An atlas of mid-infrared spectra of star-forming and active galaxies

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ABSTRACT

We present a panoramic atlas of Spitzer/Infrared Spectrograph (IRS) spectra of extragalactic sources collected from the recent literature, with value-added measurements of their spectral features obtained in a homogeneous and concise manner. The atlas covers the full spectrum of the extragalactic Universe and includes star-forming galaxies, obscured and unobscured active galaxies, luminous and ultra-luminous infrared galaxies, and hybrid objects. Measured features such as the polycyclic aromatic hydrocarbons, the strength of the silicates in emission or absorption around 9.7 $\mu$m, rest-frame monochromatic luminosities or colours, combined with measurements derived from spectral decomposition are used to establish diagnostics that allow for classification of sources, based on their infrared properties alone. Average templates of the various classes are also derived. The full atlas with the value-added measurements and ancillary archival data are publicly available at http://www.denebola.org/atlas, with full references to the original data.

Key words: galaxies: active – quasars: general – galaxies: Seyfert galaxies: starburst – infrared: galaxies – infrared: general.

1 INTRODUCTION

The mid-to-far-infrared spectral range holds the key to the physical processes that shape the life and properties of galaxies, namely star formation and nuclear activity. This spectral domain, and with the exception of the very bright emission lines of the brightest sources, was almost unaccessible from the ground and until 15 years ago, when the sensitivity and large wavelength coverage of the Infrared Space Observatory (ISO) allowed the detailed study of large numbers of nearby starburst galaxies and active galactic nuclei (AGN) and led to the first mid-infrared (MIR) diagnostic tools. ISO studies observed, among other things, the presence of polycyclic aromatic hydrocarbon (PAH) features in the majority of star-forming galaxies (Lutz et al. 1998; Rigopoulou et al. 1999) and their more scarce appearance in AGN (e.g. Sturm et al. 2000), as well as the presence of a silicate feature in absorption in type 2 AGN (Clavel et al. 2000).

Although the studies carried out with ISO brought a breakthrough in our understanding of star formation in galaxies, it was the Spitzer Space Telescope with its Infrared Array Camera (IRAC), the Multiband Imaging Photometer (MIPS), and the Infrared Spectrograph (IRS), that revolutionized our knowledge on the starburst and AGN phenomena and their connection. IRAC broad-band MIR photometry alone allowed for a rough classification among AGN and a distinction between active and star-forming galaxies (e.g. Lacy et al. 2004; Stern et al. 2005; Hatziminaoglou et al. 2005; Hatziminaoglou, Fritz & Jarrett 2009), while IRS observations of hundreds of extragalactic sources provided with more elaborate diagnostic tools (e.g. Spoon et al. 2007) and showed that their MIR spectra are richer and more complex than once assumed. The new discoveries, however, raised new issues that models are now challenged to reproduce. The silicate emission feature in type 1 AGN peaks at longer wavelengths than the 9.7 $\mu$m predicted by the models (e.g. Siebenmorgen et al. 2005; Hao et al. 2005); silicate emission has also been observed in type 2 AGN (Sturm et al. 2006; Teplitz et al. 2006; Nikutta, Elitzur & Lacy 2009) in apparent contradiction to at least some of the suggested dust geometries; and PAH emission is present in many quasars (e.g. Schweitzer et al. 2006), despite previous theories postulating their destruction in the vicinity of the active nucleus. Meanwhile, accurate measurements of PAH features in star-forming galaxies are made difficult by the presence of other features, such as the deep silicate absorption at 9.7 $\mu$m or an underlying AGN continuum.

Understanding the processes linking different galaxy populations and finding their distinctive characteristics require the comparison of the properties of large samples, selected with different but well-understood criteria. Studies of individual samples usually pursue specific goals, and basic MIR properties for diagnostics (such as the strength of the silicate features and PAH bands) are measured...
in ways adapted to the needs of each individual study, but not necessarily consistently across samples, making a direct comparison of results painful, if not impossible.

With this in mind, we compiled a list of 739 Spitzer/IRS spectra of extragalactic sources, the largest of its kind to date, previously scattered in the recent literature. The sample, though not statistical, comprises a variety of objects, namely type 1, 2 and intermediate AGN, ULIRGs, starburst and sub-mm galaxies, with a large span of spectral properties such as PAH and silicate features, continua and distinct physical characteristics. The MIR properties were measured in a concise way for all objects and can thus be directly compared. This paper is structured as follows. Section 2 describes the sample selection, overall properties and collection of ancillary data. Section 3 presents the extraction of the IRS spectra and calibration procedure followed; Sections 4 and 5 detail the methods used to obtain MIR spectral properties and the composite spectra obtained for the various subsamples, respectively; Section 6 reproduces a few common diagnostic diagrams and finally Section 7 summarizes our conclusions.

The full collection of IRS spectra with references to the original data, ancillary data and additional measurements is available at http://www.denebola.org/atlas.

