The SPITZER IRS view of stellar populations in Virgo early type galaxies.

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Abstract. We have obtained high S/N Spitzer IRS spectra of 17 Virgo early-type galaxies that lie on the colour-magnitude relation of passively evolving galaxies in the cluster. To flux calibrate these extended sources we have devised a new procedure that allows us to obtain the intrinsic spectral energy distribution and to disentangle resolved and unresolved emission within the same object. Thirteen objects of the sample (76\%) show a pronounced broad silicate feature (above 10\(\mu\)m) which is spatially extended and likely of stellar origin, in agreement with model predictions. The other 4 objects (24\%) are characterized by different levels of activity. In NGC 4486 (M87) the line emission and the broad silicate emission are evidently unresolved and, given also the typical shape of the continuum, they likely originate in the nuclear torus. NGC 4636 show emission lines superimposed to extended silicate emission (i.e. likely of stellar origin, pushing the percentage of galaxies with silicate emission to 82\%). Finally NGC 4550 and NGC 4435 are characterized by PAH and line emission, arising from a central unresolved region.

1. Introduction

We suggested that the presence of dusty circumstellar envelopes around asymptotic giant branch(AGB) stars should leave a signature, a clear excess at 10 \(\mu\)m, in the mid infrared (MIR) spectral region of passively evolving stellar systems Bressan et al. (1998). Early detections of such an excess were suspected in M32 (Impey et al. 1986) from ground-based observations, and in a few ellipticals observed with ISOCAM (Bregman et al. 1998). The first unambiguous confirmation, though barely resolved, was found with the ISO CVF spectrum of NGC 1399 (Bressan et al. 2001). Since AGB stars are luminous tracers of intermediate age and old stellar populations, an accurate analysis of this feature has been suggested as a complementary way to break the degeneracy between age and metallicity that affects optical observations of early type galaxies (Bressan et al. 1998, 2001). In fact the models show that a degeneracy between metallicity and age persists even in the MIR, since both age and metallicity affect mass-loss and
evolutionary lifetimes on the AGB. But while in the optical age and metallicity need to be anti-correlated to maintain a feature (colour or narrow band index) unchanged, in the MIR it is the opposite: the larger dust-mass loss of a higher metallicity SSP must be balanced by its older age. Thus a detailed comparison of the MIR and optical spectra of passively evolving systems constitutes perhaps one of the cleanest ways to remove the degeneracy. Besides this simple motivation and all other aspects connected with the detection of evolved mass-losing stars in passively evolving systems (e.g. Athey et al. 2002, Temi et al. 2005), a deep look into the mid infrared region may reveal even tiny amounts of activity (e.g. Kaneda et al. 2005). Here we report on the first clear detection of extended silicate features in a sample of Virgo cluster early type galaxies (Bressan et al 2006), observed with Spitzer IRS instrument\(^1\) (Houck et al. 2004) of the Spitzer Space Telescope (Werner et al. 2004).

### Table 1. Virgo galaxies observed with IRS

| Name    | V\(_T\) | Date        | SL1/2 60s | LL2 120s | S/N 6\(\mu m\) |
|---------|---------|-------------|-----------|----------|-----------------|
| NGC 4339 | 11.40   | Jun 06 2005 | 20        | 20       | 20              |
| NGC 4365 | 9.62    | Jan 10 2005 | 3         | 3        | 57              |
| NGC 4371 | 10.79   | Jun 01 2005 | 9         | 10       | 40              |
| NGC 4377 | 11.88   | Jun 01 2005 | 12        | 12       | 54              |
| NGC 4382 | 9.09    | Jul 07 2005 | 3         | 3        | 59              |
| NGC 4435 | 10.66   | Jun 01 2005 | 3         | 3        | 35              |
| NGC 4442 | 10.30   | Jan 10 2005 | 3         | 3        | 46              |
| NGC 4473 | 10.06   | Jun 01 2005 | 3         | 3        | 55              |
| NGC 4474 | 11.50   | Jun 01 2005 | 20        | 20       | 38              |
| NGC 4486 | 8.62    | Jun 03 2005 | 3         | 3        | 80              |
| NGC 4550 | 11.50   | Jun 03 2005 | 20        | 20       | 42              |
| NGC 4551 | 11.86   | Jun 03 2005 | 20        | 20       | 47              |
| NGC 4564 | 11.12   | Jun 07 2005 | 4         | 4        | 51              |
| NGC 4570 | 10.90   | Jun 06 2005 | 3         | 3        | 42              |
| NGC 4621 | 9.81    | Jan 12 2005 | 3         | 3        | 63              |
| NGC 4636 | 9.49    | Jul 08 2005 | 3         | 3        | 30              |
| NGC 4660 | 11.11   | Jan 11 2005 | 3         | 3        | 40              |

