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
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

- Afterglow Light Pattern
- 400,000 yrs.
- Dark Ages
- Development of Galaxies, Planets, etc.
- Inflation
- Quantum Fluctuations
- 1st Stars about 400 million yrs.
- Big Bang Expansion
- 13.7 billion years

Björn Malte Schäfer

Heraeus cosmology summer school
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, $\Lambda$CDM-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

- cosmic microwave background: temperature fluctuations in the microwave temperature, seeds for cosmic structures
resolution of CMB-experiments (source: PLANCK)
Nobel prize 2011: Riess, Schmidt and Perlmutter

- 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)
interacting galaxies (source: Arp atlas of peculiar galaxies)
**galaxies**

*Sombrero galaxy* (source: Hubble space telescope)
Milky Way and Andromeda galaxy (source: wikipedia)
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)
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 kpc
- size of a cluster of galaxies: 1 Mpc
- scale of the Universe: $c/H_0 = 3$ Gpc
- furtherst "object" we can see (microwave background): 15 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 $l_p = \sqrt{\frac{\hbar G}{c^3}} \simeq 10^{-35}\text{m}$
  2. Planck time $t_p = \frac{l_p}{c} \simeq 10^{-44}\text{s}$
  3. Planck mass $m_p = \sqrt{\frac{c^3 \hbar}{G}} \simeq 2 \times 10^{-8}\text{kg} \simeq 10^{16}\text{GeV}/c^2$
  4. Planck temperature $T_p = \sqrt{\frac{c^3 \hbar}{G}} \simeq 10^{+32}\text{K}$

**question:**

*can we make sense of these numbers???
• 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 $\rho_{\text{crit}} = 3H_0^2/(8\pi G) = 10^{-122}\rho_p$ with the Planck density $\rho_p = m_p/l_p^3$

• a typical temperature today is $T_0 = 3K$, 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"
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