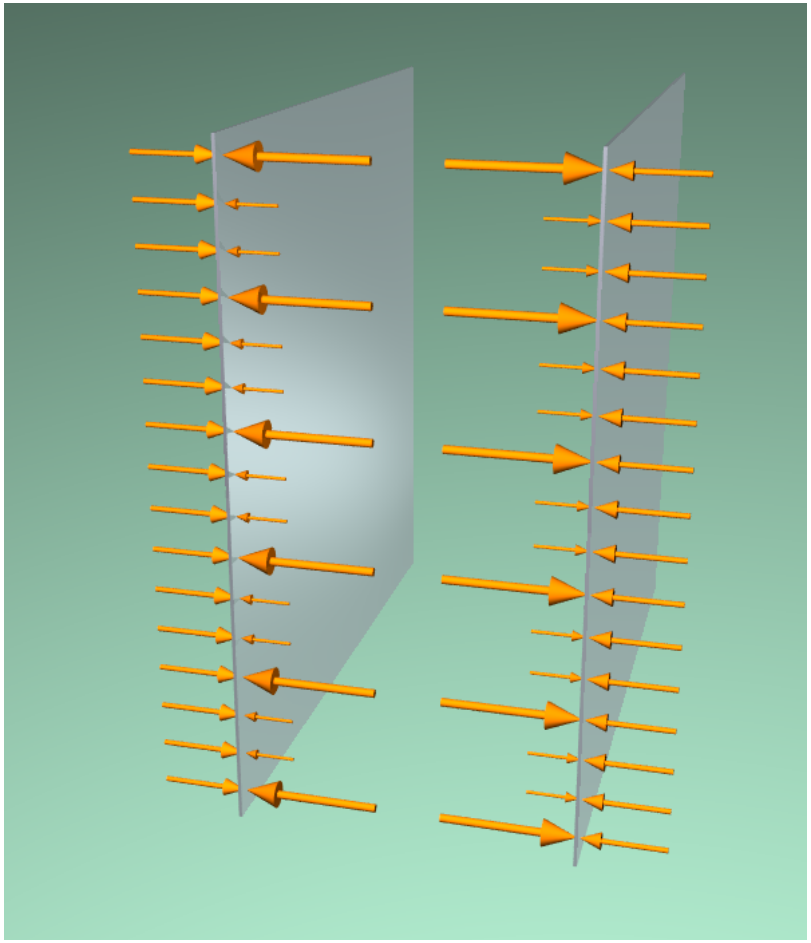


Der Casimir-Effekt

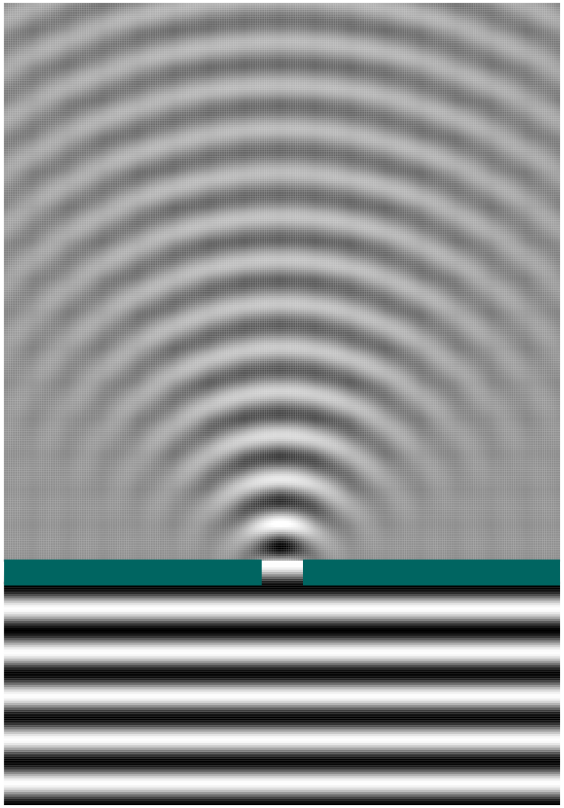
Eine Kraft aus Quantenfluktuationen

Gert-Ludwig Ingold

- Facetten des Vakuums
- Kraft aus dem Nichts: der Casimireffekt
- Anwendungen des Casimireffekts

- Facetten des Vakuums
- Kraft aus dem Nichts: der Casimireffekt
- Anwendungen des Casimireffekts

Heisenbergsche Unschärfe-relation

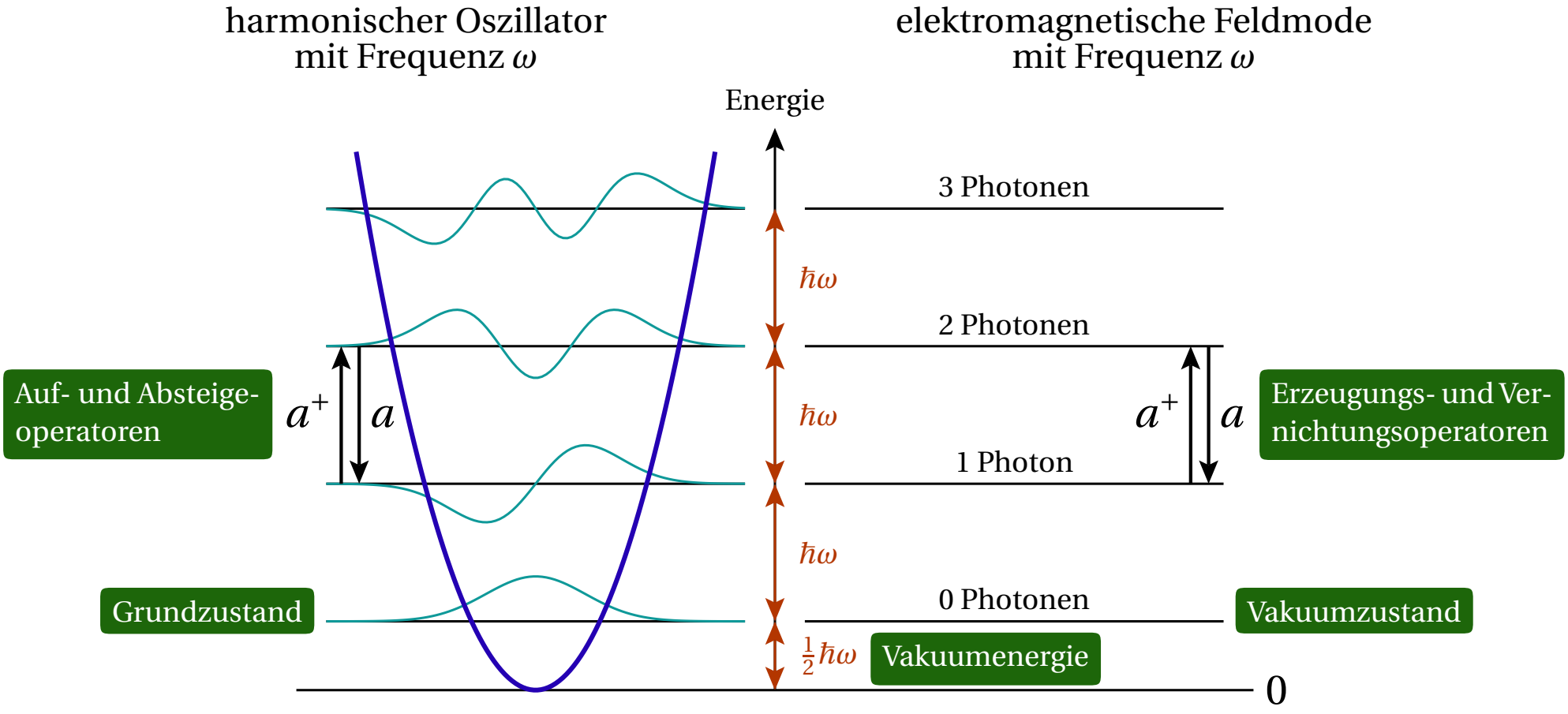


Werner Heisenberg
(1901–1976)

