

University of Groningen

A void perspective of the cosmic web

Platen, Erwin

IMPORTANT NOTE: You are advised to consult the publisher's version (publisher's PDF) if you wish to cite from it. Please check the document version below.

Document Version

Publisher's PDF, also known as Version of record

Publication date:

2009

[Link to publication in University of Groningen/UMCG research database](#)

Citation for published version (APA):

Platen, E. (2009). *A void perspective of the cosmic web*. s.n.

Copyright

Other than for strictly personal use, it is not permitted to download or to forward/distribute the text or part of it without the consent of the author(s) and/or copyright holder(s), unless the work is under an open content license (like Creative Commons).

Take-down policy

If you believe that this document breaches copyright please contact us providing details, and we will remove access to the work immediately and investigate your claim.

Downloaded from the University of Groningen/UMCG research database (Pure): <http://www.rug.nl/research/portal>. For technical reasons the number of authors shown on this cover page is limited to 10 maximum.



rijksuniversiteit
 groningen

A Void Perspective of the Cosmic Web

Proefschrift

ter verkrijging van het doctoraat in de
Wiskunde en Natuurwetenschappen
aan de Rijksuniversiteit Groningen
op gezag van de
Rector Magnificus, dr. F. Zwarts,
in het openbaar te verdedigen op
vrijdag 13 november 2009
om 13:15 uur

door

Erwin Platen

geboren op 7 april 1981
te Emmen, Nederland

Promotores : Prof. dr. M. A. M. van de Weygaert
Prof. dr. B. J. T. Jones

Beoordelingscommissie : Prof. dr. J. R. Bond
Prof. dr. P. J. E. Peebles
Prof. dr. R. K. Sheth

ISBN 978-90-367-4068-5
ISBN 978-90-367-4067-8 (electronic version)

Voor mijn grootouders



The Cover – is a Gesamtkunstwerk inspired on a ukiyo-e print from Ogata Gekkō's Views of Mt. Fuji. It is further combined with my own artwork, and digital artwork from Niels Bos.

Printed by: Ipskamp Drukkers, Enschede, the Netherlands

Contents

1	Introduction	11
1.1	A Cosmopolitan Universe, life in the slow lane	11
1.2	Large Scale Structure Formation	13
1.2.1	Gravitational Instability	14
1.2.2	Initial Fluctuations	15
1.2.3	Galaxy Biasing	17
1.2.4	Hierarchical Evolution	18
1.3	Cosmic Web	18
1.3.1	Zel'dovich Approximation	18
1.3.2	Cosmic Web in CDM	21
1.4	Voids	23
1.4.1	Basic Void properties	23
1.5	Beyond Isolation	24
1.5.1	Void Shape	25
1.5.2	Adhesion Voids and the anisotropic Void collapse	25
1.6	Void Hierarchy	26
1.7	The Evolution of the Void population	27
1.8	Voids as Cosmological Probes	27
1.9	Matter and Galaxies inside Voids	30
1.9.1	Void Haloes	30
1.10	The properties of Void galaxies	32
1.10.1	The Void Phenomenon, is it explained?	34
1.10.2	The Void Future	35
1.11	Structure Identification	35
1.11.1	Void Definition	36
1.11.2	Void Finding	36
1.11.3	Watershed Void Finder	38
1.12	This Thesis	38
2	A Cosmic Watershed: the WVF Void Detection Technique	41
2.1	Introduction	41
2.2	the Watershed Void Finder	43
2.2.1	the Watershed Transform (WST)	43
2.2.2	Watershed segments: qualities	44
2.2.3	Voids and watersheds	45
2.2.4	The Watershed Void Finder: Outline	45
2.2.5	WVF by example: Voids in a Λ CDM simulation	46
2.3	Method: detailed description	48

