

LSS2007 REPORT TOPICS

Dear students LSS2007,

In this document you find a listing of suggested topics for reports (werkstukken). Also mentioned with most topics are “some” literature suggestions. In some cases this concerns an essential key reference which then would advisably be used for the report. In other cases you find a listing of publications that would provide you with a good overview of important papers relating to the subject, and it will be up to you to select the ones you need (in addition of course to other works you find yourself as relevant).

The suggestion is to collaborate with two persons on one project report, although if you prefer you may choose to write a report on yourself. Upon selecting a topic, please contact me.

Have fun, looking forward to nice reports,

Rien van de Weygaert

Kapteyn Institute,

9700 AV Groningen

tel.: 050-3634086

e-mail: weygaert@astro.rug.nl

1. Evidence for Dark Energy.

- A discussion on the observational evidence for a cosmological constant Λ or, in a wider context, for the reality of Dark Energy. Is it realistic to measure the real equation of state of the vacuum ?
- *Literature suggestions:*
 - Albrecht A., Bernstein G., Cahn R., Freedman W., et al., 2006
Report of the Dark Energy Task Force
astro-ph
 - Carroll S.M., Press W.M., 1992
The Cosmological Constant
ARAA 30, 499
 - Huterer D., Turner M.S., 2001
Probing dark energy: Methods and strategies
Phys. Rev. D., 64, 123527
 - Kirshner R.P, 2003
Throwing Light on Dark Energy
Science 300, 1914
 - Padmanabhan T., 2003
Cosmological Constant - the Weight of the Vacuum
hep-th/0212290
 - Riess A.G., Turner M.S., 2004
From Slowdown to Speedup
Sci. Am., feb. 2004, pg. 62
 - Trotta R., Bower R., 2006
Surveying the Dark Side
Astronomy. Geophys. 47, 422
 - Weinberg S., 1989
The cosmological constant problem
Rev. Mod. Phys. 61, 1

2. Baryonic Oscillations

- Baryonic oscillations in the power spectrum of galaxy clustering have recently been detected from the 2dFGRS and SDSS galaxy redshift survey. At the moment various deep redshift surveys are being designed to measure the baryonic oscillations and get a precise measurement of the equation of state of dark energy from this purely geometric and robust method. Give a discussion of the fundamental physics behind the oscillations, on the detection and measurement of the oscillations and on the prospects to study dark energy.
- *Literature suggestions:*
 - Cole S., et al., 2005
The 2dF Galaxy Redshift Survey: power-spectrum analysis of the final data set and cosmological implications
MNRAS, 362, 505
 - Eisenstein D.J., Hu W., 1997
Baryonic Features in the Matter Transfer Function
ApJ 496, 605
 - Eisenstein D.J., et al., 2005
Detection of the Baryon Acoustic Peak in the Large-Scale Correlation Function of SDSS Luminous Red Galaxies
ApJ, 633, 560
 - Glazebrook K., et al., 2007
The WiggleZ project: AA Ω and Dark Energy
ASP, astro-ph/0701876
 - Parkinson D., et al., 2007
Optimizing Baryon Acoustic Oscillation Surveys - I. Testing the concordance Λ CDM cosmology
MNRAS, astro-ph/0702040
 - Percival et al., 2006
Measuring the Matter Density using Baryonic Oscillations in the SDSS
ApJ, astro-ph/0608635
 - Seo H-J, Eisenstein D.J., 2005
Baryon Acoustic Oscillations in Simulated Galaxy Redshift Surveys
ApJ 633, 575
 - Seo H-J, Eisenstein D.J., 2005
Probing Dark Energy with Baryonic Acoustic Oscillations
ASP, Vol. 399

- Seo H-J, Eisenstein D.J., 2007
Improved forecasts for the baryon acoustic oscillations and cosmological distance scale
astro-ph/0701079
- White M., 2005
Baryon Oscillations
Astroparticle Physics 24, 334

3. The Cosmic Web

- On scales of a few up to more than a hundred Megaparsec displays galaxies delineate a salient and pervasive weblike pattern, the *Cosmic Web* (Bond et al. 1996). Galaxies and mass are arranged into elongated filaments, sheetlike walls and dense compact clusters. These surround large *voids*, enormous regions with sizes in the range of $20-50h^{-1}$ Mpc that are practically devoid of any galaxy, usually roundish in shape and occupying the major share of space in the Universe. Write a review on observational aspects of the cosmic web, along with a discussion of N-body simulations revealing the same weblike structure. Literature is too vast to provide any decent measure of fitting references. Please contact RvdW. A few suggestions ...
- *Literature suggestions:*
 - Bond J.R., Kofman L., Pogosyan D., 1996
How filaments of galaxies are woven into the cosmic web
Nature, 380, 603
 - Dolag K. et al., 2005
Simulating the physical properties of dark matter and gas inside the cosmic web
MNRAS, 2005/2006, astro-ph/0511357
 - Gott J.R. III, et al., 2005
A map of the Universe
ApJ 624, 463
 - Lahav O., Suto Y., 2003
Measuring our universe from galaxy redshift surveys
review, astro-ph/0310642
 - Springel V., Frenk C.S., White S.D.M., 2006
The large-scale structure of the Universe
review, Nature, 440, 1137
 - van de Weygaert R., 2002
Froth across the Universe
invited review, Modern Theoretical and Observational Cosmology, eds. Plionis & Costakis, Kluwer
contact RvdW
 - van de Weygaert R., Schaap W., 2007
the Cosmic Web: Geometrical Analysis and Modelling
lecture, summerschool Cosmological Data Analysis, Valencia, 2004
contact RvdW (only concerns first part).

