Comparison between 30 micron sources in different galaxies

Marcin Gladkowski¹, Ryszard Sztczerba¹, G. C. Sloan², Eric Lagadec³ and Kevin Volk⁴

¹ Nicolaus Copernicus Astronomical Center, ul. Rabańiska 8, 87 - 100 Toruń, Poland
² Cornell Center for Astrophysics and Planetary Science, Cornell University, Ithaca, NY 14853-6801, USA
³ Laboratoire Lagrange, UMR 7293, Univ. Nice Sophia-Antipolis, CNRS, Observatoire de la Côte d’Azur, F-06300, Nice, France
⁴ Space Telescope Science Institute, 3700 San Martin Drive, Baltimore, Maryland, U.S.A.

E-mail: ¹ seyfert@ncac.torun.pl

Abstract. We present an analysis and comparison of the 30 μm dust feature in the spectra of carbon-rich objects located in the Milky Way, Magellanic Clouds and the Sagittarius dwarf spheroidal galaxy. All of these galaxies are characterized by the different metallicities. We expect that some physical and chemical processes related to the formation of the feature are a function of the metallicity. Our study should allow us to better understand the mass loss process and thus late stages of stellar evolution of carbon-rich stars in these four galaxies. Our analysis uses the “Manchester method” as a basis of estimating the temperature of dust for the carbon-rich stars and the planetary nebulae in our sample. In the case of post-AGB objects we changed the spectral ranges used for the temperature estimation, because of the presence of the 21 μm feature. We used a blackbody function with a single temperature deduced from the Manchester method to approximate the continuum under the 30 μm feature.

We have produced on-line catalogues of photometric and Spitzer IRS spectra for all objects that show the 30 μm feature. These resources are available on-line for use by the community.

1. Introduction

A broad emission dust feature peaking around 30 μm is seen in the spectra of some carbon-rich Asymptotic Giant Branch (AGB) stars, post-AGBs and planetary nebulae (PNe). This feature was observed for the first time by [1] who noticed it in the CW Leo and two other objects. Since the discovery this dust feature has been detected in many carbon-rich objects. In the carbon-rich post-AGB objects this feature is observed along with the 21 μm feature (the carrier of which is still unidentified), and is often extremely strong. The feature is generally weaker in PNe spectra.

[2] proposed solid magnesium sulfide (MgS) as the possible carrier of the 30 μm feature. Despite the MgS identification being widely accepted by the community, its identification remains unconfirmed. Other authors have proposed different materials as possible carriers of the 30 μm feature, such as hydrogenated amorphous carbon [3] or graphite [9]. It has been suggested that the feature arises from two-component grains rather than a simple homogeneous dust...
particle. For instance, [8] suggested that MgS condenses as a coating on the top of amorphous carbon and SiC grains. [5] have analysed a sample of 63 Galactic 30 µm feature spectra collected by Infrared Space Observatory. This is the biggest sample which has been analysed in a uniform way so far. The subsequent Spitzer Space Telescope mission (hereafter Spitzer), thanks to its sensitivity, was able to detect sources with 30 µm feature in nearby galaxies such as the Magellanic Clouds and the Sagittarius dwarf spheroidal galaxy (hereafter Sgr dSph).

2. The Toruń catalogues of 30 µm objects
The 30 µm feature spectra were identified by visual examination of all Spitzer Infrared Spectrograph (IRS) spectra for objects in the Magellanic Clouds, as well as spectra from programs observing carbon-rich objects in the Galaxy or Sgr dSph. We have a total 180 objects whose IRS spectra show the 30 µm feature, divided into three catalogues: 15 objects from the Small Magellanic Cloud, 100 objects from the Large Magellanic Cloud, and 65 objects divided between the Galaxy (60) and the Sgr dSph (5). The Sgr dSph sources are distinguished by special comments in the third catalogue. The catalogues are available on-line at:

- http://www.ncac.torun.pl/postagb_30smc,
- http://www.ncac.torun.pl/postagb_30lmc,
- http://www.ncac.torun.pl/postagb_30galactic.

The catalogues contain photometric data from Spitzer, WISE, 2MASS, 2MASS 6X, MCPS, AKARI and IRAS. The Galactic catalogue contains data from the GSC and USNO as well. Each catalogue also contains the Spitzer spectra.

3. Spectral analysis
3.1. The spectral sample
Our sample consists of archival data obtained by the Spitzer IRS instrument. We use optimally extracted low and high resolution spectra ([6]) from various observational programs. The spectral coverage is from 5 to 38 µm in the low resolution spectra. Discontinuities were removed between orders by multiplying each spectral segment by a scale factor to align them in the regions of overlap. For the most of objects the corrections are made up to the brightest segment, on the grounds that this segment is the one best centered in the slit.

