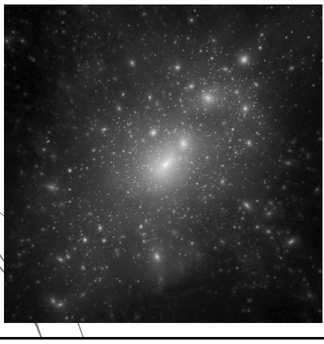
Cosmology AS7009, 2009
Lecture 1



Formal Information

- Organizer:
  - Erik Zackrisson
  - Room C6:1007
  - Telephone: 08-5537 8556
  - E-mail: ez@astro.su.se
- Course homepage:
  - www.astro.su.se/~ez/kurs/Cosmology09.html

Outline for today

- Formal Stuff
  - Course literature
  - Examination
    - Hand-in exercises
    - Seminars
    - Literature exercise
  - Grades
  - Schedule
- Course outline
- Cosmic epochs

Course literature

Introduction to cosmology
Barbara Ryden
ISBN 0-8053-8912-1
Around 500 SEK (e.g. AdLibris, Bokus)

Examination

- Hand-in exercises
  - 3 sets X 3 problems each
- Seminars
  - Seminar I: *Common misconceptions in modern cosmology*
  - Seminar II: *Strange Universe*
- Literature exercise:
  - Written essay (≈ 3 pages)
  - Oral presentation (≈10 minutes)

Hand-in exercises I

- 27 exercises downloadable from the course homepage
- Around 18 exercises will be solved (by me) on the blackboard during the tutorials
- Remember: Much easier to grasp the solutions if you have already attempted to solve these, before going to class!

Hand-in exercises II

- 9 of the exercises are hand-in problems:
  - Somewhat similar to those solved on the blackboard
  - 3 sets with deadlines: Nov 19, Nov 25, Dec 4
  - Access to Matlab or similar software may be very useful in some cases!

Seminars

- 2 Seminars:
  - Seminar I: *Common misconceptions about modern cosmology*
  - Seminar II: *Strange Universe*
- Instructions available from course homepage
- Seminar I – preparation:
  - Read suggested papers + others
  - Answer questions
  - Prepare to present answers and results in class
- Seminar II – preparation:
  - Analyze data set
  - Prepare to present your findings in class

Seminars II

- Purpose:
  - Practice finding and reading relevant research papers
  - Practice analyzing astronomical data
  - Practice critical thinking
  - Practice scientific creativity
  - Practice discussing in front of audience
- What if you cannot attend the seminars?
  - Have to present results in written report before X-mas (→ more work!)

Seminars III

- Seminar I: Nov 16, 10-12

  Common misconceptions about modern cosmology
- Seminar II: Nov 26, 10-12

  Strange Universe

Literature exercise

- Choose topic individually
- Find suitable articles
  - Published papers (ADS abstract service) http://adsabs.harvard.edu/abstract_service.html
  - Preprints: http://www.arxiv.org
- Written report (≈ 3 pages), deadline December 4
- Oral presentation (≈ 10 minutes) December 7, 13-17
- Note:
  - If you cannot meet the deadlines for the written report or the oral presentation, you may hand the report in at some later time (but before X-mas!)
  - But: You will then have to give the oral presentation at one of the Galaxies and Cosmology group meetings (Fridays at 14:00). *This is far scarier! Not recommended!*

Suggested topics I

- Parallel Universes
- Topology of the Universe
- CMBR anisotropies
- Observational indications of varying constants
- Wormholes and time travel
- Cosmic antimatter
- The anthropic principle in cosmology
- Brane cosmology

Suggested topics II

- Off-Broadway:
  - Alternative theories of gravity – in relation to dark matter
  - Alternative theories of gravity – in relation to dark energy
  - Inhomogeneous models – in relation to dark energy
  - Varying speed of light cosmology
- Off-off-Broadway:
  - Quasi Steady-State cosmology
  - Plasma cosmology

But please feel free to suggest other topics!

