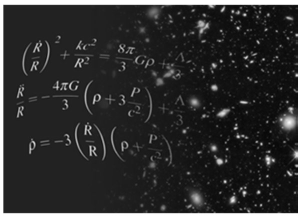
Cosmology 1FA209
2015, 10 credits
Lecture 1: Introduction

Formal Information

- Teacher:
  - Erik Zackrisson
  - Office in the astronomy corrdinor on floor 3 in house 6 – just ring the bell to get in!
  - Telephone: 018-471 5975
  - E-mail: erik.zackrisson@physics.uu.se
- Course homepage:
- http://www.astro.uu.se/~ez/kurs/Cosmology15.html

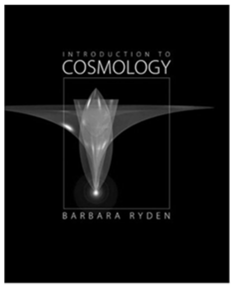
Outline for today

- Formal Stuff
- Course outline
- Cosmic epochs



Course literature

Introduction to cosmology
Barbara Ryden
Editions from 2002/2003 & 2013 – both are OK!
Around 600 SEK (e.g. AdLibris, Bokus)



Examination

- Seminars
  - Seminar I: *Common misconceptions of modern cosmology*
  - Seminar II: *Parallel Universes*
  - Seminar III: *Strange Universe*
- Literature exercise
  - Written essay (≈ 3 pages)
  - Oral presentation (≈10 minutes)
- Hand-in exercises

Hand-in exercises

- 27 exercises downloadable from the course homepage
- A fraction of these 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!
- 6 of the exercises (somewhat similar to the ones solved in class) are hand-in problems
  - Deadline January 22
  - **Grade:** Fail, 3, 4, 5

Seminars

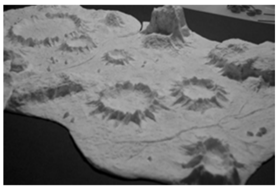
- Instructions available from course homepage
- Purpose:
  - Practice finding and reading relevant research papers
  - Practice analyzing astronomical data
  - Practice critical thinking
  - Practice scientific creativity
  - Practice illustrating abstract concepts
  - Practice discussing in front of audience
- What if you cannot attend the seminars?
  - Have to present results in written report before end of course (→ more work!)

Seminar I

- **Title:** *Common misconceptions about modern cosmology*
- **Grade:** Fail, 3, 4, 5
- Preparation:
  - Read suggested papers + others
  - Answer questions
  - Prepare to present answers and results in class

Seminar II

- **Title:** Parallel universes
- **Grade:** Fail, Pass
- Preparation:
  - Read suggested paper
  - Think about ways to explain the four levels of parallel universes and to create vizualations of these



Seminar III

- **Title:** Strange universe
- **Grade:** Fail, 3, 4, 5
- Preparation:
  - Analyze mock data set
  - Prepare to present your findings in class

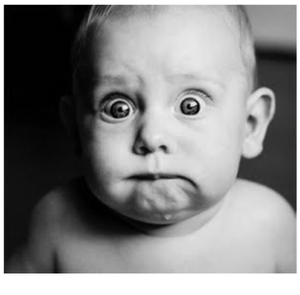
Literature exercise

- 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 January 8
  Grade: Fail, 3, 4, 5
- Oral presentation (≈ 10 minutes)
  January 15 (10-12)
  Grade: Fail, 3, 4, 5

Literature exercise

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: You will then have to give the oral presentation at one of the Galaxies and Cosmology group meetings.
This is far scarier!
Not recommended!



Suggested topics I

- Topology of the Universe
- Strange CMBR anisotropies
- Dark flow
- Varying constants of nature
- Wormholes and time travel
- The anthropic principle in cosmology
- Brane cosmology
- Gravitational waves

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!