4. Voids and the Large Scale Structure

- Voids are a major component of the Megaparsec Universe. With the arrival of the 2dFGRS and SDSS galaxy redshift surveys it is finally possible to obtain a global picture of their characteristics. Review their properties, discuss their role within the formation of large scale structure (both from an observational and theoretical point of view), discuss their sensitivity to cosmological parameters and evaluate what void galaxies can teach about galaxy formation.
- *Literature suggestions:*
 - Furlanetto S.R., Piran T., 2006
The evidence of absence: galaxy voids in the excursion set formalism
MNRAS 366, 467
 - Hoyle F., Vogeley M.S., 2004
Voids in the Two-degree Field Galaxy Redshift Survey
ApJ 607, 751
 - Kirshner R., Oemler A., Schechter P.L., Shectman S.A., 1987
A survey of the Bootes Void
ApJ 314, 493
 - Park D., Lee J., 2006
The Void Ellipticity Distribution as a Probe of Cosmology
astro-ph/0610520
 - Peebles P.J.E., 2001
The Void Phenomenon
ApJ 557, 495
 - Rojas R.R., Vogeley M.S., Hoyle F., Brinkmann J., 2004
Photometric properties of void galaxies in the Sloan Digital Sky Survey
ApJ 617, 50
 - Ryden B., Melott A.L., 1996
Voids in Real Space and in Redshift Space
ApJ, 470, 160
 - Shandarin S., Feldman H.A., Heitmann K., Habib S., 2005
Shapes and Sizes of Voids in the LCDM Universe: Excursion Set Approach
 - Sheth R., van de Weygaert R., 2004
A hierarchy of voids: much ado about nothing
MNRAS 350, 517

- van de Weygaert R., van Kampen E., 1993

Voids in gravitational instability scenarios - I. Global density and velocity field in an Einstein-de Sitter universe

MNRAS 263, 481

5. Hierarchical Clustering and the Excursion Set Formalism

- Structure in the Universe builds up in a hierarchical fashion: the first objects to form are small, larger ones form by the gradual merging of smaller clumps. To see how such structures emerge out of an initially Gaussian density field a sophisticated mathematical formalism has been developed, the so-called *excursion set formalism*. This formalism allows the computation of the resulting mass spectrum of galaxies and clusters, the development of the void distribution or even that of the *Cosmic Web*. Discuss the essential ingredients of this elegant formalism, establish the link with diffusion equations, and evaluate its successes and limitations.
- *Literature suggestions:*
 - Press W., Schechter P., 1974
Formation of Galaxies and Clusters of Galaxies by Self-Similar Gravitational Condensation
ApJ., 187, 425
 - Bond J. R., Cole S., Efstathiou G., Kaiser N.
Excursion set mass functions for hierarchical Gaussian fluctuations
ApJ., 379, 440
 - Shen J., Abel T., Mo H.J., Sheth R.K., 2006
An Excursion Set Model of the Cosmic Web: the abundance of sheets, filaments, and halos
ApJ 645, 783
 - Sheth R., 1998
An excursion set model for the distribution of dark matter and dark matter haloes
MNRAS 300, 1057
 - Sheth R., Mo H.J., Tormen G., 2001
Ellipsoidal collapse and an improved model for the number and spatial distribution of dark matter haloes
MNRAS 323, 1
 - Sheth R., Tormen G., 2002
An excursion set model of hierarchical clustering: ellipsoidal collapse and the moving barrier
MNRAS, 329, 61
 - Zentner A.R., 2006
The Excursion Set Theory of Halo Mass Functions, Halo Clustering, and Halo Growth
astro-ph/0611454

6. Cluster Evolution and Intracluster Medium

- Clusters of galaxies are the most massive fully collapsed and virialized objects in the Universe. In fact, they are huge balls of hot $10^7 - 10^8$ K intracluster gas. Describe the evolution of clusters, focussing in particular on that of the hot X-ray emitting gas.
- *Literature suggestions:*
 - Arnaud M., 2005
X-ray observations of Clusters of Galaxies
Societa Italiana di Fisica, astro-ph/0508159
 - Borgani S., Guzzo L., 2001
X-ray clusters of galaxies as tracers of structure in the Universe
Nature 409, 39
 - Cohn J.D., White M., 2005
The formation histories of galaxy clusters
Astroparticle Physics 24, 316
 - Fabian A.C., 1994
Cooling Flows in Clusters of Galaxies
ARAA, 32, 277
 - Kaiser N., 1991
Evolution of Clusters of Galaxies
ApJ, 383, 104
 - Voit G.M., 2005
Tracing cosmic evolution with clusters of galaxies
Rev. Mod. Phys. 77, 207
 - Markevitch M., Vikhlinin A., 2007
Shocks and Cold Fronts in Galaxy Clusters
Physics Reports, 67 pp, astro-ph/0701821