Grades I

- The total score P_{tot} determines the grade:

A: $P \geq 90$ % of max(P_{tot})
B: P=80-89.9 % of max(P_{tot})
C: P=70-79.9 % of max(P_{tot})
D: P=60-69.9 % of max(P_{tot})
E: P=50-59.9 % of max(P_{tot})
Fx: P=40-49.9 % of max(P_{tot})
F: P<40 % of max(P_{tot})

Grades II

- P_{tot} is made up of 5 components (with equal weights):
  1) Hand-in exercises
  2) Seminar 1
  3) Seminar 2
  4) Literature exercise, written report
  5) Literature exercise, oral report

Note: Failure to meet the deadline for any single component →
The contribution from that component is automatically lowered by 20% of the maximum

Grades III

Example:

1) Hand-in exercises (max 15 p per set of hand-ins):
5 p, 10p, 12p
But: Set 2 handed in late → Subtract 0.2*15 = 3
Hence: 5p + (10-3)p + 12p = 24 p
Contribution to total: 24/45 * 0.2 ≈ 0.11
2) Seminar 1: 3p (out of max 5p)
Contribution to total: 3/5*0.2 = 0.12
3) Seminar 2: 4p (out of max 5p)
Contribution to total: 4/5*0.2 = 0.16
4) Literature exercise, written report: 2p (out of max 5p)
Contribution to total: 2/5*0.2 = 0.08
5) Literature exercise, oral report: 5p (out of max 5p)
Contribution to total: 5/5*0.2 = 0.2

Total: 0.11 + 0.12 + 0.16 + 0.08 + 0.2 = 0.67 (i.e. 67%)
→ Grade D (interval 60-69.9%)

Schedule I

- 10 Lectures
  - L1, Nov 2, 10-12: Course information, course overview
  - L2, Nov 3, 10-12: Fundamentals, Gravity, Curvature (chapters 2-3)
  - L3, Nov 5, 10-12: Metrics, Proper distance, Cosmic dynamics (chapters 3-4)
  - L4, Nov 10, 10-12: Single and Multiple component Universes (chapters 5-6)
  - L5, Nov 11, 10-12: Cosmological parameters and dark energy (chapters 7)
  - L6, Nov 12, 10-12: Dark matter (chapter 8)
  - L7, Nov 17 , 10-12: CMBR (chapter 9)
  - L8, Nov 19, 10-12: BBNS and the early Universe (chapter 10)
  - L9, Nov 23, 10-12: Inflation and the very early Universe (chapter 11)
  - L10, Nov 25, 10-12: Structure formation (chapter 12)

Schedule II

- 3 Exercise sessions:
  - E1, Nov 12, 13-15, Exercises 1-6
  - E2, Nov 17, 13-15, Exercises 7-12
  - E3, Nov 25, 13-15, Exercises 13-18

Schedule III

- 2 seminars
  - Seminar I: Nov 16, 10-12
  - Seminar II: Nov 26, 10-12
- Oral presentation of literature review
  - December 7, 13-17

Schedule IV

- Important dates to remember:
  - November 16, Monday 10-12: Seminar 1
  - November 19, Thursday: Deadline hand-ins 1-3
  - November 25, Wednesday: Deadline hand-ins 4-6
  - November 26, Thursday: Seminar 2
  - December 4, Friday: Deadline hand-ins 7-9 & deadline written report
  - December 7, Monday: Oral presentations

Very crowded around November 16-26 and December 4-7!
Do as much work as possible during
the first two weeks of the course!

How much time will I have to spend on this course?

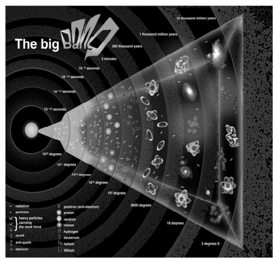
My estimates:

- Attending classes:
  17*2 h = 34 h ~ 4 days
- Studying textbook:
  6 days (two chapters a day)
- Preparing for seminars:
  2 days (one day per seminar)
- Solving exercises (including hand-ins):
  9 days (3 exercises a day)
- Literature exercise: 4 days

Sum: 25 days, i.e. 5 weeks or 7.5 hp

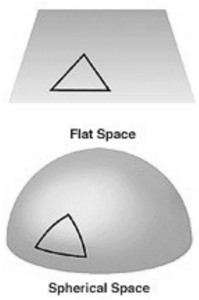
Course Outline

- Lecture 1: Introduction
  - Formal stuff
  - Course outline
  - Cosmic epochs



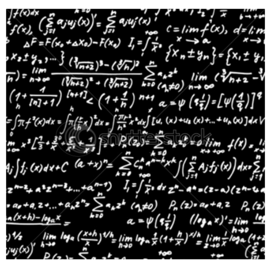
Course Outline

- Lecture 2: Basics
  - Cosmological principle
  - Cosmic expansion
  - Newton versus Einstein
  - Gravity = Curvature
  - Metrics



