DETECTION OF THE BURIED ACTIVE GALACTIC NUCLEUS IN NGC 6240 WITH THE INFRARED SPECTROGRAPH ON THE SPITZER SPACE TELESCOPE

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1. INTRODUCTION

Ultraluminous infrared galaxies (ULIRGs), i.e., those galaxies with infrared luminosity \( L_{IR} \geq 10^{12} \, L_\odot \), have the power output of quasars yet emit nearly all of their energy in the mid- and far-infrared part of the spectrum. Most ULIRGs are found in interacting and merging systems (e.g., Armus et al. 1987; Sanders, et al. 1988; Murphy, et al. 1996), where the merger has driven gas and dust toward the remnant nucleus, fueling a massive starburst, and either creating or fueling a nascent active galactic nucleus (AGN; Minhos & Hernquist 1996).

Spectroscopic observations with the Infrared Space Observer (ISO) satellite greatly expanded our understanding of the mid-infrared spectra of ULIRGs (e.g., Genzel et al. 1998; Lutz et al. 1999; Rigopoulou et al. 1999; Spoon et al. 2002; Sturm et al. 2002; Tran et al. 2001). However, the limitations in sensitivity of the ISO spectrometers left many ULIRGs, even at relatively low redshift, beyond the reach of these methods until now.

In order to adequately sample the local ULIRG population, we are obtaining mid-infrared spectra of a large number of ULIRGs (\( \sim 100 \)) having 0.02 < \( z \) < 0.93 with the Infrared Spectrograph (IRS) on the Spitzer Space Telescope. The entire sample will be observed with the low-resolution (\( \sim 80 \)) IRS modules, and about half will be observed with the high-resolution (\( R \sim 650 \)) IRS modules as well. These sources are chosen primarily from the \( IRAS \) 1 Jy (Kim & Sanders 1998), 2 Jy (Strauss et al. 1992), and the FIRST/\( IRAS \) radio far-IR sample of Stanford et al. (2000).

In this paper, we present the IRS spectra of NGC 6240, a nearby (\( z = 0.0245 \)), double-nucleus, merging galaxy (Fosbury & Wall 1979; Fried & Schulz 1983; Wright et al. 1984), with an 8–1000 \( \mu m \) luminosity (\( L_{IR} \)) of \( \sim 7 \times 10^{11} \, L_\odot \). The optical nuclear spectrum of NGC 6240 is classified as a LINER (Armus et al. 1989), and the extended optical nebula reveals the presence of a starburst-driven superwind (Heckman et al. 1987, 1990). X-ray observations with \( ASCA \) (Turner et al. 1997), \( BeppoSAX \) (Vignati et al. 1999), \( Chandra \) (Komossa et al. 2003; Ptak et al. 2003), and \( XMM-Newton \) (Netzer et al. 2005) provide clear evidence for the presence of one (or two) AGN(s) behind significant columns of absorbing material (\( N_H = 1-2 \times 10^{24} \, cm^{-2} \)).

Strong [O IV] 25.89 \( \mu m \) line emission in the \( ISO \) Short Wavelength Spectrometer (SWS) spectrum of NGC 6240 led Lutz et al. (2003) to suggest that up to 50% of the infrared energy emitted by NGC 6240 could be powered by a buried AGN, yet direct evidence for the AGN in the mid-infrared was lacking until now. In this paper we present IRS spectra that show the presence of faint [Ne V] 14.3 \( \mu m \) emission from NGC 6240, and we use fine-structure line ratios and polycyclic aromatic hydrocarbon (PAH) emission feature strengths to estimate the energetic importance of the AGN. Because it is a nearby, merging system that has a powerful starburst, a buried (pair of) AGN(s), and a superwind, NGC 6240 provides us with a close-up view of the critical processes that shape all ULIRGs. Our analysis of the IRS spectra of NGC 6240 will serve to highlight the advantages and the limitations of IRS spectroscopy for studying luminous, infrared galaxies and buried AGNs.

Throughout the paper, we adopt a flat, \( \Lambda \)-dominated universe (\( H_0 = 70 \, km \, s^{-1} \, Mpc^{-1} \), \( \Omega_M = 0.3 \), \( \Omega_\Lambda = 0.7 \)). The luminosity...
distances to NGC 6240 is then 99.2 Mpc, assuming $z = 0.0245$, and 1" subtends ~450 pc in projection.