7. Clusters and the Sunyaev-Zel'dovich effect

- The hot intracluster gas in clusters may scatter CMB photons to higher frequencies. The resulting spectrum is no longer blackbody. This effect, the Sunyaev-Zel'dovich effect, may open the way towards mapping all clusters throughout the observable Universe. There are two effects, the thermal and the kinetic SZ effect. Describe the effect, present some recent results and analyze the prospects for future experiments like the Planck satellite.
- *Literature suggestions:*
 - Birkinshaw M., 1999
The Sunyaev-Zel'dovich effect
Physics Reports 310, 97
 - Carlstrom J.E., Holder G.P., Reese E.D., 2002
Cosmology with the Sunyaev-Zeldovich Effect
ARAA 40, 643
 - Geisbuesch J., Hobson M.P., 2006
Cosmology with the Planck cluster sample
MNRAS
 - Schäfer B.M. et al., 2004
Detecting Sunyaev-Zel'dovich clusters with Planck: I. Construction of all-sky thermal and kinetic SZ-maps
MNRAS
 - Sunyaev R.A., Zeldovich Ya.B., 1980
Microwave background radiation as a probe of the contemporary structure and history of the universe
ARAA, 18, 537
 - Sunyaev R.A., Zeldovich Ya.B., 1980
The velocity of clusters of galaxies relative to the microwave background - The possibility of its measurement
MNRAS 190, 413
 - Sunyaev R.A., Zeldovich Ya.B., 1970
The Spectrum of Primordial Radiation, its Distortions and their Significance
Comments on Astrophys. Space Physics, 2, 66
 - Sunyaev R.A., Zeldovich Ya.B., 1972
The Observations of Relic Radiation as a Test of the Nature of X-Ray Radiation from the Clusters of Galaxies
Comments Astrophys. Space Phys. 4, 173

- Vale C., White M., 2006
Finding clusters in SZ surveys
New Astron. 11, 207
- Voit G.M., 2005
Tracing cosmic evolution with clusters of galaxies
Rev. Mod. Phys. 77, 207

8. Cosmology and Clusters of Galaxies

- Clusters of galaxies are the most massive fully collapsed and virialized objects in the Universe. The population of clusters and its evolution are sensitive probes of underlying cosmology and of the spectrum of density fluctuations. In particular interesting is the mass spectrum $n(M)$ of clusters of mass M . On the basis of theoretical predictions one can infer its sensitivity to the cosmological mass density Ω_m , on the power spectrum of density fluctuations and in particular its amplitude (expressed in terms of σ_8 , the root mean square of density fluctuations within a sphere of radius $8h^{-1}\text{Mpc}$). Discuss the theoretical framework of predicted cluster mass spectra (both analytically as well as by means of N-body simulations). In addition, discuss the constraints on cosmological parameters obtained from such studies, in particular on the basis of samples of X-ray clusters. Finally, show how these in combination with CMB experiments yield estimates of in particular Ω_m and Ω_Λ .
- *Literature suggestions:*
 - Borgani S., Guzzo L., 2001
X-ray clusters of galaxies as tracers of structure in the Universe
Nature 409, 39
 - Press W., Schechter P., 1974
Formation of Galaxies and Clusters of Galaxies by Self-Similar Gravitational Condensation
Astrophys. J., 187, 425
 - Bond J. R., Cole S., Efstathiou G., Kaiser N.
Excursion set mass functions for hierarchical Gaussian fluctuations
Astrophys. J., 379, 440
 - Bahcall N., Cen R., 1993
The Mass Function of Clusters of Galaxies
Astrophys. J., 407, L49
 - Cohn J.D., White M., 2005
The formation histories of galaxy clusters
Astroparticle Physics 24, 316
 - Eke V., Cole S., Frenk C., 1996
Cluster evolution as a diagnostic for Ω
MNRAS, 282, 263
 - Eke V., Cole S., Frenk C., 1998
Measuring Ω_o using cluster evolution
MNRAS 298, 1145

