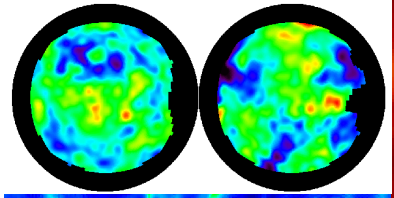
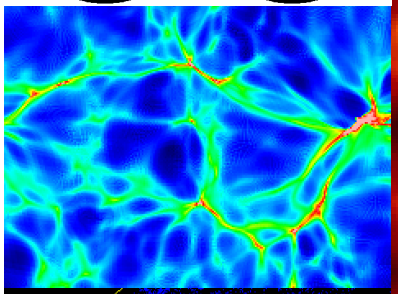
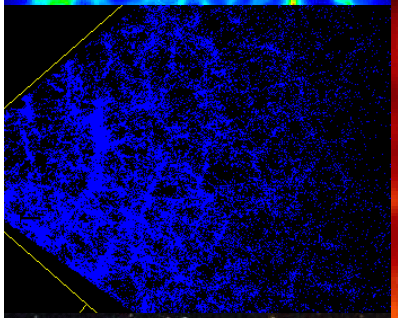






# HET VROEGE HEELAL

INTERACADEMIAAL COLLEGE STERRENKUNDE

2003

INTERUNIVERSITY LECTURES ASTRONOMY

# THE EARLY UNIVERSE

| | | | |
|---|---|---|---|
| • | Feb 5 | the GLOBAL UNIVERSE: fundamentals | Rien van de Weijgaert/ Peter Katgert |
| • | Feb 19 | OBSERVATIONAL COSMOLOGY | Peter Katgert |
| • | Mar 5 | QUANTUM COSMOLOGY and the VERY EARLY UNIVERSE | Bob Sanders |
| • | Mar 19 | BARYOSYNTHESIS and NUCLEOSYNTHESIS | Leo van den Horn/ Jan Smit |
| • | Apr 2 | STRUCTURE FORMATION | Rien van de Weijgaert |
| • | Apr 16 | MICROWAVE BACKGROUND | Rien van de Weijgaert |
| • | May 7 | INFLATIONARY UNIVERSE | Bram Achterberg |
| • | May 14 | HIGH REDSHIFT UNIVERSE | Paul van der Werf |
| • | May 28 | VIOLENT UNIVERSE: QUASARS, AGNs and GRBs | Peter Barthel |
| • | Jun 4 | workshop "the YOUTHFUL COSMOS" | (Kapteyn Institute, Groningen) |

coordinator: Rien van de Weijgaert - weygaert@astro.rug.nl
website: www.astro.rug.nl/∼weygaert/iac2003.html

LECTURES: UNIVERSITEIT UTRECHT, UITHOF
ZAAL 208, MINNAERTGEBOUW
(May 14/28: Grote Zaal Aardwetenschappen)
WEDNESDAY 11:00-15:45
Utrecht CS-Uithof: BUS 11 or 12

# THE EARLY UNIVERSE

INTERACADEMIAAL COLLEGE STERRENKUNDE

2003

INTERUNIVERSITY LECTURE SERIES ASTRONOMY

In a series of nine lectures – starting February 5, location Uithof in Utrecht – the "Early Universe" program intends to provide an interested audience of advanced undergraduate ($3^{rd}$ year onward) and beginning graduate students an overview and understanding of the the earliest epochs of our Universe. Along with a presentation of the latest exciting new developments and often mind-boggling theories, the lectures will provide a solid physical and astronomical background on a wide range of relevant topics. The intention is to equip the students with the skills and knowledge to allow a proper and critical assessment of the flow or, rather, avalanche of new results reaching us almost daily ...

The very first moments of the Big Bang, still the realm of speculative contemplation. The early phases and processes prior to the recombination epoch, hidden from vision yet unlocked by our physical understanding and intuition. The postrecombination Universe, following the splendour of the Microwave Background. Passing through a Dark Age before reviving in a spectacular Renaissance. Signalled by a burst of forming stars and galaxies accompanying the emergence of cosmic structure we witness the genesis of the magnificent astrophysical world surrounding us. And ... its Dark Lords, Dark Matter and Dark Energy, whose power appears to rule over history and fate ...

All this, and more, will form the stage cast of this lecture course. All centering around *THE* question of eons past and present, '*HOW* and *WHEN* did it all begin ???' ... and even, perhaps, ...

... '*??? WHY ???*' ...

