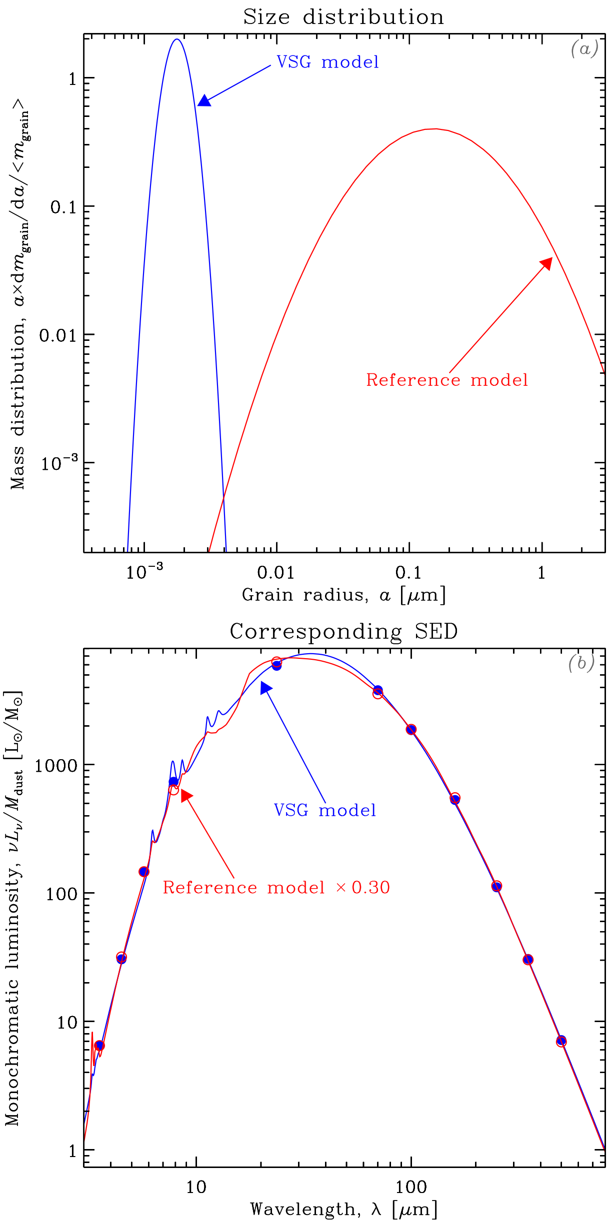

Fig. 11. Demonstration of a VSG-dominated SED. *Panel a*: size distribution of the two models we are comparing here: the reference model in red, which is simply the `THEMIS` model, with the small grains scaled down to mimic the SED of a typical ELMG; and a VSG model, in blue, which is a log-normal size distribution, peaking at 1.5 nm with a log-width of 0.2. The optical properties of the VSG model are those of `THEMIS`, and we have kept the same silicate-to-carbon grain mass ratio. In both cases, the curves represent the size distributions of a-C(:H) and silicates. *Panel b*: corresponding SEDs for the two models. The SED of the reference model has been scaled down by a factor of 0.30, to fit the VSG SED. It means the VSG SED reproduces the reference model with a dust mass 3.33 times higher. The VSG SED is uniformly illuminated by an ISRF with $U = 10$, while the reference model has a distribution of ISRFs with $\langle U \rangle = 200$. The blue filled and red empty circles show the synthetic photometry of each model in the IRAC, MIPS1, PACS, and SPIRE bands.

$\lambda \simeq 30\,\mu$m, inconsistent with our observations. Finally, VSG-dominated ELMGs would not be in agreement with theoretical dust size distribution evolution models (e.g., Hou et al. 2017; Hirashita & Aoyama 2019; Aoyama et al. 2020). At early stages, these models predict the ISM being populated of large grains. The reason is that the dust production at these stages is thought to be dominated by SN-II-condensed dust, and grains condensed in core-collapse SN ejecta are essentially large as the small ones are kinetically sputtered (e.g., Nozawa et al. 2006).

Very cold dust. A significant fraction of the dust mass could have been overlooked, hidden in the form of very cold dust ($T_{\text{dust}} \lesssim 10$ K). The emission of this component would manifest as a weakly emissive continuum at submm wavelengths, that we have not accounted for. Very cold dust has been invoked to explain the submm excess in dwarf galaxies (cf. Sect. 3.1.3). It could thus be invoked to flatten our dust-to-metal mass ratio trend, in principle. However, while the excess has been reported by numerous studies, predominantly in dwarf galaxies (e.g., Galliano et al. 2003, 2005; Dumke et al. 2004; Bendo et al. 2006; Galametz et al. 2009; Bot et al. 2010), very cold dust does not appear as one of its viable explanations. Indeed, to reach such a low temperature, very cold dust should be shielded from the general ISRF in massive dense clumps. In the LMC, Galliano et al. (2011) showed that the excess emission at 10 pc scale was diffuse and negatively correlated with the gas surface density, inconsistent with the picture of a few dense clumps. Similarly, Galametz et al. (2014) and Hunt et al. (2015) showed that this excess was more prominent in the outskirts of late-type disk galaxies, where the medium is less dense. In addition, other realistic physical processes to explain this excess have been proposed (Meny et al. 2007; Draine & Hensley 2012). Dust analogs also exhibit a flatter submm slope that could partly account for this excess (Demyk et al. 2017b). More qualitatively, it is difficult to conceive of the presence of massive dense clumps in ELMGs, where the dust-poor ISM is permeated by intense UV photons from the young stellar populations that are forming. In addition, this dust would likely be associated with dense gas that we have not accounted for, limiting its impact on the estimated dustiness.

Systematic uncertainty on the ELMG's DTM. Overall, it appears that none of our model assumptions could be demonstrated to be responsible for artificially inducing the observed variation of the DTM. The trend of Fig. 10, for nearby galaxies, is therefore likely real. It is however possible that the dustiness of the ELMGs has been underestimated. We can quote a rough systematic uncertainty for an object such as I Zw 18, the following way. Firstly, since the H I aperture is a factor of ≃1.5 times the optical radius, Z_{dust} might be underestimated by a factor at most $\simeq 1.5^2 = 2.25$. Secondly, we have discussed that the grain opacity could have been overestimated by a factor of ≃2. The systematic uncertainty on Z_{dust} is thus at most a factor of ≃2. Finally, we have discussed that our grain size distribution assumption could lead to an underestimate of Z_{dust} by a factor of at most ≃3. Overall, we can consider that the dustiness of ELMGs could have been underestimated by a factor of $\simeq \sqrt{2.25^2 + 2^2 + 3^2} = 4.25$.

4.2. Evolution of the aromatic feature emitters

We now focus our discussion on another important dust parameter, the mass fraction of aromatic feature emitting grains, q_{AF} (Sect. 3.1.1). We note that, in the `THEMIS` model, all grains are either pure a-C(:H) or a-C(:H)-coated. All of them therefore potentially carry aromatic features. However, only the smallest ones ($a \lesssim 10$ nm) will fluctuate to high enough temperatures ($T \gtrsim 300$ K) to emit these features. Finally, we remind the reader that, assuming aromatic features are carried by PAHs, q_{AF} is formally equivalent to $\simeq 2.2 \times q_{\text{PAH}}$ (Sect. 3.1.1).