Dusting the Universe
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PAH Fraction in the Magellanic Clouds

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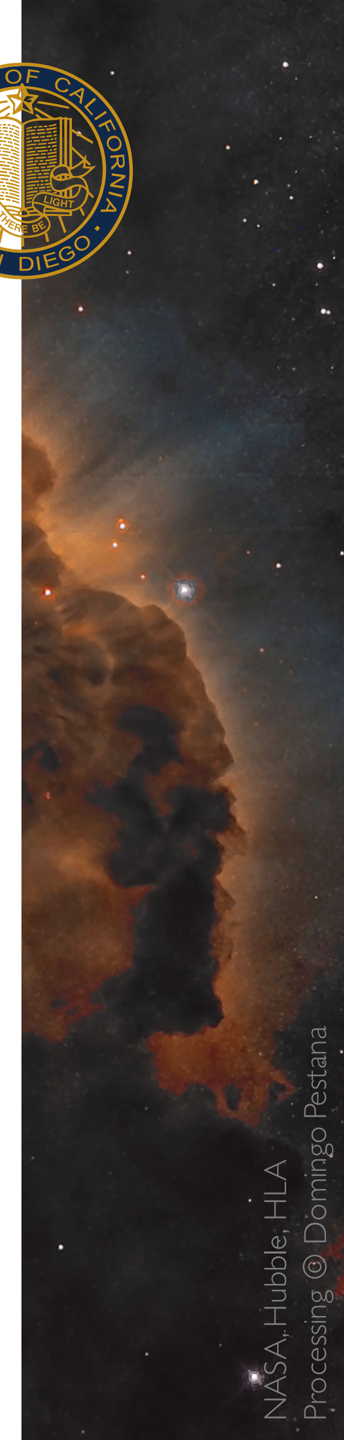


What about the PAH fraction in the Magellanic Clouds?

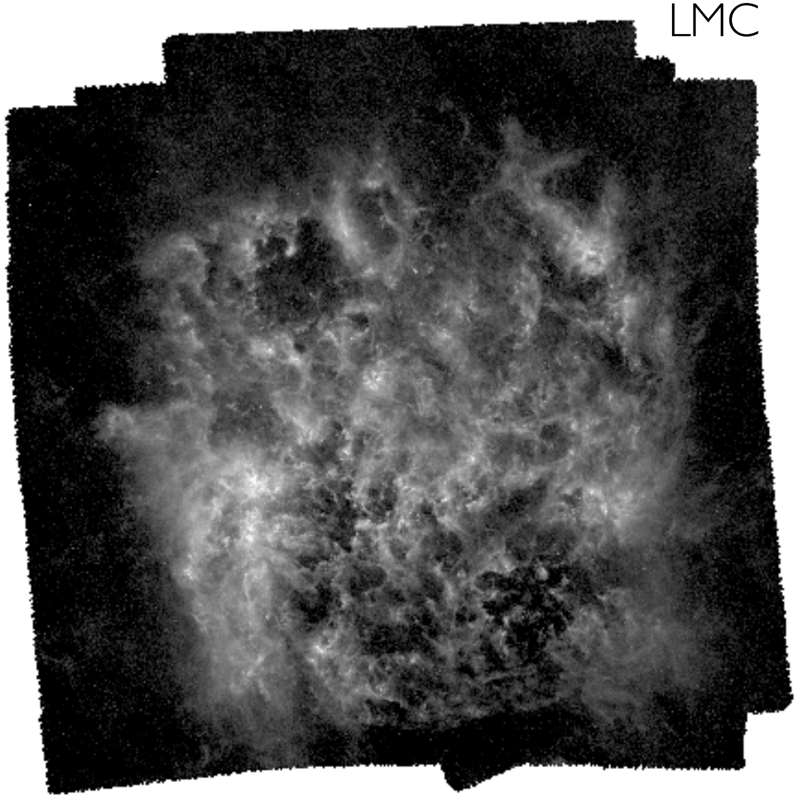
- We observe a lower average PAH fraction in the Small Magellanic Cloud (SMC) than in the Large Small Magellanic Cloud (LMC), both of which are lower than that of the Milky Way.
- *But*! In the diffuse neutral medium, the PAH fraction of the LMC is similar to that of the Milky Way.
- The PAH fraction is strongly correlated with ionized gas emission.
- A possible scenario for higher PAH fraction in the LMC is the formation of PAHs through the shattering of larger carbonaceous grains, and/or the growth of PAHs in dense medium.

Reminder: The Magellanic Clouds

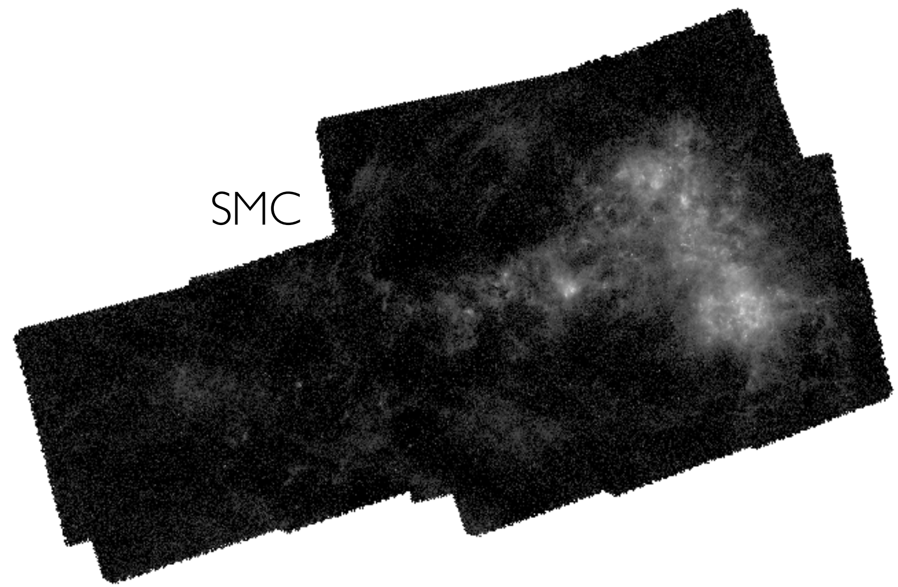
see Margaret Meixner presentation

Extensively studied nearby, low-metallicity galaxies: Bernard et al. (2008), Paradis et al. (2009), Bot et al. (2010), Galliano et al. (2011), Leroy et al. (2011), Sandstrom et al. (2010, 2012), Matsuura et al. (2013), Gordon et al. (2014), Roman-Duval et al. (2014), Jameson et al. (2016), and many more...

LMC



SMC



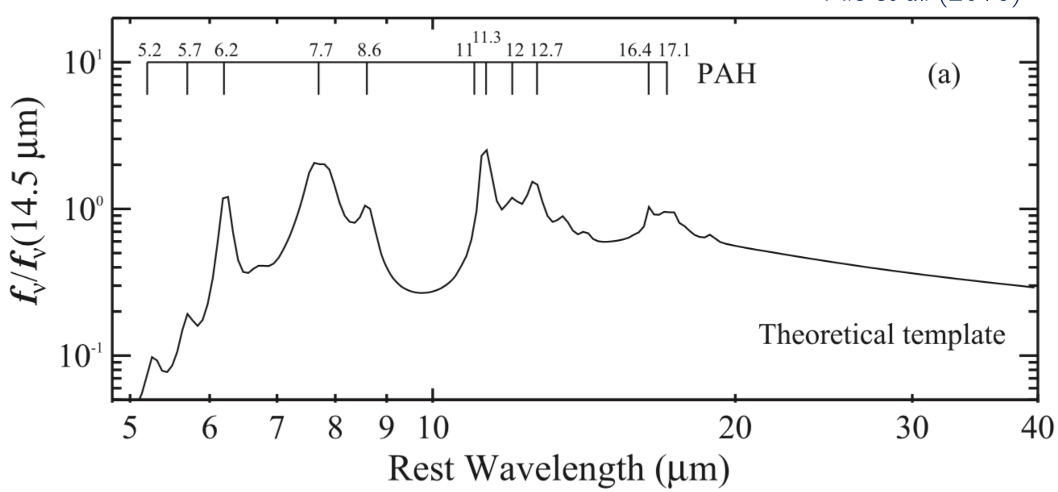
HERITAGE Collaboration (SPIRE 250)
Meixner et al. (2013, 2015)