Grading

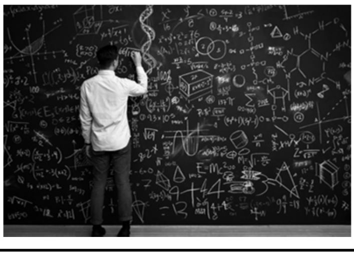
- The final grade will be the mean grade from:
  - Seminar 1
  - Seminar 3
  - Written report on literature exercise
  - Oral presentation of literature exercise
  - Hand-in exercises
- No final grade will be computed until you have a reached a passing grade (3 or higher) for each of these
- Please note that you also need a passing grade from seminar 2 to complete the course

Schedule I

- 9 Lectures
  - L1, Nov 10, 15-17: Course information, course overview
  - L2, Nov 12, 10-12: Fundamentals, Gravity, Curvature (chapters 2-3)
  - L3, Nov 13, 10-12: Metrics, Proper distance, Cosmic dynamics (chapters 3-4)
  - L4, Nov 17, 10-12: Single and Multiple component Universes (chapters 5-6)
  - L5, Nov 19, 10-12: Cosmological parameters and dark energy (chapters 7)
  - L6, Nov 20, 10-12: Dark matter (chapter 8)
  - L7, Dec 1, 10-12: CMBR (chapter 9)
  - L8, Dec 3, 13-15: BBNS, the early Universe, inflation (chapter 10, 11)
  - L9, Dec 11, 13-15: Structure formation (chapter 12)

Schedule II

- 2 Exercise sessions:
  - E1, Nov 24, 13-15, Exercises 1-6
  - E2, Dec 4, 10-12, Exercises 7-12



Schedule III

- 3 seminars
  - Seminar I: Nov 26, 15-17
  - Seminar II: Dec 15, 9-12 (Note: 3 hours!)
  - Seminar III: Jan 13, 13-15
- Oral presentation of literature review
  - Jan 14 & 15, 10-12 – both slots may not be necessary
- Spare slot (in case something else gets cancelled):
  - Dec 17, 10-12

Schedule IV

- Important dates to remember:
  - November 26: Seminar 1
  - December 15: Seminar 2
  - January 8: Deadline for written literature report
  - January 13: Seminar 3
  - January 14/15: Oral presentations
  - January 22: Deadline for hand-in exercises

Pretty crowded in January!
Advice: Do as much work as possible already in November and December

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

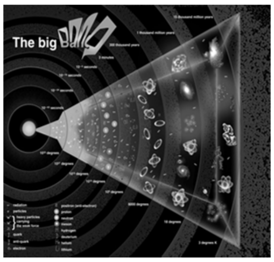
My estimates:

- Attending classes:
  15*2 h = 30 h ~ 4 days
- Studying textbook:
  12 days (one chapter a day)
- Preparing for seminars:
  6 days (two days per seminar)
- Solving exercises (12 in-class exercises + 6 hand-ins):
  6 days (3 exercises a day)
- Literature exercise: 5 days
  (3 days for written report + 2 for oral presenation)

Sum: 33 days, i.e. 6.6 weeks or 10 ECTS

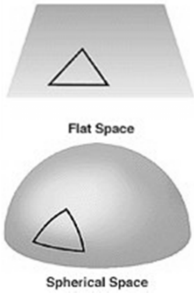
Course Outline

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



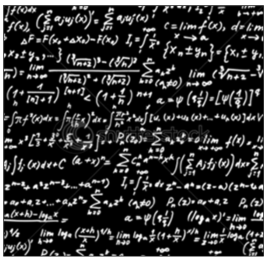
Course Outline

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



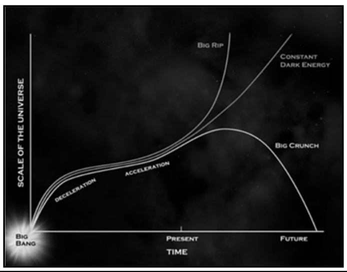
Course Outline

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



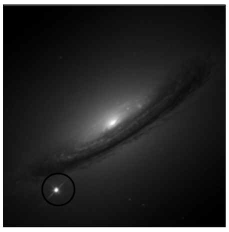
Course Outline

- 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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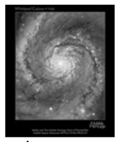
Course Outline

