THE MID-INFRARED SPECTRAL PROPERTIES OF STARBURST GALAXIES AND AGNS SEEN BY ISOCAM

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ABSTRACT

We present a new diagnostic tool based on mid-IR spectra (5-16 μm) to distinguish the emission triggered by an active galactic nucleus (AGN) from that associated with star formation activity. Mid-IR emission in galaxies integrated over large regions (from 100 pc to several kpc) can be understood as a mixing of three components (HII regions, diffuse/photodissociation regions (PDRs), and AGN). We show that AGN spectra, contrary to starburst spectra, present an important continuum below 9 μm emitted by hot dust and an absence of Unidentified Infrared Bands (UIBs) probably destroyed by photodissociation mechanism in the AGN radiation field. The diagnostic diagram derived from these features can be used to detect obscured AGNs embedded in a large concentration of dust.

Key words: galaxy; mid-infrared; active galactic nucleus; starburst

1. INTRODUCTION

Since the discovery of ultraluminous infrared galaxies (L(8-1000μm) > 10^{12}L$_\odot$) which emit the bulk of their energy in the infrared, different studies have shown that intense star formation regions as well as AGNs are necessary to explain these high luminosities (see Sanders & Mirabel 1996 for a review). Since a great amount of molecular gas is needed for fuelling nuclear starbursts and/or AGNs, these regions are usually embedded in a large concentration of dust producing a heavy obscuration. Consequently, the absorption makes the distinction between starburst and AGN activities difficult and the main problem, not yet fully resolved, concerns the estimation of their relative contributions to the total infrared luminosity. We have observed at mid-IR wavelengths ($A_V/A_{8\,\mu m}$~50) for penetrating obscured regions not visible at optical wavelengths (Mirabel et al. 1998a). In addition, at these wavelengths (5-16 μm), we detect dust emission heated preferentially by AGNs or young stars (Mirabel et al. 1998b). We address the question of the distinction between AGNs and starbursts by presenting a new diagnostic for estimating the relative importance of these two main energy sources found in galactic centers.

2. OBSERVATIONS

A sample of 22 nearby active/interacting galaxies was observed in spectro-imaging mode with the ISOCAM camera on board the Infrared Space Observatory (ISO) (Cesarsky et al. 1996a, Kessler et al. 1996). The standard data reduction was applied using the CAM Interactive Analysis (CIA)[1] software. Each galaxy was fully mapped in the wavelength band covering 5-16 μm.

3. AGN AND STARBURST SPECTRA

The imaging capabilities of the camera, which provides an angular resolution of 5 arcsec, have been fully operated in observing nearby prototype active galaxies: NGC 5128 (Mirabel et al. 1998b) and NGC 1068. Thanks to the good spatial resolution obtained at these wavelengths (~100-400 pc with FWHM = 5 arcsec), we have been able to differentiate the mid-IR emission produced by the AGN from the one produced by the circumnuclear star forming regions (see Figure 1). In addition, observations of nearby star forming galactic regions were used to identify the typical mid-IR emission of a pure ionized region (HII) heated by OB stars in M17 (Cesarsky et al. 1996b) as well as that of the interface called photo-dissociation region (PDR) between HII regions and molecular clouds in NGC 7023 (Cesarsky et al. 1996c). Assuming that galaxy spectra are composed over large spatial scales of a mixing of HII region, PDR and (if it exists) AGN spectra which are similar to these three mid-IR templates, we can decompose the emission originating from larger regions observed in our galaxy sample.

3.1. Distinction between AGN, HII and PDRs

The UIBs at 6.2, 7.7, 8.6, 11.3 and 12.7 μm presented in Figure 1 are probably emitted by complex 2-dimensional molecules with C-C and C-H bonds that have been commonly called polycyclic aromatic hydrocarbons (PAHs) (see Puget & Léger 1989 for a