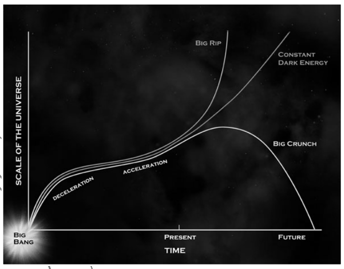
Course Outline

- Lecture 3: Dynamics
  - Robertson-Walker metric
  - Proper distance
  - Computational tools:
    - Friedmann equation
    - Fluid equation
    - Acceleration equation
    - Equation of state
  - Cosmic dynamics



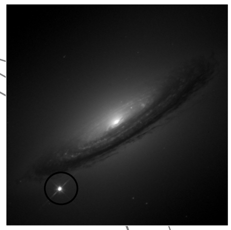
Course Outline

- Lecture 4: Towards a realistic cosmology
  - Dynamics with single and multiple components
  - Concordance cosmology (Benchmark model)
  - Fate of the Universe



Course Outline

- Lecture 5: Cosmological parameters
  - Measuring cosmological parameters
  - Dark energy



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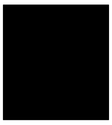
Course Outline

- Lecture 6: Dark matter
  - Evidence for dark matter
  - Baryonic and non-baryonic dark matter
  - Spatial distribution
  - Cold dark matter (CDM)
  - Problems with CDM
  - Dark matter candidates
  - Possible detections
  - Alternatives to dark matter

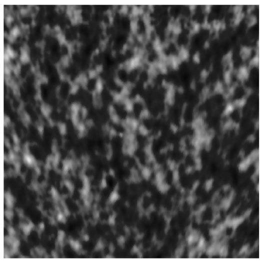


Dark matter

Luminous matter

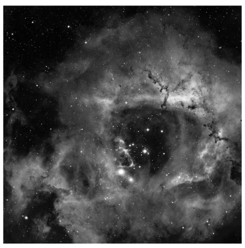
Course Outline

- Lecture 7: The Cosmic Microwave Background Radiation
  - Origin of the CMBR
  - The dipole anisotropy
  - Recombination and decoupling
  - Temperature fluctuations
  - Cosmological information extracted from the CMBR



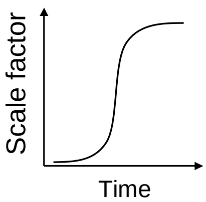
Course Outline

- Lecture 8: Big Bang Nucleosynthesis and the early Universe
  - BBNS
  - Measuring primordial abundances
  - What happened to the antimatter?



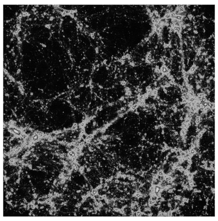
Course Outline

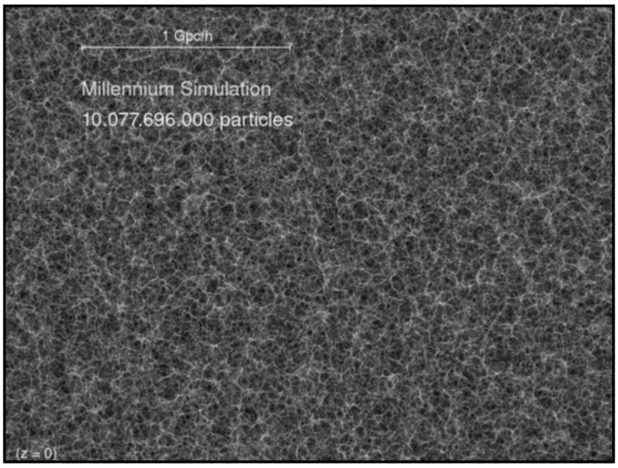
- Lecture 9: Inflation and the very early Universe
  - Problems with a non-inflationary Big Bang
  - Inflation
  - Grand Unified Theories
  - Phase transitions



