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## What is dust? Coarse graining, cosmic variance and cosmic expansion


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When Einstein first applied his field equations to cosmology he imagined a universe of stellar density, in which the energy-momentum tensor averages only over nongravitational forces. Nearly 100 years later we observe a universe which is only homogeneous in a statistical sense on scales larger than 100/h Mpc. To coarse-grain dust on these scales requires us to coarse-grain the gravitational degrees of freedom themselves. This necessitates a re-examination of foundational questions relating to the nonlocalizability of gravitational energy; issues which vexed Einstein as he struggled towards general relativity 100 years ago. I argue that a re-examination of these issues has immediate observable consequences. Indeed, a detailed study of 4,534 redshifts and distances in a model-independent manner (arXiv:1201.5371) has led us to the suggestion that the CMB dipole is partly due to a 0.6% anisotropy in the distance-redshift relation due to foreground structures on scales up to 65/h Mpc, which can only be understood as the differential expansion of space rather than as Newtonian velocity perturbations on a fixed homogeneous background. This result, if true, will have profound consequences for cosmology.