- Jenkins A., et al., 2001
The mass function of dark matter halos
MNRAS, 321, 372
- Sheth R., 1998
An excursion set model for the distribution of dark matter and dark matter haloes
MNRAS 300, 1057
- Sheth R., Mo H.J., Tormen G., 2001
Ellipsoidal collapse and an improved model for the number and spatial distribution of dark matter haloes
MNRAS 323, 1
- Sheth R., Tormen G., 2002
An excursion set model of hierarchical clustering: ellipsoidal collapse and the moving barrier
MNRAS, 329, 61
- Pierpaoli E., Scott D., White M., 2001
Power-spectrum normalization from the local abundance of rich clusters of galaxies
MNRAS, 325, 77
- Reiprich T.H., Boehringer H., 2002
The Mass Function of an X-ray flux-limited sample of galaxy clusters
Astrophys. J., 567, 716
- Rosati P, Borgani S., Norman C., 2002
The Evolution of X-ray Clusters of Galaxies
ARAA, 40, 539-77
- Viana P.T.P., Liddle A.R., 1996
The cluster abundance in flat and open cosmologies
MNRAS 281, 323
- White M., 2002
The Mass Function
ApJS, 143, 241

9. Warm and Hot Intergalactic Medium (WHIM)

- A significant fraction of the baryons in the present universe is hiding in as shock-heated warm-hot intergalactic medium spread throughout the Cosmic Web. Provide a review on the simulations of the Intergalactic medium and the predictions for tracing this gaseous medium. Also include a critical discussion of the claims for having detected this medium and the prospects for mapping the IGM.
- *Literature suggestions:*
 - Cen R., Ostriker J.P., 1999
Where are the baryons
ApJ, 514, 1
 - Cen R., Ostriker J.P., 2006
Where are the baryons II: Feedback effects
ApJ, 650, 560
 - Cen R., Ostriker J.P., 2006
Where are the baryons III: Nonequilibrium effects and observables
ApJ, 650, 573
 - Davé R., et al.
Baryons in the Warm-Hot Intergalactic Medium
ApJ, 552, 473
 - Kaastra J., et al. 2002
XMM-Newton confirmation of Soft X-ray excess emission in clusters of galaxies - the discovery of O VII emission from an extended warm baryonic component
A&A, astro-ph/0210684
 - Kravtsov A., Klypin A., Hoffman Y., 2002
Constrained simulations of the real universe II. Observational signatures of intergalactic gas in the Local Supercluster Region
ApJ 571, 563
 - Nicastro F., 2002
Chandra discovery of a tree in the X-ray forest towards PKS 2155-304: the Local Filament ?
ApJ 573, 157
 - Nicastro F. et al., 2005
The mass of the missing baryons in the X-ray forest of the warm-hot intergalactic medium
Nature, 433, 495

- Viel M., et al., 2003

Detecting X-ray filaments in the low redshift Universe with XEUS and Constellation-X

MNRAS, astro-ph/0210497

- Viel M., et al., 2004

Tracing the Warm Hot Intergalactic Medium in the Local Universe

MNRAS, astro-ph/0412566

10. Cosmic Flows and Redshift Space Distortions

- Due to the matter migration flows accompanying the formation of structure in the Universe, maps of galaxies in redshift space are a combination of their true spatial distribution and systematic distortions resulting from the peculiar velocities of galaxies. Investigate the possible effects, provide an overview on the attempt to theoretically describe this and discuss results on the basis of (recent) galaxy redshift surveys.
- *Literature suggestions:*
 - Dekel, A., 1994
Dynamics of Cosmic Flows
ARAA, 32, 371-418
 - Strauss, M., Willick, J., 1995
The density and peculiar velocity fields of nearby galaxies
Phys. Rep. 261, 271-431
 - Hamilton, A.J.S.
Linear Redshift Distortions: A Review
Invited review *Ringberg Workshop on Large-Scale Structure*, 1996
astro-ph/9708102
 - Szalay, A., Matsubara, T., Landy, S., 1998
Redshift-Space distortions of the Correlation Function in Wide-Angle Galaxy Surveys
ApJ, 498, L1-L4
 - Madgwick et al., 2003
The 2dF Galaxy Redshift Survey: galaxy clustering per spectral type
astro-ph/0303668

11. Weak Lensing by Large Scale Structure

- The finding of cosmic shear induced by the inhomogeneous matter distribution in the Universe has triggered enormous activity in trying to infer cosmological parameters, estimating the cosmic power spectrum and ultimately mapping the dark matter distribution throughout the Universe on the basis of the slight distortions of galaxy images by weak lensing by the cosmic mass distribution. Provide a review of the theoretical predictions, of analysis methods, and achieved results, culminating in the first map of the cosmic dark matter distribution.
- *Literature suggestions:*
 - Bacon D.J., Taylor A.N., 2003
Mapping the 3D dark matter potential with weak shear
MNRAS 344, 1307
 - Heavens A., 2003
3D weak lensing
MNRAS 343, 1327
 - Kaiser N., Squires G., 1993
Mapping the Dark Matter with Weak Gravitational Lensing
ApJ, 404, 441
 - Kaiser N., 1998
Weak Lensing and Cosmology
ApJ, 498, 26
 - Jain B., Seljak U., 1997
Cosmological Model Predictions for Weak Lensing: Linear and Nonlinear Regimes
ApJ, 484, 560
 - Jain B., Seljak U., White S.D.M., 2000
Ray-tracing simulations of weak lensing by Large-Scale Structure
ApJ., 530, 547-577
 - Massey et al., 2007
Dark matter maps reveal cosmic scaffolding
Science 445, 286
 - Mellier Y., 1999
Probing the Universe with Weak Lensing
ARAA, 37, 127

