Statistics of large scale structure

M. Kerscher

Ludwig–Maximilians–Universität, Theresienstraße 37, 80333 München, Germany, email: kerscher@stat.physik.uni-muenchen.de

1.1 Introduction

In this extended abstract I give a short review of the work on the statistical characterization of large–scale structures in the universe performed in the B3 group of the "SFB–375 für Astro–Teilchenphysik".

1.2 Statistics of the CMB

The temperature anisotropies in the microwave background may be modelled by a random field on the celestial sphere. This stochastic field is often described by the two–point correlation function or its angular power spectrum. The description with the angular power spectrum is complete for a Gaussian random field, as favoured by inflationary scenarios. Deviations from "Gaussianity" may be investigated with higher order correlation functions. As a complementary robust method we employ Minkowski functionals of iso–temperature contours [19] [17]. Within the resolution limits of the COBE–satellite, no significant deviation from a Gaussian random field was observed.

1.3 Two–point measures

Similar to the analysis of the microwave background maps, the two–point correlation function serves as a starting point for an analysis of the distribution of galaxies. Since all galaxy catalogues are spatially limited, finite–size corrections are mandatory. In a comparison with well–known unbiased estimators, we have shown [10] that the DD/DR–, the Landy–Szalay– [15], and the Hamilton–estimators [8] are biased by finite size effects which are significant on large scales.

1.4 Fluctuations on large scales

Are we able to constrain the clustering properties of galaxies on large scales with current redshift surveys? We address this question with a morphological analysis of large disjoint regions in the IRAS 1.2Jy galaxy survey [12]. These disjoint patches with 100Mpc/h and 200Mpc/h radius show significantly different morphologies detected with Minkowski functionals [16] (for a tutorial see [21]). Moreover the two–point properties and the so–called J–function [22] show similar fluctuations. We confirm that these fluctuations are not caused by selection effects (see also [13]). A cold dark matter simulation designed to reproduce the clustering properties in the IRAS 1.2Jy catalogue could not explain these fluctuations, probably due to the limited box size of 250Mpc/h only.

1.5 Other topics

Some indications of quasi–regular structures on large scales have been reported [3], [6]. However the regularity in the supercluster catalogue [7] can be explained from biases due to the construction procedure of the catalogue [9].

We used Minkowski functionals and also the J–function to constrain models of galaxy formation [14], [11].

The substructure of galaxy clusters linked with their dynamical evolution is studied in [2] with vector–valued Minkowski functionals.

In simulations we investigate the geometry of the largest structure [18], and also the evolution of the spatial distribution of halos compared with that of the pure dark–matter particles [20].

In a deep galaxy survey we study the evolution of morphology with redshift.

Another focus of the group B3 are analytical methods for the description of structure formation in the universe. Recent developments are the averaging formalism [5] and the inclusion of pressure [4], [1] as reported by Claus Beisbart and Christian Sicka in this volume.

References

[1] Susanne Adler and Thomas Buchert. Lagrangian theory of structure formation in pressure–supported cosmological fluids. A&A in press, astro-ph/9806320, 1998.

[2] Claus Beisbart and Thomas Buchert. Characterizing cluster morphology using vector–valued minkowski functionals. In V. Müller, S. Gottlöber, J. P. Mücket, and J. Wambsgans, editors, *Proc. Large Scale Structure: Tracks and Traces, Potsdam, Germany, Sept. 15–19, 1997*, Singapore, 1998. World Scientific. astro-ph/9711034.

[3] T. J. Broadhurst, R. S. Ellis, D. C. Koo, and A. S. Szalay. Large–scale distribution of galaxies at the galactic poles. *Nature*, 343:726, 1990.

[4] Thomas Buchert and Alvaro Domínguez. Modeling multi-stream flow in collisionless matter: approximations for large-scale structure beyond shell-crossing. *Astron. Astrophys.*, 335:395–402, 1998.

[5] Thomas Buchert and Jürgen Ehlers. Averaging inhomogeneous Newtonian cosmologies. *Astron. Astrophys.*, 320:1–7, April 1997.

