Valongo Observatory (UFRJ)

Polycyclic Aromatic Hydrocarbons in Luminous Infrared Galaxies

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Infrared Astronomy

Information about different physical processes in the observed environment

Galaxies: part of the light is emitted in infrared (IR)

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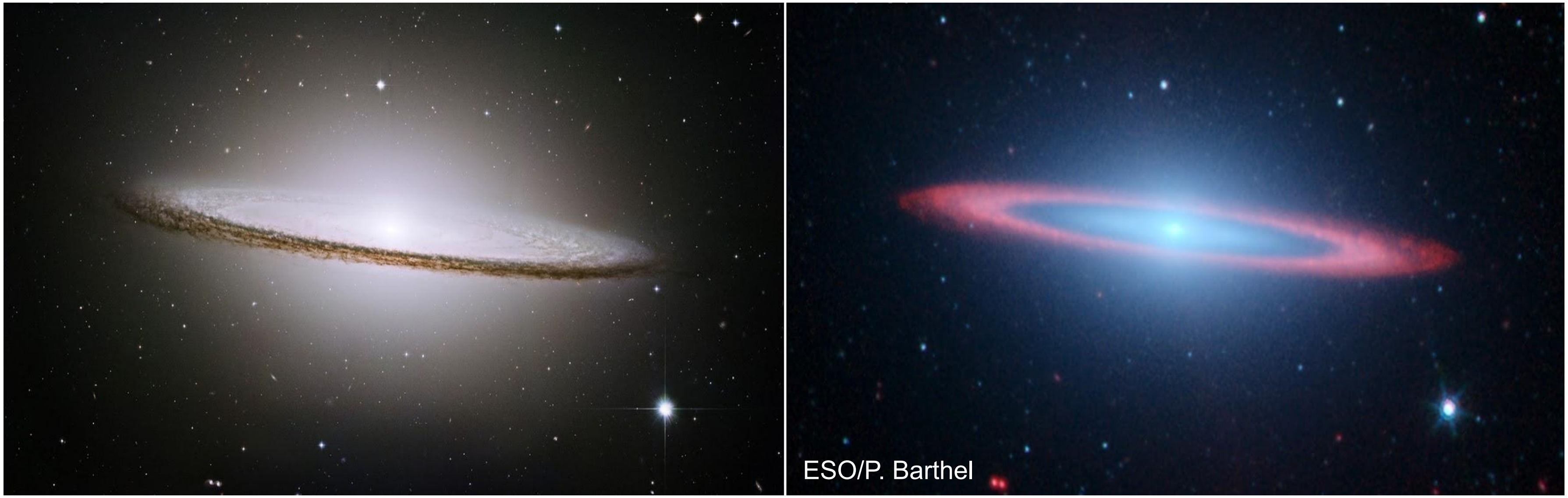
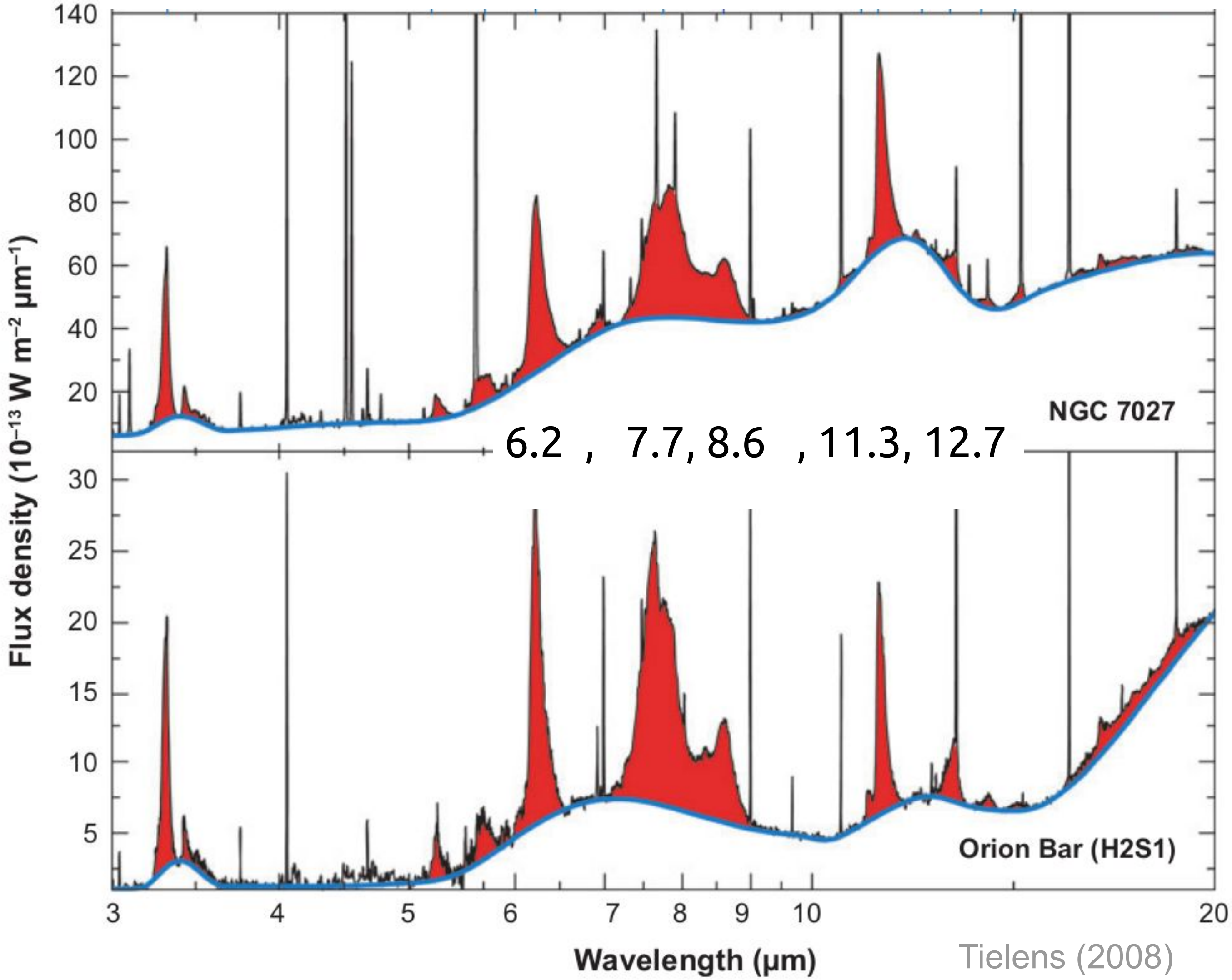
gas and dust



Unidentified Infrared Emission

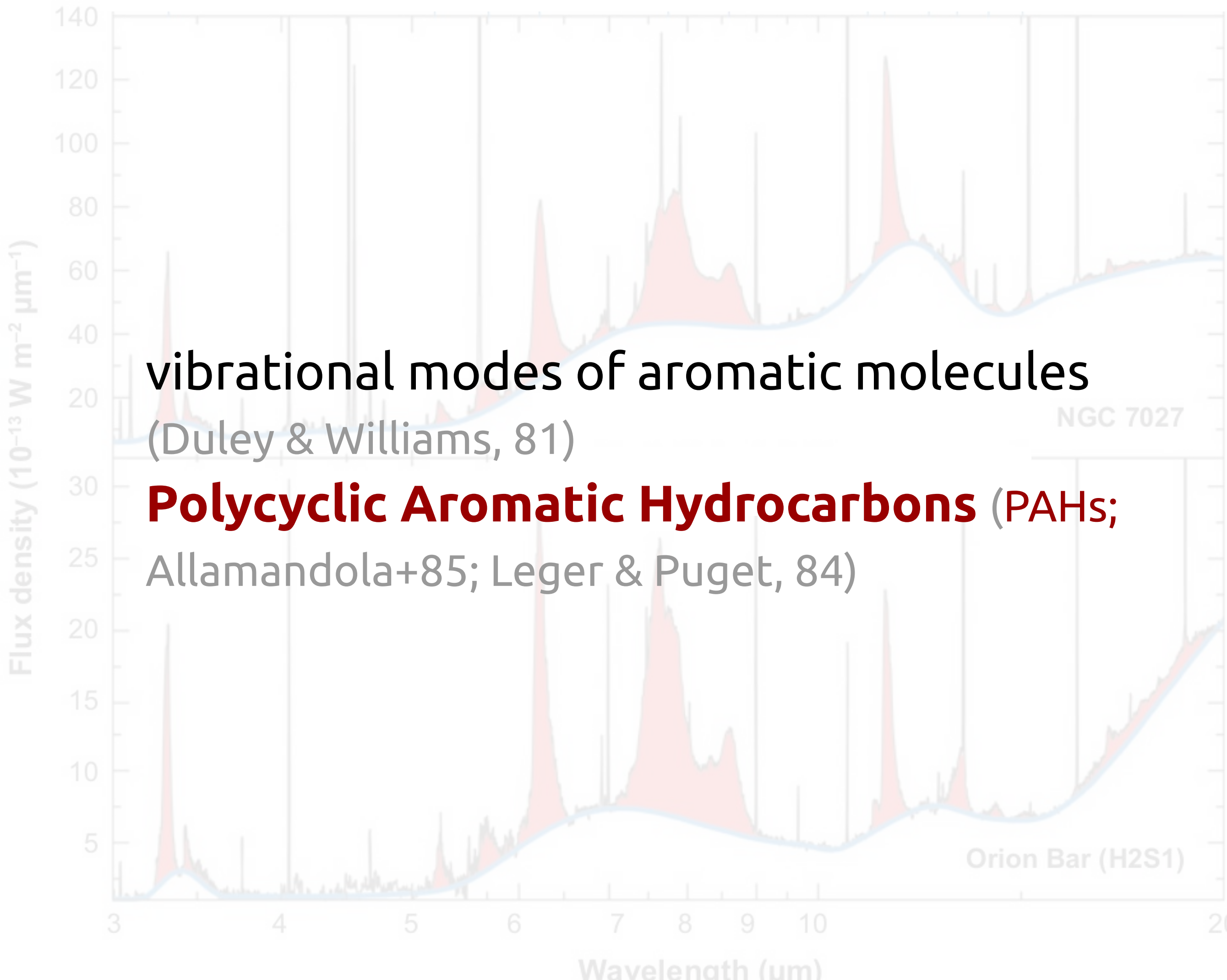
Observation of broadband emission



Tielens (2008)