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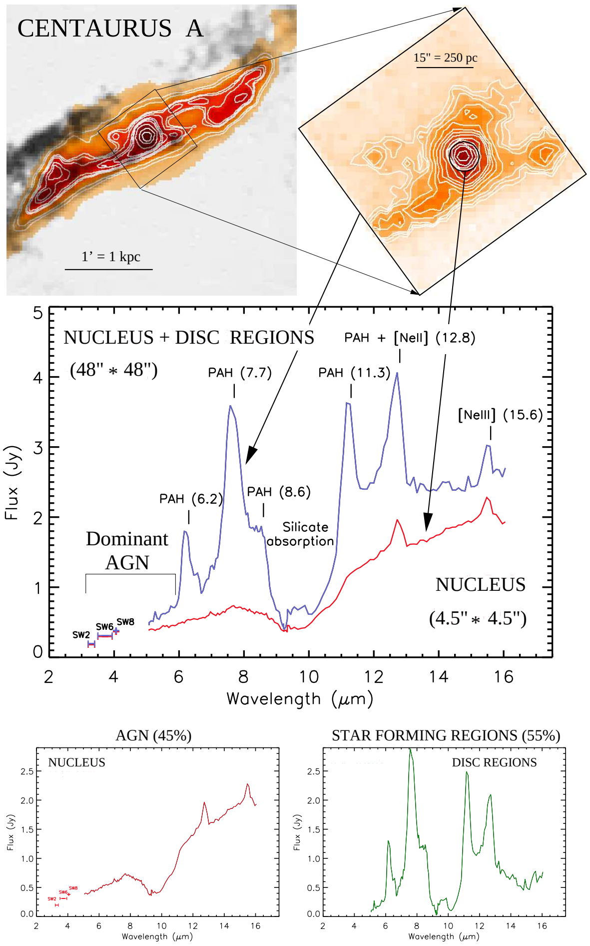

Figure 1. Upper left panel: Distribution of dust in the inner region of CenA observed at 7 μm (contours) with optical dark lanes superimposed. Upper right panel: Map between 8.2 and 8.7 μm of the nuclear region observed in spectro-imaging mode with the CVF (Circular Variable Filter) where we observe the nucleus as well as a part of the disc structure. The spatial resolution achieved is 100 pc (FWHM = 5 arcsec). Middle panel: The lower curve represents the mid-IR spectrum covering the nuclear region (100 pc in diameter) whereas the upper curve shows the spectrum integrated over a larger region (800 pc in diameter) including both disc structures and the nucleus. Bottom panel: The AGN spectrum (left) represents 45% of the energy between 5 and 16 μm and is highly dominant at short wavelengths between 3 and 6 μm. The emission associated with star formation regions (right) is not detected with the three narrow band filters at 3-4 μm. The absence of PAH bands is clearly observed in a region of 50 pc in radius containing the AGN whereas PAH bands dominate the emission outside the nucleus. In addition, the high [NeIII]/[NeII] ratio detected in the AGN reveals the presence of a hard radiation field.

review). Mid-IR observations of nearby galactic regions revealed that UIBs originate from PDRs and diffuse regions (Verstraete et al. 1996, Mattila et al. 1996, Tran 1998). Statistical studies have already shown that AGNs present faint UIBs contrary to starburst galaxies (Roche et al. 1991, Genzel et al. 1998). We confirm this result with ISOCAM observations of nearby prototypical active galaxies (NGC 5128 and NGC 1068) for which UIBs are absent in nuclear regions of several hundred parsecs. This absence of UIBs could be the result of their destruction by photodissociation mechanisms produced by the intense UV-X radiation field in AGNs (Léger et al. 1989, Allain et al. 1996). In addition, a noticeable continuum at short wavelengths [5-9 μm] commonly attributed to hot dust is present in our sample of AGN spectra (see also Barvainis 1987). In the light of these results, the UIB(6.2 μm)/continuum[5-6.7 μm] ratio can be used as a tool for distinguishing between AGNs and PDRs/diffuse regions. The combined effects of an increased continuum associated with an absence of UIBs in AGNs make this diagnostic very efficient. In Figure 2, we present in detail the method used to calculate this ratio.

We now use the information given by the mid-IR continuum shape between short(5-6 μm) and long(14-15 μm) wavelengths. In the upper panel of Fig. 3, the spectrum of a "pure" HII region presents an absence of UIBs as for AGN spectra. Nevertheless, unlike in the AGN spectra, the continuum at short wavelengths is very faint. Assuming these continuum behaviors, we can estimate the HII/AGN ratio just using the warm continuum[14-15μm]/hot continuum[5-5.6 μm] indicator.

