

AstroBioGeoChemistry: study of organic molecules in active galactic nuclei

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Abstract. This study analyzed polycyclic aromatic hydrocarbons (PAHs), ionic emission lines, and mid-infrared (MIR) continuum properties in 200 galaxies using Spitzer Space Telescope data. Key PAH bands and forbidden emission lines, such as [Si II] 34.8 μm and [Ar II] 6.9 μm , were observed in all starbursts and $\sim 80\%$ of Seyfert 2 galaxies. By comparing observed PAH intensity ratios (e.g., 6.2 $\mu\text{m}/7.7\mu\text{m} \times 11.3\mu\text{m}/7.7\mu\text{m}$) with theoretical models, the study identified distinct PAH characteristics in active galactic nuclei (AGNs) versus star-forming galaxies. PAHs in AGNs are larger, containing over 180 carbon atoms, compared to smaller PAHs (<180 carbons) in star-forming regions. They also exhibit unique ionization degrees, enabling their survival under intense radiation. Over cosmic time, these molecules evolve, incorporating nitrogen to form polycyclic aromatic nitrogen heterocycles (PANHs). PANHs influence the PAH band at 6.2 μm and may link galactic PAH biochemistry to terrestrial nucleobases essential for life. This study highlights the dynamic evolution of PAHs and their resilience in extreme environments, providing critical insights into their role in the chemical processes that bridge astrophysical and biological systems. These findings align with ongoing research using the James Webb Space Telescope (JWST), which promises further advancements in understanding PAH-related molecular evolution and its implications for astrobiology.

Resumo. Este estudo analisou hidrocarbonetos aromáticos policíclicos (PAHs), linhas de emissão iônica e propriedades do contínuo no infravermelho médio (MIR) em cerca de 200 galáxias usando dados do Telescópio Espacial Spitzer. Bandas-chave de PAHs e linhas de emissão proibidas, como [Si II] 34,8 μm e [Ar II] 6,9 μm , foram observadas em todas as galáxias starburst e em cerca de 80% das galáxias Seyfert 2. Ao comparar as razões de intensidade de PAHs observadas (por exemplo, 6,2 $\mu\text{m}/7,7\mu\text{m} \times 11,3\mu\text{m}/7,7\mu\text{m}$) com modelos teóricos, o estudo identificou características distintas de PAHs em núcleos ativos de galáxias (AGNs) em comparação com galáxias em formação estelar. Os PAHs em AGNs são maiores, contendo mais de 180 átomos de carbono, em comparação com os PAHs menores (< 180 carbonos) em regiões de formação estelar. Eles também exibem graus de ionização únicos, permitindo sua sobrevivência sob intensa radiação. Ao longo do tempo cósmico, essas moléculas evoluem, incorporando nitrogênio para formar heterociclos aromáticos nitrogenados policíclicos (PANHs). Os PANHs influenciam a banda de PAH em 6,2 μm e podem conectar a bioquímica galáctica de PAH às nucleobases terrestres essenciais para a vida. Este estudo destaca a evolução dinâmica dos PAHs e sua resiliência em ambientes extremos, fornecendo informações cruciais sobre seu papel nos processos químicos que interligam sistemas astrofísicos e biológicos. Essas descobertas estão alinhadas com pesquisas em andamento utilizando o Telescópio Espacial James Webb (JWST), que promete avanços adicionais na compreensão da evolução molecular relacionada aos PAHs e suas implicações para a astrobiologia.

Keywords. Galaxies: active – ISM: molecules – Techniques: spectroscopic

1. Introduction

Polycyclic Aromatic Hydrocarbons (PAHs) represent an effective arrangement to accumulate carbon in the Universe and are the dominant organic material in space. In addition, a considerable fraction of carbon in the interstellar medium (ISM), approximately 20% or more, is in the form of PAHs, and it is believed that PAHs are organic molecules that may have contributed to the formation of prebiotic material that led to life on Earth (e.g. Puget & Leger 1989; Draine 2003).

The mid-infrared (MIR) spectra of galaxies either with an active galactic nuclei (AGN) and a Starburst show emission features attributed to PAH molecules, which can be considered to originate in very small amorphous carbon dust grains or very large carbon-rich ring molecules Puget & Leger (1989); Draine (2003); Sales et al. (2010, 2011, 2013, 2015); Sales & Canelo (2022). The most prominent, well-known PAH emissions are the 6.2 μm , 7.7 μm , 8.6 μm , 11.2 μm , and 12.7 μm bands (e.g. Roche et al. 2007; Genzel et al. 1998).

For a long time, it was believed that galaxies with supermassive black holes (SMBH), known as active galactic nuclei (AGNs), have an intense and energetic radiation field from the SMBH's accretion disk capable of destroying PAH molecules near the SMBHs of AGNs. The lack of high angular and spectral

resolution data made it difficult to understand the physicochemical properties of PAH molecules and their use as a diagnostic tool for the ionization source in galaxies (see Sales et al. 2010 and references there). In addition, it is important highlighted that the differences among the PAH profiles in such astrophysical environments have been attributed, for example, to the local physical conditions and of the PAH's molecules size, charge, geometry, and heterogeneity (e.g. Draine 2003; Sales et al. 2011).

This study have derived the PAH's bands, ionic emission lines, and MIR continuum properties using spectroscopy data taken from Spitzer Space telescope of the ~ 200 galaxies. This study is structured as follows: in Sect. 2 we describe the data reduction process and emission line measurements. In Sect. 3 we present results and conclusions.