Unidentified Infrared Emission

Observation of broadband emission

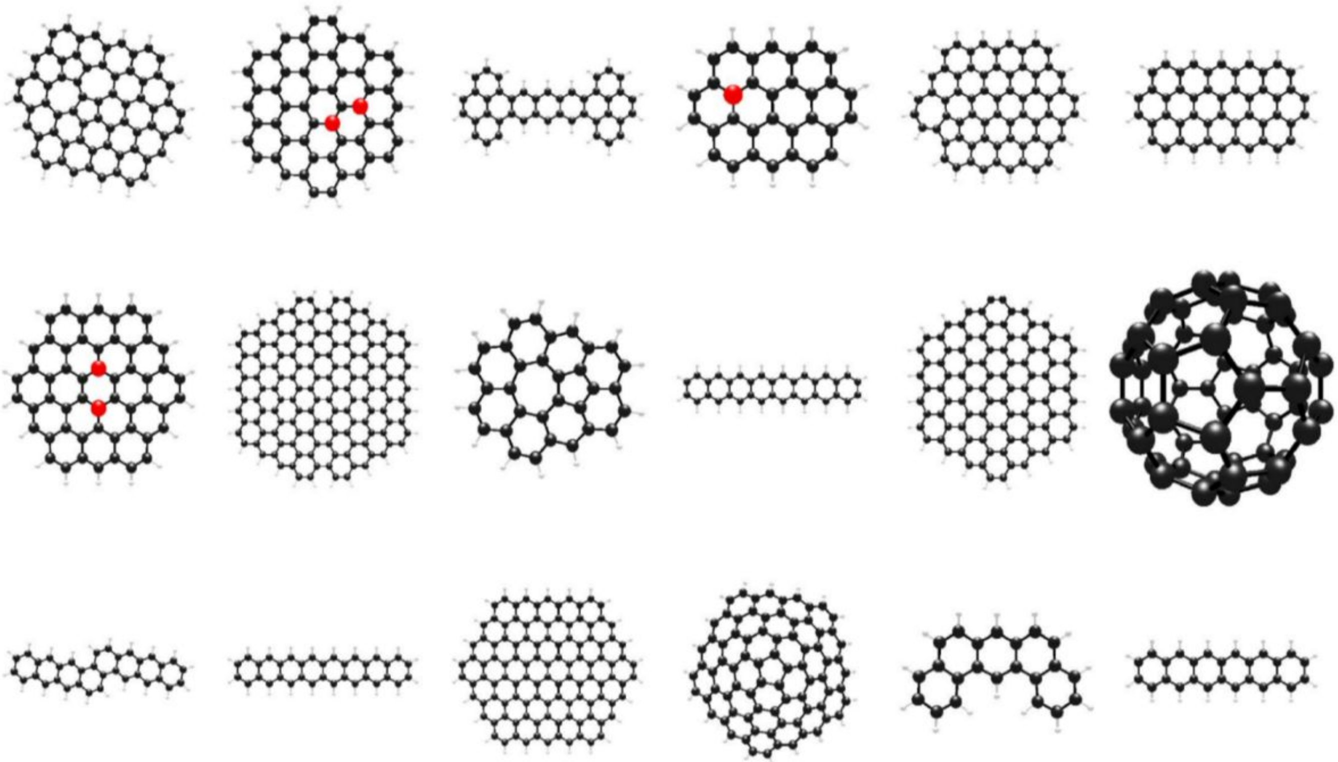


vibrational modes of aromatic molecules
(Duley & Williams, 81)

Polycyclic Aromatic Hydrocarbons (PAHs; Allamandola+85; Leger & Puget, 84)

Polycyclic Aromatic Hydrocarbons (**PAHs**)

Molecules composed by aromatic rings of benzene (C and H)

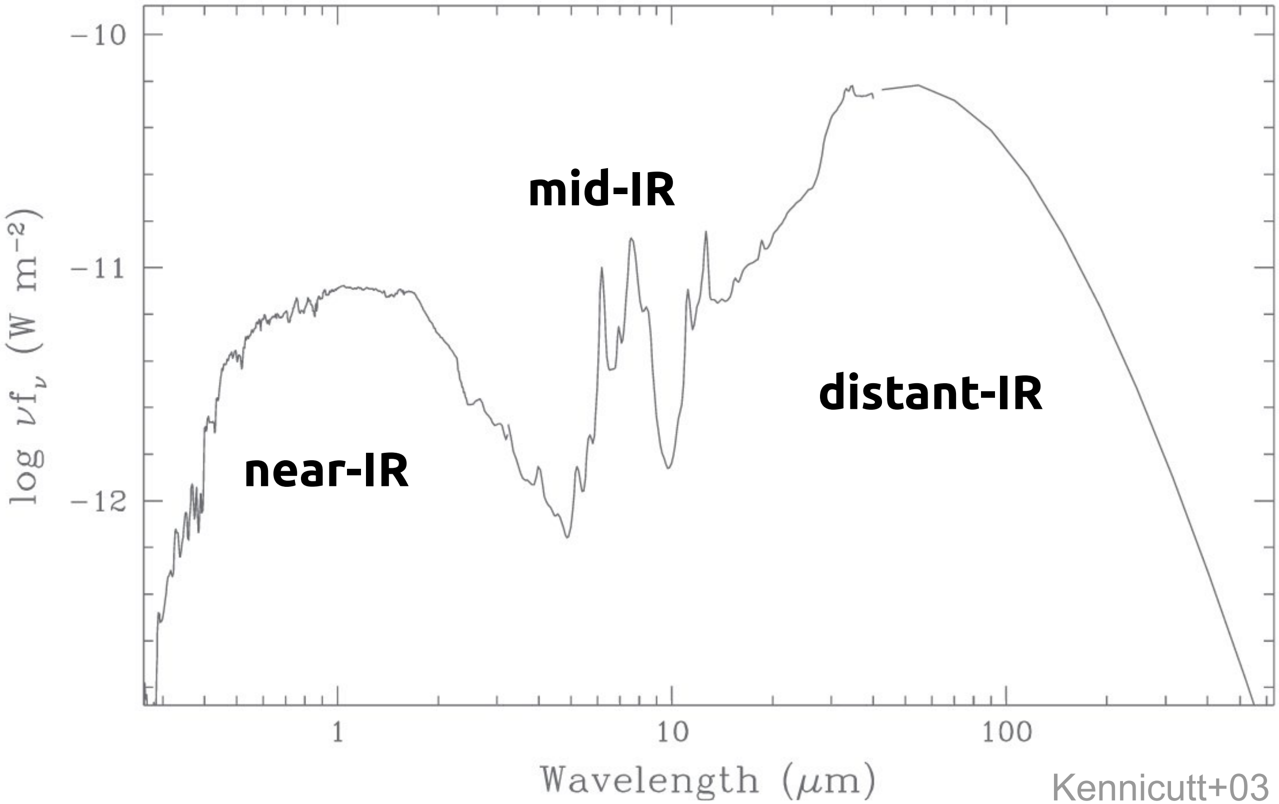


Bauschlicher+18

Infrared in galaxies

IR includes the dust reprocessed emission of galaxies:

➔ mid-IR gives dust properties related to star formation (Wu+05) and active nuclei (Díaz-Santos+17);



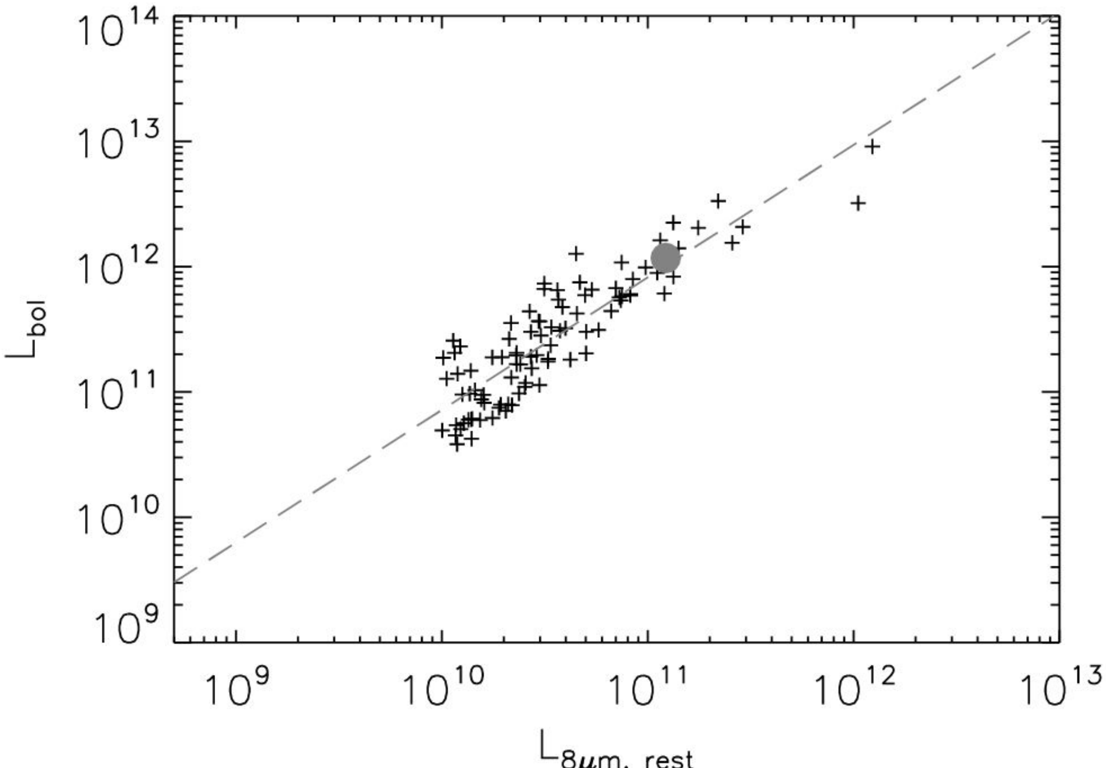
Kennicutt+03

IR Space missions: Spitzer

Spitzer (Werner+04): launched by NASA. IRAC (3–9μm) and MIPS imaging (24–160μm) and **spectroscopy by IRS** (5–19 and 14–40μm);

Extragalactic: IR luminosity attributed to star formation and growth supermassive black holes (Soifer+08).