Welle-Teilchen-Dualismus $\longrightarrow$ $\boxed{\Delta x \Delta p \geq \frac{\hbar}{2}}$

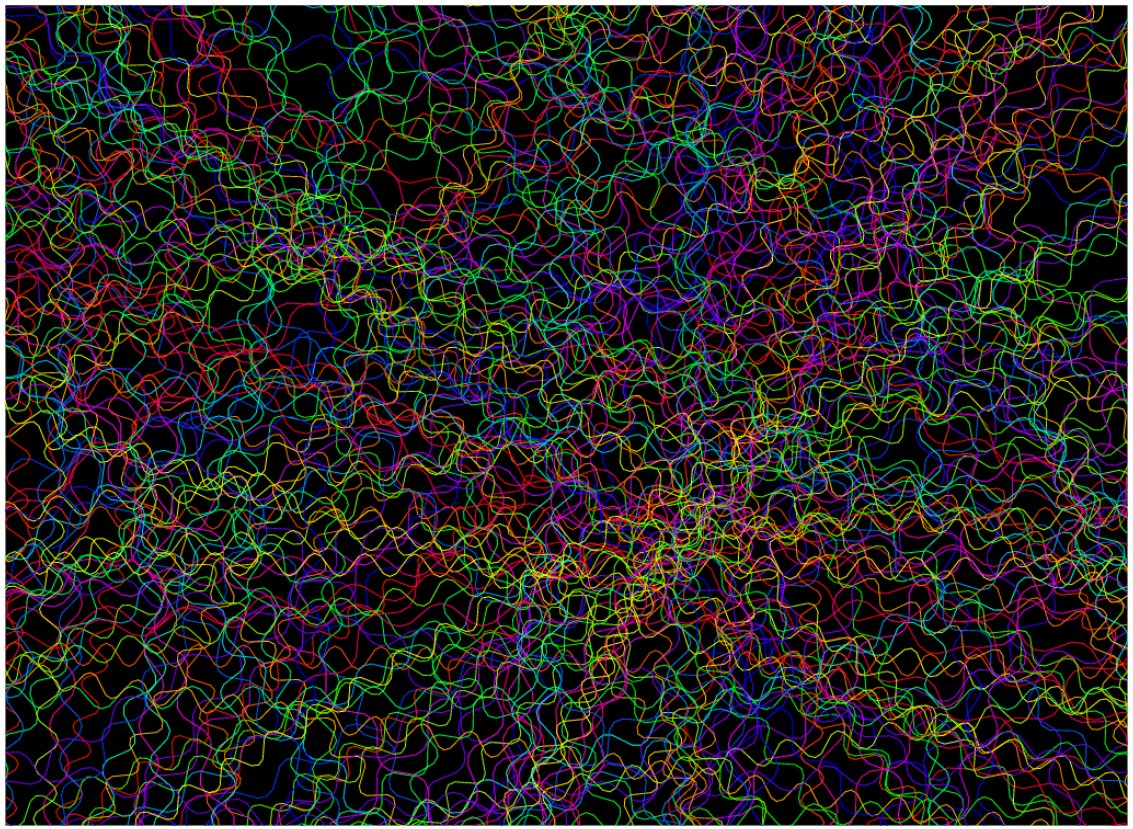
heisenbergsche Unschärferelation

Vakuumenergie



Elektromagnetisches Vakuum

$$E_0 = \sum_{\vec{k},p} \frac{1}{2} \hbar \omega_{\vec{k}}$$



Pauli und das Vakuum

Aus Wolfgang Paulis Nobelpreisvortrag (1945):

This has the consequence that the zero-point energy of the vacuum derived from the quantized field becomes infinite, a result which is directly connected with the fact that the system considered has an infinite number of degrees of freedom. It is clear that this zero-point energy has no physical reality, for instance it is not the source of a gravitational field. Formally it is easy to subtract constant infinite terms which are independent of the state considered and never change; nevertheless it seems to me that already this result is an indication that a fundamental change in the concepts underlying the present theory of quantized fields will be necessary.

Vakuum im 17. Jahrhundert

OTTONIS DE GUERICKE

EXPERIMENTA

Nova (*ut vocantur*) MAGDEBURGICA

DE

VACUO SPATIO

Primùm à R. P. *Gaspare Schotto*, è Societate Jesu, & Herbipolitanæ Academiæ Matheseos Professore:

Nunc verò ab ipso Auctore

Perfectiùs edita, variisque aliis Experimentis aucta.

Quibus accesserunt simul certa quædam

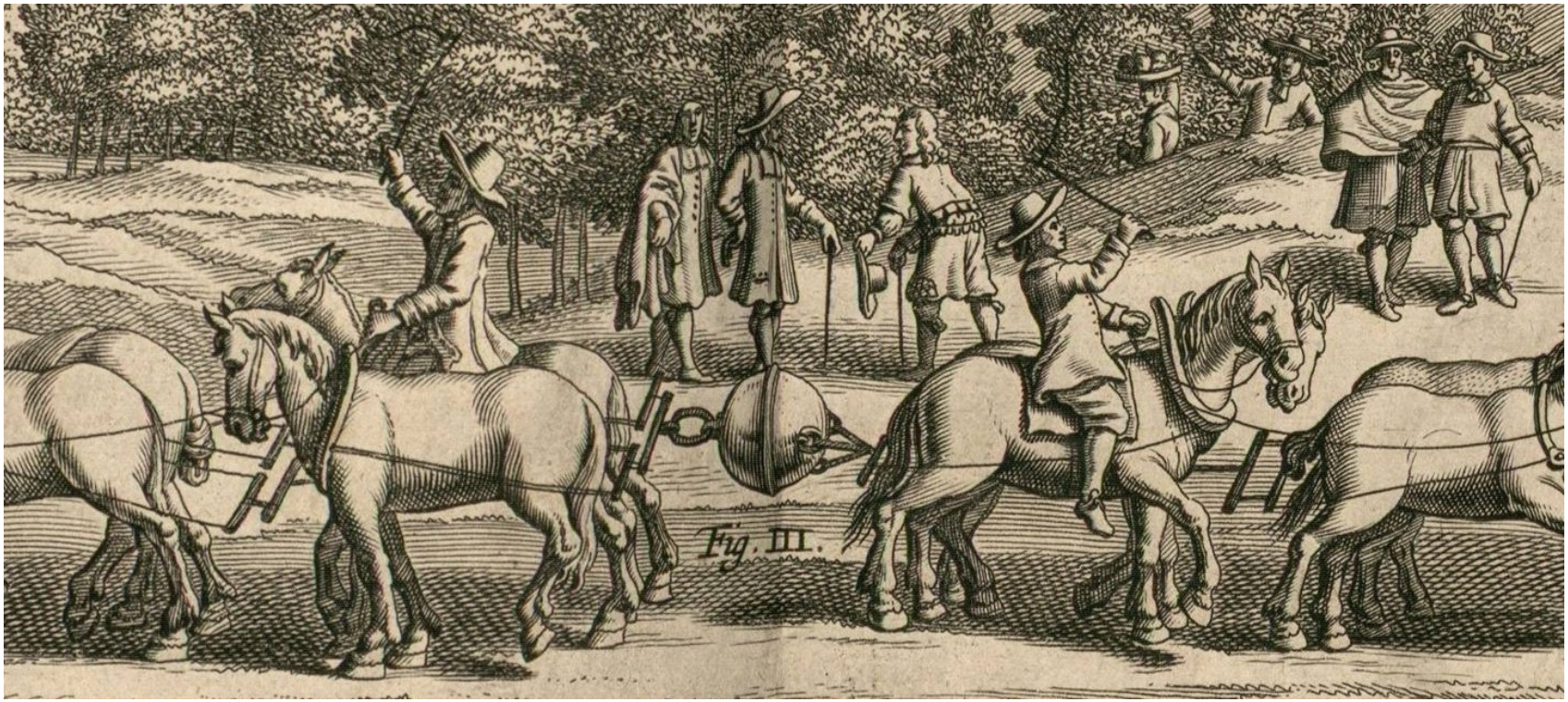
De Aeris Pondere circa Terram; de Virtutibus Mundanis, & Systemate Mundi Planetario; sicut & de Stellis Fixis, ac Spatio illo Immenso, quod tàm intra quam extra eas funditur.