### Table 1. IRS observations log.

| Sample                              | IRS modules | Spitzer archive PID(s) | Comments                                      |
|-------------------------------------|-------------|------------------------|------------------------------------------------|
| Brand et al. 2008, ApJ, 680, 119    | SL1,LL2,LL1 | 15                     | 16 optically faint QSOs with X-ray detection  |
| Brandt et al. 2006, ApJ, 653, 1129  | SL,LL       | 14                     | 22 nearby starbursts                            |
| Buchanan et al. 2006, AJ, 132, 401 | SL2,LL1 (map)| 3269                  | 87 nearby 12μm-selected Seyfert galaxies       |
| Cao et al. 2008, MNRAS, 390, 336    | SL,LL       | Various                | 19 ultraluminous IR QSOs                      |
| Dasyra et al. 2009, ApJ, 701, 1123  | SL1,LL2,LL1 | 20629                 | 150 24-μm selected IR-luminous galaxies       |
| Deo et al. 2007, ApJ, 671, 124      | SL,LL       | 3374                   | 12 Seyfert 1.8 and 1.9 galaxies               |
| Farrah et al. 2009, ApJ, 696, 2044  | SL1,LL2,LL1 | 30364                 | 16 optically faint 70 μm sources              |
| Haas et al. 2005, A&A, 442, L39     | SL,LL       | 3349                   | Seven quasars and seven radio galaxies        |
| Hao et al. 2005, ApJ, 625, L75      | SL,LL       | 3640                   | Five PG quasars                               |
| Hernán-Caballero et al. 2009, MNRAS, 395, 1695 | SL,LL | 20083 | 69 15μm-selected IR-luminous galaxies |
| Hiner et al. 2009, ApJ, 706, 508    | SL,LL       | 105.2306,3187          | Six type 1 and seven type 2 MIR-selected quasars |
| Imanishi et al. 2007, ApJ, 171, 72  | SL,LL       | 105.30407,20589        | Buried AGN in IR galaxies                     |
| Imanishi et al. 2009, ApJ, 694, 751 | SL,LL       | 50008,3187,30407       | 20 buried AGN in IR galaxies                 |
| Imanishi et al. 2010, ApJ, 709, 801 | SL,LL       | 20083                  | 17 nearby ULIRGs                              |
| Lacy et al. 2007, ApJ, 669, 61      | SL,LL2      | 20083                  | Six type 2 quasars                            |
| Leipski et al. 2009, ApJ, 701, 891  | SL,LL       | 20525                  | 25 FR-I radio galaxies                        |
| Lutz et al. 2008, ApJ, 684, 853     | LL          | 30314                  | 12 z~2 mm-bright type 1 quasars               |
| Maiolino et al. 2007, A&A, 468, 979 | LL1,LL2    | 20081                  | Four high-luminosity quasars 2<z<3.5         |
| Menéndez-Delmestre et al. 2009, ApJ, 699, 667 | LL1,LL2 | 20456 | 24 submm galaxies |
| Murphy et al. 2009, ApJ, 698, 1380  | SL,LL2,LL1i| 3187                   | 22 galaxies in GOODS-N                        |
| Netzer et al. 2007 ApJ, 666, 806    | SL,LL,SL,LLH| 20456                 | 23 Palomar Green QSOs                        |
| Polletta et al. 2008, ApJ, 675, 960 | SL,LL2,LL1 | 20456                  | 21 obscured AGNs                             |
| Pope et al. 2008, ApJ, 675, 1171    | SL,LL       | 20456                  | 13 submm galaxies                            |
| Shi et al. 2006, ApJ, 653, 127      | SL,LL       | 3187                   | 68 AGN                                        |
| Siebenmorgen et al. 2005, A&A, 436, L5 | SL,LL       | 20231                  | 3C 249.1, 3C 351                             |
| Sturm et al. 2005, ApJ, 629, L21    | SL,SL,SLH   | 3237                   | NGC 3998                                      |
| Sturm et al. 2006, ApJ, 642, 81     | SL,SLH      | 3223                   | Seven X-ray selected type 2 quasars           |
| Tommasin et al. 2008, ApJ, 676, 836 | SL,SLH     | 30291                  | 29 Seyfert galaxies                           |
| Valiante et al. 2007, ApJ, 660, 1060| SL,LL       | 3241                   | Nine submm galaxies                          |
| Weedman et al. 2005, ApJ, 633, 706  | SL,SL,SLH   | 14                    | Eight AGN                                     |
| Weedman et al. 2006a, ApJ, 651, 101 | SL,LL,SLH   | 12.15                  | 24 optically faint 24 μm selected AGN          |
| Weedman et al. 2006b, ApJ, 653, 101 | SL,LL,SLH   | 15                     | 11 AGN and nine starbursts                    |
| Weedman et al. 2009, ApJ, 693, 370  | SL,LL      | 40038,20128,20083,40539| 24 AGNs and some starbursts                   |
| Willet et al. 2010, ApJ, 713, 1393  | SL,LL,SLH   | 30515, 50591, 105     | Eight compact radio galaxies                  |
| Wu et al. 2009, ApJ, 701, 658       | SL,LL (map) | Various                | 103 Seyfert galaxies                          |
| Yan et al. 2007, ApJ, 658, 778      | SL,LL2,LL1i | 3748                   | 52 24-μm selected sources                    |
| Zakamska et al. 2008, AJ, 136, 160  | SL,LL2      | 105, 3163              | 12 QSOs from SDSS                             |

*Not all targets observed in all modules.*
of the selection criteria and properties of the individual subsamples we refer the reader to the corresponding papers.

Spitzer/IRS data for sources in the sample include observations with both the low-resolution (R \sim 100) and high-resolution (R \sim 600) IRS modules, all performed in staring-mode, except for the sources from Buchanan et al. (2006) and Wu et al. (2009), where observations were performed in spectral mapping mode, but only the spectrum obtained with the slit placed in the galactic nucleus is given. Maximum spectral coverage is 5–38 \mu m in the low-resolution module and 10–35 \mu m in the high-resolution one, but in many faint targets only a subset of low-resolution modules is applied, resulting in a reduced spectral coverage that is not uniform even within the same subsample.

Sources at intermediate and high redshift appear unresolved to the IRS, and thus the spectra integrate the emission of the whole galaxy. By contrast, in nearby targets the spectra only sample the nuclear region. Our selection does not put constraints on redshift, not even the existence of a consistent redshift estimate, but individual subsamples usually target certain redshift range, or indirectly bias the selection through flux or colour constraints.

Spectroscopic redshifts (from either optical or MIR spectroscopy) are available for 695 of the 739 sources. Redshifts are obtained from the literature and cross-checked with the NASA Extragalactic Data base (NED). 525 redshifts come from optical spectra, while 170 sources (mostly obscured high-z targets) rely on a redshift estimate from their IRS spectrum. In targets where both optical and MIR spectroscopic redshifts are available, priority is given to the former, except in cases of strong discrepancy in which the optical redshift is flagged as unreliable or the MIR spectrum shows very clear PAH bands. The remaining 44 sources have no published spectroscopic redshift, or it is uncertain. They are not removed from the sample, but will be ignored in the subsequent analysis.

About half of the sample, 347 sources, have redshifts below \( z = 0.3 \), while the rest spans a large redshift range up to \( z \sim 3.7 \) (Fig. 1). Spectral coverage in rest-frame wavelength is in all cases within 1.2 and 38 \mu m, with 389 sources sampling the 5.5–14 \mu m range in its entirety and 550 the critical 8–12 \mu m range, which contains both the 10 \mu m silicate feature and 11.3 \mu m PAH band (see Fig. 2).

Figure 1. Redshift histogram for the 695 sources with spectroscopic redshifts in the sample. The red bars indicate optical redshifts, while the green bars represent the MIR ones. Bars for the first two redshift bins are truncated to improve readability.

An optical spectroscopic classification is also available for most sources. A positional match with the 13th version of the Veron Catalogue of Quasars & AGN (VERONCAT; Veron & Veron 2006) yields 361 matches; for these sources, we adopt the activity-type designation in the VERONCAT. For the remaining ones, we adopt the optical classification in NED, when available, or at the very least a broad class (e.g. ULIRG, SMG) either from NED or the individual papers the spectra are taken from. Some sources are put in more than one classes. For example, a starburst galaxy with a Seyfert 2 nucleus will retain both starburst and Seyfert 2 classifications.

To deal with the large variety of spectral types, we group them into 10 categories, namely Seyfert 1 (Sy1), Seyfert 2 (Sy2), intermediate Seyfert type (Sy1.X), LINER, Quasar (QSO), type 2 Quasar (QSO2), Starburst, ULIRG, SMG and ‘other’ when none of the above classifications applies.

