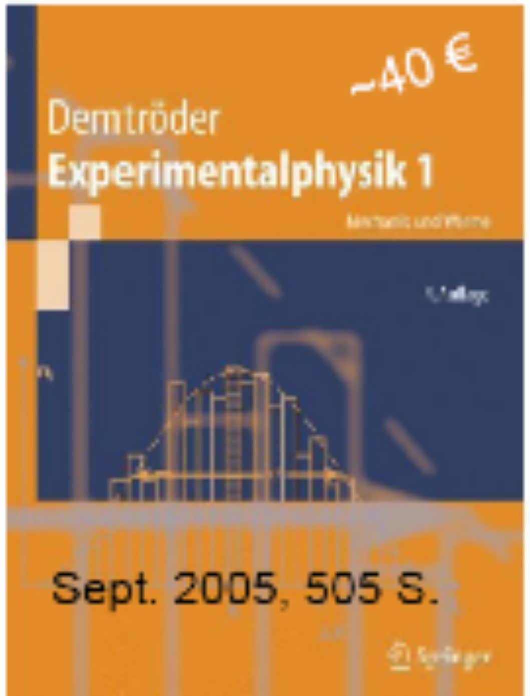
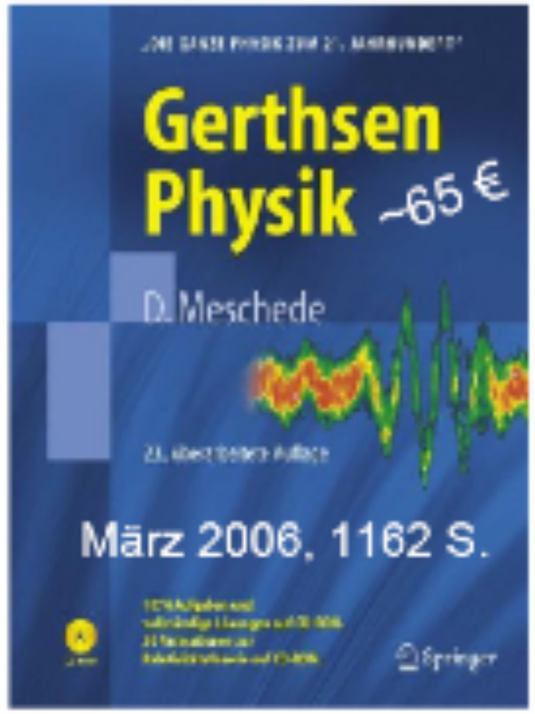
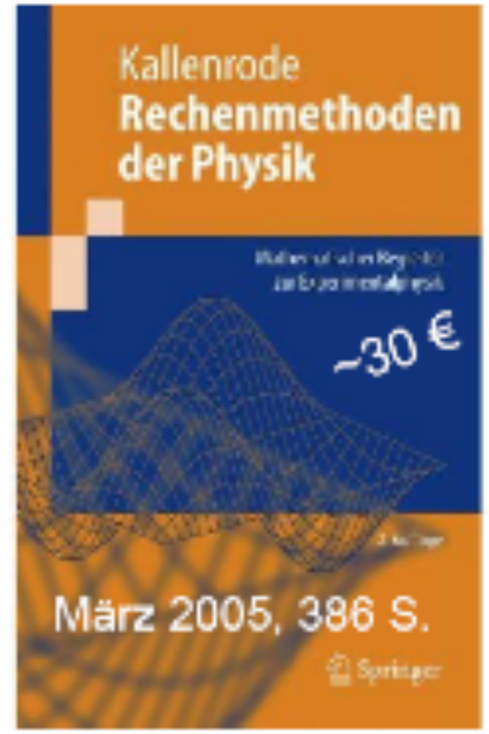
Inhalt



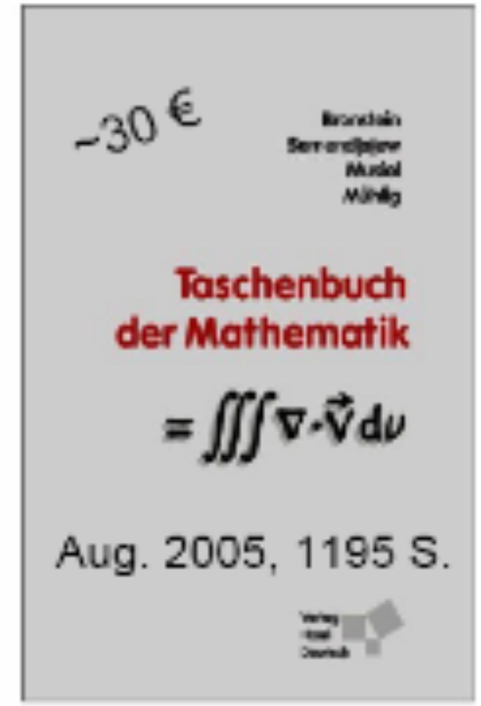
der ‚Demtröder': Teil 1 einer vier-bändigen Reihe



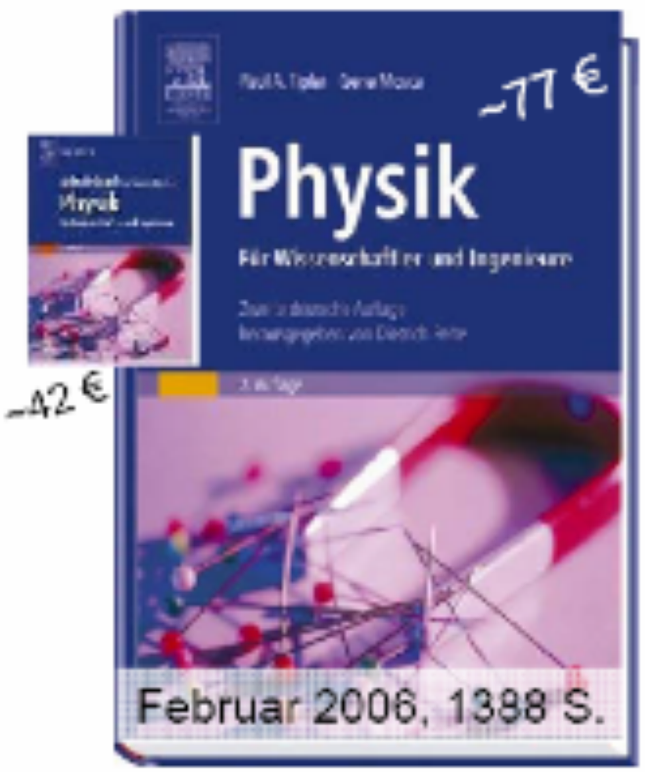
der ‚Gerthsen': Standard-Werk, gesamte Physik



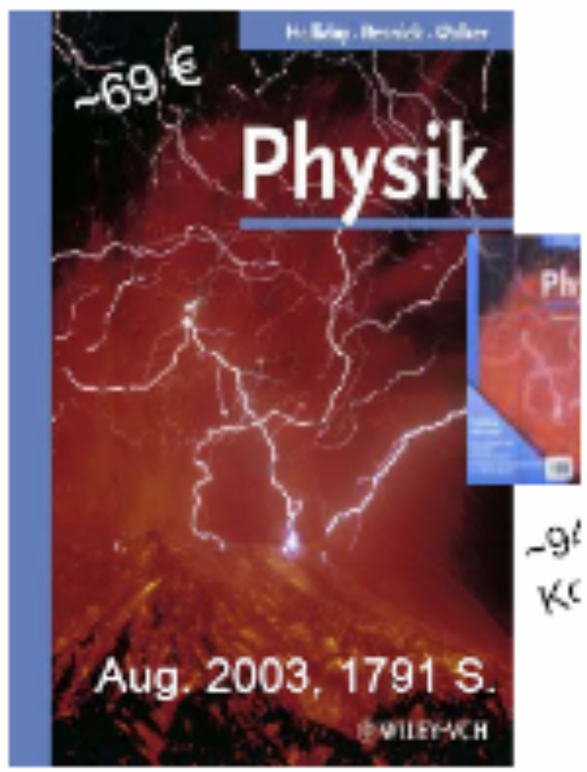
Rechenmethoden der Physik, beispiel- & praxisorientiert



der ‚Bronstein': Standard-Referenz, gesamte Mathematik



der ‚Tipler': dt. Übersetzung des US-Originals (+Arbeitsb.)



der ‚Halliday': dt. Übersetzu des US-Originals

Einführung in die mathe-matischen Methoden

Standard der Ingenieur-Mathematik, gute Didaktik

KIT-Bibliothek bietet eBooks!