REMINDER: THE PAHS

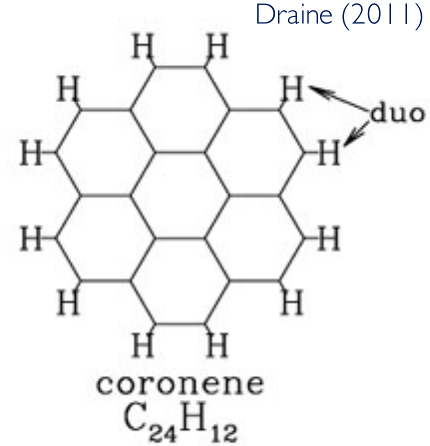
see J.D. SMITH presentation

- (Polycyclic aromatic hydrocarbons)
- Large molecules to very small grains: a few to ~10 Å in radius
- Responsible for the mid-IR emission features, aka the vibrational/rotational modes of Hydrogen atoms with their surroundings
- Can be found in neutral and ionized states, with spectral variations associated

Xie et al. (2018)



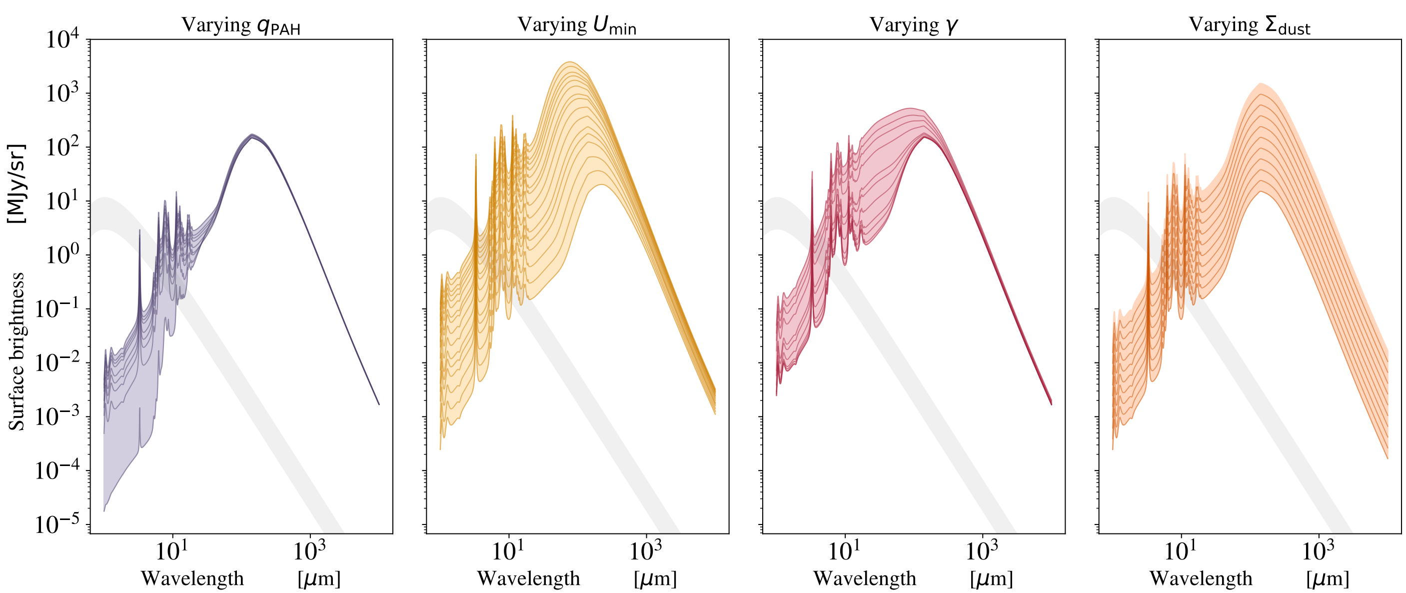
Draine (2011)



THE DRAINE & LI (2007) MODEL

The SED model adjusts:

- U_{min}: minimum radiation field heating dust grains;
- **γ**: fraction of dust mass heated by a power-law distribution of radiation fields with varying intensities;
- q_{PAH}: "fraction of PAHs",
  or fraction of dust mass contained in grains with less than 10^3 carbon atoms;
- Σ_{dust}: total dust surface density
- Ω_*: intensity of a 5,000 K blackbody, to model residual starlight.



FITTING A MODEL: DUSTBFF

Developed in Gordon et al. (2014), used in Chastenet et al. (2017), Chiang et al. (2018), Utomo et al. (2019).

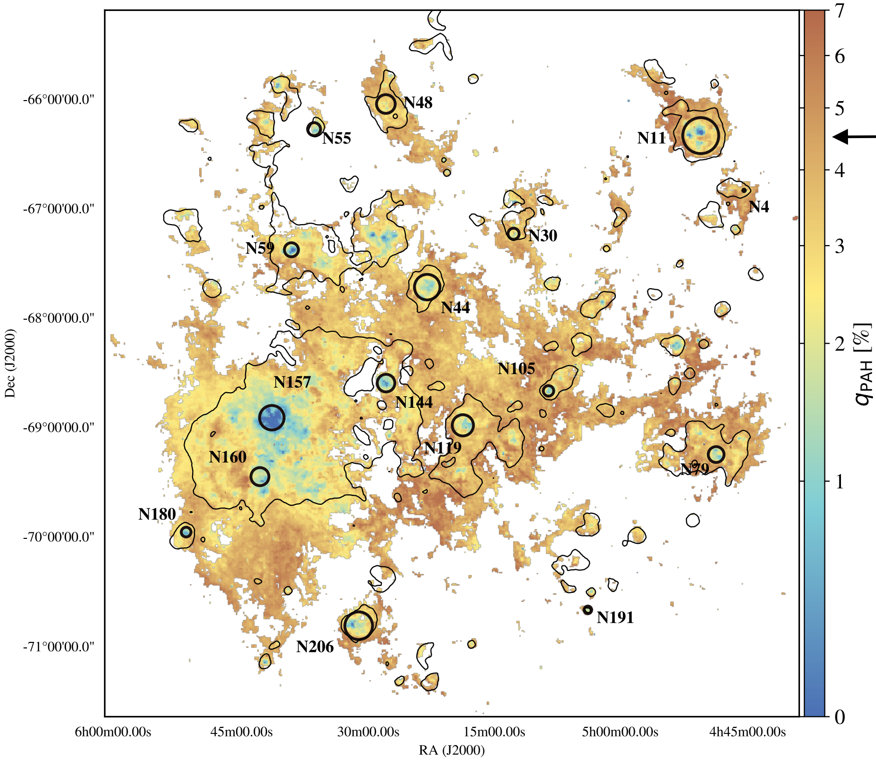
Creates a grid of models integrated in each band, finely sampled. The probability that a models fits the data is calculated through a χ^2 minimization, with

$$\chi^2 = [\vec{S}^{\rm obs} - \vec{S}^{\rm mod}(\theta)]^T \mathbb{C}^{-1} [\vec{S}^{\rm obs} - \vec{S}^{\rm mod}(\theta)]$$

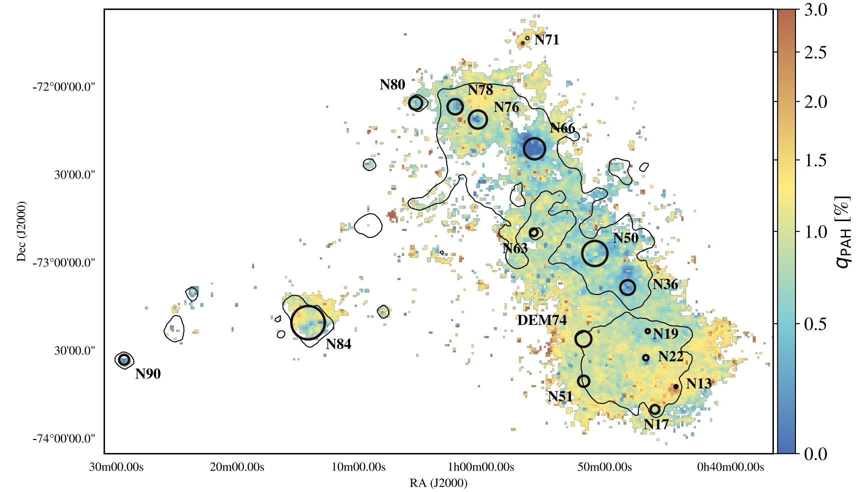
How far is the model from the data?...

Considering the uncertainties from the instruments we used? (Both correlated and uncorrelated.)

