Moderne Physik von Teilchen bis Kosmologie: Didaktische Aspekte*

I. Moderne Physik und Motivation
II. Moderne Physik und Lernen
III. Ressourcen
IV. Zusammenfassung, Ausblick

* CERN Swiss Teacher Programme, 12/11/2019; A. Müller (Uni Genf)

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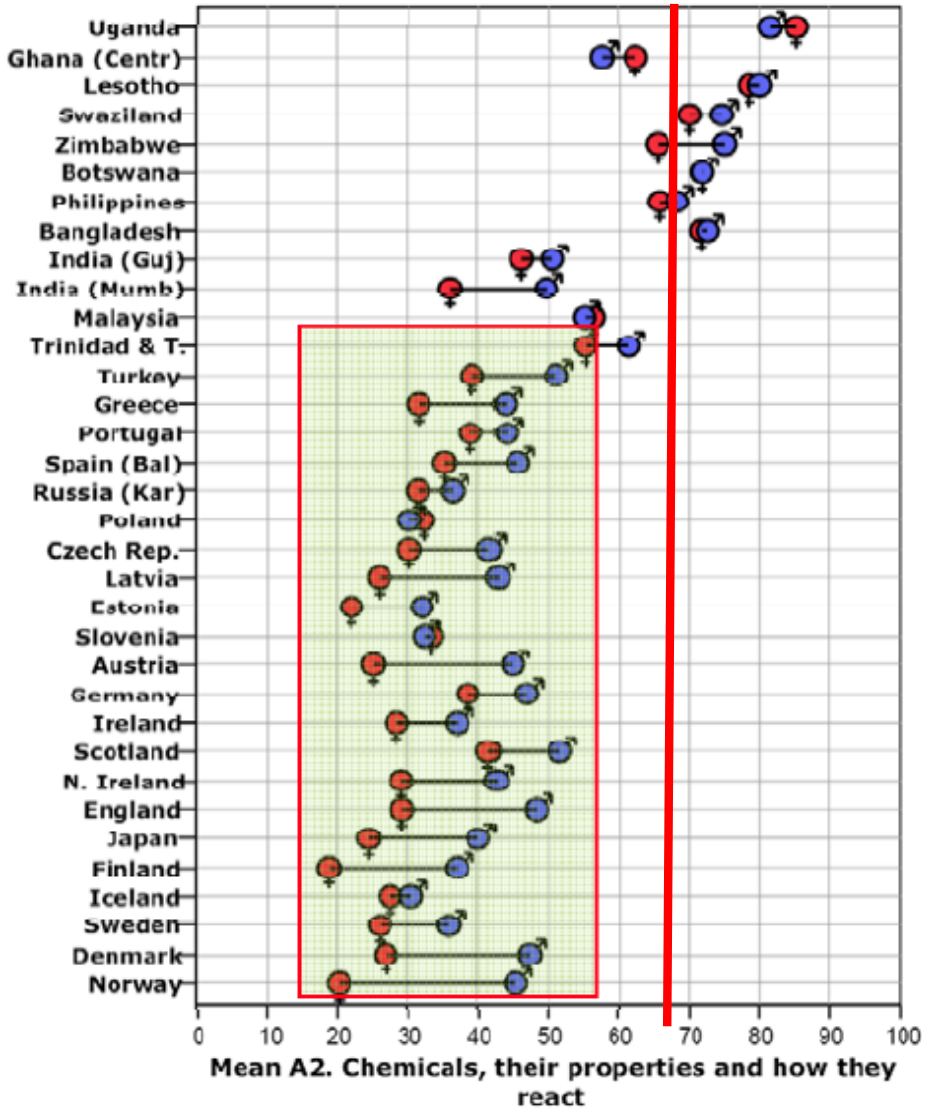
Modern Physics and Motivation: ROSE study

I.

Relevance of Science Education: ROSE
(EUR: N_C > 25, N_P > 1000/country)

Chemicals, their properties and how they react

1 = not interested (0%)
2 = a bit interested
3 = interested
4 = very interested (100%)
blue: boys, red: girls



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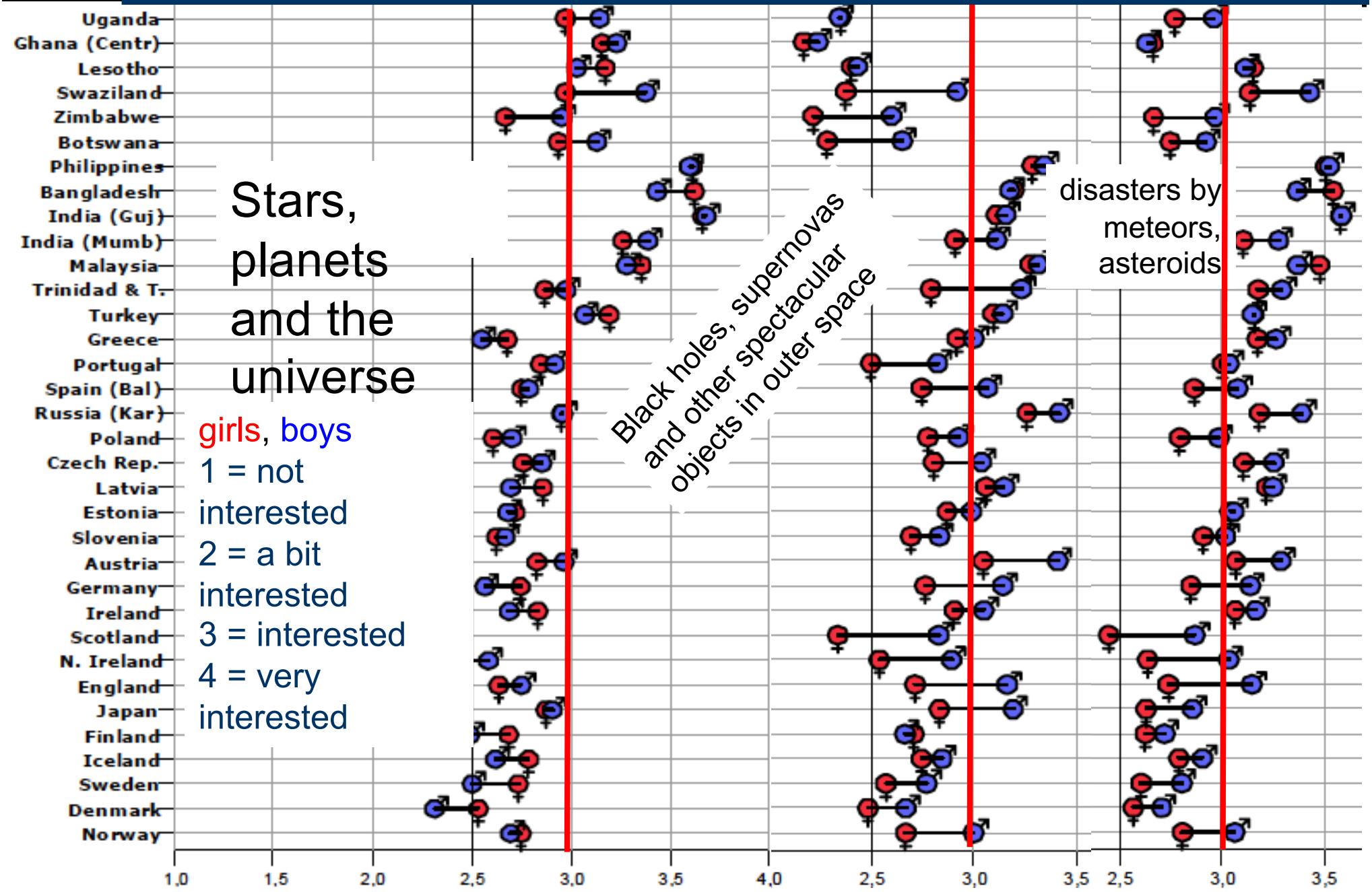
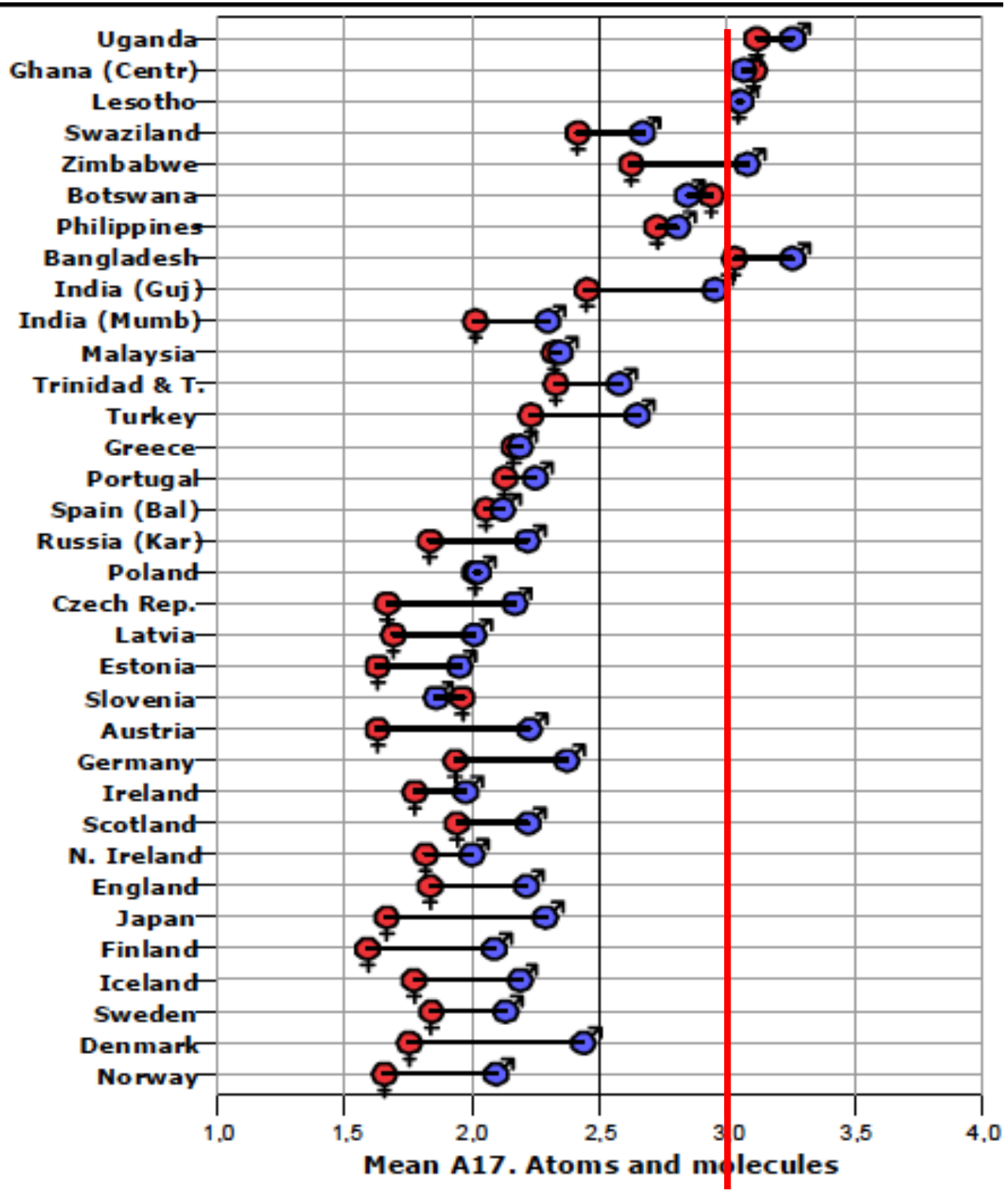
Modern Physics and Motivation: ROSE study