Course Outline

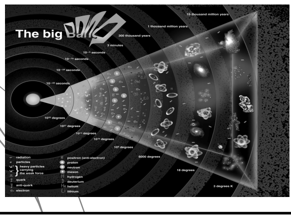
- Lecture 10: Structure formation
  - Perturbation spectrum
  - Jeans mass, Jeans length
  - Hot vs. cold dark matter
  - First light
  - Large scale structure
  - Cosmic reionization



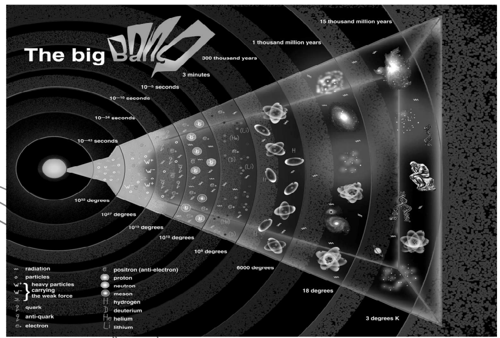


The Big Bang Scenario

- The part of the Universe observable to us today was extremely hot, dense and small ≈ 14 Gyr ago
- The Universe expanded and cooled → cosmic epochs and events



Cosmic epochs



The Planck time

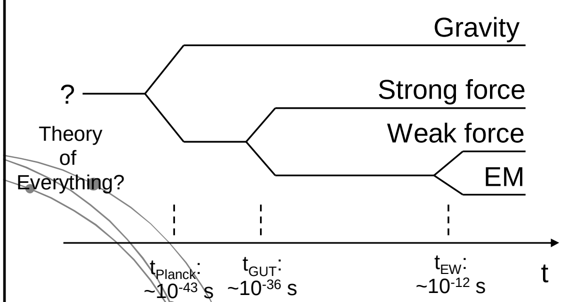
- In extremely early Universe, gravity and quantum effects operate on same scale → General relativity no good anymore! Theory of quantum gravity necessary!

t_{Planck}~10^{-43} s

Prior to the Planck era:
? ? ? ?

Current Big Bang theory only describes what happens at $t>t_{Planck}$

Grand Unification



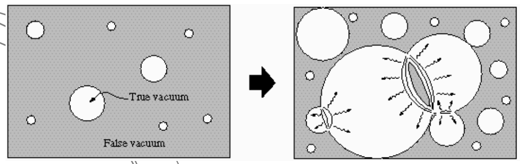
Inflation

- Universe quickly expands by factor ~ 10^{30}
- Inflation finished by $t \sim 10^{-32}$ s
- Solves the flatness, isotropy (horizon) and magnetic monopole problems of the standard Big Bang model
- Quantum fluctuations blown up to cosmic scales $\rightarrow$ seeds for large-scale structure formation later on

Phase transitions

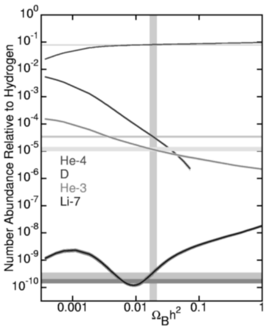
Transitions:
- Grand unification transition: $t \sim 10^{-36}$ s
- Electroweak phase transition $t \sim 10^{-12}$ s
- Quark-hadron transition: $t \sim 10^{-6}$

Defects may have formed:
- Domain walls
- Cosmic strings
- Monopoles
- Textures
- Primordial black holes
- Quark nuggets

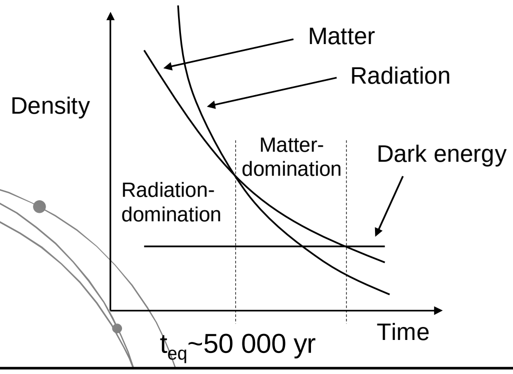


Big Bang Nucleosynthesis

- $t_{BBNS} \sim 100$ s
- Primordial abundances of D, ^{3}He, ^{4}He, ^{6}Li, ^{7}Li, ^{7}Be established