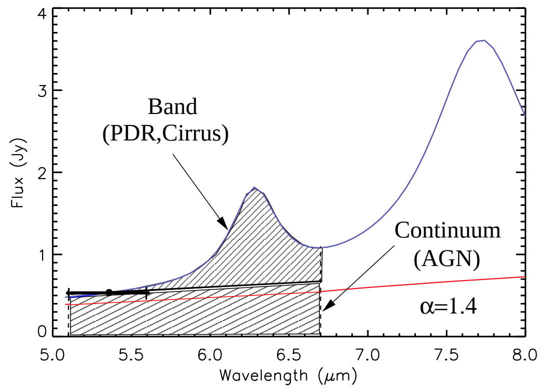

Figure 2. The spectrum between 5.1 μm and 6.7 μm is divided into two different parts. The flux above the thick line (power law with a spectral index α∼1.4 fitting the AGN spectral continuum and scaled to the average flux between 5.1 μm and 5.6 μm) estimates the flux arising from the UIB at 6.2 μm and traces the star formation activity. The flux below the line mainly selects the continuum from the AGN. The band/continuum indicator varies similarly to the (PDRs,diffuse regions)/AGN ratio.

3.2. Mid-IR diagram

In Figure 3, we present a diagram combining the strength of the UIB(6.2 μm) feature with the continuum[14-15μm]/[5-5.6 μm] ratio. We have used the three mid-IR spectra as templates for identifying the contribution of each component in our galaxy sample. In HII regions, UIBs are absent or faint and there is a strongly rising continuum associated with emission lines : [ArIII](9 μm), [SIV](10.5 μm), [NeII](12.8 μm) and [NeIII](15.6 μm). Regions dominated by PDRs, observed in galactic discs, present strong UIBs largely dominating the total emission

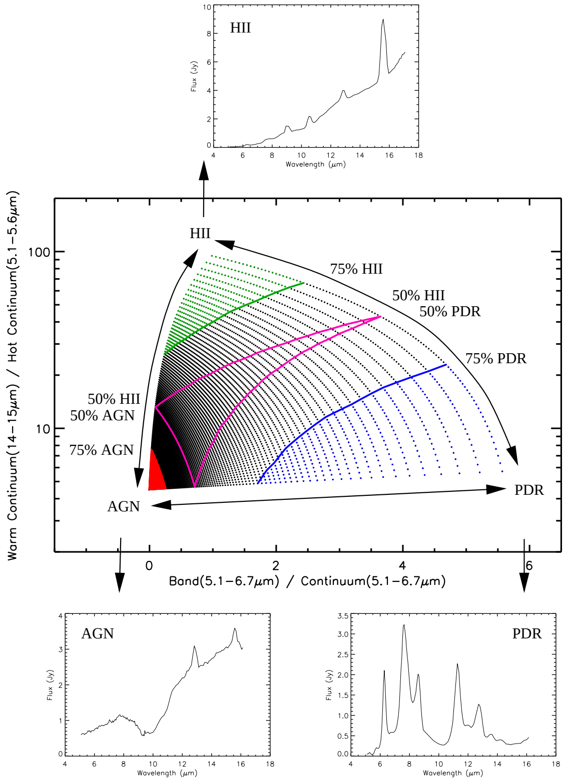

Figure 3. Based on synthetic spectra containing variable fractions of three mid-IR templates observed in a pure HII region (M17), a PDR (NGC 7023) and an AGN (NGC 5128), the diagnostic diagram defines three distinct areas. In the upper part, we select spectra dominated by HII regions (intense starbursts). On the left, AGN spectra are dominant in a very small region, and finally, PDR spectra fall in the right part. The percentages indicate the fraction of each mid-IR contribution used in the composite spectra.

with a faint continuum. Finally, AGN mid-IR emission is mainly characterized by a strong continuum at 5-6 μm without UIBs. Assuming that spectra integrated over the whole galaxy are composed of the mixing of spectra originating from HII regions, PDRs and an AGN, we have built composite spectra from the three mid-IR templates. This diagram can be decomposed into three different regions where we preferentially select AGN (bottom left), HII (top) and PDR spectra (bottom right).

Figure 5 includes in the same diagram 35 spectra containing star forming regions and/or AGNs. The starburst galaxies such as Arp 220 and Mrk 171(A) present a large fraction of pure HII regions compared to PDRs. The AGN detected for nearby objects are located in the bottom left part of the diagram. The star forming regions observed in galactic discs are situated in the region dominated by PDRs.
Using this diagram, we conclude that well-known ultraluminous galaxies like IRAS 23128-5919 and NGC 6240 have mid-IR spectra which are dominated by a strong starburst contribution. The AGN contribution is detected only in nearby objects for which we are able to separate nuclear regions from the galactic disc.

