Heraeus cosmology summer school

Haus der Astronomie, 2013

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Heraeus summer schools: astronomy from 4 perspectives

1. Heidelberg 2013: cosmology
2. Padua 2014: active galactic nuclei
3. Jena 2015: gravity
4. Florenz 2016: star formation

motivation

bring modern astrophysics and fascination for astronomy to schools!

venue 2013: Haus der Astronomie

aims of the summer school

- modern cosmology
- explanation of the cosmological standard model
- understanding of the 3 cosmology Nobel prizes
- set current, topical results into relation
- what's behind cosmological observations?
  - cosmic microwave background
  - gravitational lensing
  - galaxy surveys
- topical questions
  - new developments in cosmology
  - current and future observations
- didactical concepts for teaching cosmology in school

cosmology and philosophy

physical cosmology

is cosmology a branch of science?

- repeatability of observations given
- a few fundamental assumptions can never be tested
- observations replace experiments, no active participation in natural processes
- observations of statistical quantities
- fundamental statistical limitations, finite size of the observable universe

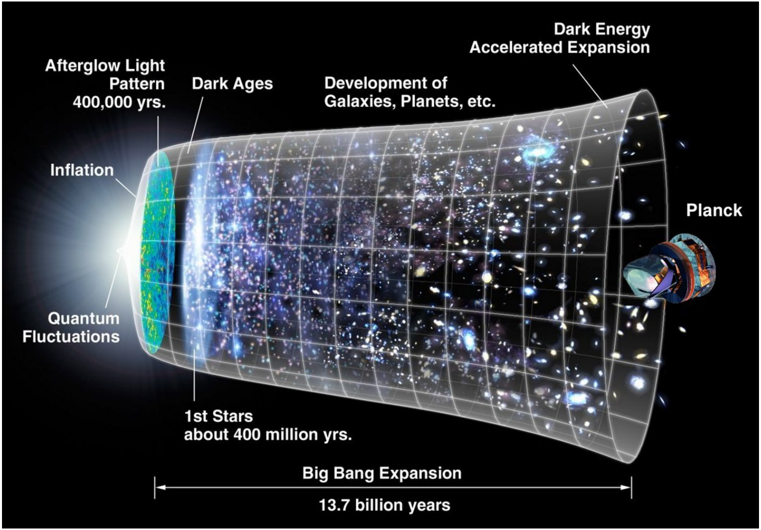
cosmology: typical questions

- why is the Universe described by general relativity?
- is the Universe really that big?
- is the Universe really that old? (common answer: yes, because gravity is so weak!)
- how do structures emerge? how old is the Milky Way?
- is the Universe expanding? into what is it expanding?
- where did the big bang happen? is there a centre of the Universe?
- can one observe the big bang?
- if the Universe expands, is the distance to the moon getting larger?
- where do the chemical elements come from?
- what exactly is the cosmic microwave background?

cosmology as new area of science

- cosmology is a young branch of astrophysics
- physical cosmology exists for about 80 years now
- quantitative theory for dynamical processes in the Universe
- **interdisciplinary**: cosmology joins
  1. general relativity
  2. classical fluid mechanics
  3. modern statistics

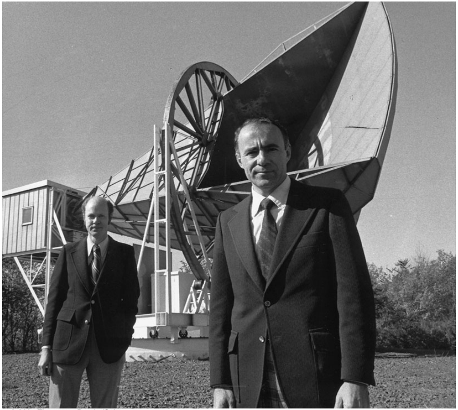
modern cosmology



time line of cosmology

- W. Herschel: star counts, structure of the Milky Way
- E. Hubble: spiral nebulae are galaxies in reality
- H. Shapley, H. Curtis: scale of the Universe
- E. Hubble: motion of galaxies, dynamical world models
- A. Einstein: general relativity
- G. Lemaître: relativistic models of the Universe
- A. Friedmann: expanding cosmologies
- A. Sacharov: synthesis of chemical elements
- J. Peebles: structure formation
- A. Guth: cosmic inflation, initial conditions for structure formation
- M. Rees, S. White: dark matter, ΛCDM-model

