Infrared Spectroscopy of AGN

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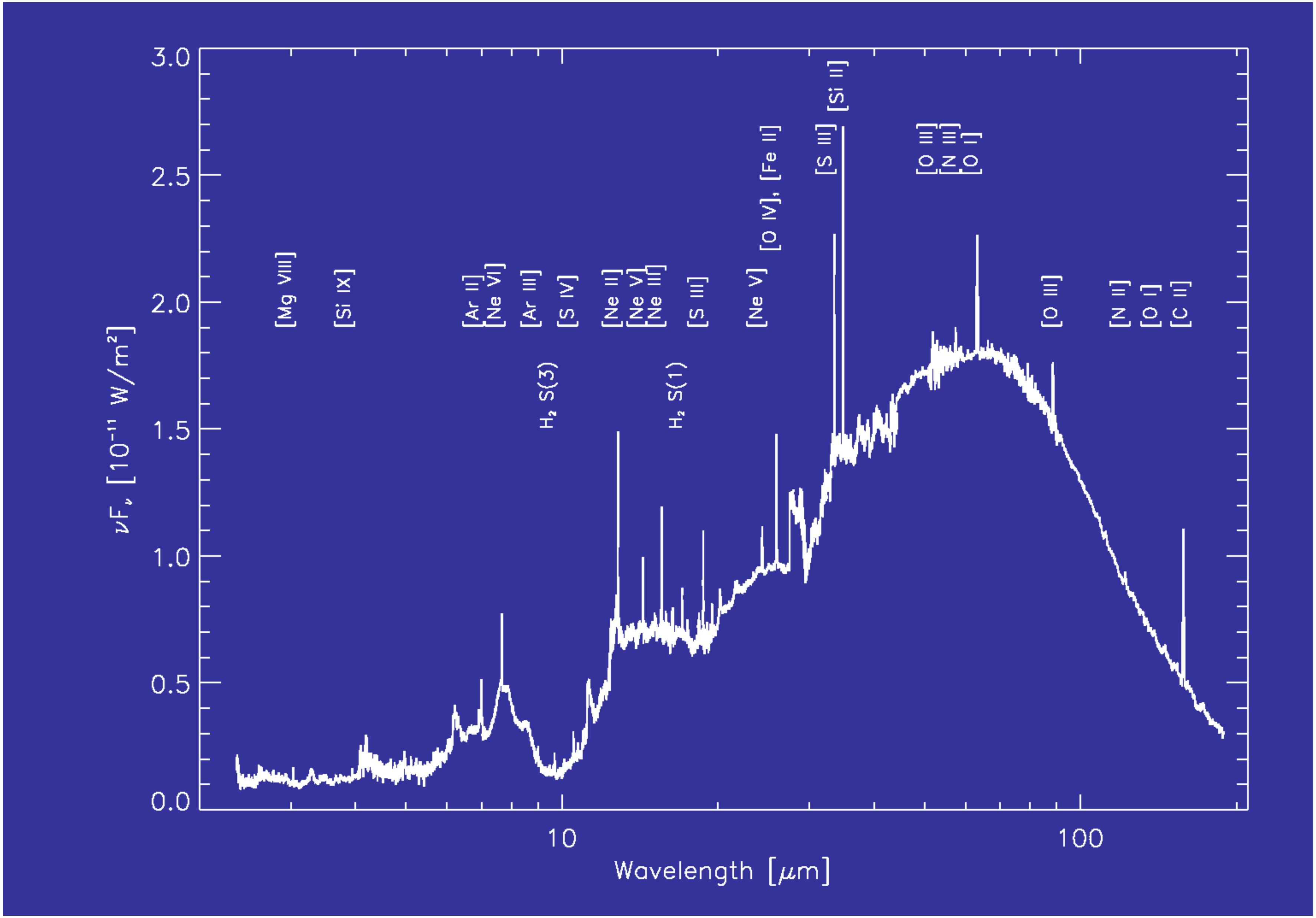
Scope

- Tools & results of mid-IR high and low resolution spectroscopy of AGN
- A case study of AGN-starburst coexistence: NGC 6240
- Probing obscuring matter by infrared BLR observations

Here: Infrared = 3-200μm … mostly a tour of ISO results

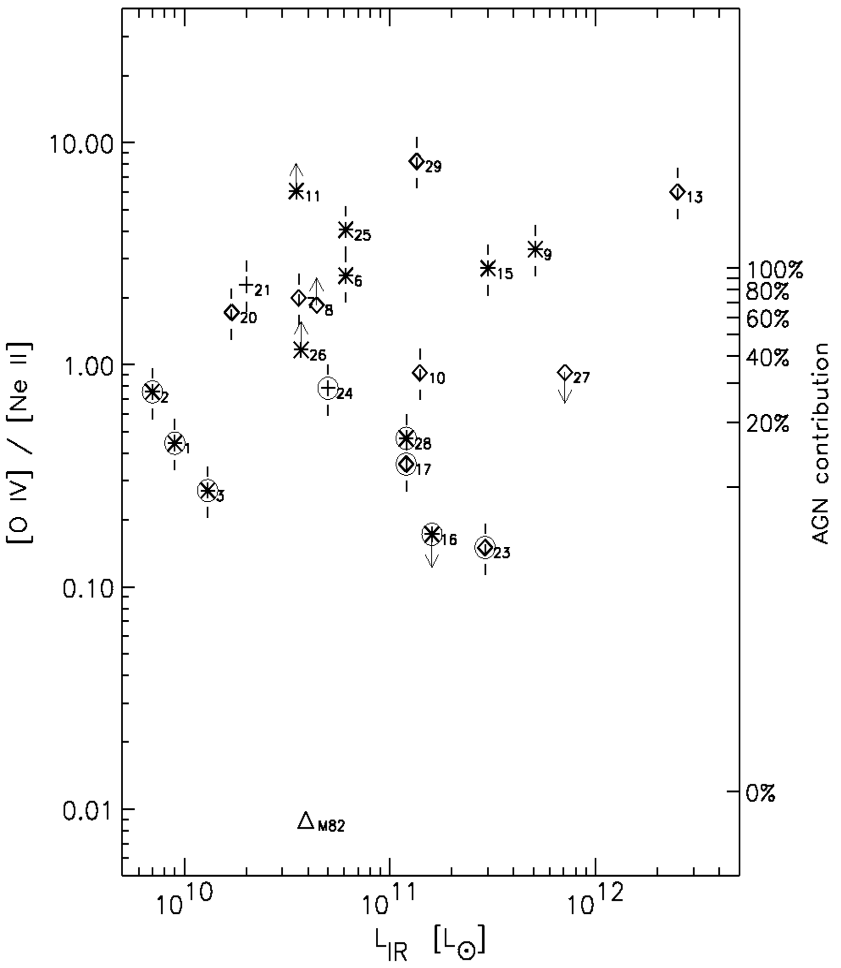
(Almost) all diagnostics in one objects: The Circinus galaxy



Fine-structure line diagnostics (1)

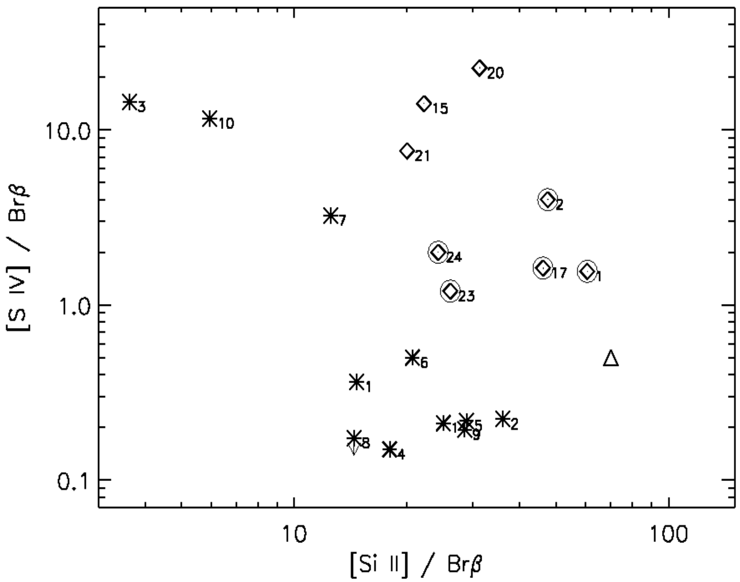
[OIV]: AGN Narrow Line Region
[NeII]: Star formation or AGN NLR

[OIV]/[NeII] AGN tracer in obscured/mixed objects

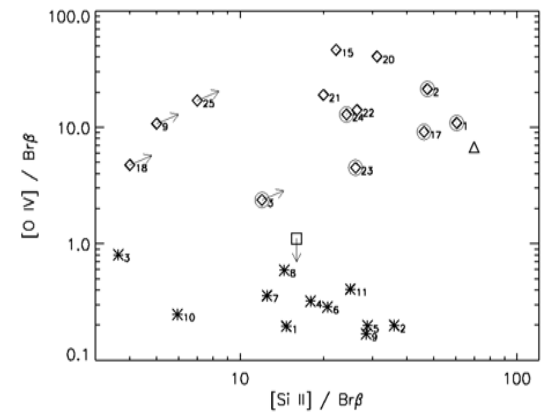


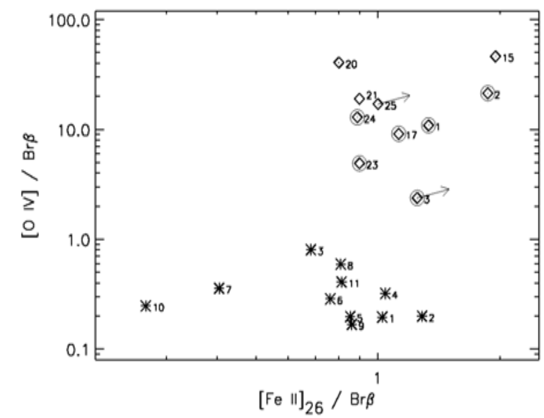
Sturm et al. 2002
Objects with PAH emission encircled

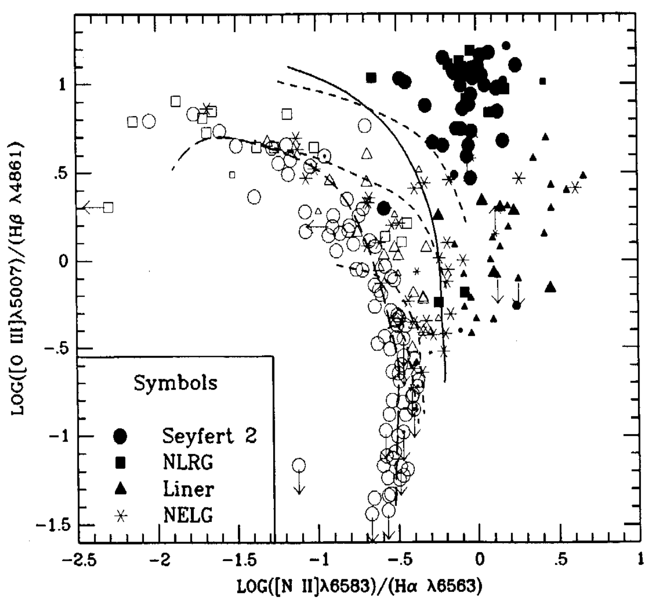
Fine-structure line diagnostics (2): Two-dimensional diagrams



IR diagnostic diagrams
Sturm et al. 2002 (AGN)
Verma et al. 2003 (Starbursts)

