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THE AGN-STARBURST CONNECTION IN THE MID-INFRARED

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Abstract

We present a new method based on mid-IR(5-16 μm) emission for classifying the origin of the mid-IR activity in galaxies. Our method was developed using a set of 33 ISOCAM spectra of extragalactic sources which exhibit diverse mid-IR spectral features. Detailed analysis of our sample enables us to identify the general properties of mid-IR emission from active galactic nuclei (AGNs), starbursts, and quiescent star forming regions. The benefits of this mid-IR classification for identifying obscured or faint AGNs and for estimating the star formation intensity in star-forming regions are investigated.

1 INTRODUCTION

The understanding of energetic phenomena due to AGN and/or star formation activity, as well as their connection observed in nearby galaxies, has been considerably improved by the contribution of the Infrared Space Observatory (ISO, Kessler et al. 1996, see Genzel & Cesarsky 2000 for a review).

In this paper, we present 33 spectra from regions of galactic nuclei and disks between 5 and 16 μm. Their mid-IR classification in the framework of a new mid-IR diagnostic diagram (Laurent et al. 2000) is also discussed.

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2 OBSERVATIONS

A large sample of nearby galaxies hosting quiescent star formation activity, starburst, and AGN signatures was observed with the ISOCAM camera (Cesarsky et al. 1996). In this sample, 22 galaxies were observed with the Circular Variable Filter (CVF), which covers a spectral range from 5 to 16 μm with a spectral resolution of ~ 40. The spectro-imaging capabilities of the instrument allow us to obtain the complete spectrum simultaneously for different regions of the galaxies. The resolution of 4-8 arcsec achieved by the instrument was essential in separating emission originating from the central regions from that coming from the galactic disks. The ISOCAM data were analyzed with the CAM Interactive Analysis software and were calibrated with the general methods described in Starck et al. 1999.

3 RESULTS

3.1 *Mid-IR templates and diagnostic diagram*

The three mid-IR templates presented in Figure 1 were used to define the global mid-IR properties of a pure Galactic HII region (M 17 from Cesarsky et al. 1996a), an isolated Galactic photo-dissociation region (PDR) (NGC 7023 from Cesarsky et al. 1996b), and a typical AGN (nucleus of Cen A from Mirabel et al. 1999). One may easily observe that:

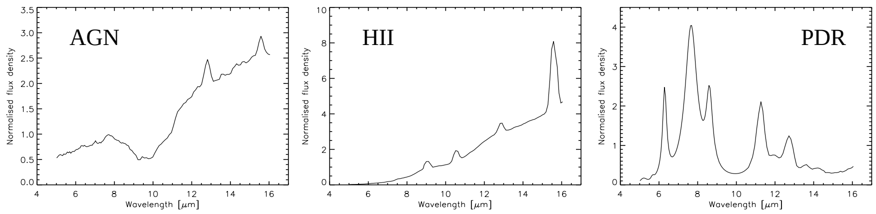

Fig. 1. Mid-IR spectral templates of an AGN (Cen A, Mirabel et al. 1999), a pure HII region (M 17, Cesarsky et al. 1996a) and an isolated PDR (NGC 7023, Cesarsky et al. 1996b).

• The AGN spectrum presents a noticeable continuum at short wavelengths (5-10 μm) which is commonly attributed to hot dust associated with a torus of molecular gas surrounding the AGN (Pier & Krolik 1992, Granato et al. 1997, Genzel & Cesarsky 2000). This continuum is faint or absent in the mid-IR spectra of star-forming complexes whose integrated emission comes from PDR and HII regions. Some intense HII regions present a similar continuum, but only in regions of a few parsecs in size located close to hot stars producing $\sim 10^5$ times the solar radiation field (see Contursi 1998). However, a such intense continuum has never been reported in starburst regions on large spatial scales (>100 pc), and thus its presence constitutes strong evidence for an AGN.