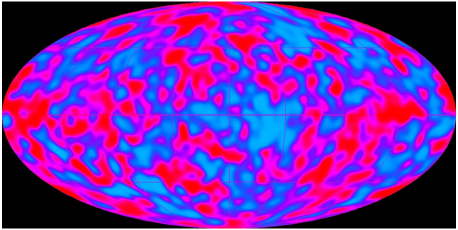
Nobel prize 1978: Penzias and Wilson



Penzias and Wilson in front of the antenna (source: University of Davidson)

- cosmic microwave background: isotropic radiation at 3K from the formation of the first atoms in the Universe, confirmation of the **hot big bang**-model

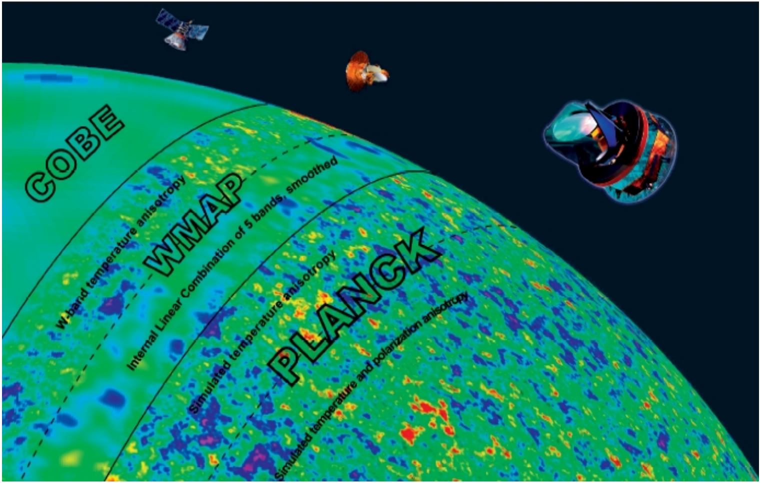
Nobel prize 2006: Smoot and Mather



temperature map of the sky (source: COBE)

- cosmic microwave background: temperature fluctuations in the microwave temperature, seeds for cosmic structures

resolution of CMB-experiments



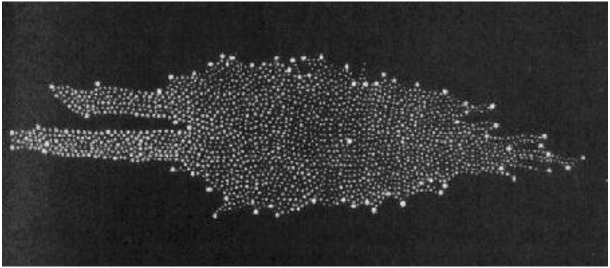
resolution of CMB-experiments (source: PLANCK)

Nobel prize 2011: Riess, Schmidt and Perlmutter

Supernova (source: Hubble space telescope)

- supernova distance-redshift relation, mapping out of the Universe's expansion dynamics, evidence for accelerated expansion

first image of the Milky Way



structure of the Milky Way according to W. Herschel (source: wikipedia)

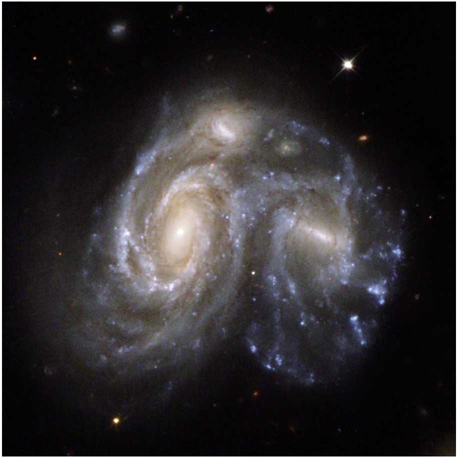
galaxy

Andromeda galaxy (source: Wendelstein-Observatorium)

galaxies

barred spiral galaxy (source: NASA)

galaxies



interacting galaxies (source: NASA)

