Observations of ULIGs with Spitzer/IRS
Early Results on Mrk 1014, Mrk 463, and UGC 5101

Mid-IR Diagnostics of ULIG Energy Sources

• Hardness of UV field
  – \([\text{O IV}]\) at 25.9 \(\mu\text{m}\), 55 eV
  – \([\text{Ne II}]\) at 12.8 \(\mu\text{m}\), 21 eV

• Intensity of the UV field
  – \(10^2 - 10^5\) in starforming regions, starburst galaxies
  – Greater than \(10^6\) in AGNs, which destroy PAHs

• Many ULIG emission lines to faint to be detected by ISO

IRS Overview

• Low Resolution modules (SL and LL)
  – 1st and 2nd order diffraction
  – R ~ 90, from 5.2 µm to 38 µm
  – Used to detect broad PAH and dust features, and the continuum

• High Resolution modules (SH and LH)
  – Cross-dispersed echelle modules operating in 11th through 20th order
  – R ~ 600, from 9.9 µm to 37.2 µm
  – Used to measure narrow atomic/molecular lines

• Peak-up Mode
  – Broad band imaging at 16 µm and 22 µm for target acquisition and science
Spitzer/IRS ULIG Survey

- Spitzer/IRS is more sensitive than ISO spectrographs
  - Detect faint emission lines missed by ISO/SWS
  - Requires shorter integration times (~15 min vs ~5 hrs)
  - Extend ULIG studies out to higher redshifts
- A study of ~110 ULIGs out to z ~ 1 is currently underway
  - Understand the energy sources (AGN vs starburst)
- Armus et al. 2004 present preliminary results from 3 sources with spectra representing the range of expected properties
• Mrk 1014 – Radio quiet QSO with broad optical emission lines
• No 10 µm silicate feature, little extinction to the nucleus
• Weak 7.7 µm PAH feature
• Mrk 463 – Seyfert 2 nuclei with broad lines in scattered light
• Depth of the 10 µm feature implies $A_V = 3-8$ mag
• Weak 7.7 µm PAH feature
• UGC 5101 – LINER optical classification
• Depth of the 10 µm feature implies $A_V = 15-30$ to the central source
• Strong 7.7 µm PAH feature
High-Res Spectra

Flux density (Jy)

rest wavelength (μm)

Mrk 1014

Mrk 463

UGC 5101

Mrk 1014

UGC 5101
Measure Electron Density

- Electron density is traced by ratio of lines from the same ion, with different critical densities
  - [Ne V] 14.3/[Ne V] 24.3
  - [S III] 18.7/[S III] 33.4

- Confirm low density (10^2 - 10^3 cm^-3) for each of the 3 sources
- \( \frac{F_{\text{line}_1}}{F_{\text{line}_2}} \sim \frac{N_1}{N_2} \)
  - Independent of temperature

- 33.4 \( \mu \)m \( n_{\text{crit}} \sim 4,000 \) cm\(^{-3}\)
- 18.7 \( \mu \)m \( n_{\text{crit}} \sim 40,000 \) cm\(^{-3}\)
Mrk 1014 and 463 have line ratios and PAH strengths characteristic of AGNs

- $\text{[Ne V]} / \text{[Ne II]}$ and $\text{[O IV]} / \text{[Ne II]}$ are large, implying > 80% - 90% of the UV/optical originates in AGN
- $\text{[Ne VI]}$ 7.65 µm feature is present, but out of the range of the high resolution spectra
- Line to continuum ratio of PAH 7.7 µm features are low

UGC 5101: Circumnuclear Starburst with a Buried AGN?

- $[\text{Ne V}]/[\text{Ne II}]$ and $[\text{O IV}]/[\text{Ne II}]$ imply an AGN contribution of only $\sim 10\%$
  - $[\text{Ne V}]$ flux $\sim 3x$ fainter than upper limit from Genzel et al. 1998
- $A_V$ is at least 15-35 mag, there may be significant extinction of the $[\text{O IV}]$ 25 $\mu$m line
  - $\tau_{\text{dust}}(\text{MIR}) \sim 1$ at $A_V \sim 50-100$ (Genzel et al. 1998)
- (Imanishi et al. 2003) find an obscured hard X-ray source they suggest originates in a buried AGN

Warm Molecular Gas

- H$_2$ lines are detected in Mrk 463 and UGC 5101
  - S(3) 9.66 µm and S(1) 17.04 µm
  - Mass and temperature of the warm molecular gas
- UGC 5101 has a warm (300 K) component
  - 1.1 x 10$^9$ M$_\odot$ (22% of total H$_2$ mass)
- Mrk 463 has a warm (400 K) component
  - 0.5 x 10$^9$ M$_\odot$ (48% of total H$_2$ mass)
References

Figure 1: Summary of IRS module properties. The slits are not parallel as depicted in this figure. Actual slit position angles relative to a Spitzer roll angle of 0° are SL = +84.7°, LL = +181.2°, SH = +221.5°, LH = +136.7°, and IRS Peak-up = +177.0°.

Molecular Gas

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- UGC 5101 has a warm (300 K) component of 1.1 x $10^9 \text{M}_\odot$ (22% of total $\text{H}_2$ mass)
- Mrk 463 has a warm (400 K) component of 0.5 x $10^9 \text{M}_\odot$ (48% of total $\text{H}_2$ mass)