• The family of UIBs at 6.2, 7.7, 8.6, 11.3, and 12.7 μm originates mainly from

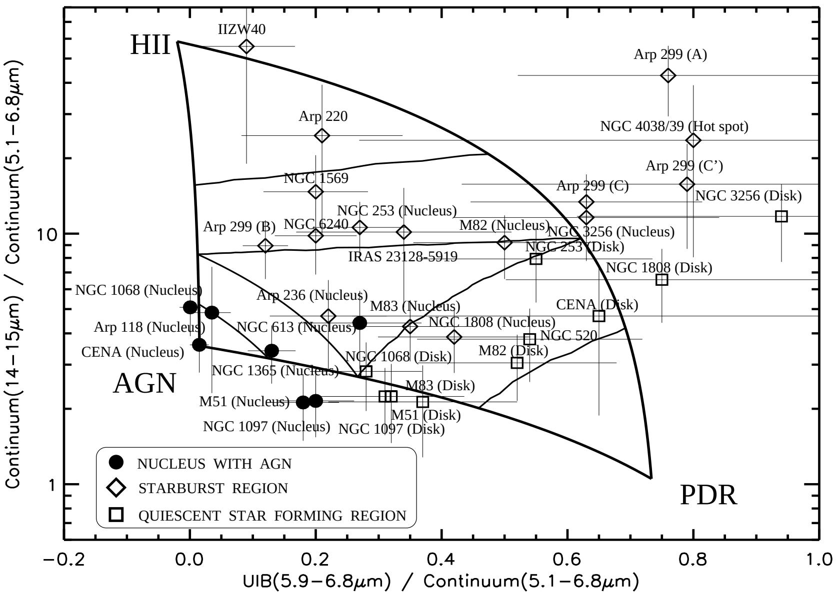

Fig. 2. Diagram based on CVF diagnostics for 33 spectra. The error bars are estimated from the rms maps at 1σ for each wavelength along the CVF spectra, added to a systematic error of 10% due to memory effects in the detector. Note that several spiral and blue compact dwarf galaxies included in this Figure belong to other samples (Roussel 1999, Madden 2000). The circles mainly located in the bottom left part of the diagram represent the central regions known to contain an AGN. The galaxies hosting starburst activity are in the upper part and are marked with diamonds. The spectra of quiescent star forming regions are found to lie close to the PDR region and are denoted with squares. The curves from the upper left to the lower right demarcate the HII fractions from 75% to 50% and the PDR fractions from 50% to 75%. From left to right in the AGN region, we indicate 75% and 50% AGN contributions.

photo-dissociation regions surrounding HII regions, so they are naturally associated with star formation activity. Their absence in highly ionized environments such as pure HII regions and AGNs may indicate their destruction by the hard radiation field produced by OB stars or the accretion disk near a nuclear black hole.

Consequently, the relative decrease of UIB strength can be used as a good indicator for distinguishing AGNs from star-forming regions, which are often dominated by PDR emission (Genzel & Cesarsky 2000). The ambiguity of the strong continuum found both in massive HII regions and in AGNs can be resolved by examining their difference in slope at 15μm and 6μm.

In Figure 2, we present the location of the galaxies of our sample in a diagnostic diagram based on those two criteria (see Laurent et al. 2000 for more details). We note that there is good agreement of their mid-IR identifications from this diagram