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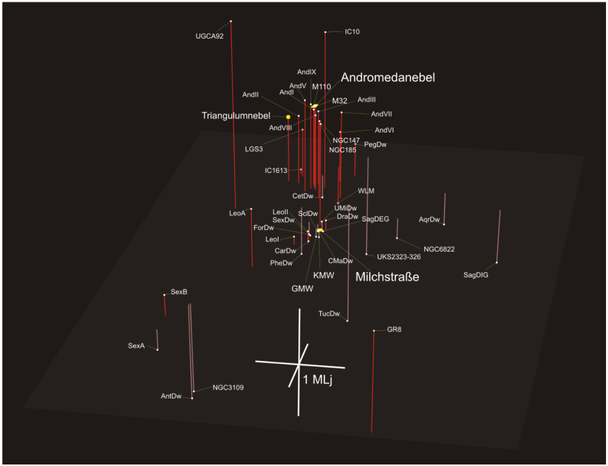
interacting galaxies (source: Arp atlas of peculiar galaxies)

galaxies

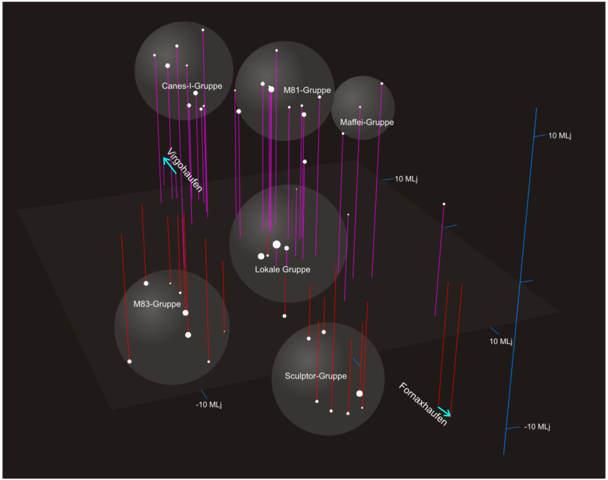
Sombrero galaxy (source: Hubble space telescope)

Milky Way and Andromeda galaxy



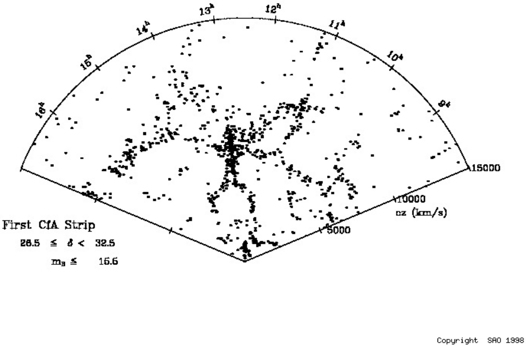
Milky Way and Andromeda galaxy (source: wikipedia)

local group



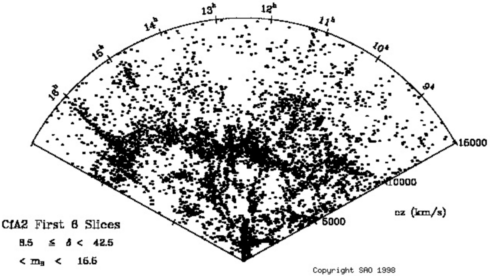
local group and neighbouring galaxies (source: wikipedia)