PAH Fraction: A Global Picture



$q_{PAH}^{MW} \sim 4.6\ \%$ (diffuse ISM; Li & Draine 2001; Weingartner & Draine 2001)

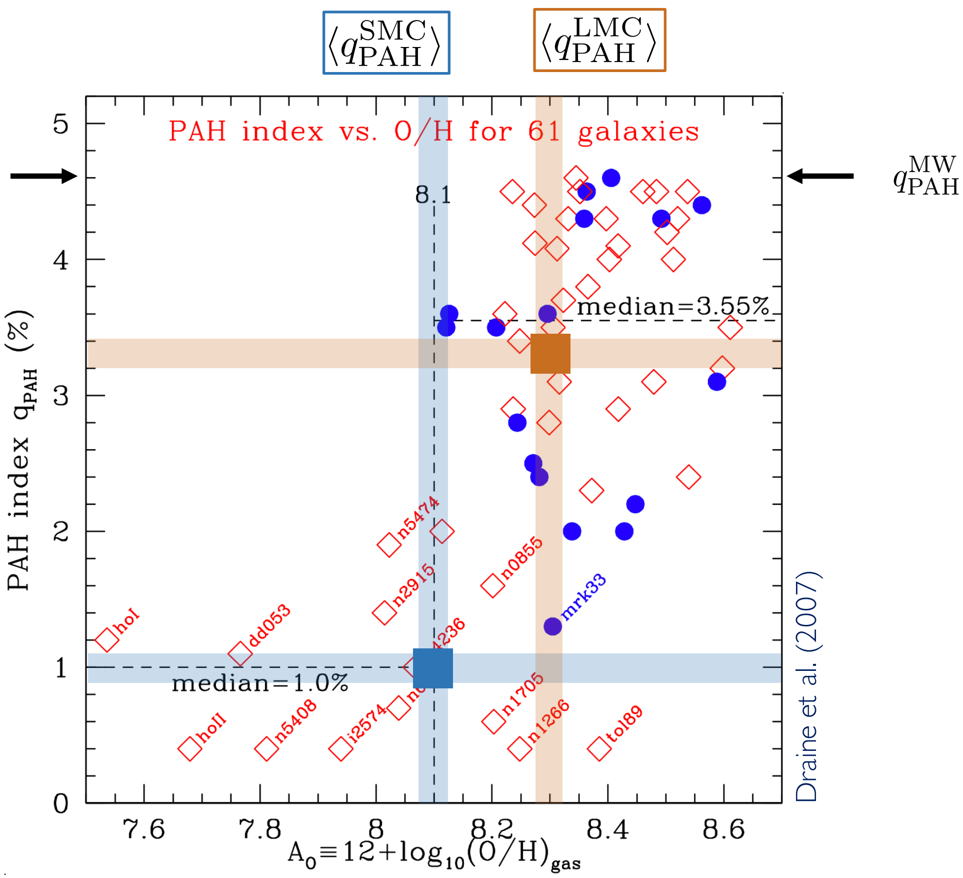


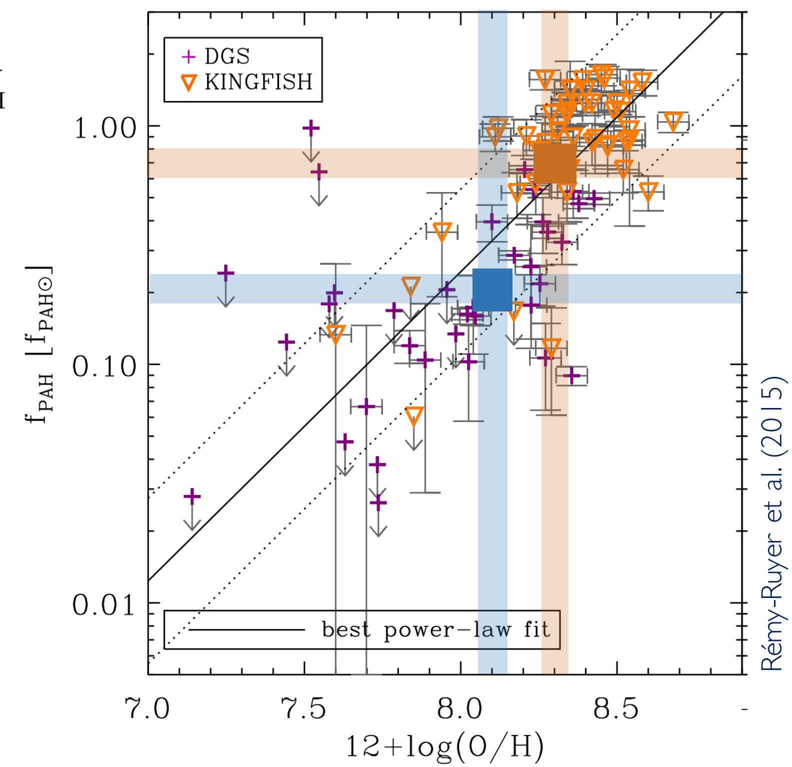
$$\langle q_{PAH}^{LMC} \rangle = 3.3^{+1.4}_{-1.3}\ \%$$

$$\langle q_{PAH}^{SMC} \rangle = 1.0^{+0.3}_{-0.3}\ \%$$

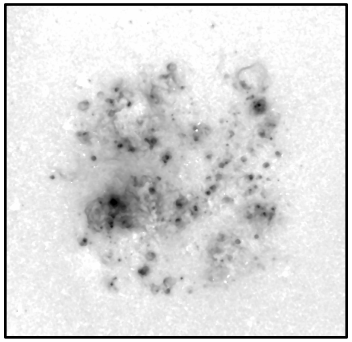
PAHs and Metallicity

Critical threshold in metallicity to observe a change in PAH abundance?
Or a power-law dependence?
Global averages sit well in both descriptions.

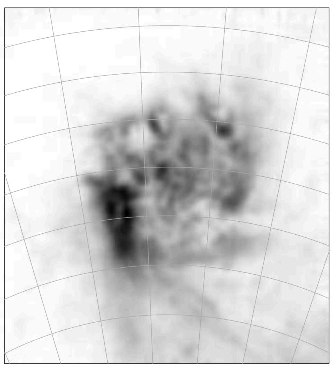




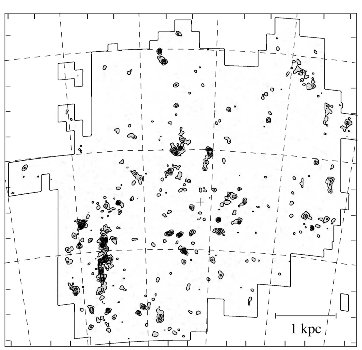
PAH Fraction: A Global Picture?



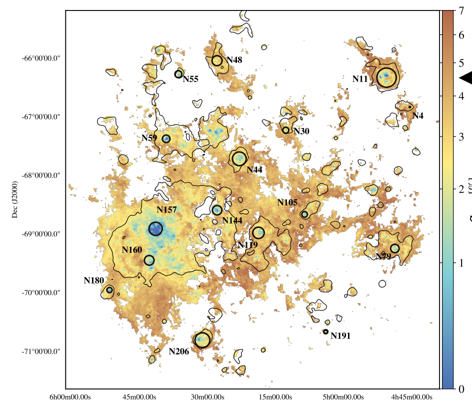
Gaustad et al. (2001)

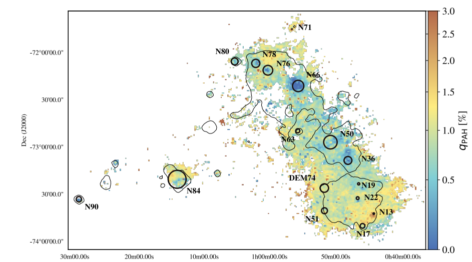


Staveley-Smith et al. (2003)



Fukui et al. (2008)