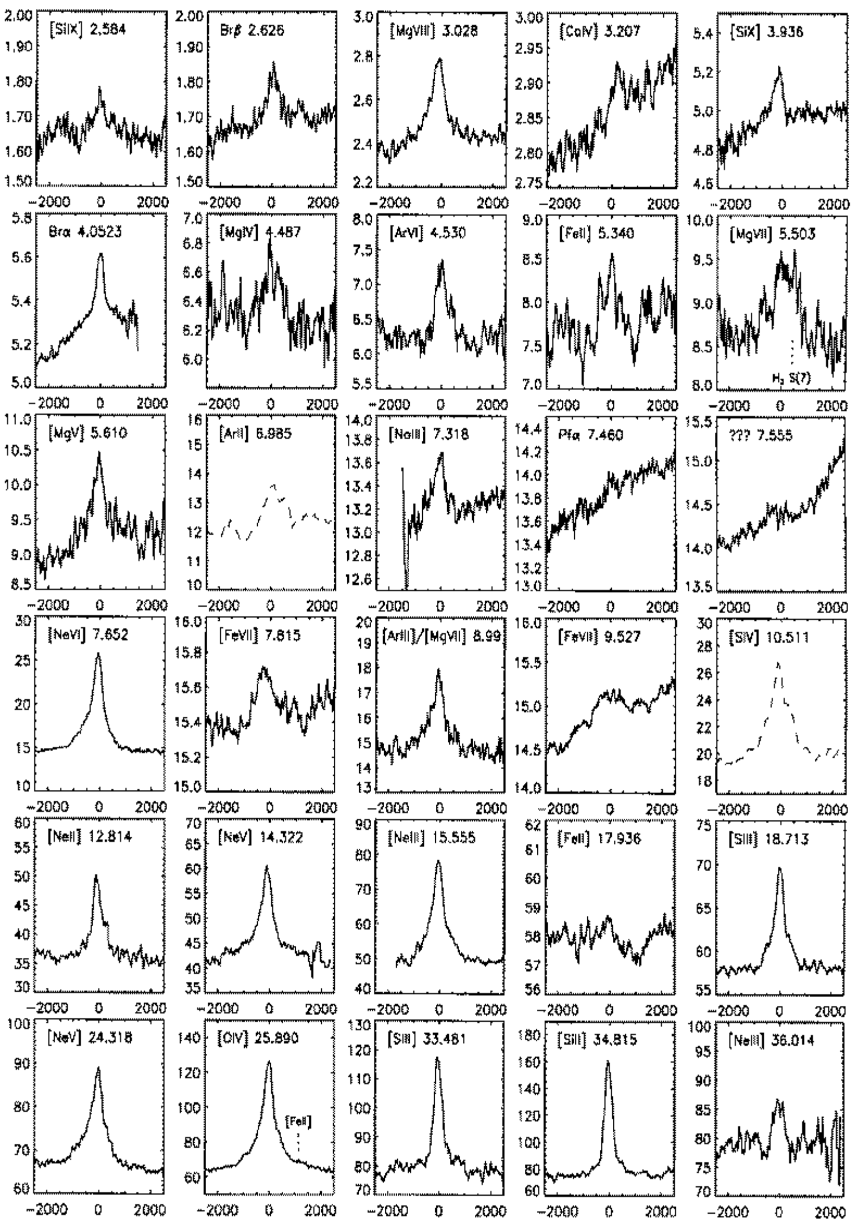


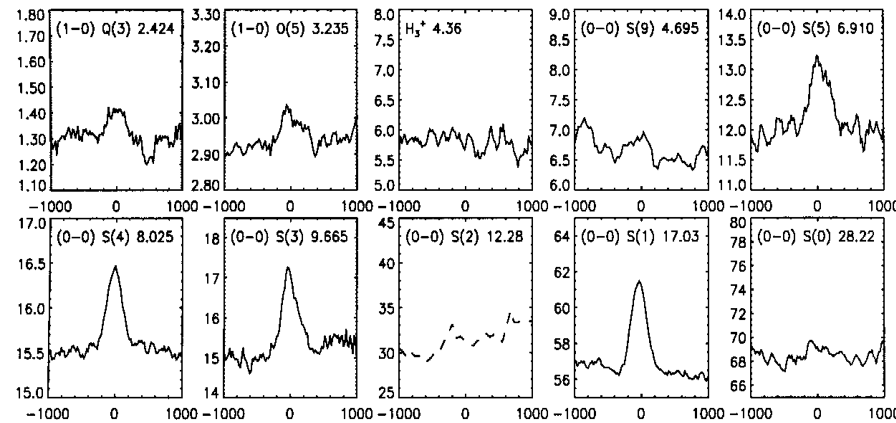


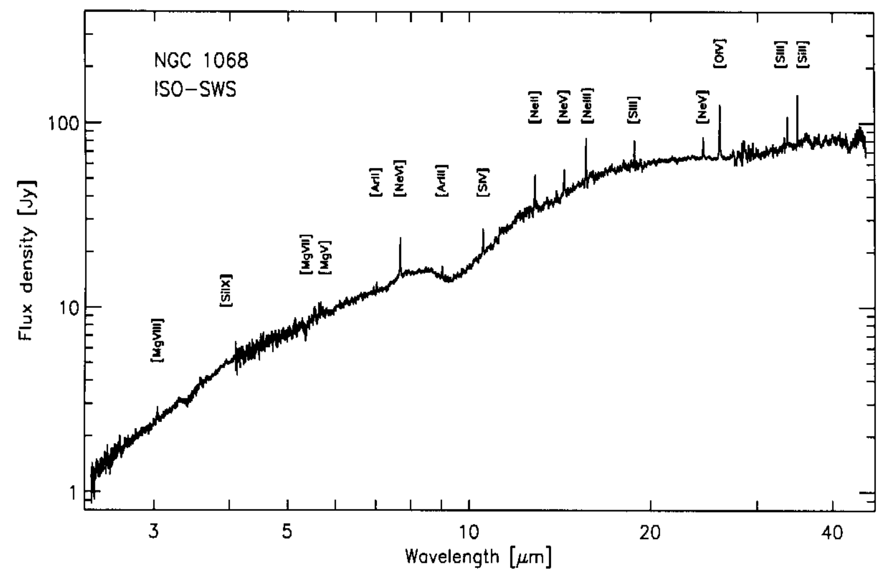


Veilleux & Osterbrock 1987:
Optical classification HII vs. AGN

AGN emission lines: NGC1068

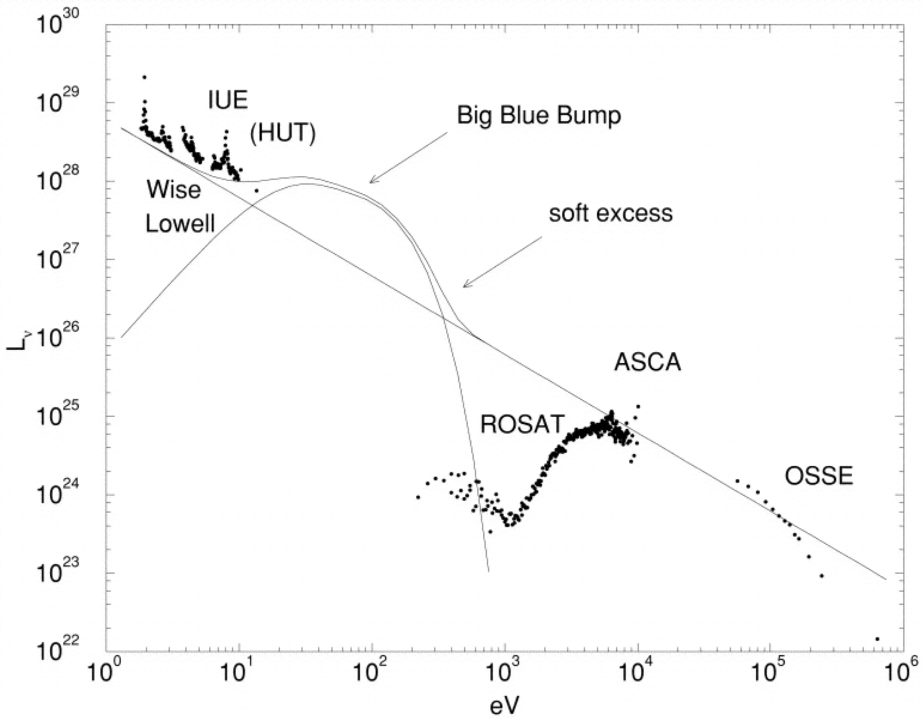


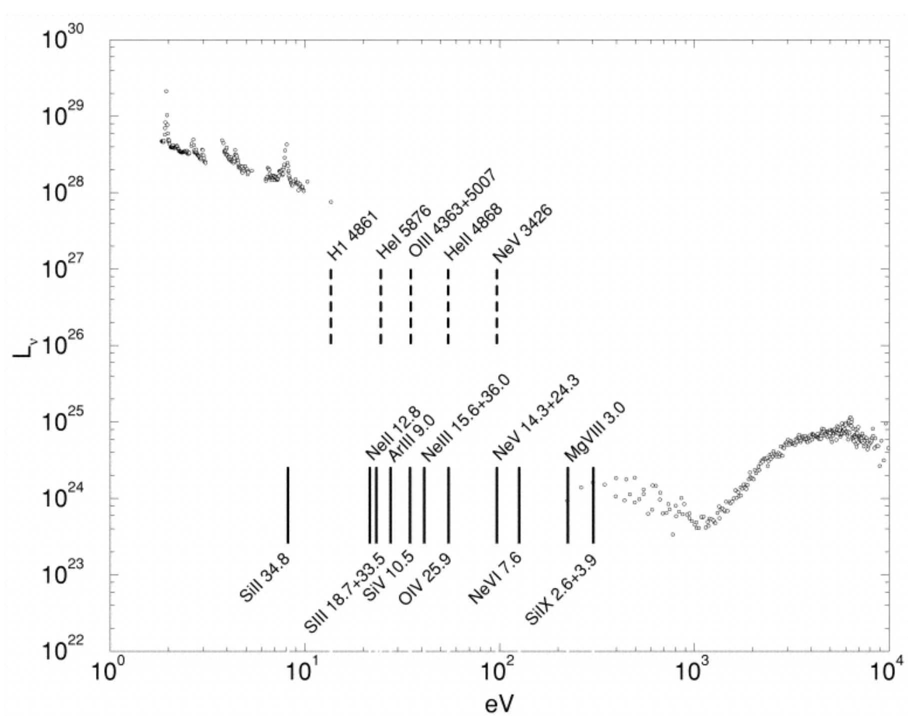




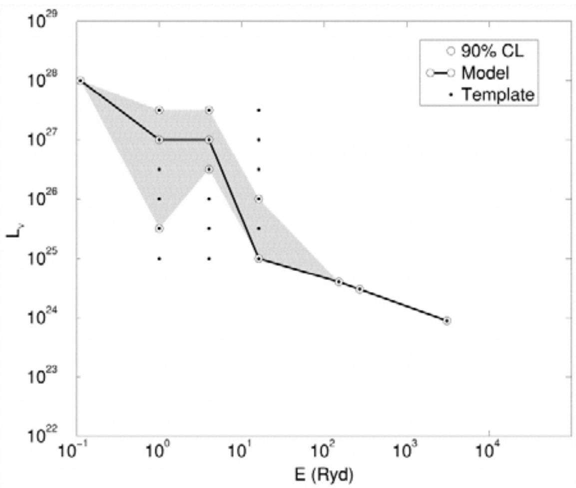
Lutz et al. 2000, ApJ 536, 697

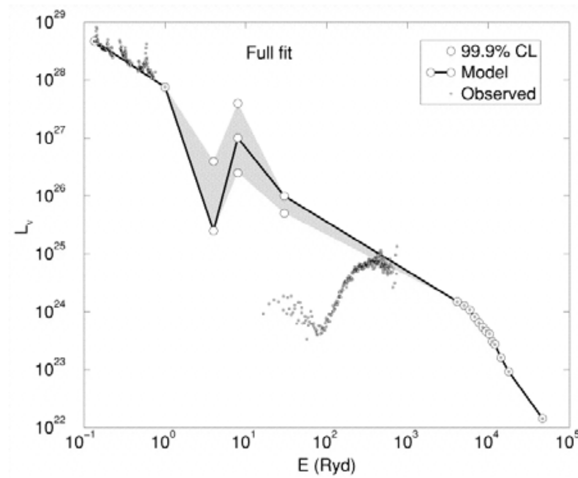
Reconstructing the ionizing SED?

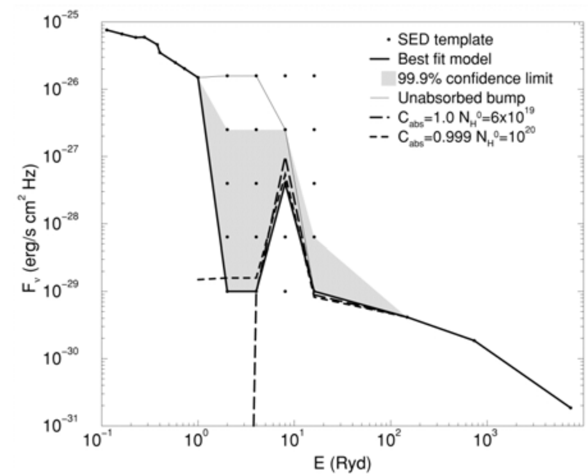




(Absorbed) big blue bump?







Circinus, NGC 4151, NGC 1068: Moorwood et al. 1996, Alexander et al. 1999,2000

Plausible … but not unique!

Satisfactory fits with different SEDs when introducing additional assumptions, e.g.:

Matter bounded clouds: Binette et al. 1997

Density distribution, metallicities: Oliva et al. 1999

Multicloud models: Martins et al. 2003

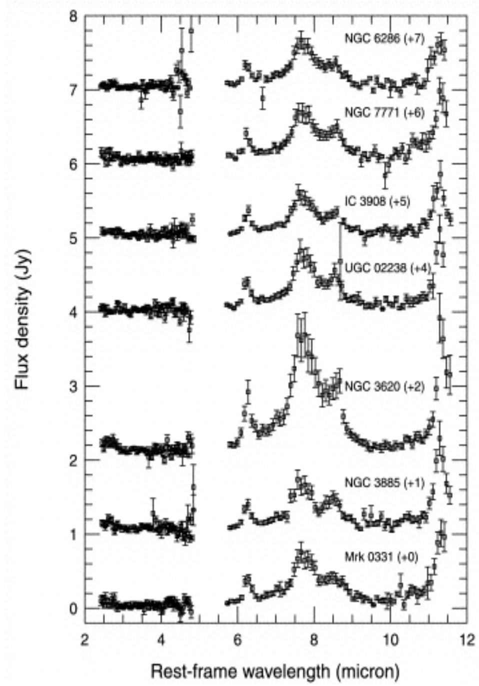
Shocks: Contini et al. 1998, 2002

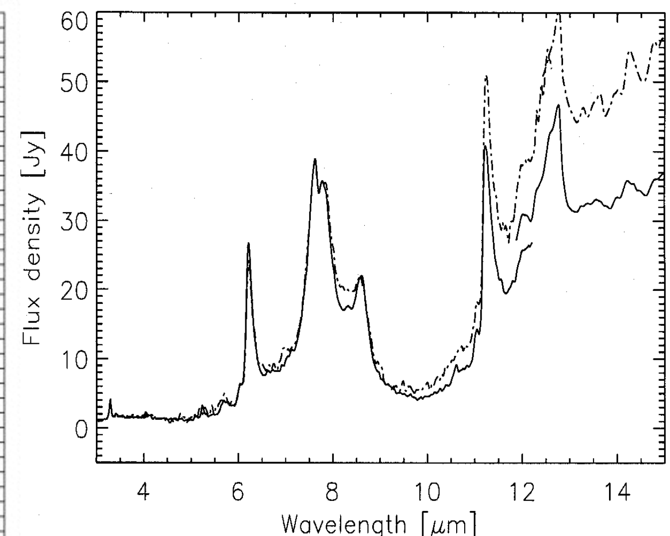
Mid-IR low resolution diagnostics

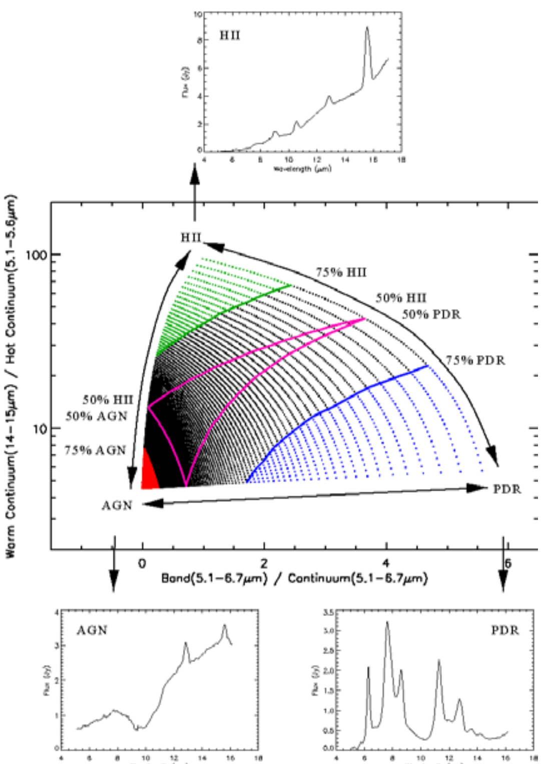
Components of mid-infrared emission:

- Aromatic (‘PAH’) features
- Steep (‘very small grain’) HII continuum
- Hot AGN dust
- Starlight (significant only for ellipticals)

… and Obscuration and ices!





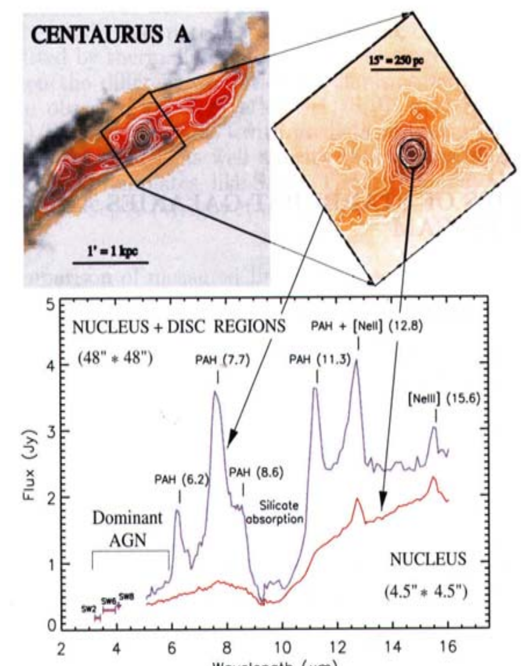


Normal galaxies: Helou et al. 2000

M82 vs. NGC 253: Sturm et al. 2000

Cen A: Mirabel et al. 1999

Diagram: Laurent et al. 2000



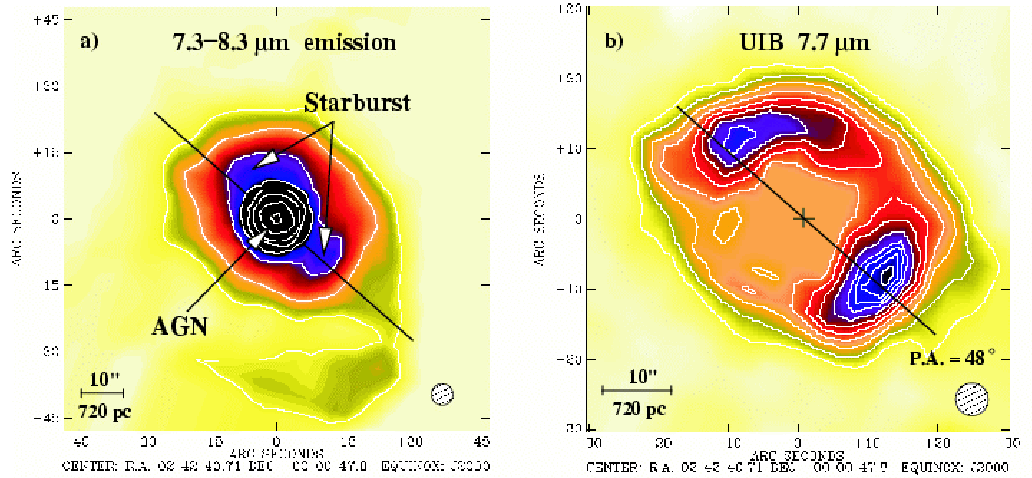
The issue of PAH 'destruction'

- AGN have low PAH equivalent widths,
- There are 'PAH-weak' molecular regions near AGN

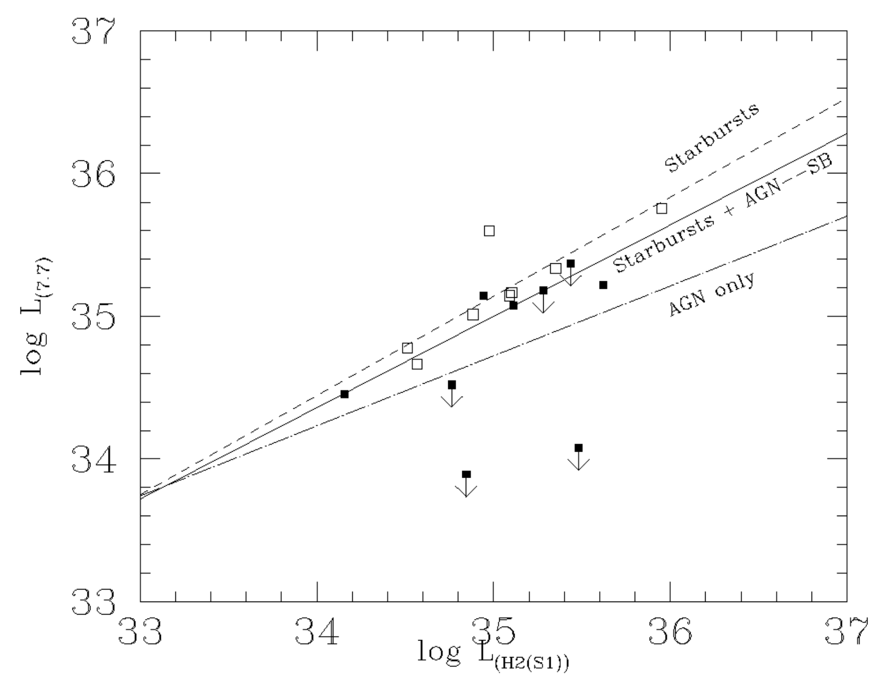
but

- What is the role of 'dilution' vs. 'destruction'?
- If destruction, what is the role of hardness vs. intensity?

