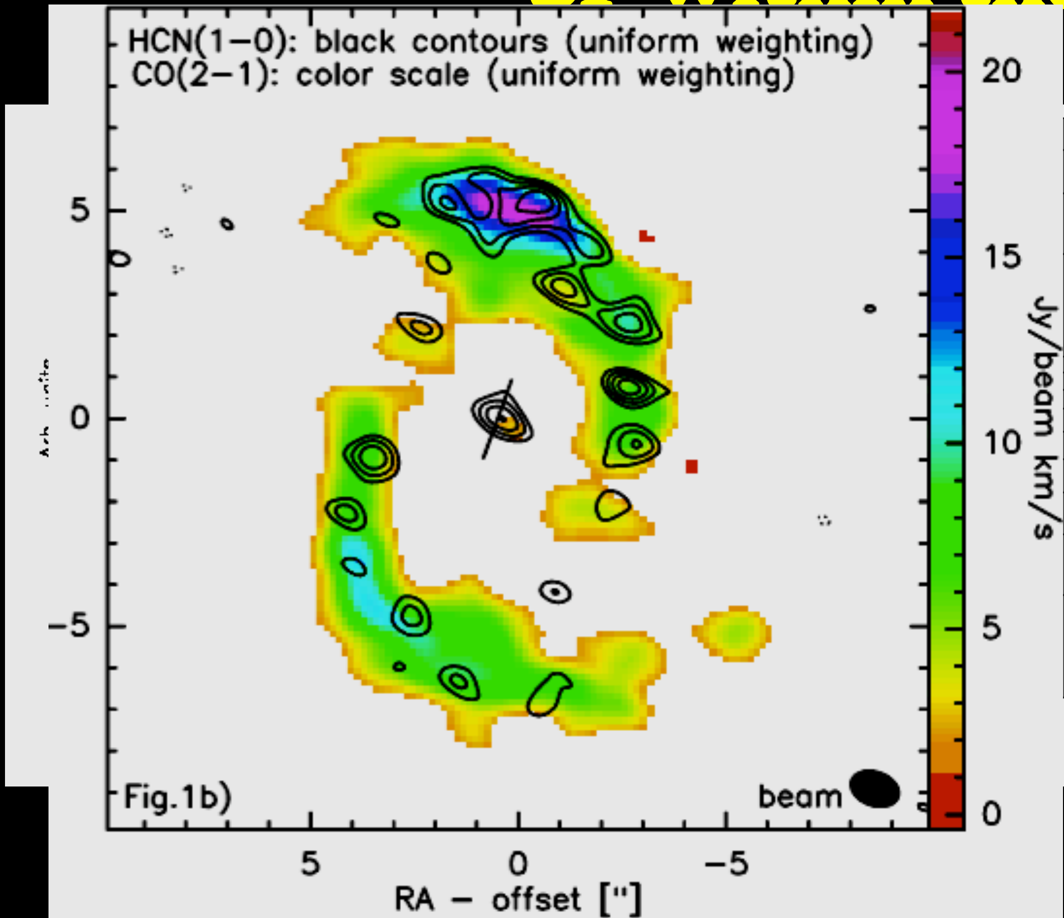
SF within the Torus?