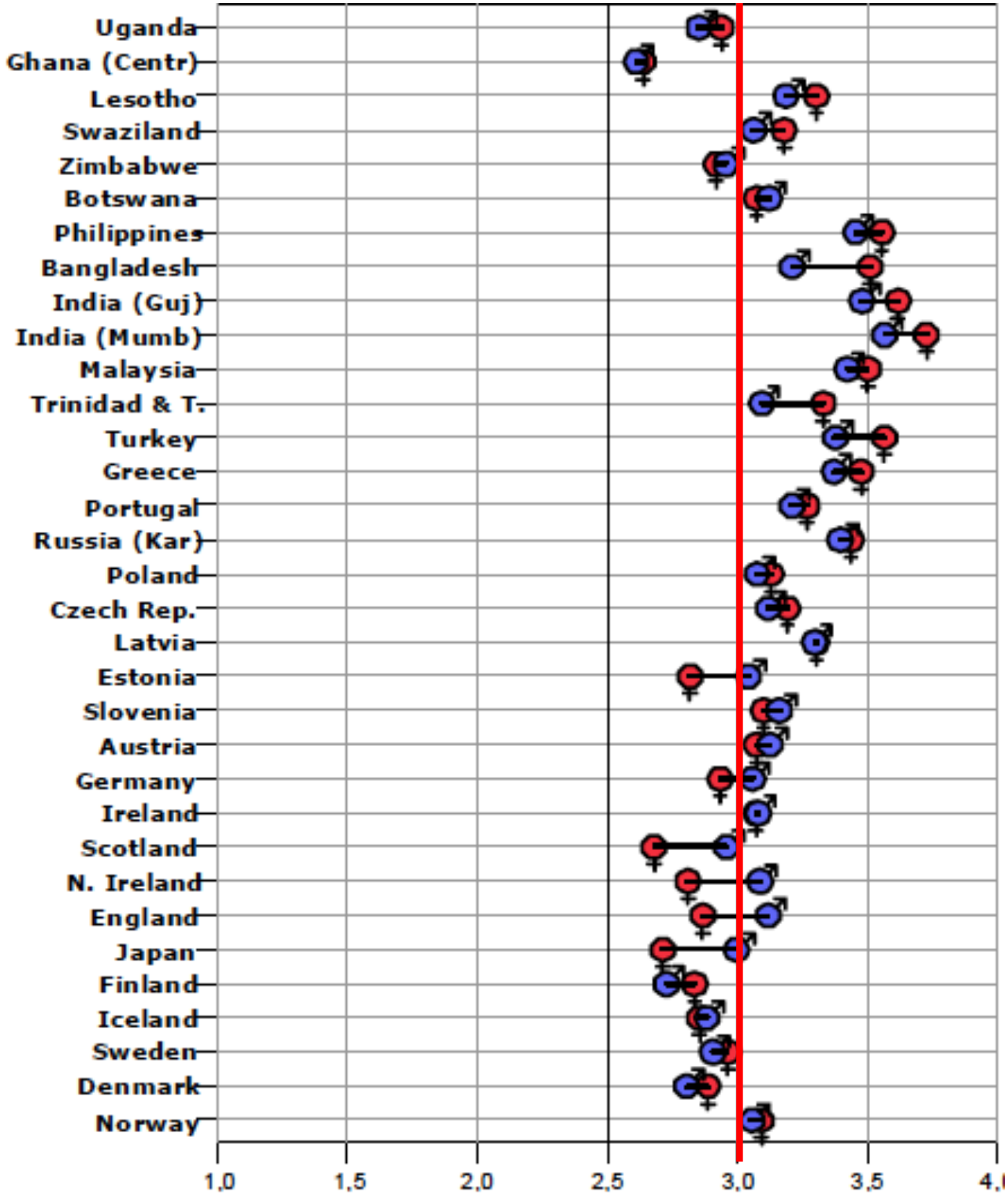
Atoms and molecules

atoms & molecules :
1.8 (UK, Ger)
how a nuclear
power plant functions:
1.72 (UK), 1.8 (Ger)



The possibility of life outside earth

The most popular for girls and boys



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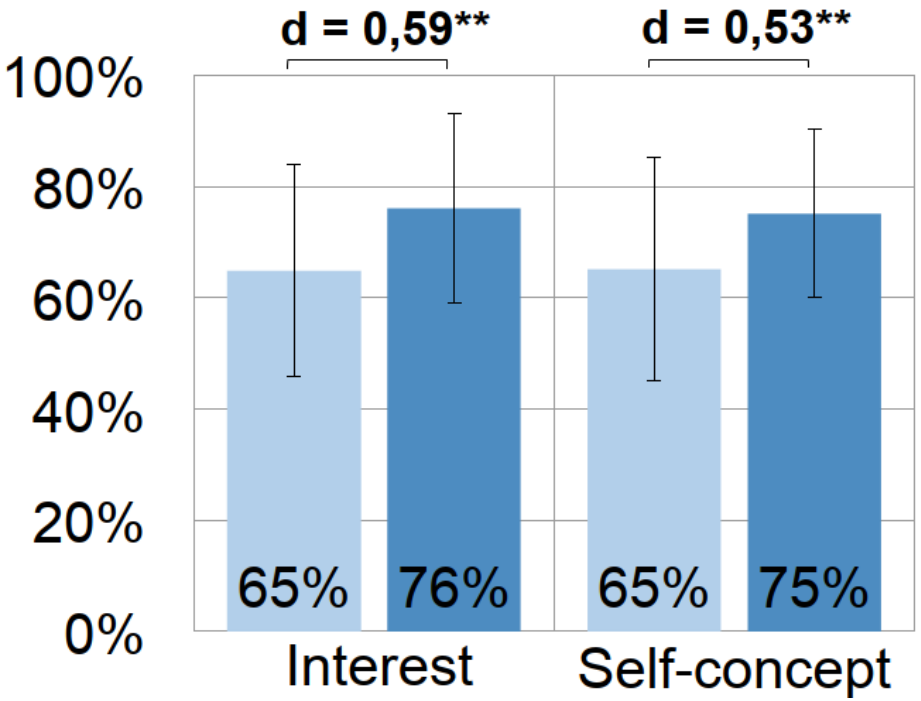
Similar effect for particle physics (Diss. J. Woithe, S'Cool LAB)

Motivation variables pre / post

- significant difference between post and pre results:
- interest / engagement: $t(510)=12{,}93$, $p<0{,}001$, ***d* = 0.59****
- self concept: $t(510)=10{,}96$, $p<0{,}001$, Cohen's ***d* = 0.53****
- post: no sign. difference between male & female participants (pre: $d = 0{,}3$**)



$d = (M_T - M_C)/SD$, i.e. difference M_T and M_C of treatment and control group, divided by standard deviation SD

i.e, d measures the impact of an intervention in units of standard deviations

Evidence for interest of pupils for topics of modern physics

I.

- **ROSE**: pronounced interest of pupils for astronomy/cosmology as topic of modern physics (particle physics not treated in that study)
- **S'CoolLAB**:
  - considerable increase of interest for CERN-related physics and of self-concept
  - as much for woman than for men
  - limitation: bias for "physics orientation" of participants

ROSE
The Relevance of Science Education

S'Cool LAB

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II.

This is all nice and well, but …

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Die Gretchenfrage

II.

Sag mir, wie steht es mit dem Lernen?

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Die Gretchenfrage

II.