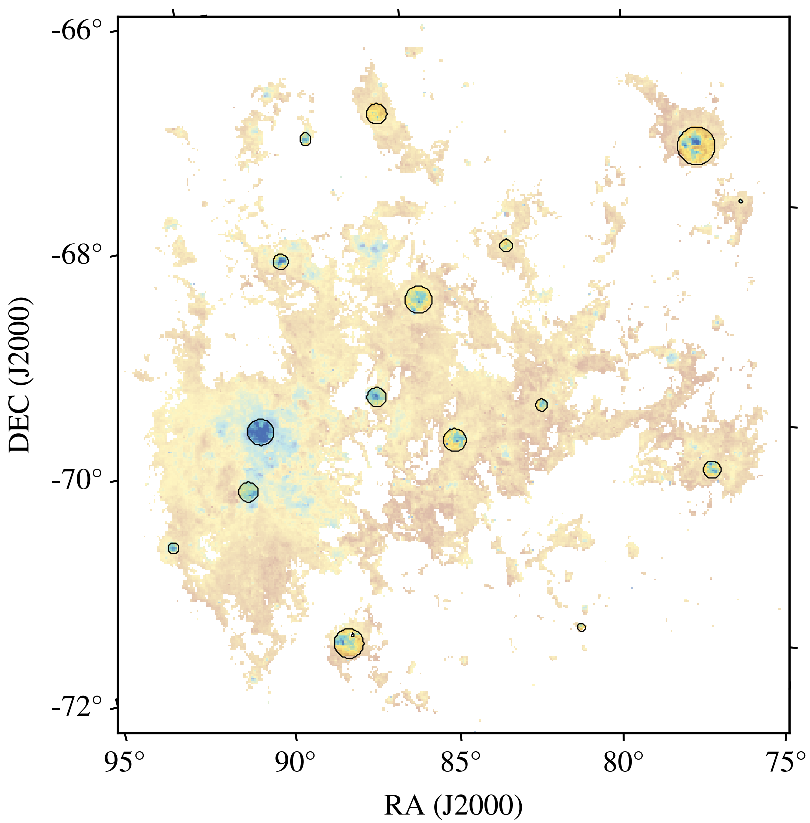


$$\langle q_{\rm PAH}^{\rm LMC} \rangle = 3.3^{+1.4}_{-1.3}\ \%$$

$$\langle q_{\rm PAH}^{\rm SMC} \rangle = 1.0^{+0.3}_{-0.3}\ \%$$

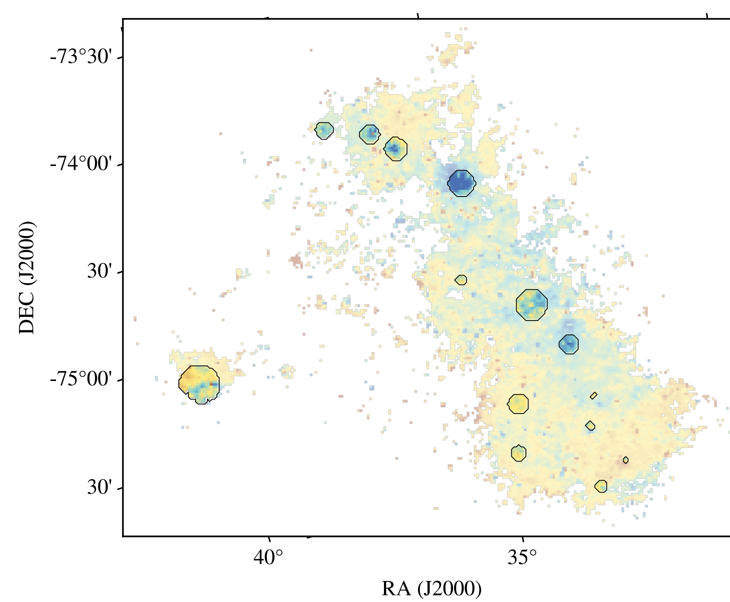
PAHs in H II Regions

Representative selection of bright H II regions (Lopez et al. 2014).



$$\langle q_{\rm PAH}^{\rm LMC,\ H\ II}\rangle = 1.8^{+1.1}_{-1.3}\ \%$$

$$\langle q_{\rm PAH}^{\rm SMC,\ H\ II}\rangle = 0.8^{+0.3}_{-0.5}\ \%$$



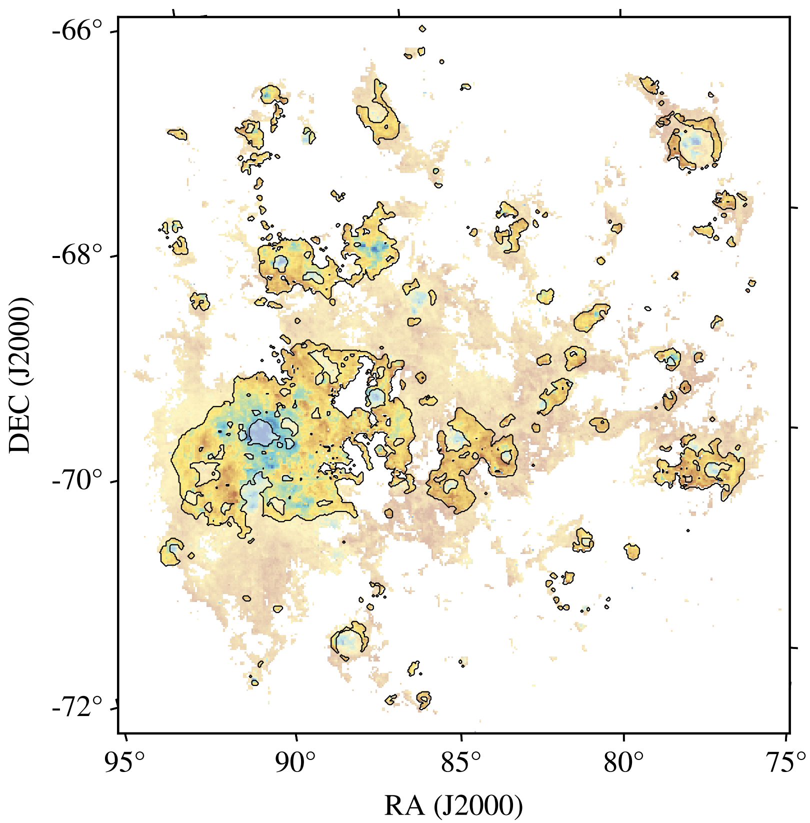
PAHs in Ionized Gas

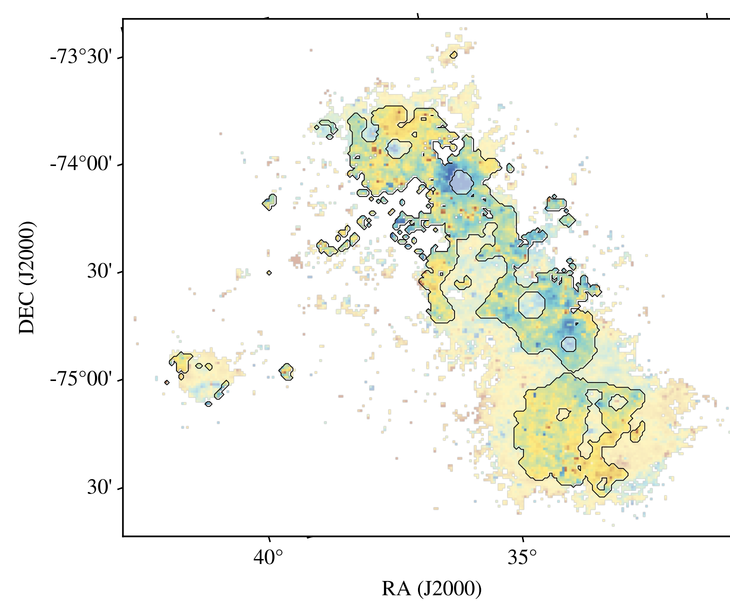
Identified in pixels above a lower limit in Hα emission (Gaustad et al. 2001).