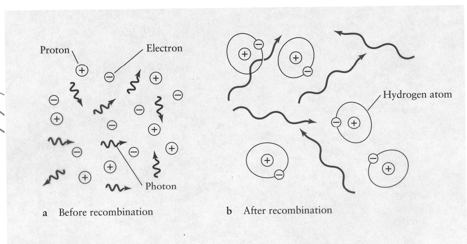


Radiation-dominated era ends and the matter-dominated era begins

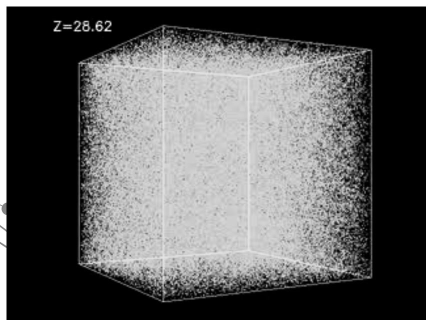


Recombination $\rightarrow$ Cosmic Microwave Background Radiation

- $t_{recomb} \sim t_{CMBR} \sim 0.3$ Myr
- $T_0 \approx 2.73$ K, Black-body spectrum
- Temperature anisotropies on $\Delta T \sim 10^{-5}$ K scale

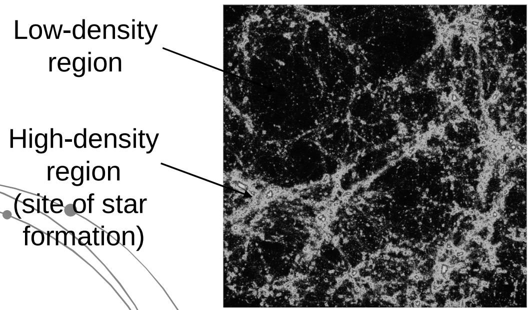


Structure formation I



Cold dark matter scenario

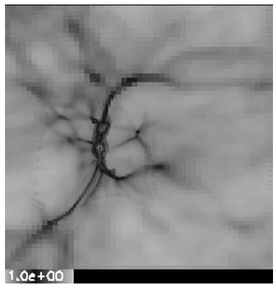
Structure formation II



Voids, walls and filaments

First stars and reionization

- t_{stars}~100 Myr
- $t_{reionization}$~ 100 — 500 Myr



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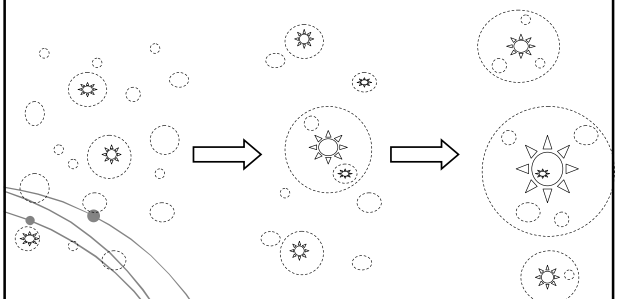
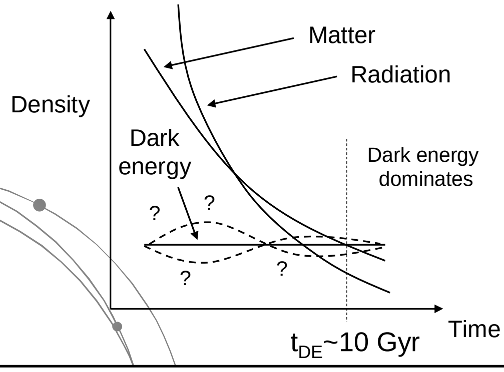
Hierarchical galaxy formation

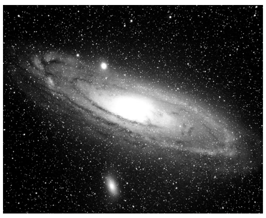


Matter-domination ends and dark energy-domination begins



Today

- $t_0 \approx 13.7$ Gyr
- Astronomical objects up to $z \approx 10$ have been detected
- The cosmic microwave background radiation has $z \approx 1100$



Quite a few unsolved problems…

- What drove inflation?
- What is the dark matter?
- What is the dark energy?
  - How will the Universe end?
- What were the initial conditions?
  - Why is the Universe expanding?
  - Why is there something instead of nothing?
- Why is there more matter than antimatter?
- Is the Universe spatially infinite?
- What caused reionization?
- What came before the Big Bang?
- Are there parallel Universes?