AMSTELODAMI,

Apud JOANNEM JANSSONIUM à WAESBERGE, ANNO 1672.

Cum Privilegio S. Cæs. Majestatis.

Vakuum im 17. Jahrhundert

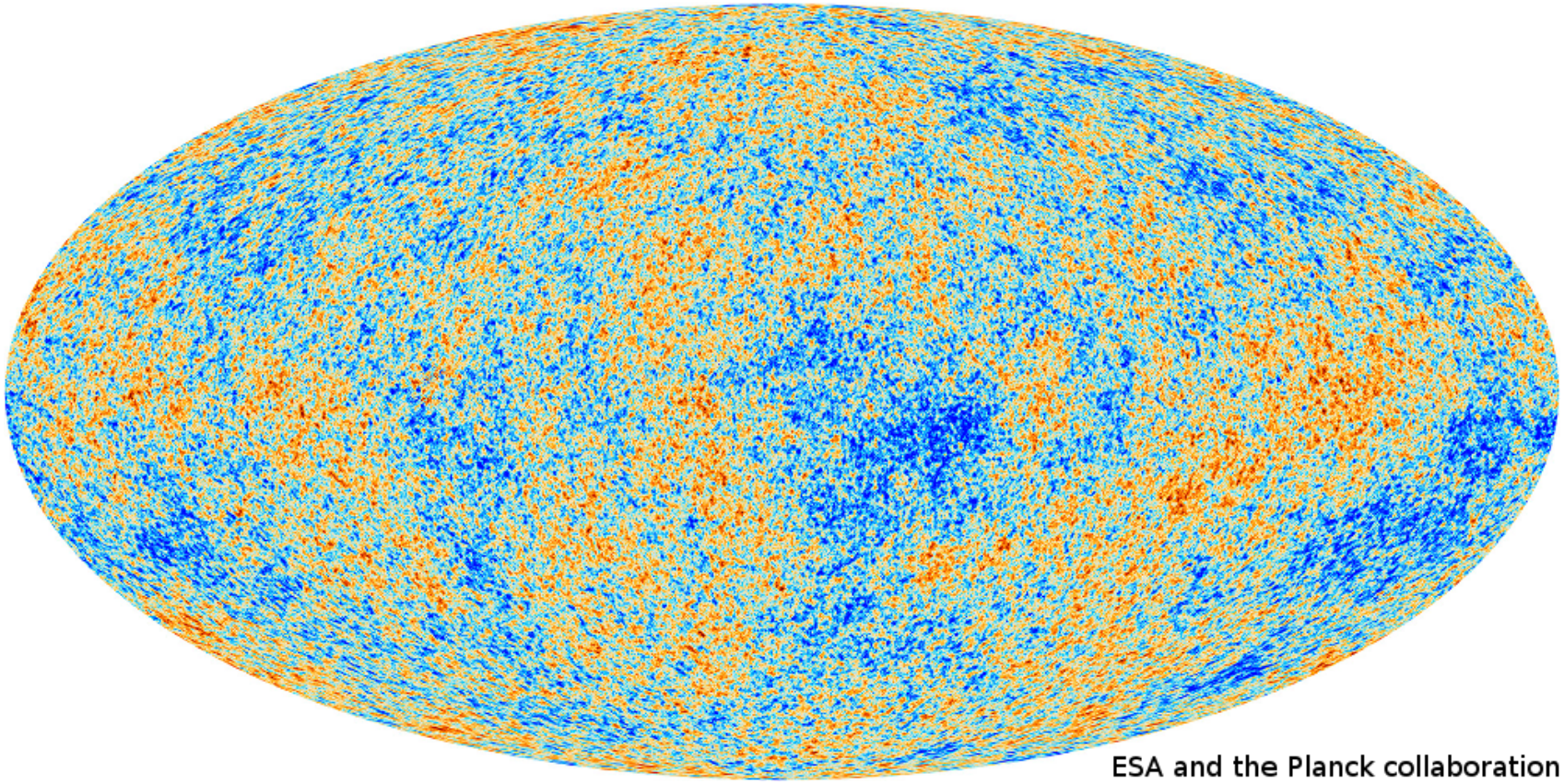


Der intergalaktische Raum

© ESA

ein paar Atome pro Kubikmeter

Das Licht vom Urknall



ESA and the Planck collaboration

Auch Licht übt Kräfte aus

Komet Donati (1858)

- Facetten des Vakuums
- Kraft aus dem Nichts: der Casimireffekt
- Anwendungen des Casimireffekts

H. B. G. Casimir 1948

Proc. K. Ned. Akad. Wet. (1948)

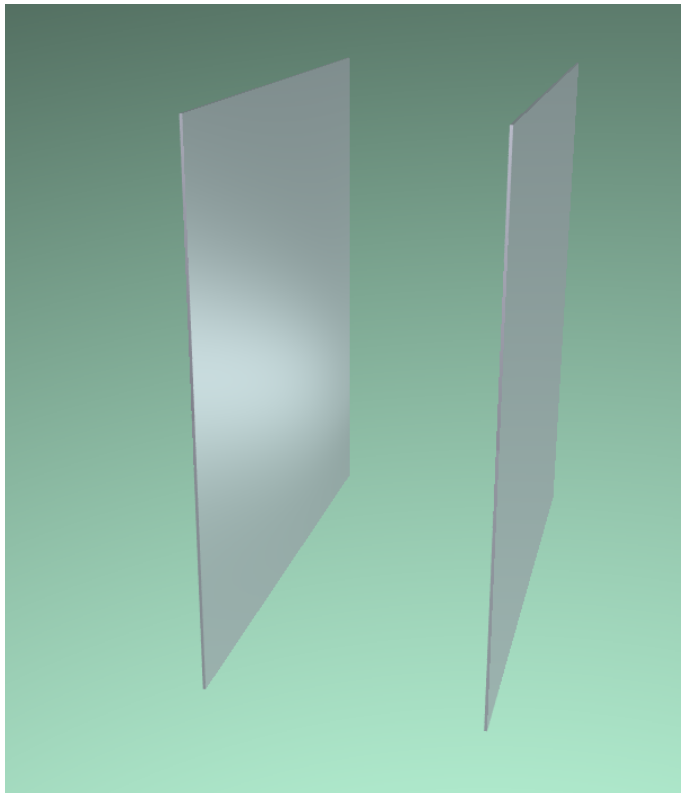
Mathematics. — *On the attraction between two perfectly conducting plates.* By H. B. G. CASIMIR.

