LSS2016 PRESENTATION TOPICS

Dear Cosmic Structure Formation 2016 students,

In this document you find a listing of suggested topics for the final presentation. 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 revelant).

Take care that your presentation is a review of relevant work, not JUST a summary of one or two papers. It should be a critical discussion, and place the topic within the context of ongoing reseach.

Have fun, looking forward to your presentations,

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1. **Evidence for Dark Energy**.

- A discussion on the observational evidence for a cosmological constant Lambda 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: AAOmega and Dark Energy
    ASP, astro-ph/0701876
  - Parkinson D., et al., 2007
    Optimizing Baryon Acoustic Oscillation Surveys - I. Testing the concordance LCDM 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 concers 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 socalled *excursion set formalism.* This formalism allows the computation of the resulting mass spectrum of galaxies and clusters, the development of the void distribution, even that of the *Cosmic Web* and the merging history of halos in a hierarchically evolving mass distribution. Discuss the essential ingredients of this elegant formalism, establish the link with diffusion equations, and evaluate its successes and limitations.

- *Literature suggestions:*
    - Appel L., Jones B.J.T., 1990
      The mass function in biased galaxy formation scenarios
      MNRAS 245, 522
    - Bond J. R., Cole S., Efstathiou G., Kaiser N.
      Excursion set mass functions for hierarchical Gaussian fluctuations
      ApJ., 379, 440
    - Bower R.G., 1991
      The evolution of groups of galaxies in the Press-Schechter formalism
      MNRAS 248, 322
    - Hanami H., 2001
      Statistics of merging peaks of random Gaussian fluctuations: skeleton tree formalism
      MNRAS 327, 721
    - Lacey C., Cole S., 1993
      Merger rates in hierarchical models of galaxy formation
      MNRAS 262, 627
    - Lacey C., Cole S., 1994
      Merger rates in hierarchical models of galaxy formation - II. Comparison with N-body simulations
      MNRAS 271, 676
    - Peacock J.A., Heavens A.F, 1990
      Alternatives to the Press-Schechter cosmological mass function
      MNRAS, 243, 133

- Press W., Schechter P., 1974
  Formation of Galaxies and Clusters of Galaxies by Self-Similar Gravitational Condensation
  ApJ., 187, 425
- 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
- Sheth R., van de Weygaert R., 2004
  A hierarchy of voids: much ado about nothing
  MNRAS 350, 517
- 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 $8h^{-1}$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:*
  - Bahcall N., Cen R., 1993
    The Mass Function of Clusters of Galaxies
    Astrophys. J., 407, L49
  - Bond J. R., Cole S., Efstathiou G., Kaiser N.
    Excursion set mass functions for hierarchical Gaussian fluctuations
    Astrophys. J., 379, 440
  - 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
  - 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

- Peacock J.A., Heavens A.F, 1990
  Alternatives to the Press-Schechter cosmological mass function
  MNRAS, 243, 133
- Press W., Schechter P., 1974
  Formation of Galaxies and Clusters of Galaxies by Self-Similar Gravitational Condensation
  Astrophys. J., 187, 425
- 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 Suvery: 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 Cmbr-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 op 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
  astroph

- 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:*
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  - Hu W.
    Cosmic Microwave Background
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    contact RvdW for pdf file
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  - Hu W., White M., 2004
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- Seljak U., Zaldarriaga M., 1996
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  - 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
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  - Hu W., White M., 1997
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  - Kamionkowski M., Kosowsky A., Stebbins A., 1997
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    Phys Rev D55, 7368
  - Kogut et al., 2003
    Wilkinson Microwave Anisotropy Probe (WMAP) First Year Observations: Temperature-Polarization Correlation
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  First-year WMAP Observations: Interpretation of the TT and TE angular power spectrum peaks
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  Phys. Rev. D., 55, 1822
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  A Polarization Primer
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- WMAP website:
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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
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    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
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    ARAA 42, 79
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    ApJ, 564, 23
  - Bromm V., Yoshida N., Hernquist L., 2003
    The First Supernova Explosions in the Universe
    ApJ, 596, L135
  - Loeb A., 2006
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- 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
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    On the density of neutral hydrogen in intergalactic space
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  Reionization observables after WMAP 3-year results
  MNRAS, astro-ph/0702099
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  First Light
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  The Reionization of the Universe by the First Stars and Quasars
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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:*
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    The Origin of the Large-Scale Structure in the Universe: Theoretical and Statistical Aspects
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  - Lineweaver C.H., 2003
    Inflation and the Cosmic Microwave Background
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  - 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