- cumulative learning
- concepts, misconceptions, conceptual tests
- orders-of-magnitude
- declarative knowledge / reasoning

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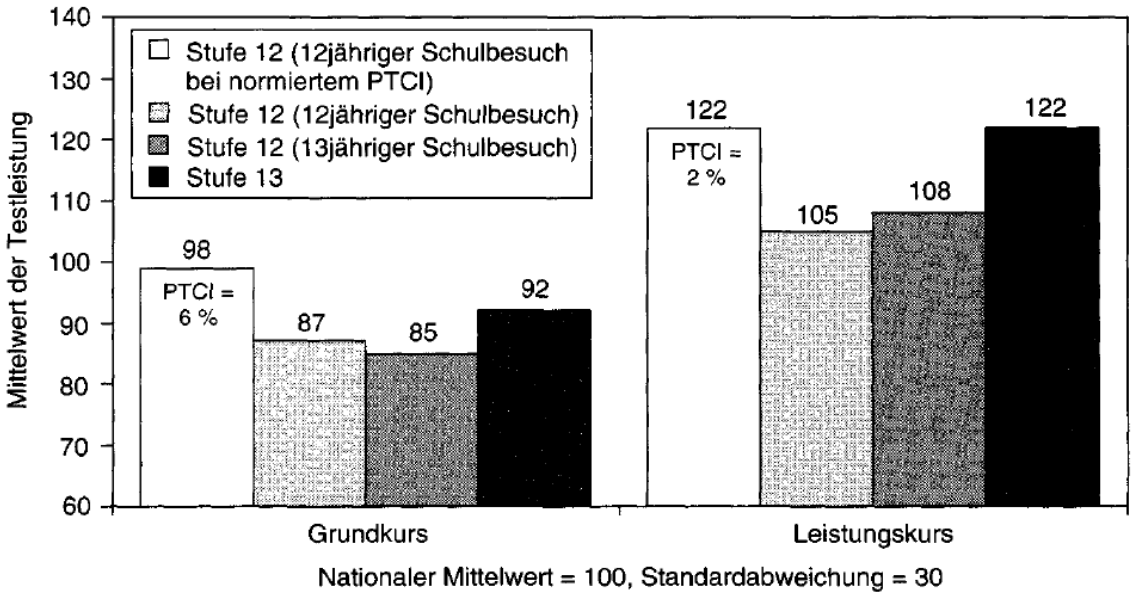
Cumulative Learning

- defined as the “sequential development of knowledge and skills”
- emphasizes the role of knowledge structures as systematic, well-structured bodies of knowledge
- considerable general research evidence for educational approaches providing support for structuring knowledge
- modern physics & cumulative learning (TIMSS, Baumert et al., 1998)

Offenbar gelingt es mit der Einführung der modernen Physik, eine Perspektive zu eröffnen, die auch die übrigen Stoffgebiete der Physik besser integriert und ein vertieftes Verständnis erschließt



Jürgen Baumert, Wilfried Bos, Rainer Watermann

TIMSS/III

Schülerleistungen in Mathematik und den Naturwissenschaften am Ende der Sekundarstufe II im internationalen Vergleich

Zusammenfassung deskriptiver Ergebnisse

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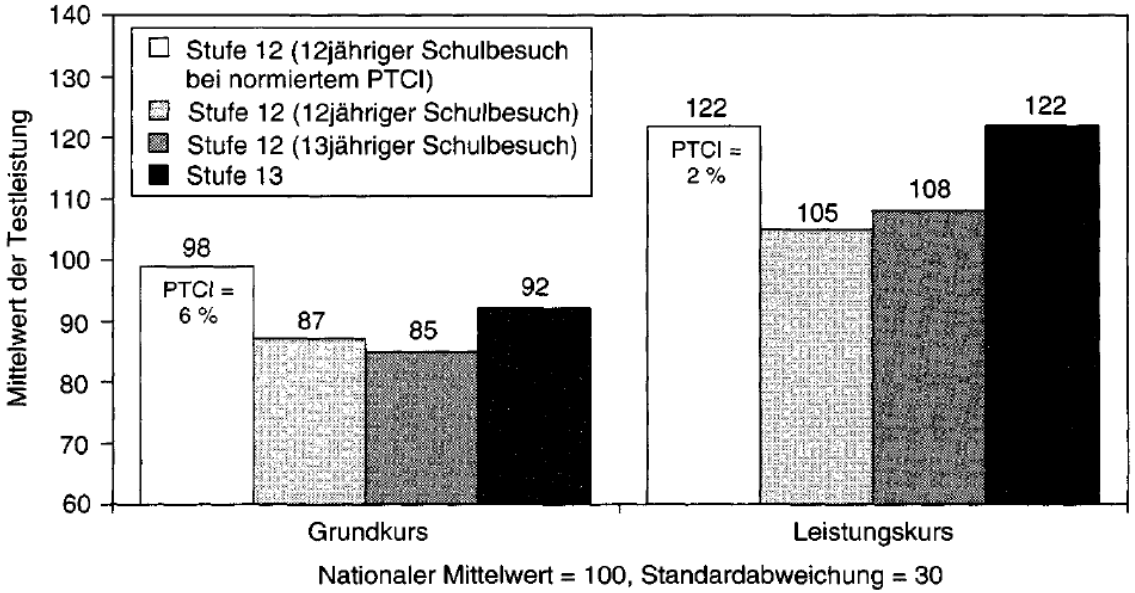
Cumulative Learning & Modern Physics

Offenbar gelingt es mit der Einführung der modernen Physik, eine Perspektive zu eröffnen, die auch die übrigen Stoffgebiete der Physik besser integriert und ein vertieftes Verständnis erschließt



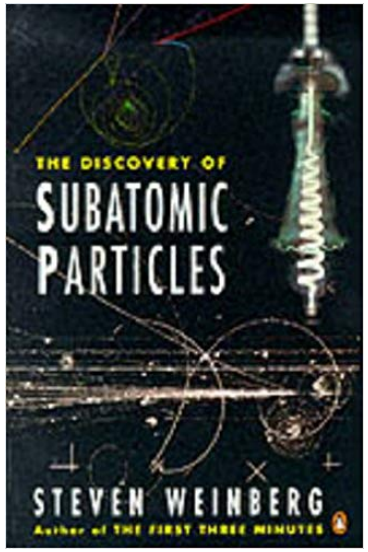
Jürgen Baumert, Wilfried Bos, Rainer Watermann

TIMSS/III

Schülerleistungen in Mathematik und den Naturwissenschaften am Ende der Sekundarstufe II im internationalen Vergleich

Zusammenfassung deskriptiver Ergebnisse

The idea of the course, in brief, was to engage students who were not assumed to have any prior training in mathematics or physics in learning about the great achievements of twentieth-century physics, building up as we went along a background in classical physics – mechanics, electromagnetism, heat, and so on – as this became necessary in order to understand the more modern developments.



Concepts, misconceptions, conceptual tests & Modern Physics

II.

- concepts
  - classical physics as basis for particle (modern) physics
  - radiation, radioactivity
  - quantum physics
  - particle physics proper
- misconceptions
  - examples from other fields
  - particle physics related (see “concepts” above)
- concept tests
  - no math or specific terminology
  - examples

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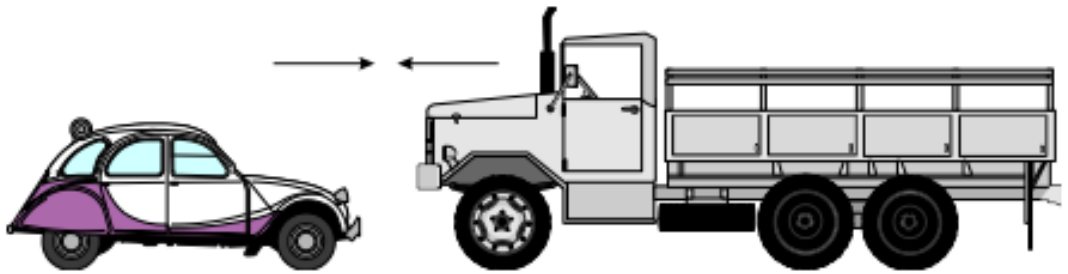
Fehlvorstellungen (Misconceptions)

- **Beispiel Mechanik**: Welche Kraft üben die Fahrzeuge beim Zusammenstoß aufeinander aus?



- A: gleiche Kräfte! (actio = reactio, 3. Newtonsches Axiom)
- Typischer Fehler: Das schwerere / größere Fahrzeug
  - *sehr* verbreitet
  - *sehr* stabil gegenüber Unterricht
  - % correct: end of Gymnasium 24% [1];
    begin/end of introductory physics course 34%/62% [2] / [3]

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[1] Planinic, M., L. Ivanjek, & Susac A., Physical Review - Physics Education Research, 6, 010103 (2010)
[2] Wang, J., & Bao, L., American Journal of Physics, 78(10), 1064-1070 (2010).
[3] Traxler, A., Henderson, R., Stewart, J., Stewart, G., Papak, A., & Lindell, R., Physical Review Physics Education Research, 14(1), 010103 (2018).

Conceptual Understanding / Misconceptions

- example: em. fields*

A, C charged, B neutral, no currents. Find and explain errors

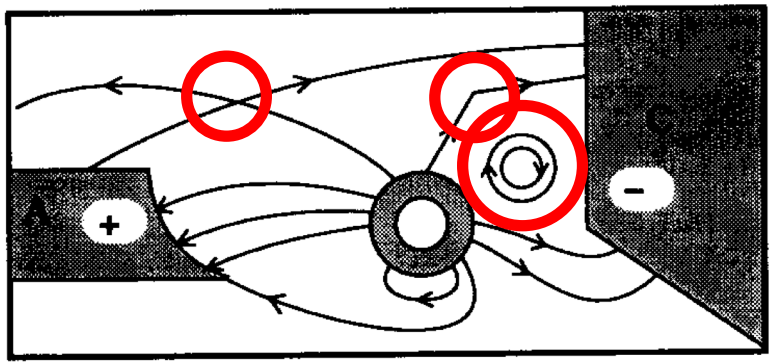


Fig. 1. Some erroneous field-lines between two charged objects and one uncharged object.