(Communicated at the meeting of May 29, 1948.)

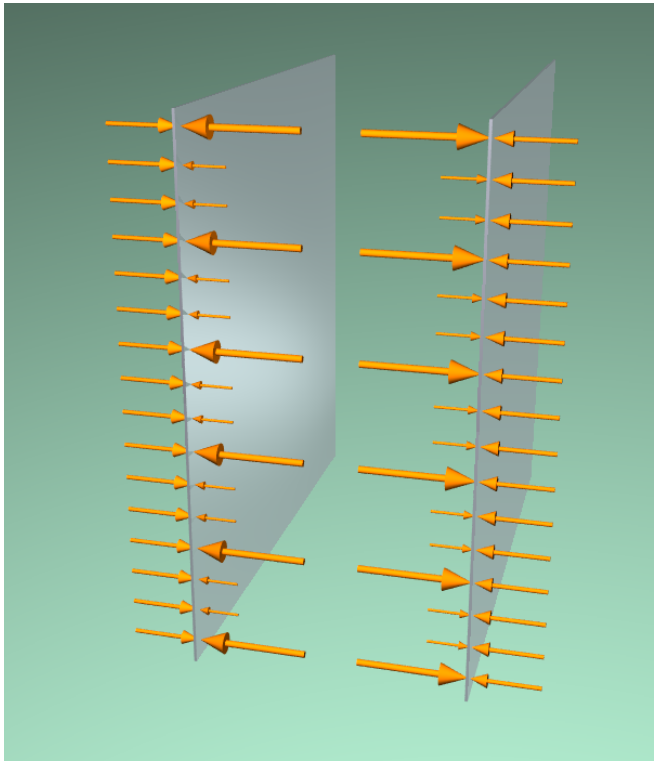
Natuurkundig Laboratorium der N.V. Philips' Gloeilampenfabrieken, Eindhoven.)

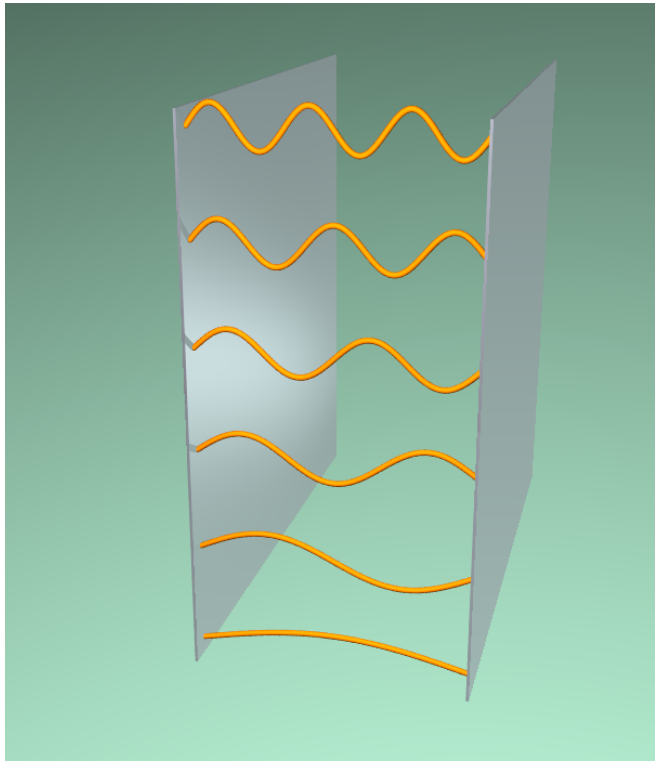
Hendrik Casimir (1909-2000)

AIP Emilio Segrè Visual Archives



Der Einfluss von Resonanzen





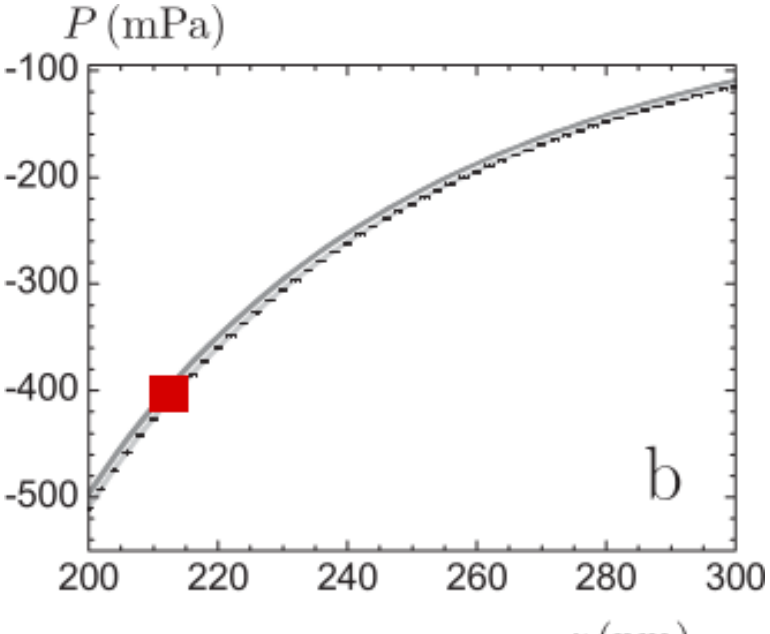
Wer gewinnt – innen oder außen?

Casimir-Kraft

für ideale Spiegel:

$$\frac{F}{A} = \frac{\hbar c \pi^2}{240 L^4}$$

Die Casimir-Kraft wird bei Abständen unterhalb einiger Mikrometer wichtig.