## PARTICIPANTS

The lecture course is intended for students astronomy, astrophysics and also (theoretical) physics, starting from 3rd year undergraduate onward. Also beginning graduate students are more than welcome to follow the course.

## REQUIREMENTS

While there are no particular requirements with respect to the background of astrophysics courses of the students, and one does not necessarily need to have followed a basic course in cosmology (the course will take care to include all necessary cosmology "basics"), the lecturers will presume all students to be familiar with basic knowledge of physics at the level of third year undergraduate.

Cosmology, and in particular the aspect of the early Universe, involves many different fields of physics, from basic Newtonian classical mechanics to advanced quantum physics and general relativity. While based upon the usual 3rd year undergraduate background of physics, the more advanced physics will be treated in the relevant lecture when deemed necessary.

## IAC2003 COORDINATOR

The coordinator of the lecture series is Rien van de Weijgaert from the Kapteyn Institute in Groningen. For any relevant issue concerning the course, such as participation, examination procedures, lecture notes, you are welcome to contact him at:

Rien van de Weijgaert
Kapteyn Astronomical Institute
University of Groningen
P.O. Box 800
9700 AV Groningen

tel. 050-3634086
e-mail: weygaert@astro.rug.nl
website: www.astro.rug.nl/~weygaert/

# LECTURERS


- Prof. dr. A. Achterberg — Sterrenkundig Instituut Utrecht, Universiteit Utrecht, e-mail: A.Achterberg@astro.uu.nl
- Dr. P.D. Barthel — Kapteyn Instituut, Rijksuniversiteit Groningen, e-mail: pdb@astro.rug.nl
- Dr. L.J. van der Horn — Instituut voor Theoretische Fysica & Sterrenkundig Instituut Anton Pannekoek (CHEAF), Universiteit van Amsterdam, e-mail: vdhorn@science.uva.nl
- Dr. P. Katgert — Sterrewacht Leiden, Universiteit Leiden, e-mail: katgert@strw.leidenuniv.nl
- Prof. dr. R.H. Sanders — Kapteyn Instituut, Rijksuniversiteit Groningen, e-mail: sanders@astro.rug.nl
- Prof. Dr. J. Smit — Instituut voor Theoretische Fysica, Universiteit van Amsterdam & Instituut voor Theoretische Fysica, Universiteit Utrecht, e-mail: jsmit@science.uva.nl
- Dr. P. van der Werf — Sterrewacht Leiden, Universiteit Leiden, e-mail: pvdwerf@strw.leidenuniv.nl
- Dr. R. van de Weijgaert — Kapteyn Instituut, Rijksuniversiteit Groningen, e-mail: weygaert@astro.rug.nl

