Systematic errors in dust mass fits: insights from laboratory opacity measurements

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Interstellar dust plays an important role in the study of interstellar medium. Especially important is the estimation of dust masses for individual molecular clouds and on galaxy scales, since dust is often used as a tracer of interstellar gas and therefore star-formation rate. One of the most common methods of recovering dust masses is to fit a dust emission model to the thermal emission of dust in the FIR and submm, assuming a single temperature and a power-law emissivity. The masses estimated with this method, however, depend on the assumptions on the FIR/submm opacity (κ): therefore, a good choice of opacity is essential for the robustness of dust-mass estimates.

Most astronomical dust models use estimated values for κ obtained when direct measurements of opacity in the FIR/submm range were limited; as a result, most dust models assume a power-law dependence which is extrapolated from the mid-IR. However, we are learning from both astronomical observations and laboratory tests on dust analogues that this opacity model is too simplistic. In particular:

1. The values of κ measured in the lab are about one order of magnitude higher than is assumed in standard astronomical models;
2. Often, κ does not follow a simple power law: its slope changes beyond a certain wavelength (400–700 μm, depending on the material);
3. The opacities depend on the material temperature as well, typically increasing for higher T.

If the κ used in dust models in the last decades is not correct, dust-mass estimates may need to be revised.

Our group is working to assess the probable extent of opacity-induced systematics in dust-mass estimates. We use opacity measurements for several candidate dust materials, collected by multiple laboratories, to parametrize the materials' κ as a function of λ and T. We use the lab-derived opacity to model dust emission for synthetic galaxies, then we fit that emission using dust models from the scientific literature. The comparison between the parameters used to create the synthetic emission and those recovered by the fit informs us on the systematics of the fitting technique.

Our main result is that fits overestimate dust masses by about one order of magnitude, largely because of their low opacity compared to lab-studied materials. The potential astrophysical implications are far-reaching. As an example, this could solve the so called "dust budget crisis", i.e. the fact that the dust masses observed in the early Universe cannot be explained by current models unless they include unrealistically top-heavy mass functions for star formation. However, it is necessary to control the consistency of these new dust-mass estimates with other long-standing results, such as the gas-to-dust ratio and elemental depletion.