2. OBSERVATIONS

NGC 6240 was observed with the IRS on 2004 March 4. The IRS is fully described in Houck et al. (2004). All four IRS modules were used in Staring mode. Two cycles of 14 s each were obtained for each nod position and each order of the Short-Low (SL) and Long-Low (LL) modules. Six cycles of 30 s each, and four cycles of 60 s each, were obtained for each nod position of the Short-High (SH) and Long-High (LH) modules, respectively. A high-accuracy blue peak-up was performed on a nearby offset star before placing the slits on NGC 6240. Since the separation of the twin nuclei in NGC 6240 is about 1.5", they are both contained within all IRS apertures, the narrowest of which (SL) has a slit width of 3.6.

3. DATA REDUCTION AND ANALYSIS

All spectra were reduced using the S11 IRS pipeline at the Spitzer Science Center. This reduction includes ramp fitting, dark sky subtraction, droop correction, linearity correction, and wavelength and flux calibration. One-dimensional spectra were extracted from the two-dimensional spectra using the SMART data reduction package (Higdon et al. 2004). The one-dimensional spectra are then scaled to a spectrum of α Lacertae, extracted in an identical manner using SMART. The SL and LL data have been sky subtracted by differencing the two nod positions along the slit, before spectral extraction. As a final step, we have normalized the SL and LL one-dimensional spectra upward to match the IRAS 25 µm FSC data (Moshir et al. 1990). The scale factor was 1.16. The low-resolution IRS spectra are displayed in Figure 1a.

Since the SH and LH slits are too small for on-slit background subtraction, we have subtracted the expected background flux...
through each slit based on the model of Reach et al. (2004). The LH data went through an additional cleaning step to remove residual hot pixels, which uses the B-mask (supplied with the Basic Calibrated Data [BCD]) and the warm pixel mask for the given IRS campaign. Hot pixels were interpolated over spatially by using the two nod positions, before extraction from two-dimensional to one-dimensional spectra. For a full description of this method, see D. Devost et al. (2006, in preparation). The SH and LH spectra were then scaled to the corresponding IRS low-resolution spectra, using a single scale factor for each module. The scale factors were 1.15 and 1.07 for SH and LH, respectively. The high-resolution IRS spectra are shown in Figures 1b and 1c.

4. RESULTS

4.1. Continuum and Dust Features

The IRS low-resolution spectrum of NGC 6240 shows a steeply rising continuum, heavily absorbed at 10 and 18 μm by amorphous silicates (Fig. 1a). There is little or no water ice or hydrocarbon absorption from 5–7.5 μm, as is seen in some nearby ULIRGs, e.g., UGC 5101 (Armus et al. 2004). Broad PAH emission features at 6.2, 7.7, 11.3, and 12.6 μm are visible. In addition, we detect the much fainter 16.4 and 17.4 μm PAH features, along with the broad “plateau” between 16 and 18 μm, which are seen in some ULIRGs and nearby starburst galaxies (Sturm et al. 2000; Armus et al. 2004; Smith et al. 2004; Brandl et al. 2006). The very weak unidentified infrared band (UIB) at 14.22 μm (see § 4.2) may also be produced by polycyclic aromatic hydrocarbons.

To estimate the contribution of dust emission at different temperatures to the luminosity of NGC 6240, and to accurately measure the strengths of the PAH emission features against the underlying, silicate-absorbed continuum, we have fit the spectral energy distribution (SED) with a multicomponent model that includes at least two graphite and silicate dust grain components, PAH emission features (fit with Drude profiles), a 3500 K black-body stellar component, and unresolved Gaussian emission lines (to fit the fine-structure and H2 lines). To extend the SED, we have added near-infrared, far-infrared, and submillimeter data to the IRS low-resolution spectra. The near-infrared photometry is from Scoville et al. (2000), the 60 and 100 μm data are from the IRAS Faint Source Catalog (Moshir et al. 1990), the 120, 150, 200, 450, and 850 μm data are from Klaas et al. (2001), and the 350 μm data are from Benford (1999). Our fit to the NGC 6240 SED is shown in Figure 2. For a full description of this model fitting, see J. A. Marshall et al. (2006, in preparation).