2. Observations and data reduction

Standard Staring mode short (SL1 and SL2) and long (LL2) low resolution IRS spectral observations of 18 early type galaxies, were obtained in the first Cycle between January and July 2005. The galaxies were selected among those that define the colour magnitude relation of Virgo cluster (Bower, Lucy & Ellis 1992), whose common explanation is in term of a sequence of passively evolving coeval objects of decreasing metallicity. The log of the observations, number of ramps (of 60s or 120s) and S/N reached at 6 \(\mu m\) are shown in Table 1. The spectra were extracted within a fixed aperture (3.6” × 18” for SL and 10.2” × 10.4” for LL) and calibrated using our own software, tested versus the SMART software package (Higdon et al. 2004). Since the reduction procedure is described in detail in Bressan et al. 2006, here we will only resume the main steps. For SL observations, the sky background was removed by subtracting observations

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\(^1\)The IRS was a collaborative venture between Cornell University and Ball Aerospace Corporation, funded by NASA through the Jet Propulsion Laboratory and the Ames Research Center.
taken in different orders, but at the same node position. LL segments were sky-subtracted by differencing the two nod positions. Since the adopted IRS pipeline (version S12) is specifically designed for point source flux extraction, we have devised a new procedure to flux calibrate the spectra, that exploits the large degree of symmetry that characterizes the light distribution in early type galaxies. We first obtained the real DN/Jy by applying the corrections for aperture losses (ALCF) and slit losses (SLCF) to the flux conversion tables provided by the Spitzer Science Center (e.g. Kennicutt et al. 2003). After the ALCF and SLCF corrections were applied we obtained the flux received by the slit, within a given aperture in the following way. For each galaxy we assumed a wavelength dependent bidimensional intrinsic surface brightness profile and, by convolving it with the instrumental point spread function (PSF), we simulated the corresponding observed linear profile along the slits, taking into account the relative position angles of the slits and the galaxy. The adopted profile is a two dimensional modified King law (Elson et al. 1987), with axial ratios taken from the literature

\[ I \equiv I_0/[1 + \frac{X^2}{R_C^2} + \frac{Y^2}{(R_C \times b/a)^2}]^{\gamma/2} \] (1)

In equation 1 X and Y are the coordinates along the major and minor axis of the galaxies and \( I_0, R_C \) and \( \gamma \) are free parameters that are functions of wavelength, and are obtained by fitting the observations with the simulated profile. In order to get an accurate determination of the parameters of the profiles, several wavelength bins have been folded together. This procedure has a twofold advantage because, it allows us both to reconstruct the intrinsic profile and the corresponding SED, and to recognise whether a particular feature is resolved or not. Finally the spectrum, extracted in a fixed width around the maximum intensity, is corrected by the ratio between the intrinsic and observed profile. Since for the LL segment the above procedure is quite unstable, we have preferred to fix one of the parameters of the profile (usually \( R_C \)) to the value derived in the nearby wavelength region of the SL segment. Finally, the LL spectrum has been rescaled to match that of SL, to account for the different extraction area.

3. Results

Silicate emission from evolved stars.