Table I. Percentages for different responses from the students.

	L	K	X
D	8	2	1
C	44	4	3
B	9	8	0
A	29	46	11
O	10	40	85

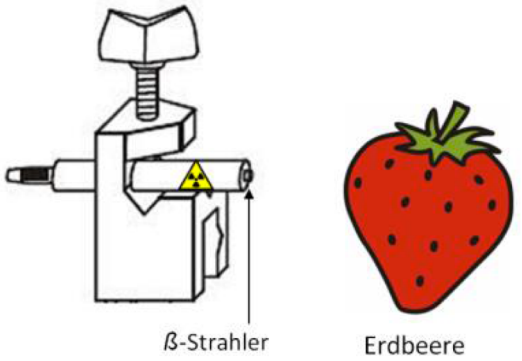
- misconceptions: L = Loop, K = Kink, X = crossing (X-ing)
- D & C: explanation by fundamental principles / essentially correct (engineering physics course)

*S. Tornkvist, K. A. Pettersson, and G. Transtromer, “Confusion by representation: On student’s comprehension of the electric field concept,” Am. J. Phys. 61(4), 335-338.

Fehlvorstellungen (“Misconceptions”)

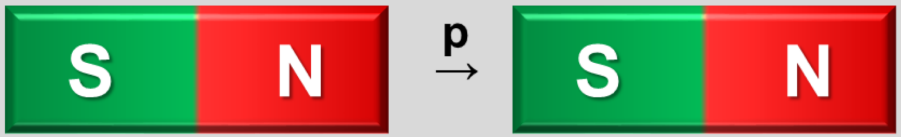
- **Beispiel Strahlung**: („Kontaminationsvorstellung“) [

Ein radioaktiver ß-Strahler wird für einige Minuten in geringer Entfernung vor einer Erdbeere platziert.
Ist die Erdbeere anschließend noch zum Verzehr geeignet?



- **Beispiel em. Wechselwirkung**

A proton is moving with constant speed to the right through the uniform magnetic field between two bar magnets.



Does a force act on the proton due to the bar magnets? ☐ yes ☐ no

analog: (p, e, n) (↓, →)

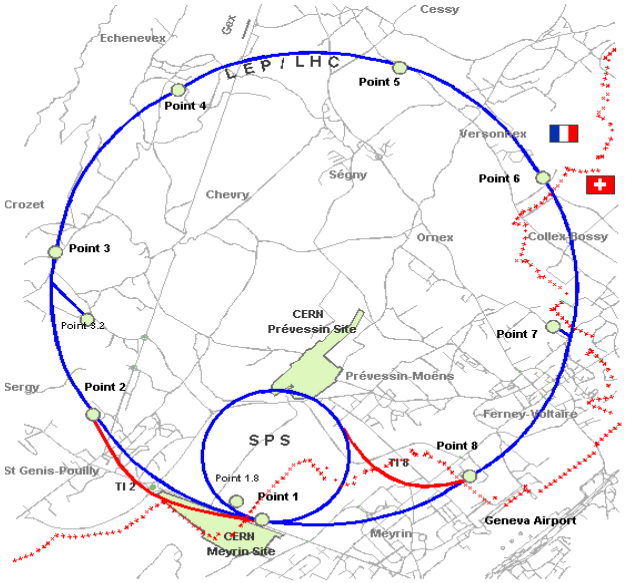
- **Beispiel Ausbreitung em. Strahlung**

Light waves travel at the speed of light, much faster than radio waves that travel at the speed of sound . % korrekt (Uni-Anfänger, Einf. Astronomie): 20 – 25 %

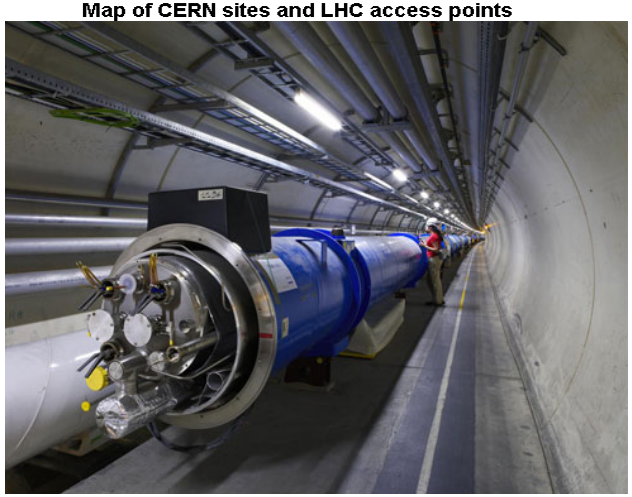
[1] Molz, A. (2016). Verbindung von Schülerlabor und Schulunterricht – Auswirkungen auf Motivation und Kognition im Fach Physik. Dissertation, TU Kaiserslautern. München: Verlag Dr. Hut
[2] Woithe, J. (2019+) Dissertation S‘CoolLAB /CERN , laufend
[3] LoPresto, M. C., & Murrell, S. R. (2011). An Astronomical Misconceptions Survey. *J. of College Sci. Teach.*, *40*(5)

Example: electron gun – particle acceleration

CERN – 6.5 TeV protons

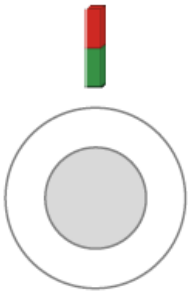


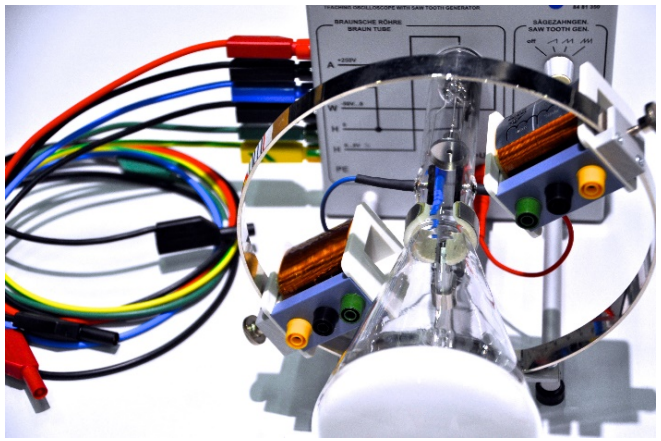
Map of CERN sites and LHC access points



S‘Cool LAB – 300 eV electrons

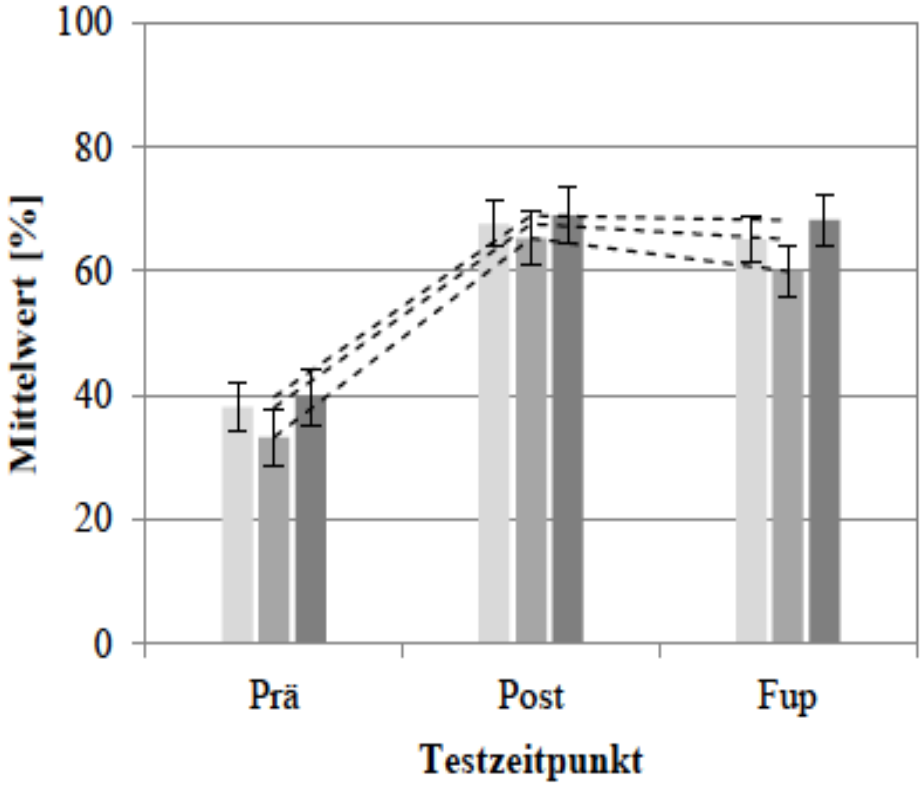
Prediction: Mark your prediction for the position of the beam spot with a **cross ✗** for the 3 magnet positions below.