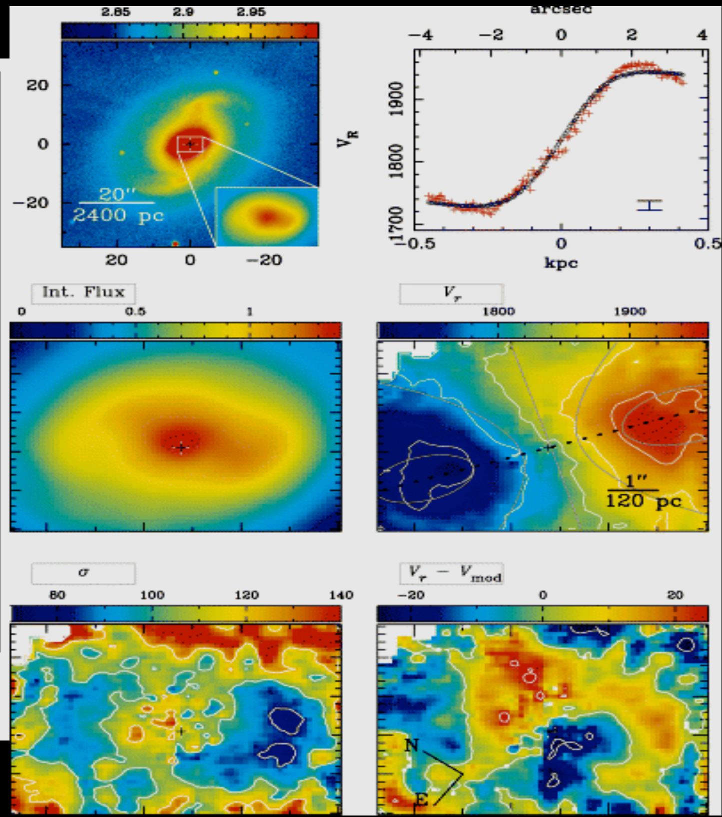




- NGC 3227: nuclear (<30 pc) SF is no more occurring (Davies +06)
- NGC 2273, NGC 3227, NGC 6951 show a circumnuclear stellar ring (Martini +03, Davies +06, Krips +07) with a decreasing stellar dispersion comp. to the nucleus (Barbosa +06)
- NGC 4051: PAH3.3 not detected within the central 50 pc (Rodrguez-Ardila & Viegas 2003)
  SF located in a circumnuclear ring

SF within the Torus?





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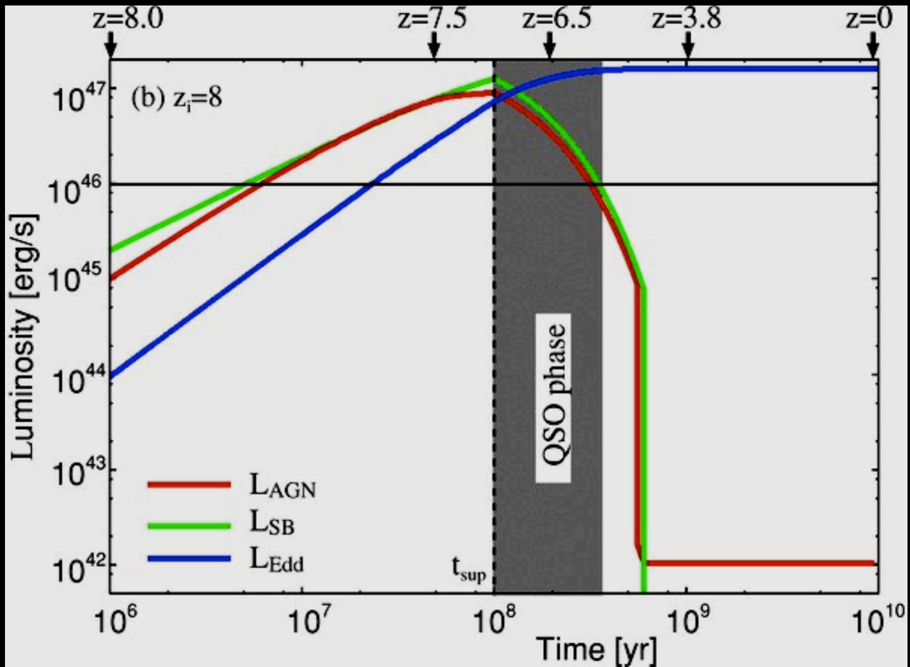
SF located in a circumnuclear ring

Are AGN fuelled with or after nuclear SF?