2. Observation and Data Reduction

We have analyzed a well defined sample of 186 galaxies which have Spitzer spectra available from public archive. Being 83 AGNs taken from Gallimore et al. (2010), 22 SB from Brandl et al. (2006), 59 HII and LINER from Smith et al. (2007) and 7 HII regions of M101 galaxy from Gordon et al. (2008), plus 15 AGNs Spitzer spectra from public archive (see Sales et al. 2010).

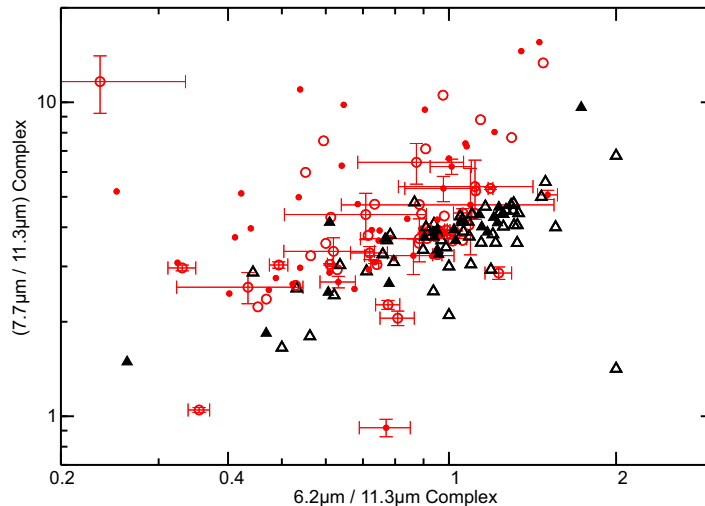


FIGURE 1. Fig. shows diagnostic diagram of $6.2\mu\text{m}/7.7\mu\text{m} \times 11.3\mu\text{m}/7.7\mu\text{m}$ PAH ratios. The long-dashed line represents theoretical intensities of neutral to ionized PAHs (Drane & Li 2001). The dash-dotted line shows the position of the PAHs formed by 180 carbon atoms. Empty triangles are HII and LINER objects, full triangles are Starburst, and full and empty circles are Seyfert 1 and Seyfert 2 of Sales et al. (2010) and Gallimore et al. (2010) sample. More information is in Sales et al. (2010).

We also include selected objects from the ATLAS MIR starburst-dominated galaxies (MIR SB sample), which is composed of 252 sources observed by Spitzer/IRS previously classified as starburst-dominated by Hernán-Caballero & Hatziminaoglou (2011). The limit set between AGN- and starburst-dominated sources was based on the fraction of a PDR (photodissociation region) component at $r\text{PDR}=0.15$, corresponding to equivalent widths (EW) of $\text{EW}_{6.2} = 0.2\mu\text{m}$ or $\text{EW}_{11.3} = 0.2\mu\text{m}$ as an alternative boundary. As our analysis are focus on PAH molecules, we have used Spitzer/IRS data in the spectral range between 5 to $13\mu\text{m}$ and we also define PAH bands to be study.

The Spitzer/IRS spectra of our sample have been decomposed using the PAHFIT code, described in detail by Smith et al. 2007. In short, they assume that the IRS spectra are composed by dust continuum, starlight, prominent emission lines, individual and blended PAH emission bands, and that the light is attenuated by extinction due to silicate grains. A result of the decomposition can be seen in Fig. 1.

3. Results and Conclusion

Sales et al. (2010) have showed that the PAH intensity ratios for neutral and ionized PAHs ($6.2\mu\text{m}/7.7\mu\text{m} \times 11.3\mu\text{m}/7.7\mu\text{m}$) were compared to theoretical intensity ratios, showing that AGNs have higher ionization fraction and larger PAH molecules (≥ 180 carbon atoms) than SB galaxies (see fig. 1). The ratio between the ionized ($7.7\mu\text{m}$) and the neutral PAH bands ($8.6\mu\text{m}$ and $11.3\mu\text{m}$) are distributed over different ranges for AGNs and SB galaxies, suggesting that these ratios could depend on the ionization fraction, as well as on the hardness of the radiation field. The ratio between the $7.7\mu\text{m}$ and $11.3\mu\text{m}$ bands is nearly constant with the increase of $[\text{Ne III}]15.5\mu\text{m}/[\text{Ne II}]12.8\mu\text{m}$, indicating that the fraction of ionized to neutral PAH bands does not depend on the hardness of the radiation field.

This study have derived the PAH's bands, ionic emission lines, and MIR continuum properties using spectroscopy data

taken from Spitzer Space telescope of the ~ 200 galaxies. The brightest PAH spectral bands and the forbidden emission lines of $[\text{Si II}]34.8\mu\text{m}$, $[\text{Ar III}]6.9\mu\text{m}$, $[\text{Si II}]18.7\mu\text{m}$ and $33.4\mu\text{m}$ were detected in all the starbursts and in $\sim 80\%$ of the Seyfert 2. The observed intensity ratios for neutral and ionized PAHs ($6.2\mu\text{m}/7.7\mu\text{m} \times 11.3\mu\text{m}/7.7\mu\text{m}$) were compared to theoretical intensity ratios (see Sales et al. 2010, 2011, 2013; ?). However, after more than a decade of studies using observational data from the Spitzer and Gemini telescopes, as well as theoretical PAH libraries and signal analysis techniques, it was possible to demonstrate that PAH molecules in AGNs, in addition to being larger (>180 carbon atoms) than the molecules found in star-forming galaxies (<180 carbon atoms), also predominantly have PAH molecules with different degrees of ionization.

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