The relation between circumnuclear star formation and black hole growth in the mid-IR and hard X-rays

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Outline

Search for evidence of the interplay between nuclear activity and star formation in the local Universe

1. Ultraluminous Infrared Galaxies
   Quantitative study of the AGN/SB relation at extreme luminosities and dust obscuration

2. Narrow-Line Seyfert 1 Galaxies
   Connection between SF and AGN at the higher end of the accretion rate distribution
1. Ultraluminous Infrared Galaxies

**ULIRGs**

\[ L_{\text{IR}} > 10^{12} \, L_\odot \]
\[ L_{\text{IR}} \sim 60-95\% \, L_{\text{bol}} \]

**Milky Way**

\[ L_{\text{IR}} \sim 10^{10} \, L_\odot \]
\[ L_{\text{IR}} \sim 10-30\% \, L_{\text{bol}} \]

Huge IR emission related to interacting/merging systems

Energy source: starburst (SB) and/or accretion on to a supermassive black hole (AGN)

Local counterparts of the mid-IR/sub-mm galaxies dominating the energy output at high \( z \)

*Sanders & Mirabel 96*
Disentangling SB and obscured AGN

1) Optical emission lines (Veilleux+99, Yuan+10)

2) Mid-IR high-ionization lines (Genzel+98, Farrah+07)

3) Mid-IR SEDs (Laurent+00, Armus+07, Veilleux+09)

4) PAH features and Silicate absorption (Spoon+07)

5) X-ray spectral analysis (Franceschini+03, Teng+05)

6) X-ray imaging (Komossa+03)

Aim: to detect faint/obscured AGN components and to estimate their contribution to the IR luminosity
**AGN/SB spectral decomposition at 5-8 µm**

- **Diagnostic method:** separation of the AGN/SB contribution to the observed emission of ULIRGs through spectral templates

- **Why 5-8 µm:** enhancement of the AGN over SB brightness ratio for equal bolometric luminosity due to the hot dust component, large difference between the average AGN/SB properties and little spectral dispersion observed within the separate classes

- **Main results:** SB events confirmed as the dominant power supply but AGN detection rate of ~70% - Sharp increase of the AGN contribution across the IR luminosity range - Strong evidence for elusive AGN missed by the standard optical diagnostics

- **Elusive AGN population:** follow-up X-ray observations of the most intriguing sources in this class (~10% of local ULIRGs)

**References:**

*Spectral decomposition of SB and AGN in Spitzer-IRS spectra of local ULIRGs,* Nardini+08 MNRAS

*Exploring the AGN/SB content of local ULIRGs through 5-8 µm spectroscopy,* Nardini+09 MNRAS

*The role of nuclear activity as the power source of ULIRGs,* Nardini+10 MNRAS
AGN/SB luminosity ratio in action

~70% Starburst
~30% unobscured AGN

~70% Starburst
~30% obscured AGN

Application: 1) Sample of 164 bright ULIRGs at $z \sim 0.02-0.35$
2) Acceptable fit for all the sources: spectral variations are due to the AGN and its obscuration
3) Estimate of the relative AGN/SB contribution to the bolometric luminosity
Results of the IR spectral decomposition

Optical classification:
Powerful but highly obscured AGN are actually at work in many sources with no optical signature of nuclear activity.

AGN contribution v. IR luminosity:
Growing AGN significance with tentative evidence for non-uniformity: a hint of mutual AGN/SB feedback?
Expected X-ray emission of ULIRGs

Diffuse soft emission (SB)

Hard AGN emission

$N_H \sim 10^{23} \text{ cm}^{-2}$
Expected X-ray emission of ULIRGs

Diffuse soft emission (SB)

Reflected spectrum $N_H > 10^{24}$ cm$^{-2}$
Observed X-ray emission of ULIRGs

**IRAS 00397-1312**

$L_{SB} \sim 4 \times 10^{12} \, L_\odot$

$L_{AGN} \sim 5 \times 10^{12} \, L_\odot$

$(\tau_{6\mu m} \sim 0.25)$

**IRAS 01003-2238**

$L_{SB} \sim 1 \times 10^{12} \, L_\odot$

$L_{AGN} \sim 1 \times 10^{12} \, L_\odot$

$(\tau_{6\mu m} \sim 1.6)$

SB as expected but no AGN $\rightarrow N_H > 10^{24} \, \text{cm}^{-2}$ and complete covering
IRAS 01298-0744