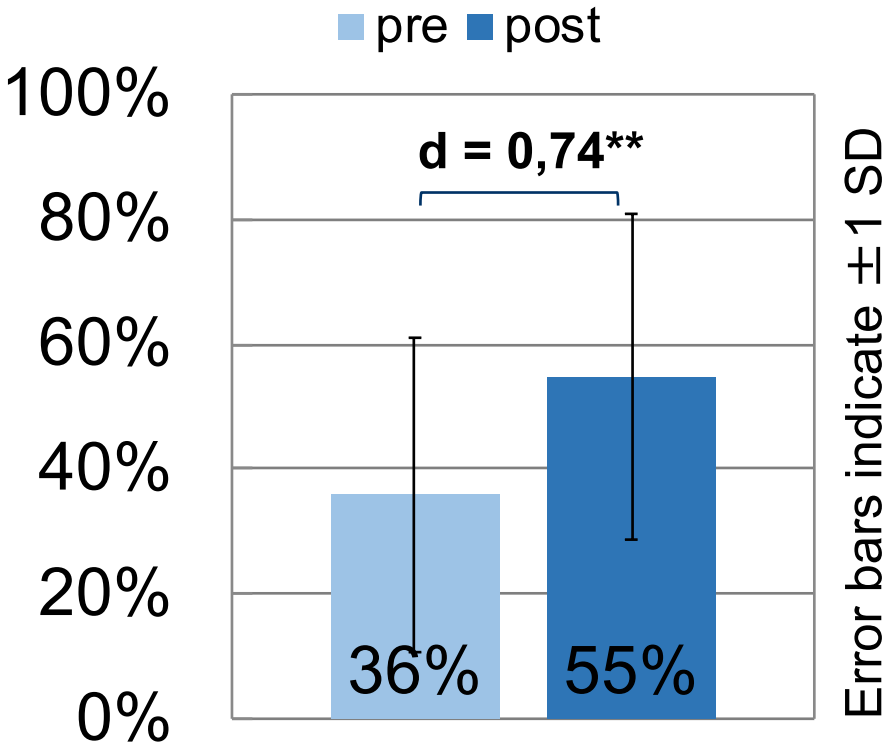
Magnet position 1	Student 1	Student 2
		
	Student 3	**Student 4**



Conceptual Learning & Modern Physics

- Strahlung, Radioaktivität (Diss. A. Molz, TU Kaiserslautern)
- CERN-bezogene Themen (Diss, J. Woithe, CERN)





Modern Physics and Learning: Intermediate Summary

II.

- cumulative learning ($d \approx 0.3 – 0.5$, Baumert & al)
- conceptual learning ($d \approx 0.5 – 0.8$; Molz, 2016; Woithe et al. 2019)
- considerable research evidence (motivation & learning)
  - astronomy, astrophysics and cosmology
  - radiation and radioactivity
  - quantum physics
- (too) little research evidence specifically on particle physics

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Ressourcen

- Konzepttests
  - Sammlungen
    http://www.flaguide.org/cat/contests/contests1.htm
    http://www.flaguide.org/default.asp
    https://www.physport.org/assessments/
  - radiation, particles: Molz (2016), Woithe (2019)*

- Fehlkonzepte (Altags-, Schülervorstellungen, …)
  - s. o.
  - und…

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Misconceptions databases STSCE and AAAS

STCSE: Students' and Teachers' Conceptions and Science Education
http://archiv.ipn.uni-kiel.de/stcse/

AAAS: Science Assessment
American Association for the Advancement of Science
http://assessment.aaas.org/topics

Select a topic to browse assessment items and resources

Select a science topic to see a list of the key ideas for that topic and options for viewing items and additional information and data.

Life Science

- Cells
- Evolution and Natural Selection
- Human Body Systems
- Interdependence in Ecosystems
- Matter and Energy in Living Systems
- Reproduction, Genes, and Heredity

Physical Science

- Atoms, Molecules, and States of Matter
- Energy: Forms, Transformation, Transfer, and Conservation
- Force and Motion

Earth Science

- Plate Tectonics
- Weathering, Erosion, and Deposition
- Weather and Climate
  (available Fall 2011)

Nature of Science

Bibliography - STCSE

Students' and Teachers' Conceptions and Science Education

Compiled by Reinders Duit

Formerly: Helga Pfundt & Reinders Duit
Bibliography - Students' Alternative Frameworks and Science Education
Bibliographie - Schülervorstellungen und naturwissenschaftlicher Unterricht

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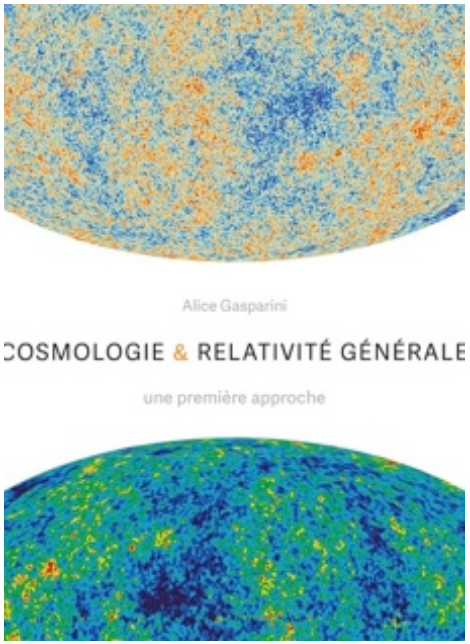
Ressourcen

III.

- Konzepttests
- Fehlkonzepte (Altags-, Schülervorstellungen, …)
- Unterrichtsmaterialien Teilchenphysik
  - Naturwissenschaften Schweiz: Teilchenphysik (SCNAT)
    https://naturwissenschaften.ch/topics/particlephysics
  - Netzwerk Teilchenwelt https://www.teilchenwelt.de/
  - Ein Quark kommt niemals allein – Elementarteilchenphysik in der Schule (Science on Stage)
    https://particleadventure.org/edumat.html
    https://www.science-on-stage.de/page/display/de/7/7/1200/ein-quark-kommt-niemals-allein-elementarteilchenphysik-in-der-schule-teache//
- Unterrichtsmaterialien Kosmologie
  - Teaching Relativity (U Hildesheim)
    https://teaching-relativity.org/
  - General Relativity and Cosmology at Secondary Level II / High chool (A. Gasparini, SwissMAP)

SwissMAP
The Mathematics of Physics
National Centre of Competence in Research

http://www.nccr-swissmap.ch/education/highschool/GRcourse
https://www.epflpress.org/produit/876/9782889152094/Cosmologie%20%20relativite%20generale



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Ressourcen

- Konzepttests
- Fehlkonzepte (Altags-, Schülervorstellungen, …)
- Unterrichtsmaterialien Teilchenphysik
- Unterrichtsmaterialien Kosmologie
- Grössenordnungsdenken

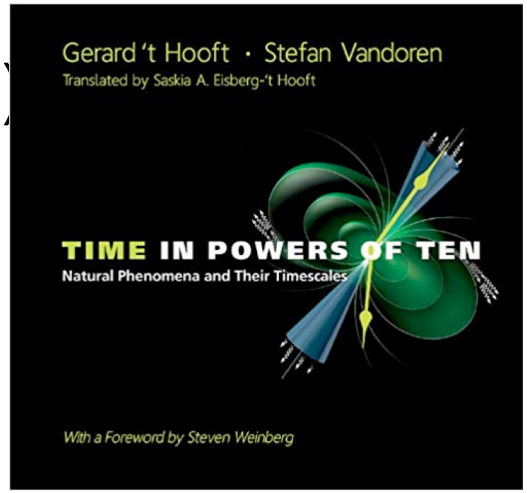
  – van t'Hofft, G.; van Dooren, S. (2014). Time in powers of ten Natural phenomena and their timescales. World Scientific

  – Powers of Ten (film); http://ippog.org/resources/2011/powers-ten

  – The Scales of the Universe (animation); http://htwins.net/scale2/

  – L. Weinstein and J. A. Adam, Guesstimation: Solving the World's Problems on the Back of a Cocktail Napkin. Princeton University Press (2008),

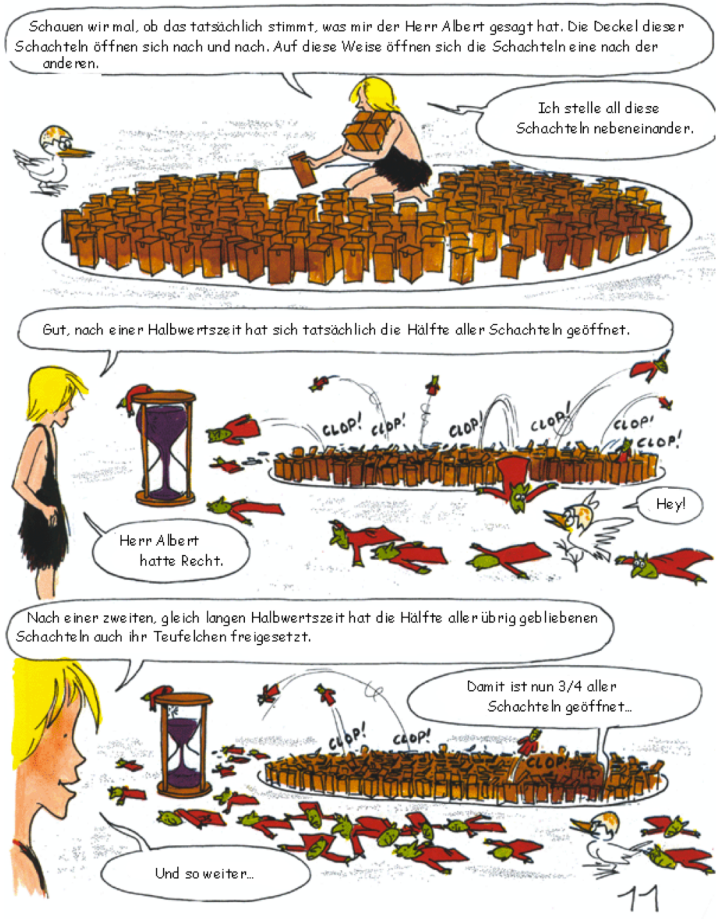
  – A. Santos, How Many Licks?: Or, How to Estimate Damn Near Anything, Running Press, Philadelphia (2009).
- Sonstiges