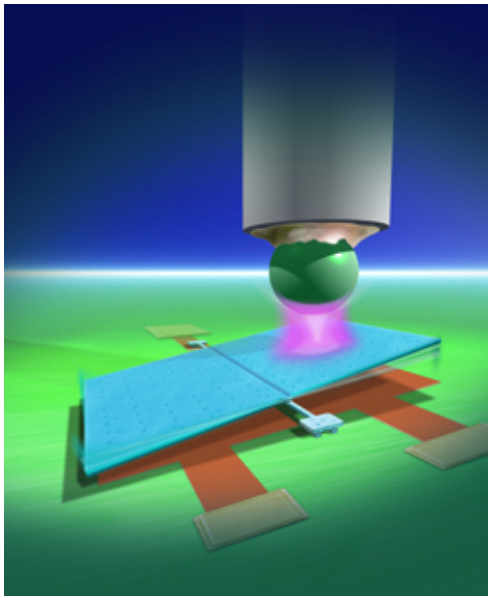
R. S. Decca et al. (2007)

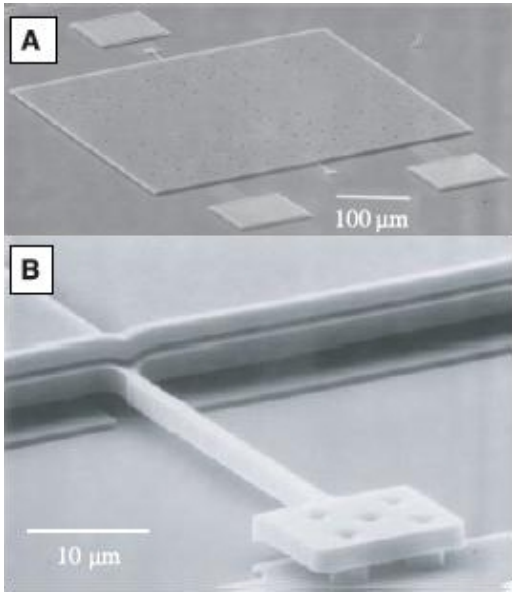
ein Reiskorn auf einem DIN A4-Blatt

Experimente alt und neu

1958 / Sparnaay

aus dem Video
Everything about nothing
©Thomas Draschan (2007)

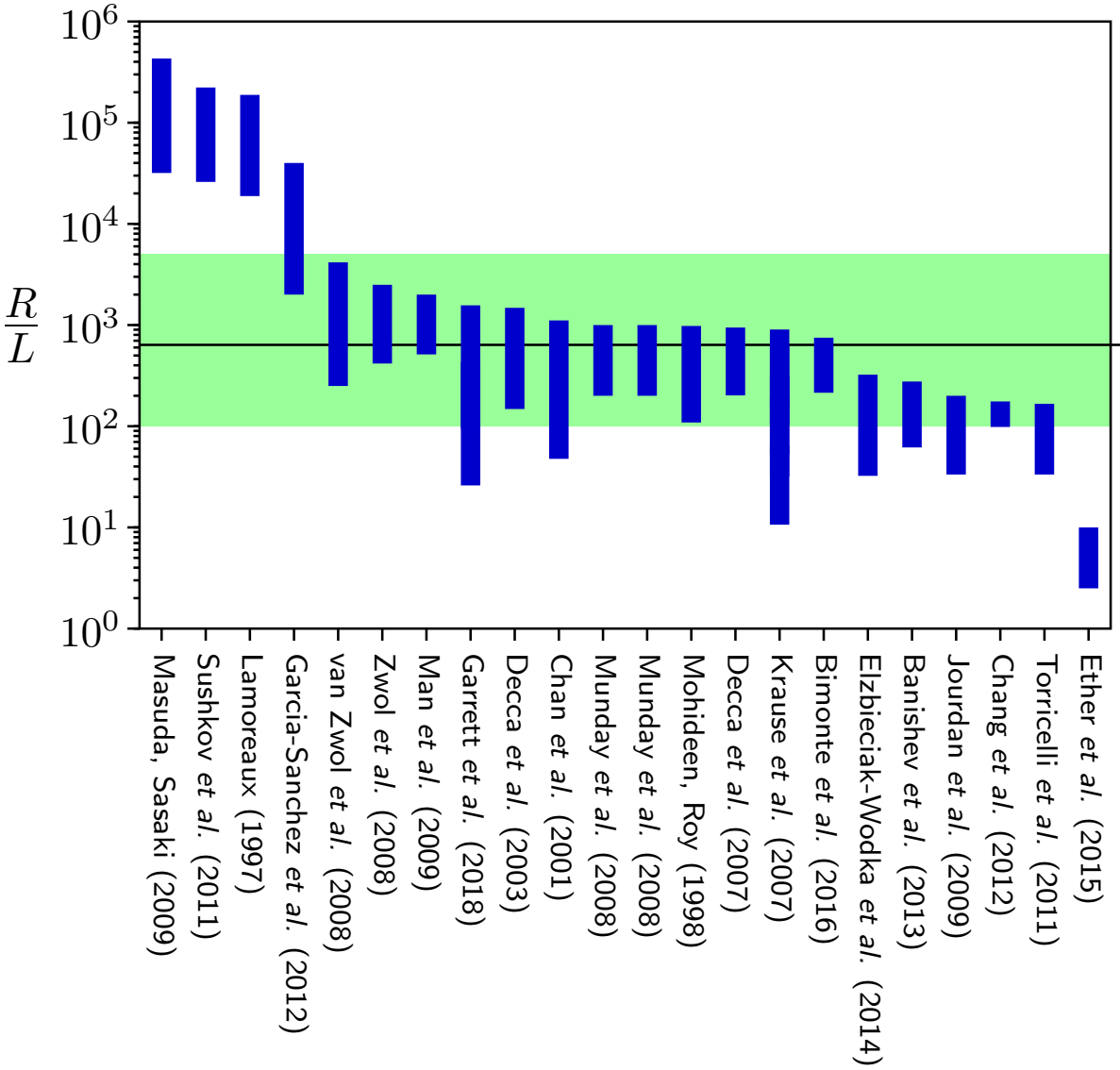




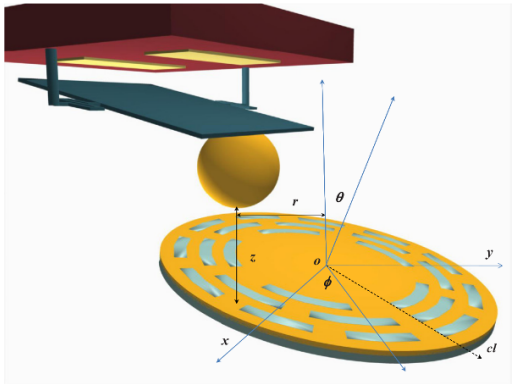
2001 / Capasso-Gruppe

H. B. Chan et al. (2001)

Wahre Größenverhältnisse



Decca-Gruppe (2016)



- Facetten des Vakuums
- Kraft aus dem Nichts: der Casimireffekt
- Anwendungen des Casimireffekts

MEMS und NEMS

aus urheberrechtlichen Gründen entfernt

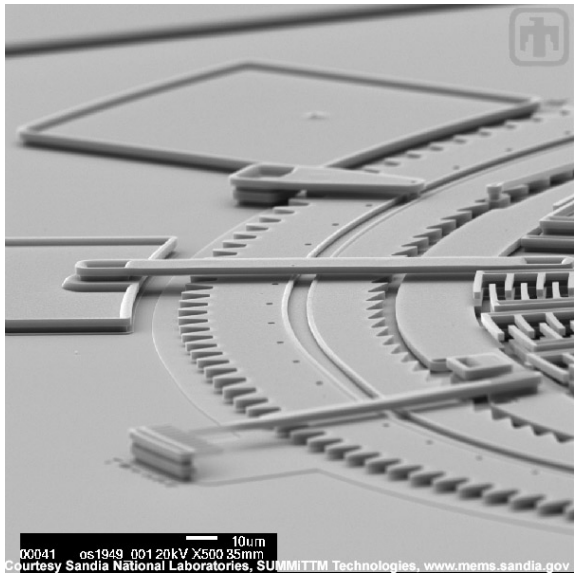
MikroElektroMechanische Systeme
NanoElektroMechanische Systeme

