

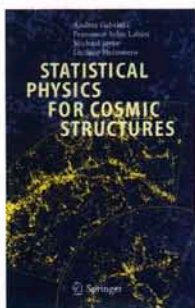
Statistical Physics for Cosmic Structures

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Michael Joyce, and
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The large-scale structure of the universe
as revealed through galaxy and cluster

catalogs is one of the observational cornerstones of physical cosmology. The importance of large-scale structure has been reinforced by the successful recent analyses of the Two Degree Field, or 2dF, Survey and the Sloan Digital Sky Survey (SDSS). The future for observing and analyzing large-scale cosmic structure is bright, with several wide-field surveys planned over the next decade, leading up to those from the anticipated Large Synoptic Survey Telescope, which will observe billions of galaxies. *Statistical Physics for Cosmic Structures* by Andrea Gabrielli, Francesco Sylos Labini, Michael Joyce, and Luciano Pietronero aims to provide a general introduction to the tools of the trade, and to review and extend the authors' work of the past decade.



The first three chapters introduce general methods for describing the statistical properties of random fields and point processes in terms of correlations. The two-point correlations of a point process are the simplest quantitative measures of its clustering properties. Any complete model of cosmic structure formation predicts those two-point correlations, as well as a hierarchy of other multipoint correlations. Cosmologists infer the viability of models by comparing those predictions to the observed correlations in galaxy catalogs.

In those models of cosmic-structure formation that are in agreement with the bulk of available data, the observed cosmic structure is a consequence of initially small perturbations in a homogeneous and isotropic universe. Textbook treatments—such as Scott Dodelson's *Modern Cosmology* (Academic Press, 2003)—start from this premise. Yet the authors of *Statistical Physics for Cosmic Structures* take a more agnostic point of view and note that galaxy surveys alone do not rule out a strongly inhomogeneous, fractal distribution of matter. This point of view reflects the authors' background in statistical physics, in which critical phenomena and the notions of self-similarity and renormalization play prominent roles.

The introductory chapters thus contain a broad set of mathematical and statistical tools to handle both asymptotically homogeneous and multifractal point sets. For example, readers are treated to a complete classification of correlated point processes in terms of their asymptotic correlation properties. The authors emphasize that distribu-

tions of matter with certain power-law correlation functions have infinite correlation length. Cosmologists who use the term "correlation length" actually refer to what statistical physicists call the "homogeneity scale." Of course in standard cosmological models, the correlation function is a power law only over a limited range of scales, and the correlation length does not diverge.

Chapters 4 and 5 provide a detailed discussion of fractal and multifractal point processes. Particularly in fractal systems, as the authors point out throughout the book, standard two-point correlation analyses are prone to finite-size effects that prevent an unbiased analysis of the large-scale structure. The authors offer the conditional density as an alternative statistic for studying two-point correlations in the strong fluctuation regime.

I found these chapters intellectually stimulating, but readers should be aware of the spectacular successes of "vanilla" cosmology as applied to the second data release from the *Wilkinson Microwave Anisotropy Probe* and the most recent power spectrum analyses from the SDSS. The data strongly indicate that any fractality of the mass distribution is limited to scales in which gravity has amplified the small initial fluctuations into the nonlinear regime.

Chapter 6 provides a brief overview of the theory of large-scale structure and cosmic microwave background (CMB) anisotropies in standard cosmological models. Recent progress in these research fields makes the chapter feel somewhat dated. The only CMB experiment mentioned in any detail is the *Cosmic Background Explorer*. Chapter 7 contains a theoretical study of correlated displacements as a tool to construct point sets with specified correlation properties, an important issue because N -body simulations of cosmic structure require such point sets as initial conditions.

The analysis of galaxy catalogs is the subject of chapters 8 through 13. The treatment focuses on systematics due to finite-size effects. The authors emphasize that in a fundamentally irregular density distribution, a blind application of power-spectrum analysis can lead to spurious results if the size of the galaxy survey is smaller than the homogeneity scale.

Chapter 13 critiques the notion of bias. Traditionally, bias is a cosmolo-

gist's way to parameterize, based on simulations and observations, the relationships of various types of visible tracers to the underlying dark-matter distribution. Galaxy bias will presumably be explained by the full theory of galaxy formation, which as yet eludes cosmologists. The authors take a different position: They argue that bias is inherently scale dependent and changes qualitatively both the large-scale and small-scale behaviors of the power spectrum.

I enjoyed reading chapter 14, a short standalone on the statistical physics of the gravitational field in stochastic particle distributions. The discussion could have been a point of departure for a detailed treatment of the statistical physics of self-gravitating systems in an expanding universe and of the emergence of bound systems with universal density profiles.

For its unusual perspective, *Statistical Physics for Cosmic Structures* is a refreshing read. It is full of insightful discussion and covers several topics of interest and importance in statistical physics, data analysis, and cosmology while providing introductions to the required mathematical tools. The choice of topics and references is somewhat eclectic and necessarily falls short of the all-encompassing scope of the title. For example, most of the book covers two-point correlations, yet the theoretical and observational frontier of research has advanced to multipoint correlation functions that contain additional information about the relationship between biased tracers and the underlying mass distribution. On the theoretical side, I was initially surprised that a book with this title could avoid mention of the Boltzmann or Vlasov equations and their solutions; but early on it became clear that the focus is on the phenomenological characterization of cosmic structures, not on the dynamics of their production.

Statistical Physics for Cosmic Structures occasionally takes the reader to the fringes of the cosmological mainstream. But in the end the monograph succeeds in delivering a stimulating, critical appraisal of the analysis techniques used for the bulk of large-scale structure data. It will be a helpful resource for those who want to use the descriptive tools of modern statistical physics to push toward a broader view of cosmic structure.

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