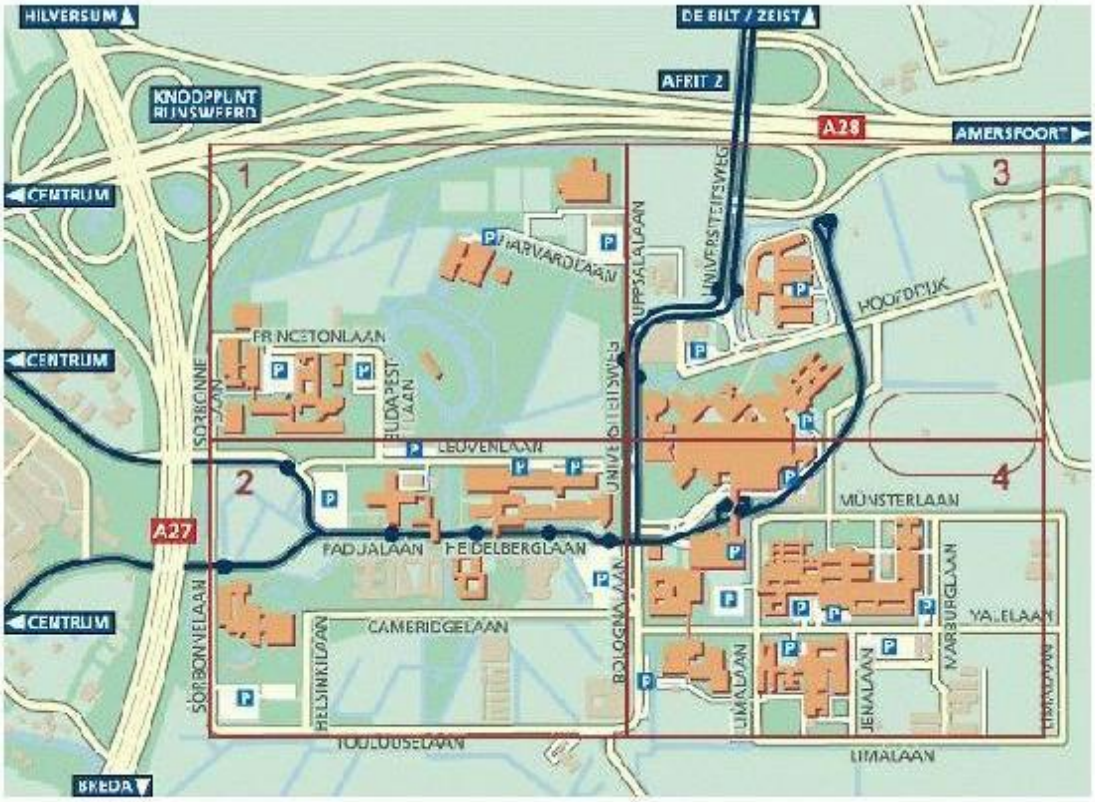
# LECTURE VENUE AND DATES

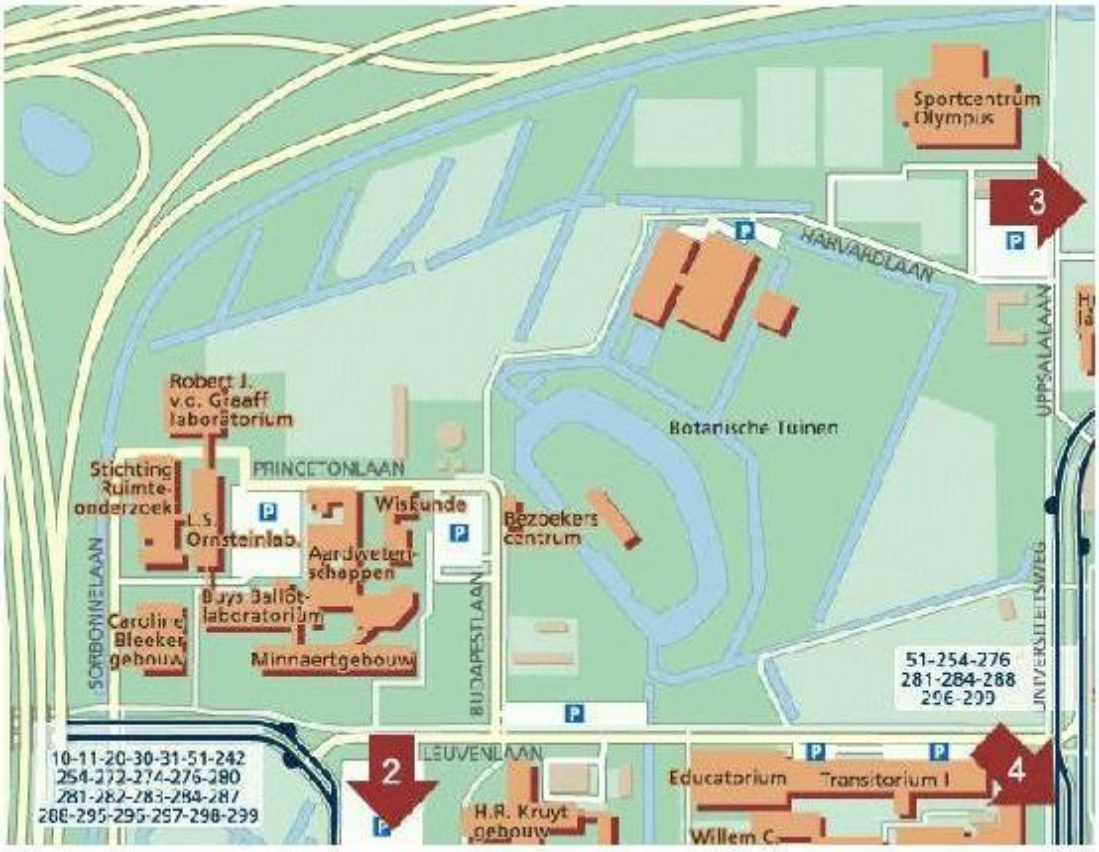
The lectures will be presented on 9 wednesdays in the months of February until May 2003, mostly with two week intervals. The lectures will mainly consist of 'hoorcolleges'. Each lecture will address a specific aspect relevant to the them of the 'Early Universe'. A lecture day will consist of 4 lecture hours of each 45 minutes, starting from 11:00 till 12:45 and from 14:00 till 15:45, marked by a lunchbreak and two coffeebreaks.