aus urheberrechtlichen Gründen entfernt

aus urheberrechtlichen Gründen entfernt

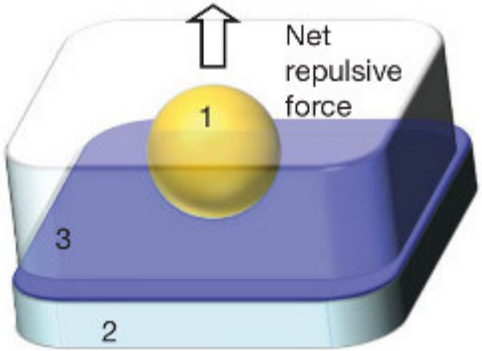
Casimirkraft bei MEMS und NEMS

Casimirkraft kann zu Defekten führen



Courtesy Sandia National Laboratories

Wechsel von Anziehung zu Abstoßung ist schwierig



J. N. Munday, F. Capasso, V. A. Parsegian (2009)

The New York Times 4. März 1986

Theory of Fifth Force Spurs New Experiments and a Sharp Debate

Was Galileo wrong when he hypothesized that any object – whether it is a feather, a cannon ball or a huge boulder – would fall at the same speed in a vacuum?

A report in January of evidence for a new force, working against gravity at short ranges, has unleashed a flurry of new research and sharp debate over the validity of the finding.

Hadley-Rille, 2.8.1971

for video see `https://nssdc.gsfc.nasa.gov/planetary/lunar/apollo_15_feather_drop.html`

Fundamentale Wechselwirkungen

1. **Gravitation**
   Kraft zwischen Massen
2. **Elektromagnetische Wechselwirkung**
   Kraft zwischen elektrischen Ladungen und Strömen
3. **Starke Wechselwirkung**
   Kraft zwischen Quarks, Kraft zwischen Nukleonen
4. **Schwache Wechselwirkung**
   Beispiel: β-Zerfall des Neutrons
5. **???**
   diverse Theorien, aber keine experimentellen Hinweise

Gibt es Abweichungen von Newtons Gravitationsgesetz?

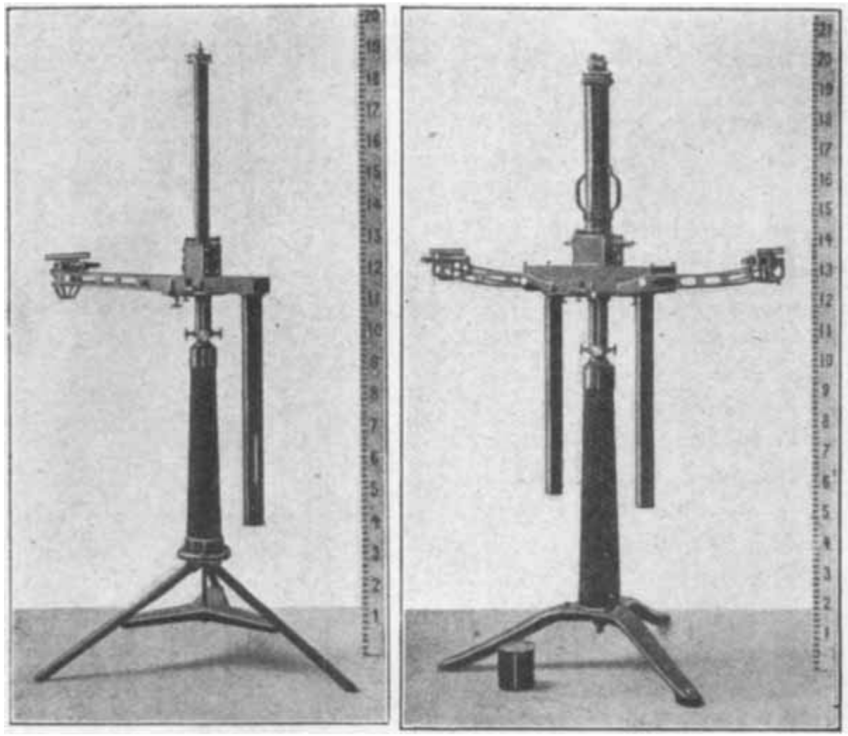
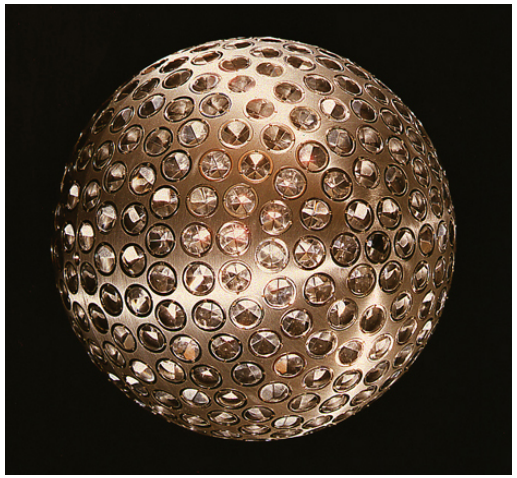
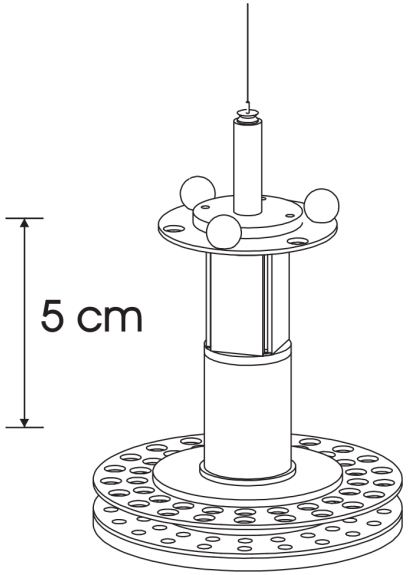


Fig. 6. Fig. 7.

Eötvös (1889)



