

A complex visualization of the cosmic web, showing a dense network of filaments and nodes. The filaments are rendered in various colors, including green, blue, orange, and yellow, and are interconnected by a web of thin, white lines. The overall structure is highly intricate and three-dimensional, representing the large-scale structure of the universe.

Cosmic Structure Formation

Lecture course
University of Groningen
November 2016 - January 2017

Practical Matters

Lectures:

Kapteynborg

monday 13:00-15:00

thursday 13:00-15:00

tuesday 11:00-13:00

Kapteynborg 5419-237

Kapteynborg 5419-124

Kapteynborg 5419-245

Lectures:

Rien van de Weygaert

rm. 186; tel. 050-3634086;

weygaert@astro.rug.nl

Tutorials:

Saikat Chatterjee

rm. 192; tel. 050-3638689

saikat@astro.rug.nl

Website:

www.astro.rug.nl/~weygaert/lss2016.html

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Tracing the Cosmic Web

Workshop: 17 – 21 February 2014, Leiden, the Netherlands

Scientific Organizers

- Noam Libeskind, AIP Potsdam
- Rien van de Weygaert, U Groningen

Scientific Organizing Committee

- Yehuda Hoffman, HUJI Jerusalem
- Fransisco Kitaura, AIP Potsdam
- Sergei Shandarin, KU Lawrence
- Thierry Sousbie, IAP Paris
- Elmo Tempel, U Tartu

Topics

- Large-Scale Distribution of Matter and Galaxies
- Voids, Sheets, Filaments and Clusters
- Geometry, Topology and Multiscale Structure
- Dynamics and Evolution of the Cosmic Web
- Techniques for Characterizing Weblike Patterns
- Galaxy Formation and the Cosmic Web

The Lorentz Center is an international center in the sciences. Its aim is to organize workshops for scientists in an atmosphere that fosters collaborative work, discussions and interactions. For registration see: www.lorentzcenter.nl

Galaxies, irregularly distributed gas and dark matter aggregate in a complex network, known as the cosmic web. Image: A. Kashlur, O. Hahn, T. Abel. Processing: M. Bos. Poster design: Suparhova Studios. NL



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IAU Symposium 308

THE ZELDOVICH UNIVERSE

GENESIS AND GROWTH OF THE COSMIC WEB

SOC

Sergei Shandarin
Rien van de Weygaert
Rashid Sunyaev
Jaan Einasto
Alexei Starobinsky
Igor Karachentsev
Bernard Jones
Dick Bond
Alex Szalay
Carlos Frenk
Pirin Erdogdu
Adi Nusser
Nelson Padilla
Varun Sahni
Joss Bland-Hawthorn
Tom Jarrett
J.P. Ying
Jounghun Lee

LOC

Enn Saar
Antti Tamm
Elmo Tempel
Jaan Einasto

Tallinn, Estonia

June 23-28, 2014

www.iau-zeldovich.org



Exam

Three Constituents:

1. Exam (written) 60% thur. Jan 26

2. Presentation 20%

Special Topic

3. Computer Tasks 20%

**Correlation Function, CMB Dipole,
Gaussian Fields, Zeldovich ...**

Literature

- **Large Scale Structure of the Universe**

P.J.E. Peebles, Princeton Univ. Press, 1981

The Classic Book, the Bible ... defining the field !!!!!!!!!!!!!

- **Galaxy Formation**

M. Longair; Springer, A&A Library, 2nd ed., 2008

Good overview of structure and galaxy formation

- **Galaxy Formation and Evolution**

H.J. Mo, F. van den Bosch, S.D.M. White, Cambridge Univ. Press, 2010

Most up to date book on cosmic structure formation

- **Structure Formation in the Universe**

T. Padmanabhan, Cambridge Univ. Press, 1993

very thorough, advanced level: hard to work through

- **Cosmology**

S. Weinberg; Oxford Univ. Press, 2008

Impressive book, covering most of relevant cosmological topics, including structure formation, inflation theory, origin perturbations, CMB

- **Cosmological Physics**

J. Peacock; Cambridge Univ. Press, 1998

very thorough treatment of relevant topics, advanced level

- **Statistics of the Galaxy Distribution**

V.J. Martinez & E. Saar; Chapman & Hall/CRC, 2001

best book on statistical analysis of galaxy distribution; treats fundamentals, little bit outdated

