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Probing PAH molecules in luminous infrared galaxies

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Abstract. A significant fraction of the infrared (IR) emission in star-forming galaxies corresponds to dust-reprocessed emission arising from complex molecules known as Polycyclic Aromatic Hydrocarbons (PAHs). PAHs are excited by ultraviolet (UV) photons and detected in the mid-IR due to their vibrational transitions. Detailed study of PAH transitions can give us insights into the radiation field within deeply dust-embedded mid-IR emitting regions. We explore the molecular complexity of PAH-emitting galaxies in the nearby universe by exploiting archival mid-IR spectra from the Infrared Spectrograph (IRS) on board the Spitzer Telescope. We focus our study on Luminous Infrared Galaxies (LIRGs; $10^{11}L_{\odot} \leq L_{IR} < 10^{12}L_{\odot}$), from the Great Observatories All-Sky LIRG Survey (GOALS). GOALS surveyed 180 low redshift ($z \leq 0.088$) LIRGs with a wide range of properties, including systems dominated by an AGN (Active Galactic Nucleus), starbursts, as well as systems in varying stages of galaxy interaction. We use the PAHFIT routine and the NASA Ames PAH IR database (PAHdb) to decompose the observed PAH features and characterize the underlying PAH population in terms of size, composition and charge. Following this approach, we will be capable of identifying how much of the IR emission in LIRGs is provided by PAHs and elucidate on how molecularly-rich these environments are. We here present preliminary results for a pilot sample of 20 LIRGs. This represents the first attempt to link the star formation history of LIRGs to the breakdown of their PAH emission.

Resumo. Uma fração significativa da emissão em infravermelho em galáxias com formação estelar correspondem a emissão por reprocessamento da poeira resultante de moléculas complexas conhecidas como Hidrocarbonetos Policíclicos Aromáticos. Os PAHs são excitados por fótons no ultravioleta e detectados no IR-médio devido a suas transições vibracionais. Estudos detalhados de transições dos PAHs podem nos dar o conhecimento do campo de radiação em regiões emissoras no IR-médio. Nesse projeto, nós exploramos a complexidade molecular de galáxias no universo local através de espectros em IR-médio do *Infrared Spectrograph* a bordo do Telescópio Espacial Spitzer. Nós focamos nosso estudo em Galáxias Luminosas no Infravermelho (LIRGs; $10^{11}L_{\odot} \leq L_{IR} < 10^{12}L_{\odot}$), do *Great Observatories All-Sky LIRG Survey*. GOALS inspecionou 180 LIRGs de baixo redshift ($z \leq 0.088$) com uma grande variedade de propriedades, incluindo sistemas dominados por AGNs, starbursts, assim como sistemas em diversos estágios de interação entre galáxias. Nós usamos a rotina PAHFIT e NASA PAHdb para decompor as bandas observadas dos PAHs e caracterizar essa população de moléculas em termos de tamanho, composição e carga. Como resultado, somos capazes de identificar o quanto da emissão em IR em LIRGs é provida pelos PAHs e elucidar o quão molecularmente rico esses ambientes são. Aqui, apresentamos nossos resultados para uma amostra piloto de 20 LIRGs. Esse projeto representa a primeira tentativa de inferir propriedades globais de galáxias, como caracterizar seu campo de radiação quanto a presença de AGNs, a partir de características específicas dos PAHs, como seu tamanho, carga e composição.

Keywords. Galaxies: star formation – Galaxies: ISM – Infrared: galaxies

1. Introduction

Luminous infrared galaxies are rare in the local universe, but become abundant at $z \geq 1$ (Casey et al. 2014). Although many works have studied this galaxy population, there are still important questions regarding their nature that have not yet been answered: what is the source of their luminosities and what mechanisms are responsible for their energy? AGNs and intense starbursts are used as energy origin of this particular type of galaxies. However, there is a consensus that LIRGs are dusty galaxies, where most part ($\sim 90\%$) of the UV radiation emitted by the stars and/or AGNs is absorbed by grains and re-emitted in IR (e.g., Armus et al. 2009).

Up to 20% of the IR emission in star-forming galaxies is in the form of broad emission bands at 6.2, 7.7, 8.6, 11.3, and 12.7 μm (Spoon et al. 2004) arising from the excitation of PAHs. It has been shown that the ratio between different PAH features can be used to constrain the size (i.e., number of carbon atoms) and ionization state of these molecules (Draine & Li 2001), while the ratio between PAH emission and dust continuum can be used as a measure of the relative contribution of an AGN (Menéndez-Delmestre et al. 2009).

Spitzer/IRS spectra of low resolution are ideal to study the PAHs features and silicate absorption at 9.7 and 18 μm (Spoon et al. 2004). The GOALS (Armus et al. 2009) database combines imaging and spectroscopy of a sample of 201 (U)LIRGs selected from the IRAS Revised Bright Galaxy Sample (Sanders et al. 2003). GOALS was created to characterize the observed diversity in properties in a statistically-significant sample of LIRGs. In the IR, the survey is mainly comprised of Spitzer data.

2. Methodology and Results

To analyze the PAH transitions in the mid-IR, we used low resolution spectra from Spitzer/IRS. The 20 LIRGs that comprise our pilot sample are selected following these two criteria: 1) they need to have low-resolution IRS spectroscopy covering the wavelength range where the main PAH features appear (i.e., $\sim$ 6 - 14 μm) and 2) they have the lowest redshifts from the GOALS sample ($z < 0.00298$).