$$\langle q_{\rm PAH}^{\rm H\ II} \rangle < \langle q_{\rm PAH}^{\rm ion} \rangle$$

$$\langle q_{\rm PAH}^{\rm LMC,\ ion} \rangle = 2.9^{+1.1}_{-1.2}\ \%$$

$$\langle q_{\rm PAH}^{\rm SMC,\ ion} \rangle = 0.9^{+0.3}_{-0.3}\ \%$$





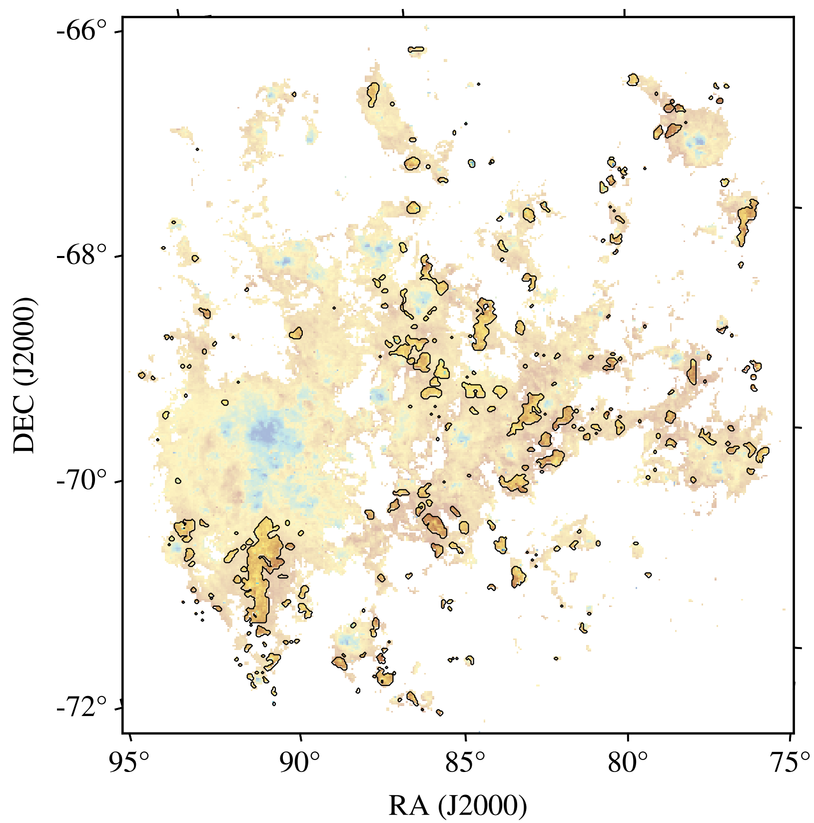
PAHs in Molecular Gas

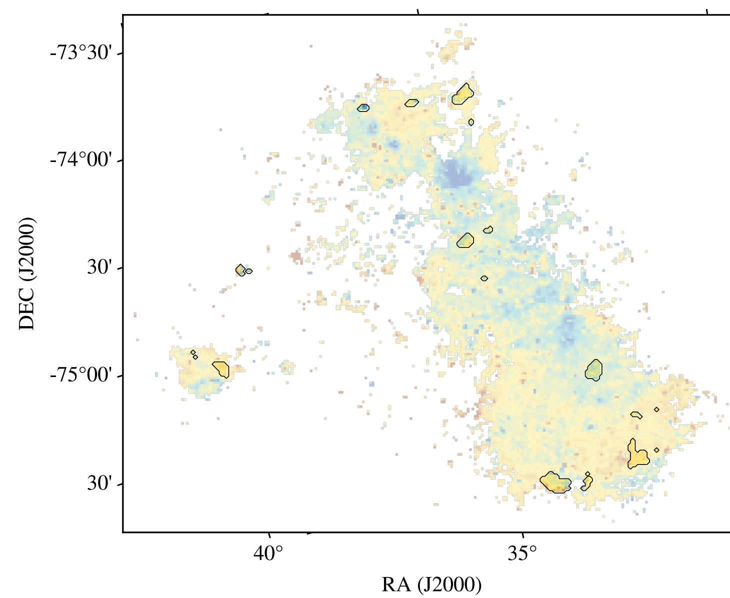
Identified in pixels above a 3σ detection of ^{12}CO (J = 1– 0) (Fukui et al. 2008).

$$\langle q_{\rm PAH}^{\rm H\ II} \rangle < \langle q_{\rm PAH}^{\rm ion} \rangle < \langle q_{\rm PAH}^{\rm mol} \rangle$$

$$\langle q_{\rm PAH}^{\rm LMC,\ mol} \rangle = 4.3^{+1.3}_{-0.9}\ \%$$

$$\langle q_{\rm PAH}^{\rm SMC,\ mol} \rangle = 1.1^{+0.1}_{-0.2}\ \%$$





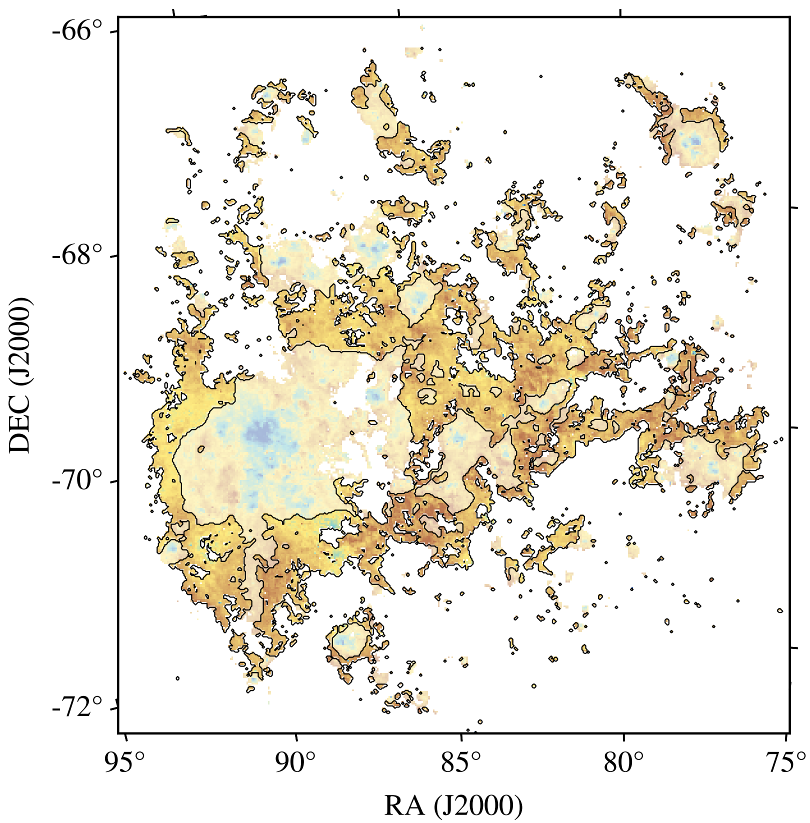
PAHs in Diffuse Neutral Gas

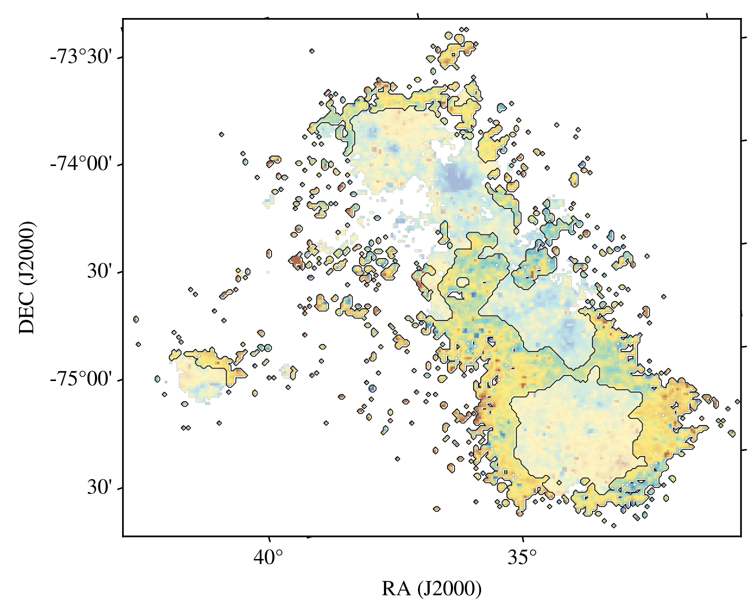
All of the other pixels!