- **Is there PAH destruction in intense starbursts?**

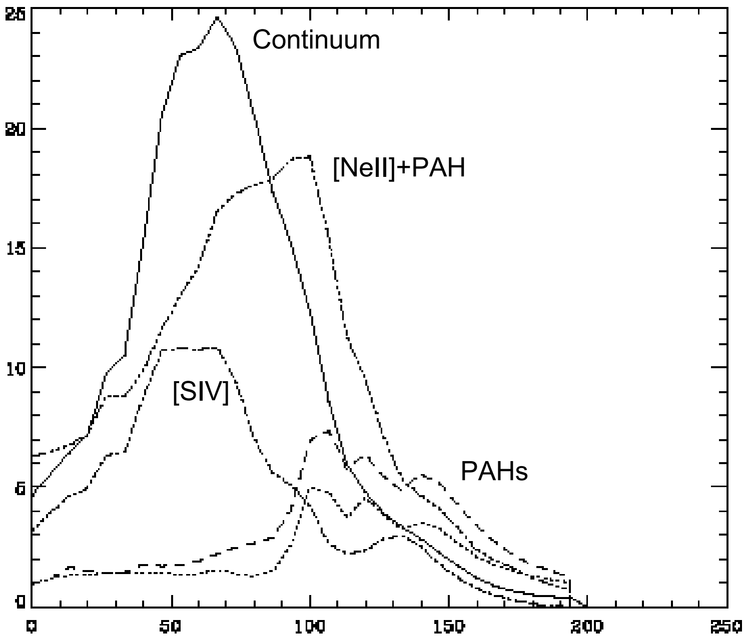


NGC 1068: Le Floc'h et al. AA 367, 487 (2001)

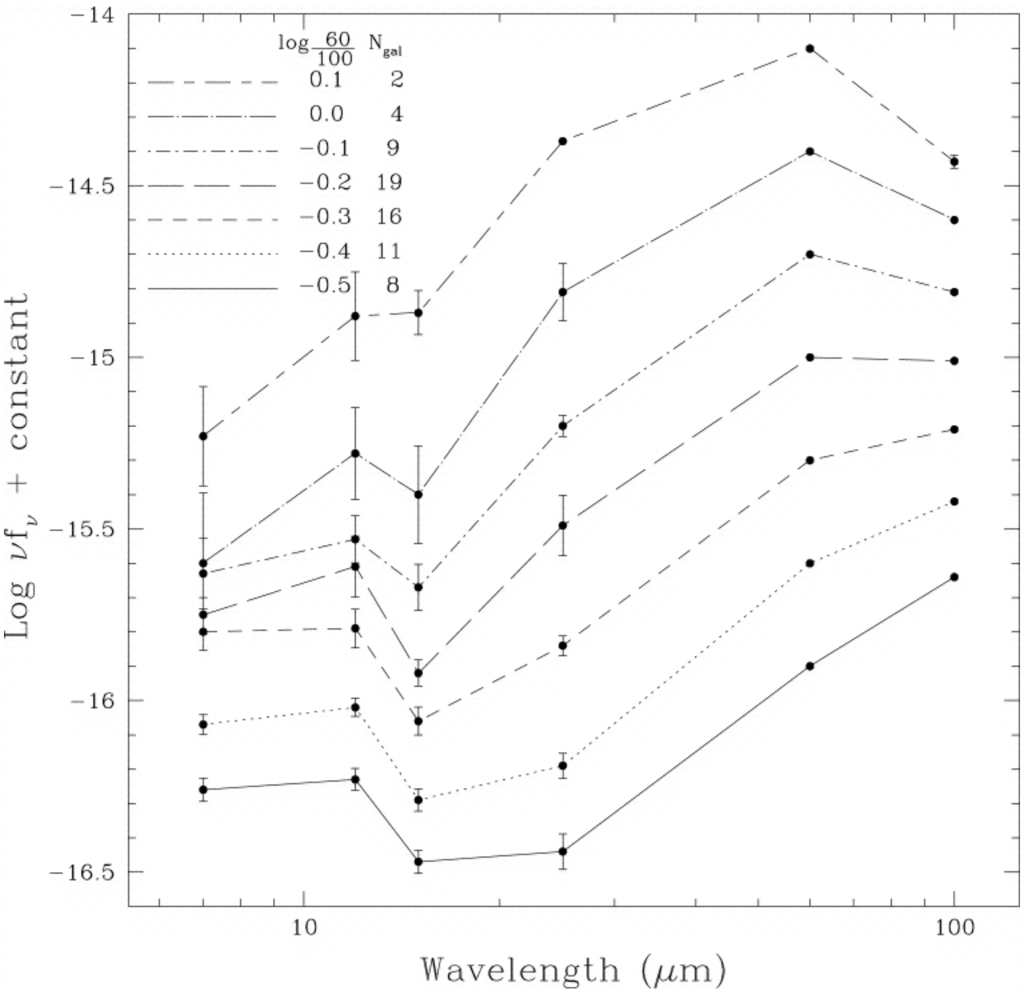


Rigopoulou et al. 2002

PAHs in intense starforming environments

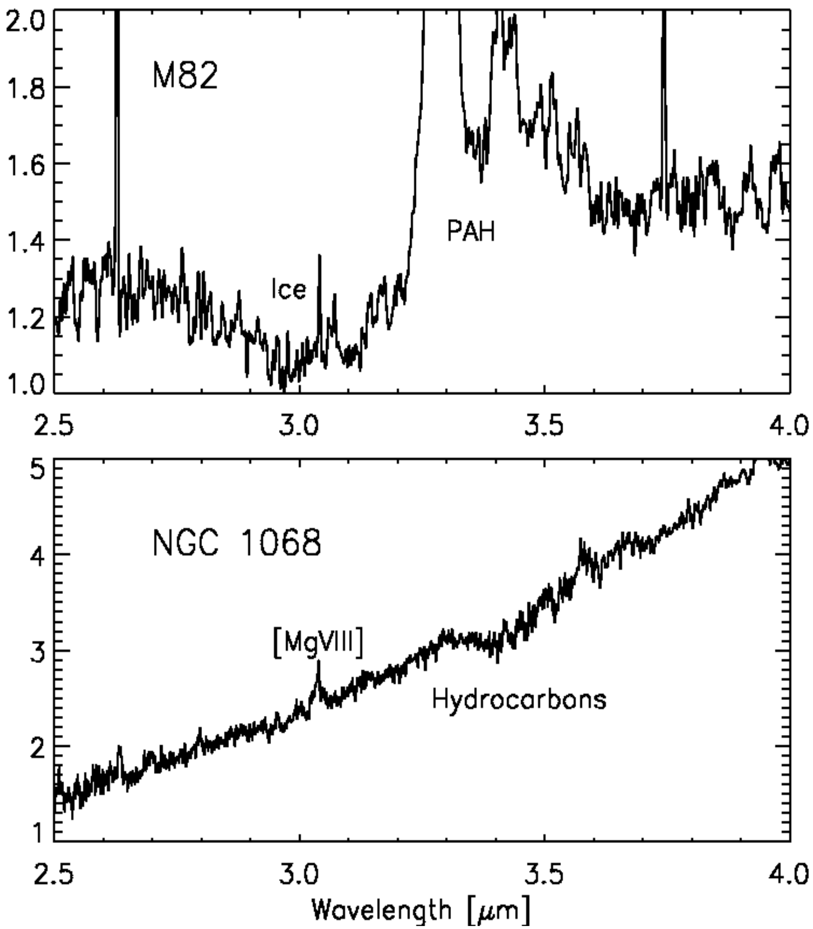


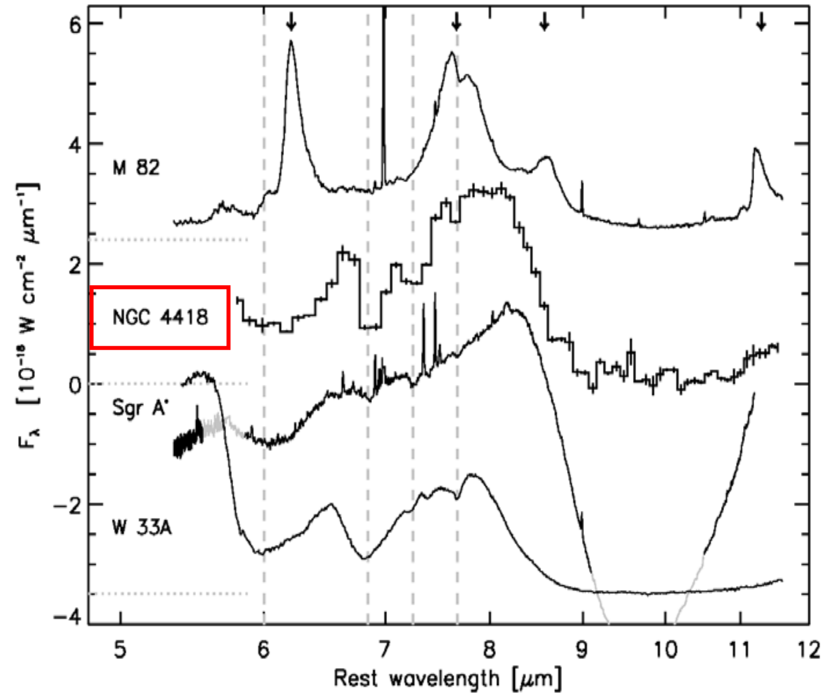
Cesarsky et al. 1996: radial cut through M17



Dale et al. 2001: Galaxy SEDs grouped by large grain Temperature

Extragalactic ices: A not so simple story?



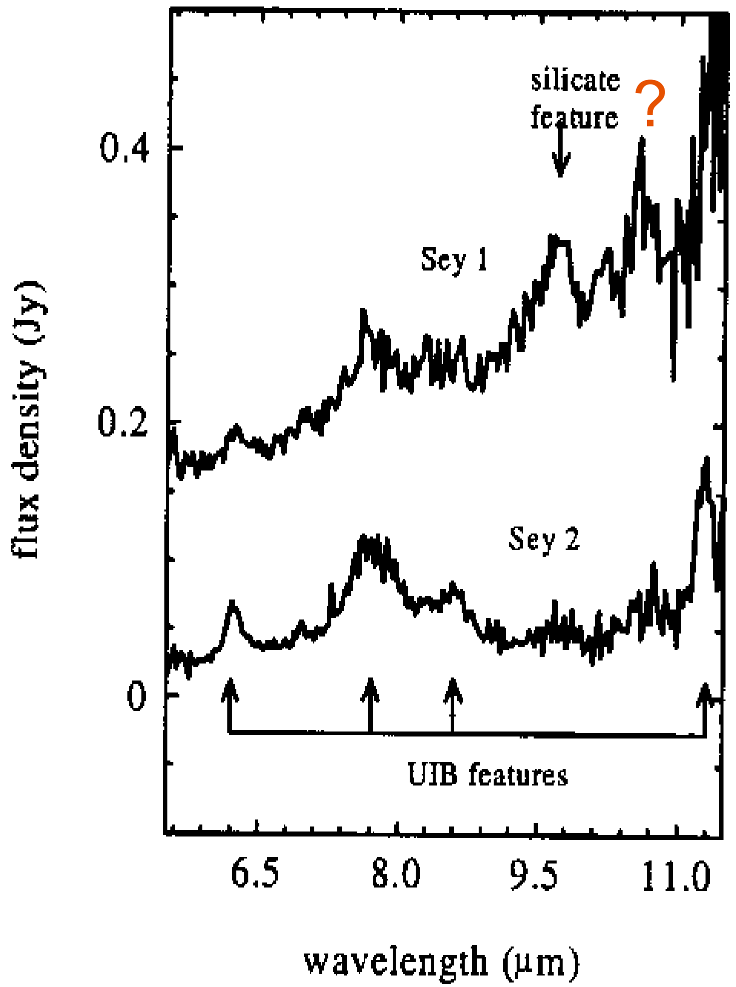


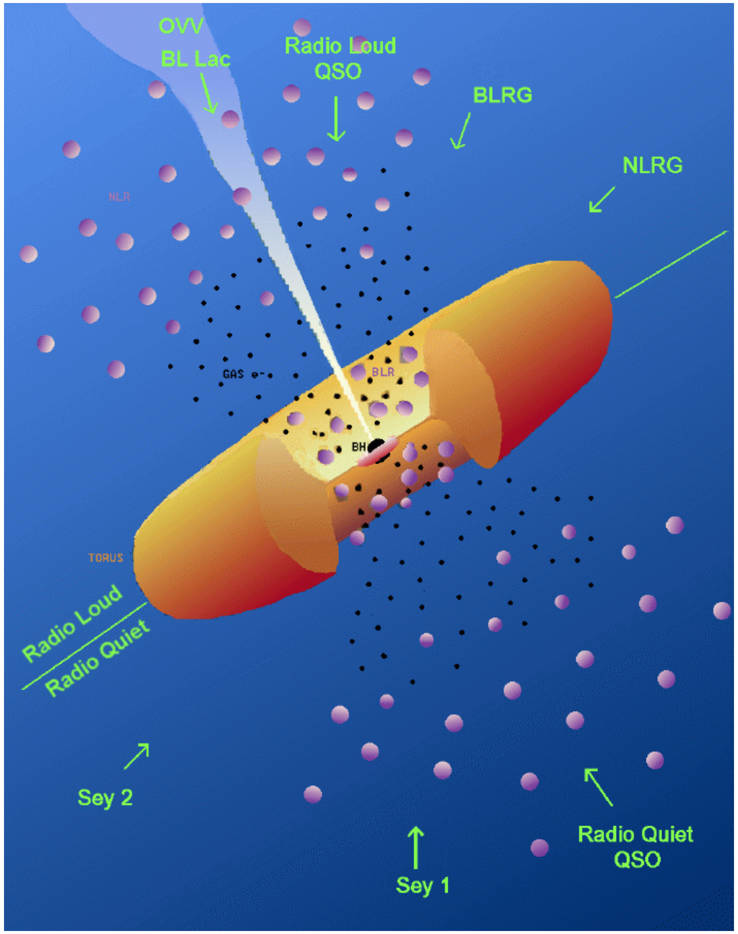
Survey of the ISO archive: 18 of 103 PHT-S spectra have some indications for ice absorption

Largest incidence in ULIRGs (Gas & dust rich…)

Sturm et al. AA 358, 481 (2000)
Spoon et al. AA 357, 898 (2000)
Spoon et al. AA 365, L353 (2001)
Spoon et al. AA 385, 1022 (2002)