- 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

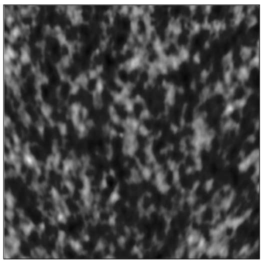
Dark matter



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

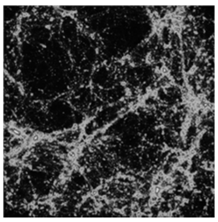


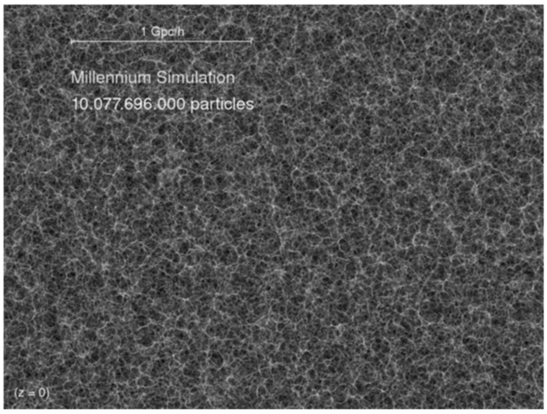
Course Outline

- Lecture 8: Big Bang Nucleosynthesis, the early Universe, cosmic inflation
  - BBNS
  - Measuring primordial abundances
  - What happened to the antimatter?
  - Problems with a non-inflationary Big Bang
  - Inflation
  - Grand Unified Theories

Course Outline

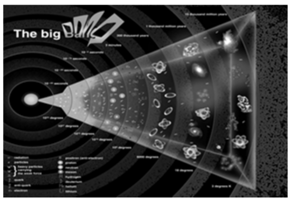
- Lecture 9: Structure formation
  - Perturbation spectrum
  - Jeans mass, Jeans length
  - Hot vs. cold dark matter
  - First light
  - Large scale structure
  - Cosmic reionization



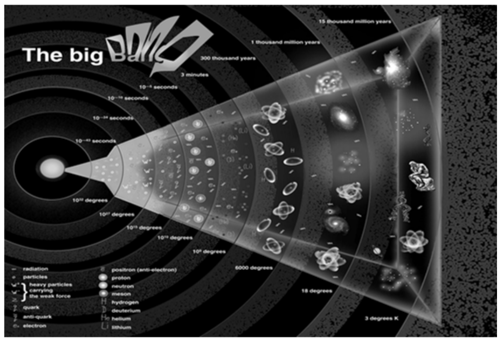


The Big Bang Scenario

- 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

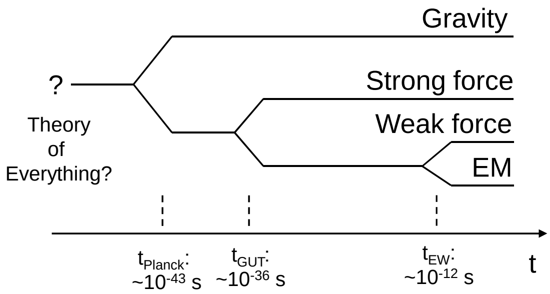
- In extremely early Universe, gravity and quantum effects operate on same scale →
  General relativity no good anymore! Theory of quantum gravity necessary!

$t_{Planck} \sim 10^{-43}$ s

Prior to the Planck era:
? ? ? ?

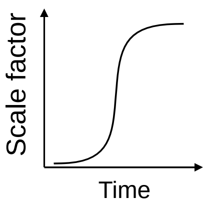
Current Big Bang theory only describes what happens at $t>t_{Planck}$

Grand Unification



Inflation

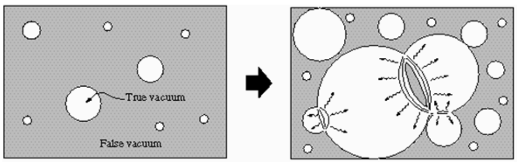
- Universe quickly expands by factor ~ 10^{30}
- Inflation finished by t~10^{-32} s
- Solves the flatness, isotropy (horizon) and magnetic monopole problems of the standard Big Bang model
- Quantum fluctuations blown up to cosmic scales → seeds for large-scale structure formation later on



Phase transitions

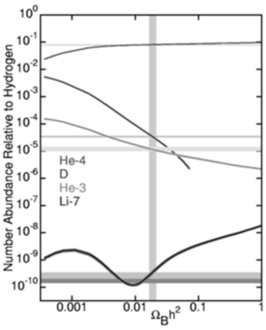
Transitions:
- Grand unification transition: t~10^{-36} s
- Electroweak phase transition t~10^{-12} s
- Quark-hadron transition: t~10^{-6}