$$\langle q_{\rm PAH}^{\rm H\ II} \rangle < \langle q_{\rm PAH}^{\rm ion} \rangle < \langle q_{\rm PAH}^{\rm mol} \rangle \sim \langle q_{\rm PAH}^{\rm dnm} \rangle$$

$$\langle q_{\rm PAH}^{\rm LMC,\ dnm} \rangle = 4.1^{+0.6}_{-0.8}\ \%$$

$$\langle q_{\rm PAH}^{\rm SMC,\ dnm} \rangle = 1.1^{+0.2}_{-0.3}\ \%$$





Gas Phases separation Take-Away

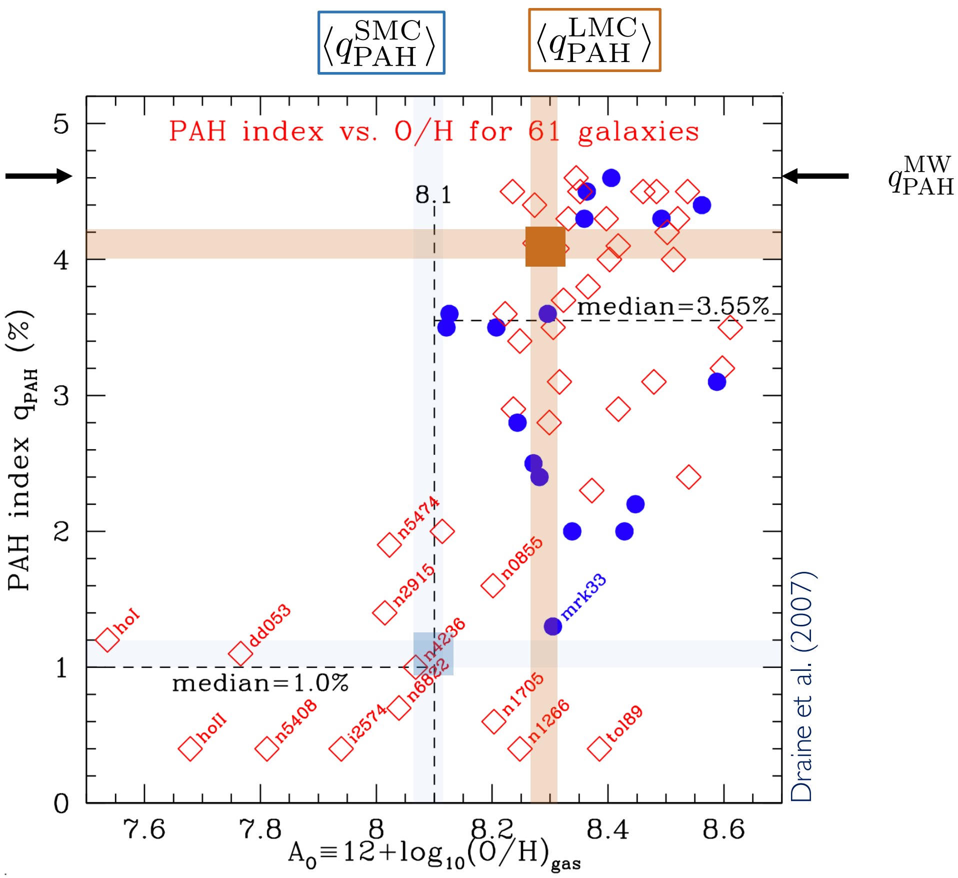
$$\langle q_{\rm PAH}^{\rm mol} \rangle \sim \langle q_{\rm PAH}^{\rm dnm} \rangle > \langle q_{\rm PAH}^{\rm ion} \rangle > \langle q_{\rm PAH}^{\rm H\ II} \rangle$$

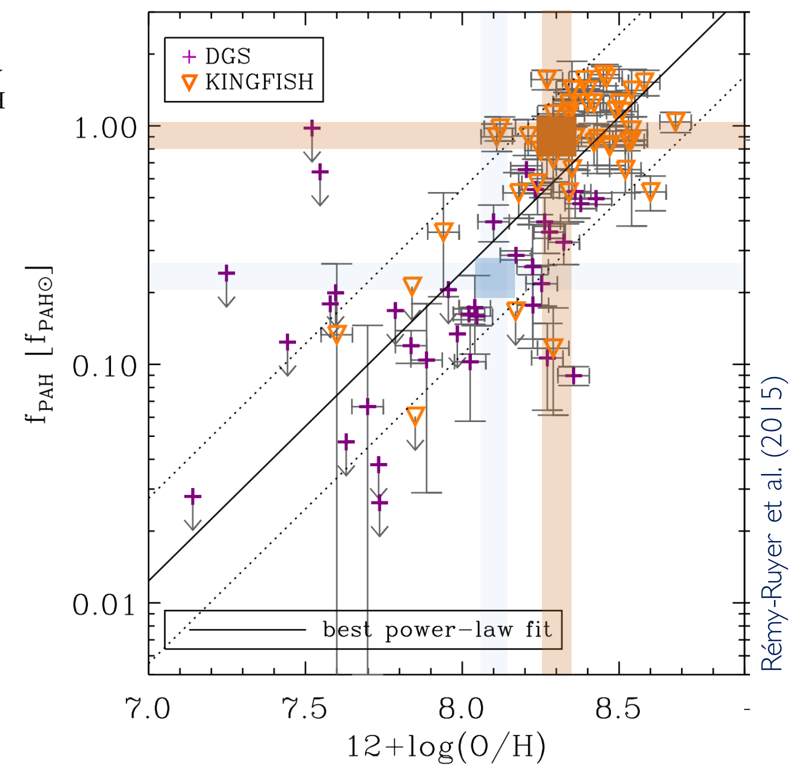
destruction

"Point of reference"

PAHs and Metallicity

The diffuse neutral medium PAH fraction of the LMC favors the existence of a critical threshold in metallicity to observe a change in PAH abundance?



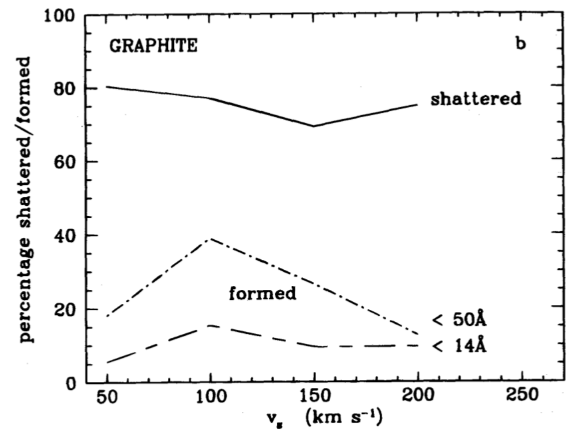


On the Life-cycle of PAHs
the higher PAH fraction in the DNM of the LMC

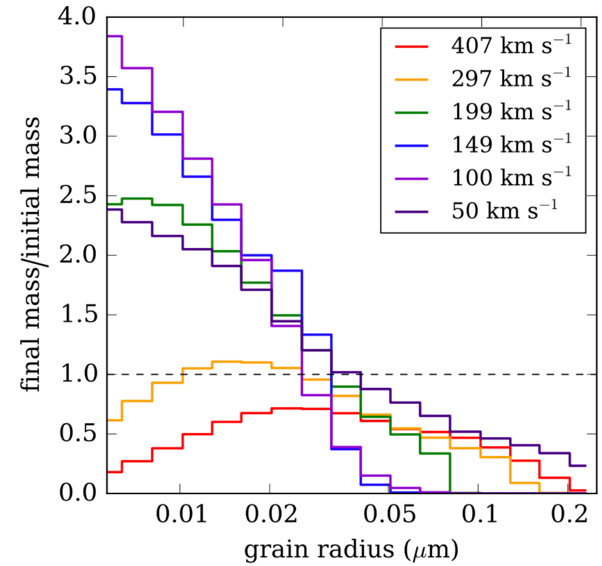
Diffuse neutral medium: not where destruction is significant.
So let's look into the formation processes.

The shattering of large carbonaceous grains can lead to the redistribution of dust mass in the form of smaller grains, or PAHs.

At equivalent rates, we need more large dust grains to form more small grains.



Jones et al. (1996)



Slevin et al. (2015)

On the Life-cycle of PAHs

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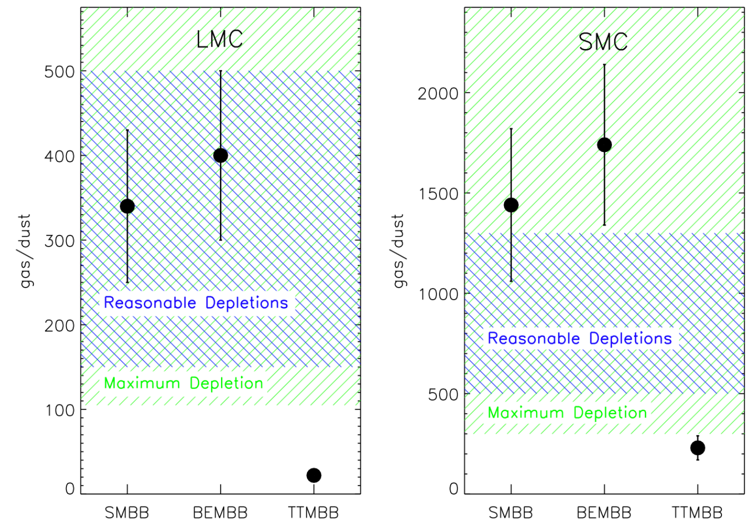
The larger dust-to-gas ratio of the LMC may be in favor of that hypothesis.