AGN: Unification, continuum and PAH features

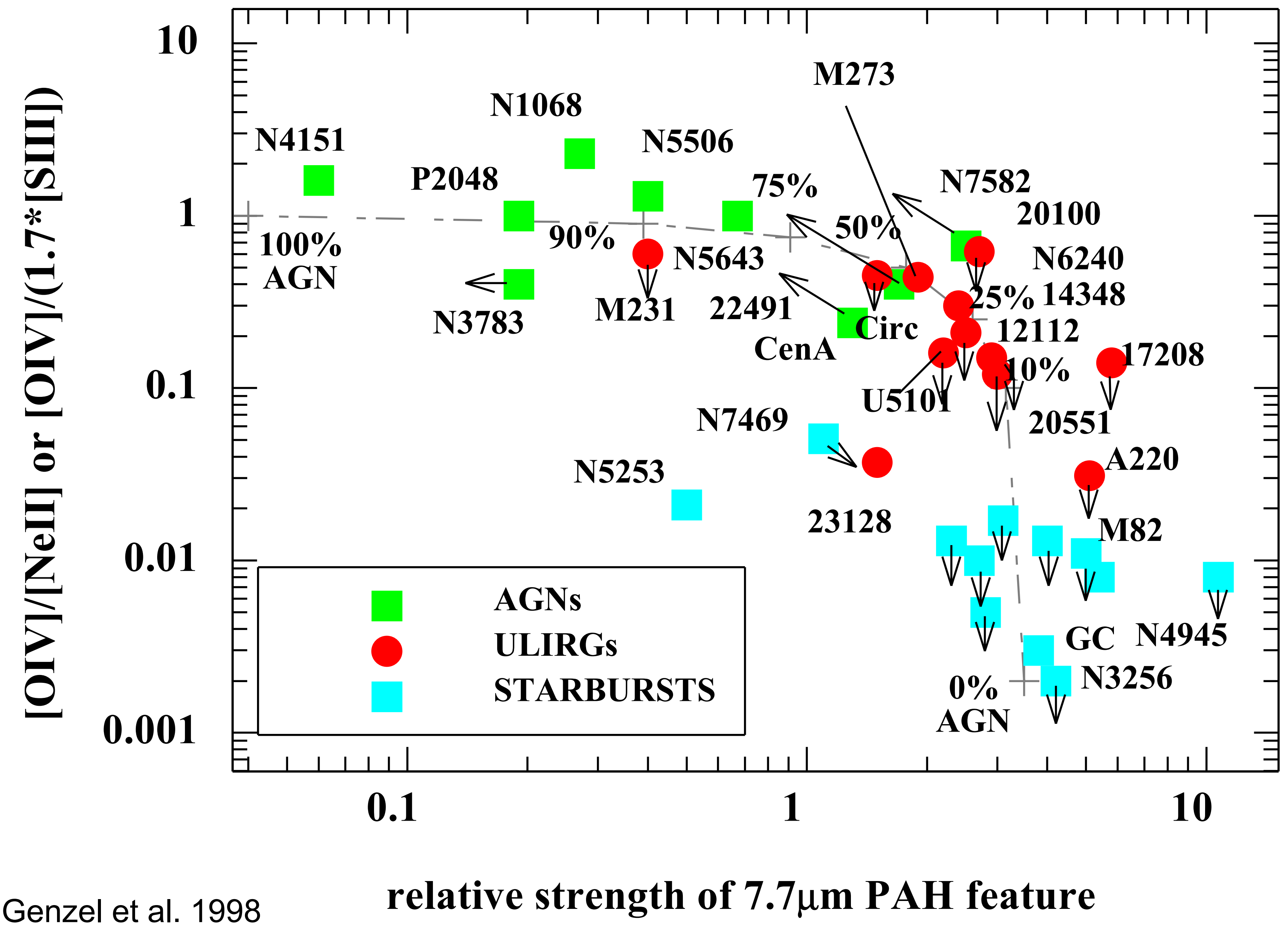




Urry & Padovani

Orientation effects on continuum of CFA Seyferts: Clavel et al. 2000

Starburst-AGN discrimination: ISO diagnostic diagram



Genzel et al. 1998

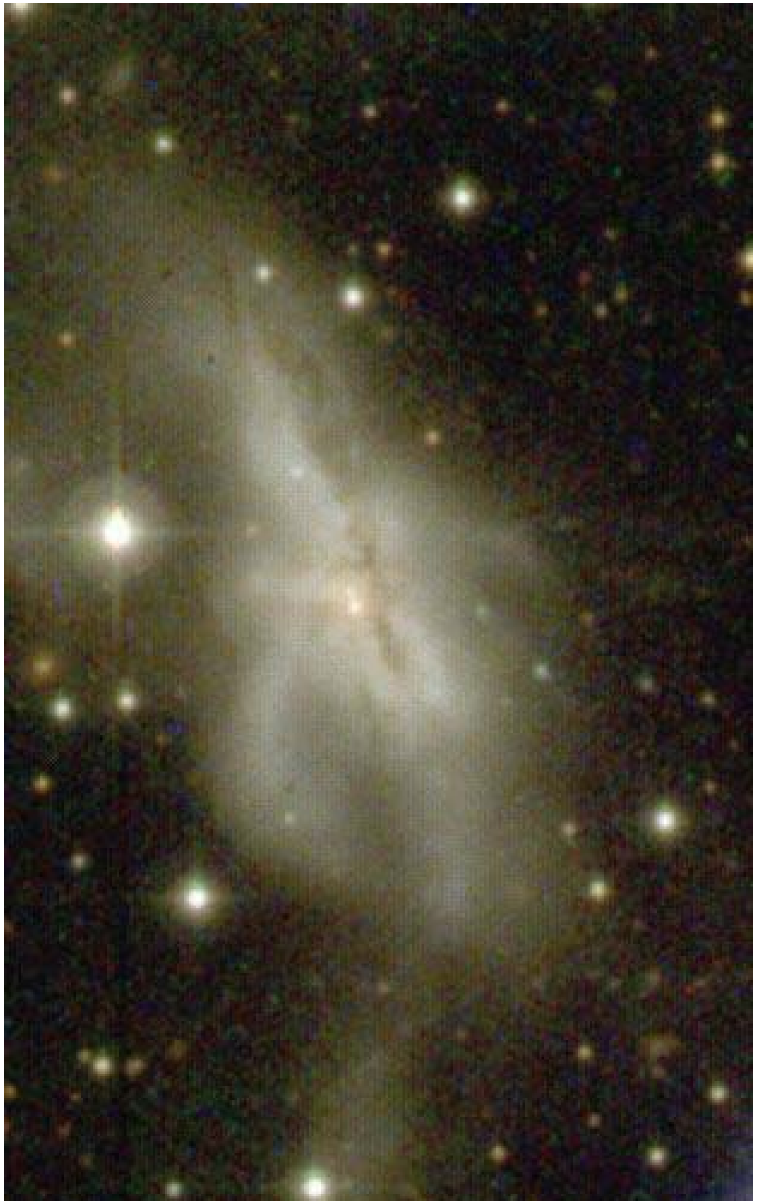
A case study: NGC 6240

Nearby luminous infrared galaxy with star formation and AGN – a key object for studying (U)LIRGs and AGN-starburst coexistence

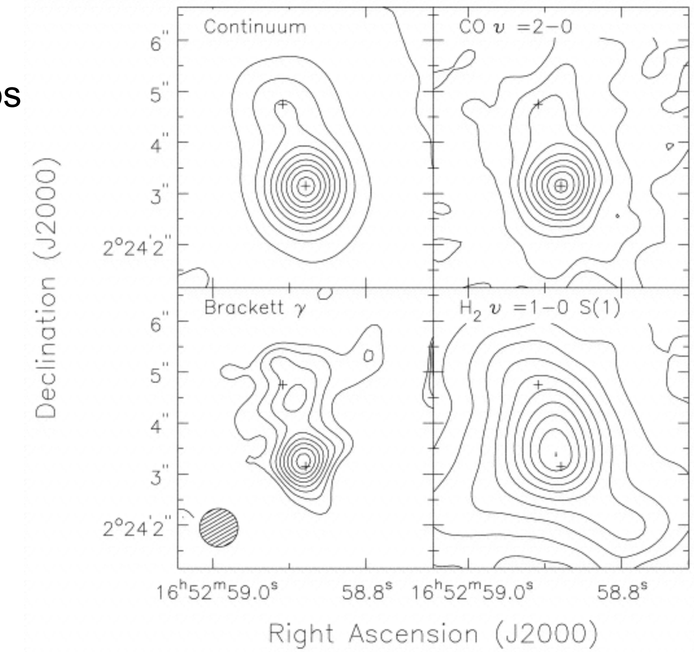
What powers (U)LIRGs?

Link between cosmic X-ray and infrared backgrounds?

An intermediate stage merger

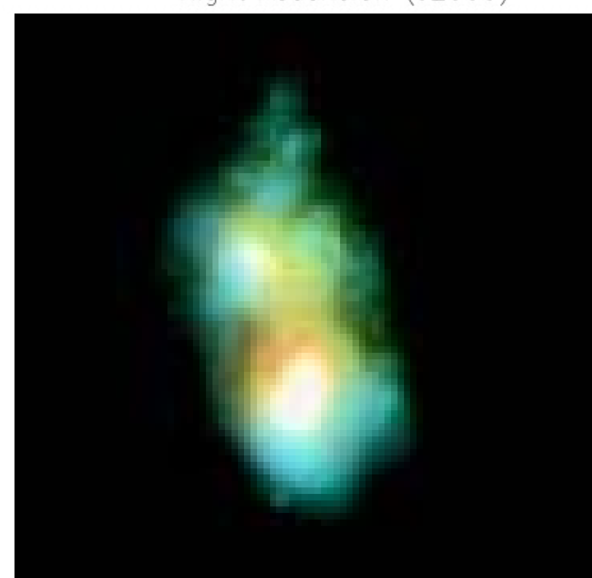


Tecza et al. 2000
near-infrared maps



Keel et al.
Optical image

Scoville et al. 2000
NICMOS K-band
image of the double
nucleus

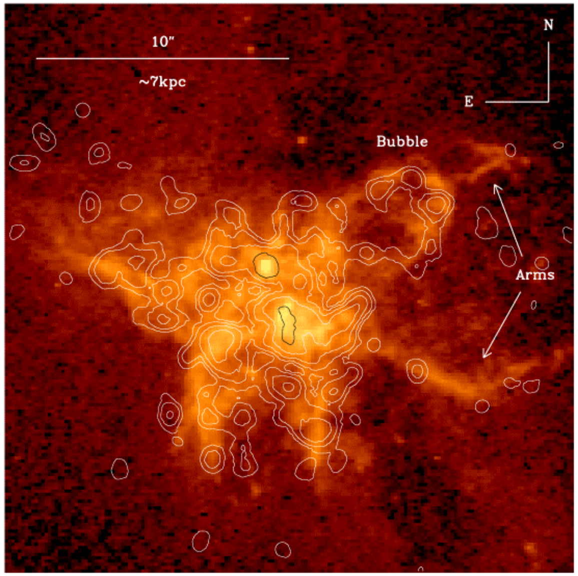


X-ray emission

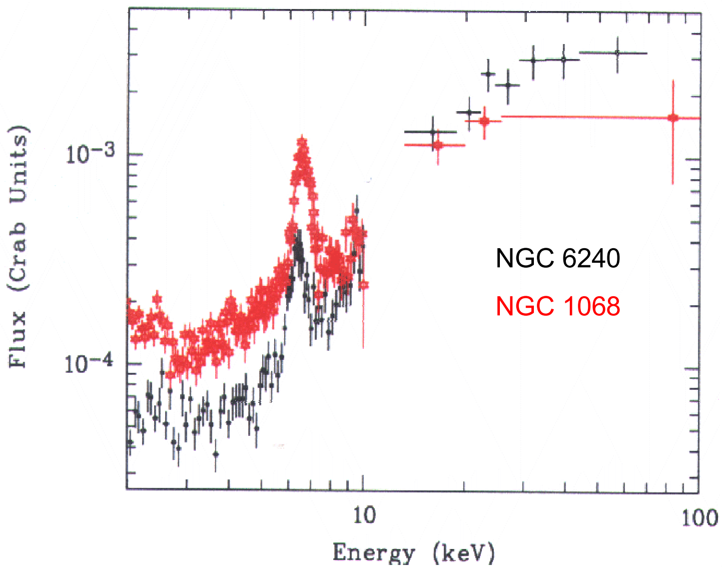
- Extended soft X-ray emission dominated by starburst superwind

- reflected AGN emission at 2-10keV with a fluorescent Fe line, direct AGN emission obscured at these energies. Two AGN!

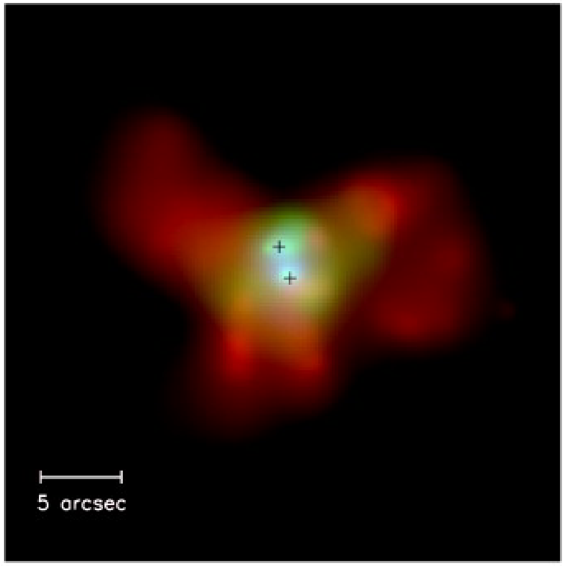
- Direct transmitted AGN emission seen at >10keV by Bepposax and RXTE