We set a threshold value of \( \nu L_\nu(7 \mu m) = 10^{44} \text{ erg s}^{-1} \) (roughly the output of the least-luminous ULIRG of this sample), above which all type 1 and type 2 AGN are considered as QSO or QSO2, while keeping the Seyfert 1 and Seyfert 2 designations for the lower luminosity Seyferts. The LINER class does not include LINER cores of ultraluminous and starburst galaxies, as their MIR spectrum is typically dominated by the host galaxy.

3 EXTRACTION OF THE SPECTRA

To obtain the IRS spectra we have not gone through the normal process of querying the Spitzer archive, reduce the raw Spitzer/IRS data and extract the spectra. Instead, we have relied on Postscript figures contained in papers submitted to the arxiv.org preprint archive. This approach has several shortcomings that we describe later, and is not optimal for a detailed analysis of individual targets. Nevertheless, it provides a cost-efficient means for performing statistical studies on the largest starburst and active galaxy sample compiled to date.
Sets of points representing the spectra in the figures are transformed from Postscript coordinates to wavelength and flux values using software developed by the authors. Paper figures represent the spectra in many different fashions: the independent variable is usually wavelength, whether in the observed or rest frame, but it can also be frequency. For the dependent variable there are several values of choice: $f_\nu$, $f_\lambda$, $vL_\nu$, etc., that in addition are expressed in different unit systems and plotted in linear or logarithmic scale.

To homogenize the sample, we convert all spectra back to the same units provided by the Spitzer IRS reduction pipeline: observed wavelength in $\mu$m and spectral flux density in Jy. The accuracy with which the original wavelength and flux values are recovered is limited by the resolution of the Postscript figure; nevertheless, the uncertainty that this introduces to the wavelength calibration is about an order of magnitude smaller than the spectral resolution ($R \sim 100$) in the low-resolution module of IRS, and thus its impact is negligible.

Since the uncertainties in the flux density of the spectra are not shown in most of the figures, we devised a procedure to estimate them based on individual exposure times, obtained from queries to the Spitzer archive when they were not indicated in the corresponding papers, using the SPEC-PET exposure time calculator. Flux uncertainties estimated by SPEC-PET are corrected for wavelength sampling (SPEC-PET assumes $R = 50$), with an additional $\sqrt{2}$ factor to account for the noise introduced by standard background subtraction. We use two different methods to evaluate the accuracy of these flux uncertainty estimates: (i) compare with the known uncertainties in the spectra from papers where this information is available (Hernán-Caballero et al. 2009; Yan et al. 2007; Menéndez-Delmestre et al. 2009; Murphy et al. 2009); (ii) compare with the rms noise of the continuum in spectra that are plotted without smoothing (e.g. Weedman et al. 2005; Lutz et al. 2008; Pope et al. 2008; Zakamska et al. 2008).

Both approaches indicate that our flux uncertainty estimates are correct within a factor of 2 in most sources. Even if a higher accuracy would be desirable, the statistical results drawn from the sample are little, if at all, affected. For an in-depth analysis of individual targets, authors should use instead the latest version of the data products available at the Spitzer archive.

### 4 Measurements

We provide measurements for several MIR spectral features that are commonly used to estimate the star formation or nuclear activity, their relative contribution to the energy output of extragalactic sources or the amount of obscuration; namely PAH features, the 10 $\mu$m silicate feature and rest-frame monochromatic luminosities.

#### 4.1 PAH features

PAH emission is a key tracer of star formation, with the luminosity of the PAH bands frequently used as an indirect estimator of the star formation rate (SFR; e.g. Rigopoulou et al. 1999; Peeters, Spoon & Tielens 2003; Brandl et al. 2006; Farrar et al. 2008) while their ratios relate to the ionization field in the interstellar medium (Draine & Li 2001; Rapacioli, Joblin & Boissel 2005; Brandl et al. 2006; Galliano et al. 2008). For nearby galaxies with strong PAH bands and high signal-to-noise ratio (S/N) spectra, it is possible to perform a detailed modelling of the continuum and Lorentzian profiles of the PAH bands (e.g. Smith et al. 2007; Treyer et al. 2010). For higher redshift sources, a similar analysis can be performed, provided adaptations are made to account for AGN emission and dust extinction (e.g. Sajina et al. 2007; Hernán-Caballero et al. 2009), but as the equivalent width (EW) of the feature, the S/N of the spectrum and the wavelength coverage decrease, degeneracy among solutions quickly becomes a major source of uncertainty. Simpler methods such as spline or linear interpolation of the local continuum and integration in the PAH band (e.g. Genzel et al. 1998; Rigopoulou et al. 1999; Brandl et al. 2006; Spoon et al. 2007) are much more resistant to weak or noisy features, but significantly underestimate PAH luminosities due to losses at the wings of the Lorentzian profiles and overlap between adjacent PAH bands (Smith et al. 2007; Treyer et al. 2010).

As already mentioned, the basic idea behind this work is to apply the same procedure when measuring the various features across all samples. We therefore opted to use an intermediate approach, in which the continuum is locally interpolated and the feature flux is integrated in a narrow band, but both measurements are later corrected for the expected width and shape of the feature’s profile.

The measurement proceeds as follows. We select two narrow, continuum bands at both sides of each PAH feature, and estimate the average flux $f_\nu$, in these bands. We perform a linear interpolation to estimate the continuum underlying the feature, and subtract it from the spectrum. Finally, we integrate the residual in a band centred at the expected wavelength of the peak of the PAH feature to obtain the integrated PAH flux. In order to maximize the S/N in the integrated PAH flux and to reduce the uncertainty in the underlying continuum, we use a rather narrow integration band (which loses a significant fraction of the PAH flux in the wings of the profile) and place the continuum bands in its close vicinity, without trying to avoid contamination by the wings of the PAH feature (see parameter values in Table 2).

The bias introduced by this procedure is compensated by a correction factor on the assumption that the PAH profile is Lorentzian with a known full width at half-maximum (FWHM). We estimate the error that this procedure introduces by measuring line and continuum fluxes in a set of model continuum+Lorentzian spectra covering a wide range of EW, FWHM and S/N values. We find that a 10 per cent increase in the FWHM causes a 5–6 per cent drop in the PAH flux, with no observable dependency on the EW or S/N of the spectrum.

Uncertainties in the PAH flux and the underlying continuum for each source are estimated by performing Monte Carlo simulations. Finally, we estimate EWs of the PAH features dividing the integrated PAH flux by the interpolated continuum at the centre of the feature, and convert PAH fluxes to luminosities assuming a concordance cold dark matter cosmology ($\Lambda = 0.7$, $\Omega = 0.3$ and $H_0 = 70\text{ km s}^{-1}\text{ Mpc}^{-1}$).