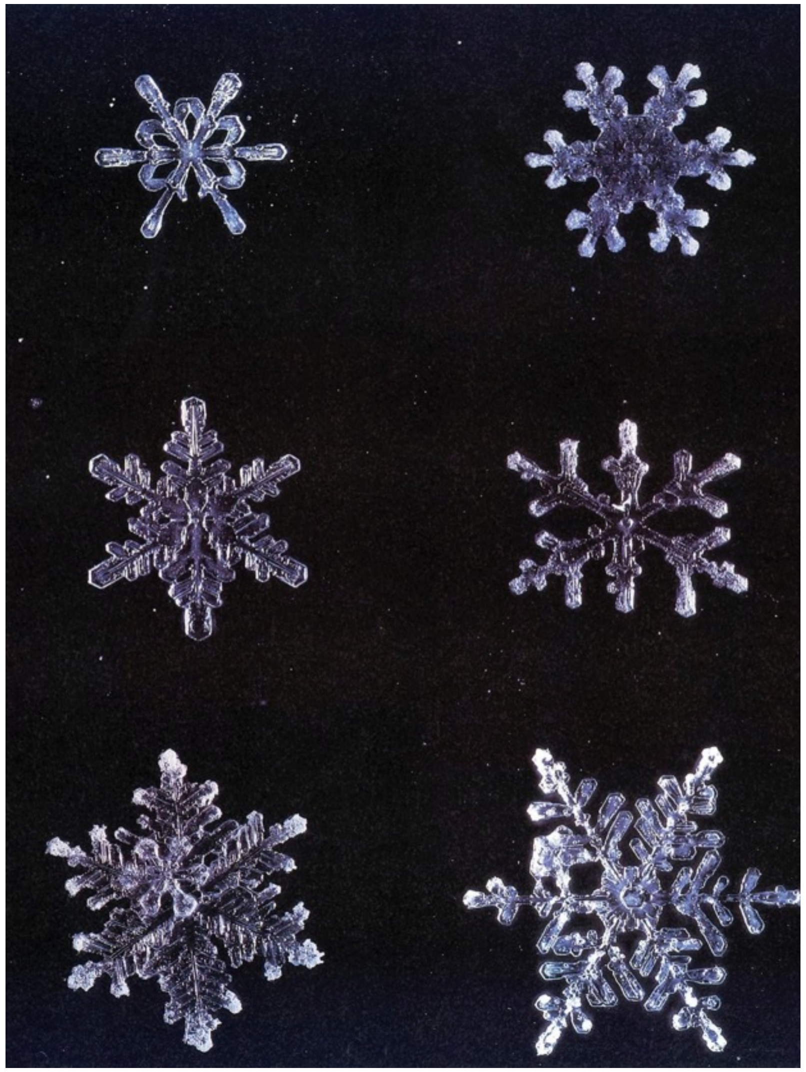
Quelle: Th. Müller Vorlesung 2007

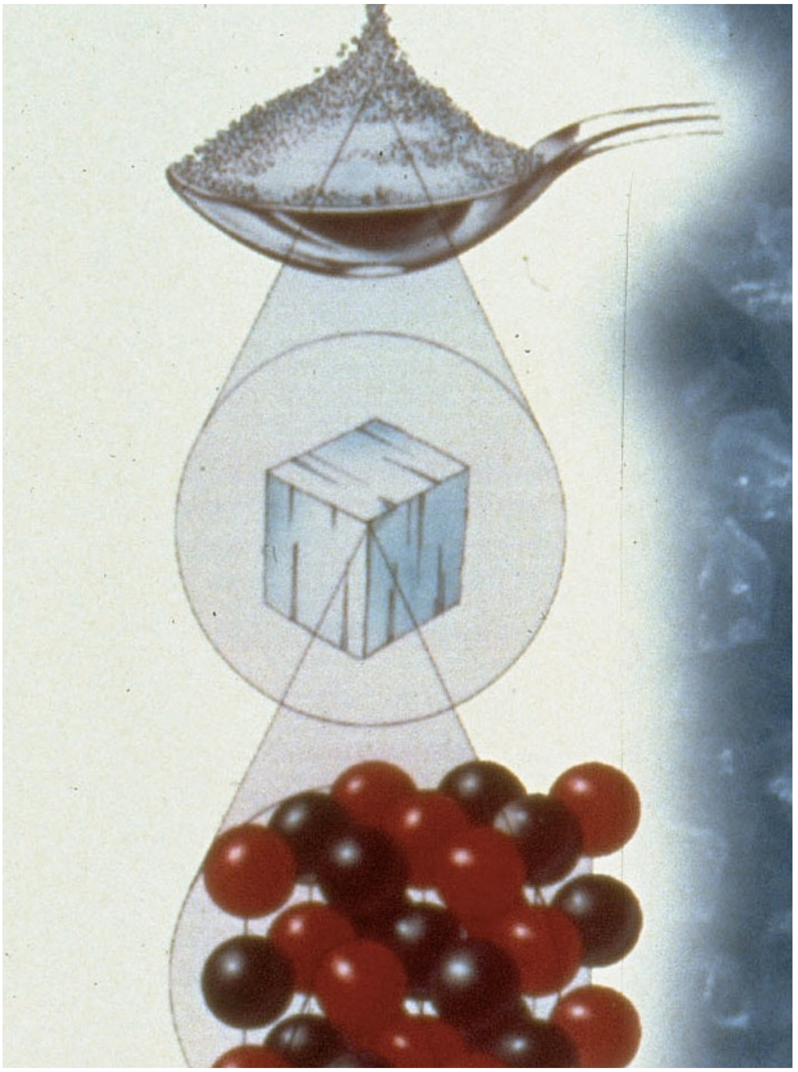
1.1 Was ist Physik?

Was ist Physik nicht?

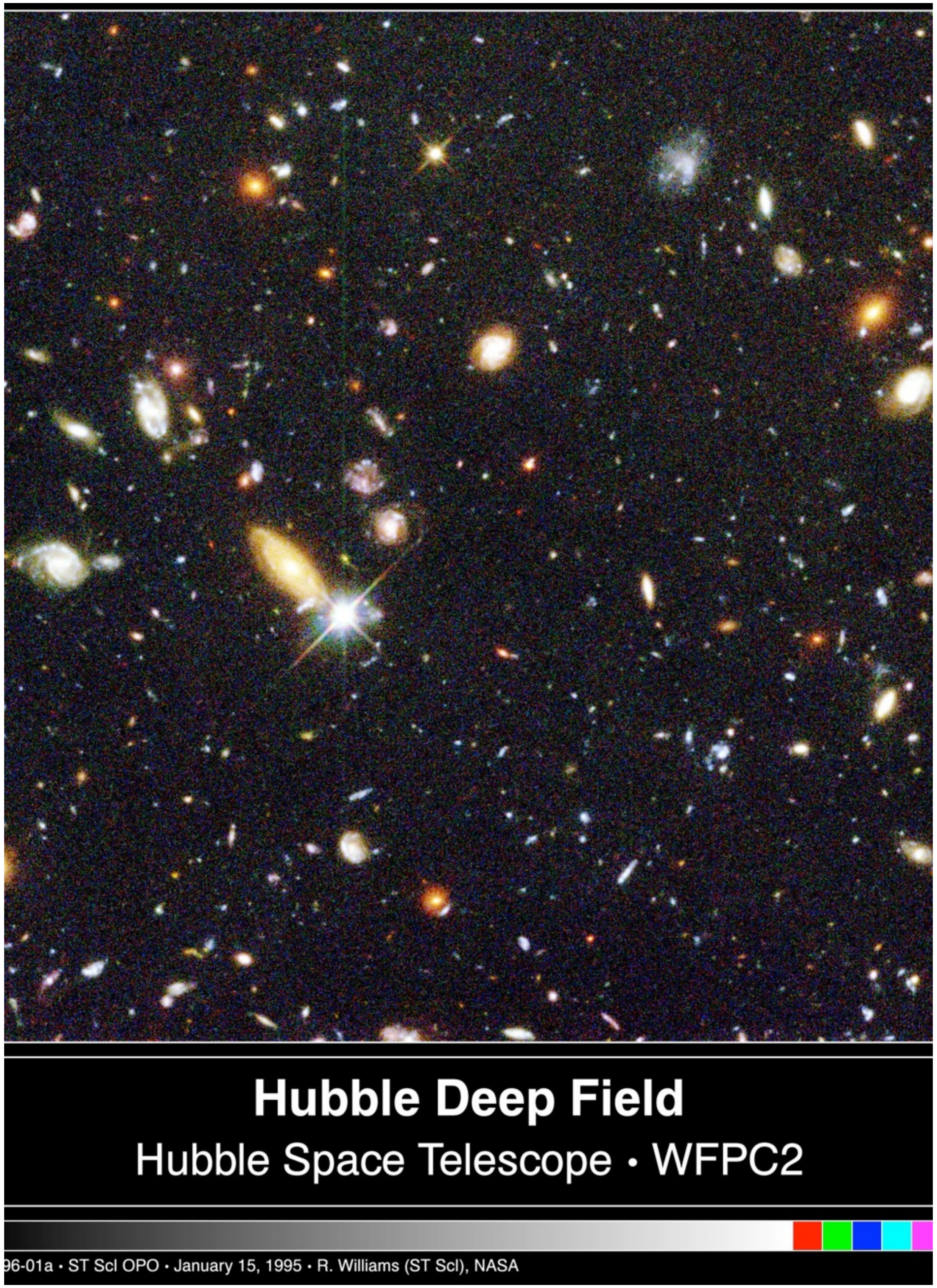
Atlas trägt die Welt

- DIMITRI: “Wenn Atlas die Welt auf seinem Rücken trägt, auf wem steht dann Atlas?”
- TASSO: “Atlas steht auf dem Rücken einer Schildkröte.”
- DIMITRI: “Aber worauf steht diese Schildkröte?”
- TASSO: “Auf einer zweiten Schildkröte.”
- DIMITRI: “Und worauf steht dann diese Schildkröte?”
- TASSO: “Mein lieber Dimitri, es sind lauter Schildkröten, bis ganz nach unten!”