The main venue of the lectures will be lecture hall 208 in the Minnaert gebouw on the Uithof campus of the University of Utrecht. For those of you who are not acquainted with the geography of the location, the Minnaertgebouw is the beautiful dark red-brown building with its pillars expressing its name. The exceptions are the May 14 and 28 lectures, for which we take refuge in the adjacent Earth Sciences building, 'Grote Zaal':

| | |
|---|---|
| Location: | Universiteit Utrecht, Uithof |
| Lecture Hall: | Minnaertgebouw, Zaal 208<br>(May 14/28:<br>Grote Zaal, Aardwetenschappen) |
| Lecture Day & Time: | wednesdays, 11:00-15:45 |
| Public Transport: | Train: Utrecht CS<br>Bus: Utrecht CS-Uithof<br>nr. 11 or 12 |

The lecture days are Feb. 5, Feb. 19, Mar. 5, Mar. 19, Apr. 2, Apr. 16, May 7, May 14 and May 28. Mark them in your agendas ! For the lecture schedule see next page, as well as the announcement poster.


HILVERSUM
DE BILT / ZEIST
KNOOPPUNT
AFRIT 2
A28
AMERSFOORT
CENTRUM
HARVARDLAAN
UPPSALALAAN
UNIVERSITEITSWEG
HOOFDDIJK
PRINCETONLAAN
BUDAPESTLAAN
LEUVENLAAN
SORBONNELAAN
MÜNSTERLAAN
A27
PADUALAAN
HEIDELBERGLAAN
CAMBRIDGELAAN
HELSINKILAAN
BOLOGNALAAN
YALELAAN
HARVARDLAAN
LIMALAAN
JENALAAN
TOULOUSELAAN
BREDA


Sportcentrum Olympos
HARVARDLAAN
UPPSALALAAN
Robert J. v.d. Graaff laboratorium
Botanische Tuinen
PRINCETONLAAN
Stichting Ruimte-onderzoek
L.S. Ornsteinlab.
Wiskunde
Bezoekers centrum
Aardwetenschappen
Buys Ballot-laboratorium
Carolina Bleeker-gebouw
Minnaertgebouw
SORBONNELAAN
BUDAPESTLAAN
UNIVERSITEITSWEG
LEUVENLAAN
Educatorium
Transitorium I
H.R. Kruyt gebouw
Willem C.

# EXAMINATION

The lecture series' examination will consist of a report ('scriptie') on a specific subject related to Cosmology and the Early Universe. The reports should testify of the student's mastering of the subject, in terms of knowing the key literature, realizing the key issues and the various existing viewpoints and opinions, having insight in the material, perhaps even to the extent of including some original research (small calculation).

Once a report has been approved, the student should make an appointment with the lecturer for an oral evaluation and discussion on the report. In this "interview" the student is also expected to display knowledge and understanding of the material treated in the lectures. That is, the students are expected to have studied the lecture notes ! The final mark will be based upon the report in conjunction with the oral review. The coordinator will collect all marks and see to it that they are informed to the appropriate university.

Each lecturer will define a few topics for a report. The full listing of all possible subjects will be made available to **all students** and **at the same time**, towards the latter part of the lecture course. **Note** that each topic may be chosen only once ! Once a student has selected and registered a topic, the topic will no longer be available to the others.

When a decision on a topic has been reached, the student should contact immediately the coordinator to allocate it (preferrably by e-mail: weygaert@astro.rug.nl). Once approved, the student may contact the related lecturer for further deliberation on practical matters, further specification and suggestions of relevant literature, etc. Although the intention is for students to work on the topic individually, it will be allowed for two students to work on a report together. This will depend on the permission of coordinator and lecturer ! They will also decide on the definition of (somewhat heavier) requirements on the resulting report. Also in exceptional cases, the students may contact a lecturer with an *original* suggestion for a topic. If the lecturer and coordinator approve upon this, the student may take this as topic for the report.

In due time further information will be posted in due on the IAC2003 website,

http://www.astro.rug.nl/∼weygaert/iac2003.html

while we will also distribute this information at the lectures.