LAGEOS

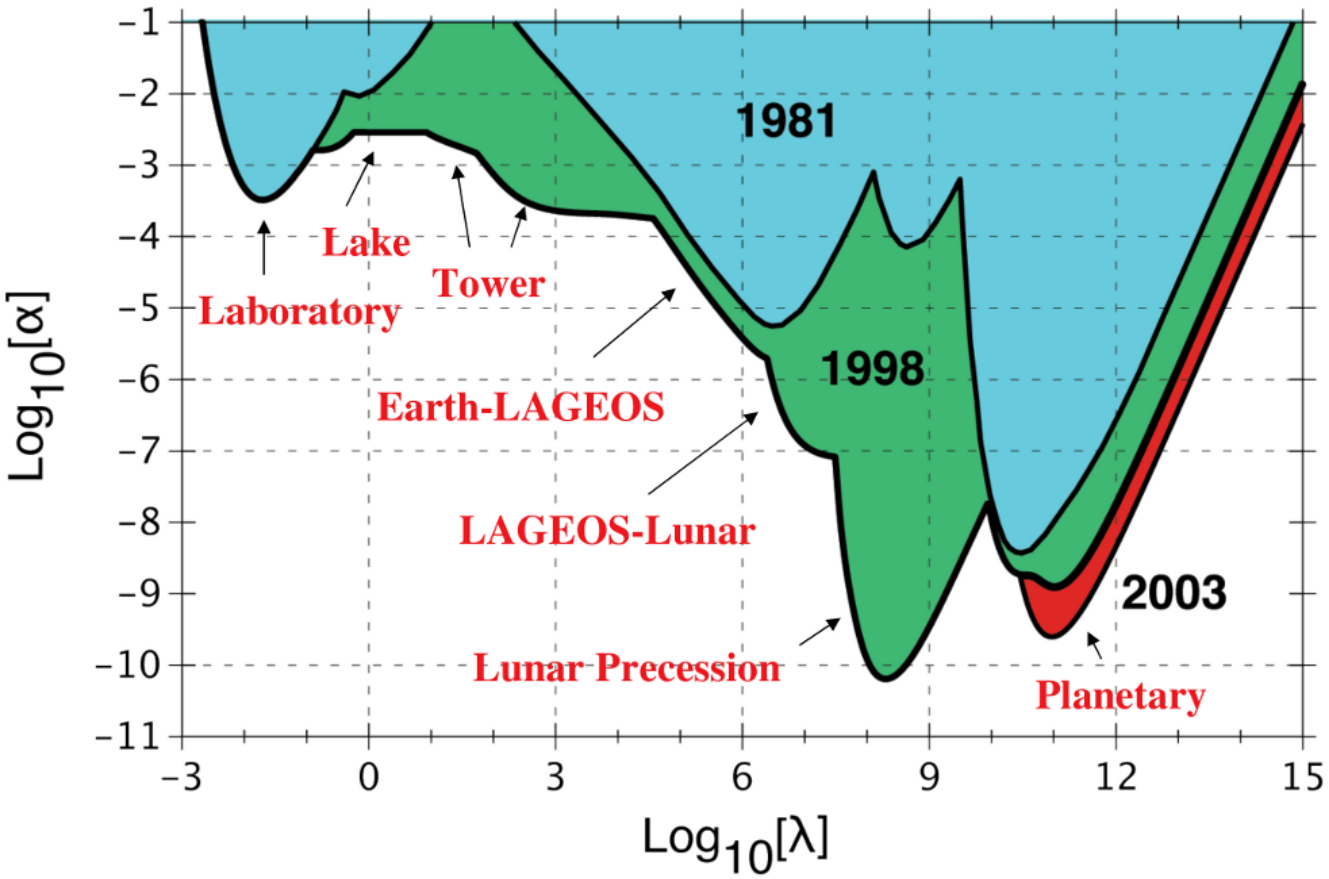


Eöt-Wash

Gibt es Abweichungen von Newtons Gravitationsgesetz?

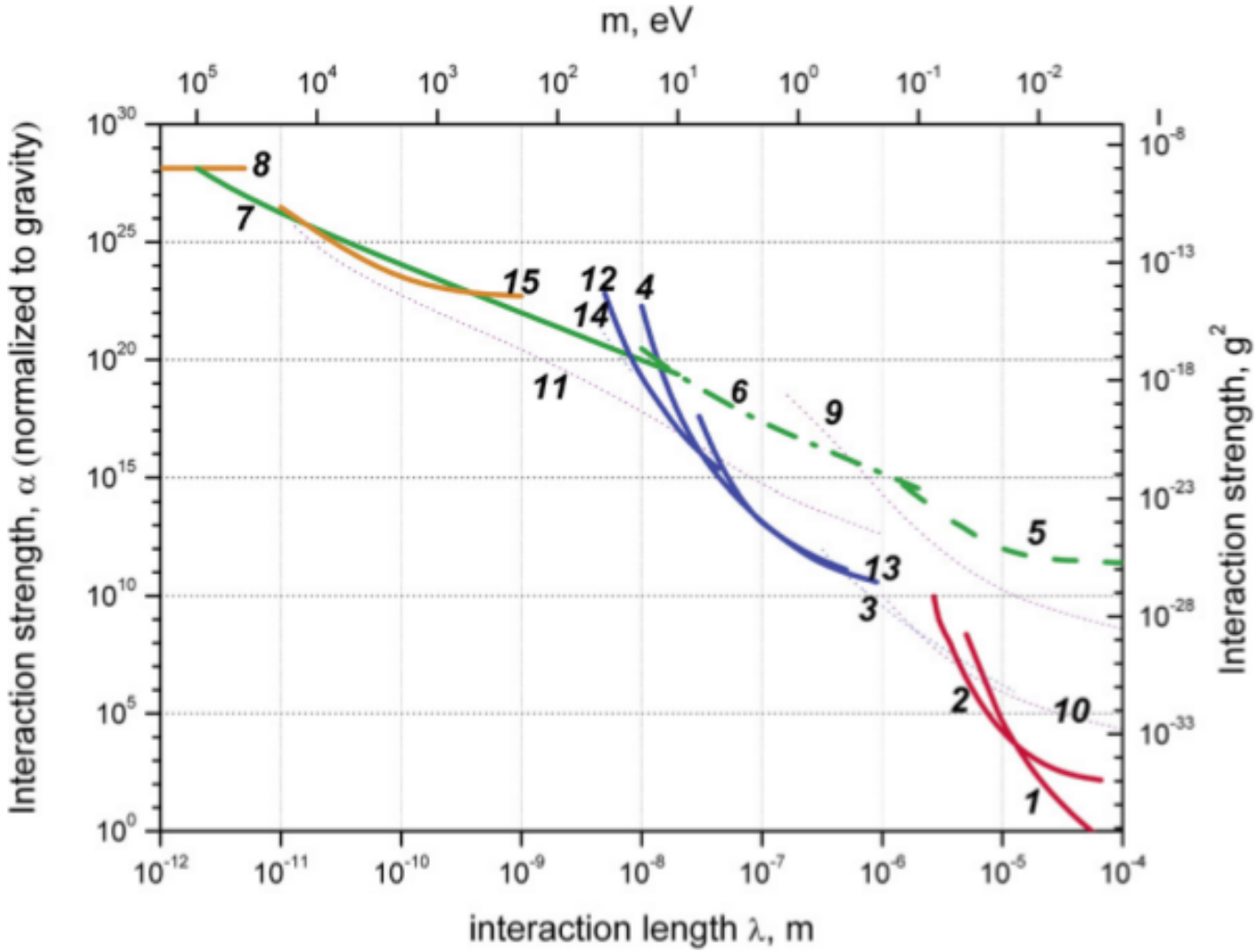
Universität Augsburg University

Yukawa-artige Abweichungen $V(r) = -\frac{Gm_1 m_2}{r}\left(1 + \alpha e^{-r/\lambda}\right)$



Coy, Fischbach, Hellings, Standish, Talmadge (2003)

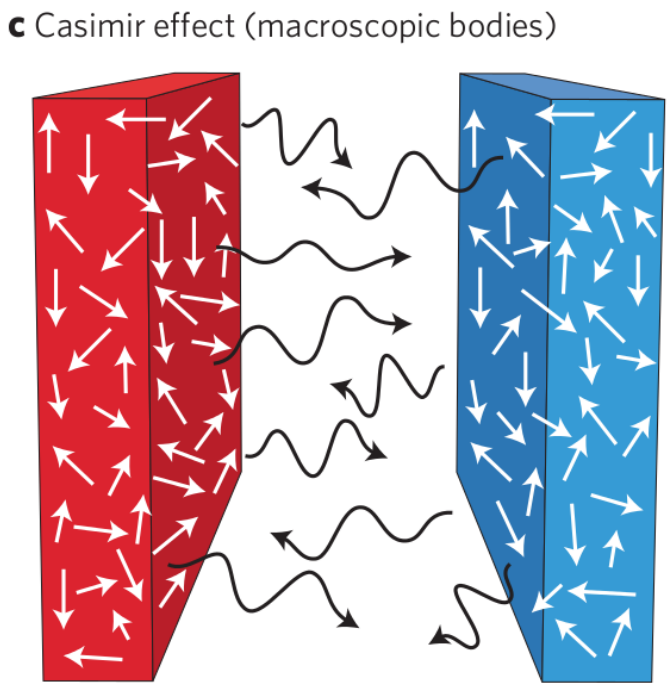
Gibt es Abweichungen von Newtons Gravitationsgesetz?



