Astroparticle Physics & Cosmology

summer term 2014

Ⓐ Astroparticle Physics (G. Sigl)
→ Apr. 2 – May 21

Ⓑ Cosmology (A. Westphal)
→ May 23 – July 11

Wednesday 10.30 am – 12 pm, Hörs. III
Friday 10.15 – 11.45 am Hörs. III

problem sessions: Friday 12.15 – 1.45 pm
SemR. 1

course homepage, part A:

www.desy.de/~westphal/cosmology_2014/cosmology.html

↳ problem sets & lecture notes as pdf's

please note:

↳ advanced theoretical course on gravitation & cosmology: winter term 14/15

23.5. **Cosmology**

literature:

Kolb & Turner: The Early Universe (1990)

Mukhanov: Physical Foundations of Cosmology (2005)

Weinberg: Gravitation & Cosmology (1972)

Cosmology (2008)

Ryden: Introduction to Cosmology (2003)

Dodelson: Modern Cosmology (2003)

Goenner: Einführung in die Kosmologie (1996)

⋮

Google/arXiv: TASI Lectures: Introduction to Cosmology (2004) Trodden, Carroll

⋮

Subject of the course (part A)

particle physics:

microscopic structure of matter

distance scale: $\sim 10^{-19}\,m$ at LHC

corresponds via uncertainty principle to an energy/temperature:

$$\lambda = \frac{\hbar}{p} \Rightarrow 1\,fm = 10^{-15}\,m \simeq \frac{\hbar c}{200\,MeV}$$

$\curvearrowright$ $10^{-18} \dots 10^{-19}\,m$ $\hat{=}$

$E \sim 100 \dots 1000\,GeV$

$T \sim 10^{15} \dots 10^{16}\,K$

$$T = \frac{E}{k} \quad \left(k = 8.5 \cdot 10^{-5} \, \frac{eV}{K} \right)$$

$\downarrow$

results of particle physics (QFT) give description of hot plasma at temperature T

theoretical extrapolation up to $\sim 10^{16}$ GeV (neutrino physics, GUTs inflation)

$\updownarrow$

LHC: Higgs mechanism (?), elementary scalar fields, QCD vacuum, cosmological phase transitions, supersymmetry? ...

... merges with the <u>early universe</u>:

since E. Hubble's observations $\rightarrow$ the universe is expanding

$$v(r) = H_0 \cdot r$$

$v(r)$: relative speed of recession of galaxies, supernovae, quasars ...

r: distance of galaxies ...

(2 plots)

H_0: present day Hubble parameter

$$H_0 = h_0 \cdot 100 \, \frac{km}{s \cdot MPc}$$

$h_0 = 0.71 \pm 0.06$ HST Key Project

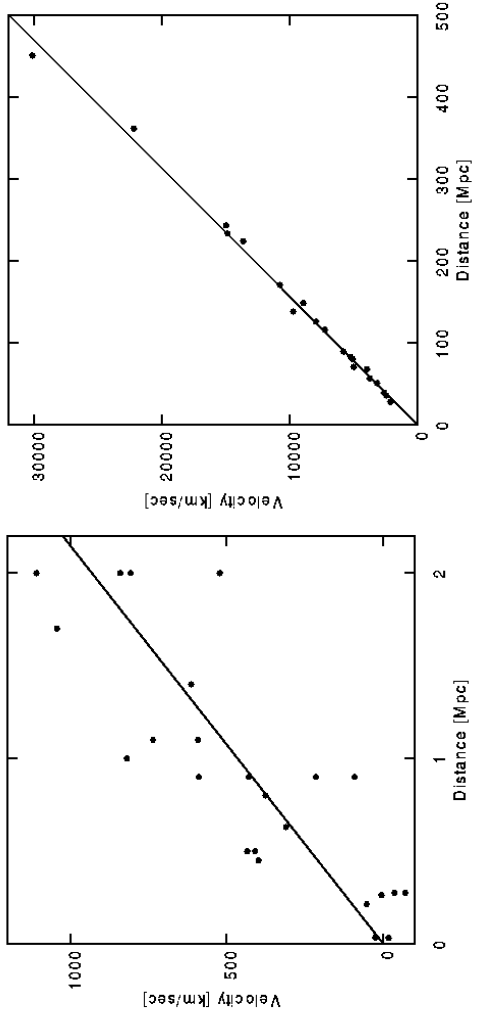


Figure 2.2: Hubble diagrams (as replotted in [17]) showing the relationship between recessional velocities of distant galaxies and their distances. The left plot shows the original data of Hubble [18] (and a rather unconvincing straight-line fit through it). To reassure you, the right plot shows much more recent data [19], using significantly more distant galaxies (note difference in scale).

[17] *Ned Wright's Cosmology Tutorial, http://www.astro.ucla.edu/ wright/cosmo$_0$1.htm*

[18] E. Hubble, Proc. Natl. Acad. Sci., **15**, 168-173 (1929).