Simultaneous
(Kawakatu & Wada 08, Wada+ 09)
inflow driven by turbulent viscosity
viscosity driven by supernovae
long periods of star formation
accretion & star formation simultaneous

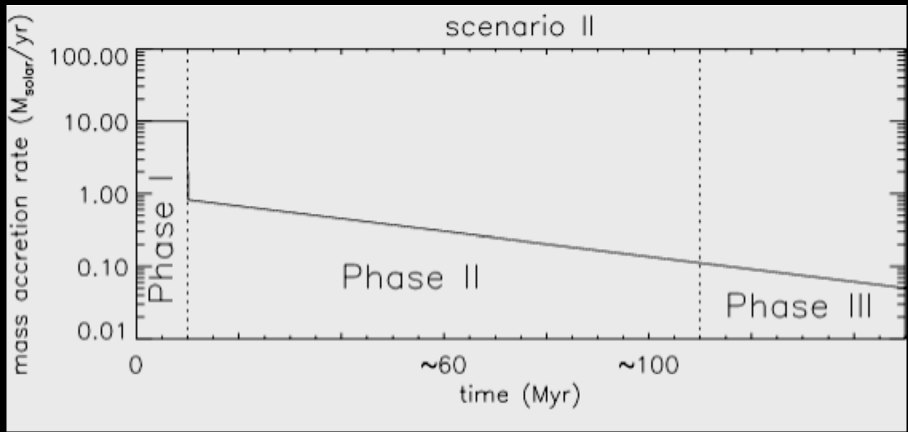


Subsequent
(Vollmer, Beckert & Davies+ 08)
clumpy 'turbulent' or 'collisional' disks
3 phases:

(i)turbulent star forming Q~1 disk; SNe blow out ISM leaving dense cloud cores in a collisional Q>1 disk.

(ii) mass accretion decreases slowly, disk stays thick; all observed AGN in this phase.

(iii) mass accretion rate low, disk becomes thin.