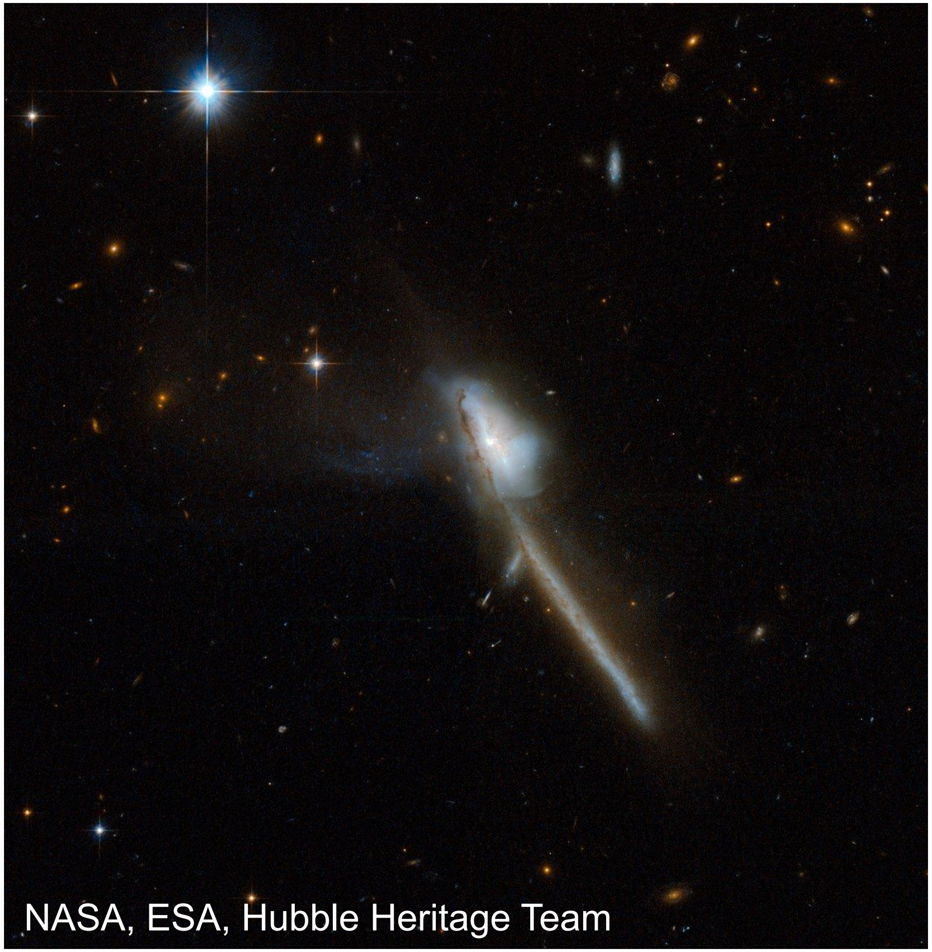
Less luminous galaxies are weak emitters in IR and for higher bolometric luminosities, the IR contribution grows (Sanders & Mirabel, 96)



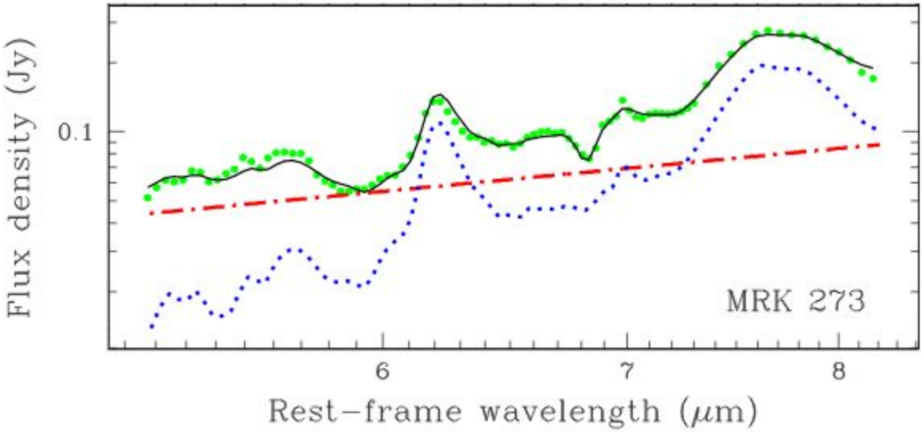
Caputi+18

Luminous IR Galaxies
(LIRGs: $10^{11} < L_{IV}\ (L_{\odot}) \leq 10^{12}$)
Ultra Luminous IR Galaxies
(ULIRGs: $L_{IV} \geq 10^{12} L_{\odot}$)

Local ULIRGs are associated to interactions and mergers (e.g., Armus+87);



ULIRGs IR emission: associated to AGN and starburst activity (Sanders+88).



Nardini+02

Goals

Does the nature of the power energy (AGN/starburst) have an impact of the kind of molecules (charge, size and composition)?

Sample: Great Observatories All-Sky LIRG Survey

(U)LIRGs of low-z, encompassing several merger states (Armus+09);

Definition: IRAS *Revised Bright Galaxy Sample* objects (Sanders+03) with galactic latitude > 5° and 60μm flux > 5.24Jy;

- 181 LIRGs + 22 ULIRGs, $z \leq 0.088$;
- imaging and spectroscopy data;
- Spitzer, Hubble, GALEX and Chandra.

Data: IRS/Spitzer

Low resolution spectra → **PAHs bands** and silicate absorptions

High resolution spectra → emission atomic lines and rotational molecular lines

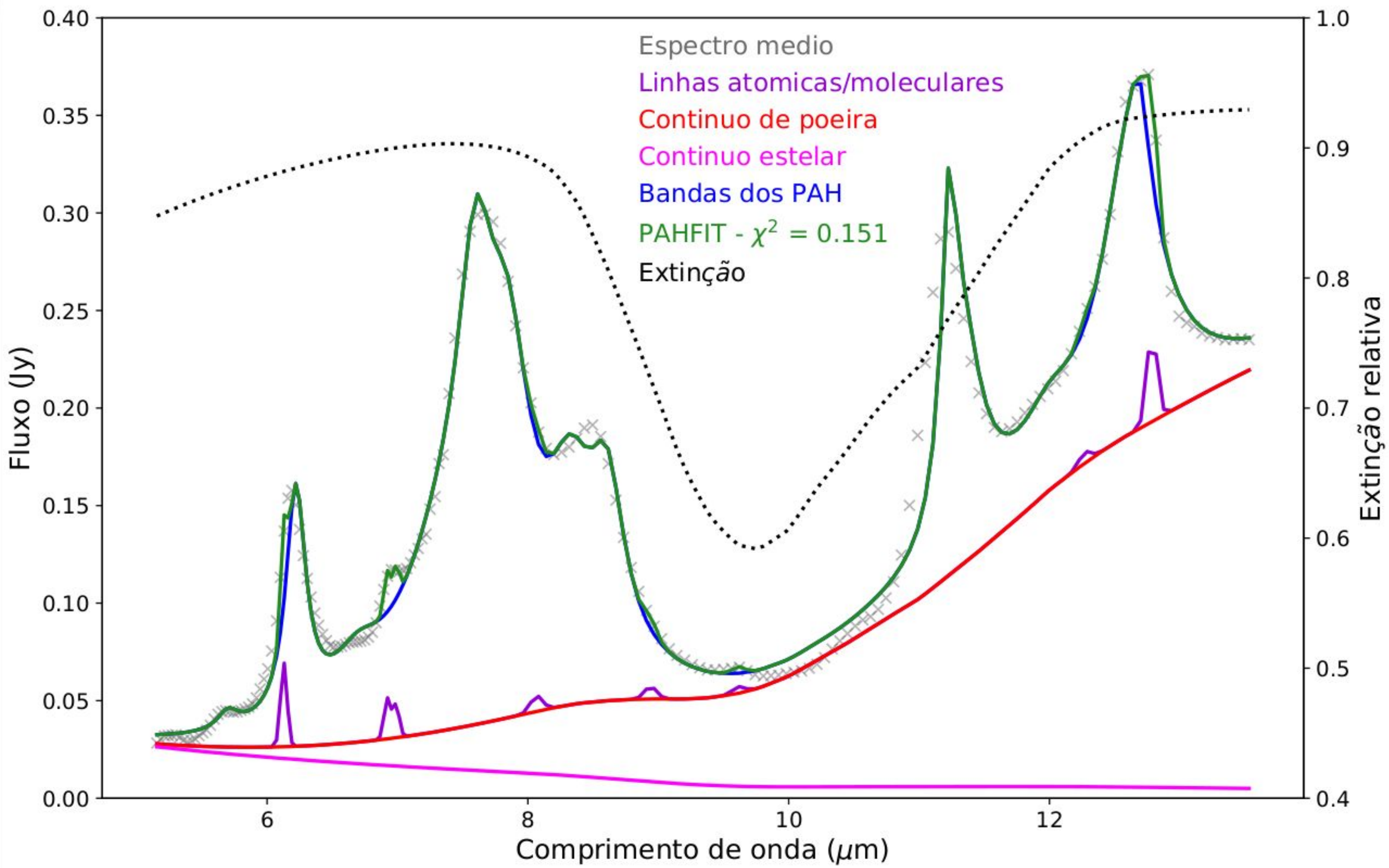
Spectral IR components

Galaxy spectral components in the mid-IR: **thermal dust continuum**, **PAHs emission** and **atomic and/or rotational emission lines**.

To analize the bands of PAHs, we need to isolate the different sources of IR emission:

PAHFIT → IDL tool to separate components of a galaxy mid-IR spectrum (Smith+07).

PAHFIT decompose low resolution IRS/Spitzer spectra into dust continuum, PAHs bands, atomic and molecular lines, stellar continuum and silicate absorption.



Dust continuum characterization

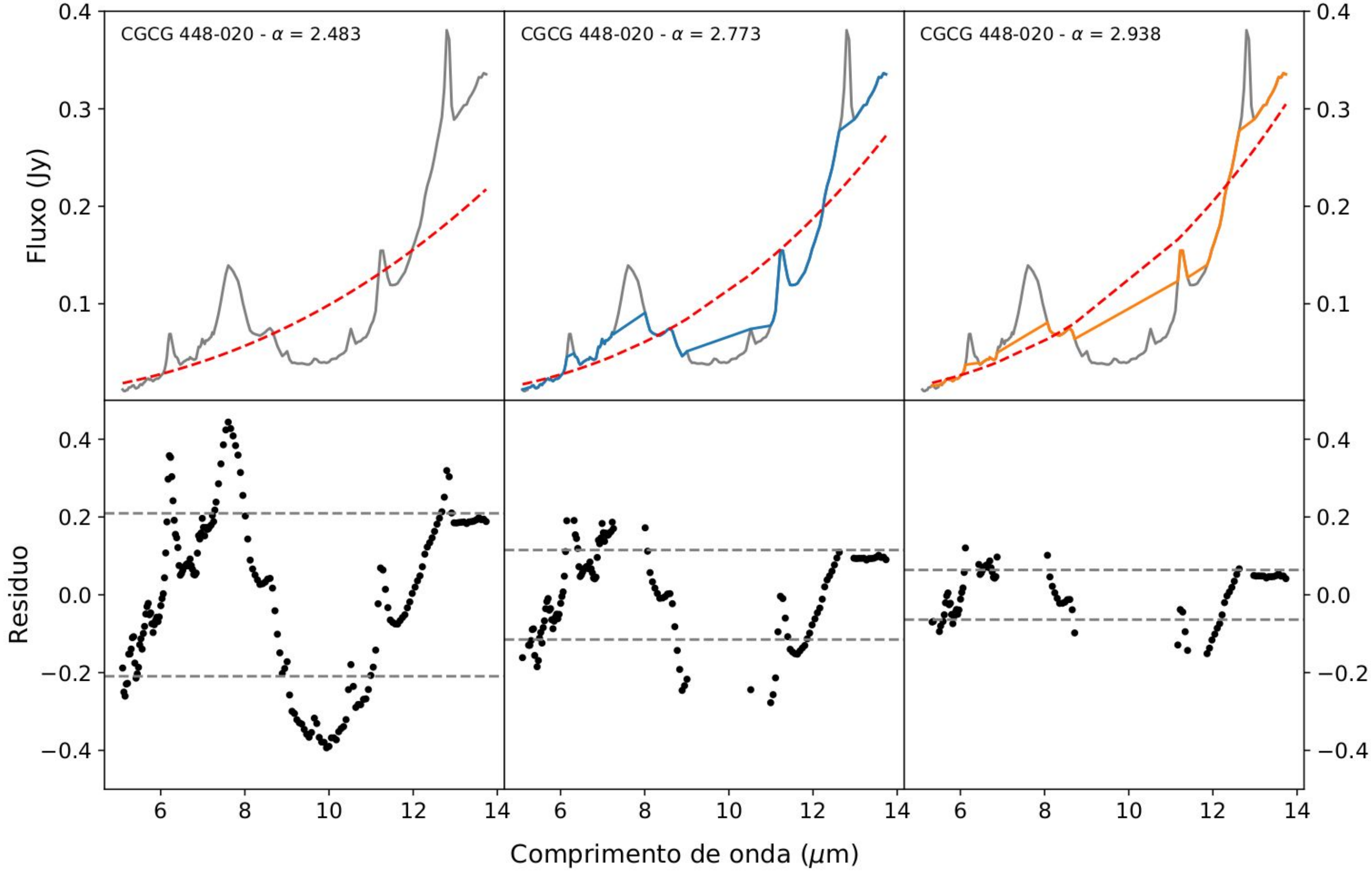
Thermal dust continuum can be described as a power-law $S_\nu \sim \nu^{-\alpha}$ (Alonso-Herrero+06):