The IRS spectra of our pilot sample[1] have been fit using the method described by Smith et al. (2007; PAHFIT). PAHFIT is an IDL-routine to decompose the low-resolution mid-IR spectra of galaxies with significant dust and PAH emission. It models the spectra by combining the contributions from (1) a stellar continuum, (2) dust continua at different temperatures, (3)

[1] http://irsa.ipac.caltech.edu/data/GOALS/galaxies.html

resolved PAH band emission, (3) emission lines and (4) dust-extinction models (i.e., simple, fully-mixed or screen). We show our PAHFIT results for NGC 5653 in Figure 1.

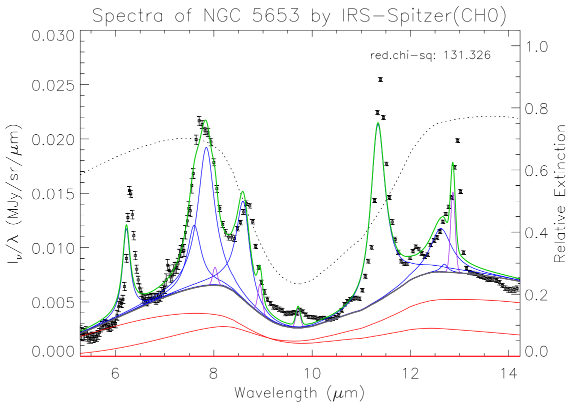

Figure 1. Decomposition of the spectrum for NGC 5653 with PAHFIT. In red, dust continua at different temperatures (200 K and 300 K); in gray, the sum of stellar and dust continua; in blue, the dust features atributed to PAHs; in purple, the atomic lines; in green, the PAHFIT model; the black dotted line represents the extinction model.

One of the results we obtain from the PAHFIT analysis is the relative contribution from dust components at different temperatures. The distribution of dust temperatures for our sample is shown in Figure 2, were each galaxy is represented by several dust temperature components. The global distribution displays a general bimodality, with hotter dust associated with the shorter-wavelength IRS channel and warmer dust associated to the longer wavelenght. Although this correspondance between dust temperature and wavelength is expected, we find that there is a tendency for a greater portion of our sample (65%) to be represented by hotter dust. This may be an indication that AGN have a greater contribution to the mid-IR emission in these galaxies when compared to the very small grain (VSG) continuum, associated to star forming regions and responsible for the warm dust continuum at $\lambda > 14\,\mu$m (Petric et al. 2011).

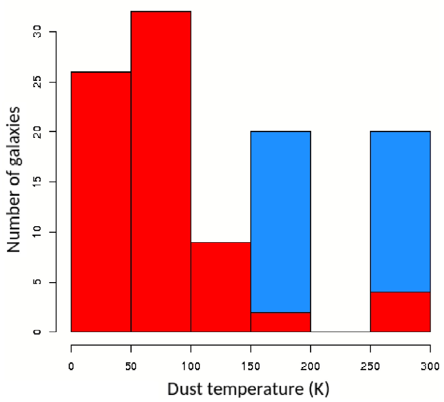

Figure 2. Dust temperature distribution for the galaxies of our LIRG sample. In red, the PAHFIT results based on the IRS longer-wavelength channel, 14-36 μm; in blue, those from the shorter-wavelength channel, 5-14 μm.

We aim break down the PAH emission into different subclasses (charge, size and type) running the PAHdb tools (Boersma et al. 2014; Bauschlicher et al. 2010) on our IRS spectra. About 700 spectra of a great variety of PAHs are present in this database. For the majority of molecules, the spectra were calculated for neutral and singly-ionized states; the spectra of multiply-ionized states are provided only for a few select molecules. PAHs composed only by carbon and hydrogen atoms (so-called "pure PAHs") comprise the majority of molecules in the database. However, PAHs with nitrogen, oxygen, silicon and other metals can also be found.

Figure 3 shows the fit obtained with PAHdb for the LIRG ESO 221-IG010, considering PAHs with no silicon, magnesium, iron, but with up to 2 atoms of oxygen and 2 of nitrogen. This type of characterization allow us to explore in details the astrochemichal richness of these galaxies.

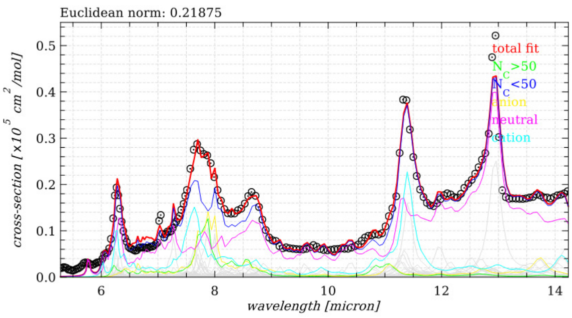

Figure 3. PAHdb decomposition for the ESO 221-IG010 spectrum (black circles) between 5-14 μm: PAHs with a carbon number less than 50 (blue curve) and greater than 50 (green curve); negatively charged (yellow curve), positively charged (cyan curve) and neutral PAHs (magenta curve). The combined contribution of these molecules is represented by the red curve.

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