Lira et al. 2002

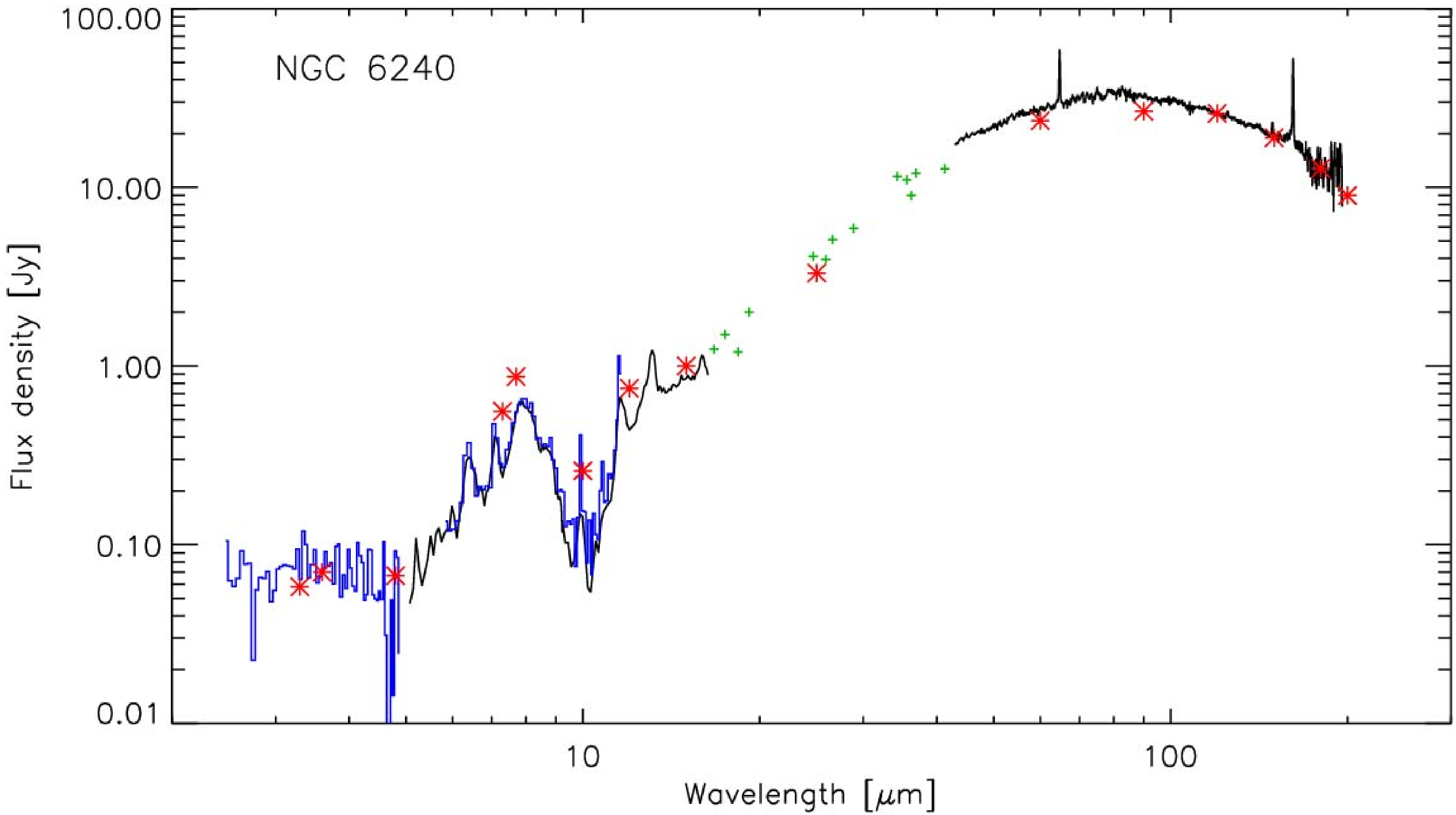


Vignati et al. 1999



Komossa et al. 2003

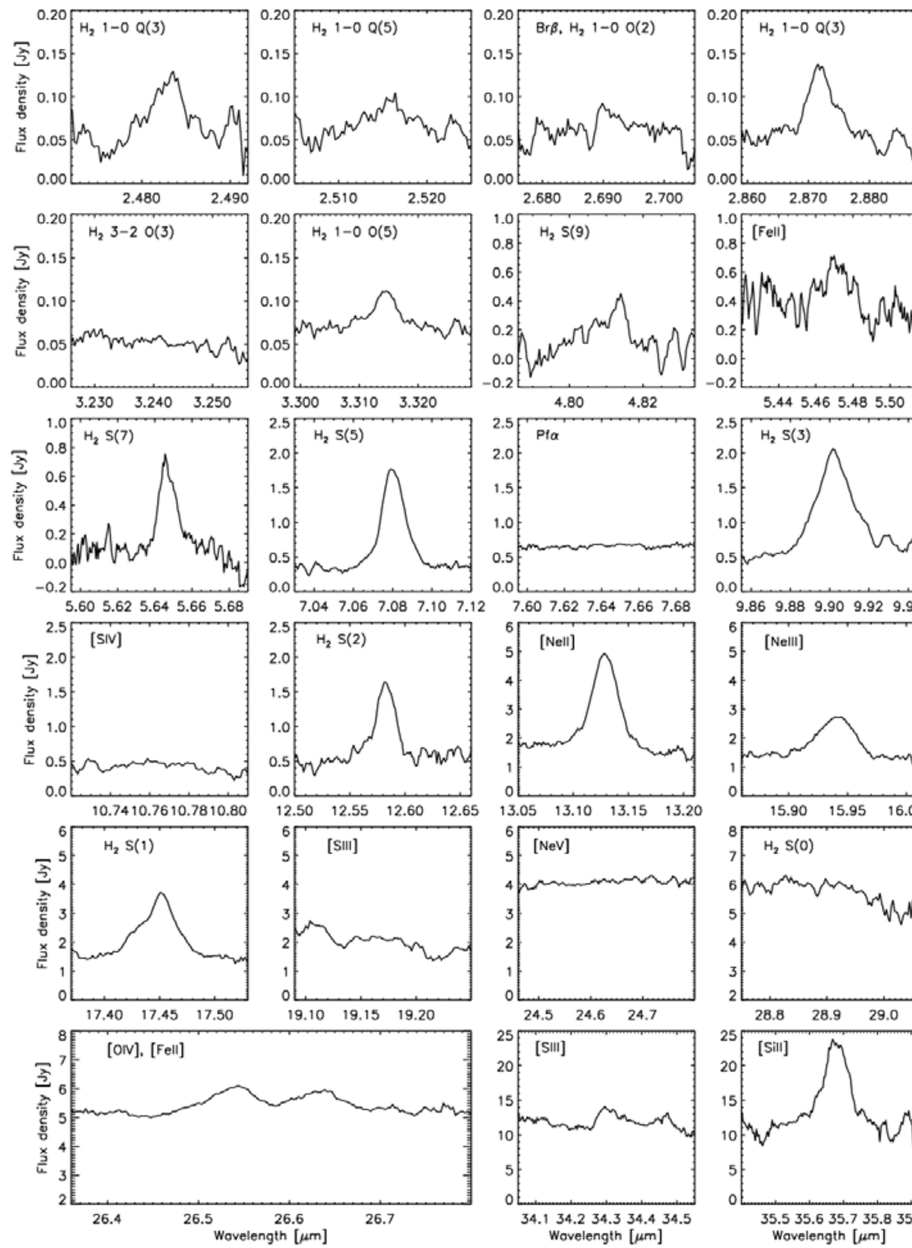
Collecting all ISO spectroscopy



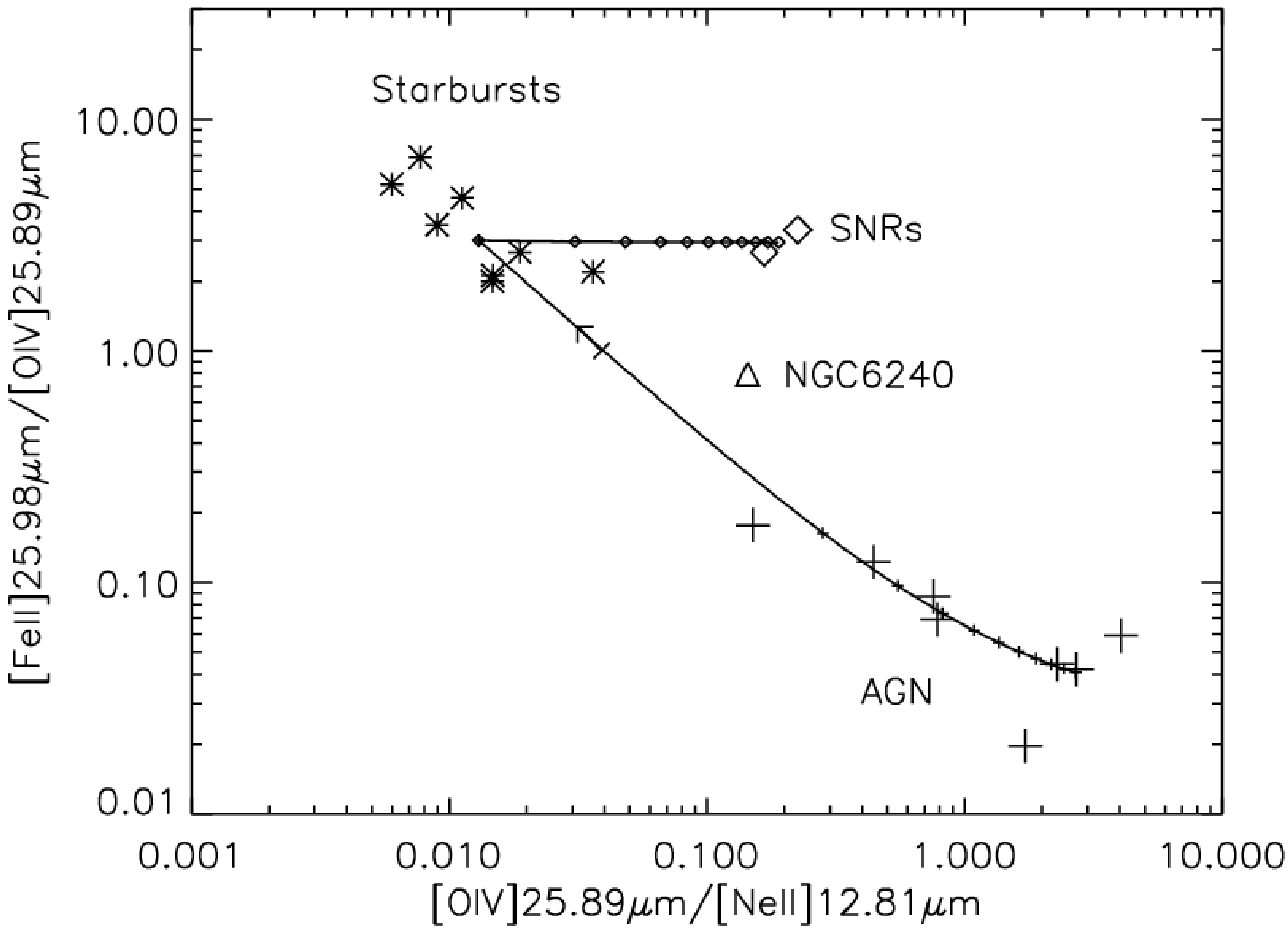
SWS spectra

- 1st order: Similar to starbursts
- Very strong H_2 lines
- [OIV] stronger than in normal starbursts
- SED also starburst-like

- Starburst [NeIII]/[NeII] ~ 0.2
- Starburst extinction not well constrained, but likely somewhat higher than in, e.g., M82



Strong [OIV] emission: mostly from an AGN



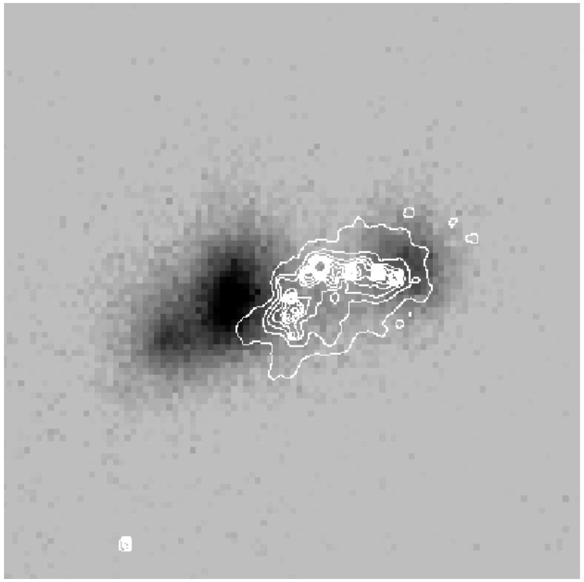
A mixed AGN+starburst system – How to be quantitative?

You can only quantify what is observed – some of the measures can be `lower limits' rather than measurements, in particular if obscuration is poorly constrained

⇒ Estimate starburst and AGN power from all available observational constraints, and try to find a balanced solution

The don'ts:

• Do not confuse detection and energetic dominance
• Do not introduce prejudices about what is unobserved
• Don't push the error bars to maximize/minimize either component



He 2-10 10μm (grey)
versus UV (contours)
Vacca et al. 2002

Models or templates?

Modelling of ratio observable/L_{IR} from first principles difficult in several cases – use starburst and AGN templates!

Directly relate observables to FIR emission

Main issues in use of templates:

• Aperture effects (large galaxies, IRAS fluxes!)

➢ careful object selection, use of proper instrument / aperture correction

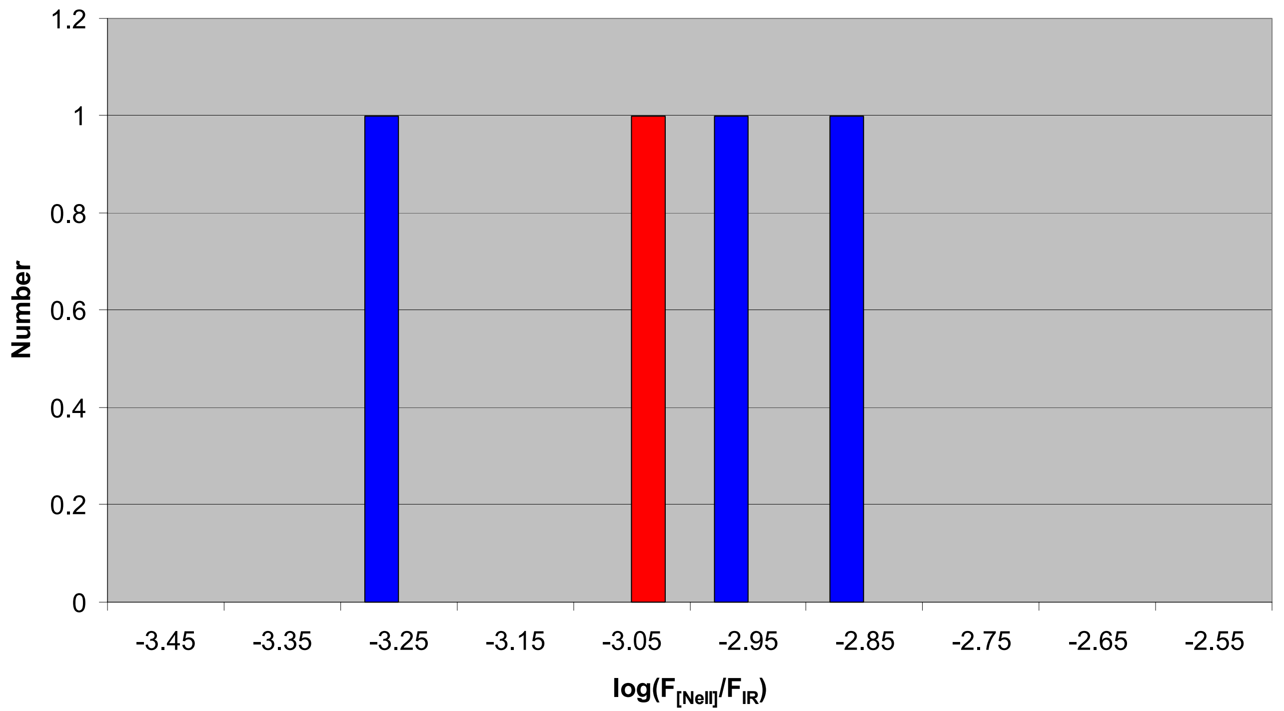
• Starburst activity in AGN templates?

➢ use of ISOPHOT database to remove AGN with significant PAH emission from comparison sample

Low-excitation starburst line emission

Ratio of [NeII] to FIR very similar (80%) to the one of starbursts of similar excitation

Uncertainty factors: Extinction correction, metallicity, (AGN contribution)



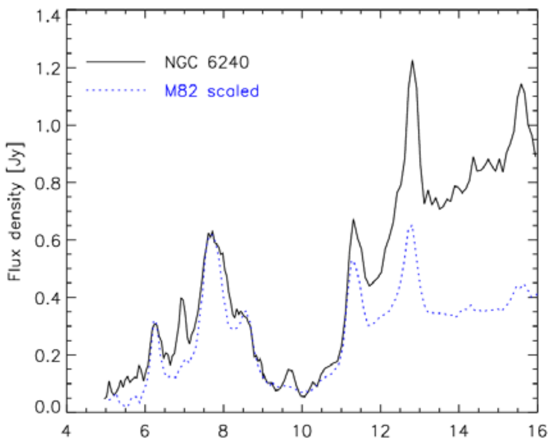
Dispersion 0.17

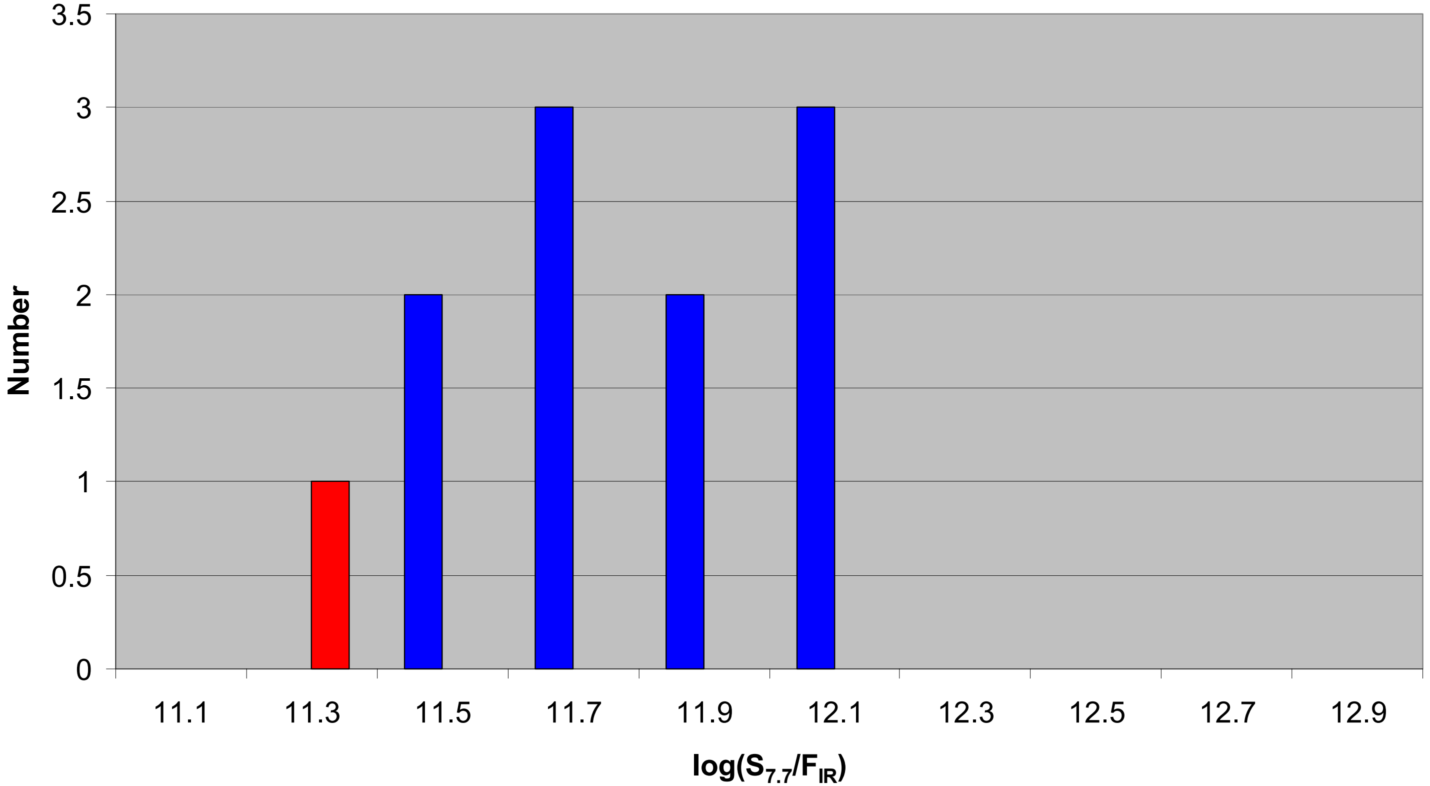
(three objects within factor ~2)