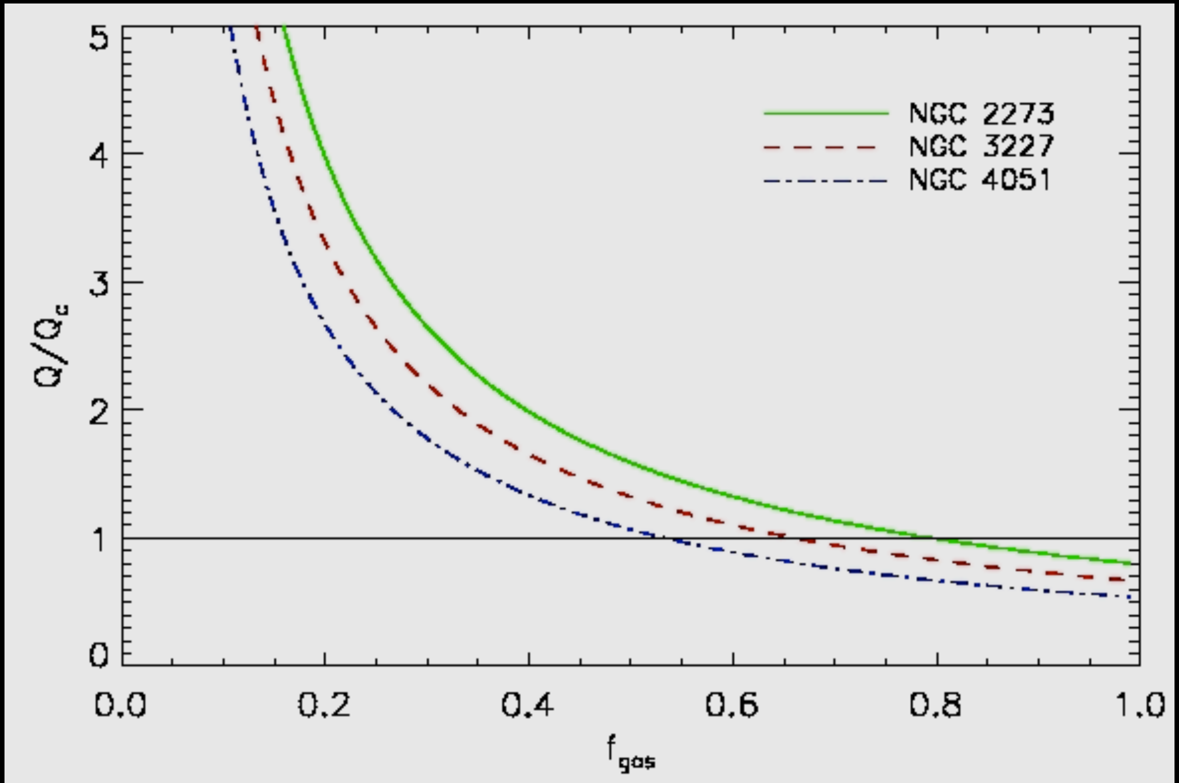


The Toomre Q parameter

$Q = \kappa\sigma/(\pi G\Sigma)$,
$\kappa = \surd 3 \times \Omega$ (Dekel +09)

$\Omega = V/R$
$\sigma = V \times R/H$ (thick disk)
$\Sigma = M/(\pi R^2)$
$M_d = (V^2+3\sigma^2)R/G$

$$Q = \surd 3 \, \frac{H}{R} \, \frac{1}{(1+3 \times H^2/R^2)\, f_{gas}}$$



Phase I:
$Q \sim Q_c$

Questions

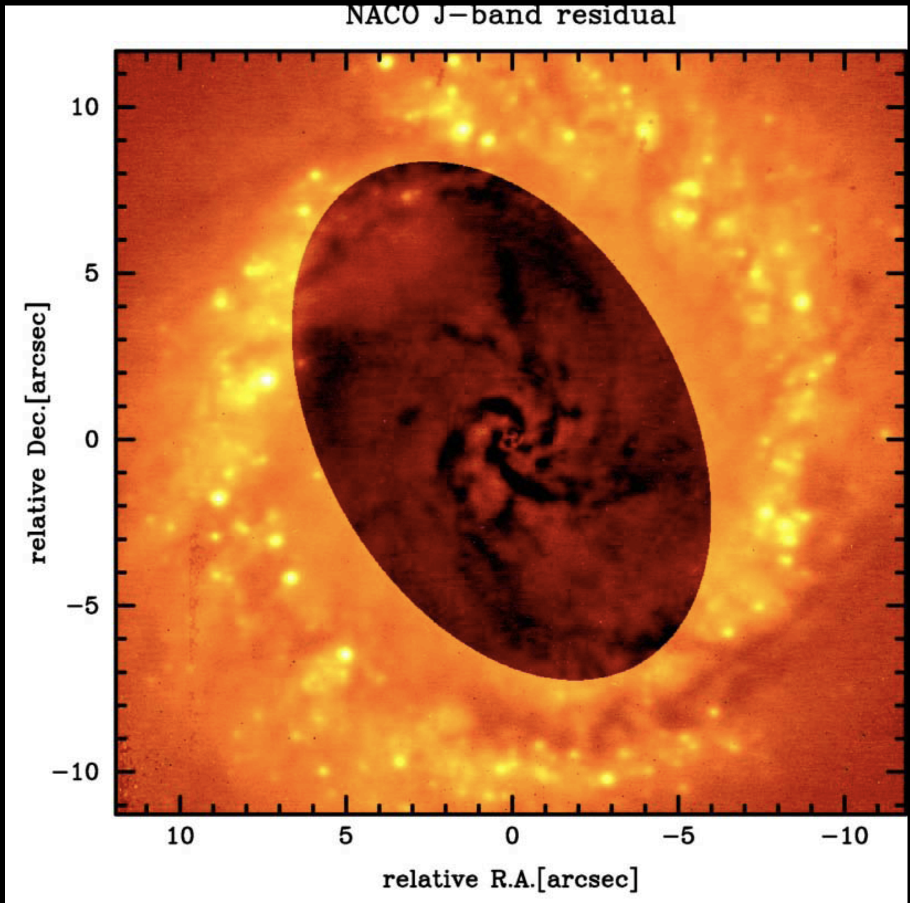
✓How the co-presence of AGN and SF alter the circumunclear environment?
- The chemical composition is NOT constant among ULIRGs
- NO standard gas-to-dust ratio
- Cocoon-like absorber

