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Appendix D: Posterior predictive p-value

We have estimated the posterior predictive p -value (PPP; e.g., Gelman et al. 2004) of our reference run (Sect. 3.2). PPPs are the Bayesian equivalent to a chi-squared test. They allow us to quantify the goodness of our fit. PPPs are estimated by generating sets of replicated observables, noted D_{rep} , from our posterior distribution, conditional on the actual data (Sect. 2), noted D :

$$p(D_{\text{rep}}|D) = \int p(D_{\text{rep}}|X)p(X|D) dX, \quad (\text{D.1})$$

where X are the model parameters. In practice, these replicated sets are simply estimated by computing the SED model for samples of the parameters drawn from the MCMC. The comparison to the data requires the assumption of a test statistic, $T(D, X)$. We adopt the commonly-used χ^2 discrepancy quantity:

$$T(D, X) \equiv \sum_i \frac{[D_i - \mu(D_i|X)]^2}{\sigma(D_i|X)^2}, \quad (\text{D.2})$$

where the index i represents every observable of every galaxy, and the quantities $\mu(D_i|X)$ and $\sigma(D_i|X)$ are the mean and standard-deviation of the replicated data. We then need to estimate the probability:

$$p_B \equiv P(T(D_{\text{rep}}|X) \geq T(D|X) | D). \quad (\text{D.3})$$

If the difference between the replicated set and the data is solely due to statistical fluctuations, this probability should be on average 50%. A model passes the test, at the 98% credence level, if $1\% < p_B < 99\%$.

In our case, we get $p_B = 0.68\%$, indicating our model fails this test (it passes the 99% credence level, though). Investigating the cause of this low p -value, we notice that a few observations are responsible for large deviations. Figure D.1 displays the SEDs containing the nine most deviant fluxes.

IC 0319 and NGC 4322. the problematic flux is PACS1. For IC 0319, it clearly lies above the rest of the observations, but has a small error bar. There is likely a problem with this particular measure. The problem is more difficult to assess for NGC 4322. However, the model is pulled well below this flux by the three SPIRE upper limits.

UGC 05336 and PGC 041994. the problems come from several far-IR upper limits. We display 3σ upper limits when the value of the measured flux is smaller than its 1σ noise level. In the case of the highlighted bands, the actual value of the fluxes are negative, either because of statistical fluctuations, or background over-subtraction. Since the modeled flux can not be negative, we have $T(D_{\text{rep}}|X) \ll T(D|X)$ for all replicated sets, pulling p_B to the tail of the distribution.

In summary, we are not in the case where the model would provide a poor fit on average. A few discrepant data, that are treated as outliers by the model (i.e., which have a very limited impact on the results), are responsible for failing the PPP test. Excluding these nine observables, which represent only 0.07% of our sample, we get $p_B = 1.3\%$, making our model pass the test. In practice, such a test is quite strict, knowing the complexity of our hierarchical model and of the data. Indeed, the frequentist equivalent would be to test the chi-squared of all our SED fits at once. Accounting for missing data, the model for our

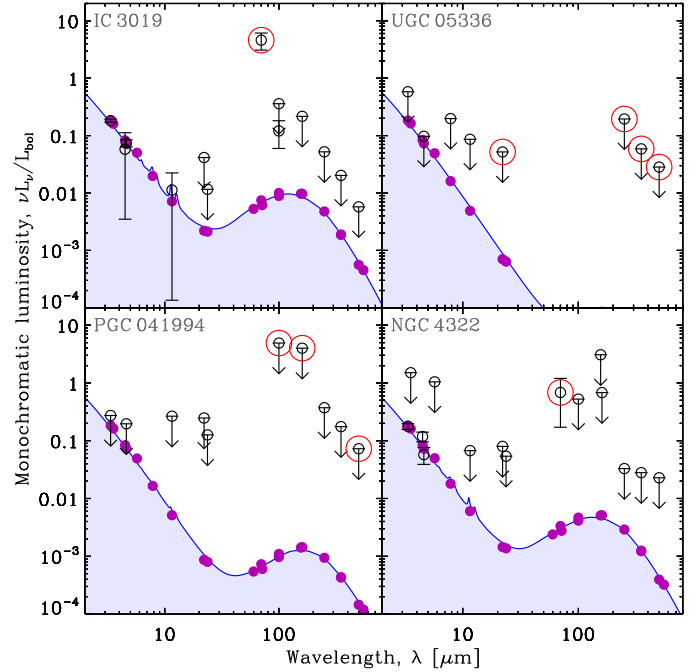


Fig. D.1. SEDs of the four galaxies causing the maximum deviations of the PPP. The black circles with error bars are the observables. Most of them are upper limits. The blue line is the maximum a posteriori model, and the purple dots are the synthetic photometry. The problematic fluxes are identified by a red circle.

798 galaxies would have 3655 degrees of freedom. For a 98% confidence level, the reduced chi-squared would be required to lie in the narrow range $0.95 < \bar{\chi}^2 < 1.05$. This is because the more data we have, the smaller the statistical fluctuations should be.

Appendix E: Derived temperature-emissivity relation

Figure E.1 shows the β - T_d relation derived from the HB MBB fit to the sample of Sect. 2 (cf. Sect. 3.3.2). We can see that most sources are clustered around $(T_d; \beta) \approx (18.7^{+5.6}_{-0.2} \text{ K}; 2.18^{+0.00}_{-0.57})$, with $\pm 1\sigma$ distribution widths $\Delta T_d = [15.7^{+0.8}_{-1.0} \text{ K}, 22.2^{+1.1}_{-1.0} \text{ K}]$ and $\Delta \beta = [1.68^{+0.02}_{-0.06}, 2.68^{+0.02}_{-0.06}]$. The correlation coefficient is $\rho(\ln T_d, \beta) \approx -0.54^{+0.18}_{-0.01}$, and $\text{CR}_{95\%}(\rho(\ln T_d, \beta)) = [-0.56, -0.13]$. There are two clear outliers to this trend: the elliptical galaxies NGC 4268 and NGC 5507 (top-right of the panel). The fit of both galaxies is constrained only with an IRAS_{100 μm} detection and three SPIRE upper limits.

This trend is consistent with the Galactic diffuse ISM (yellow star). This relation appears intrinsically scattered, with irregulars (in blue) being significantly hotter than ETGs (in red), themselves hotter than LTGs (in green). There is a significant β - T_d negative correlation (such as shown by e.g., Dupac et al. 2003). We show this plot as a reference for comparison to other studies, since the MBB is the most commonly used model. Nonetheless, we emphasize that its physical interpretation is rendered difficult by the fact that β is degenerate with the mixing of physical conditions (cf. Sect. 2.3.1 of Galliano et al. 2018, for a review).