Starburst PAH emission

Ratio of PAH to IR ~1/3 of that in comparison starbursts

Uncertainty factors: PAH emission in intense radiation fields, obscuration



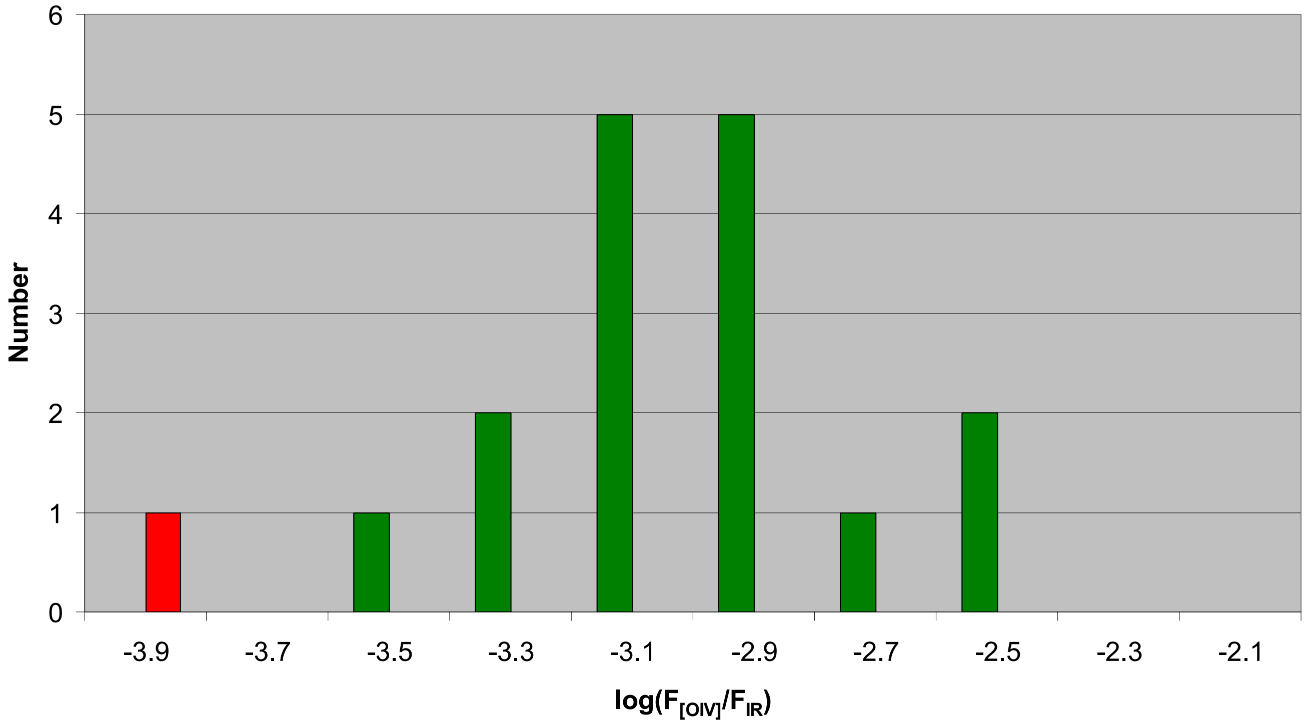


Dispersion 0.25

AGN [OIV] emission

Ratio of [OIV] and IR only ~1/10 of that in AGN

Uncertainty factors: Obscuration, shock contribution to [OIV], star formation in comparison AGN, correction IR→bolometric for comparison AGN

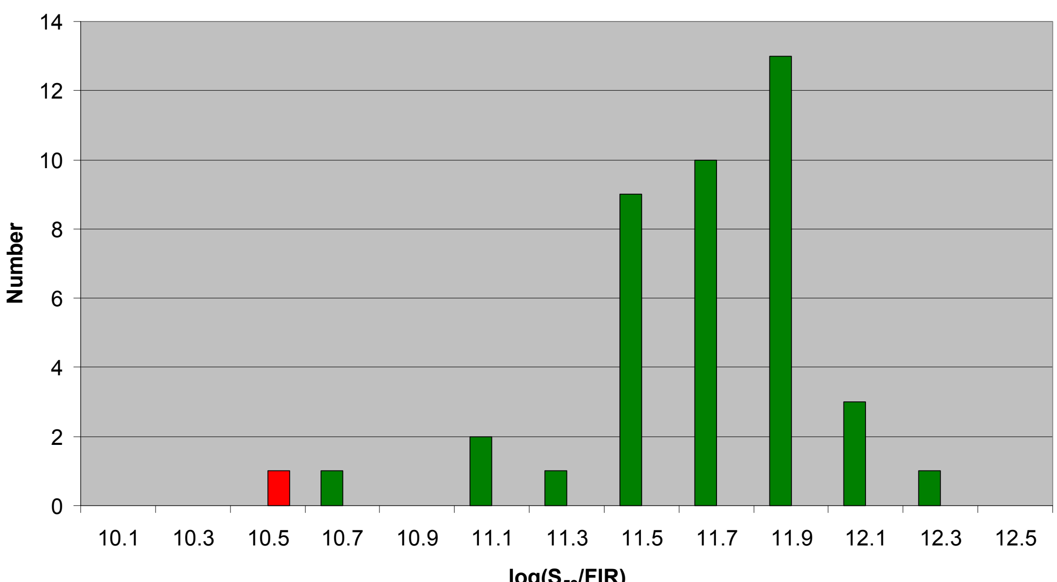


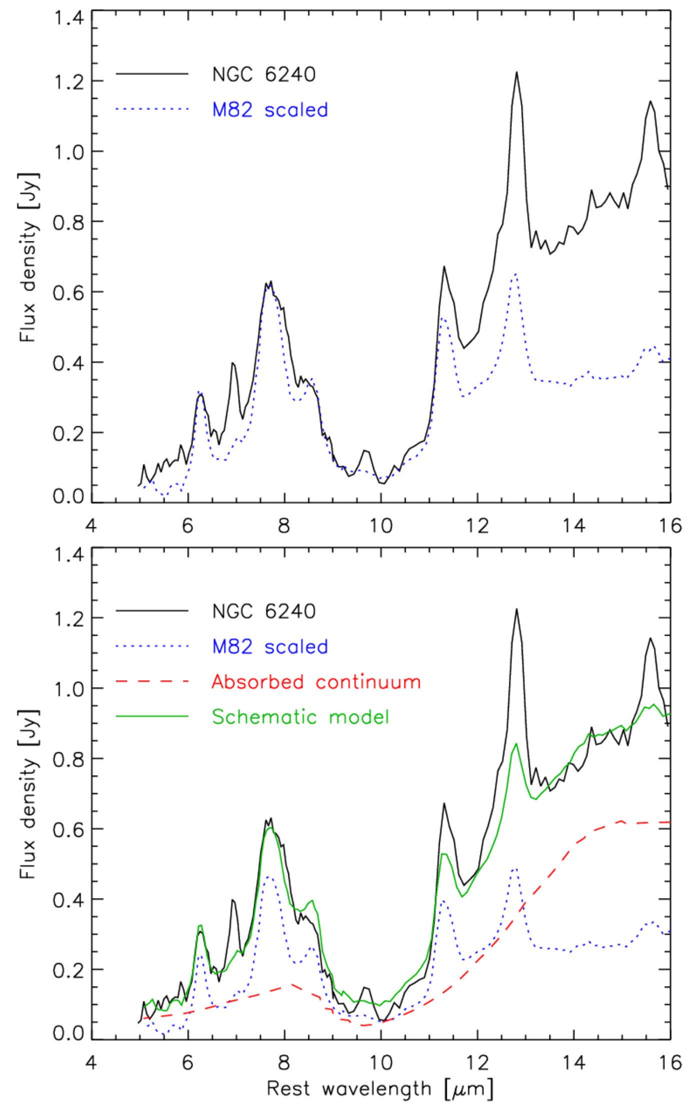
Dispersion 0.29

AGN mid-IR continuum

Ratio of 5.9µm continuum and IR only ~1/10 of that in AGN

Uncertainty factors: Obscuration, nonisotropic mid-IR emission, star formation in comparison AGN, correction IR→bolometric for comparison AGN, 5.9 µm continuum in NGC6240 not only AGN?





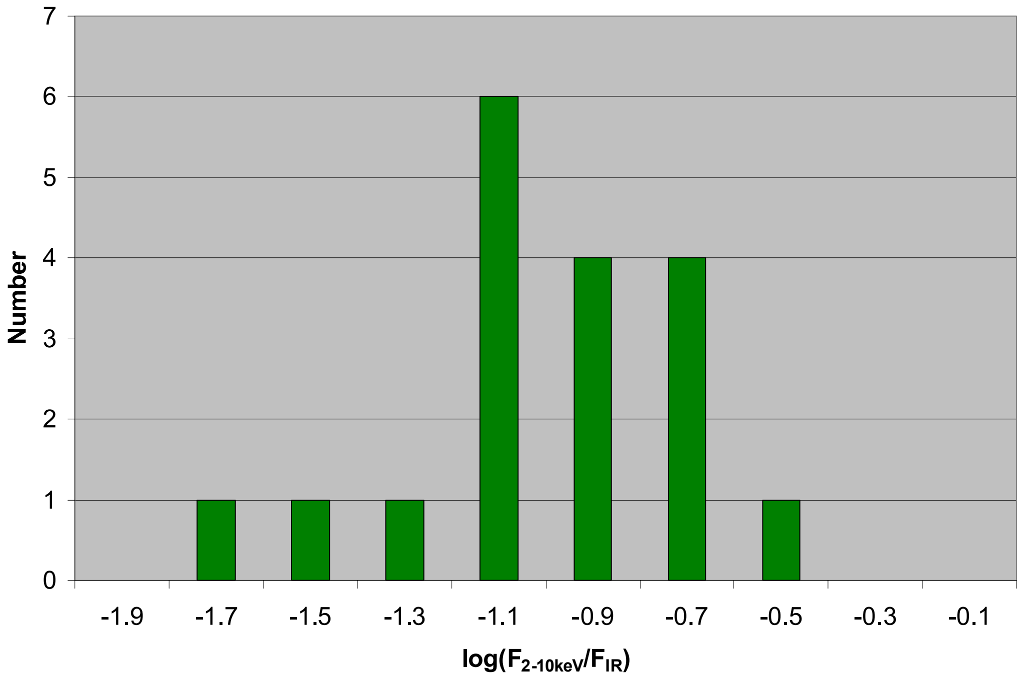
Dispersion 0.29

Extrapolation from hard-X to IR

Estimates of intrinsic hard-X ray emission in the literature cover a range of more than an order of magnitude (Vignati et al. 1999, Ikebe et al. 2000) and have to be extrapolated to IR

Between 10% and several times the IR luminosity can be produced

Uncertainty factors: geometry of reflector, scattering by absorber, spectrum of the transmitted component, extrapolation from X-ray to bolometric for comparison AGN



Dispersion 0.29

Combining constraints for starburst and AGN in NGC 6240

Constraint	Starburst	AGN
[NeII]	**50-100%**	
PAH	>33%	
[OIV]		>24%
Mid-IR continuum		>13%
Hard X-rays		**10-100%**

Best guess: 50-75% starburst – 25-50% AGN?

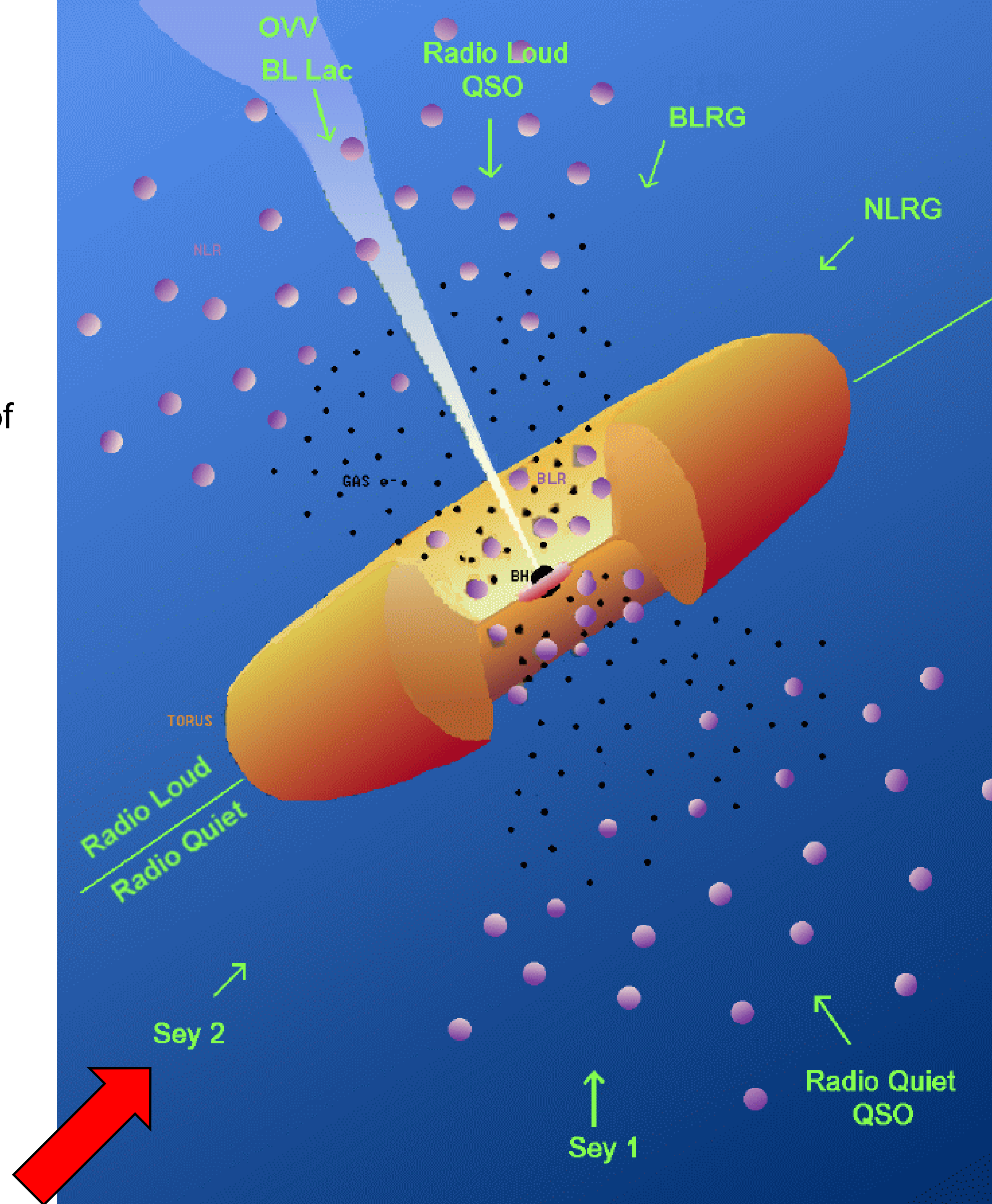
… consistent with the purely mid-IR diagnostics

Infrared BLR observations

Unified Framework…

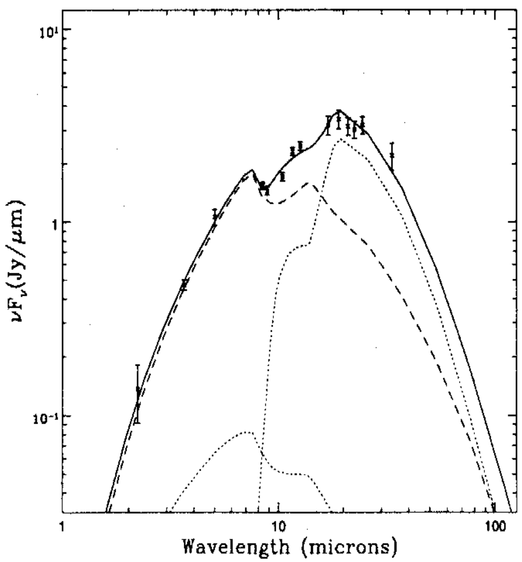
What is the distribution and state of the matter obscuring the central engine of Seyfert 2 galaxies?