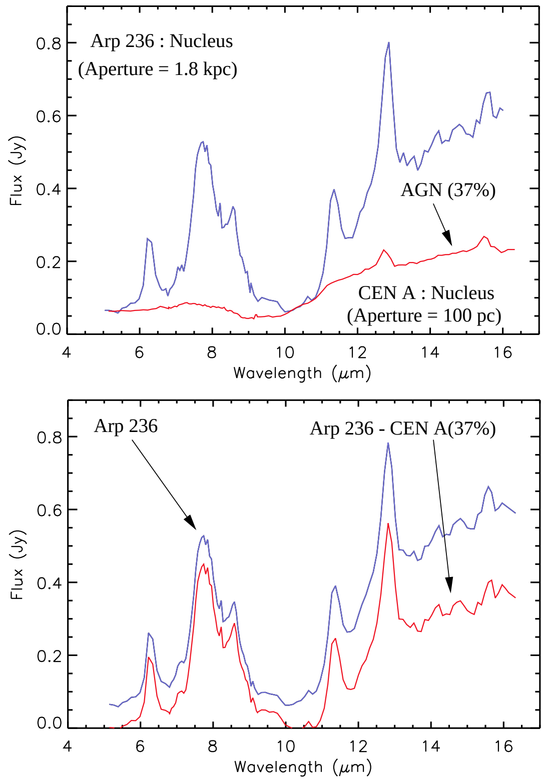

Figure 4. Indication of the presence of an optically hidden AGN in Arp 236 (IC 1623, VV114). Upper panel: the mid-IR spectrum of the more luminous region (1.8 kpc in diameter) is shown in the top curve. On the bottom, we have assumed that the AGN spectrum of CenA (100 pc in diameter) can approximately reproduce the main characteristics of any obscured AGN spectrum. The non-negligible continuum at short wavelengths may be due to an AGN contribution which amounts to ~40% of the total mid-IR flux. Lower panel: The AGN contribution is removed from the initial spectrum. The result is consistent with a typical starburst spectrum.

We have attempted to use this diagnostic diagram to find new AGNs hidden by a large column density of dust. On the diagram, the nucleus of Arp 236 (IC 1623, VV114) is close to the AGN region and as a consequence may contain a non-negligible AGN fraction. This IR luminous system ($L_{IR}=10^{11.62}\,L_\odot$) which is composed of several nuclei and/or compact starburst regions is classified as an early-stage gas-rich merger ($M(H_2) = 5.1\times10^{10}\,M_\odot$, Yun et al. 1994). Previous near-IR and radio studies showed no evidence for an AGN. Nevertheless, we could find an obscured AGN in the eastern region (knot A) observed by Doyon et al. (1995). Knot A is the brightest source in the near-IR, the reddest and also the most compact source (not resolved at 3.7 μm with a FWHM of 0.3 arcsec). In Figure 4, we present the mid-IR spectrum of the eastern nucleus including source A which comprises most of the flux at 3.7 μm (Knop et al. 1994). We estimate that ~40% of the mid-IR emission originates from an AGN (assuming the AGN spectrum of CenA).