Since this approach is not valid for the overlapping 7.7 and 8.6 PAH bands, we perform measurements only for the 6.2 and 11.3 $\mu$m PAH features (which incidentally are the most used for diagnostics). The 6.2 $\mu$m feature is measured in 587 sources, that at 11.3 $\mu$m in 577, and both of them together in 481 sources.

| Table 2. PAH measurement parameters. |
|--------------------------------------|
| 6.2 $\mu$m PAH | 11.3 $\mu$m PAH |
| Central wavelength | 6.25 | 11.3 |
| Integration band | 6.0–6.5 | 11.05–11.55 |
| Continuum intervals | 5.8–6.0, 6.5–6.7 | 10.75–11.0, 11.65–11.9 |
| Assumed FWHM | 0.2 | 0.2 |
4.2 Silicates

The 10 μm silicate feature, which can appear in emission or absorption, provides insight into the geometry of the dust distribution along the line of sight of the star-forming regions or the active nucleus as well as the amount of obscuration (e.g. Imanishi & Maloney 2003; Sturm et al. 2005; Imanishi et al. 2007). As with the PAH bands, the main difficulty in estimating the strength of the 10 μm silicate feature is the identification of the underlying continuum. In sources with weak or no PAH emission, we interpolate linearly in log(λ), log(fλ) between anchor points at rest frame 8.1 and 14.0 μm; but whenever there is significant PAH emission (τ_{PDR} > 0.1, see Section 5), we substitute the first anchor point by 5.55 μm in order to avoid the distortion introduced by the wings of the 7.7 and 8.6 μm PAH features.

We subtract from the spectrum the interpolated continuum, and integrate the residual (silicate feature) in the 9–11 μm range. The sign of this quantity allows us to determine whether the feature is in emission (integral > 0) or in absorption (integral < 0). The theoretical wavelength of the silicate peak is 9.7 μm, but it is known that in many quasars and Seyfert galaxies the feature peak is shifted to longer wavelengths when it appears in emission (e.g. Siebenmorgen et al. 2005; Netzer et al. 2007). In addition, many star-forming sources show strong emission in the S(3) 9.665 μm transition of molecular hydrogen, which contaminates the peak of the silicate absorption profile.

Since many spectra are too noisy to accurately measure where the peak of the silicate feature actually occurs, we simply assume it is located at λ_p = 9.8 μm for sources with silicate absorption and λ_p = 10.5 μm for silicate emission spectra. A detailed analysis of the 10 and 18 μm silicate features in the AGN-dominated sources of this sample, including measurement of the peak’s wavelength, is the topic of a specialized study (Hernán-Caballero et al. in preparation).

The feature’s peak flux density is used to calculate the silicate strength, S_{sil} = \ln [F(λ_p)/F_\nu(λ_p)]. As in the PAH bands, uncertainties in the silicate parameters are estimated using Monte Carlo simulations. S_{sil} measurements are obtained for 537 sources.

We also define the ‘three-band’ colour index, C_{7–10–14}, as

\[ C_{7–10–14} = -2.5 \log \left( \frac{\sqrt{f_{7}}/f_{14}}{f_{10}} \right) \]

This parameter is an alternative, easily obtained estimator of the silicate strength, that shows a good correlation with S_{sil} in sources of all types (Fig. 3).

In sources with little or no PAH emission, S_{sil} and C_{7–10–14} are mostly interchangeable, while sources with strong PAH emission show a small but consistent bias towards C_{7–10–14} < S_{sil}. This may be produced by a steeper slope of the starburst continuum component shortwards of ~8.5 μm that decreases the interpolated 9.8 μm continuum for S_{sil} (and increases thus the S_{sil} value), and also from contamination by the wings of the 6.2 and 7.7 μm PAH features in the 7.0 μm flux, that reduces the C_{7–10–14} estimate. The difference, Δ_{sil} = S_{sil} – C_{7–10–14}, increases with the strength of the starburst component as measured by EW_{6,2}, and can be as high as ~0.5 in extreme cases.

4.3 Monochromatic luminosities

Rest-frame monochromatic luminosities, νLν, allow for the comparison of spectral energy distributions of sources at different redshift without the need for K-corrections. We estimate them based on the IRS spectra at rest-frame wavelengths: 2.2, 3.6, 5.6, 7.0, 9.0, 10.0, 12.0, 14.0, 15.0, 18.0, 20.0 and 25.0 μm. To this end, each rest-frame spectrum is integrated in a narrow band (between 0.5 and 2.0 μm wide depending on the wavelength) centred at the nominal wavelength, and divided by the band width. Table 3 summarizes these measurements.

Rest-frame MIR colours and colour indices are also calculated and tabulated. Such quantities give a quick but accurate idea of the shape of a spectrum. The [5.6–15] μm colour, for instance, is a proxy for MIR continuum slope, while the three-band 7–10–14 μm colour index (C_{7–10–14}) can be used as a substitute estimate of the silicate strength in noisy or poorly sampled spectra (see Section 4.2).

5 SPECTRAL DECOMPOSITION

Decomposition of MIR spectra in several spectral components is a powerful tool that can provide considerable insight into the physics of the sources (e.g. Laurent et al. 2000; Tran et al. 2001).

MIR emission from active and star-forming galaxies arises mostly from H II regions, Photodissociation Regions (PDRs) and hot dust heated by energetic X-ray-to-UV photons from an AGN, so we have...
used a simple model comprising the superposition of three spectral templates (H II, PDR and AGN) obscured by a screen of dust.

The spectral decomposition is performed by fitting the 5–15 μm rest-frame range of the spectrum to a parametrized \( F_\lambda(\lambda) \) of the form:

\[
F_\lambda(\lambda) = e^{-b(\lambda)} (a_1 f_{\text{AGN}}(\lambda) + a_2 f_{\text{HII}}(\lambda) + a_3 f_{\text{PDR}}(\lambda)),
\]

where the free parameters \((b, a_1, a_2, a_3)\) are calculated using a Levenberg–Marquardt \( \chi^2 \)-minimization algorithm. A single optical depth value is applied to the three spectral components, but for most sources the solution is almost identical when two optical depth values (one for the AGN and the other for the PDR and H II components) are used, with an increased \( \chi^2 \) value due to the extra free parameter.

\[ \tau(\lambda) \] is obtained from the Galactic Centre extinction law (Chiar & Tielens 2006), while \( f_{\text{AGN}} \) is represented by the IRS spectrum of the PG QSO 3C273 (Wu et al. 2009), \( f_{\text{PDR}} \) by the ISO CAM spectrum of a PDR in the reflection nebula NGC 7023 (Cesarsky et al. 1996a) and \( f_{\text{HII}} \) by the ISO CAM spectrum of M17 in the vicinity of OB stars (Cesarsky et al. 1996b). Fig. 4 shows the 5–15 μm spectrum of the three spectral components. Uncertainties in the fit parameters are estimated using Monte Carlo simulations.