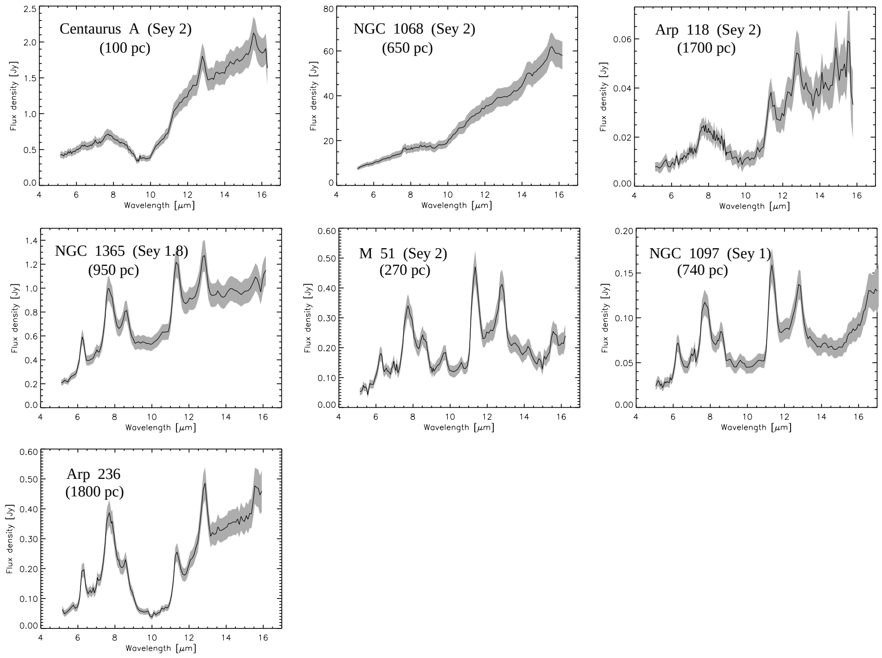

Fig. 3. ISOCAM spectra selected as AGN-dominated in the mid-infrared according to the classification in Figure 2. The shaded area corresponds to the error bars estimated at $1\,\sigma$, with a systematic error of 10% to take into account the uncertainty due to the transient correction method. The diameter of the aperture, estimated in parsec for H_o=75 $\mathrm{kms^{-1}Mpc^{-1}}$, is in parentheses.

with their optical classification as AGNs, starbursts, and quiescent star formation regions (see also Figures 3,4, and 5).

3.2 Mid-IR classification: AGN, starburst, quiescent activity.

In Figure 3, we present spectra classified as AGNs in our diagnostic diagram. All are optically selected as Seyfert 1.8-2, except for NGC 1097 which is a Seyfert 1. NGC 613 is classified as Seyfert 2; its mid-IR properties place it at the boundary between the AGN and PDR regimes, and it has been included in the PDR-dominated sample. The aperture size varies from 100 pc for Cen A up to 1800 pc for Arp 236 and is on average ~600 pc. The absorption relative to the Seyfert 2 type observed in mid-IR (Clavel et al. 2000), together with the large aperture size, makes the contribution of UIB emission from star-forming regions relatively important. Nevertheless, the continuum at 5-6 μm used in our AGN classification is clearly present in all spectra. It is important to note that using a spatial resolution of ~600 pc, one can confirm the presence of 5 AGNs in the 6 optically-selected Seyfert 2 of our sample. Furthermore, this criterion can help us to search for obscured AGNs not identified in optical. One such candidate is Arp 236 (IC 1623, VV 114), an infrared-luminous system (L_{IR} = $10^{11.62}$ $L_\odot$) classified as an early-stage gas-rich