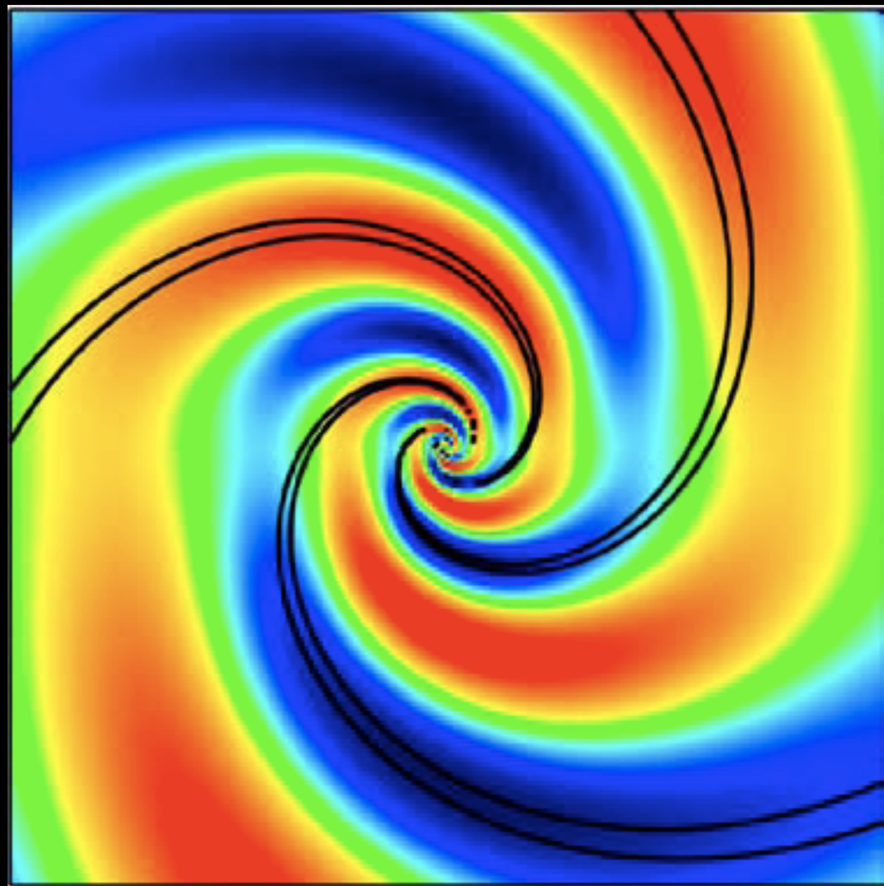
✓Is the gas creating SF related to the Torus?
- Intence SF simultanous with SMBH growth
- In standard Seyferts, BH growth is subsiquent to SF
- It depends on the Mgas supplied by the host and the timescale

❑How does the gas get from 1kpc to central 10s of pcs?

NGC 1097 with NACO
(Prieto +05)