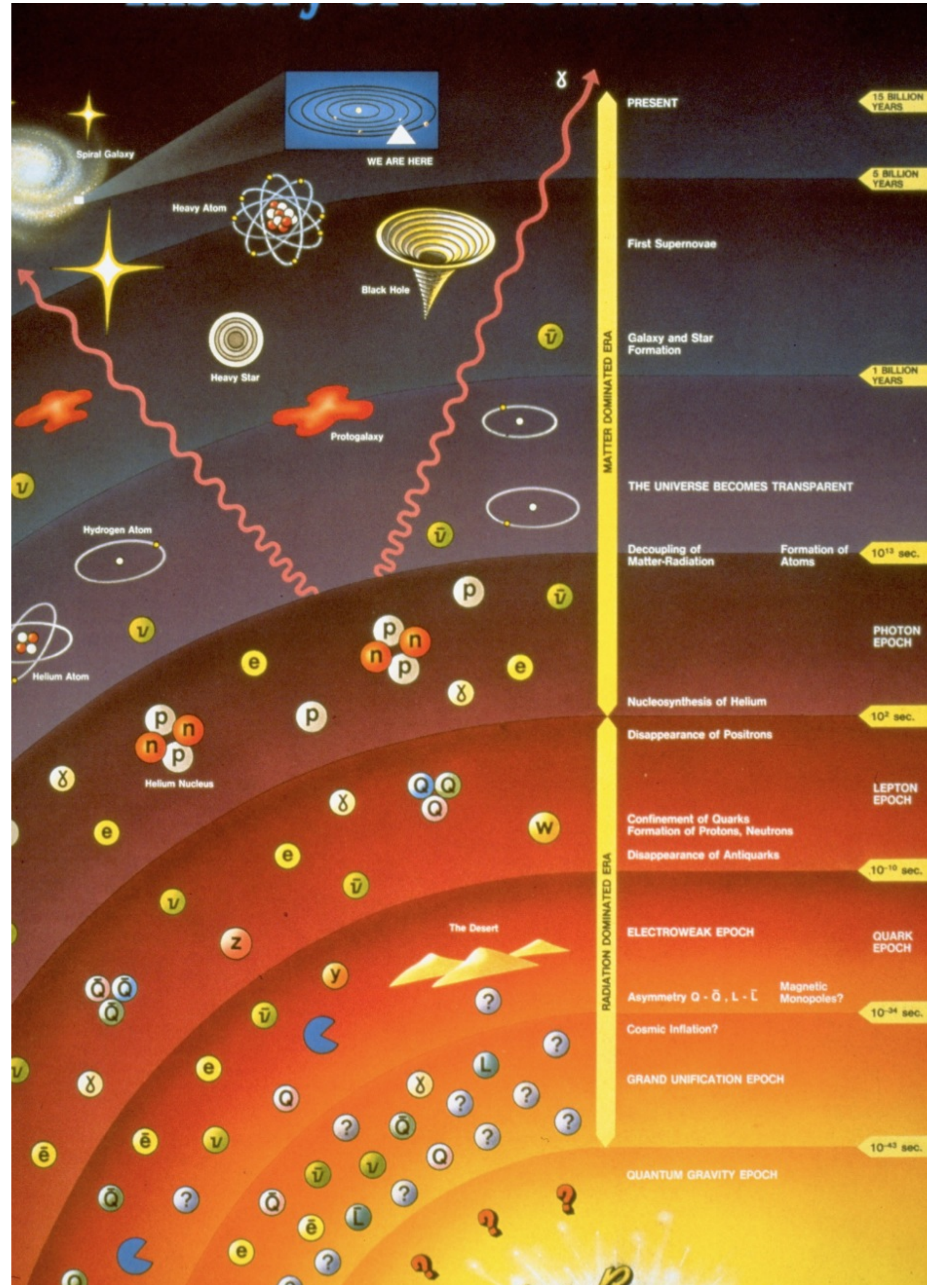




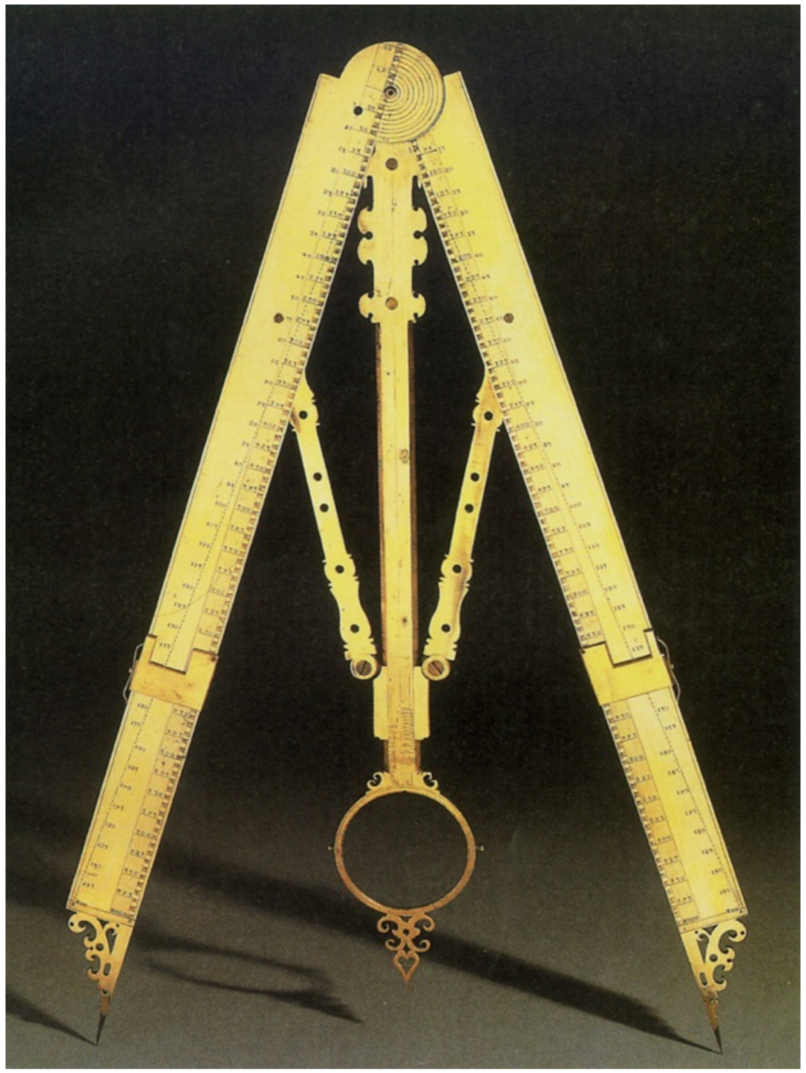
WAS ist das?


Hubble Deep Field
Hubble Space Telescope • WFPC2
96-01a • ST ScI OPO • January 15, 1995 • R. Williams (ST ScI), NASA

Wieviel?



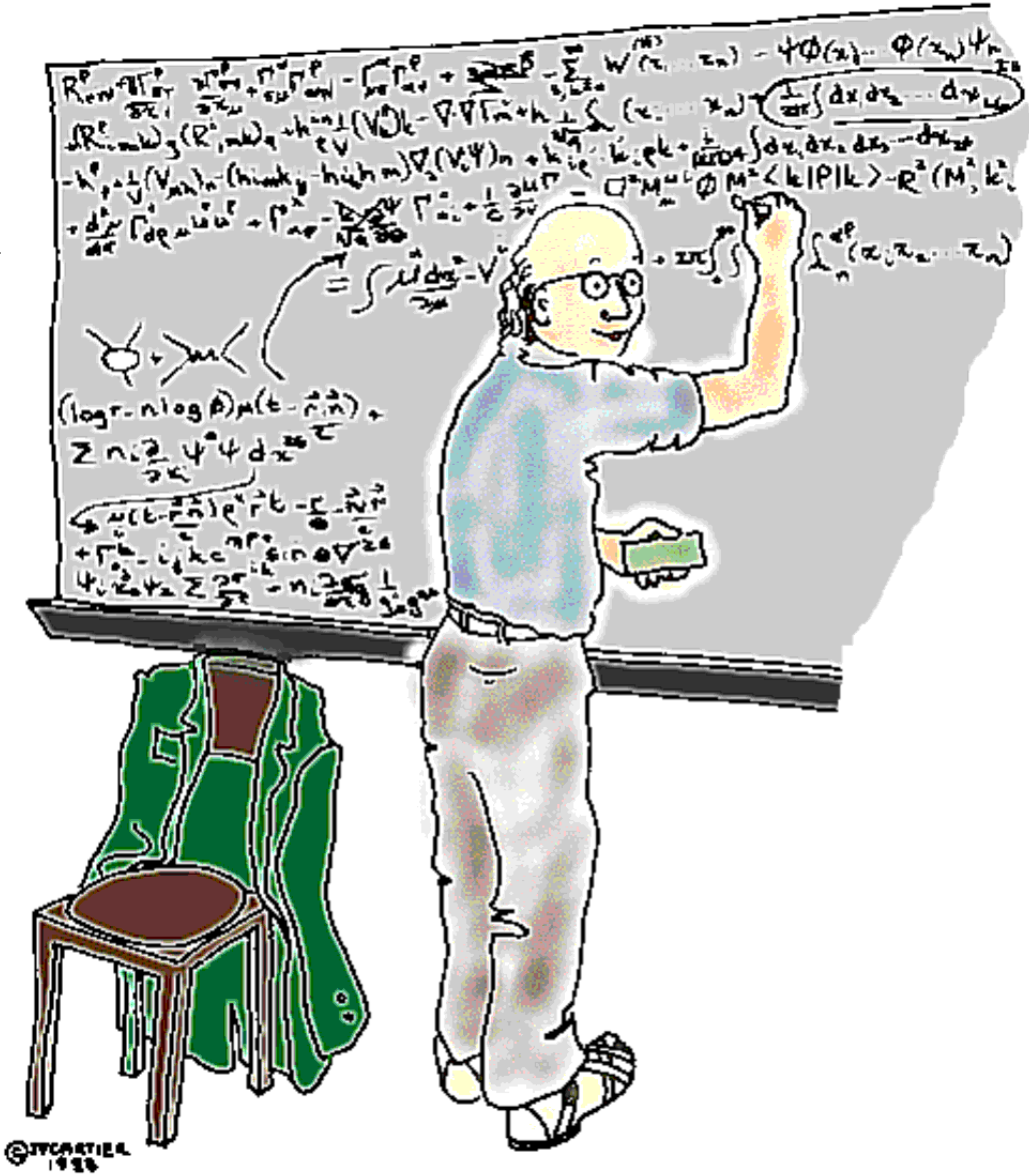
WIE kann man Vorgänge beschreiben?



Wo? Wann? Wie oft?

Was ist...

- wesentlich?
- nebensächlich?
- störend?



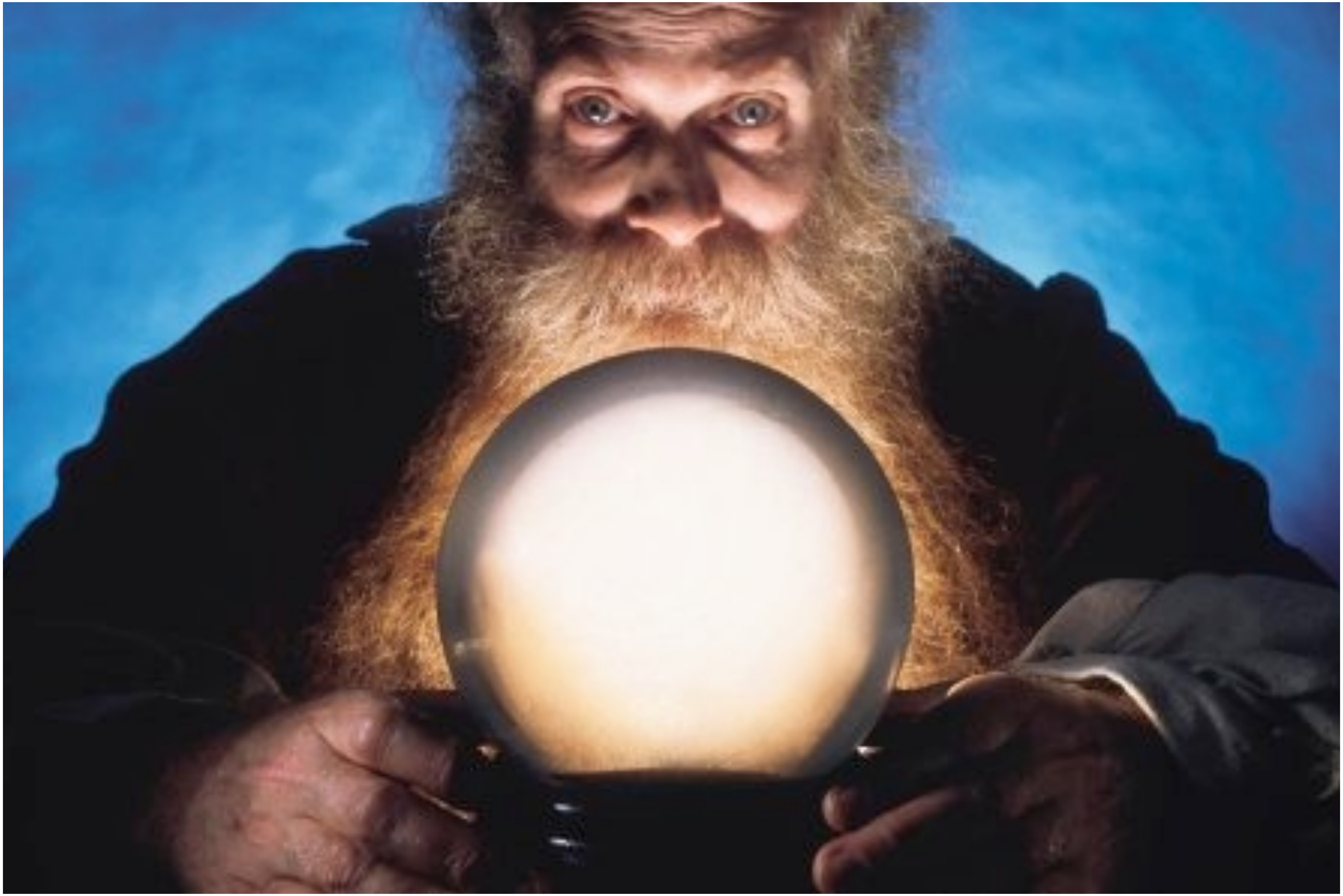
"At this point we notice that this equation is beautifully simplified if we assume that space–time has 92 dimensions."