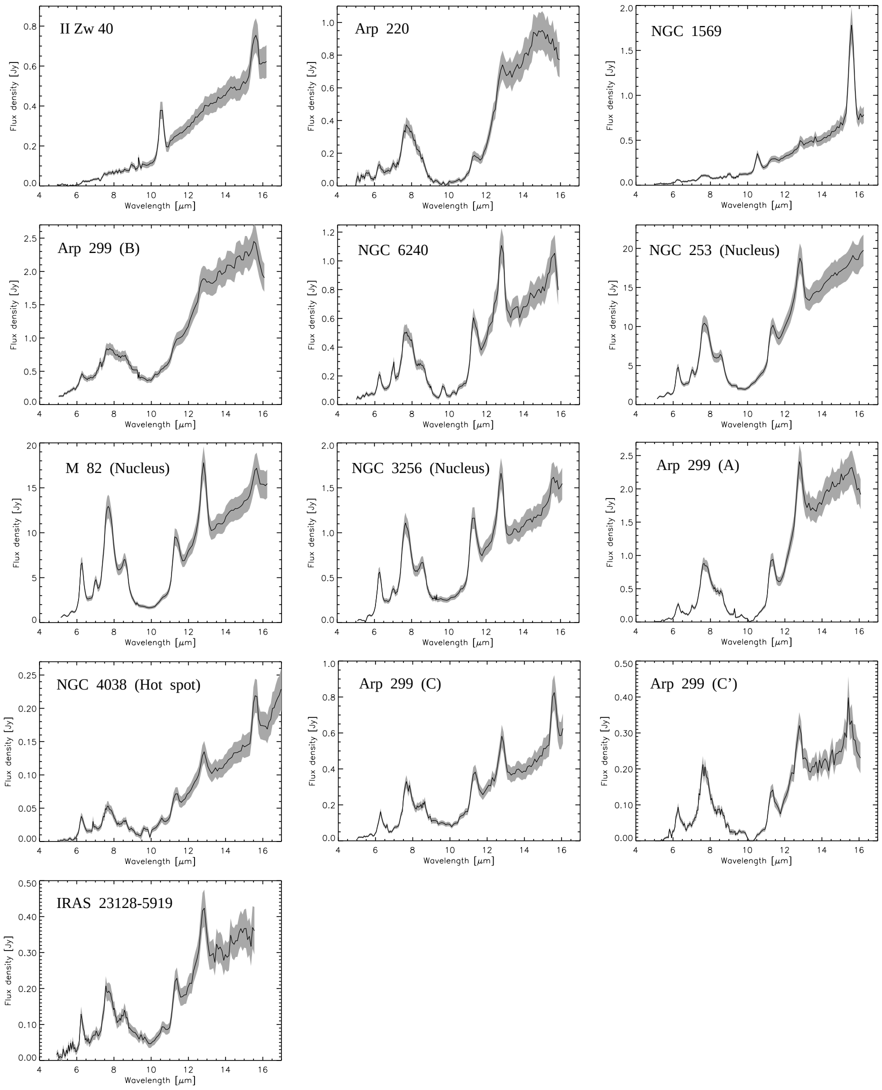

Fig. 4. ISOCAM spectra selected as HII-dominated in the mid-infrared according to the classification in Figure 2. Errors are estimated as in Figure 3.

merger (M(H_2) = 5.1×10^{10} $M_\odot$, Yun et al. 1994), and composed of several nuclei and/or compact starburst regions. Previous near-infrared and radio studies showed no evidence for an active nucleus (Knop et al. 1994, Doyon et al. 1995). However, the presence of a continuum at 5-6 μm could originate from an optically obscured AGN. The next infrared space telescope SIRTF, and in particular its mid-IR spectrograph IRS, will be in a position to confirm the definite presence of an AGN with the detection of high excitation emission lines such as [NeV] or [NeVI].