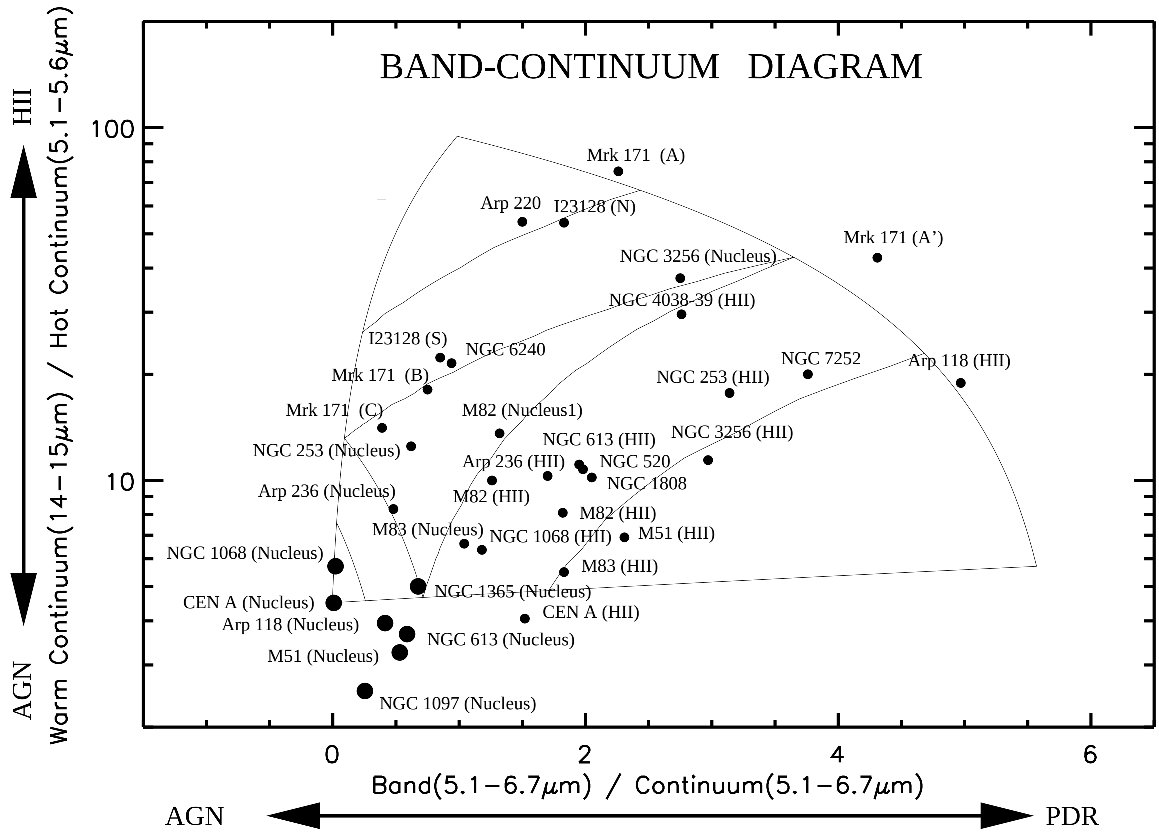

Figure 5. *Diagnostic diagram including 35 spectra covering a large sample of mid-IR emission (nuclear regions, extra-nuclear star forming regions marked HII and unresolved galaxies). Galaxies hosting an intense starburst are in the upper part. The central regions of galaxies (size of several kpc) hosting an AGN (big circles) are all located in the bottom left part of the diagram. Spectra of galactic discs lie near the PDR region. The curves demarcate the AGN, PDR and HII contributions according to Figure 3.*

4. CONCLUSIONS

We have obtained a new AGN/Starburst diagnostic using the strength of the UIB at 6.2 μm and the mid-IR continuum. This diagnostic is based on two independent points:
1) The presence, in "pure" AGN spectra, of a non-negligible continuum below 9 μm which we attribute to emission from hot dust directly heated by the central engine.
2) The absence, in "pure" AGN spectra, of UIBs whose carriers are presumably destroyed by photodissociation in the strong UV-X radiation field.

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REFERENCES

Allain, T., Leach, S. *et al.* 1996, A&A, 305, 602

Barvainis, R. 1987, ApJ, 320, 537

Cesarsky, C., Abergel, A. *et al.* 1996a, A&A, 315, L32

Cesarsky, D., Lequeux, J. *et al.* 1996b, A&A, 315, L305

Cesarsky, D., Lequeux, J. *et al.* 1996c, A&A, 315, L309

Doyon, R., Nadeau, D. *et al.* 1995, ApJ, 450, 111

Genzel, R., Lutz, D. *et al.* 1998, ApJ, 498, 579

Kessler, M.F., Steinz, J.A. *et al.* 1996, A&A, 315, L27

Knop, R.A., Soifer, B.T. *et al.* 1994, AJ, 107, 920

Léger, A., Boissel, P. *et al.* 1989, A&A, 213, 351

Mattila, K., Lemke, D. *et al.* 1996, A&A, 315, L353

Mirabel, I.F., Vigroux, L. *et al.* 1998a, A&A, 333, L1

Mirabel, I.F., Lauren,t O. *et al.* 1998b, A&A, in press

Puget, J.L., & Léger, A. 1989, ARAA, 27, 161

Roche, P.F., Aitken, D.K. *et al.* 1991,MNRAS,248,606

Sanders, D.B., & Mirabel, I.F. 1996, ARAA, 34, 749

Tran, D. 1998, PhD thesis, University of Paris XI

Verstraete, L., Puget, J.L. *et al.* 1996, A&A, 315, L337

Yun M.S., Scoville N.Z. *et al.* 1994, ApJ