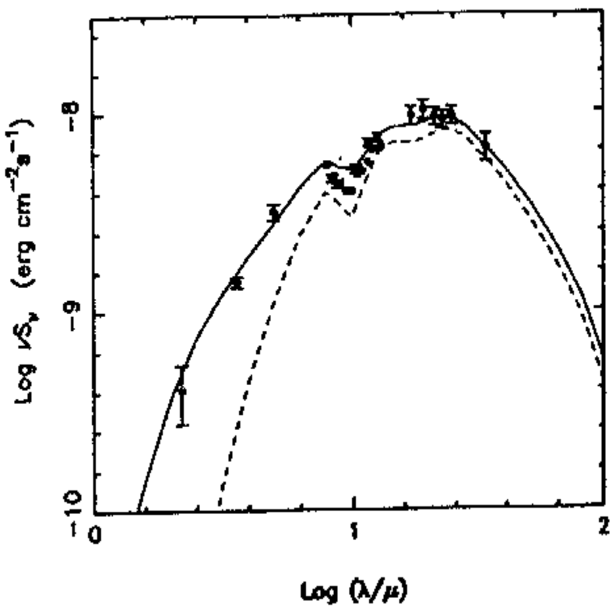
Observe in wavelength ranges *partially* penetrating the obscuring matter:
X-ray or **Infrared**
… and compare results

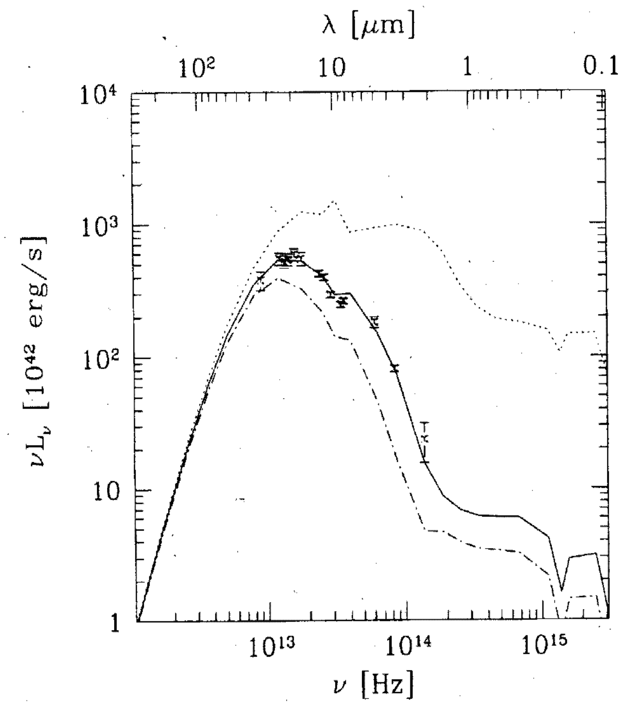


Geometry: What is the obscuring column?

3 successful models of the circumnuclear infrared SED of NGC 1068:







Pier & Krolik ApJ 418, 673 (1993)

A_V~1000mag (equator)
Torus plus narrow line region dust

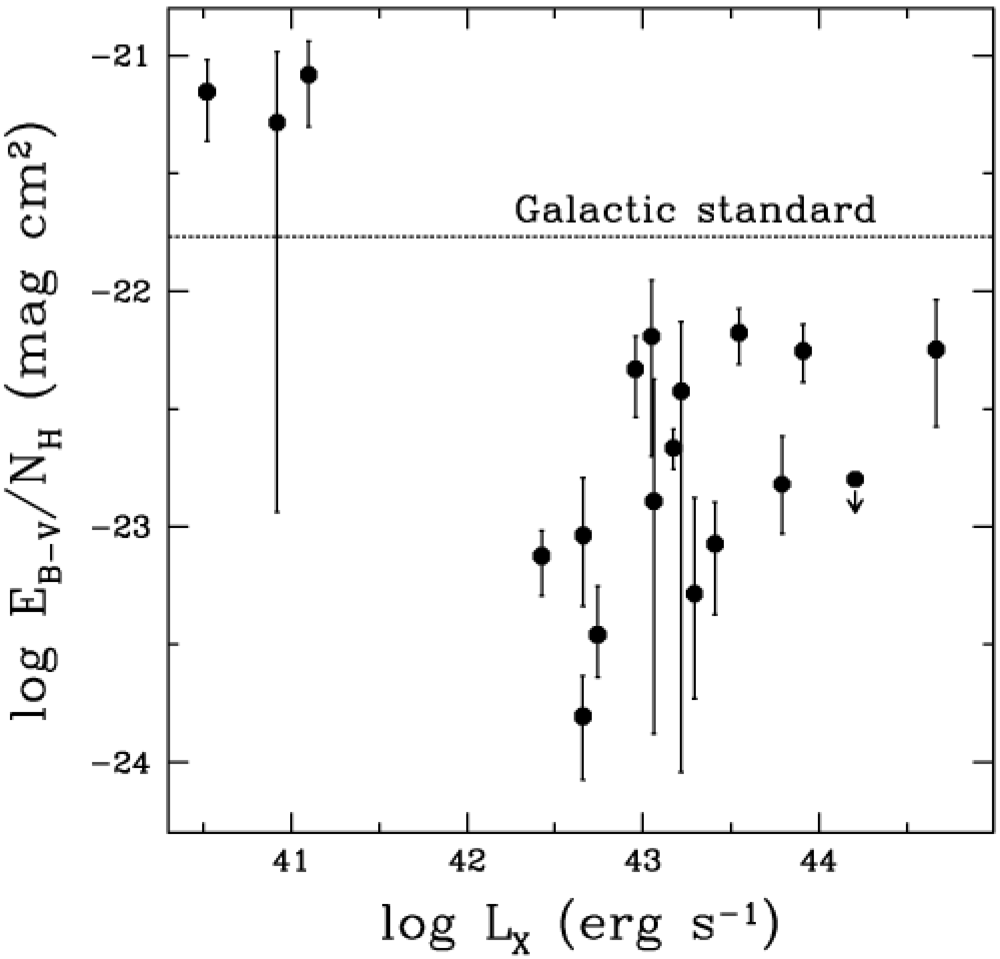
Efstathiou et al. MNRAS 277, 1134 (1995)

A_V~240mag (equator)
Tapered disc plus narrow line region dust

Granato et al. ApJ 486, 147 (1997)

A_V~72mag (LOS) (210 at equator)
Extended torus

State of the obscuring matter



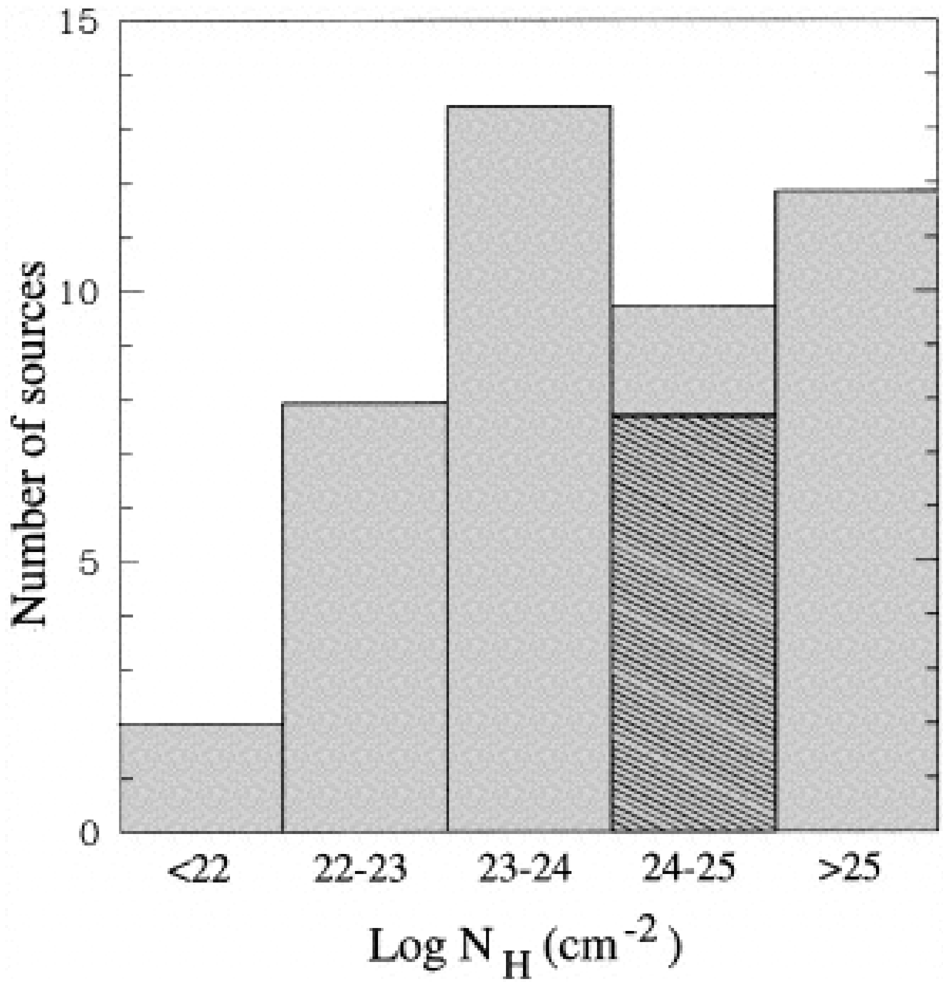
Maiolino et al. A&A 365, 28&37 (2001)

Anomalous ratios of optical reddening E(B-V) (to BLR!) and X-ray column. Evidence also for low ratio of optical extinction A_V and X-ray column N_H

Grain coagulation leading to reduced E(B-V)/N_H and A_V/N_H? (see also Laor & Draine 1993)

Low dust-to-gas ratio due to grain destruction? (but cf. emission line budget)

X-ray column density distribution

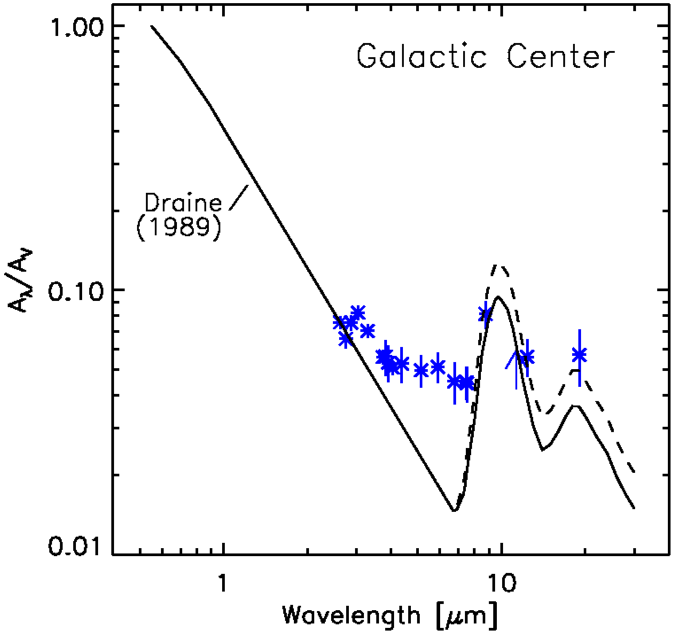


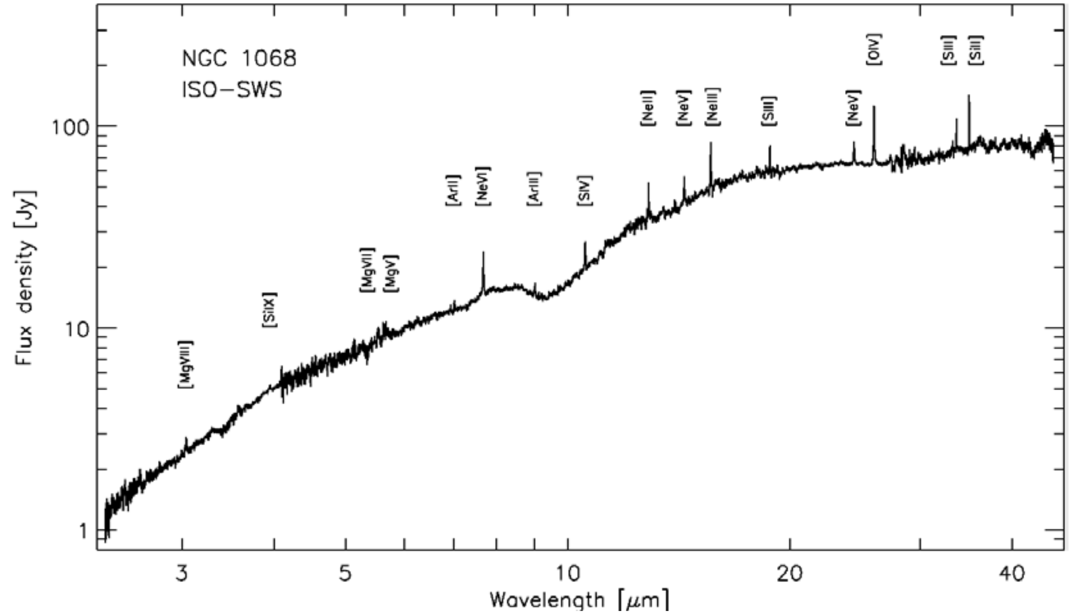
Comparison to IR results may tell about

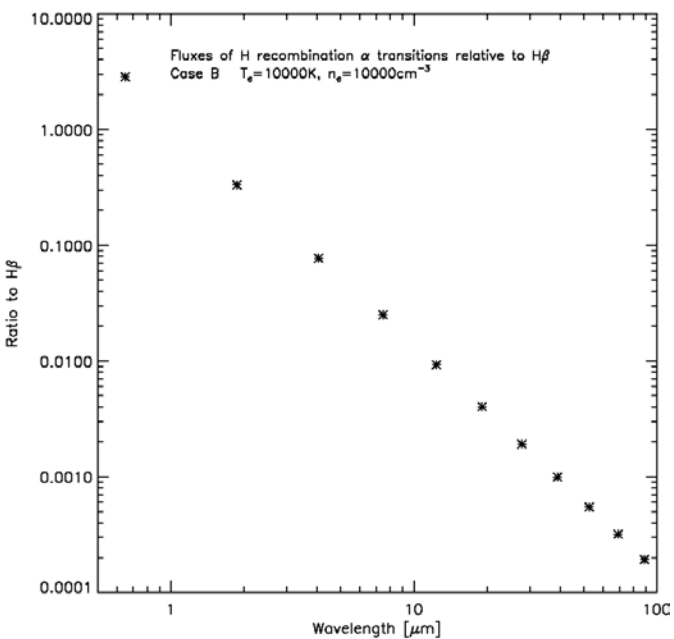
- Line of sight to BLR vs. Line of sight to central engine
- Dust content of absorbers
- Dust properties of absorbers