- Flatter continua ($\alpha \leq 0.5$) are associated to non obscured AGN with hot dust emission directly observed;
- Steeper continua ($\alpha \geq 0.5$) are usually associated with starburst activity and/or dust-obscured AGN.

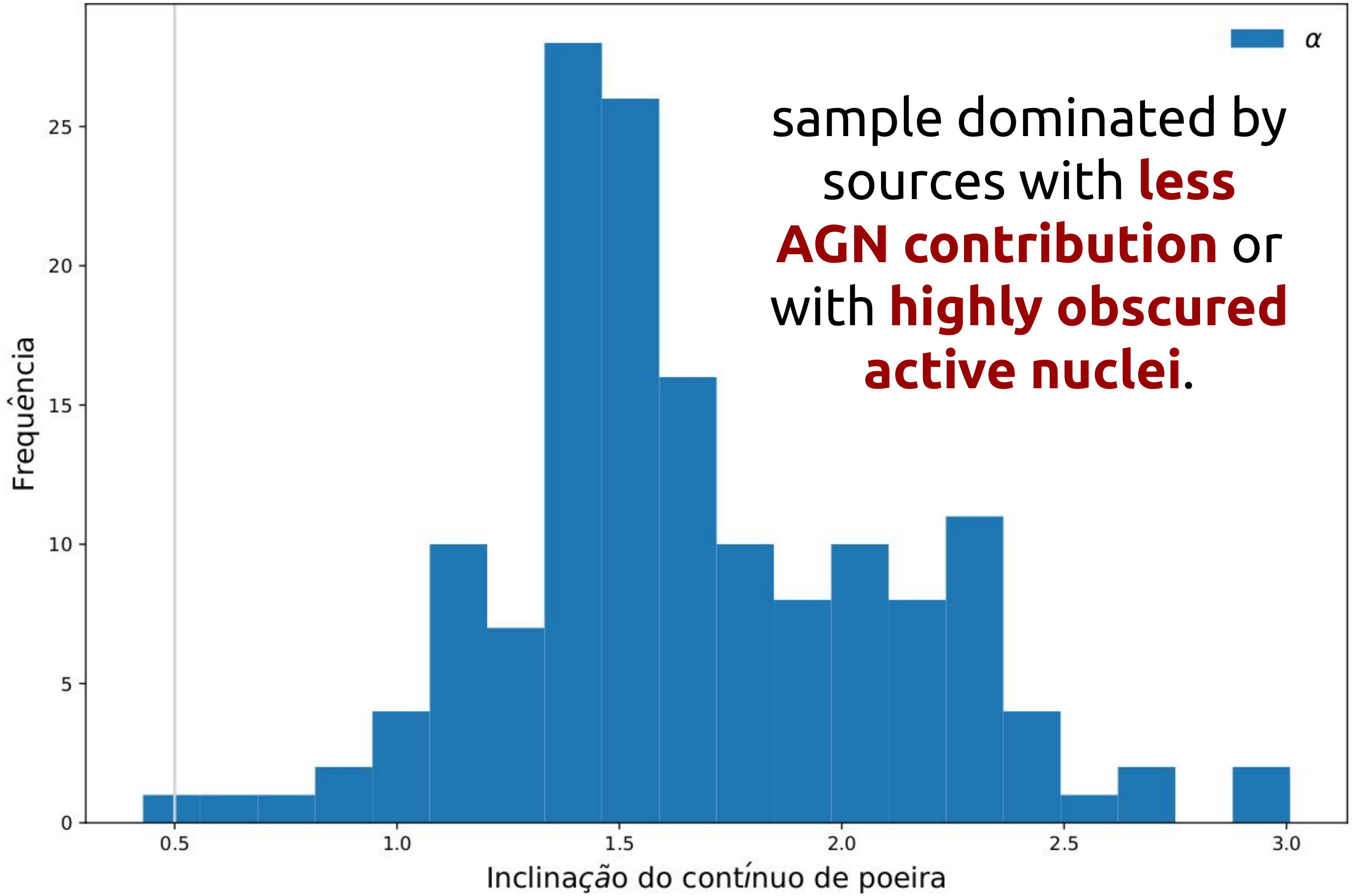
Determine α → **unveil the power source of mid-IR emission**.

Characterization of the dust continuum: `LINFIT`

`LINFIT`: determination of power law index, α, via x^2 minimization fit of mid-IR continuum.



Spectral diversity of (U)LIRGs: slope of dust continuum



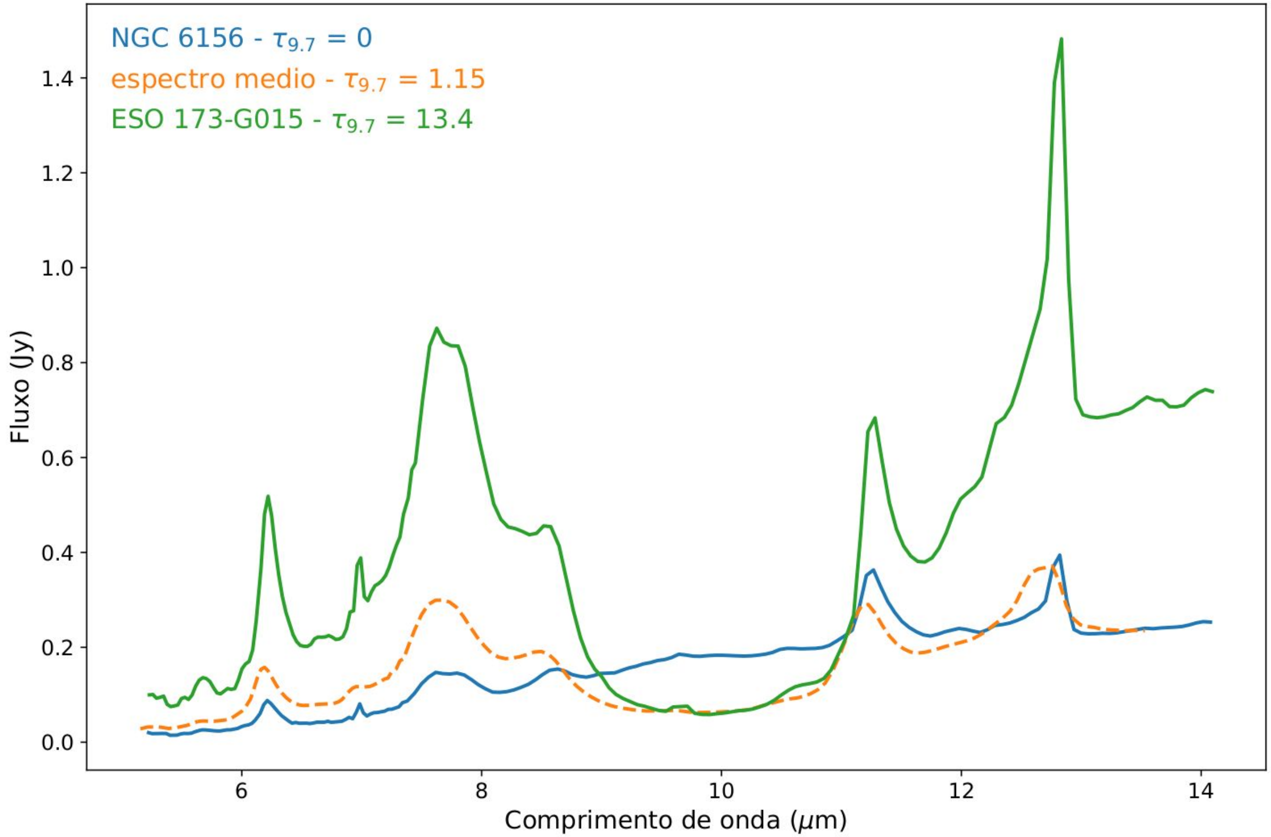
sample dominated by sources with **less AGN contribution** or with **highly obscured active nuclei**.