Richard P. Feynman

- “Physics is a number”

Danke, Teilchenforschungszentrum CERN. Deutschland ist aus dem Häuschen

Das Higgs-Boson



WAS WIRD geschehen, wenn ...?

Vorhersagekraft einer Theorie!

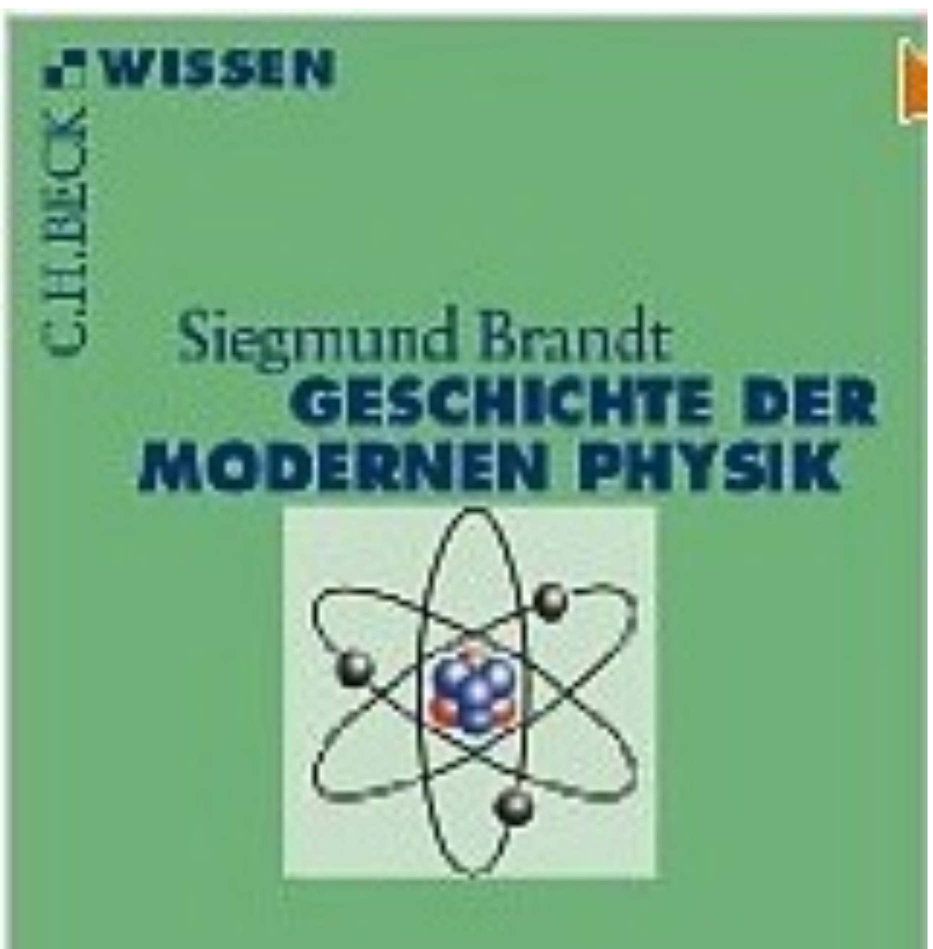
Kurze Rundschau

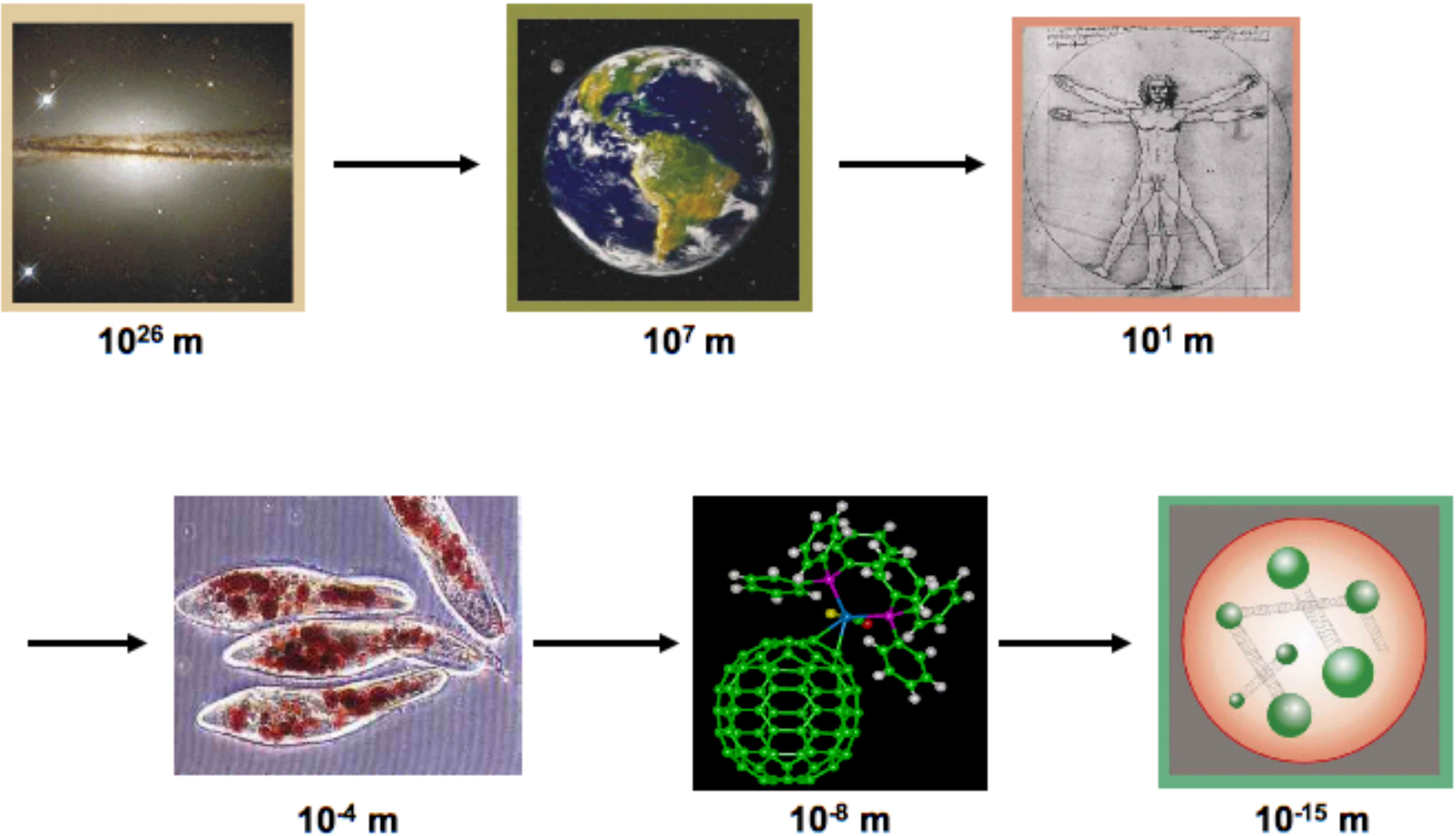
über 14 Milliarden Jahre – von Quarks zum Kosmos

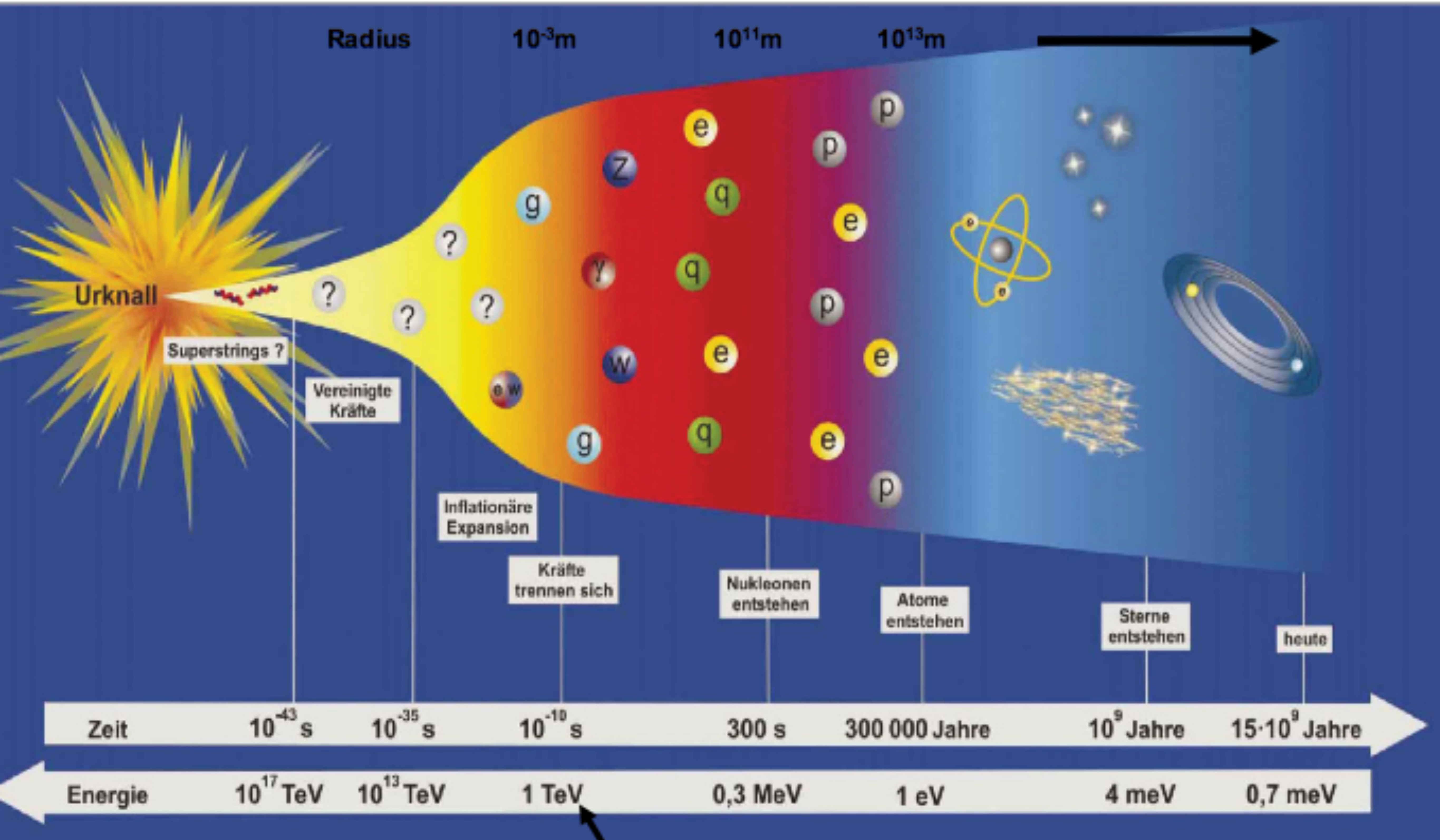
Literaturhinweise

- Allgemein:
  Demtröder 1, Kapitel 1.1 – 1.5 ▶

- Moderne Physik:




10^{26} m
10^{7} m
10^{1} m
10^{-4} m
10^{-8} m
10^{-15} m



Radius
10^-3 m
10^11 m
10^13 m
Urknall
Superstrings ?
Vereinigte Kräfte
Inflationäre Expansion
Kräfte trennen sich
Nukleonen entstehen
Atome entstehen
Sterne entstehen
heute
Zeit
10^-43 s
10^-35 s
10^-10 s
300 s
300 000 Jahre
10^9 Jahre
15·10^9 Jahre
Energie
10^17 TeV
10^13 TeV
1 TeV
0,3 MeV
1 eV
4 meV
0,7 meV
Teilchenbeschleuniger

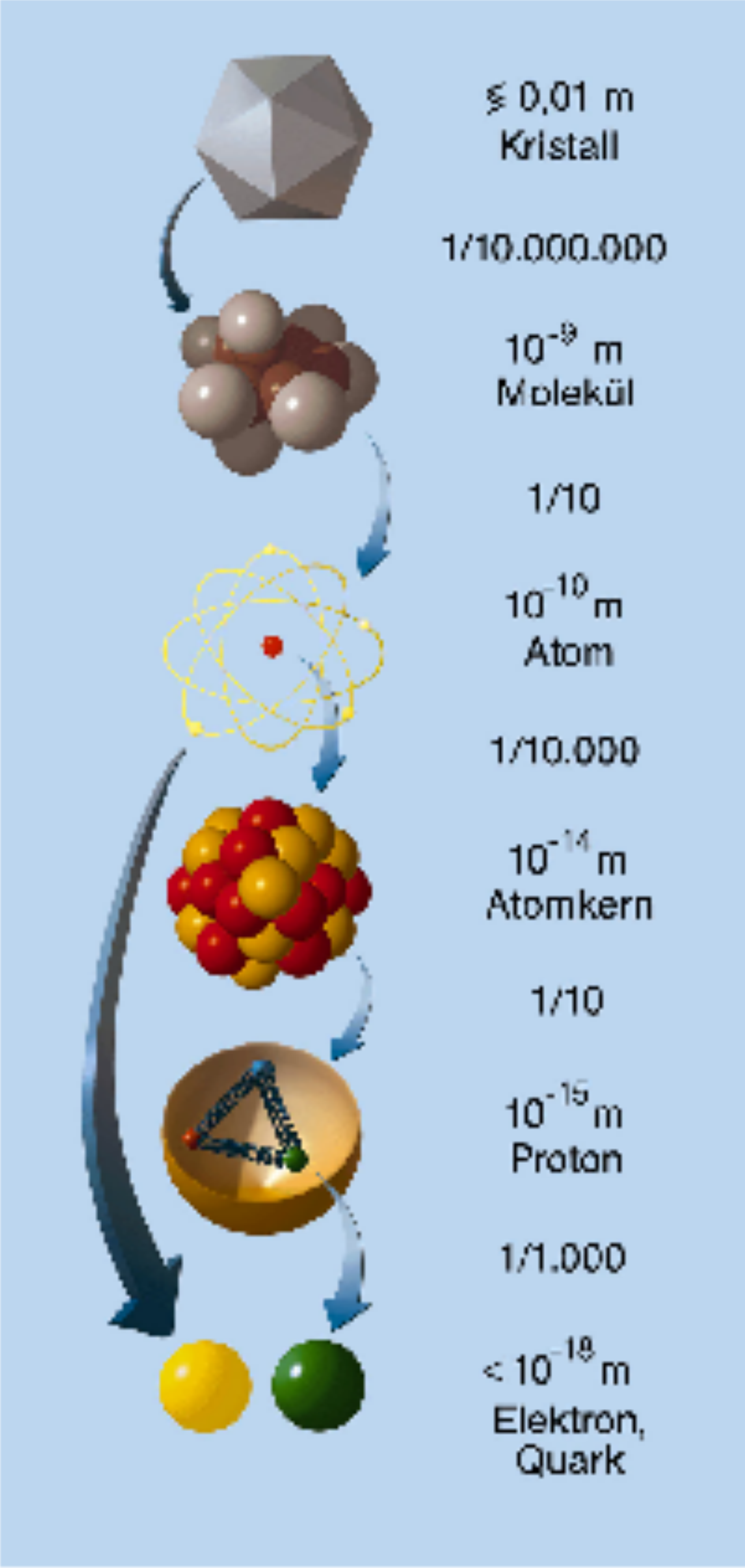
Dalton 1803-1808
Lehre von den Atomen als
Grundbausteinen der Stoffe

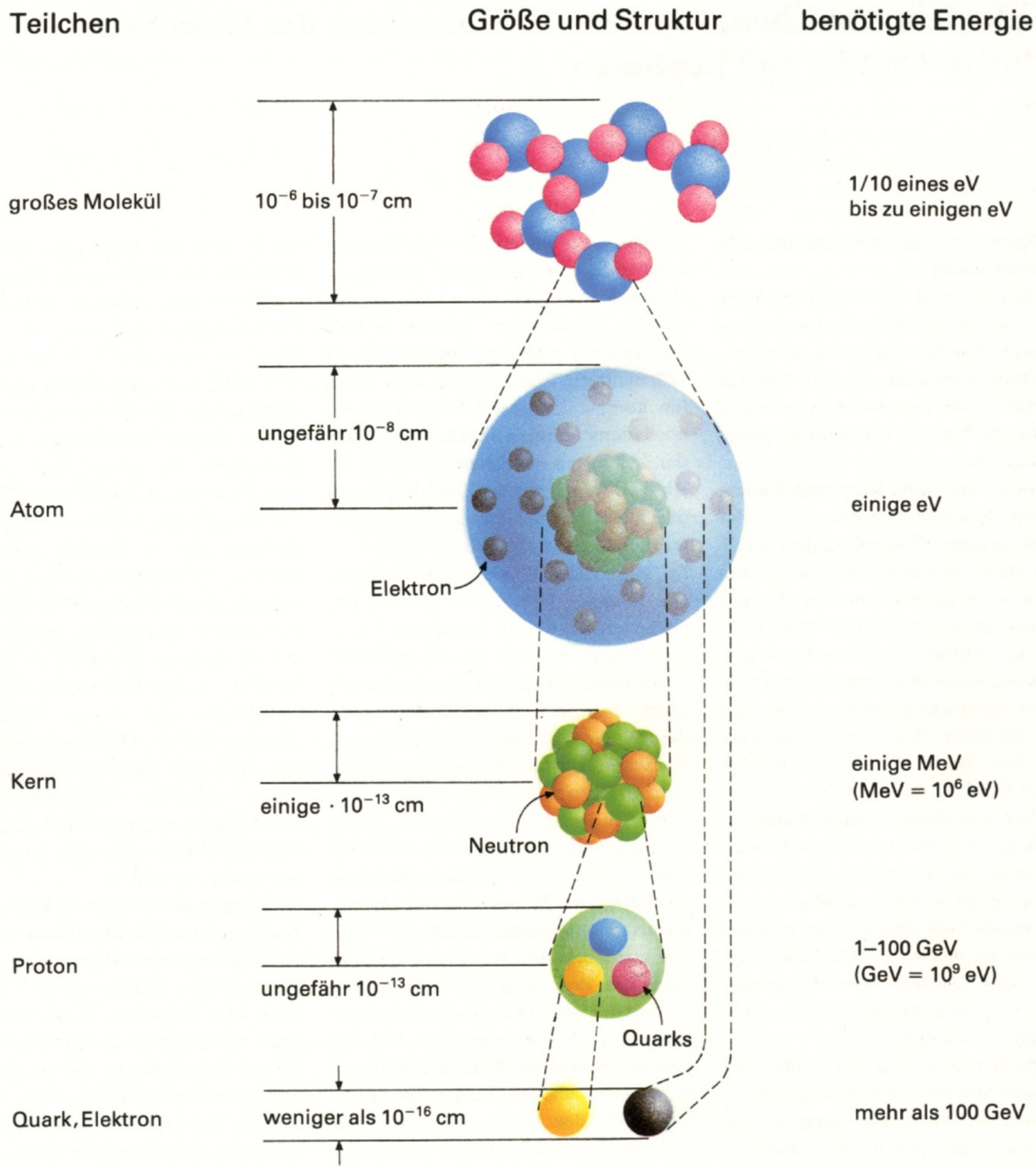
Meyer/Mendelejev 1869-1871
Periodensystem der Elemente
10^7 Chemische Verbindungen $\longrightarrow$ 112 Atome

Rutherford (1871-1937)
Atome: kompakter Kern mit Elektronenhülle

Bothe, Chadwick, Joliot (um 1932)
Neutronen und Protonen im Kern
112 Atome $\longrightarrow$ 3 Bausteine

Gell-Mann, Zweig (1964)
Protonen, Neutronen, andere Hadronen
Bestehen aus Quarks
>100 Elementarteilchen $\longrightarrow$ 6 Quarks




Teilchen
Größe und Struktur
benötigte Energie
großes Molekül
10^{-6} bis 10^{-7} cm
1/10 eines eV
bis zu einigen eV
Atom
ungefähr 10^{-8} cm
Elektron
einige eV
Kern
einige · 10^{-13} cm
Neutron
einige MeV
(MeV = 10^6 eV)
Proton
ungefähr 10^{-13} cm
Quarks
1–100 GeV
(GeV = 10^9 eV)
Quark, Elektron
weniger als 10^{-16} cm
mehr als 100 GeV