3.2. Continuum
Our analysis is based on the “Manchester Method”, which was introduced by [11, 10]. It uses two colour indices, [6.4]−[9.3] and [16.5]−[21.5]. The [6.4]−[9.3] colour is calculated by separately summing the total spectral emission from 6.25 to 6.55 µm and from 9.1 to 9.5 µm. [11] showed that the [6.4]−[9.3] colour provides a good estimate of the dust optical depth, whereas the [16.5]−[21.5] colour serves as an indicator of the dust temperature We summed over the regions 16–17 µm and 21–22 µm) to simulate the second colour value. The [6.4]−[9.3] colour shows a linear correlation with the measured mass-loss rates [4]. We used this method in the original form for the carbon-rich AGB objects and PNe.

In the case of post-AGB stars we defined three additional colour indices to estimate the dust temperature $T_d$, depending the strength of the 21 µm feature. Generally, if the 21 µm is not visible or is very weak we used the [18.4]−[22.45] colour (summing the emission from 18.1–18.7 and 22.3–22.6 µm) to estimate the dust temperature. When the 21 µm feature is relatively strong we took the [18.4]−[22.75] colour (summing the emission from 18.1–18.7 and 22.5–23 µm). For objects with a very strong 21 µm feature we used the [17.95]−[23.2] colour (summing the emission from 17.8–18.1 and 23–23.4 µm).
To model the underlying continuum we use a blackbody emission with a single temperature derived from the colours discussed above. Then we fit the blackbody continuum level at specific wavelengths, which depend on the kind of object. The typical normalization range for the carbon-rich AGB stars is 16–22 µm, for carbon-rich post-AGB stars without the 21 µm feature we use 19.5–22.5 µm, and for the PNe we use 20–23 µm.

After subtraction of the continuum we measured the strength of the 30 µm feature, which is defined as the ratio between integrated flux (from 24 to 36 µm) of the feature and the integrated flux of the continuum (L/C).

4. Circumstellar properties

Fig. 1 shows the strength of the feature (L/C) as a function of the dust temperature. This feature tends to appear in the envelopes of objects with cool dust. In the case of AGB stars, the strength of the feature increases as the dust temperature decreases until about 400 K. After that, probably self-absorption reduces the strength of the 30 µm feature. The coolest objects with this feature are post-AGBs and PNe. However, it seems that there is no correlation between L/C and \( T_d \). Fig. 2 shows the strength of the feature (L/C) as a function of \([6.4]−[9.3]\) colour. The Galactic objects show a range of values of \([6.4]−[9.3]\) colour. In the LMC the 30 µm emission become visible for the redder values of \([6.3]−[9.4]\) colour (\( \sim 0.5 \) mag). The SMC objects become visible around \([6.4]−[9.3]\) \( \sim 0.75 \) mag. This trend was also described by [10, 7]. This behaviour is consistent with a metallicity effect, because in the lower metallicity environments there is less Mg and S to form MgS, thus a higher dust production rate is needed to create the feature.

Figure 1. The strength of the 30 µm feature as a function of the dust temperature.
5. Summary/Conclusions

We present a large sample of 180 Spitzer IRS spectra of carbon-rich objects that exhibit the 30 µm feature, and a simple approach to determine the continuum under the 30 µm feature. The strength of the 30 µm feature shows a correlation with the $T_d$ for AGB stars, and dependence on the metallicity of host galaxy. The full analysis of the 30 µm feature in our and nearby galaxies will appear elsewhere (Gladkowski et al. 2016, in preparation).

Acknowledgments

This work was financially supported by the MNiSW of Poland through grant No. 2014/15/N/ST9/04629. We have made extensive use of the SIMBAD and Vizier databases operated at the Centre de Données Astronomiques de Strasbourg. We also collected low and high resolution spectra from The Cornell Atlas of Spitzer/IRS Sources (CASSIS), which is a product of the Infrared Science Center at Cornell University, supported by NASA and JPL. Special thanks to Gregory Sloan for providing optimally extracted spectra for the most of objects from our sample.

References

[1] Forrest W J, Houck J R and McCarthy J F 1981 Astrophys. J. 248 195
[2] Goebel J H and Moseley S H 1985 Astrophys. J. 290 L35
[3] Grishko V I, Tereszchuk K, Duley W W and Bernath P 2001 Astrophys. J. 558 L129
[4] Groenewegen M A T et al 2007 Mon. Not. R. Astron. Soc. 376 313
[5] Hony S, Waters L B F M and Tielens A G G M 2002 Astron. Astrophys. 390 533-53
[6] Lebouteiller V, Bernard-Salas J, Sloan G C and Barry D J 2010 Publ. Astron. Soc. Pac. 122 188
[7] Leisenring J M, Kemper F and Sloan G C 2008 Astrophys. J. 681 1557-73
[8] Lombaert R, de Vries B L, de Koter A, Decin L, Min M, Smolders K, Mutschke H and Waters L B F M 2012 Astron. Astrophys. 544 L18
[9] Otsuka M, Kemper F, Cami J, Peeters E and Bernard-Salas J 2014 Mon. Not. R. Astron. Soc. 437 2577-93
[10] Sloan G C, Klaene K E, Matsuura M, Wood P R, Price S D and Egan M F 2006 Astrophys. J. 645 1118
[11] Zijlstra A A et al 2006 Mon. Not. R. Astron. Soc. 370 1961