Three dust components are required to fit the NGC 6240 continuum spectrum. The characteristic temperatures of the three components are 27.1 ± 0.3 K (cold), 81.4 ± 1.8 K (warm), and 680 ± 12 K (hot). Each component is composed of graphite and silicate grains (with optical properties from Draine & Lee 1984), distributed in size according to the $R'_V = 3.1$ model of Weingartner & Draine (2001). The hot and warm components are modeled as spherically symmetric dust shells that are optically thin in the mid-infrared. The dust grains are distributed with uniform density around the central source, out to a distance of 10 radial scale factors (where the unit radius is taken to be the distance at which the equilibrium temperature of the grains is equal to the component temperature). The temperatures of all grains are calculated as a function of their size, composition, and distance from the illuminating source. Grain sublimation is taken into account, so that the size distribution can vary with radial distance from the central source, depending upon the temperature of the grains. The cold component is modeled as a distribution of grains immersed in a single radiation field (i.e., they are not radially distributed from a central source). As such, the grains in this component have a range of temperatures due to their varying composition and sizes, but not due to their spatial distribution. It is presumed that the cold dust is responsible for the absorption of photons from the hot and warm components. Nonetheless, the emission from the cold grains is treated as optically thin, since they are sufficiently cold to radiate predominantly at far-infrared wavelengths, where their opacity is extremely small. Note that the range of grain temperatures due to the distribution of grain sizes in the cold component produces an SED that is wider than that obtained with an average grain graybody of the same temperature. In this treatment, there is therefore not a unique temperature associated with each component, as there is in a graybody model. We instead define a “characteristic” temperature of a component to be the temperature of the most luminous grain size at the distance from the source contributing the majority of the luminosity. This luminosity-dominating distance corresponds to $τ_{UV} ≈ 0.5$,
where approximately half of the UV-source photons have been absorbed. Each component therefore contains dust above and below the characteristic temperature. With this definition, the characteristic temperature roughly corresponds to the expected peak in the dust-modified Planck function.

A hot dust component with a characteristic temperature of about 700 K, as we have found in NGC 6240, implies the existence of a significant number of grains near sublimation. As suggested by Laurent et al. (2000), an excess of hot dust can be taken as evidence for grains heated close to sublimation in the presence of an AGN. In NGC 6240, the presence of this hot dust together with the high ionization lines discussed below are consistent with this interpretation. The hottest grains in thermal equilibrium in the $T = 680$ K dust component, if illuminated with an AGN-like spectrum (Sanders et al. 1988) having the bolometric luminosity of NGC 6240, would be at a distance of about 1 pc from the central source. The hot component accounts for approximately 3.5% of the bolometric luminosity in NGC 6240.

The optical depths to both the hot and cold dust components are essentially zero, while the screen optical depth to the warm component is $\tau_w = 5.2 \pm 0.1$ (effectively the silicate optical depth, since this component dominates at $9.7 \, \mu m$), implying an $A_v \sim 95 \pm 2$ mag. This is about a factor of 3 larger than the lower limit that would be derived from a smooth continuum fit anchored at $5.3-5.6, 14,$ and $34 \, \mu m$, since the unextinguished model continuum at $9.7 \, \mu m$ is dominated by silicate emission. The warm component accounts for about 26% of the bolometric luminosity before correcting for extinction and about 80% after correcting for this extinction.

While a multicomponent SED fit is never “unique,” we have compared our best fit to alternative models that exclude a hot dust component and that tie the optical depth to the hot dust at the value derived for the warm component. The latter is most similar to a spherical-shell model in which the hot dust is closest to the (obscured) nucleus, and the coldest dust is responsible for most of the obscuration along the line of sight. Both of these constrained fits produce significantly poorer results, producing reduced $\chi^2$ values that are between 50% and a factor of 2 larger than our preferred, three-component fit described above.

Fits to the multiple PAH emission features in NGC 6240 result in 6.2/7.7 and 11.3/7.7 flux ratios of 0.21 and 0.25, respectively, suggesting a mix of neutral and ionized grains with between 200 and 400 carbon atoms each (Draine & Li 2001). The 6.2/7.7 flux ratio is between that found for NGC 253 and the Circinus galaxy, whereas the 11.3/7.7 flux ratio is about a factor of 2 larger (Sturm et al. 2000; Draine & Li). The 6.2 $\mu m$ PAH equivalent width (EQW) is 0.52, about 20%–30% smaller than what is found for pure starburst galaxies (Brandl et al. 2006), but much larger (a factor of 5–10) than is found for AGNs. The PAH-to-$L_{IR}$ luminosity ratio is about 0.023. In all cases, the extinction to the PAH features is assumed to be zero, as in a model in which the emission arises from an extended region seen against a (partially) obscured continuum. Note that our multiple component continuum fits produce significantly larger PAH flux in features (e.g., the 7.7, 8.6, and 11.3 $\mu m$ features) that are most affected by silicate absorptions than do other methods that employ spline fits to the observed continuum, even those anchored at relatively “clean” parts of the spectrum. However, the fitting we have used to derive the PAH fluxes in Table 1 are directly comparable to the Draine & Li (2001) models. This will be discussed fully in J. A. Marshall et al. (2006, in preparation).