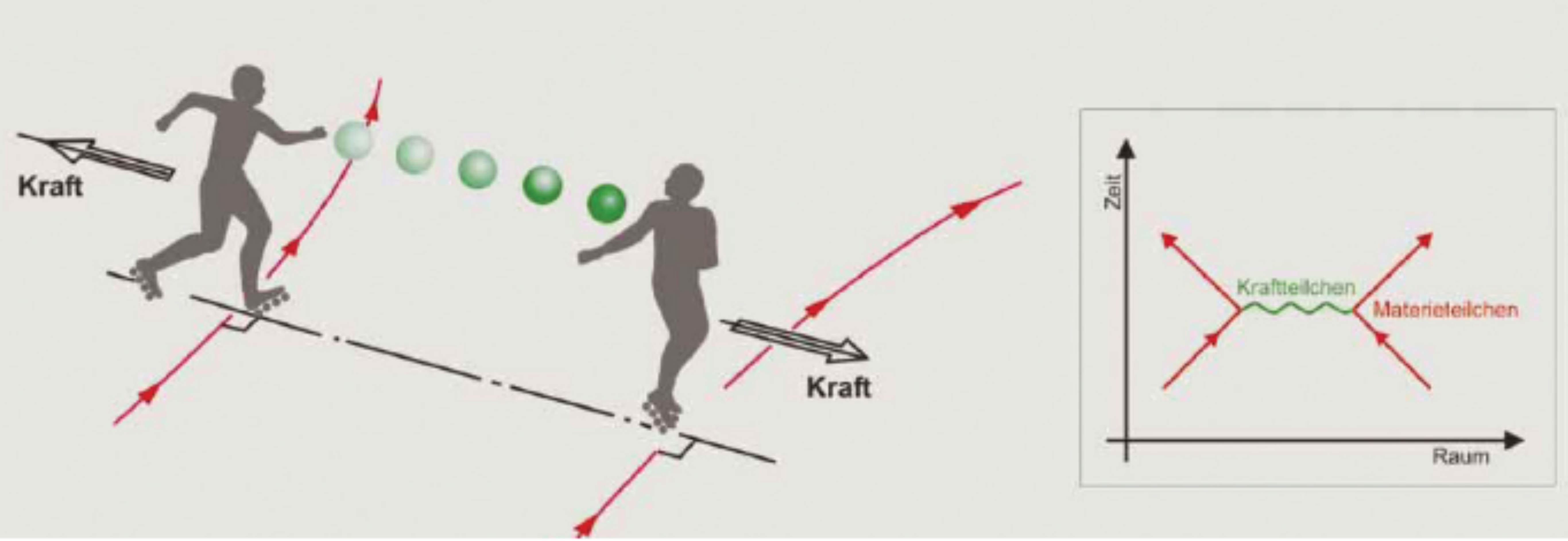
GRAVITATION:

NEWTON (1642-1727): GRAVITATIONSGESETZ

ELEKTRIZITÄT, MAGNETISMUS:

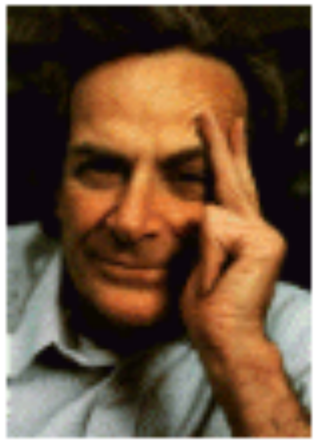
MAXWELL (1831-1879): VEREINIGUNG ELEKTROSTATIK UND MAGNETISMUS

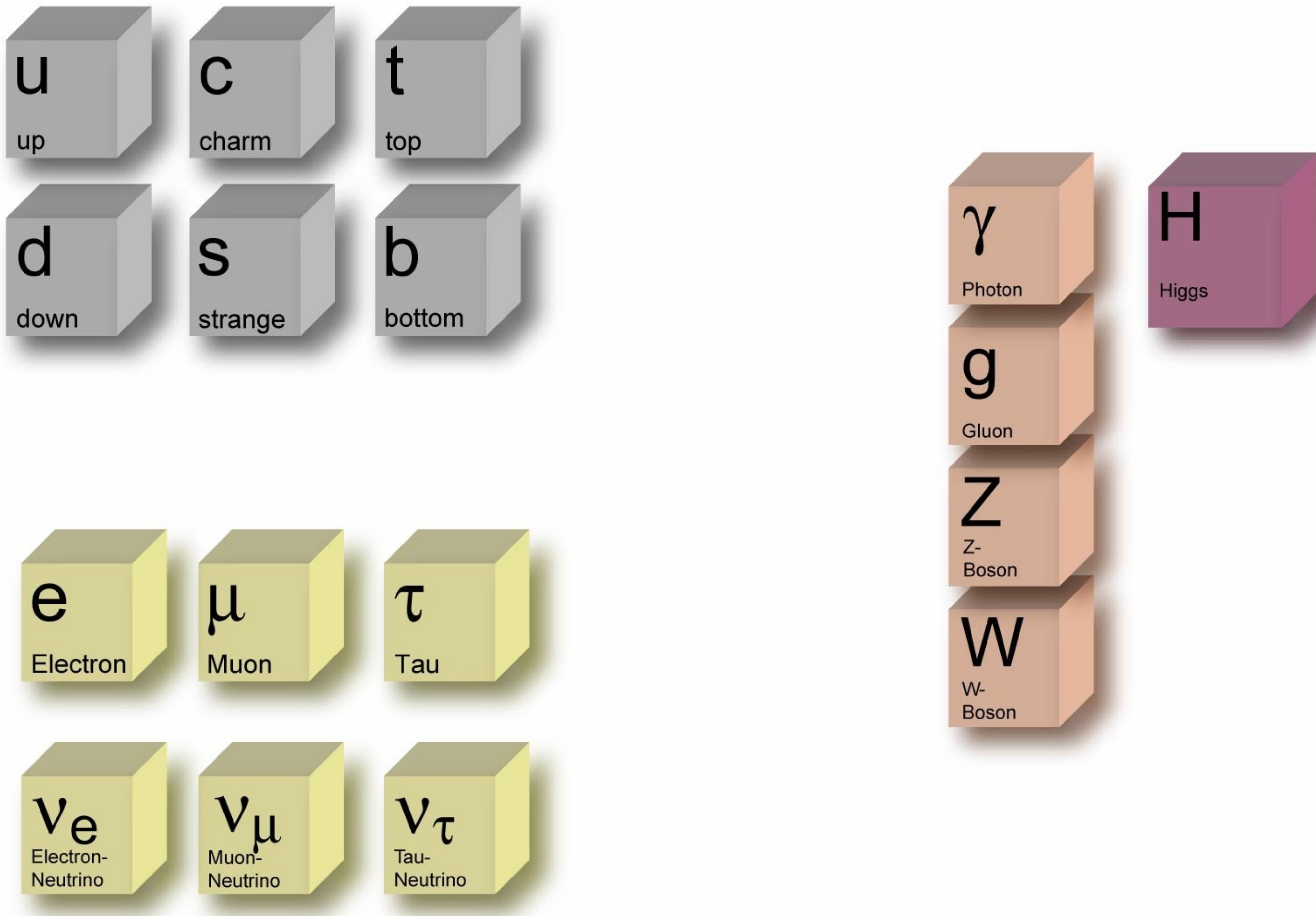
HEINRICH HERTZ (1857-94): ENTDECKUNG DER ELEKTRO-MAGNETISCHEN WELLEN IN KARLSRUHE



ALLGEMEIN:

- **KRÄFTE ENTSTEHEN DURCH AUSTAUSCH VON BOSONEN**
- **SCHEMATISCHE BESCHREIBUNG DURCH FEYNMANDIAGRAMME**




u
up
c
charm
t
top
d
down
s
strange
b
bottom
e
Electron
μ
Muon
τ
Tau
ν_e
Electron-
Neutrino
ν_μ
Muon-
Neutrino
ν_τ
Tau-
Neutrino
γ
Photon
g
Gluon
Z
Z-
Boson
W
W-
Boson
H
Higgs

Standard Model of

FUNDAMENTAL PARTICLES AND INTERACTIONS

The Standard Model summarizes the current knowledge in Particle Physics. It is the quantum theory that includes the theory of strong interactions (quantum chromodynamics or QCD) and the unified theory of weak and electromagnetic interactions (electroweak). Gravity is included on this chart because it is one of the fundamental interactions even though not part of the "Standard Model."

FERMIONS

matter constituents
spin = 1/2, 3/2, 5/2, ...

Leptons spin = 1/2

Flavor	Mass GeV/c^2	Electric charge
ν_e electron neutrino	$<1\times10^{-8}$	0
e electron	0.000511	−1
ν_μ muon neutrino	<0.0002	0
μ muon	0.106	−1
ν_τ tau neutrino	<0.02	0
τ tau	1.7771	−1

Quarks spin = 1/2

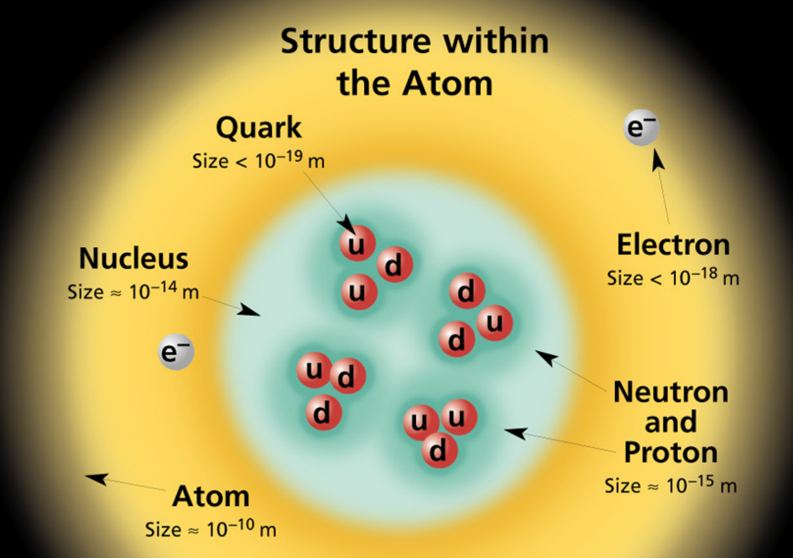
Flavor	Approx. Mass GeV/c^2	Electric charge
u up	0.003	2/3
d down	0.006	−1/3
c charm	1.3	2/3
s strange	0.1	−1/3
t top	175	2/3
b bottom	4.3	−1/3

Spin is the intrinsic angular momentum of particles. Spin is given in units of ħ, which is the quantum unit of angular momentum, where $\hbar = h/2\pi = 6.58\times10^{-25}$ GeV s $= 1.05\times10^{-34}$ J s.

Electric charges are given in units of the proton's charge. In SI units the electric charge of the proton is 1.60×10^{-19} coulombs.

