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

Reconstructing the ionizing SED?
(Absorbed) big blue bump?


Plausible … but not unique!

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


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 365, L353 (2001)
Spoon et al. AA 385, 1022 (2002)
AGN: Unification, continuum and PAH features

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

NGC 6240

Flux density [Jy]

Wavelength [$\mu$m]
SWS spectra

- 1st order: Similar to starbursts
- Very strong H₂ 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/$L_{\text{IR}}$ 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)
Starburst PAH emission

Ratio of PAH to IR \( \sim \frac{1}{3} \) 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
AGN mid-IR continuum

Ratio of 5.9\(\mu\)m continuum and IR only \(~1/10\) of that in AGN

Uncertainty factors: Obscuration, nonisotropic mid-IR emission, star formation in comparison AGN, correction IR\(\rightarrow\)bolometric for comparison AGN, 5.9 \(\mu\)m continuum in NGC6240 not only AGN?
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.
Combining constraints for starburst and AGN in NGC 6240

<table>
<thead>
<tr>
<th>Constraint</th>
<th>Starburst</th>
<th>AGN</th>
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<tbody>
<tr>
<td>[NeII]</td>
<td>50-100%</td>
<td></td>
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<tr>
<td>PAH</td>
<td>&gt;33%</td>
<td></td>
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<tr>
<td>[OIV]</td>
<td></td>
<td>&gt;24%</td>
</tr>
<tr>
<td>Mid-IR continuum</td>
<td></td>
<td>&gt;13%</td>
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<tr>
<td><strong>Hard X-rays</strong></td>
<td></td>
<td><strong>10-100%</strong></td>
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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:


$A_V \sim 1000 \text{mag (equator)}$
Torus plus narrow line region dust


$A_V \sim 240 \text{mag (equator)}$
Tapered disc plus narrow line region dust


$A_V \sim 72 \text{mag (LOS) (210 at equator)}$
Extended torus
State of the obscuring matter


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

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
- $A_V > 50$ mag to BLR
- Pfund $\alpha$ region crowded by lines and features
- Brackett $\alpha$ may be best line for future attempts

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 \times 10^{21} - >10^{25} \text{ 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 $\alpha$ with FWHM $>\sim 1000$ km/s that is not detected in the forbidden/coronal lines from the narrow line region
Detections/Limits as a function of X-ray column

Ratio broad to narrow Brα flux

X-ray obscuring column $N_H$ [cm$^{-2}$]
Results

• Br\(\alpha\) 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 \(A_V > \sim 30-50\)mag (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