4.2. Emission Lines

The IRS Short-High and Long-High spectra of NGC 6240 are dominated by unresolved atomic, fine-structure lines of Ne, O, S, and Fe, covering a large range in ionization potential, (Figs. 1b and 1c and Table 1). The [Fe II] lines at 5.34 and 25.99 $\mu m$ (partially blended with [O IV] 25.89 $\mu m$) are particularly strong in NGC 6240 when compared to other ULIRGs and starburst galaxies, as has been noted by Lutz et al. (2003). We also detect a faint feature at $\sim 17.9 \, \mu m$, which we attribute to [Fe II] emission. Grain destruction, possibly in the starburst-driven supernova, is likely the source of the increased gas-phase Fe abundance in the cooling interstellar medium (ISM) in NGC 6240 (Draine & Woods 1990).

The most striking feature of the NGC 6240 spectrum is the strength of the pure rotational emission lines of H$_2$. As noted by Draine & Woods (1990), based primarily upon the strength of the near-infrared H$_2$ lines, NGC 6240 has both the largest H$_2$ line luminosity and the largest ratio of H$_2$-to-infrared luminosity, of any known galaxy. In the IRS spectrum, we detect the $S(0)$ through $S(7)$ lines (see Table 1), except for $S(6)$, which is blended with the 6.2 $\mu m$ PAH emission feature. The line flux we measure for the $S(0)$ line is $8.6(\pm 2.4) \times 10^{-14}$ ergs cm$^{-2}$ s$^{-1}$, consistent with the upper limit ($< 22 \times 10^{-14}$ ergs cm$^{-2}$ s$^{-1}$) in Lutz et al. (2003). The H$_2$ excitation level diagram (Fig. 3) provides strong evidence for multiple temperature components in NGC 6240, a fact noted previously by Lutz et al. Fitting the $S(3)$ through $S(7)$ features, we derive a gas temperature of $T \sim 957$ K and a mass of $9.5 \times 10^6 M_{\odot}$ for this warm component. Subtracting this fit off the lower excitation lines, we can then fit the $S(0)$ and $S(1)$ lines and derive a gas temperature of $T \sim 164$ K and a corresponding mass of $1.6 \times 10^9 M_{\odot}$. In all cases an ortho-to-para ratio of 3 is assumed. Obviously the coldest component dominates the mass of “warm” H$_2$ in NGC 6240.

A mass of $1.6 \times 10^9 M_{\odot}$ is about 15% of the molecular gas mass derived from single-dish millimeter CO line measurements by Solomon et al. (1997). However, it is about 50% of the cold molecular gas, or about $\frac{1}{4}$ the total (warm plus cold) molecular gas mass, within the central 1 kpc as measured by Tacconi et al. (1999), which is itself about 50% of the dynamical mass within the central 1 kpc. The cold gas, as well as the warmer gas traced by the near-infrared $1-0 S(1)$ line (Tecza et al. 2000), is actually centered between the two nuclei in NGC 6240, the latter presumably thermally excited via slow shocks triggered by either the interaction or the outflowing wind (Tecza et al. 2000; Van der Werf 1996; Egami et al.). Although we have no spatial information on the H$_2$ emission in our IRS spectrum, the deconvolved line widths are comparable to those measured by Tecza et al. (500–600 km s$^{-1}$), suggesting that much of the warm molecular gas we measure is associated with the centrally concentrated gas seen by Tacconi et al. and Tecza et al. between the two nuclei.