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

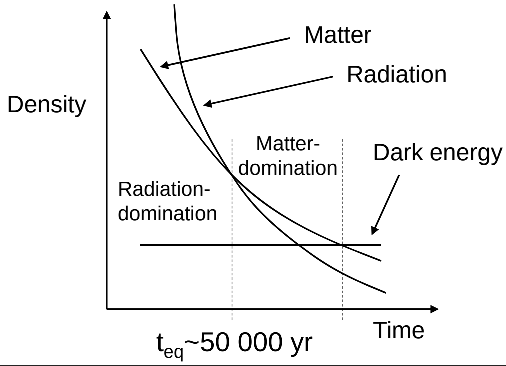


Big Bang Nucleosynthesis

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

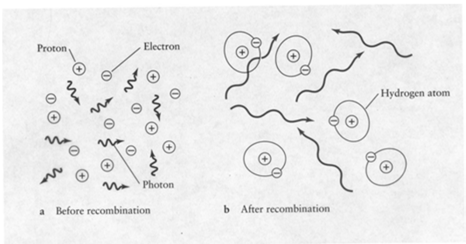


Radiation-dominated era ends and the matter-dominated era begins

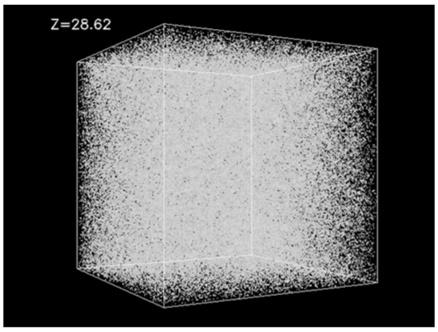


Recombination → Cosmic Microwave Background Radiation

- t_{recomb} ~ t_{CMBR} ~ 0.3 Myr
- $T_o \approx$ 2.73 K, Black-body spectrum
- Temperature anisotropies on ΔT~10^{-5} K scale

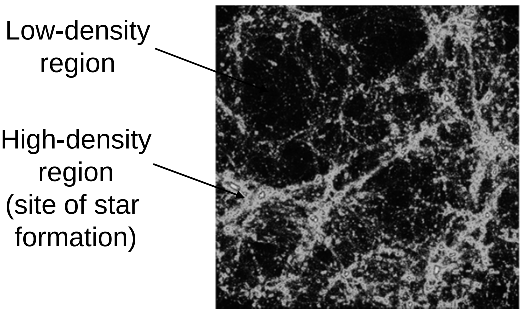


Structure formation I



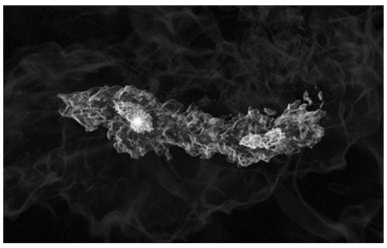
Cold dark matter scenario

Structure formation II



Voids, walls and filaments

First stars and reionization



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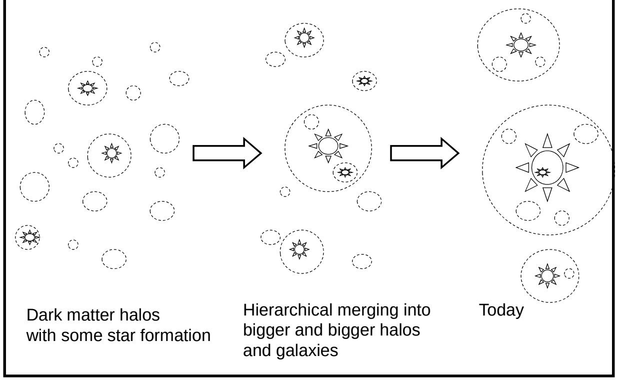
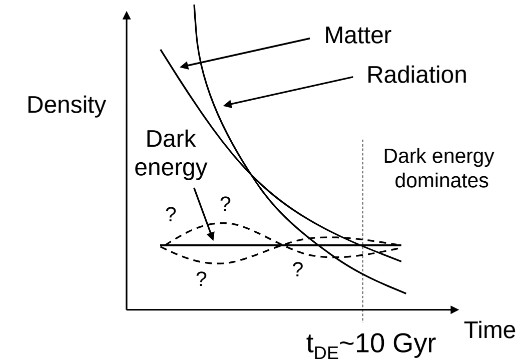
- t_{stars}~0.1 Gyr
- $t_{reionization}$~ 0.1-1 Gyr

Hierarchical galaxy formation



Matter-domination ends and dark energy-domination begins



Today

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