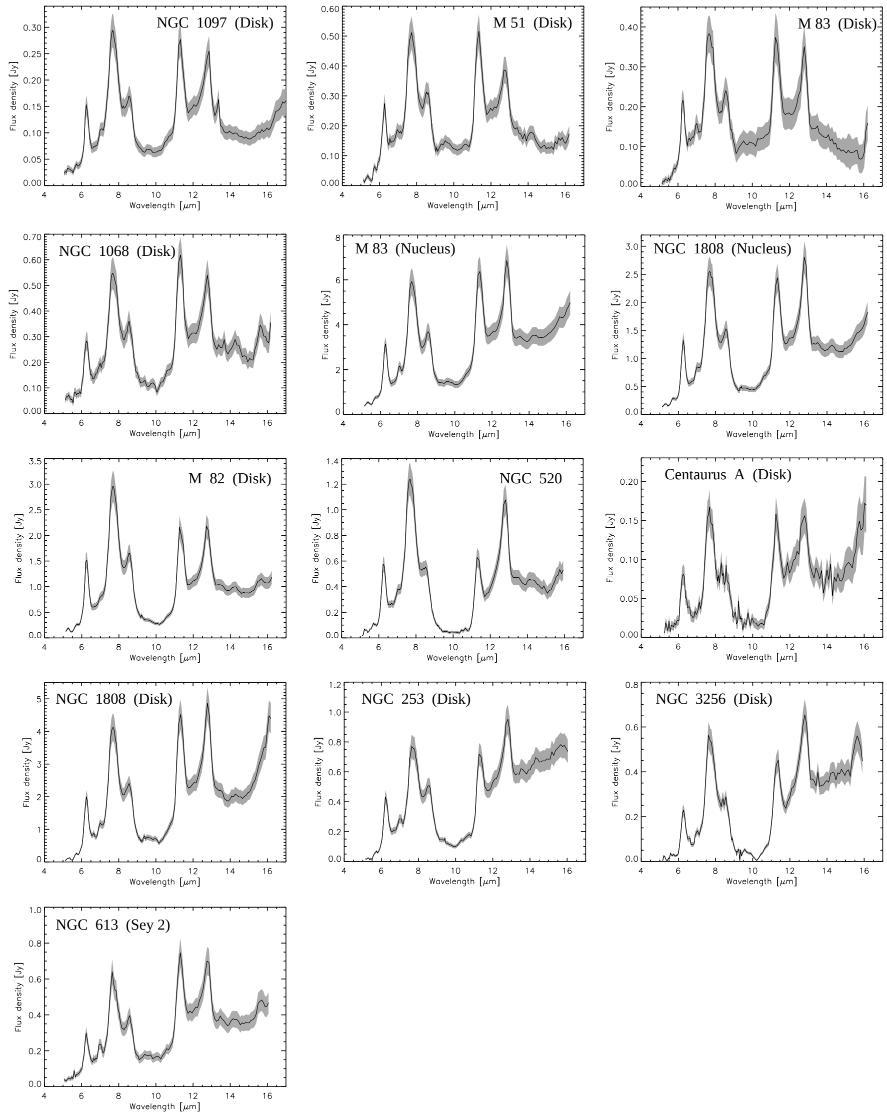

Fig. 5. ISOCAM spectra selected as PDR-dominated in the mid-infrared according to the classification in Figure 2. Errors are estimated as in Figure 3.

The area classified as HII in our diagnostic diagram contains 13 galaxies or nuclear regions harboring intense star formation activity dominated by the continuum at 14-15 μm. Their individual spectra are shown in Figure 4. The continuum at 5-6 μm is very faint or not detectable due to the presence of UIBs. In some low metallicity galaxies like IIZw40 or NGC 1569, we clearly demonstrate that without a UIB contribution, the short-wavelength continuum is still negligible compared to the long-wavelength continuum. The average HII-dominated spectrum in Fig-