The strongest H$_2$ line in our IRS spectrum, the 0–0 $S(5)$ transition at 6.9 $\mu m$, has a flux a factor of $\sim 4$–5 times larger than that of the near-infrared 1–0 $S(1)$ line (Rieke et al. 1985; Herbst et al. 1990; Fischer et al. 1990). The mid-infrared H$_2$ emission lines listed in Table 1 alone account for about 0.16% of the total energy output of NGC 6240. The model proposed by Draine & Woods (1990) for the strong H$_2$ emission in NGC 6240, that of thermal emission from gas heated by X-rays, also predicts a 16.33 $\mu m$ H$_2$ rotational feature with a flux of $\sim 2.5 \times 10^{-14}$ ergs cm$^{-2}$ s$^{-1}$. This feature is unique to the X-ray heating model. Unfortunately, this key diagnostic falls near the broad PAH emission feature at 16.4 $\mu m$, which is clearly seen in our IRS spectrum. Since our limits for unresolved features in this part of the spectrum are about $3 \times 10^{-14}$ ergs cm$^{-2}$ s$^{-1}$, even without the presence of the PAH emission, we cannot confirm or rule out the presence of the H$_2$ line at the level predicted by Draine & Woods.
Most of the emission lines are resolved in our SH and LH spectra, with the bright lines having an average line width of ~680 km s\(^{-1}\), corrected for instrumental broadening, comparable to the line widths reported by Lutz et al. (2003) from their SWS spectra. There is no obvious trend of increased line width with wavelength.

Ratios of the mid-infrared atomic fine-structure emission lines can be used to characterize the source of the UV photons that ionize the gas and heat the dust (Genzel et al. 1998; Lutz et al. 1998; Sturm et al. 2002; Verma et al. 2003). Some features, e.g., the [Ne \(v\)] lines at 14.3 and 24.3 \(\mu\)m, imply the presence of an AGN, since the ionization potential (97.1 eV) is too large to be produced by main-sequence stars. The same is not true for [O \(\text{iv}\)] since it takes only 55 eV to ionize O\(^{++}\). While the 25.89 \(\mu\)m line flux ratio is 0.12. The [S \(\text{iii}\)] 18.7/[S \(\text{ii}\)] 33.4 line flux ratio (0.75) suggests an electron density of \(n_e \sim 400 \text{ cm}^{-3}\) in the ionized nebula, for \(T = 10^4 \text{ K}\).

An expanded view of the rest-frame 13.7–15.0 \(\mu\)m region in NGC 6240 (order 14 from the SH spectrum) is shown in Figure 4a.

### Table 1: Emission Features

| Feature ID | \(\lambda_{\text{rest}}\) (\(\mu\)m) | Flux \(\times 10^{-14} \text{ ergs cm}^{-2} \text{s}^{-1}\) | EQW (\(\mu\)m) | FWHM (km s\(^{-1}\)) |
|------------|-----------------|-----------------|--------------|-----------------|
| [Fe \(\text{ii}\)] | 5.34 | 18.9 (6.9) | 0.024 (0.009) | ... |
| H\(_{2}\) \(\text{S}(7)\) | 5.51 | 33.7 (12.5) | 0.042 (0.015) | ... |
| PAH | 6.2 | 399 (44) | 0.52 (0.6) | ... |
| H\(_{2}\) \(\text{S}(5)\) | 6.90 | 95.2 (16.6) | 0.095 (0.016) | ... |
| [Ar \(\text{ii}\)] | 6.98 | 57.0 (15.5) | 0.057 (0.015) | ... |
| PAH | 7.7 | 1876 (212) | 2.60 (0.28) | ... |
| H\(_{2}\) \(\text{S}(4)\) | 8.025 | 36.4 (10.8) | 0.058 (0.017) | ... |
| PAH | 8.6 | 43 (43) | 1.35 (0.13) | ... |
| H\(_{2}\) \(\text{S}(3)\) | 9.665 | 70.9 (1.9) | 0.2393 (0.0041) | 570 (60) |
| [S \(\text{iv}\)] | 10.51 | 3.8 (0.3) | 0.0099 (0.0004) | 411 (60) |
| PAH | 11.3 | 475 (31) | 1.61 (0.10) | ... |
| H\(_{2}\) \(\text{S}(2)\) | 12.279 | 39.8 (0.5) | 0.0334 (0.0007) | 542 (60) |
| PAH | 12.6 | 522 (90) | 0.78 (0.14) | ... |
| [Ne \(\text{i}\)] | 12.814 | 193.1 (3.7) | 0.1198 (0.0018) | 799 (60) |
| PAH | 14.2 | 5.8 (1.1) | 0.005 (0.001) | ... |
| [Ne \(\text{v}\)] | 14.322 | 5.1 (0.9) | 0.0087 (0.0008) | ... |
| [Cl \(\text{ii}\)] | 14.368 | 3.6 (1.0) | 0.0072 (0.0009) | ... |
| [Ne \(\text{iii}\)] \(\text{(1)}\) | 15.555 | 70.4 (2.4) | 0.0625 (0.0019) | 828 (60) |
| PAH | 16.4 | 22.4 (0.8) | 0.0198 (0.0008) | ... |
| H\(_{2}\) \(\text{S}(1)\) | 17.03 | 50.4 (1.5) | 0.0423 (0.0017) | 585 (60) |
| PAH | 17.4 | 7.3 (1.0) | 0.0055 (0.0010) | ... |
| [Fe \(\text{ii}\)] | 17.934 | 4.6 (0.7) | 0.0039 (0.0006) | 657 (62) |
| [S \(\text{ii}\)] | 18.713 | 19.9 (1.4) | 0.0178 (0.0022) | 810 (120) |
| [Ne \(\text{v}\)] | 24.318 | <3.9 | <0.0021 | ... |
| [O \(\text{iv}\)] \(\text{(10)}\) | 25.890 | 27.2 (0.7) | 0.0234 (0.0006) | 674 (60) |
| [Fe \(\text{ii}\)] | 25.988 | 23.1 (0.1) | 0.0210 (0.0003) | 624 (60) |
| H\(_{2}\) \(\text{S}(0)\) | 28.218 | 8.6 (1.2) | 0.0032 (0.0004) | 439 (90) |
| [S \(\text{iii}\)] | 33.481 | 26.3 (8.4) | 0.0093 (0.0030) | 537 (60) |
| [Si \(\text{ii}\)] | 34.815 | 268.9 (10.1) | 0.0981 (0.0005) | 823 (60) |