## "WORKSHOP"

The intention is to conclude the lecture course in an appropriate way, providing an impression of the excitement and activity in this research field. To that end a small informal workshop is planned, to take place on wednesday June 4, at the Kapteyn Institute in Groningen. It should give an idea of the cosmological research activities in the Netherlands, to taste the flavour of ongoing projects and research and to experience the pulse of new discoveries ... Experts from astronomical and theoretical physics institutes in the Netherlands, and perhaps beyond, will be asked to tell about their recent work and results. And, of course, also the students are more than welcome to contribute themselves ...

## IAC 2003 WEBSITE

The lecture course has a website:

http://www.astro.rug.nl/~weygaert/iac2003.html

The website will serve various purposes:

- *Practical Information*: the coordinator will strive to post all relevant information on the lecture course on the website, and will seek to keep it up-to-date as much as possible.
- *Lecture notes*: It is also the intention to post the lecture notes of the various lecturers on the website.
- *Links*: links to informative and important cosmology related websites (It is, after all, the season of MAP !!!!).

Also, the intention is to assemble a collection of relevant material and images concerning new (or established) results.

## ANNOUNCEMENT POSTER

Directly relevant information can be obtained from the announcement posters, widely distributed among the various Dutch astronomical institutes. Also to be found on the website of the lecture series:

http://www.astro.rug.nl/~weygaert/tim1publicpic/iac2003.poster.a3.jpg

## LECTURE SCHEDULE and SUBJECTS

| | | |
|---|---|---|
| Feb 5 | the Global Universe fundamentals | *Rien van de Weijgaert/ Peter Katgert* |
| Feb 19 | Observational Cosmology | *Peter Katgert* |
| Mar 5 | Quantum Cosmology and the Very early Universe | *Bob Sanders* |
| Mar 19 | Baryosynthesis and Nucleosynthesis | *Leo van den Horn/ Jan Smit* |
| Apr 2 | Cosmic Structure Formation | *Rien van de Weijgaert* |
| Apr 16 | Cosmic Microwave Background | *Rien van de Weijgaert* |
| May 7 | the Inflationary Universe | *Bram Achterberg* |
| May 14 | the High Redshift Universe | *Paul van der Werf* |
| May 28 | the Violent Universe: Quasars, AGNs and GRBs | *Peter Barthel* |
| Jun 4 | workshop "the YOUTHFUL COSMOS" | (Kapteyn Institute, Groningen) |

# LECTURE OUTLINE

The following subjects are expected to be treated in the lecture course (no pretension to be complete):

- **The Global Universe**.

- *Peter Katgert, Sterrewacht Leiden, UL &*
  *Rien van de Weijgaert, Kapteyn Institute, RUG*
- *February 2*
- Introduction General Relativistic Cosmology. The Cosmological Principle. Robertson-Walker metric: open, closed and flat spatial models. Spherically symmetric solutions: Friedmann solutions. The expansion of the Universe. Horizons. Extrapolation to early phases: the Hot Big Bang. Thermodynamics and thermal history of the Universe. Successes of the Hot Big Bang model.

- **Observational Cosmology**.

- *Peter Katgert, Sterrewacht Leiden, UL*
- *February 19*
- Observational tests of RW geometries: redshift z, cosmological distances, Hubble's law, Hubble diagram, angular diameter, apparent intensities, number counts, age of the Universe. Friedmann-Robertson-Walker cosmological parameters: observational tests and constraints on $H_0$, $\Omega_0$, $\Lambda$. Dark Matter: characteristics, distribution and constraints. Cosmological constant ? The galaxy distribution: large scale structure of the Universe. Microwave Background observations.

- **Quantum Cosmology and the Very Early Universe**.

- *Bob Sanders, Kapteyn Institute, RUG*
- *March 5*
- Beyond the Standard Model. Grand Unified Theories. Supersymmetry. Towards the Planck Epoch. Cosmological Singularity Theorem. Quantum Cosmology. String Cosmology. Cosmology and Extra Dimensions. Braneworld cosmologies. Multi-Universe Cosmologies. Self-reproducing inflationary Universe. Cyclic Universes. Quintessence.

- **Baryosynthesis and Nucleosynthesis**.
- *Jan Smit, Instituut voor Theoretische Fysica, UvA, &*
  *Instituut voor Theoretische Fysica, UU*
  *Leo van den Horn, Instituut voor Theoretische Fysica &*
  *Sterrenkundig Instituut Anton Pannekoek (CHEAF), UvA*
- *March 19*
- Thermodynamics and Expansion. Freeze-out: Origin of Species. Entropy of the Universe. Neutrino Cosmology. Baryon Asymmetry. CP-violation. Lepton Asymmetry. Out-of-Equilibrium Decay. Baryogenesis. Nuclear Statistical Equilibrium. Production of Light Elements: primordial nucleosynthesis. Primordial abundances: predictions and observations. Primordial nucleosynthesis as probe of cosmological parameters.

