

Cosmic Structure Formation

Lecture course
University of Groningen
September 2018–October 2018

Practical Matters

Lectures:

Kapteynborg

tuesday 15:00-17:00

friday 13:00-15:00

friday 15:00-17:00

Kapteynborg 5419 - 237

Kapteynborg 5419 - 237/230/
105/103

Kapteynborg 5419 - 161

Lectures:

Rien van de Weygaert

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Tutorials:

Olmo Piana

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piana@astro.rug.nl

Website:

www.astro.rug.nl/~weygaert/lss2018.html

Lecture Room Schedule

Lectures Rooms:

tuesday 15:00-17:00

Kapteynborg 5419 - 237

friday 13:00-15:00

Sept. 7

Kapteynborg 5419 - 237

Sept. 14

Kapteynborg 5419 - 105

Sept. 21

Kapteynborg 5419 - 105

Sept. 28

Kapteynborg 5419 - 105

Oct. 5

Kapteynborg 5419 - 230

Oct. 12

Kapteynborg 5419 - 103

Oct. 19

Kapteynborg 5419 - 105

Oct. 26

Kapteynborg 5419 - 237

friday 15:00-17:00

Kapteynborg 5419 - 161

Exam:

wed. Oct. 31 14:00-17:00

Kapteynborg 5419 - 161

Tracing the Cosmic Web

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

Scientific
Organizers

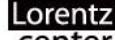
- Noam Libeskind, AIP Potsdam
- Rien van de Weygaert, U Groningen

Scientific
Organizing
Committee

- Yehuda Hoffman, HUJI Jerusalem
- Francisco Kitaura, AIP Potsdam
- Sergei Shandarin, KU Lawrence
- Thierry Sousbie, IAP Paris
- Elmo Tempel, UTartu

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

Gallery: Intergalactic gas and dark matter aggregate in a complex network, known as the 'cosmic web'. Image: R. Kaehler, O. Hahn, T. Abel. Processing: N. Bos. Poster design: SuperNova Studios, NL.

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 Tammi
Elmo Tempel
Jaan Einasto

Tallinn, Estonia

June 23-28, 2014
www.iau-zeldovich.org



Exam

Three Constituents:

1. Exam (written) 65% wed. Oct 31

2.1 Tutorial Assignments (mandatory) 15%

2.2 Computer Assignments 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 shown that it has been forming since the earliest times in the Universe, representing a universal phase in the gravitationally driven emergence and evolution of cosmic structure. IAU Symposium 308, held in Tallinn, Estonia, in June 2014, honored 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 large-scale structure of the matter field 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
Volume 308
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 broad overview of the field, with contributions by leading scientists; these books are at a level suitable for research astronomers and graduate students.



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IAU Symposium
308
23–28 June 2014
Tallinn, Estonia

The Zeldovich
Universe:
Genesis and
Growth of the
Cosmic Web

van de
Weygaert,
Shandarin,
Saar,
Einasto



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Proceedings of the International Astronomical Union

The Zeldovich Universe: Genesis and Growth of the Cosmic Web

Edited by

Rien van de Weygaert
Sergei Shandarin
Enn Saar
Jaan Einasto



"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 can model the Universe with a precision that no one would have been unthinkable. The book provides a comprehensive account of how this has been achieved.

It tells the story of how we arrived 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 the theory of the Big Bang, the theory of 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.

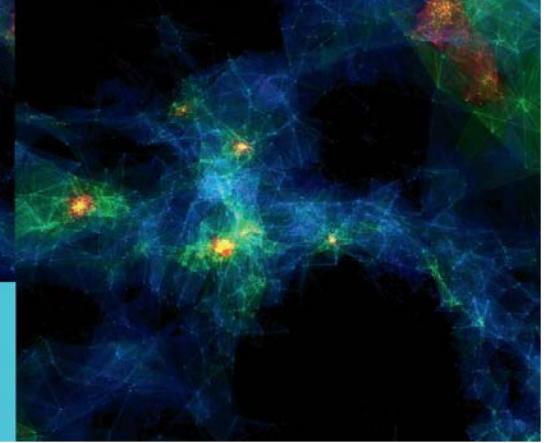
Bernard J. T. Jones is Emeritus Professor in Astronomy at the University of Groningen. His research has covered many areas of astrophysics, the Sun and stars, and cosmology, with a particular emphasis on cosmology where he is widely published and cited.