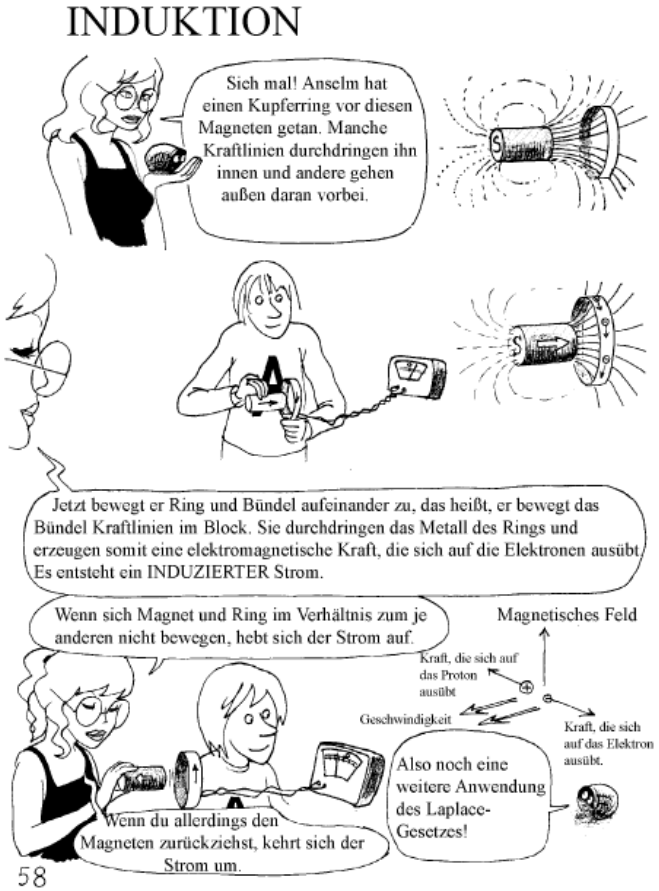
Comics & (modern) Science

- « Les aventures d'Anselme Lanturlu »
  „Die Abenteuer des Anselm Wüsstegern“ (J.P. Petit)
  https://fr.wikipedia.org/wiki/Anselme_Lanturlu
  http://www.savoir-sans-frontieres.com/

Strahlende Aussichten



Guten Tag, Herr Ampère



Enseignement fondé sur des contextes: exemples (bandes dessinées)

- « Manga Guides »
- « Les aventures d'Anselme Lanturlu » (J.P. Petit)

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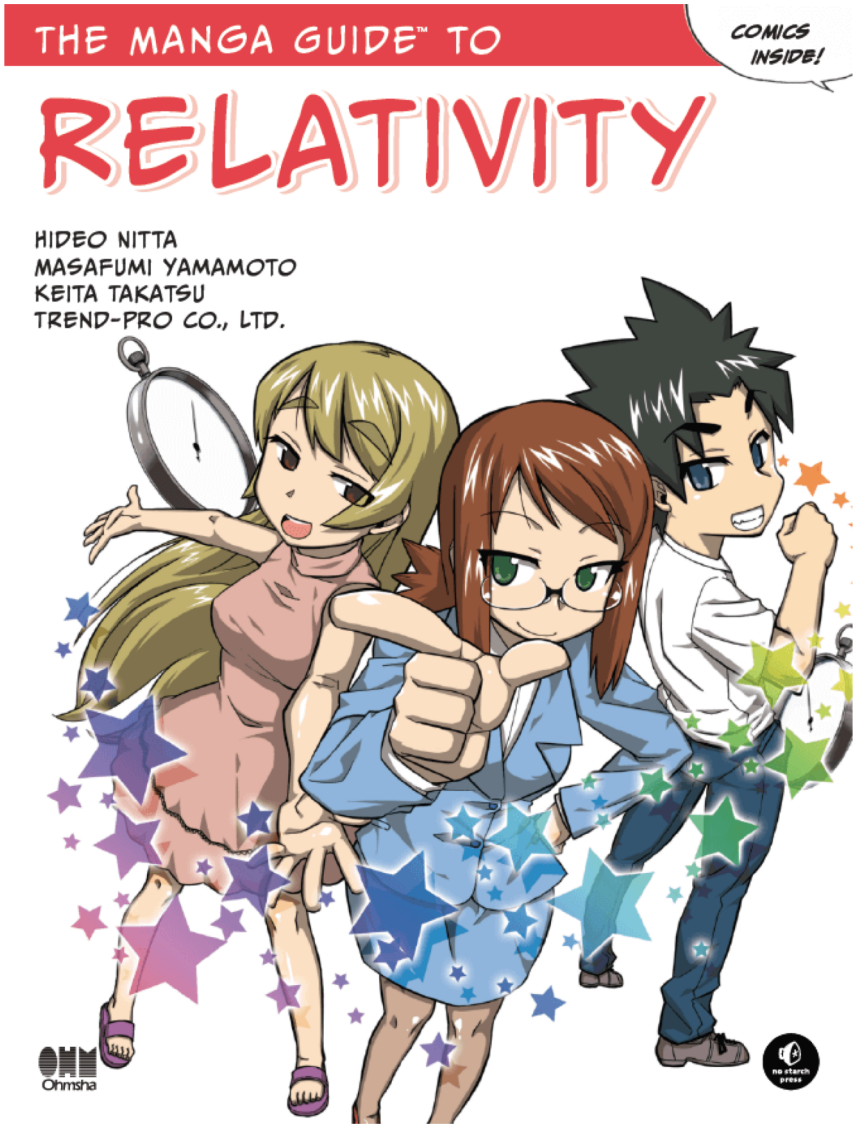
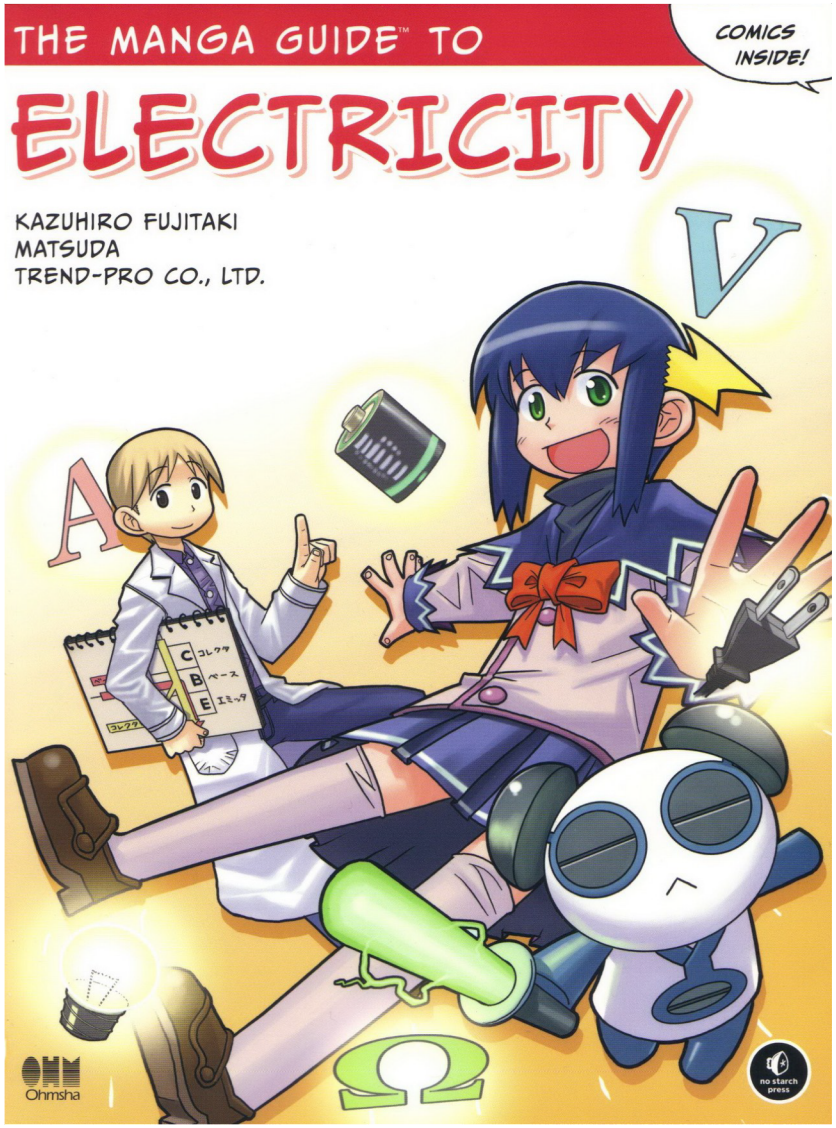
Comics & (modern) Science

2.6





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Enseignement fondé sur des contextes: exemples (bandes dessinées)

- „Manga Guides“
  (https://en.wikipedia.org/wiki/The_Manga_Guides)
  https://nostarch.com/catalog/manga

– The Manga Guide to Biochemistry (ISBN 978-1-59327-276-0)
– The Manga Guide to Molecular Biology (ISBN 978-1-59327-202-9)
– The Manga Guide to Physiology (ISBN 978-1-59327-440-5)
– The Manga Guide to Physics (ISBN 978-1-59327-196-1)
– The Manga Guide to Electricity (ISBN 978-1-59327-197-8)
– The Manga Guide to Relativity (ISBN 978-1-59327-272-2)
– The Manga Guide to the Universe (ISBN 978-1-59327-267-8)
– The Manga Guide to Calculus (ISBN 978-1-59327-194-7)
– The Manga Guide to Linear Algebra (ISBN 978-1-59327-413-9)
– The Manga Guide to Statistics (ISBN 978-1-59327-189-3)

Perspektiven

III.