Gordon et al. (2014)



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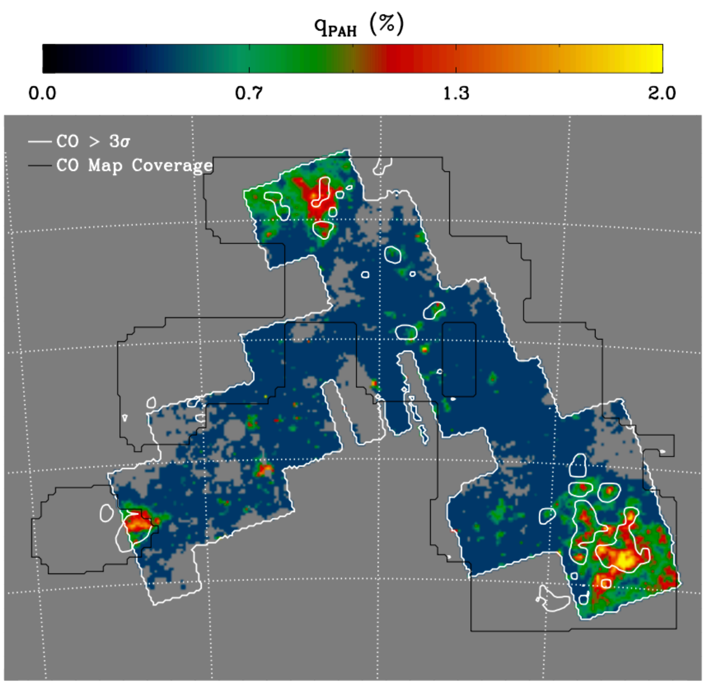
Dust production of grains from 1 to 5 nm in radius happen in gas density from 5 to 500 cm^{-3} (Zhukovska et al. 2016). Maybe?



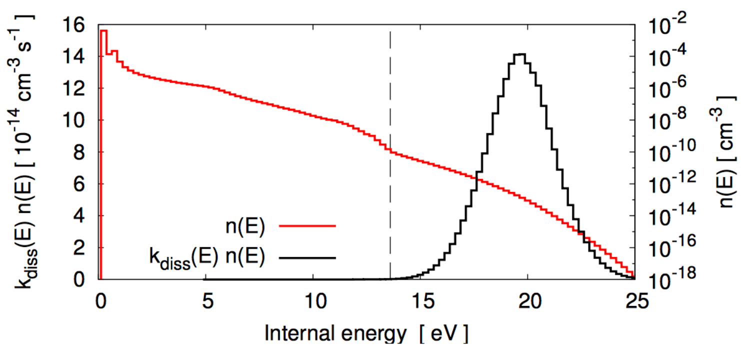
Sandstrom et al. (2010)

ON THE LIFE-CYCLE OF PAHS

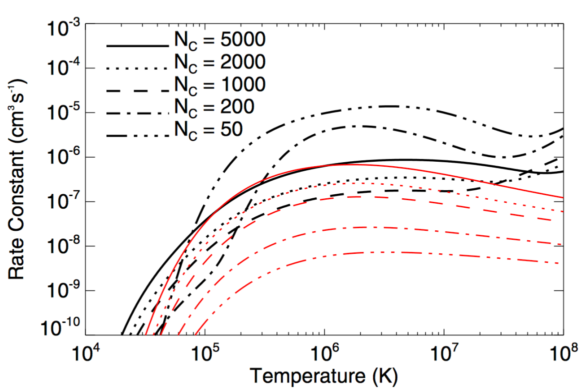
DESTRUCTION OF PAHS MORE EFFICIENT IN THE SMC?

PAHs could be destroyed in a hot gas, through destructive collisions with other particles (H, He, C...).

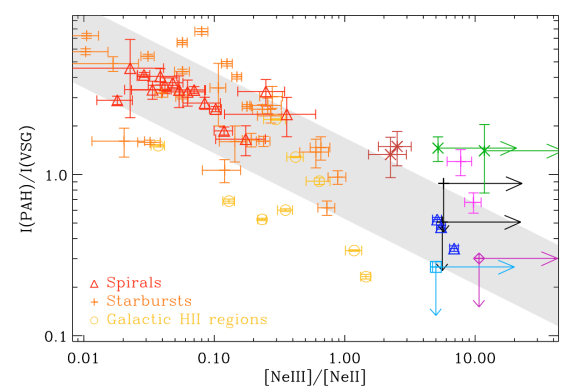
Photoionization from the radiation field could lead to multiple ionizing events and disrupt PAHs.



Montillaud et al. (2013)



Bocchiot et al. (2012)



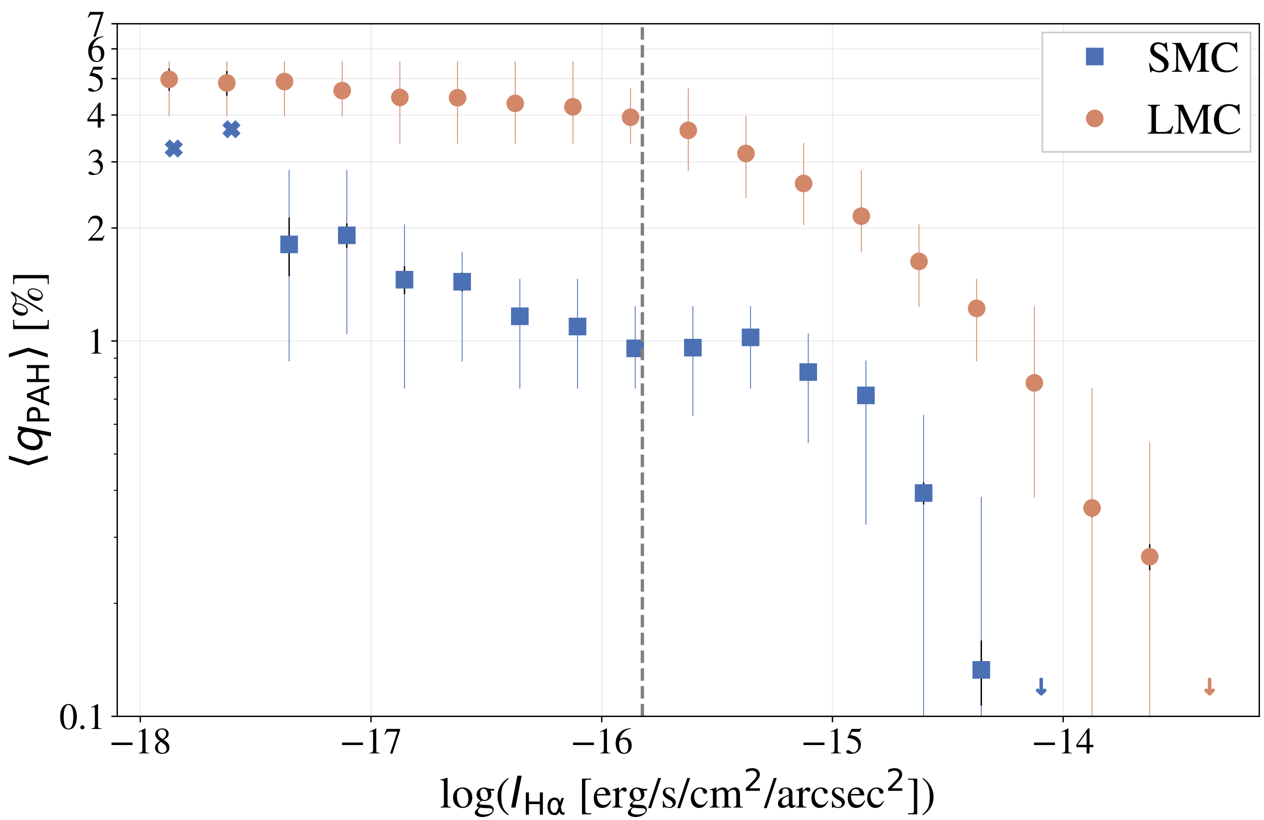
Madden et al. (2006)

On the Life-cycle of PAHs

Destruction of PAHs more efficient in the SMC?

PAHs could be destroyed in a hot gas, through destructive collisions with other particles (H, He, C...).

Photoionization from the radiation field could lead to multiple ionizing events and disrupt PAHs.