2.3.1	The DTFE density field	48
2.3.2	Natural Neighbour Rank-Ordered filtering	50
2.3.3	Markers and False Segment Removal	52
2.3.4	Hierarchy Merging	52
2.4	WVF Test: Voronoi Clustering Model	54
2.4.1	Voronoi Model: Watershed Segmentation	55
2.5	Voronoi Clustering Model: Quantitative Results Watershed	56
2.5.1	Datasets	57
2.5.2	Detection Rate	58
2.5.3	Volume Comparison	60
2.5.4	Surface Comparison	60
2.6	Discussion and Prospects	61
2.A	Appendix A: Mathematical Morphology	62
2.A.1	Images	63
2.A.2	Erosion and Dilation	63
2.A.3	Opening and Closing	64
2.A.4	Greyscale Images	65
2.B	Appendix B: Watershed Transform	65
2.B.1	Distance	66
2.B.2	Segmentation	66
2.B.3	The watershed transform: Algorithms	67
2.B.4	Ordered Queues Algorithm	69
2.C	Appendix C: Kinematic Voronoi models	70
2.C.1	Initial Conditions	71
2.C.2	Voronoi Tracks	72
3	Alignment of Voids in the Cosmic Web	75
3.1	Introduction	75
3.2	The Void Sample	78
3.2.1	Void Identification	78
3.3	Void Characteristics	78
3.3.1	Void Size	79
3.3.2	Void Shape	79
3.3.3	Results on Void Shapes	79
3.4	Void Alignments	80
3.4.1	Void Alignments: definitions	80
3.4.2	Void Alignments: significance	81
3.4.3	Void Alignments: results	82
3.5	The cause of Void Alignment	83
3.5.1	Initial conditions	83
3.5.2	Void packing	83
3.5.3	Large Scale Tidal Forces	84
3.6	Influence of Tidal Field	84
3.6.1	Tidal Field	84
3.6.2	Void-Tidal Field alignment: results	86
3.6.3	Tidal Connections	87
3.7	Conclusion and Discussion	88
3.7.1	Overview of Results	88
3.7.2	Insights	89

4	The Spine of the Cosmic Web	91
4.1	Introduction	91
4.1.1	the Cosmic Web	91
4.1.2	Closing in on the Cosmic Web	92
4.1.3	Watershed and Cosmic Spine	94
4.2	Watershed Segmentation of the Cosmic Web	95
4.2.1	Watershed Transform	95
4.2.2	A watershed search for voids	95
4.2.3	Morse theory	95
4.2.4	the Cosmic Spine	98
4.3	The Spineweb Procedure	98
4.3.1	The Discrete Watershed Transform	99
4.3.2	Watershed Implementation	99
4.3.3	from Watershed to Spineweb	100
4.3.4	Image Grid Representation	101
4.4	Voronoi Clustering models	102
4.4.1	Clean Voronoi clustering model	102
4.4.2	Spine identification	103
4.4.3	Real vs. false detections	104
4.4.4	Voronoi Clustering models with density reconstruction	105
4.5	Single-scale Λ CDM Spine	106
4.5.1	Density field estimation	106
4.5.2	Density field morphology	107
4.5.3	Cellular Morphology	107
4.5.4	Cosmic Spine: Filaments and Walls	110
4.6	Analysis Wall & Filament Sample	111
4.6.1	Density distribution	111
4.6.2	Minkowski-Bouligand dimension	114
4.6.3	LSS complexity and local density	115
4.7	Conclusion and future work	116
4.8	Acknowledgements	116
5	The SDSS Density Field Reconstruction, the Methods	117
5.1	Introduction	117
5.1.1	Reconstruction Methods	119
5.2	The Data	122
5.2.1	The SDSS galaxy sample	123
5.2.2	Selection function	124
5.2.3	The SDSS mock sample	124
5.3	Local Density Estimates	125
5.3.1	Shot noise errors	126
5.3.2	Centroidal Voronoi tessellation	127
5.4	Delaunay Tessellation Field Estimator	127
5.5	Natural Neighbour Field Estimator	130
5.6	Kriging Interpolation	131
5.6.1	The Kriging method	132
5.6.2	Practical Issues	133
5.6.3	Variogram estimation	133
5.6.4	Nonlinear Kriging	134
5.6.5	Peak-Correlation Overshoot & Gibbs oscillations	135