We quantify the contribution, \( r_i \), of each spectral component to the MIR spectrum as the ratio of its integrated luminosity to the total luminosity in the 5–15 μm rest-frame range, \( r_{\text{AGN}}, r_{\text{HII}} \) and \( r_{\text{PDR}} \) for the AGN, H II and PDR components. Fig. 5 shows the distribution of the three spectral components in the sample. Only 235 of the 695 sources with available redshifts have IRS spectra covering the 5–15 μm spectral range in its entirety. In many local galaxies, the IRS spectrum starts at 5.2–5.5 μm, while in higher redshift sources the long wavelength end of the spectrum is often shortwards of 15 μm. Nevertheless, 379 spectra cover more than 95 per cent of the 5–15 μm range, and 595 show coverage ratios above 60 per cent.

To validate the results on sources with incomplete spectral coverage, we have performed test runs of the decomposition algorithm on the subsample with full 5.5–15.5 μm coverage, but restricting the fitting range to 5–13.5 μm, 5–12 μm and 5–10.5 μm. For each spectral component, \( i \), we define the change in the estimated share of the 5–15 μm luminosity as: \( \Delta r_i = r'_i - r_i \), where \( r'_i \) is the value of \( r_i \) obtained when fitting in the restricted range.

The results (Table 4) show that decreasing the long wavelength limit to 13.5 μm has almost no effect, with typical \( \Delta r_i \) of a few per cent, and no significant bias. A further reduction of the long wavelength limit down to 12 μm significantly reduces the contribution of the H II template, by 7 percentage points on average, and increases the dispersion in all components by a factor of \( \sim 3 \). Nevertheless, moving the limit to 10.5 μm does not increase the bias, which improves slightly for the H II and PDR templates; but the dispersion further increases by another factor of \( \sim 2 \), to almost 0.2 for H II, which renders the decomposition results rather unreliable. Note that the H II component is by far the most affected by truncation of the spectrum at long wavelengths because of its steep slope.

\[ \Delta r_{9.7} \] also shows high dispersion for a 12 μm limit, but most of the strong deviations originate in spectra with poor S/N which show large parameter uncertainties even with full spectral coverage (Fig. 6). There is no significant bias for \( \Delta r_{9.7} \) except for the test in the 5–10.5 μm spectral range.

In order to obtain reliable measurements without sacrificing too many sources, we opt to require a lower limit of 60 per cent coverage in the 5–10.5 μm spectral range to perform spectral decomposition. In addition, we provide coverage ratios for all sources in the sample.

Fig. 7 shows \( S_{\text{full}} \) versus the optical depth at 9.7 μm estimated from the \( b \) parameter (\( r_{9.7} \)) for the 379 sources with >95 per cent coverage in the 5–15 μm range.

The tight correlation and the significantly larger uncertainties in \( S_{\text{full}} \) compared to \( r_{9.7} \) are noteworthy. There appears to be a slope

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**Figure 4.** 5–15 μm spectra of the AGN, H II and PDR templates used in the spectral decomposition. The silicate emission template used in the alternative spectral decomposition model for silicate emission sources is also shown.

**Figure 5.** Contribution of PDR and AGN components to the integrated 5–15 μm rest-frame luminosity as derived from the spectral decomposition. Filled symbols indicate sources with full 5.5–15 μm coverage in the IRS spectrum, while open symbols represent sources with only partial coverage. The amount of H II component can be calculated by the formula: \( r_{\text{HII}} = 1 - (r_{\text{AGN}} + r_{\text{PDR}}) \).

**Table 4.** Bias in decomposition parameters caused by incomplete spectral coverage.

|                | 5.0–13.5 μm | 5.0–12.0 μm | 5.0–10.5 μm |
|----------------|-------------|-------------|-------------|
|                | mean        | σ           | mean        | σ           | mean        | σ           |
| \( \Delta r_{\text{AGN}} \) | 0.0029      | 0.017       | 0.0426      | 0.051       | 0.0590      | 0.118       |
| \( \Delta r_{\text{HII}} \)  | −0.0081     | 0.034       | −0.0699     | 0.098       | −0.0499     | 0.193       |
| \( \Delta r_{\text{PDR}} \)  | 0.0052      | 0.029       | 0.0272      | 0.065       | −0.0092     | 0.096       |
| \( \Delta r_{9.7} \)        | −0.0005     | 0.141       | 0.0027      | 0.560       | 0.2723      | 0.820       |
change at \( S_{\text{sil}} \sim -2 \) (\( \tau_{9.7} \sim 3 \)) that might be caused by saturation of the silicate feature: since \( S_{\text{sil}} \) depends on the 9.7 \( \mu m \) flux, it is difficult to obtain an accurate measurement when the flux level nears zero; also, emission in the 9.66 \( \mu m \) S(3) line of molecular hydrogen (found in many ULIRGs) can increase the measured 9.7 \( \mu m \) flux. On the contrary, \( \tau_{9.7} \) takes advantage of the whole 5–15 \( \mu m \) spectrum, and we can obtain a sensible estimate of the 9.7 \( \mu m \) optical depth from the wings of the silicate profile, even if the feature is saturated.

When the silicate feature appears in emission, the best fit is obtained for a negative value of the opacity parameter \( b \), since this produces a 10 \( \mu m \) bump with a shape alike that of the silicate emission feature. This unphysical solution allows for a decent fit of silicate emission sources with no extra parameters in the model, and the associated negative \( \tau_{9.7} \) values correlate with \( S_{\text{sil}} \) values (Fig. 7).

In order to check the validity of this approach, and to investigate the influence of a negative \( b \) value in the relative contribution of the three spectral components, we compare the results with an alternative spectral decomposition model for sources with the silicate feature in emission. In the alternative model, we fix the opacity parameter at \( b = 0 \) and include a fourth spectral template with the silicate emission profile of PG1351 (the source with the strongest silicate emission in the sample), obtained as the excess flux over the interpolated continuum between 8 and 13.5 \( \mu m \). Fig. 4 shows the 5–15 \( \mu m \) spectrum of the four components. The opacity needs to be fixed when using a silicate emission template to avoid degeneracies, since an increase in the silicate emission component can be compensated by a simultaneous increase in the opacity parameter.

To obtain a measurement of the silicate strength we use the combined 9.7 \( \mu m \) flux of the AGN, H\( ii \) and PDR templates as the continuum estimate (\( F_{\text{cont}} \)), and the 9.7 \( \mu m \) flux of the fourth (silicate) template as the peak flux estimate of the silicate feature (\( F_{\text{sil}} \)). The silicate strength is then calculated as \( S_{\text{sil}} = \ln(1 + F_{\text{sil}}/F_{\text{cont}}) \).