$L_{SB} < 6 \times 10^{11} L_{\odot}$

$L_{AGN} \sim 2 \times 10^{12} L_{\odot}$

($\tau_{6\mu m} \sim 1.8$)

No SB and reflected AGN $\rightarrow N_H > 10^{23} \text{ cm}^{-2}$ and substantial covering

IRAS 12127-1412

$L_{SB} < 2 \times 10^{11} L_{\odot}$

$L_{AGN} \sim 1.4 \times 10^{12} L_{\odot}$

($\tau_{6\mu m} ?$)

No X-ray detection $\rightarrow N_H > 10^{24} \text{ cm}^{-2}$ and complete covering
**IRAS 12071-0444**

$L_{SB} \sim 1.5 \times 10^{12} L_\odot$

$L_{AGN} \sim 1 \times 10^{12} L_\odot$

$(\tau_{6\mu m} \sim 1.1)$

**AGN detected** at $E > 10\text{keV} \rightarrow N_H \sim 2 \times 10^{24} \text{cm}^{-2}$ and complete covering

**IRAS 00182-7112**

$L_{SB} < 5 \times 10^{11} L_\odot$

$L_{AGN} \sim 9 \times 10^{12} L_\odot$

$(\tau_{6\mu m} ?)$

**X-rays:** Reflected spectrum of a hidden Compton-thick AGN seen through $N_H \sim 10^{23} \text{cm}^{-2}$

(Nandra & Iwasawa 07)

**IRAS 08572+3915**

$L_{SB} \sim 2 \times 10^{11} L_\odot$

$L_{AGN} \sim 1.2 \times 10^{12} L_\odot$

$(\tau_{6\mu m} \sim 0.45)$

**X-rays:** Chandra 0.5-10keV flux of $\sim 5 \times 10^{-15} \text{erg s}^{-1} \text{cm}^{-2}$, no Suzaku detection \(\rightarrow N_H \sim 10^{25} \text{cm}^{-2} ?\)

(Teng+09)
2. Narrow-Line Seyfert 1 Galaxies

- Definition: FWHM (H\(\beta\)) < 2000 km/s  
  (Osterbrock & Pogge 85)
- Steep X-ray spectra and soft excess  
  (Boller, Brandt & Fink 96)
- Rapid large-amplitude X-ray variability  
  (Gallo+04)
- Evidence for large metal abundances  
  (Shemmer & Netzer 02)
- Strong FeII emission compared to H\(\beta\)  
  (Grupe+04)
- Low BH mass and high accretion rate  
  (Collin & Kawaguchi 04)

Mid-IR diagnostics: 6.2 \(\mu\)m PAH feature against 6 \(\mu\)m continuum as tracers of star formation and AGN hot dust component

Comparison between complete samples of NLS1s and BLS1s  
(59+54 sources, ~6 orders of magnitude in luminosity) to probe SF and BH accretion in type 1 AGN \(\rightarrow\) different populations?
\[ \frac{R}{\nu L_{\text{AGN}}} = \frac{F_{\text{SF}}}{\frac{R_{\text{NLS1}}}{R_{\text{BLS1}}}} \]

\[ F_{\text{SF}} \gg 1 \]
Larger SF activity at low BH masses and high accretion rates: only NLS1s are found at extreme values.

Gemini/GMOS IFU observations of NLS1s harbouring the most intense SF to probe metallicity gradients and feedback.

Summary

• Solid constraints to the AGN/SB power balance in local ULIRGs from Spitzer/IRS 5-8 \( \mu m \) spectroscopy

• Dominant SB contribution but AGN present in most ULIRGs

• Elusive AGN population not detected at other wavelengths; many of these components are heavily obscured

• Follow-up X-ray observations:
  - agreement with the IR spectral decomposition
  - large fraction of Compton-thick sources
  - evidence for unusually low dust to gas ratios
  - no X-ray reflection: almost complete covering
  - link between AGN obscuration and SB activity?

• PAH detection rate much larger in NLS1s than in BLS1s

• Intense star formation taking place in the circumnuclear environment of high accretion efficiency AGN