On the Life-cycle of PAHs

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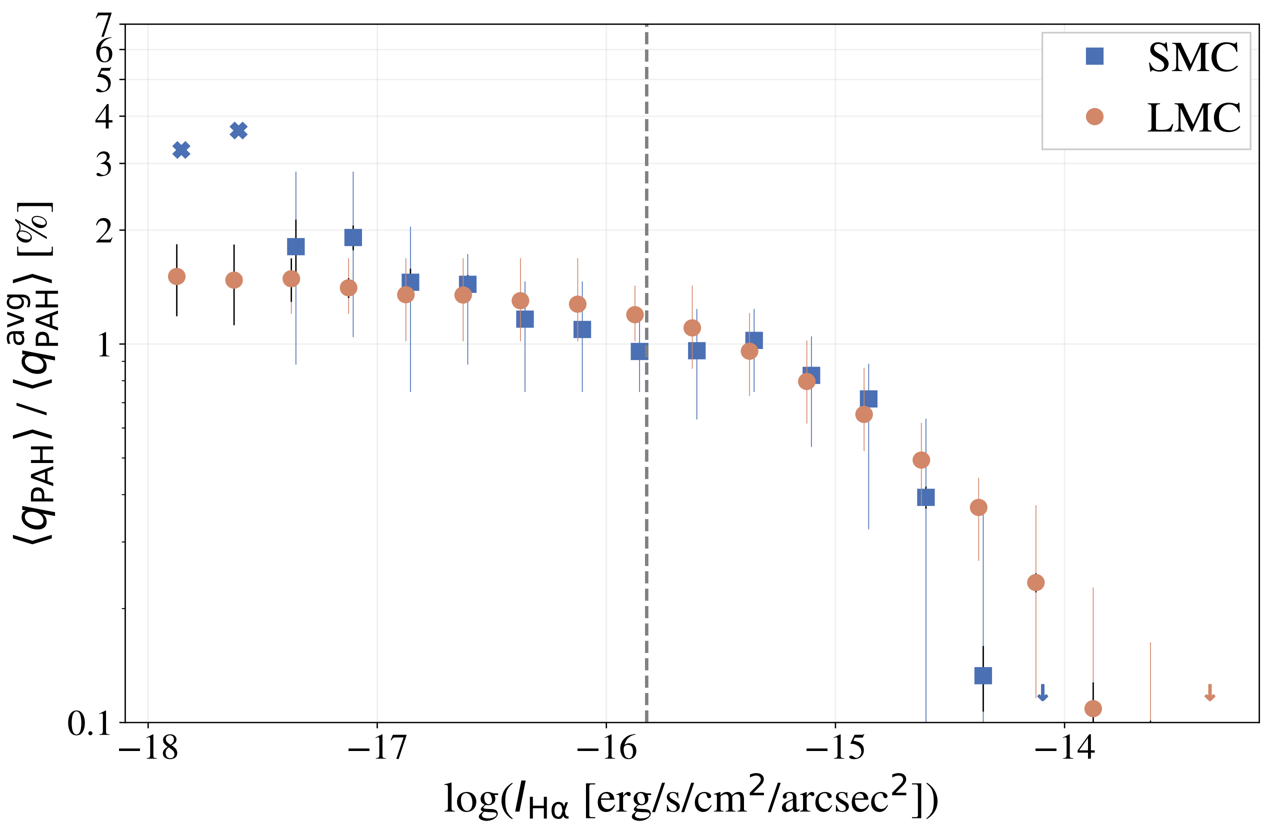
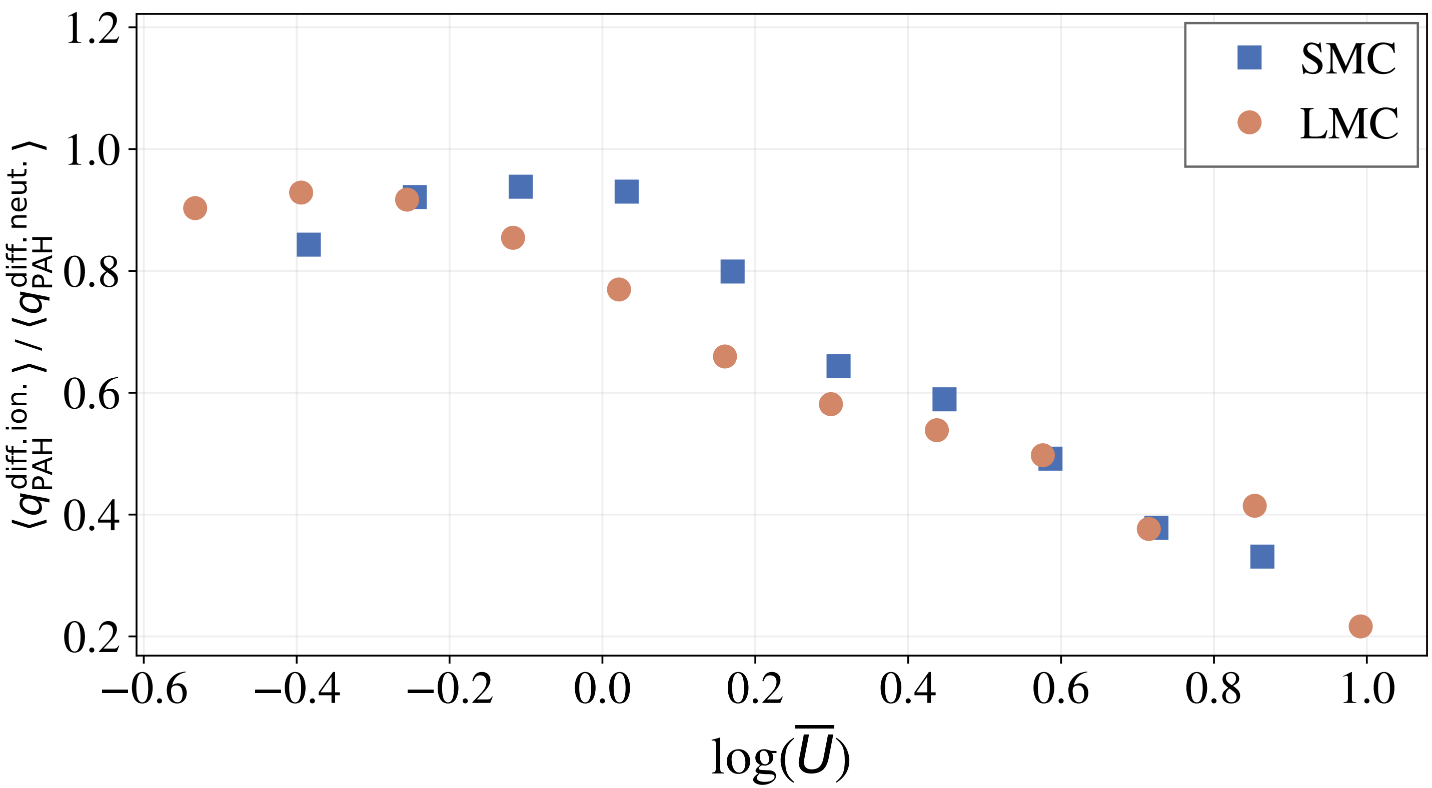


On the Life-cycle of PAHs

Destruction of PAHs more efficient from the ionized to the neutral gas?



Going from the ionized to the neutral medium, the destruction of PAHs follow the same pattern in both the LMC and the SMC.

QUICK SUM UP & Z0MGS

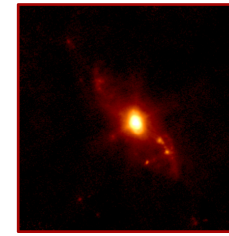
- PAH fraction in the diffuse neutral medium of the LMC is close to the value of the MW,
  PAH fraction in the SMC significantly lower!

$$\langle q_{\mathrm{PAH}}^{\mathrm{LMC}} \rangle = 3.3^{+1.4}_{-1.3}~\% \quad \langle q_{\mathrm{PAH}}^{\mathrm{SMC}} \rangle = 1.0^{+0.3}_{-0.3}~\%$$

$$\langle q_{\mathrm{PAH}}^{\mathrm{mol}} \rangle \sim \langle q_{\mathrm{PAH}}^{\mathrm{dnm}} \rangle > \langle q_{\mathrm{PAH}}^{\mathrm{ion}} \rangle > \langle q_{\mathrm{PAH}}^{\mathrm{H~II}} \rangle$$

- The ionized gas affect the abundance of PAH, even outside of H II regions

- Possible enhanced fragmentation of large carbonaceous grains in the LMC



$z = 0$ Multi-wavelength Galaxy Synthesis

- UV, NIR, MIR of local galaxies to trace recent star formation
- VLA HI archival and new maps
- Multi-resolution Herschel data of resolved nearby galaxies

Check out Dyas' poster!