(U)LIRGs spectral diversity: silicate absorption

(U)LIRGs mid-IR spectra: silicate absorption at 9.7μm → $\tau_{9.7}$ optical depth → dust obscuration

PAHFIT

$0 \leq \tau_{9.7} \leq 13.4$



Dust obscuration in (U)LIRGs

$\tau_{9.7}$ optical depth → dust obscuration:

- Galactic center with $\tau_{9.7}$ ~ 3.6 (Draine, 03);
- LIRGs and ULIRGs with $\tau_{9.7}$ ~ 2.2–3.3 (Piqueras-López+13);
- ULIRGs with $\tau_{9.7}$ >> 1.7 hosts dusty and compacts AGN (Imanishi+07);

↓

high values of τ in our sample → obscured AGN

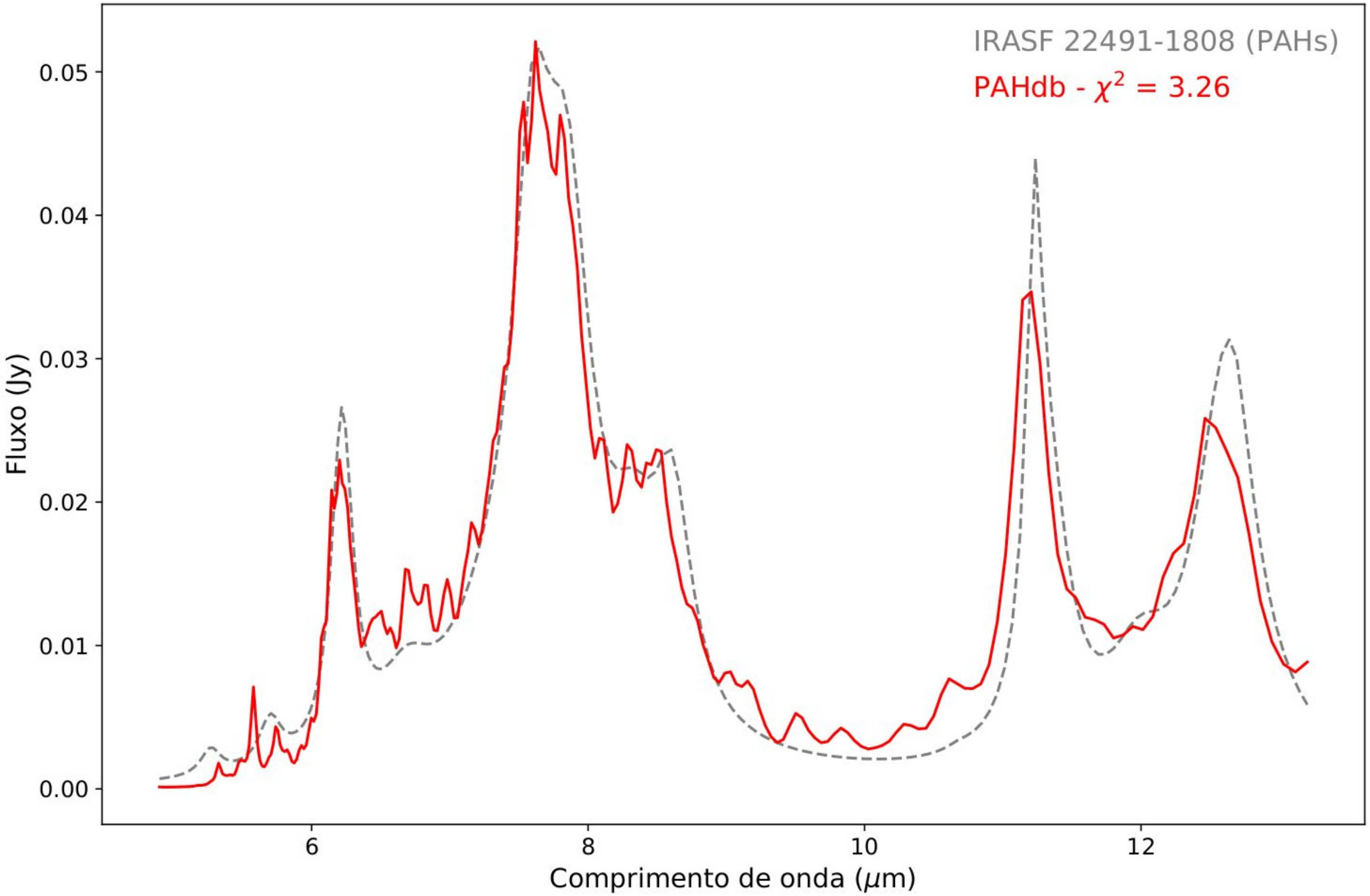
NASA Ames PAH IR Spectroscopic Database (PAHdb)

Database with molecules candidates to astronomical PAHs (Bauschlicher+10, Boersma+14, Bauschlicher+18):

- 3130 molecules and their IR spectra;
- Several sizes, from 6–384 carbons;
- Structure of aromatic rings and aliphatic branch;
- Pure molecules, fullerenes and substituted;
- Diversity in charge, with neutral, cations and anions molecules.

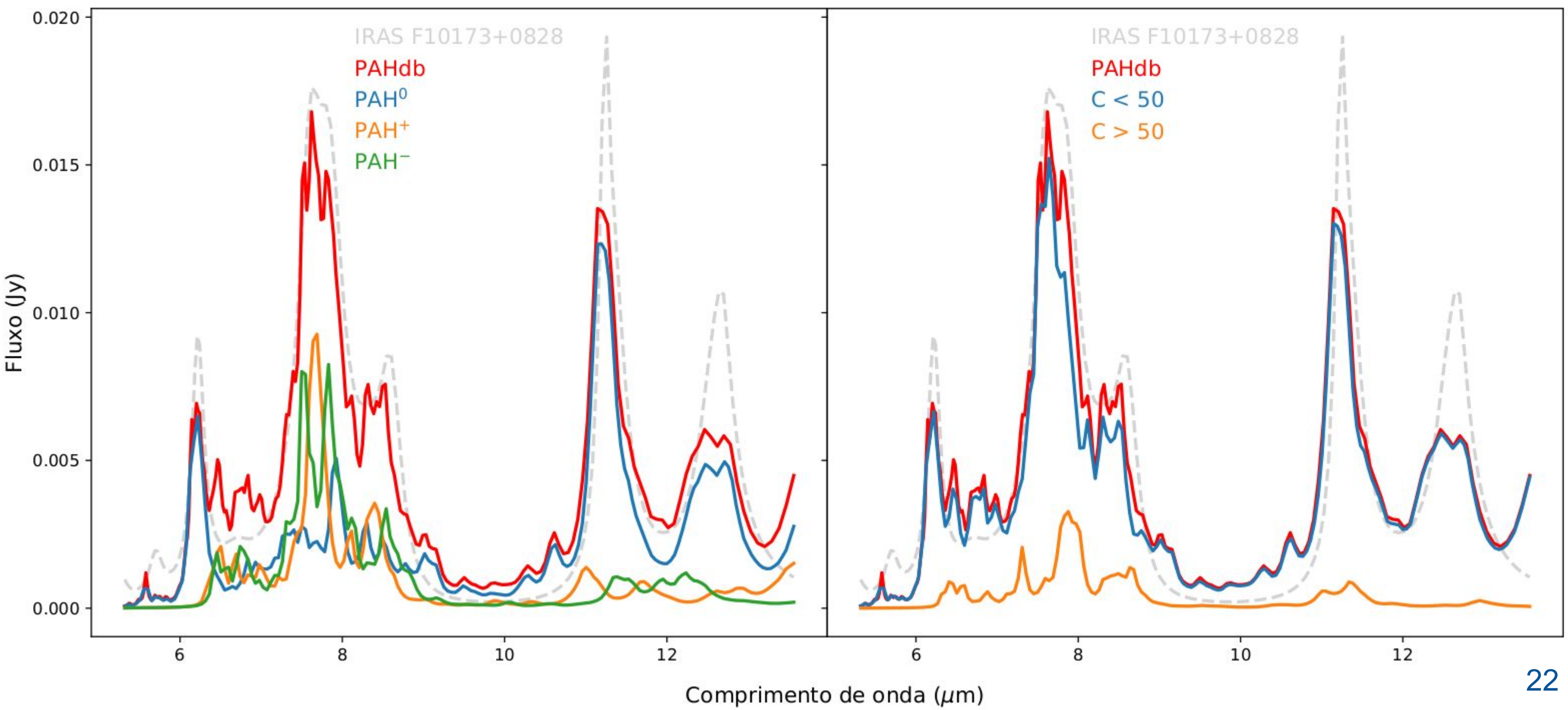
Comparison: astronomical and PAH spectra

- PAHdb provides a list of molecules (and their spectra) responsible for the PAH emission input spectra



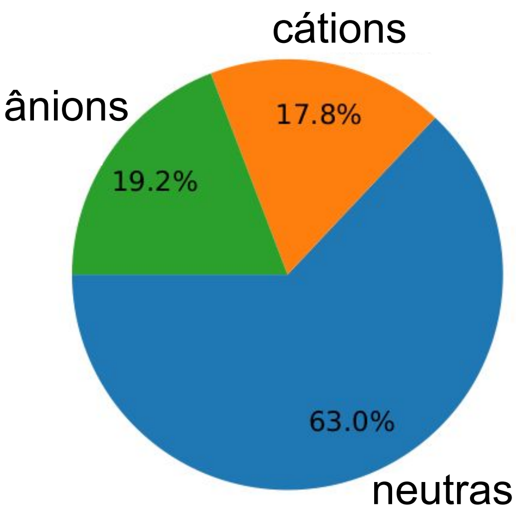
Comparison: astronomical and PAH spectra

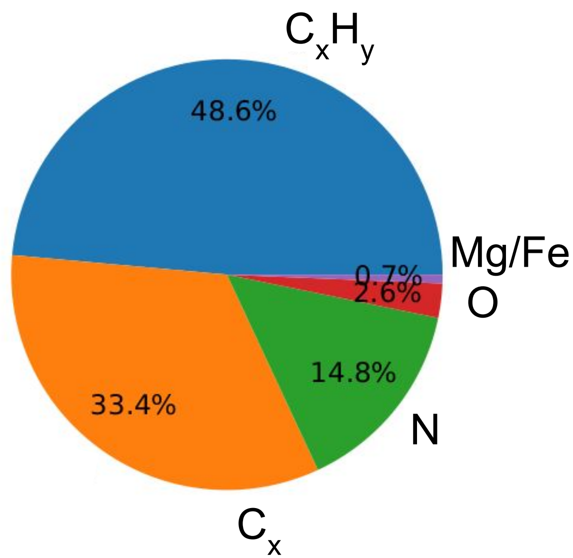
- PAHdb provides a list of molecules (and their spectra) responsible for the PAH emission input spectra
- **Decomposition of PAHs into subclasses** → population contribution in terms of **size and charge**.