- Munshi D., Valageas P., van Waerbeke L., Heavens A., 2006
Cosmology with Weak Lensing Surveys
astro-ph/0612667, 98 pp.
- Refregier A., 2003
Weak Gravitational Lensing by Large-Scale Structure
ARAA 41, 645
- Schneider P., 2005
Weak Gravitational Lensing
Saas-Fee course 2005, astro-ph/0509252, 180pp.
- Vale C., White M., 2003
Simulating Weak Lensing by Large Scale Structure
Astroparticle Physics 22, 19
- Van Waerbeke L., Mellier Y., 2003
Gravitational lensing by Large Scale Structures: A Review
astro-ph/0305089

12. Power Spectrum Estimation

- The density fluctuation power spectrum $P(k)$ is one of the most essential ingredients for any theory of structure formation: to a large extent it determines the mode, nature and rate of the emergence of galaxies, clusters and all elements of the cosmic foam in the Universe. Trying to determine the power spectrum from the many sources of information on cosmic structure is one of the major activities of cosmological studies. Provide a discussion of the various methods. Concentrate in particular on the machinery that has been developed to extract significant estimates of $P(k)$ from galaxy redshift surveys.
- *Literature suggestions:*
 - Feldman H.A., Kaiser N., Peacock J.A., 1994
Power-spectrum Analysis of Three-dimensional Redshift Surveys
ApJ., 426, 23-37
 - Vogeley M.S., Szalay A.S.
Eigenmode Analysis of Galaxy Redshift Surveys. I. Theory and Methods
ApJ., 465, 34-53
 - Tegmark M., Taylor A.N., Heavens A.F., 1997
Karhunen-Loève Eigenvalue Problems in Cosmology: How should we tackle large data sets
ApJ., 480, 22-35
 - Hamilton A.J.S., 1997
Towards optimal measurement of power spectra - I. Minimum variance pair weighting and the Fisher matrix
MNRAS 289, 285-294
 - Hamilton A.J.S., 1997
Towards optimal measurement of power spectra - II. A basis of positive, compact, statistically orthogonal kernels
MNRAS 289, 295-304
 - Tegmark M., Hamilton A.J.S., Xu Y., 2002
The power spectrum of galaxies in the 2dF 100k redshift survey
MNRAS 335, 887

13. Cosmic Microwave Background Radiation: Thermalization and Spectral Distortions

- The cosmic microwave background radiation provides the strongest observational foundation for the standard Hot Big Bang theory. The fact that its electromagnetic spectrum is almost perfectly Blackbody sets severe constraints on 1) the thermalization processes and epoch of the radiation and 2) spectrum distorting processes. While the anisotropies in the CMB provide a wealth of information on the Universe around the epoch of recombination ($z \sim 1089$), the CMB Planck spectrum forms a probe of the Universe out to redshifts $z \sim 10^7$. Investigate in detail the physical processes that lead to the thermalization of the CMB, and discuss the possible observational spectral signatures incurred by distorting energetic processes at $z < 10^7$. Discuss the observational constraints on the various observational signatures.
- *Literature suggestions:*
 - Sunyaev R.A., Zeldovich Ya.B., 1980
Microwave background radiation as a probe of the contemporary structure and history of the universe
ARAA, 18, 537
 - Stebbins A., 1997
The Cmb-Spectrum a Theoretical Introduction
The Cosmic Microwave Background, Kluwer Academic Press;
Ed. C.H. Lineweaver, J.G. Bartlett, A. Blanchard, M. Signore, and J. Silk, p.241
 - Hu W., 1995
Wandering in the Background: A Cosmic Microwave Background Explorer
Ph.D. thesis, Univ. California at Berkeley
website: <http://background.uchicago.edu/~whu/thesis/thesispage.html>
 - Zeldovich Ya.B., Sunyaev R.A., 1969
The Interaction of Matter and Radiation in a Hot-Model Universe
Astrophysics and Space Science, Vol. 4, p.301
 - Sunyaev R.A., Zeldovich Ya.B., 1970
The Interaction of Matter and Radiation in a Hot-Model Universe, II
Astrophysics and Space Science, Vol. 7, p.20
 - Sunyaev R.A., Zeldovich Ya. B., 1970
The spectrum of primordial radiation, its distortions and their significance
Comments on Astrophysics and Space Physics, vol.2, p.66-73