BERNARD J. T. JONES

PRECISION COSMOLOGY

THE FIRST HALF MILLION YEARS



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 exposé 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	September 4 (c) September 7 (c)	Introduction: Cosmic Inventory: Large Scale Structure & Cosmic Structure Formation Galaxies, Groups, Clusters, Superclusters, IGM Cosmic Structure Formation Primordial Fluctuations & the Cosmic Microwave Background Basic Cosmology: Einstein Field Equation, Cosmological Principle, Robertson-Walker metric, Redshift, Cosmic Distances Friedman Equations Cosmic Epochs	September 7 (w)	FRW Cosmology FRW universe solutions Observational Cosmology

2	<p>September 11 (c)</p> <p>Gravitational Instability: <u>(Linear) Perturbation Theory</u>, Structure Growth</p> <p>September 14 (c)</p> <p>Cosmic Components & Influence on Cosmic Structure Formation: Radiation, Matter: Baryonic Matter & Dark Matter Dark Energy <u>Cosmic Flows</u></p>		<p>September 14 (w)</p>	<p>Perturbation Theory Growth Factors</p>
3	<p>September 18 (c)</p> <p>Random Density & Velocity Fields Multidimensional Gaussian distributions Filtering Power Spectrum <u>Random Fields & Power Spectrum</u></p> <p>September 22 (c)</p> <p><u>Nonlinear Clustering & Structure Formation</u> Hierarchical Clustering, Anisotropic Collapse and the Formation of Voids Spherical Model, Ellipsoidal Model</p>		<p>September 22 (w)</p>	<p>Perturbation Theory Growth Factors</p>
4	<p>September 25 (c)</p> <p>Lagrangian Perturbation Theory Zel'dovich formalism Adhesion approximation</p> <p>September 28 (c)</p> <p>Phase Space Dynamics Phase Space Sheet</p> <p>Matter Scales Jeans Mass, Silk damping Cosmic Scenarios: Power spectra Cold Dark Matter, Hot Dark Matter</p>		<p>September 28(w)</p>	<p>Spherical Collapse & Model</p>

		non-Gaussian perturbations		
5	October 2 (c)	<u>Mapping the Universe</u> Galaxy sky surveys Galaxy redshift Surveys Lensing Surveys	October 5 (w)	<u>Power Spectrum & Spherical Model</u>
	October 5 (c)	<u>The Cosmic Web Observed</u> Cosmic Web: Filaments, Sheets and Voids Clusters of Galaxies		
6	October 9 (c)	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	October 12 (w)	<u>Two-point correlation function</u> (computer task)
	October 12 (c)	Cosmic Web Analysis Tessellation Analysis, DTFE, Phase Space Sheet Multiscale Morphology Filter Watershed (Void Finder) Morse Theory, Skeleton \& Cosmic Spine		
7	October 16 (c)	Hierarchical clustering: Press-Schechter and Excursion set formalism Peak-patch formalism Cosmic Tidal Fields & Cosmic Web Theory Virialization Cooling and Galaxy Formation Halo Model	October 19 (w)	Press-Schechter Formalism & Halo Mass Functions

		Biasing <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		
8	October 23 (c) October 26 (c)	Intergalactic Medium: Lyα forest & WHIM Gravitational Lensing, Cosmic Shear Dark Ages, First Stars & Reionization <u>Cosmic Microwave Background Anisotropies</u> CMB anisotropies, temperature perturbations CMB anisotropies, experiments & satellites CMB anisotropies, analysis & maps CMB anisotropies, secondary perturbations CMB anisotropies, polarization	October 26 (w)	<u>N-body Simulations</u> (computer task)

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