Uncovering the Active Galactic Nuclei in Low-Ionization Nuclear Emission-Line Regions with Spitzer

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Abstract. The impact of active galactic nuclei on low-ionization nuclear emission-line regions (LINERs) remains a vigorous field of study. We present preliminary results from a study of the mid-infrared atomic emission lines of LINERs with the Spitzer Space Telescope. We assess the ubiquity and properties of AGN in LINERs using this data. We discuss what powers the mid-infrared emission lines and conclude that the answer depends unsurprisingly on the emission line ionization state and, more interestingly, on the infrared luminosity.

1. Introduction

The nature of low-ionization nuclear emission-line regions (LINERs) in galaxies remains a topic of intense research 25 years after their discovery. The Spitzer Space Telescope has recently made possible very sensitive observations of the mid-infrared fine-structure emission lines in these sources. This gives us new leverage with which to understand the relative contribution of active galactic nuclei, shocks, and stellar populations to the energy of their line emission.

We pose three questions of interest. (1) Exactly how many LINERs host an AGN? This question is still open. (2) Does the AGN excite the low-ionization mid-infrared emission lines? This has been an active research question in the optical band, but we re- pose it for mid-infrared observations. (3) How do infrared-luminous and infrared-faint LINERs differ in their mid-infrared spectra? Beyond what was previously known from other wavelengths, Sturm et al. (2006) show that these sources differ greatly in their mid-infrared spectra, including spectral energy distributions, dust emission features, and atomic emission lines. Here we address in more detail the differences in atomic emission lines.

We present ongoing results from our Spitzer study using the Infrared Spectrograph. We observed 33 galactic nuclei at wavelengths from $5 - 37 \mu m$ and resolving powers of $\sim 100 (5 - 15 \mu m)$ and $\sim 600 (10 - 37 \mu m)$. Our two samples of infrared-luminous and infrared-faint LINERs are from Kim et al. (1995) and Ho, Filippenko, & Sargent (1997), respectively. Previous results from this study
can be found in Sturm et al. (2005) and Sturm et al. (2006). The full details, including data reduction, measured line fluxes, and photoionization modeling, are in preparation (Rupke et al. 2007, in prep.).

2. High-Ionization Emission Lines

There are three mid-infrared transitions that are common in our spectra and arise from ions with high enough ionization potentials to be good AGN signatures: [O IV] 25.9 \( \mu \)m and [Ne V] 14.3 \( \mu \)m and 24.3 \( \mu \)m. The [Ne V] transitions are faint in our sources, and we detect the 14.3 \( \mu \)m line in 40% of IR LINERs and 0% of IR-faint LINERs. The [O IV] transition is brighter and is visible in 90% of both samples. The latter can have some contribution from star forming regions, however.

To address this possible mixing, we show in Figure 1 that there is significant excess [O IV] emission in LINERs compared to starburst galaxies of a given 60 \( \mu \)m luminosity. We interpret this as a signature of a non-stellar power source for most of the [O IV] emission in LINERs: probably an AGN. However, there is less [O IV] emission than in Seyfert galaxies of the same luminosity, giving credence to the “low-luminosity AGN” scenario.

LINERs also have excess [O IV] emission compared to starbursts when normalized by [Ne II] 12.8 \( \mu \)m, an H II-region tracer (Figure 1). We compare observed line ratios to AGN photoionization models from Groves, Dopita, & Sutherland (2004), and assume that the starburst contribution affects primarily the [Ne II]...
The conclusion is that LINERs are consistent with either (1) AGN of moderate or Seyfert-like ionization parameter mixed with a starburst or (2) AGN with low ionization parameter. IR LINERs are on average more like the former, while IR-faint LINERs are inconsistent with Seyfert-like ionization parameter.

3. Low-Ionization Emission Lines

LINERs are defined by the relative strength of their optical low-ionization emission lines. It turns out that certain low-ionization lines are strong in the mid-infrared, as well, compared to starbursts. The [Fe II] 26.0 µm and [Si II] 34.8 µm lines are both stronger than in starbursts (relative to [Ne II]). This is especially true of [Fe II], whose relative strength is greater than in starbursts by 50% in IR LINERs and a factor ~10 in IR-faint LINERs (Figure 2).

Fe and Si are both heavily depleted in the ISM, but the lack of strong [Ca II] emission at 7291 Å and 7324 Å in LINERs (e.g., Ho, Filippenko, & Sargent 1993) argues against this being due to grain destruction (Villar-Martín & Binette 1996). Alternatively, emission from these two observed transitions can arise from photo-dissociation and X-ray dissociation regions (PDRs and XDRs). The flux ratio of the two lines can thus constrain PDR and XDR models (Kaufman et al. 2006; Meijerink et al. 2006).

In Figure 2 we show that there is a significant difference in this ratio between starbursts and LINERs, especially for IR-faint LINERs. There is also a difference between IR-luminous and IR-faint LINERs. The sense of the difference is such that, compared to IR LINERs, IR-faint LINERs should on average have a higher far-UV flux incident on the gas in PDR models and a higher X-ray flux in XDR models (M. Wolfire, pvt. comm.; R. Meijerink, pvt. comm.). This is contrary to the observation of intense star formation in IR LINERs (which is accompanied by strong UV flux) as well as the absence of a strong correlation between X-ray and IR fluxes in LINERs (Dudik et al. 2005).

Since the same model is not applicable to both subsamples simultaneously, we note that PDRs are more natural in the case of IR LINERs because of the strong star formation present. We thus conclude that the [Fe II] 26.0 µm and [Si II] 34.8 µm lines may be powered by PDRs in IR LINERs and XDRs in IR-faint LINERs. However, this conclusion is preliminary and more work is needed to confirm both the applicability of these models and the conclusions drawn from them.

4. Summary

We now revisit the three questions we posed earlier. (1) Exactly how many LINERs host an AGN? We have shown that the mid-infrared high-ionization lines are consistent with a very high AGN fraction. (2) Does the AGN excite the low-ionization mid-infrared emission lines? As in the optical, the LINERs have excess mid-infrared low-ionization line emission, especially in lines that are tracers of PDRs and XDRs. The IR-faint LINERs are good XDR candidates, and as such may indicate the presence of an AGN. (3) How do infrared-luminous and infrared-faint LINERs differ in their mid-infrared spectra? We have shown
Figure 2. Two diagnostic line ratios vs. the [Fe II] 26.0 μm line luminosity. LINERs, especially IR-faint ones, have excess [Fe II] (left) and [Si II] 34.8 μm (not shown) emission compared to starbursts when normalized by [Ne II]. (right) Because both [Fe II] and [Si II] are strong in PDRs and XDRs, the ratio of the two provides information on a region’s ionizing flux and density.

that the mid-infrared atomic emission-line data are consistent with IR-luminous LINERs having different high- and low-ionization line properties than IR-faint LINERs. Our analysis suggests that, on average, IR-luminous LINERs have buried AGN with moderate-to-high ionization parameter and may contain strong PDR emission, while IR-faint LINERs have lower ionization parameter AGN and possibly strong XDR emission.

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