- Chan K.L, Jones B.J.T., 1975
Distortions of the 3°K background radiation spectrum: observational constraints on the early thermal history of the Universe
Astrophys. J., 195, 1
- Danese L, De Zotti G., 1977
The relic radiation spectrum and the thermal history of the Universe
Nuovo Cimento, Rivista, Serie 2, vol. 7, July-Sept. 1977, p. 277-362.
- Danese L., De Zotti G., 1982
Double Compton Process and the Spectrum of the Microwave Background
A&A, 107, 39
- Burigana C., Danese L., De Zotti G., 1991
Formation and evolution of early distortions of the microwave background spectrum: a numerical study
A&A, 246, 49
- Burigana C., De Zotti G., Danese L., 1991
Constraints on the Thermal History of the Universe from the Cosmic Microwave Background Spectrum
A&A, 379, 1
- Hu W., Silk J., 1993
Thermalization and spectral distortions of the cosmic background radiation
Phys. Rev. D. 48, 485
- Fixsen et al., 1996
The Cosmic Microwave Background Spectrum from the Full COBE FIRAS Data Set
Astrophys. J., 473, 576

14. CMB Experiments: Maps, Power Spectra and Cosmological Parameter Estimation

- On the basis of the raw data of CMB temperature measurements across the sky obtained through microwave background experiments (e.g. COBE, Boomerang and WMAP), a data analysis machinery should process this into maps of the MWB sky, of the power spectrum C_l and ultimately significant estimates of cosmological parameters. Describe the various steps of this process, in this concentrating particularly on the mapmaking procedures and the estimation of the power spectrum. The latter involves a discussion on the statistical and numerical methods developed to obtain optimal estimates of C_l , including a description of the CMBFAST package for fast theoretical power spectrum computation.
- *Literature suggestions:*
 - Hu W., Dodelson S., 2002
Cosmic Microwave Background Anisotropies
ARAA, 40, 171-216
 - Seljak U., Zaldarriaga M., 1996
Line-of-sight integration approach to cosmic microwave background anisotropies
Astrophys. J. 469, 437
 - Jungman G., Kamionkowski M., Kosowsky A., Spergel D., 1996
Cosmological Parameter Determination with Microwave Background Maps
Phys. Rev. D., 54, 1332
 - Bond J.R., Efstathiou G., Tegmark M., 1997
Forecasting cosmic parameter errors from microwave background anisotropy experiments
MNRAS 291, L33
 - Zaldarriaga M., Spergel D., Seljak U., 1997
Microwave Background Constraints on Cosmological Parameters
Astrophys. J., 488, 1
 - Tegmark M., 1997
CMB mapping experiments: A designer's guide
Phys. Rev. D., 56, 4514
 - Tegmark M., 1997
How to make maps from cosmic microwave background data without losing information
Astrophys. J., 480, L87

- Bond J.R., Jaffe A.H., Knox L., 1998
Estimating the power spectrum of the cosmic microwave background
Phys. Rev. D., 57, 2117
- Bennett C.L. et al., 2003
First-year WMAP Observations: Preliminary Maps and Basic Results
ApJS, 148, 1
- Hinshaw G. et al., 2003
First-year WMAP Observations: Data processing methods and systematic error limits
ApJS, 148, 63
- Hinshaw G., et al., 2003
First-year WMAP Observations: the Angular Power Spectrum
ApJS, 148, 135
- Spergel D.N., et al., 2003
First-year WMAP Observations: Determination of Cosmological Parameters
ApJS, 148, 175
- Verde L., et al., 2003
First-year WMAP Observations: Parameter Estimation Methodology
ApJS, 148, 195
- Page L., et al., 2003
First-year WMAP Observations: Interpretation of the TT and TE angular power spectrum peaks
ApJS, 148, 233
- Spergel D.N., et al., 2006
Wilkinson Microwave Anisotropy Probe (WMAP) Three Year Results: Implications for Cosmology
astro-ph
- M. Tegmark, website:
Max Tegmark's CMB data analysis center
<http://www.hep.upenn.edu/~max/cmb/pipeline.html>
- WMAP website:
http://map.gsfc.nasa.gov/m_mm/pub_papers/firstyear.html
- Healpix website:
<http://www.eso.org/science/healpix/>
- CMBFAST website:
<http://cmbfast.org/>

- Hu W., website:

Cosmological Parameters in the CMB

<http://background.uchicago.edu/~whu/metaanim.html>

15. Cosmic Microwave Background Anisotropies: Characteristic Angular Scales

- Four characteristic angular scales are imprinted on the spectrum of Microwave Background Anisotropies. These are the scale corresponding to the radiation-matter equality ℓ_{eq} , the scale ℓ_A corresponding to the cosmic sound horizon at the epoch of decoupling, the diffusion scale ℓ_D due to (Silk) scattering diffusion and finally the scale $\ell_{K\Lambda}$ at which either the curvature or the cosmic constant takes over from matter as dominant factor behind the expansion of the Universe. Provide a discussion how the various relevant physical processes (Sachs-Wolfe, acoustic oscillations, Silk diffusion damping, Integrated Sachs-Wolfe, etc.) are relating to these characteristic scales and how this leads to differences in angular power spectrum of cosmic microwave background fluctuations.
- *Literature suggestions:*
 - Hu W., Dodelson S., 2002
Cosmic Microwave Background Anisotropies
ARAA, 40, 171-216
 - Hu W., Sugiyama N., Silk J.,
The Physics of the Microwave Background Anisotropies
Nature, Vol. 386, p. 37-43
 - Hu W., 1995
Wandering in the Background: A Cosmic Microwave Background Explorer
Ph.D. thesis, Univ. California at Berkeley
website: <http://background.uchicago.edu/~whu/thesis/thesispage.html>
 - Hu W.
Cosmic Microwave Background
lecture notes, 172 pp.
contact RvdW for pdf file
 - Hu W., Sugiyama N., 1995
Anisotropies in the Cosmic Microwave Background: an Analytic Approach
ApJ., 444, 489
 - Hu W., White M., 2004
The Cosmic Symphony
Sci. Am., feb. 2004, 44

- Bond J.R., 1996
Theory and Observations of the Cosmic Background Radiation
in “Cosmology and Large Scale Structure”, Les Houches LX, eds. R. Schaeffer, J. Silk, M. Spiro, J. Zinn-Justin, Elsevier
(contact RvdW for pdf file).
- Seljak U., Zaldarriaga M., 1996
Line-of-sight integration approach to cosmic microwave background anisotropies
ApJ. 469, 437
- Hu W., website:
 - *An Introduction to the Cosmic Microwave Background*
<http://background.uchicago.edu/~whu/intermediate/intermediate.html>
 - *A Tour of CMB Physics*
<http://background.uchicago.edu/~whu/physics/tour.html>
 - *Cosmological Parameters in the CMB*
<http://background.uchicago.edu/~whu/metaanim.html>
- CMBFAST website:
<http://cmbfast.org/>

16. Cosmic Microwave Background Polarization

- In addition to CMB temperature anisotropies, polarization of the Microwave Background Signal contains a wealth of information on processes in the early Universe (inflationary gravitational waves and primordial velocity field), on the cosmic matter distribution (weak gravitational lensing of the CMB signal) on secondary post-recombination scattering processes. Of the latter in particular that induced by gas ionized by the first generation of stars and galaxies at and around the epoch of reionization provides an exciting new avenue of research, in particular since the polarization detection by DASI and WMAP. Investigate the physical nature of the various sources of CMB polarization, describe their (expected) imprint (E and B modes) and signature (EE autocorrelation, TE cross-correlation), and the way they can and are exploited to infer important cosmological information.
- *Literature suggestions:*
 - Bond J.R., 1996
Theory and Observations of the Cosmic Background Radiation
in “Cosmology and Large Scale Structure”, Les Houches LX, eds. R. Schaeffer, J. Silk, M. Spiro, J. Zinn-Justin, Elsevier
 - Challinor A., 2005
Cosmic microwave background polarization analysis
lecture notes, “Data analysis in cosmology”, Valencia, 2004
 - Hu W., 1995
Wandering in the Background: A Cosmic Microwave Background Explorer
Ph.D. thesis, Univ. California at Berkeley
website: <http://background.uchicago.edu/~whu/thesis/thesispage.html>
 - Hu W., Dodelson S., 2002
Cosmic Microwave Background Anisotropies
ARAA, 40, 171-216
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A CMB polarization primer
New Astronomy, 2, 323
 - Kamionkowski M., Kosowsky A., Stebbins A., 1997
Statistics of Cosmic Microwave Background Polarization
Phys Rev D55, 7368
 - Kogut et al., 2003
Wilkinson Microwave Anisotropy Probe (WMAP) First Year Observations: Temperature-Polarization Correlation
ApJS, 148, 161

- Page L., et al., 2003
First-year WMAP Observations: Interpretation of the TT and TE angular power spectrum peaks
ApJS, 148, 233
- Page L., et al., 2006
Three Year Wilkinson Anisotropy Probe (WMAP) Observations: Polarization Analysis
ApJ, in press
- Seljak U., 1997
Measuring Polarization in the Cosmic Microwave Background
Astrophys. J., 482, 6
- Zaldarriaga M., 1997
Polarization of the microwave background in reionized models
Phys. Rev. D., 55, 1822
- Zaldarriaga M., 1998
Cosmic Microwave Background Polarization Experiments
Astrophys. J. 503, 1
- Hu W., website:
A Polarization Primer
<http://background.uchicago.edu/~whu/polar/webversion/polar.html>
- WMAP website:
http://map.gsfc.nasa.gov/m_mm/pub_papers/firstyear.html