**Notes.** Line fluxes and rest-frame equivalent widths for lines as measured in the IRS spectra. Uncertainties in the line fits (all single Gaussians except where noted) are listed in parentheses. In all cases, except for the [Ne \(\text{v}\)] 14.32 and [Cl \(\text{ii}\)] 14.36 lines, these uncertainties are the larger of either the Gaussian fit or the difference in the two nod positions. For [Ne \(\text{v}\)] 14.32 and [Cl \(\text{ii}\)] 14.36, the quoted errors are conservatively estimated at 20%. The FWHM reported in column five is from a Gaussian fit to the SH or LH data, after removal of the instrumental profile, in quadrature. In all cases the error given for the FWHM is the larger of either the fit or the known dispersion due to order curvature and undersampling (~60 km s\(^{-1}\)). FWHM are not listed for unresolved emission lines measured only in the SL data (those with wavelengths of \(\lambda < 9.6 \mu\)m), or for the PAH features. All lines were measured using the SMART spectral reduction package (Higdon et al. 2004), except for the PAH features which were measured as a product of the multicomponent model fits described in the text.

![Figure 3](https://example.com/figure3.png)

**Figure 3.** \(\text{H}_2\) excitation diagram for NGC 6240, showing for the lines observed with the IRS the upper level population divided by the level degeneracy as a function of upper level energy. The lines have not been corrected for extinction. Errors are indicated as vertical bars for each line. The fits to the hot (\(T \sim 957\) K) and cold (\(T \sim 164\) K) components are indicated by a dotted and a dashed line, respectively.
We have detected the [Ne v] emission line in the IRS spectrum of NGC 6240. This is the first reported detection of this feature, and it provides a direct measure of the buried AGN. Although NGC 6240 does exhibit large-scale shocks from the supernovae, it is unlikely that these shocks contribute to the [Ne v] emission. As pointed out by Voit (1992), shock models tend to enhance the low-ionization lines (e.g., [Ne ii] or [Si ii]). While our measured [Ne ii] 12.8/[Ne iii] 15.55 line flux ratio of 2.8 is larger than that found in most pure AGN models (Voit 1992), it is much lower than is typically found in shocks, where [Ne ii]/[Ne iii] \( \geq 10 \) (Binette et al. 1985). It is, however, completely consistent with a moderate-excitation starburst galaxy (Thomley et al. 2000; Verma et al. 2003). We therefore favor a model in which the [Ne v] emission in NGC 6240 comes from a coronal-line region in close proximity to one or both of the active nuclei and most of the observed [Ne ii] and [Ne iii] emission is dominated by the surrounding starburst.

