The Starburst-AGN Connection: Integral Field Spectroscopy of Merging and Seyfert 2 Galaxies

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Activity in Galaxies

In the course of their evolution, galactic nuclei occasionally light up.

Energy from a galactic nucleus may come from two sources:

- Accretion of matter onto a massive compact object (Active Galactic Nuclei or AGN)
- The sudden onset of star formation, a Starburst

Both occur within a large amount of dust.
A Starburst/AGN Connection?

- Conservation of angular momentum makes it difficult to feed an AGN directly (Gunn 1977)
- A little accreted mass turns into a large amount of spectral energy
- Nuclear starbursts may be the answer
  - Supernovae and outflows from giants and super giants may provide the necessary material
Active Galactic Nuclei

Seyfert 1

Seyfert 2

narrow line region

broad line region

~1 pc

~100 pc

Starburst?

torus

~1 pc
Project Goals

• Using integral field spectroscopy in the infrared determine the presence of a nuclear Starburst/AGN

• Estimate the strength of a possible Starburst based on infrared spectral diagnostics and stellar synthesis models

• Look for connections between the possible Starburst and AGN
Observations

• Observations of 20 merging and/or Seyfert 2 galaxies taken by R. Joseph on April 19-23, 2003
  - 15 have the S/N needed for these measurements
  - 4 of these 15 are presented

• UK Infrared Telescope Imager-Spectrometer (UIST) integral field unit
  - 1.4 - 2.4 μm
  - 6 x 3.3 arcsec$^2$
  - R~900
# H & K-band Spectral Diagnostics

<table>
<thead>
<tr>
<th>Diagnostic</th>
<th>Physics</th>
</tr>
</thead>
<tbody>
<tr>
<td>[Fe II]</td>
<td>Produced in supernova remnants, lasts for $10^4$ years</td>
</tr>
<tr>
<td>Paschen $\alpha$, Brackett $\gamma$</td>
<td>O &amp; B main sequence stars, broad and narrow line regions of AGN</td>
</tr>
<tr>
<td>[Si VI]</td>
<td>Very high ionization potential ($\sim 200$ eV), only produced in AGN</td>
</tr>
<tr>
<td>$H_2$ (1-0)</td>
<td>Shocked neutral medium, AGN, SN, mergers</td>
</tr>
<tr>
<td>He I</td>
<td>Windy O &amp; B main sequence stars</td>
</tr>
<tr>
<td>CO (2-0) band</td>
<td>Red giant stars</td>
</tr>
</tbody>
</table>
IC 3639

Type: SBbc
Nuclear Activity: Seyfert 2
Distance: 49.6 Mpc

2 companion galaxies
MRK 477

Type: Compact
Nuclear Activity: Seyfert 2
Distance: 158.1 Mpc
Interacting with companion galaxy
MRK 477

MRK 477 H–band

MRK 477 K–band

[Fe II]  Supernovae

[Si VI]  AGN

H₂ 1-0 S(1)

He I

Br γ  O & B stars

CO (2-0)?  Red Giants
NGC 2623

Type: Peculiar
Nuclear Activity: Seyfert 2
Distance: 75.9 Mpc
Merger

Palomar 5m 4050A
2.8x2.2 arcmin
NGC 2623

NGC 2623 H-band

[Fe II] Supernovae

NGC 2623 K-band

sky emission

He I

Br γ O & B stars

H₂ 1-0 S(1)

CO (2-0) Red Giants
NGC 3227

Type: SAB peculiar

Nuclear Activity: Seyfert 1.5

Distance: 18.3 Mpc

Possible companion, within a group of 13 galaxies

Palomar 200in 4050A
~9 arcmin
NGC 3227

NGC 3227 H-band

[Fe II] Supernovae

NGC 3227 K-band

[Si VI] AGN

H₂ 1-0 S(1) Br Γ O & B stars

CO (2-0) Red Giants
Starburst Stellar Synthesis

Starburst99

Predictions of the spectral properties of a stellar population based on age

- Continuous and instantaneous star formation

- Initial mass function:
  - Salpeter (-2.35, 1-100 \( M_{\text{sun}} \))
  - Steeper power law (-3.3, 1-100 \( M_{\text{sun}} \))
  - Lower mass cutoff (-2.35, 1-30 \( M_{\text{sun}} \))
Using Starburst99

