SEARCHING FOR AGN SIGNATURES IN MID-IR SPECTRA: THE CASE OF NGC1068

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ABSTRACT

We present mid-IR observations of the prototypical Seyfert 2 galaxy NGC 1068 obtained with ISOCAM between 5 and 16 μm. The proximity of this galaxy coupled with the spectro-imaging capabilities of the instrument allow us to separate the mid-IR emission of the active galactic nucleus (AGN) from the distinctly different emission of the circumnuclear star forming regions. The Unidentified Infrared Bands (UIBs), which trace the starburst contribution very well, are not detected in the spectrum of the AGN region where their carriers could be destroyed. Moreover, the featureless continuum of the AGN exhibits a strong hot dust component below 10 μm not observed in the starburst regions. Those two distinct mid-IR spectral properties, as well as the presence of high excitation ionic lines such as [NeVI](7.7 μm) and [NeV](14.3 μm) in the AGN spectrum, provide us with very powerful complementary tools to disentangle AGNs from starbursts. The effects of high extinction on the mid-IR identification of AGNs are also discussed.

Key words: Galaxies: active – Galaxies: starburst

1. INTRODUCTION

The understanding of energetic phenomena due to star formation and/or an AGN observed in nearby galaxies is of crucial importance to explaining the output luminosity produced by ultra-luminous infrared galaxies (LIR>1012L⊙, see Sanders & Mirabel 1996 for a review). Recent studies based on near-IR, mid-IR [Murphy et al. 1999, Soifer et al. 2000, Genzel & Cesarsky 2000], and X-ray [Risaliti et al. 2000] observations indicate that those galaxies are probably dominated by starbursts over their global infrared luminosity, even though weak AGNs may still be present in most of them. The possible detection of weak AGNs in all ultra-luminous galaxies is still plausible and necessitates powerful diagnostics.

In this paper, we examine the mid-IR spectral properties observed in the central region of the prototypical Seyfert 2 galaxy NGC 1068 (Le Floc’h et al. 2000). Due to the proximity of this galaxy (14.4 Mpc, 1″=72 pc), we can disentangle the AGN from the star formation regions found at 20″ from the nucleus. A comparative study of their respective mid-IR emission will be presented in order to point out, in a more general way, different methods for distinguishing an AGN within a dominant starburst environment.

2. OBSERVATIONS

The galaxy NGC 1068 was observed with the ISOCAM camera [Cesarsky et al. 1996] on board the Infrared Space Observatory (ISO, Kessler et al. 1996). It is part of the active galaxy proposal CAMACTIV (P.I. I.F. Mirabel), which contains 29 nearby galaxies hosting star formation activity and AGN signatures (see Laurent et al. 2000). We have used the circular variable filter (CVF) for mapping the central region of NGC 1068 (96″×96″) continuously from 5 to 16 μm with a spectral resolution of ∼40. The data reduction was performed with the CAM Interactive Analysis software (CIA) and calibration followed the general methods described in Starck et al. (1999). In addition, the jitter effect due to the satellite motions (amplitude ∼0.5 arcsec) which severely affects the flux distribution of the bright point-like nucleus was corrected using shifting techniques. We also applied aperture corrections to account for the overall extension of the PSF. The absolute uncertainty of our photometric measurements is ∼20%, while the error in the relative flux uncertainty mainly due to limitations on transient effect correction is ∼10%.

3. AGN AND STARBURST MID-IR EMISSION

In Figure 1, we present mid-IR spectra and images of NGC 1068 obtained with ISOCAM. The emission between 5 and 16 μm is clearly dominated by the AGN. Nevertheless, faint extended starburst emission is observed along the northeast-southwest axis (see upper and lower right panels). One may notice that the AGN and the faint surrounding starburst have distinctly different mid-IR properties:

- The most striking difference is the absence of the family of UIBs at 6.2, 7.7, 8.6, 11.3, and 12.7 μm in the AGN spectrum. The UIBs originate mainly from photodissociation regions surrounding HII regions, and as a

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Figure 1. Mid-IR spectro-imaging observations of NGC 1068 with ISOCAM. Upper left panel: HST optical image (660 nm) with the ISOCAM field of view superimposed. Upper right panel: ISOCAM image and contours in the 5-8.5 μm band which traces the intense UIB emission at 7.7 μm as well as the AGN continuum. Middle panel: Dashed line: Total integrated spectrum of the galaxy (∼40″, 29 kpc in diameter). Thick line: Spectrum of the nuclear region (∼9″, 0.7 kpc in diameter) composed of a strong featureless continuum and high excitation ionic lines ([NeV], [NeVI]). Dotted line: Spectrum of the extended star forming regions (40″<Diameter<9″) characterized by strong UIBs compared to the continuum. Lower left panel: Image of the hot continuum emission originating essentially from the AGN, and defined as being under the straight line between 7.3 and 8.2 μm. Lower right panel: Image of UIB emission above the straight line between 7.3 and 8.2 μm, tracing the starburst regions. The contours are from the deconvolved 7.7 μm map (LW6(7-8.5 μm) filter), which allows us to separate the strong AGN contamination from the starburst emission. Note that the two methods (spatial deconvolution and 7.7 μm UIB map) used for spatially separating the faint starburst emission are in good agreement.
Table 1. Spectral properties of AGNs and starbursts in the mid-IR between 5 and 16 µm.