Pure AGNs and AGN-dominated ULIRGs typically have [Ne v]/[Ne ii] and [O iv]/[Ne ii] line flux ratios of 0.8–2 and 1–5, respectively (Sturm et al. 2002; Armus et al. 2004). Starburst galaxies, on the other hand, typically have stringent upper limits on [Ne v]/[Ne ii] < 0.01, yet a large range in [O iv]/[Ne ii] flux ratios, from 0.01–0.2 (Sturm et al. 2002; Verma et al. 2003; D. Devost et al., in preparation). Therefore, both the [Ne v]/[Ne ii] and [O iv]/[Ne ii] line flux ratios in NGC 6240 are significantly below the AGN values, while the [O iv]/[Ne ii] ratio is on the high end, but still consistent with that found in some high-excitation starburst galaxies. If we use a simple linear mixing model (e.g., Sturm et al. 2002) in which the observed values of [Ne v]/[Ne ii] and [O iv]/[Ne ii] seen in NGC 6240 are due to “excess” [Ne ii] from the starburst, then both line ratios imply an apparent AGN contribution of about 3%–5% to the bolometric luminosity. The detection of a hot dust component, which is not seen in IRS spectra of starburst galaxies (Brandl et al. 2006) and which is responsible for \( \sim 3\%–4\% \) of the bolometric luminosity, is additional indirect evidence for the buried AGN.

Fits to the BeppoSAX hard X-ray spectrum (Vignati et al. 1999) suggest an H i column density toward the active nucleus of \( 1\times10^{23} \) cm\(^{-2} \), or an \( A_V \sim 500–1000 \) mag. Correcting for this H i column implies an intrinsic 2–10 keV, hard X-ray–to–bolometric luminosity of 0.7–2 \( \times 10^{44} \) erg s\(^{-1} \), or a hard X-ray–to–bolometric luminosity ratio of \( \sim 0.025–0.075 \), depending on the unknown fraction of the X-ray flux that is reflected. This range is comparable to other AGNs, which typically have hard X-ray–to–bolometric flux ratios of 0.01–0.2 (see Ptak et al. [2003] for a summary), suggesting that NGC 6240 has a rather “normal” hard X-ray–to–bolometric luminosity ratio for an AGN (Vignati et al. 1999). The extinction-corrected, hard X-ray data are therefore consistent with the buried AGN producing anywhere from 10%–100% of the luminosity in NGC 6240, with the larger values much more likely. Note that the typical (Elvis et al. 1994) QSO luminosity ratio is about 0.03.

While the [Ne v]/[Ne ii] line flux ratio is often treated as reddening independent, this is not strictly true. Since the [Ne v] is coming from gas directly heated by the AGN, while the [Ne ii] can be dominated by the extended starburst, the distribution of the dust in NGC 6240 (and other ULIRGs) can have a significant effect on the measured [Ne v]/[Ne ii] emission-line flux ratio. This effect would typically be to lower the observed ratio, causing ULIRGs to look more starburst-like. Could the low [Ne v] flux in NGC 6240 be the result of the large extinction implied by the X-ray spectrum? Correcting the measured [Ne v] emission by an \( A_V = 1000 \) mag would produce an intrinsic [Ne v]/IR flux ratio
in NGC 6240 well above any other known AGN or ULIRG, so the hard X-ray–derived extinction is not applicable. From our SED fit, the extinction to the warm dust is $A_V/C_{24}$ = 95 mag. While large, this is still likely to be a lower limit to some lines of sight to the circumnuclear region directly excited by the AGN. However, if we assume $A_V$ = 95 mag to the coronal line region and an intrinsic $[\text{Ne}\,\text{v}]/[\text{Ne}\,\text{ii}]$ line flux ratio of 1.0 for this AGN-heated gas, we derive a corrected $[\text{Ne}\,\text{v}]/[\text{Ne}\,\text{ii}]$ ratio of 0.24 (or 0.20 if we also extinction correct the $[\text{Ne}\,\text{ii}]$ that is excited by the AGN). This implies the “intrinsic” AGN contribution is likely to be between 20% and 24%, a number that is within the range estimated from the fits to the extinction-corrected, hard X-ray data.

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