Antoniadis et al. (2011)

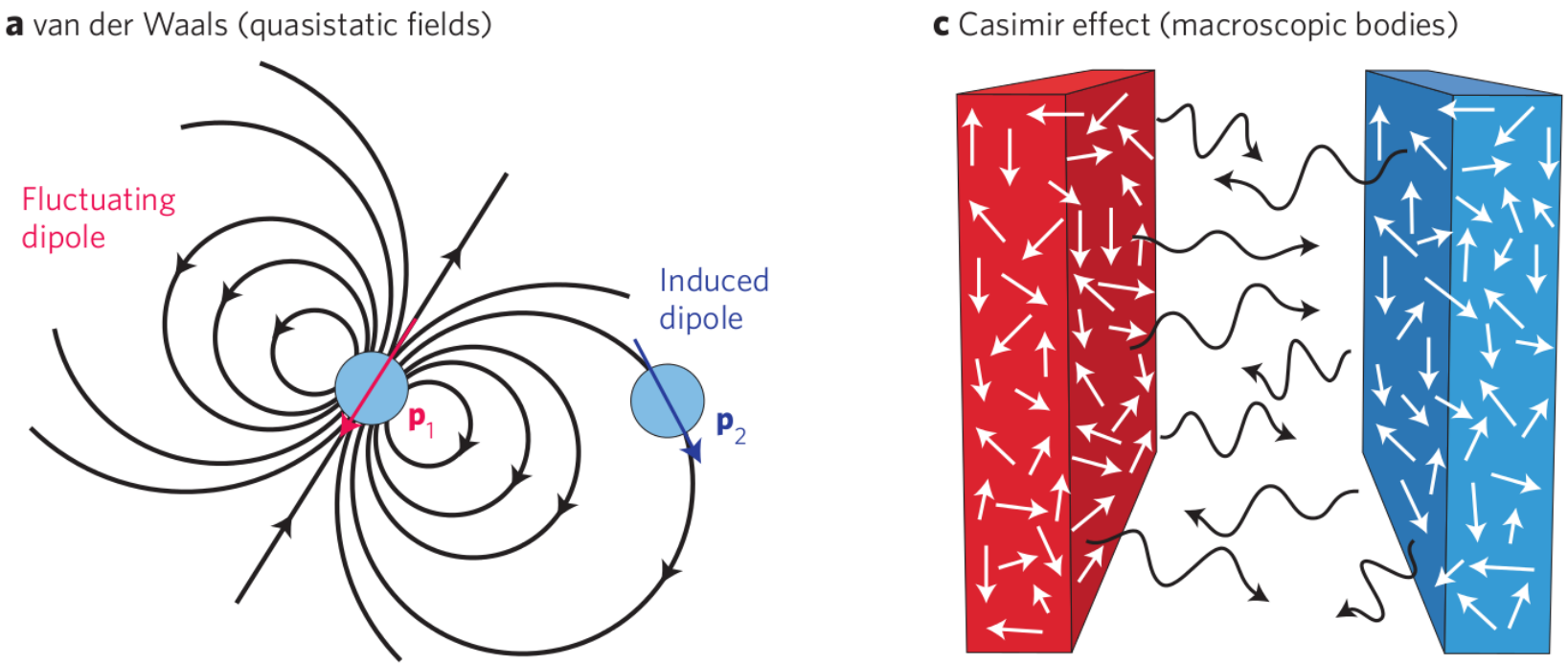
…und was ist mit dem Gecko?

Von van der Waals zu Casimir



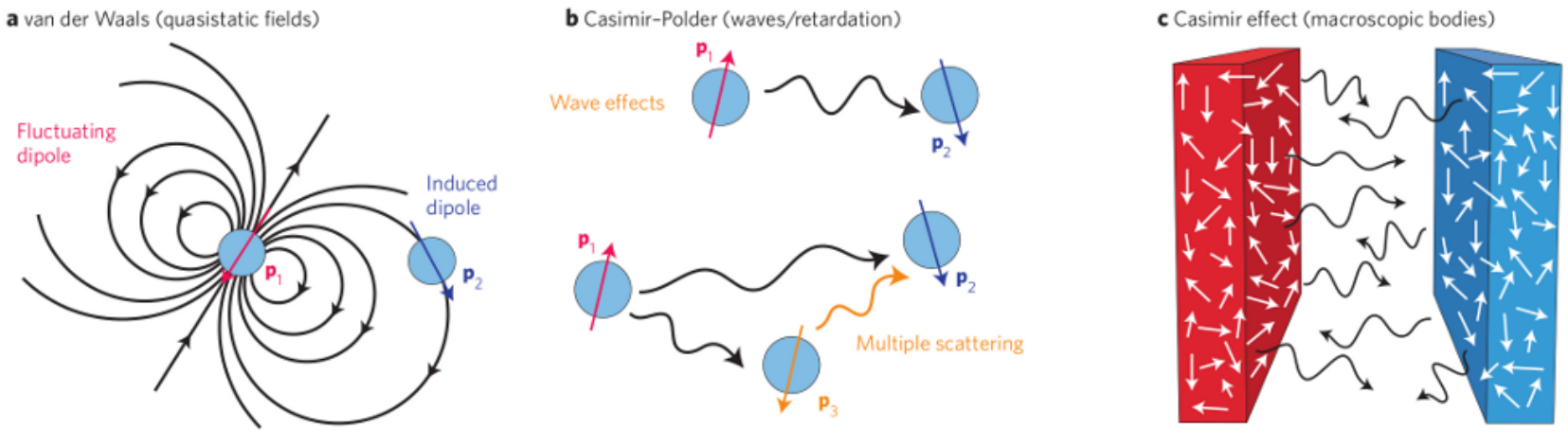
aus: A. W. Rodriguez et al., Nat. Phot. (2011)

Von van der Waals zu Casimir



aus: A. W. Rodriguez et al., Nat. Phot. (2011)

Von van der Waals zu Casimir



aus: A. W. Rodriguez et al., Nat. Phot. (2011)

Gecko nutzt die van-der-Waals-Kraft

Fig. 2. Tokay gecko (*Gekko gecko*) adhering to molecularly smooth hydrophobic GaAs semiconductor. The strong adhesion between the hydrophobic surface of the gecko's toes and the hydrophobic GaAs surfaces demonstrates that the mechanism of adhesion in geckos is van der Waals force.

K. Autumn et al. (2002)