I, a universe of atoms, an atom in the universe

R. Feynman*

- Weltbild…
- ... und Physik
- Beispiel: Größenordnungsüberlegungen
- Welches „Universum“ ist komplexer, gemessen an der Zahl seiner Konstitutenten?
  - N_{UA} ~ 10^{28} Atome im Menschen („universe of atoms“, UA »)
  - N_{SU} ~ $10^{22\text{-}24}$ Sterne im Universum (stars in universe, SU)
- kl. Rechnung dahinter (...wer es mag)

– $N_{UA} \sim 3 \cdot N$ (Mole H_20 im Körper) x $N_A \sim 3 \cdot 5 \cdot 10^3 \cdot 6 \cdot 10^{23}$
– $N_{SU} \sim N$ (Sterne in Galaxis) x N (Galaxien im Universum) ~ $10^{11\text{-}12} \cdot 10^{11\text{-}12}$

*“The Value of Science," public address at the National Academy of Sciences (1955); published in „The Pleasure of Finding Things Out: The Best Short Works of Richard P. Feynman“ (1999; edited by Jeffrey Robbins)

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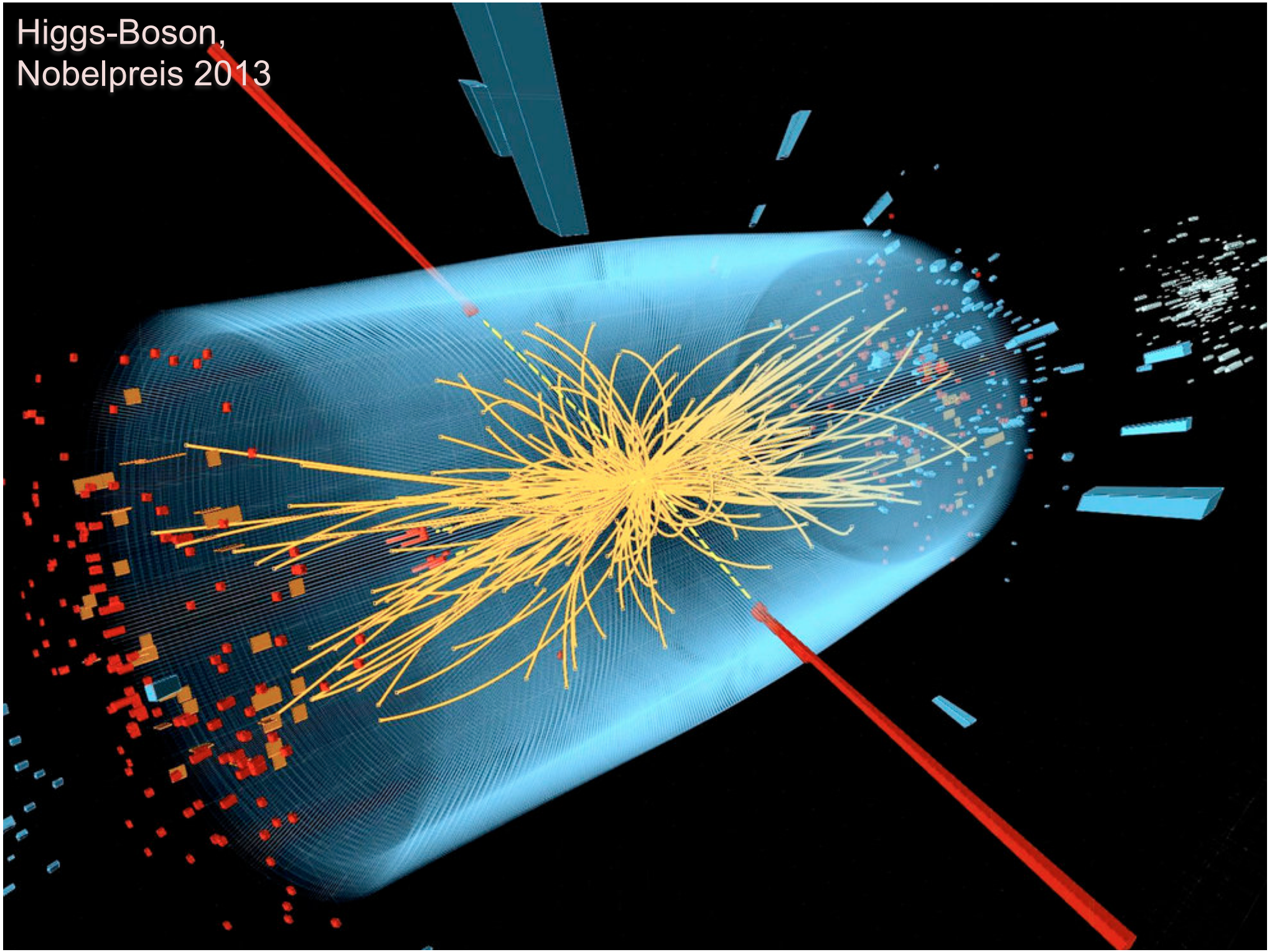
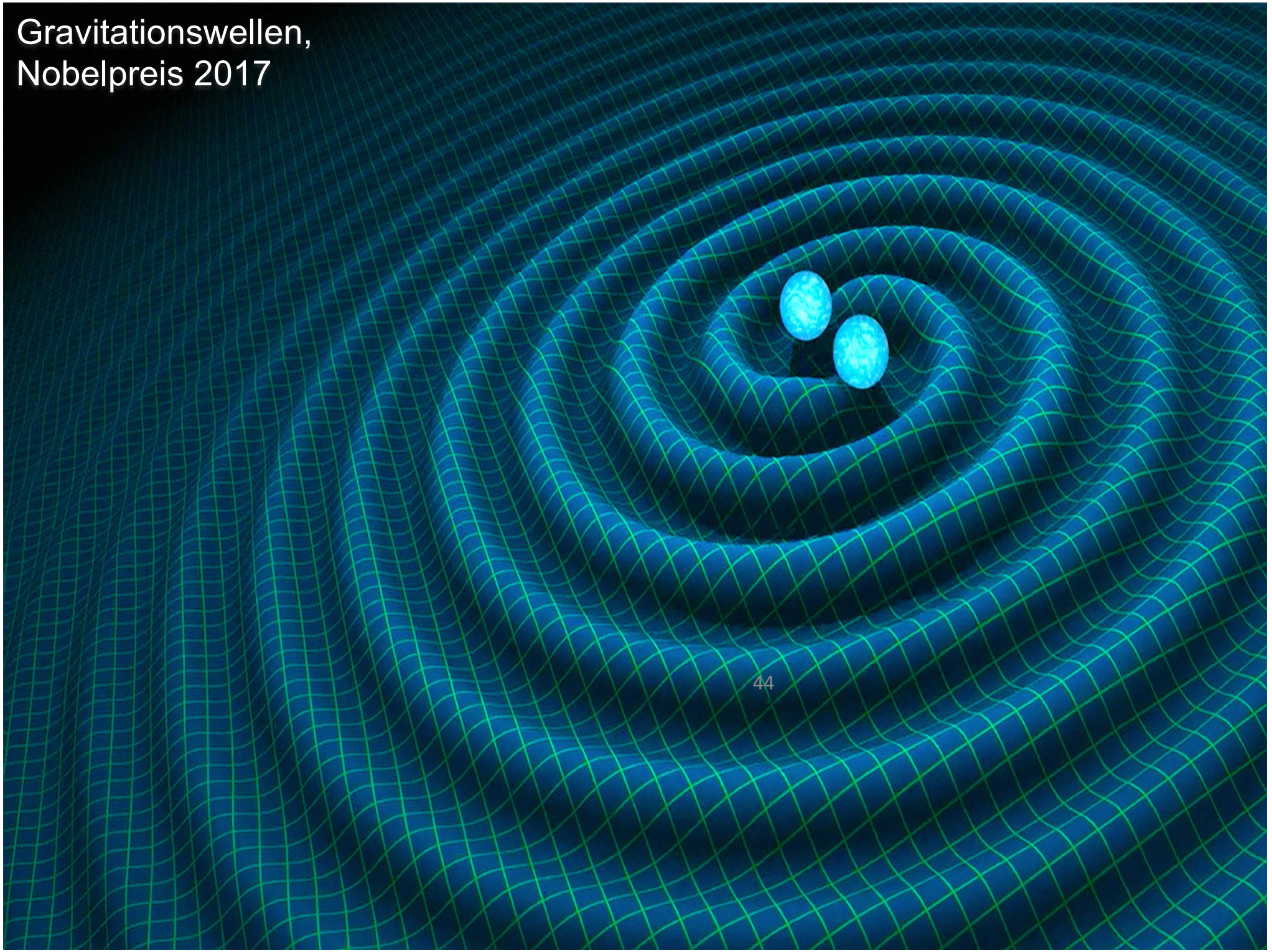
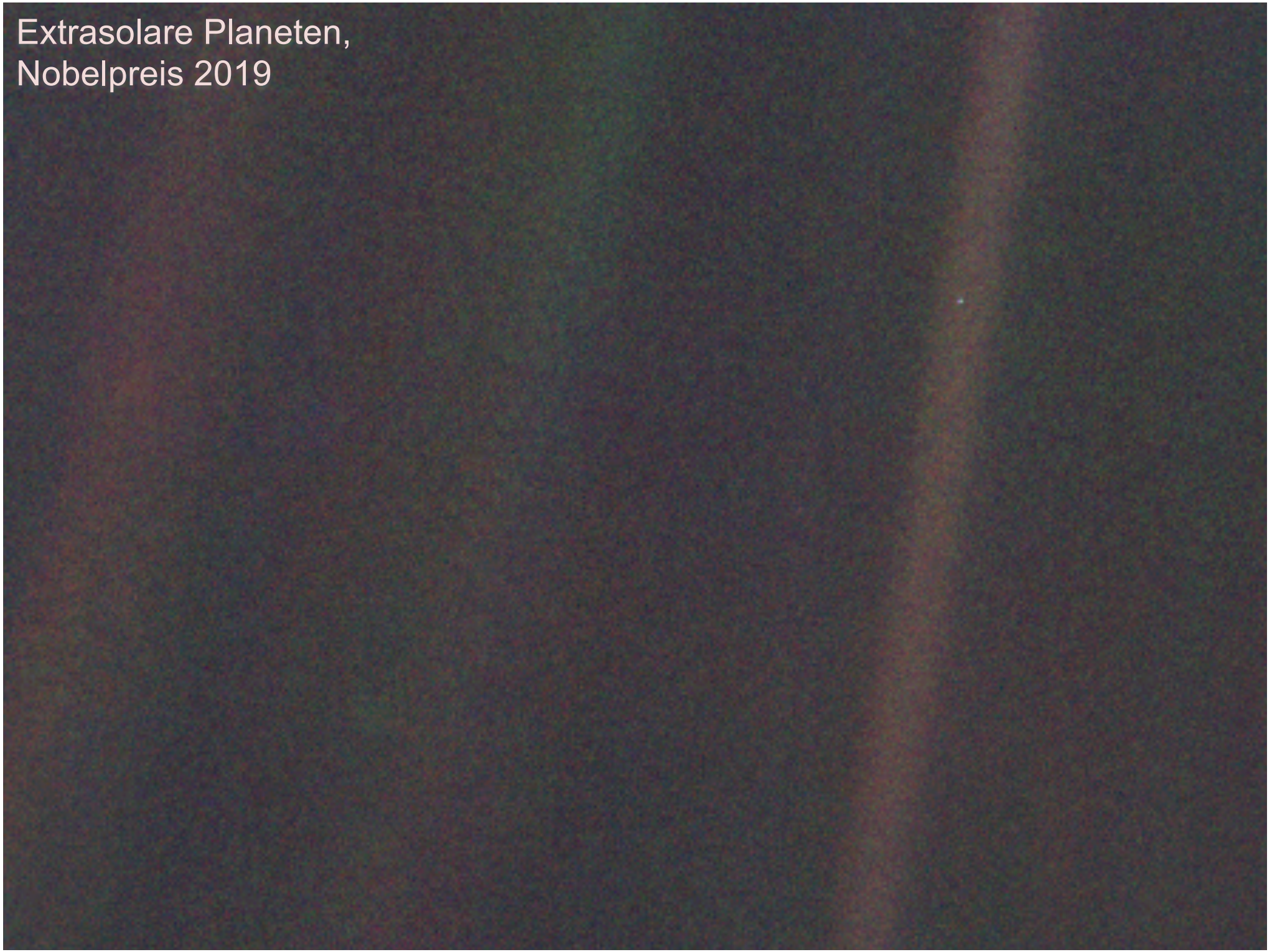
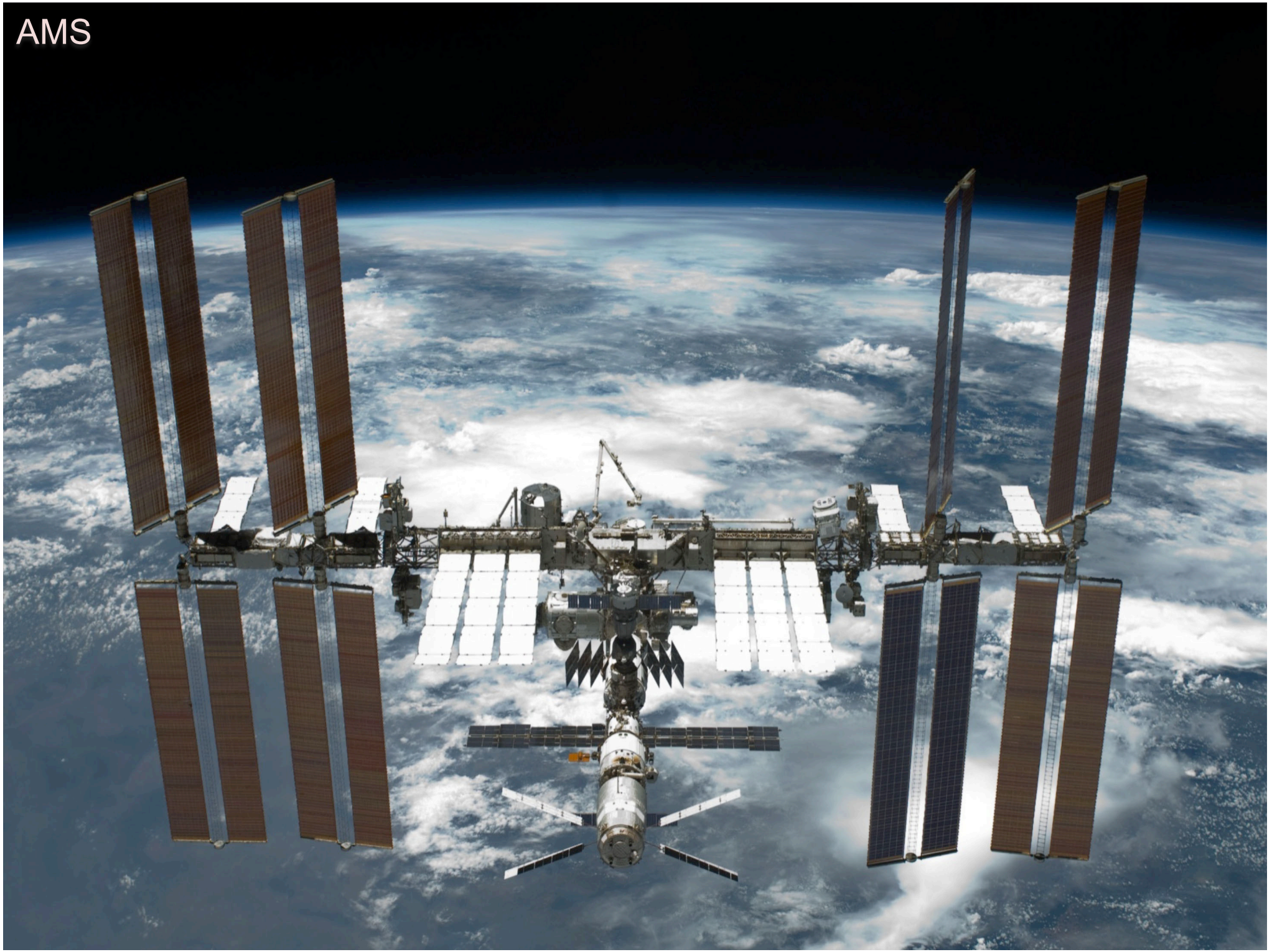