5.6.6	Natural Lognormal Kriging	137
5.7	Computational Requirements	139
5.8	Qualitative Density Comparison	139
5.8.1	Maps of the density field	139
5.8.2	Density Profiles	144
5.8.3	Intrinsic Smoothing Scale	145
5.9	Quantitative Density analysis	145
5.9.1	Error Analysis	146
5.9.2	Density field Correlation	147
5.9.3	Intrinsic Smoothing & Nonlinearities	149
5.9.4	Magnitude limited versus Volume limited	150
5.10	Topological Comparison	153
5.10.1	Quantification of Topological Errors	153
5.11	SDSS-DR6 density reconstruction	156
5.12	Improvements	156
5.12.1	Mass Conservation & Density Estimation	156
5.12.2	Grid Improvements	158
5.12.3	Kriging Improvements	158
5.13	Summary and Future Work	159
5.A	SDSS Coordinate System	161
5.B	DTFE implementation	161
5.C	Radial Basis Interpolation	163
5.D	Derivation of the Kriging equation	164
5.D.1	Gaussian Probability, alternative derivation	165
5.E	Local Lognormal Kriging Algorithm	166
5.F	Sampling schema and artifacts	167
6	The Cosmography of the SDSS Density Map	169
6.1	Introduction	169
6.2	SDSS DR7 Data set	173
6.3	Analysis and Visualisation Tools	173
6.3.1	Density Field	174
6.3.2	3D Isodensity Images	174
6.3.3	Integrated density Maps	174
6.3.4	Contour Map Slices	174
6.3.5	Connectivity Filtering	175
6.4	The Coma Great Wall	175
6.5	In between two Great Walls	176
6.5.1	Boötes & Virgo Supervoids versus Coma & Hercules Superclusters	176
6.5.2	The Bahcall-Soneira Rift	177
6.6	The Sloan Great Wall	178
6.6.1	Another Brick in the Wall	178
6.6.2	Another Gap in the Wall	178
6.6.3	The assembly of Great Walls	179
6.7	Bridging the Walls	179
6.8	Beyond the Sloan Great Wall	182
6.8.1	The Great Pillar	182
6.8.2	Sloan Supervoid	182
6.9	Summary and Discussion	183
6.A	SDSS DR7 Coordinate System	186

6.B	Sloan Large Scale Structure	187
7	Statistics and Biasing of the SDSS Density Field	197
7.1	Introduction	198
7.1.1	Galaxy Biasing	198
7.1.2	One Point Distribution	200
7.1.3	Cosmic Structure	201
7.1.4	This Work	201
7.2	Data	204
7.2.1	SDSS-DR7	204
7.2.2	Millennium Simulation	204
7.2.3	The Dark Matter Distribution	205
7.3	Systematics in the Density field	205
7.3.1	Measurement Systematics	206
7.3.2	Method Systematics	207
7.4	Galaxy Biasing	212
7.4.1	Biasing in Simulations	213
7.5	Redshift Space Distortions	218
7.5.1	The $1h^{-1}$ Mpc scale	218
7.5.2	The $4h^{-1}$ Mpc scale	220
7.6	Summary of the Distortions	220
7.7	The One-Point Distribution Function	221
7.7.1	Measuring the Observed Distribution	221
7.7.2	Higher order moments	222
7.7.3	Distribution Models	222
7.7.4	Dark Matter PDF	223
7.7.5	Millennium Galaxies PDF	225
7.8	The SDSS PDF	228
7.8.1	Comparison to SDSS Mock samples	228
7.8.2	Comparison to the Dark Matter PDF	228
7.8.3	Low Density Tail	229
7.9	Higher Order Moments	231
7.10	Discussion and Future Work	231
7.11	Summary and Conclusions	234
7.A	Biasing definitions	236
7.A.1	Measuring the Bias	237
7.B	Lognormal Fitting	237
8	Polar disk galaxy found in wall between voids	239
8.1	Introduction	239
8.2	Observations	240
8.3	Results	241
8.3.1	Galaxy Parameters	241
8.3.2	Large Scale Environment	242
8.4	Discussion	243

9	Een Leeg Perspectief op Kosmisch Structuur	247
9.1	Een Structuur van Bellen en Filamenten	248
9.1.1	De Voids in de Grote Schaal Structuur	250
9.2	Het ontstaan van een Kosmisch Web	251
9.2.1	Donkere Materie	251
9.2.2	De Ruimtelijke Verdeling	252
9.3	De Overvloedige Leegte	252
9.3.1	Void detectie, een kwestie van waterscheiding	253
9.3.2	Voidvormen	254
9.3.3	De Ruggengraat van het Kosmische Web	254
9.3.4	De Reconstructie van het Dichtheidsveld	254
9.3.5	De Kosmografie van de Grote Schaal Structuur	255
9.3.6	Statistiek van de Massaverdeling	255
9.3.7	Een Voidsterrenstelsel met een Polaire Gasschijf	256
	Dankwoord	271