| GAS     | [ArII] | [NeII] | [ArIII] | [SiV] | [NeVII] |
|---------|--------|--------|---------|-------|---------|
| Ep(eV)  | 16     | 22     | 28      | 35    | 41      |
| λ (µm)  | 6.99   | 12.81  | 8.99    | 10.51 | 15.55   |

| DUST    |        |        |         |       |         |
|---------|--------|--------|---------|-------|---------|
|        | Very small grain continuum at 10-16µm originating mainly from HII regions. | | | | |

| UIBs    | UIBS at 6.2, 7.7, 8.6, 11.3 and 12.7µm produced mainly in photo-dissociation regions surrounding the HII regions. | | | | |

| AGN     |        |        |         |       |         |
|---------|--------|--------|---------|-------|---------|
|        | Hot dust continuum at 5-16µm from the dusty torus heated by the AGN radiation field. | | | | |

|        | Absence of UIBs probably due to the destruction of their carriers by the intense UV/X-ray radiation field of the AGN. | | | | |

- The AGN spectrum presents a noticeable continuum at short wavelengths (5-10 µm), commonly attributed to hot dust, associated with the torus of molecular gas proposed in the unified model (Pier & Krolik 1992, Granato et al. 1997, Contursi 1998). Some intense HII regions present a similar continuum, but only in regions of a few parsecs in size located close to hot stars with up to 10^6 times the solar radiation field (see Contursi 1998). Nevertheless, this continuum has never been reported in starburst regions on large spatial scales (>100 pc), and thus its presence constitutes very strong evidence for an AGN.

- The large variety of ionic emission lines, with ionization potential ranging from 22 eV for [ArII] up to 126 eV for [NeVI] can be used to estimate the hardness of the radiation field (see Table 1). Highly ionized species tracing the hard radiation field of the AGN (e.g. [NeV]14.3 µm and [NeVI]7.6 µm) are detected in NGC 1068. However, due to the low spectral resolution of ISOCAM spectra (λ/Δλ ~ 40), their detection in other nearby AGNs is still difficult and requires higher resolution (Sturm et al. 2000). The [NeV] emission line can also be induced by shocks such as those created by supernova remnants (SNRs). The very weak mid-IR continuum associated with SNRs, though rules out the possibility that there is a strong contribution of SNRs to the AGN environment (Oliva et al. 1999), and the detection of these lines still represents the most direct way of identifying AGNs.

In the following section, we discuss how dust extinction in starbursts and AGNs may lead us to underestimate the AGN component.

4. THE EFFECTS OF EXTINCTION

According to the unified picture of AGNs proposed by Antonucci & Miller (1985), the central engine (a massive black hole accreting material) is surrounded by a dusty molecular torus. The additional absorption caused by this torus would normally decrease the intrinsic luminosity of the AGN compared to the adjacent starburst regions. This leads to the Seyfert 2/Seyfert 1 optical classification, depending on whether the torus is observed edge-on or face-on. Studying a sample of 28 Seyfert 1 and 29 Seyfert 2 galaxies with ISOPHOT-S, Schulz et al. (1998) have already shown that the high absorption in Seyfert 2 galaxies blocks a large fraction (90% on average) of the mid-IR continuum from the AGN inner torus. In Figure 2, we show the consequences for the mid-IR spectrum if additional extinction is applied to the AGN continuum of NGC 1068. As the extinction increases, the continuum at 5-10 µm, used as a good AGN indicator, becomes less detectable than the UIB emission, causing us to classify this galaxy as dominated by a starburst above A_v=100.

5. SIRTF/IRS PERSPECTIVES

Thanks to ISO, our knowledge of the mid-IR properties of starbursts and AGNs has been substantially improved through observations of nearby prototypical objects. In particular, different diagnostics were developed to obtain a quantitative classification of starburst and AGN-dominated galaxies using their mid-IR emission. A faint UIB to continuum ratio (Genzel et al. 1999) and the detection of a strong continuum at 5 µm (Lutz et al. 1998, Laurent et al. 2000) are only observed in galaxies containing an AGN. Nevertheless, the accuracy of the estimate depends strongly on the signal to noise of the spectra (see for example Fig. 3). Another diagnostic for distinguishing AGNs from starbursts is the ratios of high to low excitation ion
Figure 2. Extinction effects on the AGN continuum of NGC 1068. From left to right, the AGN continuum is reddened by 20, 50 and 100 mag respectively, using a screen model with the extinction law of Lutz et al. (1996). Note how the estimated contribution of the AGN to the total mid-IR decreases and the galaxy evolves from an AGN-dominated (87\%) to a starburst-dominated system (47\%).

Figure 3. ISO-CAM spectrum of the AGN in Circinus (Moorwood (1999), dashed line, 4.5′′×4.5′′). Note how the strong silicate absorption makes difficult the distinction between an obscured AGN continuum and a strong UIB feature at 7.7µm, in particular for an observation with a low signal to noise (solid line, σ_{noise}=1 Jy)

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lines, such as [NeV]/[NeII] or [OIV]/[NeII], which probe the hardness of the radiation field (Genzel et al. 1998). However, the detection of the [NeV] and [OIV] emission lines with ISO-SWS, which directly traces the presence of the AGN, is still limited to very nearby luminous objects. SIRTF, the next infrared space telescope, which directly traces the presence of weak AGNs in luminous galaxies. The use of emission line ratios such as [SIII]18.7µm/[SIII]33.5µm (Genzel et al. 1995) or the 7.7UiB/6.2UiB ratio (Rigopoulou et al. 1999) will also provide us other independent estimates of absorption in a larger sample of active galaxies. Furthermore, the full coverage from 5.3 to 40 µm will permit us to better estimate the effects of the absorption using the 9.7 and 18 µm silicate features as well as reveal the presence of a faint hot dust contribution associated with intrinsically weak or obscured AGNs.
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