PHILOSOPHICAL TRANSACTIONS OF THE ROYAL SOCIETY A
MATHEMATICAL, PHYSICAL & ENGINEERING SCIENCES

Introductory remarks to Large–scale structure in the universe. A Discussion Meeting held at the Royal Society of London on 25 and 26 March 1998

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THE ROYAL SOCIETY

Introductory remarks

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1. The development of large-scale structure

When we planned this Royal Society Discussion Meeting in 1995, we looked forward to a renaissance of observational data and theoretical developments concerning the development of large-scale structure. *Development* seemed to us to be a key word in a number of contexts.

Foremost, we can consider development in terms of the very origins of cosmic structure. Observations of large-scale structure offer one of the few probes of pre-recombination physics providing direct tests of the inflationary spectrum, the ratio of scalar and tensor components, rival theories based on cosmic defects and the basic cosmological parameters (H_0, $\Omega_{\rm b}$, $\Omega_{\rm M}$, $\Lambda, \dots$).

Secondly, the Meeting highlighted the developing field of cosmic microwave background anisotropies through the exploitation of a growing number of sensitive, ground-based experiments and discussion of ambitious space missions such as MAP and Planck Surveyor. Already it has become timely to consider the concordance of cosmological constraints from these surveys with those based on more traditional methods, including distant supernovae, gravitational lensing, and redshift surveys.

Thirdly, we considered the rapidly developing area of galaxy and quasar redshift surveys, most notably the Anglo-Australian 2dF surveys already underway, and the imminent and more ambitious Sloan Digital Sky Survey (SDSS). Not only are these surveys larger and more fully sampled than earlier surveys, but they represent more comprehensive initiatives where considerable effort has been invested in devising optimal survey strategies tuned to the scientific questions in hand. In many respects, 2dF and the SDSS herald a new era in ground-based surveys extending the traditional questions of cosmography into more detailed areas related to the astrophysics of galaxies and investigations of biased density fields.

Finally, development can be considered in its most natural sense, namely the growth of structure over cosmic history. The angular correlations in the microwave background probe structures at redshifts $z \simeq 1100$ and the 2dF/SDSS galaxy surveys do likewise at $z < 0.1$. The intervening eras are important because the rate of growth of structure is a strong constraint on the cosmological model. Deep redshift surveys, such as that conducted by the Canadian National Observational Cosmology Consortium (CNOC), quasar surveys with 2dF and deep Keck surveys using Lyman-limit-selected samples provide unique data from $z \simeq 0.5$–3. Such data could hardly have been envisaged at the time we planned our Meeting!

Although our prime motivation for this Meeting was observational, as we saw throughout this conference, theorists have risen to the challenge of interpreting the rich data-sets now emerging. Progress is being made both via numerical simulations, sophisticated interpretative techniques well-matched to the surveys underway, and

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also in the most fundamental questions concerning the origin of quantum fluctuations which make our universe inhomogeneous.

2. Summary of the Meeting

Our aim, as the above agenda suggests, was to catch the subject on the threshold of a radical transformation. A feeling of 'imminent revolution' was certainly our impression of the Meeting and we hope that this is communicated in the contributions in this issue. In a few cases, notably the cosmic microwave background radiation and galaxy formation, we are clearly beginning to see signs of solutions to long-standing questions in cosmology. The papers will, of course, speak for themselves, but we make a few observations here on certain general themes that arose during the Meeting.

(a) *Simplicity or complexity?*

The inflationary model of the early universe has provided an influential and powerful paradigm, as Michael Turner describes. According to a wide class of inflationary models, our universe can be characterized by a small number of parameters (perhaps 15 or so) that define the geometry of the universe, its composition, and initial fluctuations. If this simple idea is correct, it should be possible to establish a 'standard model of cosmology' in much the same way as the standard model of particle physics is specified by 21 parameters. As Dick Bond and Anthony Lasenby discuss in their contributions, the next generation of cosmic microwave background (CMB) experiments and galaxy surveys are capable of determining many of these cosmological parameters with exquisite precision. Jim Peebles, however, with his example of non-Gaussian isocurvature perturbations warns us that the real universe may not be so simple. Inflation may not be correct and even if it is, inflation could be complex involving, for example, more than one scalar field. Topological defects have not yet been convincingly ruled out as seeds of cosmic structure, although as Neil Turok describes, the simplest defect models appear to have problems explaining observations of the CMB anisotropies. Will the universe turn out to be simple, or complex? The observational projects described in this volume should provide an answer.

(b) *Naivety or sophistication?*

As described by Colless and Margon, within three or four years the 2dF and SDSS galaxy surveys should have produced more than a million galaxy redshifts, which represents about a 50-fold increase in the number of redshifts known 10 years ago. What will we learn with this explosion of new information? We will, of course, learn much more about the power spectrum of galaxies and their peculiar velocity field, as described by Peacock and Szalay. But as all these authors point out, one of the most important legacies of these projects will be the detailed inventory that they will provide of the local universe. In particular, it will be possible to classify galaxies by spectral class and (and also by colours for the SDSS) leading to a detailed picture of the spatial distribution of galaxies of different types. The naive assumptions concerning the relationship between galaxies and the underlying mass distribution invoked in analysing the present generation of galaxy surveys will surely have to give way to a more sophisticated picture based on theoretical models of galaxies'

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formation. Fortunately, as Simon White described†, advances in computer technology have kept pace with observational developments. Numerical simulations of galaxy formation and clustering are being carried out with increasing realism and there is a real prospect that simulations can be done on the scale necessary to interpret the new surveys.

(*c*) *Cosmology or astrophysics?*

As mentioned above, one of the biggest surprises since submitting the proposal for this Meeting to the Royal Society has been the very rapid progress in finding galaxies at redshifts $z > 3$. As Steidel describes here, the number of high redshift galaxies is now large enough that one can begin to study their spatial distribution. Our theoretical understanding of galaxy formation and the evolution of galaxy clustering has been plagued by cosmological uncertainties (world model, fluctuation spectrum, etc.) and astrophysical uncertainties (star formation rates, supernovae feedback, radiative transfer, etc.). So far, much more attention has been given to the cosmological rather than the astrophysical uncertainties. If MAP, Planck and other experiments succeed, and the universe does indeed turn out to be simple, then we will have fixed the underlying cosmology and fluctuation spectrum. We will then have no choice but to tackle thorny and difficult astrophysical problems if we are to understand galaxy formation and evolution. The inventory of the nearby universe provided by the SDSS and 2dF will be critical in understanding the astrophysics.

(*d*) *Zero or non-zero?*

Finally, one key puzzle that arose several times during the Meeting is the mounting evidence, albeit circumstantial, for a non-zero cosmological constant. If this turns out to be correct, it will be one of the most unexpected surprises in the history of cosmology and will pose a 'grand challenge' of enormous proportions to theorists.

In the organization of this highly successful Meeting, we were greatly assisted by the staff of the Society and, in particular, Kaye Pudney. During the Meeting Meghan Gray, Sarah Ellison, Katherine Gunn and Fiona Hoyle kindly assisted in coordinating the discussion. Jane Chapman at the Institute of Astronomy and Jilliene Sellner at the Royal Society kindly assisted in assembling the many manuscripts. We acknowledge financial support from the Royal Society and the Novartis Foundation.

† Unfortunately Professor White was unable to provide a written version of his talk.

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