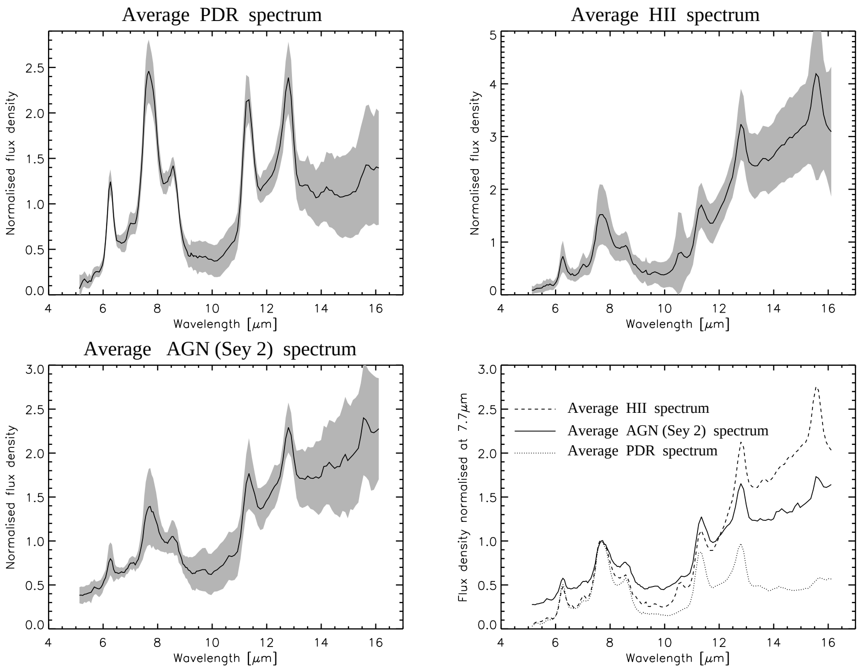

Fig. 6. Average spectra normalised to the 5-16 μm flux of 13 quiescent star-forming regions (upper left panel), 13 starbursts (upper right panel), and 6 Seyfert 2s including Arp 236 (lower left panel). The shaded areas represent the standard deviations between the selected spectra for each classification. The three average spectra normalised at 7.7 μm are superimposed in the lower right panel.

ure 6 represents the typical mid-IR emission observed in starburst galaxies. By comparing the average spectrum of quiescent star formation presented in Figure 5 with that of starburst regions, we estimate to first order that their difference is due to the strong rising continuum, which we model in Figure 7 by a power-law similar to the spectrum of M 17 or IIZw40. This HII continuum can thus be used as a powerful tool for detecting the star formation intensity in galaxies (see for more details Charmandaris et al. 2000).

The mid-IR emission from Seyfert 2s can be understood as a pure AGN contribution, similar to those of the spatially well-resolved nuclei of Cen A or NGC 1068, contaminated by the circumnuclear emission seen in galaxy disks. The AGN continuum is flatter than the HII continuum and can be characterized by a power-law of index 1.5. Estimation of the extinction for the AGN continuum is difficult in cases where UIBs are present; however, the absorption in the two featureless Seyfert 2 spectra of NGC 1068 and Cen A can be produced by relatively weak absorption with A_v=7 and 20 mag, respectively (see Laurent et al. 2000). Although this continuum contributes to all mid-IR wavelengths and becomes more prominent at 14-15 μm, its detection is only feasible at 5-6 μm where the HII continuum is always nearly absent.

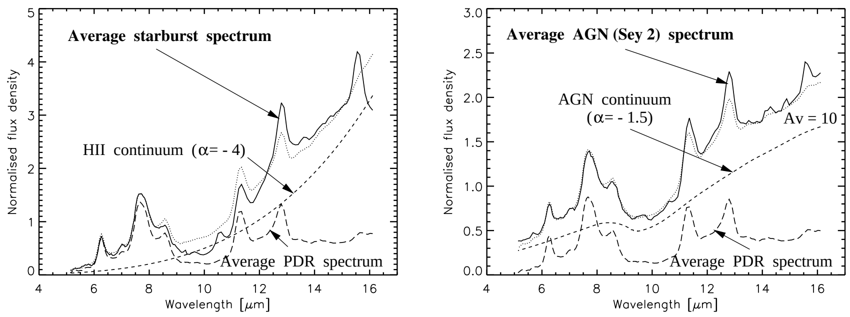

Fig. 7. Comparison between the non-active, starburst, and AGN average spectra. Left: The difference between the PDR and HII spectra can be explained by the presence of a strong rising continuum ($F_\nu \propto \nu^{-4}$) similar to that observed in pure HII regions (Sturm et al. 2000). Right: The average AGN (Sey 2) spectrum is modeled by an AGN continuum ($F_\nu \propto \nu^{-1.5}$) extinguished by 10 visual magnitudes, plus a disk contribution.

Applications of adapted versions of this classification for future instruments, such as the mid-IR spectrograph IRS (5-40 μm) on board of the next infrared space telescope SIRTF with higher sensitivity and spectral resolution than ISOCAM, should provide better insights into the heating sources of the interstellar medium in galaxies.

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