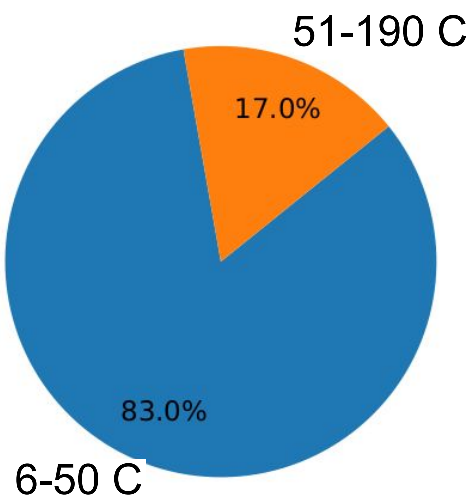


Decomposition of PAHs bands

PAHdb results in terms of charge, composition and size





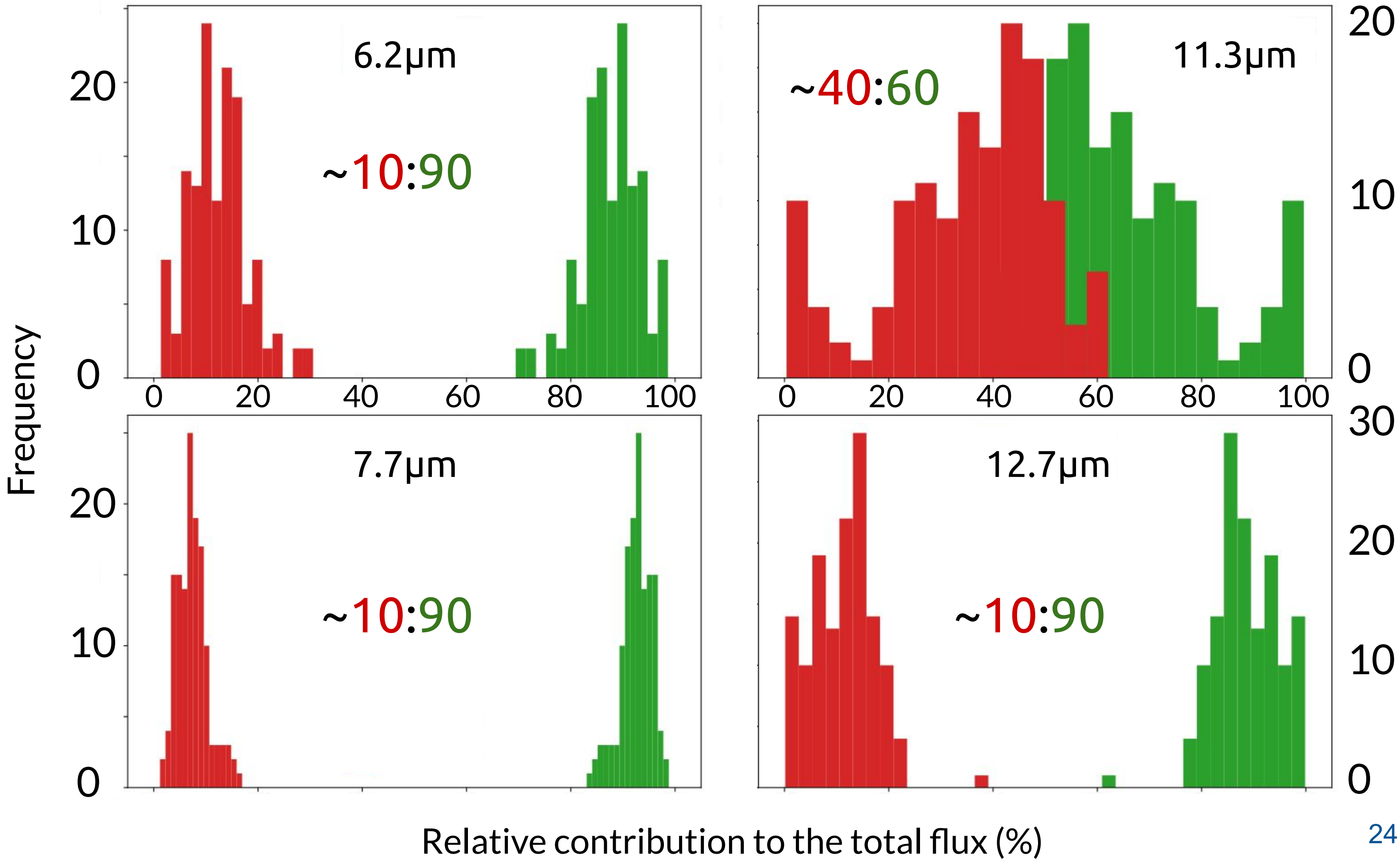


~ 100 molecules found

Predominance of neutral, pure and small PAHs

PAHs diversity: size

How much do **small** and **big** PAHs contribute to each PAH band?

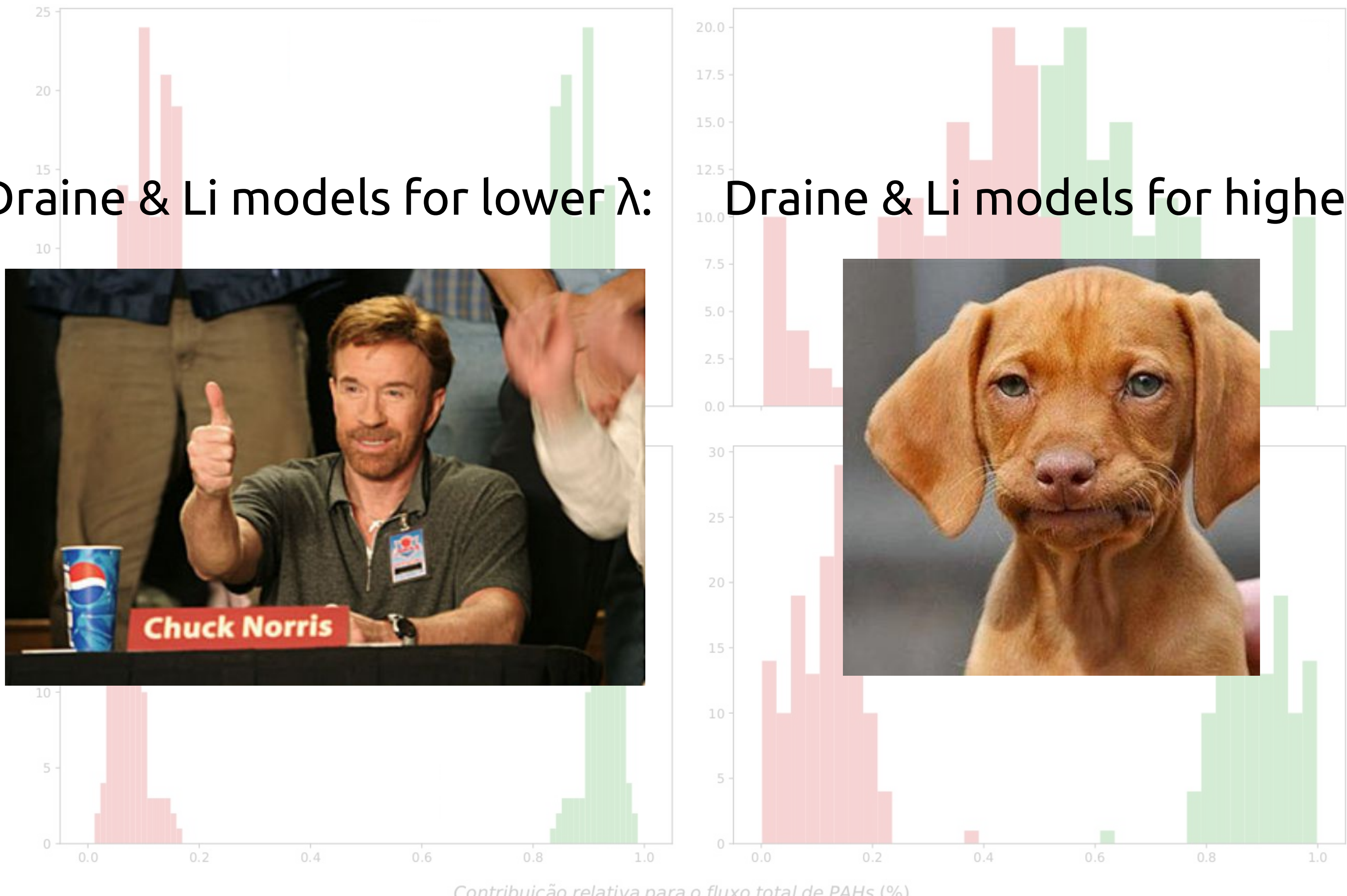


PAHs diversity: size

How much do **small** and **big** PAHs contribute to each PAH band?

Draine & Li models for lower λ:

Draine & Li models for higher λ:



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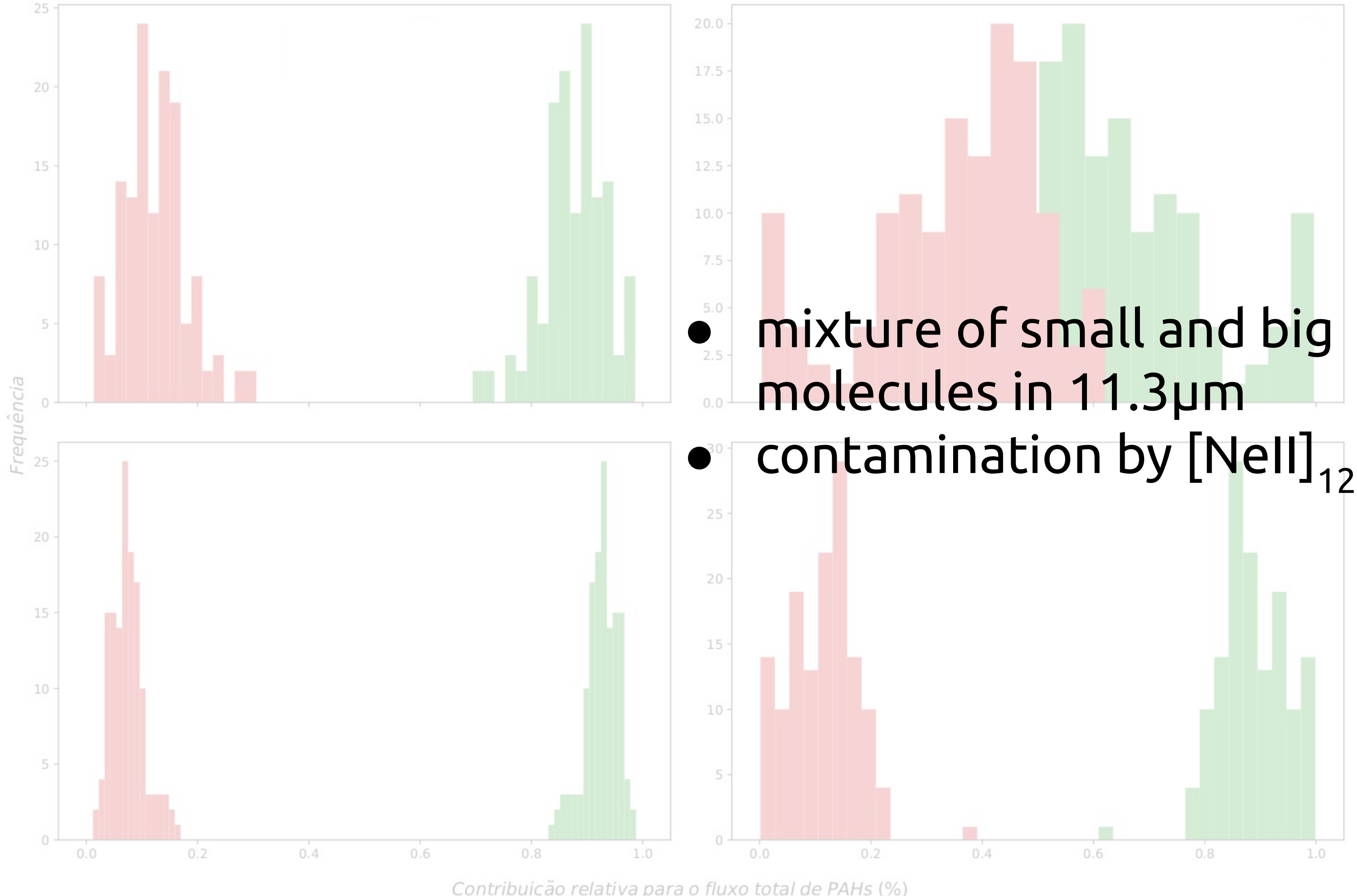
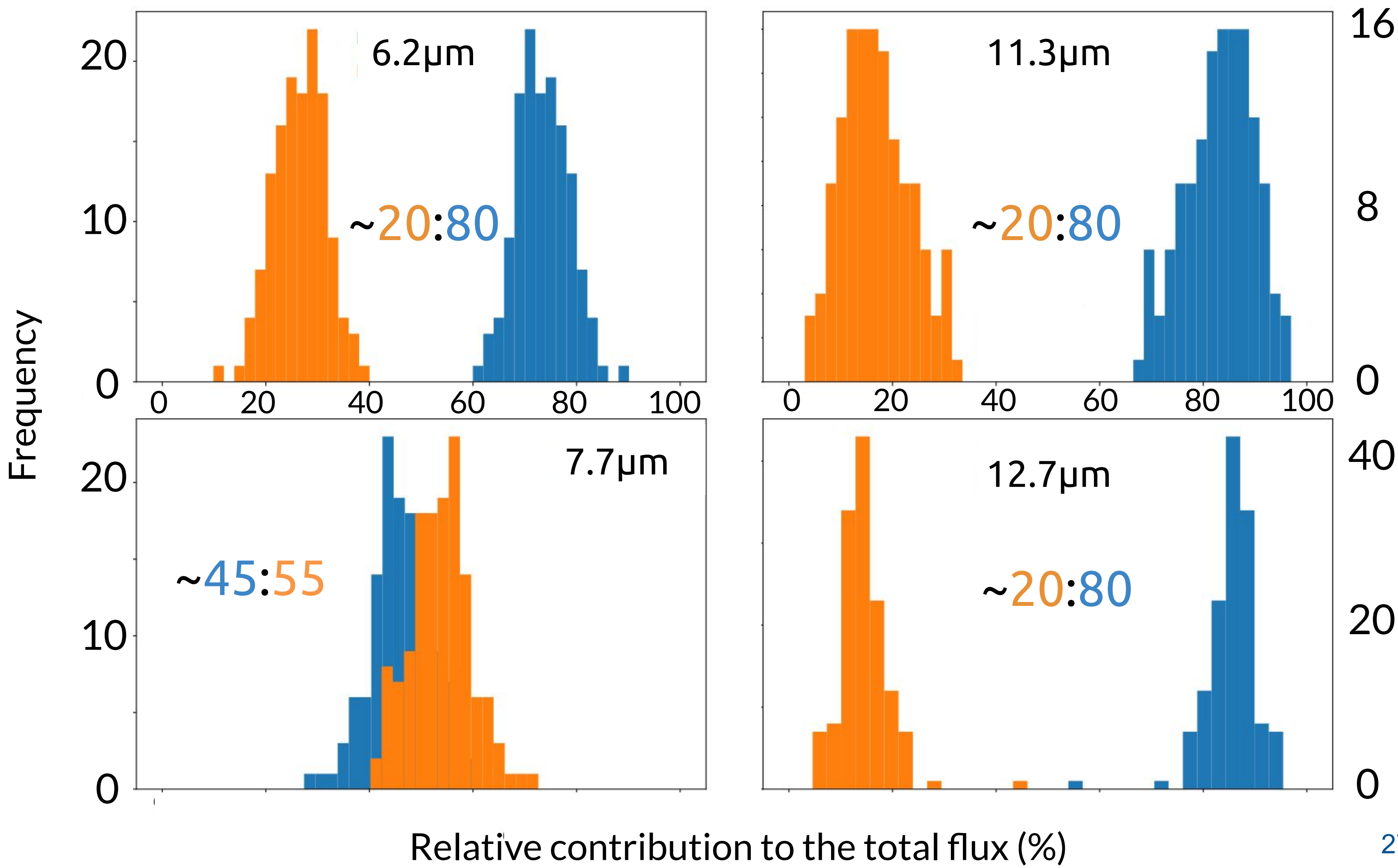


- mixture of small and big molecules in 11.3μm
- contamination by $[NeII]_{12.8}$

PAHs diversity: ionization degree

How much do **neutral** and **charged** PAHs contribute to each PAH band?



PAHs diversity: ionization degree

How much do **neutral** and **charged** PAHs contribute to each PAH band?

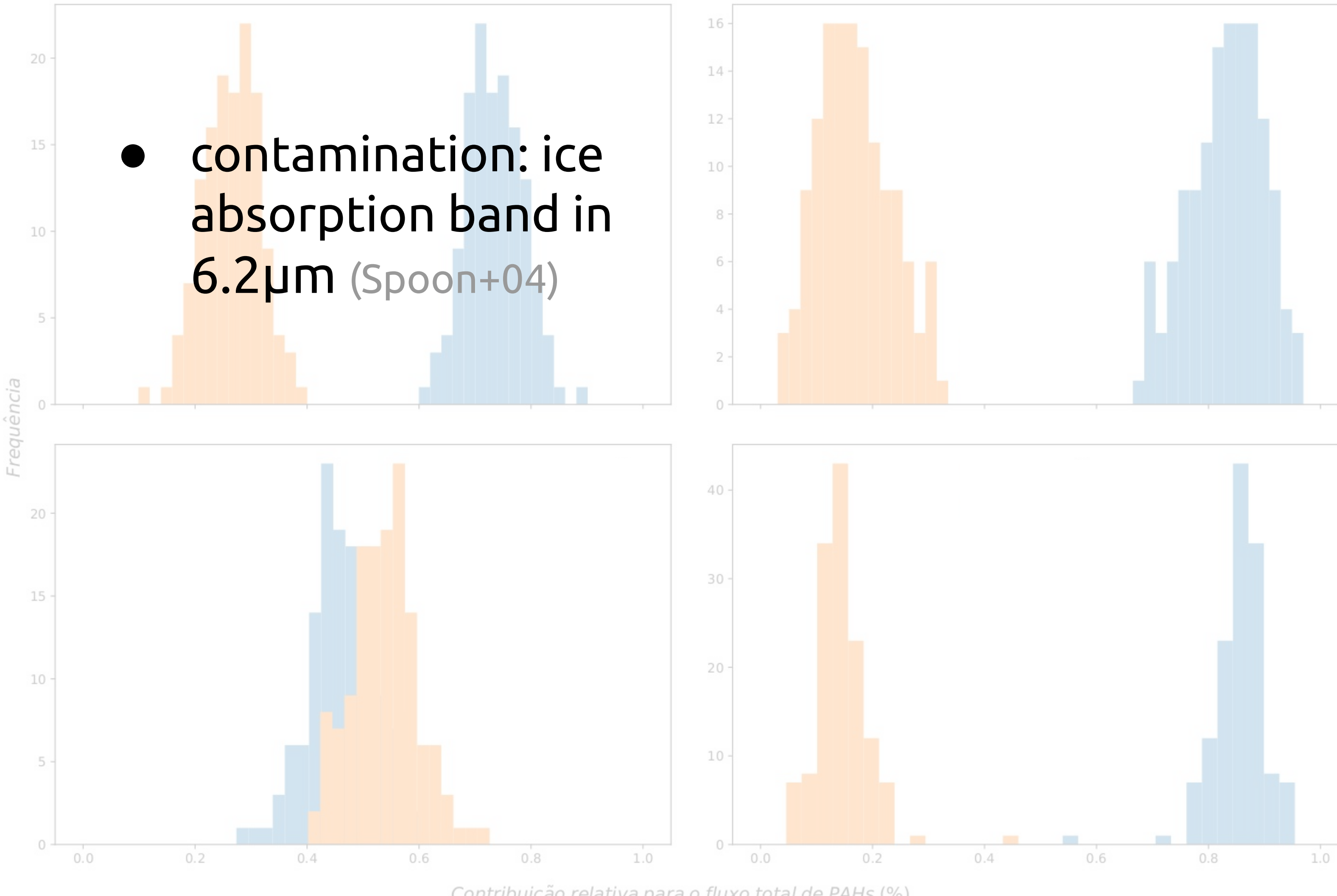
6.2μm

7.7, 11.3 and 12.7μm

PAHs diversity: ionization degree

How much do **neutral** and **charged** PAHs contribute to each PAH band?

- contamination: ice absorption band in 6.2μm (Spoon+04)



Nature of the (U)LIRGs energy sources and their impact in the PAH production

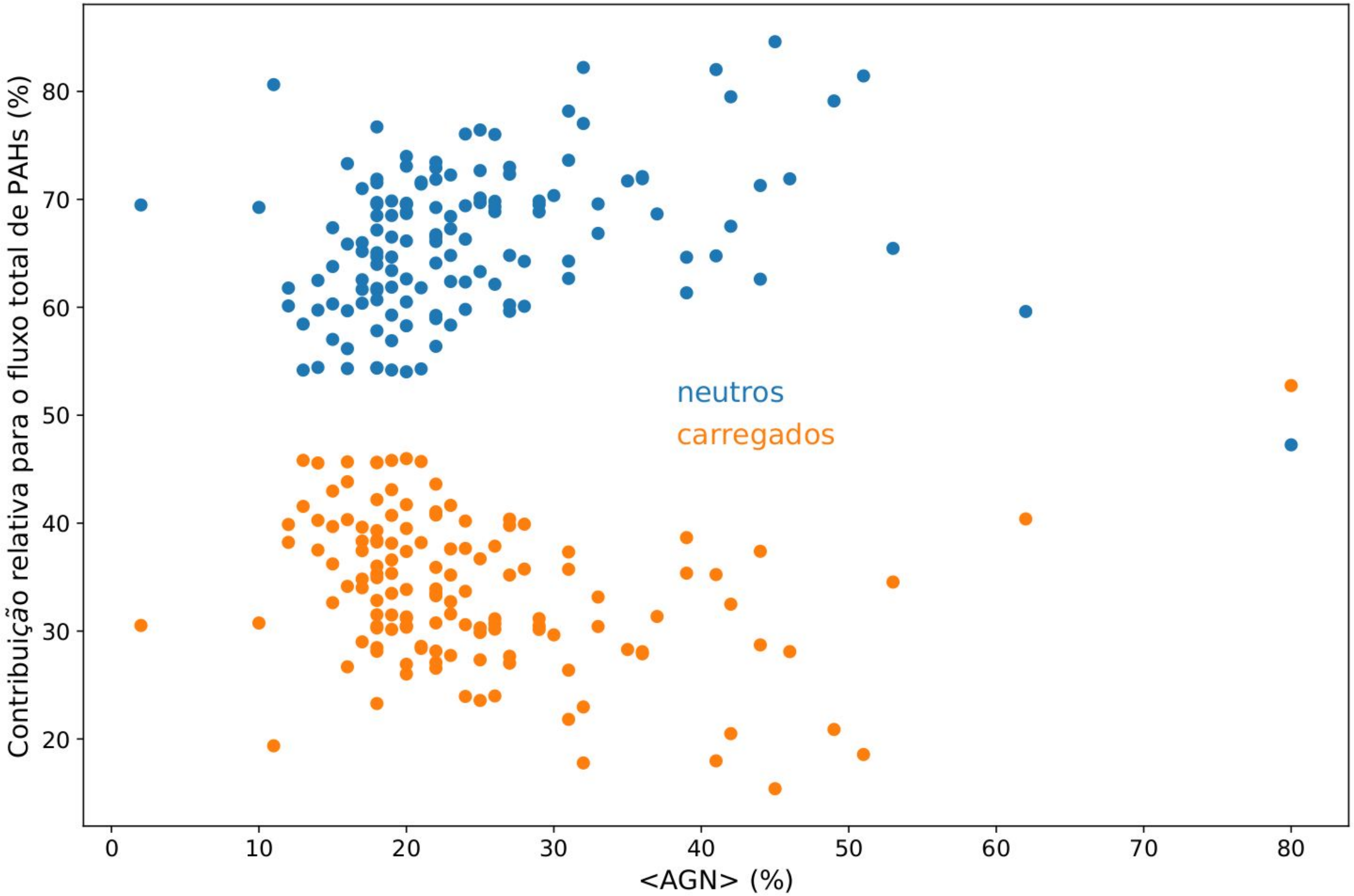
Díaz-Santos+17: AGN contribution for the GOALS galaxies beyond mid-IR diagnostics: [NeV]/[NeII], [OIV]/[NeII], equivalent width of 6.2μm, continuum slope in S_{30}/S_{15} and Laurent's diagram