filamentary structures: the stickman



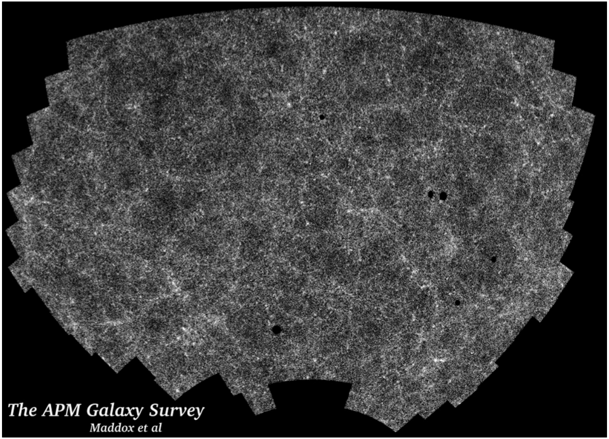
distribution of galaxies (source: CFA, Harvard)

filamentary structures: the great wall



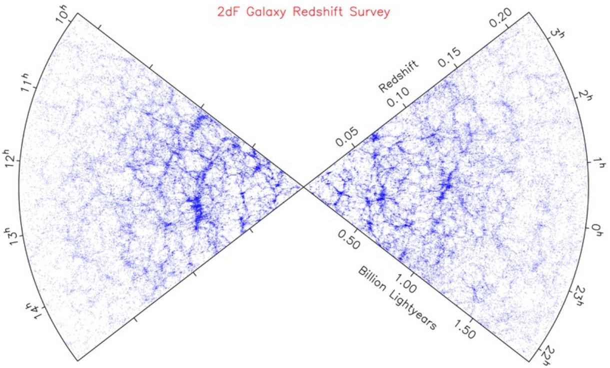
distribution of galaxies (source: CFA, Harvard)

large-scale structure: APM survey



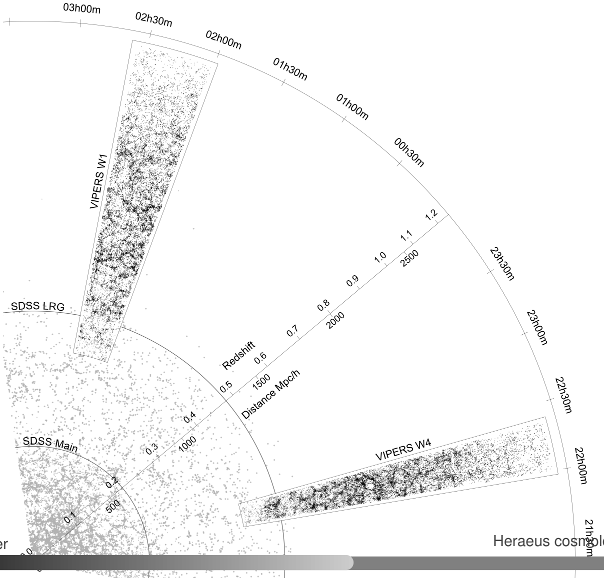
distribution of galaxies (source: APM survey)

large-scale structure: 2dF survey

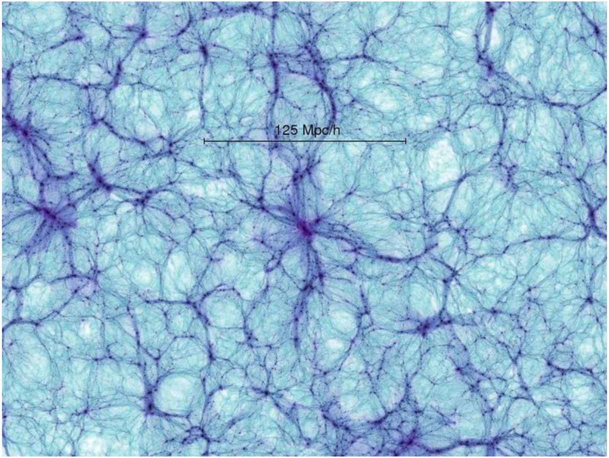


distribution of galaxies (source: 2dF survey)

large-scale structure: VIPER survey

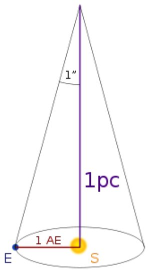


large-scale structure: simulations



cosmic large-scale structure (source: millenium simulation by V. Springel)

parsec



cosmic large-scale structure (source: wikipedia)