The **energy** unit of particle physics is the electronvolt (eV), the energy gained by one electron in crossing a potential difference of one volt. **Masses** are given in GeV/c^2 (remember $E = mc^2$), where 1 GeV $= 10^9$ eV $= 1.60\times10^{-10}$ joule. The mass of the proton is 0.938 GeV/c^2 $= 1.67\times10^{-27}$ kg.

Structure within the Atom



If the protons and neutrons in this picture were 10 cm across, then the quarks and electrons would be less than 0.1 mm in size and the entire atom would be about 10 km across.

BOSONS

force carriers
spin = 0, 1, 2, ...

Unified Electroweak spin = 1

Name	Mass GeV/c^2	Electric charge
γ photon	0	0
W^-	80.4	−1
W^+	80.4	+1
Z^0	91.187	0

Strong (color) spin = 1

Name	Mass GeV/c^2	Electric charge
g gluon	0	0

Color Charge
Each quark carries one of three types of "strong charge," also called "color charge." These charges have nothing to do with the colors of visible light. There are eight possible types of color charge for gluons. Just as electrically-charged particles interact by exchanging photons, in strong interactions color-charged particles interact by exchanging gluons. Leptons, photons, and ***W*** and ***Z*** bosons have no strong interactions and hence no color charge.

Quarks Confined in Mesons and Baryons
One cannot isolate quarks and gluons; they are confined in color-neutral particles called **hadrons**. This confinement (binding) results from multiple exchanges of gluons among the color-charged constituents. As color-charged particles (quarks and gluons) move apart, the energy in the color-force field between them increases. This energy eventually is converted into additional quark-antiquark pairs (see figure below). The quarks and antiquarks then combine into hadrons; these are the particles seen to emerge. Two types of hadrons have been observed in nature: **mesons** $q\bar{q}$ and **baryons** qqq.

Residual Strong Interaction
The strong binding of color-neutral protons and neutrons to form nuclei is due to residual strong interactions between their color-charged constituents. It is similar to the residual electrical interaction that binds electrically neutral atoms to form molecules. It can also be viewed as the exchange of mesons between the hadrons.

PROPERTIES OF THE INTERACTIONS

Property \ Interaction	Gravitational	Weak (Electroweak)	Electromagnetic (Electroweak)	Strong: Fundamental	Strong: Residual
Acts on:	Mass – Energy	Flavor	Electric Charge	Color Charge	See Residual Strong Interaction Note
Particles experiencing:	All	Quarks, Leptons	Electrically charged	Quarks, Gluons	Hadrons
Particles mediating:	Graviton (not yet observed)	W^+ W^- Z^0	γ	Gluons	Mesons
Strength relative to electromag for two u quarks at: 10^{-18} m	10^{-41}	0.8	1	25	Not applicable to quarks
Strength relative to electromag for two u quarks at: 3×10^{-17} m	10^{-41}	10^{-4}	1	60	
for two protons in nucleus	10^{-36}	10^{-7}	1	Not applicable to hadrons	20

Baryons qqq and Antibaryons $\bar{q}\bar{q}\bar{q}$

Baryons are fermionic hadrons.
There are about 120 types of baryons.

Symbol	Name	Quark content	Electric charge	Mass GeV/c^2	Spin
p	proton	uud	1	0.938	1/2
$\bar{p}$	anti-proton	$\bar{u}\bar{u}\bar{d}$	−1	0.938	1/2
n	neutron	udd	0	0.940	1/2
Λ	lambda	uds	0	1.116	1/2
Ω^-	omega	sss	−1	1.672	3/2

Mesons $q\bar{q}$

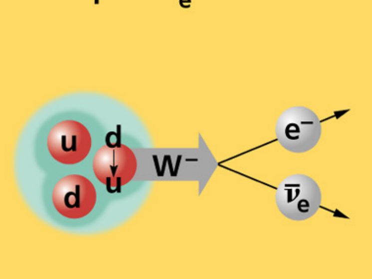
Mesons are bosonic hadrons.
There are about 140 types of mesons.

Symbol	Name	Quark content	Electric charge	Mass GeV/c^2	Spin
π^+	pion	$u\bar{d}$	+1	0.140	0
K^-	kaon	$s\bar{u}$	−1	0.494	0
ρ^+	rho	$u\bar{d}$	+1	0.770	1
B^0	B-zero	$d\bar{b}$	0	5.279	0
η_c	eta-c	$c\bar{c}$	0	2 .980	0

Matter and Antimatter
For every particle type there is a corresponding antiparticle type, denoted by a bar over the particle symbol (unless + or – charge is shown). Particle and antiparticle have identical mass and spin but opposite charges. Some electrically neutral bosons (e.g., Z^0, γ, and $\eta_c = c\bar{c}$, but not $K^0 = d\bar{s}$) are their own antiparticles.

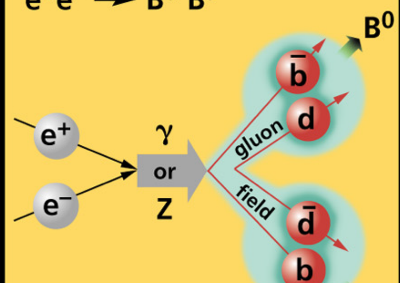
Figures
These diagrams are an artist's conception of physical processes. They are ***not*** exact and have ***no*** meaningful scale. Green shaded areas represent the cloud of gluons or the gluon field, and red lines the quark paths.

$n \rightarrow p\, e^-\, \bar{\nu}_e$



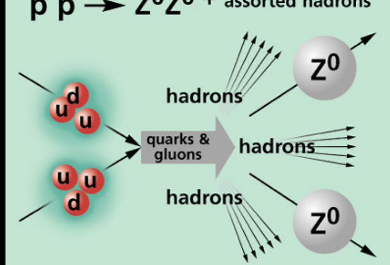
A neutron decays to a proton, an electron, and an antineutrino via a virtual (mediating) W boson. This is neutron β decay.

$e^+e^- \rightarrow B^0\, \bar{B}^0$



An electron and positron (antielectron) colliding at high energy can annihilate to produce B^0 and $\bar{B}^0$ mesons via a virtual Z boson or a virtual photon.

$p\, p \rightarrow Z^0 Z^0$ + assorted hadrons



Two protons colliding at high energy can produce various hadrons plus very high mass particles such as Z bosons. Events such as this one are rare but can yield vital clues to the structure of matter.

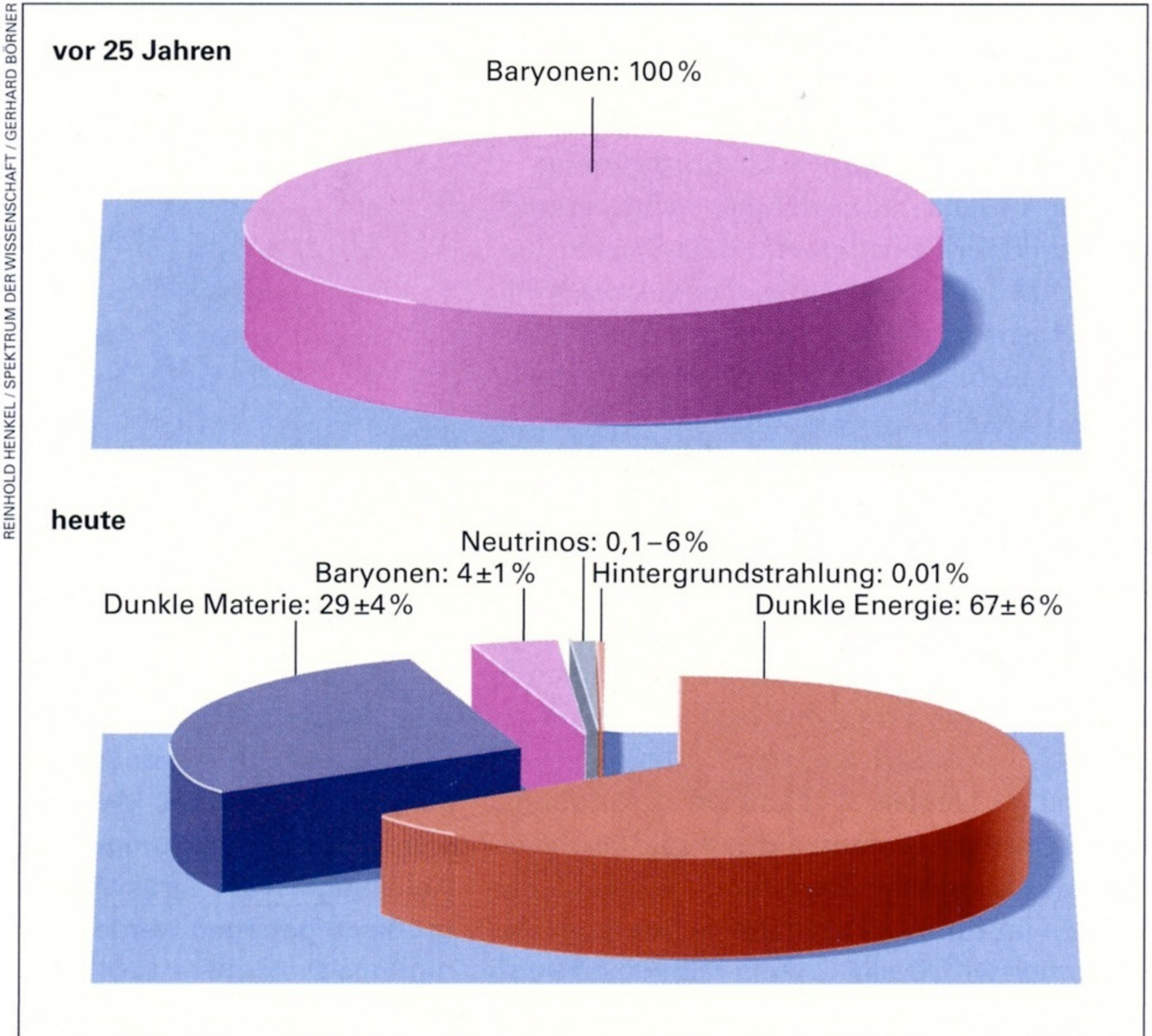
The Particle Adventure
Visit the award-winning web feature *The Particle Adventure* at
http://ParticleAdventure.org