Comparison of \( S_{\text{sil}}^{\circ} \) with \( \tau_{9.7} \) from the original decomposition model shows a good correlation, with significantly less dispersion than the correlation between \( S_{\text{sil}} \) and \( \tau_{9.7} \) (Fig. 7, inset plot). Comparison of \( S_{\text{sil}}^{\circ} \) with \( S_{\text{sil}} \) also yields a good correlation, with \( S_{\text{sil}}^{\circ} \sim 0.91 \) \( S_{\text{sil}} \). Changes in the relative contribution of spectral components, when adding the Silicate template, are small; in particular \( r_{\text{PDR}} \), a parameter we will use for diagnostics in Section 6.2, is almost unaltered with a \( \Delta r_{\text{PDR}} \) averaging 0.0016 and a standard deviation of 0.012.

The alternative spectral decomposition model assumes the silicate feature peaks at \( \sim 9.8 \mu m \), while there are instances in our sample where the peak of the emission is shifted towards longer wavelengths. These \( S_{\text{sil}}^{\circ} \) estimates should, therefore, be considered as an approximation to the real values. A more accurate measurement would require the ability to shape and/or shift the silicate template in order to reproduce the diversity observed within the ATLAS sample. This and other issues related to the silicate feature in AGN will be addressed in a forthcoming work.

The luminosity of the PDR component estimated in the fit (\( L_{\text{PDR}} \)) is a measurement of the total PAH luminosity in the galaxy. Comparison of \( L_{\text{PDR}} \) with the 6.2 \( \mu m \) PAH luminosity (Fig. 8) indicates the latter is responsible for roughly 10 per cent of the total PAH luminosity in the galaxy, in agreement with the results of Smith et al. (2007) in a sample of local starbursts, and that this ratio does not significantly change in the higher luminosity sources.

A comparison of \( \text{EW}_{6.2} \) with \( r_{\text{PDR}} \) shows significant dispersion (Fig. 9), mostly because of variations in the relative strength of PAH features. Unusually low 6.2 \( \mu m \) to total PAH luminosity ratios (\( \text{EW}_{6.2}/L_{\text{PDR}} < 0.05 \)) are found mainly in heavily obscured ULIRGs, where an absorption band of water ice overlaps with the 6.2 \( \mu m \) PAH emission, while very high ratios (\( \text{EW}_{6.2}/L_{\text{PDR}} > 0.2 \)) appear in sources with peculiar MIR spectra that suggest unusual physical properties or artefacts in the data.

6 MIR DIAGNOSTICS

6.1 The fork diagram

The ‘fork diagram’, i.e. the strength of the 10 \( \mu m \) silicate feature, \( S_{\text{sil}} \) versus the EW of the 6.2 \( \mu m \) PAH feature, \( \text{EW}_{6.2} \), first discussed by Spoon et al. (2007), is now considered a standard tool to distinguish between AGN- and starburst-dominated sources (e.g. Farrah
Figure 8. Ratio between the 6.2 µm PAH luminosity, as obtained by integration in the 5.95–6.55 µm band with corrections for flux lost in the wings of the profile (L_{62}), and the integrated PAH luminosity as derived from the PDR component in spectral decomposition (L_{PDR}) as a function of L_{62} for sources with an S/N > 2 detection of the 6.2 µm PAH feature. The dotted line represents the best-fitting linear relation.

Figure 9. EW_{6.2} versus r_{PDR} for the sources in the sample with an S/N > 2 detection of the 6.2 µm PAH feature. Symbols indicate the relative contribution of the 6.2 µm to the integrated PAH luminosity as measured by the L_{62}/L_{PDR} ratio: red squares indicate a ratio larger than 0.2, while green triangles mark ratios smaller than 0.05.

et al. 2007; Zakamska et al. 2008; Wu et al. 2009; Willett et al. 2010). Starbursts tend to have large values of EW_{6.2}, which decrease with increasing S_{160} due to depletion of the PAH band by absorption of adjacent water ice bands (Spoon et al. 2002) and increased continuum emission, while in AGN-dominated galaxies silicates appear in shallower absorption (typically type 2 objects) or emission (type 1 objects) while the PAH features are less pronounced.

A variant of the fork diagram can be obtained using the 11.3 µm PAH feature instead of the 6.2 µm one (Fig. 10). This approach has the advantage of requiring less wavelength coverage and avoids the bias introduced in deeply obscured sources by water ice absorption in the wings of the 6.2 µm PAH feature (note that the 11.3 µm flux can be heavily depleted by silicate absorption, but since the silicate feature is very broad, the EW is not significantly altered). In this variant of the diagram the starburst-dominated branch turns nearly vertical, but the topology remains unchanged.

The parameters derived from the spectral decomposition allow us to build an alternative fork-like diagram, where r_{PDR} substitutes the PAH EW and τ_{9.7} takes the place of S_{160} (Fig. 11). The advantage of this procedure is the results do not depend on the measurement of a single PAH band and the flux at the core of the silicate feature and the related caveats; instead, it uses the whole 5–15 µm spectrum, making it less vulnerable to noise.

6.2 MIR classification

We use the spectral decomposition results to obtain an MIR classification of the sources in the ATLAS sample. At a first stage, we separate AGN- and starburst-dominated sources based on the fraction of PDR component, r_{PDR}.

We set the limit between AGN- and starburst-dominated sources at r_{PDR} = 0.15, which corresponds to EW_{6.2} ~ 0.2 µm according to the relation shown in Fig. 9. Hernan-Caballero et al. (2009) showed that typical νL_ν(5.5 µm)/L_{IR} ratios for AGN have values around 0.3 (their fig. 13), and starburst sources have mean L_{62}/L_{IR} ratios of 0.01 (their table 9). Approximating the 6.2 µm continuum with the 5.5 µm luminosity would imply an EW of EW_{6.2} ~ 0.2 µm for a source with 50 per cent starburst and 50 per cent AGN contribution to the IR luminosity.

Since many spectra are noisy and there is a significant number of sources near this threshold, we require the 1σ confidence interval not to contain the threshold value in order to qualify as
AGN-dominated or starburst-dominated. The remaining sources are classified as ‘composites’ if $r_{\text{PDR}}$ has $S/N > 2$ or ‘unknown’ otherwise.

In 93 sources the spectral coverage in the 5–15 $\mu$m range is too low to estimate $r_{\text{PDR}}$, but the EW of the 6.2 or 11.3 $\mu$m PAH features is measured. For these sources we use EW$_{\text{6.2}} = 0.2$ $\mu$m (or EW$_{\text{11.3}} = 0.2$ $\mu$m) as an alternative boundary between the starburst- and AGN-dominated classes.