[6] J. Einasto, M. Einasto, S. Gottlöber, V. Müller, V. Saar, A. A. Starobinsky, E. Tago, D. Tucker, H. Andernach, and P. Frisch. A 120-mpc periodicity in the three–dimensional distribution of galaxy superclusters. *Nature*, 385:139–141, January 1997.

[7] M. Einasto, E. Tago, J. Jaaniste, J. Einasto, and H. Andernach. The supercluster–void network. I. the supercluster catalogue and large–scale distribution. *Astron. Astrophys. Suppl.*, 123:119, 1997.

[8] A. J. S. Hamilton. Toward better ways to measure the galaxy correlation function. *Ap. J.*, 417:19–35, November 1993.

[9] Martin Kerscher. Regularity in the distribution of superclusters? *Astron. Astrophys.*, 336:29–34, 1998.

[10] Martin Kerscher. The geometry of second–order statistics – biases in common estimators. A&A in press, 1999.

[11] Martin Kerscher, Maria Jesus Pons-Bordería, Jens Schmalzing, Roberto Trasarti-Battistoni, Vicent J. Martínez, Thomas Buchert, and Riccardo Valdarnini. A global descriptor of spatial pattern interaction in the galaxy distribution. ApJ in press, 1998.

[12] Martin Kerscher, Jens Schmalzing, Thomas Buchert, and Herbert Wagner. The significance of the fluctuations in the IRAS 1.2 Jy galaxy catalogue. In R. Bender, T. Buchert, and P. Schneider, editors, *Proc.* 2$^{\mathrm{nd}}$ *SFB workshop on* Astro–particle physics *Ringberg 1996, Report SFB375/P002*, pages 83–98, Ringberg, Tegernsee, 1996.

[13] Martin Kerscher, Jens Schmalzing, Thomas Buchert, and Herbert Wagner. Fluctuations in the 1.2 Jy galaxy catalogue. *Astron. Astrophys.*, 333:1–12, 1998.

[14] Martin Kerscher, Jens Schmalzing, Jörg Retzlaff, Stefano Borgani, Thomas Buchert, Stefan Gottlöber, Volker Müller, Manolis Plionis, and Herbert Wagner. Minkowski functionals of Abell/ACO clusters. *Mon. Not. Roy. Astron. Soc.*, 284:73–84, 1997.

[15] Stephen D. Landy and Alexander S. Szalay. Bias and variance of angular correlation functions. *Ap. J.*, 412:64–71, July 1993.

[16] Klaus R. Mecke, Thomas Buchert, and Herbert Wagner. Robust morphological measures for large–scale structure in the Universe. *Astron. Astrophys.*, 288:697–704, 1994.

[17] Jens Schmalzing and Thomas Buchert. Beyond genus statistics: A unifying approach to the morphology of cosmic structure. *Ap. J. Lett.*, 482:L1–L4, June 1997.

[18] Jens Schmalzing, Thomas Buchert, Adrian Melott, Varun Sahni, B.S. Sathyaprakash, and Sergei Shandarin. Disentageling the cosmic web I: Morphology of isodensity contours. in preparation, 1999.

[19] Jens Schmalzing and Krzysztof M. Górski. Minkowski functionals used in the morphological analysis of cosmic microwave background anisotropy maps. *Mon. Not. Roy. Astron. Soc.*, 297:355–365, 1998.

[20] Jens Schmalzing, Stefan Gottlöber, Andrey Kravtsov, and Anatoly Klypin. Evolution of higher order clustering in a ΛCDM simulation. in preparation, 1999.

[21] Jens Schmalzing, Martin Kerscher, and Thomas Buchert. Minkowski functionals in cosmology. In Silvio Bonometto, Joel Primack, and Antonello Provenzale, editors, *Proceedings of the international school of physics Enrico Fermi. Course CXXXII: Dark matter in the Universe*, pages 281–291, Varenna sul Lago di Como, 1996. Società Italiana di Fisica.

[22] M. N. M. van Lieshout and A. J. Baddeley. A nonparametric measure of spatial interaction in point patterns. *Statist. Neerlandica*, 50:344–361, 1996.