- a parsec is the distance at which we see the astronomical unit (the mean distance between Earth and Sun) under an angle of 1 arcsecond ($= 1/3600$ degree)
- 1 parsec $= 3 \times 10^{16}$ meters

sizes and distances in cosmology

- distance to the next stars: few pc
- size of the Milky Way: $40\ \mathrm{kpc}$
- size of a cluster of galaxies: $1\ \mathrm{Mpc}$
- scale of the Universe: $c/H_0 = 3\ \mathrm{Gpc}$
- furtherst ”object” we can see (microwave background): $15\ \mathrm{Gpc}$

ages of objects in the Universe

- age of the dinosaurs: 100 million years ago
- oldest fossils on Earth: 3.4 billion years
- oldest rocks on Earth: 4 billion years
- Earth: 4.5 billion years
- Sun: 4.6 billion years
- oldest stars: 13.2 billion years
- age of the Universe: 13.8 billion years

Planck system of units

- in physics, we're only interested in things that can be quantified in terms of **mass**, **time**, **distance** and **temperature**
- Nature provides a scale for measuring these quantities in terms of
  1. speed of light c
  2. gravitational coupling constant G/c^2
  3. Planck constant $\hbar$
  4. Boltzmann constant k_B
- these constants can be combined to form the Planck-units:
  1. Planck length $l_p = \sqrt{\frac{\hbar G}{c^3}} \simeq 10^{-35}\mathrm{m}$
  2. Planck time $t_p = \frac{l_p}{c} \simeq 10^{-44}\mathrm{s}$
  3. Planck mass $m_p = \sqrt{\frac{c\hbar}{G}} \simeq 2 \times 10^{-8}\mathrm{kg} \simeq 10^{16}\mathrm{GeV}/c^2$
  4. Planck temperatuer $T_p = \sqrt{\frac{c^3\hbar}{G}} \simeq 10^{+32}\mathrm{K}$

question:

can we make sense of these numbers???

how unusual is the Universe!

- before the inflationary epoch, the Universe was in fact described by the Planck scale: the size of the Universe was $1l_p$, typical time scales was $1t_p$, the temperature was $1T_p$
- the Hubble-constant H_0 defines an time scale $t_0 = 1/H_0 = 10^{61}t_p$
- together with Newton's constant G one can define a density $\rho_\mathrm{crit} = 3H_0^2/(8\pi G) = 10^{-122}\rho_p$ with the Planck density $\rho_p = m_p/l_p^3$
- a typical temperature today is $T_0 = 3$K, with $T_0 = 10^{-32}T_p$
- today, the Universe looks very strange in terms of the Planck units

structure of the summer school

we would like to offer 5 lectures on these topics:

1. Markus Pössel: fundamentals of cosmology
2. Camilla Hansen: nucleosynthesis and chemical elements
3. Björn Malte Schäfer: cosmic microwave background
4. Andreas Just: distances in astronomy and supernova cosmology
5. Björn Malte Schäfer: cosmic large-scale structure

together with a large programme and many activities in Heidelberg

1. lecture (ca. 90min)
2. exercises (ca. 60min)
3. presentation of results (ca. 60 min)
4. discussion on didactics (60min)

monday: fundamentals of cosmology

by Markus Pössel

- need for general relativity
- length, time and density scales
- concepts of relativity, metric as the key quantity
- Einstein’s field equation
- highly symmetric solutions, Friedmann-Lemaître models
- static and dynamic solutions, curved and flat solutions
- critical density, Hubble’s constant
- cosmic fluids, dark energy and dark matter

monday: concepts of relativity

contributions:

1. Huetten (Jena):
   ”history of the heliocentric world model”
2. Luidl (Heidelberg):
   ”joining the Hubble flow: implications for expanding space”
3. Taulien (Heidelberg):
   ”expanding confusion: common misconceptions of cosmological horizons and the superluminal expansion of the universe”
4. Sperling (Jena):
   ”misconceptions in cosmology”
5. Sansonetto (Verona):
   ”Cosmological parameters and the stability of the solutions to the Einstein Field Equations”
6. Singh (Padova):
   ”A glimpse into the beginning of time”

tuesday: nucleosynthesis

by Camilla Juul Hansen

- nuclear chemistry
- 3 modes of element synthesis
- stellar synthesis, big bang nucleosynthesis, supernova synthesis
- stellar clocks and the age of the Universe
- spallation processes
- chemical abundances

contributions:

1. Mazewsky (Jena):
   ”the standard model of particle physics”
2. Lorenz (Heidelberg):
   ”the cosmic microwave background for pedestrians: a review”
3. Vitali (Brescia):
   ”Primordial nucleosynthesis: the essential role of the early hot universe to explain the light element abundances”
4. Goetz (Jena):
   ”dark matter”
5. Baer (Heidelberg):
   ”measurements of quasar redshifts with amateur equipment”

wednesday: break

Heidelberg castle and old bridge (source: Merian)

thursday: distances and supernova cosmology

by Andreas Just

- distances in general relativity
- distance measures, distance-redshift-relations
- calibration of distances, cosmic distance ladder
- supernova measurements, standard candles
- calibration of supernova lightcurves
- cepheid distances, Hubble keystone project
- Hubble constant and deceleration parameter
- evidence for dark energy or a cosmological constant

thursday: distances and supernova cosmology

contributions:

1. Sardella (Florence):
   ”cosmic distance”
2. Zeissner (Heidelberg):
   ”a new cosmological distance measure using active galactic nuclei”
3. Voelker (Jena):
   ”the distance to the large Magellanic cloud”
4. Engelmann (Jena):
   ”cepheid stars as distance indicators”
5. Kretzer (Jena):
   ”supernovae as standard candles”

friday: cosmic microwave background

by Björn Malte Schäfer

- adiabatic equation
- thermal history of the Universe
- epochs in the thermal history, freeze-out
- formation of atoms, release of the microwave background
- anisotropies and CMB measurements
- CMB spectrum, acoustic features
- evidence for spatial flatness, standard rulers
- secondary anisotropies

friday: distances and supernova cosmology

contributions:

1. Tegon (Padova):
   ”Uniformity and isotropy tests from Wilhelm Herschel to the SLOAN surveys”
2. Vaona (Padova):
   ”From Wilhelm Herschel to the SDSS, two centuries of counts: Uniformity and Isotropy tests”
3. Brems (Heidelberg):
   ”gravitational lensing by point masses”
4. Palenta (Jena):
   ”gravitational lensing”
5. Koentges (Heidelberg):
   ”gravitational lensing by galaxy clusters”

saturday: cosmic large-scale structure

by Björn Malte Schäfer

- large-scale structure, scales, scale similarity
- statistical description, random fields, correlation functions
- growth of structure and the need for dark matter
- fluid mechanics on the largest scales
- initial conditions for structure formation
- linearity, Gaussianity, homogeneity
- nonlinear structures: halo formation, galaxies
- galaxy rotation curves: second case for dark matter

saturday: distances and supernova cosmology

contributions:

1. Loreggia (Padova):
   "Fundamental Plane of Galaxies and Applications of the Virial Theorem as a motivation of the Dark Matter hypothesis and the birth of Stars"
2. Chat (Siegen):
   "cosmology with the Sunyaev-Zel'dovich effect"
3. Deitersen (Siegen):
   "cosmological parameters from galaxy clusters"
4. Krauss (Siegen):
   "formation of galaxy clusters"
5. Weber (Siegen):
   "dark matter in galaxy clusters"

proceedings

in preparation:

J. Staude, M. Pössel, O. Fischer, B.M. Schäfer:
Modern cosmology for teachers

in English, German and Italian

all course materials available at:

http://www.mpia-hd.mpg.de/home/poessel