With these criteria, 257 sources are classified as starburst-dominated in the MIR (MIR_SB), 348 as AGN-dominated (MIR_AGN) and 29 are too close to the threshold to decide, so they get classified as composites (MIR_COMP). The spectra of another 49 sources are too noisy to tell, and in the remaining 12 the 6.2 and 11.3 PAH features are both outside of the observed spectral range.

The 348 AGN-dominated sources are further sub-classified according to their $\tau_{9.7}$ measurement into silicate emission (MIR_AGN1, 119 sources) or absorption (MIR_AGN2, 160 sources), again requiring the 1$\sigma$ confidence interval in $\tau_{9.7}$ not to cross $\tau_{9.7} = 0$ for a clean classification. Sources in which the $\sigma$ interval contains $\tau_{9.7} = 0$, but with uncertainties below 0.1, are classified as ‘flat MIR-spectrum AGN’ (MIR_AGNx, 18 sources) to indicate that there is no strong emission or absorption at 10 $\mu$m, and the remaining 51 sources retain the generic MIR_AGN classification.

Table 5 shows the distribution of sources in the sample according to their optical spectroscopic and MIR classifications. Values indicate the number of sources with a given optical and MIR classification. Sources classified in the literature as both AGN and starburst in the optical are discarded for clarity (numbers in brackets represent the counts obtained, when these sources are included).

In most sources, the optical and MIR classifications are broadly consistent with each other (i.e. type 1 AGN usually show strong continuum and silicate emission, type 2 also show strong continuum and silicate absorption and starbursts show strong PAH features on top of a fainter continuum), but there are exceptions. In particular, more than 1/4 of Seyfert 1s and QSOs show significant silicate absorption, and many sources classified as AGN in the optical are starburst dominated in the MIR. Aperture effects may be at least in part responsible for this, since the IRS spectrum of a galaxy nucleus includes a far larger share of the emission from the galaxy compared to the corresponding optical spectrum.

In the lower luminosity Seyferts, the host galaxy can contribute by a large fraction to the luminosity within the IRS slit, and composition of the (AGN-dominated) nuclear spectrum and (starburst-dominated) host galaxy spectrum can produce a silicate feature in absorption. This interpretation is supported by the strong PAH features observed in some Seyferts, that make them qualify as starburst-dominated in the MIR. Nevertheless, significant silicate absorption is also present in the spectrum of several QSOs, where the contribution from the host galaxy to the MIR luminosity is expected to be small. Thus, at least in some cases the silicate absorption feature may be caused by obscuration of the AGN emission, be it in a dusty torus or in the host galaxy.

On the other hand, there are also 15 Seyfert 2s and QSOs (1/6 of the total) with the silicate in emission, as measured by $\tau_{9.7}$ (12 of them also confirmed by $S_{\text{sil}} > 0$).

These apparent discrepancies, however, cannot be regarded as evidence against the unified model of AGN; in fact, such behaviour is predicted by both smooth and clumpy circumnuclear dust distribution models. Smooth models predict silicate absorption in compact, high-opacity face-on tori (Fritz, Franceschini & Hatziminaoglou 2006), and also allow for silicate emission in type 2 AGN (e.g. Hatziminaoglou et al. 2008). Clumpy models require a high number of clouds along the equator and high optical depth to produce silicate absorption in type 1 AGN (Nenkova et al. 2008), while some parameter combinations could give rise to silicate emission in type 2 AGN (e.g. Nikutta et al. 2009).

We therefore conclude that a silicate emission or absorption feature is not a reliable indicator, on its own, of the optical spectral type.

There are also four LINERs with silicate emission, three of them show broad Balmer lines, and a strong silicate peak, while the remaining one is a radiogalaxy with a weaker silicate feature.

Almost all optical starbursts are also classified as starbursts in the MIR, but the opposite is not true: roughly half of MIR starbursts

Figure 11. Analogue to the fork diagram obtained by representing the fraction of PDR component $r_{\text{PDR}}$ versus the optical depth at 9.7 $\mu$m, $\tau_{9.7}$, as calculated with the spectral decomposition method. Symbols as in Fig. 10.
belong to some of the optical AGN classes. These sources are mostly nearby galaxies harbouring low-luminosity AGN that can be outshined by the galaxy in the large IRS aperture. When taking into account only objects at $z > 0.1$, from 98 MIR_SB sources 54 are classified as starbursts in the optical, while 31 have LINER cores and only 13 are Seyferts or QSOs.

7 AVERAGE TEMPLATES

A number of synthetic galaxy templates have been obtained from the average spectrum of populations matching certain criteria, shown in Table 6.

We obtain average templates for Seyfert 1, Seyfert 1.X, Seyfert 2, LINER, QSO, QSO2, starburst, ULIRGs and SMGs. ULIRGs with LINER or starburst cores are discarded when composing the LINER and starburst templates, that include only sources with $L_{\nu}(7\mu m) < 10^{44}$ erg s$^{-1}$. Three additional templates are generated for sources classified in the MIR as dominated by starburst (MIR_SB), unobscured AGN (MIR_AGN1) and obscured AGN (MIR_AGN2).

The individual spectra are normalized at 7 µm rest frame and resampled to a common grid of wavelength values. The highest and lowest flux values in each wavelength bin are discarded, and the remaining ones are averaged with the arithmetic mean to obtain the template flux. The 12 templates obtained are shown in Fig. 12. Shaded areas indicate the 1σ dispersion of individual spectra, which is higher at longer wavelengths because of slope variations among sources of the same type. These templates are available as ASCII tables with columns for rest-frame wavelength, normalized average flux density, 1σ dispersion in flux density and number of sources contributing to the average for each wavelength bin.

The QSO template (e) is flat and almost featureless, while the type 2 QSOs (f) have on average a redder continuum and a somewhat pronounced silicate feature in absorption. The equivalent of the PAH features in the QSO and QSO2 templates are much lower compared to those present in the average Sy1 (a) and Sy2 (c) templates, in spite of the high SFRs derived from both the PAH features (e.g. Hernán-Caballero et al. 2009) and FIR luminosities (e.g. Hatziminaoglou et al. 2010), because the strong continuum emission from the AGN masks the underlying emission from the host galaxy. The LINER template (d) includes only nearby sources and its low PAHs EWs are indicative of weak circumnuclear star formation. Its 5–9 µm continuum is bluer than either the starburst or Seyfert templates because contribution from starlight is not negligible compared to the AGN emission. Complementary templates are generated for all sources classified as ULIRG (h) in the literature (irrespective of their optical spectral type) as well as the SMGs (i). The latter has a very limited spectral coverage, as all the objects composing the SMG sample are high-redshift objects (with an average redshift ($z$) = 1.93).