Higgs-Boson,
Nobelpreis 2013


Gravitationswellen,
Nobelpreis 2017

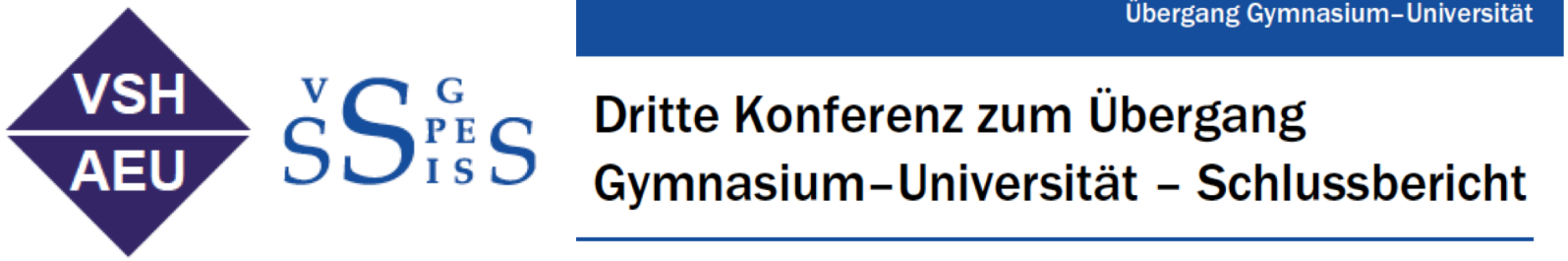

Extrasolare Planeten,
Nobelpreis 2019


AMS

Ein letztes Wort

III.

- Weltbild und Physik
- Motivations- und Lernpotential der modernen Physik



Eines [darf] nicht vergessen gehen: die Neugier und Motivation zu fördern, um die jungen Menschen für technisch – naturwissenschaftliche Themen zu gewinnen.

- UPMAP-Studie, UK (Understanding Participation rates in post-16 Mathematics and Physics)
  - Ermutigung als stärkste Lehrervariable für die Entscheidung für Physik (r = 0.5), deutlich vor allen anderen Faktoren
  - *„In every case […] their narrative tells that an adult has been significant in their becoming a physics undergraduate. Not peers, not enrichments, interventions or events, but some adult person or people – usually teachers or family members*

Ein letztes Wort

Quand tu veux construire un bâteau, ne commence pas par rassembler du bois, couper des planches et distribuer du travail, mais réveille au sein des hommes le désir de la mer grande et large. Antoine de Saint-Exupéry

My math and science teachers were always important role models in my life. My parents wanted me to go into business or something like that. (Romkey, 2007)