4.2.1. The competing small a-C(:H) evolution scenarios

The strong spatial variability of the aromatic feature strength has been known for several decades. Dramatic variations have been observed within Galactic and Magellanic H II regions (e.g., Boulanger et al. 1998; Madden et al. 2006; Galametz et al. 2013), as well as among nearby galaxies (e.g., Galliano et al. 2003, 2005; Engelbracht et al. 2005; Madden et al. 2006). The following scenarios have been proposed.

Photodestruction. The aromatic feature strength appears to be negatively correlated with the presence of intense or hard UV fields. For instance, Boulanger et al. (1998) showed that their strength in Galactic PDRs is decreasing when the intensity of the ISRF is increasing. Madden et al. (2006) showed that their strength, within Galactic and Magellanic regions, and within nearby galaxies, is negatively correlated with $[\text{Ne III}]_{15.56\,\mu\text{m}}/[\text{Ne II}]_{12.81\,\mu\text{m}}$, an ISRF hardness indicator. Numerous studies confirmed these trends, showing the depletion of aromatic features around massive stars, as a result of the photodissociation and photosublimation of small a-C(:H). At the same time, it was also shown that the aromatic feature strength is empirically correlated with metallicity. This is clear in nearby galaxies, as a whole (e.g., Engelbracht et al. 2005; Madden et al. 2006), as well as within extragalactic H II regions (e.g., Gordon et al. 2008; Khramtsova et al. 2013). This correlation is not inconsistent with photodestruction, as most low-metallicity galaxies detected at IR wavelengths to date are actively forming stars. Their ISM, less opaque due to a lower Z_{dust}, is permeated by an intense UV field, potentially destroying small a-C(:H) on wider scales. It is also consistent with the increasing strength of the 2175 Å bump with metallicity, comparing sightlines in the Small Magellanic Cloud (SMC), LMC, and Milky Way (e.g., Gordon et al. 2003). The extinction bump is indeed thought to be carried by small carbon grains with aromatic bonds (Joblin et al. 1992).

Inhibited formation. Alternatively, several studies have explored the possibility that small a-C(:H) are less efficiently formed at low-metallicity. Galliano et al. (2008b) showed that, assuming small a-C(:H) are formed from the carbon produced by AGB stars (on timescales of ≃400 Myr) and the rest of the grains are mostly made out of the elements produced by massive stars (on timescales of ≃10 Myr), the aromatic feature emitters are under-abundant at early stages of galaxy evolution. Another scenario, developed by Seok et al. (2014), reproduces the trend of aromatic feature strength with metallicity, assuming small a-C(:H) are the product of the shattering of larger carbon grains (see also Rau et al. 2019; Hirashita & Murga 2020). Finally, Greenberg et al. (2000) have proposed that aromatic feature carriers could form on grain surfaces in molecular clouds and be photoprocessed in the diffuse ISM. Sandstrom et al. (2010) and Chastenet et al. (2019) show that the spatial distribution of q_{PAH} in the Magellanic Clouds is consistent with this scenario. This process would also explain the fact that these grains are under-abundant in ELMGs, as the molecular gas fraction rises with metallicity.

4.2.2. Empirical correlations within our sample

The different processes we have just listed are not exclusive and could very well compete within the ISM. It is however important to understand which one controls the overall abundance of small a-C(:H), at galaxy-wide scales.

Figure 12 shows q_{AF} as a function of the average starlight intensity, $\langle U\rangle$ (Sect. 3.1.2), and metallicity, in our sample. Similar relations were previously shown by Draine et al. (2007), Galliano et al. (2008b), Khramtsova et al. (2013), and Rémy-Ruyer et al. (2015). The two SUEs at high $\langle U\rangle$ (panel a) are I Zw 18 and SBS 0335–052. Their SEDs indeed peaks around 30 µm. However, their q_{AF} appear higher than the extrapolation of the general trend, with $\text{CR}_{95\%}(q_{\text{AF}}) = [0.012, 0.035]$ for I Zw 18 and $\text{CR}_{95\%}(q_{\text{AF}}) = [0.024, 0.064]$ for SBS 0335–052. Mid-IR *Spitzer*-IRS spectroscopy did not detect aromatic features in these galaxies (Wu et al. 2007; Houck et al. 2004). The true value of q_{AF} is likely lower for these two objects. The reason of this overestimation lies in the difficulty to estimate aromatic feature strengths solely with broadband fluxes, when the feature-to-continuum ratio is weak. Indeed, in the weak aromatic feature regime, q_{AF} is biased by the color of the mid-IR continuum (cf. Fig. 1 of Galliano et al. 2008b).

Overall, we find clear correlations in both panels of Fig. 12, consistent with past studies. However, the relation appears more scattered with $\langle U\rangle$, than with 12 + log(O/H). The correlation coefficient of panel a is only $\rho = -0.434^{+0.038}_{-0.028}$ with $\text{CR}_{95\%}(\rho) = [-0.49, -0.35]$, while it is $\rho = 0.762^{+0.018}_{-0.030}$ with $\text{CR}_{95\%}(\rho) = [0.70, 0.79]$ for panel b. We could argue that panel b of Fig. 12 contains only the 376 sources with metallicity measurements (Table 2), while panel a contains the 798 sources with photometric fluxes, including very noisy ETG SEDs. If we consider only the subsample of panel a with metallicity measurements, the correlation coefficient does not significantly improve: $\rho = -0.486^{+0.034}_{-0.026}$ with $\text{CR}_{95\%}(\rho) = [-0.54, -0.42]$. If we also exclude the two biased estimates of I Zw 18 and SBS 0335–052, the correlation coefficients do not change much: $\rho = -0.432^{+0.040}_{-0.029}$ with $\text{CR}_{95\%}(\rho) = [-0.49, -0.35]$ for panel a and $\rho = 0.768^{+0.018}_{-0.031}$ with $\text{CR}_{95\%}(\rho) = [0.70, 0.80]$ for panel b.

We could also question the accuracy of $\langle U\rangle$ as an ISRF tracer. Indeed, $\langle U\rangle$ is a mass-averaged ISRF intensity, giving a large weight to the coldest regions within the beam. Rémy-Ruyer et al. (2015) and Nersesian et al. (2019) used sSFR, which is luminosity weighted, in place of $\langle U\rangle$ and found a good negative correlation with q_{PAH} and q_{AF}, respectively. In our sample, the correlation coefficient between $\ln q_{\text{AF}}$ and $\ln \text{sSFR}$ is not improved: $\rho = -0.488^{+0.028}_{-0.024}$ with $\text{CR}_{95\%}(\rho) = [-0.53, -0.43]$.

Therefore, it appears that q_{AF} correlates much more robustly with metallicity than ISRF indicators, in our sample. This result is worth noting, especially since several studies focussing on a narrower metallicity range concluded the opposite (e.g., Gordon et al. 2008; Wu et al. 2011). It probably relies on the fact the metallicities we have adopted (Sect. 2.2.2) correspond to well-sampled galaxy averages, while in the past a single metallicity, often central, was available and may have not been representative of the entire galaxy. This result suggests that photodestruction, although real at the scale of star-forming regions, might not be the dominant mechanism at galaxy-wide scales and that one needs to invoke one of the inhibited formation processes discussed in Sect. 4.2.1.

4.3. Approximate analytical metallicity trends

It can be interesting to have a simple analytical approximation describing how Z_{dust} and q_{AF} vary as a function of 12+log(O/H). To that purpose, we have performed polynomial fits of the relations in panel d of Fig. 8 and panel b of Fig. 12. These fits are displayed in Fig. 13.