- **Cosmic Structure Formation**
- *Rien van de Weijgaert, Kapteyn Institute, RUG*
- *April 2*
- Gravitational Instability Theory. Jeans Instability. Cosmological Mass scales. Fluctuation characteristics. Origin of fluctuations: inflation. Random Gaussian fluctuations. Power Spectrum and Power Spectrum generation. Linear fluctuation theory. Nonlinear stages: spherical and ellipsoidal Models. Nonlinear models: Zel'dovich approximation. Nonlinear models: N-body simulations, techniques & examples state-of-the-art results. Hierarchical Structure formation. Press-Schechter formalism.

  Cosmological Fossils. The spatial distribution of galaxies: galaxy sky and redshift surveys. The cosmic foam, clusters, superclusters and filaments, voids. Cosmological velocity flows and galaxy peculiar velocities. Gravitational Lensing. The Microwave Background perturbations.

- **Cosmic Microwave Background**
- *Rien van de Weijgaert, Kapteyn Institute*
- *April 16*
- Microwave Background Radiation: History. Thermal spectrum. Generation and origin cosmic background photons. Primordial thermalization processes. The cosmic photosphere and optical depth. The physics of recombination. Cosmic microwave background anisotropies: defini-

tions and terminology. The cosmic dipole. Intrinsic microwave background anisotropies: primary fluctuation mechanisms (Sachs-Wolfe effect, acoustic fluctuations, gravitational waves, polarization). Intrinsic microwave background anisotropies: predictions. Observations of CMB anisotropies: COBE (and first MAP results), balloon and earthbound experiments (Boomerang, CBI, etc.), outlook (MAP, Planck). Secondary anisotropies: Sunyaev-Zel'dovich effect and Rees-Sciama effect.

- **The Inflationary Universe**

- *Bram Achterberg, Sterrenkundig Instituut, UU*
- *May 7*
- Shortcomings Standard Cosmology: The Horizon Problem, the Flatness Problem, inhomogeneities, monopole problem. Cosmological Phase transitions. Inflation field dynamics. De Sitter space. Reheating. Density Perturbation generation. Specific Inflationary Models. Inflation and the Cosmological Constant. Quintessence Models.

- **The High Redshift Universe**

- *Paul van der Werf, Sterrewacht Leiden, UL*
- *May 14*
- Theoretical ideas on Galaxy Formation: dissipational galaxy formation, hierarchical galaxy formation, semi-analytical models, simulations. Formation first stars and galaxies. Reionization. High-redshift galaxies: the Hubble Deep Field, Lyman break galaxies, the cosmic star formation history. The Intergalactic Medium: Lyman alpha forest, heavy element systems, etc. The Infrared Background.

- **the Violent Universe**

- *Peter Barthel, Kapteyn Institute, RUG*
- *May 28*
- Quasar Cosmology. The population of active galaxies. Extended radio sources. Emission mechanisms. Evolution of active galaxies. Probing the Universe through AGNs. Black Holes as central engines. Formation of supermassive black holes. The X-ray background. Gamma Ray Bursts: characteristics. The cosmological distribution of GRBs. Cosmological potential GRBs.

# LITERATURE

There will not be a specific prescribed literature list (books) for the course, and students should not feel obliged to acquire any of the recommended books (be it that it is of course always highly recommendable to consult such books in the library). The lecture notes are intended to provide sufficient guidance to follow the course succesfully.

Cosmology is a field combining a broad range of topics from physics and astrophysics. Often the books and papers that form the essential reference for one particular aspect pay less attention to topics covered in other references. And even though there are a few excellent and nearly up-to-date basic cosmology textbooks, none may claim to be the ultimate resource covering all topics of this course in sufficient detail and depth. Certainly given the price of astrophysics textbooks nowadayts, it's hardly warranted to prescribe *ANY ONE* specific book for the course.

Instead, in addition to the lecture notes, we will regularly mention interesting, sometimes seminal, books and scientific publications that may be considered essential material for the motivated student intent on fathoming a particular subject. The students are expected to look up these essential references (library, astro-ph, ADS or elsewise).

Nonetheless, for those who wish to start orienting themselves in the exciting world of the Early Universe, we may already provide some of the key references of cosmological literature, often recommendable and nicely readable texts. In the following, I only list published books, for review papers (usually more up-to-date, and more useful) the student is referred to the lectures themselves.