[19] A. G. Riess, W. H. Press and R. P. Kirshner, Astrophys. J. **473**, 88 (1996) [arXiv:astro-ph/9604143].

extrapolating back:

⇝ the earlier, the hotter ...

we can list the early phases by their energy/temperature scale:

$\lesssim$ eV (atomic physics)

- ⇝ recombination of e^- and p into ^1H ⇒ cosmic microwave background (CMB)
- ⇝ structure formation: stars, galaxies ⟷ baryonic & dark matter

~ MeV (nuclear physics)

↝ nucleosynthesis :

^1_1H, ^4_2He, D, T, ^3_1He from n, p ...

~ 100 GeV (electroweak scale)

LHC: Higgs, supersymmetry ?

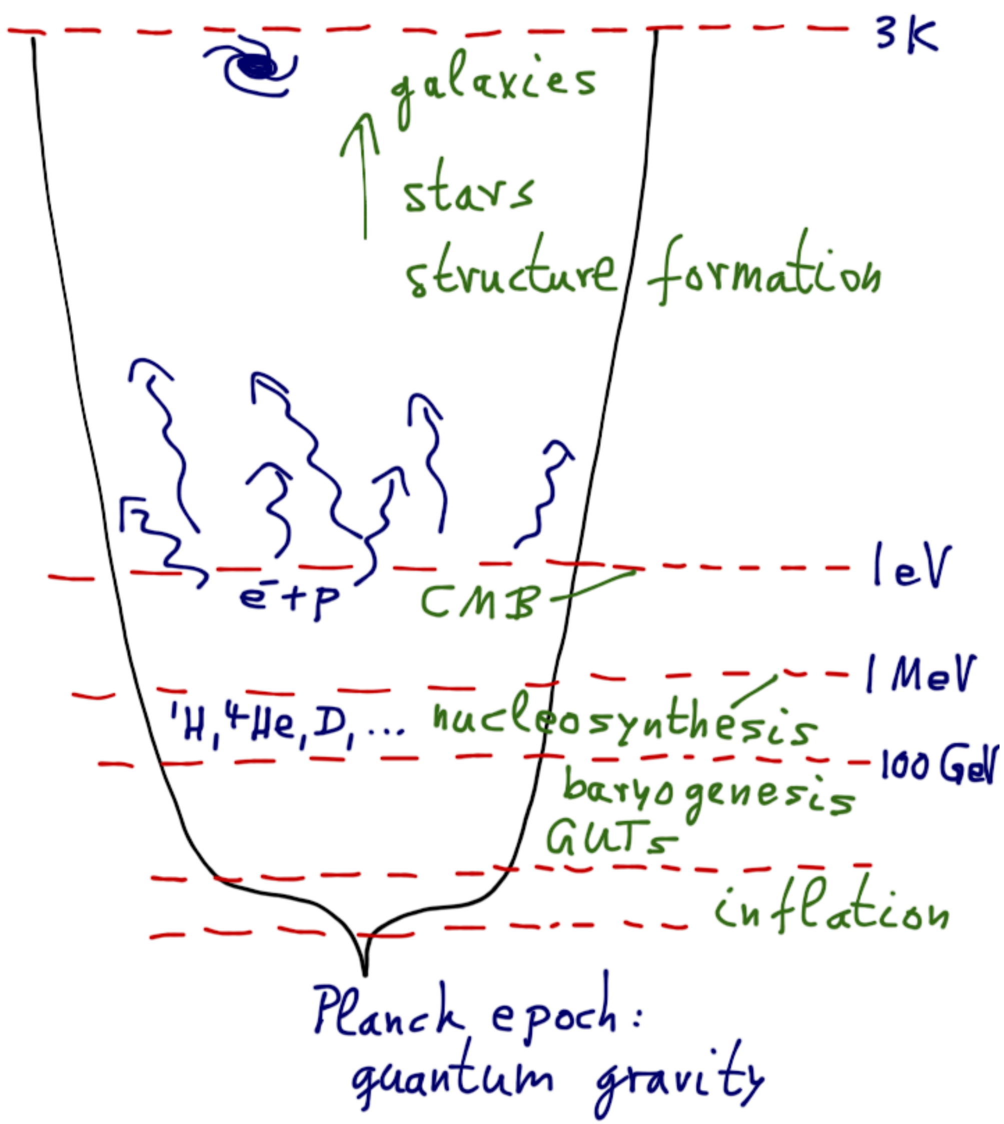
→ dark matter,

matter-antimatter / baryon asymmetry

⋮

? baryo-/leptogenesis,

inflation, ...



(I) The expanding universe

1. some cosmography:

units of distance:

light year $= l_y = c \cdot 1yr$

$= 3 \cdot 10^8 \frac{m}{s} \cdot \pi \cdot 10^7 s$

$\simeq 10^{16} m$

parsec $= P_c \simeq 3.26\, l_y$

distribution of (luminous & dark) mass:

galaxies → local groups → clusters/superclusters → quasars

	$d\,[l_y]$
center of the milky way	$2.8 \cdot 10^4$
magellanic cloud	$2 \cdot 10^5$
Andromeda galaxy (M31)	$2.1 \cdot 10^6$
Virgo cluster	$6.6 \cdot 10^7$
⋮	
quasar	10^{10}

(visible universe = CMB horizon $\sim$ a few $\times 10^{10} l_y \simeq 10^{26} m$)

(→ SDSS video)