The MIR AGN average templates (j, k) also show interesting characteristics: the objects selected to have silicate in emission at 10 µm have a flat spectrum with the silicate feature at 18 µm clearly in emission, as well. The objects selected to have the silicate feature in absorption have a redder continuum and show no feature at 18 µm, be it in emission or in absorption. In a detailed comparative study between smooth and clumpy dust distributions, Feltre et al. (in preparation) show that such silicate features’ behaviour is compatible with both clumpy and smooth dust distributions and hence we cannot derive any constraints from the average templates.

Interestingly, the average starburst template constructed from objects selected as such in the optical (g) shows more prominent PAH features and a redder continuum than the equivalent MIR template (l). This difference is most likely due to the different nature of the objects composing the two samples. The optical sample consists of low-redshift starburst galaxies alone, while the MIR template has a higher average redshift, includes many ULIRGs as well as objects with significant AGN contribution.

8 CONCLUSIONS

We have collected a sample of 739 active and starburst galaxies with Spitzer/IRS spectra from the literature. The sample, though not statistically, comprises a variety of objects, namely type 1, 2 QSOs and Seyfert galaxies, intermediate Seyfert galaxies, ULIRGs, starburst and sub-mm galaxies, with a large span of spectral properties such as PAH and silicate features, continua and distinct physical characteristics, and is the largest of its kind compiled to date. MIR properties were computed in a concise way for all objects and can thus be directly compared among the various types of objects.

We find that the silicate strength, $S_{\text{sil}}$, a measurement of the intensity of the 10 µm silicate feature that takes positive (negative) values when the feature is in emission (absorption), is well approximated by a ‘three band’ colour index, $C_{7-10-14}$, that is usually easier to obtain, except for sources with strong PAH emission that contaminates the flux at 7 µm, causing $C_{7-10-14}$ to consistently lie short of $S_{\text{sil}}$. A more elaborate measurement of dust obscuration, $\tau_{3.6}$, obtained from the scaling factor applied to the extinction law in a spectral decomposition analysis, shows also a tight correlation

Table 6. Composite spectral templates.

| Name          | N sources | $z_{\text{min}}$ | $z_{\text{max}}$ | $\lambda_{\text{min}}$ (µm) | $\lambda_{\text{max}}$ (µm) | Comments                                                                 |
|---------------|-----------|------------------|------------------|------------------------------|----------------------------|-------------------------------------------------------------------------|
| Sy1           | 11        | 0.002            | 0.041            | 0.205                        | 5.2                        | 24.6                      | Seyfert 1 with $L_{\nu}(7 \mu m) < 10^{44}$ erg s$^{-1}$               |
| Sy1x          | 72        | 0.003            | 0.091            | 0.371                        | 5.0                        | 24.6                      | Intermediate Seyfert types (1.2, 1.5, 1.8, 1.9)                        |
| Sy2           | 53        | 0.003            | 0.045            | 1.140                        | 5.2                        | 24.6                      | Seyfert 2 with $L_{\nu}(7 \mu m) < 10^{44}$ erg s$^{-1}$               |
| LINER         | 16        | 0.001            | 0.034            | 0.322                        | 5.2                        | 24.6                      | LINER with $L_{\nu}(7 \mu m) < 10^{44}$ erg s$^{-1}$                  |
| QSO           | 125       | 0.020            | 1.092            | 3.355                        | 2.5                        | 24.6                      | QSO1 and Seyfert 1 with $L_{\nu}(7 \mu m) > 10^{44}$ erg s$^{-1}$      |
| QSO2          | 65        | 0.031            | 1.062            | 3.700                        | 3.6                        | 24.6                      | QSO2 and Seyfert 2 with $L_{\nu}(7 \mu m) > 10^{44}$ erg s$^{-1}$      |
| Shbrst        | 16        | 0.001            | 0.091            | 1.316                        | 5.2                        | 24.6                      | Starburst or H II with $L_{\nu}(7 \mu m) > 10^{44}$ erg s$^{-1}$       |
| ULIRG         | 184       | 0.018            | 0.730            | 2.704                        | 4.5                        | 24.6                      | ULIRG (low- and high-redshift sources)                                 |
| SMG           | 51        | 0.557            | 1.869            | 3.350                        | 4.8                        | 12.0                      | Submillimetre galaxies                                                 |
| MIR_AGN1      | 119       | 0.002            | 0.455            | 2.190                        | 4.0                        | 24.6                      | MIR-selected AGN with silicate emission                                |
| MIR_AGN2      | 160       | 0.002            | 0.549            | 2.470                        | 4.5                        | 24.6                      | MIR-selected AGN with silicate absorption                              |
| MIR_SB        | 257       | 0.001            | 0.413            | 2.000                        | 4.6                        | 24.6                      | MIR-selected starbursts                                                |

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Figure 12. Composite templates for subsamples of the ATLAS sample. In the first three rows, sources are selected based on their optical type and MIR luminosity, except for the ULIRG and SMG templates (see text). The bottom row shows average templates of the sources grouped according to the MIR classification.

with $S_{\text{sil}}$, but with different slopes for sources with saturated ($\tau_{9.7} > 3$) and unsaturated ($\tau_{9.7} < 3$) silicate features.

We find that the ratio of the PDR component to the total luminosity of each object, integrated between 5 and 15 $\mu$m rest frame, $r_{\text{PDR}}$, and $\tau_{9.7}$, both obtained from the spectral decomposition, provides better AGN versus SB and obscuration diagnostics than the usual PAH EW and $S_{\text{sil}}$ in sources with sufficient spectral coverage, as they do not depend on a single spectral feature and thus are less vulnerable to noise. Most QSOs and Seyfert I galaxies show $\tau_{9.7}$ values clustered around zero and $r_{\text{PDR}}$ values below 0.15, while starburst galaxies have large $r_{\text{PDR}}$ values and moderate to deep silicate absorption (higher in the starburst ULIRGs than in lower luminosity starbursts). Type 2 QSOs and Seyfert 2s exhibit low $r_{\text{PDR}}$ values and usually silicate absorption, sometimes strong, while LINERs can have almost any combination of parameters, due to their nature and definition.

We then derive a simple classification of the sources, based on the values of $r_{\text{PDR}}$ and $\tau_{9.7}$. Objects with $r_{\text{PDR}} < 0.15$ are considered to be AGN-dominated, while $r_{\text{PDR}} > 0.15$ indicates starburst-dominated sources, and the AGN-dominated subsample is further divided into silicate emitters and absorbers ($\tau_{9.7} > 0$ and $\tau_{9.7} < 0$, respectively). Comparison of this simple MIR classifications with the optical classifications in the literature is not straightforward, since the much wider aperture of the IRS slit with respect to optical spectroscopy
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