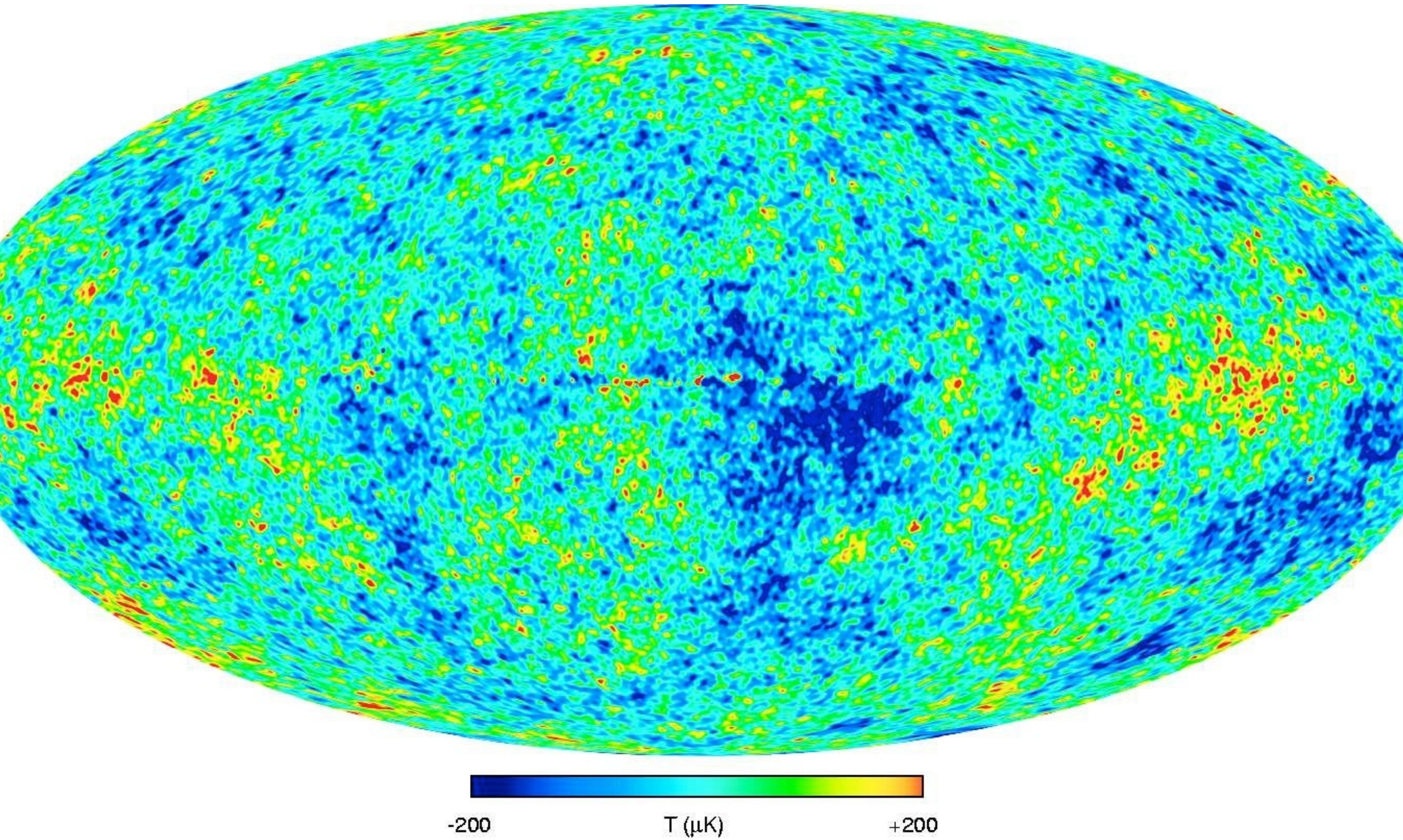
This chart has been made possible by the generous support of:
U.S. Department of Energy
U.S. National Science Foundation
Lawrence Berkeley National Laboratory
Stanford Linear Accelerator Center
American Physical Society, Division of Particles and Fields
BURLE INDUSTRIES, INC.

http://CPEPweb.org

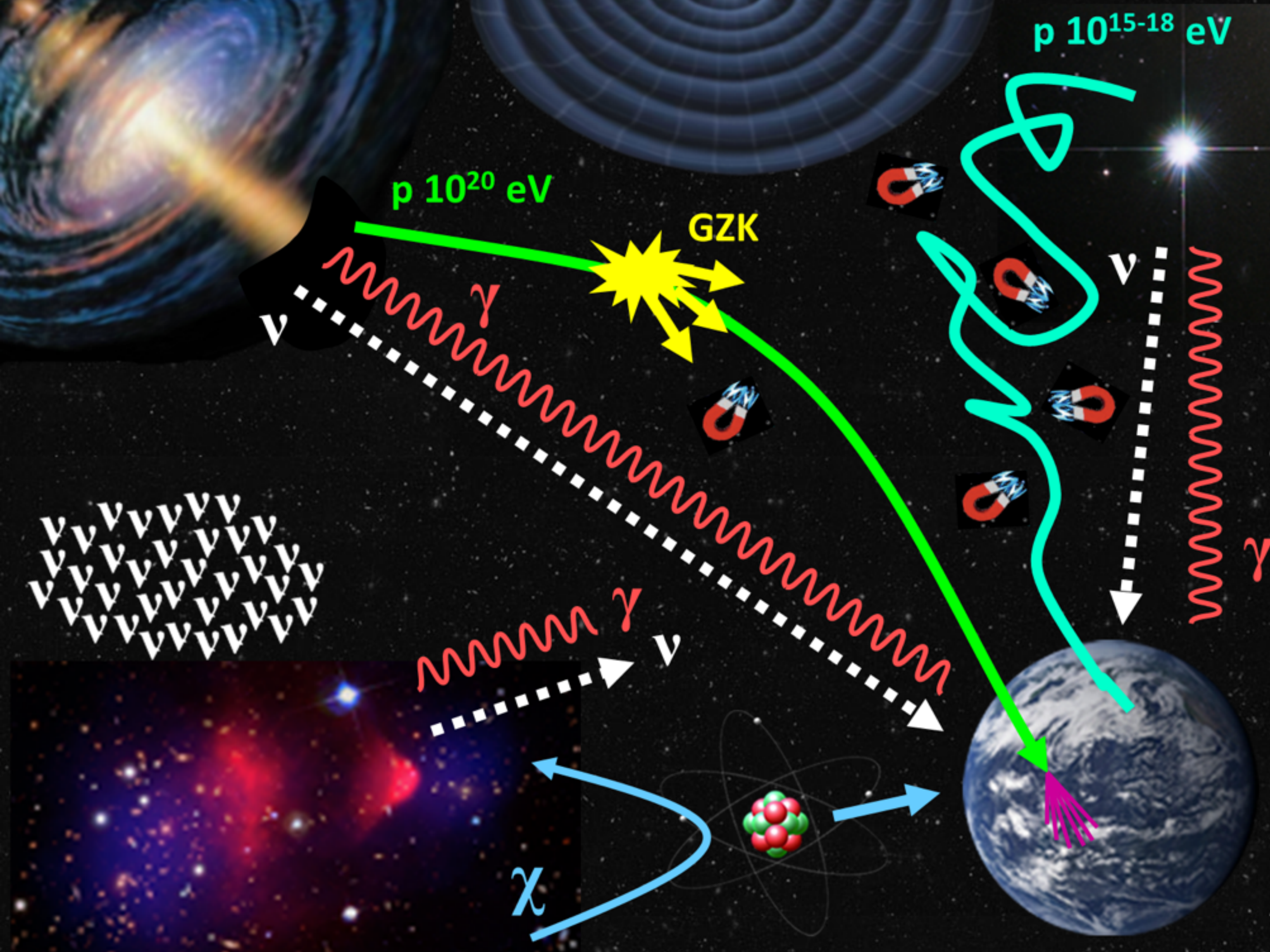
Coma-Haufen: Dunkle Materie?!

Fritz Zwicky
(1898-1974)


vor 25 Jahren
Baryonen: 100%
heute
Neutrinos: 0,1–6%
Baryonen: 4±1%
Hintergrundstrahlung: 0,01%
Dunkle Materie: 29±4%
Dunkle Energie: 67±6%



WMAP: Temperaturkarte des Universums



p 10^{15-18} eV
p 10^{20} eV
GZK
γ
ν
ν
γ
γ
ν
χ


UND WEIL SICH DAS UNIVERSUM IMMER WEITER AUSDEHNT, BRAUCHEN WIR EBEN EIN GRÖSSERES TELESKOP!
OH

1.2 Physikalische Größen und Einheiten

nur drei Basisgrößen: Länge, Zeit, Masse

Tabelle 1.1

Einige typische Längenabstände (Größenordnung)

Körper	Länge (oder Abstand)
Neutron oder Proton (Radius)	10^{-15} m
Atom	10^{-10} m
Virus (► Abbildung 1.3)	10^{-7} m
Papierbogen (Dicke)	10^{-4} m
Fingerdicke	10^{-2} m
Fußballfeldlänge	10^{2} m
Höhe des Mount Everest (► Abbildung 1.3)	10^{4} m
Erddurchmesser	10^{7} m
Erde – Sonne	10^{11} m
Nächster Fixstern	10^{16} m
Nächste Galaxie	10^{22} m
Fernste sichtbare Galaxie	10^{26} m

Tabelle 1.2

Einige Massen

Körper	Masse (Näherungswerte)
Elektron	10^{-30} kg
Proton, Neutron	10^{-27} kg
DNA-Molekül	10^{-17} kg
Bakterium	10^{-15} kg
Mücke	10^{-5} kg
Pflaume	10^{-1} kg
Person	10^{2} kg
Schiff	10^{8} kg
Erde	$6 \cdot 10^{24}$ kg
Sonne	$2 \cdot 10^{30}$ kg
Galaxis	10^{41} kg

Einige typische Zeitintervalle

Zeitintervall	Sekunden (Näherungswerte)
Lebensdauer extrem instabiler subatomarer Teilchen	10^{-23} s
Lebensdauer radioaktiver Elemente	10^{-22} bis 10^{28} s
Lebensdauer eines Muon	10^{-6} s
Zeit zwischen Herzschlägen beim Menschen	10^{0} s (= 1 s)
Ein Tag	10^{5} s
Ein Jahr	$3 \cdot 10^{7}$ s
Menschliche Lebensspanne	$2 \cdot 10^{9}$ s
Aufgezeichnete Geschichte	10^{11} s
Menschen auf Erden	10^{14} s
Alter der Erde	10^{17} s
Alter des Universums	10^{18} s

Tabelle 1.4

Metrische Vorsilben

Vorsilbe	Abkürzung	Wert
exa	E	10^{18}
peta	P	10^{15}
tera	T	10^{12}
giga	G	10^{9}
mega	M	10^{6}
kilo	k	10^{3}
hecto	h	10^{2}
deka	da	10^{1}
deci	d	10^{-1}
centi	c	10^{-2}
milli	m	10^{-3}
mikro	µ	10^{-6}
nano	n	10^{-9}
pico	p	10^{-12}
femto	f	10^{-15}
atto	a	10^{-18}

Tabelle 1.5

Basisgrößen

Größe	Einheit	Abkürzung der Einheit
Länge	Meter	m
Zeit	Sekunde	s
Masse	Kilogramm	kg
Elektrischer Strom	Ampere	A
Temperatur	Kelvin	K
Stoffmenge	Mol	mol
Lichtstärke	Candela	cd