numerous noise-induced, false correlations between parameters, encountered when fitting SEDs with least-squares or nonhierarchical Bayesian methods (Shetty et al. 2009; Kelly et al. 2012; Galliano 2018; Lamperti et al. 2019). It has recently been used to study the anomalous microwave emission in the Milky Way (Bell et al. 2019).

From a technical point of view, HerBIE uses a Markov chain Monte-Carlo (MCMC), with Gibbs sampling (Geman & Geman 1984). As mentioned in Sect. 2.2, we include the ancillary data in our prior. This process is fully demonstrated in Sect. 5.3 of G18. These ancillary data do not enter the dust model, but they provide information that helps to better constrain the hyperparameters, in a holistic way. In other words, the information provided by the gas mass or the metallicity helps to better constrain the dust SED fit. It is a Bayesian implementation of Stein's paradox (Stein 1956; Efron & Morris 1977).

3.1.1. Parametrization of the dust model

To infer dust parameters with HerBIE, we adopt the framework provided by the grain properties of the THEMIS[11] model (Jones et al. 2017). THEMIS is built, as much as possible, on laboratory data, and reproduces dust observables of the Galactic ISM. One of its originalities is that it accounts for the aromatic and aliphatic mid-IR features with a single population of small, partially hydrogenated, amorphous carbons, noted a-C(:H). Consequently, it does not include polycyclic aromatic hydrocarbons (PAH) per se. Although largely dehydrogenated, small a-C(:H) are very similar to PAHs. The other main component of THEMIS is a population of large, a-C(:H)-coated, amorphous silicates, with Fe and FeS nano-inclusions.

THEMIS is designed to model the evolution of: (i) the size distribution, (ii) the a-C(:H) hydrogenation, and (iii) the mantle thickness, with the interstellar radiation field (ISRF) and gas density. With the observational constraints of Sect. 2.1, we can not reliably constrain the mantle thickness, as its effect on the shape of the far-IR SED is too subtle. Nor can we constrain the a-C(:H) hydrogenation, as broadband fluxes do not provide unambiguous constraints on the 3.4 µm feature. We can however study the variations of the size distribution of small a-C(:H), from galaxy to galaxy, as it will affect the strength of the bright mid-IR aromatic features.

We have therefore parametrized the size distribution in the following way. We have divided the a-C(:H) component into (cf. Fig. 1):

- *Very small a-C(:H)* (denoted VSAC) of radius smaller than 7 Å, responsible for the mid-IR feature emission, with more weight in the short wavelength bands;
- *Small a-C(:H)* (denoted SAC) of radius between 7 Å and 15 Å, responsible for the mid-IR feature emission, with more weight in the long wavelength bands;
- *Medium and large a-C(:H)* (noted MLAC) of radius larger than 15 Å, carrying the featureless mid-IR continuum and a fraction of the far-IR peak.

The silicate-to-MLAC ratio is kept constant. Using q_X to denote the mass fraction of component X, the size distribution is controlled by two parameters: (i) the mass fraction of aromatic-feature-carrying grains, $q_{\rm AF} \equiv q_{\rm VSAC} + q_{\rm SAC}$; and (ii) the very-small-a-C(:H)-to-aromatic-feature-emitting-grain ratio, $f_{\rm VSAC} \equiv q_{\rm VSAC}/q_{\rm AF}$. Comparing these parameters to dust models with PAHs (e.g., Zubko et al. 2004; Draine & Li 2007; Compiègne et al. 2011), $q_{\rm AF}$ is the analog of the PAH mass fraction, $q_{\rm PAH}$ introduced by Draine & Li (2007, hereafter DL07). The difference here is that, $q_{\rm AF} = 17\%$, while $q_{\rm PAH} = 4.6\%$, in the diffuse Galactic ISM[12]. This is because a-C(:H) have a smaller fraction of aromatic bonds per C atom. More mass is therefore needed to produce the feature strength of a PAH.

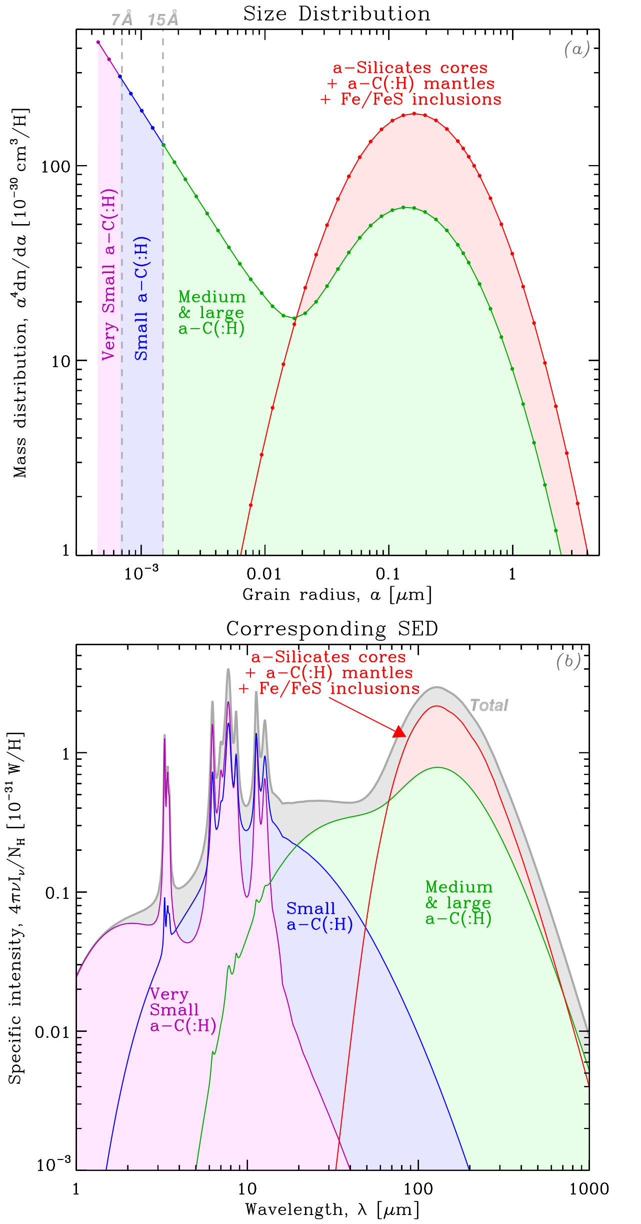

Fig. 1. Parametrization of the THEMIS model. *Panel a*: size distribution of the two main components of THEMIS: amorphous carbons and silicates. We show how we divide the a-C(:H) size distribution into three independent components. *Panel b*: SED corresponding to each component (same color code as panel a). The SED is shown for the ISRF of the solar neighborhood (Mathis et al. 1983).

[11] www.ias.u-psud.fr/themis/

[12] We note here that the estimated mass fraction of PAHs in the diffuse Galatic ISM depends on the set of mid-IR observations used to constrain it. For instance, DL07 use COBE/DIRBE broadbands, while Compiègne et al. (2011) use a scaled *Spitzer*/IRS spectrum. It results in different levels of mid-IR emission and PAH fraction: Compiègne et al. (2011) find $q_{\rm PAH} = 7.7\%$. Since THEMIS is calibrated with the same observations as Compiègne et al. (2011), it is possible to estimate the value of $q_{\rm PAH}$ that would result in the same level of mid-IR emission as $q_{\rm AF}$: $q_{\rm PAH} \simeq 0.45 \times q_{\rm AF}$ (ratio of 7.7% to 17%).