In Figure 1 we have collected all the galaxies whose MIR spectra are characterised by the presence of the broad silicate emission features at 10µm. These thirteen galaxies constitute 76% of the sample. The analysis of the IRS spectra indicates that the 10µm feature has an extended spatial distribution, consistent with that obtained in the spectral range dominated by stellar photospheres (below 8µm). This is in agreement with ISOCAM observations that indicated spatially resolved emission at 6.7 and 15 µm (Athey et al. 2002, Ferrari et al 2002, Xilouris et al. 2004). The IRS spectra are very well fitted by a combination of an M giant model spectrum (MARCS, Gustafsson et al. 2002) and dust emission from circumstellar envelope models computed by Bressan et al. (1998) for a silicate grain composition, as shown in Figure 1. The percentage
Figure 1. IRS spectra (solid lines) of passively evolving early-type galaxies in the Virgo cluster. Superimposed are best fits (dashed lines) obtained by means of simple models composed of an M giant star spectrum (dotted lines) from (MARCS, Gustafsson et al. 2002) and a dusty silicate circumstellar envelope (dot-dashed lines) from Bressan et al. 1998. Data and models are normalized at 5.5\(\mu\)m. The fractional contribution of the circumstellar envelope at 10\(\mu\)m ("d") and its optical depth at 1\(\mu\)m ("\(\tau\)") are indicated in the figure. In those cases where a combination of two dusty envelopes is needed, their optical depth at 1\(\mu\)m and relative fractions ("f") are specified.
contribution of the dusty envelope to the total flux at 10\(\mu\)m is roughly 50%. This fraction is consistent with a population of dust enshrouded evolved stars because in spite of their paucity, their 10\(\mu\)m luminosity is about 100 times the average 10\(\mu\)m luminosity of the horizontal branch and red giant branch stars, making their contribution to the integrated light comparable. If, as we believe, the 10\(\mu\)m feature is of stellar origin, it constitutes perhaps the most important mid infrared diagnostic tool for the study of the stellar populations in passively evolving systems of the local universe. We notice however that the fits obtained here are better than those obtained by making use of the full isochrones (see Bressan et al. 2006). In particular it is surprising that the observations suggest that the major contribution comes from envelopes in a quite narrow range of optical depth (\(\tau_{1\mu m} \simeq 3 - 5\)), at variance with isochrones that account for a distribution of envelopes of varying optical depth. This indicates that a revision (and understanding) of the isochrones in the advanced phases is necessary.

**Active galaxies.**

The other four galaxies shown in Figure 2 display various signatures of activity in the MIR spectra. They constitute the 24% of our sample. It is worth noticing that these galaxies had already been classified as active from optical studies (AGN -M87-, Liner or transition Liner-HII), while no signatures of activity had been detected in the former group. Spectra of NGC 4636 and NGC 4486(M87) are dominated by emission lines ([ArII]7\(\mu\)m, [NeII]12.8\(\mu\)m, [NeIII]15.5\(\mu\)m and [SII]18.7\(\mu\)m), while those of NGC 4550 and NGC 4435 by PAH emission (at 6.2, 7.7, 8.6, 11.3, 11.9, 12.7 and 16.4\(\mu\)m). NGC 4435 shows also emission lines (and H2 S(3) 9.66\(\mu\)m, H2S(2) 12.3\(\mu\)m and H2S(1)17.04\(\mu\)m). The broad continuum features at 10\(\mu\)m (and perhaps at 18\(\mu\)m) in M87 are unresolved and their likely cause is silicate emission from the dusty torus (Siebenmorgen et al. 2005, Hao et al. 2005). In NGC 4435 the continuum below \(\sim 6\mu\)m looks extended, while above this (in particular PAHs) it looks unresolved. A preliminary interpretation shows that an unresolved starburst is dominating the emission above \(\sim 6\mu\)m, while at lower wavelengths the old extended stellar component dominates the continuum (Panuzzo et al. in preparation).
4. Conclusions

We have obtained Spitzer mid infrared IRS spectra of early type galaxies selected along the colour-magnitude relation of the Virgo cluster. We present a new method to reconstruct the SED of these galaxies, that rests on a careful analysis of the spatial profile sampled by the slits. In most of the galaxies (76%) the emission looks spatially extended and presents an excess longward of 10µm, which is likely due to silicate emission from mass losing evolved stars. However, the peculiar distribution of the optical depth of the circumstellar envelopes derived from the fits requires a better understanding of the corresponding evolutionary phases. In the remaining smaller fraction (24%) we detect signatures of activity at different levels. If we exclude M87 which is noticeably an active galaxy, only two out of 16 early type galaxies observed show PAHs, which corresponds to a quite low fraction (~12%) of the observed sample. It is premature to conclude that this fraction is representative of the early type population in clusters of galaxies, in particular if we consider that our investigation is limited to the brightest cluster members. A detailed comparison of our results with those obtained for field galaxies will certainly cast light on the role of environment in the galaxy evolution process.

Acknowledgments. This work is based on observations made with the Spitzer Space Telescope, which is operated by the JPL, Caltech under a contract with NASA. We thank J.D.T. Smith for helpful suggestions on the IRS flux calibration procedure. A. B., G.L. G. and L. S. thank INAOE for warm hospitality.

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