## General Cosmology Texts

Amongst the large number of available cosmology texts (many with a popular inclination) the following ones cover most relevant aspects, each with a different focus and level of complexity:

cont'd next page

- **Cosmological Physics**
  J. Peacock
  Cambridge Univ. Press, 1999
  *Solid and thorough text on physical cosmology, possibly the best textbook reference of the moment. Highly recommendable general text on cosmology.*

- **Cosmology, the Science of the Universe**
  E. Harrison
  Cambridge Univ. Press, 2000 (2nd ed.)
  *Beautiful textbook on background and foundations of modern cosmology; provides both historical context, visual insight and understanding and genuine essence of cosmology and related (astro)physics. In my view a masterwork and major favorite !*

- **Gravitation and Cosmology**
  S. Weinberg
  Wiley, 1972
  *!!! Classic !!! Focusses on general relativistic background of cosmology. Magnificent book for those looking for a thorough and complete treatment of the physics of the expanding Universe.*

- **Physical Cosmology**
  P.J.E. Peebles
  Princeton Univ. Press, 1993

- **Cosmology, the Origin and Evolution of Cosmic Structure**
  P. Coles, F. Lucchin
  Wiley, 2002 (2nd ed.)

- **Introduction to Cosmology**
  Barbara S. Ryden
  Addison-Wesley, 2002
  *A recent nice introductory level text on cosmology.*

cont'd next page

## Specific cosmology related subjects

Various texts concentrating on specific aspects of cosmology, such as the Early Universe, Observational Cosmology, etc.

- **The Early Universe**
  E. Kolb, M. Turner
  Addison-Wesley, 1990
  *For the 'Early Universe' IAC course possibly the most to-the-point reference. Nice, readable and accessible text providing profound insight on the physics of the early Universe. Highly recommendable book !*

- **Cosmology and Astrophysics through problems**
  T. Padmanabhan
  Cambridge Univ. Press, 1996
  *A book crammed with exercises, at various levels of complexity. Great to test and extend your understanding of standard cosmology course material. Demanding !*

- **Modern Cosmological Observations and Problems**
  G. Bothun
  Taylor & Francis, 1998
  *A very nice basic text on the observational aspects of modern cosmology. Yet, given the rapid progress in cosmological observations it will suffer the same fate as so many recommendable texts on the subject and will be rendered obsolete pretty soon ...*

- **The Cosmological Distance Ladder**
  M. Rowan-Robinson
  Freeman, 1985
  *Extensive treatment of the many aspects involved with cosmological distance information and the cosmic distance ladder. While written quite some time ago it still provides a welcome insight into the intricacies involved in establishing the scale of the Universe.*

cont'd next page

- **3K: The Cosmic Microwave Background Radiation**

  R.B. Partidge

  Cambridge Univ. Press, 1995

  *A useful book on the microwave background, with a specific focus on the observational aspects. Given the recent tremendous advances in the observational study of the angular structure of the cosmic microwave background, a new edition would be warranted.*

## Structure Formation

The large scale structure of the Universe, cosmic structure formation and galaxy formation have dominated in a large fraction of astronomical and astrophysical cosmological research. It concerns a highly active field of research, making it rather difficult to write an up-to-date standard text on the subject. Yet, for the interested student we may identify a few welcome books.

- **Large-Scale Structure of the Universe**

  P.J.E. Peebles

  Princeton Univ. Press, 1980

  *The Classic Reference, the Bible on the subject. Still remains a 'must' for anyone seeking to specialize into the subject. While not an easily readable or accessible text, it contains an amazing amount of relevant material and equations.*

- **Structure Formation in the Universe**

  T. Padmanabhan

  Cambridge Univ. Press, 1993

  *Solid textbook, strong in its solid and detailed attention of the basic physical processes, yet not always simple to follow*

- **Galaxy Formation**

  M. Longair

  Springer Verlag, Astronomy and Astrophysics Library, 1998

  *A very nice text, possibly the best reference for defining and treating the basic (astro)physical processes in combination with frontline research on*

*structure and galaxy formation. A recommendable book for those who wish to make their way into the literature.*

## Collections

Amongst the large number of conference and summerschool proceedings, I would like to draw attention to a few including outstanding collections of reviews and treatises:

- **Critical Dialogues in Cosmology**

  ed. N. Turok

  World Scientific, 1997

  *Very interesting collection of some dozen 'dialogues' on major still unresolved issues in cosmology, with the opposing camps represented by leading cosmologists. Nice and effective way to get insight into the prominent unsettled cosmological issues.*