Slow ordered inflow of gas
along spiral arms

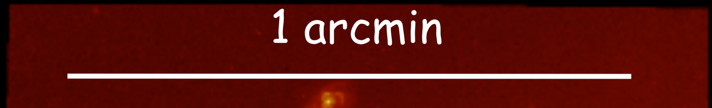


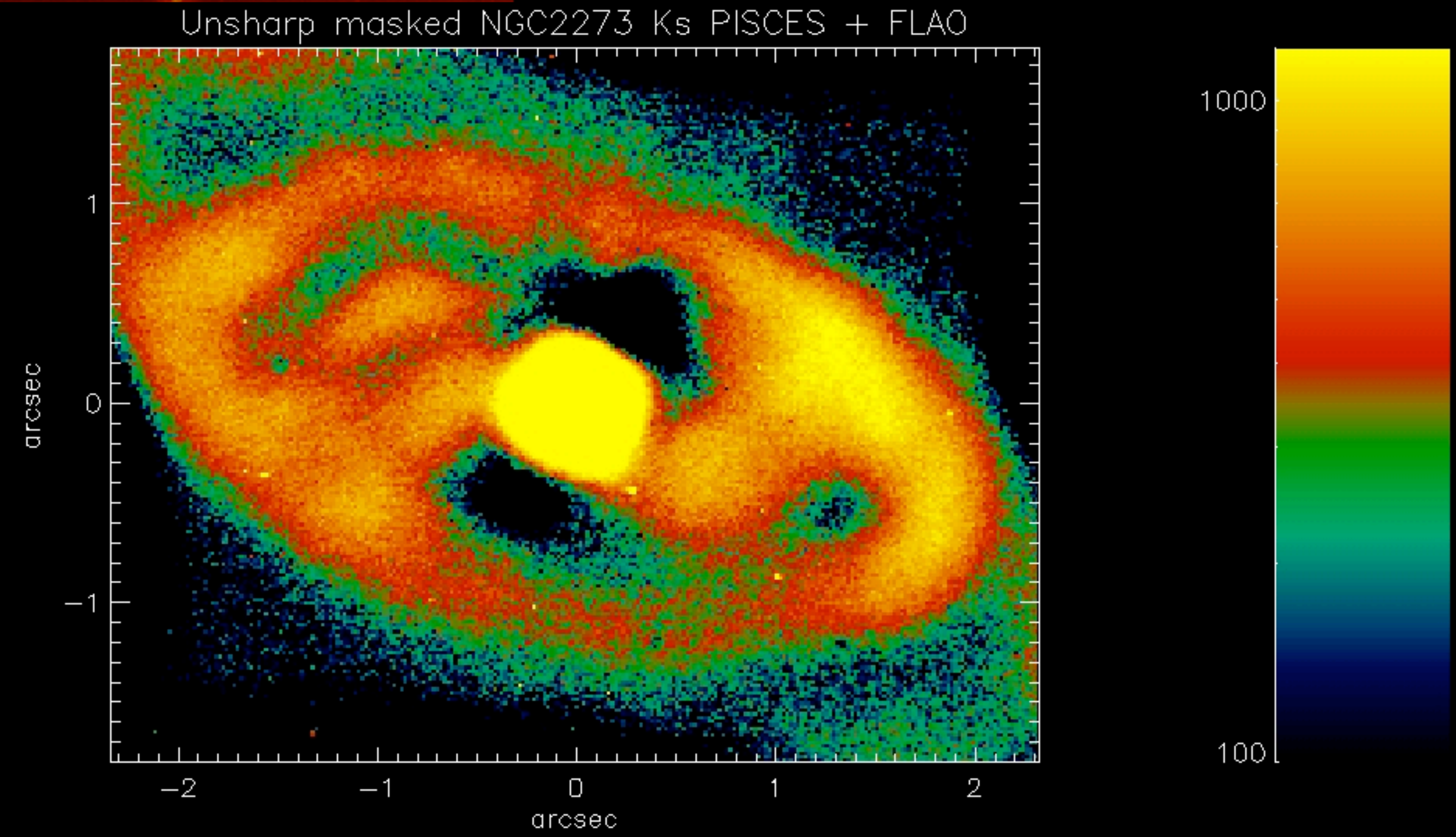


A LINER/Sy 1 with
extremely faint AGN

Maciejewski 04, Davies +09

NGC2273

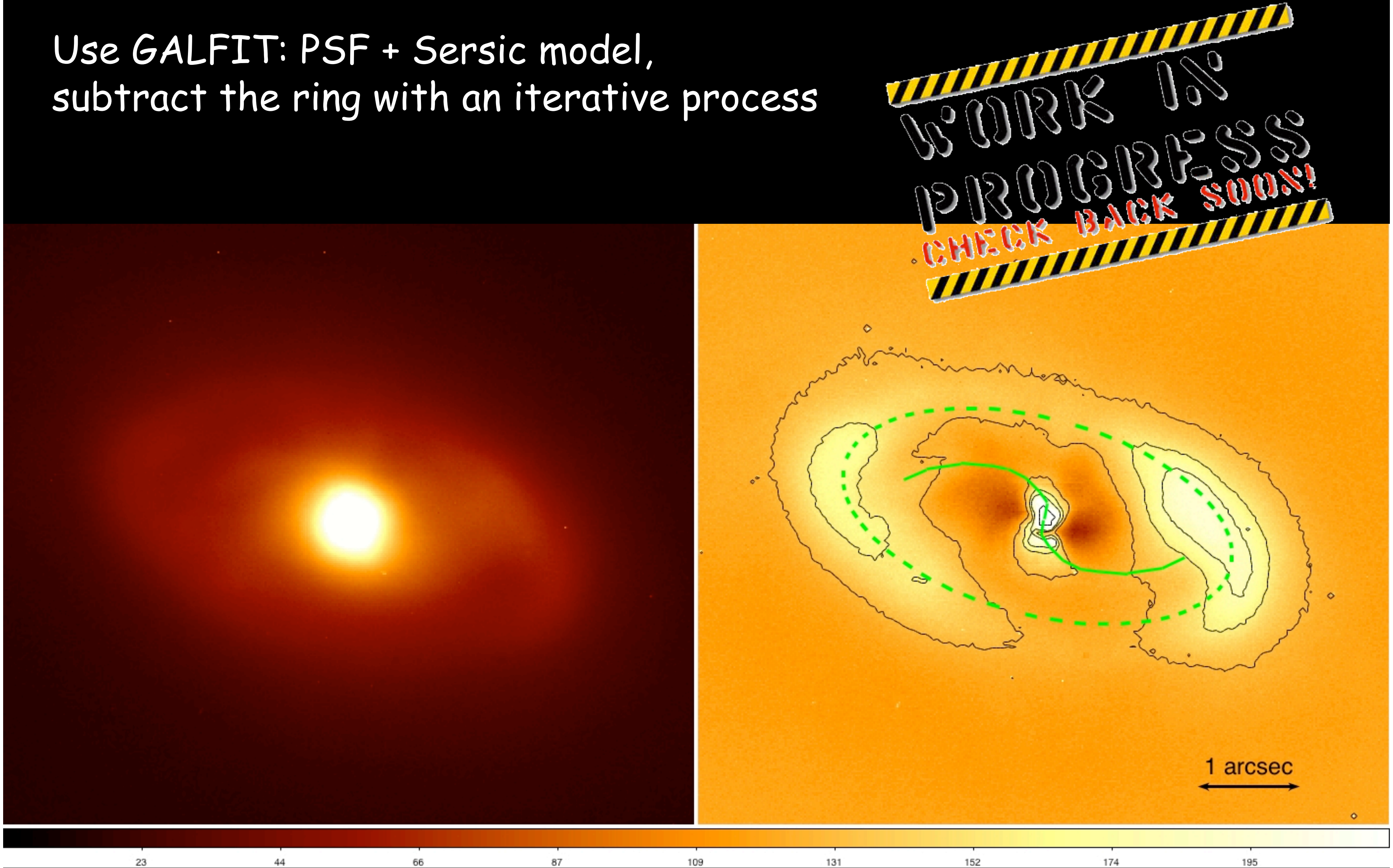




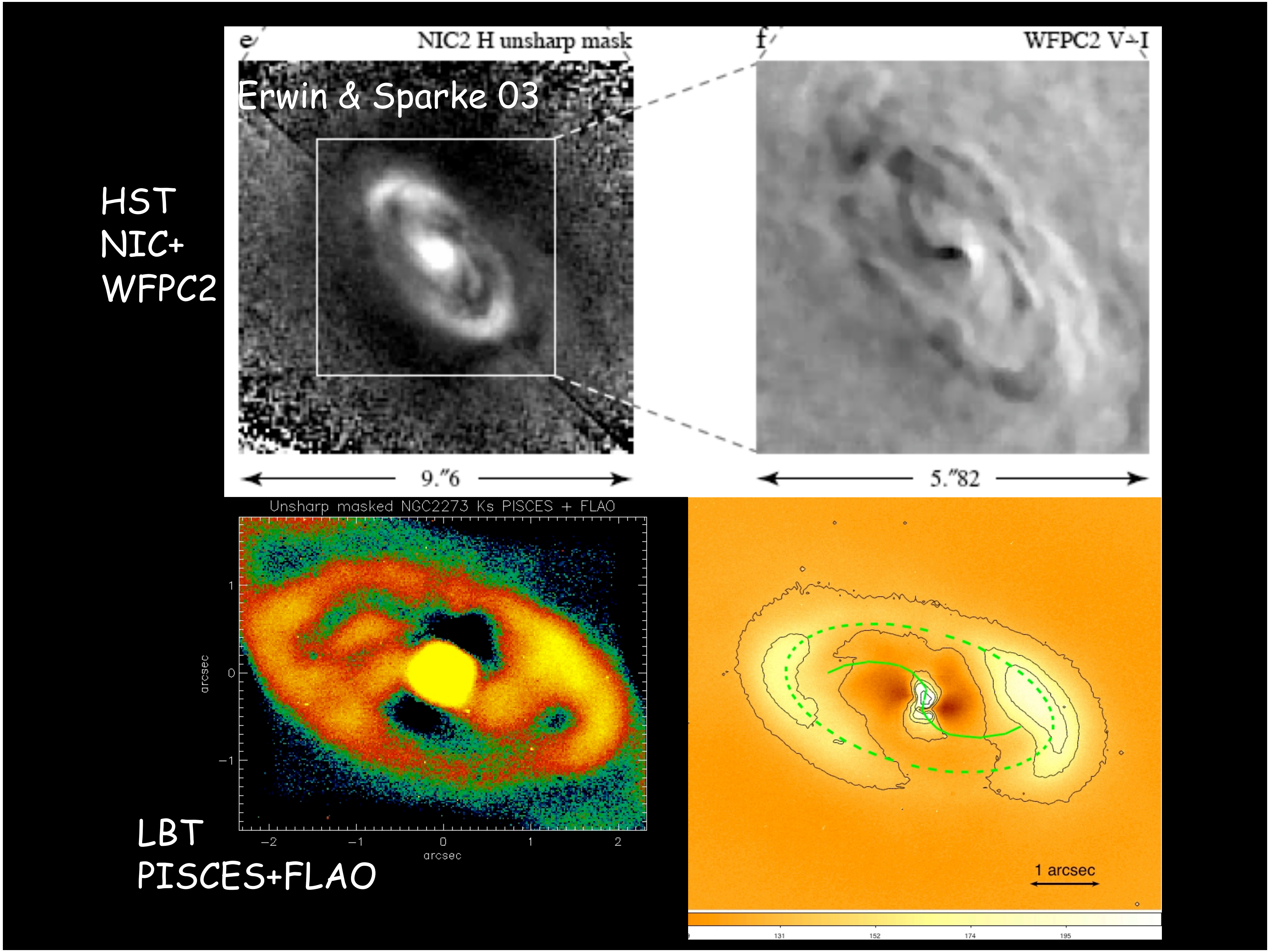
AO guiding on the AGN (R mag 14)
SR~10-20%
Spatial resolution ~100 mas

A Seyfert 2 active nucleus hosted in nearby (D_L~26 Mpc) SBa galaxy

Use GALFIT: PSF + Sersic model,
subtract the ring with an iterative process



pc scale = 130 pc/arcsec


HST
NIC+
WFPC2
e
NIC2 H unsharp mask
Erwin & Sparke 03
9.″6
f
WFPC2 V−I
5.″82
Unsharp masked NGC2273 Ks PISCES + FLAO
arcsec
arcsec
LBT
PISCES+FLAO
1 arcsec
131
152
174
195

Questions... and (perhaps) some answers

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✓Is the gas creating SF related to the Torus?
- Intense SF simultaneous with SMBH growth
- In "standard" Seyferts, BH growth is subsequent to SF
- M_{gas} supplied? T_{sup}?

✓How does the gas get from 1kpc to central 10s of pcs?
-Slow order inflows along spiral arms
-Other methods?