17. The First Stars

- One of the most important transitions in the state of the Universe is the epoch at which the first stars and galaxies arise out of the gradually unfolding matter distribution. The first generation of stars, Population III stars, are extremely metal poor and will have differed considerably from the stars we know of nowadays. Write an review on the formation and evolution of these stars and investigate the enrichment products following their explosion as supernova.
- *Literature suggestions:*
 - Abel T., Bryan G.L., Norman M.L., 2002
The Formation of the First Star in the Universe
Science 295, 93
 - Abel T., Bryan G.L., Norman M.L., 2000
The Formation and Fragmentation of Primordial Molecular Clouds
ApJ, 540, 39
 - Alvarez M.A., Bromm V., Shapiro P.R., 2006
The HII region of the first star
ApJ 639, 621
 - Barkana R., 2006
The First Stars in the Universe and Cosmic Reionization
Science 313, 931
 - Bond J.R., Arnett W.D., Carr B.J., 1984
The evolution and fate of Very Massive Objects
ApJ, 280, 825
 - Bromm V., Larson R.B., 2004
The First Stars
ARAA 42, 79
 - Bromm V., Coppi P.S., Larson R.B., 2002
The Formation of the First Stars I. Primordial star-forming cloud
ApJ, 564, 23
 - Bromm V., Yoshida N., Hernquist L., 2003
The First Supernova Explosions in the Universe
ApJ, 596, L135
 - Loeb A., 2006
First Light
Saas Fee lecture, astro-ph/0603360

- Yoshida N., Omukai K., Hernquist L., Abel T.
Formation of Primordial Stars in a LCDM Universe
ApJ, 652, 6

18. Epoch of Reionization

- One of the most important transitions in the state of the Universe is the epoch at which the first stars and galaxies arise out of the gradually unfolding matter distribution, set ablaze the surrounding gas and very soon thereafter reionizes the hydrogen gas throughout the Universe. The *Epoch of Reionization* is one of the most vigorous and active in today's cosmology, with instruments like LOFAR due to play a seminal role. Discuss in the report the processes and stages in which the reionization of the hydrogen gas proceeds, illustrate this with available computer simulations and assess the shortcomings of the present calculations along with the prospects for detection and possibly mapping of the signal.
- *Literature suggestions:*
 - Barkana R., 2006
The First Stars in the Universe and Cosmic Reionization
Science 313, 931
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The Physics and Early History of the Intergalactic Medium
Re. Prog. Phys., 36 pp.
 - Ciardi B., Madau P., 2003
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ApJ
 - Ciardi B., Ferrara A., 2004
The First Cosmic Structures and their Effects
review, astro-ph/0409018
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Observing the Reionization Epoch Through 21 Centimeter Radiation
MNRAS
 - Furlanetto S.R., Peng Oh S., Briggs F.H., 2006
Cosmology at Low Frequencies: the 21cm Transition and the High-Redshift Universe
Phys. Rep., 207 pp.
On the density of neutral hydrogen in intergalactic space
ApJ, 142, 1633
 - Gnedin N.Y., Ostriker J.P., 1997
Reionization of the Universe and the Early Production of Metals
ApJ, 486, 581

- Gnedin N.Y., 2000
Cosmological Reionization by Stellar Sources
ApJ 535, 530
- Gnedin N.Y., Fan X., 2006
Cosmic Reionization Redux
ApJ, 648, 1
- Illiev I.T. et al., 2006
Reionization observables after WMAP 3-year results
MNRAS, astro-ph/0702099
- Loeb A., 2006
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Saas Fee lecture, astro-ph/0603360
- Madau P., Meiksin A., Rees M.J., 1997
21 centimeter tomography of the Intergalactic Medium at high redshift
ApJ, 475, 429
- Loeb A., Barkana R., 2001
The Reionization of the Universe by the First Stars and Quasars
ARAA 39, 19
21 centimeter tomography of the Intergalactic Medium at high redshift
ApJ, 475, 429
- Miralda-Escudé J., 2003
The Dark Age of the Universe
Science, 300, 1904

19. Inflationary Universe and the Origin of Fluctuations

- The primordial fluctuations out of which structure in the Universe has arisen originated in the inflationary epoch shortly after the Big Bang. Give a review on its basic principles, on the mechanism to generate the fluctuations and the tests of the inflationary scenario via the measurement of the temperature and polarization fluctuations in the cosmic microwave background.
- *Literature suggestions:*
 - Garcia Y.R., 2005
The Origin of the Large-Scale Structure in the Universe: Theoretical and Statistical Aspects
Ph.D. thesis, Univ. Lancaster, astro-ph/0507701
 - Kolb E.W., Turner M.S., 1990
The Early Universe
Frontiers in Physics, Addison-Wesley
(you may inform with RvdW).
 - Liddle A.R., 1999
An introduction to cosmological inflation
astro-ph/9901124
 - Lineweaver C.H., 2003
Inflation and the Cosmic Microwave Background
World Scientific, astro-ph/0305179
 - Page L., et al., 2006
Three Year Wilkinson Anisotropy Probe (WMAP) Observations: Polarization Analysis
ApJ, in press
 - Peiris H.V., et al., 2003
First-year WMAP Observations: Implications for Inflation
ApJS, 148, 233
 - Spergel D.N., et al., 2006
Wilkinson Microwave Anisotropy Probe (WMAP) Three Year Results: Implications for Cosmology
astro-ph
 - Tegmark M., 2004
What does inflation really predict
astro-ph/0410281