- **Formation of Structure in the Universe**

  eds. A. Dekel, J.P. Ostriker

  Cambridge Univ. Press, 1999

  *Eleven solid essays by prominent experts on a variety of subjects related to cosmological structure formation. Ranging from galaxy redshift surveys, cosmological N-body simulations to gravitational lensing. Provides a nice overview of current cosmological interests.*

- **The Deep Universe**

  R.G. Kron, M.S. Longair, A. Sandage

  Saas-Fee Advanced Course 23

  Springer Verlag, 1995

  *A nice collection of three Saas-Fee lectures on the high redshift Universe. While not anymore up-to-date, its focus on the basics makes it a highly useful book.*

- **Physics of the Early Universe**.

  eds. J. Peacock, A. Heavens, A. Davies, 1990

  Proc. $36^{th}$ Scottish Univ. Summer School in Physics, Edinburgh, 1989

  NATO Adv. Study Inst.

  *Collection of summerschool contributions on the physics and astrophysics*

*of the early Universe, lectured by prominent scientists. Interesting astrophysical contributions were e.g.*

- Cosmological Perturbations — G. Efstathiou
- Physical Cosmology — S.D.M. White

- **Cosmology and Large Scale Structure**
  eds. R. Schaeffer, J. Silk, M. Spiro, J. Zinn-Justin
  Proc. Les Houches summerschool XV, 1994
  NATO ASI series, Elsevier
  *Solid collection of summerschool contributions, with particular focus on large scale structure and structure formation. Three examples of extensive and important contributions:*

- Theory and Observations of the Cosmic Background Radiation – J.R. Bond
- Observations of large-Scale Structure in the Universe – G. Efstathiou
- Formation and Evolution of Galaxies – S.D.M. White

- **General Relativity and Cosmology**
  ed. B.K. Sachs
  Proc. International School of Physics "Enrico Fermi" XLVII, Varenna, 1969
  Academic Press, 1971
  *Beautiful collection of contributions on relativistic cosmology. Particularly noteworthy references (even 30 years onward) are:*

- General relativity and kinetic theory – J. Ehlers
- Relativistic Cosmology – G.F.R. Ellis

## General Relativity

Useful and even seminal references:

- **General Relativity from A to B**
  R. Geroch
  Univ. Chicago Press, 1981
  *Excellent qualitative discussion and introduction to General Relativity. Highly recommendable for grasping the conceptual background!*

cont'd next page

- **Gravitation**
  C.W. Misner, J.A. Wheeler, K.S. Thorne
  Freeman, 1973
  *The standard reference. A majestic volume with an extensive, elaborate and profound treatment of general relativity. Biblical, also by size !*

- **Relativity: Special, General and Cosmological**
  W. Rindler
  Oxford Univ. Press, 2001
  *(upgraded version of "Essential Relativity", Springer Verlag, 1977)*

- **Problem Book in Relativity and Gravitation**
  A. Lightman, R. Price
  Princeton Univ. Press, 1975
  *Book with a very nice collection of problem sets on various aspects of general relativity. Certainly recommendable for the motivated student.*

## Popular Books

Over the past decades a large number of popular books has been published on cosmological subjects. Some involved solid overviews of scientific developments by prominent scientists themselves while others were written by science writers or journalists. Yet, an entirely different class is that of the semi-autobiographical works written by various cosmologists. Some of the finest and best known examples, "Classics", are the following texts, each highly recommendable,

- **The First Three Minutes**
  S. Weinberg
  New York: Basic Books, 1977

- **The Big Bang**
  J. Silk
  W.H. Freeman, 2001 (3rd. rev. ed.)

cont'd next page

- **A Brief History of Time**
  S. Hawking
  Bantam Books, 1988 (orig), 1998 (10th anniv. ed.)
  The Illustrated Brief History of Time
  Updated and Expanded Edition
- **The Elegant Universe: Superstrings, Hidden Dimensions, and the Quest for the Ultimate Theory**
  B. Greene
  Vintage Books, 2000

## LECTURE NOTES

The lecture notes of the various lecturers will be collected by the coordinator and multiplied to issue a copy to each institute/department with participating students. This way, each participant should be able to get a copy of the notes from the contact person for her/his institute/department.

Also, the lecturers will be urged to write the notes in a format that can be easily picked up from the net (.pdf files). Finally, of course the students are expected to keep their own notes during the lectures. It is important not only to listen passively !