- **Assuming:**
  - The starburst is the major source of the luminosity from the nucleus
  - Star formation is continuous and ongoing

- **Procedure:**
  - Use Br $\gamma$ to find the starburst age
  - Use [Fe II] luminosity to estimate the supernova rate
  - Use the SNR and the model to find the star formation rate
  - Find Starburst99 $M_\kappa$ and compare with measured $M_\kappa$
Age from the Equivalent Width of Brackett $\gamma$

<table>
<thead>
<tr>
<th>Galaxy</th>
<th>log(W(Br$\gamma$) [Å])</th>
<th>Age [Myr]</th>
</tr>
</thead>
<tbody>
<tr>
<td>IC 3639</td>
<td>1.07 ± 0.02</td>
<td>24 ± 2</td>
</tr>
<tr>
<td>MRK 477</td>
<td>1.20 ± 0.05</td>
<td>14 ± 3</td>
</tr>
<tr>
<td>NGC 2623</td>
<td>0.99 ± 0.02</td>
<td>36 ± 4</td>
</tr>
<tr>
<td>NGC 3227</td>
<td>0.68 ± 0.05</td>
<td>270 ± 10</td>
</tr>
</tbody>
</table>
Scaling from the Supernova rate

<table>
<thead>
<tr>
<th>Galaxy</th>
<th>Measured SNR([yr^{-1}])</th>
<th>SFR([yr^{-1}])</th>
</tr>
</thead>
<tbody>
<tr>
<td>IC 3639</td>
<td>0.045 ± 0.004</td>
<td>3.45 ± 0.40</td>
</tr>
<tr>
<td>MRK 477</td>
<td>1.03 ± 0.08</td>
<td>159 ± 5.0</td>
</tr>
<tr>
<td>NGC 2623</td>
<td>0.080 ± 0.03</td>
<td>4.36 ± 1.5</td>
</tr>
<tr>
<td>NGC 3227</td>
<td>0.014 ± 0.002</td>
<td>0.75 ± 0.11</td>
</tr>
</tbody>
</table>
### Comparison through $M_K$

<table>
<thead>
<tr>
<th>Galaxy</th>
<th>measured $M_K$</th>
<th>predicted $M_K$</th>
<th>% K-band flux</th>
</tr>
</thead>
<tbody>
<tr>
<td>IC 3639</td>
<td>-22.7 ± 0.2</td>
<td>-21.2 ± 0.1</td>
<td>30%</td>
</tr>
<tr>
<td>MRK 477</td>
<td>-24.8 ± 0.2</td>
<td>-25.0 ± 0.1</td>
<td>120%</td>
</tr>
<tr>
<td>NGC 2623</td>
<td>-23.9 ± 0.2</td>
<td>-21.7 ± 0.4</td>
<td>10%</td>
</tr>
<tr>
<td>NGC 3227</td>
<td>-21.6 ± 0.2</td>
<td>-20.5 ± 0.2</td>
<td>40%</td>
</tr>
</tbody>
</table>

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![Graph showing comparison through $M_K$]
Conclusions

- Three galaxies have a confirmed Seyfert nucleus (IC 3639, MRK 477, NGC 3227)
- Consistent starburst models are found for IC 3639, NGC 2623, and NGC 3227
- Observations with the IFU confirm previous results from long slit spectroscopy that the IMF is bottom-heavy
Future Work

- Improve the Starburst 99 age estimation
- Characterize the continuum emission from other sources: AGN, old stellar population
- Use an iterative method to determine the relative contributions
- Mass estimation from velocity
- Statistics with 11 more galaxies