↓

AGN modify lines and continuum of a star forming galaxy → provides an estimative of the fractional contribution to the mid-IR emission.

Nature of the (U)LIRGs energy sources: AGN × PAH ionization

Contribution of ionized and neutral molecules to the flux contained in all PAH bands



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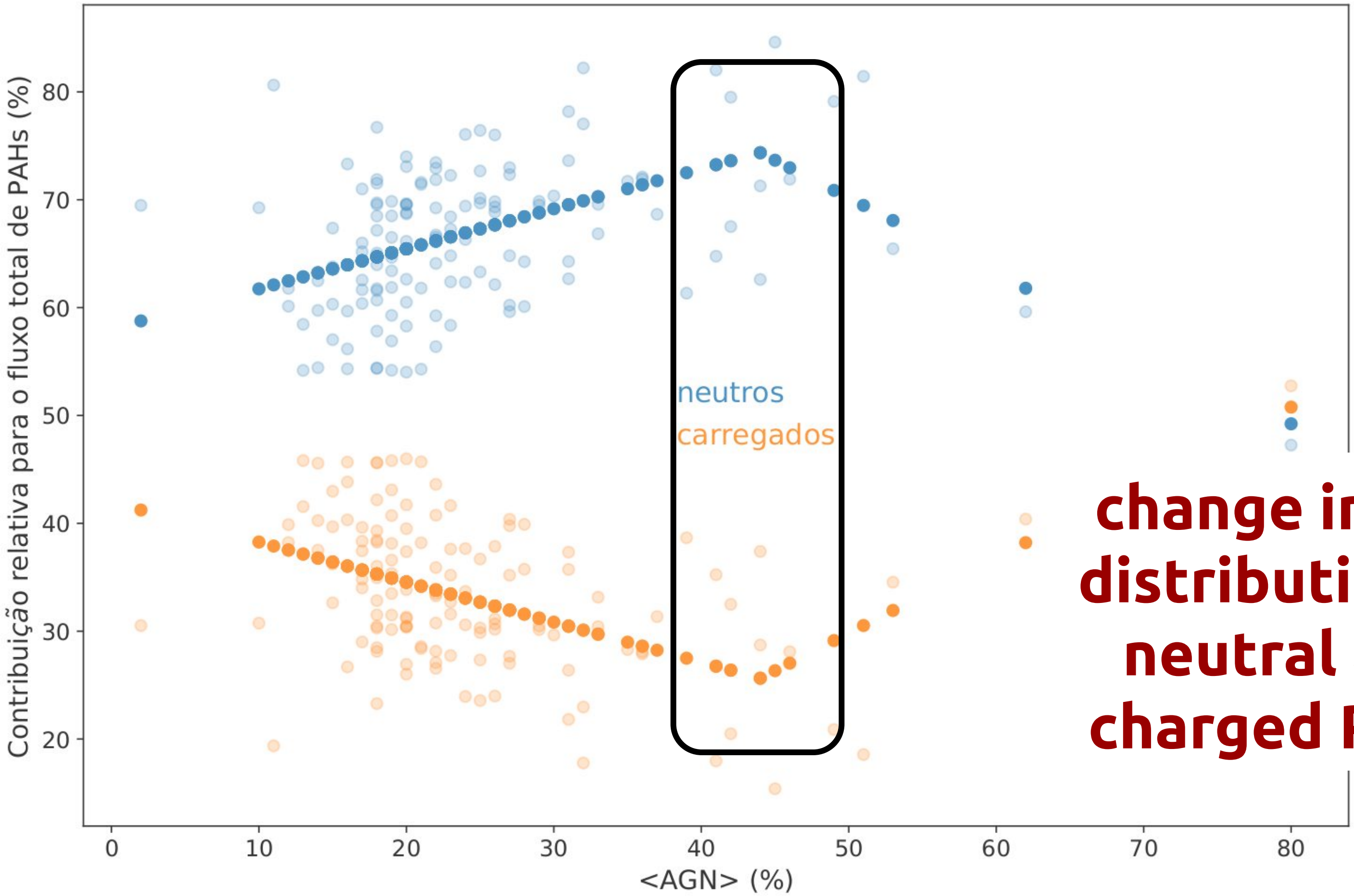
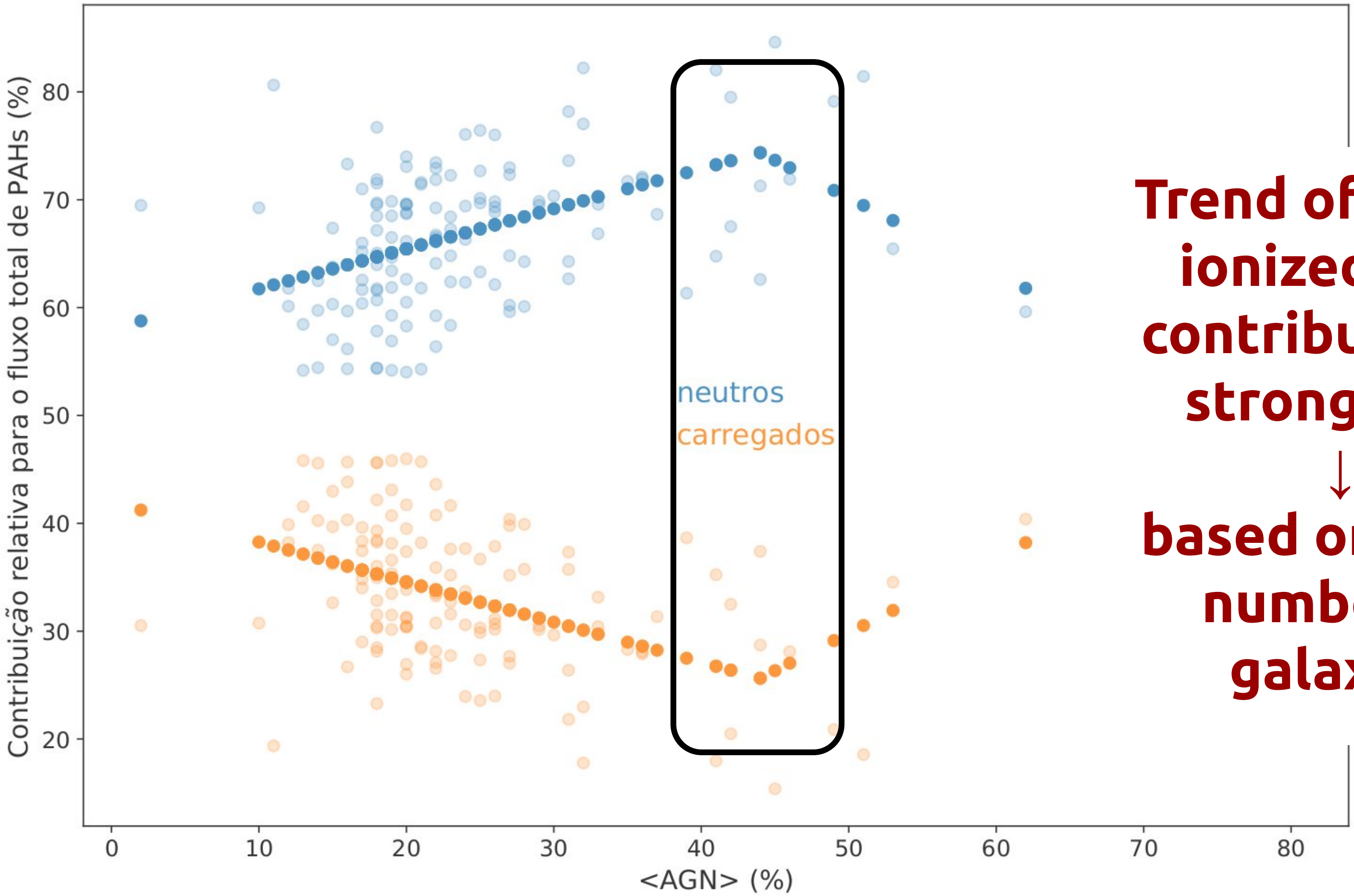


change in the distribution of neutral and charged PAHs

Nature of the (U)LIRGs energy sources: AGN × PAH ionization

Contribution of ionized and neutral molecules to the flux contained in all PAH bands



Trend of higher ionized PAH contribution in strong AGN

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based on a few number of galaxies

Nature of the (U)LIRGs energy sources: AGN × PAH ionization

Contribution of ionized and neutral molecules to the flux contained in all PAH bands

Excitation potential of mid-IR emission lines associated to AGN and found by PAHFIT (e.g. $[OIV]_{25.9}$ with 55eV)

$\gtrsim$

Ionization potential of PAHs present in PAHdb (< 10eV)

↓

Photons with enough energy to ionize PAHs are abundant

What have we learned?

- IR emission source of (U)LIRGs:
  - star formation or active nuclei?

- PAH bands can trace the physical conditions in these galaxies;

- Theoretical and observational approach to analize PAHs in the IRS/Spitzer spectra of (U)LIRGs from GOALS → spectral decomposition and molecular categorization by size and charge.

Take home message

- ~ 100 different molecules, with “pure”, neutral and small PAHs being more abundant – 11.3μm (small and big mixture) and 7.7μm (charged > neutral);

- Trend of more charged PAHs (and decreasing of neutral PAHs) for stronger AGN in the sample;

- Let’s wait for JWST for spatially resolved studies!

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