Groningen Books

The Zeldovich Universe: Genesis and Growth of the Cosmic Web

Proc. IAU Symposium 308

R. van de Weygaert et al., eds.
Cambridge Univ. Press, £80.00
Nov. 30, 2016

IAU Symposium No. 308
23–28 June 2014
Tallinn, Estonia

**The Zeldovich Universe:
Genesis and Growth of
the Cosmic Web**

On megaparsec scales, matter and galaxies have aggregated into a complex network of interconnected filaments, wall-like structures and compact clusters surrounded by large near-empty void regions. Dubbed the Cosmic Web, theoretical and observational studies have led to its recognition as a key aspect of structure in the Universe, representing a universal phase in the gravitationally driven emergence and evolution of cosmic structure. IAU Symposium 308 marked the centenary of the birth of the Russian physicist and cosmologist Yakov Zeldovich (1914–1987), who was instrumental in the development of this view of structure formation. His seminal work paved the way towards an understanding of the complex web-like structure observed in our Universe. This volume synthesizes the insights obtained from many different observational and theoretical studies, and helps prepare researchers and students working in this vibrant field for the many upcoming surveys.

Proceedings of the International Astronomical Union
Editor in Chief: Dr. Thierry Montmerle

This series contains the proceedings of major scientific meetings held by the International Astronomical Union. Each volume contains a series of articles on a topic of current interest in astronomy, giving a timely overview of research in the field. With contributions by leading scientists, these books are at a level suitable for research astronomers and graduate students.

van de Weygaert, Shandarin, Saar, Einasto

**The Zeldovich Universe:
Genesis and Growth of the Cosmic Web**

Edited by
Rien van de Weygaert
Sergei Shandarin
Enn Saar
Jaan Einasto

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BERNARD J. T. JONES

**PRECISION
COSMOLOGY**

THE FIRST HALF MILLION YEARS

"Quote."
Name, Affiliation
"Quote."
Name, Affiliation

Cosmology seeks to characterize our Universe in terms of models based on well-understood and tested physics. Today we know our Universe with a precision that once would have been unthinkable. This book develops the entire mathematical, physical and statistical framework within which this has been achieved.

It tells the story of how we arrive at our profound conclusions, starting from the early 20th century and following developments up to the latest data analysis of big astronomical datasets. It provides an enlightening description of the mathematical, physical and statistical basis for understanding and interpreting the results of key space- and ground-based data. Subjects covered include general relativity, cosmological models, the inhomogeneous Universe, physics of the cosmic background radiation, and methods and results of data analysis.

Extensive online supplementary notes, exercises, teaching materials, and exercises in Python make this the perfect companion for researchers, teachers and students in physics, mathematics, and astrophysics.

Bernard J. T. Jones is Emeritus Professor in Astronomy at the University of Groningen. His research has covered many areas of astrophysics, both theoretical and observational, with a strong emphasis on cosmology where he is widely published and cited.

BRIDGE CITY PRESS
Cambridge

Precision Cosmology the first half million years

B.J.T. Jones
Cambridge Univ. Press, £64.99
Mar. 31, 2017

Literature

- **A Pan-Chromatic View of Clusters of Galaxies and the Large-Scale Structure**
M. Plionis, O. Lopez-Cruz, D. Hughes, eds., Lect. Notes in Physics 720, Springer, 2008
Very useful reviews on in particular cluster physics.
Two chapters part of course material (Van de Weygaert & Bond 2008a, 2008b)
- **The Zeldovich Universe: Genesis and Growth of the Cosmic Web**
R. van de Weygaert, et al., Cambridge Univ. Press, Nov. 2016
proceedings IAU Symp. 308, Tallinn, 2014
nice collection of state-of-the-art papers on cosmic structure formation
- **How did the First Stars and Galaxies Form**
A. Loeb, Princeton Univ. Press, 2010
beautiful expose on the first stages of structure and galaxy formation
- **the Cosmic Microwave Background**
R. Durrer, Cambridge Univ. Press, 2008
best textbook on the physics of the CMB
- **Introduction to Cosmology**
B. Ryden, Addison-Wesley, 2003
good reference book on basic cosmology
- **Precision Cosmology**
B.J.T. Jones, Cambridge Univ. Press, 2017
perfect advance level textbook cosmology