Risaliti et al. ApJ 522,157 (1999):
X-ray columns for Seyfert 2

Picking the optimal line for infrared BLR searches

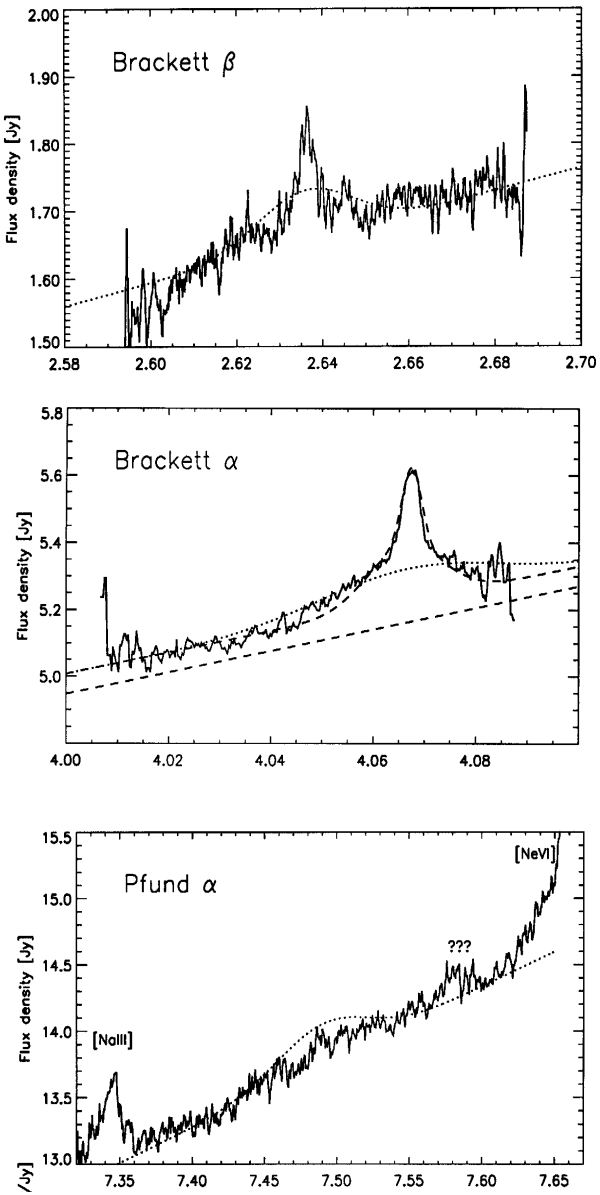


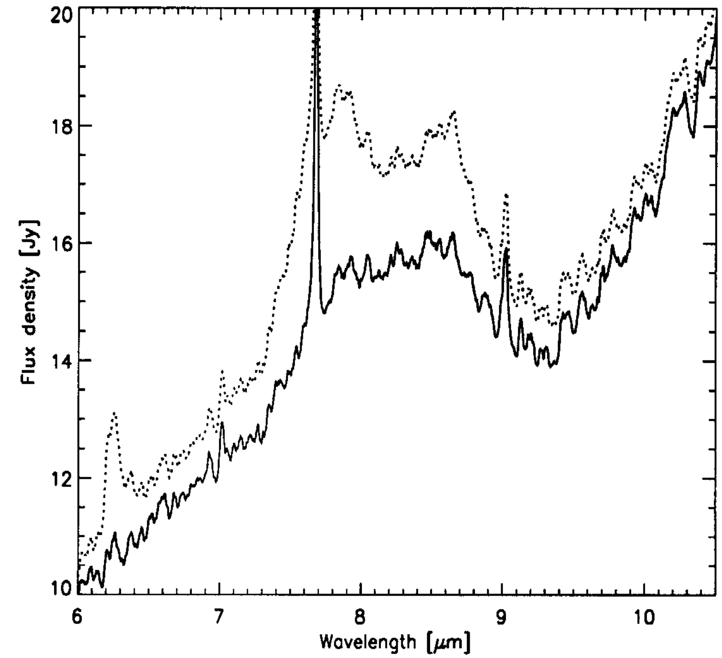




- Extinction
- Line flux
- Background continuum

ISO spectroscopy of NGC 1068





- Upper limits on broad components
- A_V>50mag to BLR
- Pfund α region crowded by lines and features
- Brackett α may be best line for future attempts

(Lutz et al. ApJ 530, 733 (2000))

VLT/ISAAC spectroscopy

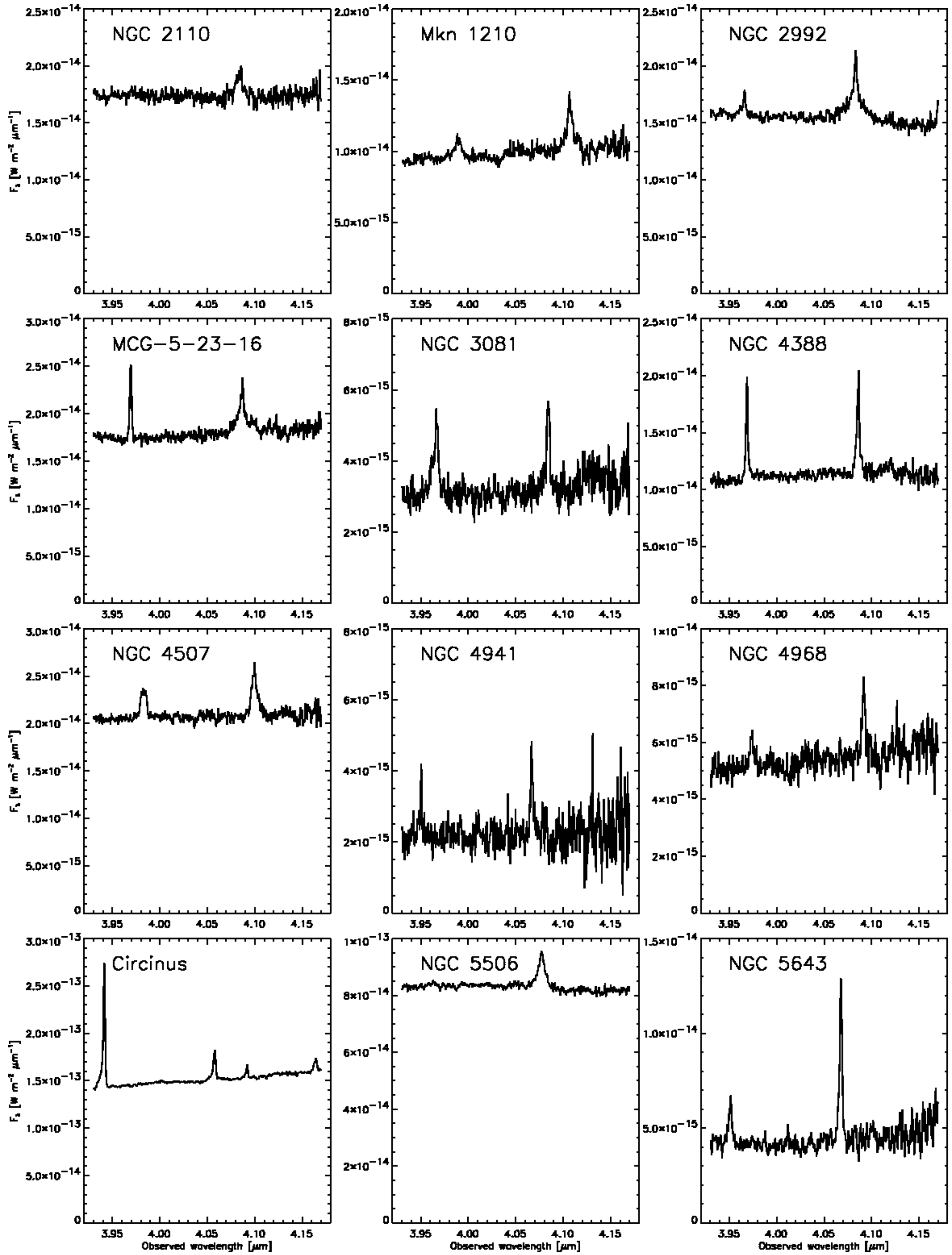
• 12 objects from Bassani et al. sample of Seyfert 2 with known X-ray obscuring columns (ApJS 121, 473 (1999))

• bright in extinction-corrected [OIII]
• covering a wide range of X-ray obscuring column densities ($7\ 10^{21}$ - $>10^{25}$ cm^{-2})
• z<0.015 (keep Br α in L band)

Published spectropolarimetry confirms presence of a hidden BLR in most of the objects

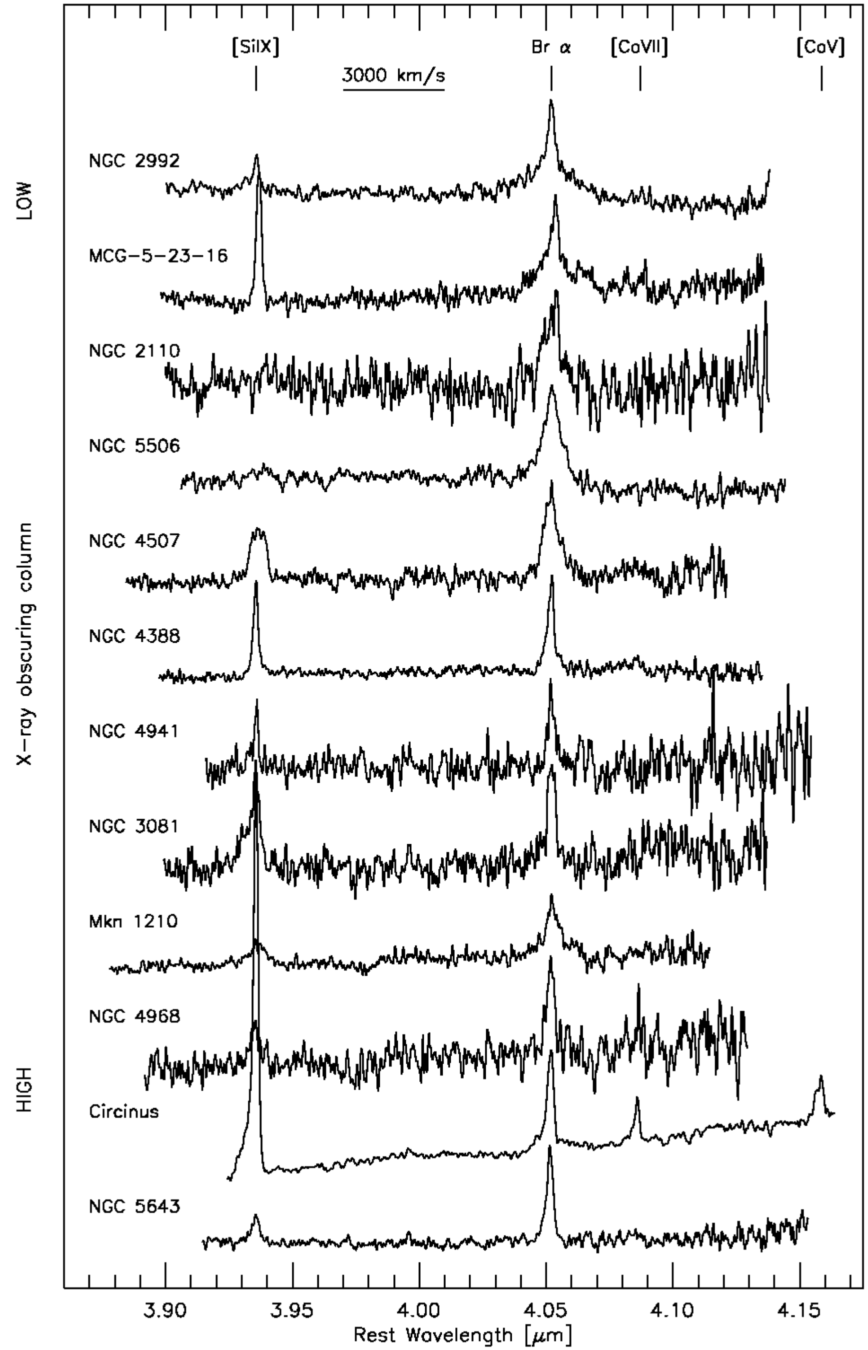
Strategy: integrate to good S/N in narrow Br α. Then, (non)detection of broad component is meaningful

(Lutz et al. 2002)

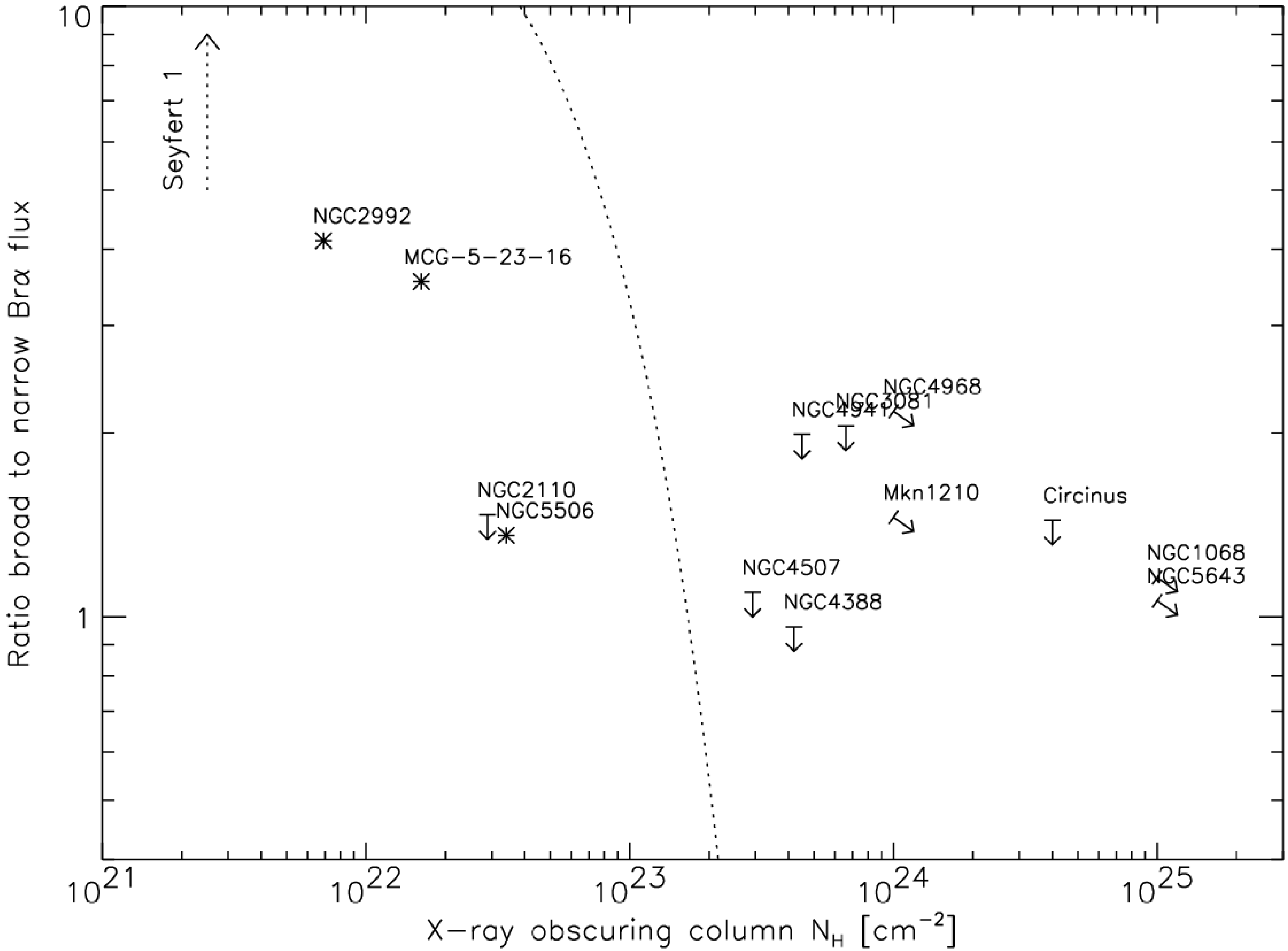


Broad line ≡

a component of Br α with FWHM >~1000km/s that is not detected in the forbidden/coronal lines from the narrow line region



Detections/Limits as a function of X-ray column



Results

- Brα detectable at good S/N in reasonable samples of nearby Seyferts

- Few BLRs found, some previously claimed are questionable: lines broadish but recombination line width and forbidden (coronal) line width very similar

- BLR in sources with nondetections must on average be obscured by A_V>~30-50mag (BLR existence often confirmed by spectropolarimetry!)

- Comparison of BLR (non)detections and X-ray column suggests obscuration that is consistent with a 'galactic' ratio of infrared and X-ray obscuration

Relation to optical / X-ray results

How can ‘normal’ IR obscuration be reconciled with ‘low’ optical reddening/obscuration when comparing both to the X-ray column?

• ‘Simple’ low dust content (put metals into gas): *not consistent, should see more infrared BLRs*

• Different dust properties along equatorial lines of sight, and lines of sight close to the axis: *possible, plausibility depends on mechanism of dust modification. Could be related to large scale dust as well as a classical torus*

• Grain modifications affecting optical/UV much more strongly than IR: *possible, to be verified quantitatively*