Lecture Schedule:

(provisional, changes possible)

Week	Dates Hoorcollege	Subject Hoorcollege	Dates Werkcollege	Subject Werkcollege
1	November 14 (c) November 17 (c)	<p><u>Introduction: Cosmic Inventory:</u> Large Scale Structure & Cosmic Structure Formation Galaxies, Groups, Clusters, Superclusters, IGM Cosmic Structure Formation Primordial Fluctuations & the Cosmic Microwave Background</p> <p><u>Basic Cosmology:</u> Einstein Field Equation, Cosmological Principle, Robertson-Walker metric, Redshift, Cosmic Distances Friedman Equations Cosmic Epochs</p>	November 15 (w)	<p><u>FRW Cosmology</u> FRW universe solutions Observational Cosmology</p>
2	November 21 (c)	<p>Gravitational Instability: <u>(Linear) Perturbation Theory,</u> Structure Growth</p>	November 22 (w)	<p><u>Perturbation Theory</u> Growth Factors</p>

	November 23 (c)	Cosmic Components & Influence on Cosmic Structure Formation: Radiation, Matter: Baryonic Matter & Dark Matter Dark Energy <u>Cosmic Flows</u>		
3	November 28 (c) December 1 (c)	Random Density & Velocity Fields Multidimensional Gaussian distributions Filtering Power Spectrum <u>Random Fields & Power Spectrum</u> <u>Nonlinear Clustering & Structure Formation</u> Hierarchical Clustering, Anisotropic Collapse and the Formation of Voids Spherical Model, Ellipsoidal Model	November 29 (w)	<u>Perturbation Theory</u> Growth Factors
4	December 5 (c) December 8 (c)	Lagrangian Perturbation Theory Zel'dovich formalism Adhesion approximation Phase Space Dynamics Phase Space Sheet Matter Scales Jeans Mass, Silk damping Cosmic Scenarios: Power spectra Cold Dark Matter, Hot Dark Matter non-Gaussian perturbations	December 6(w)	<u>Spherical Collapse & Model</u>
5	December 12 (c)	<u>Mapping the Universe</u>	December 13 (w)	<u>Power Spectrum &</u>

	December 15 (c)	<p>Galaxy sky surveys Galaxy redshift Surveys Lensing Surveys</p> <p><u>The Cosmic Web Observed</u> Cosmic Web: Filaments, Sheets and Voids Clusters of Galaxies</p>		<u>Spherical Model</u>
6	December 19 (c) December 22 (c)	<p>Analysis of the Large Scale Structure <u>Correlation functions</u> Counts in Cells <u>Power spectrum</u> Higher-order statistics Topology: Genus, Minkowski functionals, Betti numbers</p> <p>Cosmic Web Analysis Tessellation Analysis, DTFE, Phase Space Sheet Multiscale Morphology Filter Watershed (Void Finder) Morse Theory, Skeleton & Cosmic Spine</p>	December 20 (w)	<u>Two-point correlation function</u> (computer task)
7	January 9 (c) January 12 (c)	<p>Hierarchical clustering: Press-Schechter and Excursion set formalism Peak-patch formalism Cosmic Tidal Fields & Cosmic Web Theory</p> <p>Virialization Cooling and Galaxy Formation Halo Model Biasing</p>	January 10 (w)	Press-Schechter Formalism & Halo Mass Functions

		<p><u>Nonlinear Structure Formation: N-body models</u> N-body simulation techniques Cosmological Hydro simulation techniques Cosmological Computer Simulations: Cluster Simulations Large Scale Structure simulations</p>		
8	<p>January 16 (c)</p> <p>January 19 (c)</p>	<p>Intergalactic Medium: Lyα forest & WHIM Gravitational Lensing, Cosmic Shear Dark Ages, First Stars & Reionization</p> <p><u>Cosmic Microwave Background Anisotropies</u> CMB anisotropies, temperature perturbations CMB anisotropies, experiments & satellites CMB anisotropies, analysis & maps</p> <p>CMB anisotropies, secondary perturbations CMB anisotropies, polarization</p>	January 17 (w)	<p><u>N-body Simulations</u> (computer task)</p>

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